EXHAUST EMISSIONS FROM PISTON AND GAS TURBINE ENGINES USED IN NATURAL GAS TRANSMISSION

by

Harry E. Dietzmann

Karl J. Springer

Prepared for

Pipeline Research Committee
of the
American Gas Association

Project PR-15-61

January 1974

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO CORPUS CHRISTI HOUSTON

This report was furnished to the American Gas Association by Southwest Research Institute, San Antonio, Texas at the request of American Gas Association in fulfillment of Pipeline Research Committee Project PR-15-61. The contents of this report are furnished as received from the contractor. The opinions, findings and conclusions expressed are those of the authors and not necessarily those of the American Gas Association. Mention of company or product names is not to be considered an endorsement by the American Gas Association, or by Southwest Research Institute.

The object of this work as established by the Pipeline Research Committee was to develop baseline exhaust emissions from a variety of piston and turbine engine powered compressors used in gas transmission. In doing so, the sample of engines were selected by the Pipeline Research Committee on the basis of their current popularity and installed horsepower. The engines were run in the condition they were found at the time of test and no attempt was made to maintain them to a given level of performance prior to or during the testing.

Although all engines were stated by the respective station operators to be in routine operation at the time of test, engine age, maintenance and general running condition varied. The design of the experiment, to determine what is emitted by engines currently in use, necessarily precluded control over engine age, maintenance history and general operation.

Comparisons, either direct or by inference, of station-to-station, building-to-building, or engine-to-engine is not intended nor valid. No attempt was made to test any particular make or model of engine. The engines tested were those which happened to be operating at the time.

A.G.A. Catalog No. L22274
Price: $12.00

DI-00142 -
AR-923

SOUTHWEST RESEARCH INSTITUTE
Post Office Drawer 28510, 8500 Culebra Road
San Antonio, Texas 78284

EXHAUST EMISSIONS FROM PISTON AND GAS TURBINE ENGINES USED IN NATURAL GAS TRANSMISSION

by
Harry E. Dietzmann
Karl J. Springer

Prepared for
Pipeline Research Committee
of the
American Gas Association

Project PR-15-61

January 1974

Approved:

for John M. Clark, Jr.
Technical Vice President
Department of Automotive Research

FOREWORD

This project was under the overall supervision of Sam J. Cunningham, Southern California Gas Company, Chairman of the Supervising Committee on NO_x Research for Prime Mover Operations (PR-15-61). Three members of the supervising committee were selected to provide technical guidance, coordination, and cooperation at the various participating gas transmission companies. Members of this steering committee included Chairman Pete Susey, Columbia Gas System; James R. Hatfield, Northern Natural Gas; and George Broussard, Panhandle Eastern Pipe Line. During May, 1973 Don Scott of Columbia Gas System replaced Pete Susey on the steering committee and James Hatfield assumed chairmanship.

This project was entitled "Measurements of Emissions from Piston and Gas Turbine Powered Natural Gas Compressor Stations." The Southwest Research Institute project designation was 11-3438-001 and was conducted from August, 1972 to July 1973. The field engineer responsible for on-site testing was Harry E. Dietzmann and the overall project supervisor was Karl J. Springer.

ABSTRACT

A baseline emissions survey was conducted on stationary gas turbines and reciprocating engines used in natural gas transmission. A total of 59 reciprocating engines and nine gas turbines were tested over a ten-month period at ten different sites. Emission rates for all tests were calculated in pounds per hour, pounds per million BTU heat input, and grams per horsepower-hour output. Emission rates of piston engines were determined at or as near to rated speed and load as possible and relative comparisons were made. Comparisons between two and four stroke engines as well as turbocharged and normally aspirated versions of the same engine were made. Emission trends for a number of piston engines were developed as a function of engine operating parameters such as ignition timing, scavenging air pressure, engine speed and load. Gas turbine NO_x concentration comparisons were made to the level under discussion as a possible proposed Federal standard. Details are given on the test procedure used and its development.

EXECUTIVE SUMMARY

A baseline emissions survey was conducted on nine gas turbine and 59 spark ignition piston engines used in pipeline gas compression. These units, operating on natural gas, were tested over a ten-month period at ten different sites in seven states. The engines were tested in the mechanical condition at the time of test. The selection of engines and test sites was performed by the steering committee of the Supervising Committee on NO_x Research for Prime Mover Operations (PR-15-61). Fuel measurement and engine power indication was performed by personnel furnished by the participating gas transmission companies.

Prior to the survey, a number of experiments were made to develop and validate sampling and testing procedures with respect to probe design, location, and sample conditioning. Experiments were also conducted to determine the feasibility of sampling exhaust in plastic bags in lieu of the preferred continuous on-line type of sampling. Correlation studies were conducted to relate NO_x measurements by chemiluminescense, a continuous method used in this project, to the phenoldisulfonic acid procedure, a slower, less meaningful wet chemical method.

Continuous monitoring of raw exhaust was found to be a quite satisfactory method for compressor engine stack analysis. The use of nondispersive infrared instruments for CO and CO_2, hydrogen flame ionization analysis for unburned hydrocarbons, a gas chromatograph for nonmethane hydrocarbons, a polaragraphic analyzer for oxygen, and a chemiluminescent analyzer for NO and NO_x were routinely used with a high degree of accuracy. The preferred method was to locate instruments near to the stack, sample directly from a multiopening type probe inserted into the open end of the stack and continuously indicate the concentrations of emissions. The sampling and analysis procedures are described sufficiently to allow others to use them if desired.

The engines tested during the baseline survey were grouped into 25 piston and eight turbine groups. Comparisons were made using emissions measured at rated speed and load or as near as attainable. The emission rates are presented in terms of gr/hp-hr (brake specific), lbs/10^6 BTU (fuel specific) and lbs/hr (mass rate). Gas turbine emissions were corrected to 15 percent O_2.

NO_x, the most important compressor engine emission, was found to range from 20.3 to 216.7 lbs/hr, from 1.5 to 6.3 lbs/10^6 BTU, and from 4.5 to 28 .1 gr/hp-hr for the piston engines tested. Turbine NO_x emissions ranged from 46 to 130 ppm, corrected to 15 percent O_2. The level under discussion as a possible Federal standard for new stationary gas turbines, is 55 ppm NO_x corrected to 15 percent O_2. Turbine engine

NO_x ranged from 1.7 to 48 lbs/hr, from 0.14 to 0.48 lbs/10^6 BTU and from 0.8 to 2.0 gr/hp-hr. In addition to rank-ordering the emission rates for all engine groups, comparisons were made between 2- and 4-stroke cycle turbocharged engines, 2- and 4-stroke cycle normally aspirated engines, and normally aspirated and turbocharged 2-stroke engines.

Where possible, emissions were measured at speeds and loads other than rated. On several occasions, timing and scavenging air pressure were varied to gain data at other than standard operating conditions. The effect of these engine parameters on NO_x, HC and CO was then analyzed. It was found in general that NO_x could be reduced by (1) reducing power by reducing engine speed (i.e., essentially constant torque), (2) reducing horsepower at constant speed (i.e., reducing torque), (3) increasing the scavenging air pressure (i.e., decreasing the fuel-air ratio among other factors), (4) retarding ignition timing (i.e., basic spark timing later in cycle) and (5) increased engine speed at constant power output (i.e., reducing torque).

There were many exceptions found to the above general trends with occasionally two similar engines producing different trends and certain engine groups showing a counter trend to the majority. The difficulty in varying gas turbine engine operation precluded the generation of emission data for trend analysis by operating variable. The power turbine speed on one turbine was varied with as-measured NO_x ppm decreasing with a decrease in power turbine speed. Little in the way of repeat tests were possible and the strength of the piston and turbine trends should be so viewed.

The intent of this initial project was to acquire as much baseline emissions data as possible about compressor engines. In so doing, emissions were measured at conditions other than typical of normal operation. Additional analysis of this data could be made and more tests are needed to make definitive statements about the effect of certain operating parameters. Perhaps those high NO_x engines of great popularity and installed horsepower should be investigated in more detail. Sufficient baseline data have been developed, however, to permit estimation of emission inventory or national impact values and to assess the current engines in terms of existing, proposed or future emission limits. Given additional statistical information on installed horsepower, etc., one could decide on engines that have priority importance for an emissions abatement program.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

I. INTRODUCTION

It is general knowledge that the combustion of fossil fuels is a major source of air pollution. The combustion of gasoline and diesel fuels for vehicular propulsion and fuel oil, coal and natural gas for electrical power generation has been identified as a primary source of the major air pollutants. The species which have been specifically identified as major pollutants are carbon monoxide, sulful dioxide, reactive hydrocarbons, oxides of nitrogen, smoke and particulates. State and Federal regulations have been promulgated to control and reduce emission levels from various sources.

The Clean Air Act Amendment of 1970 provides for the imposition of control and other restrictive measures regarding the air pollution from new stationary sources. On December 1971, national performance standards were published in the Federal Register(1)* by which new plants would be controlled from an emissions performance standpoint. Stationary sources included in this document were steam-electric type powerplants, Portland cement plants, incineration, and sulfuric acid plants. Proposed emission standards(2) are currently under consideration for new stationary gas turbines. Previous experience has indicated that the Federal regulations, applicable to new units, sets the basis for the control and regulation of existing units by the individual state, region and local pollution control authorities. These authorities are free to impose more stringent or accelerated control measures on existing sources where felt justified.

Natural gas is the cleanest burning fossil fuel known and consequently has been in great demand as an alternative fuel to coal and oil. Emission test data from mainline compressor engines has indicated that internal combustion, spark-ignition engines operating on natural gas produce relatively low carbon monoxide and hydrocarbon levels.(3-8) Due to the inherent low sulfur content of natural gas, sulfur dioxide emissions are not of concern. Emissions of particulate, visible smoke and odor, have not been shown to be significant with natural gas fueled engines. Nevertheless, engines fueled on natural gas emit substantial amounts of oxides of nitrogen (NO_x). The emissions of NO_x from natural gas fueled engines in stationary applications ranks nationally behind gasoline-fueled engines and powerplants(9) burning coal and fuel oil. Therefore, the area of greatest air pollution concern in the use of natural gas in mainline pipeline compression is oxides of nitrogen emissions.

---

*Numbers in superscript parenthesis refer to the List of References listed at the end of this report.

A. Background

Oxides of nitrogen have been found to be an important precurser in smog formation. The nitrogen dioxide (NO_2) portion of the NO_x reacts with certain reactive hydrocarbons in the atmosphere in the presence of sunlight to produce the eye-irritating photochemical smog that is associated with the Los Angeles Basin. Nitrogen dioxide has been identified as a major pollutant itself and is capable of producing adverse health effects. The usual concentrations measured in the ambient are below the toxic levels but can give rise to the general discoloration of the atmosphere by its dirty yellow-brownish appearance. In April 1971, the Environmental Protection Agency (EPA) promulgated a National Ambient Air Quality Standard of 0.05 ppm NO_2.[10]

Although the principal nitrogen oxide formed in the internal combustion engine is nitric oxide (NO), the reaction of NO with atmospheric oxygen ultimately yields NO_2. In certain instances, the amount of NO_2 formed in exhaust can be a significant amount. Therefore, it is of prime importance to measure NO_x, the sum of NO + NO_2. Most standards are based on NO_2 rather than on an NO basis, even though NO is the primary oxide of nitrogen formed in combustion.

The Federal Government is taking action in many areas to insure that the NO_x concentration is maintained below or reduced to the National Ambient Air Quality Standard level. Existing NO_x standards[11] for automotive and diesel emissions as well as emission standards under consideration for stationary gas turbines are evidence of this action. Fossil fueled steam electric powerplants, a major source of NO_x, were included in the initial Federal rules for new performance standards. States are required to submit plans to the Federal Government on how they plan to meet National Ambient Air Quality Standards. Depending on the circumstances, both new and existing sources are identified for abatement.

Without sufficient baseline emissions data, it is difficult to promulgate fair and just standards based on best current demonstrated technology, straight roll back, or any other criteria. It is quite conceivable that a gas transmission company with pipe lines passing through five states could have five different standards on one or more emissions for compliance demonstration. This baseline emissions survey is a major step to provide factual information from which a determination of specific emissions of concern may be identified. In the event a standard is justified, it can be based on sound data.

Since this project began, the Environmental Protection Agency has determined that the air quality measurements used to set the standards of performance and other regulatory actions for oxides of nitrogen are in substantial error. The method of analysis was found to yield high values due to various interferences, etc. The inconsistency has been quite embarrasing to EPA in that no simple adjustment or factor may be made of the existing data. This has caused all state and regional implementation plans for NO_x to be held in abeyance until such times as new, hard, factual, ambient NO_x data are available.

The recent and future actions by EPA on this point are of great importance to the work reported in this project and follow-on activities by the gas compression transmission industry. As of this writing, no definitive statement of EPA policy, basic data, or NO_x measurement instrument description have been published. It is expected that such a report will be made public by EPA in the near future. The data generated in this report should be considered in light of the changing attitude toward NO_x and the revised limits that will be published.

B. Objective and Scope

The objective of this project was to determine the emission rates of reciprocating engines at rated speed and load and gas turbines as they were operating under on-site field conditions. Engine manufacturer and model as well as site selection was performed by the AGA steering committee. When convenient, changes in engine operating conditions, such as load, engine speed, scavenging air pressure, and ignition timing were employed to determine their effects on emission rates. Monitoring of engine parameters and fuel consumption was performed by the individual participating gas transmission companies. As many engines as possible were tested on site to insure that population quotas were met.

C. Approach

Once the program had been officially initiated, a steering committee was selected from members on the American Gas Association NO_x Supervising Committee, PR-15-61. Functions of this steering committee with respect to the contractor included test site and engine selection, technical guidance and coordination between the contractor and the individual participating gas companies. Selection of analytical instrumentation, method of expressing emission rates were approved by the steering committee. Engine and site selection was performed by this steering committee.

1. Analytical Instrumentation

The analytical instrumentation selected for the measurement of exhaust emissions is described in detail in Appendix A. The calibration techniques, testing procedures and sampling system schematic is also presented to describe in detail the methods of analysis employed in this program. The individual instruments are listed in Appendix A by manufacturer, model and available ranges. These instruments, as well as the original calibration gases were transported from site-to-site throughout the entire program.

2. Emission Rate Calculation Method

Emission rates were calculated using the "total carbon" method. This method utilizes fuel consumption rates and exhaust emission concentrations to calculate emissions rates. A derivation of the "total carbon" method is presented in Appendix A. Once the method of calculation was determined, a computer program was written to calculate emission rates for all engines tested during the baseline emissions survey. An explanation of the equations used in the computer program and output format and terminology may also be found in Appendix A. Figure A-3 in Appendix A is a print-out of the computer program.

During the initial planning stages of the baseline emissions survey, it was uncertain as to which method of expressing emission rates would be the most acceptable. To be assured that upon project completion emission rates would be expressed in the proper units, it was decided to report emissions data for reciprocating engines in four ways.

The methods of expression included pounds per hour (lbs/hr), mass output; pounds per million BTU (lbs/10^6 BTU), fuel input; grams per observed horsepower-hour (gr/hp-hr), work output, and parts per million (ppm) observed raw concentrations. For gas turbines, one additional method of expressing emissions was included. Since the proposed standard for NO_x emissions from stationary gas turbines is based on 15 percent oxygen, gas turbine exhaust concentrations were corrected to that basis. This would provide a comparison of in-service stationary gas turbines against the proposed standard.

3. Engine and Site Selection

The selection of engine makes and models was performed by the AGA steering committee. Population usage information, provided by Mr. Pete Susey,[12] Chairman of the steering committee, was used to select engine manufacture and model based on percentage of total horsepower then in use by the companies represented on the NO_x study group. This selection was based on the horsepower distribution information presented in Table B-1 of Appendix B, a copy of the data furnished in Reference 12. As mentioned in Reference 12, the Table B-1 data reflects the entire industry to a reasonable degree.

Once the horsepower distribution was tabulated, site selection was completed by the steering committee. Several factors were considered in the test site selection. First, the compressor stations should have the variety of engine makes and models to satisfy horsepower distribution requirements. Second, the participating company would have to be agreeable to allow testing at their station. This included a limited amount of support personnel for short periods of time, as well as a test crew for measuring horsepower and supplying fuel consumption rates. The participating gas company also supplied the fuel component analysis, higher heating value (dry) and specific gravity. Third, the locations were to be selected reasonably close to the contractor in order to minimize travel time and increase cost effectiveness of the program.

The original program had a target of 50 engines to be tested in the baseline survey. Based on the engines located at each site and the engine distribution by horsepower, an engine quota was developed. These quotas, presented according to sites on Table B-2 in Appendix B, were developed to indicate the minimum number of engines of a given make and model that should be tested.

The piston engines were then grouped according to manufacturer and model and are presented as Table B-3 of Appendix B. The actual tests conducted on each engine as well as the rated horsepower and engine speed may be found on Table B-3.

On a small number of piston engines, manufacturers rated engine speed and load could not be attained because of field modification of the engine, station operating procedure, or inability to load the engine during the site survey. For each emissions test run, engine speed, power output, fuel rate and other operational data were collected and are reported. A brief description of reciprocating engines tested during the emissions baseline study is included in Appendix B as Table B-4. This description was taken from Reference 13. Gas turbine groupings by manufacturer and model are found in Table B-5.

During testing at each site, the individual gas transmission company obtained a fuel sample and provided the fuel gas analysis according to their standard procedures. The fuel gas analysis provided at each of the sites is presented in Table B-6 of Appendix B. This analysis was used in calculating the emission rates. Some stations had more than one fuel supply and some stations provided several fuel analyses during testing.

Once the baseline emissions study was under way, it was apparent that all gas transmission companies would not use the same procedure for measuring horsepower or fuel consumption. It was also obvious that not all emissions tests could be conducted using the equal area cross lowered into the stack. A list of the sample acquisition systems and measurement methods for horsepower, fuel and sampling for all emission tests is found in Table B-7.

During the on-site testing, documentation photos were obtained at each station to illustrate the equipment, sampling systems and engines tested. Figures B-1 through B-10 illustrate various views at each of the compressor stations depicting typical testing scenes.

D. Participation in Meetings and Conferences

In the conduct of this project, a number of conferences were held to discuss planning and summarize results. The following is a chronological description of the meetings in which SwRI participated.

On May 11, 1972, members of the AGA Supervising Committee on NO_x Research for Prime Mover Operations met with SwRI personnel to discuss Proposal No. 11-8563. This proposal was issued by SwRI at the request of AGA and was entitled "Measurements of Emissions from Piston and Gas Turbine Powered Natural Gas Compressor Stations." At this meeting, a review of the SwRI proposal was made and comments solicited with respect to approach, test equipment, etc. Subsequently, the proposal was approved and a steering committee was formed consisting of the following members:

Mr. Pete Susey (Chairman)
Columbia Gas System

Mr. James R. Hatfield
Northern Natural Gas Company

Mr. George Broussard
Panhandle Eastern Pipe Line

This committee was given the responsibility for the selection of engines and test sites and was the direct contact that SwRI was to use throughout the course of the project.

On September 13, 1972, several members of the AGA pipe line committee met at the first test site for a tour and review of the experimental set-up, sampling and analysis system. Mr. Pete Susey, Columbia Gas System and Chairman of the Steering Committee; Mr. Jim Hatfield, Northern Natural Gas Company, member of the Steering Committee; and Mr. Ronald Dischinger, Transcontinental Gas Pipeline Company, were able to be present. Messrs. Harry Dietzmann and Karl Springer, Southwest Research Institute, explained the emission test program and the test procedure which has been summarized in previous parts of this report. Experiments were under way with the Clark TCVC (Engine 4) during the visit. The final series of tests at different loads and speeds were being run.

Following the tour, a brief informal status review was presented by Mr. Harry Dietzmann including obvious trends in data noticed so far. The discussion covered the variations in HC, CO, and particularly NO_x from the various engines as well as the unexpected rather large percentage of NO_x as NO_2 in the raw exhaust relative to the NO and the total NO_x. Until this series of tests with large size slow speed gas fired compressor engines, other engines, gasoline and diesel fueled, have been found to produce only a small amount, less than three percent of the NO_x as NO_2 in the exhaust. This has been the case for small gasoline and diesel engines up to the largest truck gasoline and and locomotive size diesel engines. The up to 20 percent NO_x as NO_2 found with some of the compressor piston engines was a surprise, the reasons for which were not fully understood.

The discussion also covered the next test location and the planning of test. Finally, the planning for Phase B, the field survey, was discussed. Guidelines for the Steering Committee were an average of two days per engine would be needed once on site with the equipment. The number of engines per site and site location would, of course, be up to the Steering Committee, as will obtaining approval for test and gaining the cooperation of the company and their staff.

On October 31, 1972, the AGA held a meeting at the Hyatt House in Chicago, Illinois, to review Phase A of Project PR-15-61. Southwest Research Institute was invited to discuss the results of Phase A and describe the procedures and techniques proposed for Phase B. At this time, data in the form of emission results were informally presented and comments were solicited for additional data and/or format changes that should be incorporated. The Steering Committee Chairman, Pete Susey of the Columbia Gas System, made available to Southwest Research Institute engine population and installed horsepower based on information supplied by members of the American Gas Association. Using this engine population and the test sites selected by the Steering Committee, guidelines for Phase B engine tests were developed.

On January 30, 1973, a meeting was held at AGA headquarters with Mr. Tom A. Kittleman, Office of Air Programs; and Mr. Robert E. Hall, National Environmental Research Center, of the Environmental Protection Agency, Research Triangle Park, North Carolina; Mr. Sam

Cunningham, Chairman of the Emissions Subcommittee; Mr. Pete E. Susey, Leader of the SwRI Steering Committee; and Mr. Richard Schollhammer, Manager of Pipeline Research of AGA. The purpose of the meeting was to describe the compressor engine project with representatives of EPA and to open a dialogue between AGA and EPA on this item of mutual interest.

Karl Springer gave a slide presentation covering the types of equipment and instruments being used and the procedures developed for sampling, analysis, and computation of emission rates from a variety of different piston and turbine engines. No emission rates or emission data was discussed as the purpose was to explain what we were doing and how and why we were doing it.

It was learned that although new stationary gas turbines were actively under consideration for Federal regulation, SI engines were relatively lower priority and regulations regarding their emissions would be about two years away. Several possible approaches to cooperative or joint sponsorship of continuing compressor engine work were discussed before adjournment.

On February 22, 1973, Dr. Phillip S. Meyers, Professor of Mechanical Engineering, University of Wisconsin, visited SwRI and met with Karl Springer. Dr. Meyers was working as a consultant to the Diesel Engine Manufacturers Association (DEMA) on a test code for large piston engines. On the advice of Pete Susey, all facets of this program were described with the exception of specific data and results. The methods of stack sampling, sample location, instruments, sample treatment, etc., were covered in detail as were the methods used for calculation. For additional details of this meeting and the DEMA test code, please refer to Section II, H of this report.

On April 6, 1973, a meeting of the technical steering committee of the NO_x Supervisory Committee PR-15-61 was held at Southwest Research Institute in San Antonio, Texas. Members representing the American Gas Association and Southwest Research Institute were:

Richard Schollhammer
American Gas Association

Sam Cunningham
Southern California Gas

Pete Susey
Columbia Gas System

James R. Hatfield
Northern Natural Gas

George Broussard
Panhandle Eastern Pipeline

Don Scott
Columbia Gas System

Karl Springer
Southwest Research Institute

Harry Dietzmann
Southwest Research Institute

A project review was given by Southwest Research to provide the steering committee with the current project status, although no formal report of emission results were presented. The proposed EPA standard for NO_x emissions for stationary gas turbines was discussed. Consideration was given to additional work areas that might be considered as a follow-on to the current program. Modification to the current computer print-out format for emission rate expressions was discussed.

It was announced that Don Scott, Columbia Gas System, would replace Pete Susey on the steering committee. The chairmanship of this committee was then assumed by James Hatfield.

On May 8, and 22, 1973, Karl Springer met with members of the steering committee and the AGA Project Officer to discuss a cooperative project with representatives of DEMA. The May 8 meeting was held at AGA headquarters and the May 22 meeting was held at Kansas City. At both meetings, the progress and general findings of this project were reviewed for purpose of a cooperative AGA-DEMA follow-on NO_x abatement project.

On June 4, 1973, Dick Schollhammer and Karl Springer met with officials of the Texas Air Control Board in Austin, Texas. The objective of the meeting was to describe this project to the TACB on behalf of the Exxon Company who was represented by Carl Hester.

II. TEST TECHNIQUE DEVELOPMENT

Since there was only a limited amount of emissions data available on piston engines and gas turbines and essentially no information on test procedures, the first portion of the program dealt strictly with sampling procedures and test protocol. The results of this phase, subsequently called Phase A, established the test protocol to be used in the base emissions survey, Phase B. The experiments of Phase A were conducted at two sites, while the emissions survey encompassed eight additional compressor stations. Upon completion of Phase B, a total of 59 piston engines and nine gas turbines had been tested.

For purposes of this report, the procedural development is described by separate categories or "effects-of".

A. Effect of Sampling Point

Since it was uncertain whether access to the exhaust stack exit would be available, a series of experiments were conducted to determine the effect of sampling point on exhaust emissions. Several sampling locations were available on the Worthington UTC-10, Engine 1, Site 1. These probe locations were selected to determine changes in exhaust concentrations as the exhaust travels from the engine manifold through exhaust piping and snubber to the exhaust stack. The first position was at the engine manifold while the second location was near the exhaust entry into the snubber (pre-snubber). The other two probe locations were in the snubber itself and at the exhaust stack. Equal area multipoint probes were manifolded together for the engine manifold and the pre-snubber sample locations. The stack sampling probe was a multipoint equal area cross suspended from the top of the stack extending to a depth of 3 pipe diameters into the exhaust stack. The snubber sample was obtained directly from the snubber without a sampling probe. The sample was pulled through the exhaust pipe wall tap connection to the main sampling cart. This sampling point was not originally intended to be used; however, inspection of several other engines at the first test site indicated that this location should be included. An occasion could occur where access to the stack may not be available and exhaust samples may be obtained only through existing taps in the snubber.

This particular experiment required only a steady engine condition and constant pipeline conditions. All four of the sampling points were connected to a four-way sampling valve and the various positions could be selected with minimum time delay. The results of this experiment are found in Table 1, and the actual sampling locations along the exhaust

TABLE 1. THE EFFECT OF SAMPLING POINT ON EXHAUST EMISSION CONCENTRATIONS
(Worthington UTC-10, Engine 13)

Sampling Position[1]	NO, ppm	NO_x, ppm	NO_2, ppm	CO_2, %	HC, ppmC[2]	CO, ppm	O_2, %
Manifold	1055	1345	290	3.69	1533	22.84	15.4
Pre-Snubber	990	1260	270	3.63	1525	22.84	15.5
Snubber	990	1260	270	3.63	1525	22.84	15.5
Stack	1000	1270	270	3.63	1550	22.84	15.4

1 Each position sampled 2 or 3 times, depending on repeatability.

2 HC concentrations were very unstable.

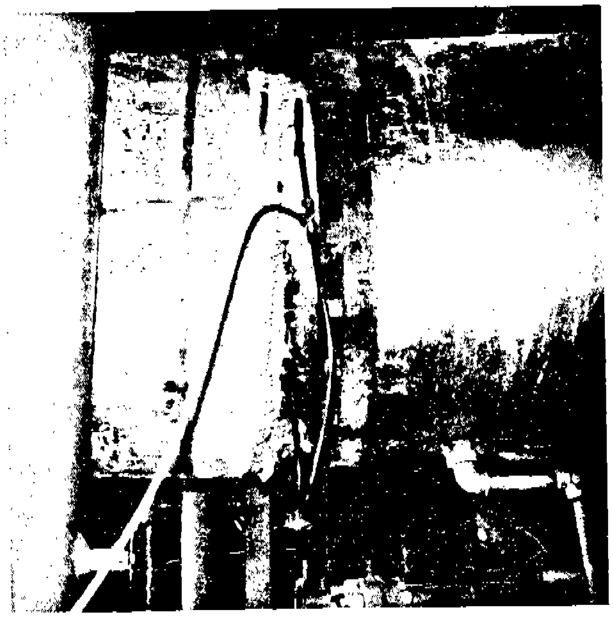
system of the Worthington UTC-10 are shown in Figure 1. Each position was sampled several times, and the order of position sampling was reversed to eliminate any possible engine or line condition changes. Three of the positions (stack, snubber and pre-snubber) produced equivalent emission results. The manifold sample position yielded slightly higher NO_x and CO_2, while the HC, CO, and O_2 levels were essentially equal to those of the other three positions.

Based on results of this 2-stroke normally aspirated Worthington UTC-10, samples could be obtained at two locations (snubber and pre-snubber) in the exhaust system and yield equivalent results to the stack. Sampling at the engine manifold should be avoided since emission concentrations may not agree with stack emission results.

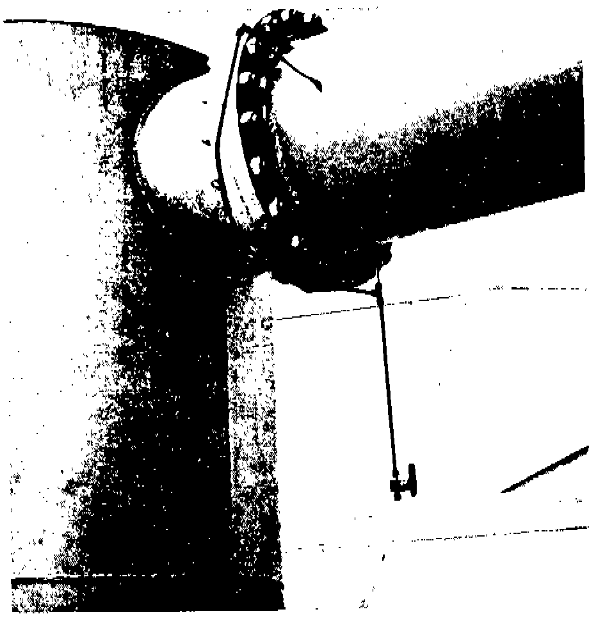
An experiment of similar design was conducted on the Clark TCVC-16, Engine Test 4, Site 1. Due to the physical limitations only two sampling points were available. The first was approximately ten feet into the stack. The second position was located in the exhaust system just prior to entry into the turbocharger. Each of the turbochargers were sampled separately and were connected to a multiport valve along with the stack sample. This allowed comparison of exhaust concentrations in the two exhaust systems as well as providing a comparison of "before and after" emission concentrations at the turbocharger. Also, changes in the exhaust concentrations as the exhaust moves through the system could be observed.

Figure 2 illustrates the sampling points in the Clark TCVC-16 exhaust system. Several tests were conducted, sampling at the stack, then the two pre-turbocharger positions and re-sampling at the stack. The results of these tests are found in Table 2, and a very interesting phenomenon was observed. As the NO_x passed through the exhaust system, little or no changes in the NO_x concentrations were observed; however, a significant change in the NO/NO_x ratio was observed. Prior to entry into the turbocharger, the NO_x was composed of typically 50 to 60 percent NO whereas the NO_x was composed of 80 to 85 percent NO in the exhaust stack.

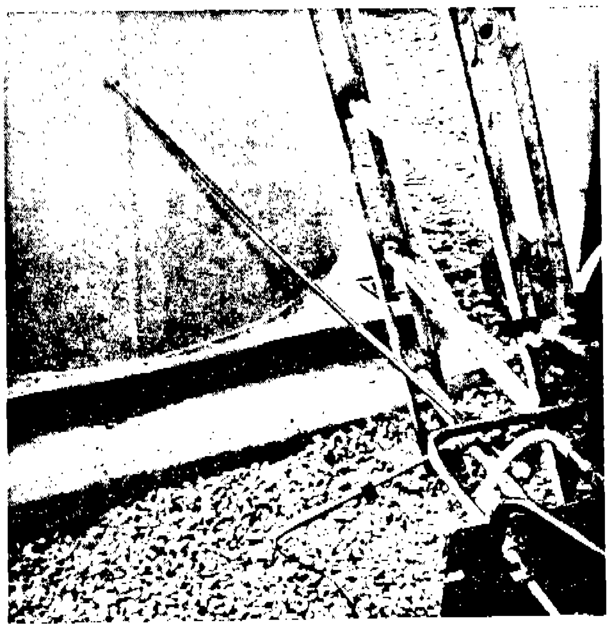
Although the temperatures of the exhaust before and after the turbocharger (TC) were not monitored, it is suspected that these temperatures were sufficiently high to enable the TC to function as a converter in the chemiluminescent analyzer. At temperatures and flow rates through the TC, it would not be expected that all the NO_2 in the exhaust would be converted to NO. The change in the NO/NO_x ratio is a significant point, particularly if sampling is performed using an instrument which is not capable of measuring NO_2, such as NDIR-NO. When exhaust samples are obtained prior to a turbocharger, extra care should be



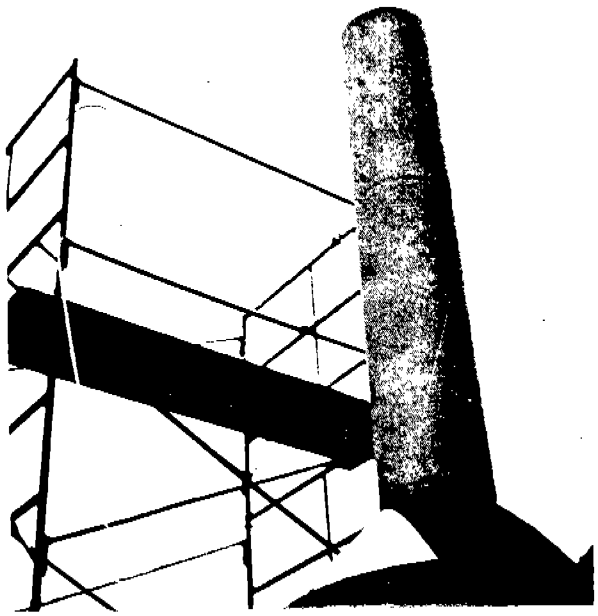
Exhaust Manifold



Pre-Snubber

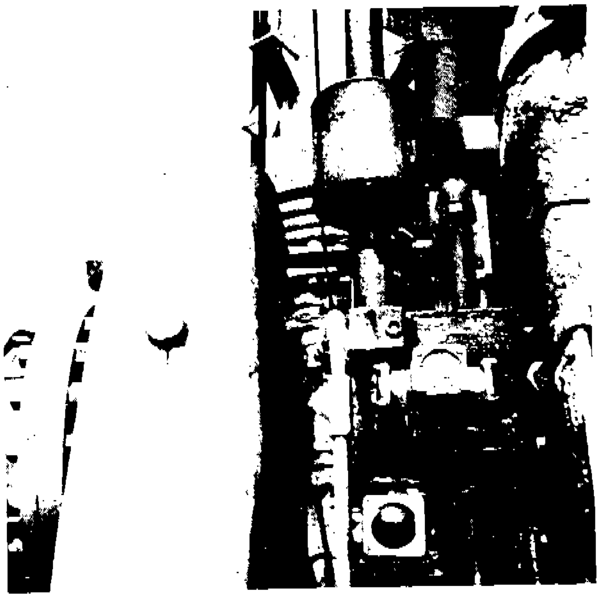


Snubber

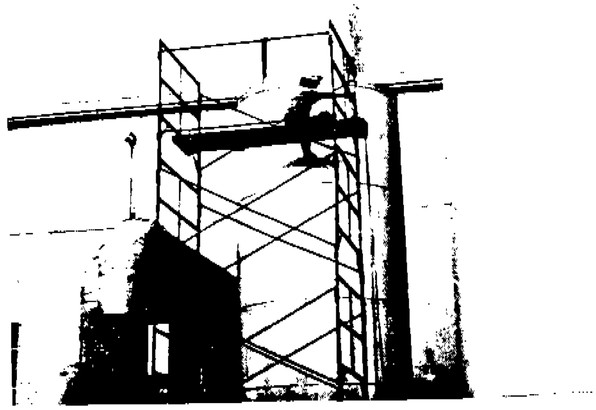


Stack

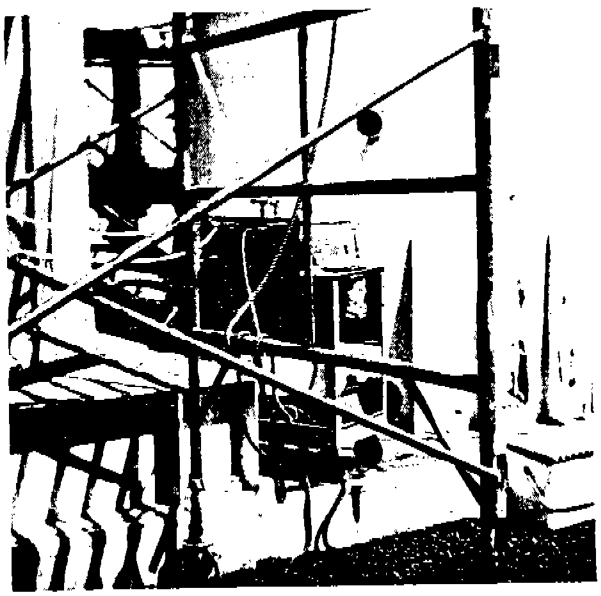
FIGURE 1. SAMPLING POINTS EMPLOYED IN DETERMINING AN EXHAUST SYSTEM EMISSION PROFILE ON A WORTHINGTON UTC-10



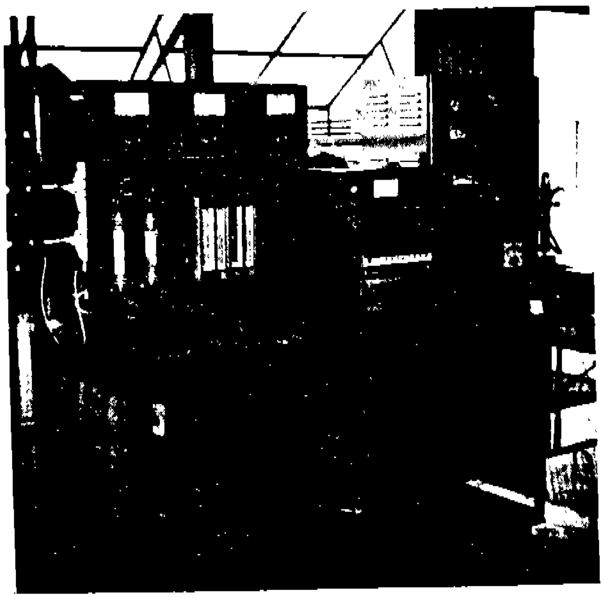
East Turbocharger Probe



Scaffolding, Probe and Stock



Ice Trap Cart



Instrument Cart

FIGURE 2. ASSORTED VIEWS OF SAMPLE LOCATIONS, AND SUPPORT EQUIPMENT EMPLOYED IN DETERMINING THE EFFECT OF SAMPLE LOCATION ON EXHAUST EMISSION OF CLARK TCVC-16, 2-STROKE TC, ENGINE 4, SITE 1

TABLE 2. THE EFFECT OF SAMPLING POINT ON EXHAUST EMISSION CONCENTRATIONS (CLARK TCVC-16, ENGINE NO. 4, SITE 1)

Test	Sample Location	NO, ppm	NO_x, ppm	NO_2, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
1	Stack	870	1035	165	4.11	630	745	13.3
1	TC-east	600	1035	435	4.24	750	660	13.3
1	TC-west	615	1065	450	4.37	600	600	13.5
1	Stack	870	1065	195	4.24	680	715	13.4
2	Stack	870	1035	165	4.05	640	690	13.4
2	TC-east	630	1035	405	4.11	710	660	13.3
2	TC-west	615	1035	420	4.24	630	715	13.3
2	Stack	870	1050	170	4.11	680	660	13.3
3	Stack	885	1080	195	4.05	620	815	13.3
3	TC-east	690	1095	405	4.11	680	815	13.2
3	TC-west	705	1155	450	4.24	585	815	13.2
3	Stack	915	1155	240	4.11	645	815	13.2

exerted to insure proper NO_x converter operation. Other species in the exhaust, namely, CO, HC, and O_2, were found to have little or no changes in concentration passing through the turbocharger. However, a slight change in CO_2 was observed. The CO_2 emissions of the east turbocharger and the second stack sample agreed well, while the west turbocharger was slightly higher.

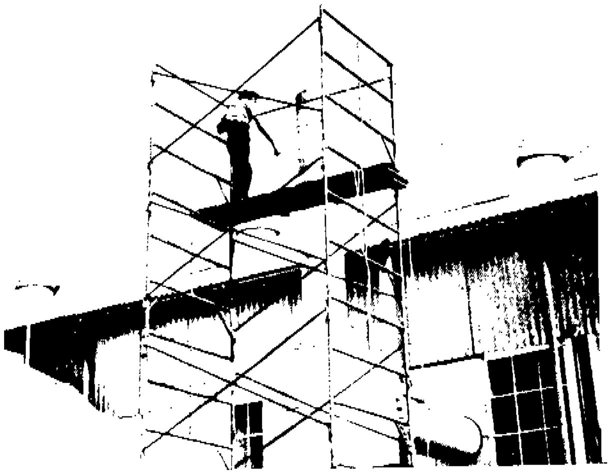
Initial plans called for sampling turbine exhaust from the General Electric Frame 3 gas turbine at two different sampling points. However, at the particular station selected, the GE Frame 3 was the only unit at the station; and it was not possible to shut the plant off for the time required to install the probes near the exhaust outlet proper. This would have involved approximately 24 hours of down time, and the practicality versus usefulness of the additional data was judged to be insufficient.

Based on several experiments on two piston engines, one 2-stroke normally aspirated and one 2-stroke turbocharged, exhaust samples may be obtained at various locations and produce results equivalent to stack samples. Two items should be noted from these experiments. First, sampling at the engine manifold produces slightly different concentrations than stack levels. Second, obtaining an exhaust sample prior to the turbocharger produced significant differences in the NO/NO_x ratios. This could be important if corrections for NO_2 losses in the ice trap system are to be applied. All gas turbine samples were obtained in the stack at a depth of four feet from the plane of the stack exit.

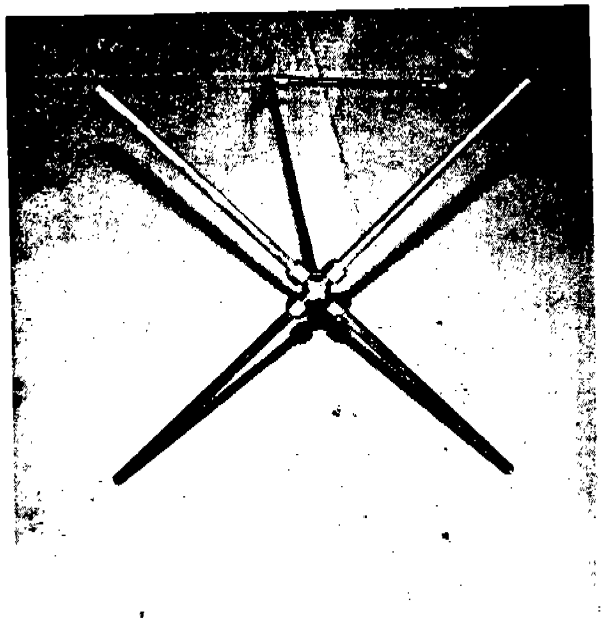
B. Effect of Stack Sampling Depth

Several experiments were conducted to determine the effect of stack sampling depth on exhaust emission concentrations. These experiments were performed to determine any possible experimental differences or errors in exhaust concentrations due to the atmospheric dilution. These experiments were performed by lowering an equal area stainless steel probe into the top of the exhaust stack. Probes were lowered manually into the stack from a scaffold adjacent to the stack. Several illustrations of the probe and assorted sample handling equipment are shown in Figure 3.

The probe was lowered to depths of 1 pipe diameter (19.5 inches), 2 diameters (38.0 inches) and 3 diameters (58.5 inches). In this manner, it could be determined if dilution was experienced near the stack exit, the depth where dilution became apparent, and to what degree were the exhaust concentrations affected. The engine and compressor suction and discharge pressures were maintained as stable as possible during the test. Approximately ten minutes were required per sample depth, with leak checks being

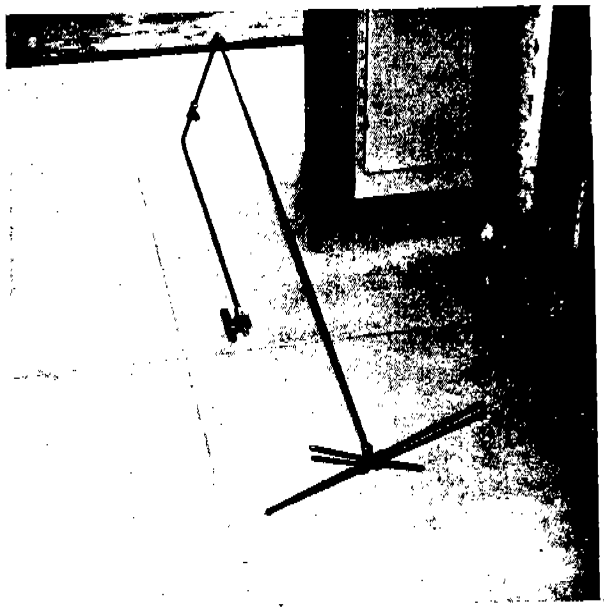


Sample Probe Location



Sample Probe - View 1

Ice Trap Cart



Sample Probe - View 2

FIGURE 3. SAMPLE DEPTH PROBES, ASSORTED SAMPLING EQUIPMENT AND EMISSION MEASUREMENT INSTRUMENTATION (Worthington UTC-10, Engine 13)

performed when changing probe depths. A tap was available in the snubber at ground level, and consequently a sample line was connected to this point. It should be noted that the snubber sample did not have an equal area probe but pulled the sample through the wall tap.

The effect of stack sampling depth on exhaust emission concentrations is presented in Table 3. The results of this experiment indicate that the probe should be kept at or below 3 pipe diameters from the tip of the stack to avoid any possible dilution. The most steady exhaust emission measured in this test was CO_2; and generally under steady engine operating parameters, a change in CO_2 concentrations is the best indicator of atmospheric dilution.

When analyzing the data in Table 3, it is apparent that several exhaust species indicate some atmospheric dilution near the stack exit. Both CO_2 and NO_x concentrations increase until a probe depth of 3 pipe diameters is reached. Although the converse was true of O_2, the slight change in O_2 is considered insignificant. These two species indicate that preservation of sample integrity may be assured by sampling three or more pipe diameters below the stack tip. The unsteadiness of HC emissions prohibit making any definite conclusions based on HC emissions. The HC concentrations varied as much as 200 to 300 ppm C, and obtaining a visual recorder average was difficult. The HC emissions trace appeared more like a gas chromatograph trace with a continuous trace of peaks. The CO concentrations were obtained using the high range CO instrument, and the CO concentrations remained near zero levels throughout the test. Any changes should be considered negligible.

It should be noted that the sample probe located at 3 pipe diameters from the stack exit produced essentially the same emission concentrations as the sample obtained from the wall of the snubber. Additional work describing the effect of sampling point (stack, snubber, manifold) is discussed elsewhere in this report.

Similar experiments were originally scheduled for the Clark TCVC-16 (Engine Test 4, Site 1) and the General Electric Frame 3 (Engine Test 5, Site 2). However, the extreme height and the unavailability of sufficient scaffolding eliminated this experiment on the Clark TCVC-16. The experiments involving the effect of sampling depth on emission concentrations from the GE Frame 3 were not necessary for several reasons. First, unlike the piston engine and its acoustic pulsating exhaust, the gas turbine is a steady flow machine. This reduces the possibility of back flow of the atmosphere into the exhaust duct and exhaust dilution down in the exhaust stack. Second, the individually customized exhaust systems are not as uniform as piston engine exhaust stacks. That is, some units are regenerative and have assorted tubing of various configurations in the exhaust

TABLE 3. THE EFFECT OF STACK SAMPLING DEPTH ON EXHAUST EMISSION CONCENTRATION (WORTHINGTON UTC-10, ENGINE TEST 1, SITE 1)

Sample Depth		Exhaust Emission Concentration					
Diameters	Inches	NO, ppm	NO_x, ppm	CO_2, %	HC, ppmC	CO, %	O_2, %
1	19.5	960	1230	3.57	1250	0.02	15.3
2	38.0	960	1230	3.57	1300	0.02	15.3
3	58.5	1050	1365	3.63	1300	0.00	15.2
Snubber		1050	1380	3.63	1300	0.00	15.2

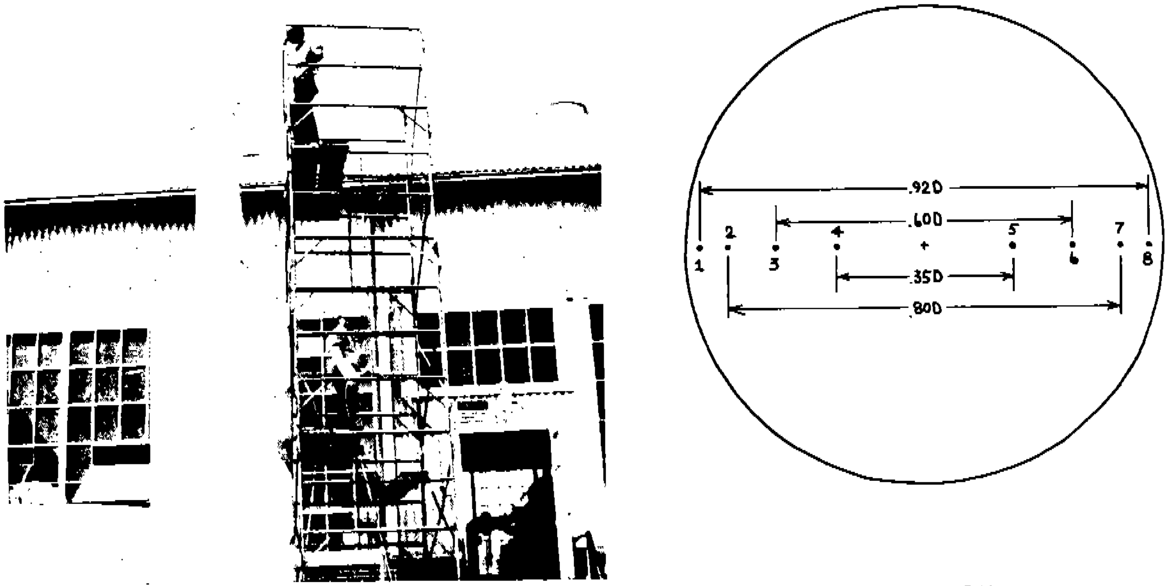
stack while other units have oil vents, etc., that vent into exhaust stack several feet from the top of the exhaust stack. When obtaining an exhaust sample from gas turbine exhaust, the procedure was to sample prior to any oil vents entering into the exhaust stack. As a result, all turbine measurements were made identically in that some turbine oil vents were separate from the main gas turbine exhaust stack.

C. Exhaust Stack Traverses

Experiments were conducted to determine if and to what extent sample stratification occurred in the exhaust system. Previous tests determining the effect of sample location on exhaust emissions provided three available locations. These three points were at the engine manifold, at the pre-snubber flange and at the stack exit. The traverse was obtained by inserting a 3/8" SS tube with a single 1/16" opening facing into the exhaust stream. The end of the traverse probe was welded shut so that the only opening was the 1/16" hole. By sliding the probe through a thermocouple connector at specific distances into the stack, an emissions profile is obtained on that particular traverse.

When obtaining the traverses at the stack, the scaffolding had to be moved, and this required 30 to 40 minutes which might make a difference when comparing the absolute emission levels of the traverses at a given location in the system. The first traverses for this exhaust stack were in an east-west position. The results of this traverse are presented in Table 4, and the stack traverse and sample positions are shown in Figure 4. As shown in Table 4, there was essentially no stratification as CO_2 values did not change from one side of the stack to the other. There was only a slight change in the NO_x which showed a slight decrease at the positions adjacent to the stack wall. It was very difficult to make a definite conclusion regarding hydrocarbons due to highly unstable HC emissions. The CO levels in this particular engine were low and provided no insight as to the extent of stratification in the exhaust sample.

Once the east-west traverse was completed, the scaffolding was moved to permit sampling from the north-south position. The results are presented in Table 5, and the traverse probe positions along with the traverse scaffolding are shown in Figure 5. As noted in Table 5, the degree of stratification observed was only slight. As a matter of fact, no stratification was indicated by the CO_2, O_2 or NO_2 concentrations. The NO concentration was slightly less at the southernmost traverse position in the exhaust stack. The unsteadiness of the HC emissions and the near zero levels of CO prohibit their evaluation as a possible indicator of stratification.



ID = 19.5"

FIGURE 4. STACK TRAVERSE (ONE PIPE DIAMETER INTO STACK, FACING WEST) ON WORTHINGTON UTC-10

TABLE 4. EMISSION SUMMARY FOR STACK TRAVERSE (ONE PIPE DIAMETER INTO STACK, FACING WEST) ON WORTHINGTON UTC-10

	Emissions Concentration						
Sample Position	CO_2, %	O_2, %	NO, ppm	NO_2, ppm	NO_x, ppm	CO, %	HC, ppmC
1	3.63	13.8	1080	435	1515	0.0	975
2	3.63	14.5	1095	450	1545	0.0	950
3	3.63	14.5	1095	465	1560	0.0	950
4	3.63	14.5	1080	480	1560	0.0	925
5	3.63	14.5	1095	480	1575	0.0	900
6	3.63	14.5	1095	465	1560	0.0	875
7	3.63	14.6	1080	480	1560	0.0	850
8	3.63	14.6	1065	450	1515	0.0	850

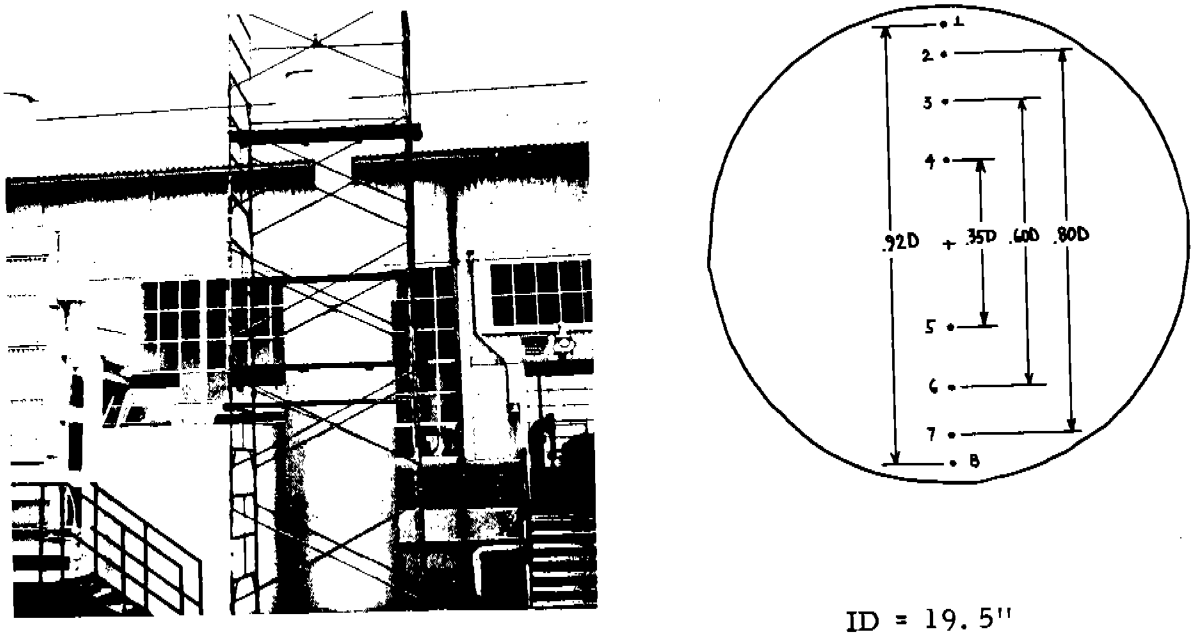


FIGURE 5. STACK TRAVERSE (ONE PIPE DIAMETER INTO STACK, FACING NORTH) ON WORTHINGTON UTC-10

TABLE 5. EMISSIONS SUMMARY FOR STACK TRAVERSE (ONE PIPE DIAMETER INTO STACK, FACING NORTH) ON WORTHINGTON UTC-10

	Emissions Concentrations						
Sample Position	CO_2, %	O_2, %	NO, ppm	NO_2, ppm	NO_x, ppm	CO, %	HC, ppmC
1	3.63	14.4	1065	360	1425	0.0	850
2	3.63	14.4	1065	345	1410	0.0	800
3	3.63	14.3	1065	345	1410	0.0	850
4	3.63	14.3	1065	345	1410	0.0	850
5	3.63	14.3	1050	345	1395	0.0	800
6	3.63	14.3	1035	345	1380	0.0	800
7	3.63	14.3	1035	345	1380	0.0	850
8	3.57	14.3	1020	345	1365	0.0	900

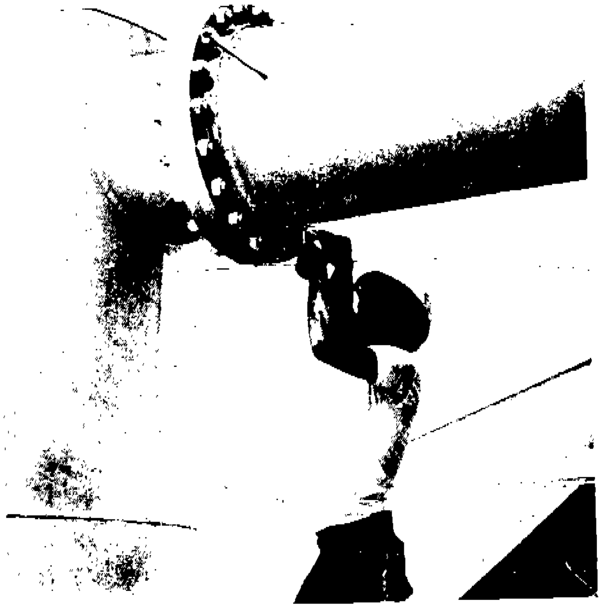
The most noticeable difference in the emission levels of the two traverses was NO_2. The decrease in the NO_2 is suspected to be due to absorption of NO_2 on the condensed water in the ice traps. The sampling period would have been sufficient to produce enough condensed water for this to occur. Subsequent traverse experiments were conducted with periodic draining of the water condensate. Changes in NO_2 concentrations as a function of sampling time were not observed.

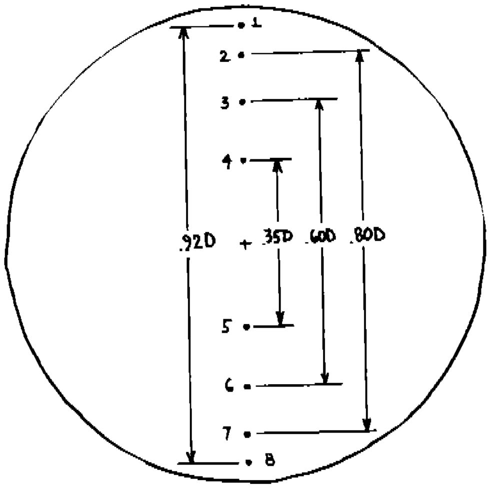
The second location for the exhaust traverses was at the pre-snubber flange. Figure 6 illustrates the position of the traverse and the location of the individual test points in the vertical traverse. The emission levels at these various positions in the vertical traverse are found in Table 6. Again, as with the stack traverses, the CO_2 level remained constant throughout the range of positions in the vertical traverse. The horizontal traverse is illustrated in Figure 7, and the emission results are presented in Table 7. The time required to change from the vertical to the horizontal traverses was only 5 to 10 minutes, and no changes in the engine operating conditions were observed. Between the two traverses, only insignificant changes in NO, NO_2, and NO_x were observed. HC levels were unsteady for both traverses and the CO levels were low.

The third location used for traverse experiments was near the engine manifold. The positions of the probe location along with photographs of the traverse locations are shown in Figure 8. The results of these traverse experiments were essentially the same as results of the pre-snubber traverse experiments. That is, no significant changes in NO, NO_2, NO_x, CO_2, O_2, or HC were observed.

A similar experiment was conducted to determine the degree of stratification that might be expected when sampling from the stack of a gas turbine. The sampling probe was a cross-section network which was designed such that the sample openings were at the center of equal areas. Each of these openings, facing directly into the exhaust flow, were sampled individually thereby allowing a traverse of the exhaust stack to be obtained.

Figure 9 illustrates a top view of the probe network schematic. The probe extended four feet down into the exhaust stack. Each probe opening was sampled separately for the traverse experiment, and the individual positions are noted in Figure 9. Typical views of gas turbine exhaust sample handling equipment and emissions instrumentation used in this study is shown in Figure 10. The corresponding emission concentrations for these positions are presented in Table 8. Position nine was the only position which produced emission concentrations different than the remaining positions. For this particular position, all emission



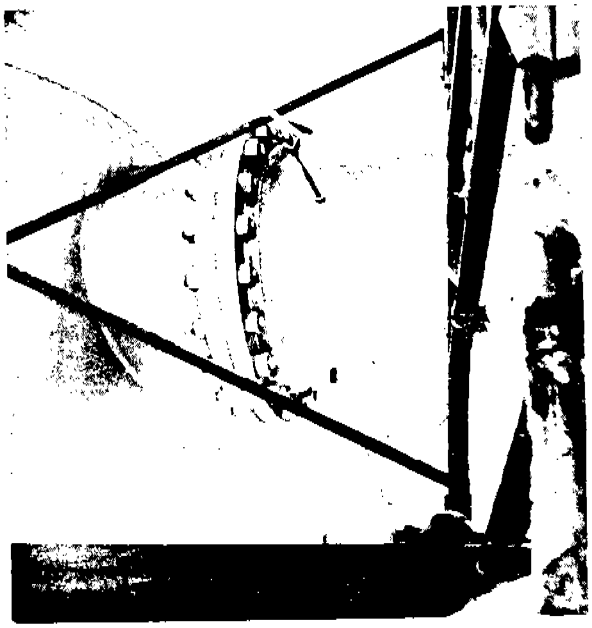


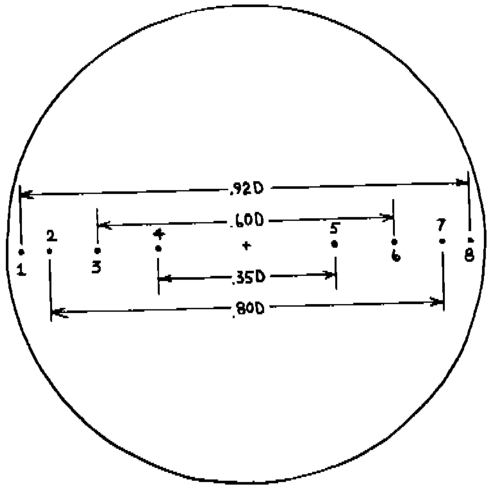
Vertical, ID = 24.0"

FIGURE 6. EXHAUST TRAVERSE (VERTICAL, AT SNUBBER FLANGE) ON WORTHINGTON UTC-10

TABLE 6. EMISSIONS SUMMARY FOR EXHAUST TRAVERSE (VERTICAL, AT SNUBBER FLANGE) ON WORTHINGTON UTC-10

	Emissions Concentration						
Sample Position	CO_2, %	O_2, %	NO, ppm	NO_2, ppm	NO_x ppm	CO, %	HC, ppmC
1	3.63	15.4	1185	240	1425	0.01	1050
2	3.63	15.6	1185	240	1425	0.01	1050
3	3.63	15.6	1155	270	1425	0.01	1050
4	3.63	15.7	1125	300	1425	0.01	1000
5	3.63	15.5	1155	270	1410	0.01	1050
6	3.63	15.4	1155	270	1425	0.01	1100
7	3.63	15.5	1185	240	1425	0.01	1050
8	3.63	15.5	1185	240	1425	0.01	1050



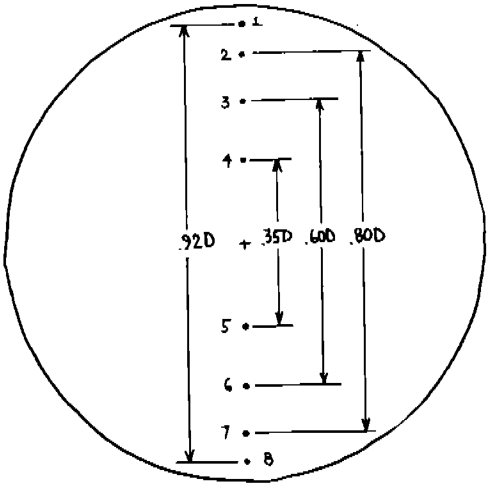


Horizontal, ID = 24.0"

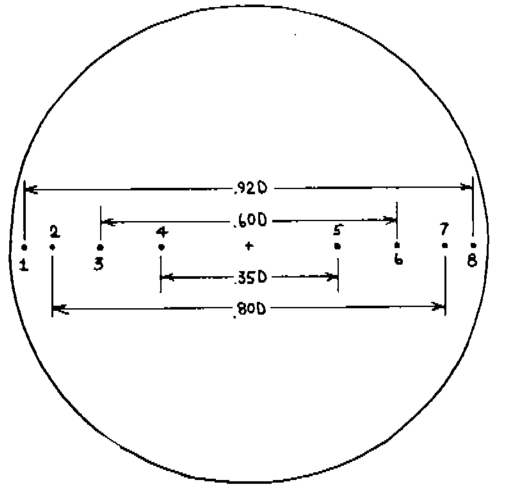
FIGURE 7. EXHAUST TRAVERSE (HORIZONTAL, AT SNUBBER FLANGE) ON WORTHINGTON UTC-10

TABLE 7. EMISSIONS SUMMARY FOR EXHAUST TRAVERSE (HORIZONTAL, AT SNUBBER FLANGE) ON WORTHINGTON UTC-10

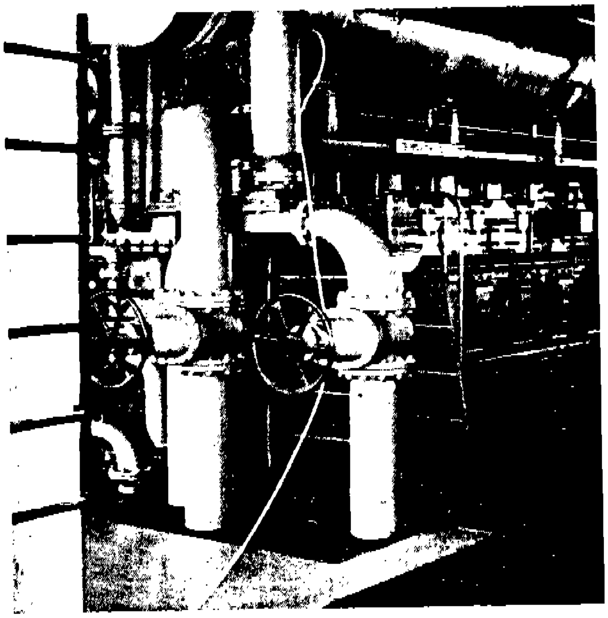
Sample Position	Emissions Concentration						
	CO_2, %	O_2, %	NO, ppm	NO_2, ppm	NO_x, ppm	CO, %	HC, ppmC
1	3.63	15.5	1185	255	1440	0.01	1050
2	3.63	15.5	1185	270	1455	0.01	1050
3	3.63	15.4	1200	255	1455	0.01	1050
4	3.63	15.5	1200	255	1455	0.01	1100
5	3.63	15.5	1200	255	1455	0.01	1050
6	3.63	15.6	1185	255	1440	0.01	1050
7	3.63	15.5	1200	255	1455	0.01	1050
8	3.63	15.5	1200	240	1440	0.01	1100



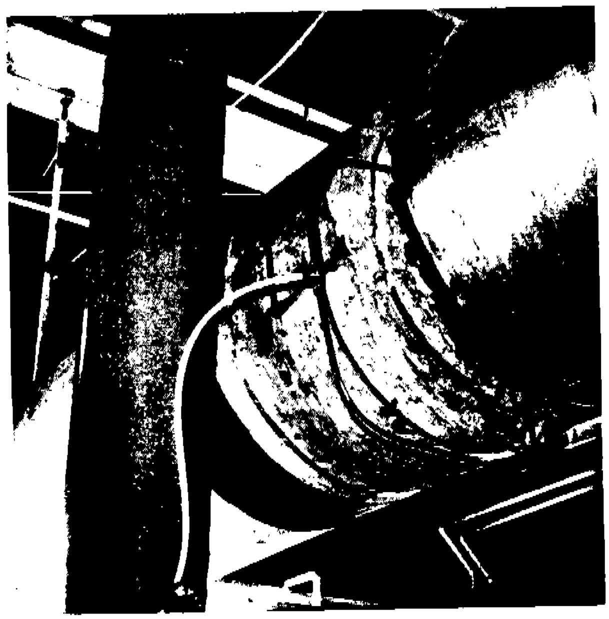
Vertical Traverse, ID = 24.0"



Horizontal Traverse, ID = 24.0"



Traverse Positions Manifolded Together - Overall



Traverse Positions Manifolded Together - Close-up

FIGURE 8. VERTICAL AND HORIZONTAL TRAVERSES AT ENGINE MANIFOLD (WORTHINGTON UTC-10)

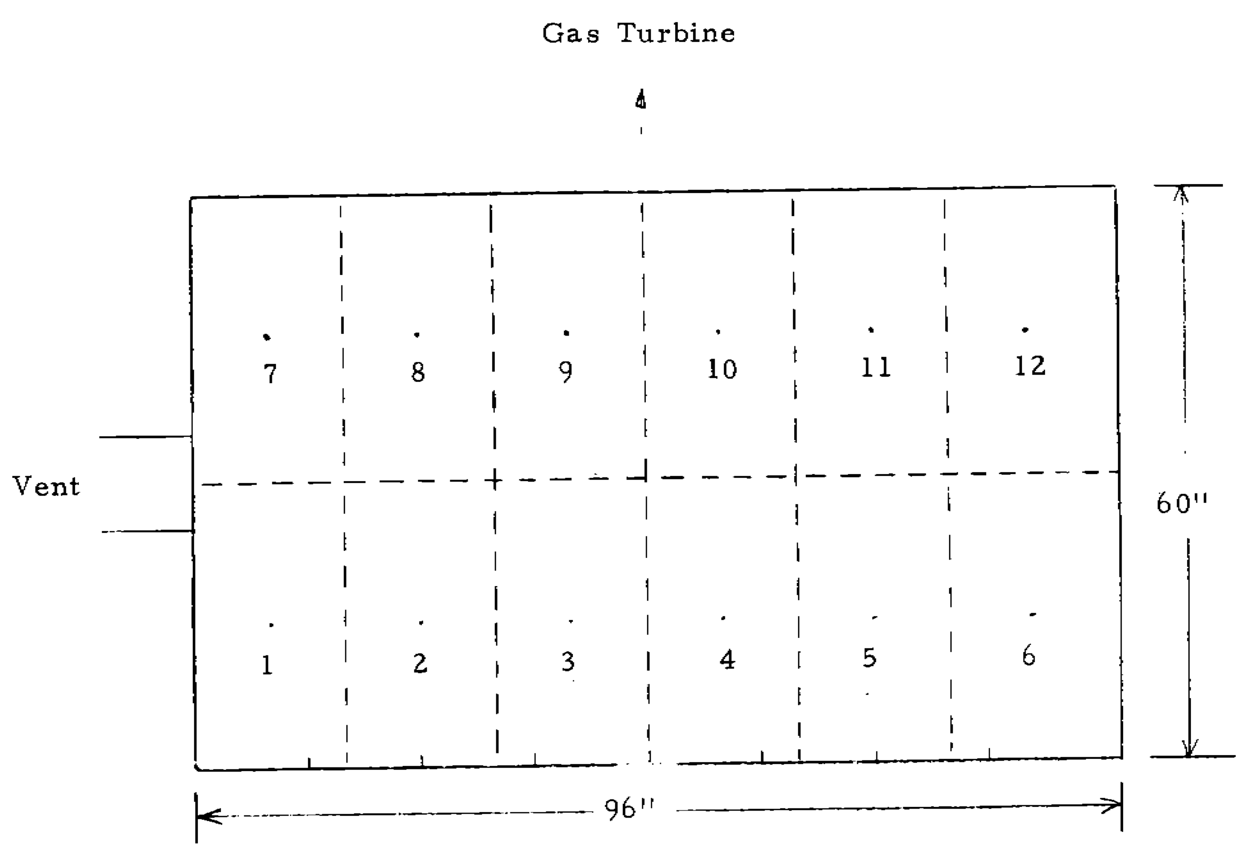
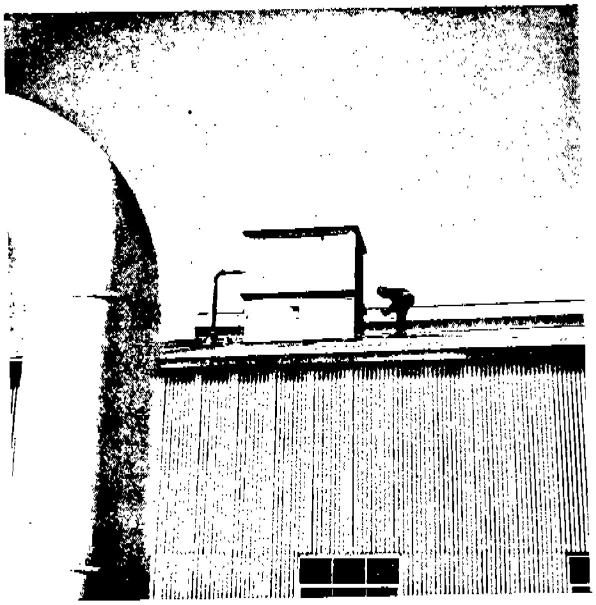


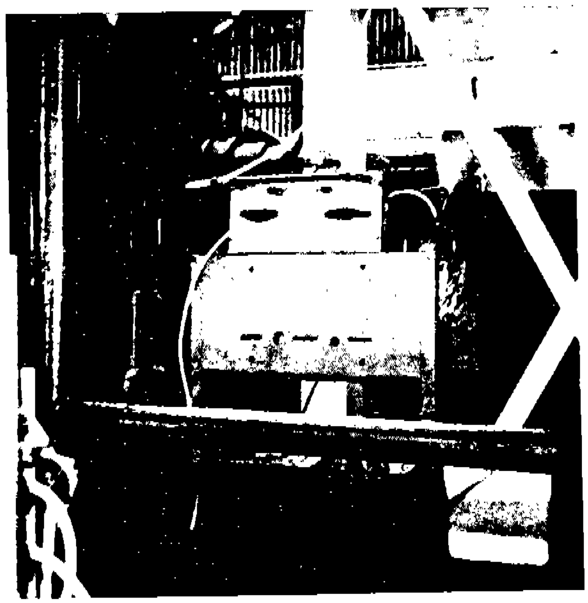
FIGURE 9. TRAVERSE SAMPLING POINTS IN GENERAL ELECTRIC FRAME 3 GAS TURBINE EXHAUST STACK



Exhaust Stack with Probe

Sample Line from Probe

Emissions Instrumentation Cart



Ice Trap Cart

FIGURE 10. TYPICAL VIEWS OF GAS TURBINE EXHAUST SAMPLE HANDLING AND EMISSIONS INSTRUMENTATION

TABLE 8. EMISSION CONCENTRATIONS AS A FUNCTION OF PROBE OPENING - GE FRAME 3

Position No.	Emission Concentrations - Traverse				
	NO_x, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
1	40.5	2.47	1.5	6.7	16.3
2	40.0	2.57	1.0	6.7	16.3
3	40.0	2.57	1.0	6.7	16.2
4	39.5	2.57	1.5	6.7	16.2
5	39.5	2.57	1.0	7.0	16.1
6	40.5	2.57	1.0	7.3	16.2
7	41.0	2.47	1.0	6.1	16.0
8	40.5	2.47	1.0	6.4	16.3
9	34.0	2.12	1.5	5.8	16.7
10	40.0	2.47	1.5	6.4	16.3
11	39.5	2.47	1.5	6.8	16.3
12	39.5	2.47	1.5	6.8	16.3

concentrations (except HC) were noticeably low, while the O_2 reading was slightly higher. The differences between opening nine and the other eleven openings was apparently real, since the experiment was repeated several times. A check was made to insure opening nine tubing was leak-tight and reliable. Regardless, the emissions data of Table 8 point to dilution as would occur with a faulty or leaky sample line. Under the adverse field test circumstances encountered, it is difficult to conclude that the exhaust was actually stratified especially since the location is quite unlikely to be stratified.

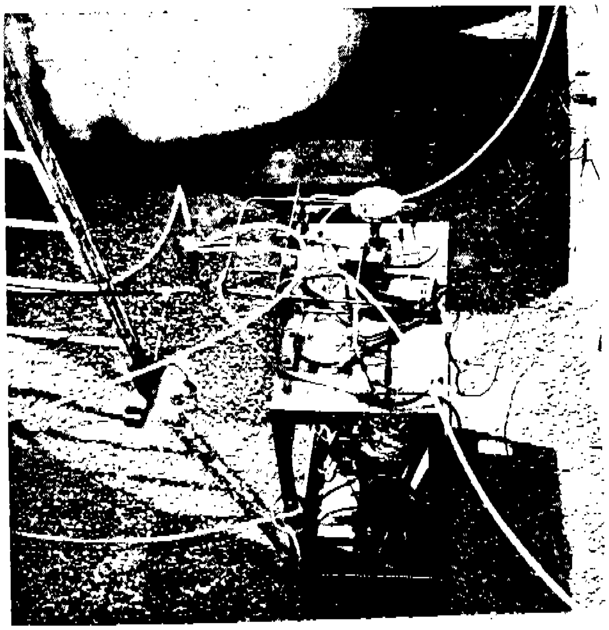
Based on traverse experiments on both piston engines and gas turbines, no significant stratification was observed. Although no stratification was observed, stack sampling from piston engines during the remainder of the project was conducted using a multipoint equal area probe lowered into the stack. Due to the amount of time required to fabricate and install probe network into each of the gas turbines, a slightly different approach was used. Generally, the participating gas companies were reluctant to change the gas turbine operating conditions and thus the time and cost required to obtain one data point from the gas turbine was excessive.

Since it was demonstrated that sample from a depth of four feet into the stack produced no significant stratification, samples were obtained using a probe similar to that used when sampling piston engines. That is, a multipoint probe connected by appropriate tubing so that it could be held from outside the stack and moved throughout the exhaust during actual sampling. This technique proved to be quite satisfactory and could be used on all gas turbines selected for testing in the baseline emissions study.

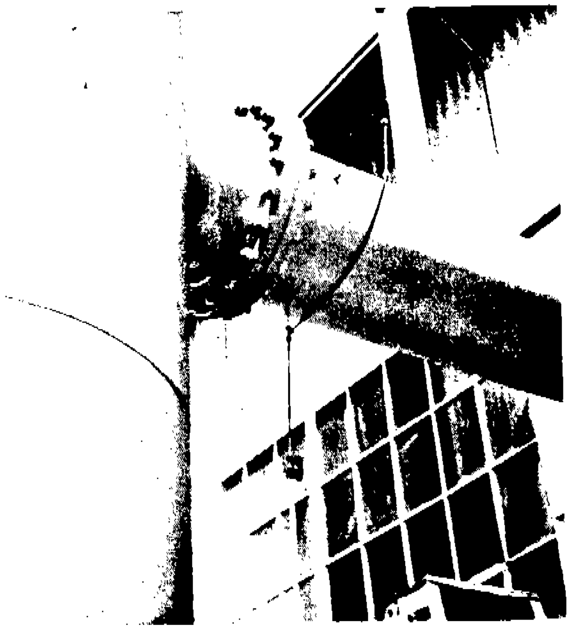
D. Bag Sampling Verification

During Phase A of the program, it was uncertain as to whether direct continuous exhaust sampling could be used on all of the piston engines selected for testing. To insure maximum utilization of test equipment when on site, several experiments were conducted to verify the bag sampling procedures. Bags used in this study were made of Tedlar® and constructed such that an SS quick-connect was the only entry into the bag. Several views of bag sampling equipment in service are presented in Figure 11. Bags were evacuated and purged with zero-grade nitrogen or air and re-evacuated prior to a bag test.

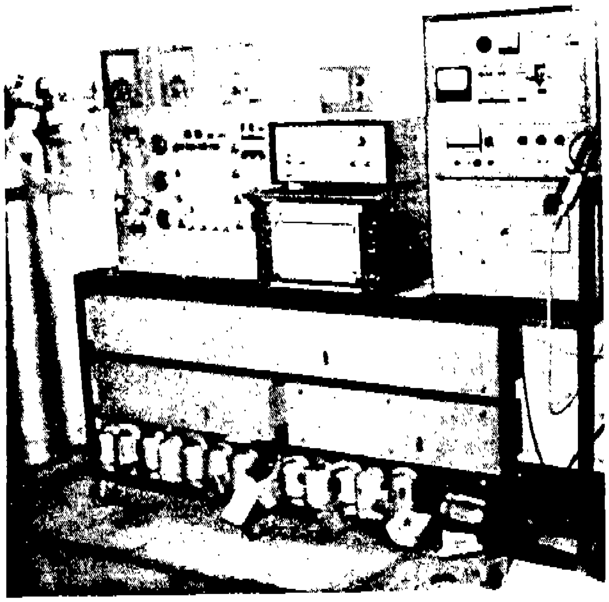
® E. I. du Pont de Nemours and Company, Inc.



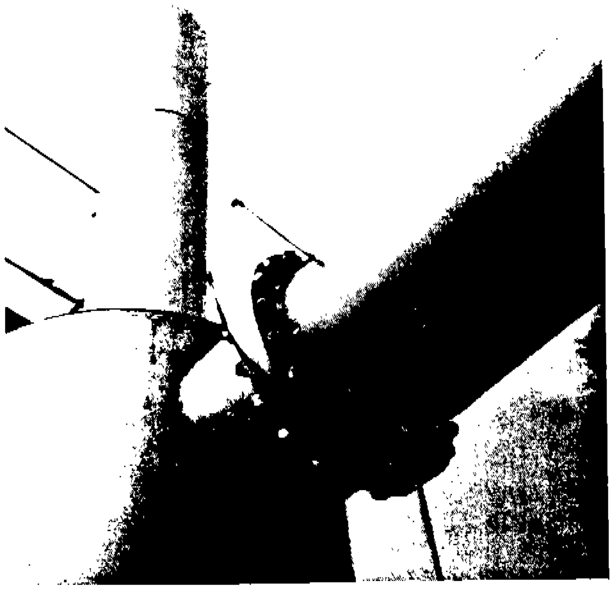
Bag Sampling Cart



Sampling Location - View 1



Instrumentation Cart



Sampling Location - View 2

FIGURE 11. VARIOUS PHOTOS OF BAG SAMPLING EQUIPMENT, PROBE LOCATION, AND INSTRUMENTATION
(Worthington UTC-10, Engine 13)

To verify that bag samples produced the same results as continuous sampling, several tests were conducted on the Worthington UTC-10. Two bags were used, one being obtained before and one after the continuous sample at a constant engine operating condition. This procedure was repeated on several different days. Hydrocarbons were very unsteady during the continuous testing and concentrations presented in Table 9, along with other emissions data, were "eye-ball" averaged and not time integrated. Therefore, since there was an excellent agreement between the bag and continuous samples for CO_2, CO and NO_x, the bag sample would be a much better approximation of the HC concentration in the continuous sample since it is actually an average sample. That is, the sample was obtained

TABLE 9. BAG SAMPLING VERIFICATION[1] FROM WORTHINGTON UTC-10, ENGINE 13

Test No.	Date	Sample	NO_x, ppm	CO_2, %	HC, ppmC[2]	CO, ppm	O_2, %
		Bag 17	1565	3.63	1180	-[3]	15.3
1	8-21-72	Continuous	1560	3.63	1200	-	15.5
		Bag 20	1565	3.63	1200	-	15.3
		Bag 21	1200	3.51	1600	22.8	15.4
2	8-22-72	Continuous	1185	3.51	1650	22.8	15.3
		Bag 13	1200	3.51	1550	21.9	15.0
		Bag 17	1200	3.51	1500	22.8	15.0
3	8-22-72	Continuous	1230	3.51	1650	22.8	15.0
		Bag 20	1230	3.51	1500	22.8	14.9
		Bag 16	1215	3.51	1550	22.8	15.2
4	8-22-72	Continuous	1245	3.51	1500	22.8	15.6
		Bag 11	1230	3.51	1600	22.8	15.4

1 Time from sampling to analysis of bag contents less than 10 minutes.
2 Continuous HC concentrations were very unstable.
3 High range CO instrument used on first day of testing, no CO found.

over a 5 to 10 minute sampling period and the concentration would be an average over the sampling period.

Results of these tests indicate that bag samples agreed well with the continuous samples. The bag samples were analyzed within 10 minutes after the bag was filled with the exhaust sample. The lag time apparently did not affect any of the CO_2, NO_x, HC, CO and O_2 emissions; however, the NO concentration was meaningless due to the NO $\longrightarrow$ NO_2 conversion.

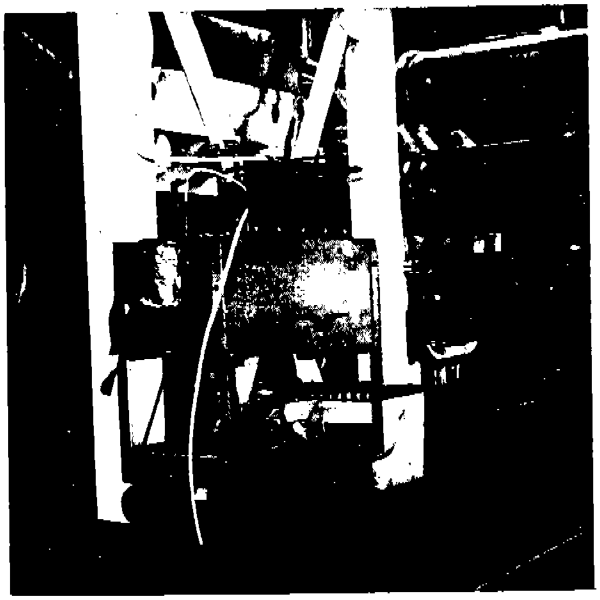
Similar tests were conducted on the Clark TCVC-16, a 2-stroke TC engine. Results of these tests agreed well with the findings of the bag versus continuous experiments conducted on the Worthington UTC-10. That is, that identical concentrations could be obtained provided the exhaust sample had been properly conditioned.

As with the two piston engines, a series of experiments was conducted to validate bag samples from a natural gas fired Frame 3 General Electric gas turbine. The objective of this study was to determine if a bag sample of gas turbine exhaust would give different readings from the continuous sample. A continuous sample was obtained directly from the exhaust stack via a multi-opening probe network lowered into the exhaust stack. After the data for the continuous sample was obtained, a previously-evacuated bag was filled with an exhaust sample. The bag sample passed through the ice trap before entering the bag just as the continuous sample. This removed most of the moisture in the exhaust sample and particulate which might be present.

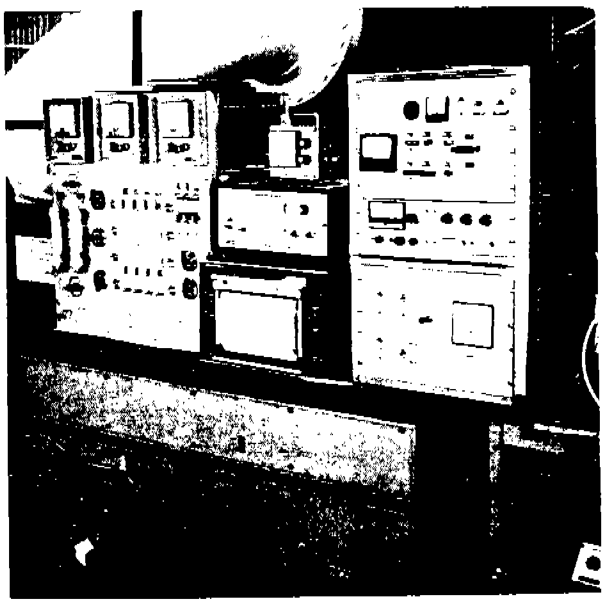
As soon as the bag was filled, it was analyzed using the continuous instrument cart. Generally, the time lapse between the start of filling the bag and the actual analysis was on the order of three to five minutes. These experiments involved six bags obtained at different times during the day and compared to a continuous sample taken before and after the bag sample. Figure 12 illustrates several operations involved in obtaining and analyzing a bag sample. The results of this study are presented in Table 10. The percent difference between the bag and continuous concentrations were calculated based on the continuous sample as the base or absolute value. When bag samples were analyzed from piston or other engines producing higher HC concentrations, the percent difference was much smaller. Most of the HC concentrations from the previously-tested engines were from 300 to 2500 ppm C. For these engines, which gave the unstable HC readings, this maximum of 2 ppm C bag-to-continuous difference represents only a 0.7 to 0.1 percent difference which would be acceptable.

Based on results of this bag verification study for gas turbine

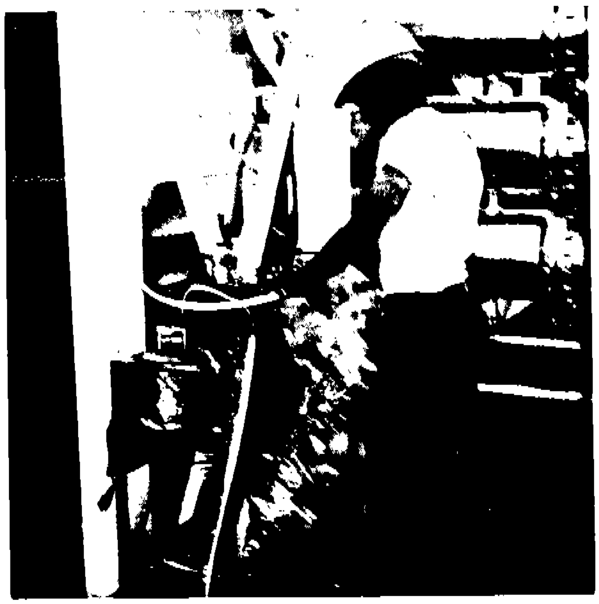
Bag Evacuation



Ice Trap Cart



Instrument Cart



Filling Sample Bag

FIGURE 12. VARIOUS OPERATIONS INVOLVED IN OBTAINING AND ANALYZING A BAG SAMPLE OF TURBINE EXHAUST

TABLE 10. CONTINUOUS SAMPLING VS BAG SAMPLES - GAS TURBINE VERIFICATION RESULTS

	Test Number 1			Test Number 2			Test Number 3		
	Bag	Cont	% Diff.	Bag	Cont	% Diff.	Bag	Cont	% Diff.
NO_x, ppm	31.5	31.0	1.6	40.5	40.0	1.3	42.2	42.2	0.0
CO_2, %	2.12	2.12	0.0	2.52	2.57	0.0	2.62	2.62	0.0
HC, ppmC	2.5	0.5	400.0	1.5	0.5	200.0	2.5	1.5	66.7
CO, ppm	11.4	11.7	-2.6	7.9	7.9	0.0	7.3	6.8	7.3
O_2, %	17.0	17.5	-2.8	17.0	17.0	0.0	17.0	17.0	0.0

	Test Number 4			Test Number 5			Test Number 6			Average
	Bag	Cont	% Diff.	Bag	Cont.	% Diff.	Bag	Cont	% Diff.	% Diff.
NO_x, ppm	40.5	41.5	-2.4	41.5	42.0	-1.2	40.5	40.5	0.0	-0.12
CO_2, %	2.62	2.62	0.0	2.52	2.52	0.0	2.57	2.57	0.0	0.0
HC, ppmC	1.0	0.5	100.0	2.0	1.0	100.	2.5	1.0	150.0	169.4
CO, ppm	6.8	7.3	-6.8	6.4	6.7	-4.5	4.9	4.6	6.5	0.02
O_2, %	17.0	17.0	0.0	16.5	16.7	1.2	16.5	16.7	1.2	-0.07

*All % differences based on continuous sample concentrations as base or absolute.

exhaust, two conclusions are apparent when analyzing bag samples without delay. First, NO_x, CO_2, CO, and O_2 concentrations have been shown to agree acceptably with continuous samples. Second, the extremely low HC concentrations from this gas turbine and the apparent residual HC in the bag produced differences which were significant. The concentrations of the HC in these bag samples should not be assumed to be absolute, since the apparent HC residual varied from one bag sample to another. The HC concentrations found in the bag should be used as approximations only and not as absolute values, since they were consistently high by up to 2 ppm C.

These experiments indicate that bag sampling results are equivalent to continuous monitoring provided certain precautions are observed. First, the bags should be evacuated, purged with zero gas, re-evacuated and leak checked. Second, the exhaust sample should be clean and dry. That is, the sample should be passed through an ice trap to remove moisture and a glass fiber filter to remove any particulate in the sample. Failure to remove the moisture in the sample could have a significant effect on NO_x and CO_2 concentrations. These two species (NO_2 and CO_2) are both water soluble, and a prolonged contact time could result in a slight loss of these compounds. Occasionally, the engine HC emissions are so unstable that the only practical manner to obtain an average concentration is by using a bag sample.

E. Bag Sample Stability

Since it was apparent that it would be necessary to obtain a bag sample occasionally, it was necessary to establish the storage stability of bag exhaust samples. Bag samples were obtained and analyzed immediately upon acquisition. Results were compared to a continuous sample analyzed prior to the bag sample. The bag was then analyzed at 10, 20, 30 minute, one hour, and 24 hour intervals for CO, CO_2, NO_x, HC and O_2 just as the continuous sample.

A total of four tests were completed, and the results are presented in Table 11. It should be noted that all bags were obtained at near equivalent load levels, and the resulting concentrations of the various emissions were quite similar. These bag samples were obtained from a Worthington UTC-10 on several different days. This particular engine produced very little CO and consequently the percent loss as a function of time for CO is not presented in Table 12. The NO_x bag stability is much more of a function of time than any of the other emissions as shown in Figure 13. Since these tests were conducted using a near consistent emission level for CO_2, NO_x, and HC, similar tests at low NO_x concentrations were conducted at the second test site.

TABLE 11. BAG SAMPLE STABILITY EXHAUST EMISSION CONCENTRATIONS (Worthington UTC-10, Engine 13)

Test No.	Elapsed Time	Exhaust Emission Concentrations				
		NO_x, ppm	CO_2, %	HC, ppmC	CO, %	O_2, %
1	Cont	1455	3.57	1250[1]	-[2]	15.3
1	0 min	1440	3.51	1100	-	15.4
1	10 min	1425	3.51	1100	-	15.3
1	20 min	1425	3.51	1100	-	15.6
1	30 min	1410	3.51	1100	-	15.3
1	1 hr	1380	3.51	1100	-	15.2
1	24 hr	720	3.33	1050	-	15.5
2	Cont	1485	3.57	930[1]	-	15.1
2	0 min	1500	3.57	1050	-	15.0
2	10 min	1500	3.57	1050	-	15.2
2	20 min	1500	3.57	1050	-	15.1
2	30 min	1515	3.57	1050	-	15.2
2	1 hr	1485	3.51	1050	-	15.2
2	24 hr	570	2.62	1050	-	16.6
3	Cont	1320	3.39	1110[1]	-	15.0
3	0 min	1275	3.39	1120	-	15.1
3	10 min	1245	3.28	1070	-	15.0
3	20 min	1260	3.33	1100	-	15.1
3	30 min	1245	3.33	1120	-	15.0
3	1 hr	1215	3.28	1120	-	15.0
4	Cont	1485	3.51	940[1]	-	15.3
4	0 min	1485	3.51	935	-	15.3
4	10 min	1470	3.45	930	-	15.4
4	20 min	1425	3.39	935	-	15.3

[1] Continuous measurement of HC was unstable due to fluctuations in concentration.

[2] CO concentrations too low for high range CO NDIR. Values considered to be consistently less than 25 ppm on this engine.

TABLE 12. EMISSION LEVEL LOSSES AS A FUNCTION OF TIME
(Worthington UTC-10, Engine 13)

Test No.	Percent Loss, NO_x[1]				
	0 min	10 min	20 min	30 min	1 hr
1	1.03	2.06	2.06	2.40	5.15
2	-1.01	-1.01	-1.01	-2.02	0.00
3	3.40	5.68	4.54	5.68	7.95
4	0.00	1.01	4.04	-	-
Average	0.85	1.94	2.41	2.02	4.37

Test No.	Percent Loss, CO_2[1]				
	0 min	10 min	20 min	30 min	1 hr
1	1.68	1.68	1.68	1.68	1.68
2	0.00	0.00	0.00	0.00	1.68
3	0.00	2.65	1.76	1.76	3.24
4	0.00	1.70	3.41	-	-
Average	0.42	1.51	1.71	1.14	2.20

Test No.	Percent Loss, HC[2]				
	0 min	10 min	20 min	30 min	1 hr
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	4.46	1.79	0.00	0.00
4	0.00	0.53	0.00	-	-
Average	0.00	1.25	0.45	0.00	0.00

---

1 NO_x and CO_2 absolute concentration based on continuous sample.

2 HC absolute concentration based on 0 min bag sample, due to very unstable HC concentrations during continuous sampling.

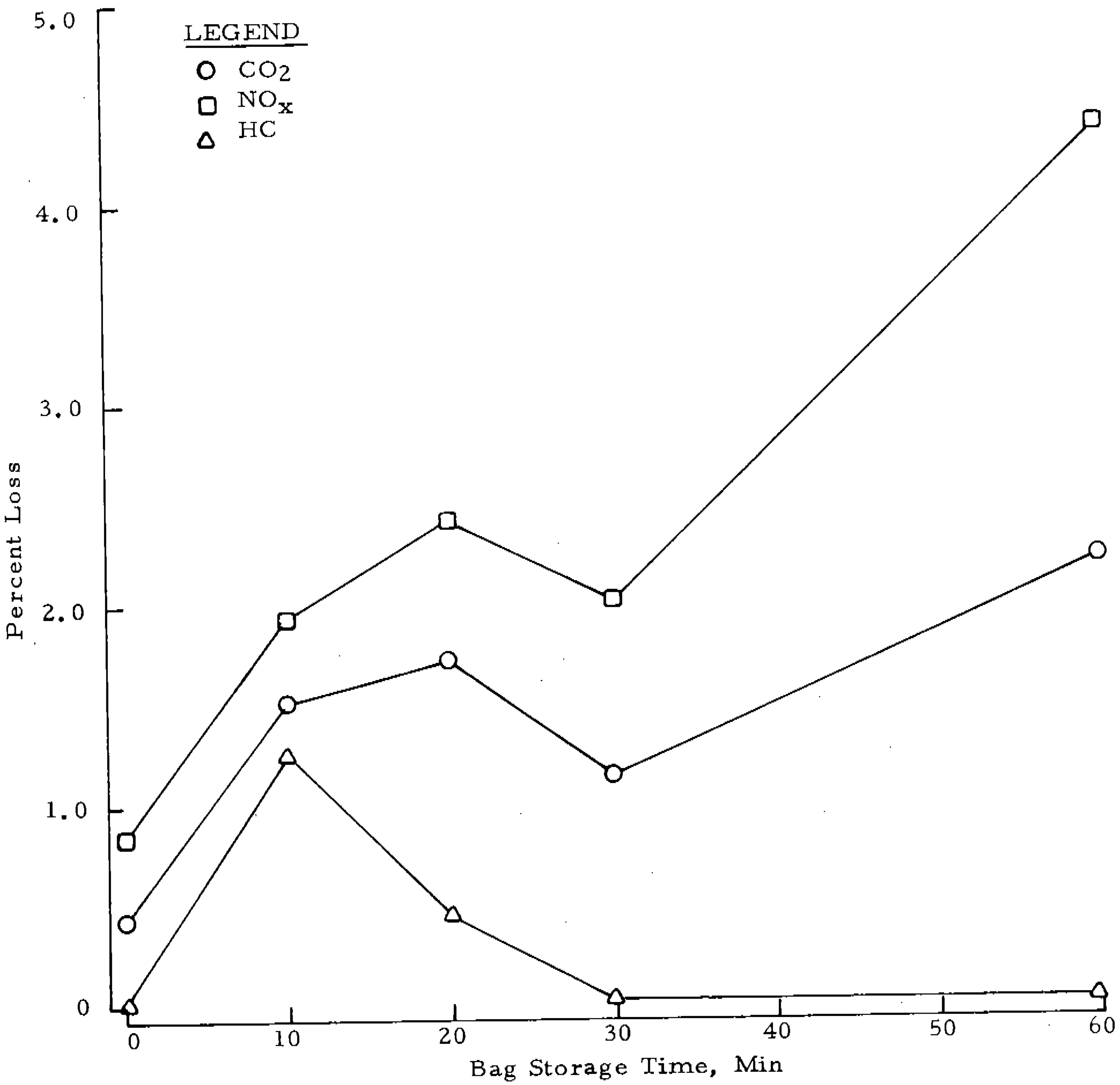


FIGURE 13. THE EFFECT OF BAG STORAGE TIME ON PERCENT LOSS OF NO_x, CO_2 AND HC EMISSIONS (Worthington UTC-10, Engine 13)

Bag sample storage stability for more than 5 to 10 minutes was found to produce a slight decrease in emission levels. Sample storage overnight is not recommended, since tests indicated there was appreciable decrease in NO_x concentrations. It should be re-emphasized that bag samples will not produce equivalent NO results since the reaction of NO with the O_2 in the bag begins as soon as the bag sample is obtained. Good agreement between samples stored one to two hours in Tedlar bags and continuous sampling has been demonstrated.

During the testing period at the second site, several experiments were conducted to determine the bag sample storage stability as a function of time for low NO_x concentrations from gas turbine exhaust. The purpose of these experiments was to determine the degree of time delay that would be acceptable for bag analysis for gas turbine samples. A total of seven bags were used in this experiment, and the results of these tests are presented in Table 13. Of all the emissions measured, the CO_2 and O_2 concentrations were generally the most constant; although several instances showed significant changes after 24 hours.

The changes as a function of time can be more easily seen in Figure 14. The two prime emissions of concern, NO_x and CO_2, appeared to be reasonably stable over the two-hour storage period. Other data presented in Table 2 indicate that the bag samples do not retain the sample integrity for storage periods greater than two hours. The NO_x concentrations decreased significantly after being stored for periods of 24 hours or more. The CO_2 and O_2 concentrations remained stable for two hours, but several instances showed that something occurred after 24 hours (Tests 5 and 6).

While the equipment and instruments are on site, there could be opportunities available to obtain samples from additional engines if bag sampling is permitted. This situation arose at the second site when it was possible to take the bag sampling equipment to the two adjacent pumping stations. These plants were located approximately 70 miles north and 70 miles south of Site 2. These two stations would not have been tested if bag sampling were not available. The bag sample storage time for each of the two plants was on the order of two hours. The raw concentrations of the exhaust of these two plants were essentially the same as those found for the GE Frame 3 gas turbine at Site 2.

F. Phenoldisulfonic Acid (PDS) versus Chemiluminescent (CL) Analysis

Existing NO_x standards for stationary source NO_x are based on the Phenoldisulfonic Acid (PDS) method.(3) Although existing Federal standards employ the PDS method of analysis, this procedure is not acceptable for continuous monitoring of NO_x. The PDS method might be called a classical

TABLE 13. BAG STORAGE STABILITY - ALL EMISSIONS

Storage Time, min	Emission Concentrations - Bag 58 - Test 1 (10-3-72)				
	NO_x, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
0	40.0	2.52	0.5	6.1	16.5
10	43.0	2.52	1.5	-	16.5
20	41.0	2.52	1.0	6.7	16.8
30	42.0	2.52	1.0	6.7	16.5
60	42.5	2.52	2.0	7.0	16.5
120	40.0	2.52	2.0	6.1	16.5
24 hr	28.0	2.52	5.0	7.9	17.2

Storage Time, min	Emission Concentrations - Bag 59 - Test 2 (10-3-72)				
	NO_x, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
0	42.0	2.52	1.5	6.7	16.5
10	42.5	2.52	1.5	6.4	16.8
20	42.0	2.47	1.5	6.4	16.6
30	42.0	2.47	1.5	6.1	16.5
60	42.0	2.47	2.0	6.4	16.5
120	40.5	2.47	2.5	6.1	16.5
24 hr	32.5	2.42	4.0	6.7	17.3

Storage Time, min	Emission Concentrations - Bag 52 - Test 3 (10-4-72)				
	NO_x, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
0	41.5	2.52	2.0	6.4	16.5
10	41.0	2.57	1.8	5.8	16.7
20	40.8	2.57	1.8	5.8	16.6
30	41.0	2.57	1.8	6.1	16.7
60	41.0	2.57	1.8	6.4	16.8
120	39.0	2.52	1.8	6.7	16.8

Storage Time, min	Emission Concentrations - Bag 57 - Test 4 (10-4-72)				
	NO_x, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
0	40.5	2.57	1.3	4.6	16.5
10	41.0	2.57	1.5	4.9	16.7
20	41.0	2.57	1.5	5.2	16.7
30	41.0	2.57	1.5	5.2	16.8
60	42.0	2.52	3.0	5.8	16.7

Storage Time, hrs	Emission Concentrations - Bag 61 - Test 5 (10-4-72)				
	NO_x, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
0	42.0	2.57	1.2	6.1	16.5
1	41.0	2.57	2.8	6.4	16.8
2	40.5	2.57	3.0	6.4	16.8
24	28.0	2.32	4.0	7.3	17.4
48	13.7	1.83	2.5	4.9	17.0

Storage Time, min	Emission Concentrations - Bag 56 - Test 6 (10-4-72)				
	NO_x, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
0	42.0	2.57	1.2	6.1	16.5
1	40.5	2.52	1.5	6.7	16.8
2	40.5	2.52	3.0	6.4	16.8
24	32.5	2.47	3.5	8.5	17.0
48	25.8	2.14	2.0	7.3	17.4

Storage Time, hrs	Emission Concentrations - Bag 51 - Test 7 (10-4-72)				
	NO_x, ppm	CO_2, %	HC, ppmC	CO, ppm	O_2, %
0	40.5	2.52	1.5	7.9	17.0
1	39.0	2.52	2.5	7.3	17.0
2	41.0	2.52	3.0	5.2	16.8

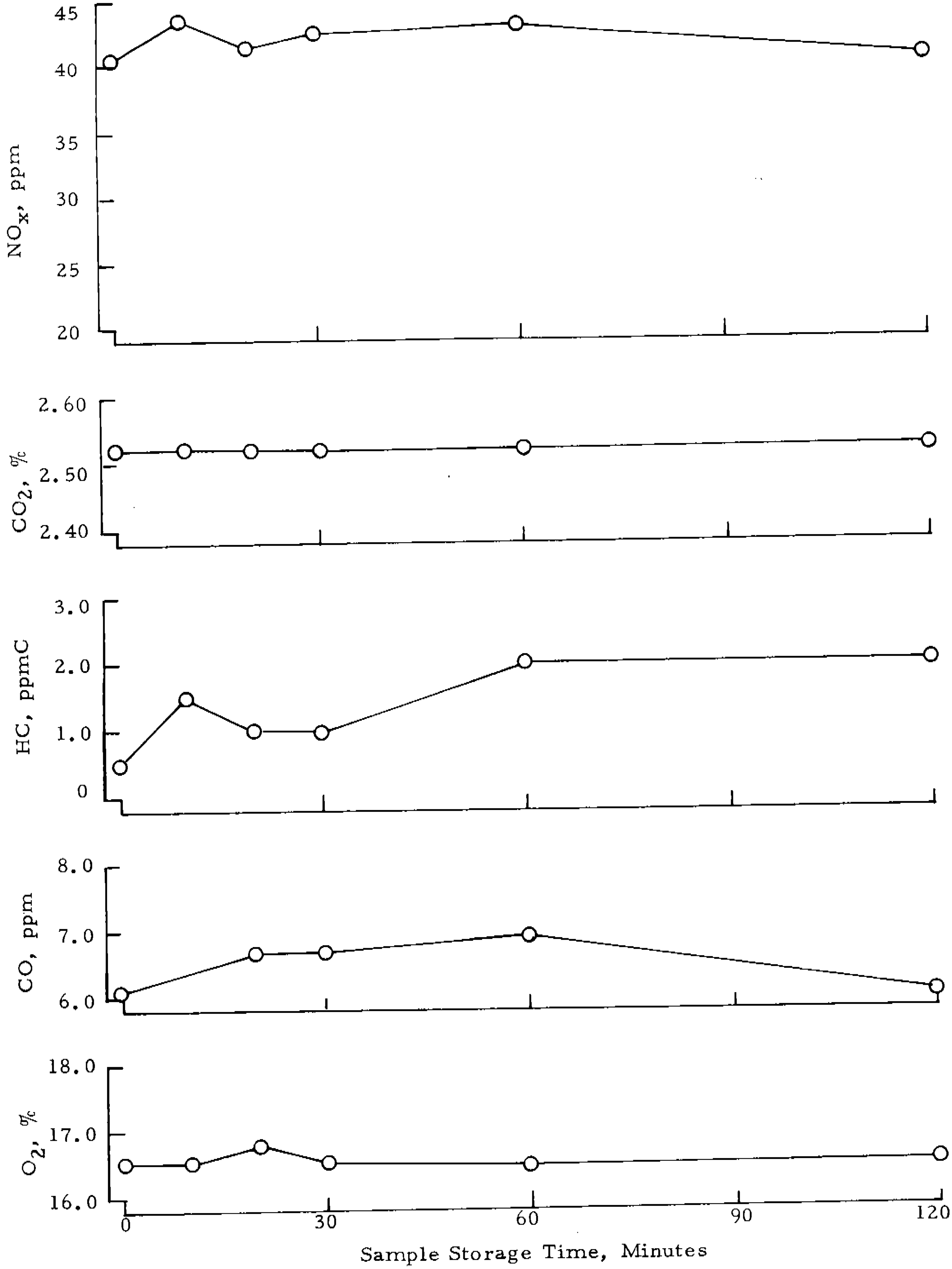


FIGURE 14. THE EFFECT OF SAMPLE STORAGE TIME ON GE FRAME 3 GAS TURBINE EMISSION CONCENTRATIONS, BAG 58 - TEST 1 (10-3-72)

wet chemical analysis and utilizes a grab sample rather than a continuous sample. In addition, this wet chemical technique provides no NO/ NO_x information. Since the chemiluminescent (CL) analyzer was to be used for NO and NO_x measurement during the baseline survey, it was decided to conduct a small amount of PDS versus CL correlation.

The first test engine at the first test site was used to supply the exhaust samples for CL versus PDS correlations. Worthington UTC-10 exhaust samples were taken on various days at various load conditions. For this particular study, the engine operating parameters were immaterial since the emission rates were not to be calculated. Each sample was analyzed by the CL in the continuous instrument cart and by PDS. Each PDS sample was taken in duplicate or triplicate depending on the number of PDS taken that particular day.

The results of these tests are shown in Table 14. A total of 11 different tests were conducted, and there was unexpected agreement between the two methods. There were two tests (4 and 11) which had apparent problems and were obviously void. However, most of the remaining PDS samples were slightly lower than the CL samples as indicated by the negative sign 0.35 to 6.26 percent. Two tests yielded slightly higher PDS results (Tests 1 and 10). The purpose of these experiments was not to prove or disprove one method or the other but to establish the correlation between the two on-site with real exhaust since both are employed to measure NO_x as NO_2 but for different purposes.

Several additional experiments were conducted to determine if the PDS versus CL correlation also held true for the Clark TCVC-16. Results from these limited experiments produced correlations of the same order as the Worthington UTC-10.

Correlation experiments were also conducted at the second test site on the General Electric Frame 3 gas turbine. Several gas turbine exhaust samples were analyzed by PDS and CL on various days. The results of these tests are presented in Table 15 and reflect the degree of correlation that might be expected. Several typical views of NO_x analysis by the PDS method are shown in Figure 15.

The agreement of the two methods is less at the lower concentrations (Tests 1 and 2) than at the higher concentrations (Tests 3 to 5). The percent differences that might be expected at low concentrations (about 40 ppm) would be from 4 to 10 percent. The percent difference of PDS-NO_x and CL-NO_x at higher concentrations (80 to 150 ppm) would be expected to be less than 3 percent. The PDS results were generally higher than the CL readings at the gas turbine test site.

TABLE 14. PHENOLDISULFONICACID (PDS) VS CHEMILUMINESCENT (CL) ANALYSIS OF NO_x EMISSIONS IN VARIOUS SAMPLES
(Worthington UTC-10, Engine 13)

Test No.	Date	NO_x Concentration, ppm NO_2					
		PDS-1	PDS-2	PDS-3	PDS-Avg.	CL	%Diff.[1]
1	8-17-72	1360	1400	1460	1406	1400	+0.43%
2	8-18-72	1440	1485	1170[2]	1462	1500	-2.53
3	8-18-72	905	880	720	835	838	-0.35
4	8-19-72	1900	1900	1850	1883	2460[2]	-31.3
5	8-19-72	760	880	710	783	813	-3.83
6	8-21-72	640	550	690	626	798	-6.26
7	8-23-72	1410	1240	-	1325	1365	-2.93
8	8-23-72	1410	1600	-	1505	1440	-4.51
9	8-24-72	1480	1560	-	1520	1560	-2.56
10	8-24-72	1440	1480	-	1460	1455	+1.03
11	8-25-72	830	830	-	830	1005	-17.4

1 Based on total NO_x CL values

$$\% \text{ Diff.} = \frac{\text{PDS Avg.} - \text{CL}}{\text{CL}}$$

+ means PDS higher than CL
- means PDS lower than CL

2 Not included in average--data point questionable

TABLE 15. PDS-NO_x VS CL-NO_x CORRELATION RESULTS

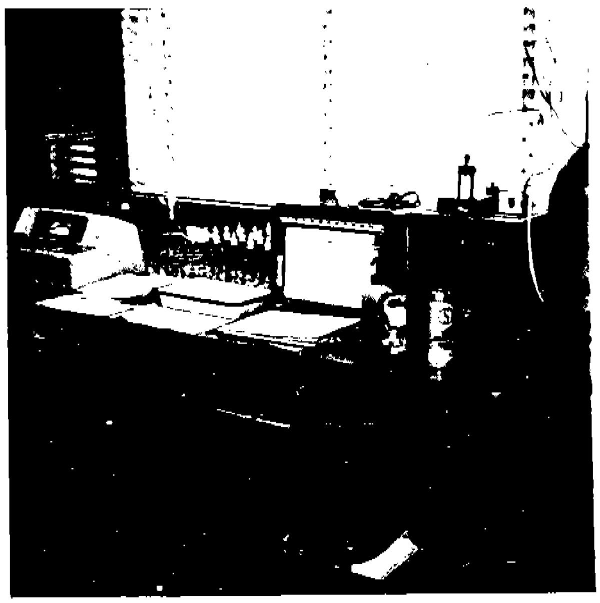
Test	Date	PDS - NO_x, ppm NO_2 1	2	3	Avg.	CL-NO_x ppm	Percent Difference[1]
1	10-3-72	44.0	44.0	-	44.0	40.0	+10.0
2	10-4-72	42.0	42.0	-	42.5	40.5	+4.9
3	10-6-72	148.0	145.0	139.0	144.0	147.0	-2.0
4	10-6-72	106.0	106.0	111.0	107.7	107.0	+0.7
5	10-6-72	86.0	83.0	89.0	86.0	85.0	+1.2

(1) NO_x by CL used as base.

PDS-NO_x Analysis

Sample Evaporation

Typical Hot Plate



PDS-NO_x and GC Instrument

FIGURE 15. TYPICAL VIEWS OF NO_x ANALYSIS BY THE PDS METHOD

G. Documentation of NO_2 Losses

Existing analytical instrumentation requires that the sample entering the instrument be clean and dry. In order to meet this requirement, the sample is passed through a trap of stainless steel tubing immersed in an ice water both to remove the moisture and then through a glass fiber filter to remove any particulate. During the process of drying the sample, the collected water provides a surface media to react with the NO_2 in the exhaust gas.

The degree of NO_2 loss in the ice water trap is largely a function of sample residence time and to a smaller extent the amount of collected water in the system. Several NO_2 concentrations were selected which were typical of NO_2 concentrations observed in raw exhaust and were analyzed both with and without the sample conditioning system to determine the degree of NO_2 losses. Employing typical sample flow rates, these losses were generally 9 to 11 percent. Sampling flow rates were decreased in order to determine possible changes in NO_2 losses as a function of sample flow rate. These lower flow rates had a significant effect on the NO_2 losses in the sampling system.

An alternative to the existing chemiluminescent analytical method would be to develop a lightly heated (160°F) chemiluminescent analyzer. This would involve heating the sample lines up to the point of the high vacuum in the instrument. All sample handling equipment such as pumps, filters and valves would be maintained at operating temperatures in an oven. At the present time, this approach has not been developed commercially and cannot be purchased.

Although the nominal 10 percent loss of NO_2 in the sample system may seem high, it is in reality only a small portion of the total NO_x. For example, if an engine emitted 1000 ppm NO_x and 90 percent of the NO_x was NO, then only 100 ppm was NO_2. If 10 percent of the 100 ppm NO_2 was lost in the sampling system, then only 10 ppm NO_2 or 1 percent of the total NO_x was lost in the ice trap.

H. Diesel Engine Manufacturers Emission Test Code

On February 22, 1973, Dr. Phillip S. Meyers, Professor of Mechanical Engineering, University of Wisconsin, visited SwRI and met with Karl Springer. Dr. Meyers was working as a consultant to the Diesel Engine Manufacturers Association (DEMA) on a test code for large piston engines. On the advice of Pete Susey, all facets of this program were described with the exception of specific data and results. The methods of stack sampling, sample location, instruments, sample treatment, etc., were covered in detail as were the methods used for calculation.

Dr. Meyers described the draft DEMA code, and no inconsistencies were noted in the sampling and measurement for HC, CO, and NO_x. Methods of calculation, expression, and selection of specific test points were discussed at length. One major concern was the expression of HC, CO, and NO_x on a grams per bhp-hr basis instead of, for example, pounds per million BTU heat input. DEMA plans to use grams per bhp-hr which is quite satisfactory for engine tests by the manufacturer or where power output can be reliably and easily measured. And it is the preferred method since it is based on usable work output and not on a heat input basis where the less efficient engine may look better than an efficient one due to the increased heat input rate in the denominator of the equation.

The reliance on brake specific expression, however, can work a hardship on the using industry such as gas transmission where in-plant monitoring of in-service engines may be required by either Federal or state regulations. Measurement of engine power output is not simply determined; and to do so accurately is both expensive, time consuming, and inefficient since generally the engine must be shut down when connecting the power indication equipment.

As a possible solution, it was suggested that the DEMA code consider a provision for in-use monitoring whereby a relationship between fuel heat input versus engine power output be established at the factory. This relationship would then be verified or changed as required after the engine is placed into service during the acceptance tests. Fuel rate could then be used as a somewhat continuous indicator of power output for the specific engine until such time as major maintenance is performed or the engine is again power tested. This might be a satisfactory way to still demonstrate compliance using power output indirectly obtained through a specific calibrated BTU versus horsepower relationship.

The other area of possible interest to readers of this report was in the selection of engine test points. The draft DEMA code involves operation at the following:

a. For an engine operated at constant (rated) speed
   BS ( ) at 50% rated torque x 0.2 =
   BS ( ) at 75% rated torque x 0.4 =
   BS ( ) at 100% rated torque x 0.4 =

   Characteristic Brake Specific Emittant = ____________

b. For engine operated at variable speed

<u>At Rated Speed</u>

BS ( ) at 50% rated torque x 0.125 =
BS ( ) at 75% rated torque x 0.25 =
BS ( ) at 100% rated torque x 0.25 =

<u>At 2/3 Rated Speed</u>

BS ( ) at 50% rated torque x 0.125 =
BS ( ) at 75% rated torque x 0.125 =
BS ( ) at 100% rated torque x 0.125 =

Characteristic Brake Specific Emittant = ____________

It was pointed out that piston engines in gas compression, from our experience to date, all run very nearly rated speed and load with operation at severe off-design essentially nil since multiple units and the system load-demand allowed this type of optimum operation. Experience has been that operation in an envelope of rated speed-rated load, 90 percent rated speed-rated load, 90 percent rated speed-90 percent rated load, and rated speed-90 percent load is possible with some occasional overload, say, 105 percent load-rated speed. This represents only a small corner of the envelopes defined by DEMA making the only test point directly applicable to compressor engines from the DEMA code the rated speed-rated load.

It was suggested to Dr. Meyers that the speed-load definition of operating points be expanded and defined in terms of end use or application. The idea of a matrix listing use or application versus speed-load points with appropriate weighting factors evolved. In the event a given operating point was not applicable to a given service, the weight factor would be zero and deleted from consideration. The addition of an idle, no load, condition was also discussed for engines where this might occur. This approach requires better knowledge about the percent of time engines, for example, in pipeline compression, spend in various operating modes than is currently available.

One way to determine percent of time would be to consider all the speed-load points run on this project. This data would at least define the envelope of possible field operation to a better extent than known now. Then, to determine percent of time, it may be possible to use the speed-load condition running at the time of survey, a fairly random number, as the typical operating point. To reinforce this, the operating records of the engine could be examined to determine if any useful loading sequence data for purposes of percent time computations could be made. Or, educated judgement could be made from operating experience on this project with the knowledge that as better weighting factors were developed, they could be used. In summary, a dialogue was set up between this project and those in DEMA regarding the test and expression of emissions from large engines.

I. Summary

Several experiments were conducted to determine the sampling and testing procedures to be used in the baseline emissions study. The piston engines selected for this study were a Worthington UTC-10 and a Clark TCVC-16, and the gas turbine was a GE Frame 3. The experiments for piston engines were conducted at the first site while those involving gas turbine sampling were at site two.

A number of sampling parameters were evaluated. These included effect of stack sample probe depth, sample location (stack, snubber, etc.), sample stratification, and bag sampling, etc. The results of these experiments indicated that sample integrity was best preserved by observing the following:

1. Sample with an equal area probe suspended into the stack at a depth of three pipe diameters for piston engines. A depth of four feet was found satisfactory for gas turbine exhaust emission sampling.

2. Use short sample lines, keep sample condensate ice traps as close to the stack as possible.

3. Maintain a high sample flow (5 SCFH) and drain condensate from ice traps after each run.

4. Leak check entire sampling system prior to each engine test.

5. Keep sample lines clean by changing glass fiber filter regularly.

6. Use ascarite and drierite to remove CO_2 and water vapor interferences in the low range CO instrument.

7. Bag samples are acceptable provided the sample is properly conditioned, and the sample is analyzed within one to two hours on turbine exhaust and five to ten minutes on piston engine exhaust.

Past field experiments indicate that certain precautions should be observed on a routine basis. Calibration and zero gases were moved from site to site along with the instrument cart to allow calibration prior to each run. Instrument calibration curves were verified on a monthly basis when possible. Chemiluminescent NO_x converter checks should be performed on a daily basis. Elimination of CO_2 and water vapor interference was insured by changing the ascarite and drierite traps after each run.

Several correlation experiments were conducted on NO_x measured by the phenoldisulfonic (PDS) acid procedure and the continuous chemiluminescent (CL) analyzer. The experiments were conducted using the Worthington UTC-10 and Clark TCVC-16 at Site one and the GE Frame 3 at the second site. The PDS NO_x concentrations for piston engines were generally slightly less by about 2 to 4 percent of the NO_x concentrations by CL. Results from the gas turbine indicated that the PDS NO_x concentrations were higher by about 3 percent of the CL NO_x concentrations. This better than expected correlation of the two methods tended to validate the use of the CL analyzer and make possible comparison with reported values to that published for the PDS.

III. BASELINE EMISSIONS SURVEY

The baseline emissions survey was conducted over a ten-month period in seven states at the compressor stations of six participating gas transmission companies. A total of 68 tests were conducted of which 59 were on reciprocating engines. Horsepower and fuel consumption rates were supplied by the individual participating company. The fuel component analysis along with the higher heating value and specific gravity were supplied by each individual gas transmission company and are presented in Table B-6 of Appendix B. All fuel analyses were conducted according to the individual member company standard operating procedures. The methods of measurement for horsepower, fuel consumption rates, and sampling as well as the sample acquisition method are listed in Table B-7 of Appendix B.

A. Reciprocating Engines

The distribution of reciprocating engines tested during the baseline survey by engine manufacturer and model is found in Table B-3. This particular grouping utilizes the four engine manufacturers (Clark, Cooper-Bessemer, Ingersoll-Rand, and Worthington) listed alphabetically with the models in increasing horsepower. A brief description of each engine group is presented in Table B-4 of Appendix B.

The primary objective of on-site emission testing was to obtain emission levels at rated speed and load. Under certain conditions, the gas transmission company test crew was unable to obtain this engine condition due to the existing pipeline conditions. When on-site, the test crews and plant personnel were extremely cooperative and in several instances the effects of timing, horsepower, scavenging air pressure and engine speed on exhaust emissions were determined.

The emission rates, concentrations and engine operating parameters for all tests conducted during the baseline emissions survey is presented in Appendix C. Engine tests were numbered consecutively, with each test being presented as a separate table in Appendix C. On most engines, a number of runs were conducted where the engine operating parameters were varied. Engine parameters considered most important for this study were horsepower, engine speed, ignition timing, scavenging air pressure and fuel consumption. Each of these parameters were recorded on reciprocating engines during each run.

Ambient conditions during the sampling period were also monitored during each run. This included such items as wet and dry temperatures and barometric pressure. Raw as-measured emission concentrations and calculated emission rates, expressed in lbs/hr, lbs/10^6 BTU, and gr/hp-hr, are included in this data format.

Average emission rates, at or near rated speed and load, are presented in Table 16 for all 25 engine groups. Emission rates of NO_x, THC and CO are presented in the three aforementioned methods of rate expression. As noted, some groups had as many as five engines included in the average where several others had only one. The engines were grouped alphabetically according to increasing rated horsepower. The emission rates presented are arithmetic averages of the individual emission tests conducted on a given engine group. These averages provide data from which engines which are the highest emitters may be identified. This information, coupled with complete installed horsepower data, will provide the basis for selection of engines best suited for control technology.

The maximum and minimum emission rates for all three emissions (NO_x, THC, and CO) are noted in Table 16. Each method of emission rate expression was arithmetically averaged to provide a typical emission rate. The arithmetic average must be used with caution since each group does not have equal installed horsepower.

Since the primary concern was obtaining emission rates at rated speed and load, Table D-1 was prepared to present the emission rates of all reciprocating engines tested at or as close as possible to this condition. The results of these tests were then grouped according to manufacturer and model, and the average is presented in Tables D-2 through D-5. In cases where more than one engine of a given make and model was tested, the emission rates were averaged. These results, that is typical emission rates observed at or closest to rated speed and load, were then reduced to include only the average emission rates. This summary of emission rates is found in Table 16. Once the typical emission rates had been determined, the engines then could be rated according to their emission levels of NO_x, THC, and CO.

It has been found that the ratio of exhaust NMHC/THC remains about the same for a given engine regardless of variation in operating parameter. It has also been found that the exhaust NMHC/THC, for a given engine, approximates the fuel gas NMHC/THC ratio. These ratios can vary widely, however, from station to station depending on fuel supply. The methane portion of the fuel gas ranged from 75 to 95 percent of the fuel making NMHC/THC ratios range from 0.05 to 0.25. This variation makes direct comparison of engines operated on different fuel gases difficult on a NMHC basis. For this reason, THC was used throughout this report for rank-ordering and other direct comparisons.

TABLE 16. EMISSION RATE SUMMARY BY ENGINE GROUPINGS (MANUFACTURER AND MODEL)

Group	Engine	Model	No.	NO_x Emission Rate			Total Hydrocarbon Emission Rate			Non-Methane HC Emission Rate			CO Emission Rate		
				lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr
P-1	Clark	BA-8	2	38,659	2,747	10,504	22,655	1,593	6,105	3,725	0,258	0,990	6,922	0,485	1,857
P-2	Clark	HBA-8T	3	25,420	1,475	5,648	37,636	2,184	8,400	1,054	0,061	0,235	10,364	0,599	2,298
P-3	Clark	TLA-6	6	43,079	2,585	9,532	18,948	1,139	4,199	1,003	0,060	0,223	10,846	0,648	2,401
P-4	Clark	TLA-8	1	59,947	2,517	9,939	45,732	1,920	7,582	2,058	0,086	0,341	13,149	0,552	2,180
P-5	Clark	TCV-12	1	70,830	2,262	8,177	48,658	1,554	5,618	3,601	0,116	0,416	27,313	0,872	3,153
P-6	Clark	TCV-16	2	54,947	1,553	4,531	87,143	2,260	7,425	6,681	0,189	0,551	26,555	0,705	2,245
P-7	Clark	TCVC-16	2	190,905	3,003	10,839	86,468	1,403	4,880	11,440	0,188	0,645	61,461	0,948	3,503
P-8	C-B	GMV-10	4	75,416	5,770	25,533	10,346	0,808	3,531	0,424	0,032	0,145	2,419	0,185	0,817
P-9	C-B	GMWA-6	3	46,004	3,630	13,816	21,088	1,661	6,338	0,457	0,036	0,138	1,749	0,138	0,526
P-10	C-B	GMWC-6	1	50,768	2,954	11,018	25,096	1,460	5,447	1,330	0,077	0,289	4,221	0,246	0,916
P-11	C-B	GMW-8	5	69,073	3,806	14,853	24,666	1,386	5,374	1,050	0,059	0,229	2,052	0,115	0,449
P-12	C-B	GMWA-8	3	41,265	2,520	8,980	16,455	1,018	3,582	0,657	0,041	0,143	2,209	0,135	0,481
P-13	C-B	GMWC-10	2	175,290	6,349	23,629	40,977	1,484	5,526	1,434	0,052	0,193	5,567	0,201	0,750
P-14	C-B	LSV-16-SG	4	94,261	2,930	9,889	58,715	1,848	6,233	2,544	0,081	0,271	12,066	0,375	1,276
P-15	C-B	LSVA-16-SG	2	87,355	2,723	8,906	13,857	0,430	1,412	0,377	0,011	0,038	40,273	1,252	4,105
P-16	C-B	10 V-250	1	89,920	4,237	12,285	30,280	1,427	4,137	5,178	0,244	0,707	3,860	0,182	0,527
P-17	C-B	14 V-250	1	195,568	5,170	18,481	49,399	1,306	4,668	3,162	0,084	0,299	9,576	0,253	0,905
P-18	C-B	16 V-250	1	216,735	5,062	17,810	47,575	1,111	3,909	1,665	0,039	0,137	18,049	0,422	1,483
P-19	I-R	KVG-8	3	20,267	2,567	12,363	2,072	0,266	1,299	0,096	0,013	0,062	0,805	0,099	0,472
P-20	I-R	412 KVS	4	70,437	3,951	15,637	13,863	0,801	3,085	1,462	0,085	0,327	2,846	0,161	0,633
P-21	I-R	616 KVT	1	69,967	2,768	8,076	24,183	0,957	2,791	1,790	0,071	0,207	9,033	0,357	1,043
P-22	I-R	616 KVR	2	134,383	3,729	10,929	27,128	0,753	2,207	2,007	0,056	0,163	11,039	0,307	0,899
P-23	Worth	26X36	1	38,203	2,441	11,087	4,725	0,302	1,371	0,385	0,025	0,111	77,871	4,976	22,599
P-24	Worth	UTC-10	1	108,472	5,710	28,088	21,330	1,123	5,525	2,560	0,135	0,663	0,683	0,036	0,177
P-25	Worth	SUTC-8	3	11,932	1,388	2,608	22,474	2,654	4,935	2,652	0,313	0,582	4,147	0,492	0,915
Maximum			59	216,735	6,349	28,088	87,143	2,654	8,400	11,440	0,313	0,990	77,871	4,976	22,599
Minimum				11,932	1,388	2,608	2,072	0,266	1,299	0,096	0,011	0,038	0,683	0,036	0,177
Arithmetic Average*				83,164	3,354	12,526	32,059	1,314	4,623	2,351	0,096	0,324	14,603	0,590	2,264

*Arithmetic average to be used with caution since each group does not have equal installed horsepower.

1. Pounds per Hour Mass Rates

The emission rates of NO_x, THC, and CO (expressed in lbs/hr) is found in Figure 16, a bar chart representation of the average typical value for each of the 25 engine groups. The four engines that emitted the highest quantities of NO_x in lbs/hr were the C-B 16 V-250, C-B 14 V-250, Clark TCVC-16 and C-B GMWC-10. Except for the number of cylinders, the C-B 16 and 14 cylinder V-250 engines are essentially identical. The two engines that emitted the greatest amounts of THC (lbs/hr) were the Clark TCV-16 and Clark TCVC-16, while the Worthington 26X36 and Clark TCVC-16 produced the most pounds of CO per hour.

Caution should be taken when using pounds per hour as the basis for comparing one engine with another. The mass rate is an excellent engineering expression and is the basis for other expressions on, say, a heat input or work output. It is also useful in emission inventory analysis where mass of contaminant discharged into the atmosphere on a unit of time is of primary importance. The basic shortcoming of pounds per hour for direct comparison lies in the method of calculation of density times concentration times exhaust flow.

For a given contaminant density and concentration, the higher the exhaust rate the higher the emission rate. This clearly makes the large engine appear to have a higher emission rate or an engine that handles more air for one reason or another to have a higher rate, all other things being equal. This is indicated by the fact that the V-250 Cooper-Bessemer and the Clark TCVC engines are both large displacement and powerful units that handle relatively large volumes of air and exhaust.

2. Fuel Specific (lbs/10^6BTU) Emission Rates

For a stricter comparison of one engine to another, a fuel specific (lbs of emission per unit of fuel or heat input) and a brake specific (grams of emission per unit of useful work output) are the preferred methods. Figure 17 is a bar chart representation of the relative emission rates (expressed in lbs/10^6BTU) of NO_x, THC, and CO of all 25 piston engine groups tested. These figures were generated from the average emission rates at rated speed and load presented in Table 16. Engines observed to be the highest NO_x emitters in lbs/10^6BTU were the C-B GMWC-10, C-B GMV-10, and Worthington UTC-10. The three engine groups observed to produce the most THC lbs/10^6BTU were the Worthington SUTC-8, Clark TCVC-16, and Clark HBA-8T. The relative CO emission rates, presented in Figure 17, illustrate that the Worthington 26X36 and C-B LSVA-16 SG produced the greatest lbs of CO/10^6BTU.

These values were determined by dividing the pounds per hour

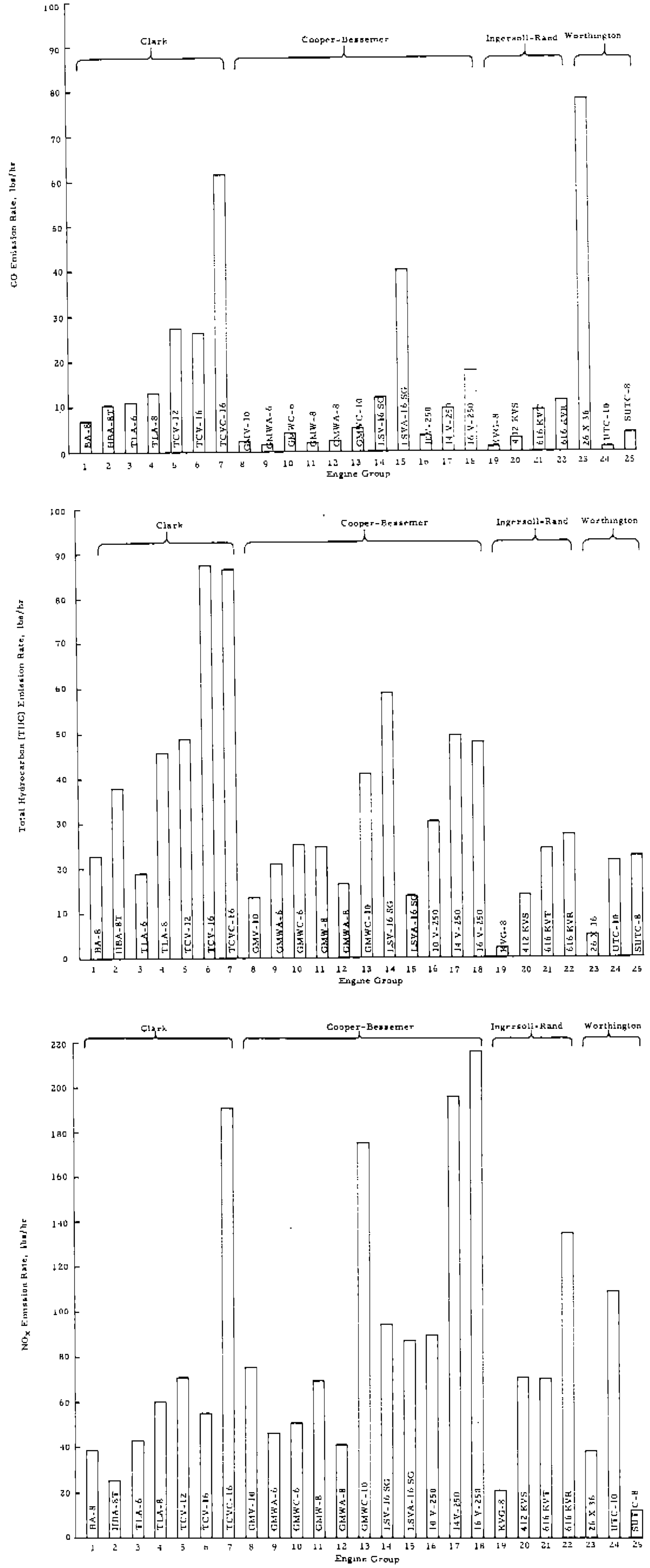


FIGURE 16. EMISSION RATE (lbs/hr) BY ENGINE GROUP

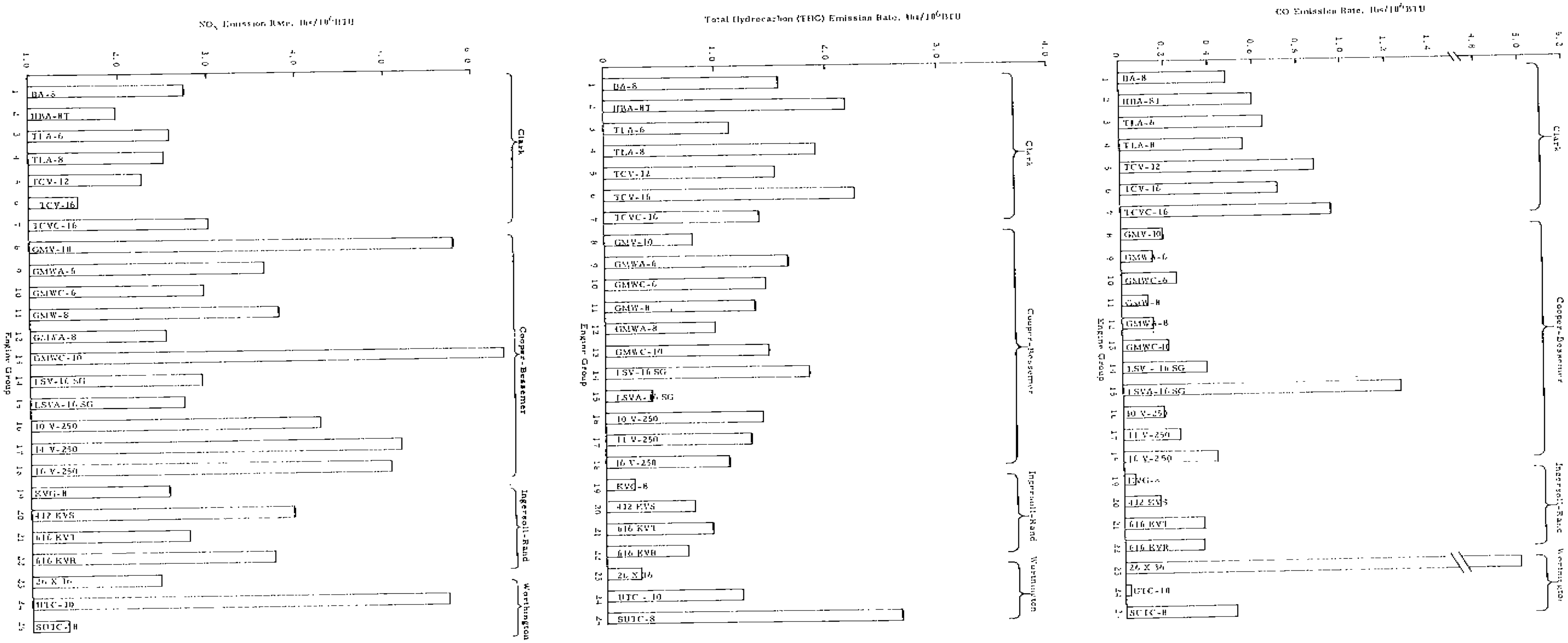


FIGURE 17. EMISSION RATE (lbs/10^6 BTU) BY ENGINE GROUP

emission rate by the heat input (fuel rate times higher heating value). Heat input is fairly easy to measure and was available on over half the engines without special installation. A temporary test orifice measuring section was used on the others without great difficulty. From a day-to-day type of operation, this is the easiest, most direct method of measurement and expression and is consistent with the new stationary source emission standards[1].

The major shortcoming is that the more fuel an engine uses, the lower the emission rate. In effect, this method penalizes the more efficient engine and could encourage fuel consumption just to meet an emission standard. It is unlikely one would do so, but this is a consideration the regulatory officials are concerned with.

3. Brake Specific (gr/hp-hr) Emission Rates

Emission rates expressed on a work output basis were also determined and relative emission rates expressed in gr/hp-hr are presented in Figure 18 for NO_x, THC, and CO. The engine groups observed to produce the most grams NO_x/hp-hr were Worthington UTC-10, C-B GMV-10, and C-B GMWC-10. Clark HBA-8T, Clark TLA-8 and Clark TCV-16 were observed to emit the most grams THC/hp-hr, while the Worthington 26X36 and C-B LSVA-16 SG were the two engines found to produce the greatest quantities of CO, expressed in gr/hp-hr.

The brake specific basis is probably the fairest method of comparison from engine to engine. It is also the most difficult to perform because of the need to accurately measure the engine power output. Although relatively simple for the manufacturer to perform, power indication in the field is at best a slow and tedious job. The power output is the best indicator of true social value and compares all engines on the basis of a horsepower-hour of work. It is not easy to adjust an engine or engine parameter to "trick" the test method and demonstrate compliance unless in fact the mass emission rate was indeed reduced.

For specific comparisons of one engine to another, this method of expression and the corresponding data from Appendix C and D and Table 16 and Figure 18 are recommended. As with the other methods of expression, no direct comparison with an emission standard is possible, as there are none at this writing.

4. Engine Rank Order by Emission Rate

An attempt was made to rank the emission rates from each engine group in decreasing order of magnitude. Such a rank-order listing could then be used to give some insight on the relative importance of each engine

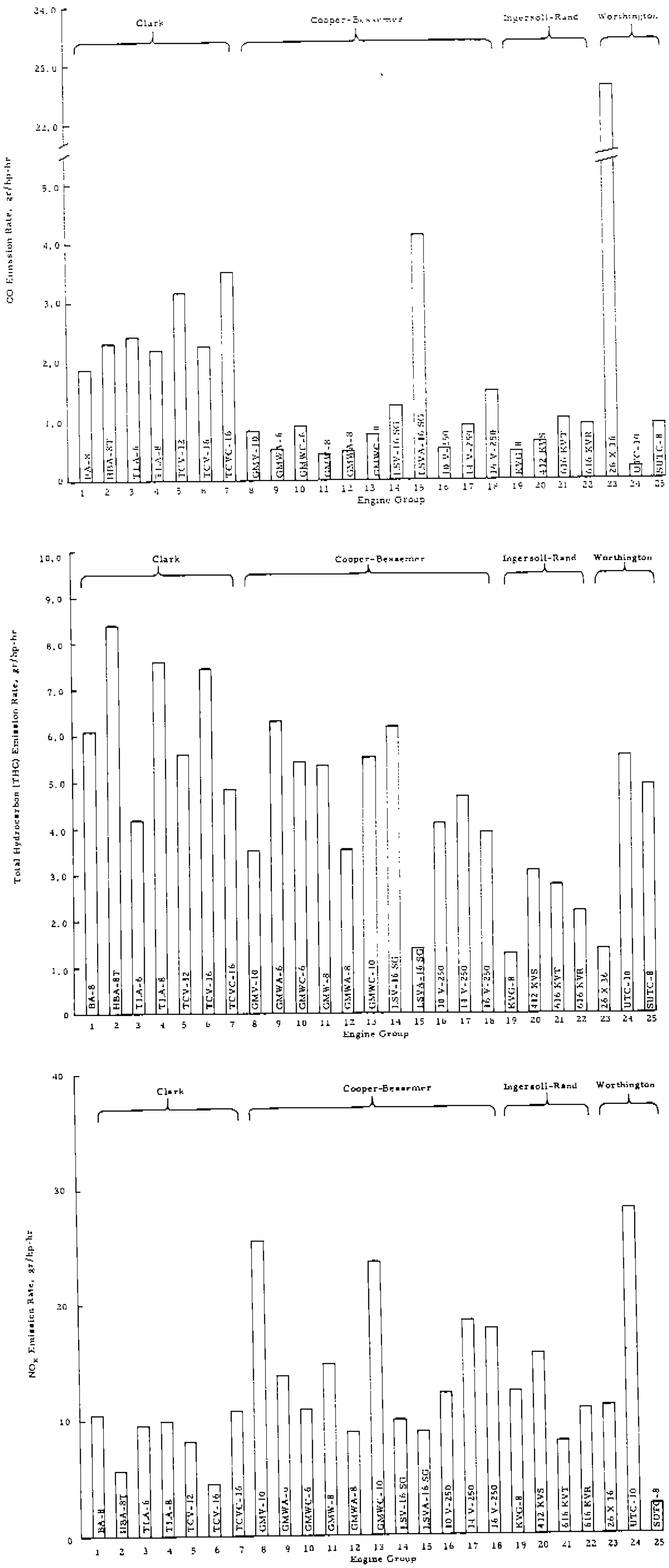


FIGURE 18. EMISSION RATE (gr/hp-hr) BY ENGINE GROUP

group as a contributor to air pollution. Since the rank-order study out of necessity had to treat each engine group (make and model) equally, the order of importance does not take into account the popularity of the engine as a source of emissions.

For a rigerous listing, it would seem necessary to weight each engine group by installed horsepower or some similar criteria. Only in this way can the most important contributors be identified properly for further study of abatement techniques, etc. This was beyond the scope of this project but could be done with the rates presented earlier assuming an adequate statistical breakdown of percent of national installed power for the 25 groups were available.

Appendix Tables D-6 through D-8 tabulate the results of this study. Table D-6 lists the rank order of NO_x, THC, and CO emission rates by engine group. The engines were then grouped by emission rate rank order, and Table D-7 presents this rank order in terms of engine make and model. These engines were then converted to the corresponding strokes per cycle and method of aspiration. Table D-8 of Appendix D lists the rank order of emission rates based on the method of aspiration and strokes per cycle.

Table D-8 best indicates the relative importance of the 2-stroke engine as being both a high and a low fuel or brake specific NO_x emitter. The five highest and, with one exception, the five lowest engine groups were 2-stroke. Whether the engines were turbocharged or not made little apparent difference on the five highest whereas, with one exception, all five low emitters were turbocharged. The middle or remaining engine categories followed no discernable pattern on NO_x. This analysis is based on equal weight or importance of each engine group and should be used with care as cautioned earlier.

5. Comparison of Emission Rates

In comparing the emission rates of 2- and 4-stroke engines, it is advisable to select engines with equivalent rated horsepower. When making these comparisons, the method of aspiration should be identical. The variety of engines in the baseline emissions survey allowed opportunities where emissions of 2- and 4-stroke TC, 2- and 4-stroke NA and 2-stroke TC and NA engines could be compared on a fairly logical basis. Table 17 lists the emission rates of various engines for 2- and 4-stroke as well as TC and NA comparisons.

The first comparison of 2- and 4-stroke normally aspirated engines was made on engines ranging in horsepower from 800 to 1600. Normally the horsepower range would be much narrower; however, these were the only engines in the baseline study where such a comparison of

TABLE 17. GENERAL COMPARISON OF STROKES PER CYCLE AND ASPIRATION METHODS

Group No.	Engine Make and Model	Stroke and Aspiration	Rated Speed	Rated Power	NO_x lbs/10^6BTU	NO_x gr/hp-hr	THC lbs/10^6BTU	THC gr/hp-hr	CO lbs/10^6BTU	CO gr/hp-hr
		2 and 4 stroke normally aspirated (800-1600 hp range)								
P-19	I-R KVG-8	4-NA	330	800	2,567	12,363	0.266	1.299	0.099	0.472
P-8	C-B GMV-10	2-NA	300	1350	5,770	25,533	0.808	3.531	0.185	0.817
P-9	C-B GMWA-6	2-NA	250	1500	3.630	13.816	1.661	6.338	0.138	0.526
P-1	Clark BA-8	2-NA	300	1600	2.747	10.504	1.593	6.105	0.485	1.857
		2 and 4 stroke turbocharged (various Hp ranges)								
P-20	I-R 412 KVS	4-TC	330	2000	3.951	15.637	0.801	3.085	0.161	0.633
P-3	Clark TLA-6	2-TC	300	2000	2,585	9.532	1.139	4.199	0.648	2.401
P-10	C-B GMWC-6	2-TC	250	2000	2.954	11.018	1.460	5.447	0.246	0.916
P-25	Worth. SUTC-8	2-TC	300	2000	1.388	2.608	2.654	4.935	0.492	0.915
P-14	C-B LSV-16SG	4-TC	327	4400	2.930	9.889	1.848	6.233	0.375	1.276
P-21	I-R 616 KVT	4-TC	350	4000	2.768	8.076	0.957	2.791	0.357	1.043
P-5	Clark TCV-12	2-TC	300	4000	2,262	8.177	1.554	5.618	0.872	3.157
P-17	C-B 14 V-250	2-TC	250	4800	5.170	18.481	1.306	4.668	0.422	1.483
P-22	I-R 616 KVR	4-TC	330	5500	3.729	10.929	0.753	2.207	0.307	0.899
P-5	Clark TCV-16	2-TC	300	5500	1.553	4.531	2.260	4.880	0.948	3.503
P-18	C-B 16V-250	2-TC	250	5500	5.062	17.810	1.111	3.909	0.422	1.483
		2 stroke normally aspirated and turbocharged								
P-1	Clark BA-8	2-NA	300	1600	2.747	10.504	1.593	6.105	0.485	1.857
P-2	Clark HBA-8T	2-TC	300	2000	1.475	5.648	2.184	8.400	0.599	2.298
P-9	C-B GMWA-6	2-NA	250	1500	3.630	13.816	1.661	6.338	0.138	0.526
P-10	C-B GMWC-6	2-TC	250	2000	2.954	11.018	1.460	5.447	0.246	0.916

emission rates of 2- and 4-stroke normally aspirated could be made. The NO_x emission rates, of the 4-stroke I-R KVG-8 were quite similar to the C-B GMWA-6 and Clark BA-8 (both 2-stroke). The 2-stroke C-B GMV-10 was significantly high than all three of the aforementioned engines.

The THC emission rates of the 4-stroke I-R KVG-8 were significantly lower than the three 2-stroke engines. The CO emission rates of the I-R KVG-8 were slightly less than the 2-stroke Clark BA-8, C-B GMWA-6, and C-B GMV-10.

Comparison of 2- and 4-stroke turbocharged engines were performed on three horsepower ranges. The first set included four different manufacturers and engines rated at 2000 hp. The engines in this group were I-R 412 KVS (4-stroke), Clark TLA-6 (2-stroke), C-B GMWC-6 (2-stroke), and Worthington SUTC-8 (2-stroke). Emission rates presented in Table 17 indicate that the 4-stroke engine produces more NO_x than the remaining three 2-stroke engines. Carbon monoxide and THC emission rates for the I-R 412 KVS were lower than the 2-stroke engines.

Although the second set of engines did not have exactly the same rated horsepower, the range was from 4000 to 4800 hp. All four engines in this category were turbocharged; and the engines in this set included Clark TCV-16 (2-stroke), C-B LSV-16 SG (4-stroke), I-R 616 KVT (4-stroke), and C-B 14 V-250 (2-stroke). A comparison of the emission rates of these engines at rated speed and load are presented in Table 17. For these four particular engines, there are no definite trends for NO_x or THC; however, the 2-stroke engines in horsepower range produced higher CO.

A comparison of 2- and 4-stroke engines was also made on a Clark TCV-16 (2-stroke), C-B 16 V-250 (2-stroke), and I-R 616 KVR (4-stroke). These engines were all turbocharged and rated at 5500 hp, and a comparison of the emission rates at rated speed and load is found in Table 17. There was no definite trend since the emission rate of the 4-stroke I-R 616 KVR was between the two other engines. However, the THC and CO emission rates of the 2-stroke engines were significantly higher.

Two sets of engines were selected which provided a logical comparison of two versions of the same engine. One version was normally aspirated while the other was turbocharged. Two different engine manufacturers were involved in this study. The two engine comparisons were Clark BA-8 and HBA-8T and C-B GMWA-6 and GMWC-6. The emission rates of these four engines at or near rated speed and load is presented in Table 17.

In these two cases, the NO_x emission rates (expressed in lbs/ 10^6 BTU and gr/hp-hr) were higher for the normally aspirated engines. A greater difference in the NA and TC NO_x emission rates was observed for the Clark engines. The THC emission rates were higher for the TC Clark HBA-8T, but the NA C-B GMWA-6 emission rates were higher than the TC C-B GMWC-6. In both sets of engines, the CO emission rates were less for the NA versions.

6. Range of Observed Emission Rates

Upon completion of emission testing from 59 reciprocating engines at rated speed and load, it was apparent that certain engines groups had unusually high or unusually low emission rates. In rank ordering these engines, they were included since that was the condition they were in at the time of testing.

When discussing the ranges of emission rates, it is noteworthy to mention these engines. The first engine was a Worthington 26X36 (P-23); and after emission testing was completed, a balance check was performed on the engine. As a result of this check, it was found that the engine was not balanced, as verified by gross differences in the emission concentrations observed from the two stacks.

The second group, the Worthington SUTC-8 (P-25), was observed to produce extremely low NO_x emission rates. Other BSFC rates from similar size (hp) engines indicated the BSFC ranges from 7000 to 8000 BTU/hp-hr. However, all three of the Worthington SUTC-8 engines had a BSFC rate of 3800 to 4500 BTU/hp-hr. Since the efficiency of most reciprocating engines are relatively close, it was apparent that some problem was present. Either the fuel rate was incorrectly measured and is low, by about 50 percent or the horsepower was higher than actual by about 50 percent even though not exceeding the manufacturer's ratings. For these three engines, horsepower was obtained from the participating gas transmission company using the manufacturer's operating curves. It is obvious that the data from these two engine groups are of concern, and consequently the range of emission rates are presented in Table 18 with and without these two groups.

As observed, the removal of these two engine groups affects the NO_x minimum (P-25) and CO maximum (P-23).

B. Gas Turbine Emission Results

During the baseline emissions survey, a total of eight gas turbine groups were tested. These gas turbines are listed in Table B-5 of Appendix B by engine manufacturer and model. Although the basic test point on the

TABLE 18. EMISSION RATE RANGES FOR ALL ENGINE GROUPS AND ALL ENGINE GROUPS LESS P-23 AND P-25.

Emission Rate	All Engine Groups		All Engines Less P-23 and P-25	
	Maximum	Minimum	Maximum	Minimum
NO_x lbs/hr	216.735	11.932	216.735	20.267
NO_x, lbs/10^6BTU	6.349	1.388	6.349	1.475
NO_x, gr/hp-hr	28.088	2.608	28.088	4.531
THC, lbs/hr	87.143	2.072	87.143	2.072
THC, lbs/10^6BTU	2.654	0.266	2.260	0.266
THC, gr/hp-hr	8.400	1.299	8.400	1.299
NMHC, lbs/hr	11.440	0.096	11.440	0.096
NMHC, lbs/10^6BTU	0.313	0.011	0.258	0.011
NMHC, gr/hp-hr	0.990	0.038	0.990	0.038
CO, lbs/hr	77.871	0.683	61.461	0.683
CO, lbs/10^6BTU	4.976	0.036	1.252	0.036
CO, gr/hp-hr	22.599	0.177	4.105	0.177

reciprocating engine was at rated speed and load, it was not always practical and frequently impossible to obtain the rated horsepower of each gas turbine. The general attitude of the participating gas transmission companies was to test the turbine as it was running rather than changing the operating conditions. At one station, the effect of power turbine speed was determined by reducing the turbine speed.

The raw data for gas turbine operating conditions and emissions data for each unit tested is found in Appendix C. The emission rates for each gas turbine except the GE LM-1500, as it was operating, is found in Table D-9. Because of inconsistencies between O_2, NO_x and HC readings for the test of the GE LM-1500, the data are judged questionable and should not be considered representative without additional tests. Consequently, these data are not included in summary Tables D-9 through D-12 in Appendix D.

1. Emission Concentrations Corrected to 15 Percent O_2

Since proposed Federal standards for stationary gas turbines are based on 15 percent O_2, it is necessary to correct NO_x concentrations to 15 percent O_2. The equation used to correct observed ppm NO_x concentrations at observed O_2 levels to the 15 percent O_2 reference is as follows:

$$\frac{\text{As-Measured ppm } NO_x}{\text{ppm } NO_x \text{ at } 15\% \; O_2} = \frac{21\% - \text{Observed } \% \; O_2}{21\% - 15\%}$$

$$\text{ppm } NO_x \text{ at } 15\% \; O_2 = \frac{6\% \times \text{As-Measured ppm } NO_x}{21\% - \text{Observed } \% \; O_2}$$

The as-measured emission concentrations as well as the concentrations corrected to 15 percent O_2 are presented in Table 19.

A relative comparison of emission concentrations corrected to 15 percent O_2 is presented in Figure 19. Of the seven groups, only one gas turbine was below the level under discussion as a possible proposed Federal standard of 55 ppm NO_x at 15 percent O_2. This unit was a 1000 hp Solar Saturn T-1001. All of the mainline transmission gas turbines (ranging from 9300 to 20,000 hp) exceed the proposed standard.

The effect of correcting all observed concentrations of a given level of free O_2 is to assume a certain fixed amount of dilution for all gas turbines. It happens that 15 percent O_2 is a good average value for most gas turbines at or near their design point and is an indicator of the excess air handled by the machine. This approach has basic simplicity in that to measure NO_x, all that is needed is the NO_x concentration, for example by CL or PDS, and the O_2 reading. No fuel rate or power output is needed nor is there a need for air flow measurement, a difficult item

TABLE 19. GAS TURBINE CONCENTRATIONS CORRECTED TO 15% OXYGEN

Turbine Group	Gas Turbine	E-S-U-R*	O_2, %	As-Measured Concentration, PPM			Concentration Corrected to 15% O_2, PPM		
				NO_x	THC	CO	NO_x	THC	CO
T-1	GE Frame 3	5A-2-1-1	17.4	48.0	0.5	4.0	80.0	0.8	6.7
		5B-2-1-5	17.8	40.5	6.0	11.0	75.9	11.3	20.6
		5C-2-1-2	16.8	40.0	4.0	4.0	57.1	5.7	5.7
		Average	17.3	42.8	3.5	6.3	71.0	5.9	11.0
T-2	GE JP-200	15-4-1-3	17.3	67.0	7.5	45.0	108.6	12.2	73.0
T-3	GE M3112R	40-7-T4-2	17.2	71.0	5.0	2.0	112.1	7.9	3.2
T-4	GE M3912R	39-7-T3-3	17.8	68.0	3.5	3.0	127.5	6.6	5.6
T-5	GE LM1500	68-10-1-2	See Appendix Table C-68, page C-89.						
T-6	P&W RT-105GT	16-4-1-5	18.60	52.0	9.5	27.0	130.0	23.8	67.5
T-7	P&W GG3C-4	30-6-1-1	17.3	39.0	11.5	30.0	63.2	18.6	48.6
T-8	Solar Saturn T-1001	37-7-T2-1	17.0	26.5	5.0	47.0	39.8	7.5	70.5
	Solar Saturn T-1001	38-7-T1-2	17.7	28.5	36.0	68.0	51.8	65.4	123.6
		Average	17.4	27.5	20.5	52.5	45.8	36.5	97.1

* E-S-U-R = Engine-Site-Unit-Run

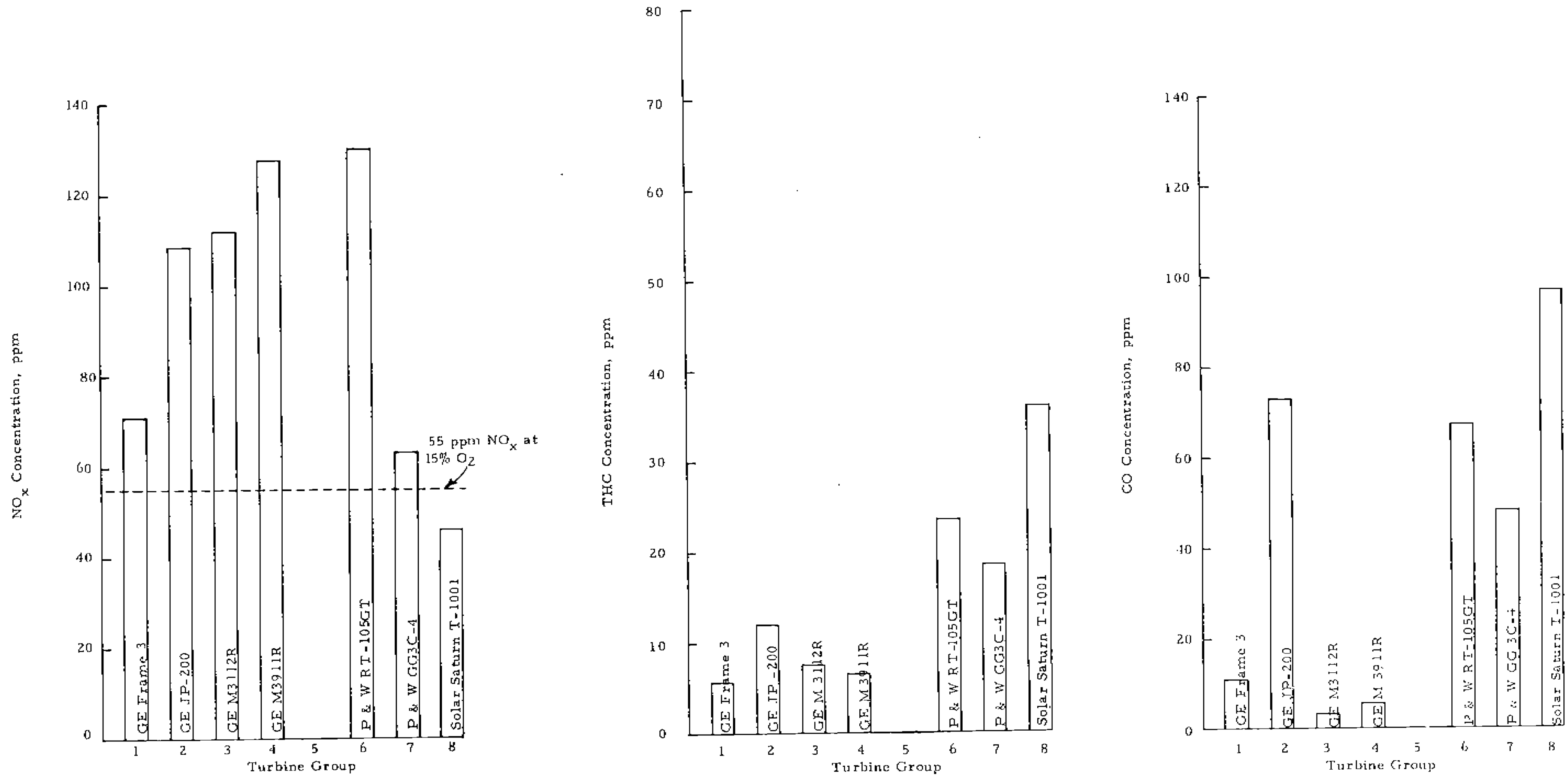


FIGURE 19. RELATIVE CONCENTRATIONS (Corrected to 15% O_2) BY TURBINE GROUP

to accurately determine for gas turbines because of differences in their installation and secondary air in the exhaust stack, etc.

This method places great importance on oxygen measurement for accuracy. The oxygen must be measured as carefully as the NO_x. The method of expression says nothing about the mass rate of emission and, therefore, is of no value in emissions inventory. Nor does it reflect the social value of a larger possibly more efficient machine as does the brake specific method. It is a relatively easy method to use in demonstrating compliance and for in-plant monitoring.

2. Mass Emission Rates (lbs/hr)

The emission rate, expressed in lbs/hr, of each of the turbine groups is presented in Figure 20. The GE M3112R, P&W RT-105GT, GE JP-200, and GE 3911R gas turbines produced the most lbs of NO_x/hr of the eight gas turbine groups tested. The P&W RT-105GT and the P&W GG3C-4 were the greatest producers of THC. The two gas turbines producing the largest quantities of CO were the GE JP-200 and P&W GG3C-4.

For a given contaminant and for equal observed concentrations, the time rate of mass of emission is governed by the total throughput of exhaust. Generally, the larger the machine or the higher the rating, the greater the flow of exhaust so that this method basically is machine size dependent. It is interesting to consider the trend of the mass rates in terms of the fuel and brake specific calculations.

3. Fuel Specific (lbs/10^6BTU) Emission Rates

On emission rates, expressed on a fuel input basis (lbs/10^6BTU), the GE M3112R and GE M3912R were the two units producing the most NO_x as shown in Figure 21. The Solar Saturn T-1001 and P&W RT-105GT gas turbines produced the most lbs of THC/10^6 BTU. The CO emission rates of Solar Saturn T-1001 and GE JP-200 were the highest of the turbine groups tested.

Comparing NO_x trends for the eight turbine groups between Figure 20 (lbs/hr) and Figure 21 (lbs/10^6BTU), it is apparent that greater differences between engine groups are indicated by the fuel specific basis. Turbine Group 2, the GE JP-200; Group 6, the P&W RT-105GT; Group 7, the P&W GG3C-4; and Group 8, the Solar Saturn T-1001 were the engine groups that were most apparent in their different behavior.

One would have a different opinion of the relative comparison of engine groups using the fuel or brake specific basis rather than the mass rate shown on Figure 20. For this reason and because the fuel of brake

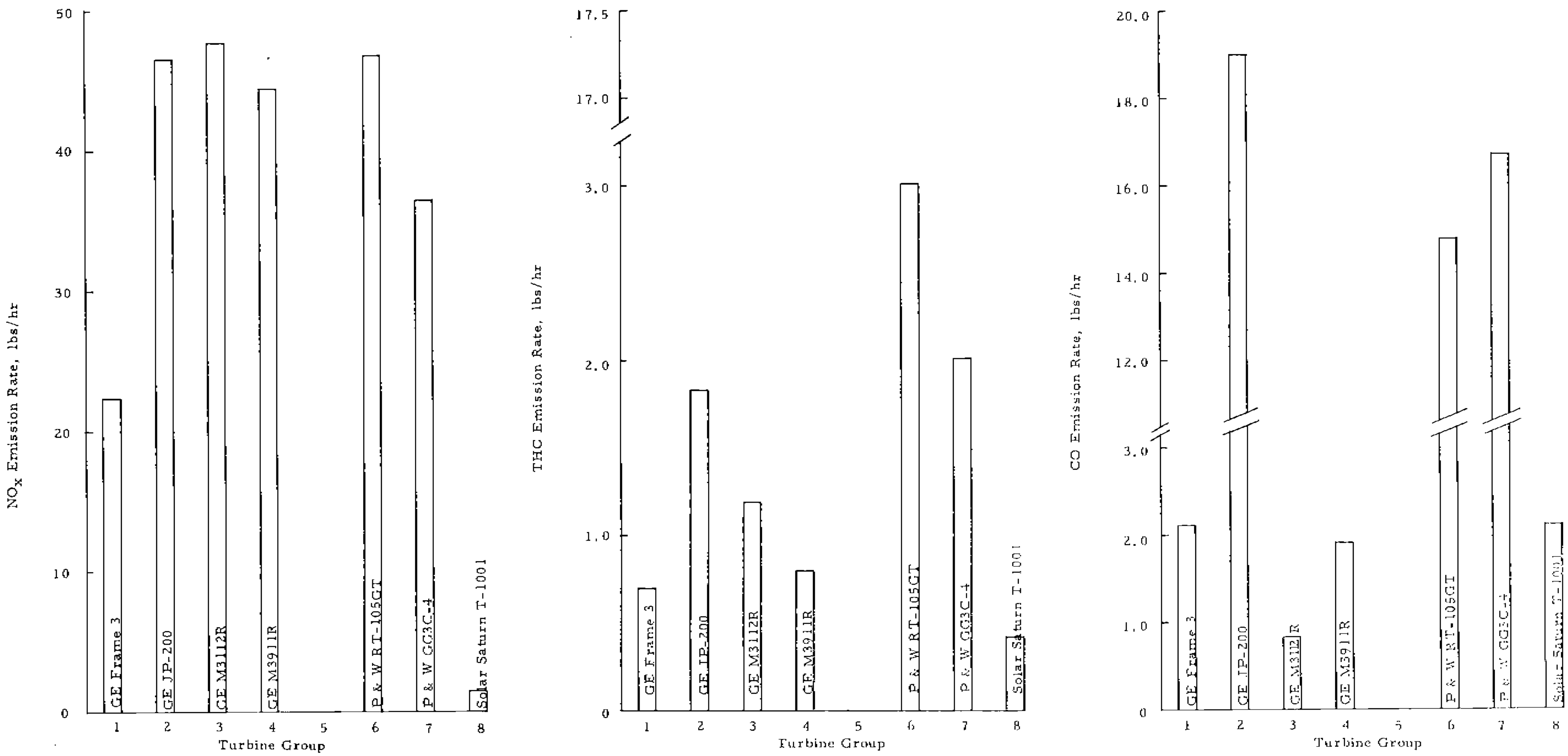


FIGURE 20. RELATIVE EMISSION RATE (lbs/hr) BY TURBINE GROUP

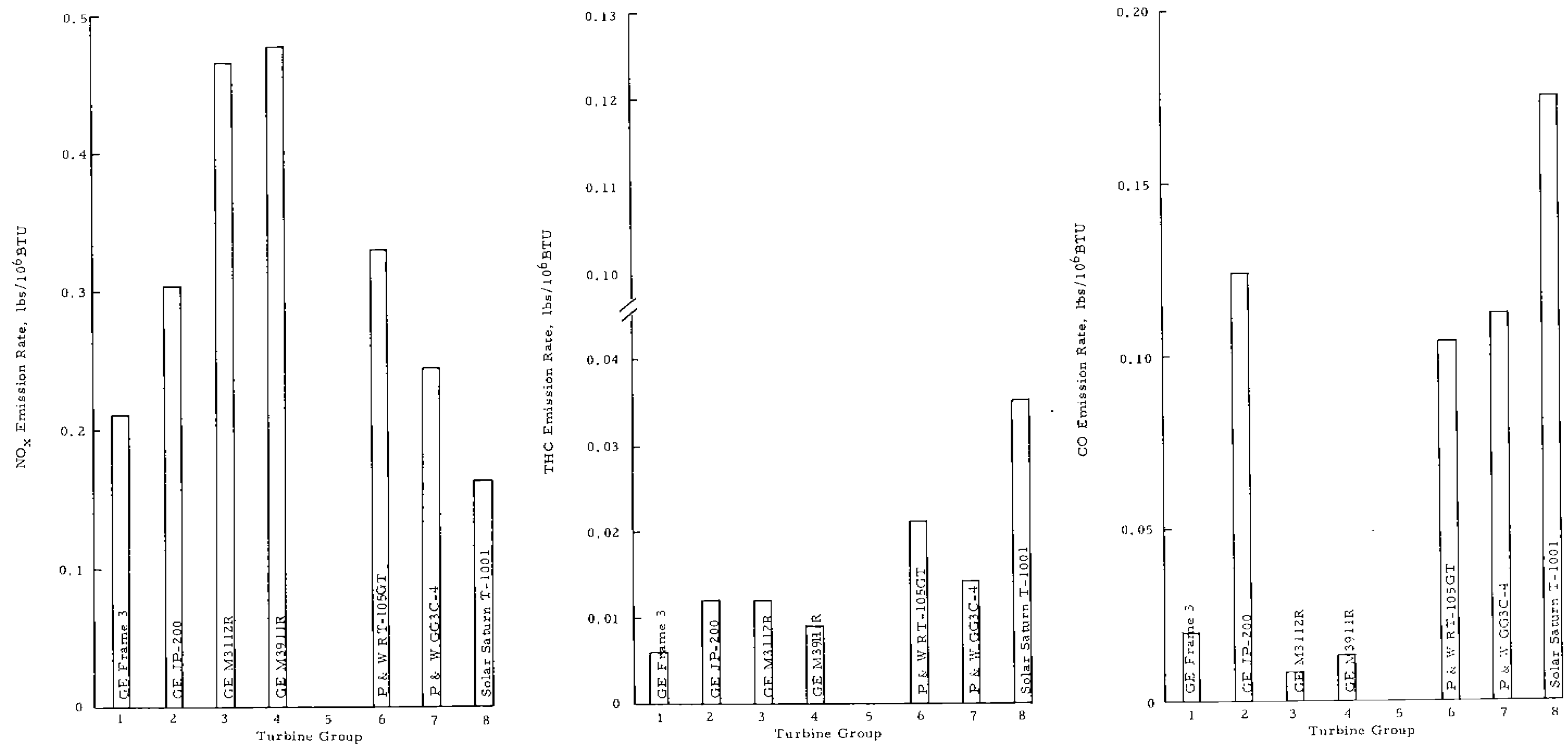


FIGURE 21. RELATIVE EMISSION (lbs/10^6 BTU) BY TURBINE GROUP

specific methods are much more acceptable for direct engine comparison, comparison of engines by mass rate, or observed concentrations (corrected to 15 percent O_2) should be avoided or made with much caution.

4. Brake Specific (gr/hp-hr) Emission Rates

The final method of expression is based on a work output, gr/hp-hr. The emission rates (gr/hp-hr) of the eight groups of gas turbines is presented in Figure 22. The three gas turbines emitting the most gr/hp-hr were GE M3911R, GE M3112R, and P&W RT-105GT; while the Solar Saturn and P&W RT-105GT produced the most THC. The Solar Saturn produced the largest amount of CO in gr/hp-hr.

The brake specific results gave comparable trends to the fuel specific bar chart in Figure 21 as expected. As with the piston engine, brake specific rates are best for engine-to-engine comparison. Power output on turbine engines is even more difficult to accurately determine, however, making the fuel specific the preferred basis. From a control and monitoring standpoint, the simplest is to use concentrations corrected to 15 percent O_2 because less instruments are needed for measurement of CO_2 and HC. Fuel measurement is not required as it is in the "carbon balance" method.

Once the emission rates were known, it was possible to rank order the gas turbines according to the emission rate levels. These turbines were rank ordered by the five methods of expression. These include emission rates expressed as lbs/hr, lbs/10^6BTU, gr/hp-hr, as-measured ppm and ppm corrected to 15 percent O_2. These results are presented in Tables D-10 through D-12 for NO_x, THC, and CO, respectively.

C. Summary

The baseline emissions data from a total of 59 piston and ten gas turbine engines in mainline pipeline compressor applications have been presented. The extensive THC, CO, and NO_x emissions data, computer reduced and expressed in concentration, lbs/hr, lbs/10^6BTU, and gr/hp-hr, have been summarized in terms of 25 piston engine groups and eight turbine groups. Bar chart representation of these various emission rates show the relative levels of each engine group and indicate the range of variation from group to group. For direct comparison, gr/hp-hr (brake specific) or alternatively lbs/10^6BTU (fuel specific) emission rates should be used. Mass rate (lbs/hr) is helpful in determining emission inventory and impact. Observed turbine engine emissions concentration corrected to 15 percent O_2 promises to be the simplest of known methods for monitoring and in-plant control. This method says little of the specific contribution

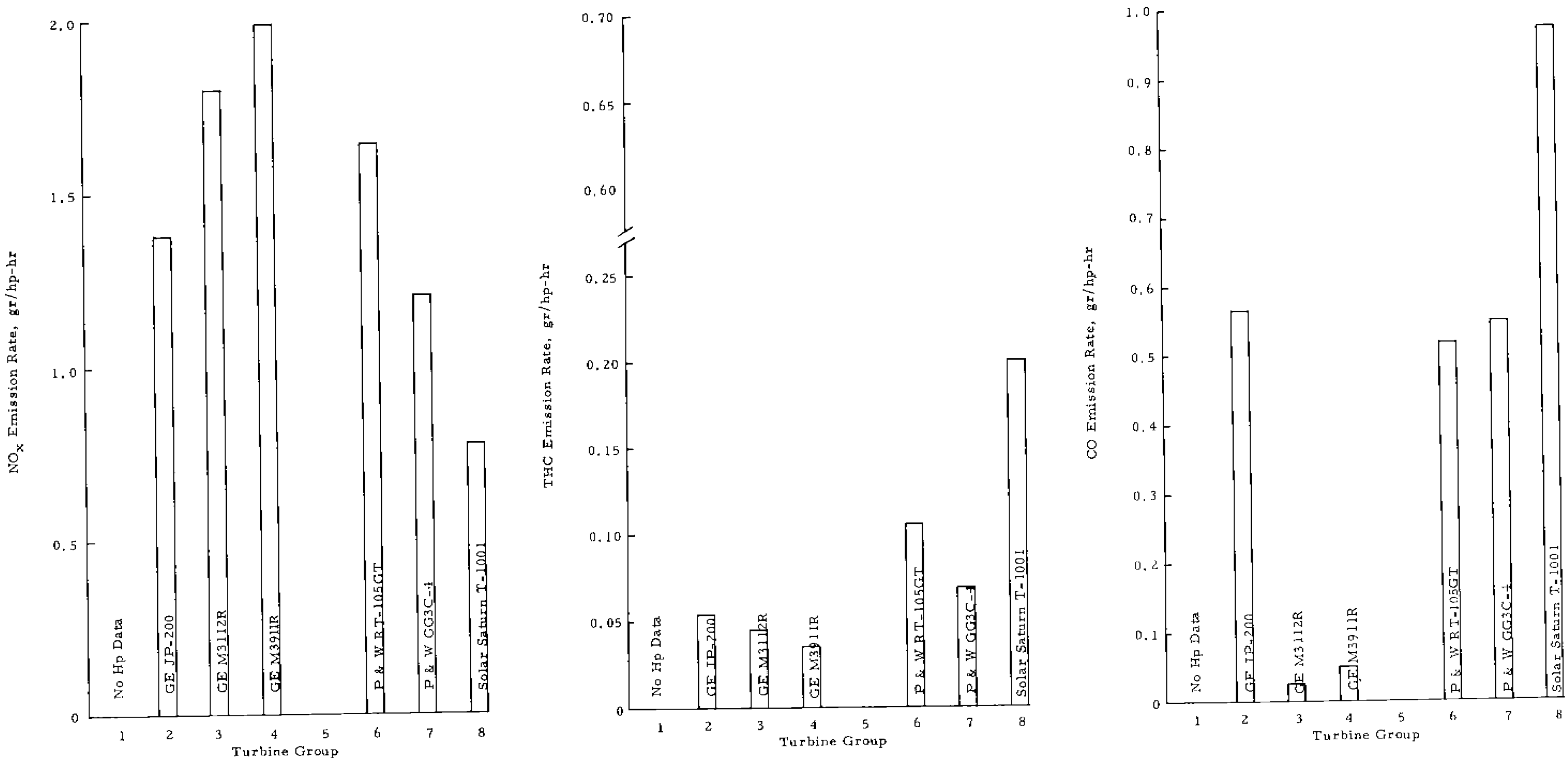


FIGURE 22. RELATIVE THC EMISSION RATES (gr/hp-hr) BY TURBINE GROUP

or social value of the engine and this is a shortcoming.

NO_x, the most important emission, was found to range from 20.3 to 216.7 lbs/hr, from 1.5 to 6.3 lbs/10^6BTU, and from 4.5 to 28.1 gr/hp-hr for the piston engines tested. These values were obtained at or as near as possible to rated speed and load and are considered typical. Turbine engine NO_x ranged from 46 to 130 ppm, corrected to 15 percent O_2. The level under discussion as a possible proposed Federal standard for new stationary gas turbines is 55 ppm NO_x at 15 percent O_2. NO_x emissions from mainline transmission gas turbines (9300-20,000 hp) ranged from 23.7 to 48.0 lbs/hr, from 0.21 to 0.48 lbs/10^6BTU and from 1.2 to 2.0 gr/hp-hr. The NO_x emissions from a smaller 1000 hp gas turbine were 1.7 lbs/hr, 0.14 lbs/10^6BTU and 0.78 gr/hp-hr.

In addition to rank-ordering the emission rates for all engine groups, comparisons were made between 2- and 4-stroke cycle turbocharged engines, 2- and 4-stroke cycle normally aspirated engines, and normally aspirated and turbocharged 2-stroke engines. In closing, much more analysis could be made of the voluminous emissions data obtained in the course of this project. An attempt to analyze the effects of certain operating variables was made and is included in the next section.

IV. EMISSION TRENDS VERSUS ENGINE OPERATING CONDITIONS

Upon completion of emission testing at rated speed and load, various changes in the engine operating conditions were employed to determine these effects on emissions. Engine operating parameters used to establish these trends were (1) changes in horsepower with variable speed (2) changes in horsepower at constant speed (3) scavenging air pressure (4) ignition timing and (5) variable engine speed at constant horsepower. The selection of engines and the various operating parameters was mutually decided by the SwRI Field Engineer and the cognizant company coordinator. The actual selection was constrained by engine availability and extent of assistance and cooperation possible by operations and company test personnel. The participating gas transmission companies were extremely cooperative in this respect.

A. Effect of Horsepower (Variable Engine Speed) on Emissions

One method employed to change the horsepower is to reduce the engine rpm from rated engine speed. Generally, engine speeds are maintained in the range of 90 percent to 100 percent rated speed. The effect of reducing engine speed (and consequently horsepower) on emission trends was tested on eleven groups of engines, including four Clark, six Cooper-Bessemer, and one Ingersoll-Rand engine. On several of the piston groups, more than one engine was tested. The emission rates were calculated and plotted as a function of horsepower (although it is understood that the changes in horsepower were obtained by reducing engine speed). Emission trends as a function of horsepower are presented in Figure 23 for the three Clark HBA-8T engines. This is an example of the general emission trends of most of the engines thus tested. Although the fuel specific lbs/10^6 BTU are used in this figure, brake specific rate shows the same effect.

Emission trends for all eleven groups, expressed in lbs/hr, lbs/10^6 BTU, gr/hp-hr and ppm, are presented as Figures E-1 through E-43 in Appendix E. Table E-1 lists each engine tested, the actual test number and the corresponding Appendix E figure number for all four emission rate expression methods.

Emission rates of a given test had similar emission trends, regardless of the method of expression. Of the eleven aforementioned tests, four (Clark HBA-8T and TLA-6, C-B LSV-16 SG, and I-R KVG-8) indicated a definite trend in that NO_x emissions increased with power. The THC emissions from these engines was reduced or remained relatively constant during these power changes. Carbon monoxide emissions

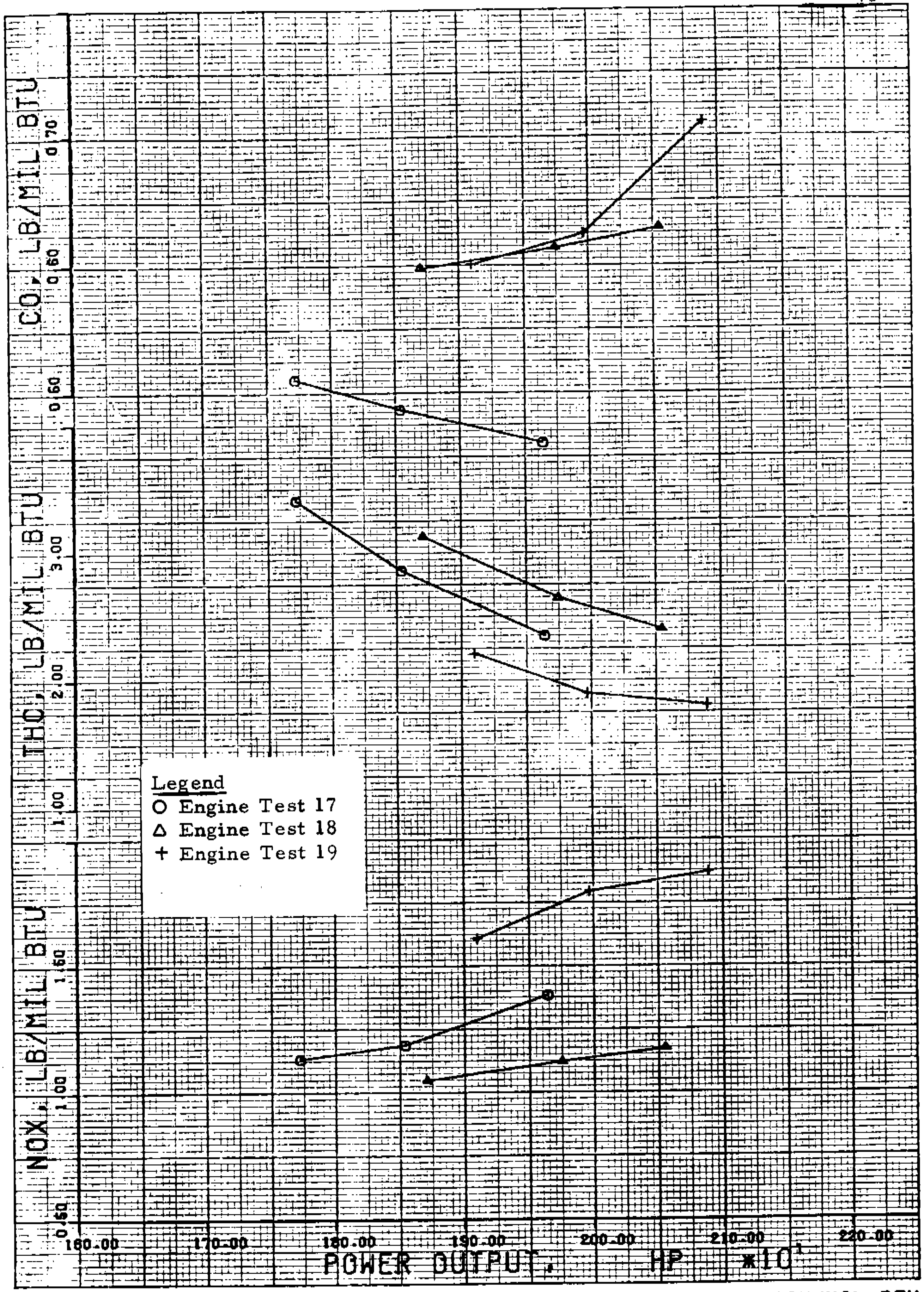


FIGURE 23. EFFECT OF POWER ON CLARK HBA-8T LB EMISSION/MIL BTU

were observed to increase or remain steady for these same power changes.

Two engines, the C-B LSVA-16 and GMW-8, produced emission trends where the NO_x emission rates peaked near rated horsepower. Carbon monoxide and THC emission trends were mixed for these two engines. The four additional engines tested produced somewhat varied emission trends.

It is interesting to note that on a given engine make and model, one test might indicate a definite change with power, whereas a second engine of the same type might be insensitive to the change in power as achieved by a change in speed. An example of this is found in Figure E-29 of Appendix E, where Test 34 (C-B GMWA-8) indicated an increase in NO_x emissions as horsepower increases and Test 36 where the NO_x emission rates were steady to slightly lower. Another example is Figure E-21 with a C-B GMWC-6 where the NO_x emission rates were observed to decrease as the power increased.

An overall review of the graphs of lbs/10^6BTU and gr/hp-hr of NO_x versus change in power (achieved through a change in speed) indicated an increase in NO_x with an increase in power. To be sure, there were exceptions to this with some engines going through a maximum, as shown in Figure E-25 for a C-B GMW-8 engine. One engine was found to produce less $NO_x/10^6$BTU with increase in power. Figure E-21 shows this effect for a C-B GMWC-6. The CO emission rate increased slightly while the THC emission rates slightly decreased with increasing horsepower.

For the same C-B GMWC-6 engine, the trend was somewhat different based on brake specific (gr of NO_x/hp-hr) where the NO_x, per Figure E-22, went through a maximum. These examples tend to confirm the difficulty of generalizations about emissions behavior for this class of engines.

B. Effect of Horsepower at Constant Rated Speed

Eight groups of engines were tested at various horsepower loads at constant rated speed. The specific engines, engine tests and the corresponding figures in Appendix E, are listed in Table E-2. An example of the emission rate, lbs/10^6BTU, as a function of horsepower at constant rated speed are presented in Figure 24. For two C-B GMWC-10 engines as a general rule, the NO_x emission rates for both engines increased with increasing horsepower while THC emissions decreased slightly and CO emissions increased slightly. Engines which fell into this category included the C-B 16 V-250, GMV-10 and GMWC-10, Clark BA-8, and I-R 412 KVS

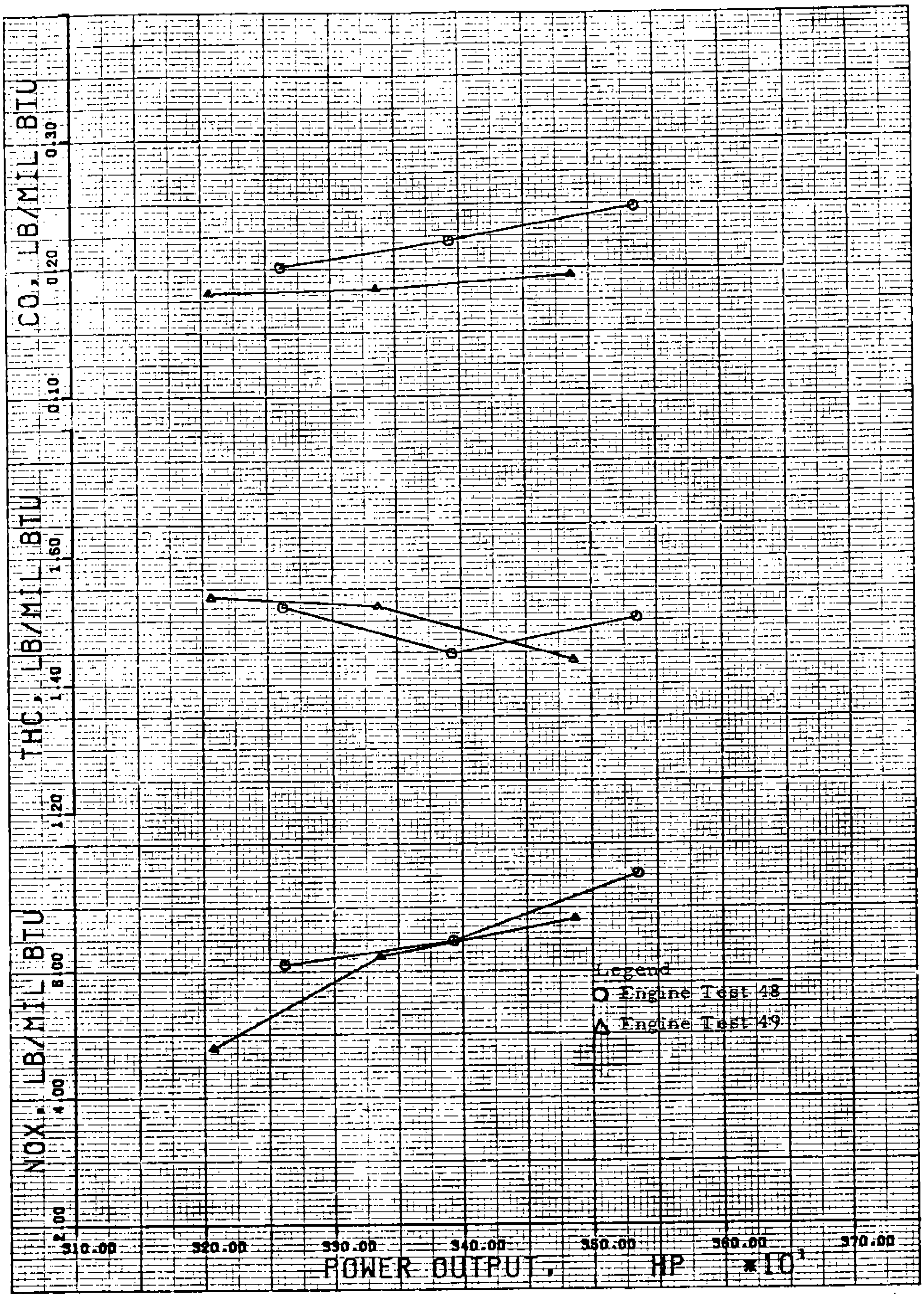


FIGURE 24. EFFECT OF POWER ON C-B GMWC-10 LB EMISSION/MIL BTU

engines.

Figures E-44 through E-74 illustrate the emission trends of all engines tested with variable horsepower at constant speed.

C. Effect of Ignition Timing of Emission Trends

The effect of ignition timing on emission rates was determined on eleven groups of engines. These groups are listed in Table E-3 of Appendix E by engine make and model along with the corresponding figures. An example of emission rates expressed in lbs/10^6BTU as a function of ignition timing on an I-R 412 KVS is shown in Figure 25. Figures E-75 through E-117 of Appendix E illustrate emission rate trends for eleven groups of engines as a function of ignition timing. Each engine has these trends expressed in lbs/hr, lbs/10^6 BTU, gr/hp-hr and ppm.

Seven groups of engines produced increasing NO_x emissions with spark advance. Included in this group were Clark TLA-6, TCV-12, C-B GMW-8, GMWC-10, LSV-16 SG, I-R KVG-8 and 616 KVT. Generally, where the NO_x emissions increased with spark advance, CO decreased slightly. The THC emission rate trends were not consistent and no conclusion may be stated.

Two engines, Clark HBA-8T and C-B GMW-10, NO_x emissions resulted in a maximum at about 10 degrees BTC and were lower at timing settings more or less advanced. Two engines, the C-B 10 V-250 and I-R 412 KVS, had the reverse trend and produced minimum NO_x emissions at standard spark timing. THC and CO trends for these four engines showed mixed behavior in that some followed the NO_x or each other and some did not.

D. The Effect of Scavenging Air Pressure

Emission tests were conducted on six engines to study the effect of scavenging air pressure on emissions at constant speed and load. The particular engines studied were the Clark HBA-8T, TLA-6, TCV-16, TCVC-16, C-B LSV-16 SG and I-R 616 KVR. Table E-4 lists the engines according to make and model, test number and the corresponding Appendix E figure number.

An example of emission trends, as a function of scavenging air pressure, is shown in Figure 26 for a Clark HBA-8T. The normal scavenging air pressure for this engine is 15.2 inches of mercury and is noted on the aforementioned figure. For this particular engine, as the scavenging air pressure increased the NO_x decreased. The THC

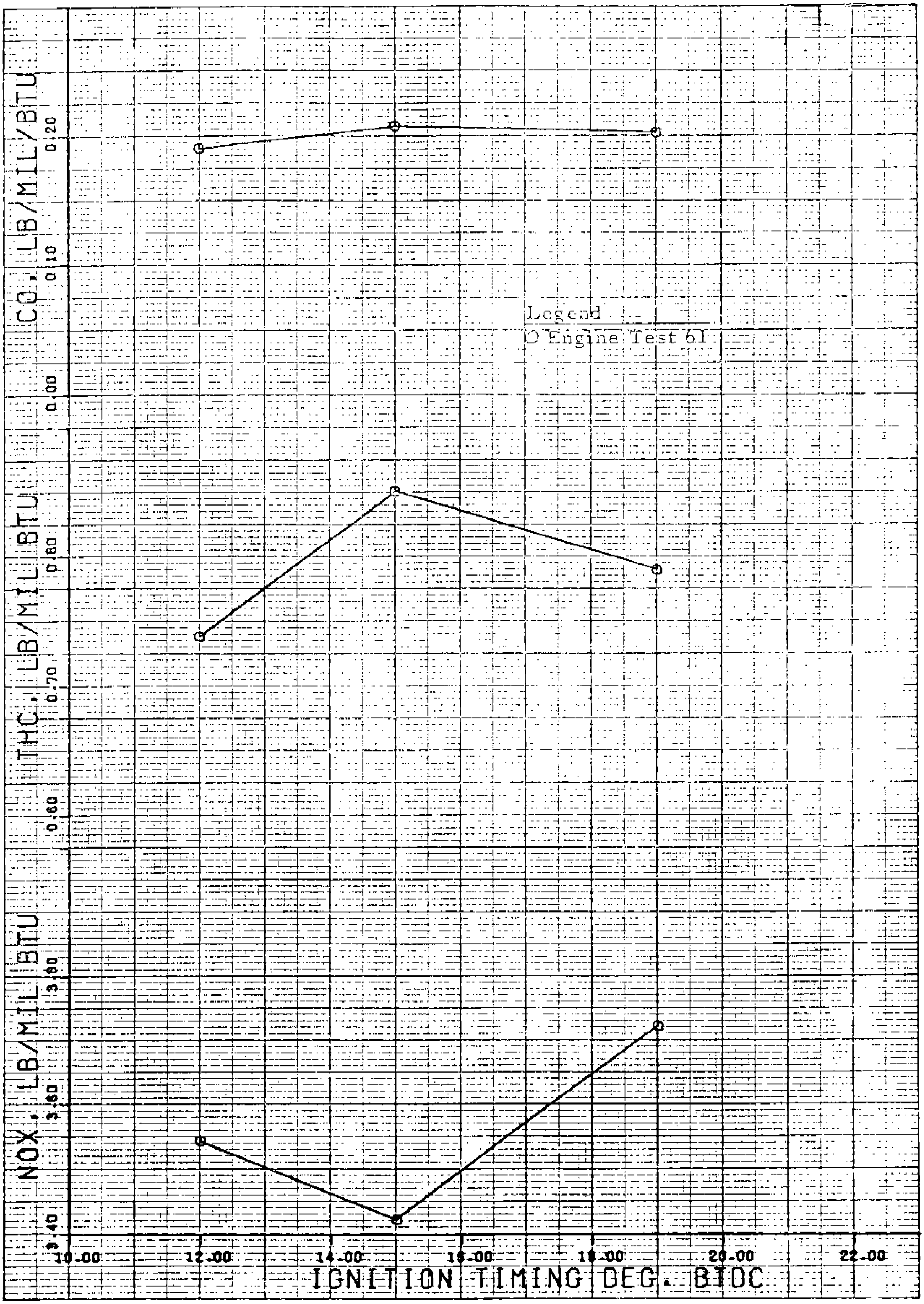


FIGURE 25. EFFECT OF TIMING ON I-R 412-KVS LB/MIL BTU EMISSIONS

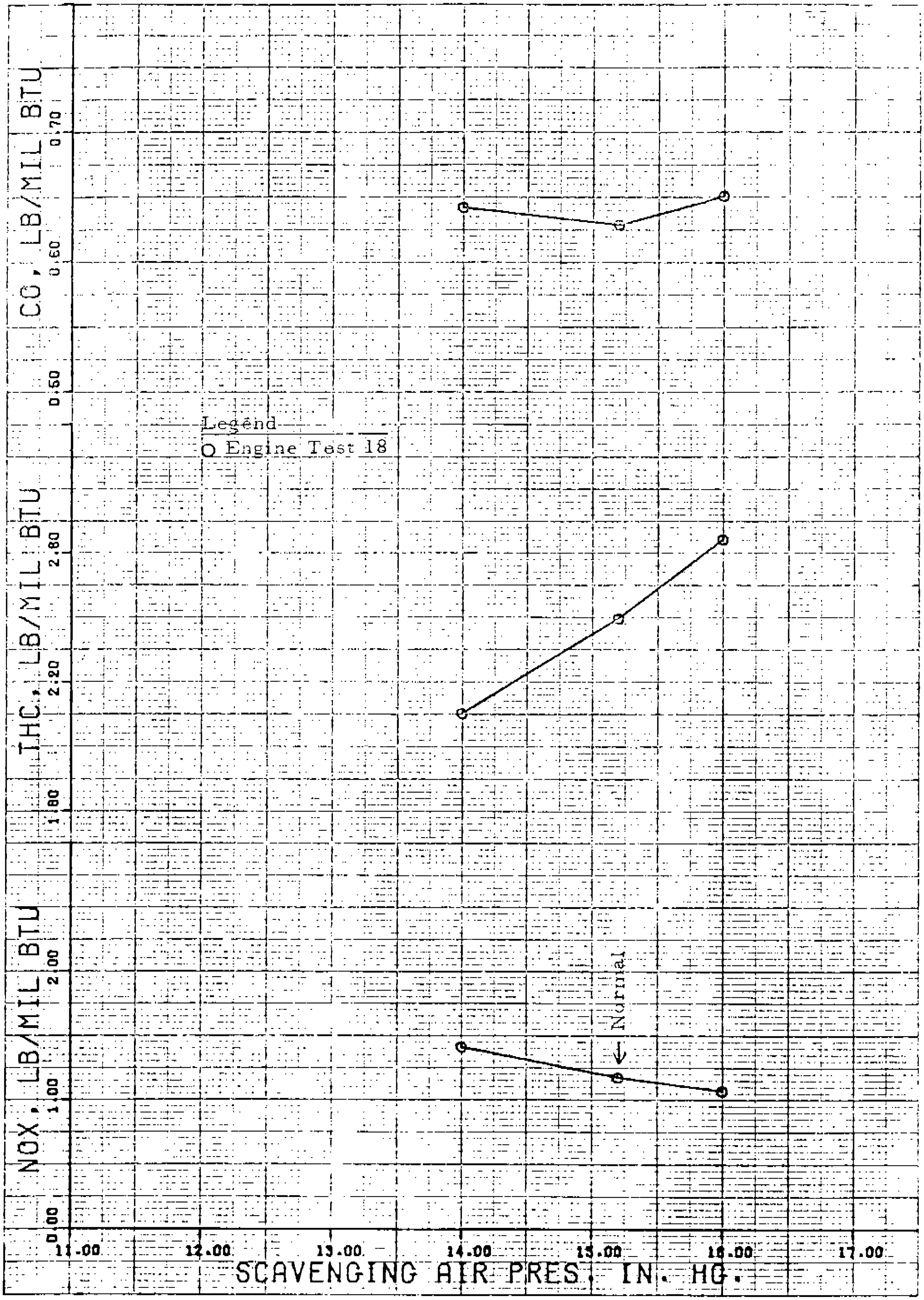


FIGURE 26. EFFECT OF SCAV. AIR ON CLARK HBA8T LB/MIL BTU EMISSIONS

and CO emission rates, however, increased. Additional engines which produced similar emission trends for NO_x, THC and CO to that in Figure 25 were the Clark TCVC-16, C-B LSV-16 SG and I-R 616 KVR.

All engines thus studied produced higher THC emissions at the higher scavenging air pressures. The Clark TLA-6 was the only engine which had a decrease in CO emission rate with increasing scavenging air pressure. The five remaining engines emitted greater quantities of CO as the scavenging air pressure was increased. The Clark TCV-16 was the only engine which did not exhibit the trend of decreasing NO_x emission rates with increasing scavenging air pressure. This engine produced maximum NO_x emissions at the normal scavenging air pressure as illustrated in Figure E-126.

E. The Effect of Engine Speed

Emission testing was conducted on one engine operating at constant rated horsepower and variable engine speed. This particular engine was a 2-stroke normally aspirated Cooper-Bessemer GMW-8. This engine was tested at Site 7 and the engine operating conditions as well as observed emission concentrations are presented in Table C-31 of Appendix C.

The initial test point was at rated speed and load. After testing at this point, the engine speed was lowered and the loading was re-adjusted to the original rated horsepower. This meant that the torque was increased with a decrease in speed. The procedure was repeated so that three speeds at constant rated load were tested and emission concentrations were obtained. The emission rates, expressed in lbs/10^6BTU, were calculated and are presented as a function of engine speed at rated load in Figure 27.

As observed, as the engine speed is increased (and torque decreased), up to rated or top speed of this specific engine, the emission of NO_x decreases. The contrary was found to be the case for the HC and CO; that is, as the engine speed was increased, at constant rated horsepower, so did the HC and CO emission rates. Torque, however, decreased. Emission rates expressed in lbs/hr, gr/hp-hr and ppm are found as Figures E-141 to E-143 in Appendix E. From this experiment, it was found that NO_x decreased and HC and CO increased with a decrease in torque.

F. Effect of Power Turbine Speed on Emissions from a Gas Turbine

At one particular location, Site 2, the operating conditions of a GE Frame 3 gas turbine were changed to obtain an emissions map over a range of turbine speeds. Figure 28 illustrates the effect of power turbine speed of this specific gas turbine on NO_x concentrations. The as-measured NO_x

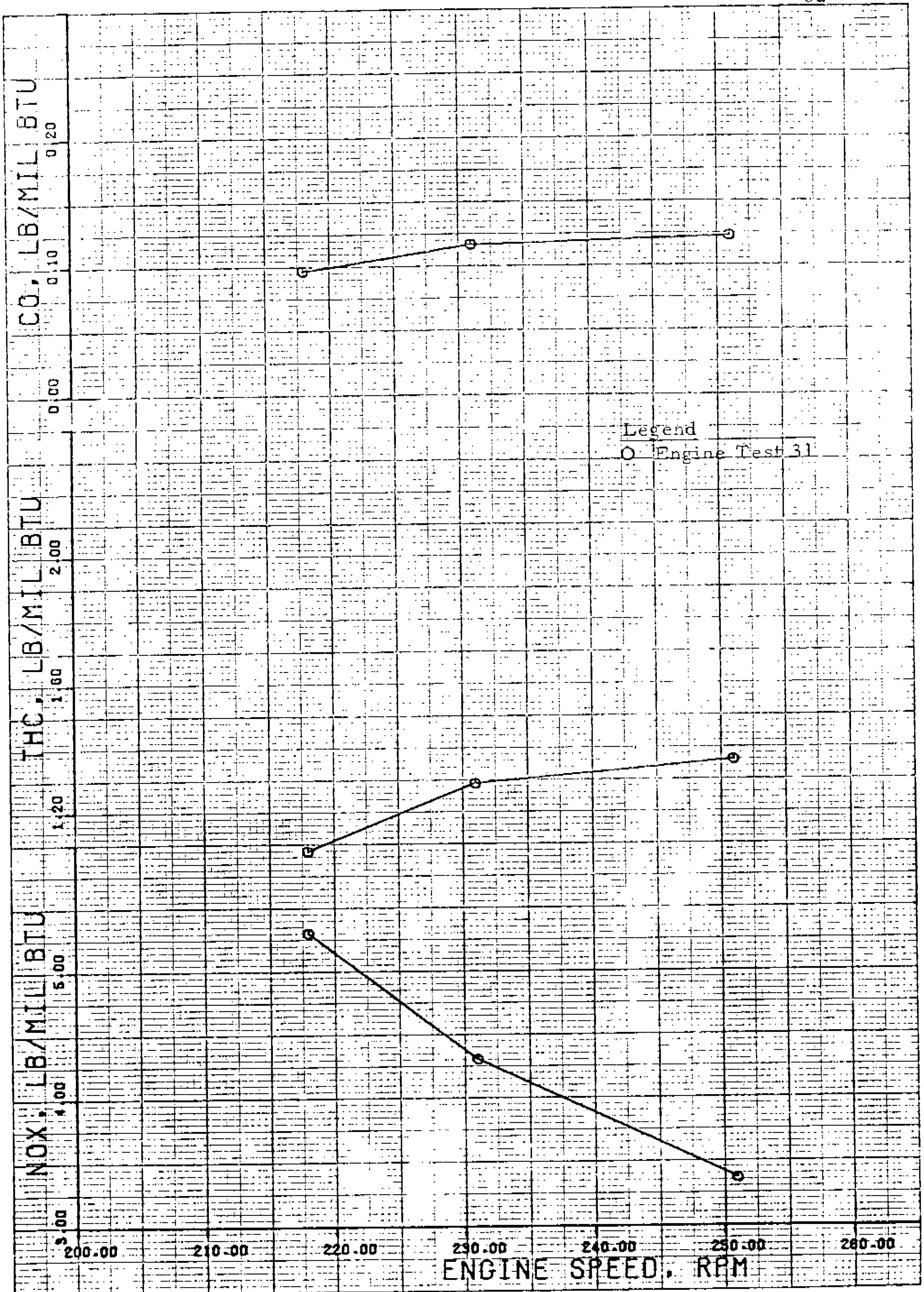


FIGURE 27. EFFECT OF ENGINE RPM ON C-B GMW-8 LB/MIL BTU EMISSIONS

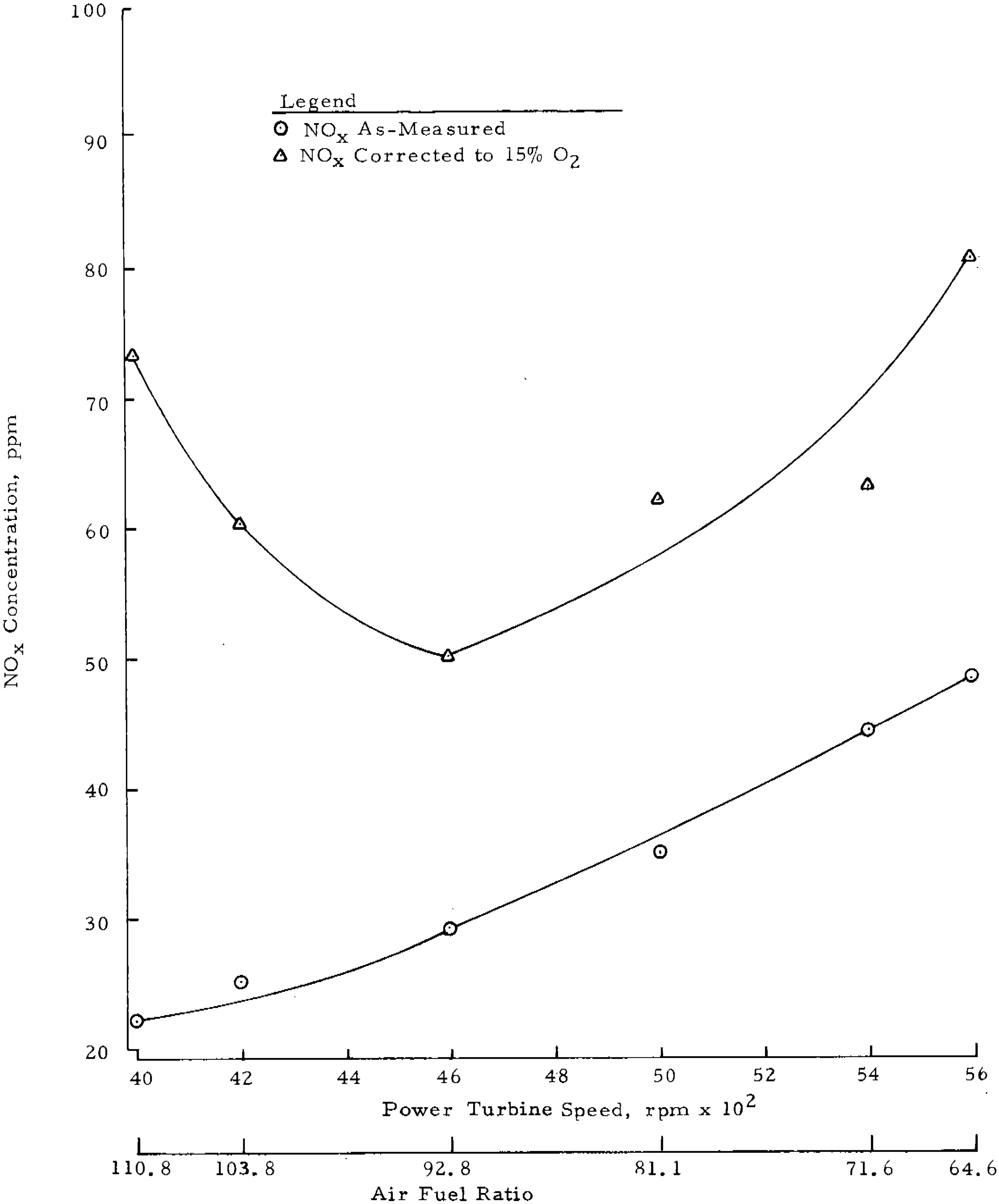


FIGURE 28. THE EFFECT OF GE FRAME 3 POWER TURBINE SPEED AND AIR-FUEL RATIO ON NO_x CONCENTRATIONS

concentrations increased with power turbine speed while the NO_x concentrations corrected to 15 percent oxygen reached a minimum at a power turbine speed of 4600 rpm.

Although the power turbine speed was the only parameter intentionally varied, the air-fuel ratio consequently changed greatly. The NO_x concentrations on an as-measured basis and corrected to 15 percent O_2 are presented in Figure 28 as a function of air fuel-ratio. As the air fuel-ratio of this GE Frame 3 gas turbine increased, the NO_x emission concentrations decreased. An air-fuel ratio of 93 produced minimum NO_x concentration when corrected to 15 percent O_2.

It is uncertain to what advantage the trend shown in Figure 28 may be, but it is felt the data should be mentioned. This was the only instance where a gas turbine's operation could be varied over a range sufficient to obtain emissions in a consistent manner. The station operators were generally unable to vary the way the turbine engine was running resulting in less data of a parametric nature than originally desired.

G. Summary

An attempt was made to illustrate the effects of various engine operating parameters on NO_x, THC and CO emissions from a number of piston engines and one gas turbine. The scope of these experiments was constrained to engine and operational availability and were subject somewhat to random selection. As such, the effects of the parameters cannot be considered all inclusive or definitive but are merely examples of what was found. Little in the way of repeat tests were possible, and the strength of the trends should be so viewed.

It was found that in general that NO_x could be reduced by (1) reducing power by reducing engine speed, (i. e. essentially constant torque), (2) reducing horsepower at constant speed (i. e. reducing torque), (3) increasing the scavenging air pressure (i. e. decreasing the fuel-air ratio among other factors), (4) retarding ignition timing (i. e. basic spark timing later in cycle) and (5) increased engine speed at constant power output (i. e. reducing torque). Items 2 and 5 are somewhat analogous in that reducing torque reduced NO_x, although the manner in which the adjustments were made and experiments were run were different.

There were many exceptions found to the above general trends with occasionally two similar engines producing different trends and certain engine groups showing a counter trend to the majority. The trends are seldom linear and some trends go through a maximum or a minimum over the range of the parameter.

The difficulty in varying gas turbine engine operation precluded the generation of emission data for trend analysis by operating variable. The power turbine speed on one turbine was varied with as-measured NO_x ppm decreased with decrease in power turbine speed. The decrease in power turbine speed increased the air-fuel ratio. On a corrected basis, the minimum NO_x was observed at a lower than design power turbine speed and higher than rated air-fuel ratio.

The nature of this project was to acquire as much baseline emissions data as possible about compressor engines. Incidental to this objective, emissions were measured at conditions other than typical of normal operation. To the extent possible, the effects of several obvious operating variables have been presented to indicate general trends. Much more analysis of this data could be made and many more tests of a more rigorous, replicative nature are needed to make definitive statements about the effect of certain operating parameters. Perhaps those high NO_x engines of great popularity and installed power should be studied in more detail with additional, more extensive field measurements obtained.

V. SUMMARY

Baseline emission rates of oxides of nitrogen, hydrocarbons and carbon monoxide have been measured from a total of 59 piston and nine gas turbine engines engaged in mainline pipeline gas compression and transmission. The engines were all fueled with natural gas and were tested in the mechanical condition at the time of test. The selection of the engines, representing four makes, was based on the installed horsepower of the companies comprising the NO_x study group and included a variety of 2- and 4-stroke cycle turbocharged and normally aspirated units ranging in size from 800 to 8000 hp. The gas turbines ranged in size from 1000 to 20,000 hp and represented three manufacturers. The tests were conducted at a total of 10 sites located in seven states during the period of August 1972 to June 1973.

A. Test Procedure

Several experiments were conducted to determine the sampling and analysis procedures for use in the baseline emissions portion of the project. The effect of sample probe location and design, sample stratification, use of plastic bags for sample collection and storage, storage stability, and correlation of CL to PDS analyzed NO_x levels were studied. Several piston and one gas turbine engine were employed. Guidelines and criteria were developed for use during the baseline emissions testing. They are described sufficiently to allow others to use all or parts of the method as desired.

Continuous monitoring of raw exhaust from large stationary gas fired piston and gas turbine engines was found to be a workable and quite satisfactory method for stack analysis. The use of non-dispersive infrared instruments for CO and (if needed, CO_2) hydrogen flame ionization analysis for unburned hydrocarbons, a gas chromatograph for determination of non-methane hydrocarbons, and a chemiluminescent analyzer for NO and NO_x were routinely used with a high degree of accuracy. The preferred method was to locate instruments near the stack, sample directly from a multiopening type probe inserted into the open end of the stack and continuously indicate the concentrations of pollutants.

B. Baseline Emissions

The baseline emission data were summarized in terms of 25 piston engine groups and eight turbine groups. For direct comparison, gr/hp-hr (brake specific) or alternatively lbs/10^6BTU (fuel specific) emission rates should be used. Mass rate (lbs/hr) will be helpful in determining emission inventory and impact. Observed turbine engine emission concentrations, corrected to 15 percent O_2 promises to be the simplest of known methods for monitoring and in-plant control. This method says little of the specific contribution or social value of the engine and this is a shortcoming.

NO_x, the most important emission, was found to vary widely from 20.3 to 216.7 lbs/hr, from 1.5 to 6.3 lbs/10^6 BTU, and from 4.5 to 28.1 gr/hp-hr for the piston engines tested. These values were obtained at or as near as possible to rated speed and load and are considered typical. Turbine engine NO_x ranged from 46 to 130 ppm, corrected to 15 percent O_2. A level of 55 ppm NO_x, corrected to 15 percent O_2, is being considered as a Federal standard. NO_x emissions from mainline transmission gas turbines (9300-20,000 hp) ranged from 23.7 to 48.0 lbs/hr, from 0.21 to 0.48 lbs/10^6 BTU and from 1.2 to 2.0 gr/hp-hr. The NO_x emissions from a smaller 1000 hp gas turbine were 1.7 lbs/hr, 0.14 lbs/10^6 BTU and 0.78 gr/hp-hr. In addition to rank-ordering the emission rates for all engine groups, comparisons were made between 2- and 4-stroke cycle turbocharged engines, 2- and 4-stroke cycle normally aspirated engines, and normally aspirated and turbocharged 2-stroke engines.

C. Emission Trends

An attempt was made to illustrate the effects of various engine operating parameters on NO_x, THC and CO emissions from a number of piston engines and one gas turbine. It was found in general that NO_x could be reduced by (1) reducing power by reducing engine speed (i.e. essentially constant torque), (2) reducing horsepower at constant speed (i.e. reducing torque), (3) increasing the scavenging air pressure (i.e. decreasing the fuel-air ratio among other factors), and (4) retarding ignition timing (i.e. basic spark timing later in cycle) and (5) increased engine speed at constant power output (i.e. reducing torque). Items 2 and 5 are somewhat analogous in that reducing torque reduced NO_x, although the manner in which the adjustments were made and experiments were run were different.

There were many exceptions found to the above general trends with occasionally two similar engines producing different trends and certain engine groups showing a counter trend to the majority. The trends are seldom linear, and some trends go through a maximum or a minimum over the range of the parameter.

The difficulty in varying gas turbine engine operation precluded the generation of emission data for trend analysis by operating variable. The power turbine speed on one turbine was varied with as-measured NO_x ppm decreased with decrease in turbine speed. The decrease in compressor speed increased the air-fuel ratio. On a corrected basis, the minimum NO_x was observed at a lower than design compressor.

speed and higher than rated air-fuel ratio. Little in the way of repeat tests were possible and the strength of the piston and turbine trends should be so viewed.

D. Closure

The nature of this project was to acquire as much baseline emissions data as possible about compressor engines. Incidental to this objective, emissions were measured at conditions other than typical of normal operation. To the extent possible, the effects of several obvious operating variables have been presented to indicate general trends. Much more analysis of this data could be made and many more tests of a more rigorous, replicative, nature are needed to make definitive statements about the effect of certain operating parameters. Perhaps those high NO_x engines of great popularity and installed power should be studied in more detail with additional, more extensive field measurements obtained.

Sufficient baseline data have been developed, however, to permit estimation of emission inventory or national impact values and to assess the current engines in terms of existing, proposed or future emission limits. Given additional statistical information on installed horsepower, etc., one could decide on engines that have priority importance for an emissions abatement program.

LIST OF REFERENCES

1. Federal Register, Part II, Vol. 36, Number 247 "Standards of Performance for New Stationary Sources," December 23, 1971.

2. Preliminary Unpublished Proposed Federal Standards Presented and Discussed in EPA Position Paper per Letter March 1, 1973 Pete Susey to Karl Springer.

3. Schaub, Fred S. and Beightol, Kenneth V., "NO_x Emission Reduction Methods for Large Bore Diesel and Natural Gas Engines," ASME paper 71-WA/DGP-2, presented at the ASME Winter Annual Meeting, Washington, D. C., November 28-December 2, 1971.

4. Haimov, H. A., "Nitrogen Oxide Emissions from Stationary Natural Gas Powered Engines," American Gas Association Transmission Conference, April 16 - 18, 1973, El Paso, Texas.

5. McGowin, Charles R. "Stationary Internal Combustion Engines in the United States," report to Environmental Protection Agency under contract No. EHSD 71-45, Task No. 24, April 1973.

6. McGowin, C. R., Schaub, F. S., and Hubbard, R. L., "Emissions Control of a Stationary Two-Stroke Spark-Gas Engine by Modification of Operating Conditions," AGA/IGT Proc. 2nd Conference, Natural Gas Research and Technology, Atlanta, Ga., (1972).

7. Nelson, A. W., "Exhaust Emission Characteristics of Aircraft Gas Turbine Engines," ASME paper 72-GT-75 for presentation at the Gas Turbine and Fluids Engineering Conference & Products Show, San Francisco, Calif., March 26-30, 1972.

8. Klapatch, R. D. and Koblish, T. R., "Nitrogen Oxide Control with Water Injection in Gas Turbines," ASME paper 71-WA/GT-9 for presentation at the ASME Winter Annual Meeting, Washinton, D. C., November 28-December 2, 1971.

9. "Control Techniques for Nitrogen Oxide Emissions from Stationary Sources," NAPCA Publication No. AP-67, March 1970.

10. Federal Register, Part II, Vol. 36, Number 84, "National Primary and Secondary Ambient Air Quality Standards," April 30, 1971.

11. Federal Register, Part II, Vol. 37, Number 221, "New Motor Vehicles and New Motor Vehicle Engines," November 15, 1972.

12. Correspondence from Peter E. Susey to Karl Springer, Nov. 6, 1972.

LIST OF REFERENCES (Cont.)

12. Directory of Reciprocating Gas Engines In Use By Various Gas Pipe Line Companies, prepared by Compressor Station Committee, Operating Section, American Gas Association, October 1972.

APPENDIX A

Analytical Instrumentation

Derivation of "Total Carbon" Method

Equations Used In Computer Program for
Reduction of Data From Natural Gas Compressor Engines

Explanation of Computer Output for
Natural Gas Compressor Emissions Programs

Computer Program

Appendix A

Exhaust Emissions Instrumentation

Selection of instruments used in the measurement of exhaust emissions from large natural gas fired piston engines and gas turbines was based on several factors. Prior to field testing it was decided that the exhaust species to be measured would be oxides of nitrogen ($NO + NO_2 = NO_x$), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), total hydrocarbons (THC), and non-methane hydrocarbons (NMHC).

Existing Federal testing procedures specify the use of continuous instrumentation for gasoline and diesel engines, whereas stack emissions from power plant generators are measured using grab samples. During the initial stages of program development, it was apparent that the approach best suited to testing several operating conditions on a number of piston engines and gas turbines would be the continuous route. Once the type of operation was determined, instruments acceptable according to Federal testing procedures for piston and gas turbine engines in mobile sources were selected for field emission testing. In addition to being continuous these instruments were selected based on previous field experience involving reliability, ruggedness, portability, etc.

Using the previously mentioned reasoning, the instruments listed in Table A-1 were selected for exhaust emissions in both phases. The chemiluminescent analyzer was built by Southwest Research Institute (SwRI) using Environmental Protection Agency (EPA) specifications. This instrument allows the distinction between NO and NO_x which was a requirement when selecting the instrument. The measurement of CO and CO_2 was accomplished by non-dispersive infrared (NDIR) analyzers. Two separate NDIR CO instruments were incorporated into the instrument cart, one low range and one high range. Total hydrocarbons (THC) were measured using a flame-ionization detector (FID). Total hydrocarbons refers to total HC response using the instrument manufacturer's recommended operating procedures and should not be construed to be absolute. Oxygen was measured using polaragraphic analyzer. All of the aforementioned instruments were capable of continuous analysis of direct stream samples as well as for analysis of bag samples of exhaust. Non-methane hydrocarbons were determined using a grab sample and analyzing in the gas chromatograph. By determining the methane fraction and knowing the total hydrocarbon concentration, the non-methane hydrocarbon concentration was determined.

A schematic of the flow system for the instrument system is presented in Figure A-1 and several views of the emissions cart are shown in Figure A-2. Calibration span and zero gases were transported from site-to-site

TABLE A-1. LIST OF EQUIPMENT USED IN THE EMISSIONS SURVEY OF NATURAL GAS COMPRESSOR ENGINES

Component	Manufacturer	Instrument Type	Nominal Instrument Ranges
NO/NO_x	SwRI per EPA Design	Chemiluminescent Analyzer	0-100, 0-300, 0-1000, 0-3000 ppm
CO	Beckman 315B	Short path NDIR	0-5%, 0-1%
CO	Beckman 315B	Long path NDIR	0-50, 0-130, 0-500 ppm
CO_2	Beckman 315B	Short path NDIR	0-16%, 0-2%
HC	Beckman 400	Flame Ionization Analyzer	0-100, 0-1000, 0-10,000 ppmC
O_2	Beckman	Polarographic	0-25%, 0-5%
GC	Varian 1740	Dual column FID	Variable
GC	Varian 600-D	Single column FID	Variable

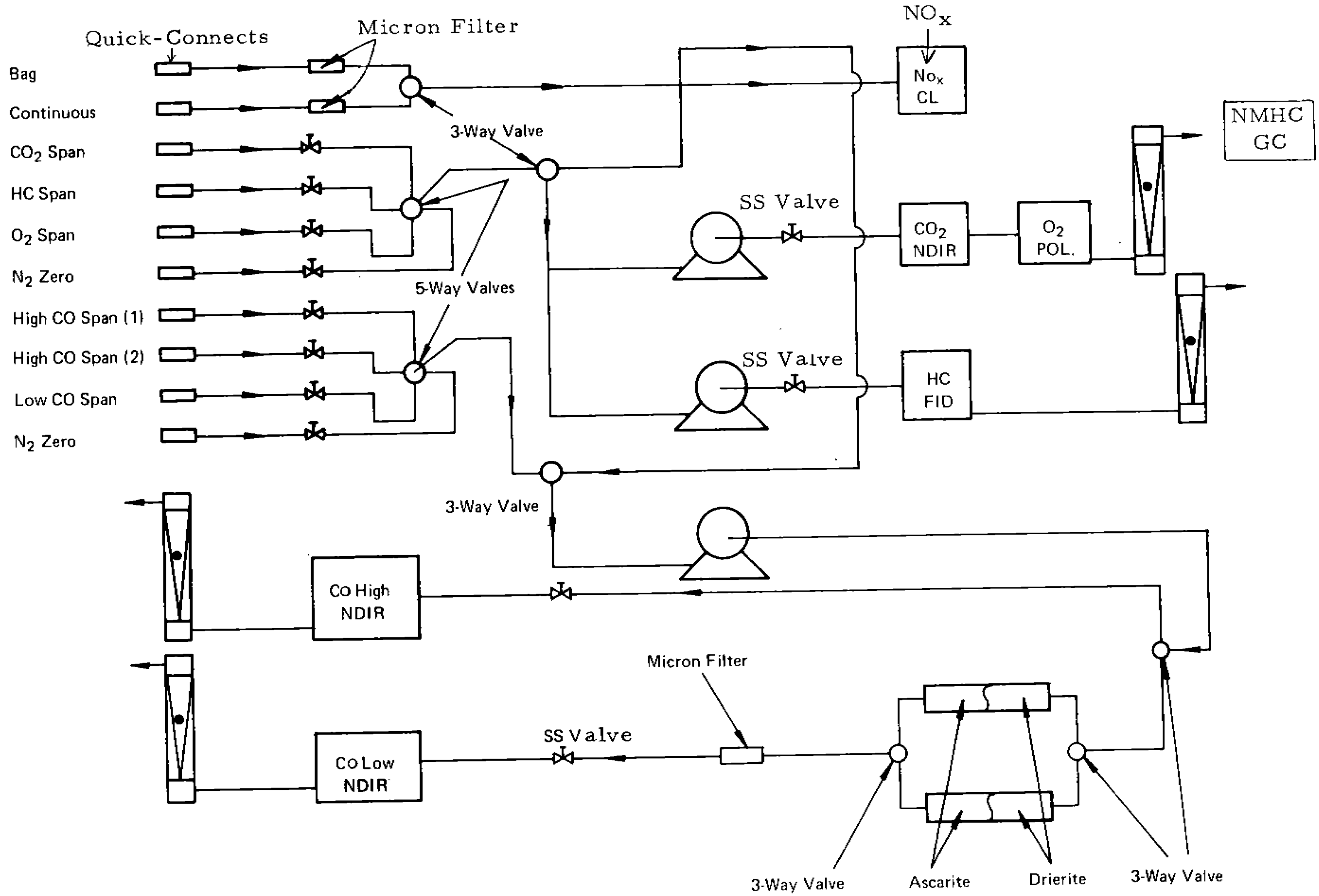
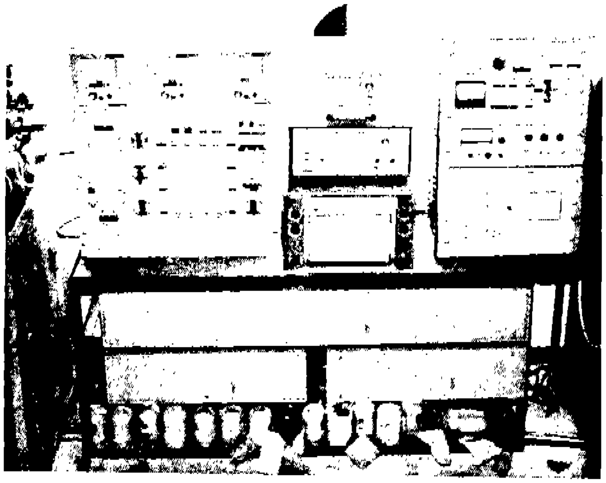
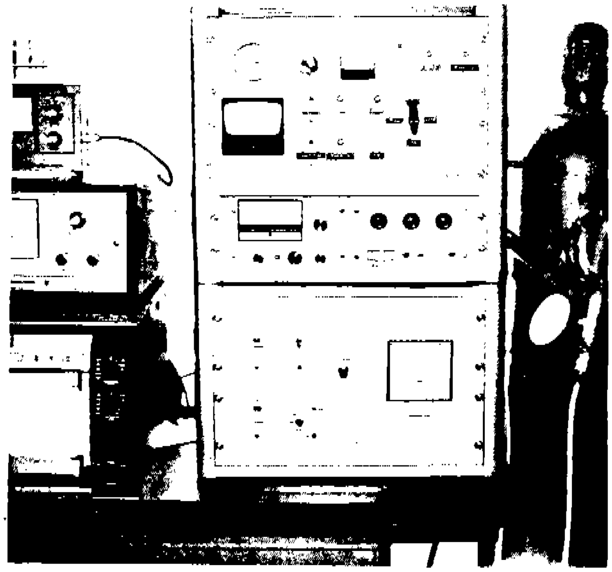


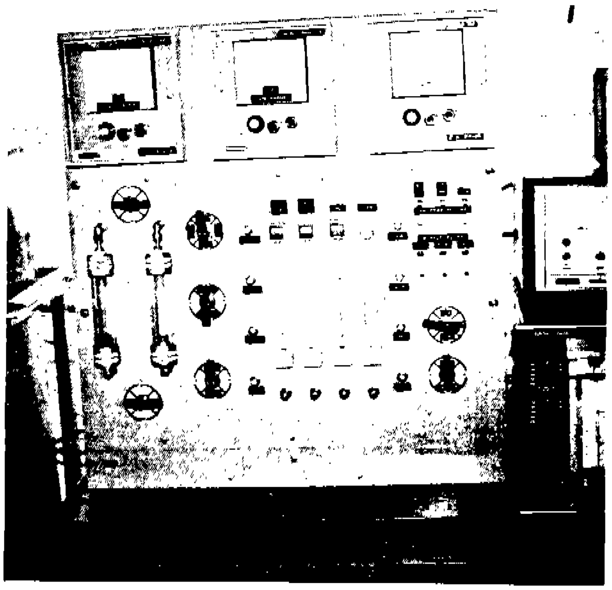
FIGURE A-1 CONTINUOUS INSTRUMENTATION EMISSIONS CART FLOW SCHEMATIC



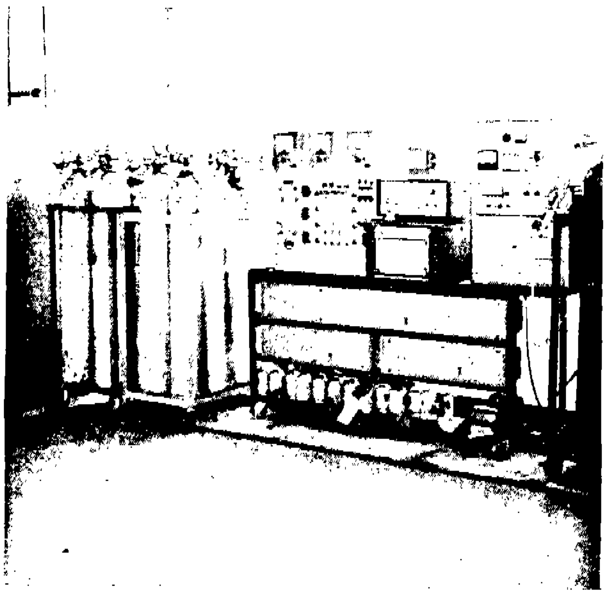
Front View



Chemiluminescent Analyzer



NDIR Instrumentation



Overall View

FIGURE A-2. VARIOUS VIEWS OF CONTINUOUS INSTRUMENTATION EMISSIONS CART and were used in routine instrument operation. Instruments were zeroed and spanned with the appropriate gases prior to and after testing to insure maximum accuracy. The accuracy of the instruments as stated by the manufacturer ranges from 1-2 percent of span. The calibration curves for instruments employed in this study were generated from "golden standard" gases named by EPA. These curves were checked periodically to insure that the curves had not changed. Several span gases were obtained for each of the instruments and utilized throughout the entire project to provide continuity.

Standard NO_x converter checks were made on a routine basis. The ascarite and Drierite traps were used in the low range CO instrument to eliminate CO_2 and water vapor interference respectively. These traps were changed before each run on a particular engine test. The instrument cart was leak checked prior to each engine test to insure sample integrity. During each engine test, a continuous record of the CO, CO_2, HC, NO and NO_x was obtained on a strip chart recorder. Oxygen readings were obtained and also recorded on the strip chart. In addition, readings were obtained and recorded on routine data sheets for subsequent data reduction. In this manner, a permanent record of the engine emissions test along with the instrument ranges was available when necessary.

EMISSIONS RESEARCH LABORATORY

Derivation of General Equation for Obtaining Engine Exhaust Emissions on a Mass Basis Using the "Total Carbon" Method

Introduction

The "total carbon" method of obtaining engine exhaust emissions on a mass basis from volumetric measurements has been used for some time in automotive exhaust emission testing.

The purpose of this paper is to derive and explain the "total carbon" method equations for converting volumetric exhaust emission measurement to a mass basis for any type of gaseous fuel. A simpler version of this procedure is possible and normally used with liquid hydrocarbon fuel such as gasoline or diesel fuel.

Derivation of "Total Carbon" Method

A. General Approach

The "total carbon" method of determining the mass of exhaust emission depends on the assumption that all of the carbon in the exhaust comes from the fuel. The 0.03% CO_2 in normal atmospheric air is neglected. It is also assumed that all the carbon in the exhaust is accounted for by measuring CO, CO_2, and hydrocarbons. The basis for the method is the fact that for each constituent of a gas mixture, the mass per mole of gas mixture can be determined from the volume fraction (mole percent) thusly:

$$\frac{\text{Mole \% of Constituent}}{100} \times \text{Molecular Weight of Constituent} = \frac{\text{Mass of Constituent}}{\text{Mole of Mixture}} \quad (1)$$

Therefore, the mass of each emission specie in the exhaust gas mixture per mole of exhaust gas can be determined from the measured volumetric concentrations. The mass per hour of each emission specie can then be obtained from as follows:

$$\text{Mass/hr} = \frac{\text{Mass of Emission}}{\text{Mole of Exhaust Gas}} \times \frac{\text{Moles of Exhaust Gas}}{\text{hr}} \qquad (2)$$

However, the moles of exhaust gas/hr produced by the combustion source is not known. It is this quantity that can be derived from the fact that the fuel and exhaust gas contain the same amount of carbon, as shown in the next section.

B. Derivation of an Expression for Moles/Hr of Exhaust Gas

An expression for the Moles of Exhaust/Hr can be derived from fuel composition and molecular weight and the measured values of fuel flow and volumetric concentrations of CO, CO_2, and hydrocarbons in the exhaust. The expression is:

$$\frac{\text{Moles of Exhaust}}{\text{hr}} = \frac{\left(\frac{\text{Mass of Carbon in Fuel}}{\text{hr}}\right)}{\left(\frac{\text{Mass of Carbon in Exhaust}}{\text{Mole of Exhaust}}\right)} \qquad (3)$$

Since the total mass of carbon/hr put into the system by the fuel must be equal to the total mass of carbon/hr leaving the system in the exhaust gas.

Sections 1 and 2 below will derive the expressions for mass of carbon from fuel/hr and mass of carbon from exhaust/mole of exhaust, respectively.

1. Derivation of Expression for Mass of Carbon from Fuel/Hr

The problem is to determine the Mass of Carbon/Hr put into the system from the fuel using either an assumed or actual fuel composition and the measured fuel flow.

If the mass (or mass rate) of a gas mixture is known, the mass (or mass rate) of each constituent can be found as follows:

$$\text{Mass of Constituent} = \text{Mass of Mixture} \times \text{Mass \%} \qquad (4)$$

where:

$$\text{Mass \%} = \frac{\text{Mass of Constituent/Mole of Mixture}}{\text{Molecular Weight of Mixture}} \qquad (5)$$

and the mass of constituent/mole of mixture is found from measured volumetric concentrations using equation (1).

Now, the mass of carbon in any carbon compound can be calculated knowing the mass of compound, the compound molecular weight, and the number of carbon atoms per molecule, thusly:

$$\frac{\text{Mass of Carbon}}{\text{Compound}} = \text{Mass of Compound} \times \frac{\text{Molecular Weight of Carbon}}{\text{Molecular Weight of Compound}} \times \frac{\text{Number of Carbon Atoms}}{\text{Molecule of Compound}} \qquad (6)$$

Substituting equations (1), (4), and (5) in equation (6) gives the following equation for the mass of carbon from one compound:

$$\frac{\text{Mass of Carbon}}{\text{Compound}} = \text{Mass of Mixture} \times \frac{\text{Vol. \% of Comp.} \times \text{Molecular Wt. of Carbon}}{\text{Molecular Weight of Mixture}} \times \frac{\text{Molecular Weight of Carbon}}{\text{Molecular Weight of Compound}} \times \frac{\text{Number of Carbon Atoms}}{\text{Molecule of Compound}}$$

Simplifying:

$$= \text{Mass of Mixture} \times \frac{\text{Vol. \%} \times \text{Molecular Weight of C} \times \text{No. of C Atoms}}{\text{Molecular Weight of Mixture}} \qquad (7)$$

Obviously, the total carbon mass in the mixture is the sum of the carbon mass from each of the carbon-bearing compounds. Thusly:

$$\text{Mass of C in Mixture} = \left(\frac{\text{Mass of Mix.} \times \text{Vol. \%Comp. 1} \times \text{Mol. Wt. of C} \times \text{No. of C Atoms}}{\text{Molecular Weight of Mixture}}\right)_1 + \left(\frac{\text{Mass of Mix.} \times \text{Vol. \%Comp. 2} \times \text{Mol. Wt. of C} \times \text{No. of C Atoms}}{\text{Molecular Weight of Mixture}}\right)_2 + \ldots + \left(\frac{\text{Mass of Mix.} \times \text{Vol. \%Comp. "n"} \times \text{Mol. Wt. of C} \times \text{No. of C Atoms}}{\text{Molecular Weight of Mixture}}\right)_{\text{"n"}}$$

More concisely expressed:

$$\text{Mass of Carbon in Mixture} = \text{Mass of Mixture} \times \frac{\text{Molecular Weight of Carbon}}{\text{Molecular Weight of Mixture}} \times \sum_i \left(\text{No. of Carbon Atoms in Compound (i)} \times \frac{\text{Vol. \%}}{100} \text{Compound (i)}\right) \qquad (8)$$

Applying this equation to the fuel, the mass of carbon per hour into the system from the fuel can be obtained from the known fuel composition, fuel molecular weight, and measured fuel flow.

2. Derivation of Expression for Mass of Carbon in Exhaust/Mole of Exhaust

Turning to the exhaust side of the system, an expression for mass of carbon in exhaust/mole of exhaust using measured volumetric concentrations of CO, CO_2, and hydrocarbons can be developed using equations (1) and (4) above.

For any carbon compound, from equation (6) is:

$$\text{Mass of C from Compound} = \text{Mass of Compound} \times \frac{\text{Mol. Wt. of Carbon}}{\text{Mol. Wt. of Compound}} \times \frac{\text{Number of C Atoms}}{\text{Molecule of Compound}}$$

The mass of carbon from a compound per mole of exhaust is then:

$$\frac{\text{Mass of C from Compound}}{\text{Mole of Exhaust}} = \frac{\text{Mass of Compound}}{\text{Mole of Exhaust}} \times \frac{\text{Mol. Wt. of Carbon}}{\text{Mol. Wt. of Compound}} \times \frac{\text{Number of C Atoms}}{\text{Molecule of Compound}}$$

Substituting equation (1) for Mass of Compound/mole of exhaust gives:

$$\frac{\text{Mass of C from Compound}}{\text{Mole of Exhaust}} = \frac{\text{Vol. \% of Compound}}{100} \times \text{Vol. Wt. of Compound} \times \frac{\text{Mol. Wt. of Carbon}}{\text{Mol. Wt. of Compound}} \times \frac{\text{Number of C Atoms}}{\text{Molecule of Compound}}$$

$$= \frac{\text{Number of C Atoms}}{\text{Molecule of Compound}} \times \frac{\text{Vol. \% of Compound}}{100} \times \text{Mol. Wt. of Carbon}$$

The total carbon mass in the exhaust gas is assumed to be in the form of CO, CO_2, or measured hydrocarbon; therefore, the expression for the total carbon mass/mole of exhaust is:

$$\frac{\text{Mass of Carbon in Exhaust}}{\text{Mole of Exhaust}} = \frac{(\text{Vol. \% CO} + \text{Vol. \% CO}_2 + \text{Vol. \% HC})}{100} \tag{9}$$

$$\times \text{ Molecular Weight of Carbon}$$

Note that Vol. % HC is expressed in percent carbon, so that there is one carbon atom per molecule.

C. General Equation for Emission Specie in Mass/Hr

Recall equation (2):

$$\text{Emission (Mass/hr)} = \frac{\text{Mass of Emission}}{\text{Mole of Exhaust}} \times \frac{\text{Moles of Exhaust}}{\text{hr}}$$

Substituting equation (1) for Mass/Mole and equation (9) for moles of exhaust/hr:

$$\text{Emission(Mass/hr)} = \frac{\text{Vol. \% of Emission}}{100} \times \text{Mol. Wt. of Emission}$$

$$\times \frac{\left(\dfrac{\text{Mass of Carbon from Fuel}}{\text{hr}}\right)}{\left(\dfrac{\text{Mass of Carbon from Exhaust}}{\text{Mole of Exhaust}}\right)}$$

Substituting equation (8) for mass of carbon/hr and equation (9) for Mass of Carbon from exhaust/mole of exhaust:

$$= \left[\frac{\text{Vol. \%}}{100} \times \text{Mol. Wt. of Emission}\right] \times \left[\frac{\dfrac{\text{Mass of Fuel} \times \text{Mol. Wt. of C}}{\text{Mol. Wt. of Fuel}} \times \sum_i \left(\dfrac{\text{\%Comp.} \times \text{No. of C Atoms}}{100}\right)}{\text{Mol. Wt. of C} \times \left(\dfrac{\text{Vol. \%CO}}{100} + \dfrac{\text{Vol. \%CO}_2}{100} + \dfrac{\text{Vol. \%HC}}{100}\right)}\right]$$

Simplifying and rearranging:

$$\text{Emission (Mass/hr)} = \frac{\text{Vol. \% Emission}}{\text{Vol. \%CO} + \text{Vol. \%CO}_2 + \text{Vol. \%HC}} \times \text{Mass of Fuel}$$

$$\times \text{ Molecular Weight of Emission} \times \frac{\sum_i \left(\dfrac{(\text{\% Compound} \times \text{No. of C Atoms})_i}{100}\right)}{\text{Molecular Weight of Fuel}} \tag{10}$$

D. Application of General Equation to Emissions from Natural Gas Fueled Combustion Sources

The composition of natural gas varies widely and often containes CO_2 as well as other gases such as H_2, He, and N_2. A gas analysis is, therefore, necessary to apply the total carbon method to natural gas fueled combustion processes.

As an example, assume that the natural gas fuel contains CH_4, C_2H_6, C_3H_{16}, H_2, He, CO_2, and N_2. The summation term in equation (10) would be:

$$\sum_i \left(\frac{(\%\text{Compound X No. C Atoms})i}{100}\right) = \frac{1}{100}\begin{pmatrix}(1X1\%CH_4)+(2X\%C_2H_6)+(3X\%C_3H_8)+(4X\%C_4H_{10})\\ +5X\%C_5H_{12})+(6X\%C_6H_{14})+(1X\%CO_2)\end{pmatrix}$$

The summation should include all carbon compounds in fuel whether part of the combustion process or not. The molecular weight of the natural gas is found by summing the product of the mole fraction of each constituent and its molecular weight, for all the constituent gases in the fuel.

$$\begin{aligned}\text{Molecular Weight} = &\left(\frac{\%CH_4}{100} X\ 16.04303\right) + \left(\frac{\%C_2H_6}{100} X\ 30.07012\right)\\ &+ \left(\frac{\%C_2H_8}{100} X\ 44.09721\right) + \left(\frac{\%C_4H_{10}}{100} X\ 58.12430\right)\\ &+ \left(\frac{\%C_5H_{12} X\ 72.15139}{100}\right) + \left(\frac{\%C_6H_{14}}{100} X\ 86.17848\right)\\ &+ \left(\frac{\%H_2}{100} X\ 2.01594\right) + \left(\frac{\%He}{100} X\ 4.00260\right)\\ &+ \left(\frac{\%CO_2}{100} X\ 44.0095\right) + \left(\frac{\%N_2}{100} X\ 28.01340\right)\end{aligned}$$

E. Application of the General Equation to Emissions from Gasoline Fueled Combustion Sources

Since gasoline is the result of a refining and blending process, it is a much more consistent product than natural gas and for all practical purposes contains only liquid hudrocarbons.

While an analysis of gasoline fuel is not normally available, the generally accepted hydrogen to carbon ratio for gasoline is 1.85. This gives a mass fraction of carbon in gasoline of .86519.

It should be recognized that the summation term in equation (10) divided by the fuel molecular weight, needs only to be multiplied by the molecular weight of carbon to be an expression for the mass fraction of carbon in the fuel. Therefore, the expression could be thought of as the mass fraction of carbon in fuel divided by the molecular weight of carbon.

Substituting the appropriate numerical values in equation (10) gives the equation for gasoline.

$$\text{Emission (Mass/hr)} = \frac{\text{Vol. \% Emission}}{\text{Vol. \% CO+Vol. \% CO}_2\text{+Vol. \% HC}} \text{ X Mass of Fuel}$$

$$\text{X Molecular Weight of Emission X } \frac{.86519}{12.000} \qquad (11)$$

As a further example, the equation for mass emissions of NO_x given in the Federal Register (Vol. 37, No. 175, Friday, Sept. 8, 1972) for heavy duty gasoline engines will be derived.

First, note that the Federal Register defines the term TC:

$$\text{TC} = \text{Vol. \% CO}_2 + \text{Vol. \% CO} + (1.8 \text{ X } 6 \text{ X \% HC})$$

The constant multipliers 1.8 and 6 come from the fact that the Federal procedure uses NDIR measurement with hydrocarbons expressed as hexane, not a flame ionization technique as assumed in this derivation.

From equation (11):

$$NO_x \text{ (grams/hr)} = \frac{\frac{\text{PPM NO}}{10000}}{\text{TC}} \text{ X Fuel (grams/hr) X 46.0055 X .0721}$$

$$NO_x \text{ (grams/hr)} = \frac{46.0055 \text{ X } .0721}{10000} \text{ NO (PPM) X } \frac{\text{Fuel (grams/hr)}}{\text{TC}}$$

$$NO_x \text{ (grams/hr)} = 3.32 \text{ X } 10^{-4} \text{ X NO (PPM) X } \frac{\text{Fuel (grams/hr)}}{\text{TC}}$$

Melvin N. Ingalls
Senior Research Engineer
Emissions Research Laboratory
Southwest Research Institute

EQUATIONS USED IN COMPUTER PROGRAM FOR REDUCTION OF DATA FROM NATURAL GAS COMPRESSOR ENGINES

A. Fuel Gas Molecular Weight

1. The fuel gas molecular weight is calculated using the mole percentages of each constituent from the gas analysis.

$$\text{Mole Wt.} = \sum_i \frac{\text{Mole \% of i}}{100} \times \text{Mole Wt. of Constituent i}$$

2. Molecular weights of gas constituents as used in the program are:

CH_4	- 16.04303	H_2	- 2.01594
C_2H_6	- 30.07012	He	- 4.00260
C_3H_8	- 44.09721	CO_2	- 44.00995
C_4H_{10}	- 58.12430	N_2	- 28.01340
C_5H_{12}	- 72.15139		
C_6H_{14}	- 86.17848		

B. Calculation for Fuel Flow

1. Fuel flow is computed from orifice data using the procedure described in AGA Report No. 3. The equation used in the program is:

$$Q = c' \sqrt{h_w P_f}$$

where:

Q = Standard Cubic Feet per Hour
c' = Orifice Constant
h_w = Orifice Differential Pressure
P_f = Orifice Static Pressure

c' is hand calculated using the procedure in AGA Report No. 3.

2. The fuel heat flow into the engine is obtained by multiplying the calculated volumetric flow rate by the fuel heating value (in BTU/SCF) obtained from a gas analysis supplied by the company operating the engine. The heating value used is the higher heating of the dry gas.

3. Fuel flow in lbs/hr is calculated from the volumetric flow rate, specific gravity of gas from gas analysis, and the density of air at standard conditions (0.076487 lbs/ft^3).

C. Exhaust Emissions

1. Total Carbon Calculations for Mass Emissions

The total carbon method for calculation of mass emissions is based on the assumption that all of the carbon in the exhaust comes from the fuel. The basis for the method is the fact that for each constituent gas of the exhaust mixture, the mass of the constituent gas per mole of exhaust gas can be determined and that an expression for the exhaust flow in moles of exhaust per hour can be derived from the fact that the carbon in the fuel is equal to the carbon in the exhaust. See "Derivation of General Equation for Obtaining Engine Exhaust Emissions on a Mass Basis Using the Total Carbon Method" for a complete derivation of the equations used.

The general equation for mass emissions from natural gas fueled engines in terms of lb/hr is:

$$E(\text{lb/hr}) = \frac{\text{Vol. \% E}}{\text{TC}} \times \text{Mol. Wt. of E} \times W_f \times \frac{\text{Fuel C Content Term}}{\text{Fuel Mol. Wt.}}$$

where:

E = The exhaust gas constituent under consideration (e.g. HC, CO, CO_2, or NO_x)

Vol. % E = The measured volumetric percentage of E

TC = Vol. % CO + Vol. % CO_2 + Vol. % HC

Mol. Wt. of E = Molecular Weight of E
= 46.0055 for NO_x
= 44.0100 for CO_2
for HC = Fuel Mol. Wt. / Fuel C Content Term,
= 28.0106 for CO
= 31.9988 for O_2

W_f = Fuel Flow, lbs/hr

Fuel Carbon Content Term = $\frac{1}{100}\left[\%CO_2 + \%CH_4 + (2x\%C_2H_6) + (3x\%C_3H_8) + \ldots\ldots + (n\ x\ \%C_nH_{2n+2})\right]$

This term is sum of the products of all carbon bearing compounds in the fuel (mole fraction) times the number of carbon atoms per compound.

Fuel Mol. Weight = Molecular weight of fuel as calculated in Section A-1

2. Emissions Expressed in lbs/million BTU

Emission(lb/million BTU) = Emission(lb/hr)/fuel heat flow(million BTU/hr)

3. Emissions Expressed in Grams/Hp-Hr

Emissions(grams/hp-hr) = Emissions(lbs/hr) x 453.6/horsepower

E. Airflow Calculations

Airflow is not measured, but is calculated from the measured composition of the exhaust gas, a calculated water vapor content of the exhaust gas, and the assumption that the remainder of the exhaust gas is nitrogen and argon in the same proportion to each other as in air. The equations used are as follows:

1. For mole fraction of water in exhaust:

$$\text{Mole Fraction } H_2O = 1 - \left[(K_d) \frac{200 - (1 + \frac{a}{2})\, y}{200 - y + \frac{a}{2}(K_d)(y)(1 - \frac{CO}{100})} \right]$$

where:

$$K_d = \frac{100}{100 + \frac{a}{2}(CO + CO_2)}$$

a = Fuel hydrogen/carbon numerical ratio. This ratio is combustible hydrogen or carbon compounds only; e.g. it does not include the carbon in CO_2, but does include H_2.

CO = Mole percent CO in dry exhaust sample

CO_2 = Mole percent CO_2 in dry exhaust sample

y = Mole percent water vapor in intake air
= (Grains of Water/lbs of Air) x .00014288

2. For mole fraction of nitrogen-argon combinations:

$$\text{Mole Percent } (N_2+A) = 100 - [\text{Mole Percent } H_2O + \text{Mole Percent } O_2 + \text{Mole Percent } CO_2 + \text{Mole Percent } NO_x + \text{Mole Percent HC} + \text{Mole Percent CO}]$$

3. For mass of water in exhaust:

$$\text{Water (lb/hr)} = \frac{\text{Mole Fraction } H_2O \times 100}{TC} \times \text{Mol. Wt. } H_2O \times W_f \times \frac{\text{Fuel Carbon Content Term}}{\text{Fuel Mol. Wt.}}$$

where: Mol. Wt. of H_2O = 18.0153

4. For mass of nitrogen-argon combination in exhaust:

$$N_2+A \text{ (lbs/hr)} = \frac{\text{Mole Percent } N_2+A}{TC} \times \text{Mol. Wt. } N_2+A \times W_f \times \frac{\text{Fuel Carbon Content Term}}{\text{Fuel Mol. Wt.}}$$

where: Mol. Wt. of N_2+A = Composite molecular weight of nitrogen and argon, weighted to reflect proportion in air = 28.159

5. Exhaust Gas Mass Flow

$$\text{Exhaust Flow (lb/hr)} = NO_x \text{ Mass} + CO_2 \text{ Mass} + \text{HC Mass} + \text{CO Mass} + O_2 \text{ Mass} + H_2O \text{ Mass} + (N_2A) \text{ Mass}$$

6. For airflow:

Airflow (lb/hr) = Exhaust Flow (lb/hr) - Fuel Flow (lb/hr)

F. Air/Fuel Ratio

A.F.R. = Airflow (lbs/hr)/Fuel Flow (lbs/hr)

G. Brake Specific Fuel Consumption (BSFC)

BSFC (BTU/hp-hr) = Fuel Heat Flow (BTU/hr)/horsepower

EXPLANATION OF COMPUTER OUTPUT FOR NATURAL GAS COMPRESSOR EMISSIONS PROGRAMS

Line Title	Explanation
RUN	Run number for the particular engine under test. (input)*
DATE	Date of test. (input)
TIME	Time of each run on a 24 hour basis. (input)
AMBIENT TEMP. DEG. F	The temperature, in degrees fahrenheit, of the area from which the engine draws its air. (input)
WET BULB TEMP. DEG. F	The wet bulb temperature, in degrees fahrenheit, of the area from which the engine draws its air. (input)
REL. HUMIDITY PERCENT	Relative humidity, in percent, of the area from which the engine draws its air. (calculated)
ABS. HUMIDITY GRAIN/LB	The absolute humidity, in grains, of moisture per pound of dry air in the area from which the engine draws its air. (calculated)
ENGINE SPEED RPM	The shaft speed of the engine in revolutions per minute. (input)
HORSEPOWER	The power output of the engine. (input)
SCAV. AIR PRES. IN. HG.	Scavage air pressure, in inches of mercury gage. (input)
IGNIT. TIME DEG. BTDC	Ignition timing in degrees before top dead center. (input)
METHANE FRACTION	Methane fraction of total hydrocarbons in exhaust.

FUEL SP. GR. (STP)	The specific gravity of the fuel gas at standard conditions, 29.92 in. Hg., pressure and 60°F temperature. (input)
HI HEAT VALUE BTU/SCF	The fuel gas higher heating value in BTU per standard cubic feet. (input)
ORIFICE CONSTANT	The orifice constant required in calculating fuel flow from orifice measurements. This constant hand calculated by the procedure in AGA Report No. 3. (input)
FUEL TEMP. DEG. F	Fuel gas temperature in degrees fahrenheit at the measuring orifice. (input)
ORIFICE DP IN. H_2O	The pressure drop across the fuel gas measuring orifice in inches of water. (input)
ORIFICE STAT. PRES. PSIA	The static pressure in pound per square inch, absolute, upstream of the orifice. (input)
FUEL FLOW SCFH	The fuel gas flow rate in standard cubic feet per hour. (calculated)
HEAT FLOW MIL. BTU/HR	The fuel gas flow rate expressed in terms of heat content, millions of BTU per hour. (calculated)
FUEL FLOW LB/HR	The fuel gas flow rate expressed on a mass basis in pounds per hour. (calculated)
AIR FLOW LB/HR	The engine inlet airflow in pounds per hour. (calculated)

EXPLANATION OF COMPUTER OUTPUT FOR NATURAL GAS COMPRESSOR EMISSIONS PROGRAMS (Cont'd)

BSFC BTU/HP HR	The brake specific fuel consumption in BTU per horsepower hour. (calculated
NO_x PPM	Measured volumetric oxides of nitrogen (assumed $NO+NO_2$) concentration in the exhaust gas in parts per million. (input)
NO PPM	Measured volumetric nitric oxide concentration in the exhaust gas in parts per million. (input)
NO_2 PPM	Volumetric concentration nitrogen dioxide in the exhaust gas in parts per million. Obtained by substracting NO from NO_x. (calculated)
CO_2 PERCENT	Measured volumetric carbon dioxide concentration in the exhaust gas in percent. (input)
HC PPM	Measured volumetric concentration of hydrocarbon compounds in the exhaust gas expressed as parts per million of carbon. (input)
CO PPM	Measured volumetric concentration of carbon monoxide in the exhaust gas in parts per million. (input)
O_2 PERCENT	Measured volumetric oxygen concentration in the exhaust gas in percent. (input)
NO/NO_x	The ratio of NO to NO_x volumetric concentrations. (calculated)
NO_x LB/HR	The mass rate of NO_x emissions (as pounds of NO_2 per hour) from the engine exhaust. (calculated)

EXPLANATION OF COMPUTER OUTPUT
FOR NATURAL GAS COMPRESSOR EMISSIONS PROGRAMS (Cont'd)

HC LB/HR	The mass rate of hydrocarbon emissions (as pounds of carbon per hour) from the engine exhaust. (calculated)
CO LB/HR	The mass rate of carbon monoxide from the engine exhaust in pounds per hour. (calculated)
NO_x LB/MILLION BTU	Pounds of NO_x (expressed as NO_2) emitted from the engine exhaust per million BTU of fuel heat added to engine. (calculated)
HC LB/MILLION BTU	Pounds of hydrocarbons (expressed as carbon) emitted from the engine exhaust per million BTU of fuel heat added to engine. (calculated)
CO LB/MILLION BTU	Pounds of carbon monoxide emitted from the engine exhaust per million BTU of fuel heat added to engine. (calculated)
NO_x GRAMS/HP HR	Grams of NO_x (expressed as NO_2) emitted from the engine exhaust per hour per horsepower output of the engine.
HC GRAMS/HP HR	Grams of hydrocarbons (expressed as carbon) emitted from the engine exhaust per hour per horsepower output of the engine.
CO GRAMS/HP HR	Grams of carbon monoxide emitted from the engine exhaust per hour per horsepower output of the engine.

*Note: The words (input) and (calculated) at the end of each explanation designate whether the item is an input value to the computer program or whether it is calculated by the program.

```
              PROGRAM NGASEM(INPUT,OUTPUT)
        C THIS PROGRAM CALCULATES THE  FUEL-SPECIFIC EMISSIONS AND BRAKE-SPECIFI(
        C EMISSIONS FOR COMBUSTION ENGINES FUELED WITH NATURAL GAS
000003        DIMENSION CP(8),HW(8),PF(8),FT(8),DBT(8),WBT(8),RPM(8),HP(8),
             1LDSP(8),SUPR(8),DISPR(8),ED(8,6),Q(8),WF(8),HF(8),AH(8),RH(8),
             2VE(8,6),TC(8,6),EM(8,6),FSE(8,6),BSE(8,6),PRTL(3,45),
             3IMON(8),IDAY(8),IYR(8),ITIME(8),PO(10),HEAD(6),XMW(5),VAR(40,8),
             4TITL1(8),TITL2(8),MODE(8),MD(8),HCR(8),TWBK(8),TDBK(8)
000003        DIMENSION BARO(8),INJT(8),SAP(8),GR(8),XHV(8),AIR(8),AFR(8),XNO(8)
             1,XNO2(8),XNR(8),Y(8),XKD(8),H2OPCT(8),PCTN2(8),H2OMAS(8),XN2MAS(8)
             1,EXMF(8),BSFC(8)
000003        DATA (PO(I),I=1,10)/5HCH4   ,5HC2H6 ,5HC3H8 ,5HC4H10,5HC5H12,
             15HC6H14,5HH2   ,5HHE   ,5HCO2  ,5HN2   /
000003        DATA (HEAD(I),I=1,6)/20HOPERATIONAL DATA     ,20HFUEL FLOW DATA
             1   ,20HEXHAUST EMISSIONS    /
000003        DATA(XMW(I),I=1,5)/46.0055,44.0100,12.0115,28.0106,31.9988/
000003        DATA(PRTL(I),I=1,48)/22HAMBIENT TEMP. DEG. F   ,
             122HWET BULB TEMP. DEG. F ,22HREL. HUMIDITY  PERCENT,
             222HSP.  HUMIDITY GRAIN/LB,22HENGINE SPEED      RPM  ,
             322HHORSEPOWER            ,22HSUCTION   PRESS. PSIG ,
             422HDISCHARGE PRESS. PSIG ,22HLOAD STEP             ,
             522HORIFICE CONSTANT      ,22HFUEL TEMP. DEG. F     ,
             622HORIFICE DP IN. H2O    ,22HORIFICE STAT.PRES.PSIA,
             722HFUEL FLOW SCFH        ,22HFUEL FLOW  LB/HR      ,
             822HHEAT FLOW MIL. BTU/HR /
000003        DATA(PRTL(I),I=49,105)/22HNOX PPM                  ,
             122HCO2 PERCENT           ,22HHC   PPM              ,
             222HCO  PPM               ,22HO2   PERCENT          ,
             322HNOX LB/HR             ,22HHC   LB/HR TOTAL      ,
             422HCO  LB/HR             ,22HNOX LB/MIL BTU        ,
             522HHC  LB/MIL BTU TOTAL  ,22HCO   LB/MIL BTU       ,
             622HNOX GR/HP HR          ,22HHC   GR/HP HR TOTAL   ,
             722HCO  GR/HP HR          ,22HBAROMETER, IN. HG.    ,
             822HIGNIT. TIME  DEG. BTDC,22HSCAV. AIR PRES. IN.HG.,
             922HFUEL SP. GR. (STP)    ,22HHI HEAT VALUE BTU/SCF /
000003        DATA(PRTL(I),I=106,135)/22HAIR FLOW  LB/HR         ,
             122HAIR/FUEL RATIO        ,22HBSFC  BTU/HP HR       ,
             222HNO  PPM               ,22HNO2 PPM               ,
             322HNO/NOX                ,22HNON-METH/TOTAL HC     ,
             422HHC  LB/HR NON-METH    ,23HHC  LB/MIL BTU NON-METH,
             522HHC  GR/HP HR NON-METH /
000003     50 READ 900, TITL1,NM
000013        IF(NM.GT.90) GO TO 500
000017        READ 901, TITL2
000024        READ 905, HV,SPGR,C1PCT,C2PCT,C3PCT,C4PCT,C5PCT,C6PCT,H2PCT,HEPCT,
             1CO2PCT,XN2PCT
        C CALCULATIONS FOR MOLECULAR WT. AND PCT. CARBON OF FUEL
000060        XMWF= (C1PCT*16.04303/100.) + (C2PCT*30.07012/100.) + (C3PCT*
             1       44.09721/100.) + (C4PCT*58.12430/100.) +(C5PCT*72.15139/100.
             2       ) + (C6PCT*86.17848/100.) + (H2PCT*2.01594/100.) + (HEPCT*
             3       4.00260/100.) + (CO2PCT*44.00995/100.)+(XN2PCT*28.0134/100.)
000114        FPCTC = (C1PCT + 2.0*C2PCT + 3.0*C3PCT + 4.0*C4PCT + 5.0*C5PCT
             1        + 6.0*C6PCT + CO2PCT)/(100.*XMWF)
000133        CCN   =         (C1PCT+2.0*C2PCT+3.0*C3PCT+4.0*C4PCT+5.0*C5PCT
             1+6.0*C6PCT)/(100.*XMWF)
000151        CHN   =          (4.0*C1PCT+6.0*C2PCT+8.0*C3PCT+10.0*C4PCT
             1+12.0*C5PCT+14.0*C6PCT+2.0*H2PCT)/(100.*XMWF)
```

FIGURE A-3. COMPUTER PROGRAM FOR EMISSION RATE CALCULATIONS

```
      CHCR =CHN/CCN
C INPUT ENGINE PARAMETERS AND EMISSIONS FOR EACH MODE
      DO 100  I=1,NM
      READ 907, MODE(I),CP(I),HW(I),PF(I),FT(I),DBT(I),WBT(I),RPM(I),
     1HP(I),INJT(I),SAP(I),BARO(I),LDSP(I),HCR(I),IMON(I),IDAY(I),IYR(I)
     2,ITIME(I)
  100 CONTINUE
      DO 110 I=1,NM
      READ 910, MD(I),XNO(I),(ED(I,J),J=1,5)
      IF(MD(I).NE.MODE(I)) GO TO 410
  110 CONTINUE
      DO 200  I=1,NM
C CALCULATIONS FOR  FUEL FLOW AND HEAT FLOW
      Q(I) = CP(I)*SQRT(HW(I)*PF(I))
      WF(I) = Q(I)*SPGR*0.076487
      HF(I) = Q(I)*HV/1.0E6
C  CALCULATION FOR ABSOLUTE AND RELATIVE HUMIDITY
      TWBK(I) = (5./9.) * (WBT(I) - 32.) + 273.16
      SM = (-7.51152E3 * TWBK(I)**(-1.)) + 96.5389644 +(2.3998970E-2*
     1      TWBK(I)) + (-1.1654551E-5 * TWBK(I)**2) + (-1.2810336E-8*
     2      TWBK(I)**3) + (2.0998405E-11 *TWBK(I)**4)
      TERM =  SM - 12.150799 * ALOG(TWBK(I))
      PWB = 2.953E-4 * EXP(TERM)
      A =  3.67E-4 * (1. + 0.00064*(TWBK(I)-32.))
      PV = PWB - (A*BARO(I)*(DBT(I)-WBT(I)))
      AH(I) = (4347.8 *PV)/(BARO(I)-PV)
      TDBK(I) =(5./9.) * (DBT(I)- 32.) + 273.16
      SMD = (-7.51152E3 * TDBK(1)**(-1.)) + 96.5389644 +(2.3998970E-2*
     1       TDBK(I)) + (-1.1654551E-5 * TDBK(I)**2) + (-1.2810336E-8*
     2       TDBK(I)**3) + (2.0998405E-11 *TDBK(I)**4)
      TERMD= SMD -12.150799 * ALOG(TDBK(I))
      PDB = 2.953E-4 * EXP(TERMD)
      RH(I) =(PV/PDB) * 100.
C  CALCULATIONS FOR EMISSIONS  IN LB/HR, LB/MILLION BTU,AND LB-BHP
      XNO2(I)= ED(I,1)-XNO(I)
      XNR(I) = XNO(I)/ED(I,1)
      VE(I,1) = ED(I,1)/10000.
      VE(I,2)=ED(I,2)
      VE(I,3) = ED(I,3)/10000.
      VE(I,4) = ED(I,4)/10000.
      VE(I,5)=ED(I,5)
      XMW(3)= 1./FPCTC
      DO 150  J=1,5
      TC(I,J)= VE(I,2) + VE(I,4) + VE(I,3)
      EM(I,J)= (VE(I,J)/TC(I,J)) *XMW(J) * WF(I) * FPCTC
      FSE(I,J) = EM(I,J)/HF(I)
      IF(HP(I).EQ.0.) GO TO 145
      BSE(I,J) = EM(I,J)*453.6 /HP(I)
      GO TO 150
  145 BSE(I,J)=0.
  150 CONTINUE
      HCR(I) =1. - HCR(I)
      VAR(31,I) = EM(I,3)*HCR(I)
      VAR(32,I) = FSE(I,3) * HCR(I)
      VAR(33,I) = BSE(I,3) * HCR(I)
C  CALCULATIONS FOR AIR FLOW AND A/F RATIO
      Y(I) = AH(I) * 1.4288E-4
      XKD(I)=  100./(100.+(CHCR*0.5*(VE(I,4)+VE(I,2))))
```

FIGURE A-3 (Cont'd). COMPUTER PROGRAM FOR EMISSION RATE CALCULATIONS

```
000537          P1 = 200.-((1.0 +(CHCR*0.5))*Y(I))
000544          P2 = 200.-Y(I)+(CHCR*0.5*XKD(I)*Y(I)*(1.-(VE(I,4)/100.)))
000555          H2OPCT(I) =(1.0-(XKD(I)*P1/P2))*100.
000562          PCTN2(I) = 100.-(H2OPCT(I) +VE(I,5)+VE(I,2)+VE(I,1)+VE(I,3)
               1+VE(I,4))
000573          H2OMAS(I) =(H2OPCT(I)/TC(I,1))*18.0153* WF(I)*FPCTC
000600          XN2MAS(I) = (PCTN2(I)/TC(I,1))*28.159 *WF(I)*FPCTC
       C*****NOTE. 28.159 IS AN ARTIFICAL MOL. WT. TO TAKE INTO ACCOUNT THE
       C*****       ARGON IN AIR
000604          EXMF(I)= XN2MAS(I)+ H2OMAS(I) +EM(I,1) + EM(I,2) + EM(I,3)
               1+EM(I,4) + EM(I,5)
000616          AIR(I) = EXMF(I)-WF(I)
000621          AFR(I) = AIR(I)/WF(I)
000623          BSFC(I) = HF(I)*1.0E6/HP(I)
000626      200 CONTINUE
000630          PRINT 950
000633          PRINT  920, TITL1
000641          PRINT  921, TITL2
000647          PRINT 925,HV,SPGR,XMWF
000661          PRINT 930,PO(1),C1PCT,PO(2),C2PCT,PO(3),C3PCT,PO(4),C4PCT,PO(5),
               1C5PCT,PO(6),C6PCT,PO(7),H2PCT,PO(8),HEPCT,PO(9),CO2PCT,PO(10),
               2XN2PCT
000735          DO  220  I=1,NM
000737          VAR(1,I) =DBT(I)
000742          VAR(2,I) =WBT(I)
000745          VAR(3,I) =RH(I)
000750          VAR(4,I) =AH(I)
000753          VAR(5,I) =RPM(I)
000756          VAR(6,I) =HP(I)
000761          VAR(7,I) =SUPR(I)
000764          VAR(8,I) =DISPR(I)
000767          VAR(11,I)=FT(I)
000772          VAR(12,I)=HW(I)
000775          VAR(13,I)=PF(I)
001000          VAR(14,I)=Q(I)
001003          VAR(15,I)=WF(I)
001006          VAR(17,I)= ED(I,1)
001011          VAR(18,I)= ED(I,2)
001014          VAR(19,I)= ED(I,3)
001017          VAR(20,I)= ED(I,4)
001022          VAR(21,I)= ED(I,5)
001025          VAR(22,I)=EM(I,1)
001030          VAR(23,I)=EM(I,3)
001033          VAR(24,I)=EM(I,4)
001036          VAR(25,I)=FSE(I,1)
001041          VAR(26,I)=FSE(I,3)
001044          VAR(27,I)=FSE(I,4)
001047          VAR(28,I)=BSE(I,1)
001052          VAR(29,I)=BSE(I,3)
001055          VAR(30,I)=BSE(I,4)
001060      220 CONTINUE
001062          PRINT 950
001066          PRINT 920, TITL1
001074          PRINT 921, TITL2
001102          PRINT 931, (MODE(I),I=1,NM)
001115          PRINT 932, (IMON(I),IDAY(I),IYR(I),I=1,NM)
001134          PRINT 933, (ITIME(I),I=1,NM)
001147          PRINT 934, HEAD(1),HEAD(2)
```

FIGURE A-3 (Cont'd). COMPUTER PROGRAM FOR EMISSION RATE CALCULATIONS

```
01157          PRINT 936,(PRTL(I,31),I=1,3),(BARO(I),I=1,NM)
01200          DO 280   J=1,6
01202      280 PRINT 937,(PRTL(I,J),I=1,3),(VAR(J,I),I=1,NM)
01227          PRINT 952,(PRTL(I,33),I=1,3),(SAP(I),I=1,NM)
01250          PRINT 953,(PRTL(I,32),I=1,3),(INJT(I),I=1,NM)
01271          DO 283 I=1,6
01273          XHV(I)=HV
01275      283 GR(I)=SPGR
01300          PRINT 951,(PRTL(I,34),I=1,3),(GR(I),I=1,NM)
01320          PRINT 937,(PRTL(I,35),I=1,3),(XHV(I),I=1,NM)
01341          PRINT 936, (PRTL(I,10),I=1,3),(CP(I),I=1,NM)
01362          DO 285  J=11,13
01364      285 PRINT 935, (PRTL(I,J),I=1,3),(VAR(J,I),I=1,NM)
01411          PRINT 937,(PRTL(I,14),I=1,3),(VAR(14,I),I=1,NM)
01433          PRINT 939, (PRTL(I,16),I=1,3),(HF(I),I=1,NM)
01454          PRINT 937,(PRTL(I,15),I=1,3),(VAR(15,I),I=1,NM)
01476          PRINT 937,(PRTL(I,36),I=1,3),(AIR(I),I=1,NM)
01517          PRINT 935,(PRTL(I,37),I=1,3),(AFR(I),I=1,NM)
01540          PRINT 937,(PRTL(I,38),I=1,3),(BSFC(I),I=1,NM)
01561          PRINT 934, HEAD(5),HEAD(6)
01571          PRINT 936,(PRTL(I,17),I=1,3),(VAR(17,I),I=1,NM)
01613          PRINT 936,(PRTL(I,39),I=1,3),(XNO(I),I=1,NM)
01634          PRINT 936,(PRTL(I,40),I=1,3),(XNO2(I),I=1,NM)
01655          DO 287  J=18,21
01657      287 PRINT 936, (PRTL(I,J),I=1,3),(VAR(J,I),I=1,NM)
01704          PRINT 939,(PRTL(I,41),I=1,3),(XNR(I),I=1,NM)
01725          PRINT 939,(PRTL(I,42),I=1,3),(HCR(I),I=1,NM)
01746          PRINT 934
01752          DO 290   J=22,23
01754      290 PRINT 939, (PRTL(I,J),I=1,3),(VAR(J,I),I=1,NM)
02001          PRINT 939,(PRTL(I,43),I=1,3),(VAR(31,I),I=1,NM)
02023          DO 292 J=24,26
02025      292 PRINT 939,(PRTL(I,J),I=1,3),(VAR(J,I),I=1,NM)
02052          PRINT 954,(PRTL(I,44),I=1,3),(VAR(32,I),I=1,NM)
02074          DO 294 J=27,29
02076      294 PRINT 939,(PRTL(I,J),I=1,3),(VAR(J,I),I=1,NM)
02123          PRINT 939,(PRTL(I,45),I=1,3),(VAR(33,I),I=1,NM)
02145          PRINT 939,(PRTL(I,30),I=1,3),(VAR(30,I),I=1,NM)
02167          GO TO 50
02170      400 PRINT 940, I
02176          GO TO 500
02177      410 PRINT 941, I
02205          GO TO 500
02206      900 FORMAT(7A10,A5,3X,I2)
02206      901 FORMAT(7A10,A5)
02206      905 FORMAT(2F5.0,10F6.0)
02206      907 FORMAT(I2,F8.0,2F6.0,3F4.0,2F6.0,A4,A5,F6.0,A3,F5.0,3I2,1X,I4)
02206      910 FORMAT(I2,4X,F4.0,5(5X,F5.0))
02206      920 FORMAT(1X,       7X,7A10,A5)
02206      921 FORMAT( 8X,7A10,A5)
02206      925 FORMAT(1X,//,8X,*FUEL GAS ANALYSIS*,/13X,*       HEATING VALUE  BTU
              1 PER SCF*,4X,F5.0,/13X,*SPECIFIC GRAVITY (60 AND 29.92)*,4X,F6.4,/
              213X,*MOLECULAR WEIGHT*,20X,F5.2,/)
02206      930 FORMAT(13X,*COMPOSITION (MOLE PERCENT)*,/,
              110(16X,A5,F7.2/))
02206      931 FORMAT(1X,///6X,*RUN *,20X,6(4X,I1,4X))
02206      932 FORMAT(6X,*DATE*,20X,6(1X,I2,*/*,I2,*/*,I2))
02206      933 FORMAT(6X,*TIME*,20X,6(I7,2X))
```

FIGURE A-3 (Cont'd). COMPUTER PROGRAM FOR EMISSION RATE CALCULATIONS

```
002206       934 FORMAT(1X,/6X,2A10)
002206       935 FORMAT(7X,2A10,A2,6F9.1)
002206       936 FORMAT(7X,2A10,A2,6F9.2)
002206       937 FORMAT(7X,2A10,A2,6F9.0)
002206       938 FORMAT(7X,2A10,A2,6I9)
002206       939 FORMAT(7X,2A10,A2,6F9.3)
002206       940 FORMAT(1X,*ENGINE PARAMETER DATA CARD OUT OF SEQUENCE. MODE*,I3)
002206       941 FORMAT(1X,*EMISSIONS DATA CARD OUT OF SEQUENCE. MODE*,I3)
002206       950 FORMAT(1H1,//,11X,*TABLE      EMISSION CONCENTRATION AND RATE SUM
               1ARY*,/)
002206       951 FORMAT(7X,2A10,A2,6F9.4)
002206       952 FORMAT(7X,2A10,A2,6(4X,A5))
002206       953 FORMAT(7X,2A10,A2,6(5X,A4))
002206       954 FORMAT(7X,2A10,A3,F8.3,5F9.3)
002206       500 STOP
002210           END
```

FIGURE A-3 (Cont'd). COMPUTER PROGRAM FOR EMISSION RATE CALCULATIONS

AGA - GAS COMPRESSOR EMISSIONS

PROJECT 11-3438-01

KEY PUNCH DATA SHEET

CALL: ______________ EXT. _____

SHEET _____ OF _____

TITLE	No. of Modes
1 5 6 7 10 20 30 40 50 60 70 72 73 75 76	80

GAS ANALYSIS

Heating Value	Specific Gravity	C_1H_4%	C_2H_6%	C_3H_8%	C_4H_{10}%	C_5H_{12}%	C_6H_{14}%	H_2%	He%	CO_2%	N_2%	
1 5	6 7 10	11 16	17 20 22	23 28	29 30 34	35 40	41 46	47 50 52	53 58	59 60 64	65 70	71 72 73 74 80

OPERATION DATA

Mode	Orifice Constant	Orifice Dif. Pres.	Orifice Stat. Pres.	Fuel Temp°F	Dry Bulb Temp°F	Wet Bulb Temp°F	Engine rpm	Horsepower	Ign. Timing	Scav. Air Pres.	Baro. In. Hg.		Load Step	Methane Fraction	Mon	Day	Yr	Time (24 Hr. Basis)
1 2	3 5 6 7 10	11 16	17 20 22	23 26	27 30	31 34	35 40	41 46	47 50	51 55	56	61	62 64	65 69	70 71	72 73	74 75	76 77 80

EXHAUST EMISSIONS

Mode	NO Meter	NO PPM	NOx Meter	NOx PPM	CO_2 Meter	CO_2 %	HC Meter	HC PPM	CO Meter	CO PPM	O_2 Meter	O_2 %		Mon	Day	Yr	Time (24 Hr. Basis)
1 2	3 5 6	7 10	11	20	21	30	31	40	41	50	51	60	61 69	70 71	72 73	74 75	76 77 80

FIGURE A-4. AGA GAS COMPRESSOR EMISSIONS COMPUTER INPUT AND RAW DATA SHEET

APPENDIX B

Engine Selection

Fuel Gas Analysis

Baseline Methods of Measurement for Horsepower and Fuel

Typical Testing Scenes

TABLE B-1. RECIPROCATING ENGINE DISTRIBUTION

Manufacturer	Engine Type	Number		Horsepower	
Worthington	UTC	107	(4.3%)*	149,800	(3.3%)**
	SUTC	92	(3.7%)	138,000	(3.0%)
		199	(8.0%)	287,800	(6.3%)
Clark	MBA	141	(5.7%)	169,200	(3.6%)
	HBA	194	(7.8%)	300,700	(6.5%)
	TLA	264	(10.7%)	556,000	(12.1%)
	TCVA/TCVC/TCVD	67	(2.7%)	403,150	(8.8%)
		666	(26.9%)	1,429,050	(31.0%)
Ingersol-Rand	KVG	218	(8.8%)	287,760	(6.3%)
	KVS	177	(7.2%)	354,000	(7.7%)
	KVT/KVH/KVR	42	(1.7%)	151,000	(3.3%)
		437	(17.7%)	792,760	(17.3%)
Cooper-Bessemer	GMV	381	(15.5%)	419,100	(9.1%)
	GMW	131	(5.3%)	327,500	(7.2%)
	LSV	43	(1.7%)	172,000	(3.7%)
	GMWA/GMWH	296	(12.0%)	600,400	(13.1%)
	GMVA/GMVC	191	(7.7%)	227,000	(5.0%)
	V-250	110	(4.5%)	255,700	(5.5%)
	W-330/Z-330	8	(0.7%)	80,678	(1.81%)
		1160	(47.4%)	2,082,378	(45.4%)
TOTAL		2462	(100%)	4,591,988	(100%)

*Numbers in parentheses are percentage of total units.

**Numbers in parentheses are percentage of total horsepower.

TABLE B-2. INITIAL ENGINE QUOTAS BY SITE

Engine Description		% Total Power	Number Needed	Site 2	1	10	6	7	5	3	4	8	9
RECIPROCATING (44)													
Worth	UTC	3.3	1 or 2		1								
	SUTC	3.0	1 or 2			1							
	24 x 36	*	1 or 2		1								
		6.3											
Clark	MBA	3.6	Delete										
	HBA	6.5	3						2				1
	TLA	12.1	6						2		3		1
	TCVA/TCVC/TCVP	8.8	4		1				1				2
		31.0											
IR	KVG	6.3	3										3
	KVS	7.7	3 or 4		1	3							
	KVT/KVH/KVR	3.3	1 or 2			2							
		17.3											
CB	GMV	9.1	4									4	
	GMW	7.2	3 or 4					2				2	
		3.7	2							2			
	GMWA/GMWH	13.1	6 or 7				3	3					
	GMVA/GMVC	5.0	Delete										
	V-250	5.5	2 or 3				1					1	1
		45.4	**	—	4	6	4	5	5	2	3	7	8
TURBINE (6-8)													
GE Frame 3-CB				1									
GE/Clark 12,500						1							
M 3912 R								1					
M 3112 R								1					
Clark CSR-97GT (5)											1		
CB RT-105GT (4)											1		
Solar T-1001								1					
P & W GG 3C-4							1						
				1	—	1	1	3	—	—	2	—	—

Unknown

* 3 Worth or 7% 9 IR or 20%

13 Clark or 30% 19 CB or 43%

TABLE B-3. ENGINE GROUPINGS BY MANUFACTURER AND MODEL

(Piston Engines)

Group No.	Engine Description	Engine Test No.	Site Code	Unit No.	Rated Hp at rpm
P-1	Clark BA-8, 2-stroke NA	53	9	19	1760 at 300
		55	9	17	1600 at 300
P-2	Clark HBA-8T, 2-stroke TC	17	5	9	2000 at 300
		18	5	8	2000 at 300
		19	5	7	2000 at 300
P-3	Clark TLA-6, 2-stroke TC	12	4	1	2000 at 300
		13	4	2	2000 at 300
		14	4	3	2000 at 300
		20	5	11	2050 at 300
		21	5	12	2050 at 300
		22	5	13	2050 at 300
P-4	Clark TLA-8, 2-stroke TC	54	9	20	2700 at 300
P-5	Clark TCV-12, 2-stroke TC	23	5	15	4000 at 300
P-6	Clark TCV-16, 2-stroke TC	24	5	16	5500 at 300
		52	9	21	5500 at 300
P-7	Clark TCVC-16, 2-stroke TC	4	1	21	8000 at 330
		50	9	24	8000 at 330

TABLE B-3(Cont'd). ENGINE GROUPINGS BY MANUFACTURER AND MODEL

Group No.	Engine Description	Engine Test No.	Site Code	Unit No.	Rated Hp at rpm
P-8	Cooper-Bessemer GMV-10, 2-stroke NA	41	8	2C	1350 at 300
		42	8	3C	1350 at 300
		43	8	4C	1350 at 300
		44	8	6C	1350 at 300
P-9	Cooper-Bessemer GMWA-6, 2-stroke NA	25	6	4	1500 at 250
		26	6	5	1500 at 250
		27	6	6	1500 at 250
P-10	Cooper-Bessemer GMWC-16, 2-stroke TC	28	6	7	2000 at 250
P-11	Cooper-Bessemer GMW-8, 2-stroke NA	31	7	1	2050 at 250
		32	7	2	2050 at 250
		33	7	3	2050 at 250
		45	8	7C	2000 at 250
		46	8	8C	2000 at 250
P-12	Cooper-Bessemer GMWA-8, 2-stroke NA	34	7	5	2000 at 250
		35	7	6	2000 at 250
		36	7	7	2000 at 250
P-13	Cooper-Bessemer GMWC-10, 2-stroke TC	47	8	1D	3400 at 250
		48	8	2D	3400 at 250
P-14	Cooper-Bessemer LSV-16 SG, 4-stroke TC	8	3	4	4400 at 327
		9	3	3	4400 at 327
		10	3	2	4400 at 327
		11	3	1	4400 at 327
P-15	Cooper-Bessemer LSVA-16 SG, 4-stroke TC	6	3	6	4400 at 327
		7	3	5	4400 at 327
P-16	Cooper-Bessemer 10 V-250, 2-stroke TC	51	9	23	3400 at 250
P-17	Cooper-Bessemer 14 V-250, 2-stroke TC	29	6	8	4800 at 250
P-18	Cooper-Bessemer 16 V-250, 2-stroke TC	49	8	38	5500 at 250

TABLE B-3(Cont'd). ENGINE GROUPINGS BY MANUFACTURER AND MODEL

Group No.	Engine Description	Engine Test No.	Site Code	Unit No.	Rated Hp at rpm
P-19	Ingersoll-Rand KVG-8, 4-stroke NA	56	9	6	800 at 330
		57	9	4	800 at 330
		58	9	10	800 at 330
P-20	Ingersoll-Rand 412-KVS, 4-stroke TC	3	1	17	2000 at 330
		59	10	26	2000 at 330
		60	10	27	2000 at 330
		61	10	28	2000 at 330
P-21	Ingersoll-Rand 616-KVT, 4-stroke TC	62	10	29	4000 at 350
P-22	Ingersoll-Rand 616-KVR, 4-stroke TC	63	10	30	5500 at 330
		64	10	31	5500 at 330
P-23	Worthington 26X36, 2-stroke NA	2	1	6	1515 at 125
P-24	Worthington UTC-10, 2-stroke NA	1	1	10	1894 at 320
P-25	Worthington SUTC-8, 2-stroke TC	65	25	10	2000 at 300
		66	23	10	2000 at 300
		67	24	10	2000 at 300

TABLE B-4. ENGINE DESCRIPTION BY MANUFACTURER AND MODEL

Group P-1 Clark Model BA

This unit was built in 5, 6, 8 and 10 cylinder models. The engine has a 17" bore and stroke. Power cylinders were in line and loop scavenging was accomplished by a deflector on the power piston head. It was non-turbocharged, had a BMEP of 68.5, compression pressure of 110 PSIG and ran at 300 rpm. This unit develops 200 hp/cyl.

Group P-2 Clark Model HBA-T

This unit is built in 5, 6, 8, and 10 cylinder models. It is the turbocharged version of the HBA and has interchangeable parts. Its BMEP is in the range of 87.5 to 88.9, with a compression pressure of 300 to 325 PSIG. The HBA-T unit runs at 300 rpm. This unit develops 258 hp/cyl.

Groups P-3, P-4 Clark Model TLA

This unit is built in 5, 6, 8, and 10 cylinder models. It is turbocharged, 17" bore and 19" stroke. Its in-line power cylinders are liner type installed in the upper cylinder block. Loop scavenging is accomplished by directional air ports. The turbocharger can be mounted either on or off the engine. Its BMEP ranges from 102 to 104, has a compression pressure of 300 to 325 PSIG and runs at 300 rpm. This unit develops 340 hp/cyl.

Groups P-5, P-6 Clark Model TCV

This 17" bore, 19" stroke unit is built in 10, 12, and 16 cylinder models. This unit is equipped with a Jet start constant pressure off mounted engine turbocharger. The liner type cylinders are mounted in the upper case in a V configuration with horizontal compressor cylinders mounted on the lower case. Loop scavenging is accomplished by directional air ports. The BMEP ranges from 102 to 105, compression pressure ranges from 300 to 350. Engine rpm is 300. This unit develops 333-344 hp/cyl.

Group P-7 Clark Model TCVC

This 18-1/2" bore, 19" stroke unit is built in 12, 16, and 20 cylinder models. This unit is equipped with a Jet start constant pressure off mounted engine turbocharger. The liner type cylinders are mounted in the upper case in a V configuration with horizontal compressor cylinders mounted on the lower case. Loop scavenging is accomplished by directional air ports. The BMEP is 117.5, compression pressure ranges from 300 to 350. Engine rpm is 330. This unit develops 500 hp/cyl.

TABLE B-4(Cont'd). ENGINE DESCRIPTION BY MANUFACTURER AND MODEL

Group P-8 Cooper-Bessemer Model GMV Description

This is a V-angle, two-cycle, spark ignited, gas engine with integrally connected horizontal compressors. The engine is built in 4, 6, 8 and 10 power cylinders. The scavenging and combustion air is supplied by the piston scavenging pumps in the crossheads. The GMV, initially built in 1938, was the first in a long line of 14" x 14" engines.

Design Data	
Bore, inches	14"
Stroke, inches	14"
Rating:	
Number of Power Cylinders	10
RPM	300
BHP	1000
BMEP	61.3

Groups P-9, P-12 Cooper-Bessemer Model GMWA Description

The Model GMWA is an atmospheric gas engine compressor that uses a built-in gear driven centrifugal blower to furnish scavenging and combustion air. The engine is built in units of 6, 8, 10, and 12 power cylinders. First built in 1953, the GMWA continued being a production engine until 1968.

Design Data				
Bore, inches	18"			
Stroke, inches	20"			
Rating:				
Number of Power Cylinders	6	8	10	12
RPM	250	250	250	250
BHP	1500	2000	2500	3000
BMEP	77.5	77.5	77.5	77.5

Group P-10, P-13 Cooper-Bessemer Model GMWC Description

This model gas engine compressor is series turbocharged. Intake air is compressed by an exhaust driven turbocharger and an engine driven centrifugal blower. (One turbocharger on 6 cylinder engines and two turbochargers on 8, 10, and 12 cylinder engines.) The scavenging and combustion air is cooled in separate aftercoolers for each air inlet manifold. Porous chrome power cylinders are used at the higher rating. The GMWC was first available to the industry in 1956

Design Data				
Bore, inches	18"			
Stroke, inches	20"			
Rating:				
Number of Power Cylinders	6	8	10	12
RPM	250	250	250	250
BHP	2000	2700	3400	4000
BMEP	103.7	105	105.8	103.7
Compression Press., psi	280	280	280	280
Peak Firing Press., psi	800	800	800	800

Group P-11 Cooper-Bessemer Model GMW Description

This unit is a V-angle, two-cycle, spark ignited, gas engine with integrally connected horizontal compressors. The engine is built in units of 6, 8, and 10 power cylinders. The scavenging and combustion air is provided by a positive displacement blower. The blower consists of two or three units, dependent upon engine size, each having an oscillating rotor driven by a connecting rod from the blower crankshaft which is directly connected to the engine crankshaft. Built initially in 1946, the GMW was the first V-angle 20" stroke engine.

Design Data			
Bore, inches	18"		
Stroke, inches	20"		
Rating:			
Number of Power Cylinders	6	8	10
RPM	250	250	250
BHP	1440	1920	2400
BMEP	74.5	74.5	74.5

Groups P-14, P-15 Cooper-Bessemer Model LSV Description

The Model LSV is a V-angle, four-cycle, supercharged, spark ignited, gas engine driver, direct connected at the flywheel to a frame that drives horizontal compressors. The combustion air is supplied by an exhaust driven supercharger. Air cooling is used to remove some of the heat of compression from the combustion air before it enters the power cylinders.

Design Data		
Bore, inches	15-1/2"	
Stroke, inches	22"	
Rating:		
Number of Power Cylinders	12	16
RPM	330	330
BHP	3000	4000
BMEP	144.6	144.6

TABLE B-4 (Cont'd). ENGINE DESCRIPTION BY MANUFACTURER AND MODEL

Groups P-16, P-17, P-18 Cooper-Bessemer Model V-250* Description

Introduced in 1962, the Model V-250 is a pure turbocharged gas engine compressor. This engine is built in units of 6, 8, 12, 14 and 16 power cylinders. The engine has a cylinder block for each bank of power cylinders.

Design Data						
Bore, inches	18"					
Stroke, inches	20"					
Rating:						
Number of Power Cylinders	6	8	10	12	14	16
RPM	250	250	250	250	250	250
BHP	2000	2700	3400	4000	4800	5300
BMEP	103.7	105.8	105.8	103.7	106.5	107

Group P-19 Ingersoll-Rand Model KVG (Old Style)

General Specifications: Heavy-duty; naturally-aspirated; 4-cycle; V-angle; 6, 8, 10 or 12 power cylinders, having a 15-1/4" bore and 18" stroke; 14" compressor stroke; 330 rpm; integral gas engine compressor.

Group P-20 Ingersoll-Rand Model KVS

General Specifications: Heavy-duty; turbocharged and non-aftercooled for normal conditions -6 & 8 power cylinder units have one turbocharger and 10 & 12 power cylinder units have two turbochargers - turbocharger(s) is engine mounted; 4-cycle; V-angle; 6, 8, 10 or 12 power cylinders, having a 15-1/4" bore and an 18" stroke; 15" compressor stroke; 330 rpm integral gas engine compressor.

Group P-21 Ingersoll-Rand Model KVT

General Specifications: Heavy-duty; turbocharged and aftercooled (off-engine turbocharger and aftercooler, employing high level constant pressure turbocharging; 4-cycle; V-angle; 8, 10, 12, or 16 power cylinders, having a 16" bore and a 22" stroke; 15-1/2" compressor stroke; 330 rpm integral gas engine compressor.

Notes:
1. Horsepower rating - 250 hp/power cylinder
2. Compression ratio - 13:1 (mechanical)

Group P-22 Model KVR

General Specifications: Heavy-duty; turbocharged and aftercooled (off-engine) turbocharger and aftercooler employing constant level, high-pressure turbocharging; 4-cycle, V-angle; 8, 10, 12 or 16 power cylinders, having a 17" bore and a 22" stroke; 15-1/2" compressor stroke; 350 rpm integral gas engine compressor.

Notes:

1. Horsepower rating: 8 power cylinders - 2750 hp, 10 power cylinders - 3400 hp, 12 power cylinders - 4000 hp and 16 power cylinders - 5500 hp.
2. The KVR is available as an ambient rated unit, permitting continuous operation at 124% of rated load, when the ambient temperature is 40%F or lower.
3. Compression ratio - 10:1 (mechanical)

Group P-23 Worthington Model 26X36

Group P-24 Worthington Model UTC

This unit, now obsolete, is a two stroke cycle angle gas engine built in 5, 6, 7, 8 and 10-cylinder models. Power cylinders are in-line. Scavenging is of the uniflo or thru scavenging type with conventional air inlet ports to each power cylinder and exhausting thru mechanically operated exhaust valves in the power cylinder head. Scavenging air is supplied by double-acting reciprocating scavenging cylinders driven from the crankshaft. The horsepower range is 1000 to 2000. This unit was offered at both 300 rpm and 320 rpm.

TABLE B-4 (Cont'd). ENGINE DESCRIPTION BY MANUFACTURER AND MODEL

Data Common to All Engines	
Hp per cylinder (sea level)	200
BMEP, psi	82 (77)
Bore, inches	16
Stroke, inches	16
Speed, rpm	300 (320)
Piston Speed, fpm	800 (853.3)

Group P-25 Worthington Model (S) UTC

This unit is not a definite model designation but is applied to field conversions of UTC units by application of pulse type turbochargers, external air aftercoolers and removal of the reciprocating scavenging cylinders. The horsepower range is 1250 to 2500.

Pertinent Data	
Hp per cylinder (sea level)	250
BMEP, psi	102
Bore, inches	16
Stroke, inches	16
Speed, rpm	300
Piston Speed, fpm	800

TABLE B-5. GAS TURBINE GROUPINGS BY MANUFACTURER AND MODEL

Group No.	Engine Description	Engine Test No.	Site Code	Unit No.	Rated Hp
T-1	General Electric Frame 3	5A	2	only	9,300 hp
		5B	2	only	9,300 hp
		5C	2	only	9,300 hp
T-2	General Electric JP-200	15	4	only	20,000 hp
T-3	General Electric M 3112R	39	7	T4	11,100 hp
T-4	General Electric M3911R	40	7	T3	9,100 hp
T-5	General Electric LM 1500	68	10	only	12,500 hp
T-6	Pratt & Whitney RT105-GT	16	4	only	10,500 hp
T-7	Pratt & Whitney GG3C-4	30	6	only	12,000 hp
T-8	Solar Saturn T-1001	37	7	T2	1,050 hp
		38	7	T1	1,050 hp

TABLE B-6. FUEL GAS ANALYSIS OBTAINED DURING BASELINE EMISSIONS STUDY

Test Site	Engine Tests	Fuel Gas Composition, Mole Percent												Heating Value	Specific Gravity
		CH_4	C_2H_6	C_3H_8	i-C_4H_{10}	n-C_4H_{10}	i-C_5H_{12}	n-C_5H_{12}	C_6H_{14}	N_2	CO_2	He	H_2	BTU/ft^3*	
1	1,2	88.18	5.50	2.04	0.21	0.53	0.11	0.12	0.12	2.51	0.53	0.15	0.01	1058	0.6390
1	3,4	87.99	5.47	1.65	0.16	0.39	0.06	0.07	0.09	3.52	0.40	0.19	0.01	1059	0.6301
2	5A, 5B, 5C	95.88	0.97	0.33	0.03	0.02	0.01	0.01	0.01	0.35	2.67	0.02	0.00	997	0.5926
3	6	96.164	2.363	0.306	0.050	0.047	0.021	0.015	0.042	0.338	0.654	0.000	0.000	1032	0.580
3	7,8	96.110	2.353	0.324	0.054	0.051	0.023	0.016	0.041	0.369	0.659	0.000	0.000	1033	0.581
3	9,10	96.111	2.353	0.315	0.051	0.047	0.022	0.015	0.043	0.375	0.668	0.000	0.000	1032	0.581
3	11	96.090	2.373	0.322	0.051	0.046	0.021	0.015	0.044	0.374	0.664	0.000	0.000	1032	0.581
4	12-16	96.85	2.08	0.12	0.02	0.02	0.01	0.00	0.00	0.08	0.79	0.00	0.00	1025	0.5762
5	17-22	96.223	2.307	0.234	0.052	0.045	0.017	0.013	0.051	0.369	0.689	0.000	0.000	1031	0.580
5	23	96.073	2.403	0.274	0.058	0.051	0.021	0.017	0.057	0.358	0.688	0.000	0.000	1033	0.581
5	24	96.222	2.298	0.230	0.051	0.045	0.019	0.014	0.066	0.366	0.689	0.000	0.000	1031	0.580
6	25-30	97.088	1.826	0.071	0.017	0.011	0.001	0.008	0.000	0.350	0.619	0.000	0.000	1018	0.5729
7	31-39	97.088	1.826	0.071	0.017	0.011	0.001	0.008	0.000	0.350	0.619	0.000	0.000	1018	0.5729
8	40-46	96.45	2.36	0.27	0.02	0.02	0.01	0.01	0.00	0.32	0.54	0.00	0.00	1030	0.5770
8	47-49	95.69	2.71	0.54	0.08	0.09	0.04	0.02	0.01	0.31	0.51	0.00	0.00	1042	0.5839
9	50-52	84.61	5.94	1.33	0.08	0.11	0.02	0.02	0.02	7.61	0.24	0.02	0.00	990	0.6350
9	53-58	84.03	5.89	1.21	0.08	0.11	0.02	0.02	0.02	8.39	0.20	0.03	0.00	998	0.6364
10	59-61	74.78	6.69	2.76	0.22	0.40	0.01	0.01	0.01	14.64	0.05	0.43	0.00	971	0.6857
10	62-64, 68	87.82	4.76	1.66	0.14	0.30	0.05	0.06	0.06	4.40	0.75	0.00	0.00	1007	0.630
10	65-67	74.78	6.69	2.76	0.22	0.40	0.01	0.01	0.01	14.64	0.05	0.43	0.00	971	0.6857

* BTU/ft^3 using higher heating value expressed on dry basis

TABLE B-7. LIST OF SAMPLE ACQUISITION SYSTEMS AND MEASUREMENT METHODS FOR HORSEPOWER, FUEL AND SAMPLING

Test	Test Site	Sample Acquisition System	Method of Measurement: Horsepower	Fuel	Sampling
1	1	Equal area cross in stack	MIT	orifice plate	continuous
2	1	Equal area cross in stack	MIT and beta	orifice plate	continuous
3	1	Equal area cross in stack	MIT and beta	orifice plate	continuous
4	1	Multiperforated probe in stack	MIT and beta	orifice plate	continuous
5A	2	Equal area probe network in stack	none	orifice plate	continuous
5B	2	Single point probe in stack*	none	orifice plate	bag
5C	2	Single point probe in stack*	none	orifice plate	bag
6	3	Equal area cross in stack	elbow meter	orifice plate	continuous
7	3	Equal area cross in stack	elbow meter	orifice plate	continuous
8	3	Equal area cross in stack	elbow meter	orifice plate	continuous
9	3	Equal area cross in stack	elbow meter	orifice plate	continuous
10	3	Equal area cross in stack	elbow meter	orifice plate	continuous
11	3	Equal area cross in stack	elbow meter	orifice plate	continuous
12	4	Equal area cross in stack	curves	orifice plate	continuous
13	4	Equal area cross in stack	curves	orifice plate	continuous
14	4	Equal area cross in stack	curves	orifice plate	continuous
15	4	Equal area probe network in stack	curves	turbometer	bag
16	4	Single point probe in stack	curves	orifice plate	continuous
17	5	Equal area cross in stack	beta	orifice plate	continuous
18	5	Equal area cross in stack	beta	orifice plate	continuous
19	5	Equal area cross in stack	beta	orifice plate	continuous
20	5	Equal area cross in stack	beta	orifice plate	continuous
21	5	Equal area cross in stack	beta	orifice plate	continuous
22	5	Equal area cross in stack	beta	orifice plate	continuous
23	5	Equal area cross in stack	beta	orifice plate	continuous
24	5	Multiperforated probe before TC	beta	orifice plate	continuous

TABLE B-7 (Cont'd). LIST OF SAMPLE ACQUISITION SYSTEMS AND MEASUREMENT METHODS FOR HORSEPOWER, FUEL AND SAMPLING

Test	Test Site	Sample Acquisition System	Method of Measurement		
			Horsepower	Fuel	Sampling
25	6	Equal area cross in stack	Special System	orifice plate	continuous
26	6	Equal area cross in stack	Special System	orifice plate	continuous
27	6	Equal area cross in stack	Special System	orifice plate	continuous
28	6	Equal area cross in stack	Special System	orifice plate	continuous
29	6	Equal area cross in stack	Special System	orifice plate	continuous
30	6	Single point probe in stack	Special System	orifice plate	bag
31	7	Equal area cross in stack	Special System	orifice plate	continuous
32	7	Equal area cross in stack	Special System	orifice plate	continuous
33	7	Equal area cross in stack	Special System	orifice plate	continuous
34	7	Equal area cross in stack	Special System	orifice plate	continuous
35	7	Equal area cross in stack	Special System	orifice plate	continuous
36	7	Equal area cross in stack	Special System	orifice plate	continuous
37	7	Equal area cross in stack	Special System	orifice plate	bag
38	7	Equal area cross in stack	Special System	orifice plate	bag
39	7	Single point probe in stack	Special System	orifice plate	bag
40	7	Single point probe in stack	Special System	orifice plate	bag
41	8	Equal area cross in stack	MIT	turbometer	continuous
42	8	Equal area cross in stack	MIT	turbometer	continuous
43	8	Equal area cross in stack	MIT	turbometer	continuous
44	8	Equal area cross in stack	MIT	turbometer	continuous
45	8	Equal area cross in stack	MIT	turbometer	continuous
46	8	Equal area cross in stack	MIT	turbometer	continuous
47	8	Equal area cross in stack	MIT	turbometer	continuous
48	8	Equal area cross in stack	MIT	turbometer	continuous
49	8	Equal area cross in stack	MIT	turbometer	continuous

TABLE B-7 (Cont'd). LIST OF SAMPLE ACQUISITION SYSTEMS AND MEASUREMENT METHODS FOR HORSEPOWER, FUEL AND SAMPLING

Test	Test Site	Sample Acquisition System	Method of Measurement		
			Horsepower	Fuel	Sampling
50	9	Equal area cross in stack	beta	orifice plate	continuous
51	9	Multiperforated probe after TC	beta	orifice plate	continuous
52	9	Multiperforated probe after TC	beta	orifice plate	continuous
53	9	Equal area cross in stack	beta	orifice plate	continuous
54	9	Equal area cross in stack	beta	orifice plate	continuous
55	9	Equal area cross in stack	beta	annubar	bag
56	9	Equal area cross in stack	beta	annubar	continuous
57	9	Equal area cross in stack	beta	annubar	continuous
58	9	Equal area cross in stack	beta	annubar	continuous
59	10	Equal area cross in stack	curves	orifice plate	continuous
60	10	Equal area cross in stack	curves	orifice plate	continuous
61	10	Equal area cross in stack	curves	orifice plate	continuous
62	10	Equal area cross in stack	curves	orifice plate	continuous
63	10	Equal area cross in stack	curves	orifice plate	continuous
64	10	Equal area cross in stack	curves	orifice plate	continuous
65	10	Equal area cross in stack	curves	orifice plate	continuous
66	10	Equal area cross in stack	curves	orifice plate	continuous
67	10	Equal area cross in stack	curves	orifice plate	continuous
68	10	Multipoint probe in stack	curves	orifice plate	bag

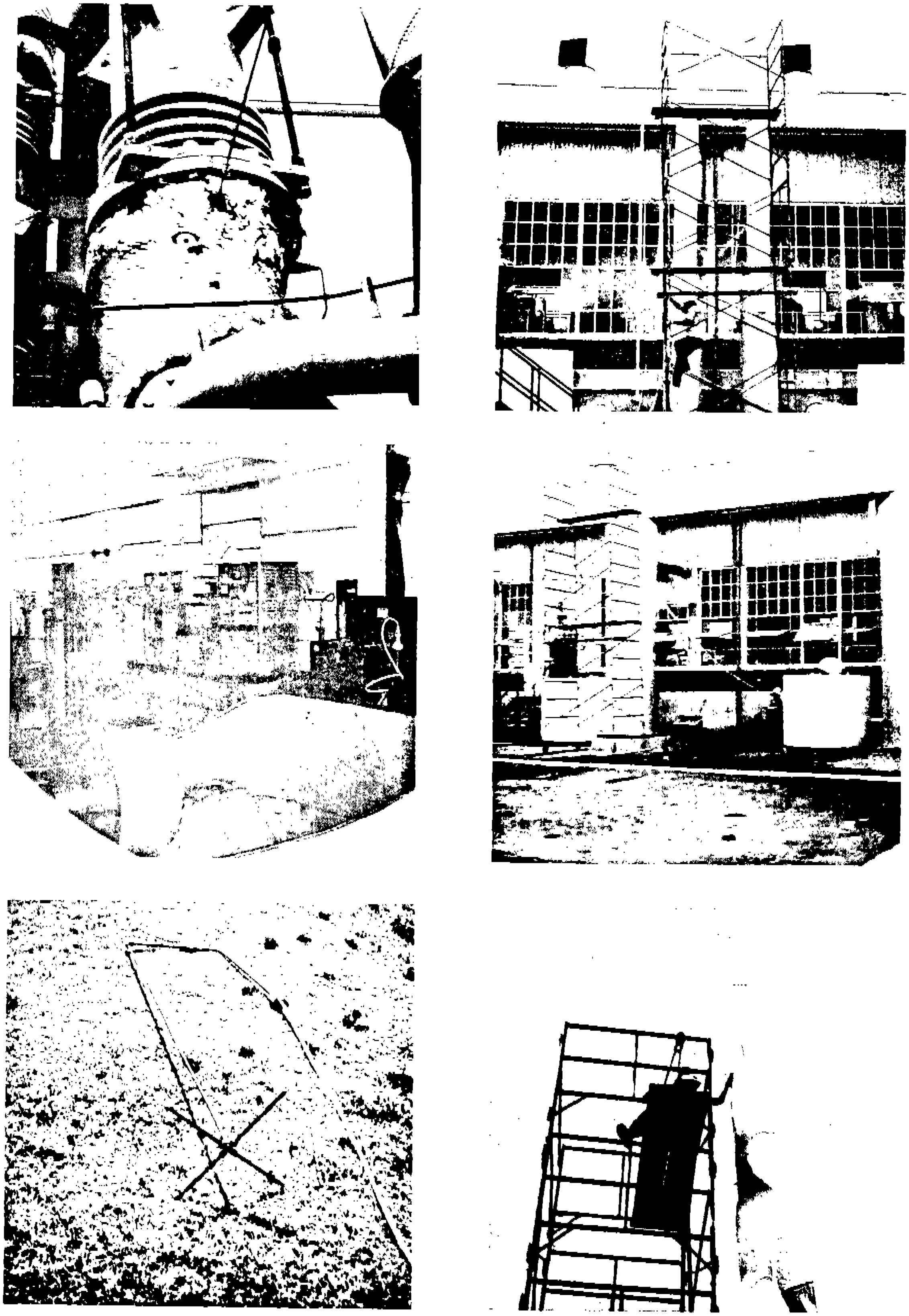


FIGURE B-1. VARIOUS VIEWS OF TEST SITE NUMBER 1

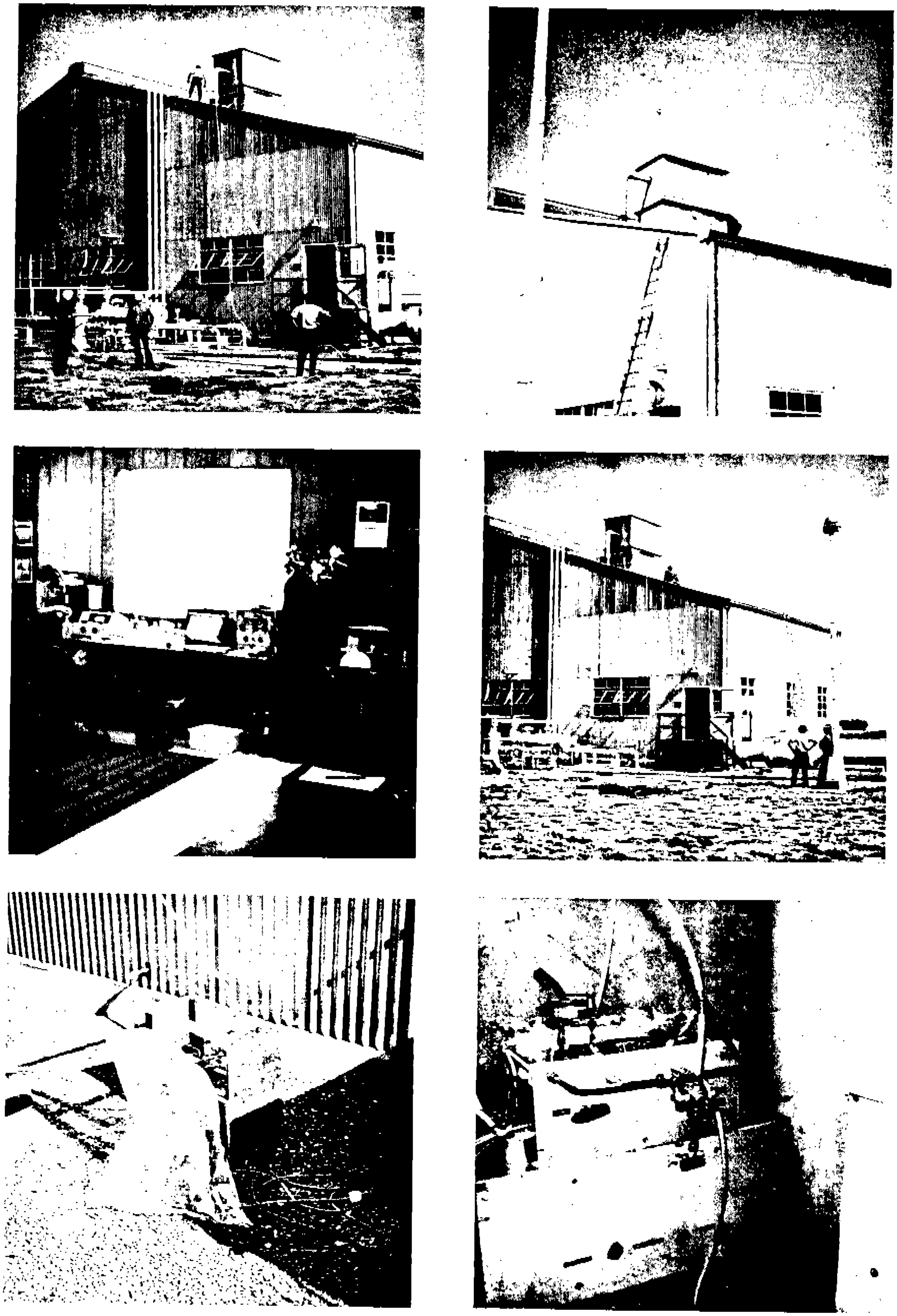


FIGURE B-2. VARIOUS VIEWS OF TEST SITE NUMBER 2

FIGURE B-3. VARIOUS VIEWS OF TEST SITE NUMBER 3

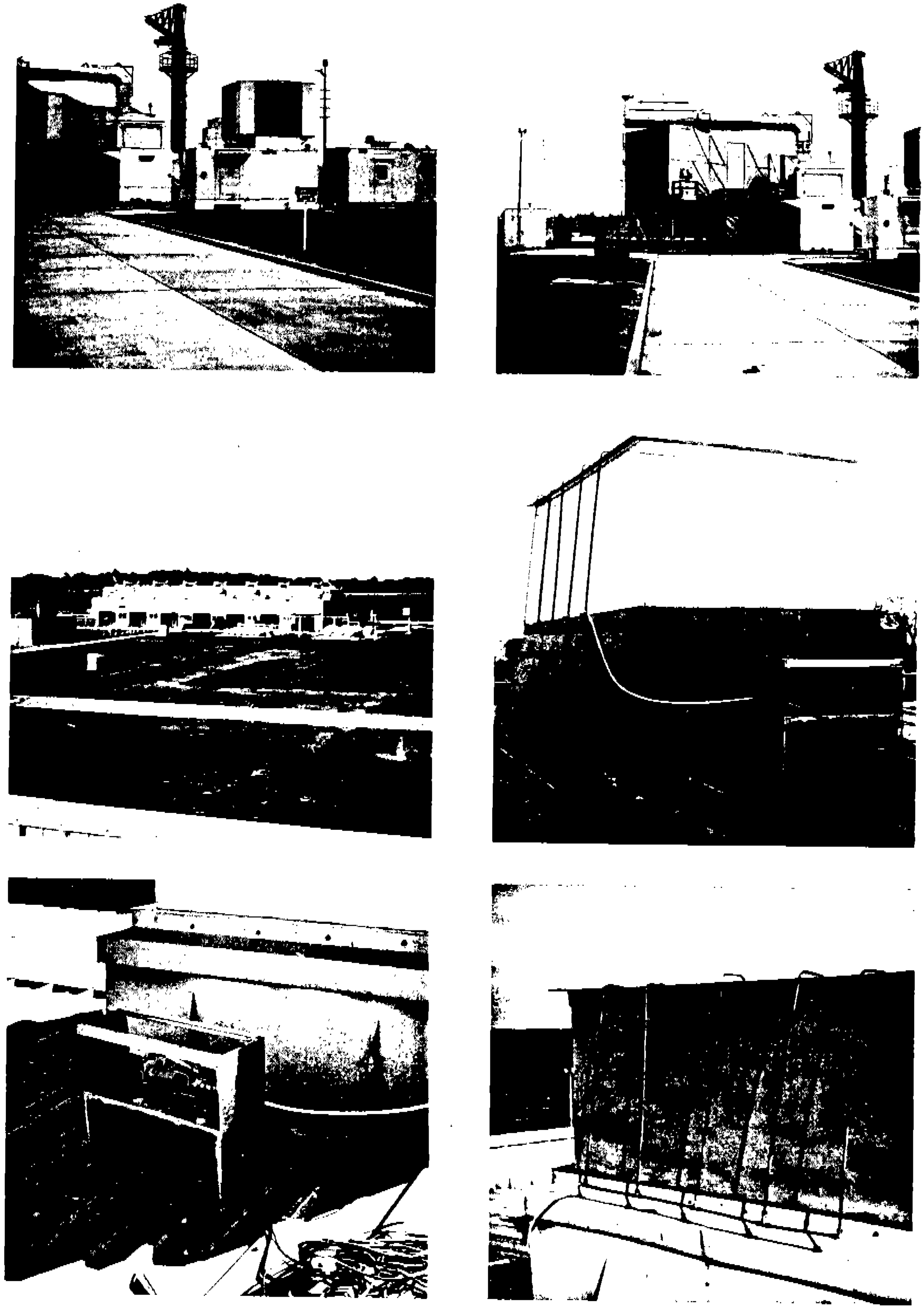


FIGURE B-4. VARIOUS VIEWS OF TEST SITE NUMBER 4

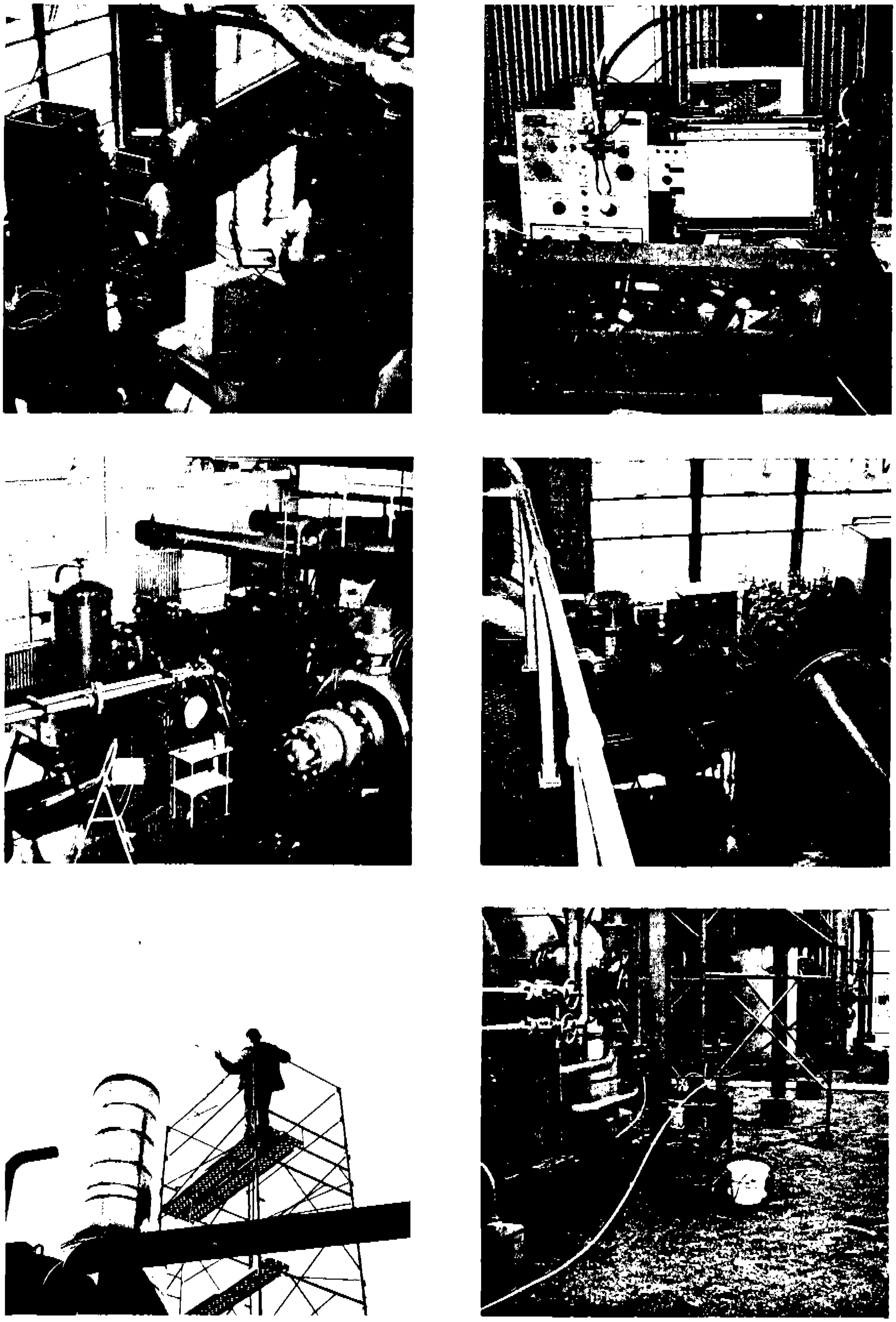


FIGURE B-5. VARIOUS VIEWS OF TEST SITE NUMBER 5

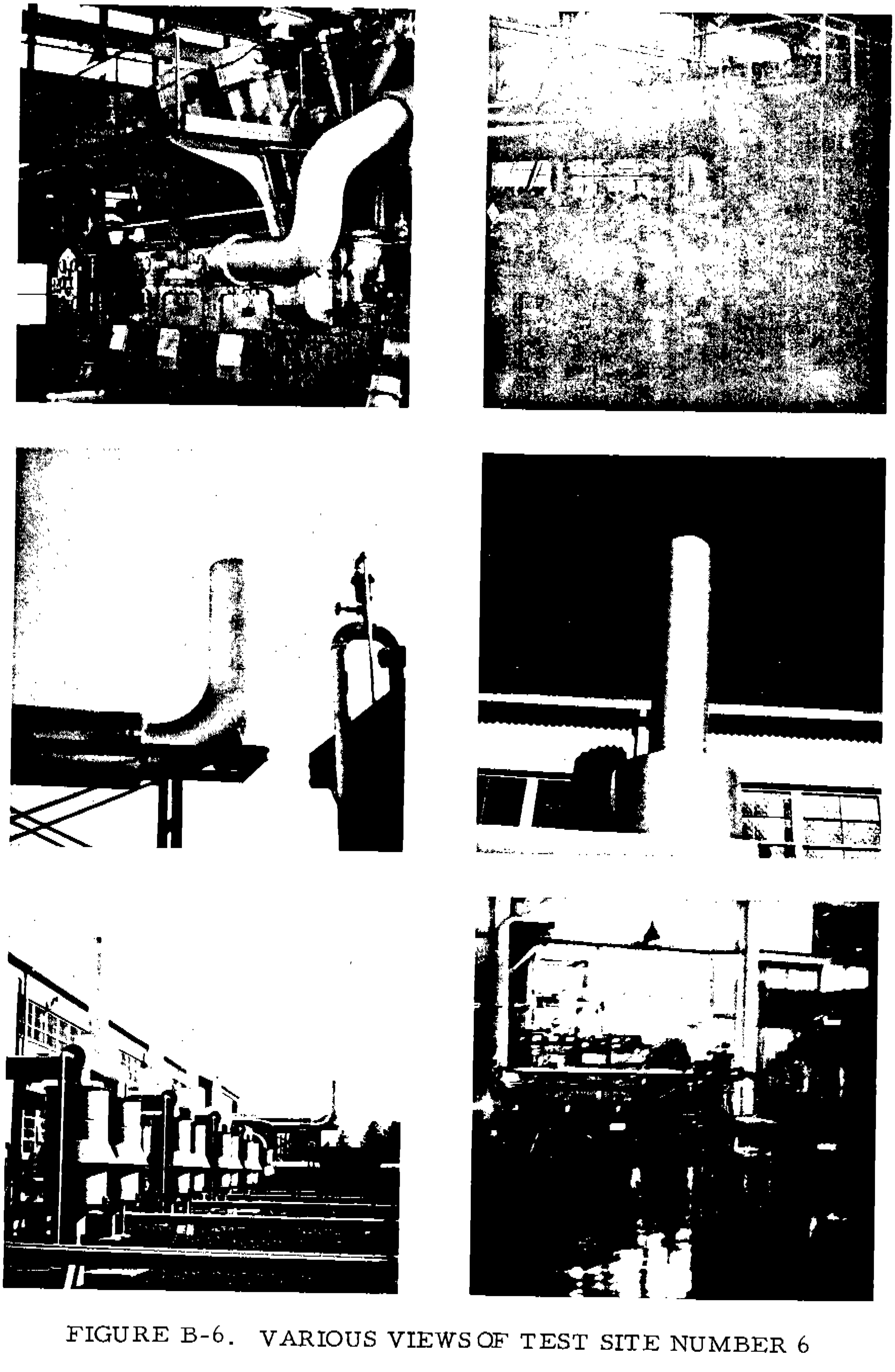


FIGURE B-6. VARIOUS VIEWS OF TEST SITE NUMBER 6

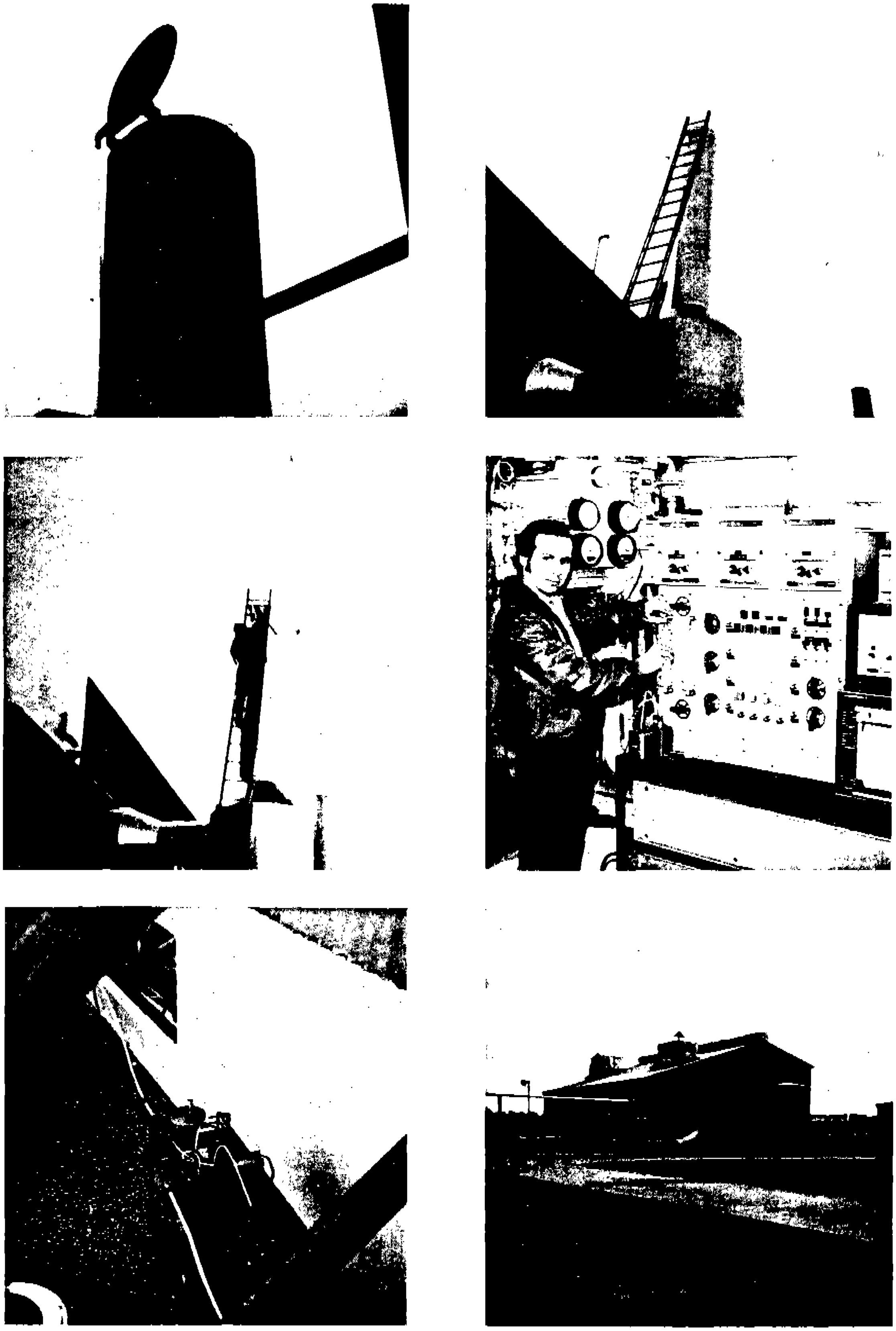


FIGURE B-7. VARIOUS VIEWS OF TEST SITE NUMBER 7

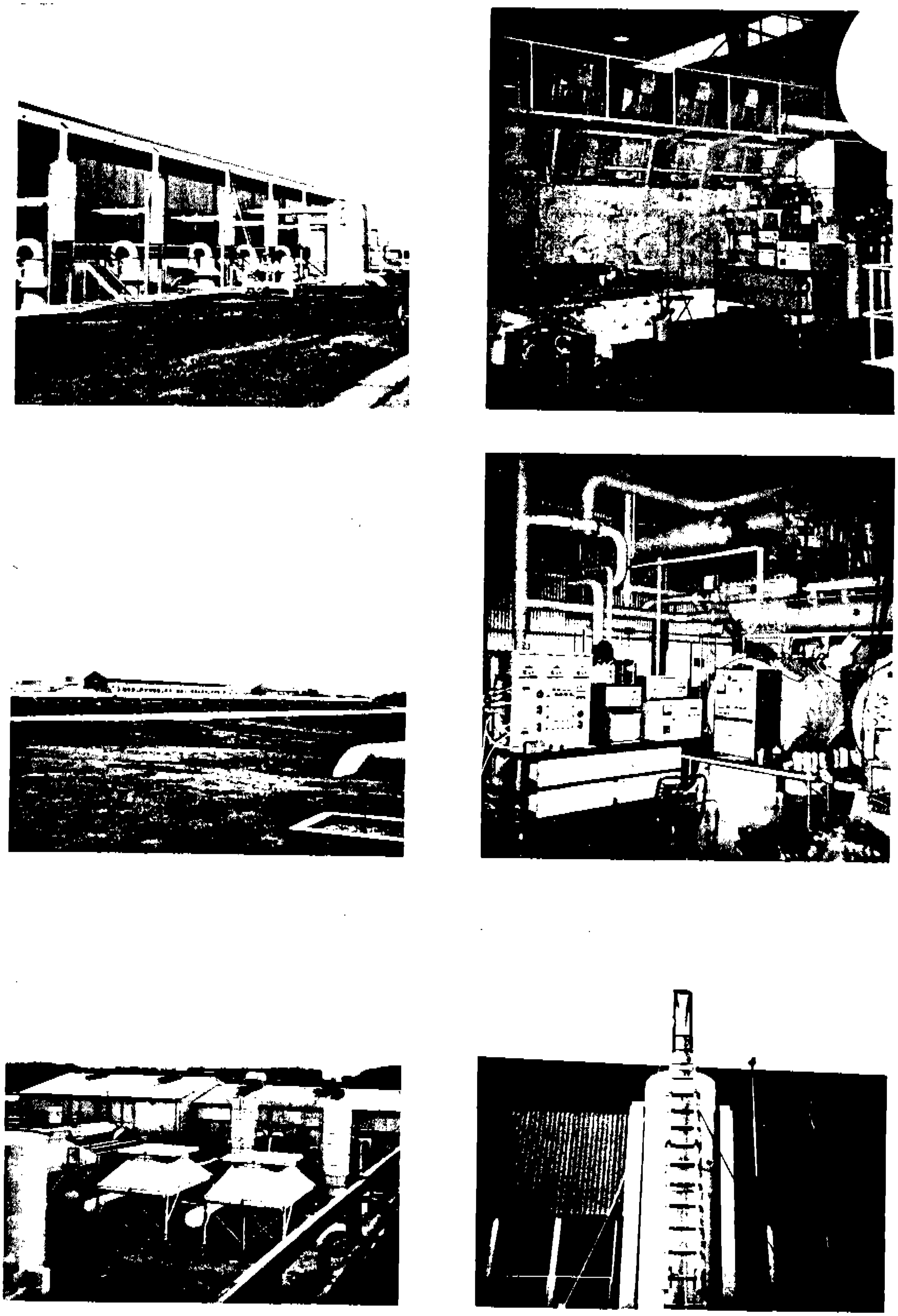


FIGURE B-8. VARIOUS VIEWS OF TEST SITE NUMBER 8

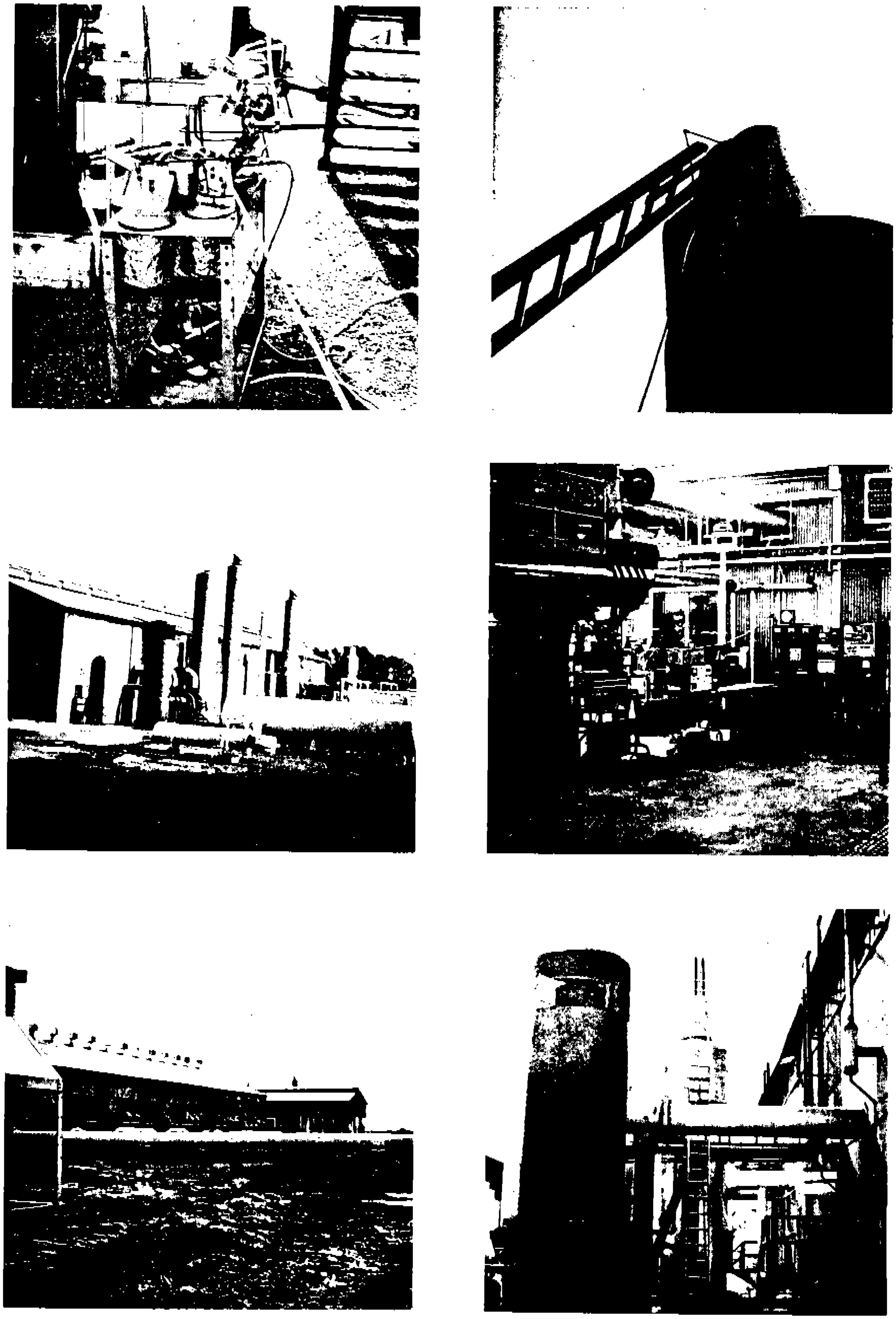


FIGURE B-9. VARIOUS VIEWS OF TEST SITE NUMBER 9

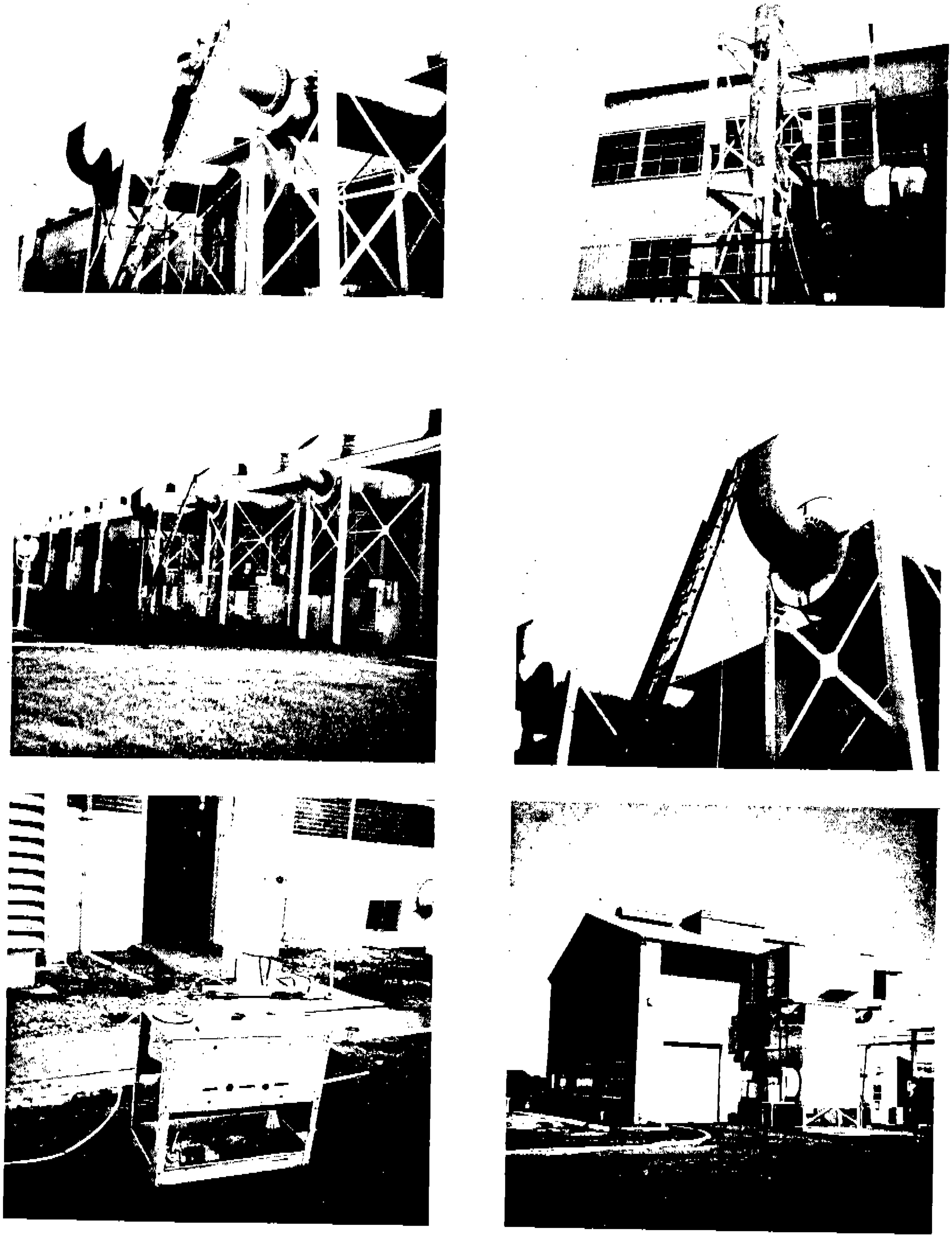


FIGURE B-10. VARIOUS VIEWS OF TEST SITE NUMBER 10

APPENDIX C

EMISSION CONCENTRATION AND RATE SUMMARY

Table numbers throughout Appendix C correspond to the test number preceded by C. For example, the data from test number 25 is found in Appendix C as Table C-25.

TABLE C-1 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 1, TEST SITE CODE 1
WORTHINGTON UTC-10, RATED 1894 HP, RATED 320 RPM, 2-STROKE N/A

RUN	1	2	3	4	5	6
DATE	8/23/72	8/23/72	8/23/72	8/23/72	8/24/72	8/25/72
TIME	930	1130	1330	1530	630	1000
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.82	29.82	29.82	29.82	29.82	29.82
AMBIENT TEMP. DEG. F	79	83	84	89	74	75
WET BULB TEMP. DEG. F	66	70	71	75	73	62
REL. HUMIDITY PERCENT	48	50	51	51	95	45
SP. HUMIDITY GRAIN/LB	71	85	89	104	121	58
ENGINE SPEED RPM	305	306	320	320	320	315
HORSEPOWER	1525	1547	1751	1421	1745	1463
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	9	9	9	9	9	9
FUEL SP. GR. (STP)	.6390	.6390	.6390	.6390	.6390	.6390
HI HEAT VALUE BTU/SCF	1058	1058	1058	1058	1058	1058
ORIFICE CONSTANT	436.15	435.28	435.28	434.85	438.26	436.97
FUEL TEMP. DEG. F	51.0	53.0	53.0	54.0	46.0	49.0
ORIFICE DP IN. H2O	22.0	22.5	25.0	19.0	21.5	23.5
ORIFICE STAT.PRES.PSIA	68.0	68.0	68.0	68.0	67.0	67.0
FUEL FLOW SCFH	16869	17026	17947	15630	16634	17339
HEAT FLOW MIL. BTU/HR	17.848	18.014	18.988	16.537	17.598	18.345
FUEL FLOW LB/HR	824	832	877	764	813	847
AIR FLOW LB/HR	37884	37761	37984	34992	38153	39302
AIR/FUEL RATIO	45.9	45.4	43.3	45.8	46.9	46.4
BSFC BTU/HP HR	11704	11644	10844	11638	10085	12539
EXHAUST EMISSIONS						
NOX PPM	1485.00	1515.00	1740.00	1455.00	1005.00	1335.00
NO PPM	1185.00	1200.00	1395.00	1155.00	840.00	1065.00
NO2 PPM	300.00	315.00	345.00	300.00	165.00	270.00
CO2 PERCENT	3.57	3.63	3.81	3.57	3.39	3.51
HC PPM	1150.00	1000.00	950.00	1250.00	2150.00	1400.00
CO PPM	21.00	21.00	18.00	21.00	26.00	21.00
O2 PERCENT	15.50	15.40	15.30	15.30	15.20	15.30
NO/NOX	.798	.792	.802	.794	.836	.798
NON-METH/TOTAL HC	.094	.064	.120	.067	.068	.065
NOX LB/HR	92.164	93.754	108.427	83.443	62.857	85.976
HC LB/HR TOTAL	25.716	22.297	21.330	25.829	48.450	32.486
HC LB/HR NON-METH	2.417	1.427	2.560	1.731	3.295	2.112
CO LB/HR	.794	.791	.683	.733	.990	.823
NOX LB/MIL BTU	5.164	5.205	5.710	5.046	3.572	4.687
HC LB/MIL BTU TOTAL	1.441	1.238	1.123	1.562	2.753	1.771
HC LB/MIL BTU NON-METH	.135	.079	.135	.105	.187	.115
CO LB/MIL BTU	.044	.044	.036	.044	.056	.045
NOX GR/HP HR	27.413	27.490	28.088	26.636	16.339	26.657
HC GR/HP HR TOTAL	7.649	6.538	5.525	8.245	12.594	10.072
HC GR/HP HR NON-METH	.719	.418	.663	.552	.856	.655
CO GR/HP HR	.236	.232	.177	.234	.257	.255

TABLE C-1 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 1, TEST SITE CODE 1
WORTHINGTON UTC-10, RATED 1894 HP, RATED 320 RPM, 2-STROKE N/A

RUN	7	8	9	10	11	12
DATE	8/31/72	8/31/72	8/31/72	8/31/72	8/31/72	8/31/72
TIME	930	1030	1130	1300	1400	1500
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.75	29.75	29.75	29.75	29.75	29.75
AMBIENT TEMP. DEG. F	89	89	88	88	91	91
WET BULB TEMP. DEG. F	74	74	73	73	74	74
REL. HUMIDITY PERCENT	48	48	47	47	43	43
SP. HUMIDITY GRAIN/LB	98	98	94	94	94	94
ENGINE SPEED RPM	306	306	305	305	306	306
HORSEPOWER	1855	1855	1780	1780	1720	1720
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	9	9	9	9	9	9
FUEL SP. GR. (STP)	.6390	.6390	.6390	.6390	.6390	.6390
HI HEAT VALUE BTU/SCF	1058	1058	1058	1058	1058	1058
ORIFICE CONSTANT	436.97	436.97	436.58	436.58	436.58	436.58
FUEL TEMP. DEG. F	49.0	49.0	50.0	50.0	50.0	50.0
ORIFICE DP IN. H2O	19.5	19.5	18.8	18.8	18.2	18.2
ORIFICE STAT.PRES.PSIA	67.0	67.0	67.0	67.0	67.0	67.0
FUEL FLOW SCFH	15795	15795	15495	15495	15245	15245
HEAT FLOW MIL. BTU/HR	16.711	16.711	16.393	16.393	16.130	16.130
FUEL FLOW LB/HR	772	772	757	757	745	745
AIR FLOW LB/HR	36824	37464	37170	37237	38219	38975
AIR/FUEL RATIO	47.7	48.5	49.1	49.2	51.3	52.3
BSFC BTU/HP HR	9008	9008	9210	9210	9378	9378
EXHAUST EMISSIONS						
NOX PPM	1305.00	1305.00	1110.00	1140.00	900.00	875.00
NO PPM	1030.00	1030.00	900.00	915.00	705.00	690.00
NO2 PPM	275.00	275.00	210.00	225.00	195.00	185.00
CO2 PERCENT	3.39	3.33	3.28	3.28	3.11	3.05
HC PPM	1620.00	1630.00	1750.00	1700.00	1980.00	1960.00
CO PPM	0.00	0.00	0.00	0.00	0.00	0.00
O2 PERCENT	15.20	15.30	15.50	15.70	15.40	15.60
NO/NOX	.789	.789	.811	.803	.783	.789
NON-METH/TOTAL HC	.080	.080	.068	.068	.075	.075
NOX LB/HR	78.716	80.045	67.526	69.452	56.264	55.746
HC LB/HR TOTAL	35.208	36.023	38.358	37.316	44.599	44.992
HC LB/HR NON-METH	2.817	2.882	2.608	2.538	3.345	3.374
CO LB/HR	0.000	0.000	0.000	0.000	0.000	0.000
NOX LB/MIL BTU	4.711	4.790	4.119	4.237	3.488	3.456
HC LB/MIL BTU TOTAL	2.107	2.156	2.340	2.276	2.765	2.789
HC LB/MIL BTU NON-METH	.169	.172	.159	.155	.207	.209
CO LB/MIL BTU	0.000	0.000	0.000	0.000	0.000	0.000
NOX GR/HP HR	19.248	19.573	17.208	17.698	14.838	14.701
HC GR/HP HR TOTAL	8.609	8.809	9.775	9.509	11.762	11.865
HC GR/HP HR NON-METH	.689	.705	.665	.647	.882	.890
CO GR/HP HR	0.000	0.000	0.000	0.000	0.000	0.000

TABLE C-2E EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 2E, TEST SITE CODE 1
WORTHINGTON 26X36, RATED 1515 HP, RATED 125 RPM, 2-STROKE N/A

RUN	1	2	3	4	5	6
DATE	8/29/72	8/29/72	8/29/72	8/29/72	8/29/72	8/29/72
TIME	930	1030	1130	1300	1345	1430
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.81	29.81	29.81	29.81	29.81	29.81
AMBIENT TEMP. DEG. F	81	76	81	84	84	84
WET BULB TEMP. DEG. F	73	71	72	75	75	75
REL. HUMIDITY PERCENT	67	77	63	65	65	65
SP. HUMIDITY GRAIN/LB	107	105	101	114	114	114
ENGINE SPEED RPM	120	118	120	119	110	100
HORSEPOWER	1423	1574	1563	1565	1376	1221
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	15	15	15	15	15	15
FUEL SP. GR. (STP)	.6410	.6410	.6410	.6410	.6410	.6410
HI HEAT VALUE BTU/SCF	1058	1058	1058	1058	1058	1058
ORIFICE CONSTANT	560.01	561.12	561.12	561.12	561.12	561.12
FUEL TEMP. DEG. F	49.0	47.0	47.0	47.0	47.0	47.0
ORIFICE DP IN. H2O	42.5	43.0	43.0	42.7	42.7	41.6
ORIFICE STAT.PRES.PSIA	16.1	16.2	16.2	16.2	16.2	16.2
FUEL FLOW SCFH	14667	14791	14791	14740	14744	14553
HEAT FLOW MIL. BTU/HR	15.518	15.649	15.649	15.595	15.599	15.397
FUEL FLOW LB/HR	719	725	725	723	723	714
AIR FLOW LB/HR	18302	19509	20462	19550	17598	16060
AIR/FUEL RATIO	25.5	26.9	28.2	27.1	24.3	22.5
BSFC BTU/HP HR	10905	9942	10012	9965	11337	12610
EXHAUST EMISSIONS						
NOX PPM	145.00	520.00	830.00	550.00	75.00	30.00
NO PPM	145.00	500.00	750.00	520.00	70.00	26.00
NO2 PPM	0.00	20.00	80.00	30.00	5.00	4.00
CO2 PERCENT	4.70	5.39	5.39	5.32	4.43	3.87
HC PPM	570.00	445.00	365.00	465.00	800.00	1200.00
CO PPM	16800.00	7200.00	4600.00	7400.00	21900.00	31900.00
O2 PERCENT	10.80	12.90	12.80	11.20	11.00	10.80
NO/NOX	1.000	.962	.904	.945	.933	.867
NON-METH/TOTAL HC	.082	.075	.073	.070	.090	.085
NOX LB/HR	4.496	17.006	28.380	18.065	2.246	.827
HC LB/HR TOTAL	6.368	5.244	4.497	5.503	8.631	11.925
HC LB/HR NON-METH	.522	.393	.328	.385	.777	1.014
CO LB/HR	317.142	143.363	95.763	147.985	399.283	535.686
NOX LB/MIL BTU	.290	1.087	1.813	1.158	.144	.054
HC LB/MIL BTU TOTAL	.410	.335	.287	.353	.553	.774
HC LB/MIL BTU NON-METH	.034	.025	.021	.025	.050	.066
CO LB/MIL BTU	20.437	9.161	6.119	9.489	25.596	34.791
NOX GR/HP HR	1.433	4.901	8.236	5.236	.740	.307
HC GR/HP HR TOTAL	2.030	1.511	1.305	1.595	2.845	4.430
HC GR/HP HR NON-METH	.166	.113	.095	.112	.256	.377
CO GR/HP HR	101.093	41.315	27.791	42.892	131.624	199.007

TABLE C-2E EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 2E, TEST SITE CODE 1
WORTHINGTON 26X36, RATED 1515 HP, RATED 125 RPM, 2-STROKE N/A

RUN	7	8	9	10	11	12
DATE	8/31/72	8/31/72	8/31/72	8/31/72	8/31/72	8/31/72
TIME	930	1030	1115	1330	1430	1515
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.85	29.85	29.85	29.85	29.85	29.85
AMBIENT TEMP. DEG. F	79	81	83	88	87	91
WET BULB TEMP. DEG. F	73	74	74	76	74	74
REL. HUMIDITY PERCENT	74	71	64	56	53	43
SP. HUMIDITY GRAIN/LB	111	113	109	112	101	94
ENGINE SPEED RPM	118	118	120	118	110	100
HORSEPOWER	1375	1420	1465	1485	1384	1258
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	15	15	15	15	15	15
FUEL SP. GR. (STP)	.6410	.6410	.6410	.6410	.6410	.6410
HI HEAT VALUE BTU/SCF	1058	1058	1058	1058	1058	1058
ORIFICE CONSTANT	562.23	562.23	562.23	561.12	561.12	560.57
FUEL TEMP. DEG. F	45.0	45.0	45.0	47.0	47.0	48.0
ORIFICE DP IN. H2O	42.0	42.5	43.0	43.0	43.1	43.0
ORIFICE STAT.PRES.PSIA	16.2	16.2	16.2	16.2	16.2	16.2
FUEL FLOW SCFH	14647	14734	14821	14791	14809	14777
HEAT FLOW MIL. BTU/HR	15.497	15.589	15.680	15.649	15.668	15.634
FUEL FLOW LB/HR	718	722	727	725	726	724
AIR FLOW LB/HR	17007	18002	18373	18985	17485	16542
AIR/FUEL RATIO	23.7	24.9	25.3	26.2	24.1	22.8
BSFC BTU/HP HR	11270	10978	10703	10538	11320	12428
EXHAUST EMISSIONS						
NOX PPM	41.00	103.00	192.00	405.00	67.00	25.00
NO PPM	39.00	103.00	192.00	405.00	55.00	21.00
NO2 PPM	2.00	0.00	0.00	0.00	12.00	4.00
CO2 PERCENT	4.24	4.70	4.90	5.18	4.37	3.75
HC PPM	980.00	695.00	580.00	510.00	835.00	150.00
CO PPM	25300.00	18000.00	15300.00	10600.00	23100.00	33200.00
O2 PERCENT	11.20	11.40	11.30	11.20	10.80	11.30
NO/NOX	.951	1.000	1.000	1.000	.821	.840
NON-METH/TOTAL HC	.089	.089	.089	.089	.089	.089
NOX LB/HR	1.190	3.143	5.968	12.957	1.996	.710
HC LB/HR TOTAL	10.247	7.642	6.496	5.879	8.963	1.534
HC LB/HR NON-METH	.912	.680	.578	.523	.798	.137
CO LB/HR	447.029	334.469	289.558	206.483	419.027	573.680
NOX LB/MIL BTU	.077	.202	.381	.828	.127	.045
HC LB/MIL BTU TOTAL	.661	.490	.414	.376	.572	.098
HC LB/MIL BTU NON-METH	.059	.044	.037	.033	.051	.009
CO LB/MIL BTU	28.846	21.456	18.466	13.194	26.745	36.694
NOX GR/HP HR	.393	1.004	1.848	3.958	.654	.256
HC GR/HP HR TOTAL	3.380	2.441	2.011	1.796	2.938	.553
HC GR/HP HR NON-METH	.301	.217	.179	.160	.261	.049
CO GR/HP HR	147.471	106.842	89.654	63.071	137.334	206.853

TABLEC-2W EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 2W, TEST SITE CODE 1
WORTHINGTON 26X36, RATED 1515 HP, RATED 125 RPM, 2-STROKE N/A

RUN	1	2	3	4	5	6
DATE	8/29/72	8/29/72	8/29/72	8/29/72	8/29/72	8/29/72
TIME	930	1030	1130	1300	1345	1430
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.81	29.81	29.81	29.81	29.81	29.81
AMBIENT TEMP. DEG. F	81	76	81	84	84	84
WET BULB TEMP. DEG. F	73	71	72	75	75	75
REL. HUMIDITY PERCENT	67	77	63	65	65	65
SP. HUMIDITY GRAIN/LB	107	105	101	114	114	114
ENGINE SPEED RPM	120	118	120	119	110	100
HORSEPOWER	1423	1574	1563	1565	1376	1221
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	15	15	15	15	15	15
FUEL SP. GR. (STP)	.6410	.6410	.6410	.6410	.6410	.6410
HI HEAT VALUE BTU/SCF	1058	1058	1058	1058	1058	1058
ORIFICE CONSTANT	560.01	561.12	561.12	561.12	561.12	561.12
FUEL TEMP. DEG. F	49.0	47.0	47.0	47.0	47.0	47.0
ORIFICE DP IN. H2O	42.5	43.0	43.0	42.7	42.7	41.6
ORIFICE STAT.PRES.PSIA	16.1	16.2	16.2	16.2	16.2	16.2
FUEL FLOW SCFH	14667	14791	14791	14740	14744	14553
HEAT FLOW MIL. BTU/HR	15.518	15.649	15.649	15.595	15.599	15.397
FUEL FLOW LB/HR	719	725	725	723	723	714
AIR FLOW LB/HR	22804	24025	24746	23985	21955	19874
AIR/FUEL RATIO	31.7	33.1	34.1	33.2	30.4	27.9
BSFC BTU/HP HR	10905	9942	10012	9965	11337	12610
EXHAUST EMISSIONS						
NOX PPM	1125.00	1020.00	1170.00	1245.00	1290.00	1215.00
NO PPM	930.00	870.00	975.00	1020.00	1080.00	1155.00
NO2 PPM	195.00	150.00	195.00	225.00	210.00	60.00
CO2 PERCENT	4.63	4.70	4.63	4.70	4.66	4.63
HC PPM	305.00	345.00	335.00	410.00	580.00	650.00
CO PPM	5800.00	3100.00	2400.00	3000.00	7500.00	12300.00
O2 PERCENT	10.80	12.90	12.80	13.60	12.00	11.50
NO/NOX	.827	.853	.833	.819	.837	.951
NON-METH/TOTAL HC	.089	.089	.089	.089	.089	.089
NOX LB/HR	42.845	40.697	48.025	49.536	47.333	40.609
HC LB/HR TOTAL	4.185	4.960	4.954	5.878	7.668	7.828
HC LB/HR NON-METH	.372	.441	.441	.523	.682	.697
CO LB/HR	134.488	75.308	59.979	72.674	167.550	250.300
NOX LB/MIL BTU	2.761	2.601	3.069	3.176	3.034	2.637
HC LB/MIL BTU TOTAL	.270	.317	.317	.377	.492	.508
HC LB/MIL BTU NON-METH	.024	.028	.028	.034	.044	.045
CO LB/MIL BTU	8.667	4.812	3.833	4.660	10.741	16.256
NOX GR/HP HR	13.657	11.728	13.937	14.357	15.603	15.086
HC GR/HP HR TOTAL	1.334	1.429	1.438	1.704	2.528	2.908
HC GR/HP HR NON-METH	.119	.127	.128	.152	.225	.259
CO GR/HP HR	42.870	21.702	17.407	21.064	55.233	92.986

TABLE C-2W EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 2W, TEST SITE CODE 1
WORTHINGTON 26X36, RATED 1515 HP, RATED 125 RPM, 2-STROKE N/A

RUN	7	8	9	10	11	12
DATE	8/31/72	8/31/72	8/31/72	8/31/72	8/31/72	8/31/72
TIME	930	1030	1115	1330	1430	1515
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.85	29.85	29.85	29.85	29.85	29.85
AMBIENT TEMP. DEG. F	79	81	83	85	87	91
WET BULB TEMP. DEG. F	73	74	74	74	74	74
REL. HUMIDITY PERCENT	74	71	64	58	53	43
SP. HUMIDITY GRAIN/LB	111	113	109	105	101	94
ENGINE SPEED RPM	118	118	120	118	110	100
HORSEPOWER	1375	1420	1465	1485	1384	1258
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	15	15	15	15	15	15
FUEL SP. GR. (STP)	.6410	.6410	.6410	.6410	.6410	.6410
HI HEAT VALUE BTU/SCF	1058	1058	1058	1058	1058	1058
ORIFICE CONSTANT	562.23	562.23	562.23	561.12	561.12	561.12
FUEL TEMP. DEG. F	45.0	45.0	45.0	47.0	47.0	48.0
ORIFICE DP IN. H2O	42.0	42.5	43.0	43.0	43.1	43.0
ORIFICE STAT.PRES.PSIA	16.2	16.2	16.2	16.2	16.2	16.2
FUEL FLOW SCFH	14647	14734	14821	14791	14809	14791
HEAT FLOW MIL. BTU/HR	15.497	15.589	15.680	15.649	15.668	15.649
FUEL FLOW LB/HR	718	722	727	725	726	725
AIR FLOW LB/HR	21435	22510	22648	23066	22119	24775
AIR/FUEL RATIO	29.8	31.2	31.2	31.8	30.5	34.2
BSFC BTU/HP HR	11270	10978	10703	10538	11320	12440
EXHAUST EMISSIONS						
NOX PPM	1215.00	1230.00	1185.00	1305.00	1245.00	1110.00
NO PPM	1065.00	1035.00	1020.00	1170.00	1110.00	990.00
NO2 PPM	150.00	195.00	165.00	135.00	135.00	120.00
CO2 PERCENT	4.76	4.76	4.76	4.76	4.63	4.56
HC PPM	530.00	425.00	425.00	420.00	470.00	610.00
CO PPM	7500.00	5400.00	5400.00	4400.00	7800.00	2700.00
O2 PERCENT	12.30	12.30	12.50	12.50	12.80	12.00
NO/NOX	.877	.841	.861	.897	.892	.892
NON-METH/TOTAL HC	.089	.089	.089	.089	.089	.089
NOX LB/HR	43.531	46.160	44.732	50.107	45.973	45.678
HC LB/HR TOTAL	6.842	5.747	5.780	5.810	6.253	9.045
HC LB/HR NON-METH	.609	.511	.514	.517	.557	.805
CO LB/HR	163.606	123.386	124.109	102.861	175.365	67.649
NOX LB/MIL BTU	2.809	2.961	2.853	3.202	2.934	2.919
HC LB/MIL BTU TOTAL	.441	.369	.369	.371	.399	.578
HC LB/MIL BTU NON-METH	.039	.033	.033	.033	.036	.051
CO LB/MIL BTU	10.557	7.915	7.915	6.573	11.193	4.323
NOX GR/HP HR	14.361	14.745	13.850	15.305	15.068	16.470
HC GR/HP HR TOTAL	2.257	1.836	1.790	1.775	2.049	3.261
HC GR/HP HR NON-METH	.201	.163	.159	.158	.182	.290
CO GR/HP HR	53.972	39.414	38.427	31.420	57.475	24.392

TABLE C-3 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 3, TEST CODE 1
INGERSOLL-RAND 412-KVS, RATED 2000 HP, RATED 330 RPM, 4-STROKE TC

RUN	1	2	3	4	5	6
DATE	9/ 6/72	9/ 6/72	9/ 7/72	9/ 7/72	9/ 7/72	9/ 7/72
TIME	1230	1500	910	930	1045	1130
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.70	29.70	29.75	29.75	29.75	29.75
AMBIENT TEMP. DEG. F	85	95	77	76	77	78
WET BULB TEMP. DEG. F	74	73	70	68	68	69
REL. HUMIDITY PERCENT	58	32	69	65	62	62
SP. HUMIDITY GRAIN/LB	106	80	97	88	86	89
ENGINE SPEED RPM	330	330	330	330	300	315
HORSEPOWER	1749	2189	2126	1843	1910	2011
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	ND	ND	ND	ND	ND	ND
FUEL SP. GR. (STP)	.6300	.6300	.6300	.6300	.6300	.6300
HI HEAT VALUE BTU/SCF	1059	1059	1059	1059	1059	1059
ORIFICE CONSTANT	429.40	429.40	430.63	430.63	430.78	430.78
FUEL TEMP. DEG. F	50.0	50.0	47.0	47.0	48.0	48.0
ORIFICE DP IN. H2O	21.6	28.7	28.0	23.5	22.8	25.5
ORIFICE STAT.PRES.PSIA	66.0	66.0	66.0	66.0	66.0	66.0
FUEL FLOW SCFH	16213	18689	18512	16959	16711	17672
HEAT FLOW MIL. BTU/HR	17.169	19.791	19.604	17.960	17.697	18.715
FUEL FLOW LB/HR	781	901	892	817	805	852
AIR FLOW LB/HR	16265	19986	21200	20367	19423	20232
AIR/FUEL RATIO	20.8	22.2	23.8	24.9	24.1	23.8
BSFC BTU/HP HR	9817	9041	9221	9745	9265	9306
EXHAUST EMISSIONS						
NOX PPM	2860.00	3600.00	2655.00	2250.00	2790.00	2790.00
NO PPM	2310.00	2800.00	2310.00	1710.00	2520.00	2490.00
NO2 PPM	550.00	800.00	345.00	540.00	270.00	300.00
CO2 PERCENT	7.66	7.21	6.71	6.14	6.62	6.71
HC PPM	455.00	470.00	900.00	3500.00	800.00	800.00
CO PPM	150.00	174.00	205.00	293.00	195.00	268.00
O2 PERCENT	6.30	7.20	8.80	10.20	8.20	8.10
NO/NOX	.808	.778	.870	.760	.903	.892
NON-METH/TOTAL HC	.067	.058	.059	.067	.059	.013
NOX LB/HR	79.050	121.731	94.847	77.039	91.323	95.201
HC LB/HR TOTAL	4.604	5.818	11.771	43.874	9.587	9.994
HC LB/HR NON-METH	.308	.337	.694	2.940	.566	.130
CO LB/HR	2.524	3.582	4.459	6.108	3.886	5.568
NOX LB/MIL BTU	4.604	6.151	4.838	4.289	5.160	5.087
HC LB/MIL BTU TOTAL	.268	.294	.600	2.443	.542	.534
HC LB/MIL BTU NON-METH	.018	.017	.035	.164	.032	.007
CO LB/MIL BTU	.147	.181	.227	.340	.220	.298
NOX GR/HP HR	20.501	25.225	20.236	18.961	21.688	21.473
HC GR/HP HR TOTAL	1.194	1.206	2.511	10.798	2.277	2.254
HC GR/HP HR NON-METH	.080	.070	.148	.723	.134	.029
CO GR/HP HR	.655	.742	.951	1.503	.923	1.256

TABLE C-3 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 3, TEST SITE CODE 1
INGERSOLL-RAND 412-KVS, RATED 2000 HP, RATED 330 RPM, 4-STROKE TC

RUN	7	8	9
DATE	9/ 7/72	9/ 7/72	9/ 7/72
TIME	945	1030	1145
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.85	29.85	29.85
AMBIENT TEMP. DEG. F	90	90	90
WET BULB TEMP. DEG. F	72	72	72
REL. HUMIDITY PERCENT	39	39	39
SP. HUMIDITY GRAIN/LB	83	83	83
ENGINE SPEED RPM	330	330	330
HORSEPOWER	1910	1730	1645
SCAV. AIR PRES. IN.HG.	ND	ND	ND
IGNIT. TIME DEG. BTDC	8	8	8
FUEL SP. GR. (STP)	.6301	.6301	.6301
HI HEAT VALUE BTU/SCF	1059	1059	1059
ORIFICE CONSTANT	428.97	428.97	428.97
FUEL TEMP. DEG. F	51.0	51.0	51.0
ORIFICE DP IN. H2O	25.5	21.5	21.3
ORIFICE STAT.PRES.PSIA	66.0	66.0	66.0
FUEL FLOW SCFH	17598	16159	16084
HEAT FLOW MIL. BTU/HR	18.637	17.113	17.033
FUEL FLOW LB/HR	848	779	775
AIR FLOW LB/HR	19237	18804	19090
AIR/FUEL RATIO	22.7	24.1	24.6
BSFC BTU/HP HR	9757	9892	10354
EXHAUST EMISSIONS			
NOX PPM	3200.00	2670.00	2310.00
NO PPM	2700.00	2190.00	1980.00
NO2 PPM	500.00	480.00	330.00
CO2 PERCENT	7.04	6.54	6.38
HC PPM	650.00	1500.00	1850.00
CO PPM	174.00	213.00	262.00
O2 PERCENT	7.80	8.80	9.80
NO/NOX	.844	.820	.857
NON-METH/TOTAL HC	.082	.082	.082
NOX LB/HR	104.021	84.577	74.159
HC LB/HR TOTAL	7.740	17.406	21.757
HC LB/HR NON-METH	.635	1.427	1.784
CO LB/HR	3.444	4.108	5.121
NOX LB/MIL BTU	5.582	4.942	4.354
HC LB/MIL BTU TOTAL	.415	1.017	1.277
HC LB/MIL BTU NON-METH	.034	.083	.105
CO LB/MIL BTU	.185	.240	.301
NOX GR/HP HR	24.704	22.176	20.449
HC GR/HP HR TOTAL	1.838	4.564	5.999
HC GR/HP HR NON-METH	.151	.374	.492
CO GR/HP HR	.818	1.077	1.412

TABLE C-4 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 4, TEST SITE 1
CLARK TCVC-16, RATED 8000 HP, RATED 330 RPM, 2-STROKE TC

RUN	1	2	3	4
DATE	9/13/72	9/13/72	9/13/72	9/13/72
TIME	930	1115	1245	1500
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.99	29.99	29.99	29.99
AMBIENT TEMP. DEG. F	78	81	86	89
WET BULB TEMP. DEG. F	71	72	73	73
REL. HUMIDITY PERCENT	70	63	52	44
SP. HUMIDITY GRAIN/LB	100	100	97	91
ENGINE SPEED RPM	330	315	300	315
HORSEPOWER	7907	7547	6708	8688
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	8	8	8	8
FUEL SP. GR. (STP)	.6301	.6301	.6301	.6301
HI HEAT VALUE BTU/SCF	1059	1059	1059	1059
ORIFICE CONSTANT	1145.78	1145.78	1144.13	1143.00
FUEL TEMP. DEG. F	51.0	51.0	51.0	51.0
ORIFICE DP IN. H2O	37.0	32.6	27.8	47.5
ORIFICE STAT.PRES.PSIA	83.0	83.0	84.0	81.0
FUEL FLOW SCFH	63495	59600	55289	70898
HEAT FLOW MIL. BTU/HR	67.241	63.117	58.551	75.081
FUEL FLOW LB/HR	3060	2872	2665	3417
AIR FLOW LB/HR	119185	113737	105609	126445
AIR/FUEL RATIO	38.9	39.6	39.6	37.0
BSFC BTU/HP HR	8504	8363	8729	8642
EXHAUST EMISSIONS				
NOX PPM	1035.00	1035.00	1155.00	1125.00
NO PPM	870.00	870.00	885.00	900.00
NO2 PPM	165.00	165.00	270.00	225.00
CO2 PERCENT	4.11	4.05	4.05	4.37
HC PPM	630.00	640.00	620.00	450.00
CO PPM	720.00	640.00	620.00	450.00
O2 PERCENT	13.30	13.40	13.30	12.80
NO/NOX	.841	.841	.766	.800
NON-METH/TOTAL HC	.077	.082	.066	.075
NOX LB/HR	203.628	194.202	201.233	235.227
HC LB/HR TOTAL	45.415	44.001	39.580	34.475
HC LB/HR NON-METH	3.497	3.608	2.612	2.586
CO LB/HR	86.247	73.115	65.769	57.287
NOX LB/MIL BTU	3.028	3.077	3.437	3.133
HC LB/MIL BTU TOTAL	.675	.697	.676	.459
HC LB/MIL BTU NON-METH	.052	.057	.045	.034
CO LB/MIL BTU	1.283	1.158	1.123	.763
NOX GR/HP HR	11.681	11.672	13.608	12.281
HC GR/HP HR TOTAL	2.605	2.645	2.676	1.800
HC GR/HP HR NON-METH	.201	.217	.177	.135
CO GR/HP HR	4.948	4.394	4.447	2.991

TABLE C-4 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 4, TEST SITE 1
CLARK TCVC-16, RATED 8000 HP, RATED 330 RPM, 2-STROKE TC

RUN	5	6	7	8	9
DATE	9/14/72	9/14/72	9/14/72	9/14/72	9/14/72
TIME	1000	1045	1115	1200	1230
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.62	29.62	29.62	29.62	29.62
AMBIENT TEMP. DEG. F	65	70	64	64	65
WET BULB TEMP. DEG. F	61	63	61	61	62
REL. HUMIDITY PERCENT	79	66	84	84	84
SP. HUMIDITY GRAIN/LB	73	73	75	75	78
ENGINE SPEED RPM	330	315	300	300	300
HORSEPOWER	8322	7551	7191	7191	7191
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	8	8	8	8	8
FUEL SP. GR. (STP)	.6301	.6301	.6301	.6301	.6301
HI HEAT VALUE BTU/SCF	1059	1059	1059	1059	1059
ORIFICE CONSTANT	1145.27	1145.27	1160.33	1160.33	1160.33
FUEL TEMP. DEG. F	51.0	51.0	46.0	46.0	46.0
ORIFICE DP IN. H2O	41.3	34.0	28.5	28.3	28.2
ORIFICE STAT.PRES.PSIA	82.0	82.0	84.0	84.0	84.0
FUEL FLOW SCFH	66648	60472	56773	56574	56474
HEAT FLOW MIL. BTU/HR	70.581	64.040	60.123	59.912	59.806
FUEL FLOW LB/HR	3212	2914	2736	2727	2722
AIR FLOW LB/HR	123013	115224	108666	108283	111466
AIR/FUEL RATIO	38.3	39.5	39.7	39.7	41.0
BSFC BTU/HP HR	8481	8481	8361	8331	8317
EXHAUST EMISSIONS					
NOX PPM	1080.00	1080.00	1065.00	1050.00	1035.00
NO PPM	855.00	825.00	855.00	825.00	780.00
NO2 PPM	225.00	255.00	210.00	225.00	255.00
CO2 PERCENT	4.18	4.05	4.05	4.05	3.93
HC PPM	750.00	850.00	850.00	850.00	850.00
CO PPM	600.00	500.00	320.00	320.00	290.00
O2 PERCENT	13.20	13.50	13.50	13.50	13.50
NO/NOX	.792	.764	.803	.786	.754
NON-METH/TOTAL HC	.080	.075	.082	.075	.071
NOX LB/HR	219.415	205.265	190.855	187.505	190.111
HC LB/HR TOTAL	55.830	59.194	55.813	55.617	57.207
HC LB/HR NON-METH	4.466	4.440	4.577	4.171	4.062
CO LB/HR	74.217	57.859	34.915	34.793	32.432
NOX LB/MIL BTU	3.109	3.205	3.174	3.130	3.179
HC LB/MIL BTU TOTAL	.791	.924	.928	.928	.957
HC LB/MIL BTU NON-METH	.063	.069	.076	.070	.068
CO LB/MIL BTU	1.052	.903	.581	.581	.542
NOX GR/HP HR	11.959	12.331	12.039	11.828	11.992
HC GR/HP HR TOTAL	3.043	3.556	3.521	3.508	3.609
HC GR/HP HR NON-METH	.243	.267	.289	.263	.256
CO GR/HP HR	4.045	3.476	2.202	2.195	2.046

TABLE C-4 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 4, TEST SITE 1
CLARK TCVC-16, RATED 8000 HP, RATED 330 RPM, 2-STROKE TC

RUN	10	11	12
DATE	9/15/72	9/15/72	9/15/72
TIME	900	1000	1045
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.80	29.80	29.80
AMBIENT TEMP. DEG. F	72	73	74
WET BULB TEMP. DEG. F	68	68	69
REL. HUMIDITY PERCENT	81	77	77
SP. HUMIDITY GRAIN/LB	95	93	97
ENGINE SPEED RPM	330	315	300
HORSEPOWER	8852	8316	7940
SCAV. AIR PRES. IN.HG.	ND	ND	ND
IGNIT. TIME DEG. BTDC	8	8	8
FUEL SP. GR. (STP)	.6301	.6301	.6301
HI HEAT VALUE BTU/SCF	1059	1059	1059
ORIFICE CONSTANT	1145.27	1145.27	1145.27
FUEL TEMP. DEG. F	51.0	51.0	51.0
ORIFICE DP IN. H2O	47.6	42.8	40.0
ORIFICE STAT.PRES.PSIA	81.0	81.0	81.0
FUEL FLOW SCFH	71114	67433	65190
HEAT FLOW MIL. BTU/HR	75.310	71.412	69.036
FUEL FLOW LB/HR	3427	3250	3142
AIR FLOW LB/HR	127691	123031	121543
AIR/FUEL RATIO	37.3	37.9	38.7
BSFC BTU/HP HR	8508	8587	8695
EXHAUST EMISSIONS			
NOX PPM	1185.00	1155.00	1065.00
NO PPM	945.00	900.00	840.00
NO2 PPM	240.00	255.00	225.00
CO2 PERCENT	4.30	4.24	4.11
HC PPM	600.00	650.00	800.00
CO PPM	700.00	580.00	820.00
O2 PERCENT	12.80	13.00	13.20
NO/NOX	.797	.779	.789
NON-METH/TOTAL HC	.082	.082	.082
NOX LB/HR	250.208	234.802	213.763
HC LB/HR TOTAL	46.419	48.417	58.835
HC LB/HR NON-METH	3.806	3.970	4.824
CO LB/HR	89.990	71.789	100.209
NOX LB/MIL BTU	3.322	3.288	3.096
HC LB/MIL BTU TOTAL	.616	.678	.852
HC LB/MIL BTU NON-METH	.051	.056	.070
CO LB/MIL BTU	1.195	1.005	1.452
NOX GR/HP HR	12.821	12.807	12.212
HC GR/HP HR TOTAL	2.379	2.641	3.361
HC GR/HP HR NON-METH	.195	.217	.276
CO GR/HP HR	4.611	3.916	5.725

TABLE C-5A EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 5A, TEST SITE 2
GENERAL ELECTRIC FRAME 3, RATED 9300 HP

RUN	1	2	3	4	5	6
DATE	10/ 5/72	10/ 5/72	10/ 5/72	10/ 5/72	10/ 5/72	10/ 5/72
TIME	900	910	925	940	955	1005
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.75	29.75	29.75	29.75	29.75	29.75
AMBIENT TEMP. DEG. F	67	69	69	70	70	70
WET BULB TEMP. DEG. F	60	61	61	62	62	62
REL. HUMIDITY PERCENT	65	61	61	62	62	62
SP. HUMIDITY GRAIN/LB	64	65	65	68	68	68
POWER TURBINE SPEED RPM	5400	5000	4600	4200	4000	4200
HORSEPOWER	ND	ND	ND	ND	ND	ND
SCAV. AIR PRES. IN.HG.	ND	ND	ND	ND	ND	ND
IGNIT. TIME DEG. BTDC	ND	ND	ND	ND	ND	ND
FUEL SP. GR. (STP)	.5930	.5930	.5930	.5930	.5930	.5930
HI HEAT VALUE BTU/SCF	997	997	997	997	997	997
ORIFICE CONSTANT	1606.74	1606.57	1606.84	1607.06	1605.75	1607.03
FUEL TEMP. DEG. F	48.0	49.0	49.0	49.0	50.0	49.0
ORIFICE DP IN. H2O	27.0	22.0	15.0	11.5	10.2	12.0
ORIFICE STAT.PRES.PSIA	178.0	178.0	178.0	178.0	178.0	178.0
FUEL FLOW SCFH	111388	100536	83029	72709	68421	74272
HEAT FLOW MIL. BTU/HR	111.054	100.234	82.780	72.491	68.216	74.049
FUEL FLOW LB/HR	5052	4560	3766	3298	3103	3369
AIR FLOW LB/HR	316413	317029	299400	289796	286609	294844
AIR/FUEL RATIO	62.6	69.5	79.5	87.9	92.4	87.5
BSFC BTU/HP HR	ND	ND	ND	ND	ND	ND
EXHAUST EMISSIONS						
NOX PPM	44.00	38.00	31.00	27.00	24.00	26.00
NO PPM	39.00	34.00	27.00	22.00	19.00	22.00
NO2 PPM	5.00	4.00	4.00	5.00	5.00	4.00
CO2 PERCENT	2.68	2.42	2.12	1.92	1.83	1.93
HC PPM	.50	.70	.60	1.00	1.10	1.00
CO PPM	7.00	7.00	12.00	17.00	18.00	16.00
O2 PERCENT	17.00	17.50	17.50	17.50	18.40	18.40
NO/NOX	.886	.895	.871	.815	.792	.846
NON-METH/TOTAL HC	.014	.014	.014	.014	.014	.014
NOX LB/HR	22.654	19.555	15.035	12.658	11.107	12.387
HC LB/HR TOTAL	.094	.132	.107	.172	.186	.174
HC LB/HR NON-METH	.001	.002	.001	.002	.003	.002
CO LB/HR	2.194	2.193	3.544	4.852	5.072	4.641
NOX LB/MIL BTU	.204	.195	.182	.175	.163	.167
HC LB/MIL BTU TOTAL	.001	.001	.001	.002	.003	.002
HC LB/MIL BTU NON-METH	.000	.000	.000	.000	.000	.000
CO LB/MIL BTU	.020	.022	.043	.067	.074	.063
NOX GR/HP HR	ND	ND	ND	ND	ND	ND
HC GR/HP HR TOTAL	ND	ND	ND	ND	ND	ND
HC GR/HP HR NON-METH	ND	ND	ND	ND	ND	ND
CO GR/HP HR	ND	ND	ND	ND	ND	ND

TABLE C-5A EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 5A, TEST SITE 2
GENERAL ELECTRIC FRAME 3, RATED 9300 HP

RUN	7	8	9
DATE	10/ 5/72	10/ 5/72	10/ 5/72
TIME	1015	1030	1045
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.75	29.75	29.75
AMBIENT TEMP. DEG. F	70	70	70
WET BULB TEMP. DEG. F	62	62	62
REL. HUMIDITY PERCENT	62	62	62
SP. HUMIDITY GRAIN/LB	68	68	68
POWER TURBINE SPEED RPM	4600	5000	5200
HORSEPOWER	ND	ND	ND
SCAV. AIR PRES. IN.HG.	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA
FUEL SP. GR. (STP)	.5930	.5930	.5930
HI HEAT VALUE BTU/SCF	997	997	997
ORIFICE CONSTANT	1606.84	1606.57	1605.07
FUEL TEMP. DEG. F	49.0	49.0	50.0
ORIFICE DP IN. H2O	16.8	23.0	24.7
ORIFICE STAT.PRES.PSIA	178.0	178.0	178.0
FUEL FLOW SCFH	87869	102795	106427
HEAT FLOW MIL. BTU/HR	87.606	102.487	106.108
FUEL FLOW LB/HR	3985	4662	4827
AIR FLOW LB/HR	302491	310958	309367
AIR/FUEL RATIO	75.9	66.7	64.1
BSFC BTU/HP HR	ND	ND	ND
EXHAUST EMISSIONS			
NOX PPM	32.00	38.00	40.00
NO PPM	28.00	35.00	36.00
NO2 PPM	4.00	3.00	4.00
CO2 PERCENT	2.22	2.52	2.62
HC PPM	.70	.50	.50
CO PPM	10.00	7.00	7.00
O2 PERCENT	17.70	17.20	17.00
NO/NOX	.875	.921	.900
NON-METH/TOTAL HC	.014	.014	.014
NOX LB/HR	15.687	19.202	20.128
HC LB/HR TOTAL	.126	.092	.092
HC LB/HR NON-METH	.002	.001	.001
CO LB/HR	2.985	2.154	2.145
NOX LB/MIL BTU	.179	.187	.190
HC LB/MIL BTU TOTAL	.001	.001	.001
HC LB/MIL BTU NON-METH	.000	.000	.000
CO LB/MIL BTU	.034	.021	.020
NOX GR/HP HR	ND	ND	ND
HC GR/HP HR TOTAL	ND	ND	ND
HC GR/HP HR NON-METH	ND	ND	ND
CO GR/HP HR	ND	ND	ND

TABLE C-5A EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 5A, TEST SITE 2
GENERAL ELECTRIC FRAME 3, RATED 9300 HP

RUN	10	11	12	13	14	15
DATE	10/ 6/72	10/ 6/72	10/ 6/72	10/ 6/72	10/ 6/72	10/ 6/72
TIME	845	900	905	915	930	935
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.62	29.62	29.62	29.62	29.62	29.62
AMBIENT TEMP. DEG. F	48	48	48	48	48	48
WET BULB TEMP. DEG. F	43	43	43	43	43	43
REL. HUMIDITY PERCENT	64	64	64	64	64	64
SP. HUMIDITY GRAIN/LB	32	32	32	32	32	32
POWER TURBINE SPEED RPM	5600	5400	5000	4600	4200	4000
HORSEPOWER	ND	ND	ND	ND	ND	ND
SCAV. AIR PRES. IN.HG.	NA	NA	NA	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA	NA	NA	NA
FUEL SP. GR. (STP)	.5930	.5930	.5930	.5930	.5930	.5930
HI HEAT VALUE BTU/SCF	997	997	997	997	997	997
ORIFICE CONSTANT	1614.79	1614.84	1616.33	1618.14	1618.39	1618.48
FUEL TEMP. DEG. F	43.0	43.0	43.0	42.0	42.0	42.0
ORIFICE DP IN. H2O	29.9	27.0	19.9	14.5	11.0	10.0
ORIFICE STAT.PRES.PSIA	178.0	178.0	178.0	180.0	180.0	180.0
FUEL FLOW SCFH	117804	111949	96198	82668	72014	68666
HEAT FLOW MIL. BTU/HR	117.451	111.613	95.910	82.420	71.798	68.460
FUEL FLOW LB/HR	5343	5078	4363	3750	3266	3114
AIR FLOW LB/HR	345361	363408	353745	347864	339134	345121
AIR/FUEL RATIO	64.6	71.6	81.1	92.8	103.8	110.8
BSFC BTU/HP HR	ND	ND	ND	ND	ND	ND
EXHAUST EMISSIONS						
NOX PPM	48.00	44.00	35.00	29.00	25.00	22.00
NO PPM	44.00	41.00	31.00	25.00	20.00	18.00
NO2 PPM	4.00	3.00	4.00	4.00	5.00	4.00
CO2 PERCENT	2.60	2.35	2.08	1.82	1.63	1.53
HC PPM	.50	.50	.70	1.00	1.20	1.70
CO PPM	4.00	5.00	10.00	15.00	19.00	15.00
O2 PERCENT	17.40	16.80	17.60	17.50	18.50	19.20
NO/NOX	.917	.932	.886	.862	.800	.818
NON-METH/TOTAL HC	.014	.014	.014	.014	.014	.014
NOX LB/HR	26.945	25.967	20.048	16.308	13.669	12.221
HC LB/HR TOTAL	.103	.108	.147	.206	.240	.346
HC LB/HR NON-METH	.001	.002	.002	.003	.003	.005
CO LB/HR	1.367	1.797	3.487	5.136	6.325	5.073
NOX LB/MIL BTU	.229	.233	.209	.198	.190	.179
HC LB/MIL BTU TOTAL	.001	.001	.002	.002	.003	.005
HC LB/MIL BTU NON-METH	.000	.000	.000	.000	.000	.000
CO LB/MIL BTU	.012	.016	.036	.062	.088	.074
NOX GR/HP HR	ND	ND	ND	ND	ND	ND
HC GR/HP HR TOTAL	ND	ND	ND	ND	ND	ND
HC GR/HP HR NON-METH	ND	ND	ND	ND	ND	ND
CO GR/HP HR	ND	ND	ND	ND	ND	ND

TABLE C-5A EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 5A, TEST SITE 2
GENERAL ELECTRIC FRAME 3, RATED 9300 HP

RUN	16	17	18	19
DATE	10/ 6/72	10/ 6/72	10/ 6/72	10/ 6/72
TIME	945	955	1005	1020
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.62	29.62	29.62	29.62
AMBIENT TEMP. DEG. F	49	49	49	49
WET BULB TEMP. DEG. F	43	43	43	43
REL. HUMIDITY PERCENT	58	58	58	58
SP. HUMIDITY GRAIN/LB	30	30	30	30
POWER TURBINE SPEED RPM	4200	4600	5000	5400
HORSEPOWER	ND	ND	ND	ND
SCAV. AIR PRES. IN.HG.	NA	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA	NA
FUEL SP. GR. (STP)	.5930	.5930	.5930	.5930
HI HEAT VALUE BTU/SCF	997	997	997	997
ORIFICE CONSTANT	1621.40	1619.70	1619.47	1616.38
FUEL TEMP. DEG. F	40.0	41.0	41.0	42.0
ORIFICE DP IN. H2O	13.2	15.2	21.0	28.3
ORIFICE STAT.PRES.PSIA	180.0	180.0	180.0	178.0
FUEL FLOW SCFH	79034	84721	99568	114722
HEAT FLOW MIL. BTU/HR	78.797	84.467	99.269	114.378
FUEL FLOW LB/HR	3585	3843	4516	5203
AIR FLOW LB/HR	333295	345470	349209	351390
AIR/FUEL RATIO	93.0	89.9	77.3	67.5
BSFC BTU/HP HR	ND	ND	ND	ND
EXHAUST EMISSIONS				
NOX PPM	29.00	31.00	39.00	44.00
NO PPM	24.00	26.00	35.00	40.00
NO2 PPM	5.00	5.00	4.00	4.00
CO2 PERCENT	1.82	1.88	2.18	2.49
HC PPM	1.00	1.00	.50	.70
CO PPM	10.00	17.00	10.00	4.00
O2 PERCENT	18.90	18.60	17.80	17.30
NO/NOX	.828	.839	.897	.909
NON-METH/TOTAL HC	.014	.014	.014	.014
NOX LB/HR	15.595	17.294	22.061	25.115
HC LB/HR TOTAL	.197	.204	.104	.146
HC LB/HR NON-METH	.003	.003	.001	.002
CO LB/HR	3.274	5.774	3.444	1.390
NOX LB/MIL BTU	.198	.205	.222	.220
HC LB/MIL BTU TOTAL	.002	.002	.001	.001
HC LB/MIL BTU NON-METH	.000	.000	.000	.000
CO LB/MIL BTU	.042	.068	.035	.012
NOX GR/HP HR	ND	ND	ND	ND
HC GR/HP HR TOTAL	ND	ND	ND	ND
HC GR/HP HR NON-METH	ND	ND	ND	ND
CO GR/HP HR	ND	ND	ND	ND

TABLE C-5B EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 5B, TEST SITE 2
GENERAL ELECTRIC FRAME 3, RATED 9300 HP

RUN	1	2	3	4
DATE	10/ 9/72	10/ 9/72	10/ 9/72	10/ 9/72
TIME	1015	1025	1030	1035
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.78	29.78	29.78	29.78
AMBIENT TEMP. DEG. F	74	74	74	74
WET BULB TEMP. DEG. F	65	65	65	65
REL. HUMIDITY PERCENT	60	60	60	60
SP. HUMIDITY GRAIN/LB	75	75	75	75
POWER TURBINE SPEED RPM	4600	4800	5000	5000
HORSEPOWER	ND	ND	ND	ND
SCAV. AIR PRES. IN.HG.	NA	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA	NA
FUEL SP. GR. (STP)	.5926	.5926	.5926	.5926
HI HEAT VALUE BTU/SCF	997	997	997	997
ORIFICE CONSTANT	1610.02	1609.89	1609.79	1609.79
FUEL TEMP. DEG. F	47.0	47.0	47.0	47.0
ORIFICE DP IN. H2O	14.5	17.2	20.0	20.0
ORIFICE STAT.PRES.PSIA	185.0	185.0	185.0	185.0
FUEL FLOW SCFH	83388	90813	97920	97920
HEAT FLOW MIL. BTU/HR	83.137	90.540	97.626	97.626
FUEL FLOW LB/HR	3780	4116	4438	4438
AIR FLOW LB/HR	329085	333953	333864	338454
AIR/FUEL RATIO	87.1	81.1	75.2	76.3
BSFC BTU/HP HR	ND	ND	ND	ND
EXHAUST EMISSIONS				
NOX PPM	28.50	30.00	36.50	36.00
NO PPM	ND	ND	ND	ND
NO2 PPM	28.50	30.00	36.50	36.00
CO2 PERCENT	1.94	2.08	2.24	2.21
HC PPM	4.50	7.50	5.50	6.00
CO PPM	17.00	15.00	13.00	13.00
O2 PERCENT	18.50	18.50	18.00	18.00
NO/NOX	ND	ND	ND	ND
NON-METH/TOTAL HC	.014	.014	.014	.014
NOX LB/HR	15.154	16.203	19.744	19.737
HC LB/HR TOTAL	.876	1.483	1.089	1.204
HC LB/HR NON-METH	.012	.021	.015	.017
CO LB/HR	5.504	4.933	4.281	4.339
NOX LB/MIL BTU	.182	.179	.202	.202
HC LB/MIL BTU TOTAL	.011	.016	.011	.012
HC LB/MIL BTU NON-METH	.000	.000	.000	.000
CO LB/MIL BTU	.066	.054	.044	.044
NOX GR/HP HR	ND	ND	ND	ND
HC GR/HP HR TOTAL	ND	ND	ND	ND
HC GR/HP HR NON-METH	ND	ND	ND	ND
CO GR/HP HR	ND	ND	ND	ND

TABLE C-5B EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 5B, TEST SITE 2
GENERAL ELECTRIC FRAME 3, RATED 9300 HP

RUN	5	6	7
DATE	10/ 9/72	10/ 9/72	10/ 9/72
TIME	1040	1045	1050
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.78	29.78	29.78
AMBIENT TEMP. DEG. F	74	74	74
WET BULB TEMP. DEG. F	65	65	65
REL. HUMIDITY PERCENT	60	60	60
SP. HUMIDITY GRAIN/LB	75	75	75
POWER TURBINE SPEED RPM	5300	5300	5300
HORSEPOWER	ND	ND	ND
SCAV. AIR PRES. IN.HG.	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA
FUEL SP. GR. (STP)	.5926	.5926	.5926
HI HEAT VALUE BTU/SCF	997	997	997
ORIFICE CONSTANT	1609.68	1609.68	1609.68
FUEL TEMP. DEG. F	47.0	47.0	47.0
ORIFICE DP IN. H2O	23.5	23.5	23.5
ORIFICE STAT.PRES.PSIA	185.0	185.0	185.0
FUEL FLOW SCFH	106135	106135	106135
HEAT FLOW MIL. BTU/HR	105.817	105.817	105.817
FUEL FLOW LB/HR	4811	4811	4811
AIR FLOW LB/HR	340211	334396	340148
AIR/FUEL RATIO	70.7	69.5	70.7
BSFC BTU/HP HR	ND	ND	ND
EXHAUST EMISSIONS			
NOX PPM	40.50	41.50	40.20
NO PPM	ND	ND	ND
NO2 PPM	40.50	41.50	40.20
CO2 PERCENT	2.38	2.42	2.38
HC PPM	6.00	7.00	6.00
CO PPM	11.00	11.00	9.00
O2 PERCENT	17.80	17.60	17.60
NO/NOX	ND	ND	ND
NON-METH/TOTAL HC	.014	.014	.014
NOX LB/HR	22.351	22.524	22.187
HC LB/HR TOTAL	1.212	1.390	1.212
HC LB/HR NON-METH	.017	.019	.017
CO LB/HR	3.696	3.635	3.024
NOX LB/MIL BTU	.211	.213	.210
HC LB/MIL BTU TOTAL	.011	.013	.011
HC LB/MIL BTU NON-METH	.000	.000	.000
CO LB/MIL BTU	.035	.034	.029
NOX GR/HP HR	ND	ND	ND
HC GR/HP HR TOTAL	ND	ND	ND
HC GR/HP HR NON-METH	ND	ND	ND
CO GR/HP HR	ND	ND	ND

TABLE C-5C EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 5C, TEST SITE 2
GENERAL ELECTRIC FRAME 3, RATED 9300 HP

RUN	1	2	3	4	5	6
DATE	10/10/72	10/10/72	10/10/72	10/10/72	10/10/72	10/10/72
TIME	1000	1005	1015	1025	1030	1035
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.85	29.85	29.85	29.85	29.85	29.85
AMBIENT TEMP. DEG. F	78	78	78	78	78	78
WET BULB TEMP. DEG. F	69	69	69	69	69	69
REL. HUMIDITY PERCENT	62	62	62	62	62	62
SP. HUMIDITY GRAIN/LB	89	89	89	89	89	89
POWER TURBINE SPEED RPM	6200	6200	6200	5550	5550	5550
HORSEPOWER	ND	ND	ND	ND	ND	ND
SCAV. AIR PRES. IN.HG.	NA	NA	NA	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA	NA	NA	NA
FUEL SP. GR. (STP)	.5926	.5926	.5926	.5926	.5926	.5926
HI HEAT VALUE BTU/SCF	997	997	997	997	997	997
ORIFICE CONSTANT	1609.62	1609.62	1609.62	1609.87	1609.87	1609.87
FUEL TEMP. DEG. F	47.0	47.0	47.0	47.0	47.0	47.0
ORIFICE DP IN. H2O	26.5	26.5	26.5	17.5	17.5	17.5
ORIFICE STAT.PRES.PSIA	185.0	185.0	185.0	185.0	185.0	185.0
FUEL FLOW SCFH	112702	112702	112702	91600	91600	91600
HEAT FLOW MIL. BTU/HR	112.364	112.364	112.364	91.325	91.325	91.325
FUEL FLOW LB/HR	5108	5108	5108	4152	4152	4152
AIR FLOW LB/HR	327036	335141	355097	336814	354204	361673
AIR/FUEL RATIO	64.0	65.6	69.5	81.1	85.3	87.1
BSFC BTU/HP HR	ND	ND	ND	ND	ND	ND
EXHAUST EMISSIONS						
NOX PPM	39.00	40.00	40.00	31.00	30.00	27.00
NO PPM	ND	ND	ND	ND	ND	ND
NO2 PPM	39.00	40.00	40.00	31.00	30.00	27.00
CO2 PERCENT	2.63	2.56	2.42	2.08	1.98	1.94
HC PPM	4.50	4.00	4.20	4.30	4.20	0.00
CO PPM	4.00	4.00	4.00	7.00	7.00	10.00
O2 PERCENT	19.00	16.80	17.30	18.00	18.30	18.40
NO/NOX	0.000	0.000	0.000	0.000	0.000	0.000
NON-METH/TOTAL HC	.014	.014	.014	.014	.014	.014
NOX LB/HR	20.691	21.802	23.063	16.898	17.179	15.781
HC LB/HR TOTAL	.874	.798	.886	.858	.880	0.000
HC LB/HR NON-METH	.012	.011	.012	.012	.012	0.000
CO LB/HR	1.292	1.327	1.404	2.323	2.441	3.559
NOX LB/MIL BTU	.184	.194	.205	.185	.188	.173
HC LB/MIL BTU TOTAL	.008	.007	.008	.009	.010	0.000
HC LB/MIL BTU NON-METH	.000	.000	.000	.000	.000	0.000
CO LB/MIL BTU	.011	.012	.012	.025	.027	.039
NOX GR/HP HR	ND	ND	ND	ND	ND	ND
HC GR/HP HR TOTAL	ND	ND	ND	ND	ND	ND
HC GR/HP HR NON-METH	ND	ND	ND	ND	ND	ND
CO GR/HP HR	ND	ND	ND	ND	ND	ND

TABLE C-5C EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 5C, TEST SITE 2
GENERAL ELECTRIC FRAME 3, RATED 9300 HP

RUN	7	8
DATE	10/10/72	10/10/72
TIME	1045	1055
OPERATIONAL DATA		
BAROMETER, IN. HG.	29.85	29.85
AMBIENT TEMP. DEG. F	78	78
WET BULB TEMP. DEG. F	69	69
REL. HUMIDITY PERCENT	62	62
SP. HUMIDITY GRAIN/LB	89	89
POWER TURBINE SPEED RPM	5000	5000
HORSEPOWER	ND	ND
SCAV. AIR PRES. IN.HG.	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA
FUEL SP. GR. (STP)	.5926	.5926
HI HEAT VALUE BTU/SCF	997	997
ORIFICE CONSTANT	1611.92	1611.92
FUEL TEMP. DEG. F	47.0	47.0
ORIFICE DP IN. H2O	13.0	13.0
ORIFICE STAT.PRES.PSIA	185.0	185.0
FUEL FLOW SCFH	79050	79050
HEAT FLOW MIL. BTU/HR	78.813	78.813
FUEL FLOW LB/HR	3583	3583
AIR FLOW LB/HR	327520	322191
AIR/FUEL RATIO	91.4	89.9
BSFC BTU/HP HR	ND	ND
EXHAUST EMISSIONS		
NOX PPM	28.50	28.00
NO PPM	ND	ND
NO2 PPM	28.50	28.00
CO2 PERCENT	1.85	1.88
HC PPM	4.00	3.80
CO PPM	10.00	10.00
O2 PERCENT	18.60	18.50
NO/NOX	0.000	0.000
NON-METH/TOTAL HC	ND	ND
NOX LB/HR	15.071	14.571
HC LB/HR TOTAL	.774	.724
HC LB/HR NON-METH	.011	.010
CO LB/HR	3.220	3.168
NOX LB/MIL BTU	.191	.185
HC LB/MIL BTU TOTAL	.010	.009
HC LB/MIL BTU NON-METH	.000	.000
CO LB/MIL BTU	.041	.040
NOX GR/HP HR	ND	ND
HC GR/HP HR TOTAL	ND	ND
HC GR/HP HR NON-METH	ND	ND
CO GR/HP HR	ND	ND

TABLE C-6 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 6, TEST SITE 3
COOPER-BESSEMER LSVA-16 SG, RATED 4400 HP, RATED 327 RPM, 4-STROKE TC

RUN	1	2	3	4	5
DATE	11/13/72	11/13/72	11/13/72	11/13/72	11/13/72
TIME	1500	1525	1555	1615	1640
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.48	29.48	29.48	29.48	29.48
AMBIENT TEMP. DEG. F	72	71	68	68	68
WET BULB TEMP. DEG. F	68	68	66	66	66
REL. HUMIDITY PERCENT	81	85	90	90	90
SP. HUMIDITY GRAIN/LB	97	98	93	93	93
ENGINE SPEED RPM	318	312	306	300	324
HORSEPOWER	4365	4006	3773	3580	4461
SCAV. AIR PRES. IN.HG.	11.1	9.3	9.2	8.2	13.4
IGNIT. TIME DEG. BTDC	+20	+20	+20	+20	+20
FUEL SP. GR. (STP)	.5800	.5800	.5800	.5800	.5800
HI HEAT VALUE BTU/SCF	1032	1032	1032	1032	1032
ORIFICE CONSTANT	867.83	866.60	866.25	866.33	865.70
FUEL TEMP. DEG. F	73.0	74.0	74.0	74.0	74.0
ORIFICE DP IN. H2O	34.3	30.8	28.0	25.8	36.9
ORIFICE STAT.PRES.PSIA	36.2	35.5	34.8	34.1	36.7
FUEL FLOW SCFH	30580	28656	27040	25696	31858
HEAT FLOW MIL. BTU/HR	31.558	29.572	27.906	26.519	32.877
FUEL FLOW LB/HR	1357	1271	1200	1140	1413
AIR FLOW LB/HR	31908	29867	28537	27109	33555
AIR/FUEL RATIO	23.5	23.5	23.8	23.8	23.7
BSFC BTU/HP HR	7230	7382	7396	7407	7370
EXHAUST EMISSIONS					
NOX PPM	1380.00	1425.00	1365.00	1305.00	1335.00
NO PPM	1170.00	1140.00	1050.00	1050.00	1050.00
NO2 PPM	210.00	285.00	315.00	255.00	285.00
CO2 PERCENT	6.96	6.96	6.87	6.87	6.87
HC PPM	680.00	650.00	680.00	710.00	750.00
CO PPM	980.00	1075.00	1075.00	1075.00	1150.00
O2 PERCENT	8.80	8.70	8.50	8.60	8.70
NO/NOX	.848	.800	.769	.805	.787
NON-METH/TOTAL HC	.032	.019	.018	.032	.018
NOX LB/HR	74.418	71.943	65.833	59.785	75.701
HC LB/HR TOTAL	12.945	11.585	11.578	11.483	15.014
HC LB/HR NON-METH	.414	.220	.208	.367	.270
CO LB/HR	32.176	33.044	31.567	29.985	39.703
NOX LB/MIL BTU	2.358	2.433	2.359	2.254	2.303
HC LB/MIL BTU TOTAL	.410	.392	.415	.433	.457
HC LB/MIL BTU NON-METH	.013	.007	.007	.014	.008
CO LB/MIL BTU	1.020	1.117	1.131	1.131	1.208
NOX GR/HP HR	7.733	8.146	7.915	7.575	7.697
HC GR/HP HR TOTAL	1.345	1.312	1.392	1.455	1.527
HC GR/HP HR NON-METH	.043	.025	.025	.047	.027
CO GR/HP HR	3.344	3.742	3.795	3.799	4.037

TABLE C-7 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 7, TEST SITE 3
COOPER-BESSEMER LSVA-16 SG, RATED 4400 HP, RATED 327 RPM, 4-STROKE TC

RUN	1	2	3	4	5
DATE	11/14/72	11/14/72	11/14/72	11/14/72	11/14/72
TIME	850	910	930	1005	1015
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.71	29.71	29.71	29.71	29.71
AMBIENT TEMP. DEG. F	52	52	51	51	51
WET BULB TEMP. DEG. F	46	46	45	45	45
REL. HUMIDITY PERCENT	60	60	60	60	60
SP. HUMIDITY GRAIN/LB	35	35	33	33	33
ENGINE SPEED RPM	318	312	306	324	330
HORSEPOWER	4201	4029	3779	4440	4611
SCAV. AIR PRES. IN.HG.	9.4	8.0	7.4	10.7	12.3
IGNIT. TIME DEG. BTDC	+20	+20	+20	+20	+20
FUEL SP. GR. (STP)	.5810	.5810	.5810	.5810	.5810
HI HEAT VALUE BTU/SCF	1033	1033	1033	1033	1033
ORIFICE CONSTANT	872.58	871.34	871.42	873.47	872.89
FUEL TEMP. DEG. F	65.0	66.0	66.0	65.0	65.0
ORIFICE DP IN. H2O	25.4	23.1	20.9	28.7	31.6
ORIFICE STAT.PRES.PSIA	43.3	43.1	42.6	42.5	42.7
FUEL FLOW SCFH	28938	27494	26002	30506	32064
HEAT FLOW MIL. BTU/HR	29.893	28.401	26.860	31.513	33.122
FUEL FLOW LB/HR	1286	1222	1155	1356	1425
AIR FLOW LB/HR	29798	28264	27540	31732	33851
AIR/FUEL RATIO	23.2	23.1	23.8	23.4	23.8
BSFC BTU/HP HR	7116	7049	7108	7097	7183
EXHAUST EMISSIONS					
NOX PPM	1785.00	1770.00	1545.00	1845.00	1560.00
NO PPM	1650.00	1650.00	1440.00	1590.00	1350.00
NO2 PPM	135.00	120.00	105.00	255.00	210.00
CO2 PERCENT	7.04	7.04	6.87	6.96	6.87
HC PPM	670.00	660.00	640.00	670.00	675.00
CO PPM	1150.00	1250.00	960.00	1250.00	1125.00
O2 PERCENT	8.30	8.10	8.40	8.30	8.30
NO/NOX	.924	.932	.932	.862	.865
NON-METH/TOTAL HC	.037	.040	.024	.038	.027
NOX LB/HR	89.986	84.671	71.896	99.010	89.265
HC LB/HR TOTAL	11.930	11.152	10.519	12.700	13.643
HC LB/HR NON-METH	.441	.446	.252	.483	.368
CO LB/HR	35.298	36.407	27.200	40.842	39.194
NOX LB/MIL BTU	3.010	2.981	2.677	3.142	2.695
HC LB/MIL BTU TOTAL	.399	.393	.392	.403	.412
HC LB/MIL BTU NON-METH	.015	.016	.009	.015	.011
CO LB/MIL BTU	1.181	1.282	1.013	1.296	1.183
NOX GR/HP HR	9.716	9.533	8.630	10.115	8.781
HC GR/HP HR TOTAL	1.288	1.256	1.263	1.297	1.342
HC GR/HP HR NON-METH	.048	.050	.030	.049	.036
CO GR/HP HR	3.811	4.099	3.265	4.172	3.856

TABLE C-8 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 8, TEST SITE 3
COOPER-BESSEMER LSV-16 SG, RATED 4400 HP, RATED 327 RPM, 4-STROKE TC

RUN	1	2	3	4	5	6
DATE	11/14/72	11/14/72	11/14/72	11/14/72	11/14/72	11/14/72
TIME	1405	1415	1435	1500	1520	1540
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.72	29.72	29.72	29.72	29.72	29.72
AMBIENT TEMP. DEG. F	53	53	55	55	55	53
WET BULB TEMP. DEG. F	47	47	47	47	47	46
REL. HUMIDITY PERCENT	61	61	51	51	51	55
SP. HUMIDITY GRAIN/LB	37	37	33	33	33	33
ENGINE SPEED RPM	321	315	310	305	320	320
HORSEPOWER	4118	3959	3745	3543	4120	4141
SCAV. AIR PRES. IN.HG.	10.4	9.5	9.0	8.2	10.3	9.9
IGNIT. TIME DEG. BTDC	+20	+20	+20	+20	+24	+28
FUEL SP. GR. (STP)	.5810	.5810	.5810	.5810	.5810	.5810
HI HEAT VALUE BTU/SCF	1033	1033	1033	1033	1033	1033
ORIFICE CONSTANT	870.53	870.16	870.22	869.77	869.74	870.55
FUEL TEMP. DEG. F	68.0	68.0	68.0	68.0	68.0	68.0
ORIFICE DP IN. H2O	28.1	25.2	23.3	21.3	27.2	26.8
ORIFICE STAT.PRES.PSIA	41.2	41.4	41.5	41.7	41.2	41.3
FUEL FLOW SCFH	29620	28106	27060	25922	29115	28963
HEAT FLOW MIL. BTU/HR	30.597	29.034	27.953	26.777	30.076	29.918
FUEL FLOW LB/HR	1316	1249	1203	1152	1294	1287
AIR FLOW LB/HR	33955	33033	32136	30803	34171	33626
AIR/FUEL RATIO	25.8	26.4	26.7	26.7	26.4	26.1
BSFC BTU/HP HR	7430	7334	7464	7558	7300	7225
EXHAUST EMISSIONS						
NOX PPM	1320.00	1050.00	1050.00	900.00	1035.00	1500.00
NO PPM	1080.00	900.00	930.00	780.00	900.00	1260.00
NO2 PPM	240.00	150.00	120.00	120.00	135.00	240.00
CO2 PERCENT	6.14	5.99	5.91	5.91	5.99	6.06
HC PPM	3550.00	3500.00	3680.00	3650.00	3600.00	3600.00
CO PPM	300.00	293.00	290.00	277.00	277.00	238.00
O2 PERCENT	10.30	10.30	10.50	10.50	10.30	10.00
NO/NOX	.818	.857	.886	.867	.870	.840
NON-METH/TOTAL HC	.045	.043	.052	.049	.053	.049
NOX LB/HR	75.389	58.294	56.679	46.570	59.446	84.823
HC LB/HR TOTAL	71.614	68.634	70.165	66.710	73.034	71.905
HC LB/HR NON-METH	3.223	2.951	3.649	3.269	3.871	3.523
CO LB/HR	10.432	9.904	9.531	8.727	9.687	8.194
NOX LB/MIL BTU	2.464	2.008	2.028	1.739	1.977	2.835
HC LB/MIL BTU TOTAL	2.341	2.364	2.510	2.491	2.428	2.403
HC LB/MIL BTU NON-METH	.105	.102	.131	.122	.129	.118
CO LB/MIL BTU	.341	.341	.341	.326	.322	.274
NOX GR/HP HR	8.304	6.679	6.865	5.962	6.545	9.291
HC GR/HP HR TOTAL	7.888	7.864	8.498	8.541	8.041	7.876
HC GR/HP HR NON-METH	.355	.338	.442	.418	.426	.386
CO GR/HP HR	1.149	1.135	1.154	1.117	1.066	.898

TABLE C-8 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 8, TEST SITE 3
COOPER-BESSEMER LSV-16 SG, RATED 4400 HP, RATED 327 RPM, 4-STROKE TC

RUN	7
DATE	11/14/72
TIME	1445
OPERATIONAL DATA	
BAROMETER, IN. HG.	29.72
AMBIENT TEMP. DEG. F	52
WET BULB TEMP. DEG. F	45
REL. HUMIDITY PERCENT	54
SP. HUMIDITY GRAIN/LB	31
ENGINE SPEED RPM	320
HORSEPOWER	4073
SCAV. AIR PRES. IN.HG.	12.1
IGNIT. TIME DEG. BTDC	+16
FUEL SP. GR. (STP)	.5810
HI HEAT VALUE BTU/SCF	1033
ORIFICE CONSTANT	870.48
FUEL TEMP. DEG. F	68.0
ORIFICE DP IN. H2O	30.3
ORIFICE STAT.PRES.PSIA	41.1
FUEL FLOW SCFH	30719
HEAT FLOW MIL. BTU/HR	31.732
FUEL FLOW LB/HR	1365
AIR FLOW LB/HR	35950
AIR/FUEL RATIO	26.3
BSFC BTU/HP HR	7791
EXHAUST EMISSIONS	
NOX PPM	750.00
NO PPM	620.00
NO2 PPM	130.00
CO2 PERCENT	5.99
HC PPM	3700.00
CO PPM	344.00
O2 PERCENT	10.40
NO/NOX	.827
NON-METH/TOTAL HC	.050
NOX LB/HR	45.330
HC LB/HR TOTAL	78.989
HC LB/HR NON-METH	3.949
CO LB/HR	12.659
NOX LB/MIL BTU	1.429
HC LB/MIL BTU TOTAL	2.489
HC LB/MIL BTU NON-METH	.124
CO LB/MIL BTU	.399
NOX GR/HP HR	5.048
HC GR/HP HR TOTAL	8.797
HC GR/HP HR NON-METH	.440
CO GR/HP HR	1.410

TABLE C-9 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 9, TEST SITE 3
COOPER-BESSEMER LSV-16 SG, RATED 4400 HP, RATED 327 RPM, 4-STROKE TC

UN	1	2	3	4	5	6
ATE	11/15/72	11/15/72	11/15/72	11/15/72	11/15/72	11/15/72
IME	835	850	910	945	1005	1020
PERATIONAL DATA						
BAROMETER, IN. HG.	29.81	29.81	29.81	29.81	29.81	29.81
AMBIENT TEMP. DEG. F	44	44	44	44	44	44
WET BULB TEMP. DEG. F	39	39	39	39	39	39
REL. HUMIDITY PERCENT	61	61	61	61	61	61
SP. HUMIDITY GRAIN/LB	26	26	26	26	26	26
ENGINE SPEED RPM	325	320	315	315	310	305
HORSEPOWER	4193	3886	3703	3702	3557	3471
SCAV. AIR PRES. IN.HG.	10.2	9.6	9.3	7.2	7.2	6.9
IGNIT. TIME DEG. BTDC	+20	+20	+20	+20	+20	+20
FUEL SP. GR. (STP)	.5810	.5810	.5810	.5810	.5810	.5810
HI HEAT VALUE BTU/SCF	1032	1032	1032	1032	1032	1032
ORIFICE CONSTANT	877.26	876.88	876.93	876.43	876.49	876.54
FUEL TEMP. DEG. F	64.0	64.0	64.0	64.0	64.0	64.0
ORIFICE DP IN. H2O	27.9	25.7	23.7	23.2	21.3	19.8
ORIFICE STAT.PRES.PSIA	42.5	42.7	42.8	42.9	43.0	43.1
FUEL FLOW SCFH	30208	29048	27929	27650	26526	25606
HEAT FLOW MIL. BTU/HR	31.175	29.978	28.823	28.534	27.375	26.425
FUEL FLOW LB/HR	1342	1291	1241	1229	1179	1138
AIR FLOW LB/HR	32863	32745	32656	30466	29545	28873
AIR/FUEL RATIO	24.5	25.4	26.3	24.8	25.1	25.4
BSFC BTU/HP HR	7435	7714	7784	7708	7696	7613
XHAUST EMISSIONS						
NOX PPM	1320.00	1410.00	1080.00	1635.00	1485.00	1110.00
NO PPM	1200.00	1245.00	900.00	1380.00	1260.00	975.00
NO2 PPM	120.00	165.00	180.00	255.00	225.00	135.00
CO2 PERCENT	6.54	6.30	6.06	6.46	6.38	6.30
HC PPM	2900.00	3000.00	3100.00	2800.00	2900.00	2950.00
CO PPM	327.00	320.00	327.00	333.00	351.00	323.00
O2 PERCENT	10.40	10.40	10.60	9.60	9.90	10.20
NO/NOX	.909	.883	.833	.844	.848	.878
NON-METH/TOTAL HC	.046	.062	.048	.046	.049	.040
NOX LB/HR	73.080	77.677	59.254	83.947	73.891	53.942
HC LB/HR TOTAL	56.727	58.393	60.093	50.794	50.983	50.651
HC LB/HR NON-METH	2.609	3.620	2.884	2.337	2.498	2.026
CO LB/HR	11.023	10.733	10.923	10.410	10.634	9.557
NOX LB/MIL BTU	2.344	2.591	2.056	2.942	2.699	2.041
HC LB/MIL BTU TOTAL	1.820	1.948	2.085	1.780	1.862	1.917
HC LB/MIL BTU NON-METH	.084	.121	.100	.082	.091	.077
CO LB/MIL BTU	.354	.358	.379	.365	.388	.362
NOX GR/HP HR	7.906	9.067	7.258	10.286	9.423	7.049
HC GR/HP HR TOTAL	6.137	6.816	7.361	6.224	6.502	6.619
HC GR/HP HR NON-METH	.282	.423	.353	.286	.319	.265
CO GR/HP HR	1.192	1.253	1.338	1.275	1.356	1.249

TABLE C-9 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 9, TEST SITE 3
COOPER-BESSEMER LSV-16 SG, RATED 4400 HP, RATED 327 RPM, 4-STROKE TC

RUN	7	8	9	10	11
DATE	11/15/72	11/15/72	11/15/72	11/15/72	11/15/72
TIME	1035	1100	1110	1120	1130
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.81	29.81	29.81	29.81	29.81
AMBIENT TEMP. DEG. F	43	43	43	43	43
WET BULB TEMP. DEG. F	39	39	39	39	39
REL. HUMIDITY PERCENT	67	67	67	67	67
SP. HUMIDITY GRAIN/LB	28	28	28	28	28
ENGINE SPEED RPM	330	324	324	324	324
HORSEPOWER	4372	4090	4052	4126	4052
SCAV. AIR PRES. IN.HG.	10.4	9.2	8.3	11.5	12.6
IGNIT. TIME DEG. BTDC	+20	+20	+20	+20	+20
FUEL SP. GR. (STP)	.5810	.5810	.5810	.5810	.5810
HI HEAT VALUE BTU/SCF	1032	1032	1032	1032	1032
ORIFICE CONSTANT	873.87	873.51	873.51	871.75	871.74
FUEL TEMP. DEG. F	64.0	64.0	64.0	64.0	64.0
ORIFICE DP IN. H2O	30.7	27.3	27.3	28.1	28.4
ORIFICE STAT.PRES.PSIA	42.3	42.4	42.4	42.4	42.4
FUEL FLOW SCFH	31491	29719	29719	30090	30250
HEAT FLOW MIL. BTU/HR	32.499	30.670	30.670	31.053	31.218
FUEL FLOW LB/HR	1399	1321	1321	1337	1344
AIR FLOW LB/HR	33901	32741	31555	36094	37130
AIR/FUEL RATIO	24.2	24.8	23.9	27.0	27.6
BSFC BTU/HP HR	7433	7499	7569	7526	7704
EXHAUST EMISSIONS					
NOX PPM	1890.00	1860.00	2235.00	1350.00	885.00
NO PPM	1710.00	1635.00	2010.00	1095.00	750.00
NO2 PPM	180.00	225.00	225.00	255.00	135.00
CO2 PERCENT	6.62	6.46	6.71	5.91	5.76
HC PPM	2700.00	2800.00	2700.00	3000.00	3150.00
CO PPM	340.00	333.00	340.00	348.00	340.00
O2 PERCENT	9.20	9.40	8.80	10.20	10.60
NO/NOX	.905	.879	.899	.811	.847
NON-METH/TOTAL HC	.050	.057	.046	.053	.057
NOX LB/HR	108.115	102.645	119.107	81.816	55.118
HC LB/HR TOTAL	54.570	54.595	50.839	64.238	69.316
HC LB/HR NON-METH	2.729	3.112	2.339	3.405	3.951
CO LB/HR	11.842	11.189	11.032	12.841	12.893
NOX LB/MIL BTU	3.327	3.347	3.884	2.635	1.766
HC LB/MIL BTU TOTAL	1.679	1.780	1.658	2.069	2.220
HC LB/MIL BTU NON-METH	.084	.101	.076	.110	.127
CO LB/MIL BTU	.364	.365	.360	.414	.413
NOX GR/HP HR	11.217	11.384	13.333	8.995	6.170
HC GR/HP HR TOTAL	5.662	6.055	5.691	7.062	7.760
HC GR/HP HR NON-METH	.283	.345	.262	.374	.442
CO GR/HP HR	1.229	1.241	1.235	1.412	1.443

TABLE C-10 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 10, TEST SITE 3
COOPER-BESSEMER LSV-16 SG, RATED 4400 HP, RATED 327 RPM, 4-STROKE TC

RUN	1	2	3	4	5
DATE	11/15/72	11/15/72	11/15/72	11/15/72	11/15/72
TIME	1430	1445	1500	1530	1545
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.77	29.77	29.77	29.77	29.77
AMBIENT TEMP. DEG. F	45	45	46	46	46
WET BULB TEMP. DEG. F	41	41	41	41	41
REL. HUMIDITY PERCENT	69	69	62	62	62
SP. HUMIDITY GRAIN/LB	30	30	29	29	29
ENGINE SPEED RPM	321	315	310	326	336
HORSEPOWER	3826	3909	3741	4274	4735
SCAV. AIR PRES. IN.HG.	10.0	9.2	8.8	10.8	11.8
IGNIT. TIME DEG. BTDC	+20	+20	+20	+20	+20
FUEL SP. GR. (STP)	.5810	.5810	.5810	.5810	.5810
HI HEAT VALUE BTU/SCF	1032	1032	1032	1032	1032
ORIFICE CONSTANT	873.51	873.59	872.24	873.91	874.32
FUEL TEMP. DEG. F	64.0	64.0	65.0	64.0	64.0
ORIFICE DP IN. H2O	27.3	24.4	22.4	29.1	34.9
ORIFICE STAT.PRES.PSIA	42.1	42.4	42.7	42.1	41.8
FUEL FLOW SCFH	29614	28099	26976	30588	33394
HEAT FLOW MIL. BTU/HR	30.561	28.998	27.839	31.567	34.463
FUEL FLOW LB/HR	1316	1249	1199	1359	1484
AIR FLOW LB/HR	33904	32574	31603	34205	35546
AIR/FUEL RATIO	25.8	26.1	26.4	25.2	24.0
BSFC BTU/HP HR	7988	7418	7442	7386	7278
EXHAUST EMISSIONS					
NOX PPM	1350.00	1350.00	1020.00	1920.00	1950.00
NO PPM	1230.00	1200.00	960.00	1710.00	1800.00
NO2 PPM	120.00	150.00	60.00	210.00	150.00
CO2 PERCENT	6.22	6.14	6.06	6.38	6.71
HC PPM	2800.00	2850.00	3000.00	2700.00	2550.00
CO PPM	306.00	300.00	300.00	303.00	316.00
O2 PERCENT	10.00	10.30	10.50	9.70	8.80
NO/NOX	.911	.889	.941	.891	.923
NON-METH/TOTAL HC	.045	.047	.045	.049	.054
NOX LB/HR	76.996	73.913	54.159	110.575	117.062
HC LB/HR TOTAL	56.423	55.131	56.281	54.940	54.086
HC LB/HR NON-METH	2.539	2.591	2.533	2.692	2.921
CO LB/HR	10.626	10.000	9.698	10.625	11.550
NOX LB/MIL BTU	2.519	2.549	1.945	3.503	3.397
HC LB/MIL BTU TOTAL	1.846	1.901	2.022	1.740	1.569
HC LB/MIL BTU NON-METH	.083	.089	.091	.085	.085
CO LB/MIL BTU	.348	.345	.348	.337	.335
NOX GR/HP HR	9.128	8.577	6.567	11.735	11.214
HC GR/HP HR TOTAL	6.689	6.397	6.824	5.831	5.181
HC GR/HP HR NON-METH	.301	.301	.307	.286	.280
CO GR/HP HR	1.260	1.160	1.176	1.128	1.106

TABLE C-11 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 11, TEST SITE 3
COOPER-BESSEMER LSV-16 SG, RATED 4400 HP, RATED 327 RPM, 4-STROKE TC

RUN	1	2
DATE	11/16/72	11/16/72
TIME	910	1000
OPERATIONAL DATA		
BAROMETER, IN. HG.	29.79	29.79
AMBIENT TEMP. DEG. F	50	50
WET BULB TEMP. DEG. F	44	44
REL. HUMIDITY PERCENT	59	59
SP. HUMIDITY GRAIN/LB	31	31
ENGINE SPEED RPM	322	341
HORSEPOWER	4003	4609
SCAV. AIR PRES. IN.HG.	8.7	10.7
IGNIT. TIME DEG. BTDC	+20	+16
FUEL SP. GR. (STP)	.5810	.5810
HI HEAT VALUE BTU/SCF	1032	1032
ORIFICE CONSTANT	871.93	871.41
FUEL TEMP. DEG. F	66.0	68.0
ORIFICE DP IN. H2O	24.4	36.4
ORIFICE STAT.PRES.PSIA	42.2	40.7
FUEL FLOW SCFH	27979	33541
HEAT FLOW MIL. BTU/HR	28.874	34.614
FUEL FLOW LB/HR	1243	1491
AIR FLOW LB/HR	32013	35275
AIR/FUEL RATIO	25.7	23.7
BSFC BTU/HP HR	7213	7510
EXHAUST EMISSIONS		
NOX PPM	1275.00	1980.00
NO PPM	1155.00	1770.00
NO2 PPM	120.00	210.00
CO2 PERCENT	6.22	6.79
HC PPM	2900.00	2450.00
CO PPM	284.00	446.00
O2 PERCENT	10.40	8.90
NO/NOX	.906	.894
NON-METH/TOTAL HC	.028	.032
NOX LB/HR	68.631	117.999
HC LB/HR TOTAL	55.147	51.581
HC LB/HR NON-METH	1.544	1.651
CO LB/HR	9.308	16.183
NOX LB/MIL BTU	2.377	3.409
HC LB/MIL BTU TOTAL	1.910	1.490
HC LB/MIL BTU NON-METH	.053	.048
CO LB/MIL BTU	.322	.468
NOX GR/HP HR	7.777	11.613
HC GR/HP HR TOTAL	6.249	5.076
HC GR/HP HR NON-METH	.175	.162
CO GR/HP HR	1.055	1.593

TABLE C-12 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 12, TEST SITE 4
CLARK TLA-6, RATED 2000 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4
DATE	12/ 5/72	12/ 5/72	12/ 5/72	12/ 5/72
TIME	915	945	1000	1025
OPERATIONAL DATA				
BAROMETER, IN. HG.	30.03	30.03	30.03	30.03
AMBIENT TEMP. DEG. F	68	68	69	69
WET BULB TEMP. DEG. F	66	66	66	66
REL. HUMIDITY PERCENT	90	90	85	85
SP. HUMIDITY GRAIN/LB	91	91	90	90
ENGINE SPEED RPM	300	285	270	300
HORSEPOWER	2041	1904	1837	1953
SCAV. AIR PRES. IN.HG.	18.3	17.5	17.4	17.5
IGNIT. TIME DEG. BTDC	10	10	10	10
FUEL SP. GR. (STP)	.5762	.5762	.5762	.5762
HI HEAT VALUE BTU/SCF	1025	1025	1025	1025
ORIFICE CONSTANT	340.66	340.67	340.18	340.36
FUEL TEMP. DEG. F	71.0	71.5	72.0	72.5
ORIFICE DP IN. H2O	28.0	24.5	21.5	26.0
ORIFICE STAT.PRES.PSIA	94.7	94.7	94.7	94.7
FUEL FLOW SCFH	17542	16409	15350	16889
HEAT FLOW MIL. BTU/HR	17.980	16.820	15.734	17.311
FUEL FLOW LB/HR	773	723	676	744
AIR FLOW LB/HR	29736	30068	29965	29897
AIR/FUEL RATIO	38.5	41.6	44.3	40.2
BSFC BTU/HP HR	8810	8834	8565	8864
EXHAUST EMISSIONS				
NOX PPM	850.00	740.00	630.00	695.00
NO PPM	720.00	630.00	540.00	600.00
NO2 PPM	130.00	110.00	90.00	95.00
CO2 PERCENT	4.30	3.99	3.75	4.11
HC PPM	1150.00	1100.00	1120.00	1200.00
CO PPM	459.00	370.00	287.00	450.00
O2 PERCENT	14.00	14.30	14.60	13.80
NO/NOX	.847	.851	.857	.863
NON-METH/TOTAL HC	.023	.023	.023	.023
NOX LB/HR	41.752	36.664	31.047	34.297
HC LB/HR TOTAL	19.930	19.229	19.474	20.893
HC LB/HR NON-METH	.458	.442	.448	.481
CO LB/HR	13.727	11.161	8.611	13.520
NOX LB/MIL BTU	2.322	2.180	1.973	1.981
HC LB/MIL BTU TOTAL	1.108	1.143	1.238	1.207
HC LB/MIL BTU NON-METH	.025	.026	.028	.028
CO LB/MIL BTU	.763	.664	.547	.781
NOX GR/HP HR	9.279	8.735	7.666	7.966
HC GR/HP HR TOTAL	4.429	4.581	4.809	4.853
HC GR/HP HR NON-METH	.102	.105	.111	.112
CO GR/HP HR	3.051	2.659	2.126	3.140

TABLE C-13 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 13, TEST SITE 4
CLARK TLA-6, RATED 2000 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4
DATE	12/ 5/72	12/ 5/72	12/ 5/72	12/ 5/72
TIME	1400	1410	1425	1435
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.98	29.98	29.98	29.98
AMBIENT TEMP. DEG. F	67	67	67	67
WET BULB TEMP. DEG. F	64	64	64	64
REL. HUMIDITY PERCENT	84	84	84	84
SP. HUMIDITY GRAIN/LB	83	83	83	83
ENGINE SPEED RPM	300	285	270	300
HORSEPOWER	2041	1904	1837	1953
SCAV. AIR PRES. IN.HG.	17.1	17.1	17.0	17.1
IGNIT. TIME DEG. BTDC	10	10	10	10
FUEL SP. GR. (STP)	.5672	.5672	.5672	.5672
HI HEAT VALUE BTU/SCF	1025	1025	1025	1025
ORIFICE CONSTANT	267.49	267.34	267.35	267.34
FUEL TEMP. DEG. F	74.0	74.0	74.0	74.0
ORIFICE DP IN. H2O	32.5	28.5	26.0	31.0
ORIFICE STAT.PRES.PSIA	92.7	92.7	92.7	92.7
FUEL FLOW SCFH	14682	13741	13125	14331
HEAT FLOW MIL. BTU/HR	15.049	14.085	13.453	14.690
FUEL FLOW LB/HR	637	596	569	622
AIR FLOW LB/HR	24362	24099	24119	24342
AIR/FUEL RATIO	38.2	40.4	42.4	39.2
BSFC BTU/HP HR	7373	7397	7324	7522
EXHAUST EMISSIONS				
NOX PPM	960.00	900.00	900.00	945.00
NO PPM	915.00	735.00	705.00	825.00
NO2 PPM	45.00	165.00	195.00	120.00
CO2 PERCENT	4.30	4.05	3.75	4.18
HC PPM	1400.00	1600.00	2700.00	1600.00
CO PPM	442.00	408.00	400.00	442.00
O2 PERCENT	13.80	14.20	14.20	14.00
NO/NOX	.953	.817	.783	.873
NON-METH/TOTAL HC	.023	.023	.023	.023
NOX LB/HR	38.649	35.774	35.776	37.983
HC LB/HR TOTAL	19.886	22.439	37.868	22.690
HC LB/HR NON-METH	.457	.516	.871	.522
CO LB/HR	10.834	9.874	9.681	10.817
NOX LB/MIL BTU	2.568	2.540	2.659	2.586
HC LB/MIL BTU TOTAL	1.321	1.593	2.815	1.545
HC LB/MIL BTU NON-METH	.030	.037	.065	.036
CO LB/MIL BTU	.720	.701	.720	.736
NOX GR/HP HR	8.590	8.523	8.834	8.822
HC GR/HP HR TOTAL	4.420	5.346	9.350	5.270
HC GR/HP HR NON-METH	.102	.123	.215	.121
CO GR/HP HR	2.408	2.352	2.390	2.512

TABLE C-14 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 14, TEST SITE 4
CLARK TLA-6, RATED 2000 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4
DATE	12/ 6/72	12/ 6/72	12/ 6/72	12/ 6/72
TIME	850	910	920	935
OPERATIONAL DATA				
BAROMETER, IN. HG.	30.21	30.21	30.21	30.21
AMBIENT TEMP. DEG. F	39	39	39	39
WET BULB TEMP. DEG. F	36	36	36	36
REL. HUMIDITY PERCENT	73	73	73	73
SP. HUMIDITY GRAIN/LB	25	25	25	25
ENGINE SPEED RPM	300	285	270	300
HORSEPOWER	2047	1910	1842	1952
SCAV. AIR PRES. IN.HG.	17.5	17.5	17.4	17.5
IGNIT. TIME DEG. BTDC	10	10	10	10
FUEL SP. GR. (STP)	.5762	.5762	.5762	.5762
HI HEAT VALUE BTU/SCF	1025	1025	1025	1025
ORIFICE CONSTANT	273.19	273.48	273.32	273.47
FUEL TEMP. DEG. F	53.0	52.0	52.0	52.0
ORIFICE DP IN. H2O	41.5	34.5	32.3	38.2
ORIFICE STAT.PRES.PSIA	93.7	93.7	93.7	92.7
FUEL FLOW SCFH	17036	15549	15036	16274
HEAT FLOW MIL. BTU/HR	17.462	15.938	15.412	16.680
FUEL FLOW LB/HR	751	685	663	717
AIR FLOW LB/HR	30768	30722	30763	30168
AIR/FUEL RATIO	41.0	44.8	46.4	42.1
BSFC BTU/HP HR	8530	8344	8367	8545
EXHAUST EMISSIONS				
NOX PPM	945.00	640.00	630.00	650.00
NO PPM	885.00	500.00	560.00	540.00
NO2 PPM	60.00	140.00	70.00	110.00
CO2 PERCENT	4.05	3.69	3.57	3.93
HC PPM	1060.00	1200.00	1150.00	1200.00
CO PPM	442.00	362.00	330.00	412.00
O2 PERCENT	15.00	14.80	14.90	14.50
NO/NOX	.937	.781	.889	.831
NON-METH/TOTAL HC	.023	.023	.030	.035
NOX LB/HR	47.876	32.319	31.825	32.296
HC LB/HR TOTAL	18.948	21.380	20.497	21.036
HC LB/HR NON-METH	.436	.492	.615	.736
CO LB/HR	13.634	11.130	10.150	12.464
NOX LB/MIL BTU	2.742	2.028	2.065	1.936
HC LB/MIL BTU TOTAL	1.085	1.341	1.330	1.261
HC LB/MIL BTU NON-METH	.025	.031	.040	.044
CO LB/MIL BTU	.781	.698	.659	.747
NOX GR/HP HR	10.609	7.675	7.837	7.505
HC GR/HP HR TOTAL	4.199	5.078	5.047	4.888
HC GR/HP HR NON-METH	.097	.117	.151	.171
CO GR/HP HR	3.021	2.643	2.499	2.896

TABLE C-15 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 15, TEST SITE 4
GENERAL ELECTRIC JP-200, RATED 20000 HP

RUN	1	2	3
DATE	12/ 6/72	12/ 6/72	12/ 6/72
TIME	1300	1315	1330
OPERATIONAL DATA			
BAROMETER, IN. HG.	30.22	30.22	30.22
AMBIENT TEMP. DEG. F	44	44	44
WET BULB TEMP. DEG. F	38	38	38
REL. HUMIDITY PERCENT	53	53	53
SP. HUMIDITY GRAIN/LB	22	22	22
ENGINE SPEED RPM	8600	8600	8600
HORSEPOWER	15200	15200	15200
SCAV. AIR PRES. IN.HG.	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA
FUEL SP. GR. (STP)	.5762	.5762	.5762
HI HEAT VALUE BTU/SCF	1025	1025	1025
ORIFICE CONSTANT	852.56	852.56	852.56
FUEL TEMP. DEG. F	72.0	72.0	72.0
ORIFICE DP IN. H2O	40.0	40.0	40.0
ORIFICE STAT.PRES.PSIA	765.0	765.0	765.0
FUEL FLOW SCFH	149137	149137	149137
HEAT FLOW MIL. BTU/HR	152.866	152.866	152.866
FUEL FLOW LB/HR	6573	6573	6573
AIR FLOW LB/HR	426468	426476	426783
AIR/FUEL RATIO	64.9	64.9	64.9
BSFC BTU/HP HR	10057	10057	10057
EXHAUST EMISSIONS			
NOX PPM	67.00	65.00	67.00
NO PPM	ND	ND	ND
NO2 PPM	67.00	65.00	67.00
CO2 PERCENT	2.68	2.68	2.68
HC PPM	5.50	5.00	7.50
CO PPM	45.00	45.00	45.00
O2 PERCENT	16.70	16.70	17.30
NO/NOX	ND	ND	ND
NON-METH/TOTAL HC	.023	.023	.023
NOX LB/HR	46.485	45.098	46.481
HC LB/HR TOTAL	1.346	1.224	1.836
HC LB/HR NON-METH	.031	.028	.042
CO LB/HR	19.009	19.009	19.008
NOX LB/MIL BTU	.304	.295	.304
HC LB/MIL BTU TOTAL	.009	.008	.012
HC LB/MIL BTU NON-METH	.000	.000	.000
CO LB/MIL BTU	.124	.124	.124
NOX GR/HP HR	1.387	1.346	1.387
HC GR/HP HR TOTAL	.040	.037	.055
HC GR/HP HR NON-METH	.001	.001	.001
CO GR/HP HR	.567	.567	.567

TABLE C-16 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 16, TEST SITE 4
~~COOPER-BESSEMER~~ PRATT + WHITNEY RT-105GT, RATED 10500 HP

RUN	1	2	3	4	5
DATE	12/ 6/72	12/ 6/72	12/ 6/72	12/ 6/72	12/ 6/72
TIME	1530	1540	1550	1605	1620
OPERATIONAL DATA					
BAROMETER, IN. HG.	30.22	30.22	30.22	30.22	30.22
AMBIENT TEMP. DEG. F	44	44	44	44	44
WET BULB TEMP. DEG. F	38	38	38	38	38
REL. HUMIDITY PERCENT	53	53	53	53	53
SP. HUMIDITY GRAIN/LB	22	22	22	22	22
ENGINE SPEED RPM	9121	9121	9121	9121	9121
HORSEPOWER	12900	12900	12900	12900	12900
SCAV. AIR PRES. IN.HG.	NA	NA	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA	NA	NA
FUEL SP. GR. (STP)	.5762	.5762	.5762	.5762	.5762
HI HEAT VALUE BTU/SCF	1025	1025	1025	1025	1025
ORIFICE CONSTANT	626.24	626.24	626.24	626.24	626.24
FUEL TEMP. DEG. F	112.0	112.0	112.0	112.0	112.0
ORIFICE DP IN. H2O	52.0	52.0	52.0	52.0	52.0
ORIFICE STAT.PRES.PSIA	942.0	942.0	942.0	942.0	942.0
FUEL FLOW SCFH	138601	138601	138601	138601	138601
HEAT FLOW MIL. BTU/HR	142.067	142.067	142.067	142.067	142.067
FUEL FLOW LB/HR	6108	6108	6108	6108	6108
AIR FLOW LB/HR	600769	557383	557412	557580	557431
AIR/FUEL RATIO	98.4	91.2	91.3	91.3	91.3
BSFC BTU/HP HR	11013	11013	11013	11013	11013
EXHAUST EMISSIONS					
NOX PPM	50.00	44.00	42.00	52.00	52.00
NO PPM	ND	ND	ND	ND	ND
NO2 PPM	50.00	44.00	42.00	52.00	52.00
CO2 PERCENT	1.78	1.92	1.92	1.92	1.92
HC PPM	16.00	9.50	8.50	7.00	9.50
CO PPM	23.00	26.00	26.00	27.00	27.00
O2 PERCENT	17.50	18.50	18.50	18.70	18.60
NO/NOX	ND	ND	ND	ND	ND
NON-METH/TOTAL HC	.023	.023	.023	.023	.023
NOX LB/HR	48.525	39.602	37.804	46.806	46.800
HC LB/HR TOTAL	5.479	3.017	2.699	2.223	3.017
HC LB/HR NON-METH	.126	.069	.062	.051	.069
CO LB/HR	13.591	14.248	14.249	14.797	14.795
NOX LB/MIL BTU	.342	.279	.266	.329	.329
HC LB/MIL BTU TOTAL	.039	.021	.019	.016	.021
HC LB/MIL BTU NON-METH	.001	.000	.000	.000	.000
CO LB/MIL BTU	.096	.100	.100	.104	.104
NOX GR/HP HR	1.706	1.393	1.329	1.646	1.646
HC GR/HP HR TOTAL	.193	.106	.095	.078	.106
HC GR/HP HR NON-METH	.004	.002	.002	.002	.002
CO GR/HP HR	.478	.501	.501	.520	.520

TABLE C-17 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 17, TEST SITE 5
CLARK HBA8T, RATED 2050 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3
DATE	1/ 8/73	1/ 8/73	1/ 8/73
TIME	1545	1600	1615
OPERATIONAL DATA			
BAROMETER, IN. HG.	30.24	30.24	30.24
AMBIENT TEMP. DEG. F	31	31	31
WET BULB TEMP. DEG. F	29	29	29
REL. HUMIDITY PERCENT	77	77	77
SP. HUMIDITY GRAIN/LB	19	19	19
ENGINE SPEED RPM	300	290	280
HORSEPOWER	1965	1855	1773
SCAV. AIR PRES. IN.HG.	14.6	14.6	14.5
IGNIT. TIME DEG. BTDC	10	10	10
FUEL SP. GR. (STP)	.5800	.5800	.5800
HI HEAT VALUE BTU/SCF	1031	1031	1031
ORIFICE CONSTANT	421.98	421.99	421.72
FUEL TEMP. DEG. F	72.0	72.0	72.0
ORIFICE DP IN. H2O	30.0	27.6	25.8
ORIFICE STAT.PRES.PSIA	49.5	50.1	50.3
FUEL FLOW SCFH	16261	15692	15192
HEAT FLOW MIL. BTU/HR	16.765	16.178	15.663
FUEL FLOW LB/HR	721	696	674
AIR FLOW LB/HR	26965	26445	26895
AIR/FUEL RATIO	37.4	38.0	39.9
BSFC BTU/HP HR	8532	8721	8834
EXHAUST EMISSIONS			
NOX PPM	520.00	440.00	400.00
NO PPM	480.00	350.00	300.00
NO2 PPM	40.00	90.00	100.00
CO2 PERCENT	4.30	4.18	3.93
HC PPM	2500.00	3000.00	3400.00
CO PPM	284.00	296.00	296.00
O2 PERCENT	14.40	15.00	15.30
NO/NOX	.923	.795	.750
NON-METH/TOTAL HC	.028	.028	.028
NOX LB/HR	23.178	19.214	17.737
HC LB/HR TOTAL	39.391	46.310	53.295
HC LB/HR NON-METH	1.103	1.297	1.492
CO LB/HR	7.707	7.870	7.991
NOX LB/MIL BTU	1.382	1.188	1.132
HC LB/MIL BTU TOTAL	2.350	2.862	3.403
HC LB/MIL BTU NON-METH	.066	.080	.095
CO LB/MIL BTU	.460	.486	.510
NOX GR/HP HR	5.350	4.698	4.538
HC GR/HP HR TOTAL	9.093	11.324	13.635
HC GR/HP HR NON-METH	.255	.317	.382
CO GR/HP HR	1.779	1.924	2.044

TABLE C-18 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 18, TEST SITE 5
CLARK HBA8T, RATED 2050 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5
DATE	1/ 9/73	1/ 9/73	1/ 9/73	1/ 9/73	1/ 9/73
TIME	1030	1045	1100	1130	1145
OPERATIONAL DATA					
BAROMETER, IN. HG.	30.25	30.25	30.25	30.25	30.25
AMBIENT TEMP. DEG. F	31	31	31	31	31
WET BULB TEMP. DEG. F	30	30	30	30	30
REL. HUMIDITY PERCENT	89	89	89	89	89
SP. HUMIDITY GRAIN/LB	22	22	22	22	22
ENGINE SPEED RPM	300	290	280	300	300
HORSEPOWER	2056	1976	1872	2040	2040
SCAV. AIR PRES. IN.HG.	15.2	15.2	14.1	14.0	16.1
IGNIT. TIME DEG. BTDC	10	10	10	10	10
FUEL SP. GR. (STP)	.5800	.5800	.5800	.5800	.5800
HI HEAT VALUE BTU/SCF	1031	1031	1031	1031	1031
ORIFICE CONSTANT	420.93	420.94	420.41	420.68	420.93
FUEL TEMP. DEG. F	75.0	75.0	75.0	75.0	75.0
ORIFICE DP IN. H2O	37.5	35.6	33.0	37.1	38.2
ORIFICE STAT.PRES.PSIA	43.9	43.9	43.9	43.9	43.9
FUEL FLOW SCFH	17079	16641	16002	16977	17237
HEAT FLOW MIL. BTU/HR	17.608	17.157	16.498	17.504	17.772
FUEL FLOW LB/HR	758	738	710	753	765
AIR FLOW LB/HR	27725	27702	27591	26144	28671
AIR/FUEL RATIO	36.6	37.5	38.9	34.7	37.5
BSFC BTU/HP HR	8564	8683	8813	8580	8712
EXHAUST EMISSIONS					
NOX PPM	450.00	420.00	380.00	570.00	400.00
NO PPM	380.00	340.00	300.00	480.00	330.00
NO2 PPM	70.00	80.00	80.00	90.00	70.00
CO2 PERCENT	4.37	4.24	4.05	4.63	4.24
HC PPM	2600.00	2800.00	3200.00	2400.00	2800.00
CO PPM	396.00	377.00	355.00	425.00	400.00
O2 PERCENT	13.80	14.00	14.30	13.30	13.80
NO/NOX	.844	.810	.789	.842	.825
NON-METH/TOTAL HC	.028	.028	.028	.028	.028
NOX LB/HR	20.655	19.244	17.321	24.721	18.976
HC LB/HR TOTAL	42.186	45.353	51.562	36.796	46.955
HC LB/HR NON-METH	1.181	1.270	1.444	1.030	1.315
CO LB/HR	11.067	10.517	9.852	11.223	11.553
NOX LB/MIL BTU	1.173	1.122	1.050	1.412	1.068
HC LB/MIL BTU TOTAL	2.396	2.643	3.125	2.102	2.642
HC LB/MIL BTU NON-METH	.067	.074	.088	.059	.074
CO LB/MIL BTU	.628	.613	.597	.641	.650
NOX GR/HP HR	4.557	4.418	4.197	5.497	4.219
HC GR/HP HR TOTAL	9.307	10.411	12.494	8.182	10.441
HC GR/HP HR NON-METH	.261	.292	.350	.229	.292
CO GR/HP HR	2.442	2.414	2.387	2.495	2.569

TABLE C-19 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 19, TEST SITE 5
CLARK HBA8T, RATED 2050 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5	6
DATE	1/ 9/73	1/ 9/73	1/ 9/73	1/ 9/73	1/ 9/73	1/ 9/73
TIME	1435	1450	1530	1600	1615	1630
OPERATIONAL DATA						
BAROMETER, IN. HG.	30.41	30.41	30.41	30.41	30.41	30.41
AMBIENT TEMP. DEG. F	32	32	32	32	32	32
WET BULB TEMP. DEG. F	30	30	30	30	30	30
REL. HUMIDITY PERCENT	78	78	78	78	78	78
SP. HUMIDITY GRAIN/LB	20	20	20	20	20	20
ENGINE SPEED RPM	300	290	280	300	300	300
HORSEPOWER	2090	1998	1911	2065	2065	2065
SCAV. AIR PRES. IN.HG.	14.0	13.9	13.8	15.0	14.0	14.0
IGNIT. TIME DEG. BTDC	10.0	10.0	10.0	10.0	12.0	8.5
FUEL SP. GR. (STP)	.5800	.5800	.5800	.5800	.5800	.5800
HI HEAT VALUE BTU/SCF	1031	1031	1031	1031	1031	1031
ORIFICE CONSTANT	420.39	420.16	419.89	420.78	420.53	420.78
FUEL TEMP. DEG. F	75.0	75.0	75.0	74.0	74.0	74.0
ORIFICE DP IN. H2O	33.0	30.0	27.2	32.5	31.3	33.2
ORIFICE STAT.PRES.PSIA	48.5	49.5	49.7	48.7	48.7	48.3
FUEL FLOW SCFH	16818	16191	15438	16740	16419	16850
HEAT FLOW MIL. BTU/HR	17.340	16.693	15.917	17.259	16.927	17.372
FUEL FLOW LB/HR	746	718	685	743	728	748
AIR FLOW LB/HR	26051	25800	25600	28108	25408	26144
AIR/FUEL RATIO	34.9	35.9	37.4	37.8	34.9	35.0
BSFC BTU/HP HR	8296	8355	8329	8358	8197	8413
EXHAUST EMISSIONS						
NOX PPM	750.00	700.00	605.00	615.00	710.00	690.00
NO PPM	635.00	590.00	515.00	525.00	600.00	600.00
NO2 PPM	115.00	110.00	90.00	90.00	110.00	90.00
CO2 PERCENT	4.63	4.50	4.30	4.24	4.63	4.63
HC PPM	2050.00	2100.00	2350.00	2350.00	2150.00	2000.00
CO PPM	468.00	400.00	370.00	400.00	417.00	425.00
O2 PERCENT	12.70	12.80	13.30	13.00	12.80	12.50
NO/NOX	.847	.843	.851	.854	.845	.870
NON-METH/TOTAL HC	.028	.028	.028	.028	.028	.028
NOX LB/HR	32.426	29.944	25.637	28.616	29.937	29.945
HC LB/HR TOTAL	31.331	31.756	35.203	38.653	32.046	30.683
HC LB/HR NON-METH	.877	.889	.986	1.082	.897	.859
CO LB/HR	12.319	10.418	9.546	11.332	10.705	11.230
NOX LB/MIL BTU	1.870	1.794	1.611	1.658	1.769	1.724
HC LB/MIL BTU TOTAL	1.807	1.902	2.212	2.240	1.893	1.766
HC LB/MIL BTU NON-METH	.051	.053	.062	.063	.053	.049
CO LB/MIL BTU	.710	.624	.600	.657	.632	.646
NOX GR/HP HR	7.037	6.798	6.085	6.286	6.576	6.578
HC GR/HP HR TOTAL	6.800	7.209	8.356	8.491	7.039	6.740
HC GR/HP HR NON-METH	.190	.202	.234	.238	.197	.189
CO GR/HP HR	2.674	2.365	2.266	2.489	2.352	2.467

TABLE C-20 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 20, TEST SITE 5
CLARK TLA-6, RATED 2100 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5
DATE	1/10/73	1/10/73	1/10/73	1/10/73	1/10/73
TIME	1045	1105	1125	1300	1330
OPERATIONAL DATA					
BAROMETER, IN. HG.	30.40	30.40	30.40	30.40	30.40
AMBIENT TEMP. DEG. F	32	32	32	32	32
WET BULB TEMP. DEG. F	30	31	31	31	31
REL. HUMIDITY PERCENT	78	89	89	89	89
SP. HUMIDITY GRAIN/LB	20	23	23	23	23
ENGINE SPEED RPM	300	290	280	300	300
HORSEPOWER	2022	1910	1833	1937	1937
SCAV. AIR PRES. IN.HG.	14.0	13.8	13.6	13.0	15.0
IGNIT. TIME DEG. BTDC	10	10	10	10	10
FUEL SP. GR. (STP)	.5800	.5800	.5800	.5800	.5800
HI HEAT VALUE BTU/SCF	1031	1031	1031	1031	1031
ORIFICE CONSTANT	426.00	425.72	425.74	426.00	426.00
FUEL TEMP. DEG. F	62.0	62.0	62.0	62.0	62.0
ORIFICE DP IN. H2O	34.5	31.0	28.8	33.8	33.5
ORIFICE STAT.PRES.PSIA	42.1	42.3	42.5	42.1	42.1
FUEL FLOW SCFH	16235	15416	14895	16070	15998
HEAT FLOW MIL. BTU/HR	16.739	15.894	15.357	16.568	16.494
FUEL FLOW LB/HR	720	684	661	713	710
AIR FLOW LB/HR	26265	26754	26999	25966	28139
AIR/FUEL RATIO	36.5	39.1	40.9	36.4	39.6
BSFC BTU/HP HR	8278	8321	8378	8553	8515
EXHAUST EMISSIONS					
NOX PPM	1050.00	885.00	820.00	1230.00	830.00
NO PPM	960.00	840.00	750.00	1125.00	800.00
NO2 PPM	90.00	45.00	70.00	105.00	30.00
CO2 PERCENT	4.50	4.18	3.99	4.50	4.11
HC PPM	1550.00	1700.00	1800.00	1500.00	1800.00
CO PPM	340.00	300.00	281.00	400.00	300.00
O2 PERCENT	13.80	14.00	14.00	13.00	13.50
NO/NOX	.914	.949	.915	.915	.964
NON-METH/TOTAL HC	.119	.058	.061	.075	.077
NOX LB/HR	45.624	39.090	36.511	52.889	38.574
HC LB/HR TOTAL	23.808	26.544	28.332	22.800	29.572
HC LB/HR NON-METH	2.833	1.540	1.728	1.710	2.277
CO LB/HR	8.995	8.068	7.618	10.472	8.489
NOX LB/MIL BTU	2.726	2.459	2.378	3.192	2.339
HC LB/MIL BTU TOTAL	1.422	1.670	1.845	1.376	1.793
HC LB/MIL BTU NON-METH	.169	.097	.113	.103	.138
CO LB/MIL BTU	.537	.508	.496	.632	.515
NOX GR/HP HR	10.235	9.283	9.035	12.385	9.033
HC GR/HP HR TOTAL	5.341	6.304	7.011	5.339	6.925
HC GR/HP HR NON-METH	.636	.366	.428	.400	.533
CO GR/HP HR	2.018	1.916	1.885	2.452	1.988

TABLE C-21 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 21, TEST SITE 5
CLARK TLA-6, RATED 2100 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5
DATE	1/10/73	1/10/73	1/10/73	1/10/73	1/10/73
TIME	1415	1425	1445	1500	1515
OPERATIONAL DATA					
BAROMETER, IN. HG.	30.40	30.40	30.40	30.40	30.40
AMBIENT TEMP. DEG. F	34	34	34	33	33
WET BULB TEMP. DEG. F	30	30	31	31	31
REL. HUMIDITY PERCENT	59	59	69	79	79
SP. HUMIDITY GRAIN/LB	17	17	19	21	21
ENGINE SPEED RPM	300	280	290	300	300
HORSEPOWER	2084	1882	1983	2062	2062
SCAV. AIR PRES. IN.HG.	14.2	14.2	14.0	14.0	14.0
IGNIT. TIME DEG. BTDC	10	10	10	8	12
FUEL SP. GR. (STP)	.5800	.5800	.5800	.5800	.5800
HI HEAT VALUE BTU/SCF	1031	1031	1031	1031	1031
ORIFICE CONSTANT	426.26	425.75	426.02	426.25	426.02
FUEL TEMP. DEG. F	62.0	62.0	62.0	62.0	62.0
ORIFICE DP IN. H2O	35.2	29.0	32.0	35.6	32.7
ORIFICE STAT.PRES.PSIA	40.3	40.7	40.5	40.5	40.5
FUEL FLOW SCFH	16055	14627	15337	16185	15504
HEAT FLOW MIL. BTU/HR	16.552	15.080	15.812	16.687	15.984
FUEL FLOW LB/HR	712	649	680	718	688
AIR FLOW LB/HR	27961	27918	27607	27357	27883
AIR/FUEL RATIO	39.3	43.0	40.6	38.1	40.5
BSFC BTU/HP HR	7943	8013	7974	8093	7752
EXHAUST EMISSIONS					
NOX PPM	990.00	840.00	870.00	850.00	1110.00
NO PPM	900.00	800.00	830.00	820.00	1050.00
NO2 PPM	90.00	40.00	40.00	30.00	60.00
CO2 PERCENT	4.24	3.87	4.11	4.37	4.11
HC PPM	880.00	1000.00	890.00	860.00	920.00
CO PPM	355.00	233.00	281.00	362.00	287.00
O2 PERCENT	13.50	14.00	13.80	13.50	13.70
NO/NOX	.909	.952	.954	.965	.946
NON-METH/TOTAL HC	.054	.030	.039	.035	.052
NOX LB/HR	45.711	38.612	39.613	38.433	51.047
HC LB/HR TOTAL	14.364	16.249	14.325	13.746	14.956
HC LB/HR NON-METH	.776	.487	.559	.481	.778
CO LB/HR	9.980	6.521	7.790	9.966	8.036
NOX LB/MIL BTU	2.762	2.560	2.505	2.303	3.194
HC LB/MIL BTU TOTAL	.868	1.078	.906	.824	.936
HC LB/MIL BTU NON-METH	.047	.032	.035	.029	.049
CO LB/MIL BTU	.603	.432	.493	.597	.503
NOX GR/HP HR	9.949	9.306	9.061	8.454	11.229
HC GR/HP HR TOTAL	3.126	3.916	3.277	3.024	3.290
HC GR/HP HR NON-METH	.169	.117	.128	.106	.171
CO GR/HP HR	2.172	1.572	1.782	2.192	1.768

TABLE C-22 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 22, TEST SITE 5
CLARK TLA-6, RATED 2100 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5
DATE	1/10/73	1/10/73	1/10/73	1/10/73	1/10/73
TIME	1600	1620	1630	1640	1655
OPERATIONAL DATA					
BAROMETER, IN. HG.	30.40	30.40	30.40	30.40	30.40
AMBIENT TEMP. DEG. F	33	33	33	33	33
WET BULB TEMP. DEG. F	32	32	32	32	32
REL. HUMIDITY PERCENT	89	89	89	89	89
SP. HUMIDITY GRAIN/LB	24	24	24	24	24
ENGINE SPEED RPM	300	290	280	300	300
HORSEPOWER	2067	1953	1892	2142	1895
SCAV. AIR PRES. IN.HG.	13.8	12.8	12.8	16.0	14.0
IGNIT. TIME DEG. BTDC	10	10	10	10	10
FUEL SP. GR. (STP)	.5800	.5800	.5800	.5800	.5800
HI HEAT VALUE BTU/SCF	1031	1031	1031	1031	1031
ORIFICE CONSTANT	426.27	426.03	425.75	426.25	426.04
FUEL TEMP. DEG. F	62.0	62.0	62.0	62.0	62.0
ORIFICE DP IN. H2O	34.5	31.8	29.5	36.9	30.5
ORIFICE STAT.PRES.PSIA	39.7	39.7	39.9	39.5	39.9
FUEL FLOW SCFH	15776	15137	14607	16273	14862
HEAT FLOW MIL. BTU/HR	16.265	15.607	15.060	16.778	15.323
FUEL FLOW LB/HR	700	672	648	722	659
AIR FLOW LB/HR	28730	27120	27107	31498	27371
AIR/FUEL RATIO	41.1	40.4	41.8	43.6	41.5
BSFC BTU/HP HR	7869	7991	7960	7833	8086
EXHAUST EMISSIONS					
NOX PPM	820.00	900.00	1050.00	915.00	870.00
NO PPM	795.00	750.00	960.00	780.00	740.00
NO2 PPM	25.00	150.00	90.00	135.00	130.00
CO2 PERCENT	4.05	4.11	3.99	3.81	3.99
HC PPM	1000.00	1100.00	1100.00	1050.00	1150.00
CO PPM	274.00	274.00	250.00	233.00	287.00
O2 PERCENT	13.50	14.00	17.70	13.80	13.80
NO/NOX	.970	.833	.914	.852	.851
NON-METH/TOTAL HC	.063	.087	.062	.059	.065
NOX LB/HR	38.862	40.253	46.660	47.448	39.255
HC LB/HR TOTAL	16.753	17.391	17.280	19.247	18.343
HC LB/HR NON-METH	1.055	1.513	1.071	1.136	1.192
CO LB/HR	7.906	7.461	6.764	7.356	7.884
NOX LB/MIL BTU	2.389	2.579	3.098	2.828	2.562
HC LB/MIL BTU TOTAL	1.030	1.114	1.147	1.147	1.197
HC LB/MIL BTU NON-METH	.065	.097	.071	.068	.078
CO LB/MIL BTU	.486	.478	.449	.438	.515
NOX GR/HP HR	8.528	9.349	11.187	10.048	9.396
HC GR/HP HR TOTAL	3.676	4.039	4.143	4.076	4.391
HC GR/HP HR NON-METH	.232	.351	.257	.240	.285
CO GR/HP HR	1.735	1.733	1.622	1.558	1.887

TABLE C-23 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 23, TEST SITE 5
CLARK TCV-12, RATED 4000 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5
DATE	1/11/73	1/11/73	1/11/73	1/11/73	1/11/73
TIME	1115	1145	1320	1340	1405
OPERATIONAL DATA					
BAROMETER, IN. HG.	30.08	30.08	30.08	30.08	30.08
AMBIENT TEMP. DEG. F	36	36	36	36	36
WET BULB TEMP. DEG. F	33	33	33	33	33
REL. HUMIDITY PERCENT	71	71	71	71	71
SP. HUMIDITY GRAIN/LB	22	22	22	22	22
ENGINE SPEED RPM	280	290	300	300	300
HORSEPOWER	3667	3786	3929	3937	3937
SCAV. AIR PRES. IN.HG.	12.7	13.0	13.9	13.5	13.4
IGNIT. TIME DEG. BTDC	10	10	10	8	12
FUEL SP. GR. (STP)	.5810	.5810	.5810	.5810	.5810
HI HEAT VALUE BTU/SCF	1033	1033	1033	1033	1033
ORIFICE CONSTANT	747.96	748.38	748.12	748.12	747.69
FUEL TEMP. DEG. F	55.0	55.0	56.0	56.0	56.0
ORIFICE DP IN. H2O	32.9	34.7	38.0	38.2	36.5
ORIFICE STAT.PRES.PSIA	43.2	43.2	43.2	42.7	43.5
FUEL FLOW SCFH	28198	28975	30311	30215	29793
HEAT FLOW MIL. BTU/HR	29.129	29.932	31.312	31.212	30.776
FUEL FLOW LB/HR	1253	1288	1347	1343	1324
AIR FLOW LB/HR	56507	56373	59750	56862	56106
AIR/FUEL RATIO	45.1	43.8	44.4	42.3	42.4
BSFC BTU/HP HR	7943	7906	7969	7928	7817
EXHAUST EMISSIONS					
NOX PPM	680.00	640.00	720.00	675.00	815.00
NO PPM	640.00	600.00	690.00	650.00	785.00
NO2 PPM	40.00	40.00	30.00	25.00	30.00
CO2 PERCENT	3.63	3.75	3.69	3.87	3.87
HC PPM	1450.00	1350.00	1400.00	1400.00	1400.00
CO PPM	393.00	389.00	456.00	442.00	425.00
O2 PERCENT	13.80	13.40	13.70	13.60	13.70
NO/NOX	.941	.938	.958	.963	.963
NON-METH/TOTAL HC	.041	.052	.074	.046	.092
NOX LB/HR	63.231	59.444	70.830	63.275	75.364
HC LB/HR TOTAL	47.636	44.300	48.658	46.366	45.738
HC LB/HR NON-METH	1.953	2.304	3.601	2.133	4.208
CO LB/HR	22.250	21.998	27.313	25.227	23.928
NOX LB/MIL BTU	2.171	1.986	2.262	2.027	2.449
HC LB/MIL BTU TOTAL	1.635	1.480	1.554	1.486	1.486
HC LB/MIL BTU NON-METH	.067	.077	.115	.068	.137
CO LB/MIL BTU	.764	.735	.872	.808	.777
NOX GR/HP HR	7.822	7.122	8.177	7.290	8.683
HC GR/HP HR TOTAL	5.892	5.308	5.618	5.342	5.270
HC GR/HP HR NON-METH	.242	.276	.416	.246	.485
CO GR/HP HR	2.752	2.636	3.153	2.907	2.757

TABLE C-24 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 24, TEST SITE 5
CLARK TCV-16, RATED 5500 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5
DATE	1/12/73	1/12/73	1/12/73	1/12/73	1/12/73
TIME	915	1000	1040	1115	1125
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.98	29.98	29.98	29.98	29.98
AMBIENT TEMP. DEG. F	37	37	37	37	37
WET BULB TEMP. DEG. F	30	30	30	30	30
REL. HUMIDITY PERCENT	35	35	35	35	35
SP. HUMIDITY GRAIN/LB	11	11	11	11	11
ENGINE SPEED RPM	280	290	300	300	300
HORSEPOWER	4900	5052	5208	5208	5208
SCAV. AIR PRES. IN.HG.	11.8	12.3	14.1	12.2	16.9
IGNIT. TIME DEG. BTDC	10	10	10	10	10
FUEL SP. GR. (STP)	.5800	.5800	.5800	.5800	.5800
HI HEAT VALUE BTU/SCF	1031	1031	1031	1031	1031
ORIFICE CONSTANT	1170.58	1169.45	1169.89	1169.89	1169.89
FUEL TEMP. DEG. F	85.0	86.0	86.0	86.0	86.0
ORIFICE DP IN. H2O	22.2	23.4	26.9	26.9	26.9
ORIFICE STAT.PRES.PSIA	43.7	43.7	43.2	43.2	43.2
FUEL FLOW SCFH	36460	37396	39881	39881	39881
HEAT FLOW MIL. BTU/HR	37.590	38.556	41.117	41.117	41.117
FUEL FLOW LB/HR	1617	1659	1769	1769	1769
AIR FLOW LB/HR	73980	77336	85173	79664	89631
AIR/FUEL RATIO	45.7	46.6	48.1	45.0	50.7
BSFC BTU/HP HR	7672	7632	7895	7895	7895
EXHAUST EMISSIONS					
NOX PPM	300.00	280.00	280.00	240.00	165.00
NO PPM	270.00	250.00	250.00	230.00	150.00
NO2 PPM	30.00	30.00	30.00	10.00	15.00
CO2 PERCENT	3.51	3.45	3.28	3.57	2.94
HC PPM	2200.00	2100.00	2600.00	2100.00	4250.00
CO PPM	344.00	362.00	400.00	417.00	408.00
O2 PERCENT	15.00	15.20	15.00	14.90	15.50
NO/NOX	.900	.893	.893	.958	.909
NON-METH/TOTAL HC	.094	.092	.037	.102	.049
NOX LB/HR	36.470	35.557	39.149	31.434	24.250
HC LB/HR TOTAL	94.528	94.256	128.490	97.217	220.774
HC LB/HR NON-METH	8.886	8.672	4.754	9.916	10.818
CO LB/HR	25.461	27.989	34.052	33.254	36.509
NOX LB/MIL BTU	.970	.922	.952	.765	.590
HC LB/MIL BTU TOTAL	2.515	2.445	3.125	2.364	5.369
HC LB/MIL BTU NON-METH	.236	.225	.116	.241	.263
CO LB/MIL BTU	.677	.726	.828	.809	.888
NOX GR/HP HR	3.376	3.192	3.410	2.738	2.112
HC GR/HP HR TOTAL	8.751	8.463	11.191	8.467	19.229
HC GR/HP HR NON-METH	.823	.779	.414	.864	.942
CO GR/HP HR	2.357	2.513	2.966	2.896	3.180

TABLE C-25 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 25, TEST CODE 6
COOPER-BESSEMER GMWA-6, RATED 1500 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3	4
DATE	1/17/73	1/17/73	1/17/73	1/17/73
TIME	1100	1200	1215	1235
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.92	29.92	29.92	29.92
AMBIENT TEMP. DEG. F	67	80	80	83
WET BULB TEMP. DEG. F	59	66	66	67
REL. HUMIDITY PERCENT	60	45	45	41
SP. HUMIDITY GRAIN/LB	59	69	69	68
ENGINE SPEED RPM	249	250	232	213
HORSEPOWER	1595	1508	1390	1300
SCAV. AIR PRES. IN.HG.	4.15	4.10	3.70	3.35
IGNIT. TIME DEG. BTDC	7.5	7.5	7.5	7.5
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018
ORIFICE CONSTANT	276.06	275.52	275.30	274.90
FUEL TEMP. DEG. F	59.0	61.0	62.0	63.0
ORIFICE DP IN. H2O	22.0	21.0	17.0	14.0
ORIFICE STAT.PRES.PSIA	95.9	96.4	97.0	97.5
FUEL FLOW SCFH	12680	12397	11179	10156
HEAT FLOW MIL. BTU/HR	12.908	12.620	11.381	10.339
FUEL FLOW LB/HR	556	543	490	445
AIR FLOW LB/HR	38264	37394	35172	33934
AIR/FUEL RATIO	68.9	68.8	71.8	76.2
BSFC BTU/HP HR	8093	8369	8187	7953
EXHAUST EMISSIONS				
NOX PPM	790.00	635.00	570.00	395.00
NO PPM	770.00	580.00	460.00	215.00
NO2 PPM	20.00	55.00	110.00	180.00
CO2 PERCENT	2.42	2.42	2.32	2.17
HC PPM	1050.00	1050.00	1000.00	1100.00
CO PPM	34.00	44.00	45.00	45.00
O2 PERCENT	17.20	17.30	16.60	16.50
NO/NOX	.975	.913	.807	.544
NON-METH/TOTAL HC	.020	.020	.020	.020
NOX LB/HR	49.093	38.563	32.568	21.760
HC LB/HR TOTAL	23.075	22.550	20.205	21.429
HC LB/HR NON-METH	.461	.451	.404	.429
CO LB/HR	1.286	1.627	1.565	1.509
NOX LB/MIL BTU	3.803	3.056	2.862	2.105
HC LB/MIL BTU TOTAL	1.788	1.787	1.775	2.073
HC LB/MIL BTU NON-METH	.036	.036	.036	.041
CO LB/MIL BTU	.100	.129	.138	.146
NOX GR/HP HR	13.962	11.600	10.628	7.593
HC GR/HP HR TOTAL	6.562	6.783	6.594	7.477
HC GR/HP HR NON-METH	.131	.136	.132	.150
CO GR/HP HR	.366	.489	.511	.527

TABLE C-26 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 26, TEST SITE 6
COOPER-BESSEMER GMWA-6, RATED 1500 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3	4
DATE	1/17/73	1/18/73	1/18/73	1/18/73
TIME	1500	930	1015	1130
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.92	29.92	29.92	29.92
AMBIENT TEMP. DEG. F	80	68	68	68
WET BULB TEMP. DEG. F	65	63	63	63
REL. HUMIDITY PERCENT	42	75	75	75
SP. HUMIDITY GRAIN/LB	63	76	76	76
ENGINE SPEED RPM	250	250	230	210
HORSEPOWER	1595	1505	1400	1285
SCAV. AIR PRES. IN.HG.	3.8	3.8	3.35	2.9
IGNIT. TIME DEG. BTDC	7.5	7.5	7.5	7.5
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018
ORIFICE CONSTANT	274.89	275.26	275.29	275.32
FUEL TEMP. DEG. F	64.0	62.0	62.0	62.0
ORIFICE DP IN. H2O	26.5	22.5	19.0	16.0
ORIFICE STAT.PRES.PSIA	89.1	94.1	94.3	95.2
FUEL FLOW SCFH	13357	12666	11653	10745
HEAT FLOW MIL. BTU/HR	13.598	12.894	11.862	10.939
FUEL FLOW LB/HR	585	555	511	471
AIR FLOW LB/HR	34363	35300	32477	31866
AIR/FUEL RATIO	58.7	63.6	63.6	67.7
BSFC BTU/HP HR	8525	8567	8473	8513
EXHAUST EMISSIONS				
NOX PPM	950.00	650.00	645.00	610.00
NO PPM	795.00	615.00	515.00	490.00
NO2 PPM	155.00	35.00	130.00	120.00
CO2 PERCENT	2.84	2.62	2.62	2.47
HC PPM	1050.00	1050.00	1050.00	950.00
CO PPM	110.00	60.00	52.00	40.00
O2 PERCENT	16.80	16.50	16.30	16.40
NO/NOX	.837	.946	.798	.803
NON-METH/TOTAL HC	.025	.025	.025	.025
NOX LB/HR	53.193	37.354	34.112	31.615
HC LB/HR TOTAL	20.791	21.338	19.637	17.412
HC LB/HR NON-METH	.520	.533	.491	.435
CO LB/HR	3.750	2.099	1.674	1.262
NOX LB/MIL BTU	3.912	2.897	2.876	2.890
HC LB/MIL BTU TOTAL	1.529	1.655	1.655	1.592
HC LB/MIL BTU NON-METH	.038	.041	.041	.040
CO LB/MIL BTU	.276	.163	.141	.115
NOX GR/HP HR	15.128	11.258	11.052	11.160
HC GR/HP HR TOTAL	5.913	6.431	6.363	6.146
HC GR/HP HR NON-METH	.148	.161	.159	.154
CO GR/HP HR	1.066	.633	.543	.446

TABLE C-27 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 27, TEST SITE 6
COOPER-BESSEMER GMWA-6, RATED 1500 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3	4
DATE	1/18/73	1/18/73	1/18/73	1/18/73
TIME	1305	1340	1420	1445
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.92	29.92	29.92	29.92
AMBIENT TEMP. DEG. F	75	75	75	75
WET BULB TEMP. DEG. F	68	68	68	68
REL. HUMIDITY PERCENT	69	69	69	69
SP. HUMIDITY GRAIN/LB	89	89	89	89
ENGINE SPEED RPM	249	249	232	210
HORSEPOWER	1650	1620	1515	1342
SCAV. AIR PRES. IN.HG.	4.3	4.3	3.85	3.15
IGNIT. TIME DEG. BTDC	7.5	7.5	7.5	7.5
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018
ORIFICE CONSTANT	282.06	281.65	281.67	281.97
FUEL TEMP. DEG. F	65.0	64.0	64.0	65.0
ORIFICE DP IN. H2O	24.0	23.0	20.5	15.0
ORIFICE STAT.PRES.PSIA	93.4	93.2	93.8	94.2
FUEL FLOW SCFH	13354	13040	12351	10599
HEAT FLOW MIL. BTU/HR	13.595	13.275	12.574	10.790
FUEL FLOW LB/HR	585	571	541	464
AIR FLOW LB/HR	38165	37276	37468	32016
AIR/FUEL RATIO	65.2	65.2	69.2	68.9
BSFC BTU/HP HR	8239	8194	8300	8040
EXHAUST EMISSIONS				
NOX PPM	975.00	925.00	1020.00	900.00
NO PPM	915.00	805.00	900.00	720.00
NO2 PPM	60.00	120.00	120.00	180.00
CO2 PERCENT	2.57	2.57	2.42	2.42
HC PPM	900.00	900.00	900.00	1000.00
CO PPM	41.00	41.00	41.00	41.00
O2 PERCENT	16.20	16.40	16.70	16.60
NO/NOX	.938	.870	.882	.800
NON-METH/TOTAL HC	.020	.020	.020	.020
NOX LB/HR	60.561	56.103	62.094	46.830
HC LB/HR TOTAL	19.769	19.304	19.375	18.401
HC LB/HR NON-METH	.395	.386	.388	.368
CO LB/HR	1.551	1.514	1.520	1.299
NOX LB/MIL BTU	4.455	4.226	4.938	4.340
HC LB/MIL BTU TOTAL	1.454	1.454	1.541	1.705
HC LB/MIL BTU NON-METH	.029	.029	.031	.034
CO LB/MIL BTU	.114	.114	.121	.120
NOX GR/HP HR	16.649	15.709	18.591	15.829
HC GR/HP HR TOTAL	5.435	5.405	5.801	6.219
HC GR/HP HR NON-METH	.109	.108	.116	.124
CO GR/HP HR	.426	.424	.455	.439

TABLE C-28 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 28, TEST SITE 6
COOPER-BESSEMER GMWC-6, RATED 2000 HP, RATED 250 RPM, 2-STROKE TC

RUN	1	2	3	4
DATE	1/19/73	1/19/73	1/19/73	1/19/73
TIME	850	915	1015	1230
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.92	29.92	29.92	29.92
AMBIENT TEMP. DEG. F	56	71	71	75
WET BULB TEMP. DEG. F	50	55	55	58
REL. HUMIDITY PERCENT	63	30	30	31
SP. HUMIDITY GRAIN/LB	42	34	34	39
ENGINE SPEED RPM	250	240	230	209
HORSEPOWER	2090	2042	1915	1795
SCAV. AIR PRES. IN.HG.	13.0	12.7	10.8	8.8
IGNIT. TIME DEG. BTDC	7.5	7.5	7.5	7.5
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018
ORIFICE CONSTANT	276.48	276.21	275.53	275.41
FUEL TEMP. DEG. F	59.0	60.0	62.0	62.0
ORIFICE DP IN. H2O	42.0	42.5	36.0	27.0
ORIFICE STAT.PRES.PSIA	88.8	89.0	90.0	89.0
FUEL FLOW SCFH	16885	16987	15683	13501
HEAT FLOW MIL. BTU/HR	17.189	17.293	15.966	13.744
FUEL FLOW LB/HR	740	744	687	592
AIR FLOW LB/HR	33224	33148	31201	26872
AIR/FUEL RATIO	44.9	44.5	45.4	45.4
BSFC BTU/HP HR	8224	8469	8337	7657
EXHAUST EMISSIONS				
NOX PPM	930.00	990.00	1215.00	1215.00
NO PPM	870.00	825.00	1065.00	945.00
NO2 PPM	60.00	165.00	150.00	270.00
CO2 PERCENT	3.69	3.69	3.63	3.63
HC PPM	1300.00	1600.00	1500.00	1500.00
CO PPM	127.00	123.00	122.00	94.00
O2 PERCENT	14.90	14.60	14.90	14.70
NO/NOX	.935	.833	.877	.778
NON-METH/TOTAL HC	.053	.048	.018	.045
NOX LB/HR	50.768	53.955	62.265	53.639
HC LB/HR TOTAL	25.096	30.837	27.184	23.418
HC LB/HR NON-METH	1.330	1.480	.489	1.054
CO LB/HR	4.221	4.081	3.807	2.527
NOX LB/MIL BTU	2.954	3.120	3.900	3.903
HC LB/MIL BTU TOTAL	1.460	1.783	1.703	1.704
HC LB/MIL BTU NON-METH	.077	.086	.031	.077
CO LB/MIL BTU	.246	.236	.238	.184
NOX GR/HP HR	11.018	11.985	14.748	13.555
HC GR/HP HR TOTAL	5.447	6.850	6.439	5.918
HC GR/HP HR NON-METH	.289	.329	.116	.266
CO GR/HP HR	.916	.907	.902	.638

TABLE C-29 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 29, TEST SITE 6
COOPER-BESSEMER 14 V-250, RATED 4800 HP, RATED 250 RPM, 2-STROKE TC

RUN	1	2	3	4	5
DATE	1/22/73	1/22/73	1/22/73	1/22/73	1/22/73
TIME	830	1135	1330	1420	1500
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.92	29.92	29.92	29.92	29.92
AMBIENT TEMP. DEG. F	61	80	82	86	86
WET BULB TEMP. DEG. F	49	58	62	63	63
REL. HUMIDITY PERCENT	36	20	28	23	23
SP. HUMIDITY GRAIN/LB	29	30	45	42	42
ENGINE SPEED RPM	250	250	249	248	210
HORSEPOWER	4800	4850	4740	4740	4068
SCAV. AIR PRES. IN.HG.	9.2	8.9	12.0	8.7	6.8
IGNIT. TIME DEG. BTDC	9	9	10.3	8.5	8.5
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018	1018
ORIFICE CONSTANT	716.08	715.10	715.08	714.44	712.95
FUEL TEMP. DEG. F	54.0	55.0	55.0	56.0	58.0
ORIFICE DP IN. H2O	31.5	30.0	30.5	30.5	19.5
ORIFICE STAT.PRES.PSIA	85.5	86.4	88.4	88.8	95.1
FUEL FLOW SCFH	37162	36407	37130	37181	30702
HEAT FLOW MIL. BTU/HR	37.831	37.062	37.799	37.850	31.255
FUEL FLOW LB/HR	1628	1595	1627	1629	1345
AIR FLOW LB/HR	62665	60390	69464	59893	52908
AIR/FUEL RATIO	38.5	37.9	42.7	36.8	39.3
BSFC BTU/HP HR	7881	7642	7974	7985	7683
EXHAUST EMISSIONS					
NOX PPM	1890.00	2025.00	1785.00	2235.00	2070.00
NO PPM	1800.00	1635.00	1605.00	1770.00	1875.00
NO2 PPM	90.00	390.00	180.00	465.00	195.00
CO2 PERCENT	4.30	4.37	3.81	4.50	4.24
HC PPM	1350.00	1350.00	2000.00	1300.00	1000.00
CO PPM	152.00	161.00	130.00	192.00	170.00
O2 PERCENT	13.70	13.50	14.10	13.00	13.50
NO/NOX	.952	.807	.899	.792	.906
NON-METH/TOTAL HC	.064	.038	.037	.015	.020
NOX LB/HR	195.568	202.060	204.143	221.481	180.744
HC LB/HR TOTAL	49.399	47.637	80.887	45.557	30.878
HC LB/HR NON-METH	3.162	1.810	2.993	.683	.618
CO LB/HR	9.576	9.781	9.052	11.584	9.038
NOX LB/MIL BTU	5.170	5.452	5.401	5.851	5.783
HC LB/MIL BTU TOTAL	1.306	1.285	2.140	1.204	.988
HC LB/MIL BTU NON-METH	.084	.049	.079	.018	.020
CO LB/MIL BTU	.253	.264	.239	.306	.289
NOX GR/HP HR	18.481	18.898	19.536	21.195	20.154
HC GR/HP HR TOTAL	4.668	4.455	7.741	4.360	3.443
HC GR/HP HR NON-METH	.299	.169	.286	.065	.069
CO GR/HP HR	.905	.915	.866	1.109	1.008

TABLE C-30 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 30, TEST SITE 6
PRATT AND WHITNEY GG3C-4 GAS TURBINE, RATED 12000 HP

RUN	1	2	3	4	5	6
DATE	1/18/73	1/18/73	1/18/73	1/19/73	1/19/73	1/19/73
TIME	1045	1100	1115	835	840	850
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.92	29.92	29.92	29.92	29.92	29.92
AMBIENT TEMP. DEG. F	74	74	74	56	56	56
WET BULB TEMP. DEG. F	67	67	67	50	50	50
REL. HUMIDITY PERCENT	68	68	68	63	63	63
SP. HUMIDITY GRAIN/LB	86	86	86	42	42	42
ENGINE SPEED RPM	4950	4950	4950	5070	5070	5070
HORSEPOWER	13700	13700	13700	14100	14100	14100
SCAV. AIR PRES. IN.HG.	NA	NA	NA	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA	NA	NA	NA
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018	1018	1018
ORIFICE CONSTANT	730.81	730.81	730.81	731.55	731.55	731.55
FUEL TEMP. DEG. F	73.0	73.0	73.0	72.0	72.0	72.0
ORIFICE DP IN. H2O	64.0	64.0	64.0	65.5	65.5	65.5
ORIFICE STAT.PRES.PSIA	625.0	625.0	625.0	616.0	616.0	616.0
FUEL FLOW SCFH	146162	146162	146162	146945	146945	146945
HEAT FLOW MIL. BTU/HR	148.793	148.793	148.793	149.590	149.590	149.590
FUEL FLOW LB/HR	6405	6405	6405	6439	6439	6439
AIR FLOW LB/HR	584972	564139	564183	555526	555428	555092
AIR/FUEL RATIO	91.3	88.1	88.1	86.3	86.3	86.2
BSFC BTU/HP HR	10861	10861	10861	10609	10609	10609
EXHAUST EMISSIONS						
NOX PPM	39.00	40.00	39.50	41.00	40.50	39.50
NO PPM	ND	ND	ND	ND	ND	ND
NO2 PPM	39.00	40.00	39.50	41.00	40.50	39.50
CO2 PERCENT	1.91	1.98	1.98	2.02	2.02	2.02
HC PPM	11.50	6.50	5.00	9.50	11.00	18.00
CO PPM	30.00	30.00	30.00	43.00	45.00	50.00
O2 PERCENT	17.30	17.20	17.20	17.40	17.40	17.40
NO/NOX	ND	ND	ND	ND	ND	ND
NON-METH/TOTAL HC	.020	.020	.020	.020	.020	.020
NOX LB/HR	36.901	36.521	36.067	36.862	36.406	35.486
HC LB/HR TOTAL	3.848	2.099	1.615	3.020	3.497	5.719
HC LB/HR NON-METH	.077	.042	.032	.060	.070	.114
CO LB/HR	17.283	16.677	16.678	23.538	24.629	27.349
NOX LB/MIL BTU	.248	.245	.242	.246	.243	.237
HC LB/MIL BTU TOTAL	.026	.014	.011	.020	.023	.038
HC LB/MIL BTU NON-METH	.001	.000	.000	.000	.000	.001
CO LB/MIL BTU	.116	.112	.112	.157	.165	.183
NOX GR/HP HR	1.222	1.209	1.194	1.186	1.171	1.142
HC GR/HP HR TOTAL	.127	.069	.053	.097	.112	.184
HC GR/HP HR NON-METH	.003	.001	.001	.002	.002	.004
CO GR/HP HR	.572	.552	.552	.757	.792	.880

TABLE C-31 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 31, TEST SITE 7
COOPER-BESSEMER GMW-8, RATED 2050 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3	4
DATE	2/20/73	2/21/73	2/21/73	2/21/73
TIME	1500	900	1000	1030
OPERATIONAL DATA				
BAROMETER, IN. HG.	30.15	30.12	30.20	30.22
AMBIENT TEMP. DEG. F	50	47	52	52
WET BULB TEMP. DEG. F	46	44	46	45
REL. HUMIDITY PERCENT	72	77	60	54
SP. HUMIDITY GRAIN/LB	38	37	34	30
ENGINE SPEED RPM	251	231	217	218
HORSEPOWER	2045	2005	1890	2005
SCAV. AIR PRES. IN.HG.	5.3	4.5	4.0	3.9
IGNIT. TIME DEG. BTDC	7	7	7	7
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018
ORIFICE CONSTANT	708.86	710.44	709.94	709.19
FUEL TEMP. DEG. F	63.0	61.0	62.0	63.0
ORIFICE DP IN. H2O	7.5	6.0	5.3	5.5
ORIFICE STAT.PRES.PSIA	99.2	99.7	99.7	99.9
FUEL FLOW SCFH	19335	17376	16320	16624
HEAT FLOW MIL. BTU/HR	19.683	17.689	16.613	16.923
FUEL FLOW LB/HR	847	761	715	728
AIR FLOW LB/HR	40387	37584	34767	33119
AIR/FUEL RATIO	47.7	49.4	48.6	45.5
BSFC BTU/HP HR	9625	8822	8790	8440
EXHAUST EMISSIONS				
NOX PPM	1005.00	1238.00	1388.00	1650.00
NO PPM	960.00	1038.00	1263.00	1388.00
NO2 PPM	45.00	200.00	125.00	262.00
CO2 PERCENT	3.51	3.39	3.45	3.69
HC PPM	1150.00	1050.00	980.00	950.00
CO PPM	60.00	55.00	53.00	49.00
O2 PERCENT	18.00	16.00	16.00	15.10
NO/NOX	.955	.838	.910	.841
NON-METH/TOTAL HC	.050	.050	.050	.050
NOX LB/HR	66.314	76.148	78.991	89.681
HC LB/HR TOTAL	26.834	22.839	19.723	18.260
HC LB/HR NON-METH	1.342	1.142	.986	.913
CO LB/HR	2.410	2.060	1.836	1.622
NOX LB/MIL BTU	3.369	4.305	4.755	5.299
HC LB/MIL BTU TOTAL	1.363	1.291	1.187	1.079
HC LB/MIL BTU NON-METH	.068	.065	.059	.054
CO LB/MIL BTU	.122	.116	.111	.096
NOX GR/HP HR	14.709	17.227	18.958	20.289
HC GR/HP HR TOTAL	5.952	5.167	4.733	4.131
HC GR/HP HR NON-METH	.298	.258	.237	.207
CO GR/HP HR	.535	.466	.441	.367

TABLE C-32 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 32, TEST SITE 7
COOPER-BESSEMER GMW-8, RATED 2050 HP, RATED 250 RPM

RUN	1	2	3
DATE	2/21/73	2/21/73	2/21/73
TIME	1330	1415	1500
OPERATIONAL DATA			
BAROMETER, IN. HG.	30.12	30.12	30.12
AMBIENT TEMP. DEG. F	56	57	57
WET BULB TEMP. DEG. F	46	47	47
REL. HUMIDITY PERCENT	41	42	42
SP. HUMIDITY GRAIN/LB	27	28	28
ENGINE SPEED RPM	251	232	218
HORSEPOWER	2035	2018	1940
SCAV. AIR PRES. IN.HG.	5.3	4.5	4.0
IGNIT. TIME DEG. BTDC	7.0	7.0	7.0
FUEL SP. GR. (STP)	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018
ORIFICE CONSTANT	709.09	709.31	707.91
FUEL TEMP. DEG. F	63.0	63.0	65.0
ORIFICE DP IN. H2O	6.0	5.0	5.0
ORIFICE STAT.PRES.PSIA	99.4	99.4	102.7
FUEL FLOW SCFH	17317	15813	16042
HEAT FLOW MIL. BTU/HR	17.629	16.098	16.330
FUEL FLOW LB/HR	759	693	703
AIR FLOW LB/HR	35096	31504	31451
AIR/FUEL RATIO	46.3	45.5	44.7
BSFC BTU/HP HR	8663	7977	8418
EXHAUST EMISSIONS			
NOX PPM	1113.00	1500.00	1788.00
NO PPM	1013.00	1350.00	1563.00
NO2 PPM	100.00	150.00	225.00
CO2 PERCENT	3.63	3.69	3.75
HC PPM	880.00	910.00	910.00
CO PPM	64.00	60.00	60.00
O2 PERCENT	14.80	14.60	14.50
NO/NOX	.910	.900	.874
NON-METH/TOTAL HC	.040	.050	.040
NOX LB/HR	64.125	77.611	92.387
HC LB/HR TOTAL	17.929	16.650	16.628
HC LB/HR NON-METH	.717	.833	.665
CO LB/HR	2.245	1.890	1.888
NOX LB/MIL BTU	3.638	4.821	5.657
HC LB/MIL BTU TOTAL	1.017	1.034	1.018
HC LB/MIL BTU NON-METH	.041	.052	.041
CO LB/MIL BTU	.127	.117	.116
NOX GR/HP HR	14.293	17.445	21.601
HC GR/HP HR TOTAL	3.996	3.743	3.888
HC GR/HP HR NON-METH	.160	.187	.156
CO GR/HP HR	.500	.425	.441

TABLE C-33 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 33, TEST SITE 7
COOPER-BESSEMER GMW-8, RATED 2050 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3	4	5
DATE	2/22/73	2/22/73	2/22/73	2/22/73	2/22/73
TIME	915	935	1100	1125	1230
OPERATIONAL DATA					
BAROMETER, IN. HG.	30.03	30.03	30.02	30.02	30.02
AMBIENT TEMP. DEG. F	41	41	45	48	48
WET BULB TEMP. DEG. F	34	34	39	40	40
REL. HUMIDITY PERCENT	41	41	54	43	43
SP. HUMIDITY GRAIN/LB	15	15	24	21	21
ENGINE SPEED RPM	248	240	231	220	209
HORSEPOWER	2000	1945	1845	1760	1645
SCAV. AIR PRES. IN.HG.	5.4	5.0	4.6	4.2	3.6
IGNIT. TIME DEG. BTDC	7.0	7.0	7.0	7.0	7.0
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018	1018
ORIFICE CONSTANT	706.06	706.10	707.03	706.32	707.44
FUEL TEMP. DEG. F	67.0	67.0	66.0	67.0	66.0
ORIFICE DP IN. H2O	4.8	4.6	4.0	4.0	3.0
ORIFICE STAT.PRES.PSIA	102.2	102.2	100.1	99.9	100.6
FUEL FLOW SCFH	15638	15310	14148	14119	12290
HEAT FLOW MIL. BTU/HR	15.920	15.585	14.402	14.373	12.511
FUEL FLOW LB/HR	685	671	620	619	539
AIR FLOW LB/HR	35053	36215	33395	33267	28921
AIR/FUEL RATIO	51.2	54.0	53.9	53.8	53.7
BSFC BTU/HP HR	7960	8013	7806	8167	7606
EXHAUST EMISSIONS					
NOX PPM	585.00	600.00	650.00	610.00	570.00
NO PPM	530.00	550.00	630.00	590.00	510.00
NO2 PPM	55.00	50.00	20.00	20.00	60.00
CO2 PERCENT	3.22	3.05	3.05	3.05	3.05
HC PPM	1500.00	1450.00	1500.00	1550.00	1600.00
CO PPM	68.00	68.00	68.00	70.00	70.00
O2 PERCENT	15.60	15.20	14.80	14.70	15.00
NO/NOX	.906	.917	.969	.967	.895
NON-METH/TOTAL HC	.040	.050	.040	.040	.050
NOX LB/HR	33.570	35.550	35.534	33.226	26.983
HC LB/HR TOTAL	30.440	30.382	28.998	29.856	26.785
HC LB/HR NON-METH	1.218	1.519	1.160	1.194	1.339
CO LB/HR	2.376	2.453	2.263	2.321	2.018
NOX LB/MIL BTU	2.109	2.281	2.467	2.312	2.157
HC LB/MIL BTU TOTAL	1.912	1.949	2.013	2.077	2.141
HC LB/MIL BTU NON-METH	.076	.097	.081	.083	.107
CO LB/MIL BTU	.149	.157	.157	.162	.161
NOX GR/HP HR	7.614	8.291	8.736	8.563	7.440
HC GR/HP HR TOTAL	6.904	7.085	7.129	7.695	7.386
HC GR/HP HR NON-METH	.276	.354	.285	.308	.369
CO GR/HP HR	.539	.572	.556	.598	.556

TABLE C-34 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 34, TEST SITE 7
COOPER-BESSEMER GMWA-8, RATED 2000 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3	4	5
DATE	2/22/73	2/23/73	2/23/73	2/23/73	2/23/73
TIME	1500	800	820	855	920
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.88	29.83	29.83	29.83	29.83
AMBIENT TEMP. DEG. F	52	43	43	47	48
WET BULB TEMP. DEG. F	46	40	40	41	41
REL. HUMIDITY PERCENT	60	75	75	56	50
SP. HUMIDITY GRAIN/LB	35	31	31	27	25
ENGINE SPEED RPM	251	240	230	221	210
HORSEPOWER	2050	2015	1895	1832	1714
SCAV. AIR PRES. IN.HG.	4.8	4.5	4.2	3.8	3.5
IGNIT. TIME DEG. BTDC	7.5	7.5	7.5	7.5	7.5
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018	1018
ORIFICE CONSTANT	708.09	706.95	707.84	707.76	707.72
FUEL TEMP. DEG. F	64.0	66.0	65.0	65.0	65.0
ORIFICE DP IN. H2O	5.0	4.2	3.5	3.8	3.8
ORIFICE STAT.PRES.PSIA	100.6	101.1	101.1	98.4	101.9
FUEL FLOW SCFH	15881	14568	13315	13686	13926
HEAT FLOW MIL. BTU/HR	16.167	14.830	13.555	13.932	14.177
FUEL FLOW LB/HR	696	638	583	600	610
AIR FLOW LB/HR	35884	35279	31621	33087	34107
AIR/FUEL RATIO	51.6	55.3	54.2	55.2	55.9
BSFC BTU/HP HR	7886	7360	7153	7605	8271
EXHAUST EMISSIONS					
NOX PPM	700.00	430.00	360.00	410.00	360.00
NO PPM	620.00	420.00	350.00	400.00	360.00
NO2 PPM	80.00	10.00	10.00	10.00	0.00
CO2 PERCENT	3.28	3.05	3.11	3.05	3.00
HC PPM	620.00	750.00	750.00	800.00	900.00
CO PPM	60.00	64.00	64.00	66.00	68.00
O2 PERCENT	14.80	15.70	15.60	15.70	15.70
NO/NOX	.886	.977	.972	.976	1.000
NON-METH/TOTAL HC	.040	.050	.050	.040	.040
NOX LB/HR	41.143	24.788	18.611	22.167	20.061
HC LB/HR TOTAL	12.887	15.289	13.712	15.296	17.735
HC LB/HR NON-METH	.515	.764	.686	.612	.709
CO LB/HR	2.147	2.246	2.015	2.173	2.307
NOX LB/MIL BTU	2.545	1.671	1.373	1.591	1.415
HC LB/MIL BTU TOTAL	.797	1.031	1.012	1.098	1.251
HC LB/MIL BTU NON-METH	.032	.052	.051	.044	.050
CO LB/MIL BTU	.133	.151	.149	.156	.163
NOX GR/HP HR	9.104	5.580	4.455	5.489	5.309
HC GR/HP HR TOTAL	2.851	3.442	3.282	3.787	4.694
HC GR/HP HR NON-METH	.114	.172	.164	.151	.188
CO GR/HP HR	.475	.506	.482	.538	.611

TABLE C-35 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 35, TEST SITE 7
COOPER-BESSEMER GMWA-8, RATED 2000 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3
DATE	2/23/73	2/23/73	2/23/73
TIME	1045	1150	1310
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.83	29.81	29.81
AMBIENT TEMP. DEG. F	55	55	63
WET BULB TEMP. DEG. F	47	47	51
REL. HUMIDITY PERCENT	51	51	39
SP. HUMIDITY GRAIN/LB	33	33	33
ENGINE SPEED RPM	251	252	252
HORSEPOWER	2087	2095	2120
SCAV. AIR PRES. IN.HG.	4.7	4.8	4.7
IGNIT. TIME DEG. BTDC	7.5	11.0	3.0
FUEL SP. GR. (STP)	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018
ORIFICE CONSTANT	273.16	273.16	273.40
FUEL TEMP. DEG. F	69.0	69.0	68.0
ORIFICE DP IN. H2O	34.5	35.0	37.2
ORIFICE STAT.PRES.PSIA	96.2	96.7	96.7
FUEL FLOW SCFH	15737	15891	16398
HEAT FLOW MIL. BTU/HR	16.020	16.178	16.693
FUEL FLOW LB/HR	690	696	719
AIR FLOW LB/HR	36554	36783	35654
AIR/FUEL RATIO	53.0	52.8	49.6
BSFC BTU/HP HR	7676	7722	7874
EXHAUST EMISSIONS			
NOX PPM	510.00	660.00	635.00
NO PPM	500.00	660.00	590.00
NO2 PPM	10.00	0.00	45.00
CO2 PERCENT	3.11	3.11	3.33
HC PPM	1480.00	1600.00	1450.00
CO PPM	60.00	60.00	60.00
O2 PERCENT	15.50	15.60	15.20
NO/NOX	.980	1.000	.929
NON-METH/TOTAL HC	.040	.050	.040
NOX LB/HR	30.500	39.713	37.104
HC LB/HR TOTAL	31.267	34.010	29.930
HC LB/HR NON-METH	1.251	1.701	1.197
CO LB/HR	2.185	2.198	2.135
NOX LB/MIL BTU	1.904	2.455	2.223
HC LB/MIL BTU TOTAL	1.952	2.102	1.793
HC LB/MIL BTU NON-METH	.078	.105	.072
CO LB/MIL BTU	.136	.136	.128
NOX GR/HP HR	6.629	8.599	7.939
HC GR/HP HR TOTAL	6.796	7.364	6.404
HC GR/HP HR NON-METH	.272	.368	.256
CO GR/HP HR	.475	.476	.457

TABLE C-36 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 36, TEST SITE 7
COOPER-BESSEMER GMWA-8, RATED 2000 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3	4
DATE	2/23/73	2/23/73	2/23/73	2/23/73
TIME	1435	1450	1515	1545
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.82	29.82	29.82	29.82
AMBIENT TEMP. DEG. F	63	63	63	63
WET BULB TEMP. DEG. F	51	51	51	51
REL. HUMIDITY PERCENT	39	39	39	39
SP. HUMIDITY GRAIN/LB	33	33	33	33
ENGINE SPEED RPM	250	240	238	219
HORSEPOWER	2111	2020	1950	1865
SCAV. AIR PRES. IN.HG.	4.8	4.2	4.1	3.7
IGNIT. TIME DEG. BTDC	7.5	7.5	7.5	7.5
FUEL SP. GR. (STP)	.5729	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018	1018
ORIFICE CONSTANT	272.63	272.48	272.24	271.98
FUEL TEMP. DEG. F	71.0	71.0	72.0	73.0
ORIFICE DP IN. H2O	37.0	33.0	31.0	27.5
ORIFICE STAT.PRES.PSIA	98.7	99.7	100.7	101.9
FUEL FLOW SCFH	16475	15629	15211	14398
HEAT FLOW MIL. BTU/HR	16.772	15.911	15.484	14.657
FUEL FLOW LB/HR	722	685	667	631
AIR FLOW LB/HR	38437	37049	36054	34141
AIR/FUEL RATIO	53.2	54.1	54.1	54.1
BSFC BTU/HP HR	7945	7877	7941	7859
EXHAUST EMISSIONS				
NOX PPM	830.00	795.00	840.00	840.00
NO PPM	790.00	750.00	775.00	670.00
NO2 PPM	40.00	45.00	65.00	170.00
CO2 PERCENT	3.22	3.17	3.17	3.17
HC PPM	230.00	230.00	225.00	220.00
CO PPM	60.00	64.00	60.00	60.00
O2 PERCENT	15.60	15.80	15.50	15.70
NO/NOX	.952	.943	.923	.798
NON-METH/TOTAL HC	.040	.050	.040	.040
NOX LB/HR	52.153	48.123	49.499	46.860
HC LB/HR TOTAL	5.111	4.923	4.689	4.340
HC LB/HR NON-METH	.204	.246	.188	.174
CO LB/HR	2.295	2.359	2.153	2.038
NOX LB/MIL BTU	3.110	3.025	3.197	3.197
HC LB/MIL BTU TOTAL	.305	.309	.303	.296
HC LB/MIL BTU NON-METH	.012	.015	.012	.012
CO LB/MIL BTU	.137	.148	.139	.139
NOX GR/HP HR	11.206	10.806	11.514	11.397
HC GR/HP HR TOTAL	1.098	1.106	1.091	1.056
HC GR/HP HR NON-METH	.044	.055	.044	.042
CO GR/HP HR	.493	.530	.501	.496

TABLE C-37 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 37, TEST SITE 7
SOLAR SATURN T-1001S-4 GAS TURBINE, RATED 1050 HP

RUN	1	2	3
DATE	2/26/73	2/26/73	2/26/73
TIME	1400	1405	1410
OPERATIONAL DATA			
BAROMETER, IN. HG.	31.03	31.03	31.03
AMBIENT TEMP. DEG. F	50	50	50
WET BULB TEMP. DEG. F	46	46	46
REL. HUMIDITY PERCENT	71	71	71
SP. HUMIDITY GRAIN/LB	37	37	37
ENGINE SPEED RPM	22300	22300	22300
HORSEPOWER	980	980	980
SCAV. AIR PRES. IN.HG.	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA
FUEL SP. GR. (STP)	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018
ORIFICE CONSTANT	460.60	460.60	460.60
FUEL TEMP. DEG. F	52.0	52.0	52.0
ORIFICE DP IN. H2O	3.0	3.0	3.0
ORIFICE STAT.PRES.PSIA	222.0	222.0	222.0
FUEL FLOW SCFH	11887	11887	11887
HEAT FLOW MIL. BTU/HR	12.101	12.101	12.101
FUEL FLOW LB/HR	521	521	521
AIR FLOW LB/HR	38207	37405	39042
AIR/FUEL RATIO	73.4	71.8	75.0
BSFC BTU/HP HR	12348	12348	12348
EXHAUST EMISSIONS			
NOX PPM	26.50	27.00	27.00
NO PPM	ND	ND	ND
NO2 PPM	26.50	27.00	27.00
CO2 PERCENT	2.37	2.42	2.32
HC PPM	5.00	4.50	4.50
CO PPM	47.00	49.00	47.00
O2 PERCENT	17.00	17.00	17.00
NO/NOX	ND	ND	ND
NON-METH/TOTAL HC	ND	ND	ND
NOX LB/HR	1.643	1.640	1.710
HC LB/HR TOTAL	.110	.097	.101
HC LB/HR NON-METH	ND	ND	ND
CO LB/HR	1.775	1.812	1.813
NOX LB/MIL BTU	.136	.136	.141
HC LB/MIL BTU TOTAL	.009	.008	.008
HC LB/MIL BTU NON-METH	ND	ND	ND
CO LB/MIL BTU	.147	.150	.150
NOX GR/HP HR	.761	.759	.792
HC GR/HP HR TOTAL	.051	.045	.047
HC GR/HP HR NON-METH	ND	ND	ND
CO GR/HP HR	.821	.839	.839

TABLE C-38 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 38, TEST SITE 7
SOLAR SATURN T-1001S-4 GAS TURBINE, RATED 1050 HP

RUN	1	2	3
DATE	2/26/72	2/26/72	2/26/72
TIME	1420	1430	1440
OPERATIONAL DATA			
BAROMETER, IN. HG.	31.03	31.03	31.03
AMBIENT TEMP. DEG. F	50	50	50
WET BULB TEMP. DEG. F	46	46	46
REL. HUMIDITY PERCENT	71	71	71
SP. HUMIDITY GRAIN/LB	37	37	37
ENGINE SPEED RPM	22300	22300	22300
HORSEPOWER	980	980	980
SCAV. AIR PRES. IN.HG.	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA
FUEL SP. GR. (STP)	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018
ORIFICE CONSTANT	460.60	460.60	460.60
FUEL TEMP. DEG. F	52.0	52.0	52.0
ORIFICE DP IN. H2O	3.0	3.0	3.0
ORIFICE STAT.PRES.PSIA	222.0	222.0	222.0
FUEL FLOW SCFH	11887	11887	11887
HEAT FLOW MIL. BTU/HR	12.101	12.101	12.101
FUEL FLOW LB/HR	521	521	521
AIR FLOW LB/HR	37348	36595	37358
AIR/FUEL RATIO	71.7	70.3	71.7
BSFC BTU/HP HR	12348	12348	12348
EXHAUST EMISSIONS			
NOX PPM	28.00	28.50	28.50
NO PPM	ND	ND	ND
NO2 PPM	28.00	28.50	28.50
CO2 PERCENT	2.42	2.47	2.42
HC PPM	36.00	36.00	37.50
CO PPM	66.00	68.00	69.00
O2 PERCENT	17.40	17.70	17.70
NO/NOX	ND	ND	ND
NON-METH/TOTAL HC			
NOX LB/HR	1.697	1.692	1.727
HC LB/HR TOTAL	.772	.756	.804
HC LB/HR NON-METH	ND	ND	ND
CO LB/HR	2.436	2.459	2.509
NOX LB/MIL BTU	.140	.140	.143
HC LB/MIL BTU TOTAL	.064	.062	.066
HC LB/MIL BTU NON-METH	ND	ND	ND
CO LB/MIL BTU	.201	.203	.207
NOX GR/HP HR	.785	.783	.799
HC GR/HP HR TOTAL	.357	.350	.372
HC GR/HP HR NON-METH	ND	ND	ND
CO GR/HP HR	1.127	1.138	1.161

TABLE C-39 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 39, TEST SITE 7
GENERAL ELECTRIC M 3912R GAS TURBINE, RATED 9100 HP

RUN	1	2	3
DATE	2/27/73	2/27/73	2/27/73
TIME	830	840	850
OPERATIONAL DATA			
BAROMETER, IN. HG.	30.10	30.10	30.10
AMBIENT TEMP. DEG. F	41	41	41
WET BULB TEMP. DEG. F	38	38	38
REL. HUMIDITY PERCENT	74	74	74
SP. HUMIDITY GRAIN/LB	28	28	28
ENGINE SPEED RPM	6900	6900	6900
HORSEPOWER	10150	10150	10150
SCAV. AIR PRES. IN.HG.	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA
FUEL SP. GR. (STP)	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018
ORIFICE CONSTANT	1220.87	1220.87	1220.87
FUEL TEMP. DEG. F	48.0	48.0	48.0
ORIFICE DP IN. H2O	21.0	21.0	21.0
ORIFICE STAT.PRES.PSIA	265.0	265.0	265.0
FUEL FLOW SCFH	91076	91076	91076
HEAT FLOW MIL. BTU/HR	92.715	92.715	92.715
FUEL FLOW LB/HR	3991	3991	3991
AIR FLOW LB/HR	403905	426363	403959
AIR/FUEL RATIO	101.2	106.8	101.2
BSFC BTU/HP HR	9134	9134	9134
EXHAUST EMISSIONS			
NOX PPM	69.00	63.00	68.00
NO PPM	ND	ND	ND
NO2 PPM	69.00	63.00	68.00
CO2 PERCENT	1.73	1.64	1.73
HC PPM	3.50	4.00	3.50
CO PPM	3.00	3.00	3.00
O2 PERCENT	17.70	17.80	17.80
NO/NOX	ND	ND	ND
NON-METH/TOTAL HC	ND	ND	ND
NOX LB/HR	44.994	43.334	44.342
HC LB/HR TOTAL	.807	.973	.807
HC LB/HR NON-METH	ND	ND	ND
CO LB/HR	1.191	1.256	1.191
NOX LB/MIL BTU	.485	.467	.478
HC LB/MIL BTU TOTAL	.009	.010	.009
HC LB/MIL BTU NON-METH	ND	ND	ND
CO LB/MIL BTU	.013	.014	.013
NOX GR/HP HR	2.011	1.937	1.982
HC GR/HP HR TOTAL	.036	.043	.036
HC GR/HP HR NON-METH	ND	ND	ND
CO GR/HP HR	.053	.056	.053

TABLE C-40 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 40, TEST SITE 7
GENERAL ELECTRIC M 3112R GAS TURBINE, RATED 11100 HP

RUN	1	2	3
DATE	2/27/72	2/27/72	2/27/72
TIME	810	820	830
OPERATIONAL DATA			
BAROMETER, IN. HG.	30.10	30.10	30.10
AMBIENT TEMP. DEG. F	41	41	41
WET BULB TEMP. DEG. F	38	38	38
REL. HUMIDITY PERCENT	74	74	74
SP. HUMIDITY GRAIN/LB	28	28	28
ENGINE SPEED RPM	6890	6890	6890
HORSEPOWER	12000	12000	12000
SCAV. AIR PRES. IN.HG.	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA
FUEL SP. GR. (STP)	.5729	.5729	.5729
HI HEAT VALUE BTU/SCF	1018	1018	1018
ORIFICE CONSTANT	1212.30	1212.30	1212.30
FUEL TEMP. DEG. F	48.0	48.0	48.0
ORIFICE DP IN. H2O	31.0	31.0	31.0
ORIFICE STAT.PRES.PSIA	225.0	225.0	225.0
FUEL FLOW SCFH	101247	101247	101247
HEAT FLOW MIL. BTU/HR	103.069	103.069	103.069
FUEL FLOW LB/HR	4437	4437	4437
AIR FLOW LB/HR	414783	403796	403872
AIR/FUEL RATIO	93.5	91.0	91.0
BSFC BTU/HP HR	8589	8589	8589
EXHAUST EMISSIONS			
NOX PPM	67.00	71.00	72.00
NO PPM	ND	ND	ND
NO2 PPM	67.00	71.00	72.00
CO2 PERCENT	1.87	1.92	1.92
HC PPM	5.00	5.00	4.00
CO PPM	2.00	2.00	2.00
O2 PERCENT	17.30	17.20	17.30
NO/NOX	ND	ND	ND
NON-METH/TOTAL HC	ND	ND	ND
NOX LB/HR	44.933	46.376	47.032
HC LB/HR TOTAL	1.186	1.155	.924
HC LB/HR NON-METH	ND	ND	ND
CO LB/HR	.817	.795	.795
NOX LB/MIL BTU	.436	.450	.456
HC LB/MIL BTU TOTAL	.012	.011	.009
HC LB/MIL BTU NON-METH	ND	ND	ND
CO LB/MIL BTU	.008	.008	.008
NOX GR/HP HR	1.698	1.753	1.778
HC GR/HP HR TOTAL	.045	.044	.035
HC GR/HP HR NON-METH	ND	ND	ND
CO GR/HP HR	.031	.030	.030

TABLE C-41 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 41, TEST SITE 8
COOPER-BESSEMER GMV-10, RATED 1350 HP, RATED 300 RPM, 2-STROKE NA

RUN	1	2	3	4
DATE	3/12/73	3/12/73	3/12/73	3/12/73
TIME	1000	1130	1325	1400
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.35	29.35	29.35	29.35
AMBIENT TEMP. DEG. F	68	70	73	73
WET BULB TEMP. DEG. F	56	55	58	58
REL. HUMIDITY PERCENT	46	36	36	36
SP. HUMIDITY GRAIN/LB	47	40	45	45
ENGINE SPEED RPM	300	300	301	301
HORSEPOWER	1420	1609	1306	1240
SCAV. AIR PRES. IN.HG.	5.70	5.78	5.66	5.70
IGNIT. TIME DEG. BTDC	7.2	7.2	7.2	7.2
FUEL SP. GR. (STP)	.5770	.5770	.5770	.5770
HI HEAT VALUE BTU/SCF	1030	1030	1030	1030
ORIFICE CONSTANT	225.00	225.00	225.00	225.00
FUEL TEMP. DEG. F	67.0	67.0	68.0	68.0
ORIFICE DP IN. H2O	55.5	61.5	52.1	55.7
ORIFICE STAT.PRES.PSIA	64.8	64.6	64.5	64.5
FUEL FLOW SCFH	13488	14179	13046	13492
HEAT FLOW MIL. BTU/HR	13.893	14.604	13.437	13.897
FUEL FLOW LB/HR	595	626	576	595
AIR FLOW LB/HR	23660	23445	24001	24030
AIR/FUEL RATIO	39.7	37.5	41.7	40.4
BSFC BTU/HP HR	9784	9076	10289	11207
EXHAUST EMISSIONS				
NOX PPM	1912.00	2312.00	1525.00	1900.00
NO PPM	1737.00	1950.00	1450.00	1612.00
NO2 PPM	175.00	362.00	75.00	288.00
CO2 PERCENT	4.24	4.50	4.05	4.18
HC PPM	800.00	790.00	820.00	815.00
CO PPM	80.00	86.00	74.00	74.00
O2 PERCENT	13.70	14.10	15.30	14.50
NO/NOX	.908	.843	.951	.848
NON-METH/TOTAL HC	.041	.041	.041	.041
NOX LB/HR	74.607	89.465	60.175	75.187
HC LB/HR TOTAL	11.003	10.775	11.405	11.368
HC LB/HR NON-METH	.451	.442	.468	.466
CO LB/HR	1.901	2.026	1.778	1.783
NOX LB/MIL BTU	5.370	6.126	4.478	5.410
HC LB/MIL BTU TOTAL	.792	.738	.849	.818
HC LB/MIL BTU NON-METH	.032	.030	.035	.034
CO LB/MIL BTU	.137	.139	.132	.128
NOX GR/HP HR	23.832	25.221	20.900	27.504
HC GR/HP HR TOTAL	3.515	3.038	3.961	4.159
HC GR/HP HR NON-METH	.144	.125	.162	.171
CO GR/HP HR	.607	.571	.617	.652

TABLE C-42 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 42, TEST SITE 8
COOPER-BESSEMER GMV-10, RATED 1350 HP, RATED 300 RPM, 2-STROKE NA

RUN	1	2	3
DATE	3/12/73	3/12/73	3/12/73
TIME	1600	1630	1700
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.35	29.35	29.35
AMBIENT TEMP. DEG. F	71	71	71
WET BULB TEMP. DEG. F	57	57	57
REL. HUMIDITY PERCENT	38	37	37
SP. HUMIDITY GRAIN/LB	43	43	43
ENGINE SPEED RPM	306	300	300
HORSEPOWER	1409	1557	1316
SCAV. AIR PRES. IN.HG.	5.75	5.74	5.60
IGNIT. TIME DEG. BTDC	4.2	4.2	4.2
FUEL SP. GR. (STP)	.5770	.5770	.5770
HI HEAT VALUE BTU/SCF	1030	1030	1030
ORIFICE CONSTANT	225.00	225.00	225.00
FUEL TEMP. DEG. F	71.0	70.0	70.0
ORIFICE DP IN. H2O	49.6	60.9	49.6
ORIFICE STAT.PRES.PSIA	65.2	65.1	65.2
FUEL FLOW SCFH	12791	14169	12798
HEAT FLOW MIL. BTU/HR	13.175	14.595	13.182
FUEL FLOW LB/HR	565	625	565
AIR FLOW LB/HR	23772	24091	24541
AIR/FUEL RATIO	42.1	38.5	43.5
BSFC BTU/HP HR	9351	9373	10017
EXHAUST EMISSIONS			
NOX PPM	1975.00	2525.00	1525.00
NO PPM	1800.00	1850.00	1225.00
NO2 PPM	175.00	675.00	300.00
CO2 PERCENT	4.00	4.37	3.87
HC PPM	830.00	810.00	860.00
CO PPM	98.00	104.00	98.00
O2 PERCENT	14.00	13.40	13.50
NO/NOX	.911	.733	.803
NON-METH/TOTAL HC	.041	.041	.041
NOX LB/HR	77.283	100.407	61.616
HC LB/HR TOTAL	11.448	11.354	12.248
HC LB/HR NON-METH	.469	.465	.502
CO LB/HR	2.335	2.518	2.411
NOX LB/MIL BTU	5.866	6.880	4.674
HC LB/MIL BTU TOTAL	.869	.778	.929
HC LB/MIL BTU NON-METH	.036	.032	.038
CO LB/MIL BTU	.177	.173	.183
NOX GR/HP HR	24.880	29.251	21.238
HC GR/HP HR TOTAL	3.686	3.308	4.222
HC GR/HP HR NON-METH	.151	.136	.173
CO GR/HP HR	.752	.734	.831

TABLE C-43 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 43, TEST SITE 8
COOPER-BESSEMER GMV-10, RATED 1350 HP, RATED 300 RPM, 2-STROKE NA

RUN	1	2	3
DATE	3/13/73	3/13/73	3/13/73
TIME	945	1045	1115
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.25	29.25	29.25
AMBIENT TEMP. DEG. F	71	71	73
WET BULB TEMP. DEG. F	56	56	58
REL. HUMIDITY PERCENT	35	35	36
SP. HUMIDITY GRAIN/LB	40	40	45
ENGINE SPEED RPM	301	298	300
HORSEPOWER	1422	1423	1347
SCAV. AIR PRES. IN.HG.	5.49	5.40	5.42
IGNIT. TIME DEG. BTDC	6.2	6.2	6.2
FUEL SP. GR. (STP)	.5770	.5770	.5770
HI HEAT VALUE BTU/SCF	1030	1030	1030
ORIFICE CONSTANT	225.00	225.00	225.00
FUEL TEMP. DEG. F	70.0	71.0	71.0
ORIFICE DP IN. H2O	54.0	56.9	47.5
ORIFICE STAT.PRES.PSIA	65.1	65.0	65.0
FUEL FLOW SCFH	13345	13688	12509
HEAT FLOW MIL. BTU/HR	13.746	14.099	12.884
FUEL FLOW LB/HR	589	604	552
AIR FLOW LB/HR	22746	22402	21950
AIR/FUEL RATIO	38.6	37.1	39.8
BSFC BTU/HP HR	9666	9908	9565
EXHAUST EMISSIONS			
NOX PPM	2463.00	2400.00	2275.00
NO PPM	2288.00	2088.00	1975.00
NO2 PPM	175.00	312.00	300.00
CO2 PERCENT	4.37	4.56	4.24
HC PPM	655.00	670.00	690.00
CO PPM	128.00	170.00	116.00
O2 PERCENT	13.00	15.70	12.50
NO/NOX	.929	.870	.868
NON-METH/TOTAL HC	.041	.041	.041
NOX LB/HR	92.517	88.570	82.465
HC LB/HR TOTAL	8.672	8.716	8.816
HC LB/HR NON-METH	.356	.357	.361
CO LB/HR	2.927	3.820	2.560
NOX LB/MIL BTU	6.731	6.282	6.401
HC LB/MIL BTU TOTAL	.631	.618	.684
HC LB/MIL BTU NON-METH	.026	.025	.028
CO LB/MIL BTU	.213	.271	.199
NOX GR/HP HR	29.512	28.233	27.770
HC GR/HP HR TOTAL	2.766	2.778	2.969
HC GR/HP HR NON-METH	.113	.114	.122
CO GR/HP HR	.934	1.218	.862

TABLE C-44 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 44, TEST SITE 8
COOPER-BESSEMER GMV-10, RATED 1350 HP, RATED 300 RPM, 2-STROKE NA

JN	1	2	3	4	5	6
ATE	3/13/73	3/13/73	3/13/73	3/13/73	3/13/73	3/13/73
IME	1340	1400	1410	1420	1430	1435
'ERATIONAL DATA						
BAROMETER, IN. HG.	29.14	29.14	29.14	29.14	29.14	29.14
AMBIENT TEMP. DEG. F	78	78	78	78	79	79
WET BULB TEMP. DEG. F	61	61	61	62	62	62
REL. HUMIDITY PERCENT	34	34	34	37	35	35
SP. HUMIDITY GRAIN/LB	50	50	50	55	53	53
ENGINE SPEED RPM	300	300	300	300	300	300
HORSEPOWER	1361	1361	1361	1361	1361	1361
SCAV. AIR PRES. IN.HG.	5.24	5.28	5.28	5.35	5.21	5.20
IGNIT. TIME DEG. BTDC	8.3	5.8	3.4	114	10.2	12.5
FUEL SP. GR. (STP)	.5770	.5770	.5770	.5770	.5770	.5770
HI HEAT VALUE BTU/SCF	1030	1030	1030	1030	1030	1030
ORIFICE CONSTANT	225.00	225.00	225.00	225.00	225.00	225.00
FUEL TEMP. DEG. F	75.0	75.0	75.0	75.0	75.0	75.0
ORIFICE DP IN. H2O	46.5	48.2	50.5	52.3	45.8	45.7
ORIFICE STAT.PRES.PSIA	64.7	64.7	64.6	64.6	64.7	64.6
FUEL FLOW SCFH	12344	12562	12849	13076	12247	12225
HEAT FLOW MIL. BTU/HR	12.714	12.939	13.234	13.468	12.614	12.592
FUEL FLOW LB/HR	545	554	567	577	540	540
AIR FLOW LB/HR	21671	21743	21865	21603	21497	21762
AIR/FUEL RATIO	39.8	39.2	38.6	37.4	39.8	40.3
BSFC BTU/HP HR	9342	9507	9724	9896	9268	9252
'HAUST EMISSIONS						
NOX PPM	2835.00	2715.00	2655.00	2522.00	2955.00	2445.00
NO PPM	2220.00	2445.00	2355.00	2145.00	2445.00	1860.00
NO2 PPM	615.00	270.00	300.00	377.00	510.00	585.00
O2 PERCENT	4.24	4.30	4.37	4.50	4.24	4.18
HC PPM	730.00	705.00	690.00	650.00	740.00	740.00
CO PPM	122.00	134.00	152.00	176.00	110.00	104.00
CO2 PERCENT	13.40	13.20	12.80	12.60	13.20	13.10
NO/NOX	.783	.901	.887	.851	.827	.761
NON-METH/TOTAL HC	.041	.041	.041	.041	.041	.041
OX LB/HR	101.303	97.408	95.890	90.099	104.764	87.760
C LB/HR TOTAL	9.195	8.916	8.784	8.185	9.248	9.363
C LB/HR NON-METH	.377	.366	.360	.336	.379	.384
O LB/HR	2.654	2.927	3.342	3.828	2.374	2.273
OX LB/MIL BTU	7.968	7.528	7.246	6.690	8.305	6.970
C LB/MIL BTU TOTAL	.723	.689	.664	.608	.733	.744
C LB/MIL BTU NON-METH	.030	.028	.027	.025	.030	.030
O LB/MIL BTU	.209	.226	.253	.284	.188	.180
OX GR/HP HR	33.763	32.465	31.959	30.029	34.916	29.249
C GR/HP HR TOTAL	3.064	2.971	2.928	2.728	3.082	3.120
C GR/HP HR NON-METH	.126	.122	.120	.112	.126	.128
O GR/HP HR	.885	.976	1.114	1.276	.791	.757

TABLE C-44 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 44, TEST SITE 8
COOPER-BESSEMER GMV-10, RATED 1350 HP, RATED 300 RPM, 2-STROKE NA

RUN	7	8
DATE	3/13/73	3/13/73
TIME	1445	1515
OPERATIONAL DATA		
BAROMETER, IN. HG.	29.14	29.14
AMBIENT TEMP. DEG. F	81	83
WET BULB TEMP. DEG. F	63	63
REL. HUMIDITY PERCENT	33	29
SP. HUMIDITY GRAIN/LB	54	50
ENGINE SPEED RPM	300	300
HORSEPOWER	1479	1529
SCAV. AIR PRES. IN.HG.	5.24	5.24
IGNIT. TIME DEG. BTDC	7.7	7.7
FUEL SP. GR. (STP)	.5770	.5770
HI HEAT VALUE BTU/SCF	1030	1030
ORIFICE CONSTANT	225.00	225.00
FUEL TEMP. DEG. F	75.0	75.0
ORIFICE DP IN. H2O	51.4	55.1
ORIFICE STAT.PRES.PSIA	64.5	64.4
FUEL FLOW SCFH	12956	13402
HEAT FLOW MIL. BTU/HR	13.345	13.804
FUEL FLOW LB/HR	572	591
AIR FLOW LB/HR	21375	22070
AIR/FUEL RATIO	37.4	37.3
BSFC BTU/HP HR	9023	9028
EXHAUST EMISSIONS		
NOX PPM	2535.00	2535.00
NO PPM	2220.00	2205.00
NO2 PPM	315.00	330.00
CO2 PERCENT	4.50	4.50
HC PPM	745.00	750.00
CO PPM	140.00	152.00
O2 PERCENT	12.50	11.50
NO/NOX	.876	.870
NON-METH/TOTAL HC	.041	.041
NOX LB/HR	89.622	92.668
HC LB/HR TOTAL	9.284	9.664
HC LB/HR NON-METH	.381	.396
CO LB/HR	3.014	3.383
NOX LB/MIL BTU	6.716	6.713
HC LB/MIL BTU TOTAL	.696	.700
HC LB/MIL BTU NON-METH	.029	.029
CO LB/MIL BTU	.226	.245
NOX GR/HP HR	27.486	27.491
HC GR/HP HR TOTAL	2.847	2.867
HC GR/HP HR NON-METH	.117	.118
CO GR/HP HR	.924	1.004

TABLE C-45 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 45, TEST SITE 8
COOPER-BESSEMER GMW-8, RATED 2000 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3	4	5
DATE	3/13/73	3/13/73	3/13/73	3/13/73	3/13/73
TIME	1725	1730	1745	1805	1820
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.08	29.08	29.08	29.08	29.08
AMBIENT TEMP. DEG. F	73	73	72	72	72
WET BULB TEMP. DEG. F	60	60	60	60	60
REL. HUMIDITY PERCENT	44	44	47	47	47
SP. HUMIDITY GRAIN/LB	55	55	56	56	56
ENGINE SPEED RPM	250	250	250	250	250
HORSEPOWER	2127	2127	2127	2127	2127
SCAV. AIR PRES. IN.HG.	4.10	4.14	4.09	4.14	4.14
IGNIT. TIME DEG. BTDC	7.5	9.1	10.7	5.9	3.5
FUEL SP. GR. (STP)	.5770	.5770	.5770	.5770	.5770
HI HEAT VALUE BTU/SCF	1030	1030	1030	1030	1030
ORIFICE CONSTANT	300.00	300.00	300.00	300.00	300.00
FUEL TEMP. DEG. F	76.0	75.0	75.0	75.0	75.0
ORIFICE DP IN. H2O	57.2	56.5	53.8	58.7	75.0
ORIFICE STAT.PRES.PSIA	63.3	63.5	63.5	63.3	63.3
FUEL FLOW SCFH	18046	17965	17536	18293	19021
HEAT FLOW MIL. BTU/HR	18.587	18.504	18.062	18.842	19.592
FUEL FLOW LB/HR	796	793	774	807	839
AIR FLOW LB/HR	32482	32862	33018	32235	32593
AIR/FUEL RATIO	40.8	41.4	42.7	39.9	38.8
BSFC BTU/HP HR	8739	8699	8492	8858	9211
EXHAUST EMISSIONS					
NOX PPM	1725.00	1787.00	1850.00	1563.00	1350.00
NO PPM	1663.00	1663.00	1713.00	1475.00	1250.00
NO2 PPM	62.00	124.00	137.00	88.00	100.00
CO2 PERCENT	4.11	4.05	3.93	4.18	4.30
HC PPM	1050.00	1000.00	1050.00	1150.00	1100.00
CO PPM	41.00	35.00	34.00	48.00	57.00
O2 PERCENT	13.60	13.60	13.60	12.40	12.00
NO/NOX	.964	.931	.926	.944	.926
NON-METH/TOTAL HC	.041	.041	.041	.041	.041
NOX LB/HR	92.376	96.771	100.582	83.257	72.811
HC LB/HR TOTAL	19.820	19.088	20.123	21.593	20.912
HC LB/HR NON-METH	.813	.783	.825	.885	.857
CO LB/HR	1.337	1.154	1.125	1.557	1.872
NOX LB/MIL BTU	4.970	5.230	5.569	4.419	3.716
HC LB/MIL BTU TOTAL	1.066	1.032	1.114	1.146	1.067
HC LB/MIL BTU NON-METH	.044	.042	.046	.047	.044
CO LB/MIL BTU	.072	.062	.062	.083	.096
NOX GR/HP HR	19.700	20.637	21.450	17.755	15.528
HC GR/HP HR TOTAL	4.227	4.071	4.291	4.605	4.460
HC GR/HP HR NON-METH	.173	.167	.176	.189	.183
CO GR/HP HR	.285	.246	.240	.332	.399

TABLE C-46 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 46, TEST SITE 8
COOPER-BESSEMER GMW-8, RATED 2000 HP, RATED 250 RPM, 2-STROKE NA

RUN	1	2	3
DATE	3/14/73	3/14/73	3/14/73
TIME	940	1010	1030
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.01	29.01	29.01
AMBIENT TEMP. DEG. F	73	73	73
WET BULB TEMP. DEG. F	66	66	66
REL. HUMIDITY PERCENT	68	68	68
SP. HUMIDITY GRAIN/LB	85	85	85
ENGINE SPEED RPM	250	250	250
HORSEPOWER	2195	2222	2099
SCAV. AIR PRES. IN.HG.	3.94	3.93	3.90
IGNIT. TIME DEG. BTDC	7.5	7.5	7.5
FUEL SP. GR. (STP)	.5770	.5770	.5770
HI HEAT VALUE BTU/SCF	1030	1030	1030
ORIFICE CONSTANT	300.00	300.00	300.00
FUEL TEMP. DEG. F	75.0	75.0	75.0
ORIFICE DP IN. H2O	52.7	65.8	52.4
ORIFICE STAT.PRES.PSIA	64.7	64.7	64.7
FUEL FLOW SCFH	17518	19571	17471
HEAT FLOW MIL. BTU/HR	18.043	20.158	17.995
FUEL FLOW LB/HR	773	864	771
AIR FLOW LB/HR	31634	34831	32502
AIR/FUEL RATIO	40.9	40.3	42.2
BSFC BTU/HP HR	8220	9072	8573
EXHAUST EMISSIONS			
NOX PPM	1600.00	1562.00	1662.00
NO PPM	1500.00	1437.00	1550.00
NO2 PPM	100.00	125.00	112.00
CO2 PERCENT	4.05	4.11	3.93
HC PPM	1500.00	1500.00	1500.00
CO PPM	52.00	58.00	58.00
O2 PERCENT	13.70	13.80	13.80
NO/NOX	.938	.920	.933
NON-METH/TOTAL HC	.041	.041	.041
NOX LB/HR	83.451	89.726	88.981
HC LB/HR TOTAL	27.577	30.372	28.307
HC LB/HR NON-METH	1.131	1.245	1.161
CO LB/HR	1.651	2.029	1.891
NOX LB/MIL BTU	4.625	4.451	4.945
HC LB/MIL BTU TOTAL	1.528	1.507	1.573
HC LB/MIL BTU NON-METH	.063	.062	.064
CO LB/MIL BTU	.092	.101	.105
NOX GR/HP HR	17.245	18.317	19.229
HC GR/HP HR TOTAL	5.699	6.200	6.117
HC GR/HP HR NON-METH	.234	.254	.251
CO GR/HP HR	.341	.414	.409

TABLE C-47 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 47, TEST SITE 8
COOPER-BESSEMER 16 V-250, RATED 5500 HP, RATED 250 RPM, 2-STROKE TC

RUN	1	2	3
DATE	3/14/73	3/14/73	3/14/73
TIME	1600	1645	1735
OPERATIONAL DATA			
BAROMETER, IN. HG.	28.93	28.93	28.93
AMBIENT TEMP. DEG. F	69	69	69
WET BULB TEMP. DEG. F	66	66	67
REL. HUMIDITY PERCENT	85	85	90
SP. HUMIDITY GRAIN/LB	93	93	99
ENGINE SPEED RPM	250	250	250
HORSEPOWER	5520	5701	5213
SCAV. AIR PRES. IN.HG.	12.3	13.0	11.5
IGNIT. TIME DEG. BTDC	9.0	9.0	9.0
FUEL SP. GR. (STP)	.5840	.5840	.5840
HI HEAT VALUE BTU/SCF	1042	1042	1042
ORIFICE CONSTANT	600.00	600.00	600.00
FUEL TEMP. DEG. F	79.0	79.0	79.0
ORIFICE DP IN. H2O	76.4	78.5	69.4
ORIFICE STAT.PRES.PSIA	61.4	62.9	61.3
FUEL FLOW SCFH	41089	42169	39149
HEAT FLOW MIL. BTU/HR	42.815	43.940	40.793
FUEL FLOW LB/HR	1835	1884	1749
AIR FLOW LB/HR	74574	75423	70868
AIR/FUEL RATIO	40.6	40.0	40.5
BSFC BTU/HP HR	7756	7707	7825
EXHAUST EMISSIONS			
NOX PPM	1762.00	1900.00	1612.00
NO PPM	1650.00	1737.00	1250.00
NO2 PPM	112.00	163.00	362.00
CO2 PERCENT	4.11	4.18	4.10
HC PPM	1100.00	1000.00	1300.00
CO PPM	241.00	244.00	247.00
O2 PERCENT	13.30	13.10	13.40
NO/NOX	.936	.914	.775
NON-METH/TOTAL HC	.035	.035	.035
NOX LB/HR	216.735	236.493	188.450
HC LB/HR TOTAL	47.570	43.760	53.431
HC LB/HR NON-METH	1.665	1.532	1.870
CO LB/HR	18.049	18.491	17.581
NOX LB/MIL BTU	5.062	5.382	4.620
HC LB/MIL BTU TOTAL	1.111	.996	1.310
HC LB/MIL BTU NON-METH	.039	.035	.046
CO LB/MIL BTU	.422	.421	.431
NOX GR/HP HR	17.810	18.817	16.398
HC GR/HP HR TOTAL	3.909	3.482	4.649
HC GR/HP HR NON-METH	.137	.122	.163
CO GR/HP HR	1.483	1.471	1.530

TABLE C-48 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 48, TEST SITE 8
COOPER-BESSEMER GMWC-10, RATED 3400 HP, RATED 250 RPM, 2-STROKE TC

RUN	1	2	3	4	5	6
DATE	3/15/73	3/15/73	3/15/73	3/15/73	3/15/73	3/15/73
TIME	1015	1045	1110	1135	1150	1155
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.14	29.16	29.15	29.15	29.15	29.15
AMBIENT TEMP. DEG. F	70	69	69	65	65	65
WET BULB TEMP. DEG. F	64	63	63	61	61	61
REL. HUMIDITY PERCENT	71	71	71	79	79	79
SP. HUMIDITY GRAIN/LB	80	77	77	74	74	74
ENGINE SPEED RPM	248	248	249	249	249	249
HORSEPOWER	3393	3535	3262	3262	3262	3262
SCAV. AIR PRES. IN.HG.	13.5	13.9	13.3	13.2	13.1	12.9
IGNIT. TIME DEG. BTDC	8.6	8.6	8.6	7.5	11.6	15.8
FUEL SP. GR. (STP)	.5840	.5840	.5840	.5840	.5840	.5840
HI HEAT VALUE BTU/SCF	1042	1042	1042	1042	1042	1042
ORIFICE CONSTANT	400.00	400.00	400.00	400.00	400.00	400.00
FUEL TEMP. DEG. F	77.0	78.0	78.0	78.0	78.0	78.0
ORIFICE DP IN. H2O	76.3	82.7	72.1	71.8	72.1	71.3
ORIFICE STAT.PRES.PSIA	58.2	58.2	58.4	58.4	58.4	58.3
FUEL FLOW SCFH	26662	27752	25959	25896	25952	25798
HEAT FLOW MIL. BTU/HR	27.782	28.918	27.050	26.984	27.042	26.882
FUEL FLOW LB/HR	1191	1240	1160	1157	1159	1152
AIR FLOW LB/HR	57706	58916	57134	56995	57127	55748
AIR/FUEL RATIO	48.5	47.5	49.3	49.3	49.3	48.4
BSFC BTU/HP HR	8188	8180	8292	8272	8290	8241
EXHAUST EMISSIONS						
NOX PPM	1900.00	2250.00	1762.00	1875.00	2025.00	2237.00
NO PPM	1887.00	1475.00	1425.00	1675.00	1800.00	1437.00
NO2 PPM	13.00	775.00	337.00	200.00	225.00	800.00
CO2 PERCENT	3.45	3.51	3.39	3.39	3.39	3.45
HC PPM	1210.00	1280.00	1250.00	1250.00	1250.00	1300.00
CO PPM	106.00	121.00	95.00	93.00	91.00	83.00
O2 PERCENT	14.80	14.70	15.10	15.00	15.00	14.90
NO/NOX	.993	.656	.809	.893	.889	.642
NON-METH/TOTAL HC	.035	.035	.035	.035	.035	.035
NOX LB/HR	179.704	217.351	164.887	175.045	189.467	204.339
HC LB/HR TOTAL	40.235	43.472	41.125	41.028	41.118	41.749
HC LB/HR NON-METH	1.408	1.522	1.439	1.436	1.439	1.461
CO LB/HR	6.104	7.117	5.413	5.286	5.184	4.616
NOX LB/MIL BTU	6.468	7.516	6.096	6.487	7.006	7.601
HC LB/MIL BTU TOTAL	1.448	1.503	1.520	1.520	1.521	1.553
HC LB/MIL BTU NON-METH	.051	.053	.053	.053	.053	.054
CO LB/MIL BTU	.220	.246	.200	.196	.192	.172
NOX GR/HP HR	24.024	27.890	22.928	24.341	26.347	28.415
HC GR/HP HR TOTAL	5.379	5.578	5.719	5.705	5.718	5.805
HC GR/HP HR NON-METH	.188	.195	.200	.200	.200	.203
CO GR/HP HR	.816	.913	.753	.735	.721	.642

TABLE C-48 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 48, TEST SITE 8
COOPER-BESSEMER GMWC-10, RATED 3400 HP, RATED 250 RPM, 2-STROKE TC

RUN	7
DATE	3/15/73
TIME	1205
OPERATIONAL DATA	
BAROMETER, IN. HG.	29.15
AMBIENT TEMP. DEG. F	65
WET BULB TEMP. DEG. F	61
REL. HUMIDITY PERCENT	79
SP. HUMIDITY GRAIN/LB	74
ENGINE SPEED RPM	249
HORSEPOWER	3262
SCAV. AIR PRES. IN.HG.	14.7
IGNIT. TIME DEG. BTDC	0.0
FUEL SP. GR. (STP)	.5840
HI HEAT VALUE BTU/SCF	1042
ORIFICE CONSTANT	400.00
FUEL TEMP. DEG. F	78.0
ORIFICE DP IN. H2O	83.2
ORIFICE STAT.PRES.PSIA	58.3
FUEL FLOW SCFH	27853
HEAT FLOW MIL. BTU/HR	29.023
FUEL FLOW LB/HR	1244
AIR FLOW LB/HR	61260
AIR/FUEL RATIO	49.2
BSFC BTU/HP HR	8897
EXHAUST EMISSIONS	
NOX PPM	1300.00
NO PPM	975.00
NO2 PPM	325.00
CO2 PERCENT	3.39
HC PPM	1150.00
CO PPM	203.00
O2 PERCENT	15.00
NO/NOX	.750
NON-METH/TOTAL HC	.035
NOX LB/HR	130.499
HC LB/HR TOTAL	40.586
HC LB/HR NON-METH	1.421
CO LB/HR	12.407
NOX LB/MIL BTU	4.496
HC LB/MIL BTU TOTAL	1.398
HC LB/MIL BTU NON-METH	.049
CO LB/MIL BTU	.427
NOX GR/HP HR	18.147
HC GR/HP HR TOTAL	5.644
HC GR/HP HR NON-METH	.198
CO GR/HP HR	1.725

TABLE C-49 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 49, TEST SITE 8
COOPER-BESSEMER GMWC-10, RATED 3400 HP, RATED 250 RPM, 2-STROKE TC

RUN	1	2	3
DATE	3/15/73	3/15/73	3/15/73
TIME	1500	1550	1650
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.13	29.13	29.13
AMBIENT TEMP. DEG. F	64	65	65
WET BULB TEMP. DEG. F	60	61	61
REL. HUMIDITY PERCENT	79	79	79
SP. HUMIDITY GRAIN/LB	72	75	75
ENGINE SPEED RPM	250	249	250
HORSEPOWER	3336	3487	3207
SCAV. AIR PRES. IN.HG.	13.2	13.4	13.0
IGNIT. TIME DEG. BTDC	8.3	8.3	8.3
FUEL SP. GR. (STP)	.5840	.5840	.5840
HI HEAT VALUE BTU/SCF	1042	1042	1042
ORIFICE CONSTANT	400.00	400.00	400.00
FUEL TEMP. DEG. F	80.0	80.0	80.0
ORIFICE DP IN. H2O	74.4	78.3	68.0
ORIFICE STAT.PRES.PSIA	58.2	58.2	58.4
FUEL FLOW SCFH	26328	26996	25201
HEAT FLOW MIL. BTU/HR	27.434	28.129	26.260
FUEL FLOW LB/HR	1176	1206	1126
AIR FLOW LB/HR	57985	58503	58470
AIR/FUEL RATIO	49.3	48.5	51.9
BSFC BTU/HP HR	8224	8067	8188
EXHAUST EMISSIONS			
NOX PPM	1800.00	2000.00	1312.00
NO PPM	1650.00	1800.00	975.00
NO2 PPM	150.00	200.00	337.00
CO2 PERCENT	3.39	3.45	3.22
HC PPM	1250.00	1200.00	1200.00
CO PPM	87.00	93.00	81.00
O2 PERCENT	15.40	15.20	15.50
NO/NOX	.917	.900	.743
NON-METH/TOTAL HC	.035	.035	.035
NOX LB/HR	170.876	191.649	125.471
HC LB/HR TOTAL	41.719	40.427	40.347
HC LB/HR NON-METH	1.460	1.415	1.412
CO LB/HR	5.029	5.426	4.716
NOX LB/MIL BTU	6.229	6.813	4.778
HC LB/MIL BTU TOTAL	1.521	1.437	1.536
HC LB/MIL BTU NON-METH	.053	.050	.054
CO LB/MIL BTU	.183	.193	.180
NOX GR/HP HR	23.234	24.930	17.747
HC GR/HP HR TOTAL	5.673	5.259	5.707
HC GR/HP HR NON-METH	.199	.184	.200
CO GR/HP HR	.684	.706	.667

TABLE C-50 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 50, TEST SITE 9
CLARK TCVC-16, RATED 8000 HP, RATED 330 RPM, 2-STROKE TC

IN	1	2	3	4	5	6
TE	4/16/73	4/16/73	4/16/73	4/18/73	4/18/73	4/18/73
ME	1450	1630	1700	1025	1100	1115
ERATIONAL DATA						
AROMETER, IN. HG.	28.73	28.72	28.72	28.41	28.40	28.40
MBIENT TEMP. DEG. F	55	55	55	73	74	74
ET BULB TEMP. DEG. F	45	45	45	64	64	64
EL. HUMIDITY PERCENT	41	41	41	60	57	57
P. HUMIDITY GRAIN/LB	27	27	27	77	75	75
NGINE SPEED RPM	325	325	325	330	330	330
ORSEPOWER	8505	8084	9110	8176	8035	8035
CAV. AIR PRES. IN.HG.	21.9	19.0	21.9	21.2	16.7	17.7
GNIT. TIME DEG. BTDC	8	8	8	8	8	8
UEL SP. GR. (STP)	.6350	.6350	.6350	.6350	.6350	.6350
I HEAT VALUE BTU/SCF	990	990	990	990	990	990
RIFICE CONSTANT	1038.65	1038.24	1039.17	1017.20	1015.27	1015.27
UEL TEMP. DEG. F	43.0	43.0	43.0	64.0	65.0	65.0
RIFICE DP IN. H2O	60.5	50.8	65.3	61.2	44.9	46.2
RIFICE STAT.PRES.PSIA	66.7	66.7	65.7	66.7	66.7	66.7
UEL FLOW SCFH	65980	60436	68065	64990	55561	56359
EAT FLOW MIL. BTU/HR	65.320	59.831	67.385	64.340	55.005	55.796
UEL FLOW LB/HR	3205	2935	3306	3157	2699	2737
IR FLOW LB/HR	128452	109436	121019	117652	102646	106524
IR/FUEL RATIO	40.1	37.3	36.6	37.3	38.0	38.9
SFC BTU/HP HR	7680	7401	7397	7869	6846	6944
HAUST EMISSIONS						
OX PPM	775.00	985.00	1038.00	805.00	640.00	500.00
O PPM	650.00	890.00	900.00	750.00	605.00	485.00
O2 PPM	125.00	95.00	138.00	55.00	35.00	15.00
O2 PERCENT	3.63	3.93	3.99	3.93	3.87	3.75
C PPM	2000.00	1800.00	2050.00	1800.00	1550.00	1850.00
O PPM	340.00	333.00	337.00	337.00	385.00	396.00
2 PERCENT	14.00	13.30	15.30	13.30	13.50	13.70
O/NOX	.839	.904	.867	.932	.945	.970
ON-METH/TOTAL HC	.170	.152	.219	.180	.175	.210
OX LB/HR	164.117	178.181	207.203	156.579	108.524	87.927
C LB/HR TOTAL	165.869	127.521	160.263	137.117	102.934	127.410
C LB/HR NON-METH	28.198	19.383	35.098	24.681	18.014	26.756
O LB/HR	43.837	36.676	40.958	39.910	39.748	42.399
OX LB/MIL BTU	2.513	2.978	3.075	2.434	1.973	1.576
C LB/MIL BTU TOTAL	2.539	2.131	2.378	2.131	1.871	2.284
C LB/MIL BTU NON-METH	.432	.324	.521	.384	.327	.480
O LB/MIL BTU	.671	.613	.608	.620	.723	.760
OX GR/HP HR	8.753	9.998	10.317	8.687	6.127	4.964
C GR/HP HR TOTAL	8.846	7.155	7.980	7.607	5.811	7.193
C GR/HP HR NON-METH	1.504	1.088	1.748	1.369	1.017	1.510
O GR/HP HR	2.338	2.058	2.039	2.214	2.244	2.394

TABLE C-50 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 50, TEST SITE 9
CLARK TCVC-16, RATED 8000 HP, RATED 330 RPM, 2-STROKE TC

RUN	7
DATE	4/18/73
TIME	1130
OPERATIONAL DATA	
BAROMETER, IN. HG.	28.40
AMBIENT TEMP. DEG. F	74
WET BULB TEMP. DEG. F	64
REL. HUMIDITY PERCENT	57
SP. HUMIDITY GRAIN/LB	75
ENGINE SPEED RPM	330
HORSEPOWER	8035
SCAV. AIR PRES. IN.HG.	18.2
IGNIT. TIME DEG. BTDC	8
FUEL SP. GR. (STP)	.6350
HI HEAT VALUE BTU/SCF	990
ORIFICE CONSTANT	1015.27
FUEL TEMP. DEG. F	65.0
ORIFICE DP IN. H2O	45.1
ORIFICE STAT.PRES.PSIA	66.7
FUEL FLOW SCFH	55684
HEAT FLOW MIL. BTU/HR	55.127
FUEL FLOW LB/HR	2705
AIR FLOW LB/HR	108123
AIR/FUEL RATIO	40.0
BSFC BTU/HP HR	6861
EXHAUST EMISSIONS	
NOX PPM	460.00
NO PPM	415.00
NO2 PPM	45.00
CO2 PERCENT	3.63
HC PPM	2000.00
CO PPM	400.00
O2 PERCENT	13.80
NO/NOX	.902
NON-METH/TOTAL HC	.129
NOX LB/HR	82.044
HC LB/HR TOTAL	139.770
HC LB/HR NON-METH	18.030
CO LB/HR	43.437
NOX LB/MIL BTU	1.488
HC LB/MIL BTU TOTAL	2.535
HC LB/MIL BTU NON-METH	.327
CO LB/MIL BTU	.788
NOX GR/HP HR	4.632
HC GR/HP HR TOTAL	7.890
HC GR/HP HR NON-METH	1.018
CO GR/HP HR	2.452

TABLE C-51 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 51, TEST SITE 9
COOPER-BESSEMER 10 V-250, RATED 3400 HP, RATED 250 RPM, 2-STROKE TC

RUN	1	2	3	4
DATE	4/17/73	4/17/73	4/17/73	4/17/73
TIME	1015	1050	1120	1140
OPERATIONAL DATA				
BAROMETER, IN. HG.	28.62	28.62	28.62	28.59
AMBIENT TEMP. DEG. F	60	63	63	64
WET BULB TEMP. DEG. F	51	53	53	53
REL. HUMIDITY PERCENT	51	49	49	45
SP. HUMIDITY GRAIN/LB	41	43	43	42
ENGINE SPEED RPM	250	250	250	250
HORSEPOWER	3603	3320	3320	3320
SCAV. AIR PRES. IN.HG.	10.65	9.4	11.3	8.0
IGNIT. TIME DEG. BTDC	7.5	6.5	7.5	5.0
FUEL SP. GR. (STP)	.6350	.6350	.6350	.6350
HI HEAT VALUE BTU/SCF	990	990	990	990
ORIFICE CONSTANT	318.17	317.54	317.54	317.54
FUEL TEMP. DEG. F	56.0	58.0	58.0	58.0
ORIFICE DP IN. H2O	63.2	59.1	59.8	59.1
ORIFICE STAT.PRES.PSIA	76.2	76.2	76.2	76.2
FUEL FLOW SCFH	22080	21309	21435	21309
HEAT FLOW MIL. BTU/HR	21.859	21.096	21.221	21.096
FUEL FLOW LB/HR	1072	1035	1041	1035
AIR FLOW LB/HR	45746	43327	47134	39373
AIR/FUEL RATIO	42.7	41.9	45.3	38.0
BSFC BTU/HP HR	6067	6354	6392	6354
EXHAUST EMISSIONS				
NOX PPM	1013.00	790.00	1163.00	1288.00
NO PPM	925.00	725.00	1075.00	1213.00
NO2 PPM	88.00	65.00	88.00	75.00
CO2 PERCENT	3.57	3.63	3.33	3.99
HC PPM	630.00	690.00	1000.00	680.00
CO PPM	81.00	89.00	82.00	97.00
O2 PERCENT	14.40	14.40	15.00	13.70
NO/NOX	.913	.918	.924	.942
NON-METH/TOTAL HC	.203	.212	.171	.165
NOX LB/HR	76.182	56.305	89.920	83.679
HC LB/HR TOTAL	18.555	19.260	30.280	17.302
HC LB/HR NON-METH	3.767	4.083	5.178	2.855
CO LB/HR	3.709	3.862	3.860	3.837
NOX LB/MIL BTU	3.485	2.669	4.237	3.967
HC LB/MIL BTU TOTAL	.849	.913	1.427	.820
HC LB/MIL BTU NON-METH	.172	.194	.244	.135
CO LB/MIL BTU	.170	.183	.182	.182
NOX GR/HP HR	9.591	7.693	12.285	11.433
HC GR/HP HR TOTAL	2.336	2.631	4.137	2.364
HC GR/HP HR NON-METH	.474	.558	.707	.390
CO GR/HP HR	.467	.528	.527	.524

TABLE C-52 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 52, TEST SITE 9
CLARK TCV-16, RATED 5500 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3
DATE	4/17/73	4/17/73	4/17/73
TIME	1350	1540	1610
OPERATIONAL DATA			
BAROMETER, IN. HG.	28.51	28.51	28.51
AMBIENT TEMP. DEG. F	70	70	70
WET BULB TEMP. DEG. F	58	58	58
REL. HUMIDITY PERCENT	46	46	46
SP. HUMIDITY GRAIN/LB	52	52	52
ENGINE SPEED RPM	300	300	296
HORSEPOWER	5116	5679	5309
SCAV. AIR PRES. IN.HG.	16.0	18.0	18.1
IGNIT. TIME DEG. BTDC	9	9	5
FUEL SP. GR. (STP)	.6350	.6350	.6350
HI HEAT VALUE BTU/SCF	990	990	990
ORIFICE CONSTANT	395.41	395.37	395.37
FUEL TEMP. DEG. F	48.0	48.0	48.0
ORIFICE DP IN. H2O	73.4	81.6	81.6
ORIFICE STAT.PRES.PSIA	86.2	86.2	86.7
FUEL FLOW SCFH	31452	33159	33255
HEAT FLOW MIL. BTU/HR	31.138	32.827	32.923
FUEL FLOW LB/HR	1528	1611	1615
AIR FLOW LB/HR	65164	71144	70056
AIR/FUEL RATIO	42.7	44.2	43.4
BSFC BTU/HP HR	6086	5781	6201
EXHAUST EMISSIONS			
NOX PPM	590.00	605.00	495.00
NO PPM	525.00	565.00	430.00
NO2 PPM	65.00	40.00	65.00
CO2 PERCENT	3.51	3.39	3.45
HC PPM	950.00	1000.00	1000.00
CO PPM	313.00	268.00	313.00
O2 PERCENT	13.80	14.30	14.60
NO/NOX	.890	.934	.869
NON-METH/TOTAL HC	.236	.188	.154
NOX LB/HR	63.288	70.744	57.004
HC LB/HR TOTAL	39.909	45.795	45.100
HC LB/HR NON-METH	9.419	8.609	6.945
CO LB/HR	20.442	19.080	21.946
NOX LB/MIL BTU	2.033	2.155	1.731
HC LB/MIL BTU TOTAL	1.282	1.395	1.370
HC LB/MIL BTU NON-METH	.302	.262	.211
CO LB/MIL BTU	.657	.581	.667
NOX GR/HP HR	5.611	5.651	4.870
HC GR/HP HR TOTAL	3.538	3.658	3.853
HC GR/HP HR NON-METH	.835	.688	.593
CO GR/HP HR	1.812	1.524	1.875

TABLE C-53 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 53, TEST SITE 9
CLARK BA-8, RATED 1760 HP, RATED 300 RPM, 2-STROKE NA

RUN	1	2	3
DATE	4/19/73	4/19/73	4/19/73
TIME	1020	1410	1525
OPERATIONAL DATA			
BAROMETER, IN. HG.	27.95	27.94	27.92
AMBIENT TEMP. DEG. F	74	77	72
WET BULB TEMP. DEG. F	55	57	52
REL. HUMIDITY PERCENT	25	25	19
SP. HUMIDITY GRAIN/LB	33	36	24
ENGINE SPEED RPM	295	302	302
HORSEPOWER	1720	1864	1689
SCAV. AIR PRES. IN.HG.	1.3	1.3	1.2
IGNIT. TIME DEG. BTDC	12	12	12
FUEL SP. GR. (STP)	.6360	.6360	.6360
HI HEAT VALUE BTU/SCF	998	998	998
ORIFICE CONSTANT	1087.98	1087.98	1085.90
FUEL TEMP. DEG. F	63.0	63.0	65.0
ORIFICE DP IN. H2O	5.2	5.2	5.2
ORIFICE STAT.PRES.PSIA	34.7	35.7	35.7
FUEL FLOW SCFH	14615	14824	14795
HEAT FLOW MIL. BTU/HR	14.585	14.794	14.766
FUEL FLOW LB/HR	711	721	720
AIR FLOW LB/HR	24107	23076	23077
AIR/FUEL RATIO	33.9	32.0	32.1
BSFC BTU/HP HR	8480	7937	8742
EXHAUST EMISSIONS			
NOX PPM	1125.00	1314.00	1230.00
NO PPM	975.00	1170.00	1065.00
NO2 PPM	150.00	144.00	165.00
CO2 PERCENT	4.24	4.50	4.50
HC PPM	2000.00	1820.00	1900.00
CO PPM	433.00	575.00	425.00
O2 PERCENT	13.00	12.50	12.80
NO/NOX	.867	.890	.866
NON-METH/TOTAL HC	.210	.167	.154
NOX LB/HR	44.970	50.397	47.154
HC LB/HR TOTAL	31.715	27.691	28.896
HC LB/HR NON-METH	6.660	4.624	4.450
CO LB/HR	10.538	13.427	9.920
NOX LB/MIL BTU	3.083	3.407	3.193
HC LB/MIL BTU TOTAL	2.174	1.872	1.957
HC LB/MIL BTU NON-METH	.457	.313	.301
CO LB/MIL BTU	.723	.908	.672
NOX GR/HP HR	11.860	12.264	12.664
HC GR/HP HR TOTAL	8.364	6.739	7.760
HC GR/HP HR NON-METH	1.756	1.125	1.195
CO GR/HP HR	2.779	3.267	2.664

TABLE C-54 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 54, TEST SITE 9
CLARK TLA-8, RATED 2700 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5	6
DATE	4/23/73	4/23/73	4/23/73	4/23/73	4/23/73	4/23/
TIME	1400	1600	1620	1640	1705	1725
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.97	29.93	29.93	29.92	29.91	29.9
AMBIENT TEMP. DEG. F	76	82	82	84	83	7
WET BULB TEMP. DEG. F	57	57	58	59	59	5
REL. HUMIDITY PERCENT	25	14	16	16	17	1
SP. HUMIDITY GRAIN/LB	33	22	26	27	29	2
ENGINE SPEED RPM	300	300	300	292	280	27
HORSEPOWER	2860	2736	2500	2630	2560	245
SCAV. AIR PRES. IN.HG.	16.0	15.6	14.6	15.6	14.4	12.
IGNIT. TIME DEG. BTDC	8	8	8	8	8	
FUEL SP. GR. (STP)	.6360	.6360	.6360	.6360	.6360	.636
HI HEAT VALUE BTU/SCF	998	998	998	998	998	99
ORIFICE CONSTANT	327.97	328.62	328.43	328.62	328.43	328.7
FUEL TEMP. DEG. F	61.0	59.0	59.0	59.0	59.0	58.
ORIFICE DP IN. H2O	58.5	55.7	48.9	53.0	47.6	43.
ORIFICE STAT.PRES.PSIA	94.7	94.7	94.7	94.7	94.7	94.
FUEL FLOW SCFH	24411	23867	22350	23281	22051	2109
HEAT FLOW MIL. BTU/HR	24.362	23.819	22.305	23.235	22.007	21.05
FUEL FLOW LB/HR	1187	1161	1087	1133	1073	102
AIR FLOW LB/HR	48453	46650	43677	45396	43007	3974
AIR/FUEL RATIO	40.8	40.2	40.2	40.1	40.1	38.
BSFC BTU/HP HR	8518	8706	8922	8834	8596	859
EXHAUST EMISSIONS						
NOX PPM	940.00	780.00	750.00	940.00	1080.00	1080.0
NO PPM	740.00	700.00	680.00	840.00	990.00	990.0
NO2 PPM	200.00	80.00	70.00	100.00	90.00	90.0
CO2 PERCENT	3.57	3.63	3.63	3.63	3.63	3.7
HC PPM	1500.00	1500.00	1500.00	1600.00	1600.00	1700.0
CO PPM	327.00	281.00	281.00	268.00	262.00	293.0
O2 PERCENT	14.50	14.30	14.20	14.20	14.20	14.5
NO/NOX	.787	.897	.907	.894	.917	.91
NON-METH/TOTAL HC	.076	.045	.049	.044	.048	.03
NOX LB/HR	74.981	59.947	53.977	70.310	76.524	70.75
HC LB/HR TOTAL	47.466	45.732	42.825	47.476	44.973	44.18
HC LB/HR NON-METH	3.607	2.058	2.098	2.089	2.159	1.32
CO LB/HR	15.881	13.149	12.313	12.205	11.303	11.68
NOX LB/MIL BTU	3.078	2.517	2.420	3.026	3.477	3.36
HC LB/MIL BTU TOTAL	1.948	1.920	1.920	2.043	2.044	2.09
HC LB/MIL BTU NON-METH	.148	.086	.094	.090	.098	.06
CO LB/MIL BTU	.652	.552	.552	.525	.514	.55
NOX GR/HP HR	11.892	9.939	9.794	12.126	13.559	13.09
HC GR/HP HR TOTAL	7.528	7.582	7.770	8.188	7.969	8.16
HC GR/HP HR NON-METH	.572	.341	.381	.360	.382	.24
CO GR/HP HR	2.519	2.180	2.234	2.105	2.003	2.16

TABLE C-55 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 55, TEST SITE 9
CLARK BA-8, RATED 1600 HP, RATED 300 HP, 2-STROKE NA

RUN	1	2	3	4	5
DATE	4/26/73	4/26/73	4/26/73	4/26/73	4/26/73
TIME	1000	1020	1045	1120	1145
OPERATIONAL DATA					
BAROMETER, IN. HG.	30.13	30.13	30.13	30.13	30.13
AMBIENT TEMP. DEG. F	73	73	73	73	73
WET BULB TEMP. DEG. F	58	58	58	58	58
REL. HUMIDITY PERCENT	36	36	36	36	36
SP. HUMIDITY GRAIN/LB	43	43	43	43	43
ENGINE SPEED RPM	300	285	270	300	300
HORSEPOWER	1604	1524	1444	1700	1575
SCAV. AIR PRES. IN.HG.	8.1	7.7	7.0	8.5	7.1
IGNIT. TIME DEG. BTDC	10	10	10	10	10
FUEL SP. GR. (STP)	.6360	.6360	.6360	.6360	.6360
HI HEAT VALUE BTU/SCF	998	998	998	998	998
ORIFICE CONSTANT	305.50	305.50	305.50	305.50	305.50
FUEL TEMP. DEG. F	60.0	60.0	60.0	60.0	60.0
ORIFICE DP IN. H2O	29.1	38.4	34.9	49.5	35.4
ORIFICE STAT.PRES.PSIA	66.5	66.5	66.5	66.5	66.5
FUEL FLOW SCFH	13451	15446	14713	17521	14831
HEAT FLOW MIL. BTU/HR	13.424	15.415	14.684	17.486	14.801
FUEL FLOW LB/HR	654	751	716	852	721
AIR FLOW LB/HR	23280	26369	25444	30142	25286
AIR/FUEL RATIO	35.6	35.1	35.5	35.4	35.0
BSFC BTU/HP HR	8369	10115	10169	10286	9398
EXHAUST EMISSIONS					
NOX PPM	840.00	835.00	822.00	1020.00	840.00
NO PPM	580.00	615.00	620.00	750.00	660.00
NO2 PPM	260.00	220.00	202.00	270.00	180.00
CO2 PERCENT	4.18	4.24	4.18	4.18	4.24
HC PPM	890.00	845.00	900.00	1070.00	915.00
CO PPM	141.00	132.00	136.00	156.00	139.00
O2 PERCENT	13.50	13.00	13.00	12.50	13.40
NO/NOX	.690	.737	.754	.735	.786
NON-METH/TOTAL HC	.058	.059	.045	.052	.065
NOX LB/HR	32.348	36.461	34.622	50.933	35.156
HC LB/HR TOTAL	13.596	14.637	15.038	21.196	15.192
HC LB/HR NON-METH	.789	.864	.677	1.102	.987
CO LB/HR	3.306	3.509	3.488	4.743	3.542
NOX LB/MIL BTU	2.410	2.365	2.358	2.913	2.375
HC LB/MIL BTU TOTAL	1.013	.950	1.024	1.212	1.026
HC LB/MIL BTU NON-METH	.059	.056	.046	.063	.067
CO LB/MIL BTU	.246	.228	.238	.271	.239
NOX GR/HP HR	9.148	10.852	10.876	13.590	10.125
HC GR/HP HR TOTAL	3.845	4.357	4.724	5.655	4.375
HC GR/HP HR NON-METH	.223	.257	.213	.294	.284
CO GR/HP HR	.935	1.045	1.096	1.265	1.020

TABLE C-56 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 56, TEST SITE 9
INGERSOLL-RAND KVG-8, RATED 800 HP, RATED 330 RPM, 4-STROKE NA

RUN	1	2	3	4	5
DATE	4/24/73	4/24/73	4/24/73	4/24/73	4/24/73
TIME	1435	1500	1610	1635	1655
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.77	29.77	29.76	29.78	29.77
AMBIENT TEMP. DEG. F	86	84	71	63	63
WET BULB TEMP. DEG. F	66	68	64	59	59
REL. HUMIDITY PERCENT	31	41	67	78	78
SP. HUMIDITY GRAIN/LB	58	72	76	67	67
ENGINE SPEED RPM	330	315	300	330	330
HORSEPOWER	599	569	500	597	597
SCAV. AIR PRES. IN.HG.	-1.2	-1.0	-1.0	-1.5	-1.5
IGNIT. TIME DEG. BTDC	20	20	20	12	16
FUEL SP. GR. (STP)	.6360	.6360	.6360	.6360	.6360
HI HEAT VALUE BTU/SCF	998	998	998	998	998
ORIFICE CONSTANT	260.00	260.00	260.00	260.00	260.00
FUEL TEMP. DEG. F	60.0	60.0	60.0	60.0	60.0
ORIFICE DP IN. H2O	10.2	9.4	8.6	12.8	11.3
ORIFICE STAT.PRES.PSIA	66.5	66.5	66.5	66.5	66.5
FUEL FLOW SCFH	6781	6504	6218	7574	7137
HEAT FLOW MIL. BTU/HR	6.768	6.491	6.205	7.559	7.122
FUEL FLOW LB/HR	330	316	302	368	347
AIR FLOW LB/HR	7669	7650	7941	7657	7975
AIR/FUEL RATIO	23.2	24.2	26.3	20.8	23.0
BSFC BTU/HP HR	11299	11408	12411	12661	11930
EXHAUST EMISSIONS					
NOX PPM	920.00	870.00	680.00	990.00	940.00
NO PPM	890.00	820.00	660.00	945.00	905.00
NO2 PPM	30.00	50.00	20.00	45.00	35.00
CO2 PERCENT	6.38	6.14	5.68	7.04	6.38
HC PPM	380.00	420.00	350.00	1000.00	1100.00
CO PPM	29.00	30.00	37.00	8.00	16.00
O2 PERCENT	8.70	9.00	9.70	8.00	8.50
NO/NOX	.967	.943	.971	.955	.963
NON-METH/TOTAL HC	.062	.048	.042	.060	.059
NOX LB/HR	11.915	11.219	9.066	12.876	12.672
HC LB/HR TOTAL	1.952	2.148	1.851	5.159	5.883
HC LB/HR NON-METH	.121	.103	.078	.310	.347
CO LB/HR	.229	.236	.300	.063	.131
NOX LB/MIL BTU	1.761	1.728	1.461	1.703	1.779
HC LB/MIL BTU TOTAL	.288	.331	.298	.683	.826
HC LB/MIL BTU NON-METH	.018	.016	.013	.041	.049
CO LB/MIL BTU	.034	.036	.048	.008	.018
NOX GR/HP HR	9.023	8.943	8.225	9.783	9.628
HC GR/HP HR TOTAL	1.478	1.713	1.679	3.920	4.470
HC GR/HP HR NON-METH	.092	.082	.071	.235	.264
CO GR/HP HR	.173	.188	.272	.048	.100

TABLE C-57 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 57, TEST SITE 9
INGERSOLL-RAND KVG-8, RATED 800 HP, RATED 330 RPM, 4-STROKE NA

RUN	1	2	3	4	5
DATE	4/25/73	4/25/73	4/25/73	4/25/73	4/25/73
TIME	1000	1100	1130	1315	1325
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.90	29.92	29.92	29.91	29.91
AMBIENT TEMP. DEG. F	78	79	82	75	75
WET BULB TEMP. DEG. F	63	64	65	62	62
REL. HUMIDITY PERCENT	40	41	37	45	45
SP. HUMIDITY GRAIN/LB	57	60	60	58	58
ENGINE SPEED RPM	327	315	300	325	327
HORSEPOWER	764	802	764	830	830
SCAV. AIR PRES. IN.HG.	-4.3	-3.8	-3.9	-3.6	-3.7
IGNIT. TIME DEG. BTDC	20	20	20	12	16
FUEL SP. GR. (STP)	.6360	.6360	.6360	.6360	.6360
HI HEAT VALUE BTU/SCF	998	998	998	998	998
ORIFICE CONSTANT	205.14	205.14	205.14	205.14	205.14
FUEL TEMP. DEG. F	60.0	60.0	60.0	60.0	60.0
ORIFICE DP IN. H2O	22.5	20.5	18.2	25.8	25.1
ORIFICE STAT.PRES.PSIA	66.5	66.5	66.5	66.5	66.5
FUEL FLOW SCFH	7935	7576	7137	8499	8389
HEAT FLOW MIL. BTU/HR	7.919	7.561	7.122	8.482	8.373
FUEL FLOW LB/HR	386	369	347	413	408
AIR FLOW LB/HR	8772	9311	9386	9001	8823
AIR/FUEL RATIO	22.7	25.3	27.0	21.8	21.6
BSFC BTU/HP HR	10365	9428	9323	10219	10087
EXHAUST EMISSIONS					
NOX PPM	1590.00	1590.00	1545.00	1350.00	1275.00
NO PPM	1470.00	1440.00	1365.00	1200.00	1185.00
NO2 PPM	120.00	150.00	180.00	150.00	90.00
CO2 PERCENT	6.54	5.91	5.54	6.79	6.71
HC PPM	215.00	240.00	250.00	300.00	280.00
CO PPM	81.00	73.00	73.00	170.00	1400.00
O2 PERCENT	9.20	10.10	11.00	8.50	8.50
NO/NOX	.925	.906	.883	.889	.929
NON-METH/TOTAL HC	.017	.035	.033	.036	.033
NOX LB/HR	23.550	24.862	24.265	20.578	19.070
HC LB/HR TOTAL	1.263	1.489	1.558	1.814	1.661
HC LB/HR NON-METH	.021	.052	.051	.065	.055
CO LB/HR	.730	.695	.698	1.578	12.749
NOX LB/MIL BTU	2.974	3.288	3.407	2.426	2.278
HC LB/MIL BTU TOTAL	.160	.197	.219	.214	.198
HC LB/MIL BTU NON-METH	.003	.007	.007	.008	.007
CO LB/MIL BTU	.092	.092	.098	.186	1.523
NOX GR/HP HR	13.982	14.062	14.406	11.246	10.422
HC GR/HP HR TOTAL	.750	.842	.925	.991	.908
HC GR/HP HR NON-METH	.013	.029	.031	.036	.030
CO GR/HP HR	.434	.393	.414	.862	6.968

TABLE C-58 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 58, TEST SITE 9
INGERSOLL-RAND KVG-8, RATED 800 HP, RATED 300 RPM, 4-STROKE NA

RUN	1	2	3	4	5
DATE	4/25/73	4/25/73	4/25/73	4/25/73	4/25/73
TIME	1505	1530	1600	1630	1700
OPERATIONAL DATA					
BAROMETER, IN. HG.	28.88	28.88	28.88	28.88	28.88
AMBIENT TEMP. DEG. F	78	81	83	85	80
WET BULB TEMP. DEG. F	62	63	64	65	63
REL. HUMIDITY PERCENT	38	34	32	31	36
SP. HUMIDITY GRAIN/LB	55	55	56	57	56
ENGINE SPEED RPM	330	330	330	330	330
HORSEPOWER	816	780	750	816	816
SCAV. AIR PRES. IN.HG.	-2.3	-2.1	-2.0	-2.4	-2.6
IGNIT. TIME DEG. BTDC	20	20	20	12	16
FUEL SP. GR. (STP)	.6360	.6360	.6360	.6360	.6360
HI HEAT VALUE BTU/SCF	998	998	998	998	998
ORIFICE CONSTANT	255.00	255.00	255.00	255.00	255.00
FUEL TEMP. DEG. F	60.0	60.0	60.0	60.0	60.0
ORIFICE DP IN. H2O	17.0	15.3	14.8	17.2	18.0
ORIFICE STAT.PRES.PSIA	66.5	66.5	66.5	66.5	66.5
FUEL FLOW SCFH	8561	8126	8008	8629	8822
HEAT FLOW MIL. BTU/HR	8.544	8.110	7.992	8.612	8.805
FUEL FLOW LB/HR	416	395	390	420	429
AIR FLOW LB/HR	10476	9943	9805	10343	10549
AIR/FUEL RATIO	25.2	25.2	25.2	24.6	24.6
BSFC BTU/HP HR	10471	10397	10656	10554	10790
EXHAUST EMISSIONS					
NOX PPM	1440.00	1395.00	1380.00	1215.00	1140.00
NO PPM	1260.00	1215.00	1185.00	1065.00	990.00
NO2 PPM	180.00	180.00	195.00	150.00	150.00
CO2 PERCENT	5.91	5.91	5.91	5.91	5.91
HC PPM	430.00	410.00	410.00	400.00	430.00
CO PPM	136.00	173.00	114.00	1300.00	1400.00
O2 PERCENT	10.30	10.50	10.20	10.10	10.00
NO/NOX	.875	.871	.859	.877	.868
NON-METH/TOTAL HC	.049	.057	.065	.075	.049
NOX LB/HR	25.337	23.290	22.728	21.146	20.242
HC LB/HR TOTAL	3.001	2.715	2.679	2.762	3.029
HC LB/HR NON-METH	.147	.155	.174	.207	.148
CO LB/HR	1.457	1.759	1.143	13.775	15.135
NOX LB/MIL BTU	2.965	2.872	2.844	2.455	2.299
HC LB/MIL BTU TOTAL	.351	.335	.335	.321	.344
HC LB/MIL BTU NON-METH	.017	.019	.022	.024	.017
CO LB/MIL BTU	.171	.217	.143	1.600	1.719
NOX GR/HP HR	14.084	13.544	13.746	11.755	11.252
HC GR/HP HR TOTAL	1.668	1.579	1.620	1.535	1.684
HC GR/HP HR NON-METH	.082	.090	.105	.115	.082
CO GR/HP HR	.810	1.023	.691	7.657	8.413

TABLE C-59 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 59, TEST SITE 10
INGERSOLL-RAND 412-KVS, RATED 2000 HP, RATED 330 RPM, 4-STROKE TC

RUN	1	2	3	4	5
DATE	5/16/73	5/16/73	5/16/73	5/16/73	5/16/73
TIME	925	1010	1017	1035	1105
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.49	29.50	29.51	29.51	29.52
AMBIENT TEMP. DEG. F	61	61	65	65	65
WET BULB TEMP. DEG. F	51	51	50	50	50
REL. HUMIDITY PERCENT	46	46	28	28	28
SP. HUMIDITY GRAIN/LB	37	37	26	26	26
ENGINE SPEED RPM	330	330	330	315	300
HORSEPOWER	2075	1975	1870	1885	1795
SCAV. AIR PRES. IN.HG.	4.7	4.6	4.3	4.0	3.5
IGNIT. TIME DEG. BTDC	14	14	14	14	14
FUEL SP. GR. (STP)	.6860	.6860	.6860	.6860	.6860
HI HEAT VALUE BTU/SCF	971	971	971	971	971
ORIFICE CONSTANT	531.38	531.38	531.43	531.43	531.60
FUEL TEMP. DEG. F	53.0	52.0	53.0	53.0	53.0
ORIFICE DP IN. H2O	13.0	12.5	11.1	11.0	9.0
ORIFICE STAT.PRES.PSIA	90.2	90.7	90.7	90.7	90.7
FUEL FLOW SCFH	18196	17892	16862	16786	15188
HEAT FLOW MIL. BTU/HR	17.668	17.373	16.373	16.299	14.748
FUEL FLOW LB/HR	955	939	885	881	797
AIR FLOW LB/HR	21359	20072	18646	18619	15172
AIR/FUEL RATIO	22.4	21.4	21.1	21.1	19.0
BSFC BTU/HP HR	8515	8797	8756	8647	8216
EXHAUST EMISSIONS					
NOX PPM	2160.00	1860.00	1590.00	1680.00	1965.00
NO PPM	1710.00	1560.00	1440.00	1440.00	1800.00
NO2 PPM	450.00	300.00	150.00	240.00	165.00
CO2 PERCENT	6.06	6.30	6.38	6.38	7.04
HC PPM	530.00	750.00	800.00	650.00	720.00
CO PPM	60.00	92.00	97.00	75.00	65.00
O2 PERCENT	9.50	9.00	8.80	8.90	7.50
NO/NOX	.792	.839	.906	.857	.916
NON-METH/TOTAL HC	.118	.118	.118	.118	.119
NOX LB/HR	77.826	63.160	50.210	52.954	50.799
HC LB/HR TOTAL	8.270	11.029	10.940	8.872	8.061
HC LB/HR NON-METH	.976	1.301	1.291	1.047	.951
CO LB/HR	1.316	1.902	1.865	1.439	1.023
NOX LB/MIL BTU	4.405	3.635	3.067	3.249	3.444
HC LB/MIL BTU TOTAL	.468	.635	.668	.544	.547
HC LB/MIL BTU NON-METH	.055	.075	.079	.064	.064
CO LB/MIL BTU	.074	.109	.114	.088	.069
NOX GR/HP HR	17.013	14.506	12.179	12.743	12.837
HC GR/HP HR TOTAL	1.808	2.533	2.654	2.135	2.037
HC GR/HP HR NON-METH	.213	.299	.313	.252	.240
CO GR/HP HR	.288	.437	.452	.346	.259

TABLE C-60 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 60, TEST SITE 10
INGERSOLL-RAND 412-KVS, RATED 2000 HP, RATED 330 RPM,4-STROKE TC

RUN	1	2	3	4
DATE	5/16/73	5/16/73	5/16/73	5/16/73
TIME	1200	1215	1230	1245
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.55	29.54	29.54	29.54
AMBIENT TEMP. DEG. F	67	67	68	68
WET BULB TEMP. DEG. F	51	51	50	50
REL. HUMIDITY PERCENT	26	26	20	20
SP. HUMIDITY GRAIN/LB	26	26	20	20
ENGINE SPEED RPM	330	330	330	325
HORSEPOWER	1450	1725	2050	2216
SCAV. AIR PRES. IN.HG.	3.1	3.3	3.8	4.1
IGNIT. TIME DEG. BTDC	17.0	17.0	17.0	17.0
FUEL SP. GR. (STP)	.6860	.6860	.6860	.6860
HI HEAT VALUE BTU/SCF	971	971	971	971
ORIFICE CONSTANT	532.14	532.14	532.03	531.94
FUEL TEMP. DEG. F	53.0	53.0	53.0	53.0
ORIFICE DP IN. H2O	8.0	8.8	10.5	12.2
ORIFICE STAT.PRES.PSIA	93.7	93.7	92.7	92.7
FUEL FLOW SCFH	14569	15280	16599	17889
HEAT FLOW MIL. BTU/HR	14.147	14.837	16.117	17.370
FUEL FLOW LB/HR	764	802	871	939
AIR FLOW LB/HR	18654	18928	19621	20707
AIR/FUEL RATIO	24.4	23.6	22.5	22.1
BSFC BTU/HP HR	9756	8601	7862	7838
EXHAUST EMISSIONS				
NOX PPM	890.00	1245.00	1710.00	2040.00
NO PPM	730.00	1005.00	1425.00	1650.00
NO2 PPM	160.00	240.00	285.00	390.00
CO2 PERCENT	5.18	5.54	5.91	6.06
HC PPM	4200.00	2500.00	1500.00	1250.00
CO PPM	292.00	216.00	150.00	102.00
O2 PERCENT	11.00	10.50	9.60	9.00
NO/NOX	.820	.807	.833	.809
NON-METH/TOTAL HC	.118	.118	.118	.118
NOX LB/HR	27.910	39.663	56.610	71.372
HC LB/HR TOTAL	57.037	34.490	21.504	18.939
HC LB/HR NON-METH	6.730	4.070	2.538	2.235
CO LB/HR	5.575	4.190	3.023	2.173
NOX LB/MIL BTU	1.973	2.673	3.512	4.109
HC LB/MIL BTU TOTAL	4.032	2.325	1.334	1.090
HC LB/MIL BTU NON-METH	.476	.274	.157	.129
CO LB/MIL BTU	.394	.282	.188	.125
NOX GR/HP HR	8.731	10.430	12.526	14.609
HC GR/HP HR TOTAL	17.843	9.069	4.758	3.877
HC GR/HP HR NON-METH	2.105	1.070	.561	.457
CO GR/HP HR	1.744	1.102	.669	.445

TABLE C-61 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 61, TEST SITE 10
INGERSOLL-RAND 412-KVS, RATED 2000 HP, RATED 330 RPM, 4-STROKE TC

RUN	1	2	3	4	5	6
DATE	5/16/73	5/16/73	5/16/73	5/16/73	5/16/73	5/16/73
TIME	1343	1353	1405	1425	1440	1500
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.60	29.60	29.60	29.61	29.61	29.61
AMBIENT TEMP. DEG. F	67	67	67	67	71	71
WET BULB TEMP. DEG. F	50	50	50	50	52	53
REL. HUMIDITY PERCENT	22	22	22	22	20	23
SP. HUMIDITY GRAIN/LB	22	22	22	22	22	26
ENGINE SPEED RPM	330	330	330	324	330	330
HORSEPOWER	1500	1790	1850	1993	1840	1840
SCAV. AIR PRES. IN.HG.	3.1	3.6	3.7	4.0	3.5	4.2
IGNIT. TIME DEG. BTDC	15	15	15	15	19	12
FUEL SP. GR. (STP)	.6360	.6360	.6360	.6360	.6360	.6360
HI HEAT VALUE BTU/SCF	971	971	971	971	971	971
ORIFICE CONSTANT	529.29	529.13	529.13	529.61	529.66	529.66
FUEL TEMP. DEG. F	58.0	58.0	58.0	57.0	57.0	57.0
ORIFICE DP IN. H2O	8.8	10.8	11.4	12.5	11.2	11.8
ORIFICE STAT.PRES.PSIA	94.7	93.7	93.7	93.5	93.7	93.7
FUEL FLOW SCFH	15280	16832	17294	18106	17158	17612
HEAT FLOW MIL. BTU/HR	14.836	16.344	16.792	17.581	16.661	17.101
FUEL FLOW LB/HR	743	819	841	881	835	857
AIR FLOW LB/HR	16134	18521	18605	18077	17986	19002
AIR/FUEL RATIO	21.7	22.6	22.1	20.5	21.5	22.2
BSFC BTU/HP HR	9891	9131	9077	8821	9055	9294
EXHAUST EMISSIONS						
NOX PPM	1635.00	1680.00	1830.00	2190.00	2040.00	1890.00
NO PPM	1320.00	1260.00	1380.00	1800.00	1410.00	1110.00
NO2 PPM	315.00	420.00	450.00	390.00	630.00	780.00
CO2 PERCENT	6.14	5.91	6.06	6.54	6.22	6.06
HC PPM	1300.00	1200.00	1050.00	840.00	1000.00	910.00
CO PPM	224.00	220.00	182.00	112.00	182.00	166.00
O2 PERCENT	9.30	9.60	9.40	8.50	9.20	9.50
NO/NOX	.807	.750	.754	.822	.691	.587
NON-METH/TOTAL HC	.118	.118	.118	.118	.118	.118
NOX LB/HR	44.598	52.488	57.494	67.129	62.036	60.626
HC LB/HR TOTAL	15.356	16.236	14.286	11.150	13.169	12.641
HC LB/HR NON-METH	1.812	1.916	1.686	1.316	1.554	1.492
CO LB/HR	3.720	4.185	3.481	2.090	3.370	3.242
NOX LB/MIL BTU	3.006	3.211	3.424	3.818	3.723	3.545
HC LB/MIL BTU TOTAL	1.035	.993	.851	.634	.790	.739
HC LB/MIL BTU NON-METH	.122	.117	.100	.075	.093	.087
CO LB/MIL BTU	.251	.256	.207	.119	.202	.190
NOX GR/HP HR	13.486	13.301	14.097	15.278	15.293	14.946
HC GR/HP HR TOTAL	4.644	4.114	3.503	2.538	3.246	3.116
HC GR/HP HR NON-METH	.548	.485	.413	.299	.383	.368
CO GR/HP HR	1.125	1.060	.854	.476	.831	.799

ONS DATA CARD OUT OF SEQUENCE. MODE 1

TABLE C-62 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 62, TEST SITE 10
INGERSOLL-RAND 616-KVT, RATED 4000 HP, RATED 330 RPM, 4-STROKE TC

RUN	1	2	3	4
DATE	5/16/73	5/16/73	5/16/73	5/16/73
TIME	945	1000	1035	1055
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.55	29.55	29.55	29.55
AMBIENT TEMP. DEG. F	64	66	68	71
WET BULB TEMP. DEG. F	51	52	53	54
REL. HUMIDITY PERCENT	35	33	31	27
SP. HUMIDITY GRAIN/LB	32	32	32	31
ENGINE SPEED RPM	330	315	330	330
HORSEPOWER	3930	3751	3940	3940
SCAV. AIR PRES. IN.HG.	13.0	10.5	15.4	11.7
IGNIT. TIME DEG. BTDC	15.5	14.5	10.0	16.0
FUEL SP. GR. (STP)	.6300	.6300	.6300	.6300
HI HEAT VALUE BTU/SCF	1007	1007	1007	1007
ORIFICE CONSTANT	1056.02	1056.13	1056.02	1056.02
FUEL TEMP. DEG. F	39.0	39.0	39.0	39.0
ORIFICE DP IN. H2O	7.0	5.9	7.9	6.8
ORIFICE STAT.PRES.PSIA	80.7	80.7	80.7	80.7
FUEL FLOW SCFH	25099	23045	26664	24738
HEAT FLOW MIL. BTU/HR	25.275	23.206	26.850	24.911
FUEL FLOW LB/HR	1209	1110	1285	1192
AIR FLOW LB/HR	33572	30054	37734	31955
AIR/FUEL RATIO	27.8	27.1	29.4	26.8
BSFC BTU/HP HR	6431	6187	6815	6323
EXHAUST EMISSIONS				
NOX PPM	1245.00	1950.00	660.00	1830.00
NO PPM	1035.00	1590.00	480.00	1470.00
NO2 PPM	210.00	360.00	180.00	360.00
CO2 PERCENT	5.61	5.76	5.32	5.83
HC PPM	1150.00	1100.00	920.00	1000.00
CO PPM	264.00	203.00	370.00	186.00
O2 PERCENT	10.40	9.60	11.00	10.10
NO/NOX	.831	.815	.727	.803
NON-METH/TOTAL HC	.074	.074	.074	.074
NOX LB/HR	69.967	98.246	41.590	98.002
HC LB/HR TOTAL	24.183	20.738	21.693	20.039
HC LB/HR NON-METH	1.790	1.535	1.605	1.483
CO LB/HR	9.033	6.227	14.196	6.065
NOX LB/MIL BTU	2.768	4.234	1.549	3.934
HC LB/MIL BTU TOTAL	.957	.894	.808	.804
HC LB/MIL BTU NON-METH	.071	.066	.060	.060
CO LB/MIL BTU	.357	.268	.529	.243
NOX GR/HP HR	8.076	11.881	4.786	11.283
HC GR/HP HR TOTAL	2.791	2.508	2.497	2.307
HC GR/HP HR NON-METH	.207	.186	.185	.171
CO GR/HP HR	1.043	.753	1.634	.698

TABLE C-63 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 63, TEST SITE 10
INGERSOLL-RAND 616-KVR, RATED 5500 HP, RATED 350 RPM, 4-STROKE TC

RUN	1	2	3	4	5	6
DATE	5/17/73	5/17/73	5/17/73	5/17/73	5/17/73	5/17/73
TIME	1245	1310	1325	1345	1400	1410
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.48	29.48	29.48	29.45	29.45	29.45
AMBIENT TEMP. DEG. F	74	74	74	73	73	73
WET BULB TEMP. DEG. F	57	57	57	57	57	57
REL. HUMIDITY PERCENT	30	30	30	33	33	33
SP. HUMIDITY GRAIN/LB	38	38	38	40	40	40
ENGINE SPEED RPM	350	350	350	350	350	350
HORSEPOWER	4700	5000	5200	5550	6000	5550
SCAV. AIR PRES. IN.HG.	14.3	14.5	14.8	15.5	16.5	15.4
IGNIT. TIME DEG. BTDC	19.0	18.3	18.0	17.3	16.5	20.0
FUEL SP. GR. (STP)	.6300	.6300	.6300	.6300	.6300	.6300
HI HEAT VALUE BTU/SCF	1007	1007	1007	1007	1007	1007
ORIFICE CONSTANT	1583.01	1583.01	1582.84	1582.69	1582.37	1582.53
FUEL TEMP. DEG. F	42.0	42.0	42.0	42.0	42.0	42.0
ORIFICE DP IN. H2O	5.2	5.4	5.7	6.1	6.8	6.3
ORIFICE STAT.PRES.PSIA	81.7	81.2	81.2	80.7	80.7	80.7
FUEL FLOW SCFH	32628	33148	34053	35115	37068	35683
HEAT FLOW MIL. BTU/HR	32.857	33.380	34.291	35.361	37.327	35.933
FUEL FLOW LB/HR	1572	1597	1641	1692	1786	1719
AIR FLOW LB/HR	52710	54392	53541	55275	57447	54555
AIR/FUEL RATIO	33.5	34.1	32.6	32.7	32.2	31.7
BSFC BTU/HP HR	6991	6676	6594	6371	6221	6474
EXHAUST EMISSIONS						
NOX PPM	1380.00	1320.00	1380.00	1335.00	1440.00	1830.00
NO PPM	1080.00	1050.00	1080.00	1065.00	1170.00	1560.00
NO2 PPM	300.00	270.00	300.00	270.00	270.00	270.00
CO2 PERCENT	4.70	4.63	4.83	4.83	4.90	4.97
HC PPM	800.00	760.00	770.00	730.00	800.00	760.00
CO PPM	225.00	216.00	208.00	199.00	174.00	182.00
O2 PERCENT	12.00	11.60	11.60	11.70	11.60	11.50
NO/NOX	.783	.795	.783	.798	.813	.852
NON-METH/TOTAL HC	.074	.074	.074	.074	.074	.074
NOX LB/HR	120.738	119.187	122.805	122.629	137.548	166.049
HC LB/HR TOTAL	26.191	25.678	25.640	25.092	28.594	25.804
HC LB/HR NON-METH	1.938	1.900	1.897	1.857	2.116	1.910
CO LB/HR	11.986	11.875	11.270	11.130	10.119	10.055
NOX LB/MIL BTU	3.675	3.571	3.581	3.468	3.685	4.621
HC LB/MIL BTU TOTAL	.797	.769	.748	.710	.766	.718
HC LB/MIL BTU NON-METH	.059	.057	.055	.053	.057	.053
CO LB/MIL BTU	.365	.356	.329	.315	.271	.280
NOX GR/HP HR	11.653	10.813	10.712	10.022	10.399	13.571
HC GR/HP HR TOTAL	2.528	2.329	2.237	2.051	2.162	2.109
HC GR/HP HR NON-METH	.187	.172	.166	.152	.160	.156
CO GR/HP HR	1.157	1.077	.983	.910	.765	.822

TABLE C-63 EMISSION CONCENTRATION AND RATE SUMMARY (Cont'd)

ENGINE TEST 63, TEST SITE 10
INGERSOLL-RAND 616-KVR, RATED 5500 HP, RATED 350 RPM, 4-STROKE TC

RUN	7
DATE	5/17/73
TIME	1420
OPERATIONAL DATA	
BAROMETER, IN. HG.	29.45
AMBIENT TEMP. DEG. F	73
WET BULB TEMP. DEG. F	57
REL. HUMIDITY PERCENT	33
SP. HUMIDITY GRAIN/LB	40
ENGINE SPEED RPM	350
HORSEPOWER	5550
SCAV. AIR PRES. IN.HG.	16.8
IGNIT. TIME DEG. BTDC	14.0
FUEL SP. GR. (STP)	.6300
HI HEAT VALUE BTU/SCF	1007
ORIFICE CONSTANT	1582.53
FUEL TEMP. DEG. F	42.0
ORIFICE DP IN. H2O	6.7
ORIFICE STAT.PRES.PSIA	80.7
FUEL FLOW SCFH	36798
HEAT FLOW MIL. BTU/HR	37.056
FUEL FLOW LB/HR	1773
AIR FLOW LB/HR	57572
AIR/FUEL RATIO	32.5
BSFC BTU/HP HR	6677
EXHAUST EMISSIONS	
NOX PPM	930.00
NO PPM	750.00
NO2 PPM	180.00
CO2 PERCENT	4.83
HC PPM	1000.00
CO PPM	203.00
O2 PERCENT	11.70
NO/NOX	.806
NON-METH/TOTAL HC	.074
NOX LB/HR	89.025
HC LB/HR TOTAL	35.820
HC LB/HR NON-METH	2.651
CO LB/HR	11.832
NOX LB/MIL BTU	2.402
HC LB/MIL BTU TOTAL	.967
HC LB/MIL BTU NON-METH	.072
CO LB/MIL BTU	.319
NOX GR/HP HR	7.276
HC GR/HP HR TOTAL	2.928
HC GR/HP HR NON-METH	.217
CO GR/HP HR	.967

TABLE C-64 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 64, TEST SITE 10
INGERSOLL-RAND 616-KVR, RATED 5500 HP, RATED 350 RPM, 4-STROKE TC

RUN	1	2	3	4	5	6
DATE	5/17/73	5/17/73	5/17/73	5/17/73	5/17/73	5/17/73
TIME	1515	1525	1540	1550	1605	1620
OPERATIONAL DATA						
BAROMETER, IN. HG.	29.40	29.40	29.40	29.40	29.40	29.40
AMBIENT TEMP. DEG. F	78	78	78	78	78	78
WET BULB TEMP. DEG. F	61	61	61	60	60	60
REL. HUMIDITY PERCENT	34	34	34	31	31	31
SP. HUMIDITY GRAIN/LB	49	49	49	44	44	44
ENGINE SPEED RPM	350	350	350	350	350	350
HORSEPOWER	4700	4920	5200	5600	5600	5600
SCAV. AIR PRES. IN.HG.	15.4	15.6	16.2	16.9	19.7	21.2
IGNIT. TIME DEG. BTDC	19.0	18.5	18.2	17.6	18.7	18.8
FUEL SP. GR. (STP)	.6300	.6300	.6300	.6300	.6300	.6300
HI HEAT VALUE BTU/SCF	1007	1007	1007	1007	1007	1007
ORIFICE CONSTANT	1564.62	1564.46	1564.31	1564.15	1563.99	1563.99
FUEL TEMP. DEG. F	43.0	43.0	43.0	43.0	43.0	43.0
ORIFICE DP IN. H2O	5.8	6.0	6.3	6.7	7.1	7.5
ORIFICE STAT.PRES.PSIA	80.7	80.7	80.7	80.7	80.7	80.7
FUEL FLOW SCFH	33850	34425	35272	36371	37437	38477
HEAT FLOW MIL. BTU/HR	34.087	34.666	35.519	36.625	37.699	38.746
FUEL FLOW LB/HR	1631	1659	1700	1753	1804	1854
AIR FLOW LB/HR	50043	51003	51526	53136	58680	60625
AIR/FUEL RATIO	30.7	30.7	30.3	30.3	32.5	32.7
BSFC BTU/HP HR	7253	7046	6831	6540	6732	6919
EXHAUST EMISSIONS						
NOX PPM	1560.00	1575.00	1680.00	1650.00	1185.00	1110.00
NO PPM	1140.00	1185.00	1260.00	1275.00	900.00	810.00
NO2 PPM	420.00	390.00	420.00	375.00	285.00	300.00
CO2 PERCENT	5.11	5.11	5.18	5.18	4.76	4.63
HC PPM	1000.00	880.00	880.00	880.00	1500.00	2500.00
CO PPM	216.00	216.00	208.00	203.00	316.00	372.00
O2 PERCENT	11.70	11.50	11.10	11.10	11.80	12.20
NO/NOX	.731	.752	.750	.773	.759	.730
NON-METH/TOTAL HC	.074	.074	.074	.074	.074	.074
NOX LB/HR	129.983	133.769	144.284	146.136	115.608	111.852
HC LB/HR TOTAL	31.178	27.967	28.280	29.164	54.759	94.265
HC LB/HR NON-METH	2.307	2.070	2.093	2.158	4.052	6.976
CO LB/HR	10.958	11.170	10.876	10.947	18.770	22.823
NOX LB/MIL BTU	3.813	3.859	4.062	3.990	3.067	2.887
HC LB/MIL BTU TOTAL	.915	.807	.796	.796	1.453	2.433
HC LB/MIL BTU NON-METH	.068	.060	.059	.059	.107	.180
CO LB/MIL BTU	.321	.322	.306	.299	.498	.589
NOX GR/HP HR	12.545	12.333	12.586	11.837	9.364	9.060
HC GR/HP HR TOTAL	3.009	2.578	2.467	2.362	4.435	7.635
HC GR/HP HR NON-METH	.223	.191	.183	.175	.328	.565
CO GR/HP HR	1.058	1.030	.949	.887	1.520	1.849

TABLE C-65 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 65, TEST SITE 65
WORTHINGTON SUTC-8, RATED 2000 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3	4	5
DATE	5/18/73	5/18/73	5/18/73	5/18/73	5/18/73
TIME	1250	1310	1325	1340	1400
OPERATIONAL DATA					
BAROMETER, IN. HG.	29.23	29.23	29.23	29.23	29.23
AMBIENT TEMP. DEG. F	86	86	87	88	88
WET BULB TEMP. DEG. F	62	62	62	63	63
REL. HUMIDITY PERCENT	21	21	19	20	20
SP. HUMIDITY GRAIN/LB	39	39	37	40	40
ENGINE SPEED RPM	300	306	290	280	300
HORSEPOWER	2100	2142	2030	1960	1900
SCAV. AIR PRES. IN.HG.	12.0	12.3	11.3	10.7	11.9
IGNIT. TIME DEG. BTDC	15	15	15	15	15
FUEL SP. GR. (STP)	.6860	.6860	.6860	.6860	.6860
HI HEAT VALUE BTU/SCF	971	971	971	971	971
ORIFICE CONSTANT	567.09	567.07	567.12	567.19	567.09
FUEL TEMP. DEG. F	75.0	75.0	75.0	75.0	75.0
ORIFICE DP IN. H2O	2.9	3.0	2.8	2.6	2.9
ORIFICE STAT.PRES.PSIA	74.7	74.7	74.7	74.7	74.7
FUEL FLOW SCFH	8347	8489	8202	7905	8347
HEAT FLOW MIL. BTU/HR	8.105	8.243	7.964	7.675	8.105
FUEL FLOW LB/HR	438	445	430	415	438
AIR FLOW LB/HR	14355	15492	15671	15310	15691
AIR/FUEL RATIO	32.8	34.8	36.4	36.9	35.8
BSFC BTU/HP HR	3859	3848	3923	3916	4266
EXHAUST EMISSIONS					
NOX PPM	295.00	311.00	270.00	276.00	250.00
NO PPM	270.00	280.00	240.00	250.00	230.00
NO2 PPM	25.00	31.00	30.00	26.00	20.00
CO2 PERCENT	3.96	3.75	3.57	3.51	3.63
HC PPM	2500.00	2200.00	2300.00	2400.00	2300.00
CO PPM	386.00	404.00	362.00	362.00	382.00
O2 PERCENT	13.60	13.40	13.60	13.70	13.80
NO/NOX	.915	.900	.889	.906	.920
NON-METH/TOTAL HC	.118	.118	.118	.118	.118
NOX LB/HR	7.022	7.976	6.994	6.982	6.486
HC LB/HR TOTAL	25.770	24.435	25.802	26.290	25.840
HC LB/HR NON-METH	3.041	2.883	3.045	3.102	3.049
CO LB/HR	5.594	6.309	5.710	5.575	6.034
NOX LB/MIL BTU	.866	.968	.878	.910	.800
HC LB/MIL BTU TOTAL	3.180	2.964	3.240	3.425	3.188
HC LB/MIL BTU NON-METH	.375	.350	.382	.404	.376
CO LB/MIL BTU	.690	.765	.717	.726	.744
NOX GR/HP HR	1.517	1.689	1.563	1.616	1.548
HC GR/HP HR TOTAL	5.566	5.174	5.765	6.084	6.169
HC GR/HP HR NON-METH	.657	.611	.680	.718	.728
CO GR/HP HR	1.208	1.336	1.276	1.290	1.440

TABLE C-66 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 66, TEST SITE 10
WORTHINGTON SUTC-8, RATED 2000 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3
DATE	5/18/73	5/18/73	5/18/73
TIME	1510	1530	1545
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.19	29.19	29.19
AMBIENT TEMP. DEG. F	90	91	92
WET BULB TEMP. DEG. F	63	63	63
REL. HUMIDITY PERCENT	17	16	14
SP. HUMIDITY GRAIN/LB	37	35	33
ENGINE SPEED RPM	300	290	280
HORSEPOWER	1900	1836	1773
SCAV. AIR PRES. IN.HG.	11.1	10.7	10.2
IGNIT. TIME DEG. BTDC	15	15	15
FUEL SP. GR. (STP)	.6860	.6860	.6860
HI HEAT VALUE BTU/SCF	971	971	971
ORIFICE CONSTANT	385.48	385.48	385.52
FUEL TEMP. DEG. F	76.0	76.0	76.0
ORIFICE DP IN. H2O	7.1	6.9	6.2
ORIFICE STAT.PRES.PSIA	74.3	74.3	74.3
FUEL FLOW SCFH	8854	8728	8274
HEAT FLOW MIL. BTU/HR	8.597	8.475	8.034
FUEL FLOW LB/HR	465	458	434
AIR FLOW LB/HR	15109	14839	14226
AIR/FUEL RATIO	32.5	32.4	32.8
BSFC BTU/HP HR	4525	4616	4532
EXHAUST EMISSIONS			
NOX PPM	340.00	325.00	330.00
NO PPM	280.00	270.00	275.00
NO2 PPM	60.00	55.00	55.00
CO2 PERCENT	4.11	4.11	4.05
HC PPM	1500.00	1650.00	1800.00
CO PPM	220.00	208.00	203.00
O2 PERCENT	13.50	13.20	13.40
NO/NOX	.824	.831	.833
NON-METH/TOTAL HC	.118	.118	.118
NOX LB/HR	8.518	8.001	7.784
HC LB/HR TOTAL	16.274	17.590	18.387
HC LB/HR NON-METH	1.920	2.076	2.170
CO LB/HR	3.356	3.118	2.915
NOX LB/MIL BTU	.991	.944	.969
HC LB/MIL BTU TOTAL	1.893	2.076	2.288
HC LB/MIL BTU NON-METH	.223	.245	.270
CO LB/MIL BTU	.390	.368	.363
NOX GR/HP HR	2.034	1.977	1.991
HC GR/HP HR TOTAL	3.885	4.346	4.704
HC GR/HP HR NON-METH	.458	.513	.555
CO GR/HP HR	.801	.770	.746

TABLE C-67 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 67, TEST SITE 10
WORTHINGTON SUTC-8, RATED 2000 HP, RATED 300 RPM, 2-STROKE TC

RUN	1	2	3
DATE	5/19/73	5/19/73	5/19/73
TIME	940	955	1015
OPERATIONAL DATA			
BAROMETER, IN. HG.	29.15	29.15	29.15
AMBIENT TEMP. DEG. F	76	76	77
WET BULB TEMP. DEG. F	60	61	63
REL. HUMIDITY PERCENT	36	39	43
SP. HUMIDITY GRAIN/LB	49	53	61
ENGINE SPEED RPM	300	290	280
HORSEPOWER	2150	2078	2006
SCAV. AIR PRES. IN.HG.	10.4	9.6	9.1
IGNIT. TIME DEG. BTDC	15	15	15
FUEL SP. GR. (STP)	.6860	.6860	.6860
HI HEAT VALUE BTU/SCF	971	971	971
ORIFICE CONSTANT	570.56	570.65	570.76
FUEL TEMP. DEG. F	73.0	73.0	73.0
ORIFICE DP IN. H2O	3.3	3.0	2.5
ORIFICE STAT.PRES.PSIA	76.2	76.2	76.7
FUEL FLOW SCFH	9048	8628	7904
HEAT FLOW MIL. BTU/HR	8.785	8.378	7.674
FUEL FLOW LB/HR	475	453	415
AIR FLOW LB/HR	15376	14867	14448
AIR/FUEL RATIO	32.4	32.8	34.8
BSFC BTU/HP HR	4086	4032	3826
EXHAUST EMISSIONS			
NOX PPM	795.00	700.00	625.00
NO PPM	710.00	610.00	570.00
NO2 PPM	85.00	90.00	55.00
CO2 PERCENT	4.05	4.05	3.87
HC PPM	2300.00	1700.00	1100.00
CO PPM	225.00	248.00	244.00
O2 PERCENT	14.00	13.90	13.10
NO/NOX	.893	.871	.912
NON-METH/TOTAL HC	.118	.118	.118
NOX LB/HR	20.256	17.239	14.946
HC LB/HR TOTAL	25.378	18.131	11.392
HC LB/HR NON-METH	2.995	2.139	1.344
CO LB/HR	3.490	3.719	3.553
NOX LB/MIL BTU	2.306	2.058	1.948
HC LB/MIL BTU TOTAL	2.889	2.164	1.484
HC LB/MIL BTU NON-METH	.341	.255	.175
CO LB/MIL BTU	.397	.444	.463
NOX GR/HP HR	4.274	3.763	3.380
HC GR/HP HR TOTAL	5.354	3.958	2.576
HC GR/HP HR NON-METH	.632	.467	.304
CO GR/HP HR	.736	.812	.803

TABLE C-68 EMISSION CONCENTRATION AND RATE SUMMARY

ENGINE TEST 68, TEST SITE 10
GENERAL ELECTRIC LM-1500, RATED 12500 HP

RUN	1	2	3	4
DATE	5/19/73	5/19/73	5/19/73	5/19/73
TIME	1115	1120	1125	1130
OPERATIONAL DATA				
BAROMETER, IN. HG.	29.60	29.60	29.60	29.60
AMBIENT TEMP. DEG. F	77	77	77	77
WET BULB TEMP. DEG. F	62	62	62	62
REL. HUMIDITY PERCENT	42	42	42	42
SP. HUMIDITY GRAIN/LB	59	59	59	59
ENGINE SPEED RPM	7100	7100	7100	7100
HORSEPOWER	12500	12500	12500	12500
SCAV. AIR PRES. IN.HG.	NA	NA	NA	NA
IGNIT. TIME DEG. BTDC	NA	NA	NA	NA
FUEL SP. GR. (STP)	.6860	.6860	.6860	.6860
HI HEAT VALUE BTU/SCF	971	971	971	971
ORIFICE CONSTANT	1666.45	1666.45	1666.45	1666.45
FUEL TEMP. DEG. F	53.0	53.0	53.0	53.0
ORIFICE DP IN. H2O	27.0	27.0	27.0	27.0
ORIFICE STAT.PRES.PSIA	300.0	300.0	300.0	300.0
FUEL FLOW SCFH	149980	149980	149980	149980
HEAT FLOW MIL. BTU/HR	145.631	145.631	145.631	145.631
FUEL FLOW LB/HR	7869	7869	7869	7869
AIR FLOW LB/HR	626720	627007	627092	609781
AIR/FUEL RATIO	79.6	79.7	79.7	77.5
BSFC BTU/HP HR	11650	11650	11650	11650
EXHAUST EMISSIONS				
NOX PPM	26.00	26.50	26.00	26.50
NO PPM	20.00	20.00	20.00	19.50
NO2 PPM	6.00	6.50	6.00	7.00
CO2 PERCENT	1.78	1.78	1.78	1.83
HC PPM	40.00	39.00	39.00	40.00
CO PPM	28.00	21.00	21.00	20.00
O2 PERCENT	15.40	15.40	15.50	15.50
NO/NOX	.769	.755	.769	.736
NON-METH/TOTAL HC	.118	.118	.118	.118
NOX LB/HR	26.442	26.963	26.454	26.229
HC LB/HR TOTAL	17.617	17.184	17.184	17.145
HC LB/HR NON-METH	2.079	2.028	2.028	2.023
CO LB/HR	17.338	13.009	13.009	12.052
NOX LB/MIL BTU	.182	.185	.182	.180
HC LB/MIL BTU TOTAL	.121	.118	.118	.118
HC LB/MIL BTU NON-METH	.014	.014	.014	.014
CO LB/MIL BTU	.119	.089	.089	.083
NOX GR/HP HR	.960	.978	.960	.952
HC GR/HP HR TOTAL	.639	.624	.624	.622
HC GR/HP HR NON-METH	.075	.074	.074	.073
CO GR/HP HR	.629	.472	.472	.437

Because of inconsistencies between O_2, NO_x and HC readings for the test of the GE LM-1500, the data are judged questionable and should not be considered representative without additional tests. Consequently, these data are not included in the summary.

Average Concentration Corrected to 15% O_2

NO_x	28.4 ppm
HC	41.7 ppm
CO	22.5 ppm

APPENDIX D

SUPPLEMENTARY BASELINE TABLES

TABLE D-1. PISTON ENGINE EMISSION RATE SUMMARY - TYPICAL VALUES

Engine No.	Engine Description	Site Code	Unit No.	Run No.	Emission Rate, lbs/hr				Emission Rate, lbs/10^6 BTU				Emission Rate, gr/Bhp-hr			
					NO_x	THC	NMHC	CO	NO_x	THC	NMHC	CO	NO_x	THC	NMHC	CO
1	Worthington UTC-10	1	10	3	108.427	21.330	2.560	0.683	5.710	1.123	0.135	0.036	28.088	5.525	0.663	0.177
2E	Worthington 26X36	1	6	3	28.380	4.497	0.328	95.763	1.813	0.287	0.021	6.119	8.236	1.305	0.095	27.791
2W	Worthington 26X36	1	6	3	48.025	4.954	0.441	59.979	3.069	0.317	0.028	3.833	13.937	1.438	0.128	17.407
3	Ingersoll-Rand 412 KVS	1	17	3	94.847	11.771	0.694	4.459	4.838	0.600	0.035	0.227	20.236	2.511	0.148	0.951
4	Clark TCVC-16	1	21	1	203.628	45.415	3.497	86.247	3.028	0.675	0.052	1.283	11.681	2.605	0.201	4.948
6	C-B LSVA-16 SG	3	6	5	75.701	15.014	0.270	39.703	2.303	0.457	0.008	1.208	7.697	1.527	0.027	4.037
7	C-B LSVA-16 SG	3	5	4	99.010	12.700	0.483	40.842	3.142	0.403	0.015	1.296	10.115	1.297	0.049	4.172
8	C-B LSV-16 SG	3	4	1	75.389	71.614	3.223	10.432	2.464	2.341	0.105	0.341	8.304	7.888	0.355	1.149
9	C-B LSV-16 SG	3	3	1	73.080	56.727	2.609	11.023	2.344	1.820	0.084	0.354	7.906	6.137	0.282	1.192
10	C-B LSV-16 SG	3	2	4	110.575	54.940	2.692	10.625	3.503	1.740	0.085	0.337	11.735	5.831	0.286	1.128
11	C-B LSV-16 SG	3	1	2	117.999	51.581	1.651	16.183	3.409	1.490	0.048	0.468	11.613	5.076	0.162	1.593
12	Clark TLA-6	4	1	1	41.752	19.930	0.458	13.727	2.322	1.108	0.025	0.763	9.279	4.429	0.102	3.051
13	Clark TLA-6	4	2	1	38.649	19.886	0.457	10.834	2.568	1.321	0.030	0.720	8.590	4.420	0.102	2.408
14	Clark TLA-6	4	3	1	47.876	18.948	0.436	13.634	2.742	1.085	0.025	0.781	10.609	4.199	0.097	3.021
17	Clark HBA-8T	5	7	1	23.178	39.391	1.103	7.707	1.382	2.305	0.066	0.460	5.350	9.093	0.255	1.779
18	Clark HBA-8T	5	8	1	20.655	42.186	1.181	11.067	1.173	2.396	0.067	0.628	4.557	9.307	0.261	2.442
19	Clark HBA-8T	5	9	1	32.426	31.331	0.877	12.319	1.870	1.807	0.051	0.710	7.037	6.800	0.190	2.674
20	Clark TLA-6	5	11	1	45.624	23.808	2.833	8.995	2.726	1.422	0.169	0.537	10.235	5.341	0.636	2.018
21	Clark TLA-6	5	12	1	45.711	14.364	0.776	9.980	2.762	0.868	0.047	0.603	9.949	3.126	0.169	2.172
22	Clark TLA-6	5	13	1	38.862	16.753	1.055	7.906	2.389	1.030	0.065	0.486	8.528	3.676	0.232	1.735
23	Clark TCV-12	5	15	3	70.830	48.658	3.601	27.313	2.262	1.554	0.115	0.872	8.177	5.618	0.416	3.153
24	Clark TCV-16	5	16	3	39.149	128.490	4.754	34.052	0.952	3.125	0.116	0.828	3.410	11.191	0.414	2.966

TABLE D-1(Cont'd). PISTON ENGINE EMISSION RATE SUMMARY - TYPICAL VALUES

Engine No.	Engine Description	Site Code	Unit No.	Run No.	Emission Rate, lbs/hr				Emission Rate, lbs/10^6BTU				Emission Rate, gr/Bhp-hr			
					NO_x	THC	NMHC	CO	NO_x	THC	NMHC	CO	NO_x	THC	NMHC	CO
25	C-B GMWA-6	6	4	2	38.563	22.550	0.451	1.627	3.056	1.787	0.036	0.129	11.600	6.783	0.136	0.489
26	C-B GMWA-6	6	5	2	37.354	21.338	0.533	2.099	2.897	1.655	0.041	0.163	11.258	6.431	0.161	0.633
27	C-B GMWA-6	6	6	2	62.094	19.375	0.388	1.520	4.938	1.541	0.031	0.121	18.591	5.801	0.116	0.455
28	C-B GMWC-6	6	7	1	50.768	25.096	1.330	4.221	2.954	1.460	0.077	0.246	11.018	5.447	0.289	0.916
29	C-B 14 V-250	6	8	1	195.568	49.399	3.162	9.576	5.170	1.306	0.084	0.253	18.481	4.668	0.299	0.905
31	C-B GMW-8	7	1	1	66.314	26.834	1.342	2.410	3.369	1.363	0.068	0.122	14.709	5.952	0.298	0.535
32	C-B GMW-8	7	2	1	64.125	17.929	0.717	2.245	3.638	1.017	0.041	0.127	14.293	3.996	0.160	0.500
33	C-B GMW-8	7	3	1	33.570	30.440	1.218	2.376	2.109	1.912	0.076	0.149	7.614	6.904	0.276	0.539
34	C-B GMWA-8	7	5	1	41.143	12.887	0.515	2.147	2.545	0.797	0.032	0.133	9.104	2.851	0.114	0.475
35	C-B GMWA-8	7	6	1	30.500	31.267	1.251	2.185	1.904	1.952	0.078	0.136	6.629	6.796	0.272	0.475
36	C-B GMWA-8	7	7	1	52.153	5.111	0.204	2.295	3.110	0.305	0.012	0.137	11.206	1.098	0.044	0.493
41	C-B GMV-10	8	2C	3	60.175	11.405	0.468	1.778	4.478	0.849	0.035	0.132	20.900	3.961	0.162	0.617
42	C-B GMV-10	8	3C	3	61.616	12.248	0.502	2.411	4.674	0.929	0.038	0.183	21.238	4.222	0.173	0.831
43	C-B GMV-10	8	4C	3	82.465	8.816	0.361	2.560	6.401	0.684	0.028	0.199	27.770	2.969	0.122	0.862
44	C-B GMV-10	8	6C	2	97.408	8.916	0.366	2.927	7.528	0.689	0.028	0.226	32.465	2.971	0.122	0.976
45	C-B GMW-8	8	7C	1	92.376	19.820	0.813	1.337	4.970	1.066	0.044	0.072	19.700	4.227	0.173	0.285
46	C-B GMW-8	8	8C	3	88.981	28.307	1.161	1.891	4.945	1.573	0.064	0.105	19.229	6.117	0.251	0.409
47	C-B 16 V-250	8	3D	1	216.735	47.570	1.665	18.049	5.062	1.111	0.039	0.422	17.810	3.909	0.137	1.483
48	C-B GMWC-10	8	2D	1	179.704	40.235	1.408	6.104	6.468	1.448	0.051	0.220	24.024	5.379	0.188	0.816
49	C-B GMWC-10	8	1D	1	170.876	41.719	1.460	5.029	6.229	1.521	0.053	0.183	23.234	5.673	0.199	0.684

TABLE D-1(Cont'd). PISTON ENGINE EMISSION RATE SUMMARY - TYPICAL VALUES

Engine No.	Engine Description	Site Code	Unit No.	Run No.	Emission Rate, lbs/hr				Emission Rate, lbs/10^6BTU				Emission Rate, gr/Bhp-hr			
					NO_x	THC	NMHC	CO	NO_x	THC	NMHC	CO	NO_x	THC	NMHC	CO
50	Clark TCVC-16	9	24	2	178.181	127.521	19.383	36.676	2.978	2.131	0.324	0.613	9.998	7.155	1.088	2.058
51	C-B 10 V-250	9	23	2	56.305	19.260	4.083	3.862	2.669	0.913	0.194	0.183	7.693	2.631	0.558	0.528
52	Clark TCV-16	9	21	2	70.744	45.795	8.609	19.080	2.155	1.395	0.262	0.581	5.651	3.658	0.688	1.524
53	Clark BA-8	9	19	1	44.970	31.715	6.660	10.538	3.083	2.174	0.457	0.723	11.860	8.364	1.756	2.779
54	Clark TLA-8	9	20	2	59.947	45.732	2.058	13.149	2.517	1.920	0.086	0.552	9.939	7.582	0.341	2.180
55	Clark BA-8	9	17	1	32.348	13.596	0.789	3.306	2.410	1.013	0.059	0.246	9.148	3.845	0.223	0.935
56*	I-R KVG-8	9	6	1	11.915	1.952	0.121	0.229	1.761	0.288	0.018	0.034	9.023	1.478	0.092	0.173
57	I-R KVG-8	9	4	1	23.550	1.263	0.021	0.730	2.974	0.160	0.003	0.092	13.982	0.750	0.013	0.434
58	I-R KVG-8	9	10	1	25.337	3.001	0.147	1.457	2.965	0.351	0.017	0.171	14.084	1.668	0.082	0.810
59	I-R 412 KVS	10	26	2	63.160	11.029	1.301	1.902	3.635	0.635	0.075	0.109	14.506	2.533	0.299	0.437
60	I-R 412 KVS	10	27	3	56.610	21.504	2.538	3.023	3.512	1.334	0.157	0.188	12.526	4.758	0.561	0.669
61	I-R 412 KVS	10	28	4	67.129	11.150	1.316	2.090	3.818	0.634	0.075	0.119	15.278	2.538	0.299	0.476
62	I-R 616 KVT	10	29	1	69.967	24.183	1.790	9.033	2.768	0.957	0.071	0.357	8.076	2.791	0.207	1.043
63	I-R 616 KVR	10	30	4	122.629	25.092	1.857	11.130	3.468	0.710	0.053	0.315	10.022	2.051	0.152	0.910
64	I-R 616 KVR	10	31	4	146.136	29.164	2.158	10.947	3.990	0.796	0.059	0.299	11.837	2.362	0.175	0.887
65	Worthington SUTC-8	10	25	1	7.022	25.770	3.041	5.594	0.866	3.180	0.375	0.690	1.517	5.566	0.657	1.208
66	Worthington SUTC-8	10	23	1	8.518	16.274	1.920	3.356	0.991	1.893	0.223	0.390	2.034	3.885	0.458	0.801
67	Worthington SUTC-8	10	24	1	20.256	25.378	2.995	3.490	2.306	2.889	0.341	0.397	4.274	5.354	0.632	0.736

* Grossly under rated load and speed

TABLE D-2. CLARK ENGINE EMISSION RATES AT RATED SPEED AND LOAD

Group	Type	E-S-U-R*	NO_x Emission Rate lbs/hr	NO_x Emission Rate lbs/10^6BTU	NO_x Emission Rate gr/hp-hr	Total Hydrocarbon Emission Rate lbs/hr	Total Hydrocarbon Emission Rate lbs/10^6BTU	Total Hydrocarbon Emission Rate gr/hp-hr	Non-Methane HC Emission Rate lbs/hr	Non-Methane HC Emission Rate lbs/10^6BTU	Non-Methane HC Emission Rate gr/hp-hr	CO Emission Rate lbs/hr	CO Emission Rate lbs/10^6BTU	CO Emission Rate gr/hp-hr
P-1	BA-8	53-9-19-1	44.970	3.083	11.860	31.715	2.174	8.364	6.660	0.457	1.756	10.538	0.723	2.779
P-1	BA-8	55-9-17-1	32.348	2.410	9.148	13.596	1.013	3.845	0.789	0.059	0.223	3.306	0.246	0.935
		AVERAGE	38.659	2.747	10.504	22.655	1.593	6.105	3.725	0.258	0.990	6.922	0.485	1.857
P-2	HBA-8T	17-5-7-1	23.178	1.382	5.350	39.391	2.350	9.093	1.103	0.066	0.255	7.707	0.460	1.779
P-2	HBA-8T	18-5-8-1	20.655	1.173	4.557	42.186	2.396	9.307	1.181	0.067	0.261	11.067	0.628	2.442
P-2	HBA-8T	19-5-9-1	32.426	1.870	7.037	31.331	1.807	6.800	0.877	0.050	0.190	12.319	0.710	2.674
		AVERAGE	25.420	1.475	5.648	37.636	2.184	8.400	1.054	0.061	0.235	10.364	0.599	2.298
P-3	TLA-6	12-4-1-1	41.752	2.322	9.279	19.930	1.108	4.429	0.458	0.025	0.102	13.727	0.763	3.051
P-3	TLA-6	13-4-2-1	38.649	2.568	8.590	19.886	1.321	4.420	0.457	0.030	0.102	10.834	0.720	2.408
P-3	TLA-6	14-4-3-1	47.876	2.742	10.609	18.948	1.085	4.199	0.436	0.025	0.097	13.634	0.781	3.021
P-3	TLA-6	20-5-11-1	45.624	2.726	10.235	23.808	1.422	5.341	2.833	0.169	0.636	8.995	0.537	2.018
P-3	TLA-6	21-5-12-1	45.711	2.762	9.949	14.364	0.868	3.126	0.776	0.047	0.169	9.980	0.603	2.172
P-3	TLA-6	22-5-13-1	38.862	2.389	8.528	16.753	1.030	3.676	1.055	0.065	0.232	7.906	0.486	1.735
		AVERAGE	43.079	2.585	9.532	18.948	1.139	4.199	1.003	0.060	0.223	10.846	0.648	2.401
P-4	TLA-8	54-9-20-2	59.947	2.517	9.939	45.732	1.920	7.582	2.058	0.086	0.341	13.149	0.552	2.180
P-5	TCV-12	23-5-15-3	70.830	2.262	8.177	48.658	1.554	5.618	3.601	0.116	0.416	27.313	0.872	3.153
P-6	TCV-16	24-5-16-3	39.149	0.952	3.410	128.490	3.125	11.191	4.754	0.116	0.414	34.052	0.828	2.966
P-6	TCV-16	52-9-21-2	70.744	2.155	5.651	45.795	1.395	3.658	8.609	0.262	0.688	19.080	0.581	1.524
		AVERAGE	54.947	1.553	4.531	87.143	2.260	7.425	6.681	0.189	0.551	26.566	0.705	2.245
P-7	TCVC-16	4-1-21-1	203.628	3.028	11.681	45.415	0.675	2.605	3.497	0.052	0.201	86.247	1.283	4.948
P-7	TCVC-16	50-9-24-2	178.181	2.978	9.998	127.521	2.131	7.155	19.383	0.324	1.088	36.676	0.613	2.058
		AVERAGE	190.905	3.003	10.839	86.468	1.403	4.880	11.440	0.188	0.645	61.461	0.948	3.503

* E-S-U-R = Engine - Site - Unit - Run

TABLE D-3. COOPER-BESSEMER ENGINE EMISSION RATES AT RATED SPEED AND LOAD

Group	Type	E-S-U-R*	NO_x Emission Rate lbs/hr	NO_x lbs/10^6BTU	NO_x gr/hp-hr	Total Hydrocarbon Emission Rate lbs/hr	THC lbs/10^6BTU	THC gr/hp-hr	Non-Methane HC Emission Rate lbs/hr	NMHC lbs/10^6BTU	NMHC gr/hp-hr	CO Emission Rate lbs/hr	CO lbs/10^6BTU	CO gr/hp-hr
P-8	GMV-10	41-8-2C-3	60.175	4.478	20.900	11.405	0.849	3.961	0.468	0.035	0.162	1.778	0.132	0.617
P-8	GMV-10	42-8-3C-3	61.616	4.674	21.238	12.248	0.929	4.222	0.502	0.038	0.173	2.411	0.183	0.813
P-8	GMV-10	43-8-4C-3	82.465	6.401	27.770	8.816	0.684	2.969	0.361	0.028	0.122	2.560	0.199	0.862
P-8	GMV-10	44-8-6C-2	97.408	7.528	32.465	8.916	0.689	2.971	0.366	0.028	0.122	2.927	0.226	0.976
		AVERAGE	75.416	5.770	25.533	10.346	0.808	3.531	0.424	0.032	0.145	2.419	0.185	0.817
P-9	GMWA-6	25-6-4-2	38.563	3.056	11.600	22.550	1.787	6.783	0.451	0.036	0.136	1.627	0.129	0.489
P-9	GMWA-6	26-6-5-2	37.354	2.897	11.258	21.338	1.655	6.431	0.533	0.041	0.161	2.099	0.163	0.633
P-9	GMWA-6	27-6-6-2	62.094	4.938	18.591	19.375	1.541	5.801	0.388	0.031	0.116	1.520	0.121	0.455
		AVERAGE	46.004	3.630	13.816	21.088	1.661	6.338	0.457	0.036	0.138	1.749	0.138	0.526
P-10	GMWC-6	28-6-7-1	50.768	2.954	11.018	25.096	1.460	5.447	1.330	0.077	0.289	4.221	0.246	0.916
P-11	GMW-8	31-7-1-1	66.314	3.369	14.709	26.834	1.363	5.952	1.342	0.068	0.298	2.410	0.122	0.535
P-11	GMW-8	32.7-2-1	64.125	3.638	14.293	17.929	1.017	3.996	0.717	0.041	0.160	2.245	0.127	0.500
P-11	GMW-8	33-7-3-1	33.570	2.109	7.614	30.440	1.912	6.904	1.218	0.076	0.276	2.376	0.149	0.539
P-11	GMW-8	45-8-7C-1	92.376	4.970	18.909	19.820	1.066	4.057	0.813	0.044	0.166	1.337	0.072	0.274
P-11	GMW-8	46-8-8C-3	88.981	4.945	18.738	28.307	1.573	5.961	1.161	0.064	0.244	1.891	0.105	0.398
		AVERAGE	69.073	3.806	14.853	24.666	1.386	5.374	1.050	0.059	0.229	2.052	0.115	0.449
P-12	GMWA-8	34-7-5-1	41.143	2.545	9.104	12.887	0.797	2.851	0.515	0.032	0.114	2.147	0.133	0.475
P-12	GMWA-8	35-7-6-1	30.500	1.904	6.629	31.267	1.952	6.796	1.251	0.078	0.272	2.185	0.136	0.475
P-12	GMWA-8	36-7-7-1	52.153	3.110	11.206	5.111	0.305	1.098	0.204	0.012	0.044	2.295	0.137	0.493
		AVERAGE	41.265	2.520	8.980	16.455	1.018	3.582	0.657	0.041	0.143	2.209	0.135	0.481
P-13	GMWC-10	48-8-2D-1	179.704	6.468	24.024	40.235	1.448	5.379	1.408	0.051	0.188	6.104	0.220	0.816
P-13	GMWC-10	49-8-3D-1	170.876	6.229	23.234	41.719	1.521	5.673	1.460	0.053	0.199	5.029	0.183	0.684
		AVERAGE	175.290	6.349	23.629	40.977	1.484	5.526	1.434	0.052	0.193	5.567	0.201	0.750

* E-S-U-R = Engine - Site - Unit - Run

TABLE D-3(Cont'd). COOPER-BESSEMER ENGINE EMISSION RATES AT RATED SPEED AND LOAD

Group	Type	E-S-U-R*	NO_x Emission Rate			Total Hydrocarbon Emission Rate			Non-Methane HC Emission Rate			CO Emission Rate		
			lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr
P-14	LSV-16 SG	8-3-3-1	75.389	2.464	8.304	71.614	2.341	7.888	3.223	0.105	0.355	10.432	0.341	1.149
P-14	LSV-16 SG	9-3-2-1	73.080	2.344	7.906	56.727	1.820	6.137	2.609	0.084	0.282	11.023	0.354	1.192
P-14	LSV-16 SG	10-3-2-4	110.575	3.503	11.735	54.940	1.740	5.831	2.692	0.085	0.286	10.625	0.337	1.128
P-14	LSV-16 SG	11-3-1-2	117.999	3.409	11.613	51.581	1.490	5.076	1.651	0.048	0.162	16.183	0.468	1.593
		AVERAGE	94.261	2.930	9.889	58.715	1.848	6.233	2.544	0.081	0.271	12.066	0.375	1.276
P-15	LSVA-16-SG	6-3-6-5	75.701	2.303	7.697	15.014	0.457	1.527	0.270	0.008	0.027	39.703	1.208	4.037
P-15	LSVA-16-SG	7-3-5-4	99.010	3.142	10.115	12.700	0.403	1.297	0.483	0.015	0.049	40.842	1.296	4.172
		AVERAGE	87.355	2.723	8.906	13.857	0.430	1.412	0.377	0.011	0.038	40.273	1.252	4.105
P-16	10 V-250	51-9-23-3	89.920	4.237	12.285	30.280	1.427	4.137	5.178	0.244	0.707	3.860	0.182	0.527
P-17	14 V-250	29-6-8-1	195.568	5.170	18.481	49.399	1.306	4.668	3.162	0.084	0.299	9.576	0.253	0.905
P-18	16 V-250	47-8-3D-1	216.735	5.062	17.810	47.575	1.111	3.909	1.665	0.039	0.137	18.049	0.422	1.483

* E-S-U-R = Engine - Site - Unit - Run

TABLE D-4. INGERSOLL-RAND ENGINE EMISSION RATES AT RATED SPEED AND LOAD

Group	Type	E-S-U-R*	NO_x Emission Rate			Total Hydrocarbon Emission Rate			Non-Methane HC Emission Rate			CO Emission Rate		
			lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr
P-19	KVG-8	56-9-6-1	11.915	1.761	9.023	1.952	0.288	1.478	0.121	0.018	0.092	0.229	0.034	0.173
P-19	KVG-8	57-9-4-1	23.550	2.974	13.982	1.263	0.160	0.750	0.021	0.003	0.013	0.730	0.092	0.434
P-19	KVG-8	58-9-10-1	25.337	2.965	14.084	3.001	0.351	1.668	0.147	0.017	0.082	1.457	0.171	0.810
		AVERAGE	20.267	2.567	12.363	2.072	0.266	1.299	0.096	0.013	0.062	0.805	0.099	0.472
P-20	412-KVS	3-1-17-3	94.847	4.838	20.236	11.771	0.600	2.511	0.694	0.035	0.148	4.459	0.227	0.951
P-20	412-KVS	59-10-26-2	63.160	3.635	14.506	11.029	0.635	2.533	1.301	0.075	0.299	1.902	0.109	0.437
P-20	412-KVS	60-10-27-3	56.610	3.512	12.526	21.504	1.334	4.758	2.537	0.157	0.561	3.023	0.188	0.669
P-20	412-KVS	61-10-28-4	67.129	3.818	15.278	11.150	0.634	2.538	1.316	0.075	0.299	2.090	0.119	0.476
		AVERAGE	70.437	3.951	15.637	13.863	0.801	3.085	1.462	0.085	0.327	2.846	0.161	0.633
P-21	616 KVT	62-10-29-1	69.967	2.768	8.076	24.183	0.957	2.791	1.790	0.071	0.207	9.033	0.357	1.043
P-22	616 KVR	63-10-30-4	122.629	3.468	10.022	25.092	0.710	2.051	1.857	0.053	0.152	11.130	0.315	0.910
P-22	616 KVR	64-10-31-4	146.136	3.990	11.837	29.164	0.796	2.362	2.158	0.059	0.175	10.947	0.299	0.887
		AVERAGE	134.383	3.729	10.929	27.128	0.753	2.207	2.007	0.056	0.163	11.039	0.307	0.899

* E-S-U-R = Engine - Site - Unit - Run

TABLE D-5. WORTHINGTON ENGINE EMISSION RATES AT RATED SPEED AND LOAD

Group	Type	E-S-U-R*	NO_x Emission Rate			Total Hydrocarbon Emission Rate			Non-Methane HC Emission Rate			CO Emission Rate		
			lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr
P-23	26X36	2E-1-6-3	28.380	1.813	8.236	4.497	0.287	1.305	0.328	0.021	0.095	95.763	6.119	27.791
P-23	26X36	2W-1-6-3	48.025	3.069	13.937	4.954	0.317	1.438	0.441	0.028	0.128	59.979	3.833	17.407
		AVERAGE	38.203	2.441	11.087	4.725	0.302	1.371	0.385	0.025	0.111	77.871	4.976	22.599
P-24	UTC-10	1-1-13-3	108.472	5.710	28.088	21.330	1.123	5.525	2.560	0.135	0.663	0.683	0.036	0.177
P-25	SUTC-8	65-10-25-1	7.022	0.866	1.517	25.770	3.180	5.566	3.041	0.375	0.657	5.594	0.690	1.208
P-25	SUTC-8	66-10-23-1	8.518	0.991	2.034	16.274	1.893	3.885	1.920	0.223	0.458	3.356	0.390	0.801
P-25	SUTC-8	67-10-24-1	20.256	2.306	4.274	25.378	2.889	5.354	2.995	0.341	0.632	3.490	0.397	0.736
		AVERAGE	11.932	1.388	2.608	22.474	2.654	4.935	2.652	0.313	0.582	4.147	0.492	0.915

* E-S-U-R = Engine - Site - Unit - Run

TABLE D-6. EMISSION RATE RANK ORDER FOR NO_x, THC AND CO BY ENGINE GROUP

Group	Engine	NO_x Emission Rate Rank Order*			THC Emission Rate Rank Order*			CO Emission Rate Rank Order*		
		lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr	lbs/hr	lbs/10^6BTU	gr/hp-hr
P-1	Clark BA-8	21	15	15	15	7	6	14	10	9
P-2	Clark HBA-8T	23	23	23	9	3	1	11	7	6
P-3	Clark TLA-6	19	17	18	19	16	15	10	6	5
P-4	Clark TLA-8	15	20	16	7	4	2	7	8	8
P-5	Clark TCV-12	11	22	21	5	8	7	4	4	4
P-6	Clark TCV-16	16	24	24	1	2	3	5	5	7
P-7	Clark TCVC-16	3	11	14	2	12	13	2	3	3
P-8	C-B GMV-10	10	2	2	23	20	19	20	18	17
P-9	C-B GMWA-6	18	10	8	18	6	4	23	21	21
P-10	C-B GMWC-6	17	12	12	12	10	10	16	16	13
P-11	C-B GMW-8	14	8	7	13	13	11	22	23	24
P-12	C-B GMWA-8	20	19	19	20	18	18	21	22	22
P-13	C-B GMWC-10	4	1	3	8	9	8	15	17	18
P-14	C-B LSV-16 SG	7	13	17	3	5	5	8	12	11
P-15	C-B LSVA-16 SG	9	16	20	22	23	23	3	2	2
P-16	C-B 10 V-250	8	6	10	10	11	16	18	19	20
P-17	C-B 14 V-250	2	4	4	4	14	14	12	15	15
P-18	C-B 16 V-250	1	5	5	6	17	17	6	11	10
P-19	I-R KVG-8	24	18	9	25	25	25	24	24	23
P-20	I-R 412 KVS	12	7	6	21	21	20	19	20	19
P-21	I-R 616 KVT	13	14	22	14	19	21	13	13	12
P-22	I-R 616 KVR	5	9	13	11	22	22	9	14	16
P-23	Worth 26X36	22	21	11	24	24	24	1	1	1
P-24	Worth UTC-10	6	3	1	17	15	9	25	25	25
P-25	Worth SUTC-8	25	25	25	16	1	12	17	9	14

* 1 = highest emitter; 25 = lowest emitter

TABLE D-7. EMISSION RATE RANK ORDER FOR NO_x, THC AND CO BY ENGINE

Rank Order*	NO_x lbs/hr	NO_x lbs/10^6BTU	NO_x gr/hp-hr	THC lbs/hr	THC lbs/10^6BTU	THC gr/hp-hr	CO lbs/hr	CO lbs/10^6BTU	CO gr/hp-hr
1	C-B 16 V-250	C-B GMWC-10	Worth UTC-10	Clark TCV-16	Worth SUTC-8	Clark HBA-8T	Worth 26X36	Worth 26X36	Worth 26X36
2	C-B 14 V-250	C-B GMV-10	C-B GMV-10	Clark TCVC-16	Clark TCV-16	Clark TLA-8	Clark TCVC-16	C-B LSVA-16 SG	C-B LSVA-16 SG
3	Clark TCVC-16	Worth UTC-10	C-B GMWC-10	C-B LSV-16 SG	Clark HBA-8T	Clark TCV-16	C-B LSVA-16 SG	Clark TCVC-16	Clark TCVC-16
4	C-B GMWC-10	C-B 14 V-250	C-B 14 V-250	C-B 14 V-250	Clark TLA-8	C-B GMWA-6	Clark TCV-12	Clark TCV-12	Clark TCV-12
5	I-R 616 KVR	C-B 16 V-250	C-B 16 V-250	Clark TCV-12	C-B LSV-16 SG	C-B LSV-16 SG	Clark TCV-16	Clark TCV-16	Clark TLA-6
6	Worth UTC-10	C-B 10 V-250	I-R 412 KVS	C-B 16 V-250	C-B GMWA-6	Clark BA-8	C-B 16 V-250	Clark TLA-6	Clark HBA-8T
7	C-B LSV-16 SG	I-R 412 KVS	C-B GMW-8	Clark TLA-8	Clark BA-8	Clark TCV-12	Clark TLA-8	Clark HBA-8T	Clark TCV-16
8	C-B 10 V-250	C-B GMW-8	C-B GMWA-6	C-B GMWC-10	Clark TCV-12	C-B GMWC-10	C-B LSV-16 SG	Clark TLA-8	Clark TLA-8
9	C-B LSVA-16 SG	I-R 616 KVR	I-R KVG-8	Clark HBA-8T	C-B GMWC-10	Worth UTC-10	I-R 616 KVR	Worth SUTC-8	Clark BA-8
10	C-B GMV-10	C-B GMWA-6	C-B 10 V-250	C-B 10 V-250	C-B GMWC-6	C-B GMWC-6	Clark TLA-6	Clark BA-8	C-B 16 V-250
11	Clark TCV-12	Clark TCVC-16	Worth 26X36	I-R 616 KVR	C-B 10 V-250	C-B GMW-8	Clark HBA-8T	C-B 16 V-250	C-B LSV-16 SG
12	I-R 412 KVS	C-B GMWC-6	C-B GMWC-6	C-B GMWC-6	Clark TCVC-16	Worth SUTC-8	C-B 14 V-250	C-B LSV-16 SG	I-R 616 KVT
13	I-R 616 KVT	C-B LSV-16 SG	I-R 616 KVR	C-B GMW-8	C-B GMW-8	Clark TCVC-16	I-R 616 KVT	I-R 616 KVT	C-B GMWC-6
14	C-B GMW-8	I-R 616 KVT	Clark TCVC-16	I-R 616 KVT	C-B 14 V-250	C-B 14 V-250	Clark BA-8	I-R 616 KVR	Worth SUTC-8
15	Clark TLA-8	Clark BA-8	Clark BA-8	Clark BA-8	Worth UTC-10	Clark TLA-6	C-B GMWC-10	C-B 14 V-250	C-B 14 V-250
16	Clark TCV-16	C-B LSVA-16 SG	Clark TLA-8	Worth SUTC-8	Clark TLA-6	C-B 10 V-250	C-B GMWC-6	C-B GMWC-6	I-R 616 KVR
17	C-B GMWC-6	Clark TLA-6	C-B LSV-16 SG	Worth UTC-10	C-B 16 V-250	C-B 16 V-250	Worth SUTC-8	C-B GMWC-10	C-B GMV-10
18	C-B GMWA-6	I-R KVG-8	Clark TLA-6	C-B GMWA-6	C-B GMWA-8	C-B GMWA-8	C-B 10 V-250	C-B GMV-10	C-B GMWC-10
19	Clark TLA-6	C-B GMWA-8	C-B GMWA-8	Clark TLA-6	I-R 616 KVT	C-B GMV-10	I-R 412 KVS	C-B 10 V-250	I-R 412 KVS
20	C-B GMWA-8	Clark TLA-8	C-B LSVA-16 SG	C-B GMWA-8	C-B GMV-10	I-R 412 KVS	C-B GMV-10	I-R 412 KVS	C-B 10 V-250
21	Clark BA-8	Worth 26X36	Clark TCV-12	I-R 412 KVS	I-R 412 KVS	I-R 616 KVT	C-B GMWA-8	C-B GMWA-6	C-B GMWA-6
22	Worth 26X36	Clark TCV-12	I-R 616 KVT	C-B LSVA-16 SG	I-R 616 KVR	I-R 616 KVR	C-B GMW-8	C-B GMWA-8	C-B GMWA-8
23	Clark HBA-8T	Clark HBA-8T	Clark HBA-8T	C-B GMV-10	C-B LSVA-16 SG	C-B LSVA-16 SG	C-B GMWA-6	C-B GMW-8	I-R KVG-8
24	I-R KVG-8	Clark TCV-16	Clark TCV-16	Worth 26X36	Worth 26X36	Worth 26X36	I-R KVG-8	I-R KVG-8	C-B GMW-8
25	Worth SUTC-8	Worth SUTC-8	Worth SUTC-8	I-R KVG-8	I-R KVG-8	I-R KVG-8	Worth UTC-10	Worth UTC-10	Worth UTC-10

* 1 = highest emitter; 25 = lowest emitter

TABLE D-8. RANK ORDER OF EMISSION RATES BY STROKES/CYCLE AND ASPIRATION (HIGH TO LOW)

Rank Order	NO_x Emission Rates lbs/hr	NO_x lbs/10^6BTU	NO_x gr/hp-hr	THC Emission Rates lbs/hr	THC lbs/10^6BTU	THC gr/hp-hr	CO Emission Rates lbs/hr	CO lbs/10^6BTU	CO gr/hp-hr
1	2-TC	2-TC	2-NA	2-TC	2-TC	2-TC	2-NA	2-NA	2-NA
2	2-TC	2-NA	2-NA	2-TC	2-TC	2-TC	2-TC	4-TC	4-TC
3	2-TC	2-NA	2-TC	4-TC	2-TC	2-TC	4-TC	2-TC	2-TC
4	2-TC	2-TC	2-TC	2-TC	2-TC	2-NA	2-TC	2-TC	2-TC
5	4-TC	2-TC	2-TC	2-TC	4-TC	4-TC	2-TC	2-TC	2-TC
6	2-NA	2-TC	4-TC	2-TC	2-NA	2-NA	2-TC	2-TC	2-TC
7	4-TC	4-TC	2-NA	2-TC	2-NA	2-TC	2-TC	2-TC	2-TC
8	2-TC	2-NA	2-NA	2-TC	2-TC	2-TC	4-TC	2-TC	2-TC
9	4-TC	4-TC	4-NA	2-TC	2-TC	2-NA	4-TC	2-TC	2-NA
10	2-NA	2-NA	2-TC	2-TC	2-TC	2-TC	2-TC	2-NA	2-TC
11	2-TC	2-TC	2-NA	4-TC	2-TC	2-NA	2-TC	2-TC	4-TC
12	4-TC	2-TC	2-TC	2-TC	2-TC	2-TC	2-TC	4-TC	4-TC
13	4-TC	4-TC	4-TC	2-NA	2-NA	2-TC	4-TC	4-TC	2-TC
14	2-NA	4-TC	2-TC	4-TC	2-TC	2-TC	2-NA	4-TC	2-TC
15	2-TC	2-NA	2-NA	2-NA	2-NA	2-TC	2-TC	2-TC	2-TC
16	2-TC	4-TC	2-TC	2-TC	2-TC	2-TC	2-TC	2-TC	4-TC
17	2-TC	2-TC	4-TC	2-NA	2-TC	2-TC	2-TC	2-TC	2-NA
18	2-NA	4-NA	2-TC	2-NA	2-NA	2-NA	2-TC	2-NA	2-TC
19	2-TC	2-NA	2-NA	2-TC	4-TC	2-NA	4-TC	2-TC	4-TC
20	2-NA	2-TC	4-TC	2-NA	2-NA	4-TC	2-NA	4-TC	2-TC
21	2-NA	2-NA	2-TC	4-TC	4-TC	4-TC	2-NA	2-NA	2-NA
22	2-NA	2-TC	4-TC	4-TC	4-TC	4-TC	2-NA	2-NA	2-NA
23	2-TC	2-TC	2-TC	2-NA	4-TC	4-TC	2-NA	2-NA	4-NA
24	4-NA	2-TC	2-TC	2-NA	2-NA	2-NA	4-NA	4-NA	2-NA
25	2-TC	2-TC	2-TC	4-NA	4-NA	4-NA	2-NA	2-NA	2-NA

TABLE D-9. BASELINE GAS TURBINE EMISSION RATES

GROUP	GAS TURBINE	E-S-U-R	NO_x Emission Rate lbs/hr	NO_x lbs/10^6 BTU	NO_x gr/hp-hr	THC Emission Rate lbs/hr	THC lbs/10^6 BTU	THC gr/hp-hr	NMHC Emission Rate lbs/hr	NMHC lbs/10^6 BTU	NMHC gr/hp-hr	CO Emission Rate lbs/hr	CO lbs/10^6 BTU	CO gr/hp-hr
T-1	GE Frame 3	SA-2-1-10	26.945	0.229	ND	0.103	0.001	ND	0.001	0.000	ND	1.367	0.012	ND
	GE Frame 3	5B-2-1-5	22.351	0.211	ND	1.212	0.011	ND	0.017	0.000	ND	3.696	0.035	ND
	GE Frame 3	5C-2-1-2	21.802	0.194	ND	0.798	0.007	ND	0.011	0.000	ND	1.327	0.012	ND
		Average	23.699	0.211	ND	0.704	0.006	ND	0.010	0.000	ND	2.130	0.020	ND
T-2	GE JP-200	15-4-1-3	46.481	0.304	1.387	1.836	0.012	0.055	0.042	0.000	0.000	19.008	0.124	0.567
T-3	GE M3112R	40-7-T4-2	47.971	0.465	1.813	1.195	0.012	0.045	ND	ND	ND	0.823	0.008	0.031
T-4	GE M3912R	39-7-T3-3	44.342	0.478	1.982	0.807	0.009	0.036	ND	ND	ND	1.191	0.013	0.053
T-5	GE LM1500	68-10-1-2	See Appendix Table C-69 on page C-89.											
T-6	P&W RT-105GT	16-4-1-5	46.800	0.329	1.646	3.017	0.021	0.106	0.069	0.000	0.002	14.795	0.104	0.520
T-7	P&W GG3C-4	30-6-1-1	36.521	0.245	1.209	2.099	0.014	0.069	0.042	0.000	0.001	16.677	0.112	0.552
T-8	Solar Saturn T-1001	37-7-T2-1	1.643	0.136	0.761	0.110	0.009	0.051	ND	ND	ND	1.775	0.147	0.821
T-8	Solar Saturn T-1001	38-7-T1-2	1.692	0.140	0.783	0.756	0.062	0.350	ND	ND	ND	2.459	0.203	1.138
		Average	1.667	0.138	0.772	0.433	0.035	0.201	ND	ND	ND	2.117	0.175	0.979

TABLE D-10. RANK ORDER OF GAS TURBINE NO_x EMISSIONS

Rank Order	Emission Rate			Concentration, PPM	
	lbs/hr	lbs/10^6 BTU	gr/hp-hr	As-Measured	Corrected - 15% O_2
1	GE M3112R	GE M3912R	GE M3912R	GE M3112R	P&W RT-105GT
2	P&W RT-105GT	GE M3112R	GE M3112R	GE M3912R	GE JP-200
3	GE JP-200	P&W RT-105GT	P&W RT-105GT	GE JP-200	GE M3912R
4	GE M3912R	GE JP-200	GE JP-200	P&W RT-105GT	GE M3112R
5	P&W GG3C-4	P&W GG3C-4	P&W GG3C-4	GE FRAME 3	P&W GG3C-4
6	GE FRAME 3	GE FRAME 3	SOLAR SATURN T-1001	P&W GG3C-4	GE FRAME 3
7	SOLAR SATURN T-1001	SOLAR SATURN T-1001	GE FRAME 3 (ND)	SOLAR SATURN T-1001	SOLAR SATURN T-1001

TABLE D-11. RANK ORDER OF GAS TURBINE THC EMISSIONS

Rank Order	Emission Rate			Concentration, PPM	
	lbs/hr	$lbs/10^6$ BTU	gr/hp-hr	As-Measured	Corrected - 15% O_2
1	P&W RT-105GT	SOLAR SATURN T-1001	SOLAR SATURN T-1001	SOLAR SATURN T-1001	SOLAR SATURN T-1001
2	P&W GG3C-4	P&W RT-105GT	P&W RT-105GT	P&W GG3C-4	P&W RT-105GT
3	GE JP 200	P&W GG3C-4	P&W GG3C-4	P&W RT-105GT	P&W GG3C-4
4	GE M3112R	GE JP 200	GE JP 200	GE JP 200	GE JP 200
5	GE M3912 R	GE M3112 R	GE M3112R	GE M3112R	GE M3112R
6	GE FRAME 3	GE M3912R	GE M3912R	GE FRAME 3	GE M3912R
7	SOLAR SATURN T-1001	GE FRAME 3	GE FRAME 3 (ND)	GE M3912R	GE FRAME 3

TABLE D-12. RANK ORDER OF GAS TURBINE CO EMISSIONS

Rank Order	Emission Rate			Concentration, PPM	
	lbs/hr	$lbs/10^6$ BTU	gr/hp-hr	As-Measured	Corrected - 15% O_2
1	GE JP-200	SOLAR SATURN T-1001	SOLAR SATURN T-1001	SOLAR SATURN T-1001	SOLAR SATURN T-1001
2	P&W GG3C-4	GE JP-200	GE JP-200	GE JP-200	GE JP-200
3	P&W RT-105GT	P&W GG3C-4	P&W GG3C-4	P&W GG3C-4	P&W RT-105GT
4	GE FRAME 3	P&W RT-105GT	P&W RT-105GT	P&W RT-105GT	P&W GG3C-4
5	SOLAR SATURN T-1001	GE FRAME 3	GE M3912R	GE FRAME 3	GE FRAME 3
6	GE M3912R	GE M3912R	GE M3112R	GE M3912R	GE M3912R
7	GE M3112R	GE M3112R	GE FRAME 3 (ND)	GE M3112R	GE M3112R

APPENDIX E

Emission Trends as a Function of Engine Operating Parameters

TABLE E-1. EMISSION TESTS CONDUCTED TO DETERMINE THE EFFECT OF HORSEPOWER (VARIABLE RPM) ON EMISSION RATES

			Appendix E Figure Number			
Group	Engine Model	Tests	lbs/hr	lbs/10^6 BTU	gr/hp-hr	ppm
P-2	Clark HBA-8T	17, 18, 19	E-1	text	E-2	E-3
P-3	Clark TLA-6	12, 13, 4	E-4	E-5	E-6	E-7
P-5	Clark TCV-12	23	E-8	E-9	E-10	E-11
P-6	Clark TCV-16	24	E-12	E-13	E-14	E-15
P-9	C-B GMWA-6	25, 26, 27	E-16	E-17	E-18	E-19
P-10	C-B GMWC-6	28	E-20	E-21	E-22	E-23
P-11	C-B GMW-8	33	E-24	E-25	E-26	E-27
P-12	C-B GMWA-8	34, 36	E-28	E-29	E-30	E-31
P-14	C-B LSV-16SG	8, 9, 10	E-32	E-33	E-34	E-35
P-15	C-B LSVA-16SG	6, 7	E-36	E-37	E-38	E-39
P-19	I-R KVG-8	56, 57	E-40	E-41	E-42	E-43

TABLE E-2. EMISSION TESTS CONDUCTED TO DETERMINE THE EFFECT OF HORSEPOWER (CONSTANT SPEED) ON EMISSION RATES

Group	Engine Model	Tests	Figure Number			
			lbs/hr	lbs/10^6 BTU	gr/hp-hr	ppm
P-1	Clark BA-8	53, 55	E-44	E-45	E-46	E-47
P-3	Clark TLA-6	22	E-48	E-49	E-50	E-51
P-7	Clark TCVC-16	50	E-52	E-53	E-54	E-55
P-8	C-B GMV-10	41	E-56	E-57	E-58	E-59
P-13	C-B GMWC-10	48, 49	E-60	text	E-61	E-62
P-18	C-B 16 V-250	47	E-63	E-64	E-65	E-66
P-20	I-R 412 KVS	59, 60, 61	E-67	E-68	E-69	E-70
P-22	I-R 616 KVR	63, 64	E-71	E-72	E-73	E-74

TABLE E-3. EMISSION TESTS CONDUCTED TO DETERMINE THE EFFECT OF IGNITION TIMING ON EMISSION RATES

Group	Engine Model	Tests	Figure Number lbs/hr	lbs/10^6 BTU	gr/hp-hr	ppm
P-2	Clark HBA-8T	19	E-75	E-76	E-77	E-78
P-3	Clark TLA-6	21	E-79	E-80	E-81	E-82
P-5	Clark TCV-12	23	E-83	E-84	E-85	E-86
P-8	C-B GMW-10	44	E-87	E-88	E-89	E-90
P-11	C-B GMW-8	45	E-91	E-92	E-93	E-94
P-13	C-B GMWC-10	48	E-95	E-96	E-97	E-98
P-14	C-B LSV-16 SG	8	E-99	E-100	E-101	E-102
P-16	C-B 10 V-250	51	E-103	E-104	E-105	E-106
P-19	I-R KVG-8	57	E-107	E-108	E-109	E-110
P-20	I-R 412 KVS	61	E-111	text	E-112	E-113
P-21	I-R 616 KVT	62	E-114	E-115	E-116	E-117

TABLE E-4. EMISSION TESTS CONDUCTED TO DETERMINE THE EFFECT OF SCAVENGING AIR PRESSURE OR EMISSION RATES

Group	Engine Model	Tests	Figure Number			
			lbs/hr	lbs/10^6 BTU	gr/hp-hr	ppm
P-2	Clark HBA-8	18	E-118	text	E-119	E-120
P-3	Clark TLA-6	20	E-121	E-122	E-123	E-124
P-6	Clark TCV-16	24	E-125	E-126	E-127	E-128
P-7	Clark TCVC-16	50	E-129	E-130	E-131	E-132
P-14	C-B LSV-16 SG	9	E-133	E-134	E-135	E-136
P-22	I-R 616 KVR	64	E-137	E-138	E-139	E-140

TABLE E-5. EMISSION TESTS CONDUCTED TO DETERMINE THE EFFECT OF ENGINE SPEED AT CONSTANT HORSEPOWER OR EMISSION RATES

Group	Engine Model	Tests	Figure Number			
			lbs/hr	lbs/10^6 BTU	gr/hp-hr	ppm
P-11	C-B GMW-8	31	E-141	text	E-142	E-143

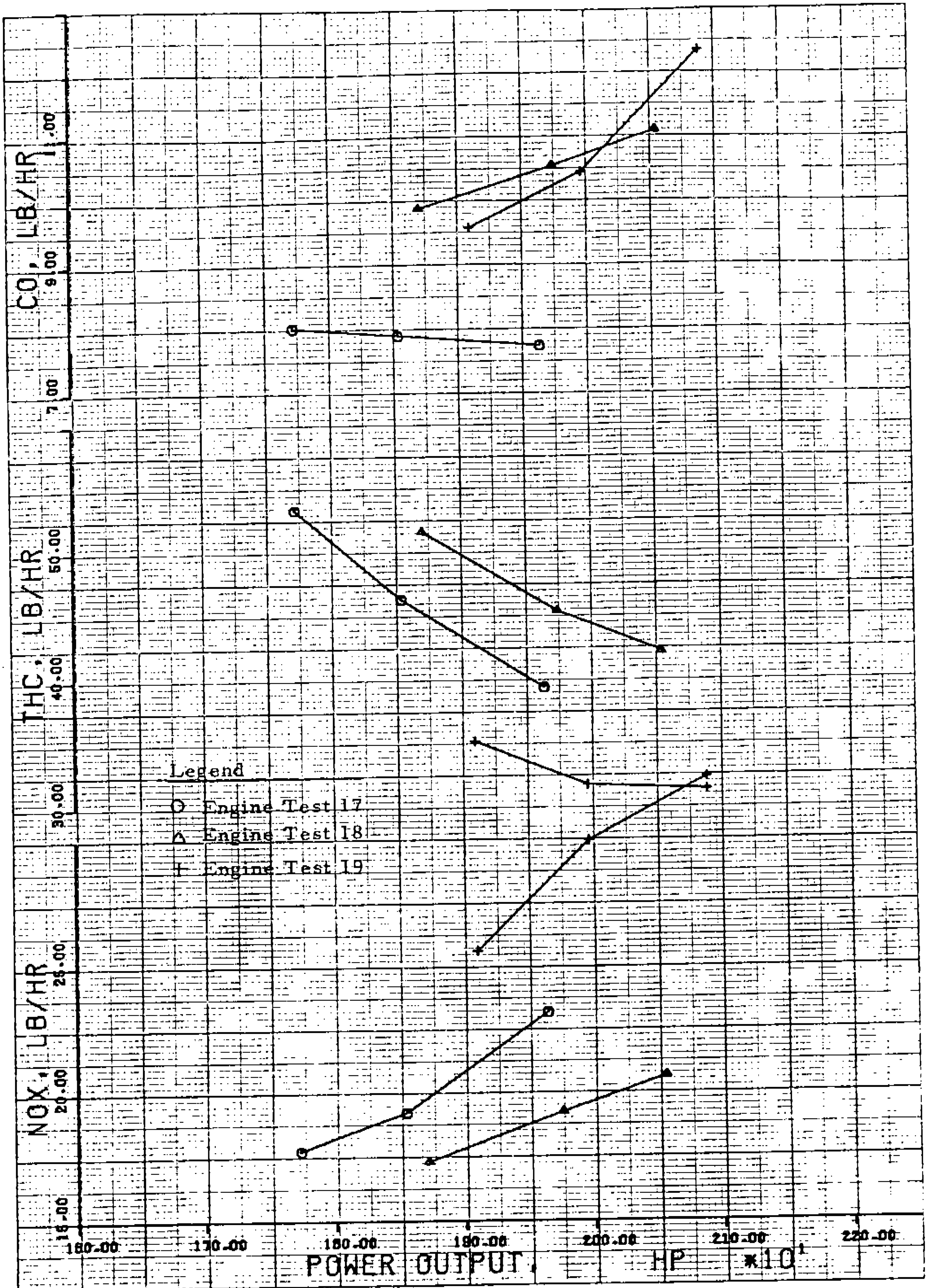


FIGURE E-1 EFFECT OF POWER ON CLARK HBA-8T LB/HR EMISSIONS

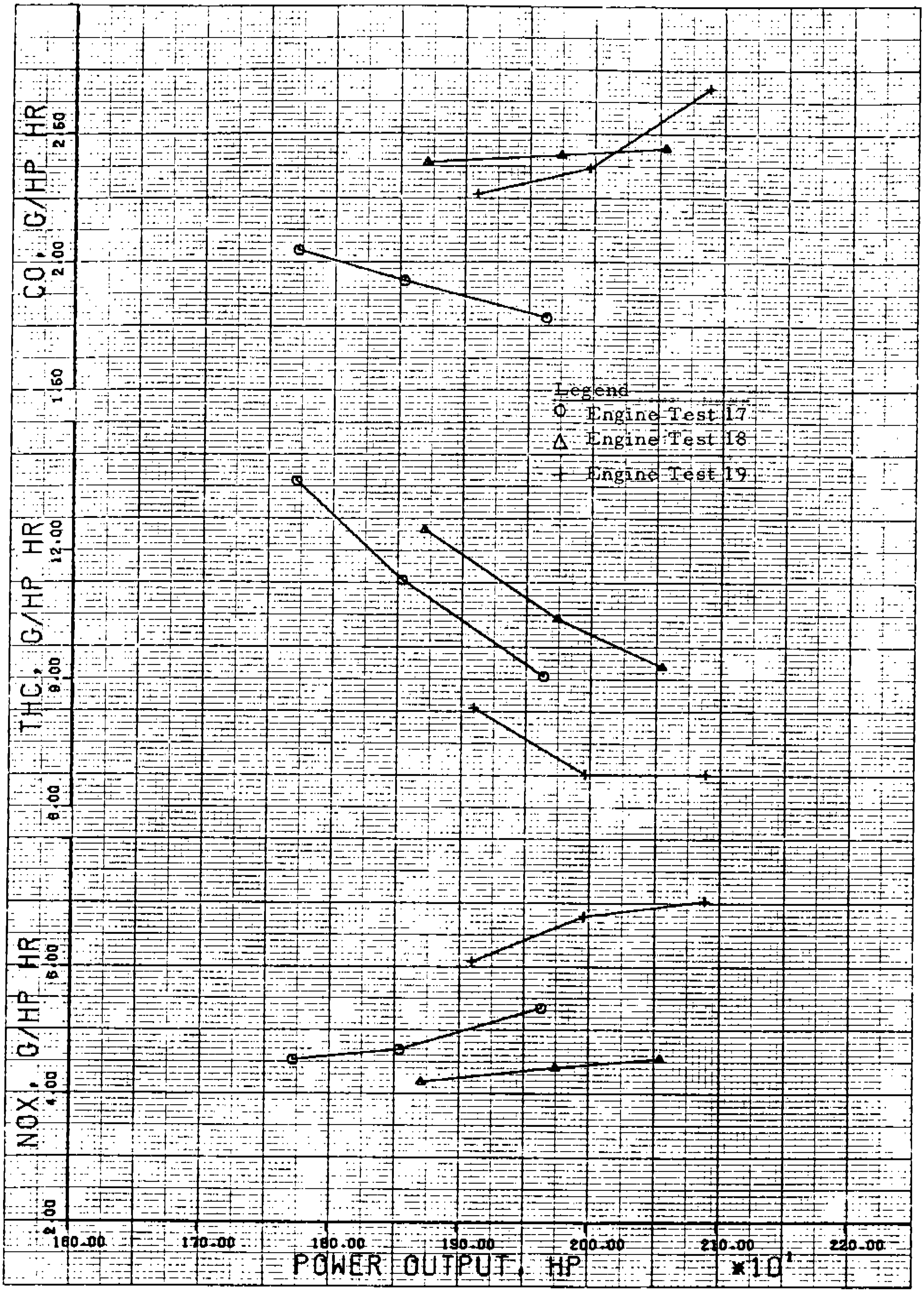


FIGURE E-2 EFFECT OF POWER ON CLARK HBA-8T G/HP-HR EMISSIONS

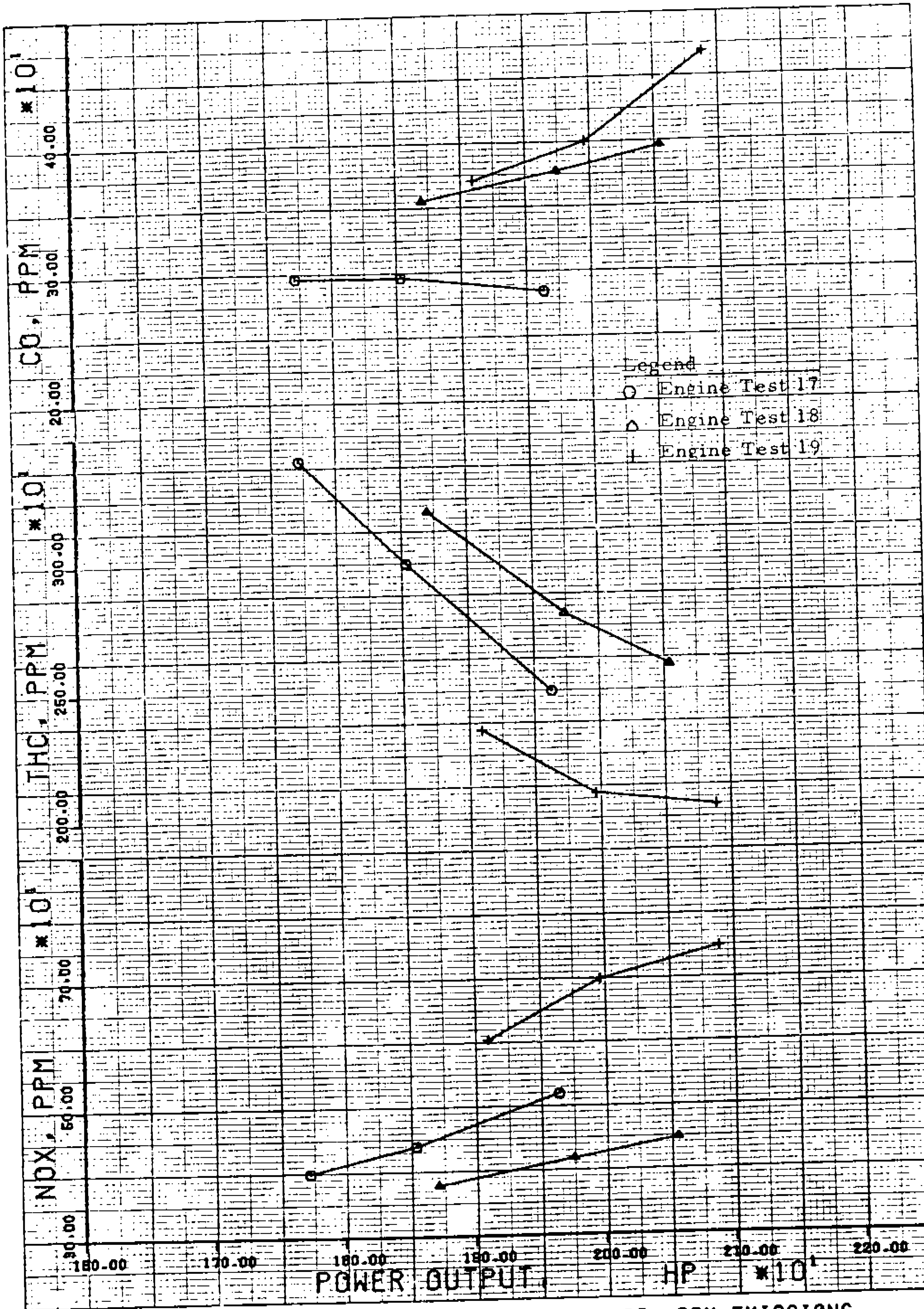


FIGURE E-3 EFFECT OF POWER ON CLARK HBA-8T PPM EMISSIONS

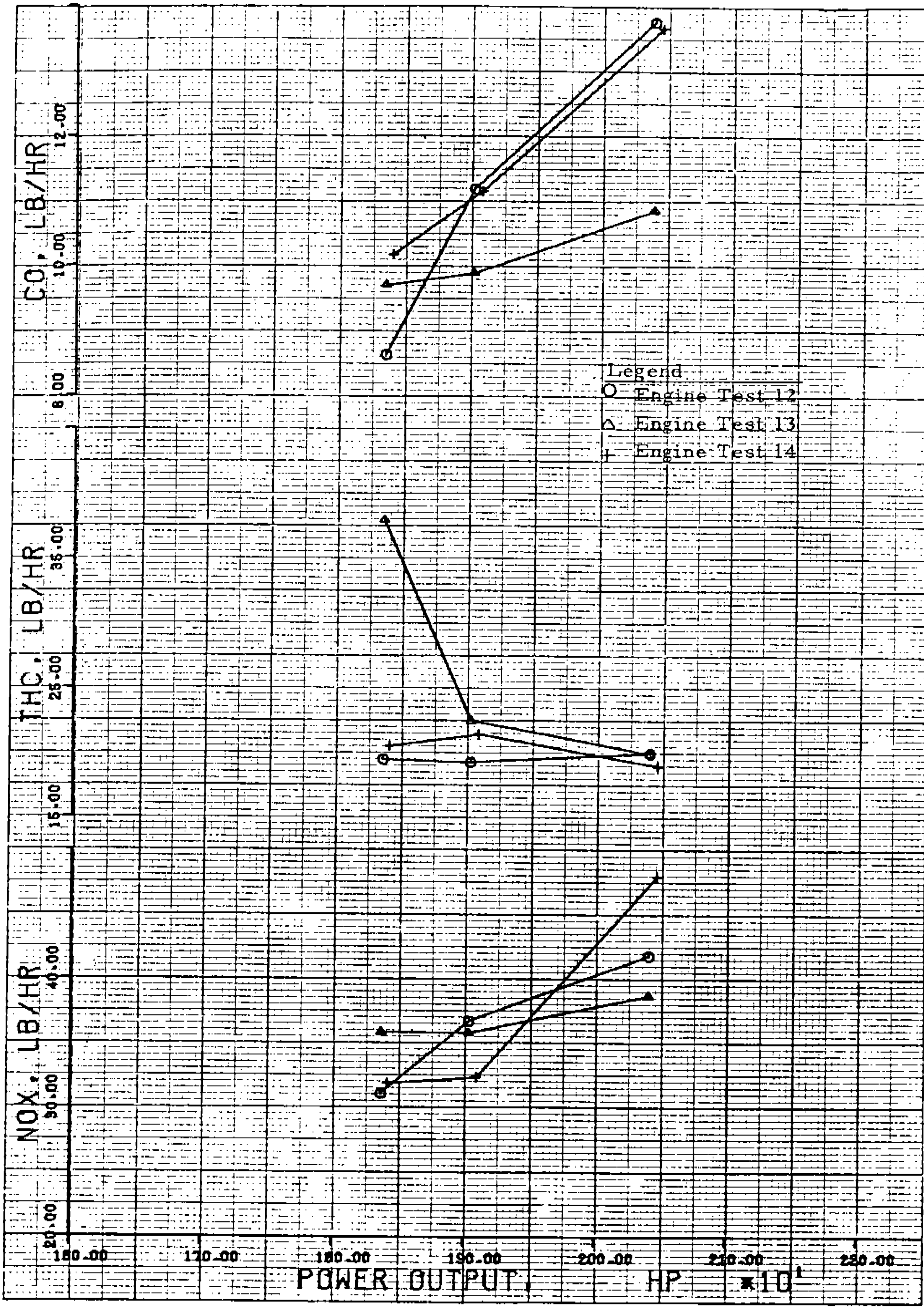


FIGURE E-4 EFFECT OF POWER ON CLARK TLA-6 LB/HR EMISSIONS

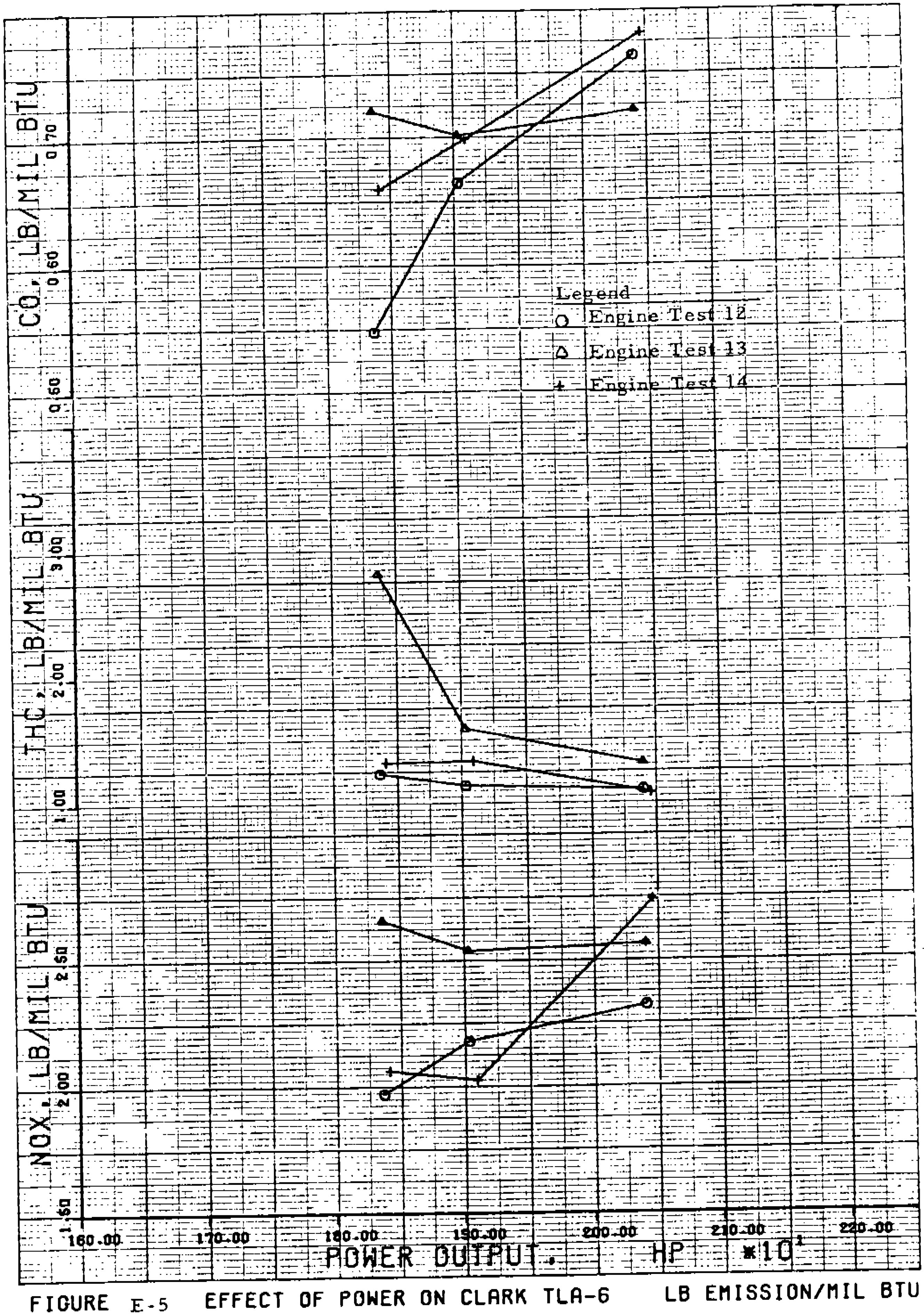


FIGURE E-5 EFFECT OF POWER ON CLARK TLA-6 LB EMISSION/MIL BTU

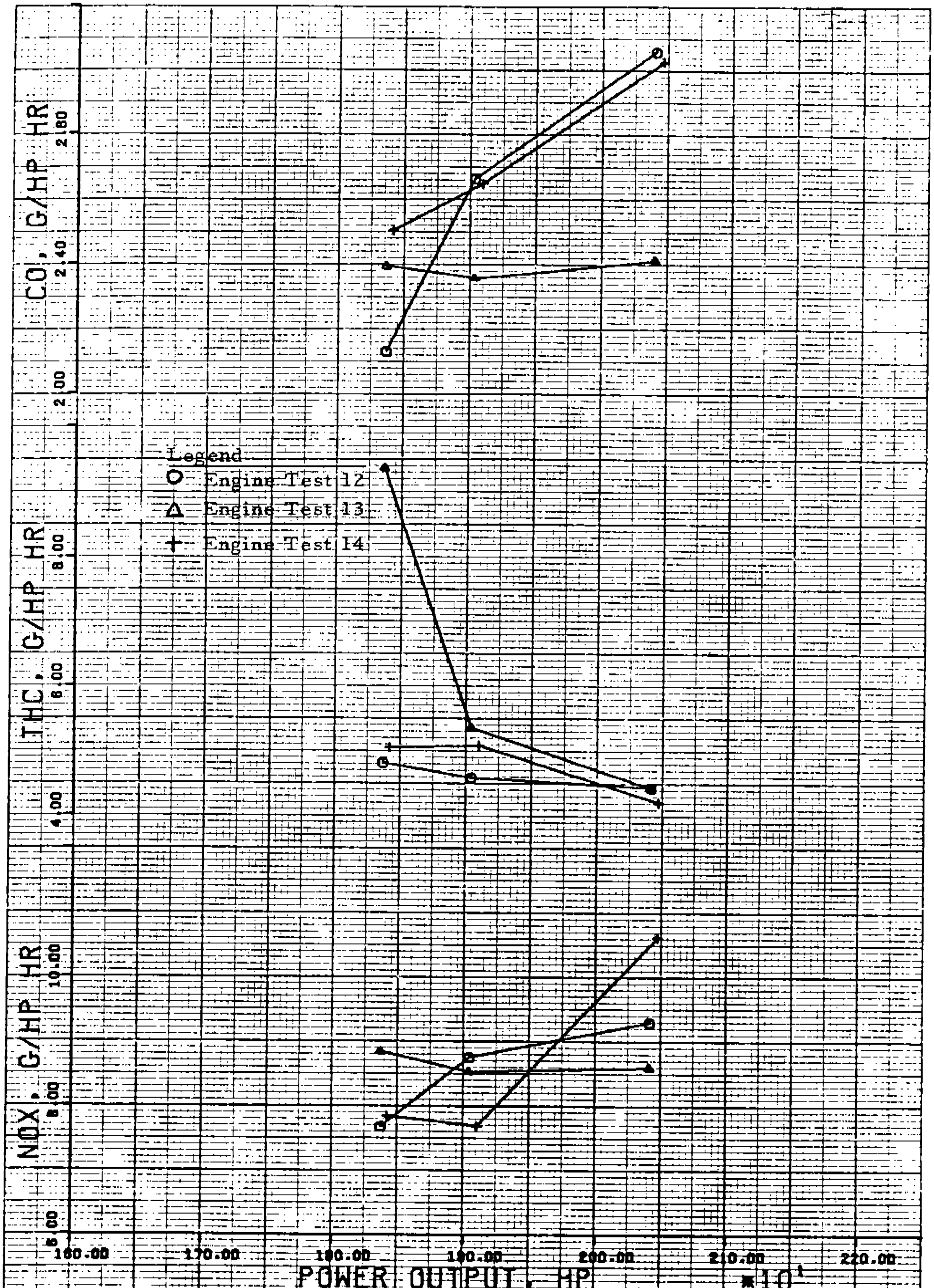


FIGURE E-6 EFFECT OF POWER ON CLARK TLA-6 G/HP-HR EMISSIONS

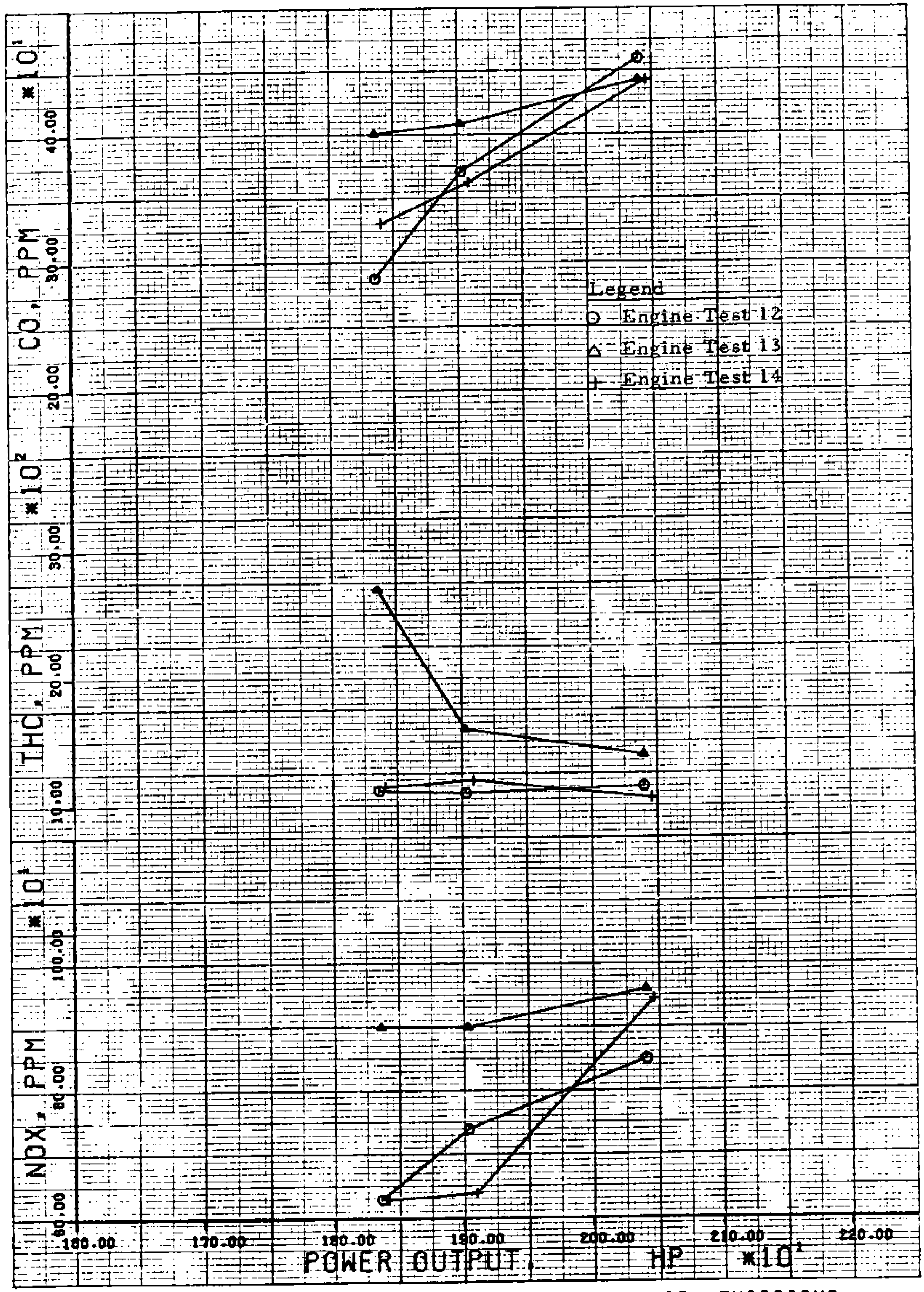


FIGURE E-7 EFFECT OF POWER ON CLARK TLA-6 PPM EMISSIONS

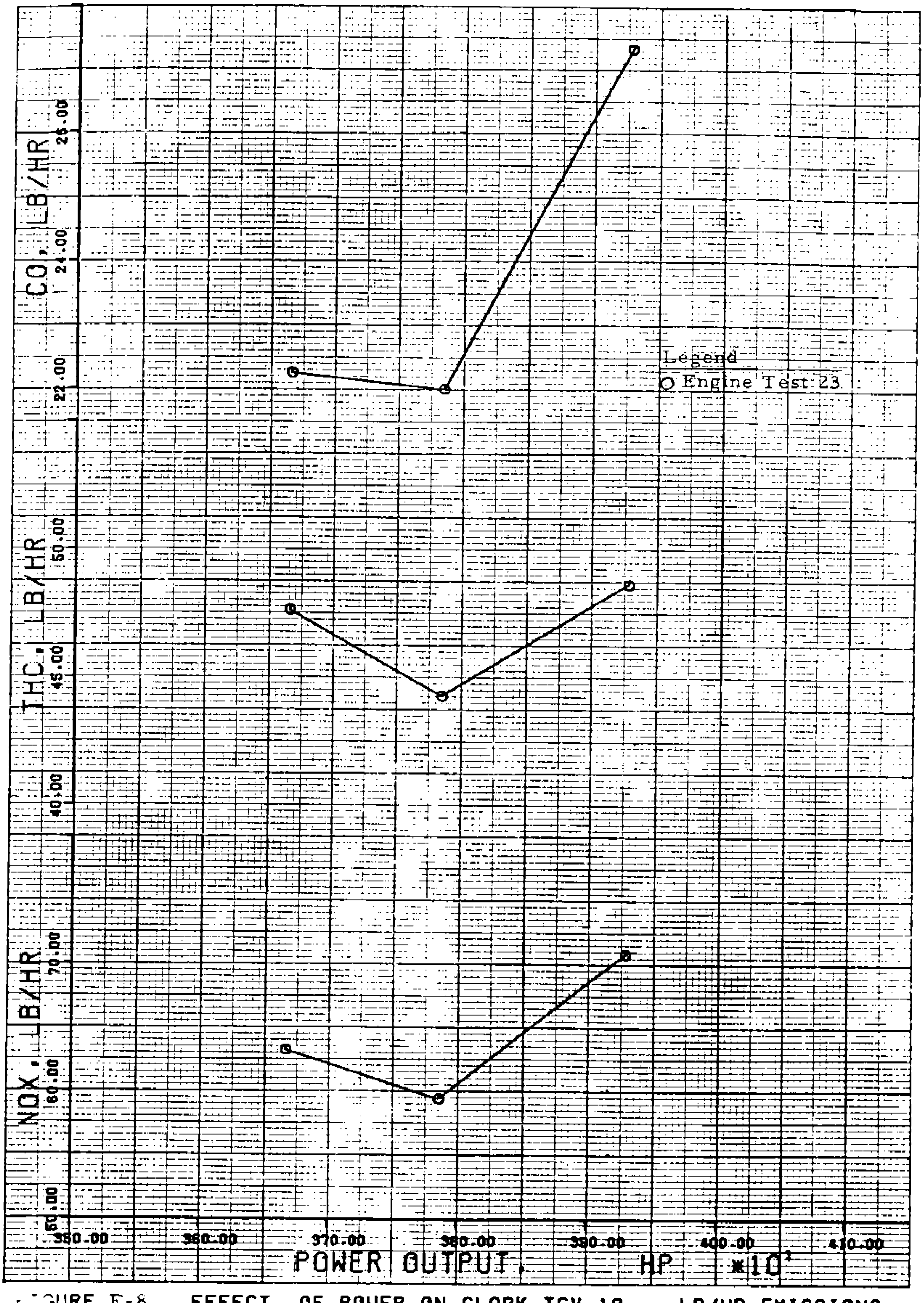


FIGURE E-8 EFFECT OF POWER ON CLARK TCV-12 LB/HR EMISSIONS

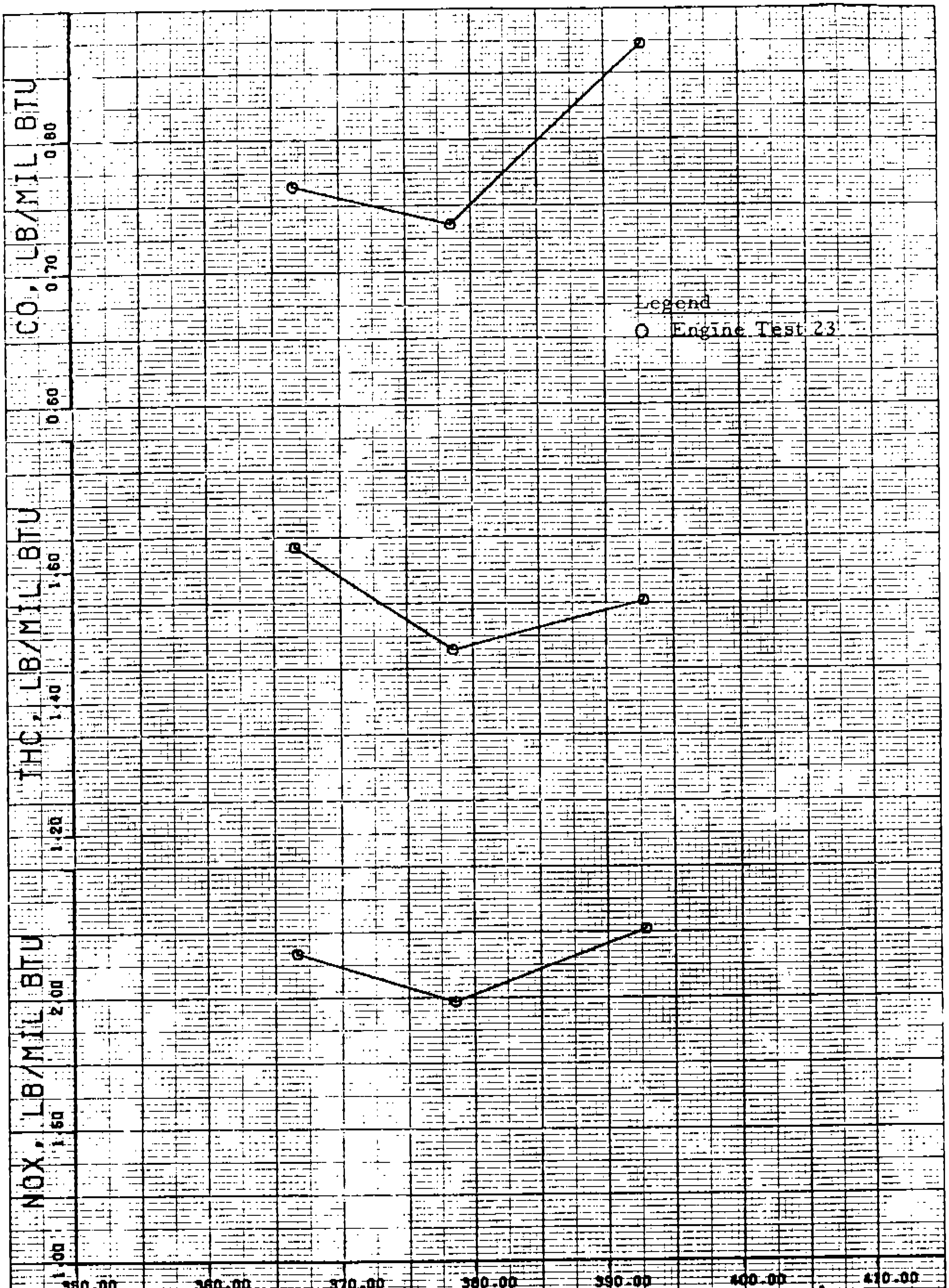


FIGURE E-9 EFFECT OF POWER ON CLARK TCV-12 LB EMISSION/MIL BTU

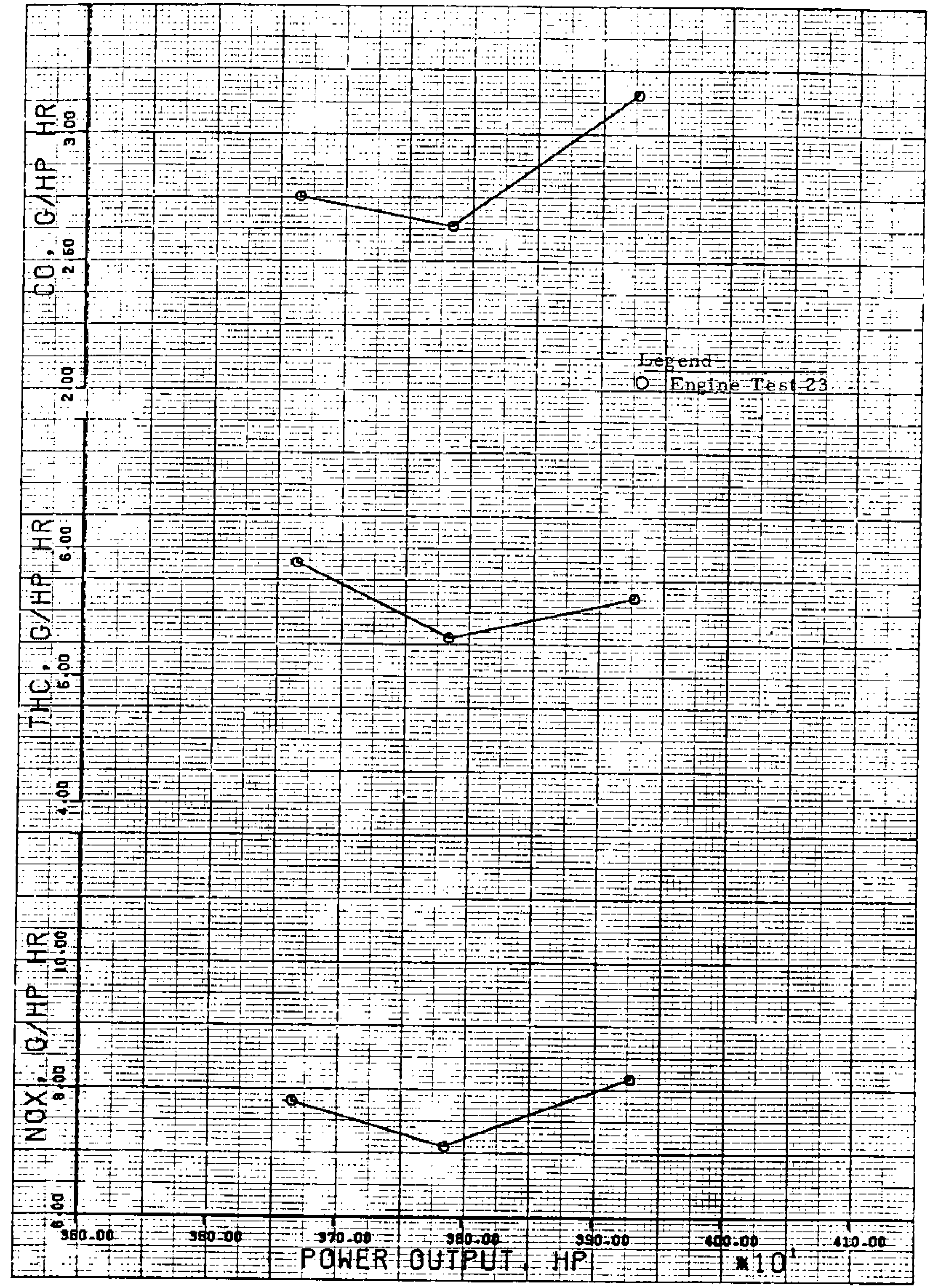


FIGURE E-10 EFFECT OF POWER ON CLARK TCV-12 G/HP-HR EMISSIONS

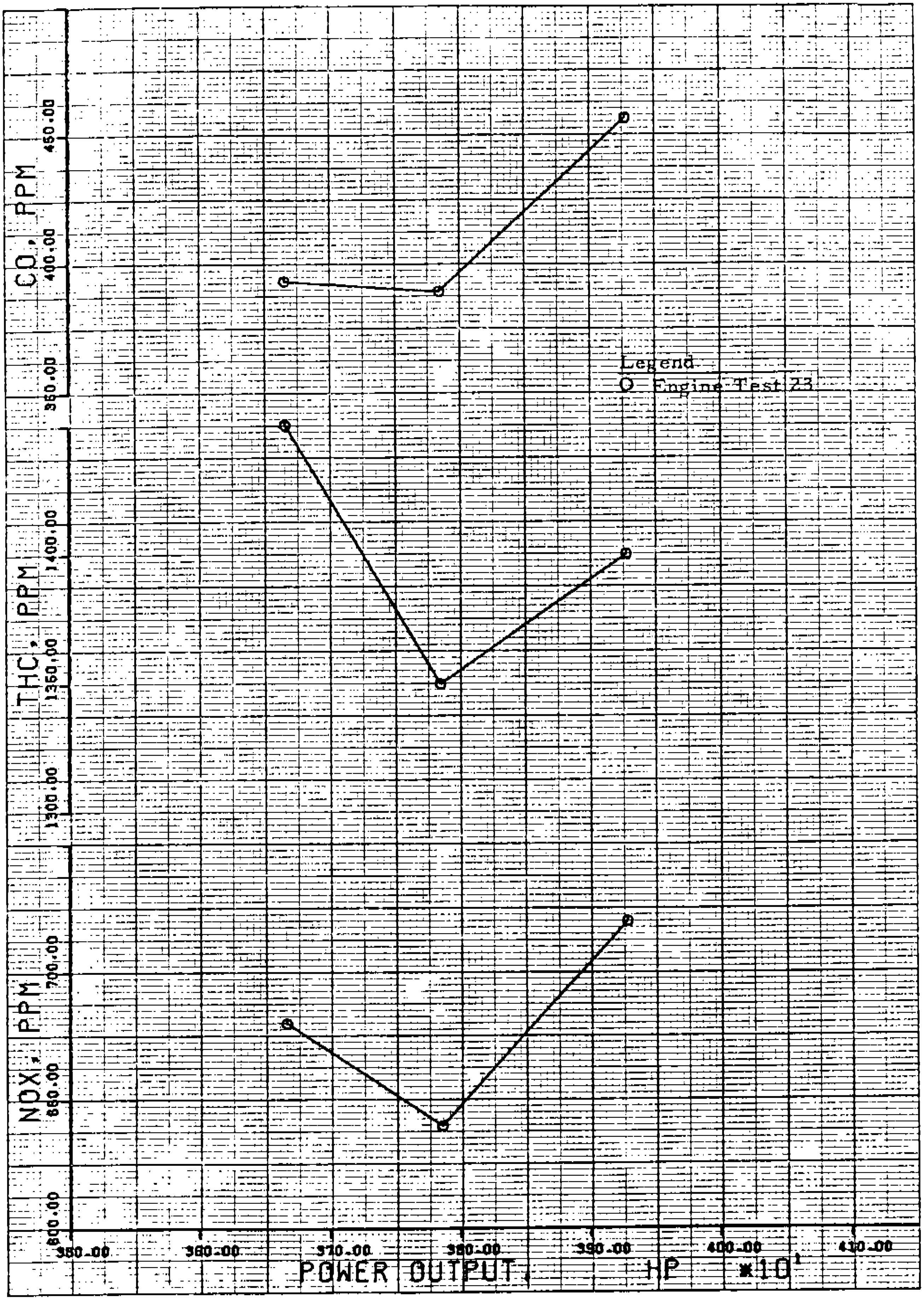


FIGURE E-11 EFFECT OF POWER ON CLARK TCV-12 PPM EMISSIONS

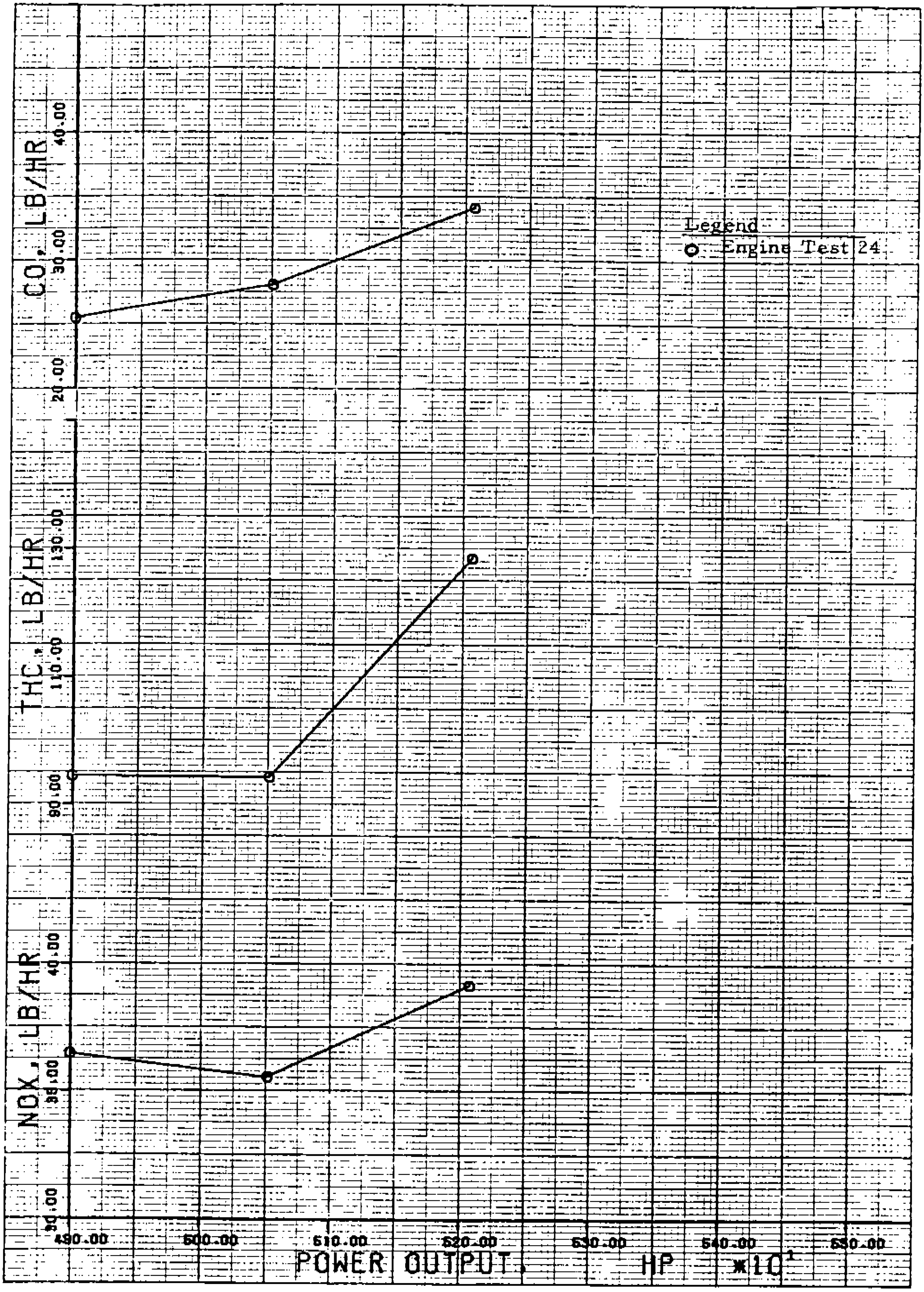


FIGURE E-12 EFFECT OF POWER ON CLARK TCV-16 LB/HR EMISSIONS

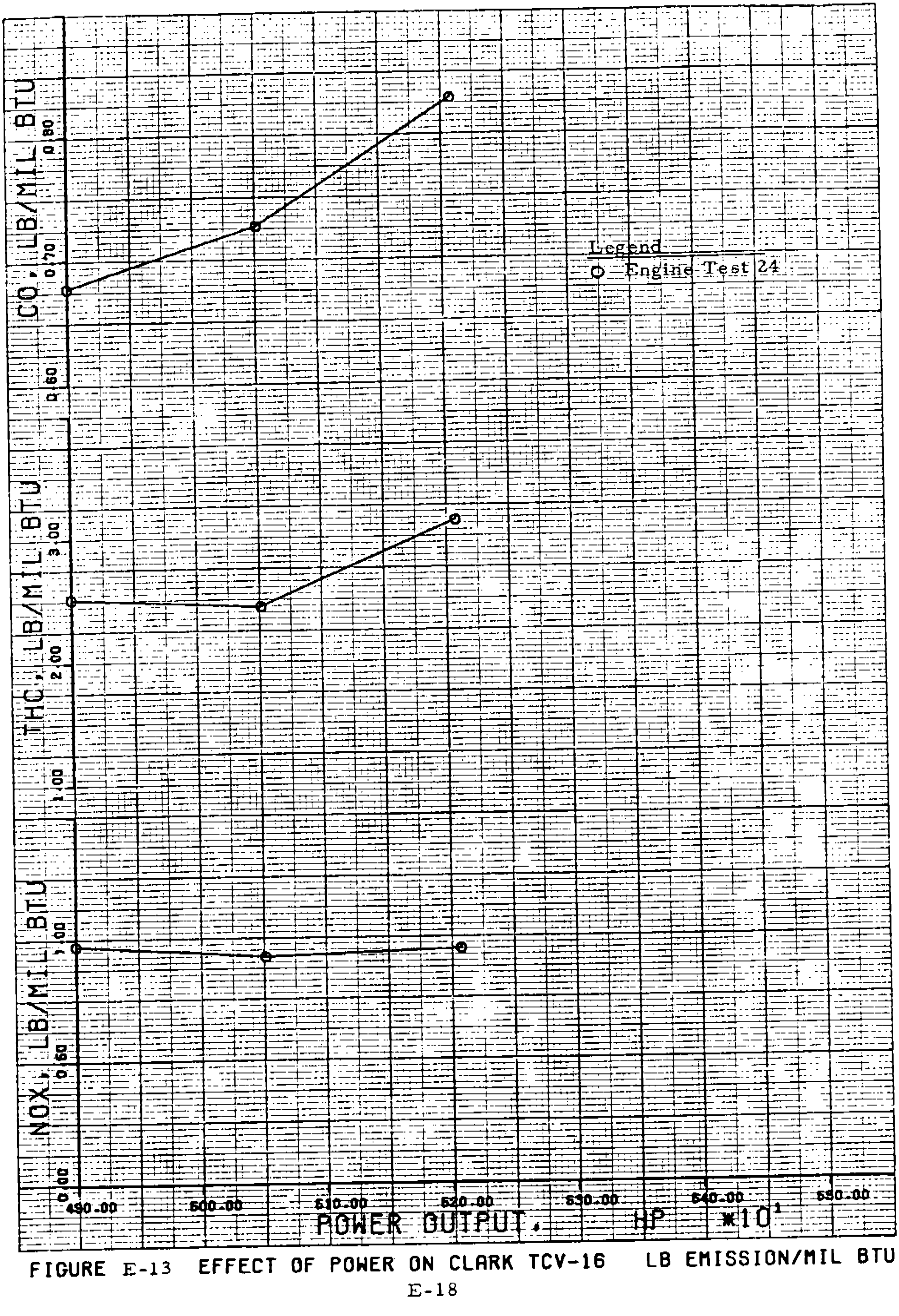


FIGURE E-13 EFFECT OF POWER ON CLARK TCV-16 LB EMISSION/MIL BTU

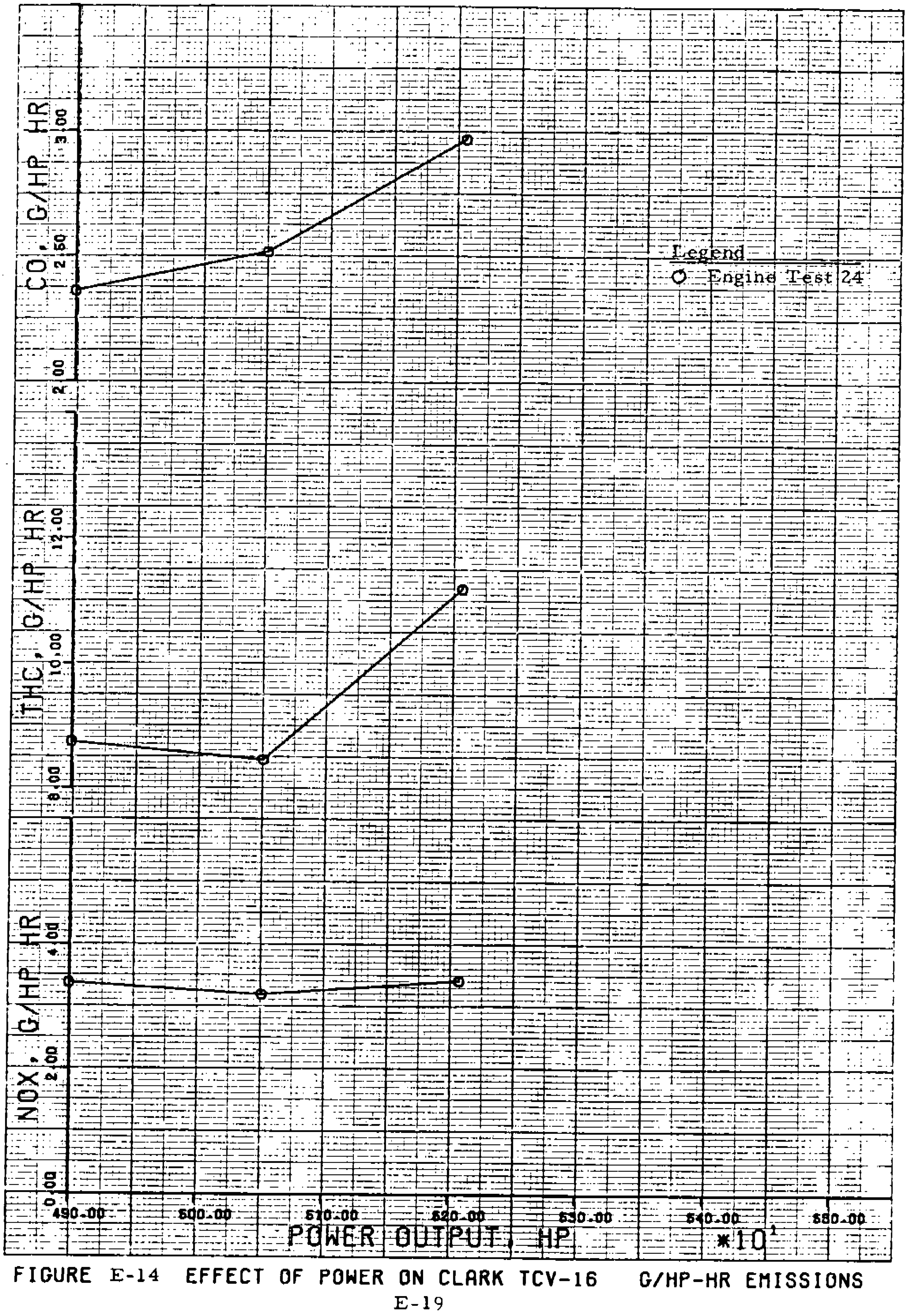


FIGURE E-14 EFFECT OF POWER ON CLARK TCV-16 G/HP-HR EMISSIONS

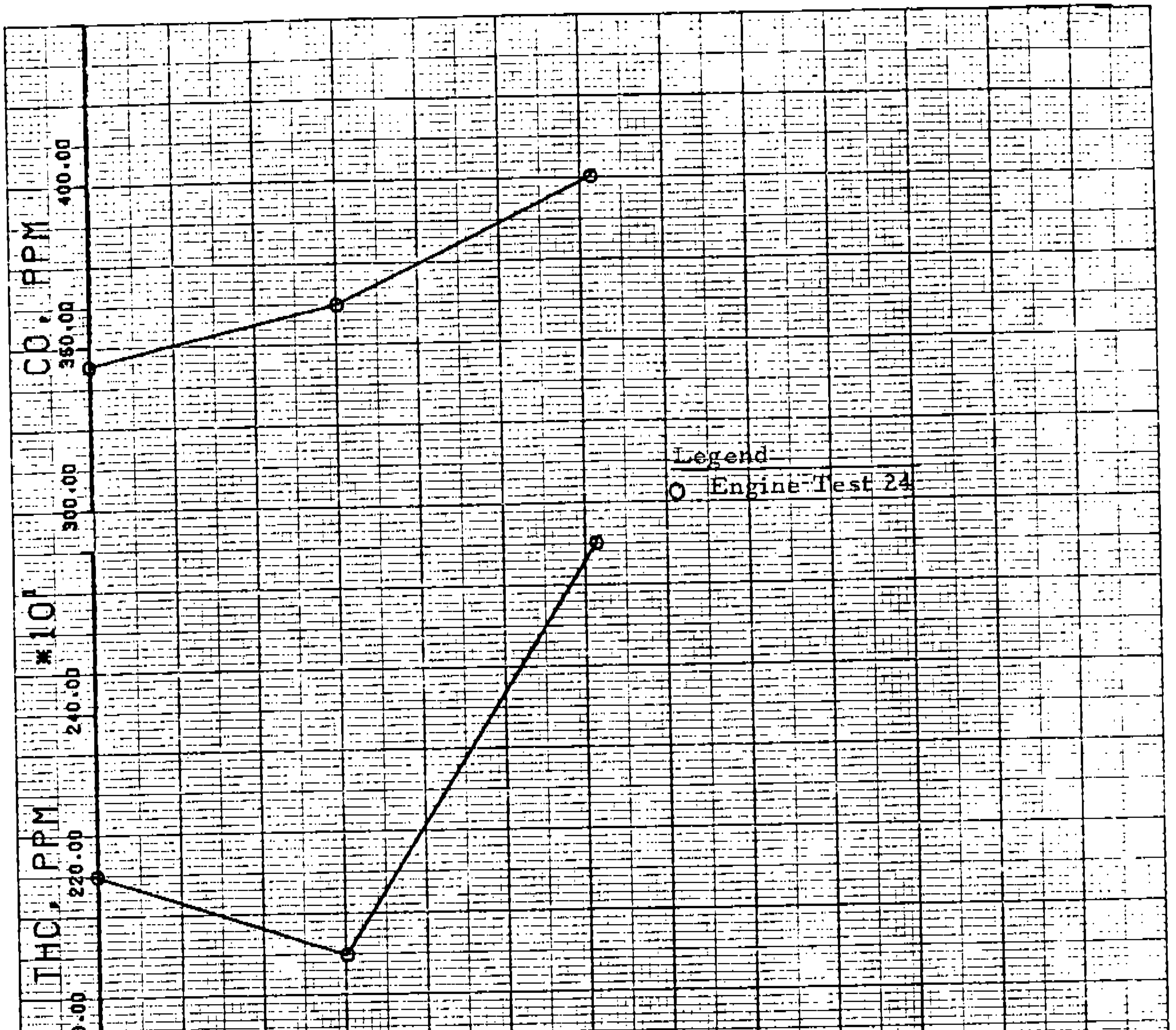


FIGURE E-15 EFFECT OF POWER ON CLARK TCV-16 PPM EMISSIONS

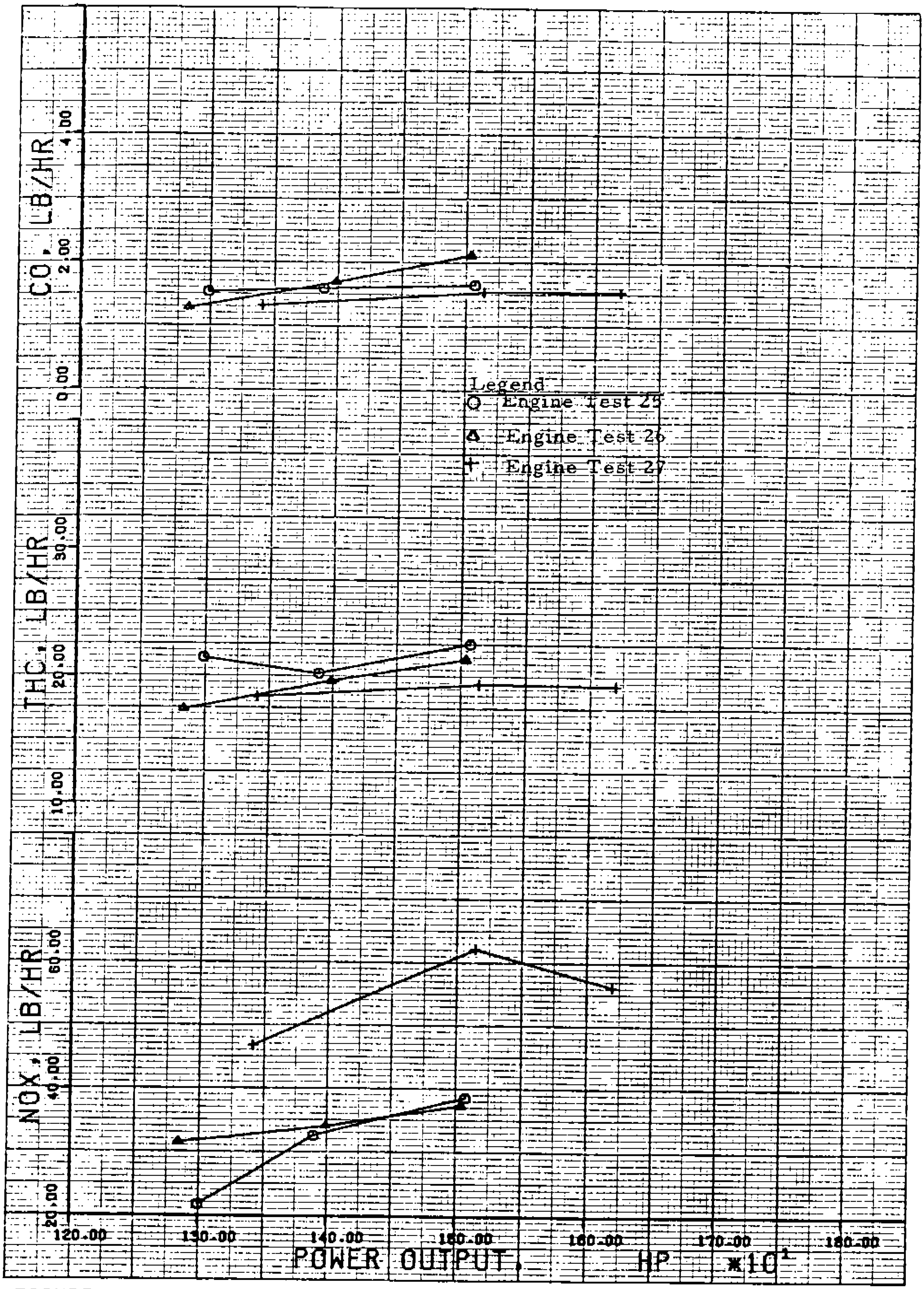


FIGURE E-16 EFFECT OF POWER ON C-B GMWA-6 LB/HR EMISSIONS

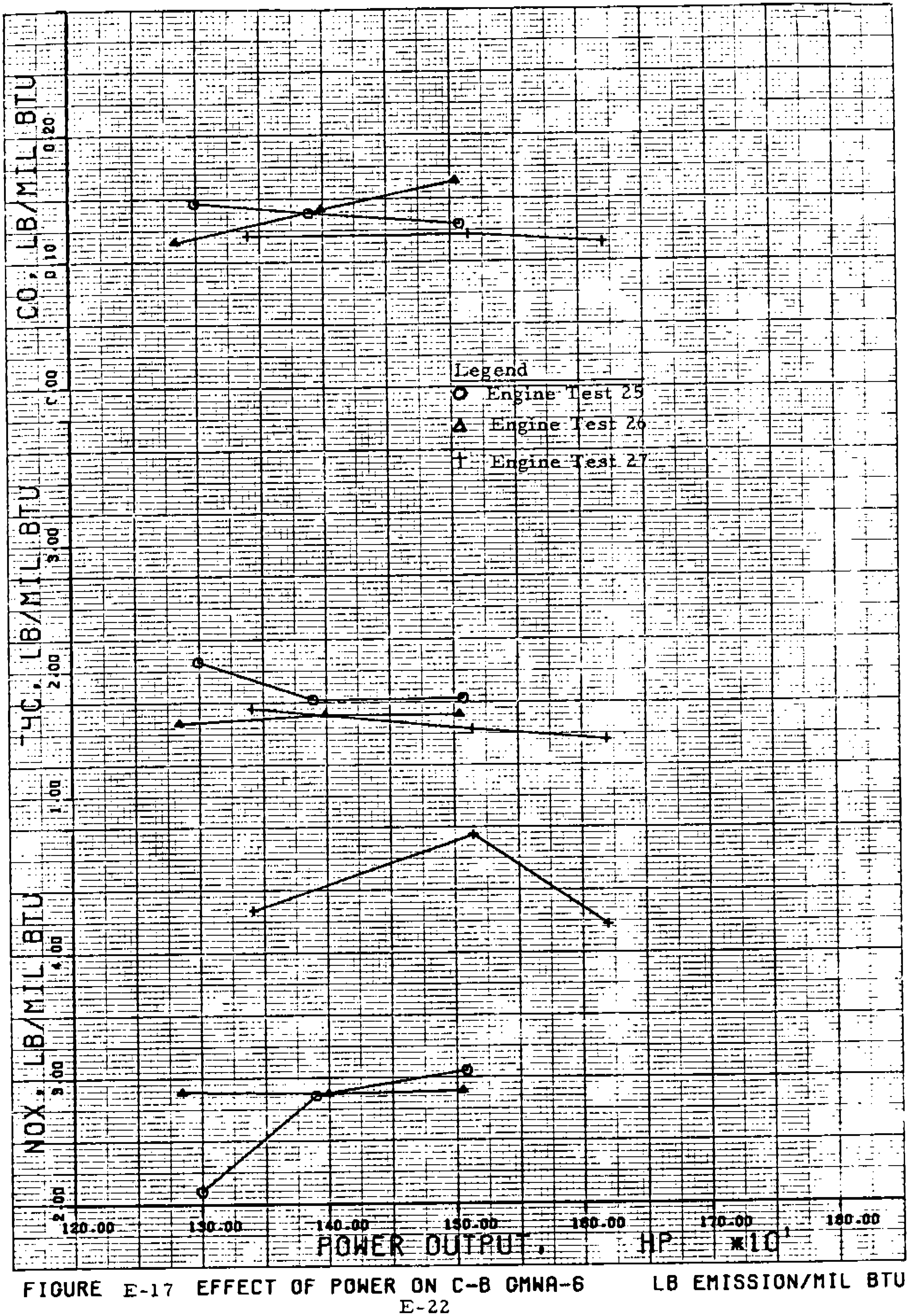


FIGURE E-17 EFFECT OF POWER ON C-B GMWA-6 LB EMISSION/MIL BTU

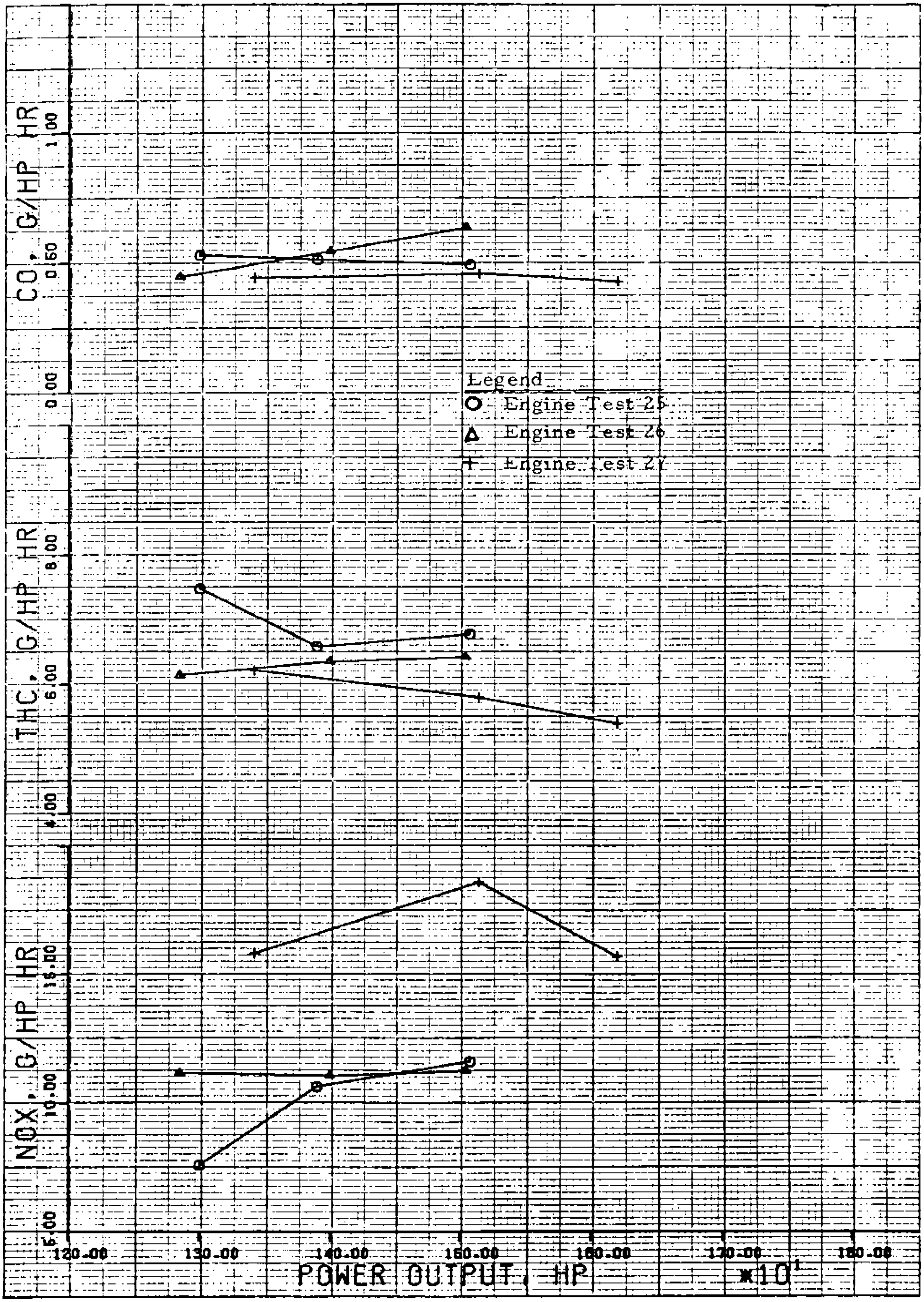


FIGURE E-18 EFFECT OF POWER ON C-B GMWA-6 G/HP-HR EMISSIONS

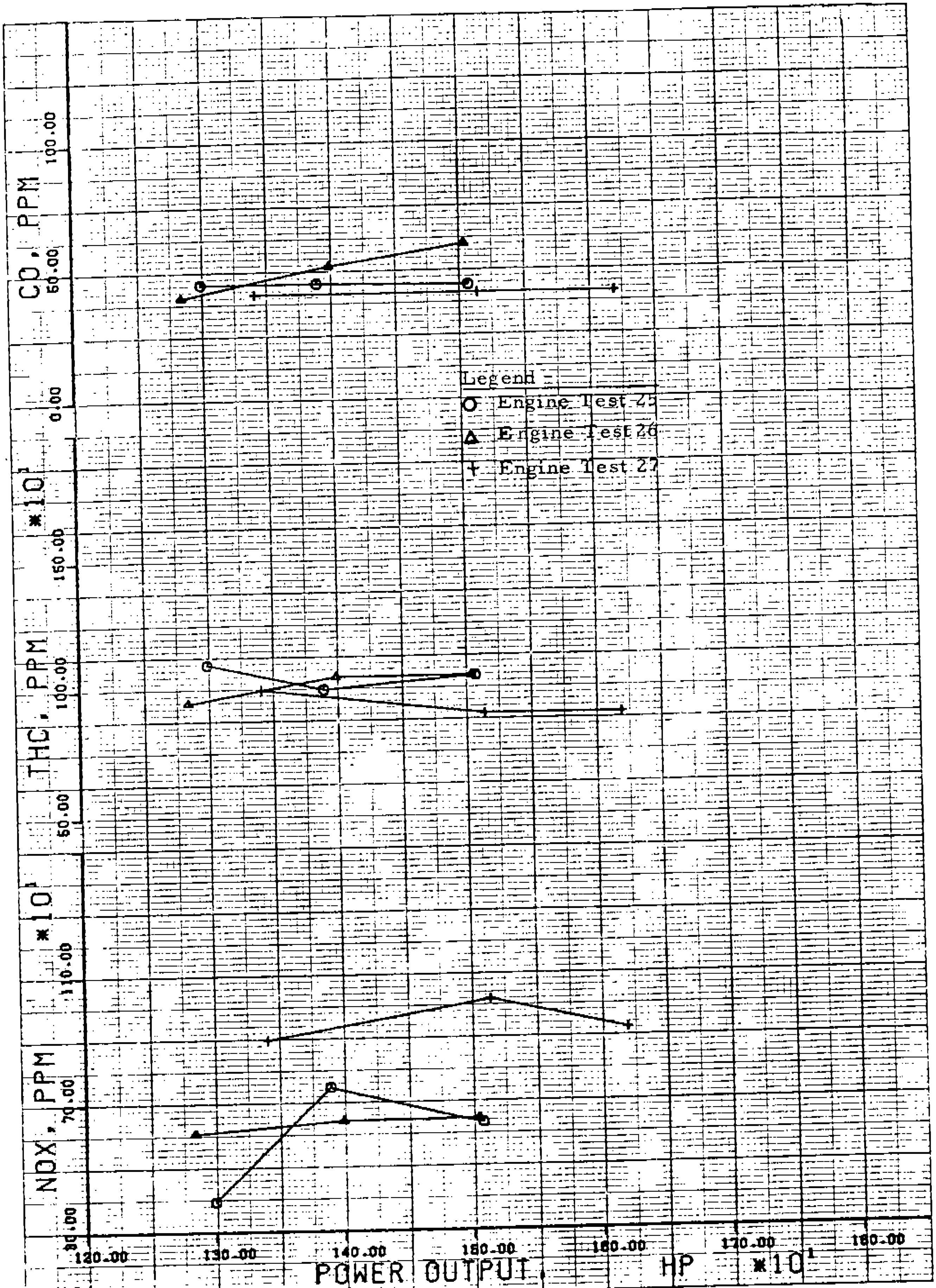


FIGURE E-19 EFFECT OF POWER ON C-B GMWA-6 PPM EMISSIONS

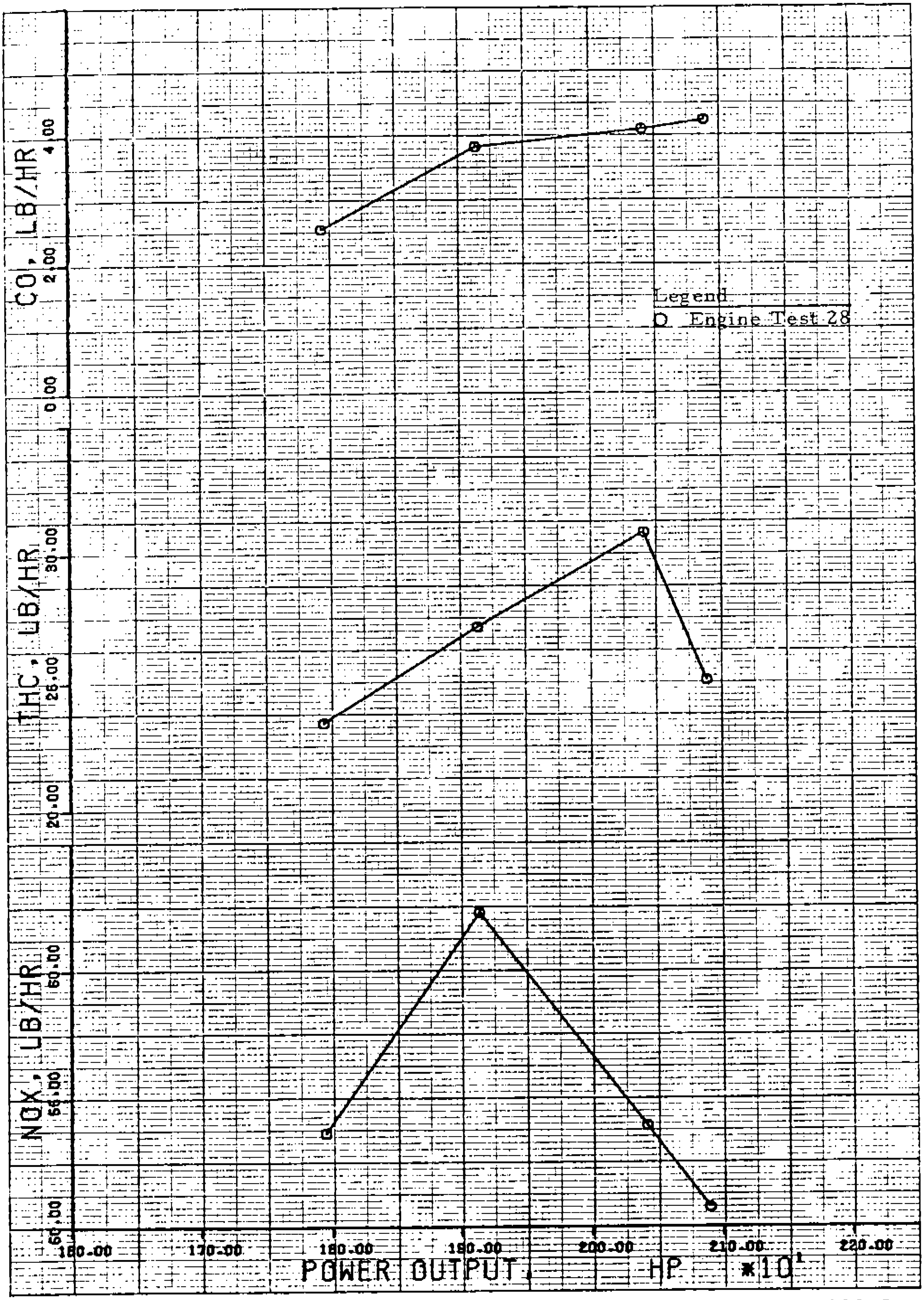


FIGURE E-20 EFFECT OF POWER ON C-B GMWC-6 LB/HR EMISSIONS

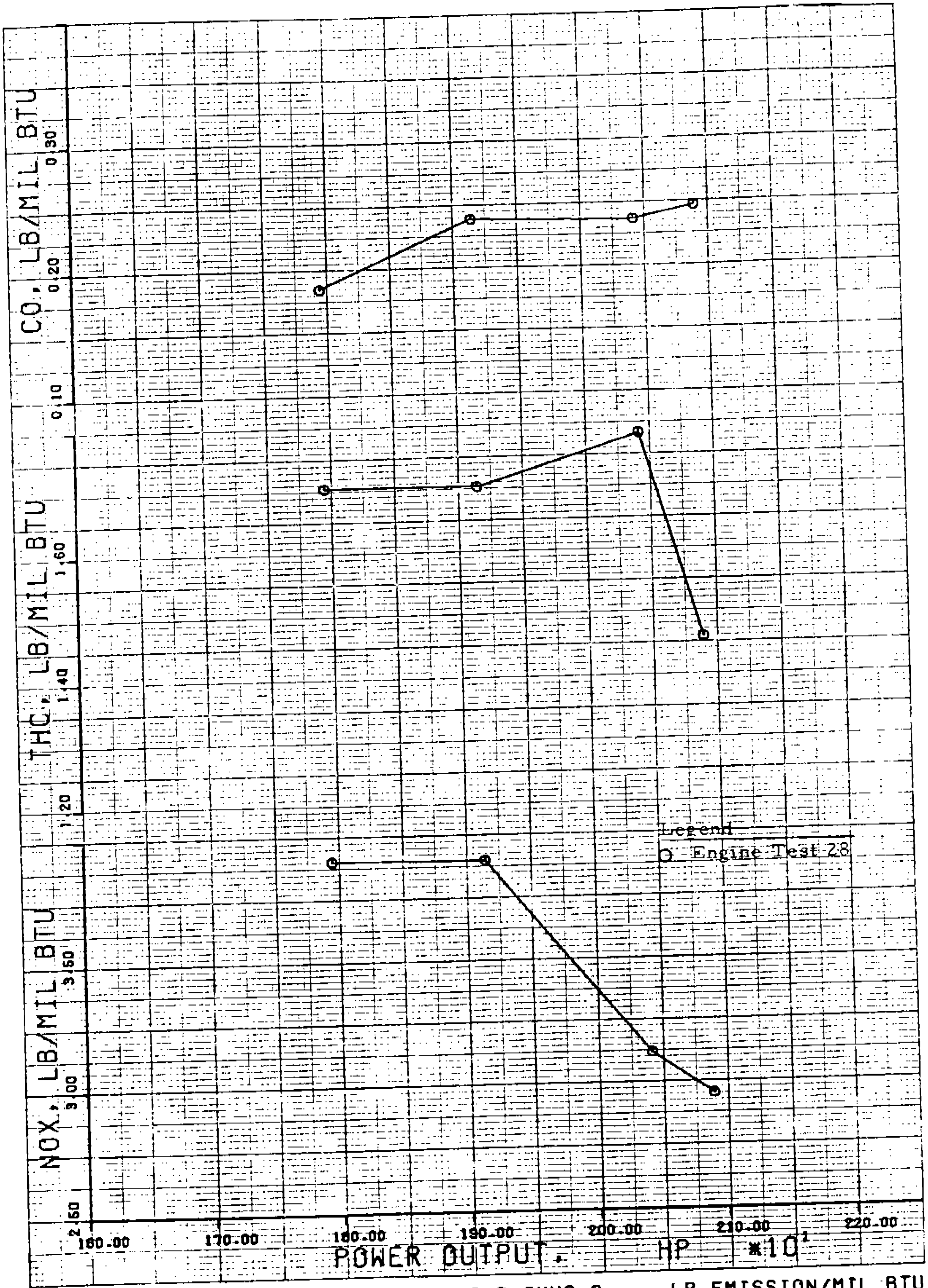


FIGURE E-21 EFFECT OF POWER ON C-B GMWC-6 LB EMISSION/MIL BTU

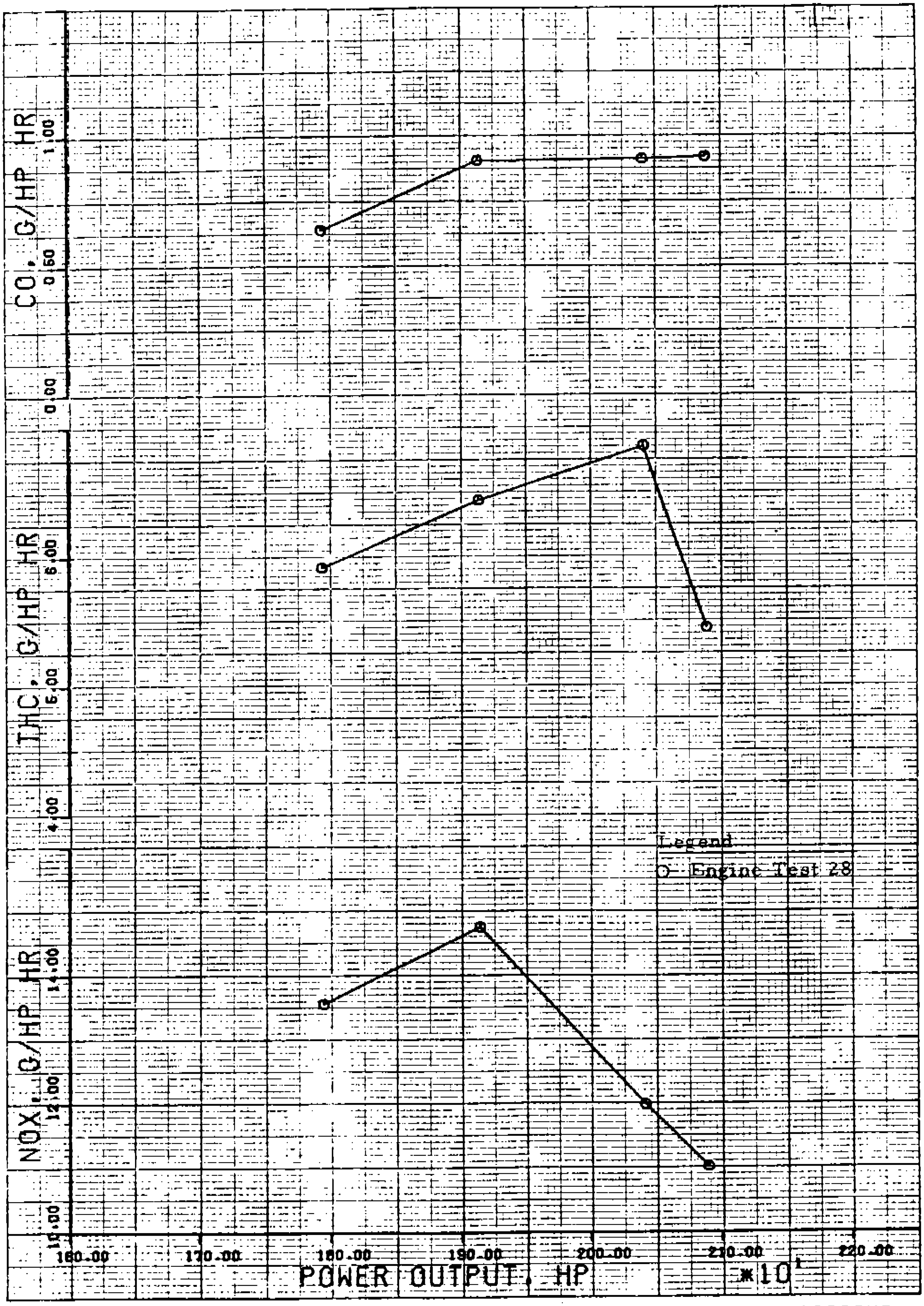


FIGURE E-22 EFFECT OF POWER ON C-B GMWC-6 G/HP-HR EMISSIONS

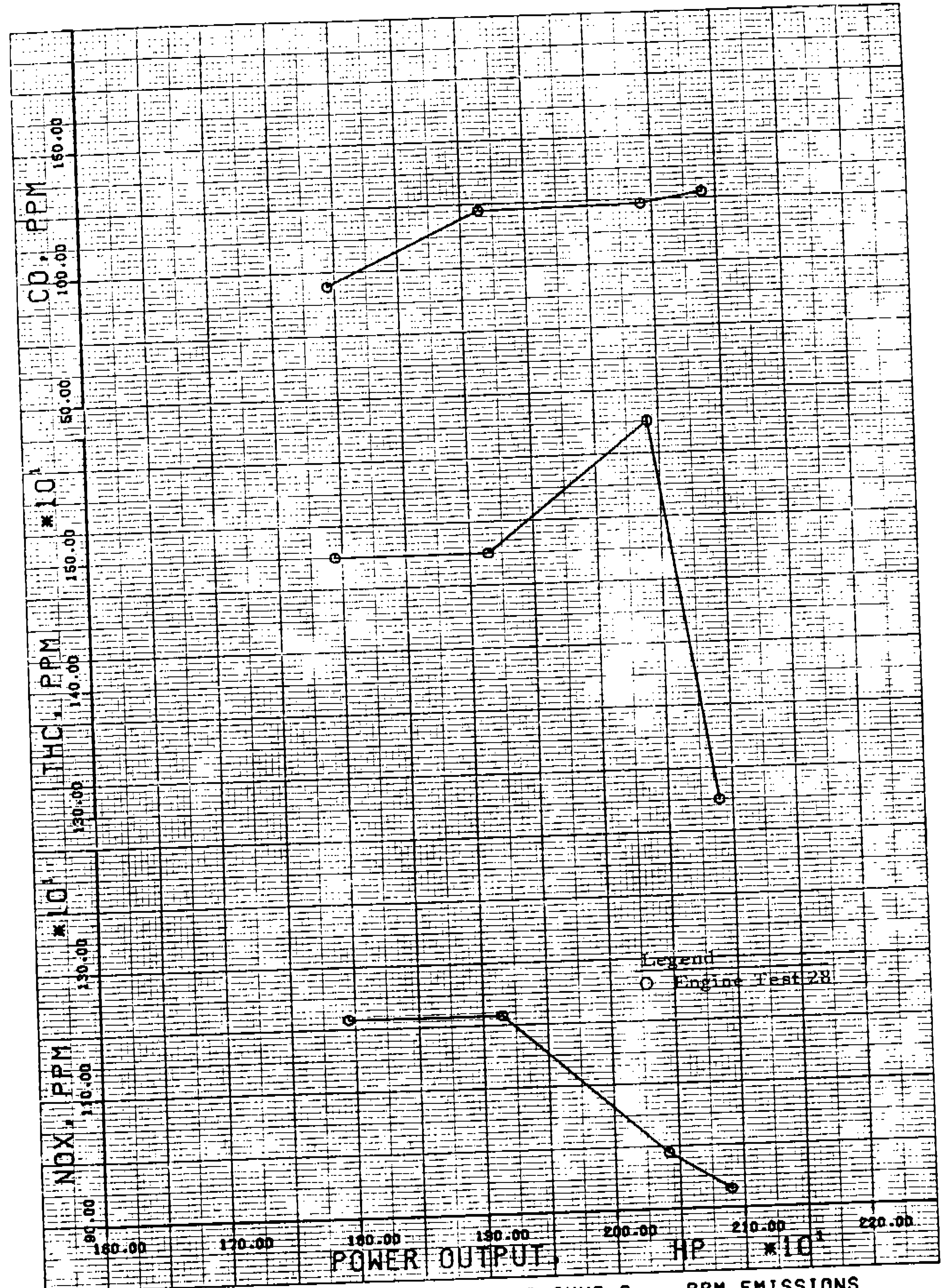


FIGURE E-23 EFFECT OF POWER ON C-B GMWC-6 PPM EMISSIONS

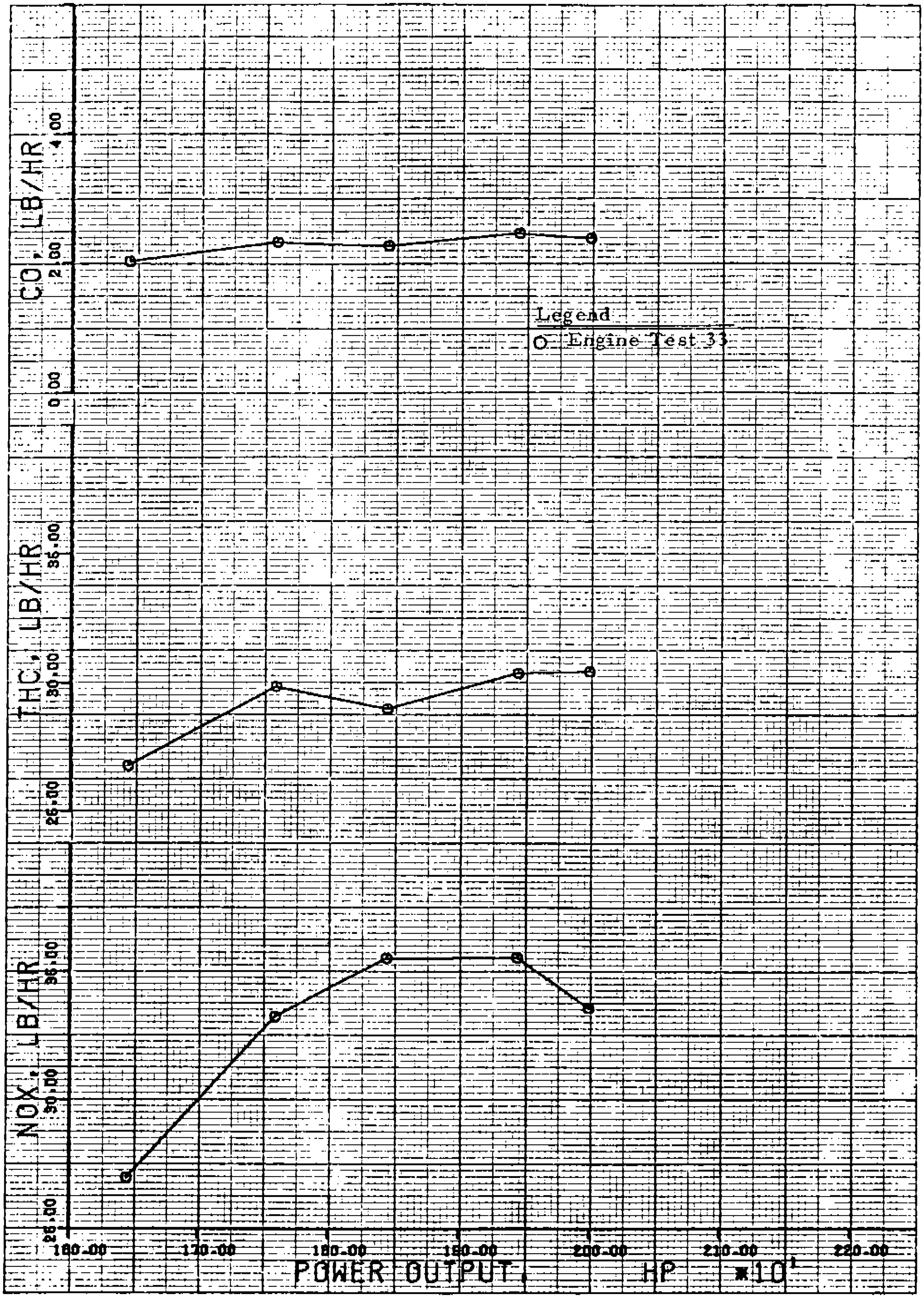


FIGURE E-24 EFFECT OF POWER ON C-8 GMW-8 LB/HR EMISSIONS

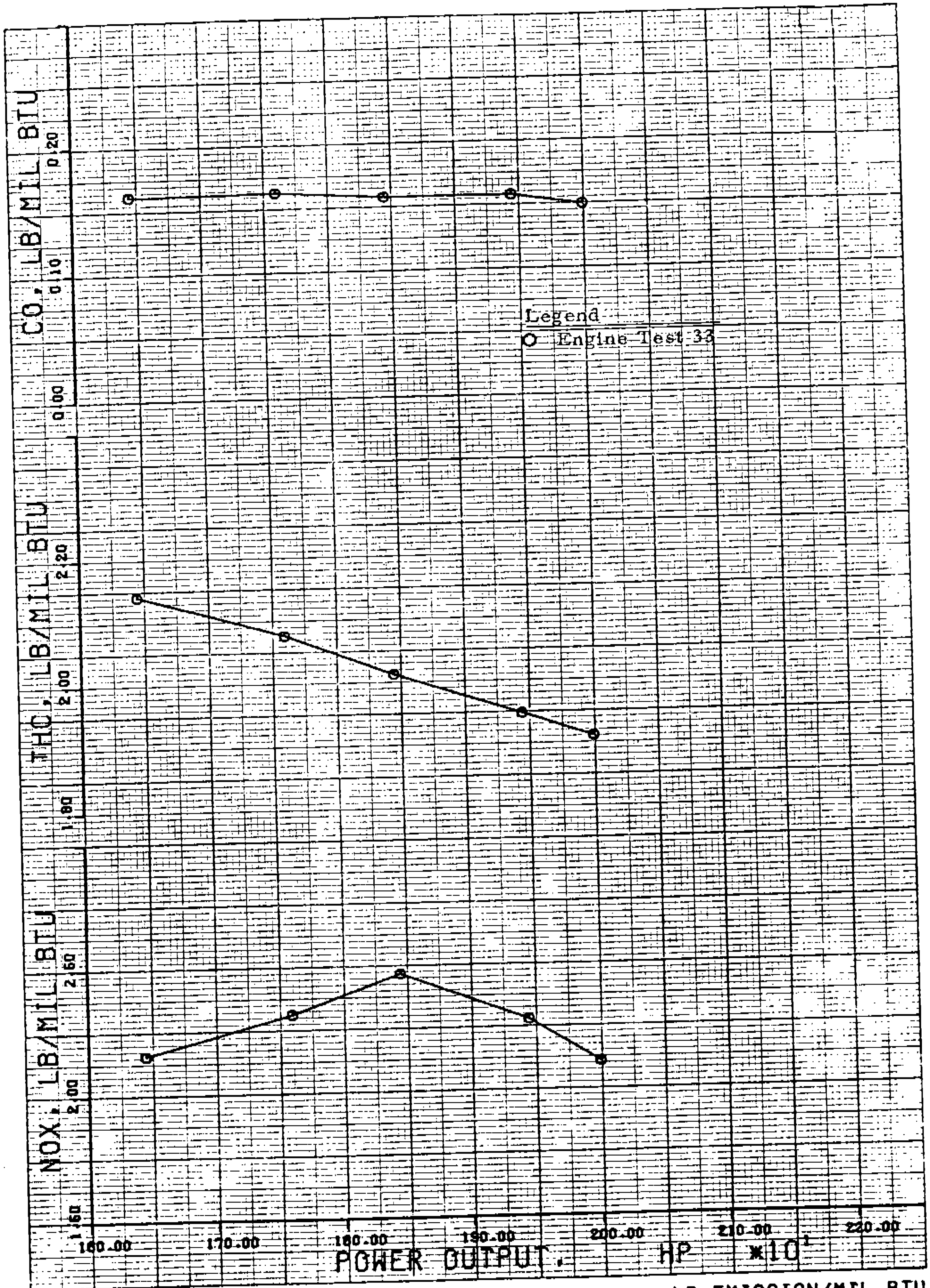


FIGURE E-25 EFFECT OF POWER ON C-B GMW-8

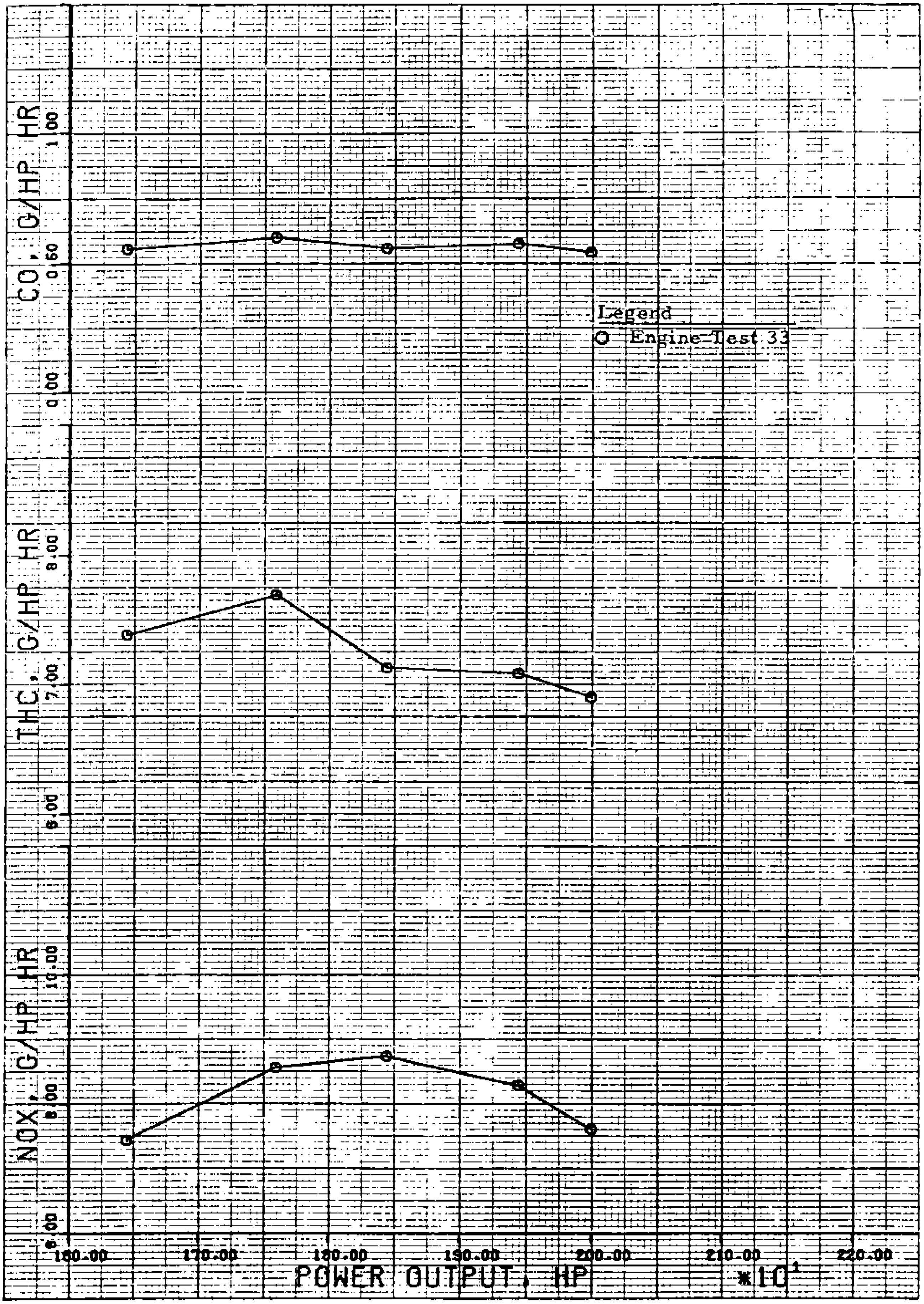


FIGURE E-26 EFFECT OF POWER ON C-8 GMW-8 G/HP-HR EMISSIONS

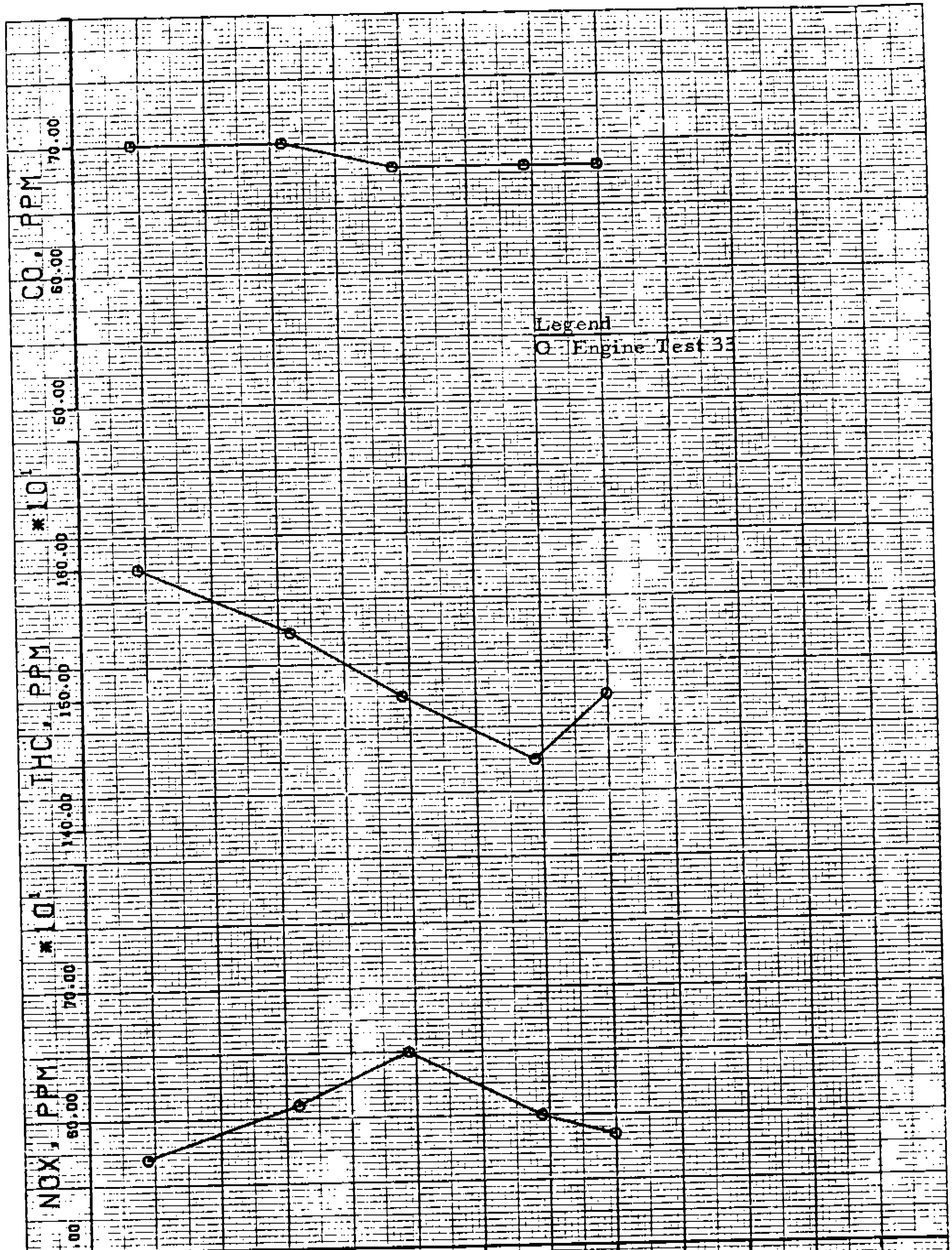


FIGURE E-27 EFFECT OF POWER ON C-B GMW-8 PPM EMISSIONS

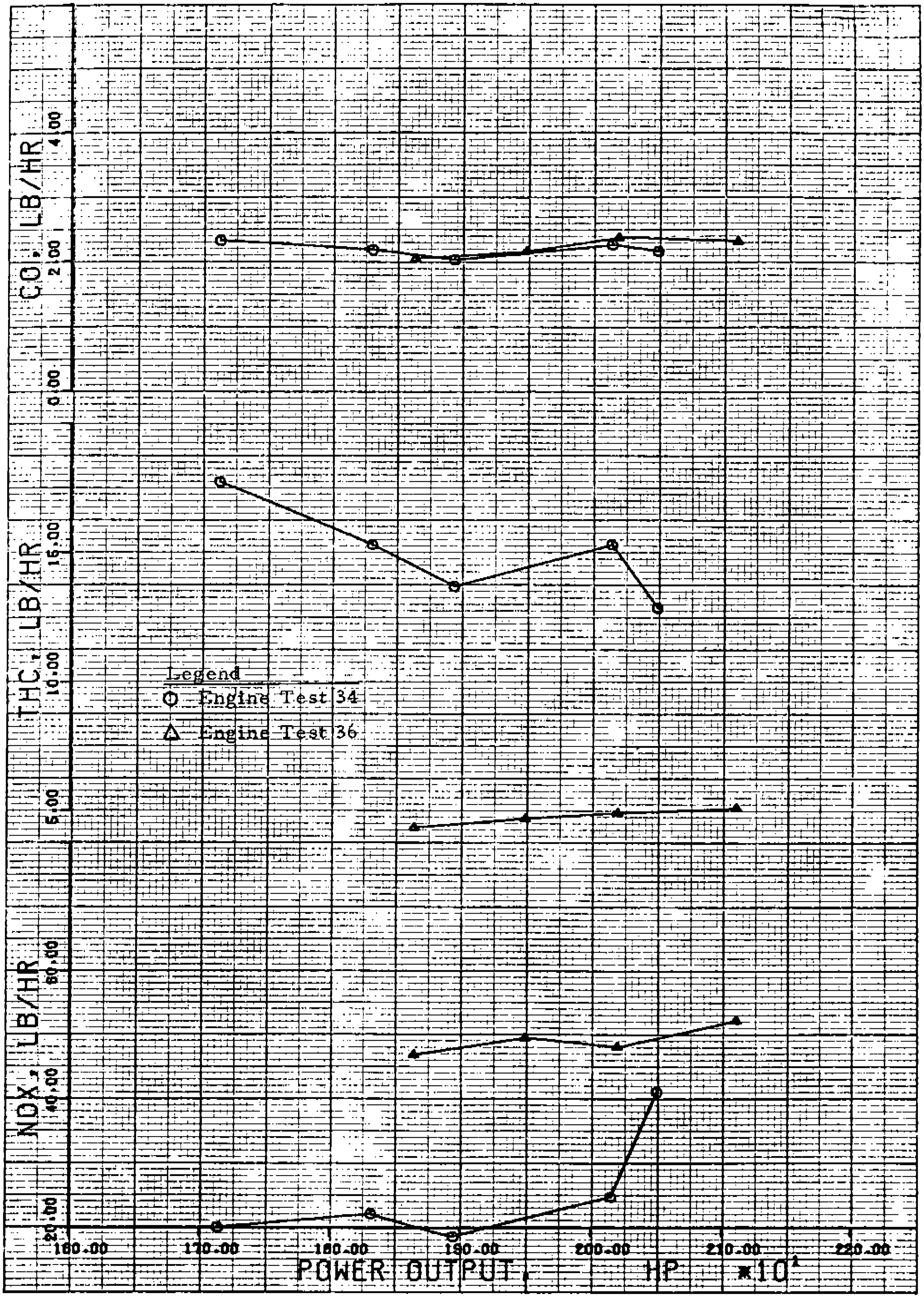


FIGURE E-28 EFFECT OF POWER ON C-B GMWA-8 LB/HR EMISSIONS

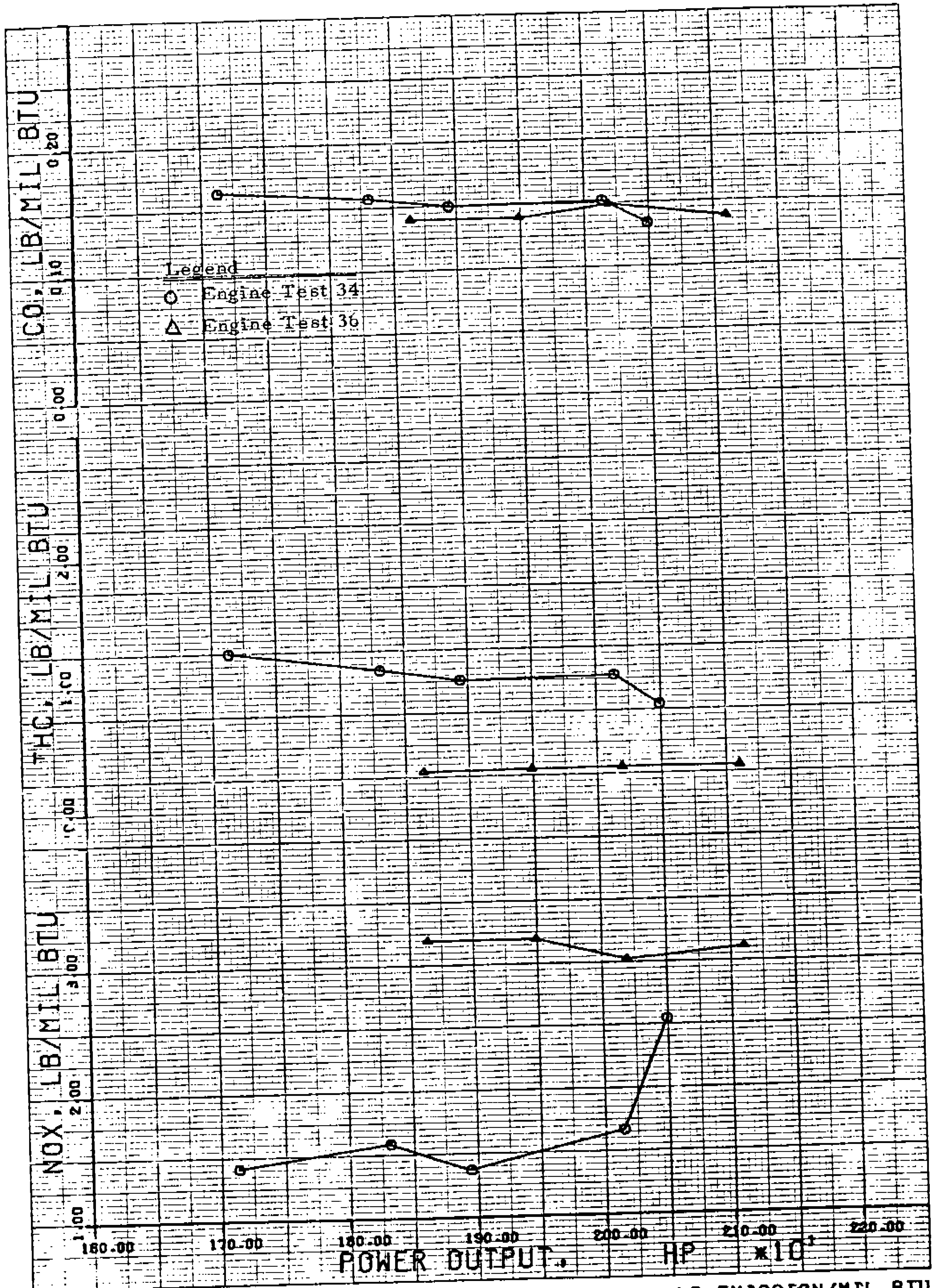


FIGURE E-29 EFFECT OF POWER ON C-B GMWA-8 LB EMISSION/MIL BTU

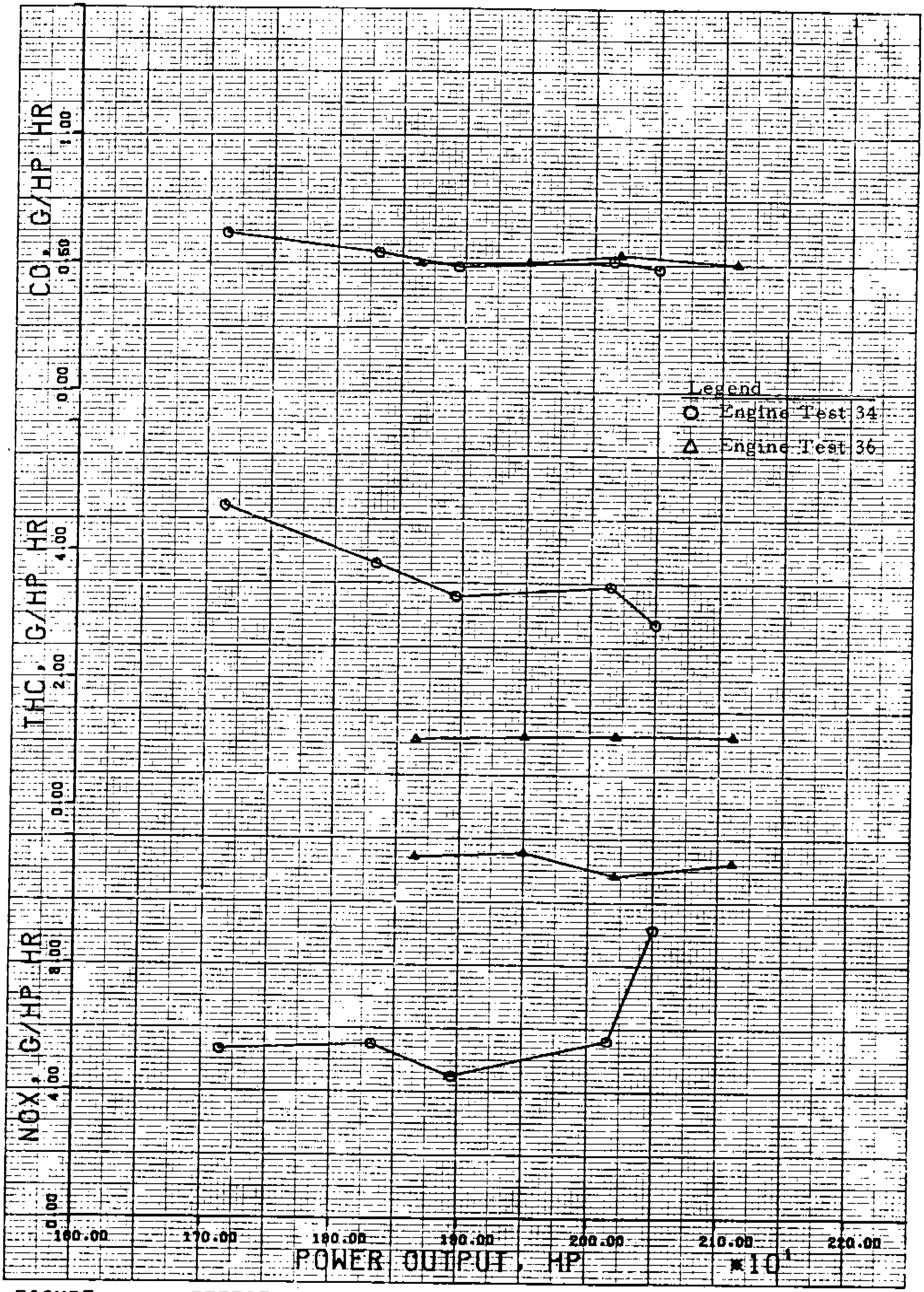


FIGURE E-30 EFFECT OF POWER ON C-B GMWA-8 G/HP-HR EMISSIONS

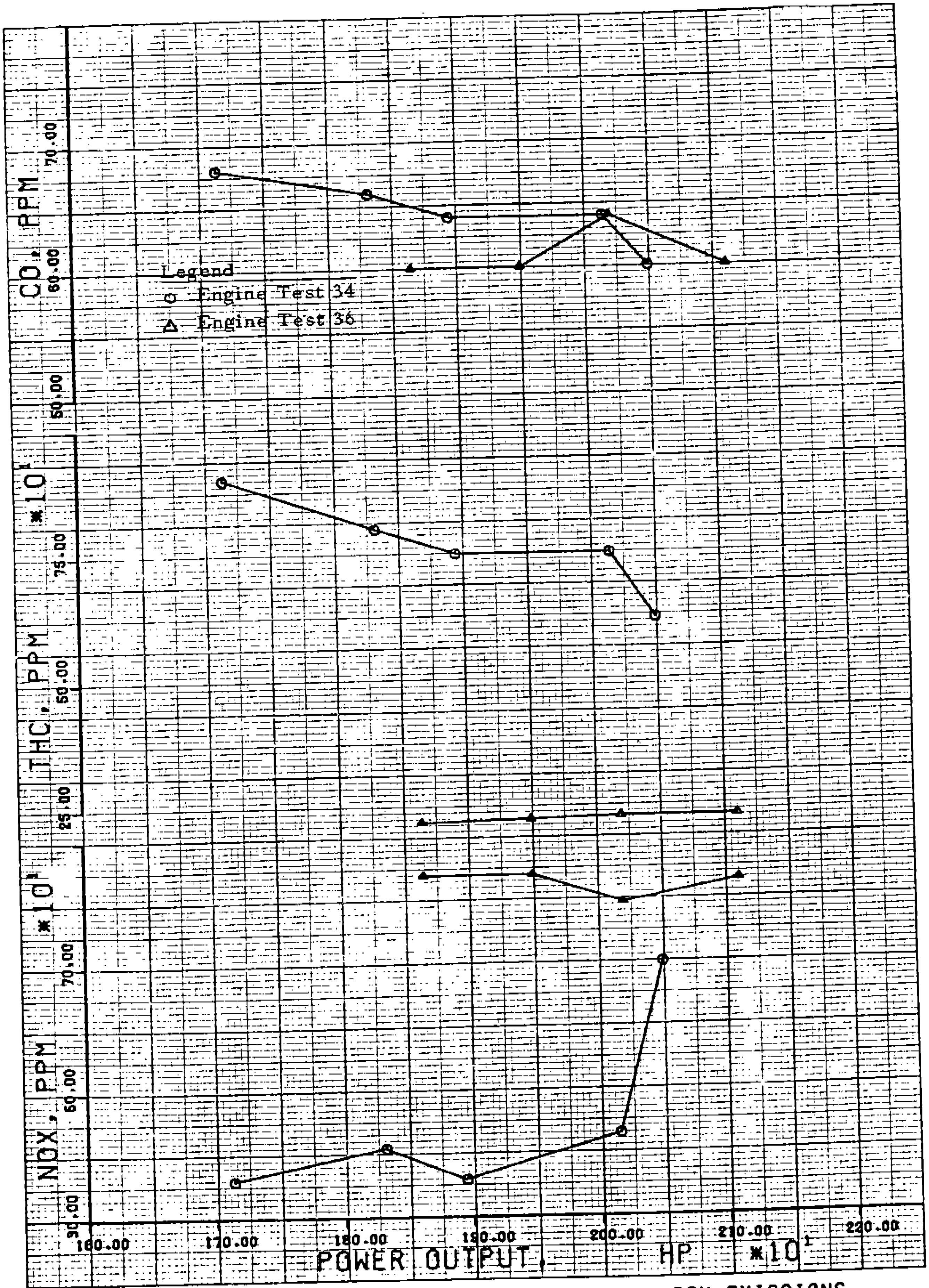


FIGURE E-31 EFFECT OF POWER ON C-B GMWA-8 PPM EMISSIONS

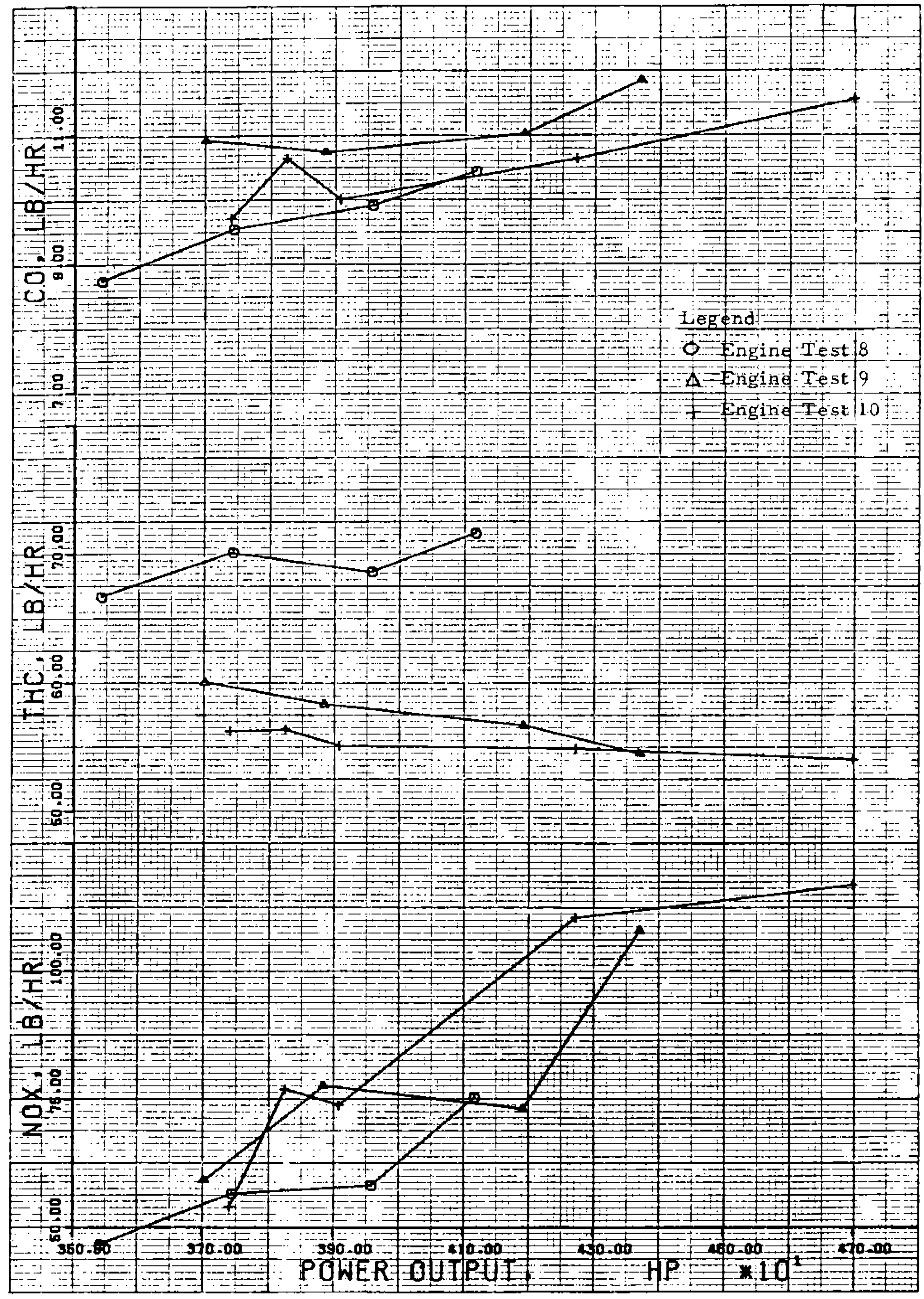


FIGURE E-32 EFFECT OF POWER ON C-B LSV-16SG LB/HR EMISSIONS

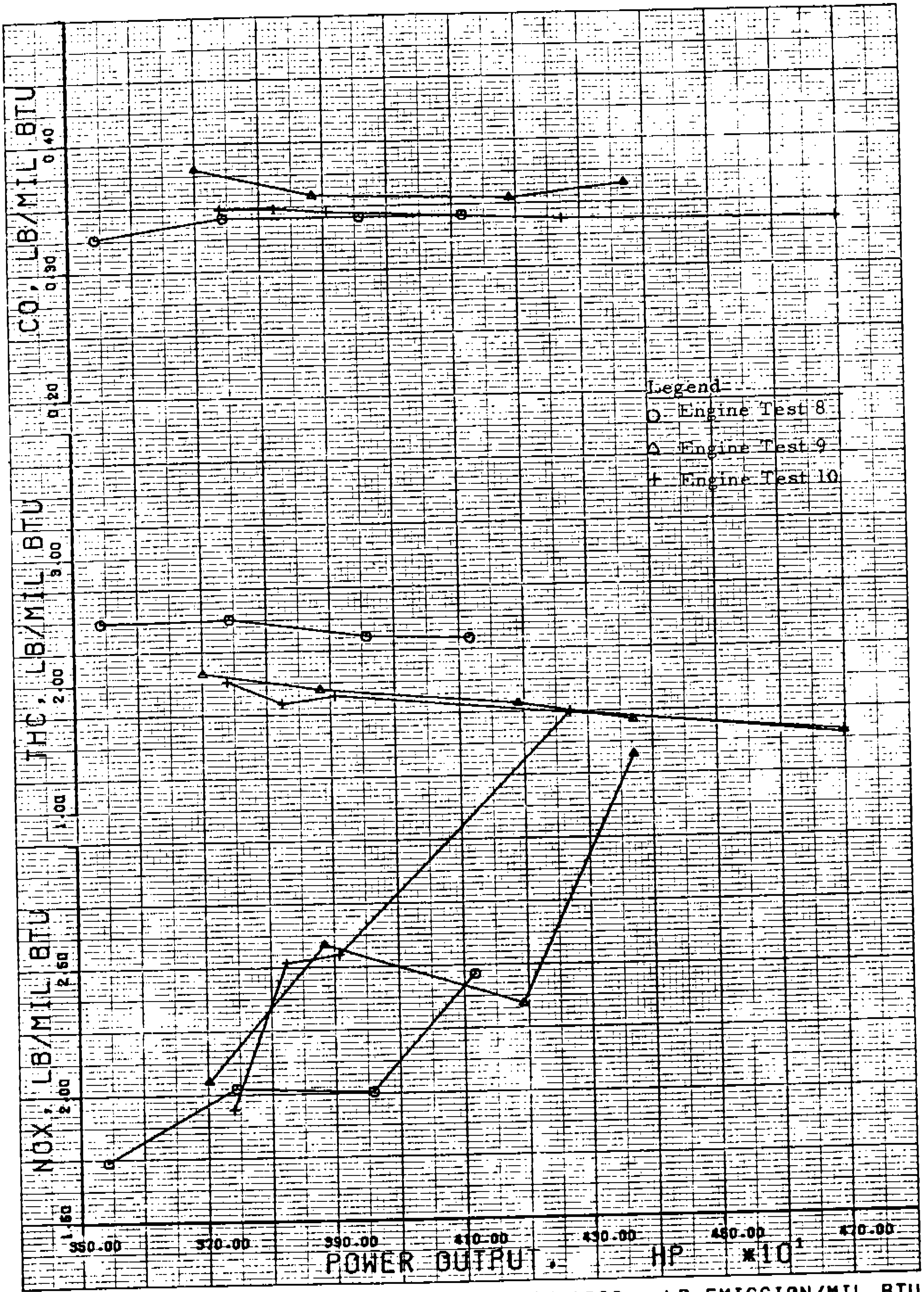


FIGURE E-33 EFFECT OF POWER ON C-B LSV-16SG LB EMISSION/MIL BTU

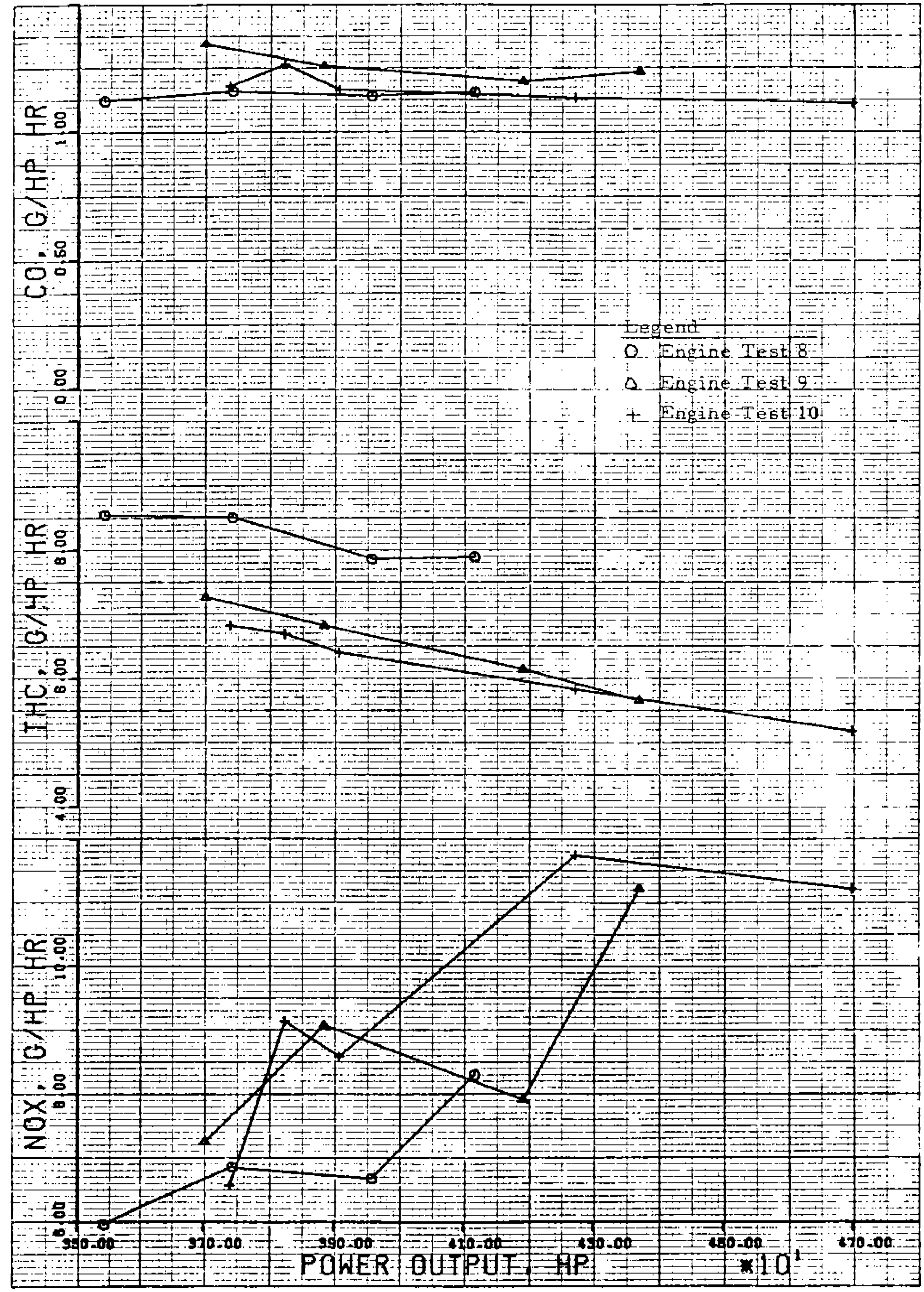


FIGURE E-34 EFFECT OF POWER ON C-B LSV-16SG G/HP-HR EMISSIONS

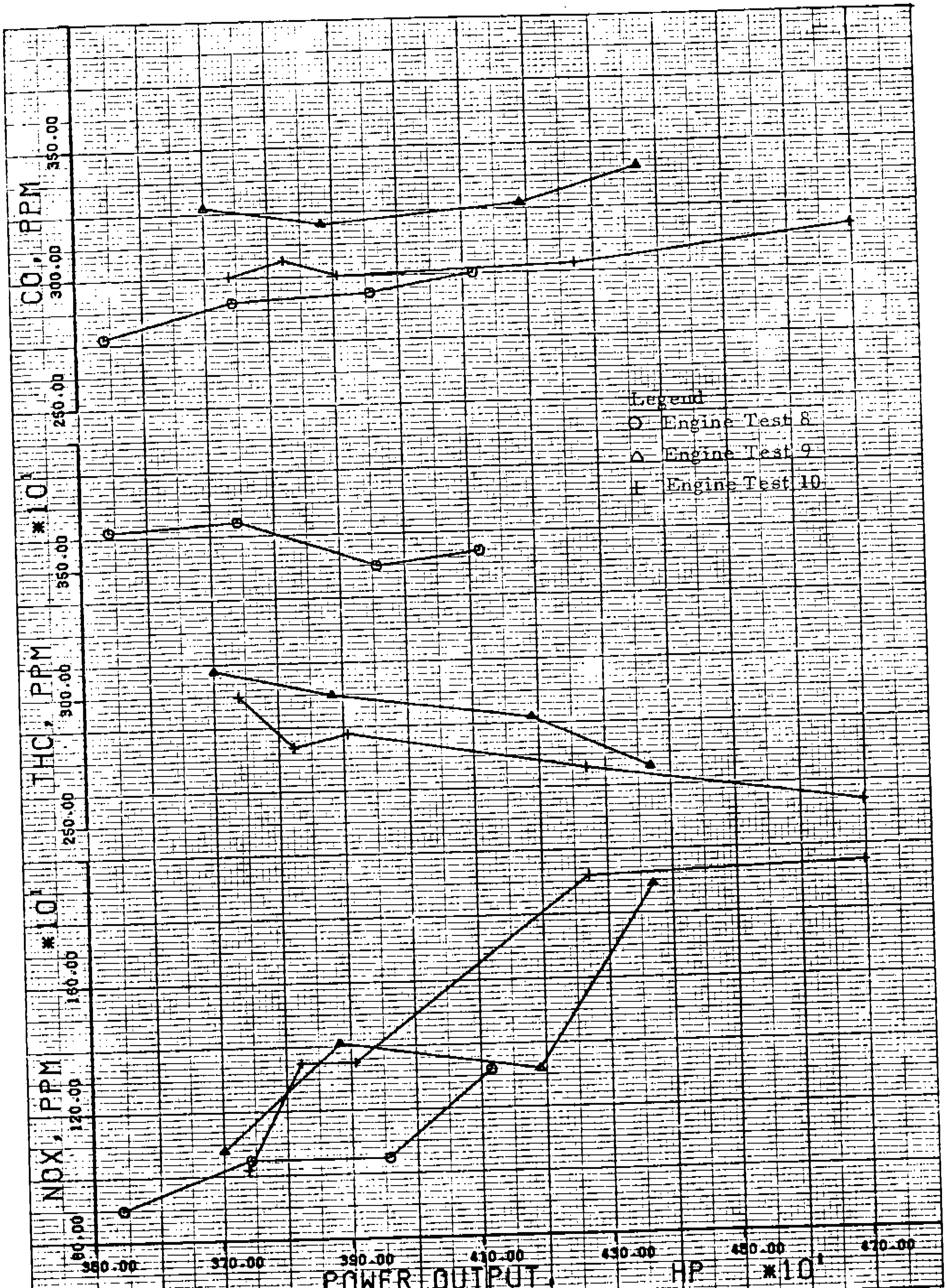


FIGURE E-35 EFFECT OF POWER ON C-B LSV-16SG PPM EMISSIONS

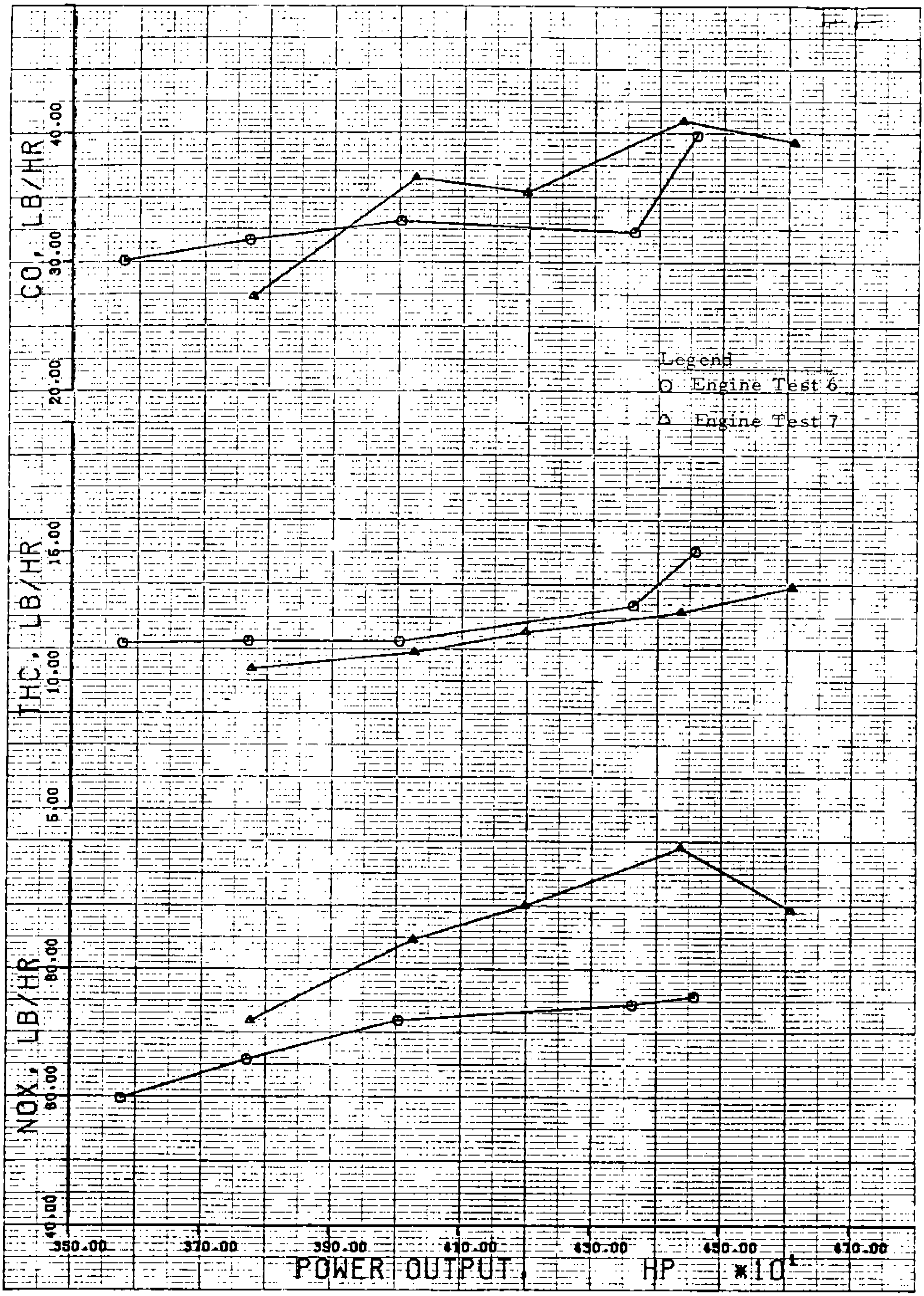


FIGURE E-36 EFFECT OF POWER ON C-B LSVA-16SG LB/HR EMISSIONS

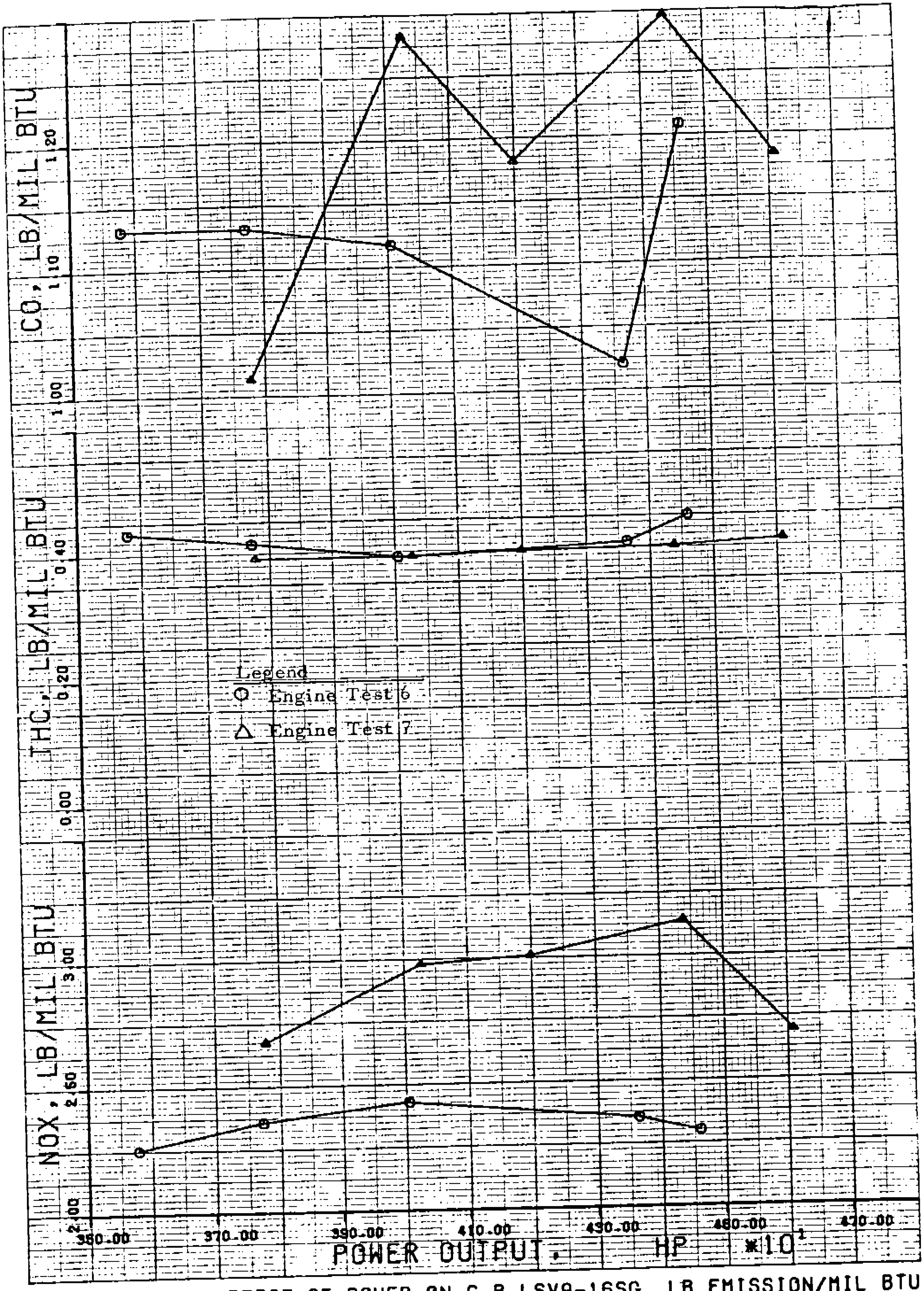


FIGURE E-37 EFFECT OF POWER ON C-B LSVA-16SG LB EMISSION/MIL BTU

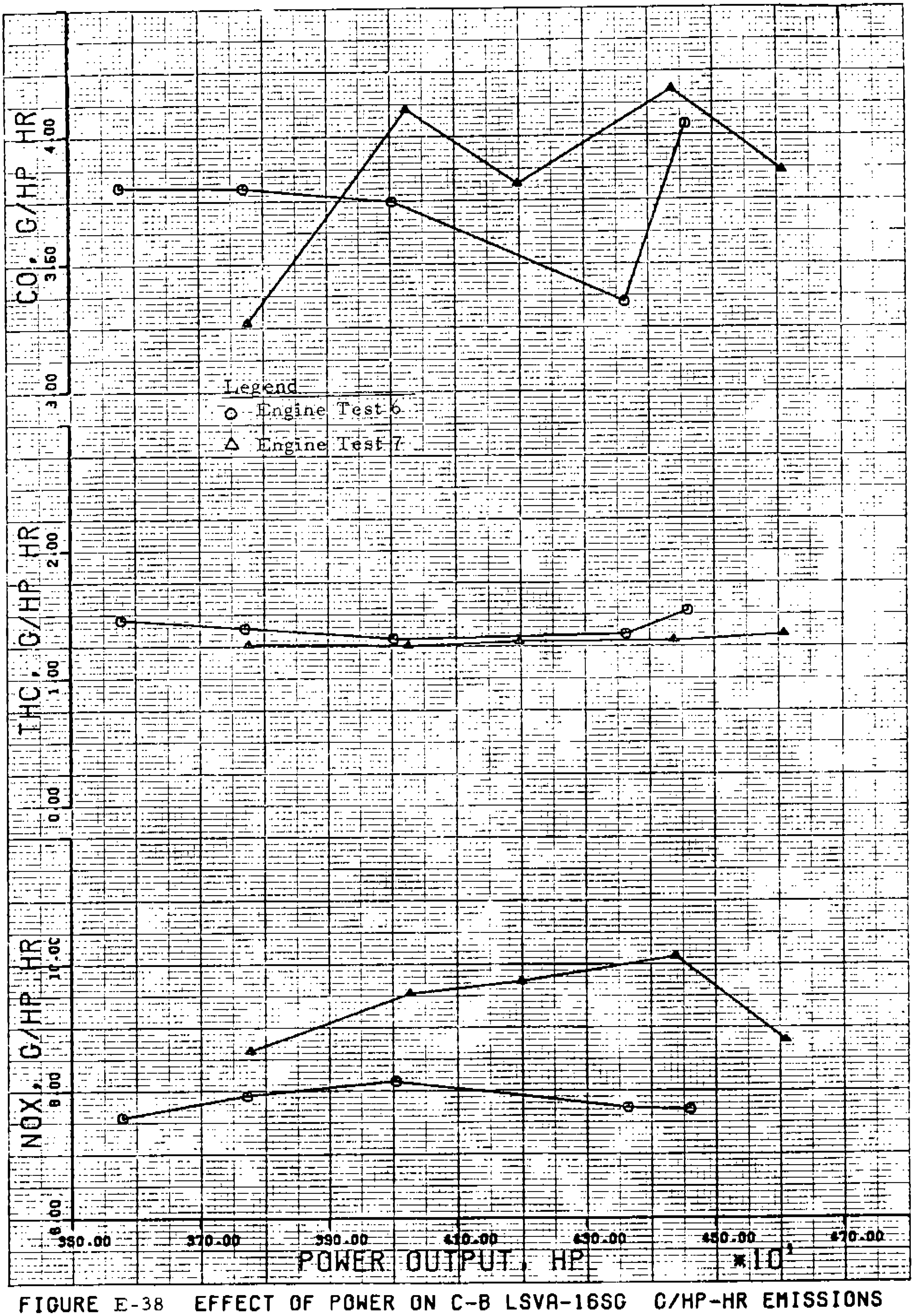


FIGURE E-38 EFFECT OF POWER ON C-B LSVA-16SG G/HP-HR EMISSIONS

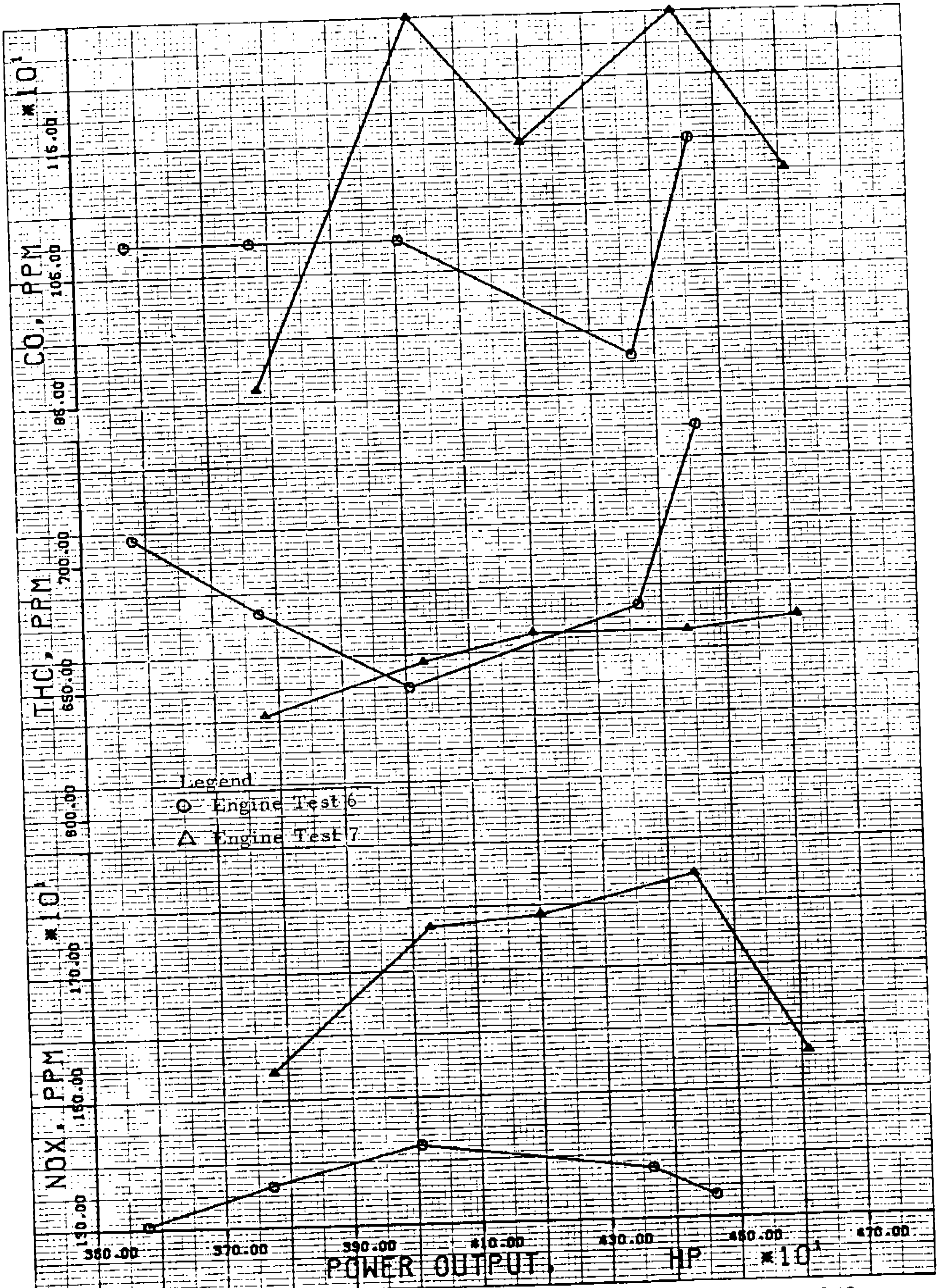


FIGURE E-39 EFFECT OF POWER ON C-B LSVA-16SO PPM EMISSIONS

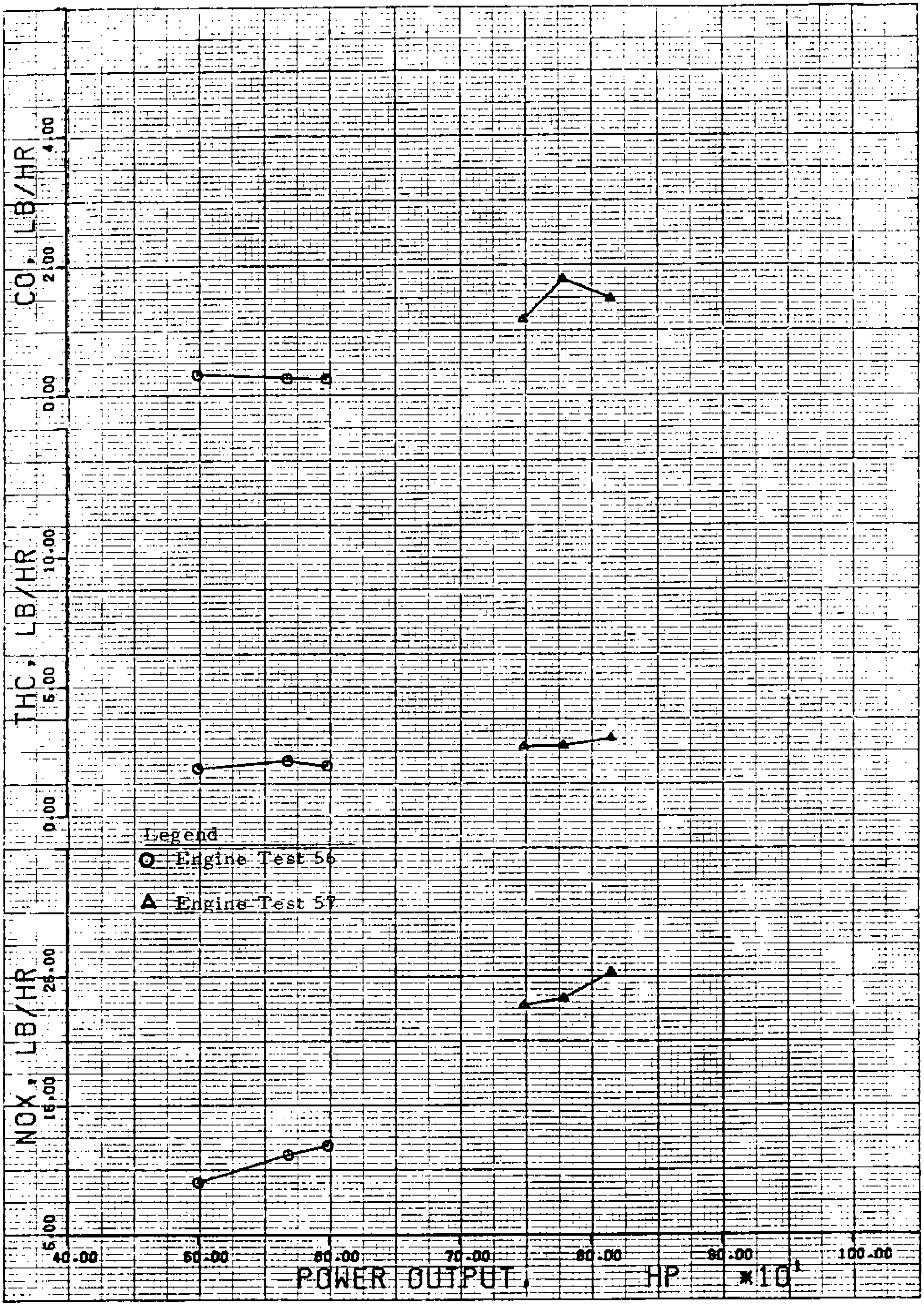


FIGURE E-40 EFFECT OF POWER ON I-R KVG-8 LB/HR EMISSIONS

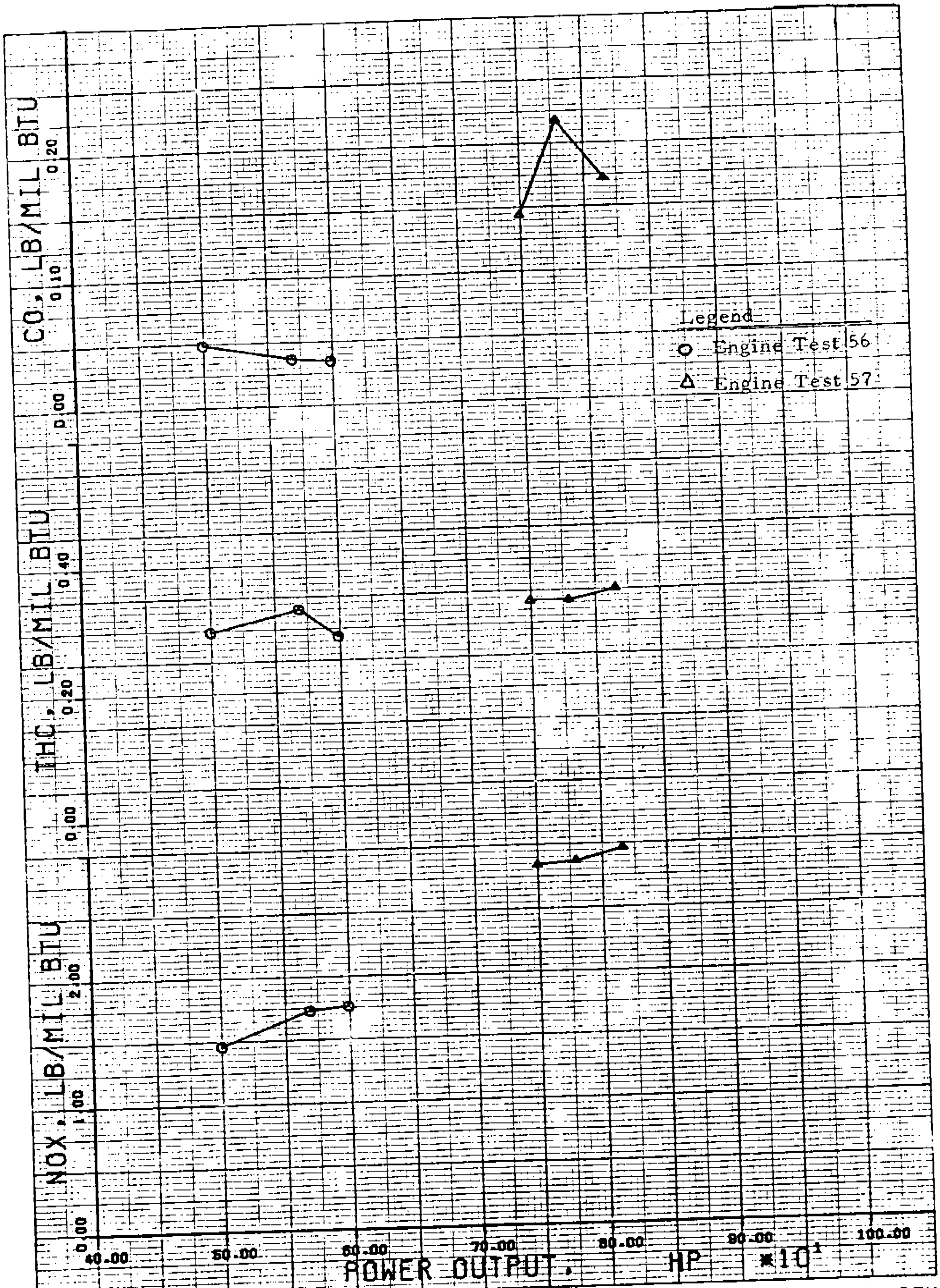


FIGURE E-41 EFFECT OF POWER ON I-R KVG-8 LB EMISSION/MIL BTU

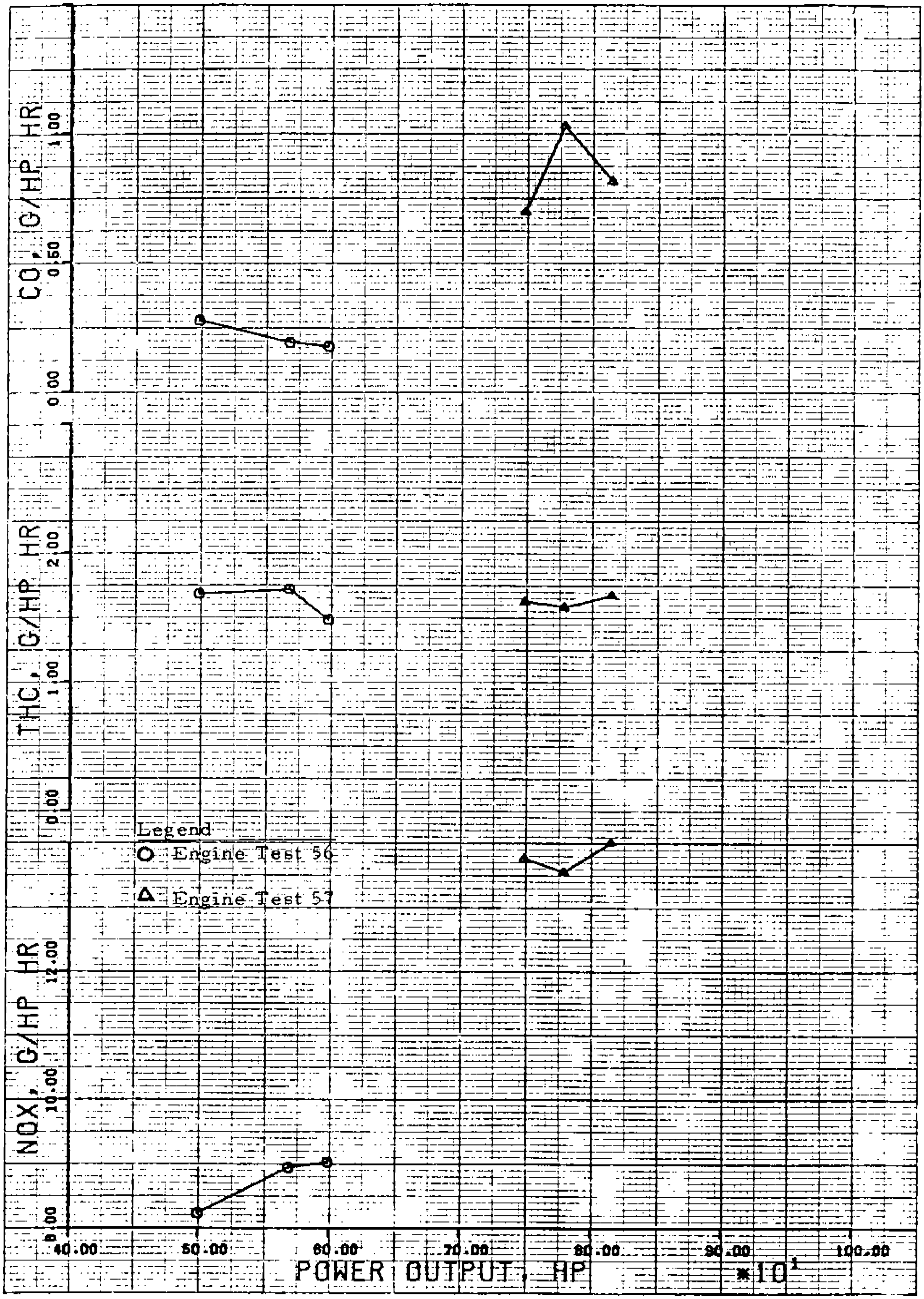


FIGURE E-42 EFFECT OF POWER ON I-R KVG-8 G/HP-HR EMISSIONS

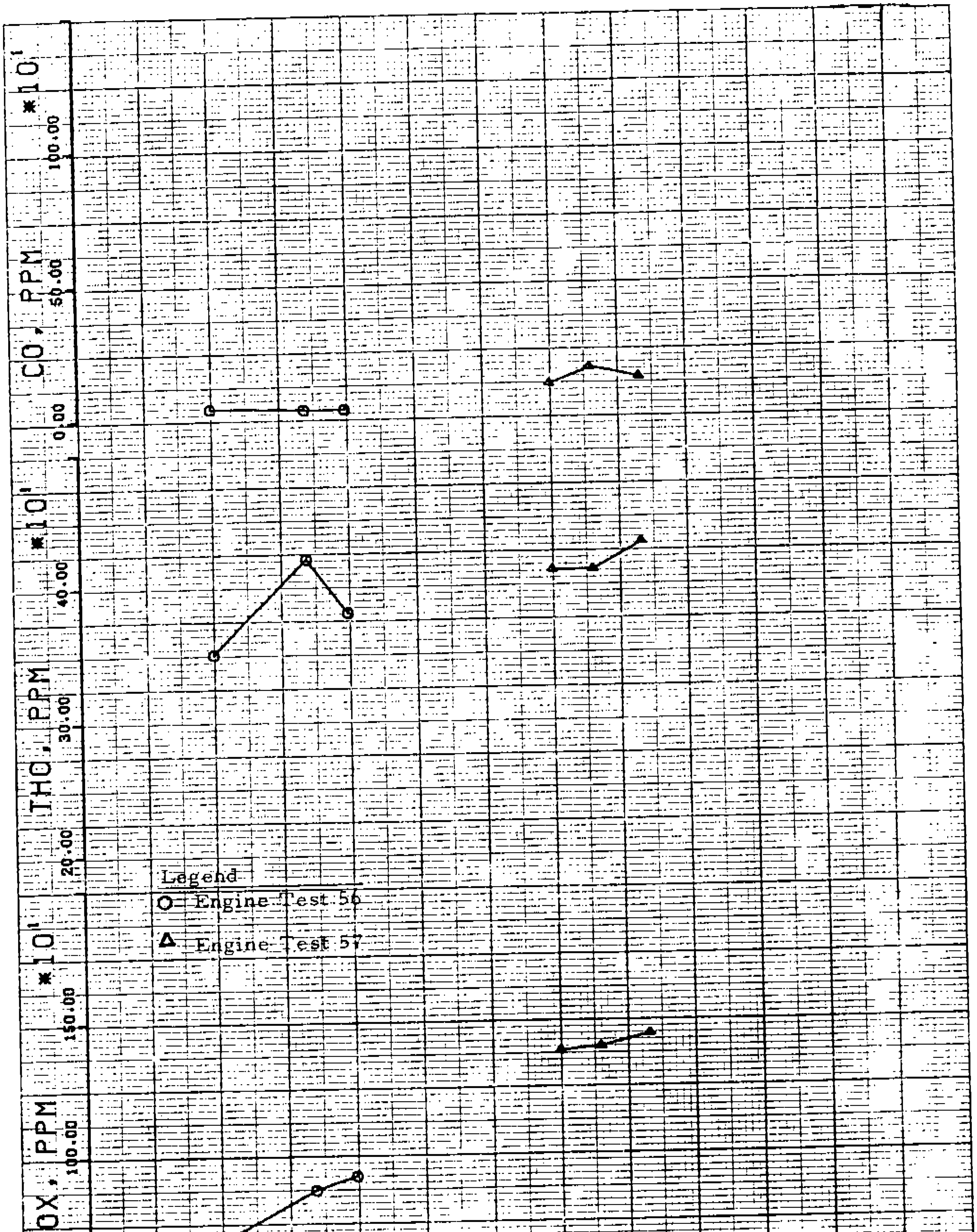


FIGURE E-43 EFFECT OF POWER ON I-R KVG-8 PPM EMISSIONS

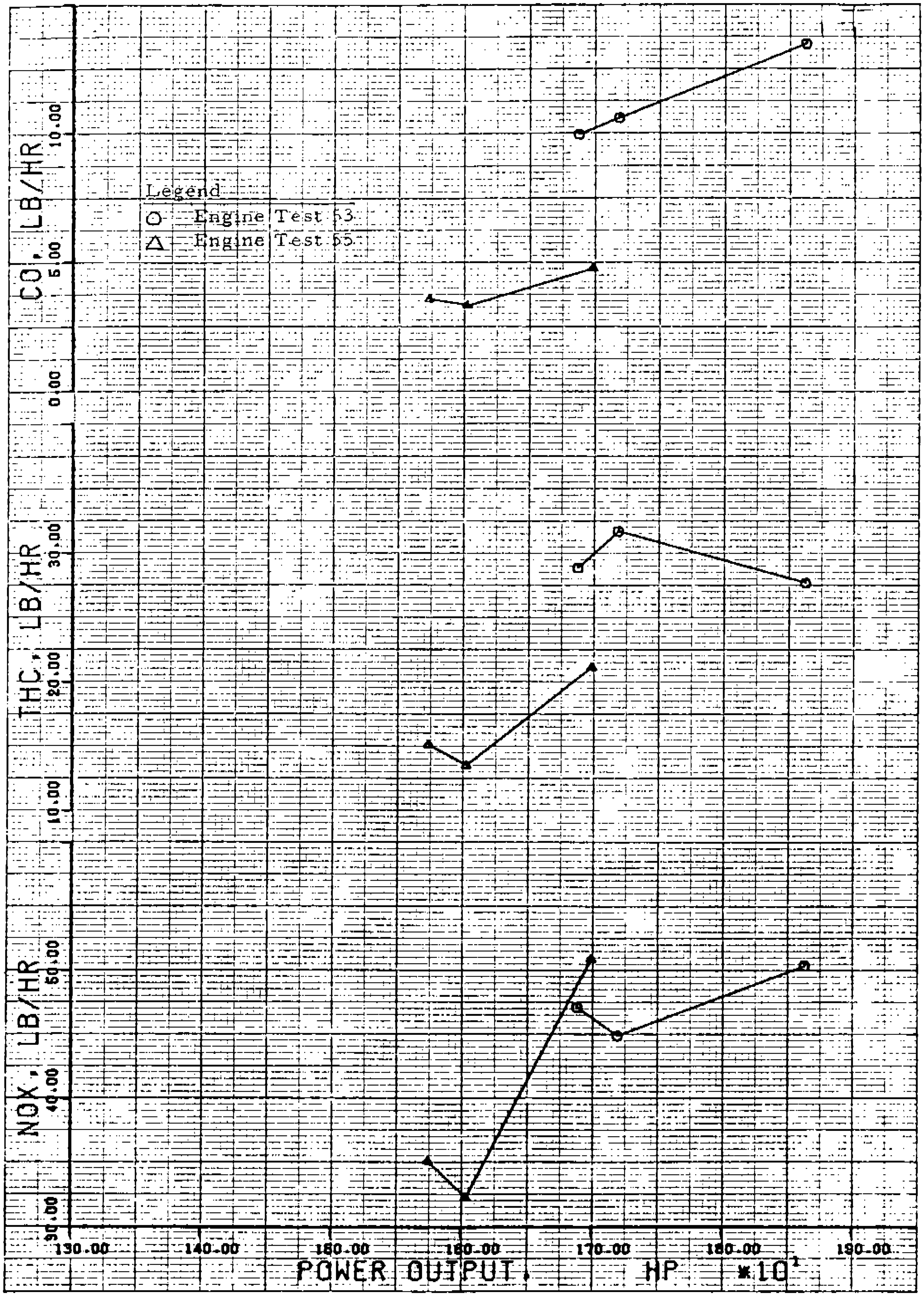


FIGURE E-44 EFFECT OF POWER ON CLARK BA-8 LB/HR EMISSIONS

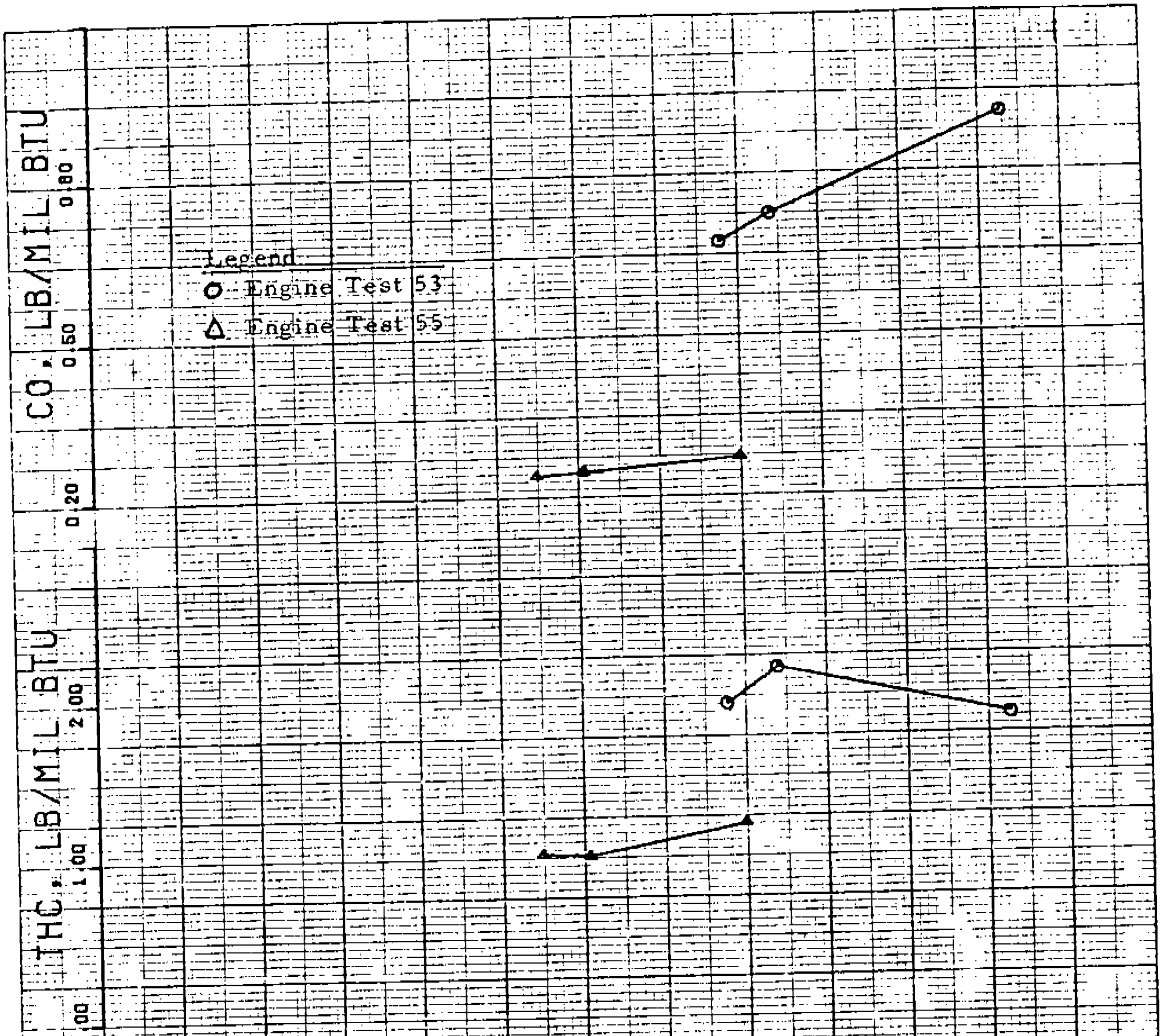


FIGURE E-45 EFFECT OF POWER ON CLARK BA-8 LB EMISSION/MIL BTU

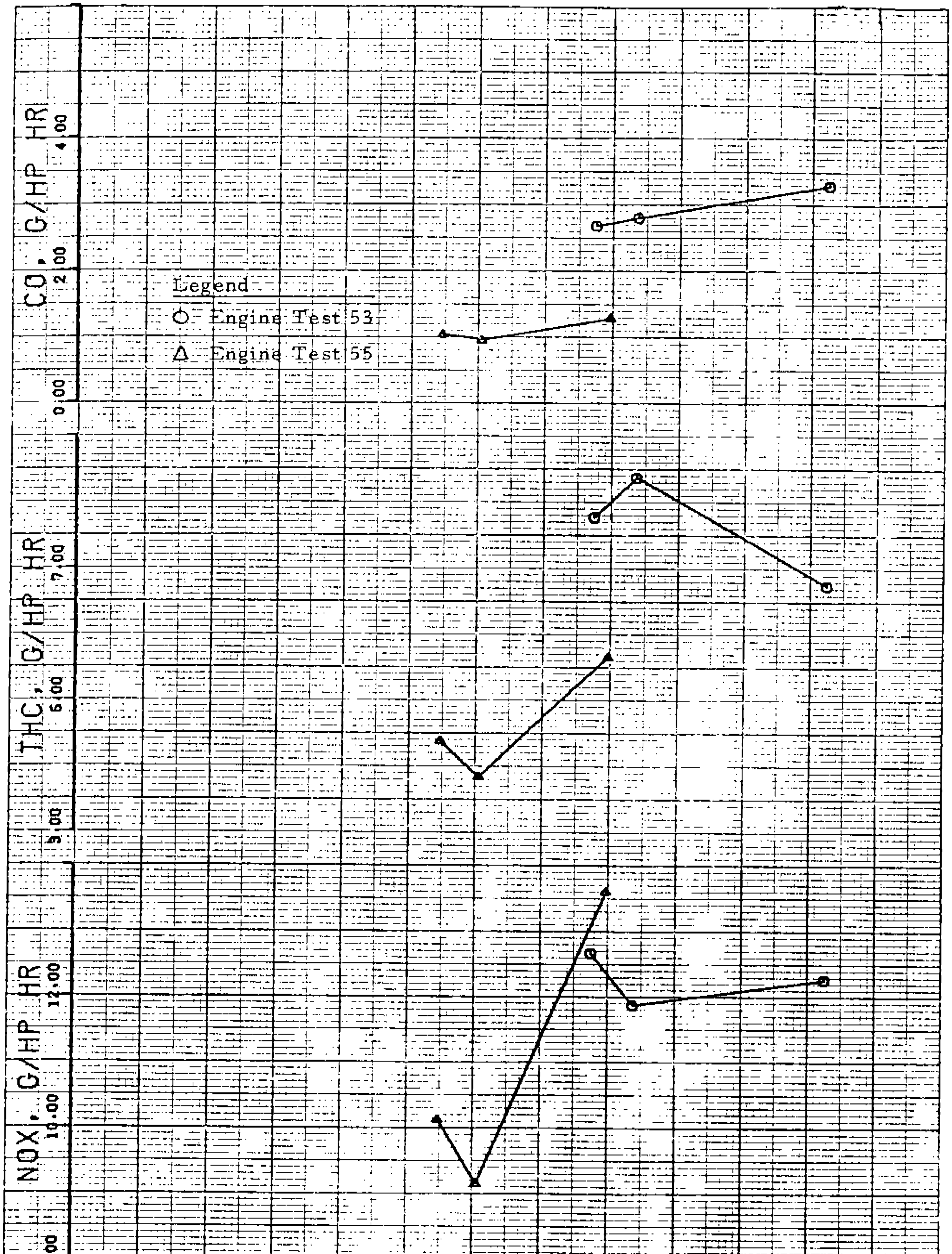


FIGURE E-46 EFFECT OF POWER ON CLARK BA-8 G/HP-HR EMISSIONS

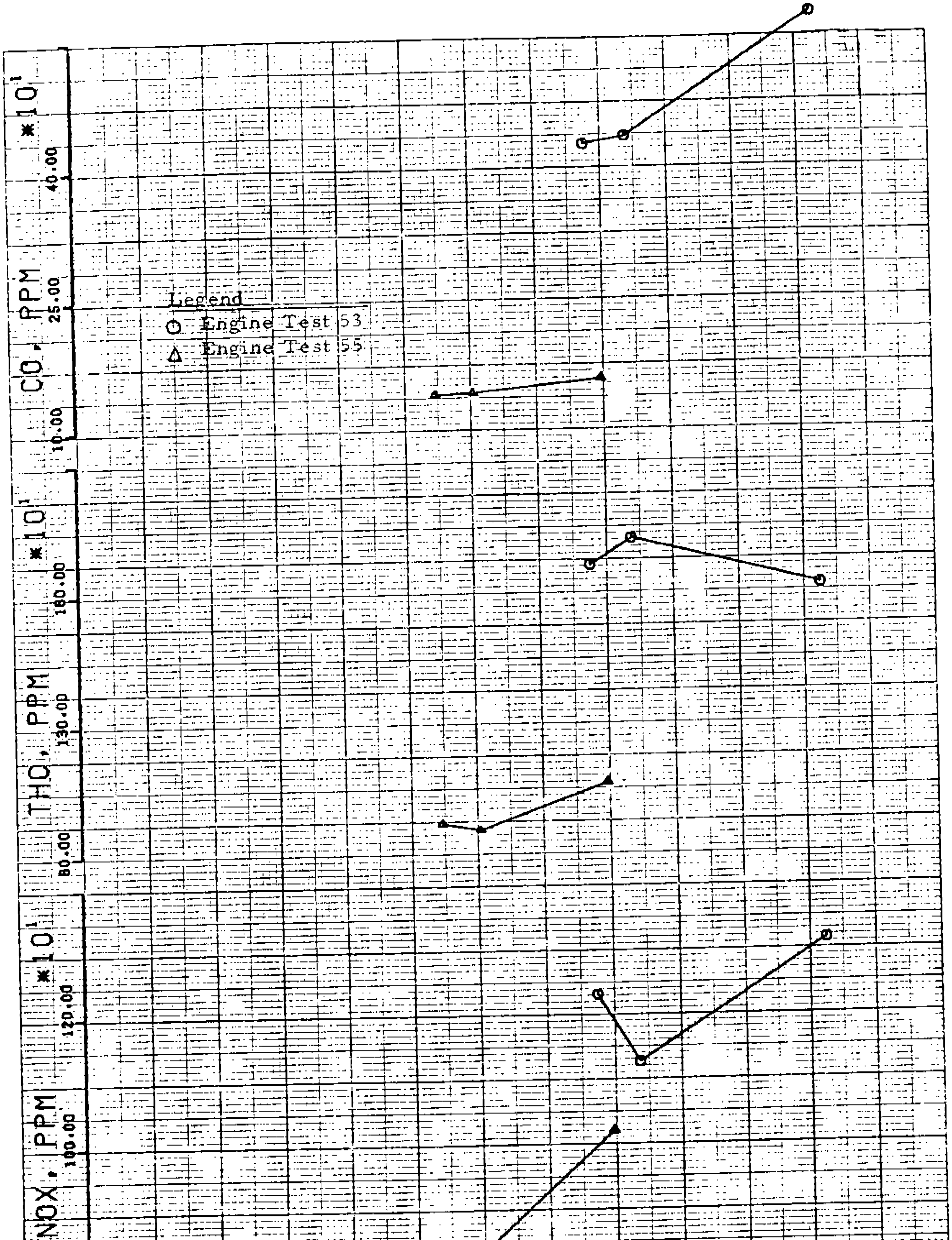


FIGURE E-47 EFFECT OF POWER ON CLARK BA-8 PPM EMISSIONS

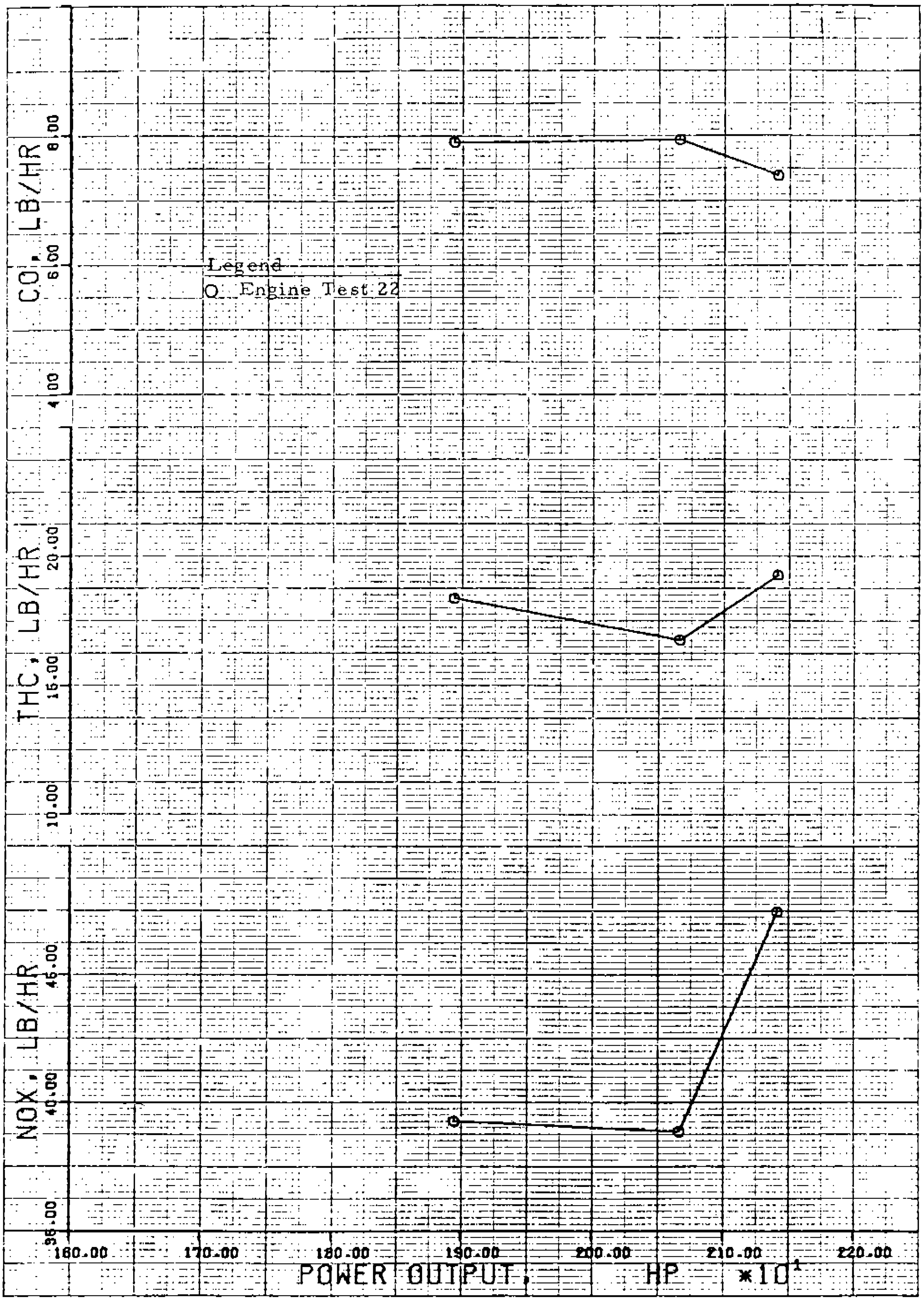


FIGURE E-48 EFFECT OF POWER ON CLARK TLA-6 LB/HR EMISSIONS

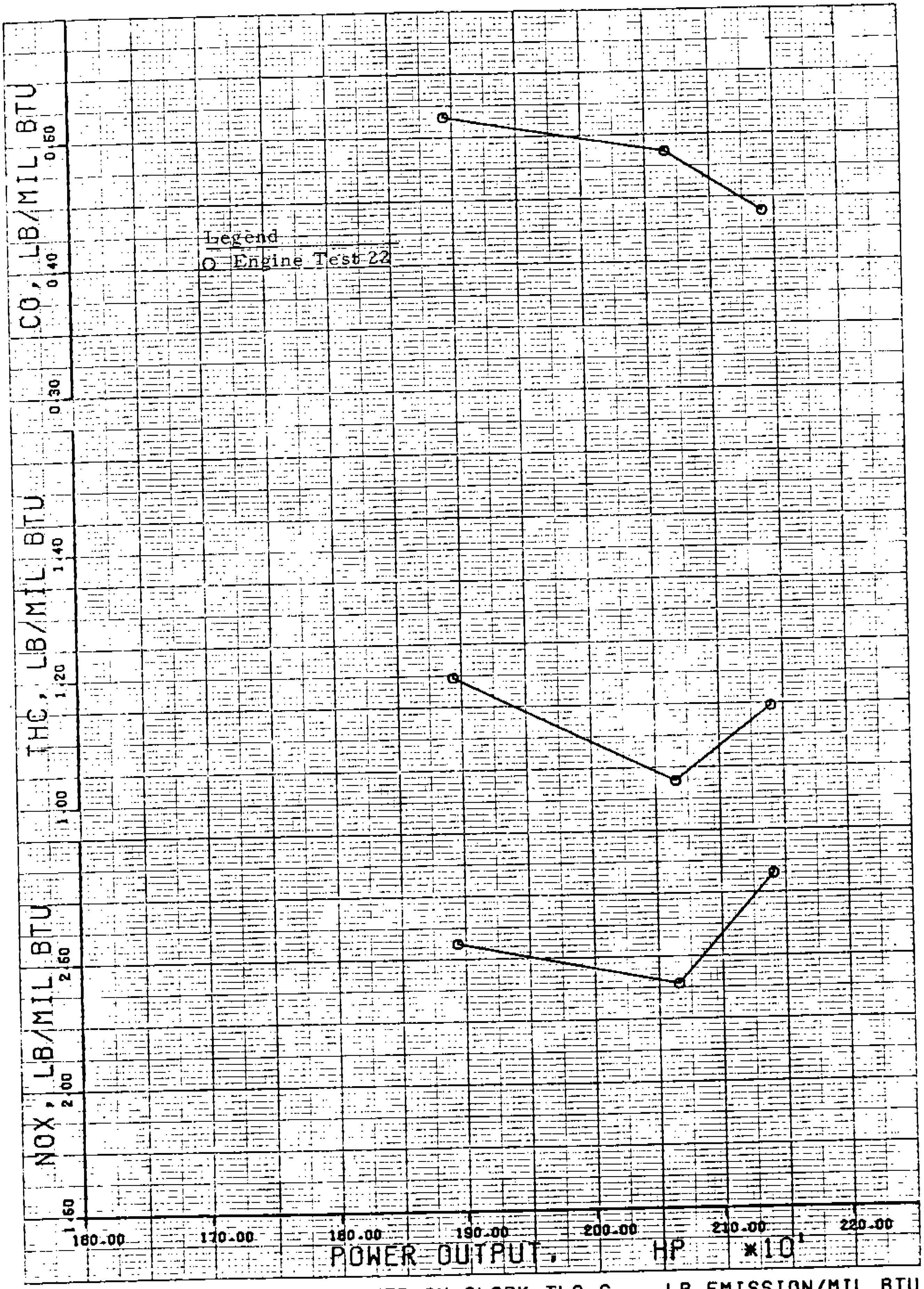


FIGURE E-49 EFFECT OF POWER ON CLARK TLA-6 LB EMISSION/MIL BTU

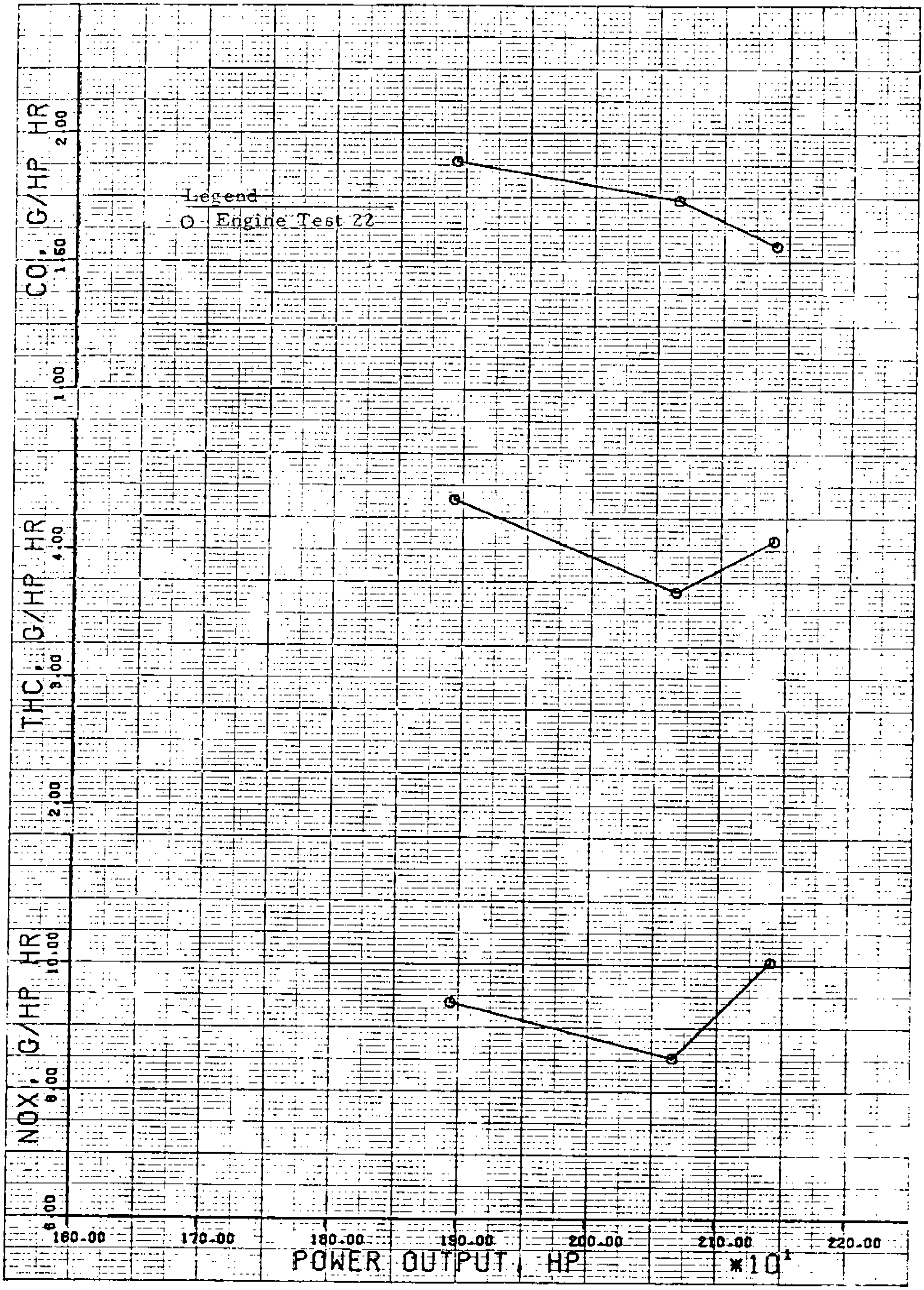


FIGURE E-50 EFFECT OF POWER ON CLARK TLA-6 G/HP-HR EMISSIONS

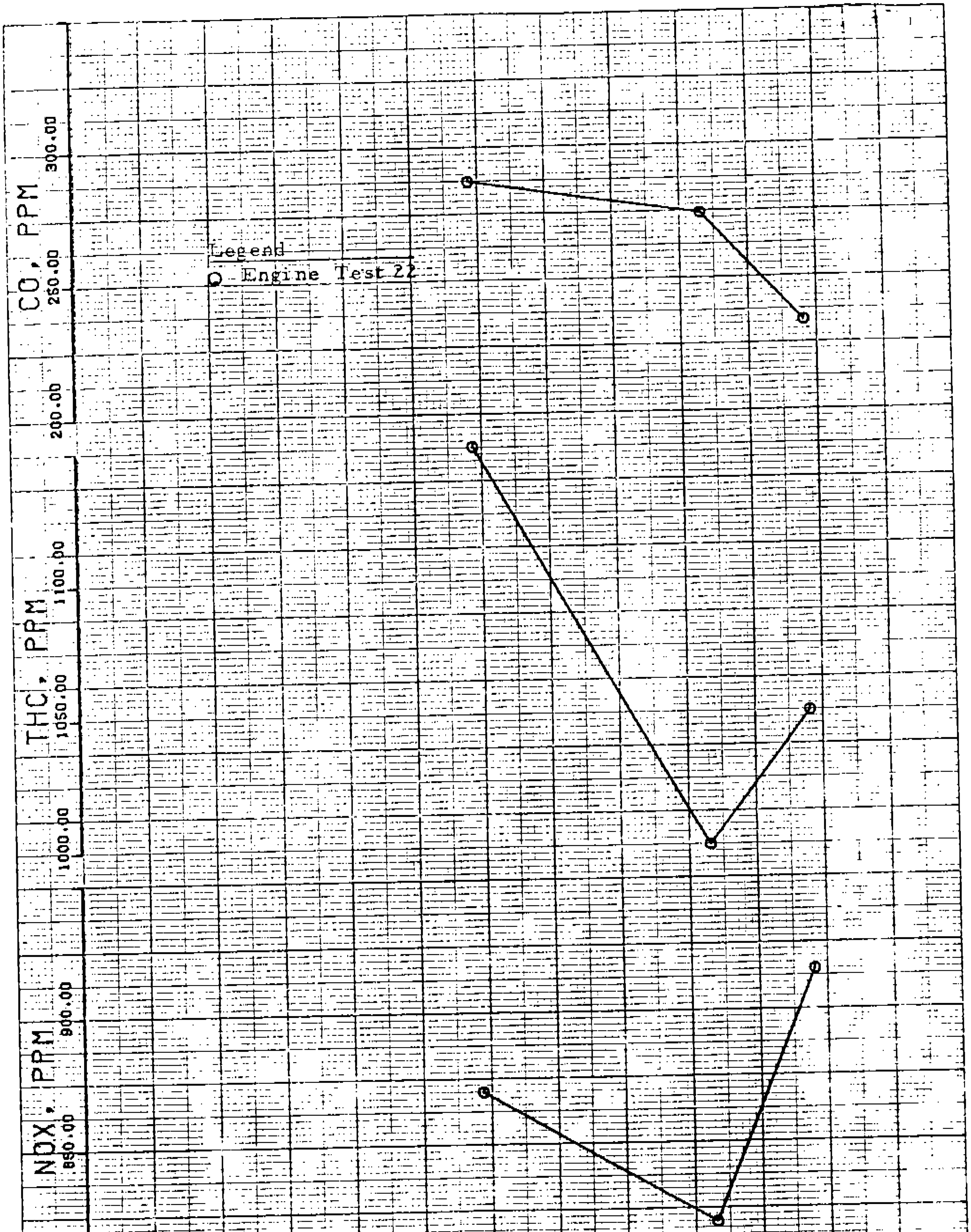


FIGURE E-51 EFFECT OF POWER ON CLARK TLA-6 PPM EMISSIONS

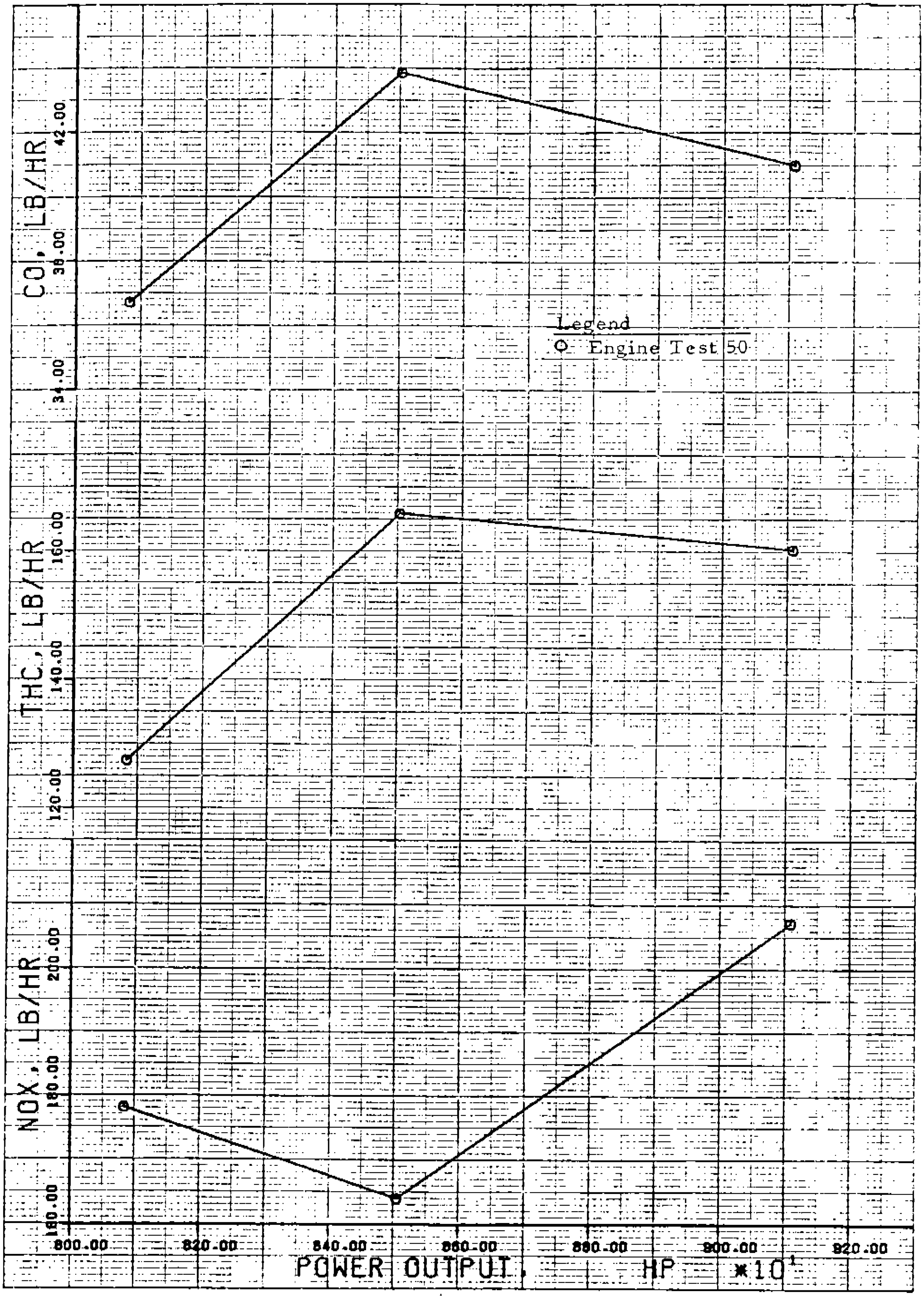


FIGURE E-52 EFFECT OF POWER ON CLARK TCVC-16 LB/HR EMISSIONS

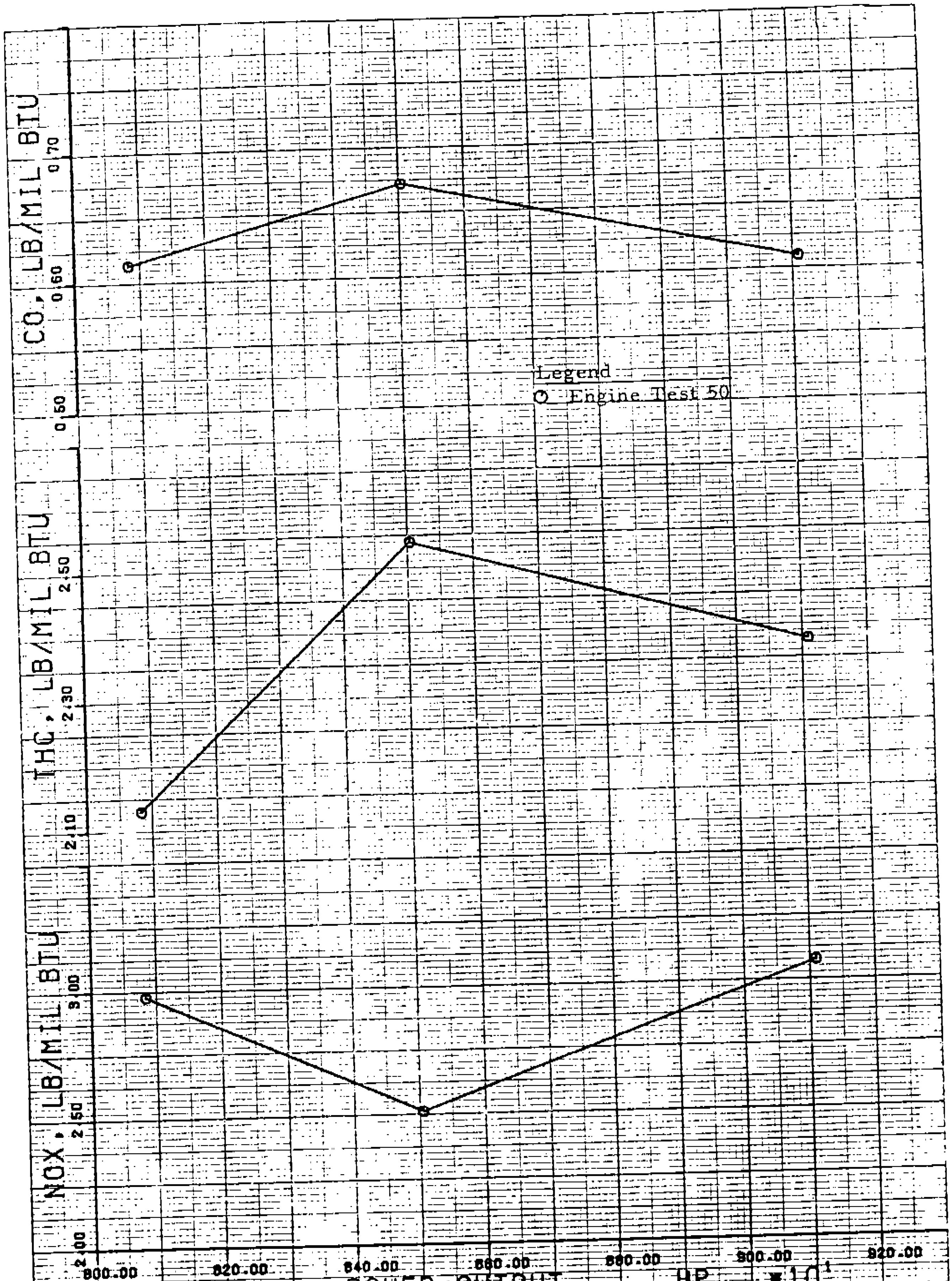


FIGURE E-53 EFFECT OF POWER ON CLARK TCVC-16 LB EMISSION/MIL BTU

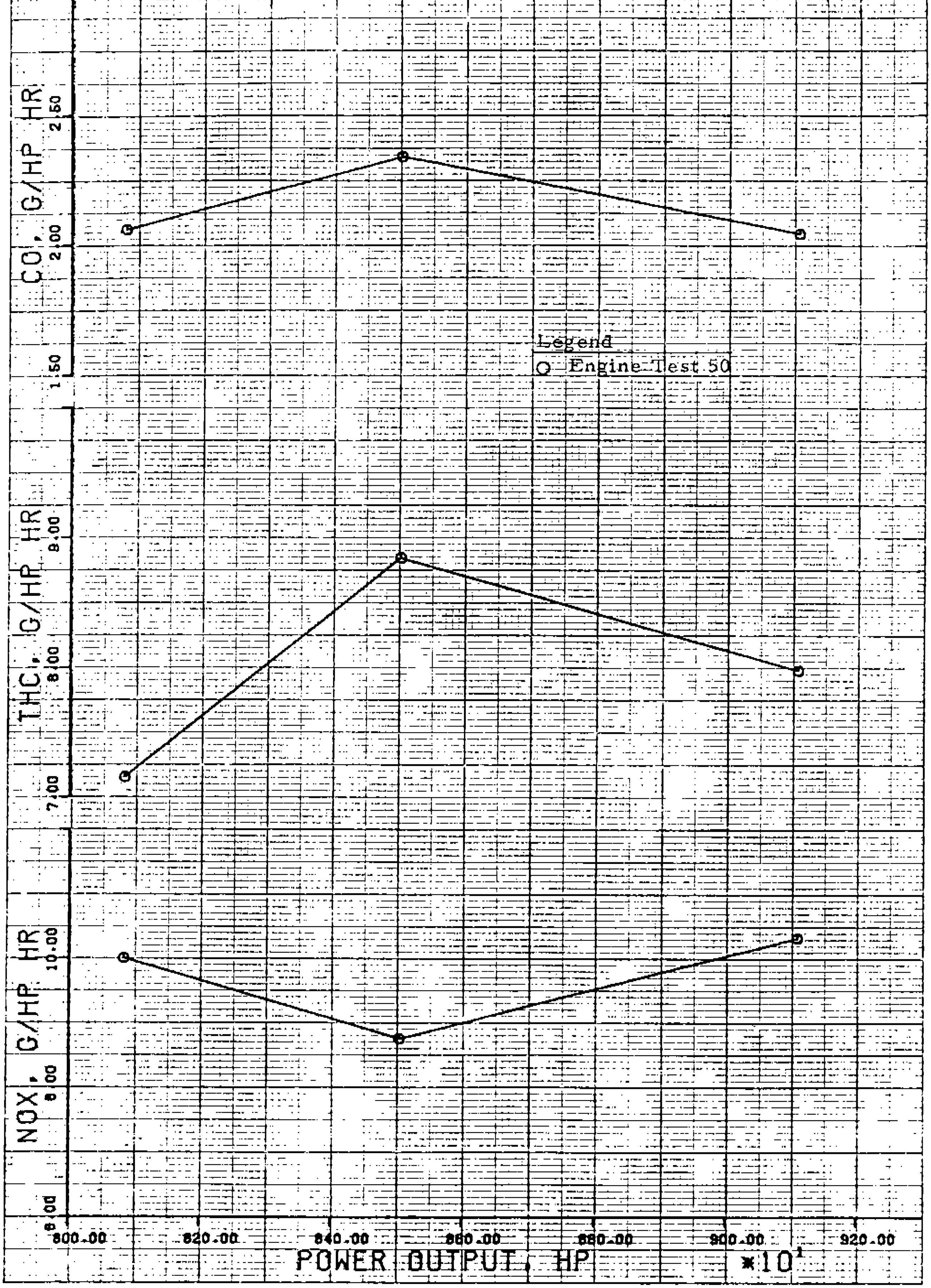


FIGURE E-54 EFFECT OF POWER ON CLARK TCVC-16 G/HP-HR EMISSIONS

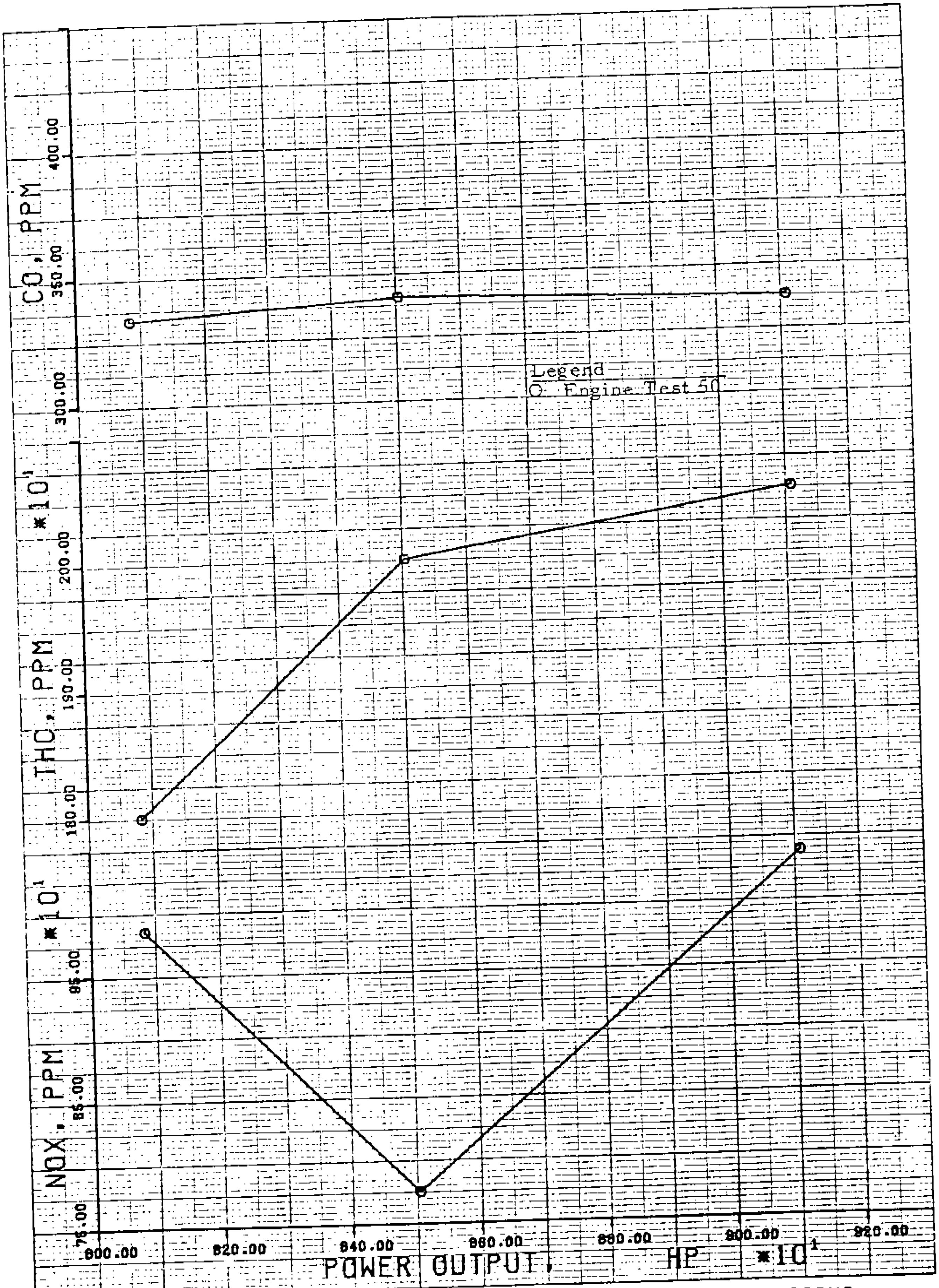


FIGURE E-55 EFFECT OF POWER ON CLARK TCVC-16 PPM EMISSIONS

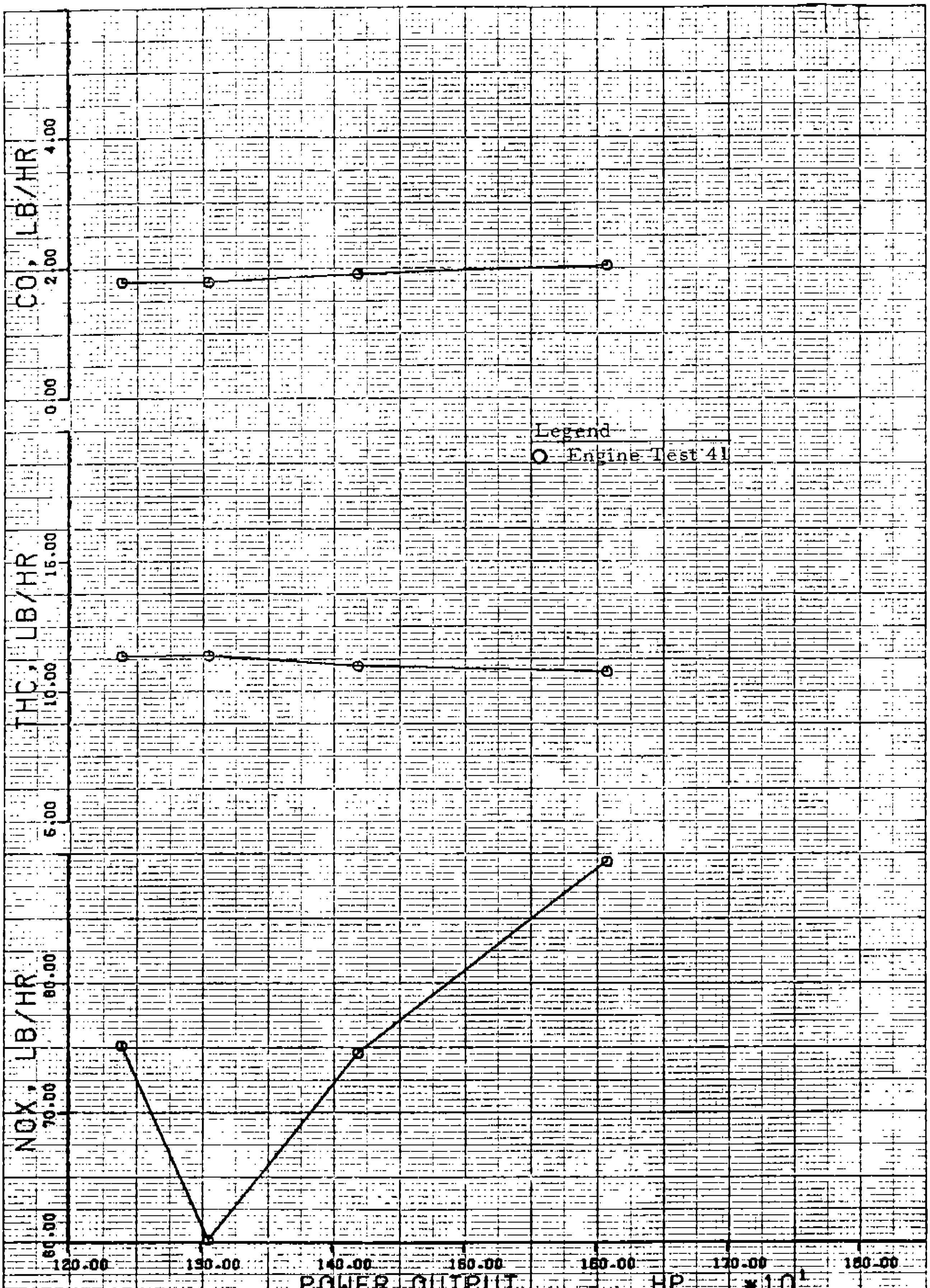


FIGURE E-56 EFFECT OF POWER ON C-B GMV-10 LB/HR EMISSIONS

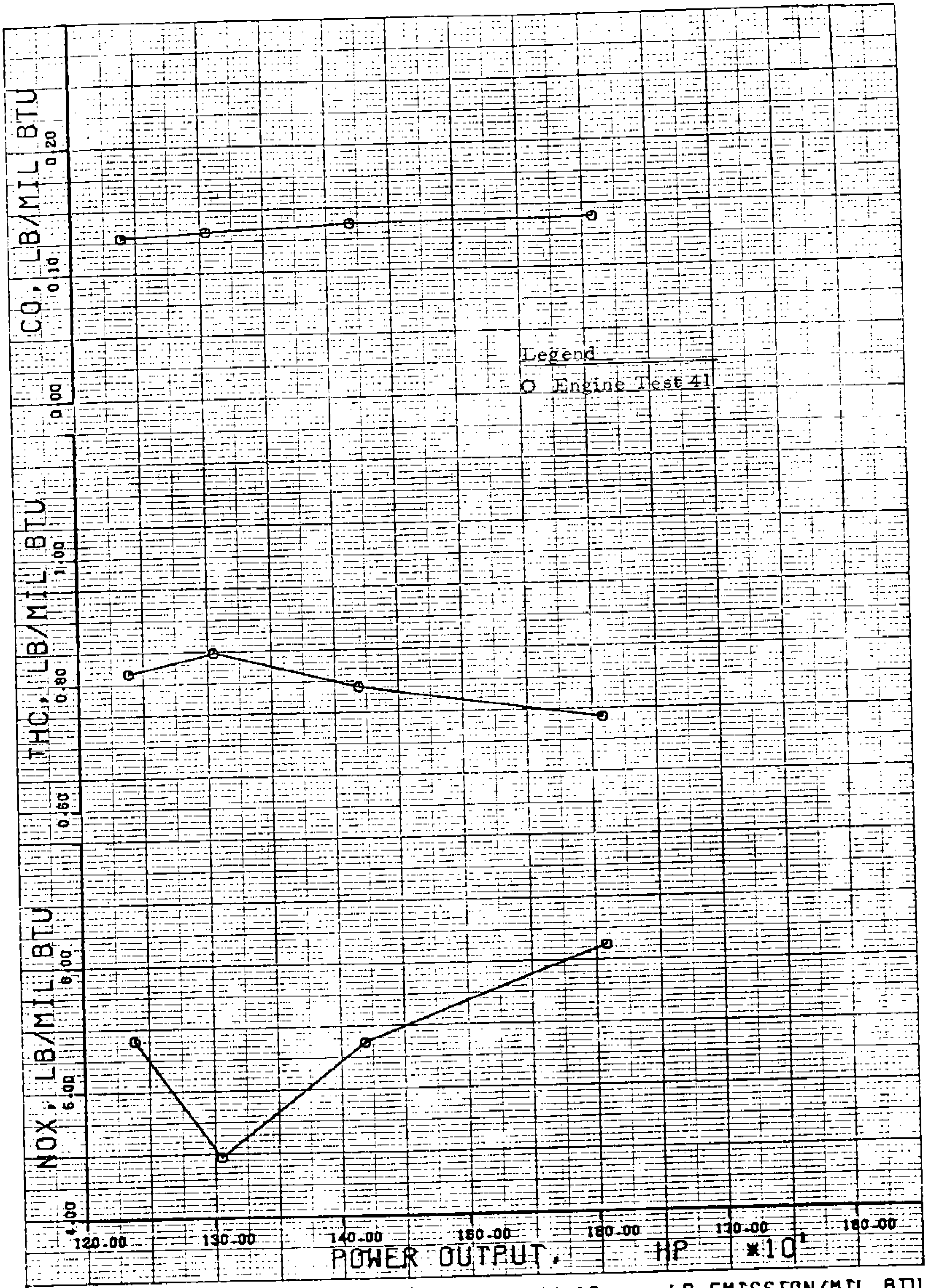


FIGURE E-57 EFFECT OF POWER ON C-B GMV-10 LB EMISSION/MIL BTU

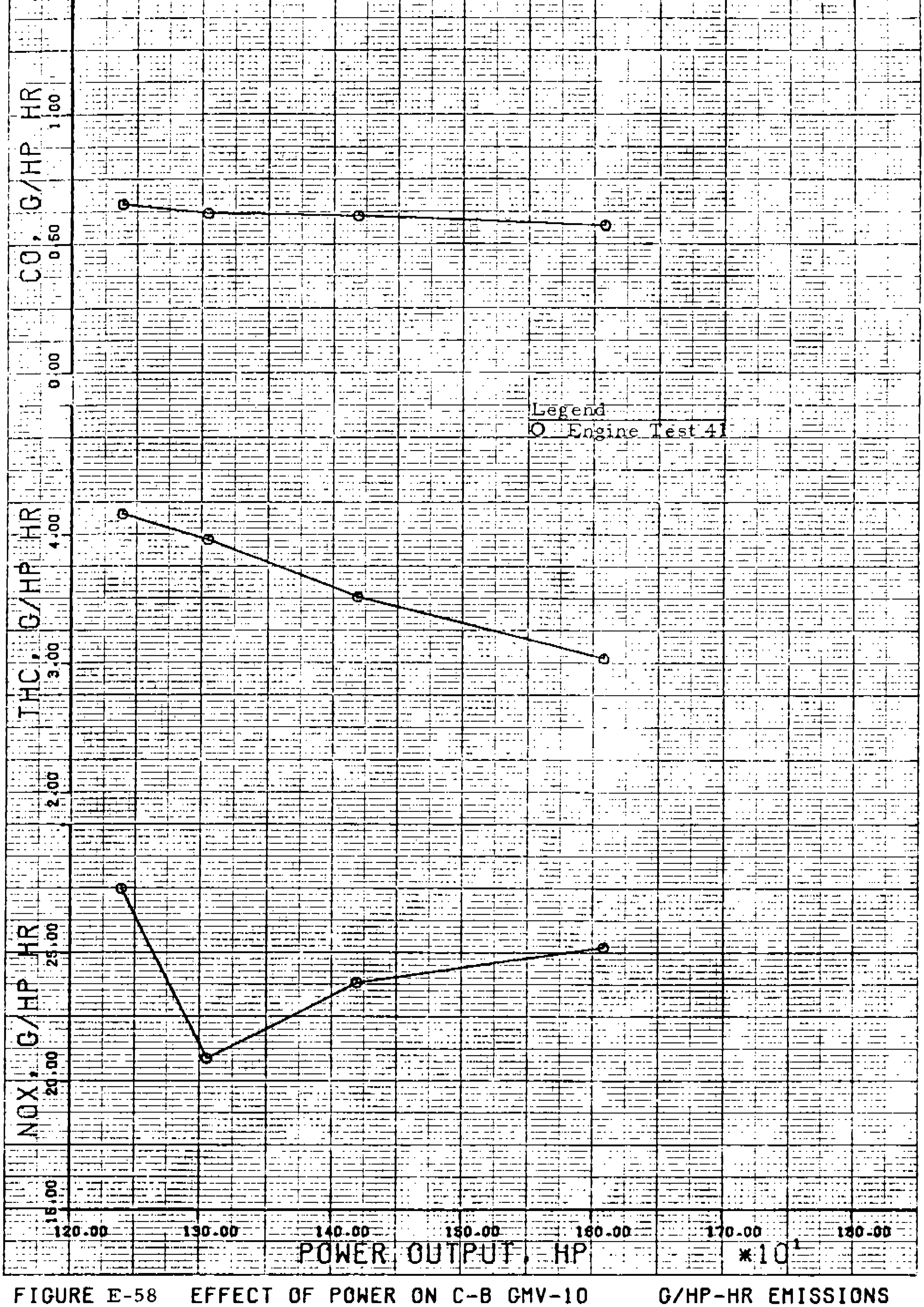


FIGURE E-58 EFFECT OF POWER ON C-B GMV-10 G/HP-HR EMISSIONS

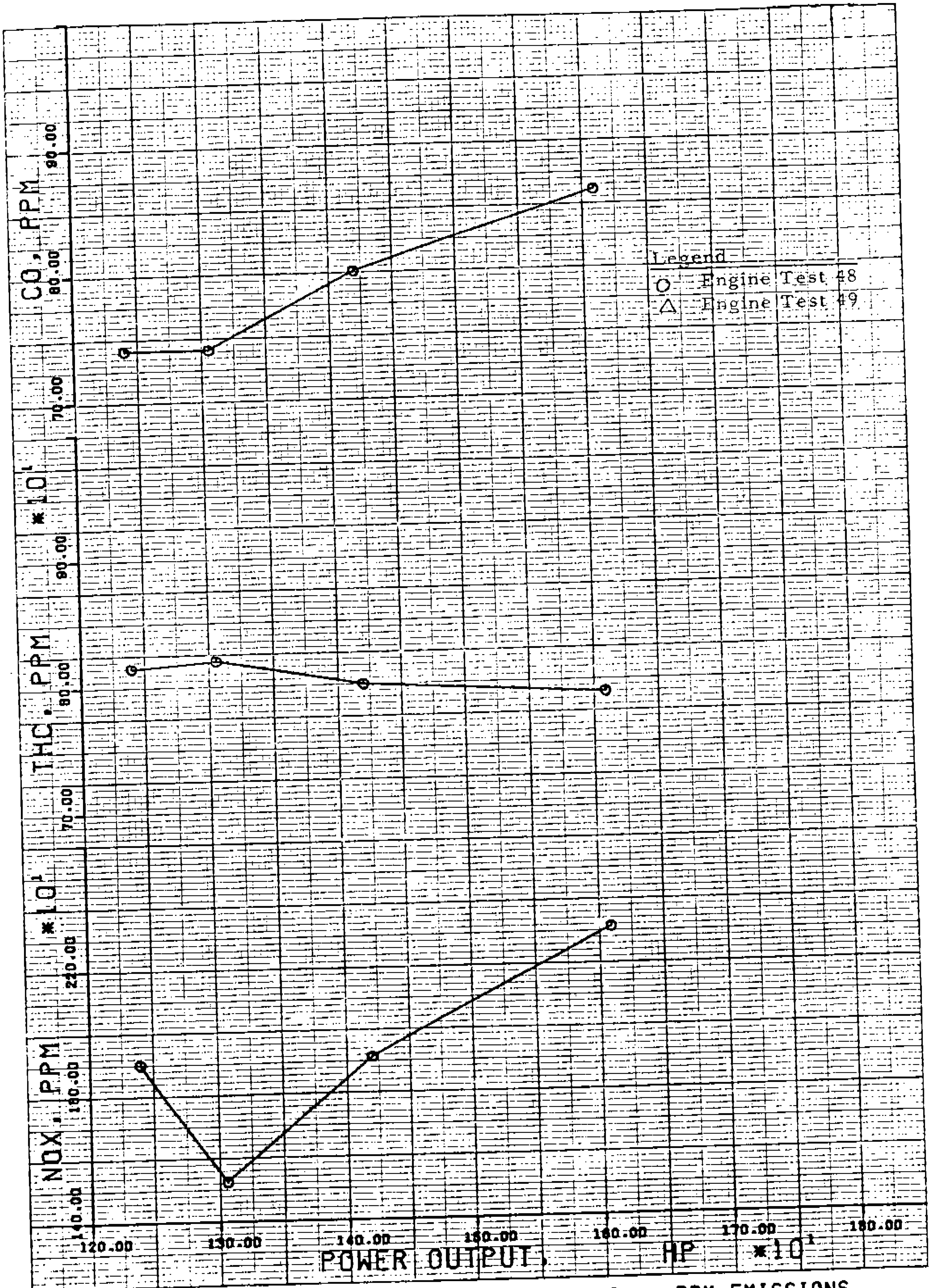


FIGURE E-59 EFFECT OF POWER ON C-B GMV-10 PPM EMISSIONS

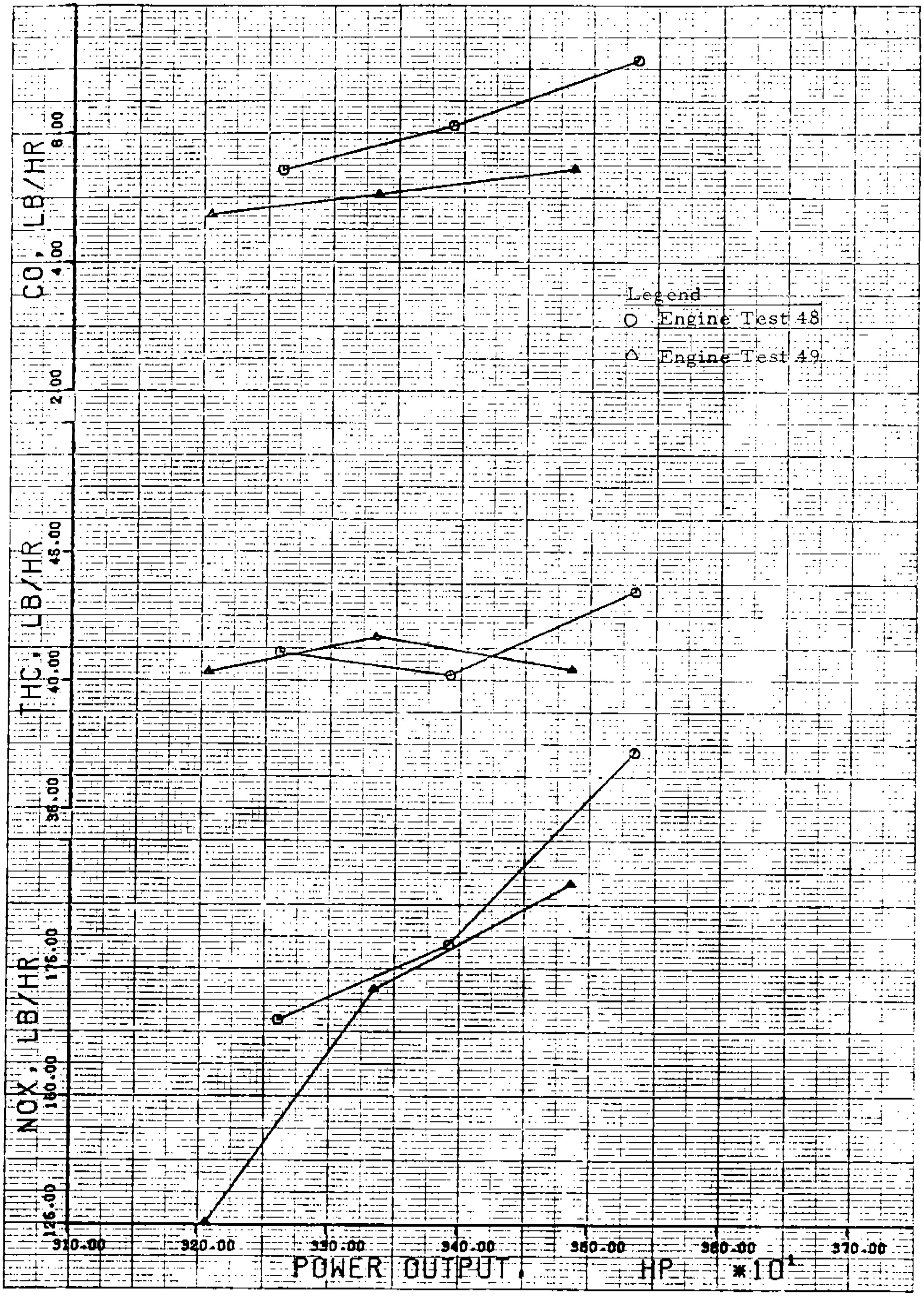


FIGURE E-60 EFFECT OF POWER ON C-B GMWC-10 LB/HR EMISSIONS

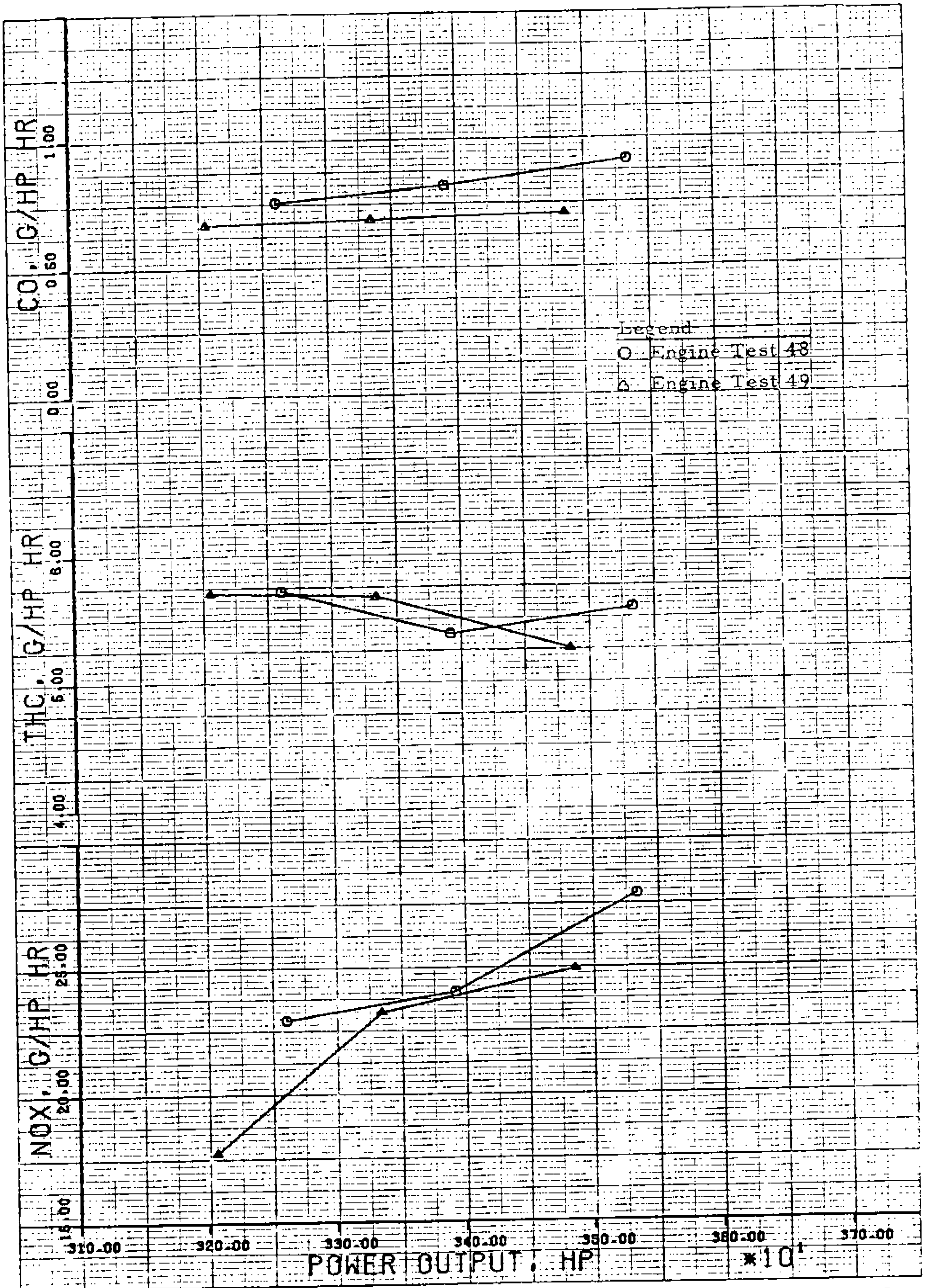


FIGURE E-61 EFFECT OF POWER ON C-B GMWC-10 G/HP-HR EMISSIONS

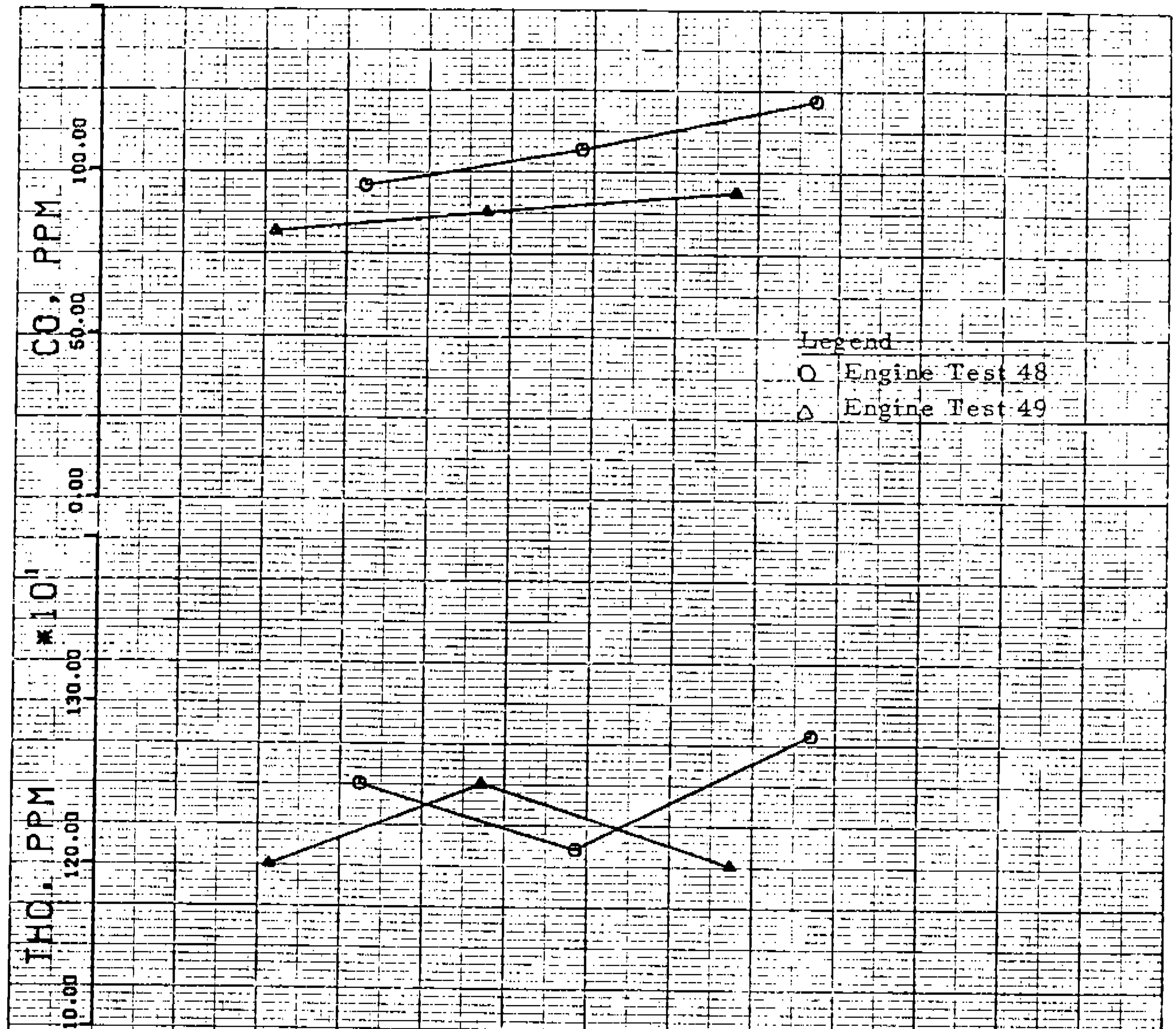


FIGURE E-62 EFFECT OF POWER ON C-B GMWC-10 PPM EMISSIONS

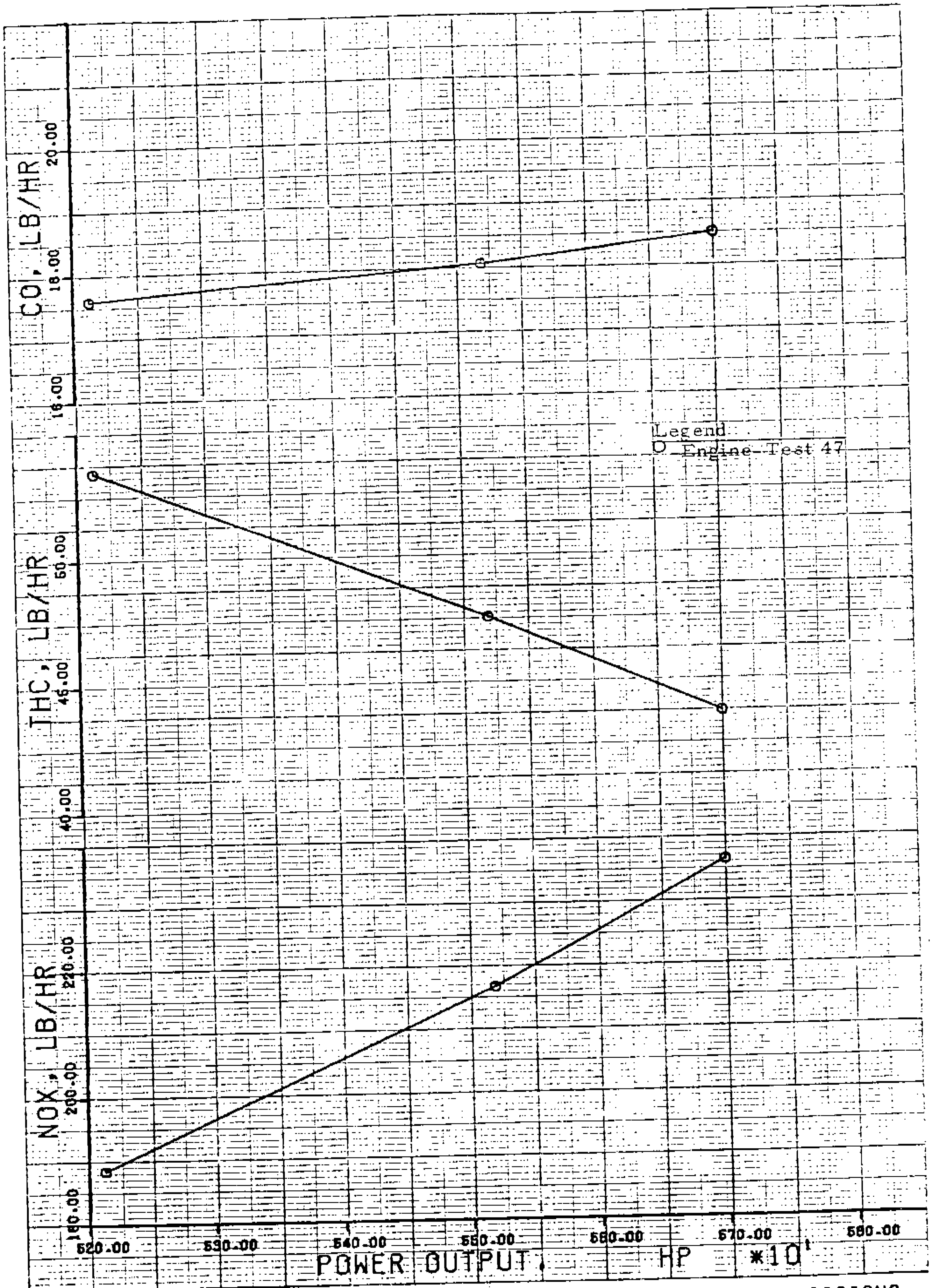


FIGURE E-63 EFFECT OF POWER ON C-B 16V-250 LB/HR EMISSIONS

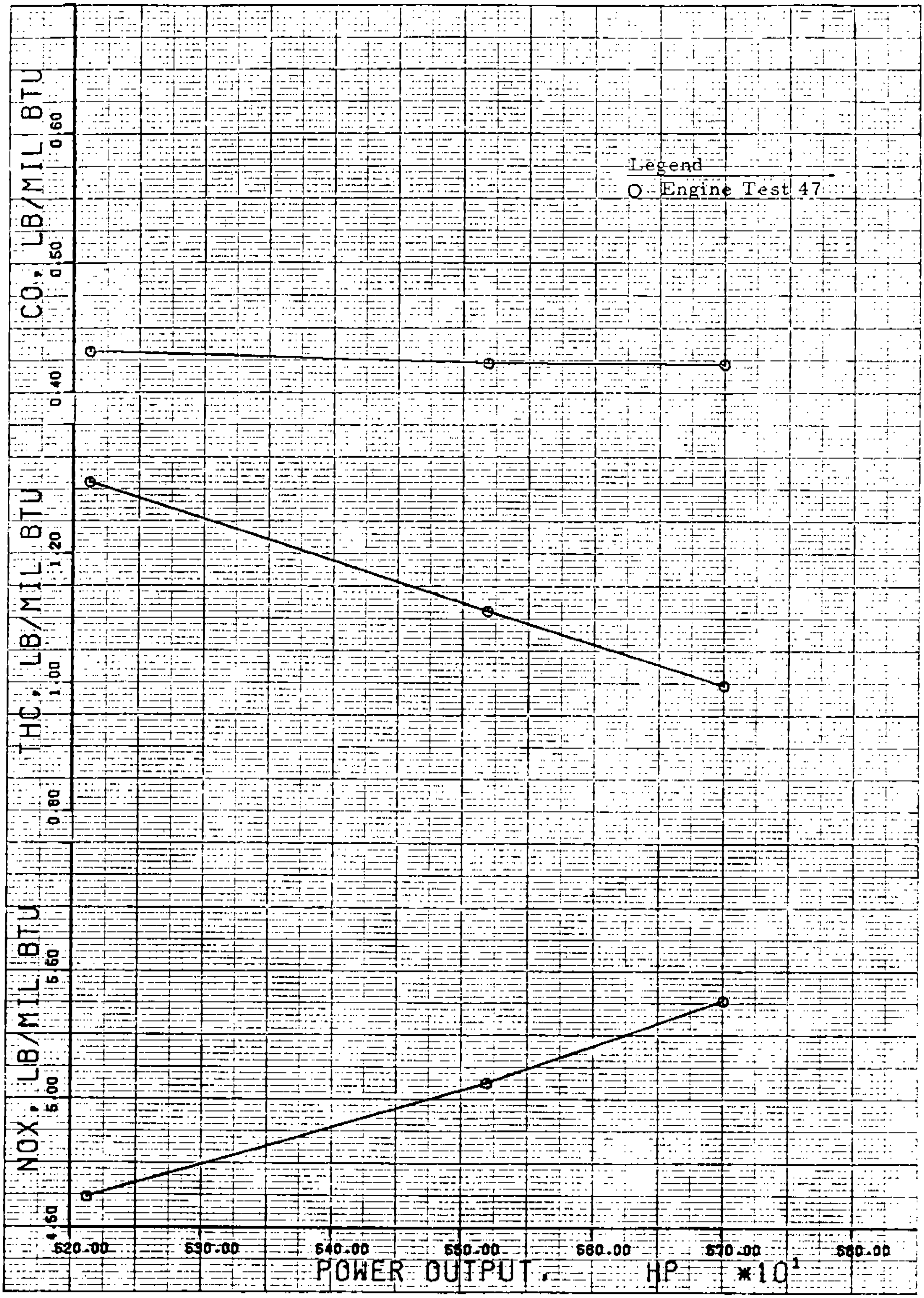


FIGURE E-64 EFFECT OF POWER ON C-B 16V-250 LB EMISSION/MIL BTU

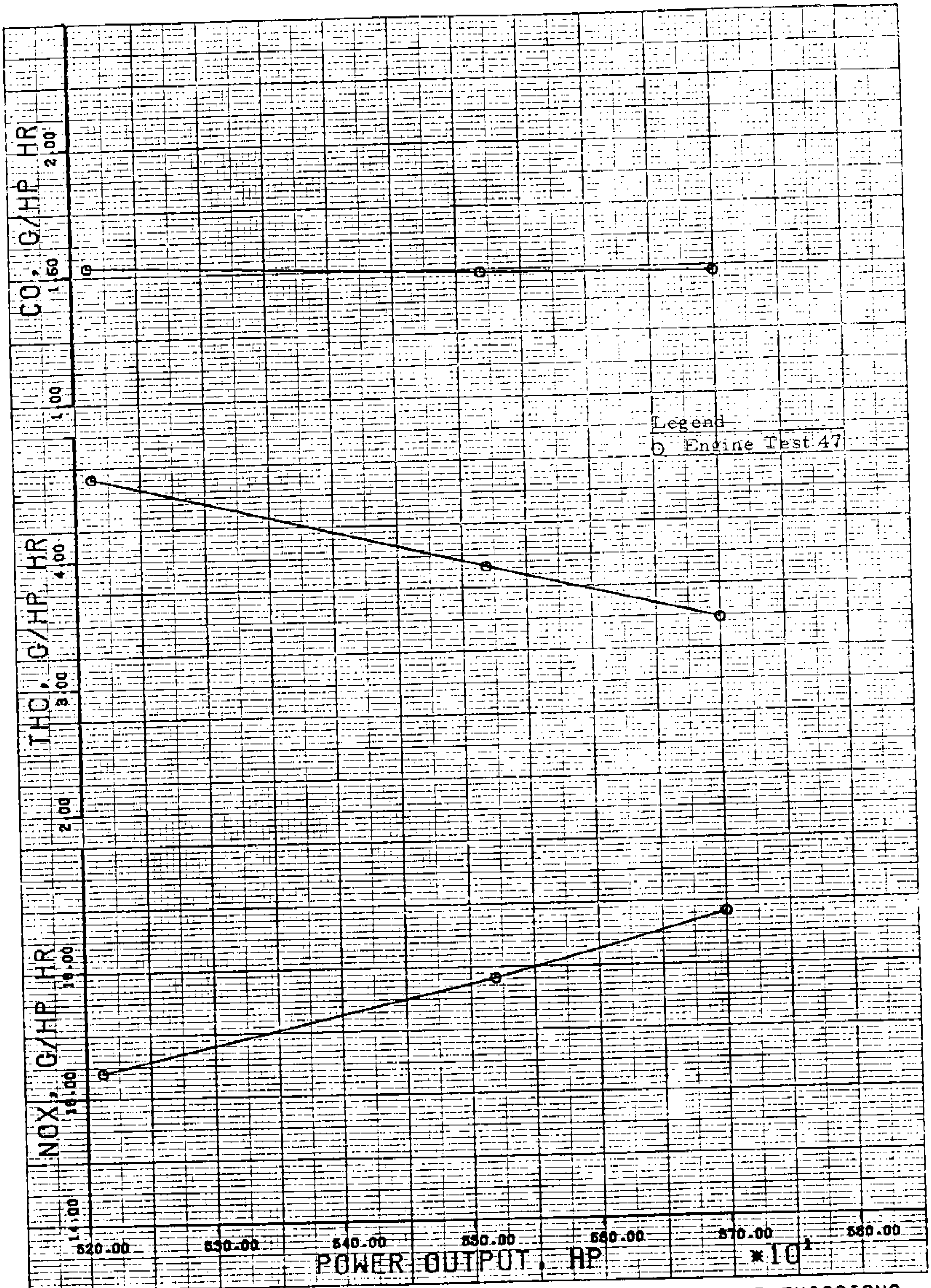


FIGURE E-65 EFFECT OF POWER ON C-B 16V-250 G/HP-HR EMISSIONS

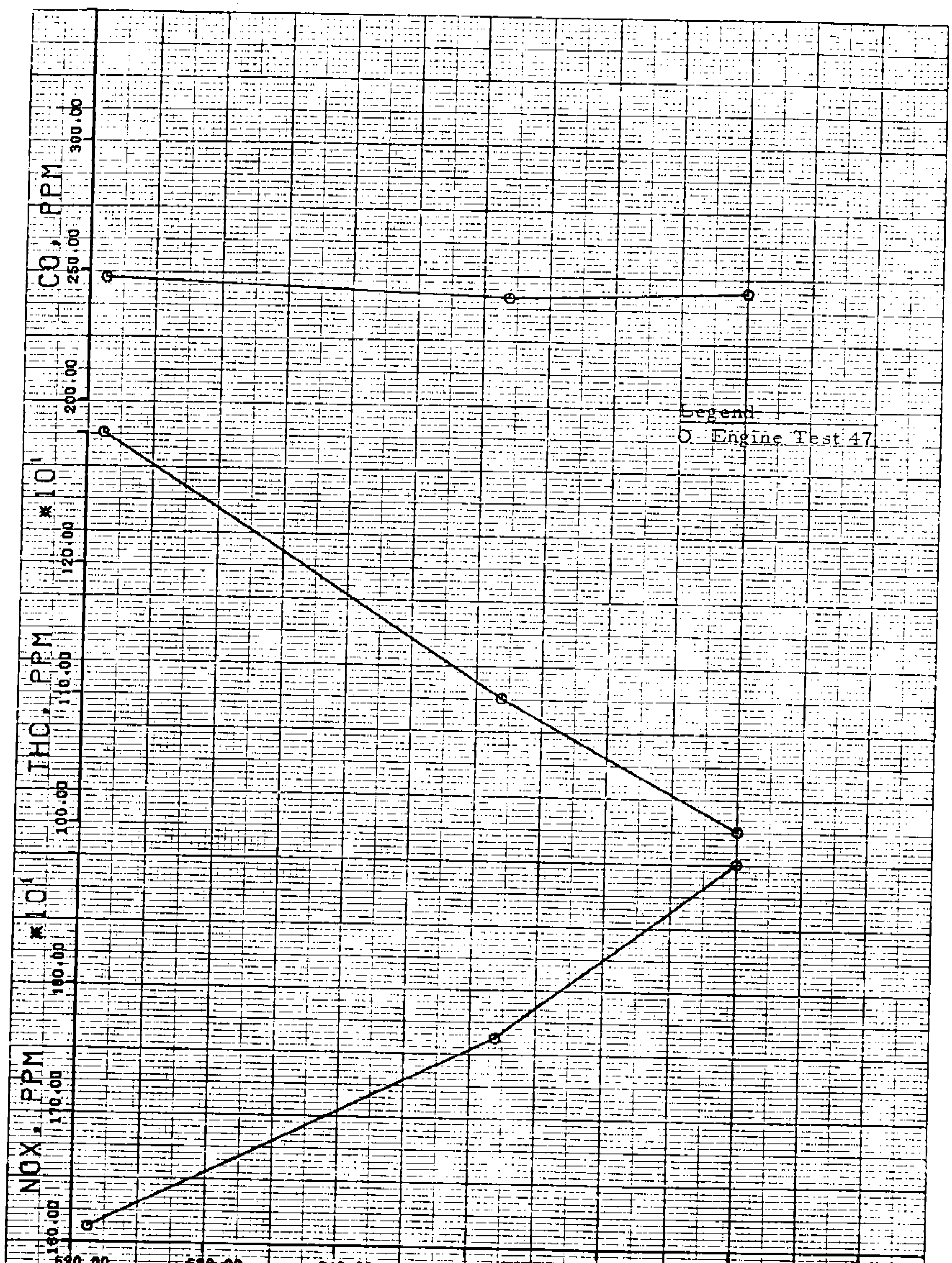


FIGURE E-66 EFFECT OF POWER ON C-B 16V-250 PPM EMISSIONS

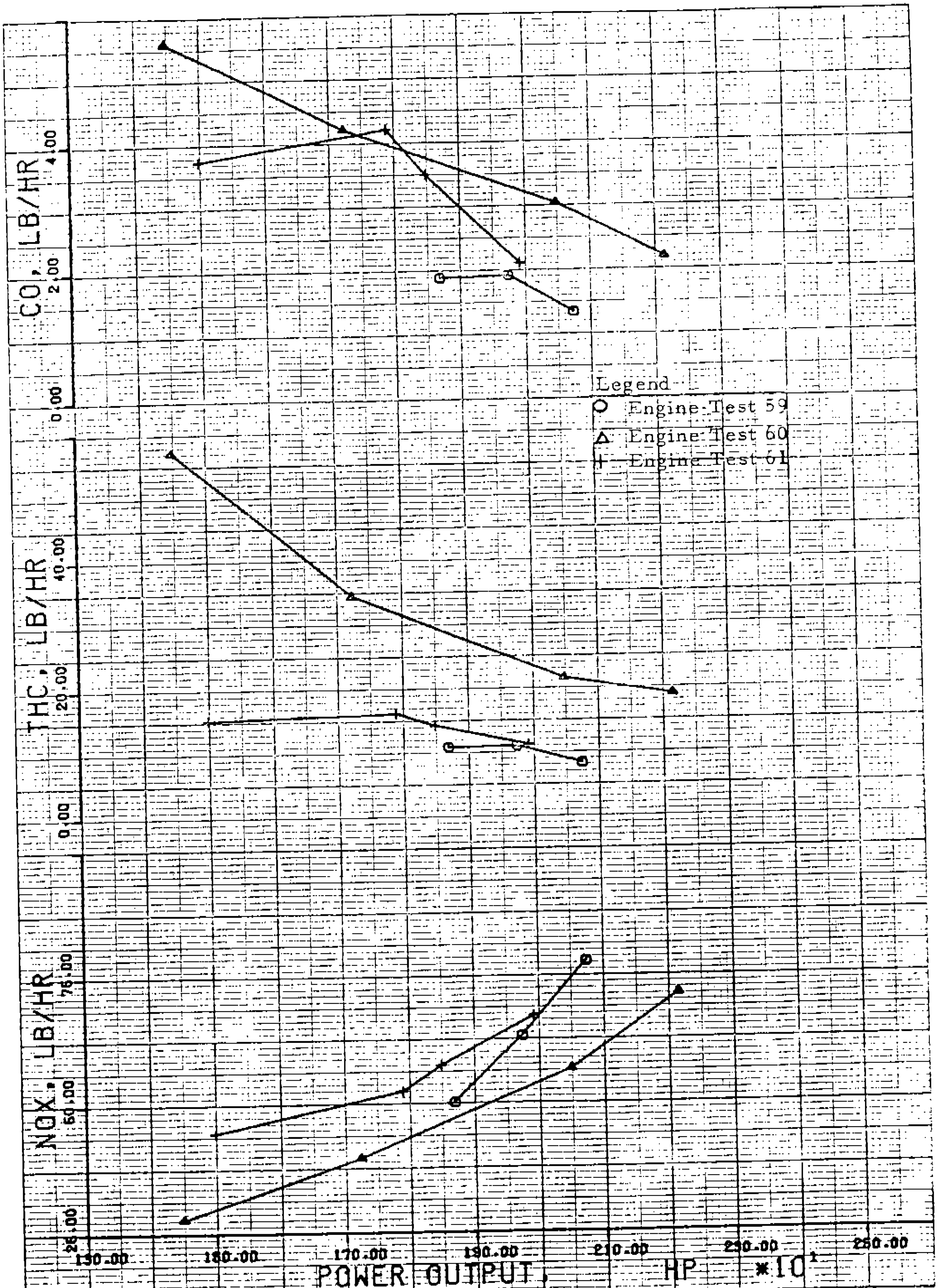


FIGURE E-67 EFFECT OF POWER ON I-R 412 KVS LB/HR EMISSIONS

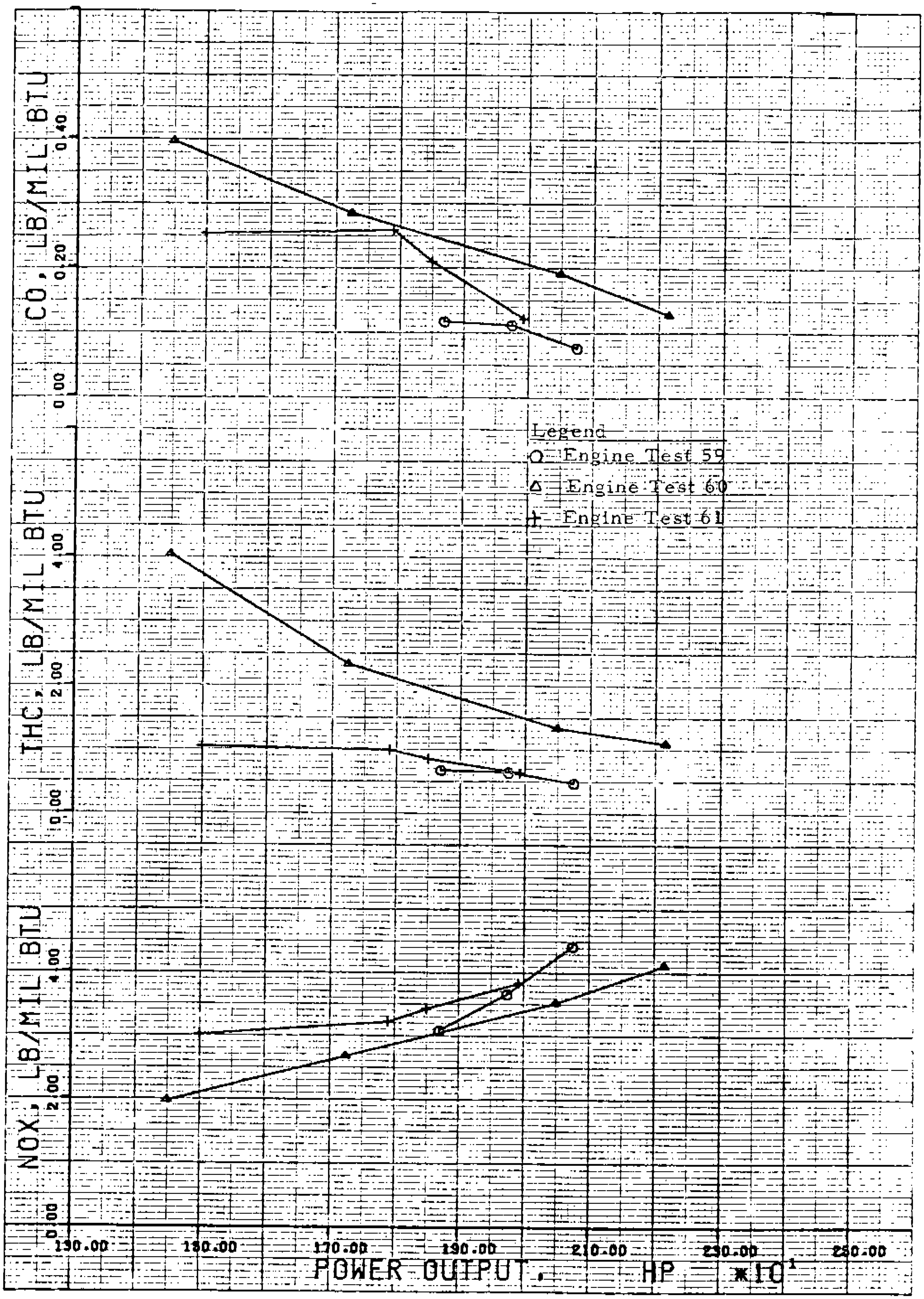


FIGURE E-68 EFFECT OF POWER ON I-R 412 KVS LB EMISSION/MIL BTU

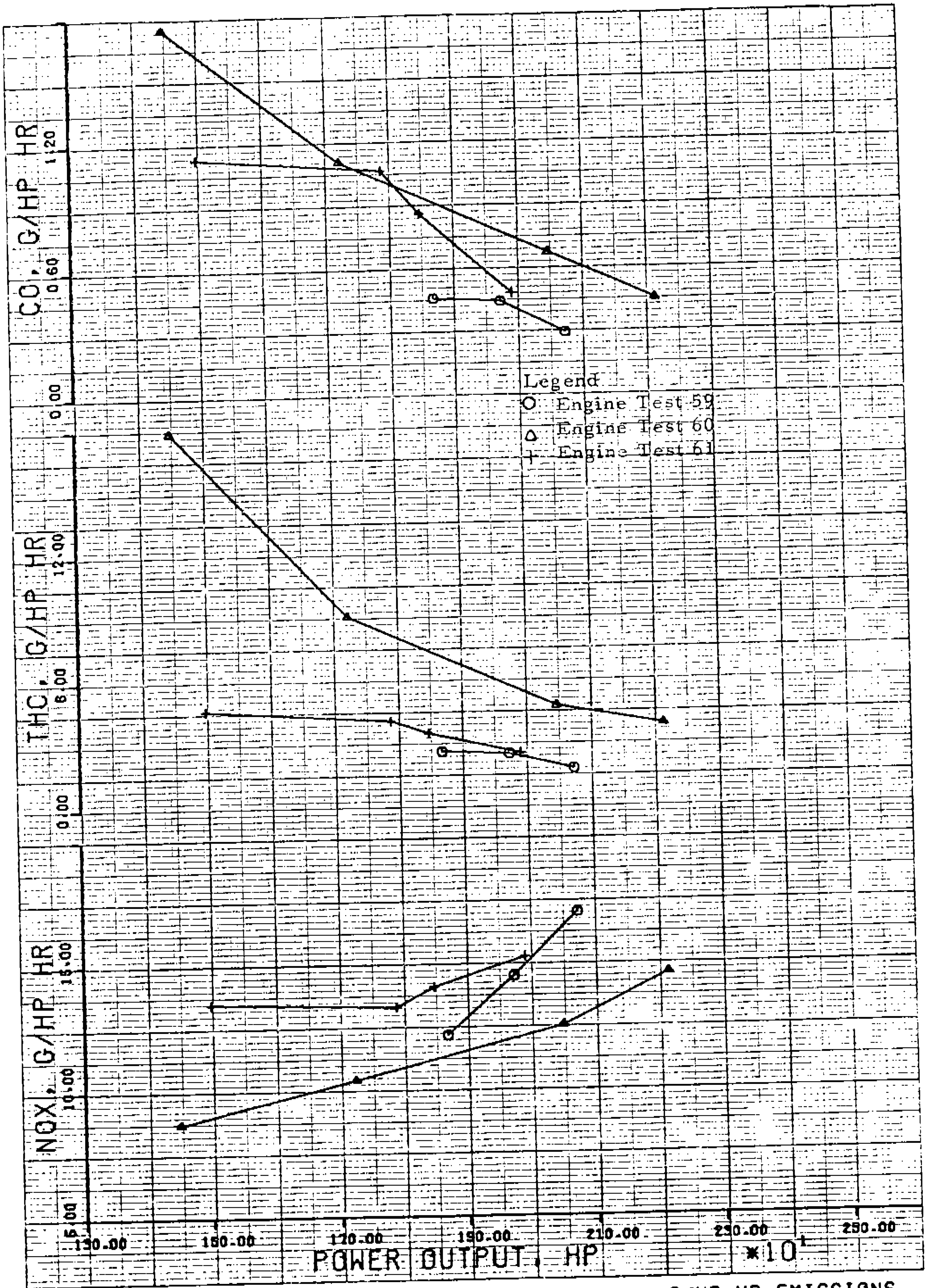


FIGURE E-69 EFFECT OF POWER ON I-R 412 KVS G/HP-HR EMISSIONS

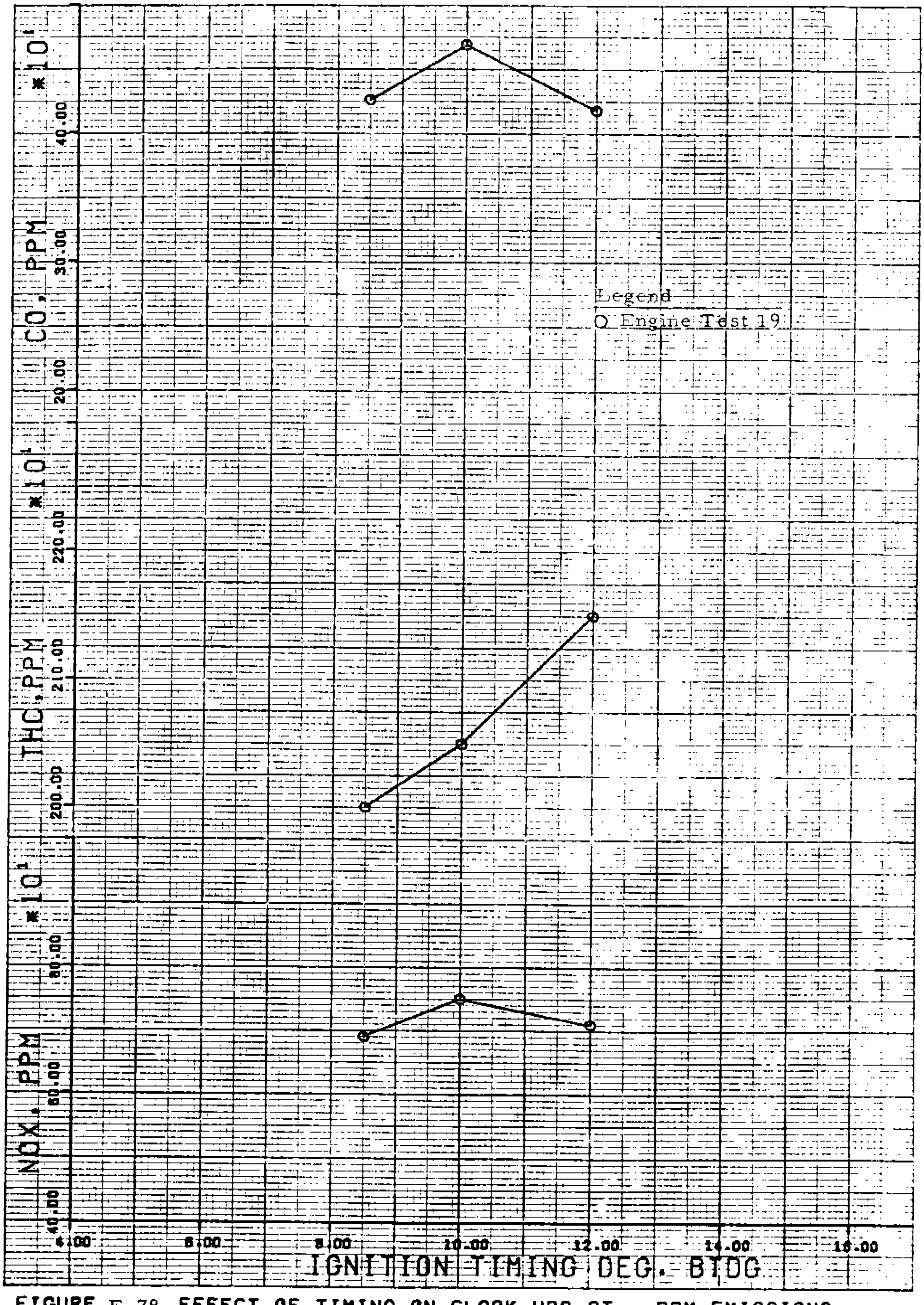


FIGURE E-78 EFFECT OF TIMING ON CLARK HBA-8T PPM EMISSIONS

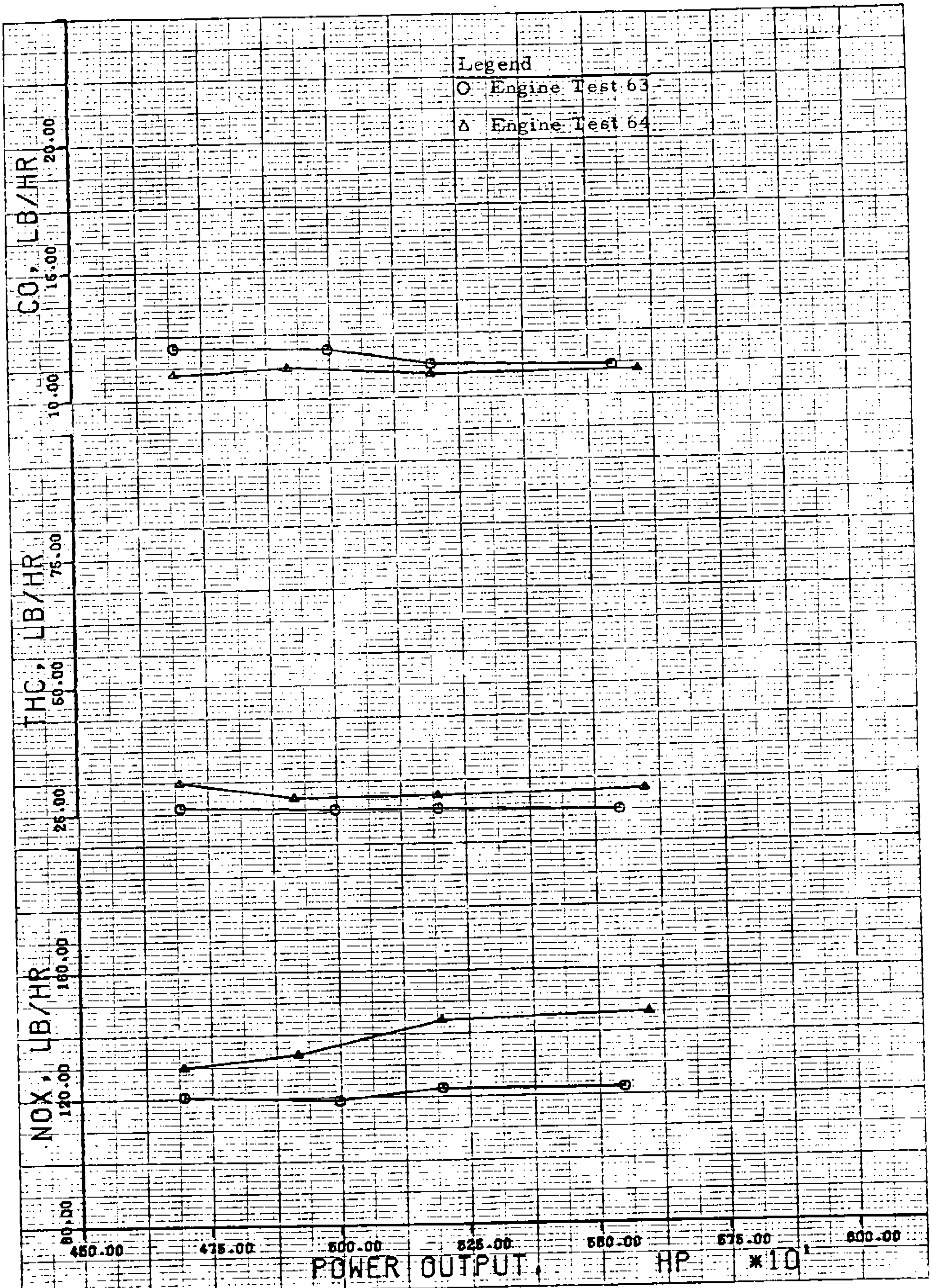


FIGURE E-71 EFFECT OF POWER ON I-R 616 KVR LB/HR EMISSIONS

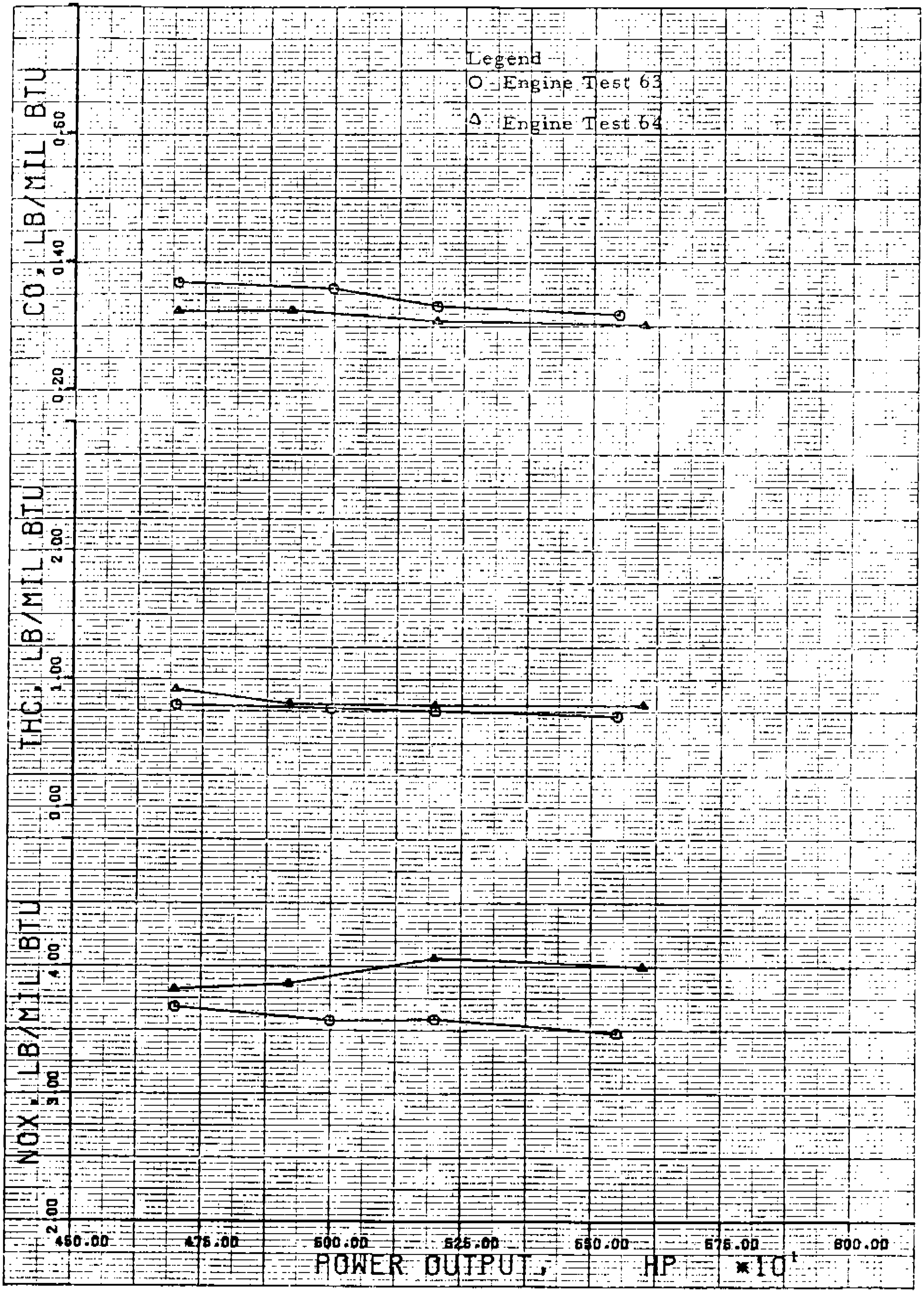


FIGURE E-72 EFFECT OF POWER ON I-R 616 KVR LB EMISSION/MIL BTU

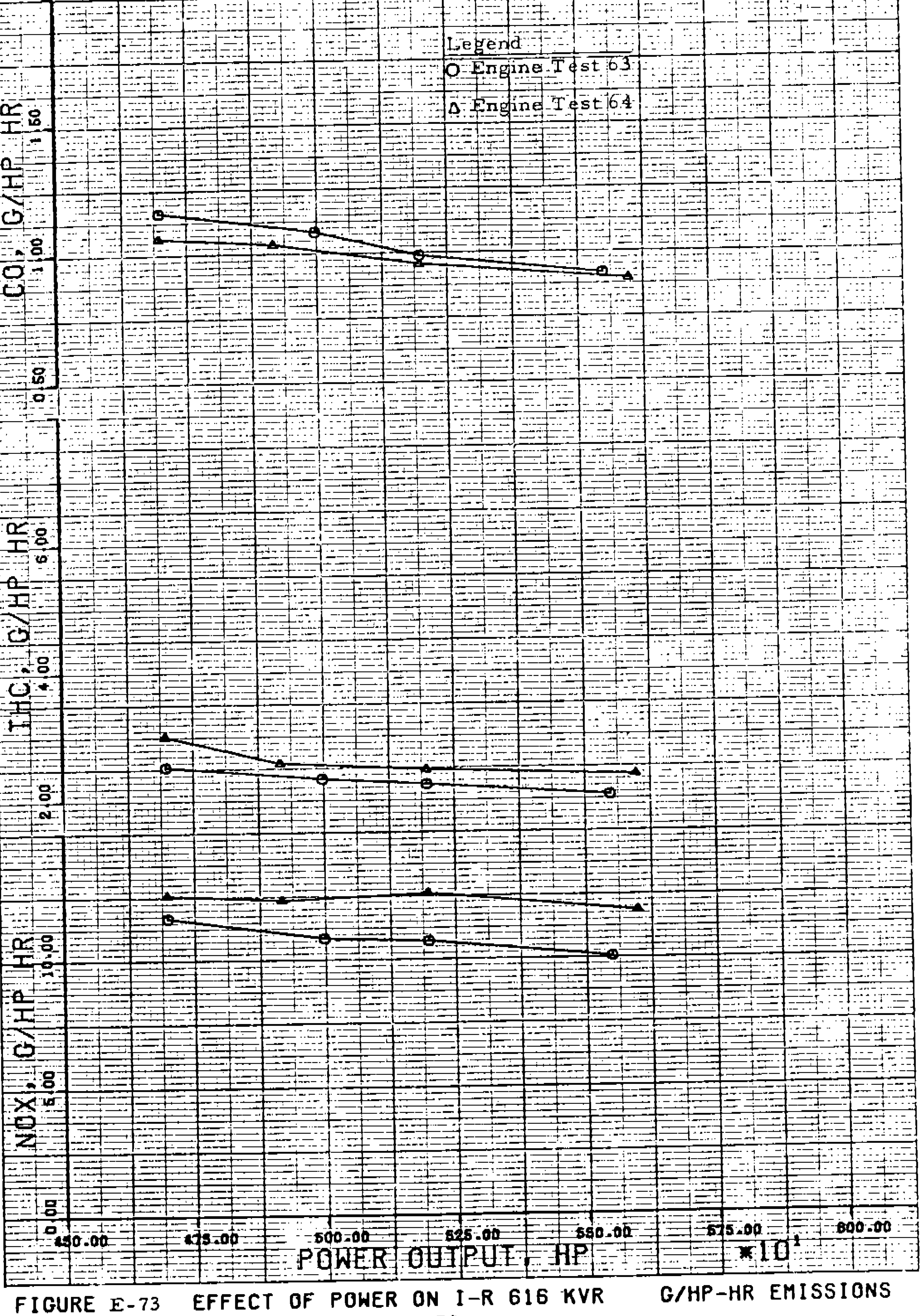


FIGURE E-73 EFFECT OF POWER ON I-R 616 KVR G/HP-HR EMISSIONS

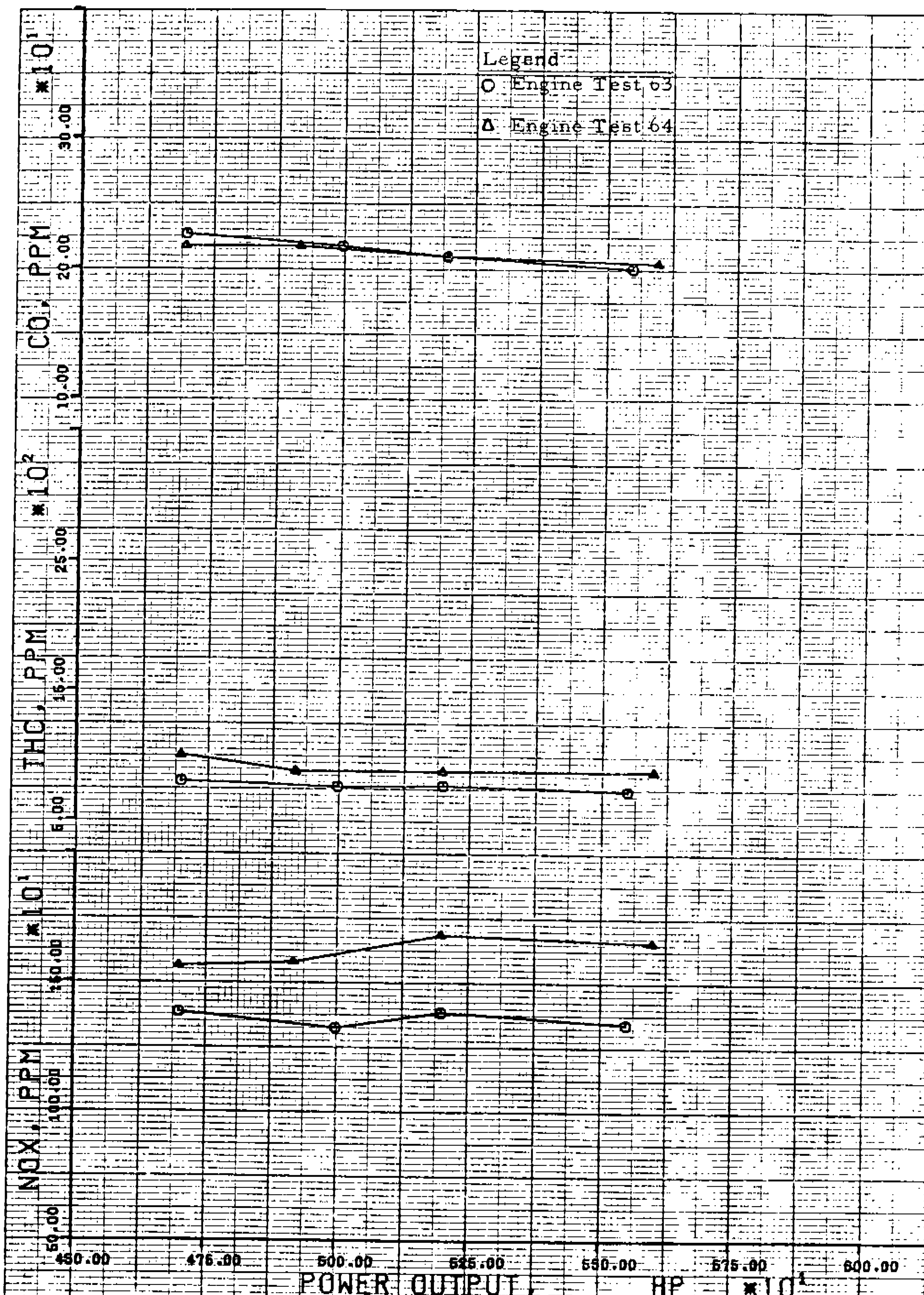


FIGURE E-74 EFFECT OF POWER ON I-R 616 KVR PPM EMISSIONS

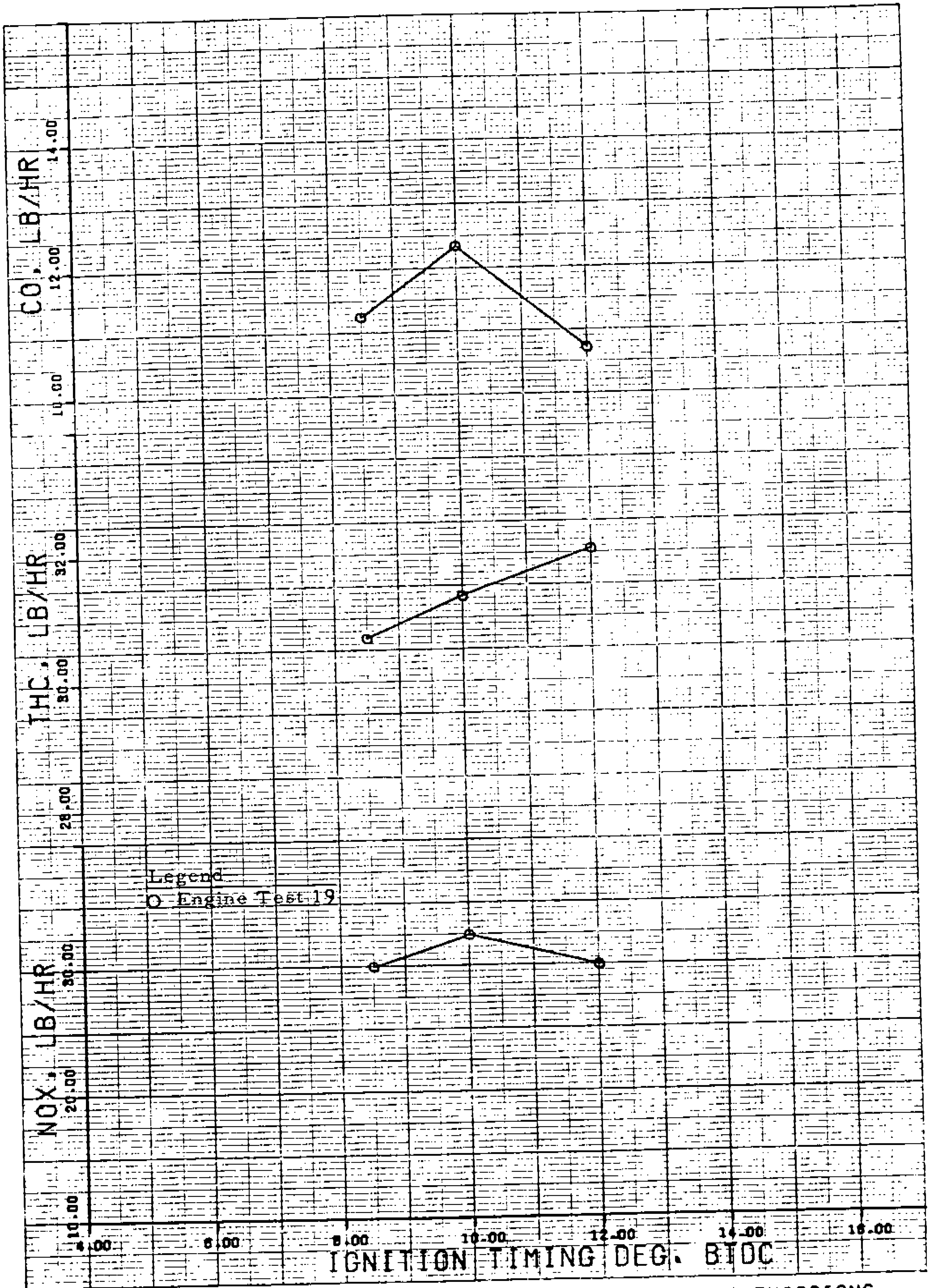


FIGURE E-75 EFFECT OF TIMING ON CLARK HBA-8T LB/HR EMISSIONS

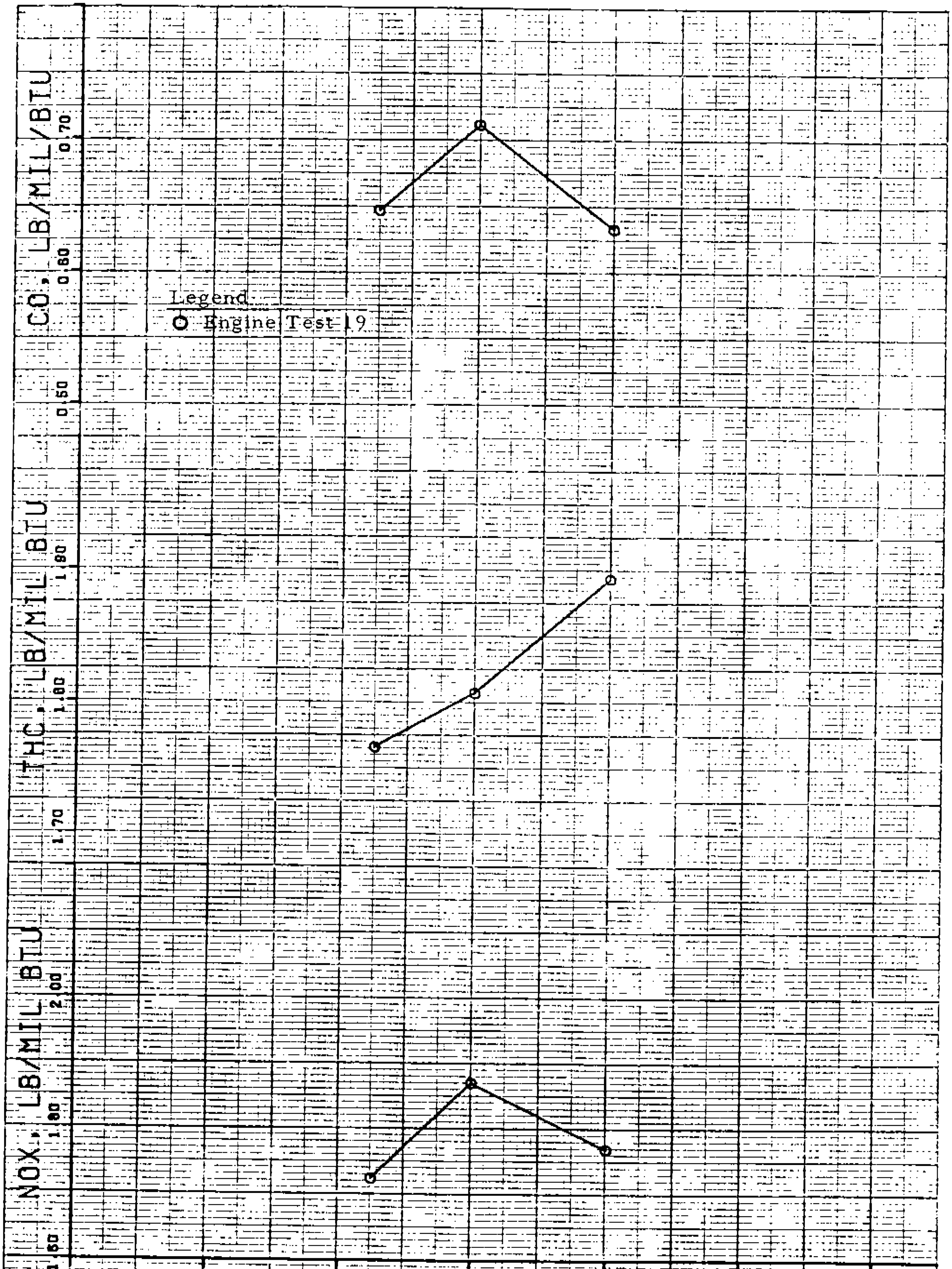


FIGURE E-76 EFFECT OF TIMING ON CLARK HBA-8T LB/MIL BTU EMISSIONS

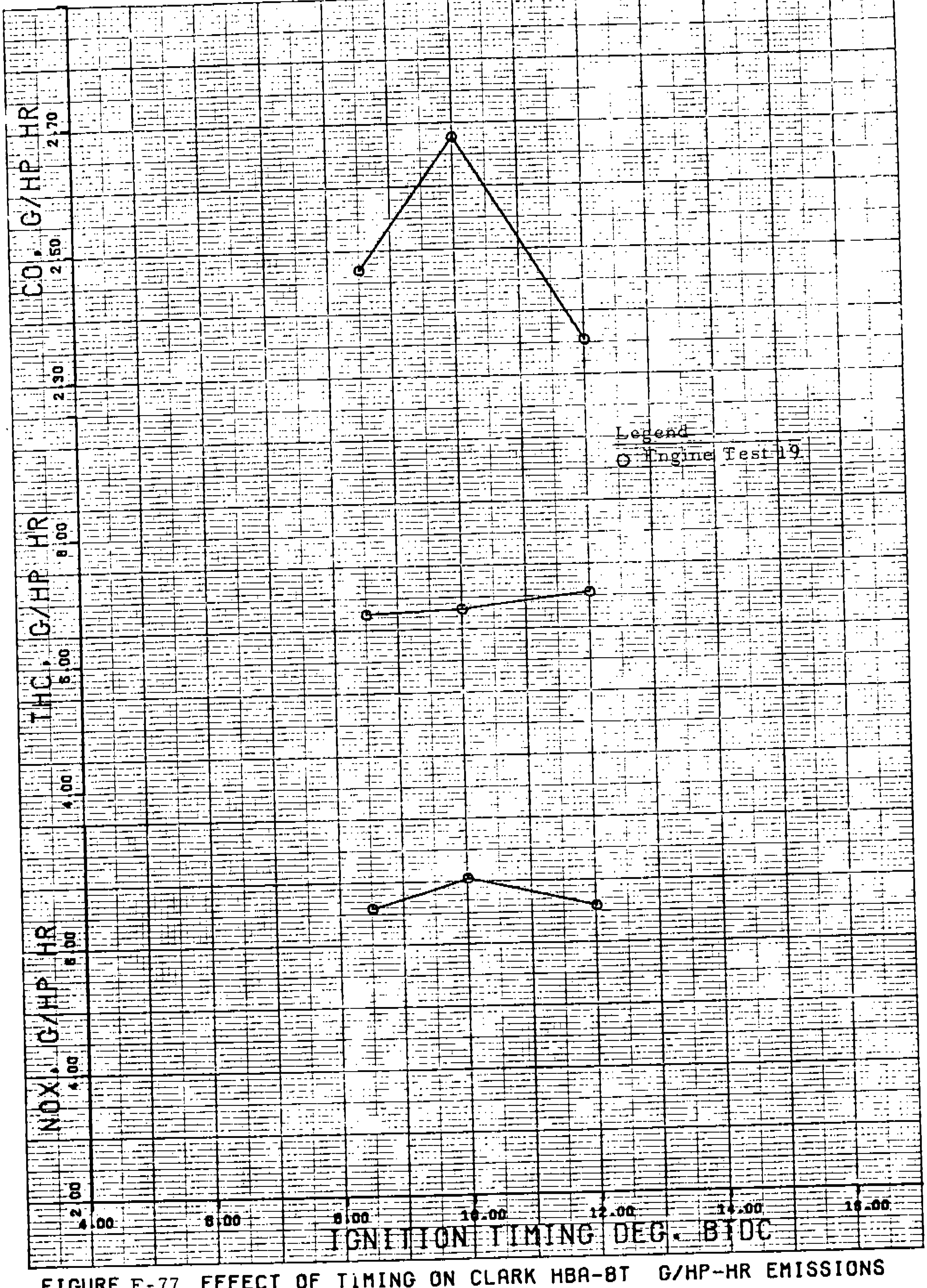


FIGURE E-77 EFFECT OF TIMING ON CLARK HBA-8T G/HP-HR EMISSIONS

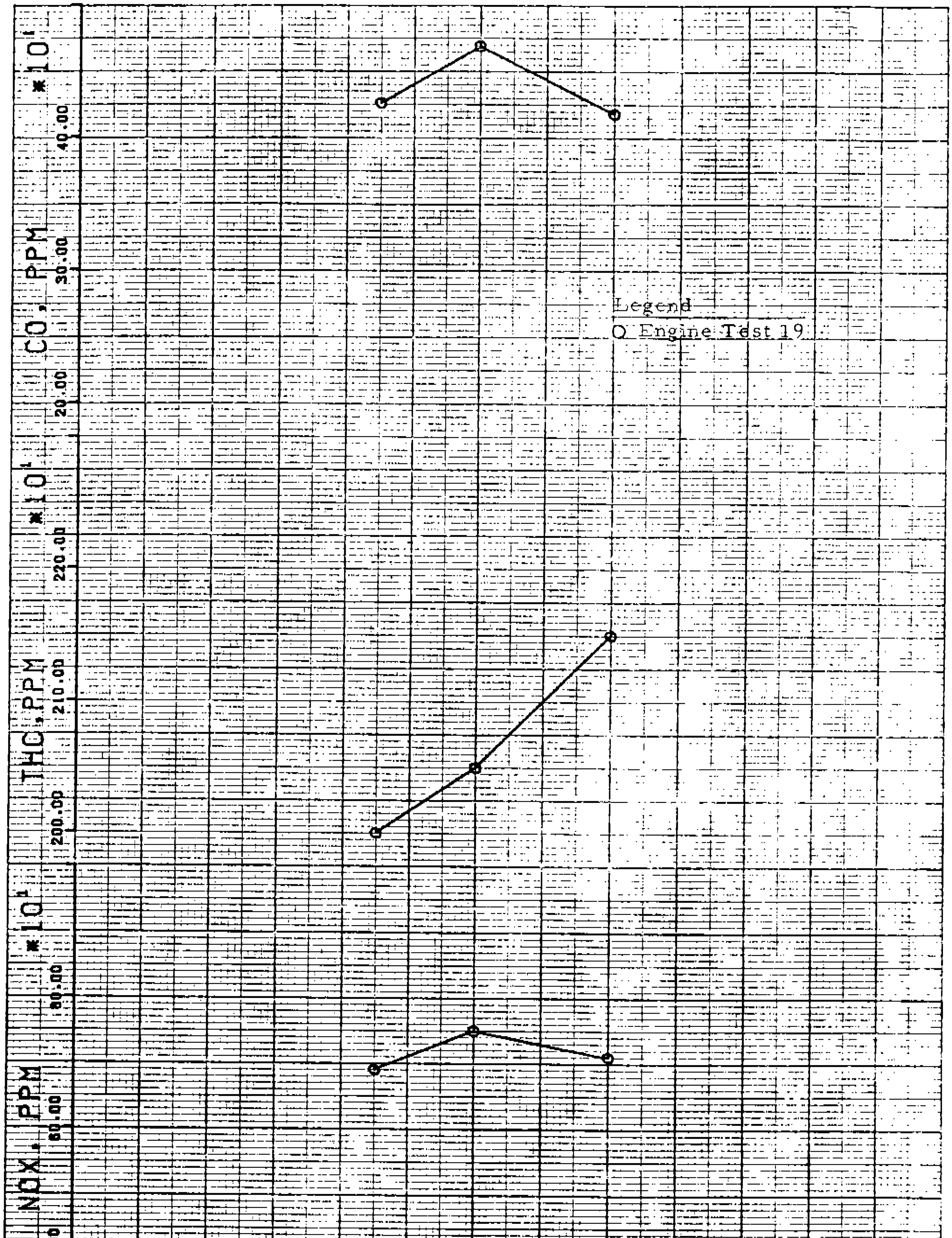


FIGURE E-78 EFFECT OF TIMING ON CLARK HBA-8T PPM EMISSIONS

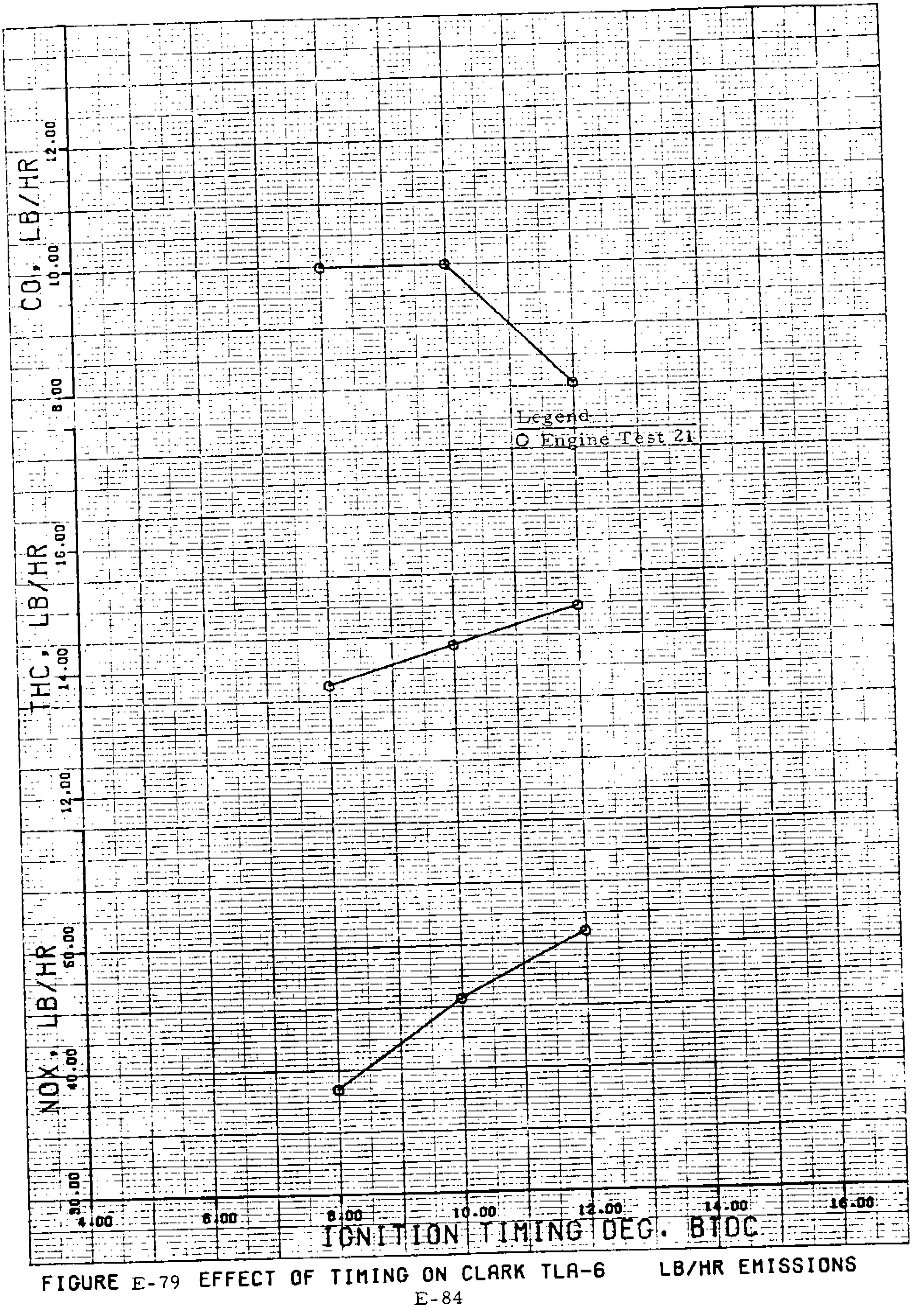


FIGURE E-79 EFFECT OF TIMING ON CLARK TLA-6 LB/HR EMISSIONS

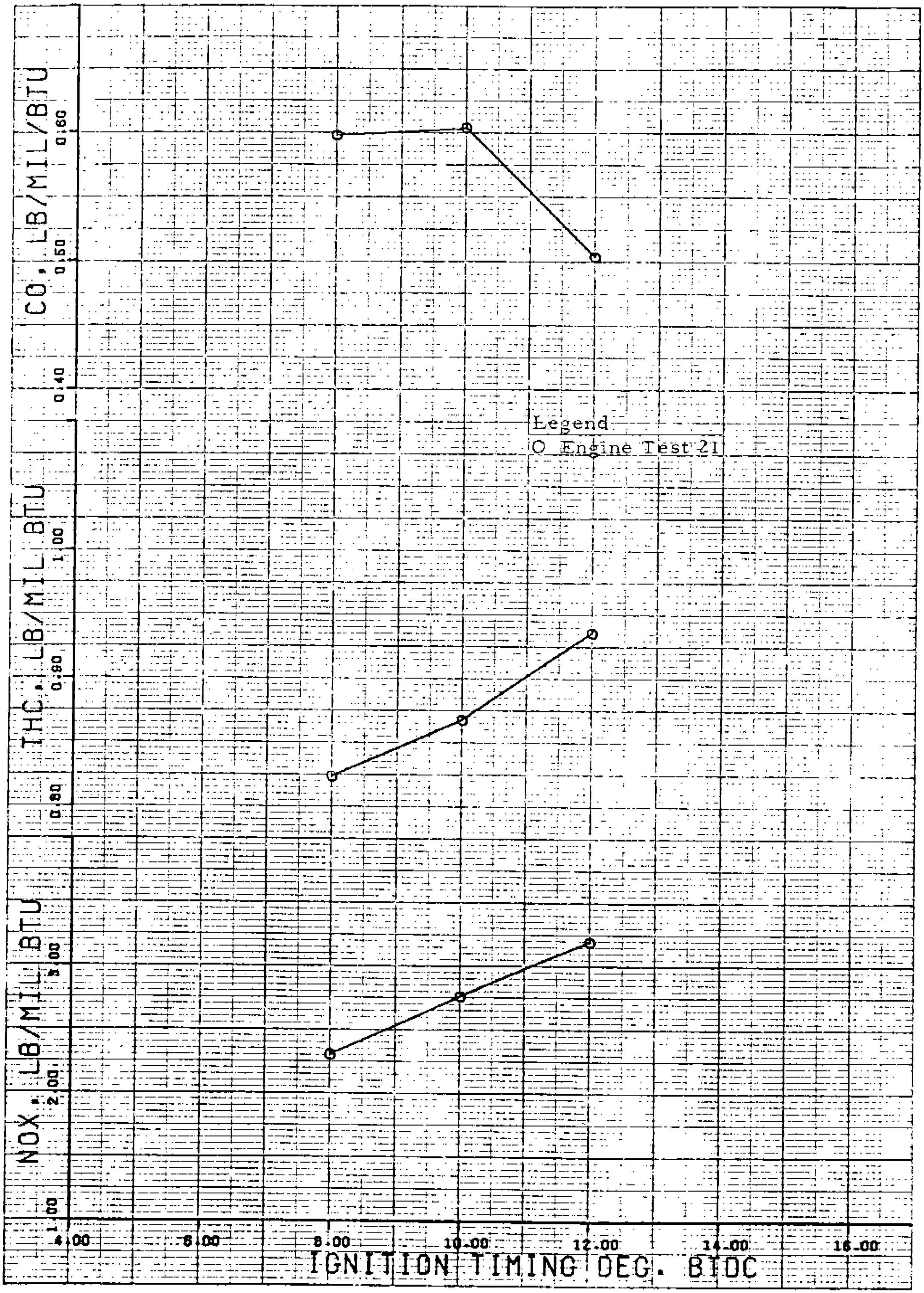


FIGURE E-80 EFFECT OF TIMING ON CLARK TLA-6 LB/MIL BTU EMISSIONS

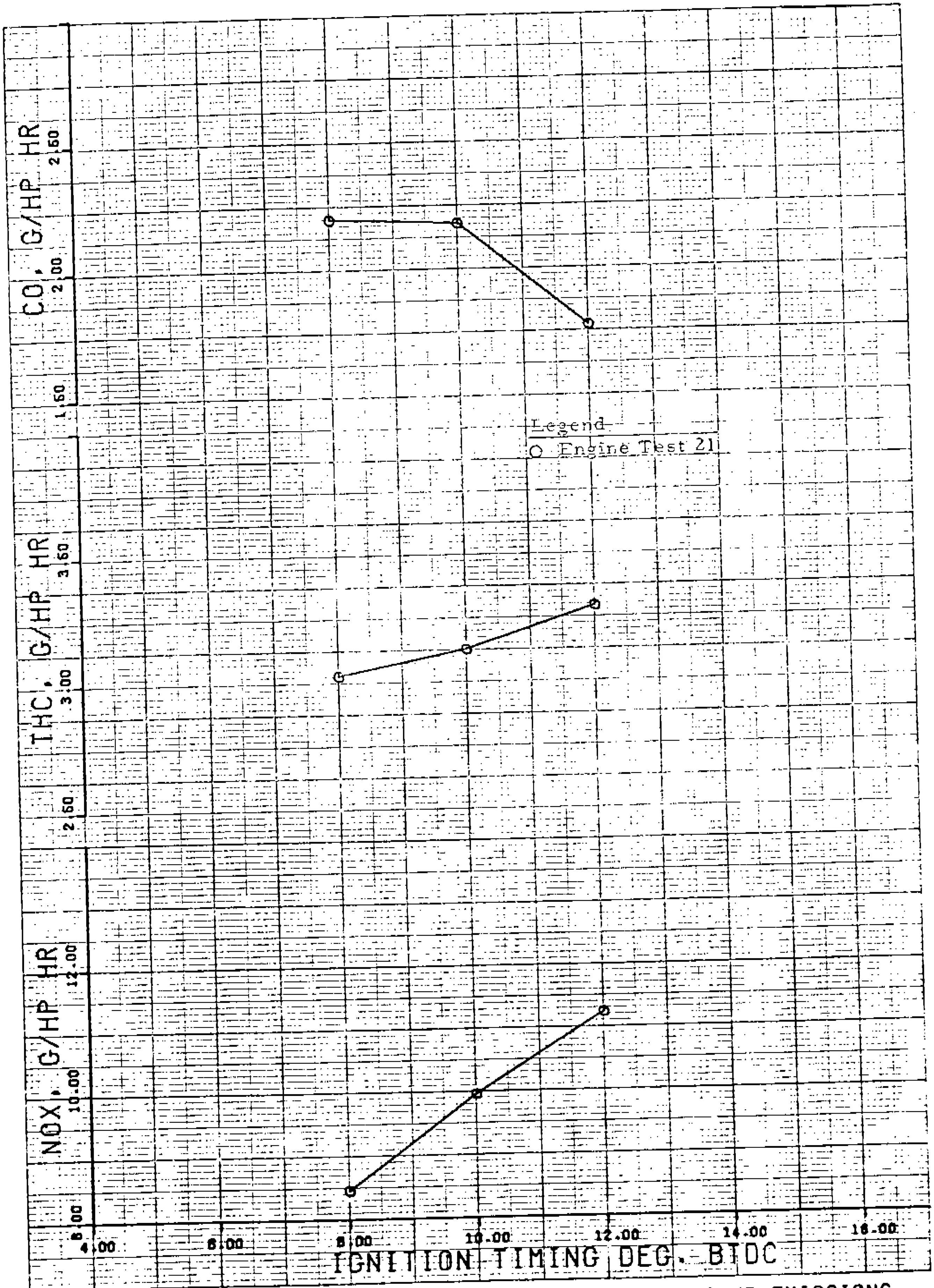


FIGURE E-81 EFFECT OF TIMING ON CLARK TLA-6 G/HP-HR EMISSIONS

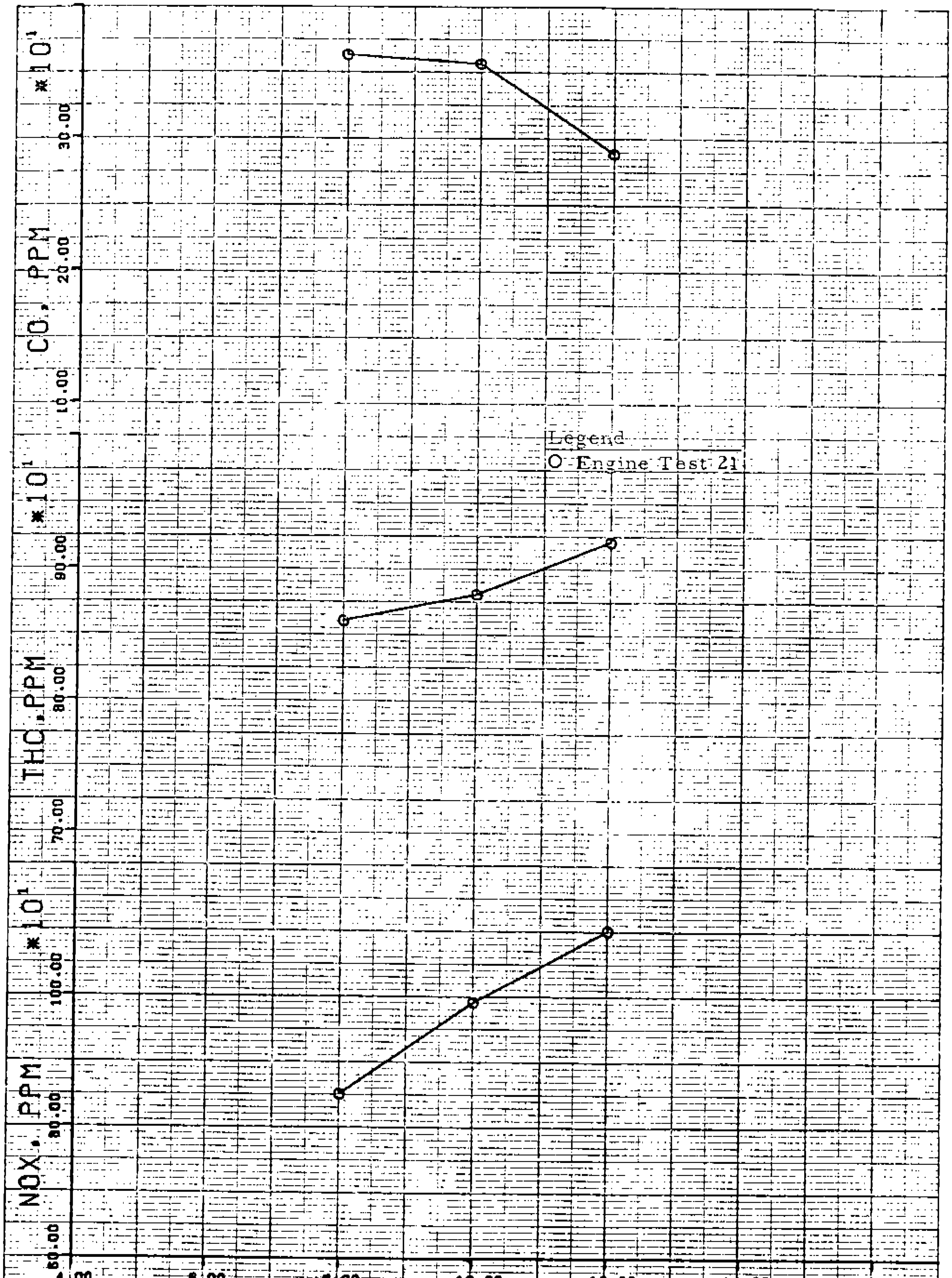


FIGURE E-82 EFFECT OF TIMING ON CLARK TLA-6 PPM EMISSIONS

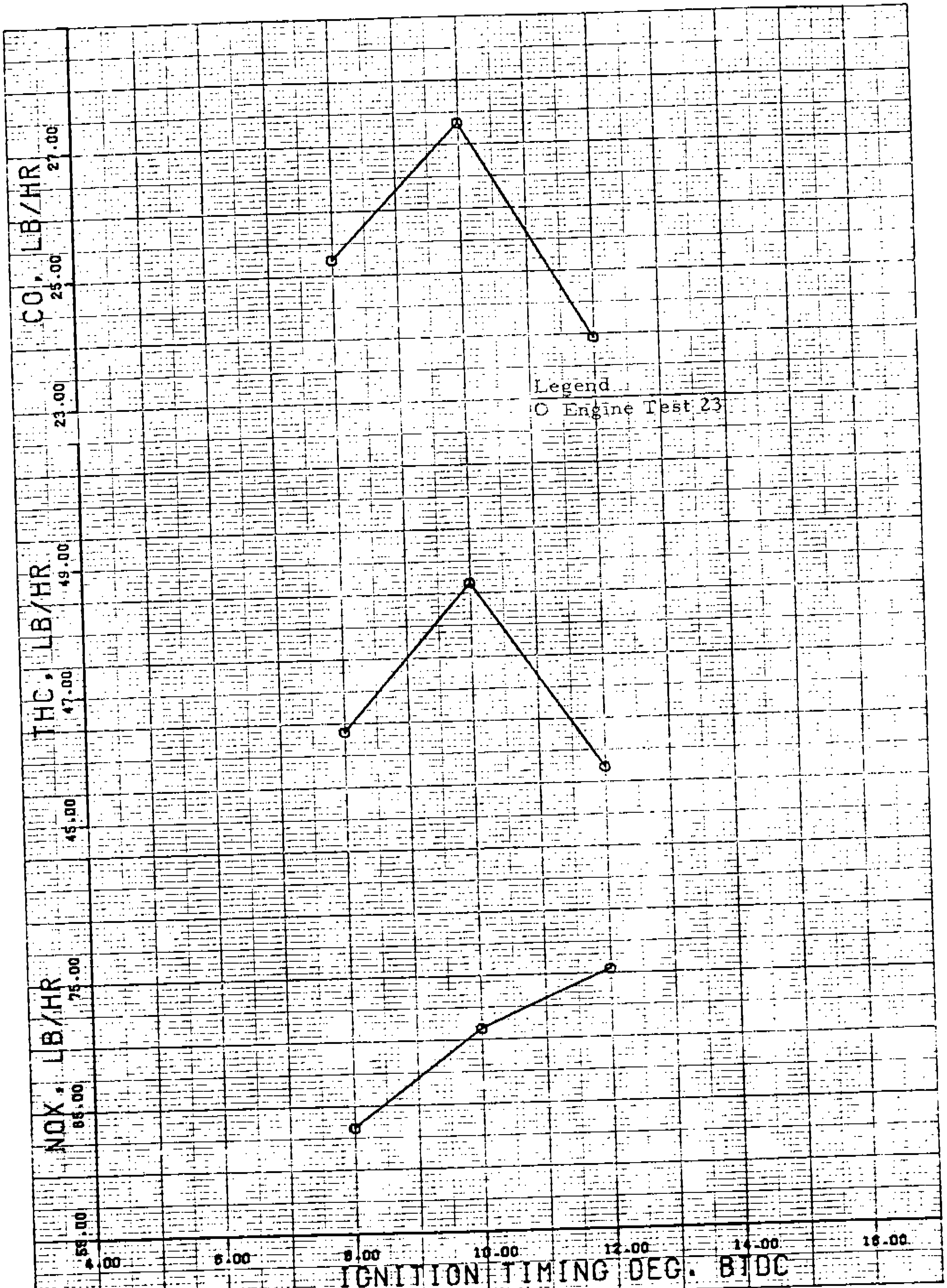


FIGURE E-83 EFFECT OF TIMING ON CLARK TCV-12 LB/HR EMISSIONS

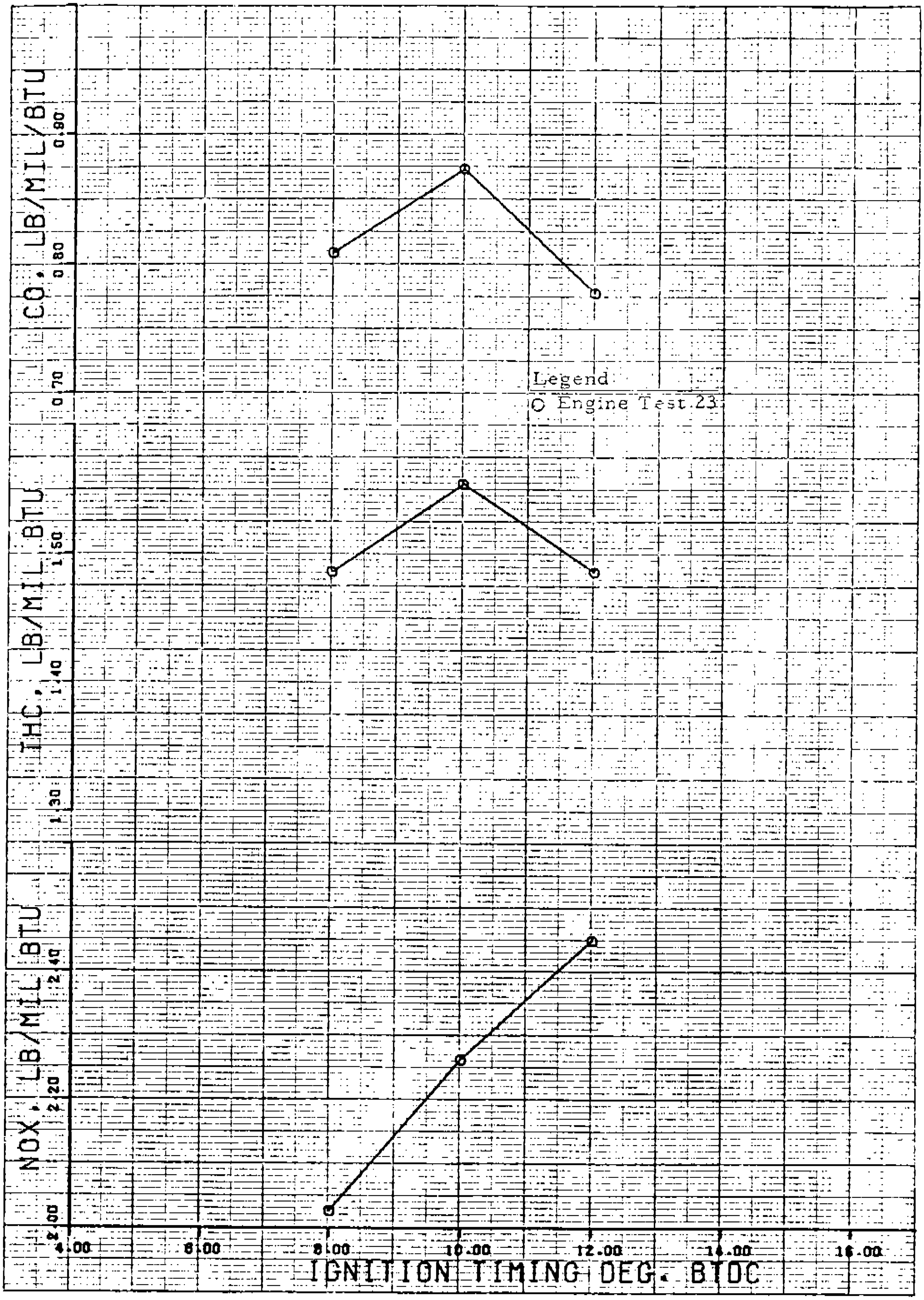


FIGURE E-84 EFFECT OF TIMING ON CLARK TCV-12 LB/MIL BTU EMISSIONS

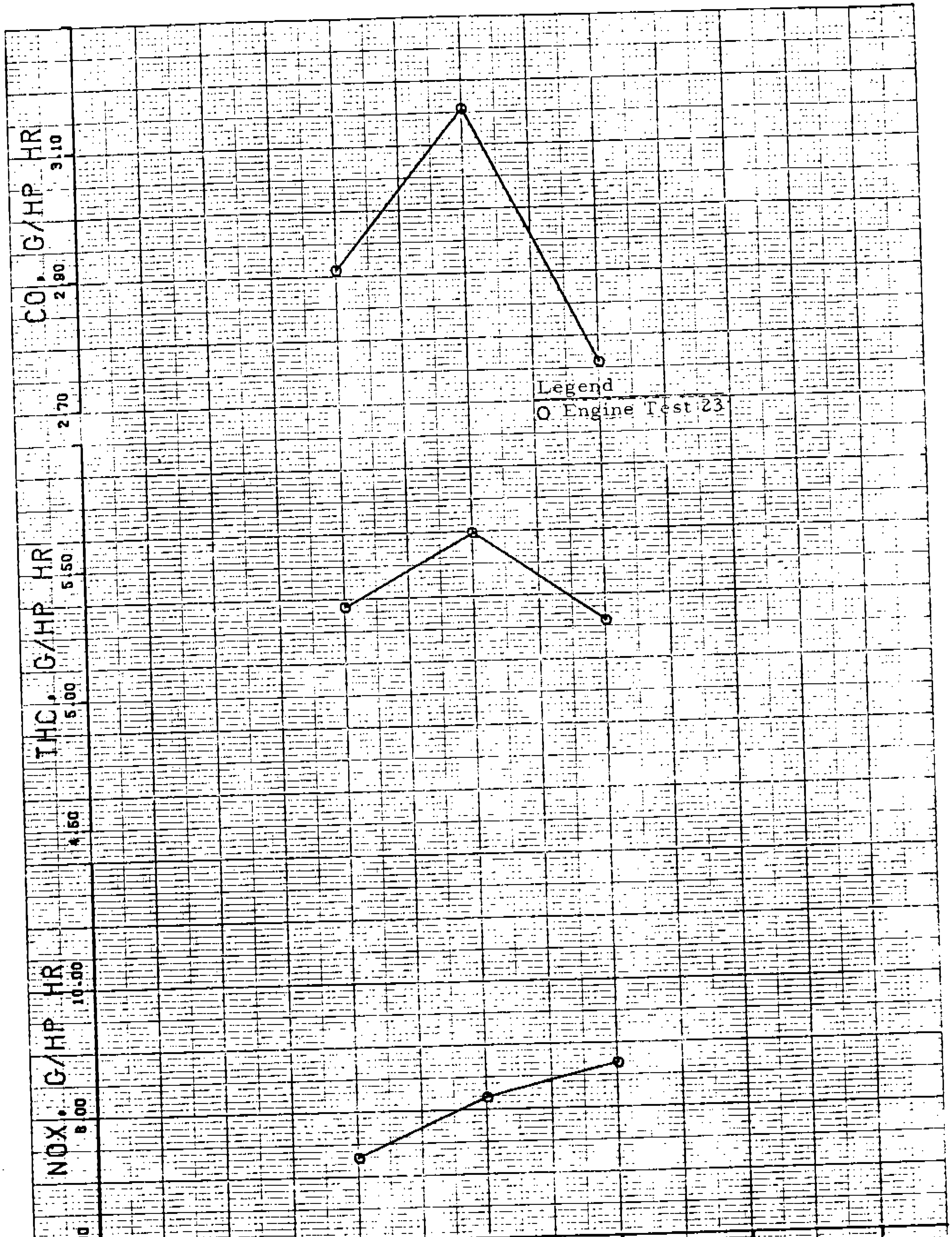


FIGURE E-85 EFFECT OF TIMING ON CLARK TCV-12 G/HP-HR EMISSIONS

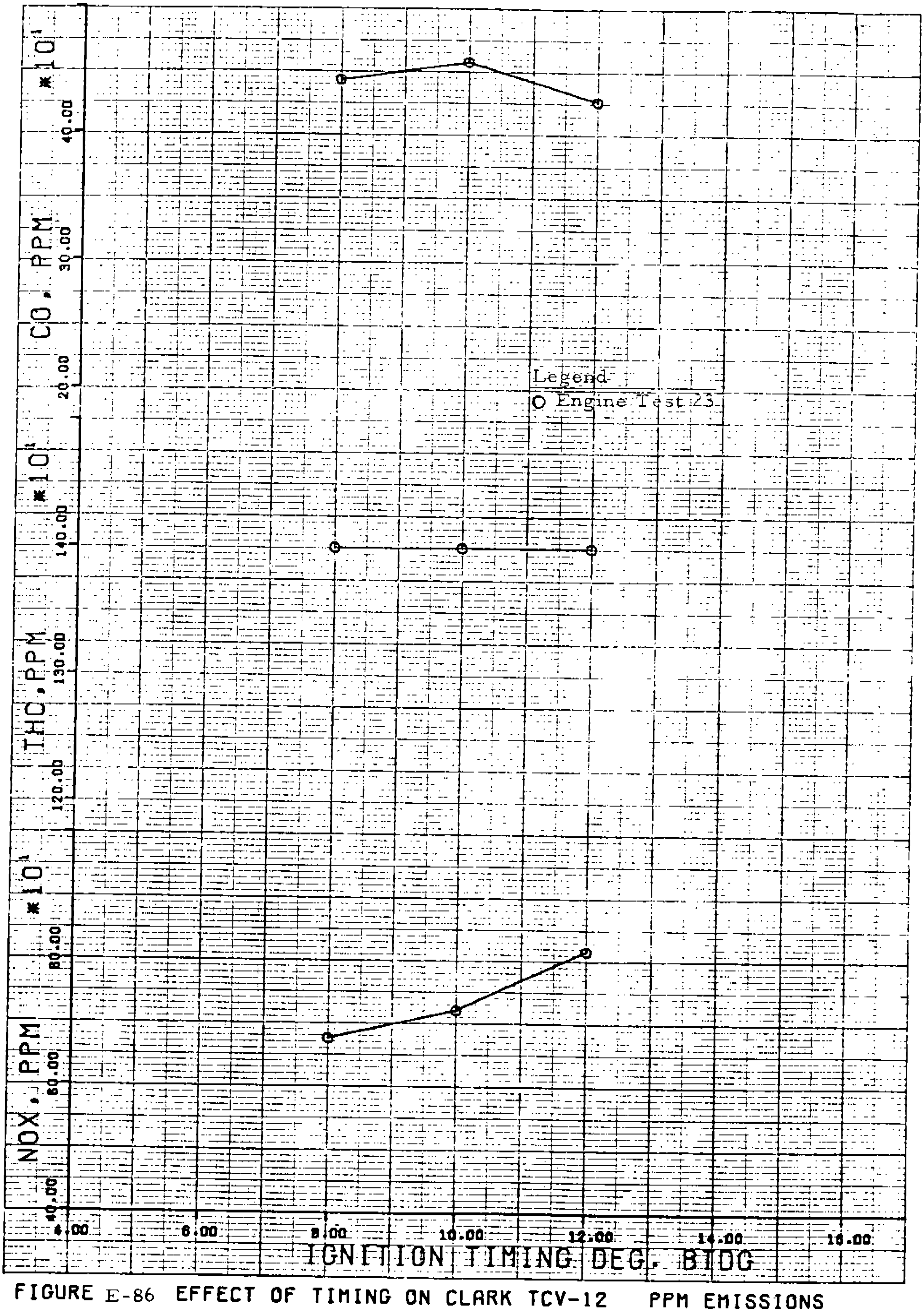


FIGURE E-86 EFFECT OF TIMING ON CLARK TCV-12 PPM EMISSIONS

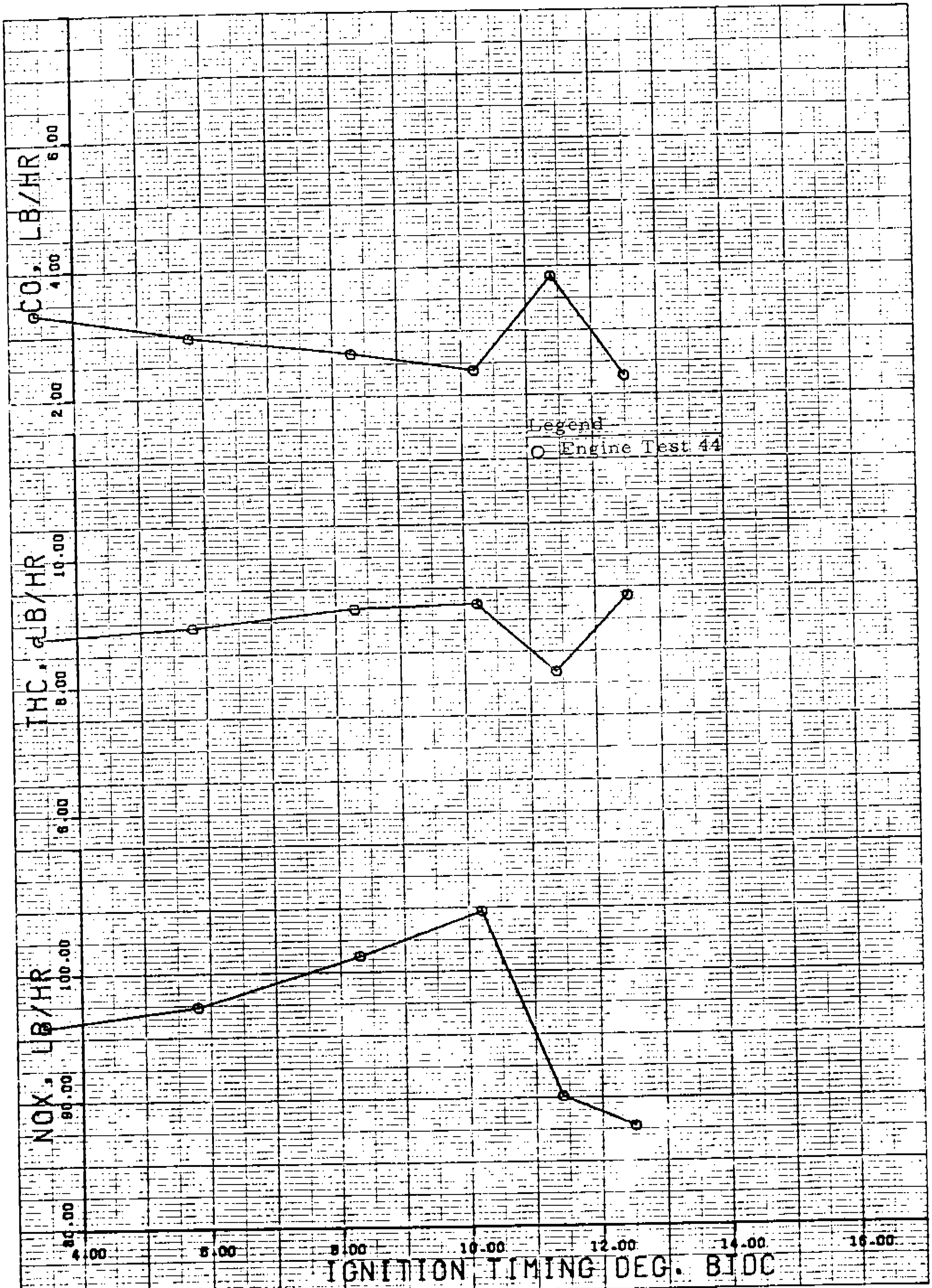


FIGURE E-87 EFFECT OF TIMING ON C-B GMV-10 LB/HR EMISSIONS

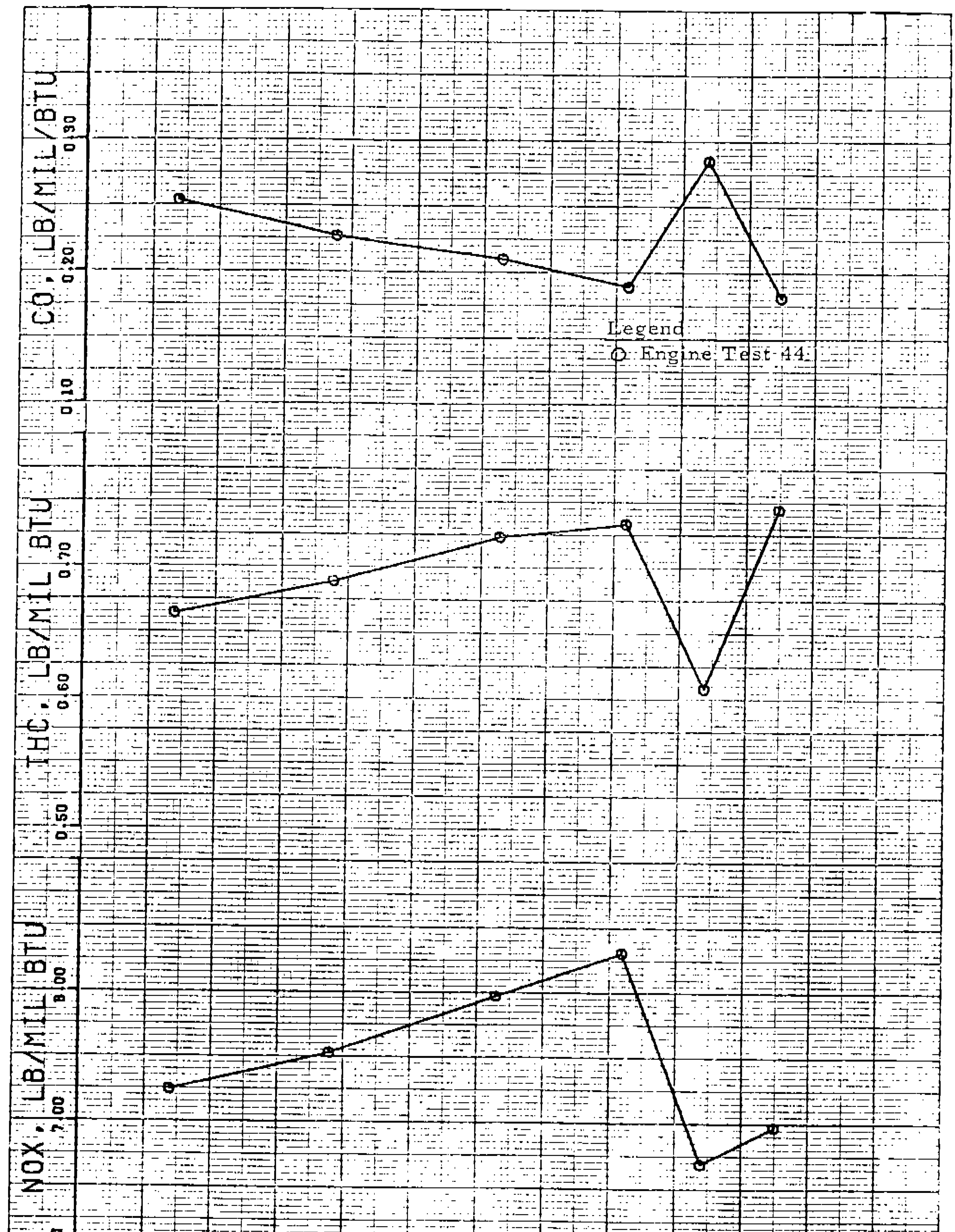


FIGURE E-88 EFFECT OF TIMING ON C-B GMV-10 LB/MIL BTU EMISSIONS

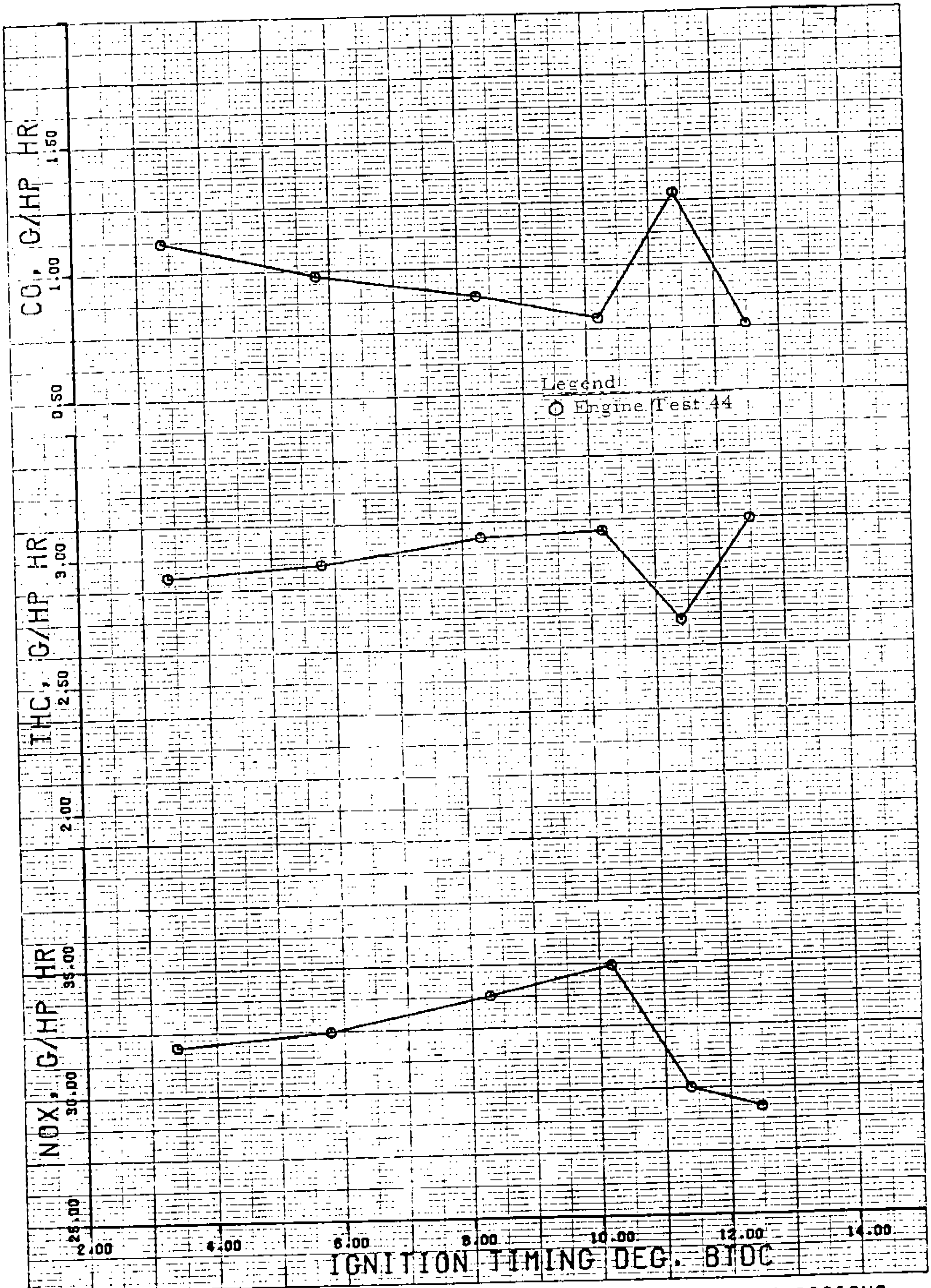


FIGURE E-89 EFFECT OF TIMING ON C-B GMV-10 G/HP-HR EMISSIONS

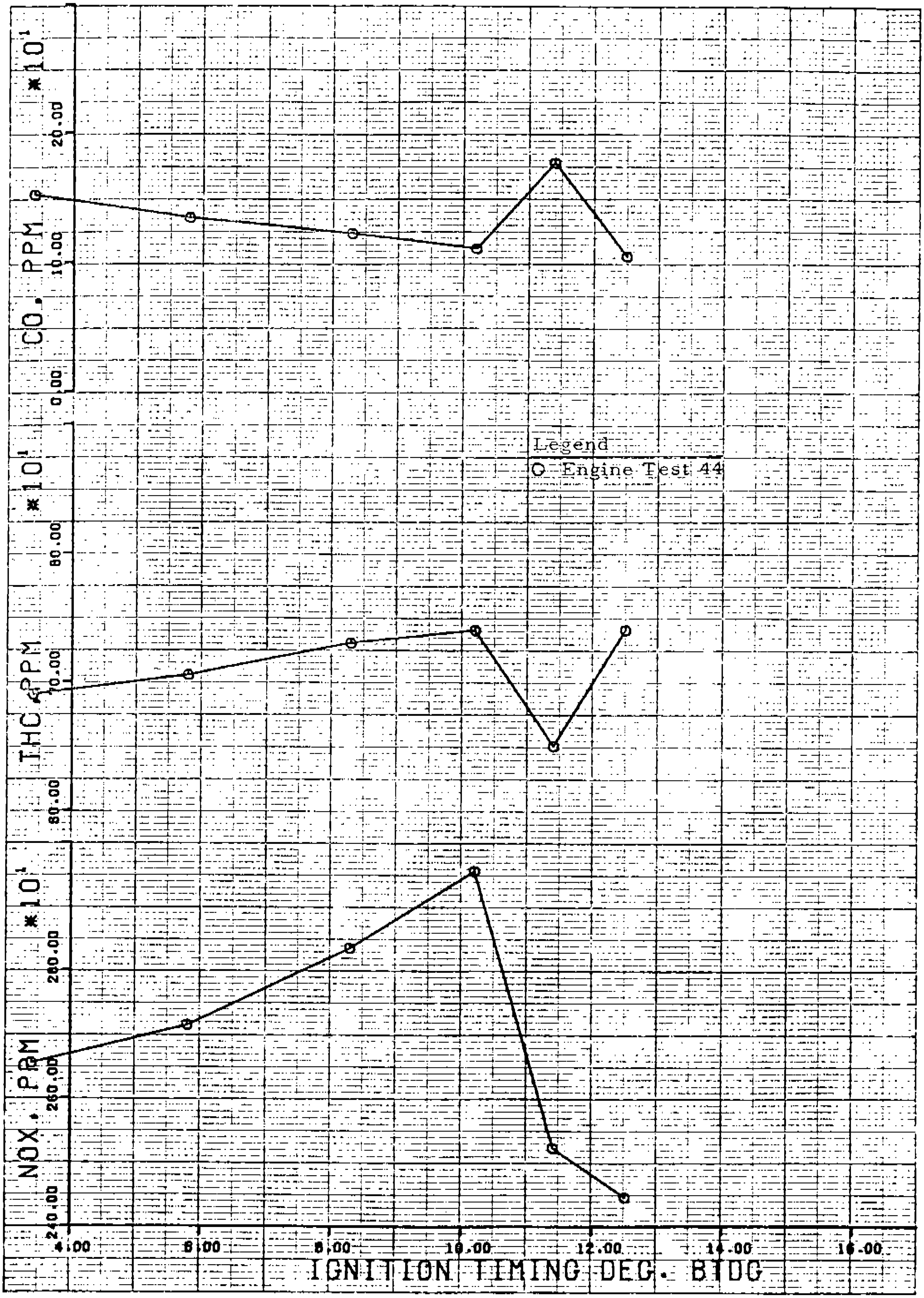


FIGURE E-90 EFFECT OF TIMING ON C-B GMV-10 PPM EMISSIONS

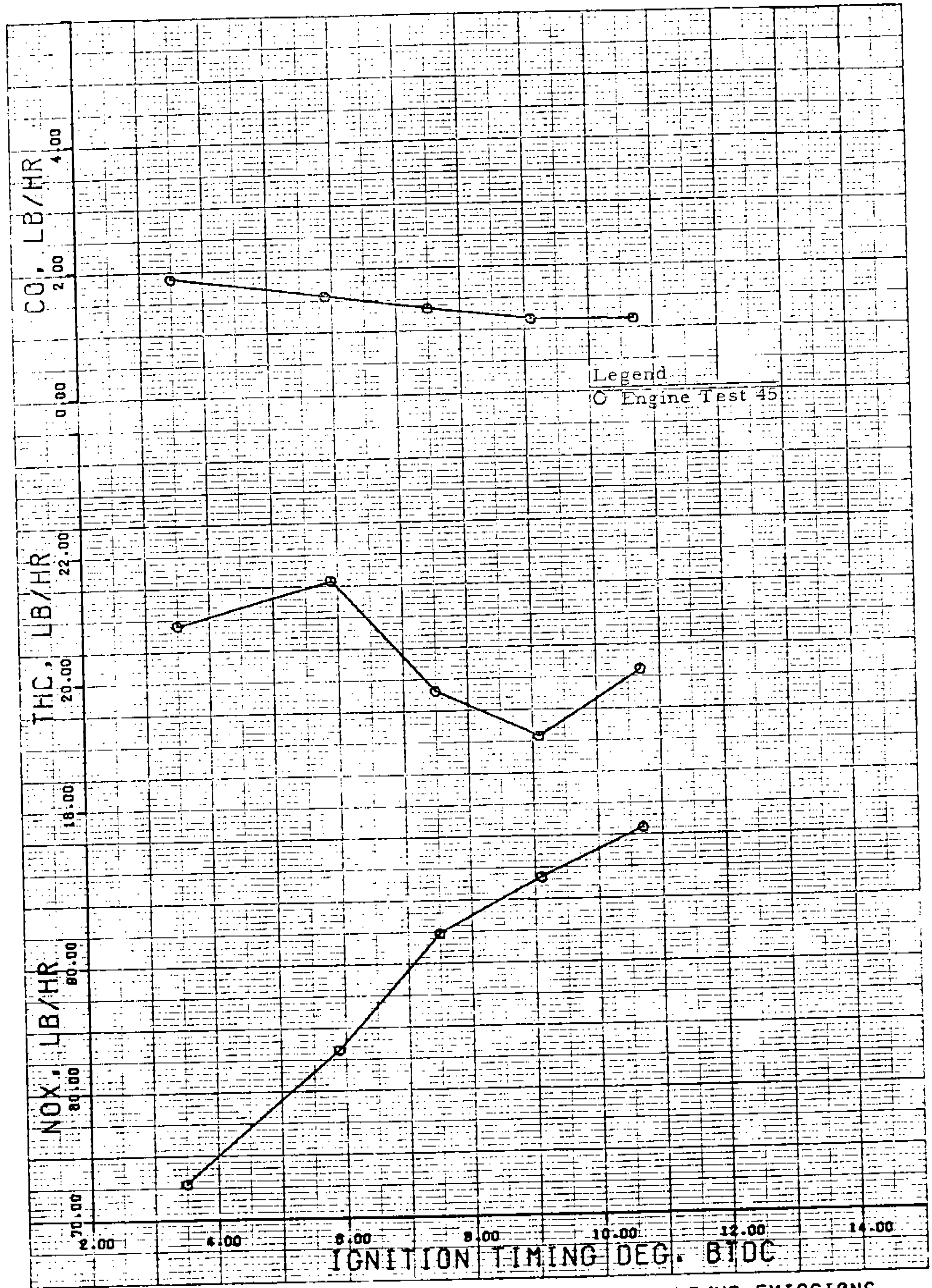


FIGURE E-91 EFFECT OF TIMING ON C-B GMW-8 LB/HR EMISSIONS

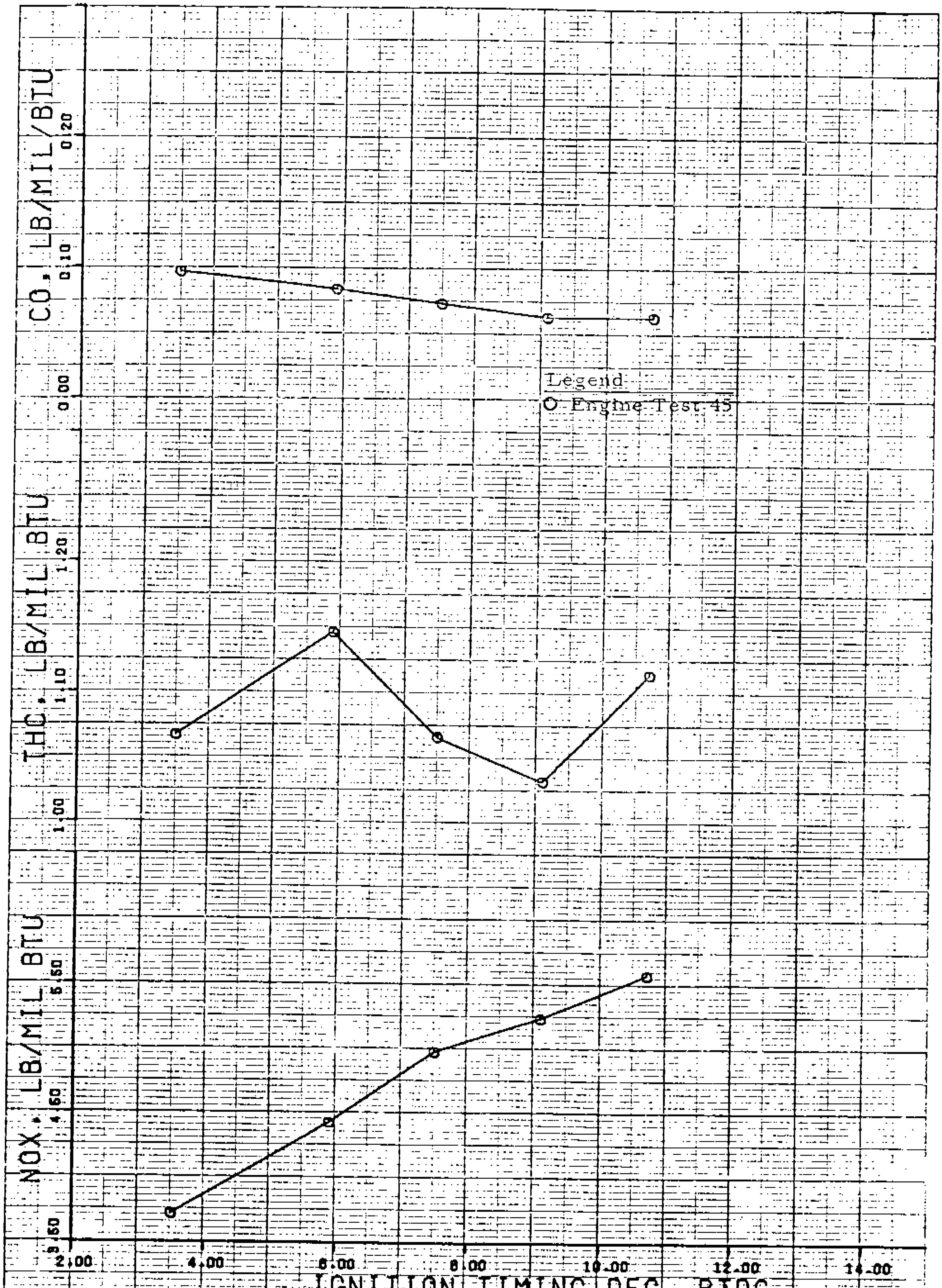


FIGURE E-92 EFFECT OF TIMING ON C-B GMW-8 LB/MIL BTU EMISSIONS

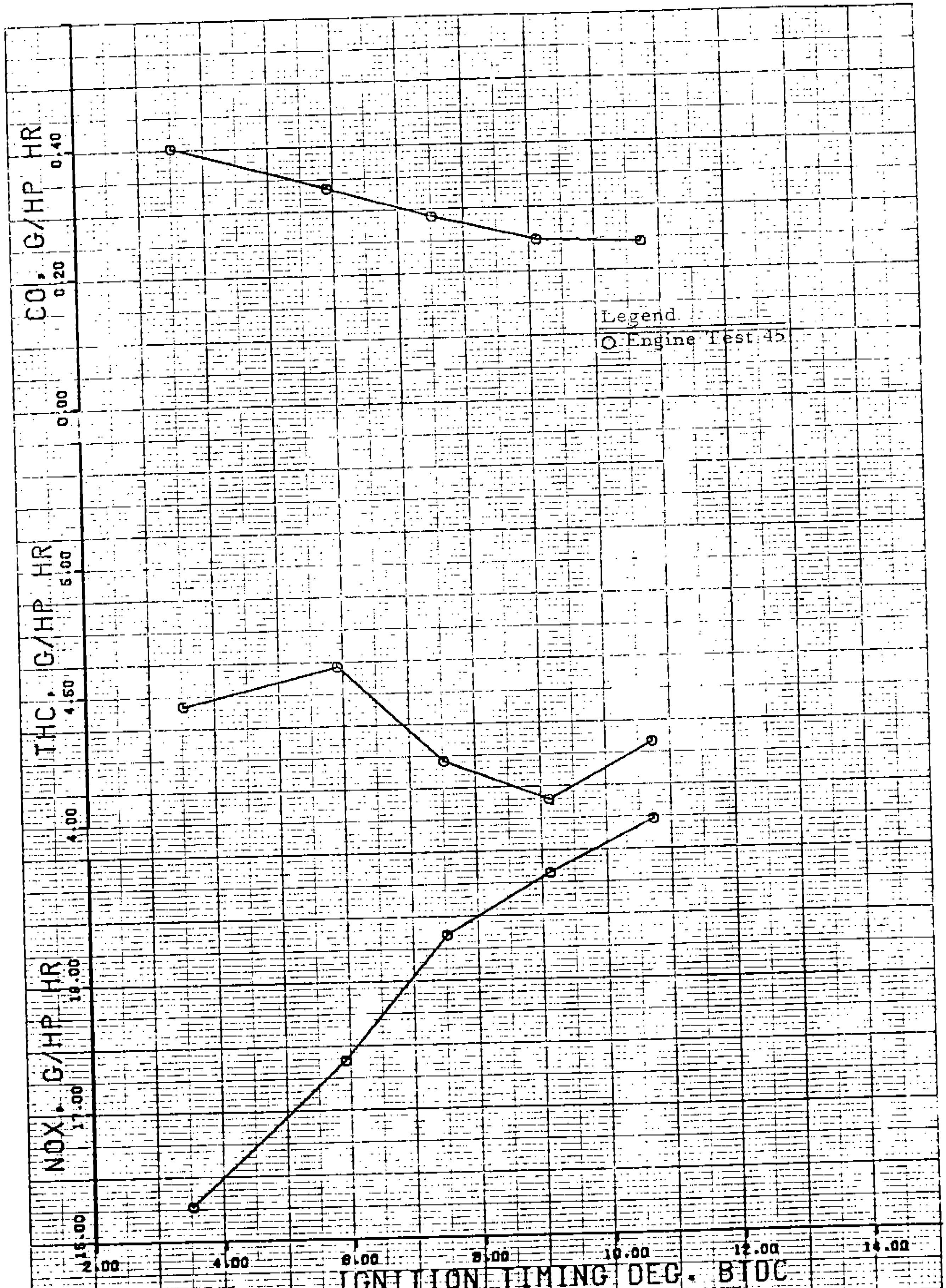


FIGURE E-93 EFFECT OF TIMING ON C-B GMW-8 G/HP-HR EMISSIONS

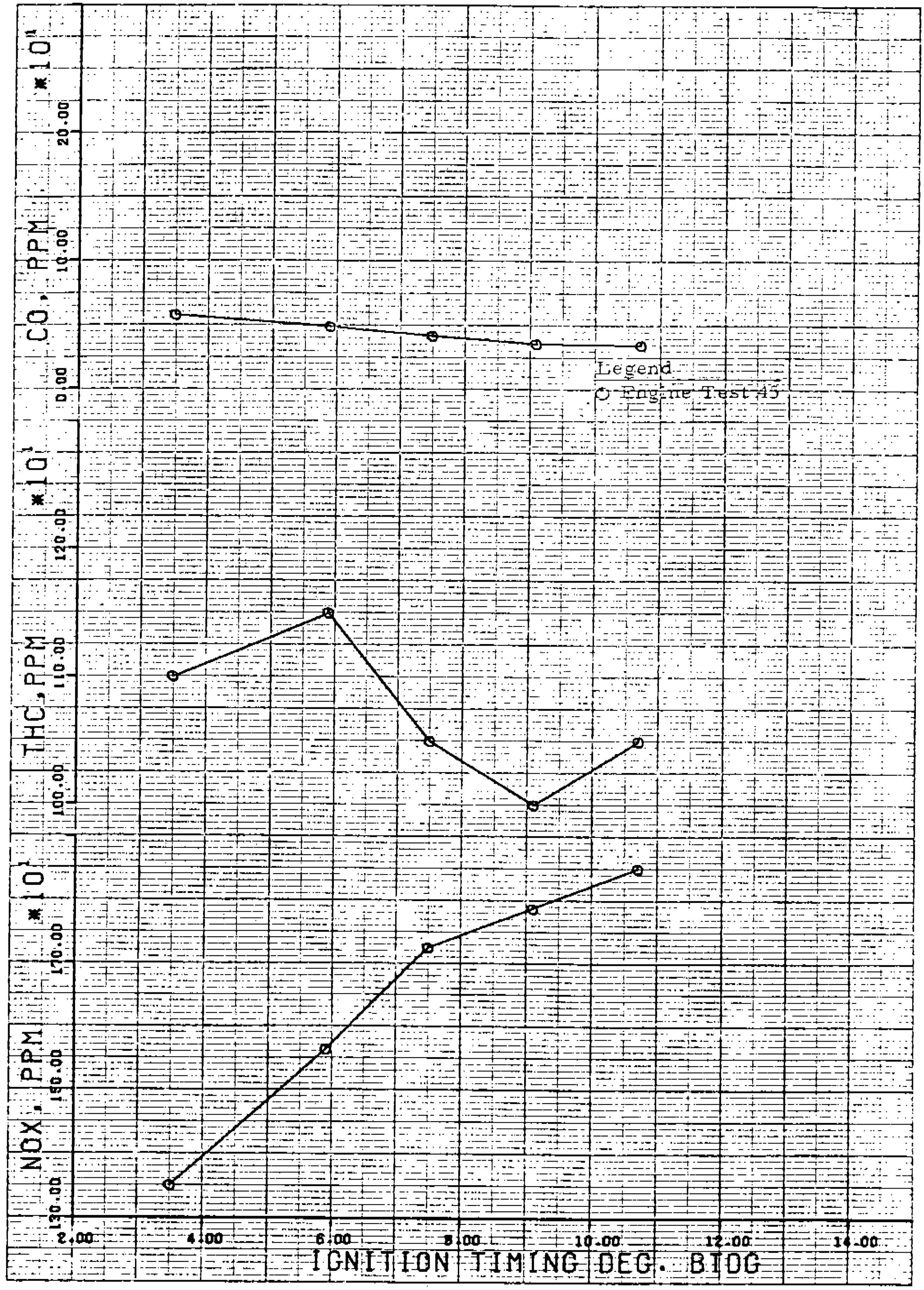


FIGURE E-94 EFFECT OF TIMING ON C-B GMW-8 PPM EMISSIONS

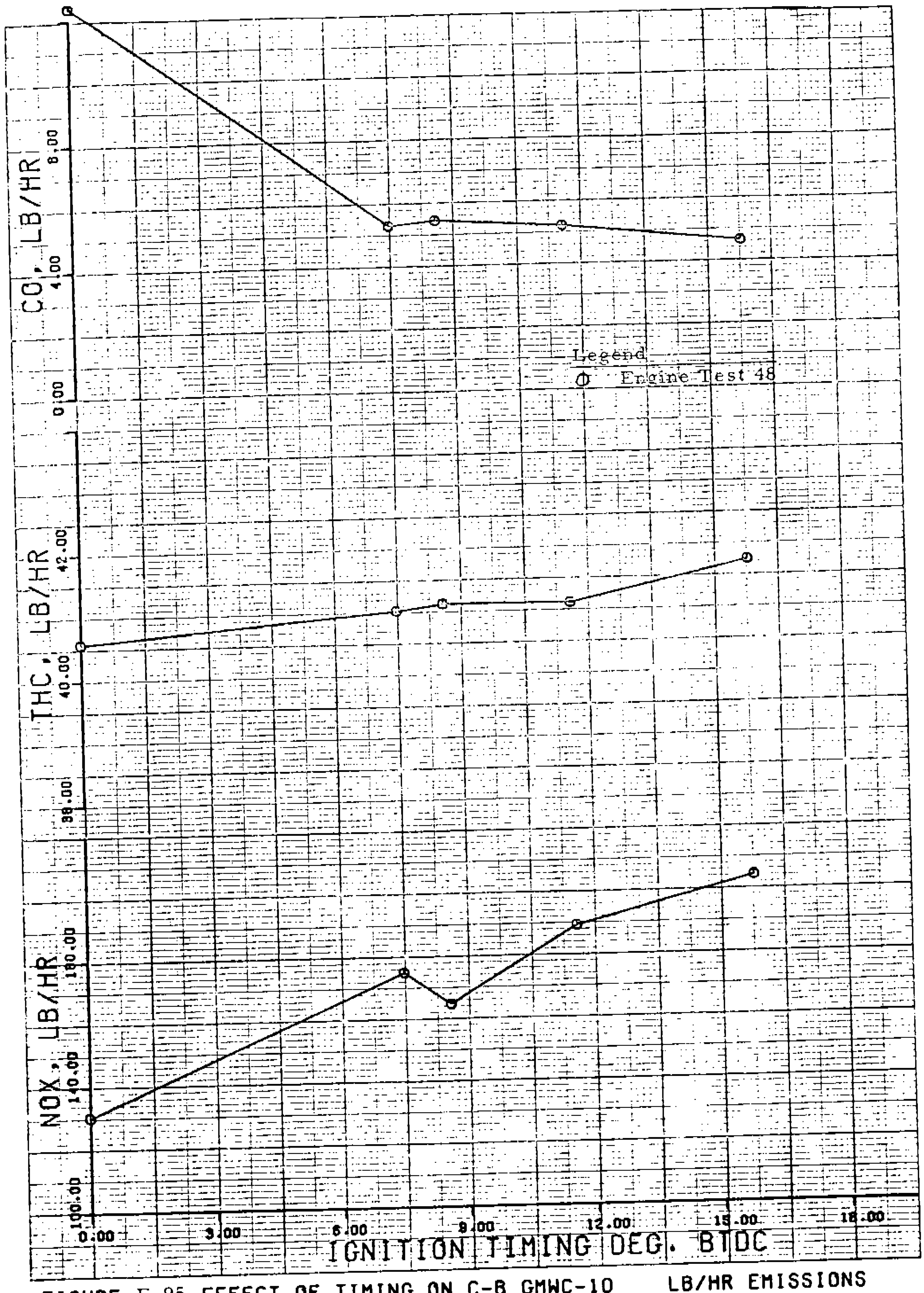


FIGURE E-95 EFFECT OF TIMING ON C-B GMWC-10 LB/HR EMISSIONS

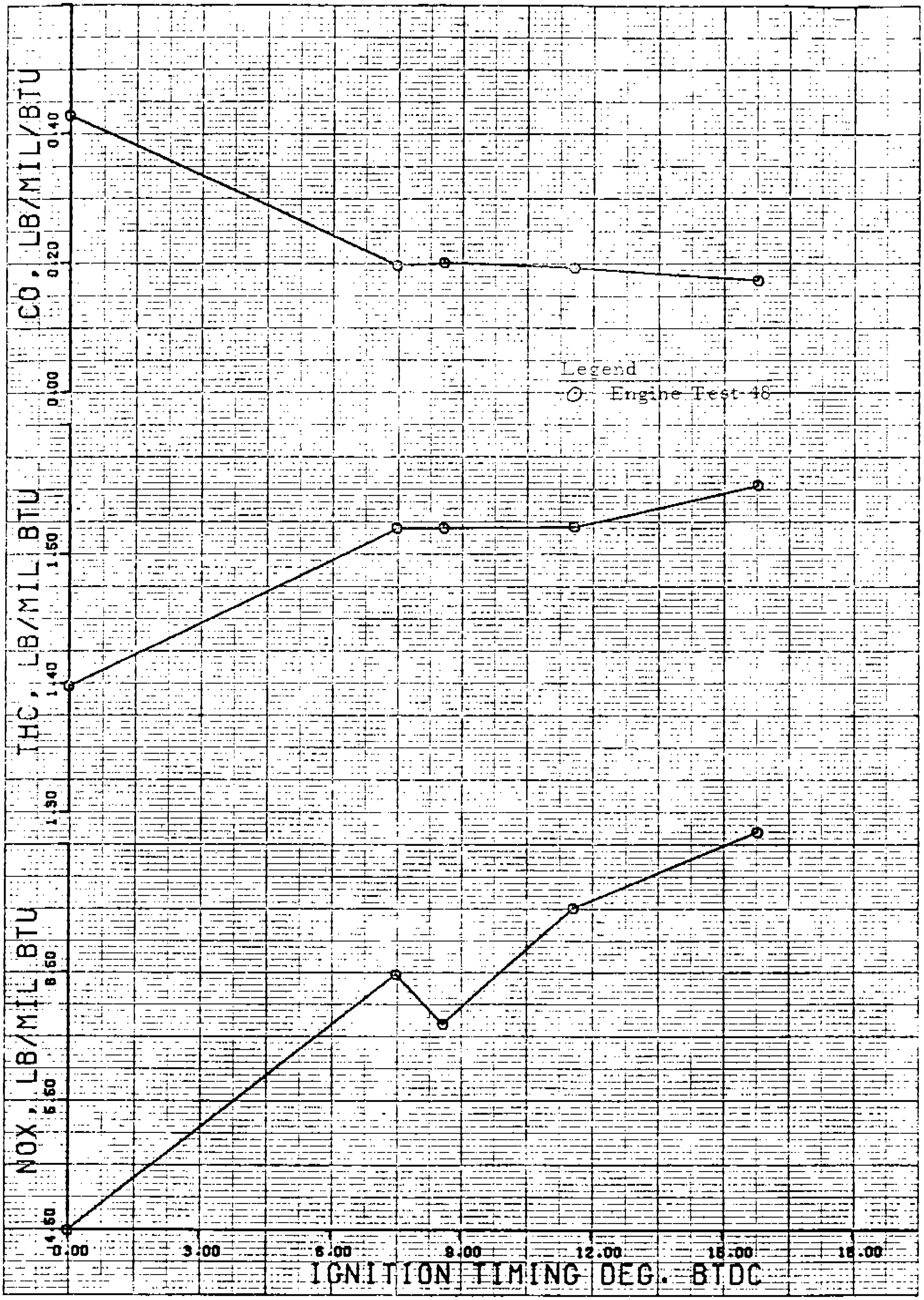


FIGURE E-96 EFFECT OF TIMING ON C-B GMWC-10 LB/MIL BTU EMISSIONS

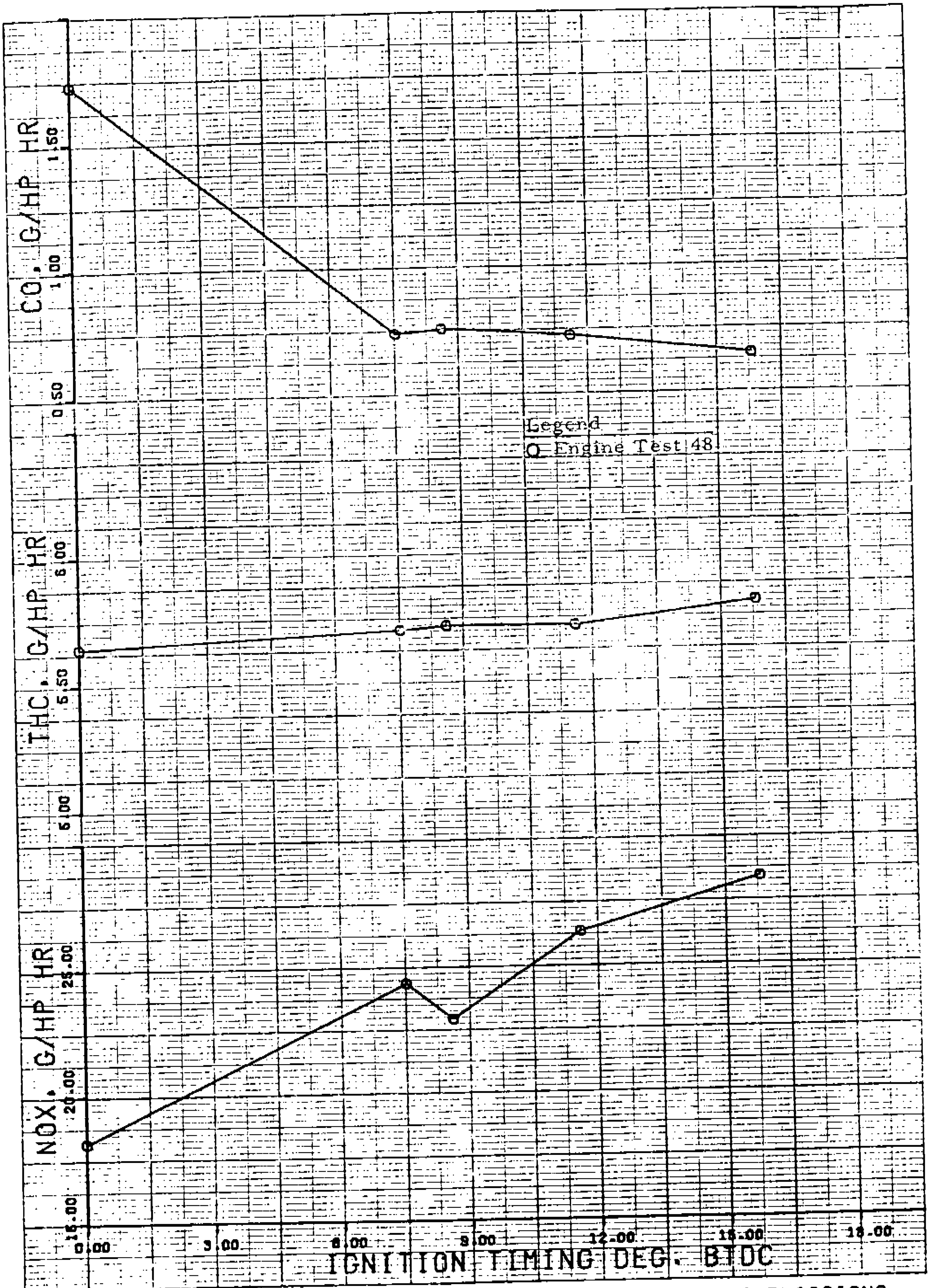


FIGURE E-97 EFFECT OF TIMING ON C-B GMWC-10 G/HP-HR EMISSIONS

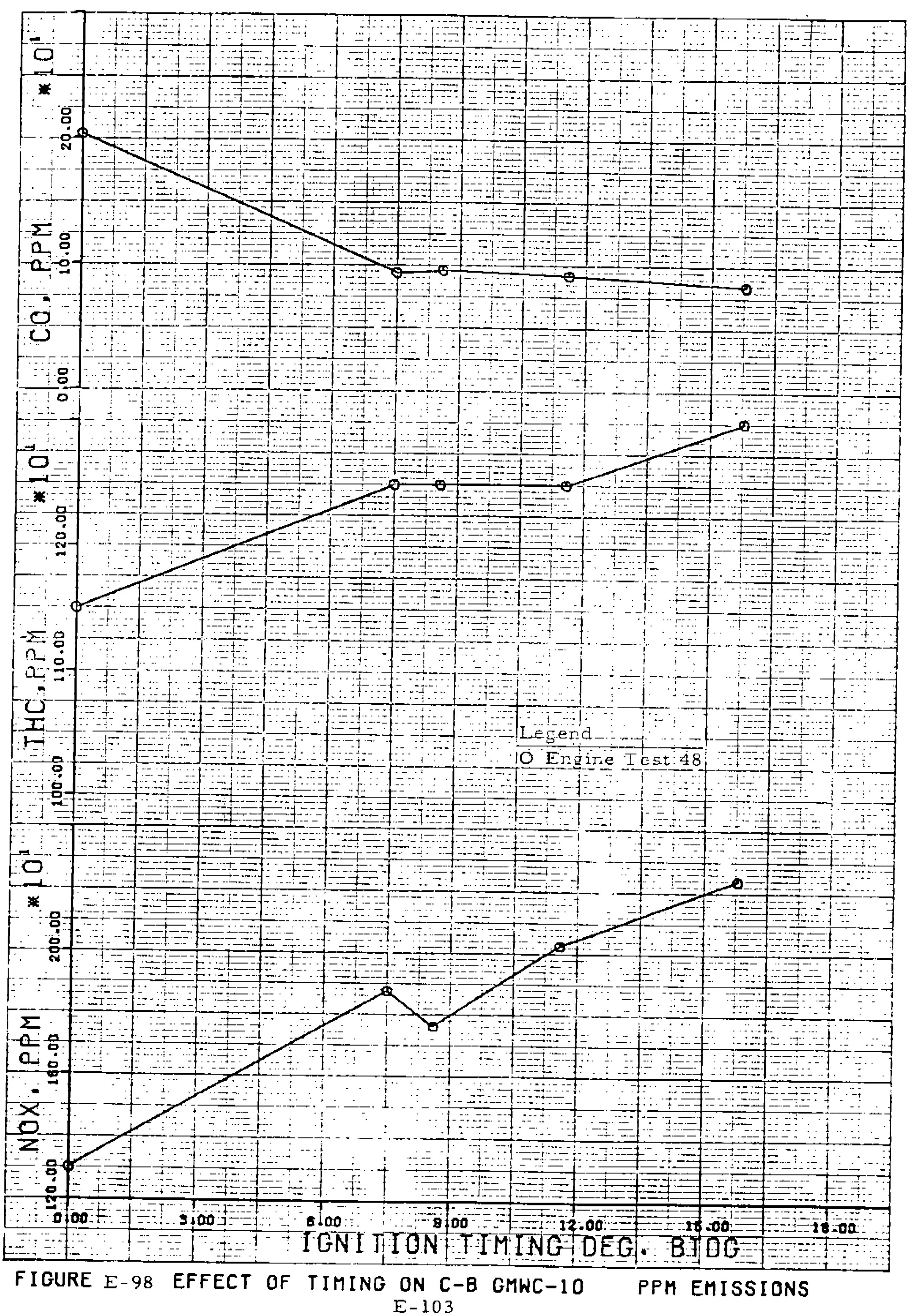


FIGURE E-98 EFFECT OF TIMING ON C-B GMWC-10 PPM EMISSIONS

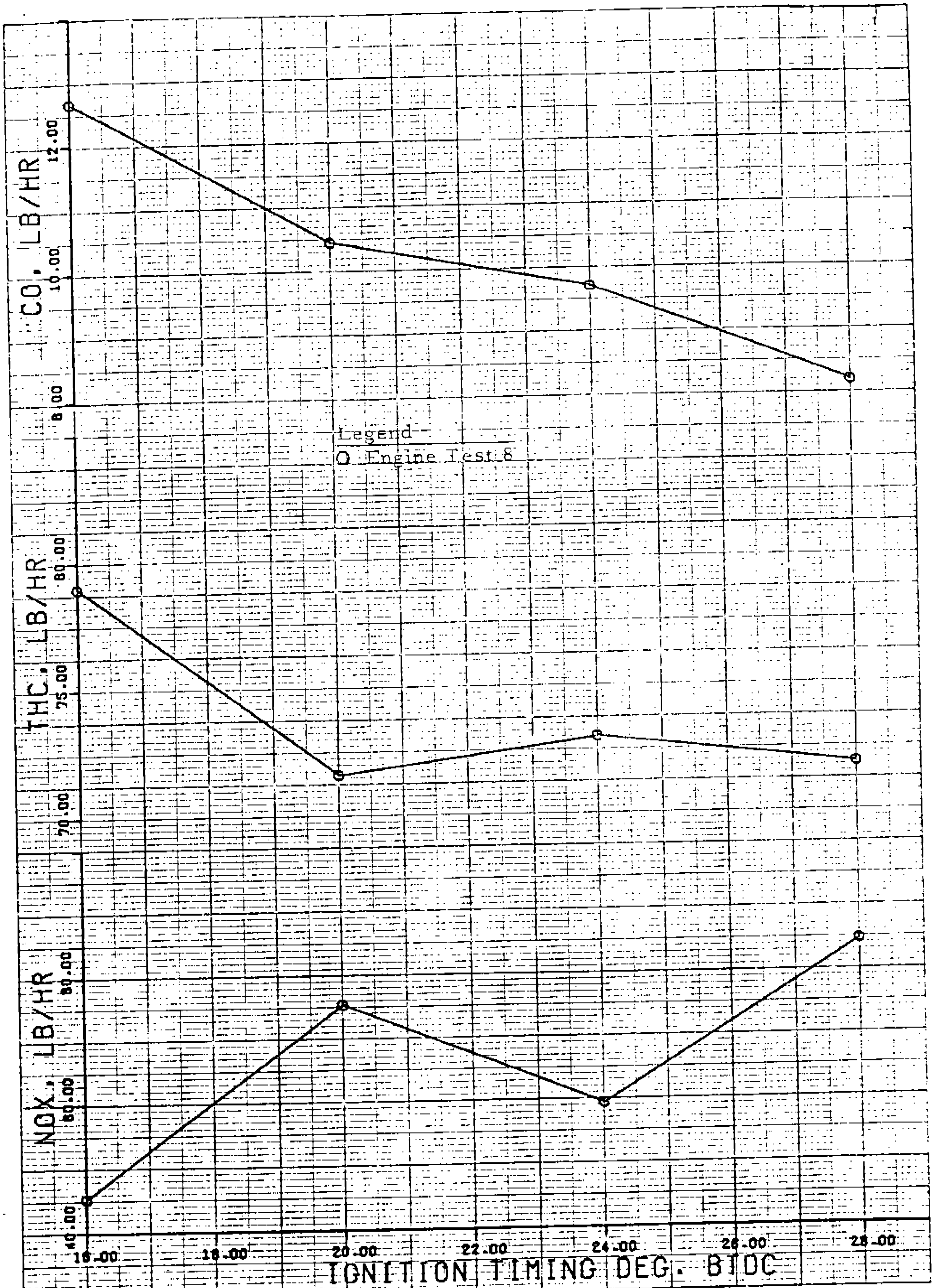


FIGURE E-99 EFFECT OF TIMING ON C-B LSV-16SG LB/HR EMISSIONS

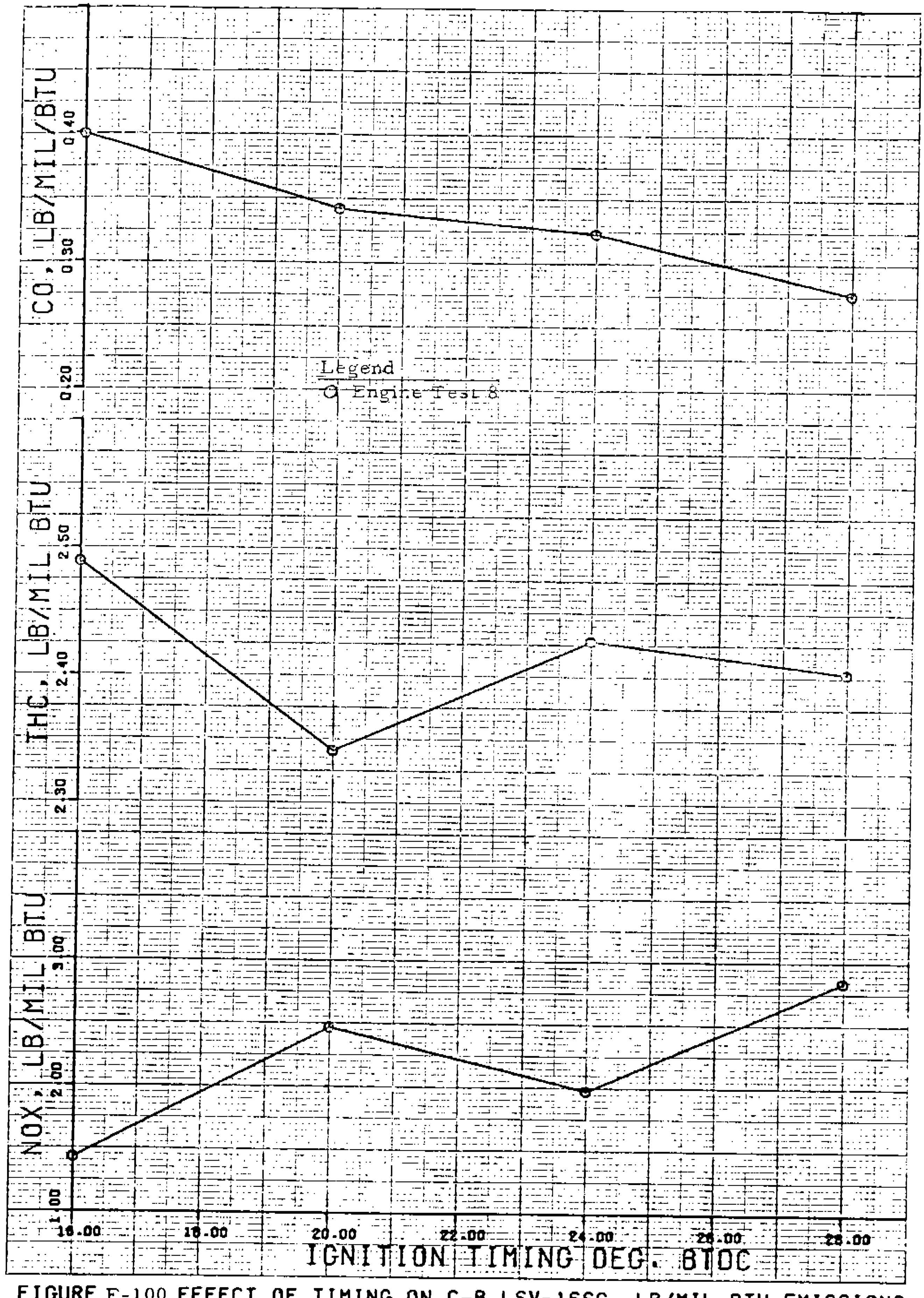
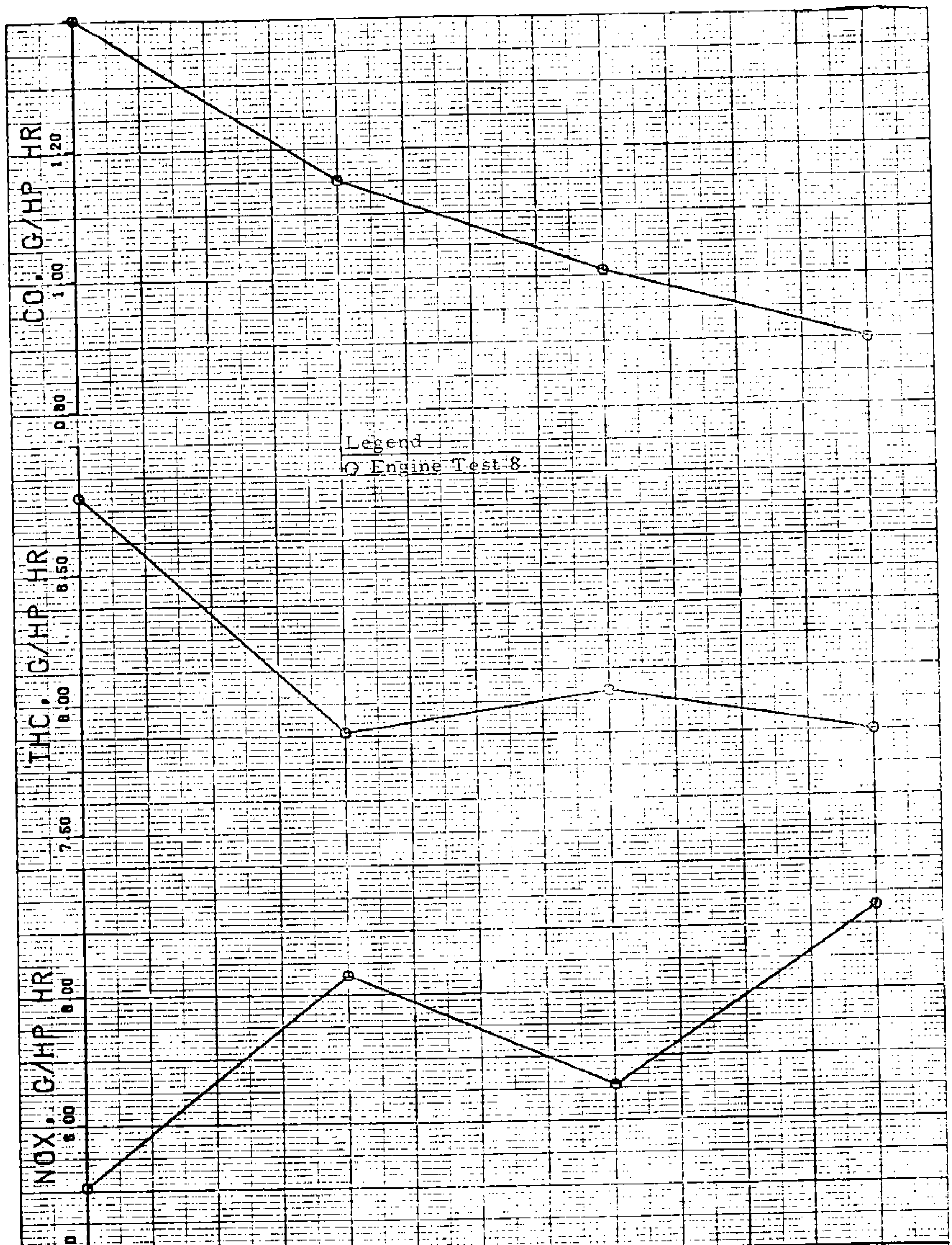


FIGURE E-100 EFFECT OF TIMING ON C-B LSV-16SG LB/MIL BTU EMISSIONS



FIGUREE-101 EFFECT OF TIMING ON C-B LSV-16SG G/HP-HR EMISSIONS

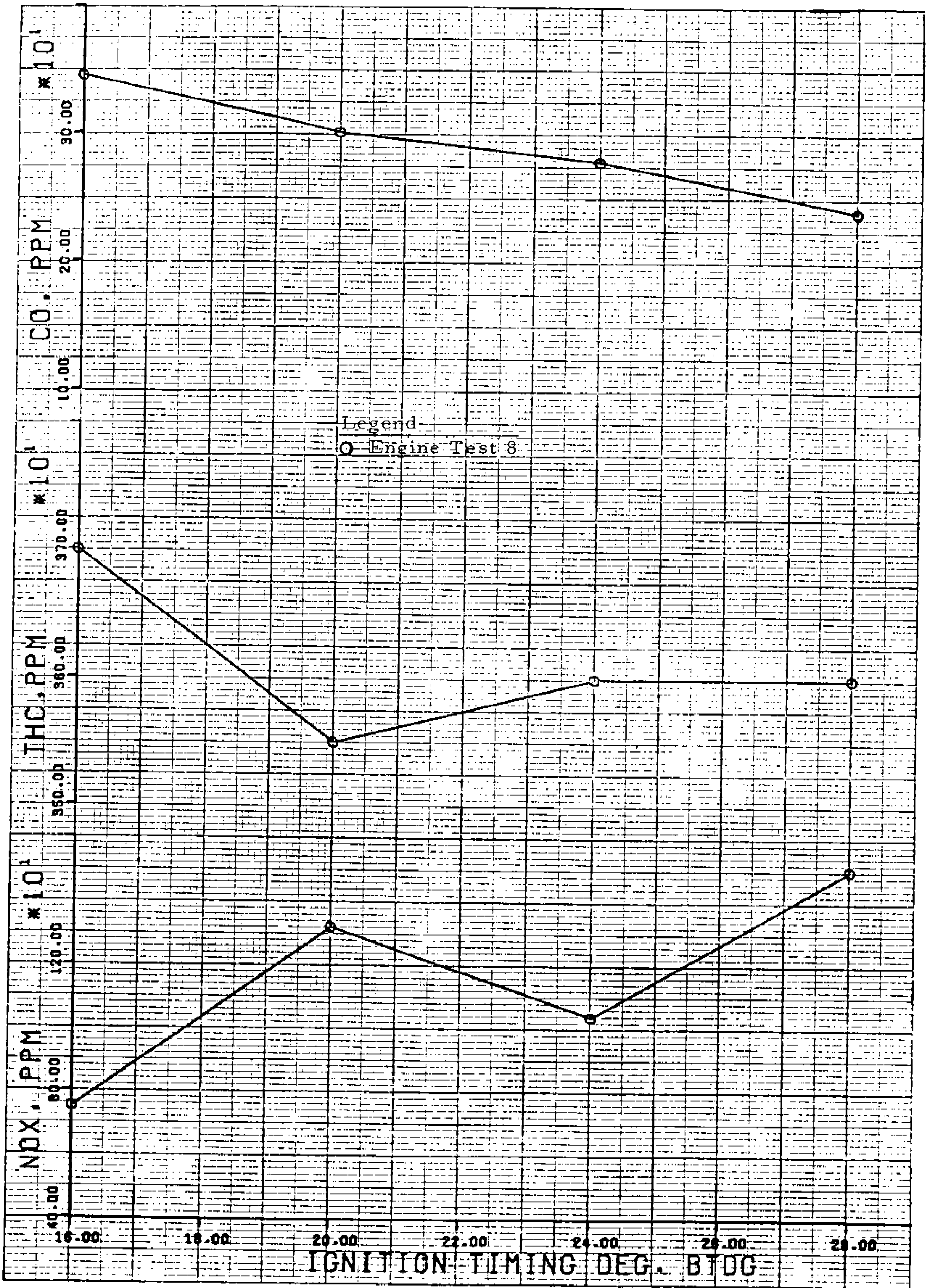


FIGURE E-102 EFFECT OF TIMING ON C-B LSV-16SG PPM EMISSIONS

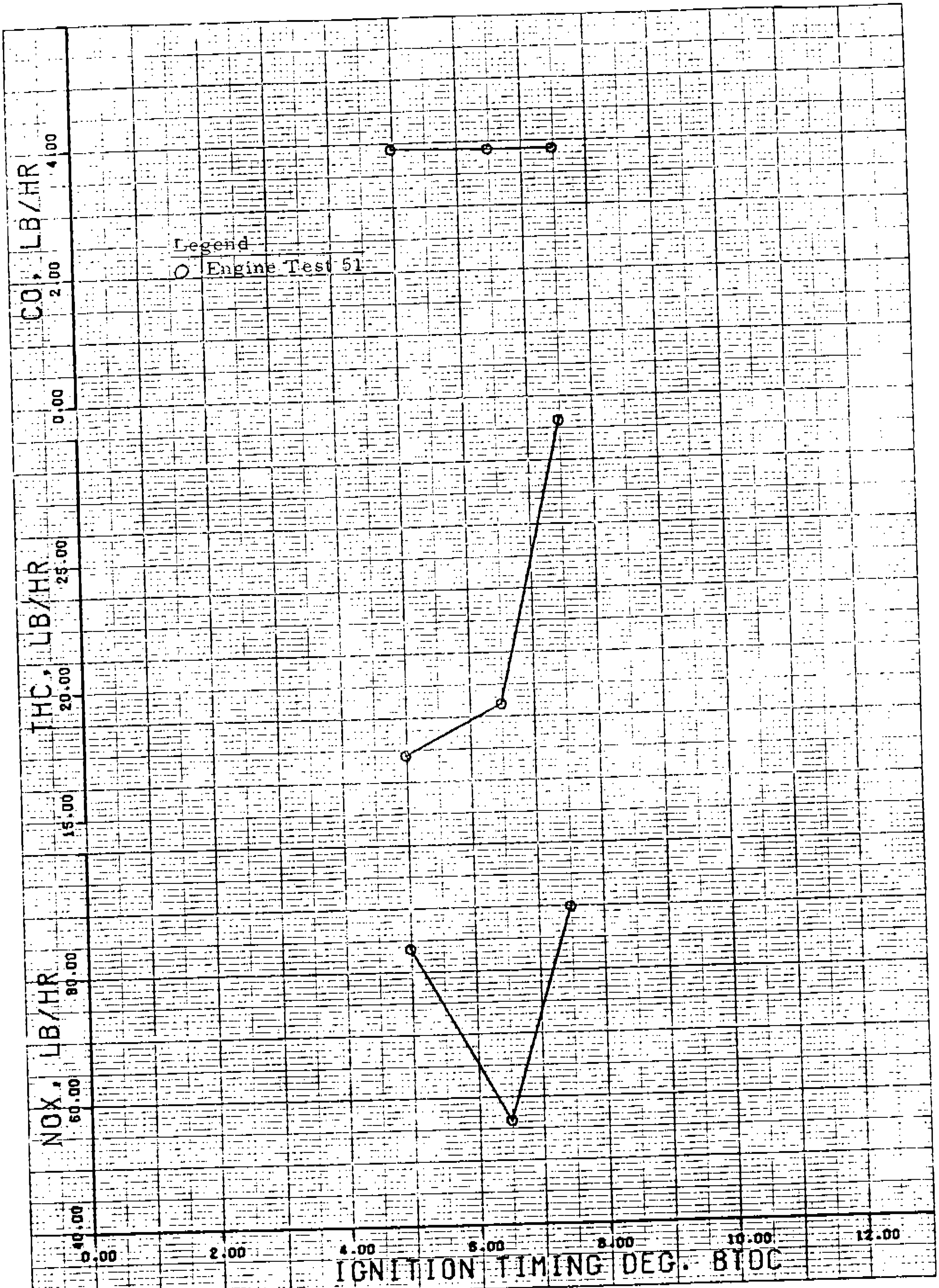


FIGURE E-103 EFFECT OF TIMING ON C-B 10V-250 LB/HR EMISSIONS

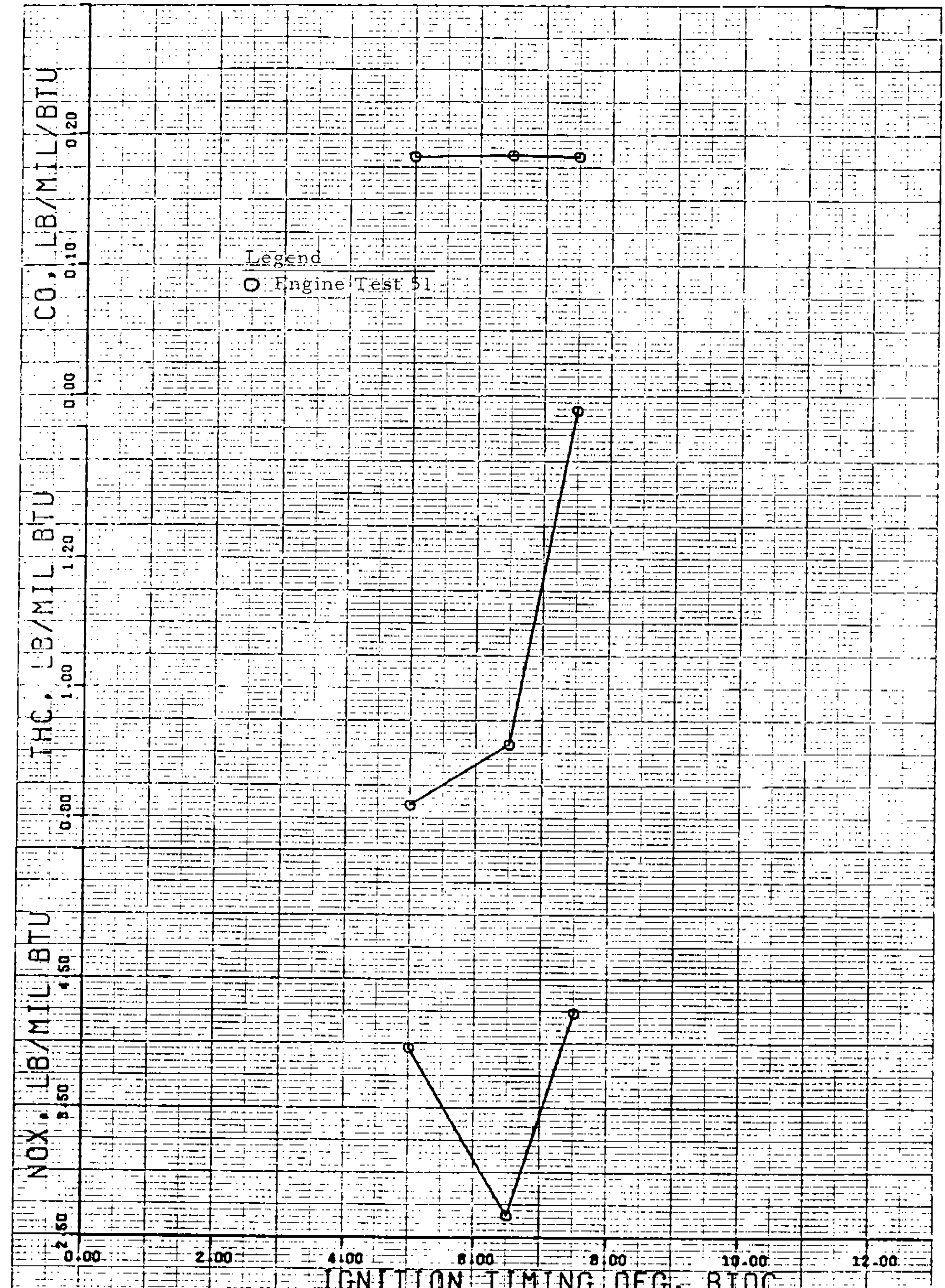


FIGURE E-104 EFFECT OF TIMING ON C-B 10V-250 LB/MIL BTU EMISSIONS

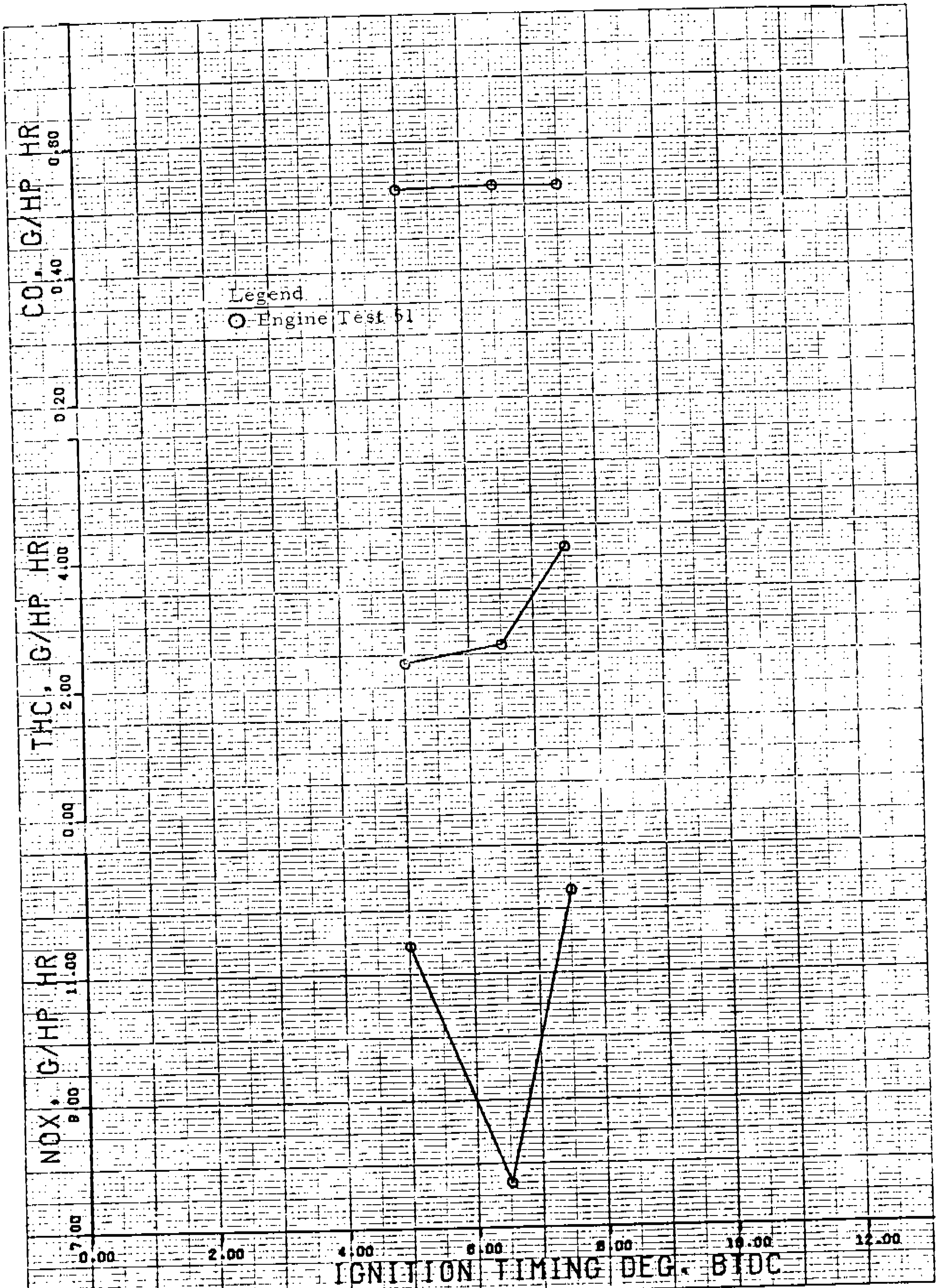


FIGURE E-105 EFFECT OF TIMING ON C-B 10V-250 G/HP-HR EMISSIONS

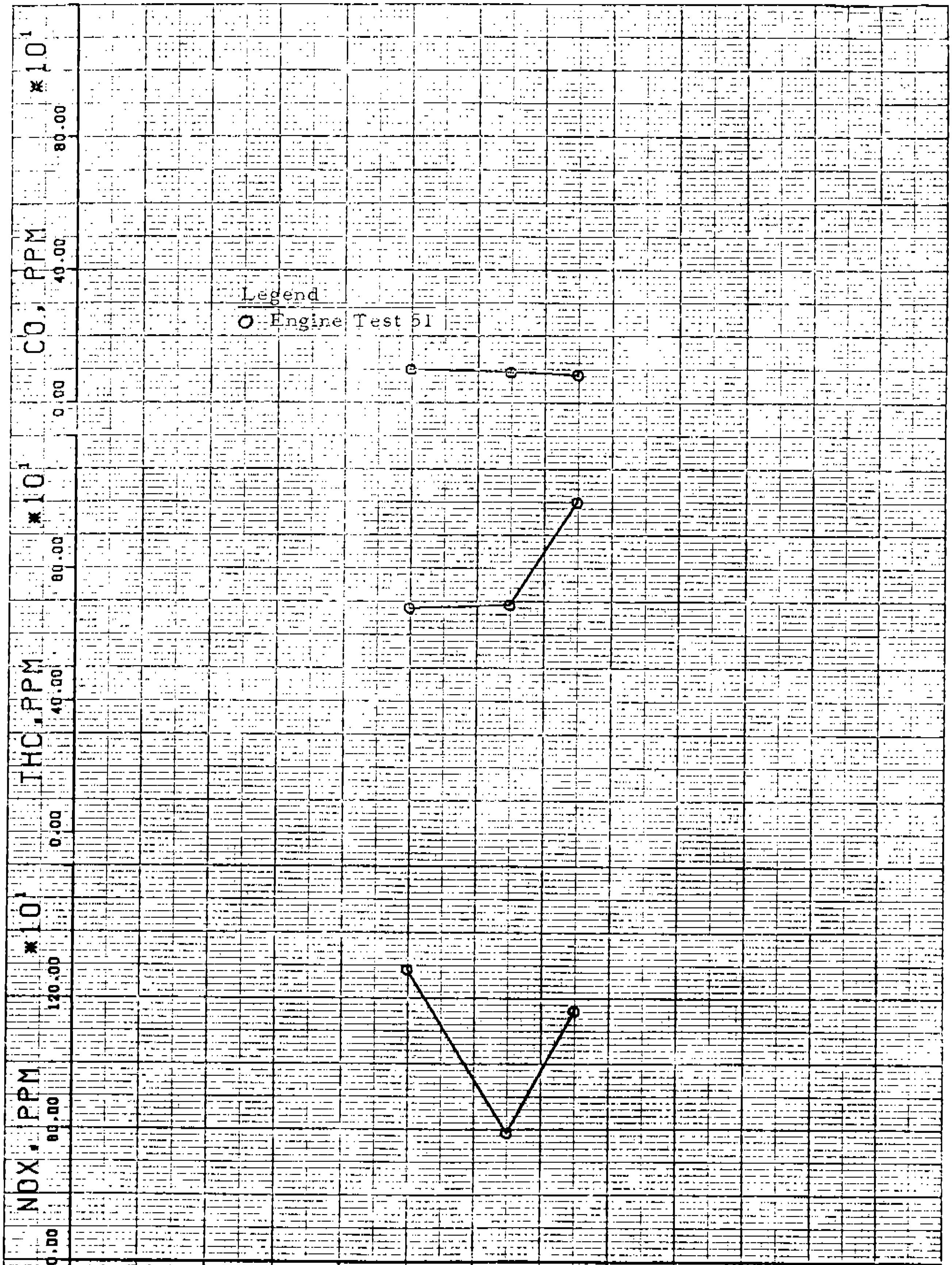


FIGURE E-106 EFFECT OF TIMING ON C-B 10V-250 PPM EMISSIONS

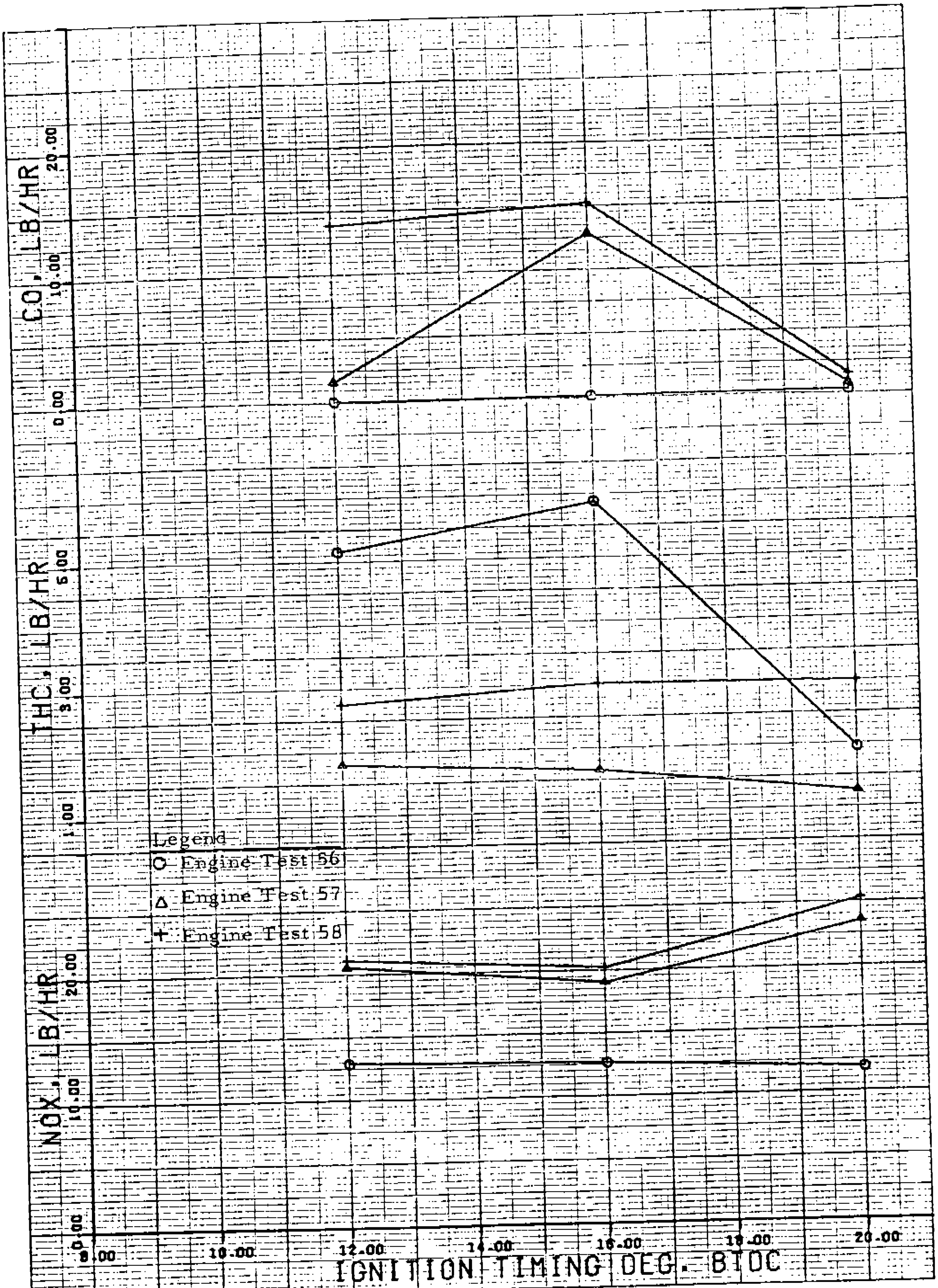


FIGURE E-107 EFFECT OF TIMING ON I-R KVG-8 LB/HR EMISSIONS

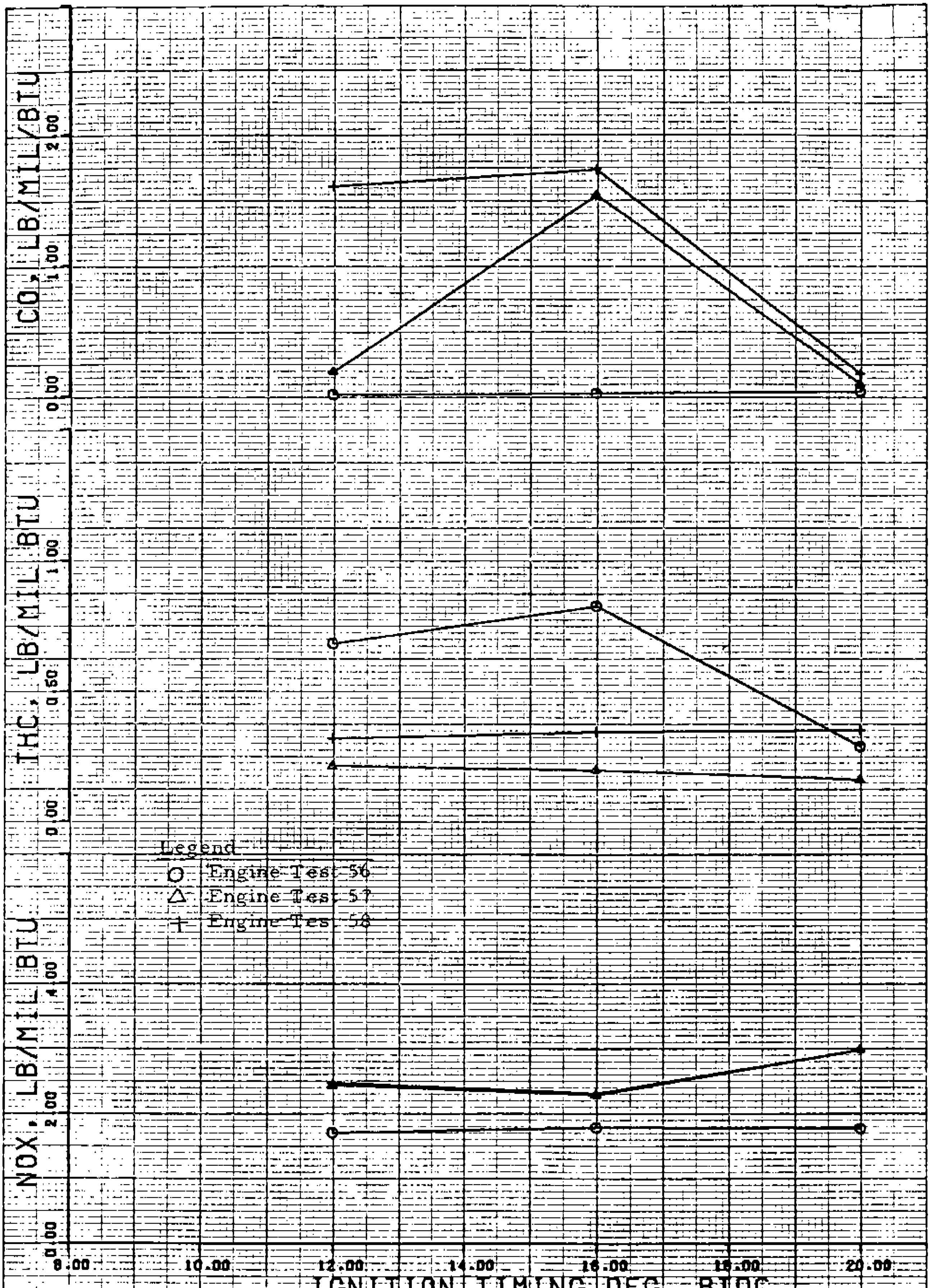


FIGURE E-108 EFFECT OF TIMING ON I-R KVG-8 LB/MIL BTU EMISSIONS

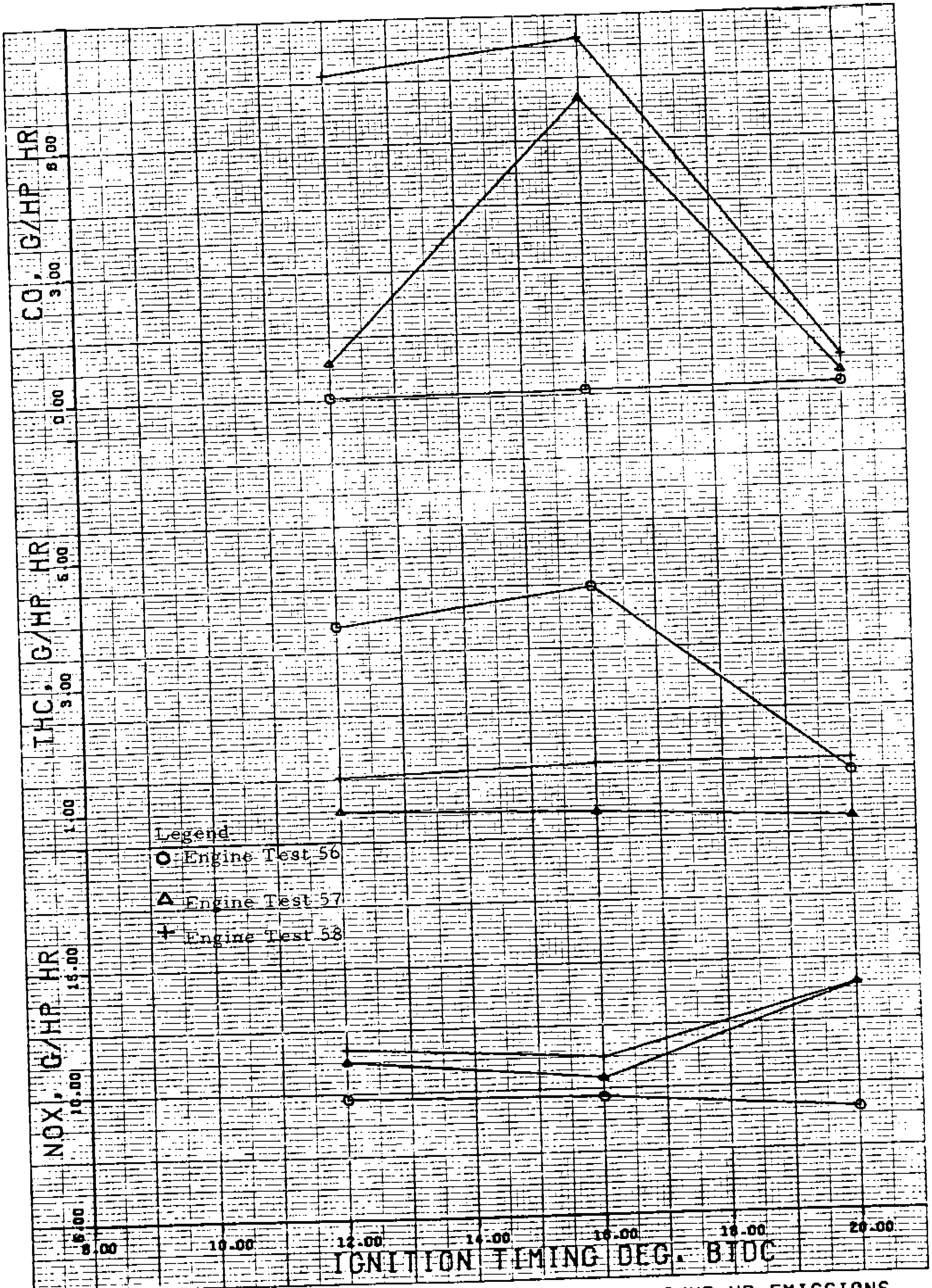


FIGURE E-109 EFFECT OF TIMING ON I-R KVG-8 G/HP-HR EMISSIONS

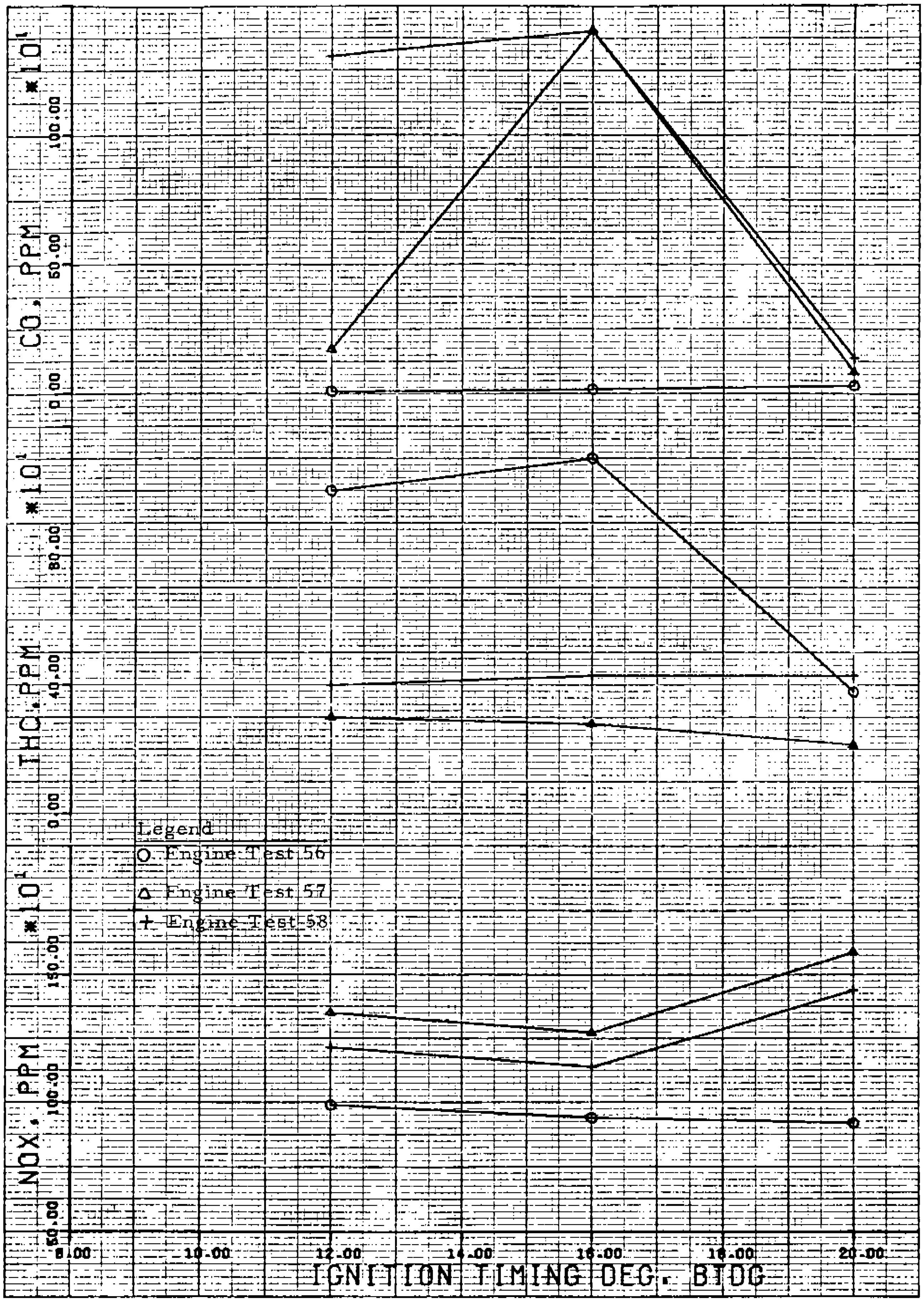


FIGURE E-110 EFFECT OF TIMING ON I-R KVG-8 PPM EMISSIONS

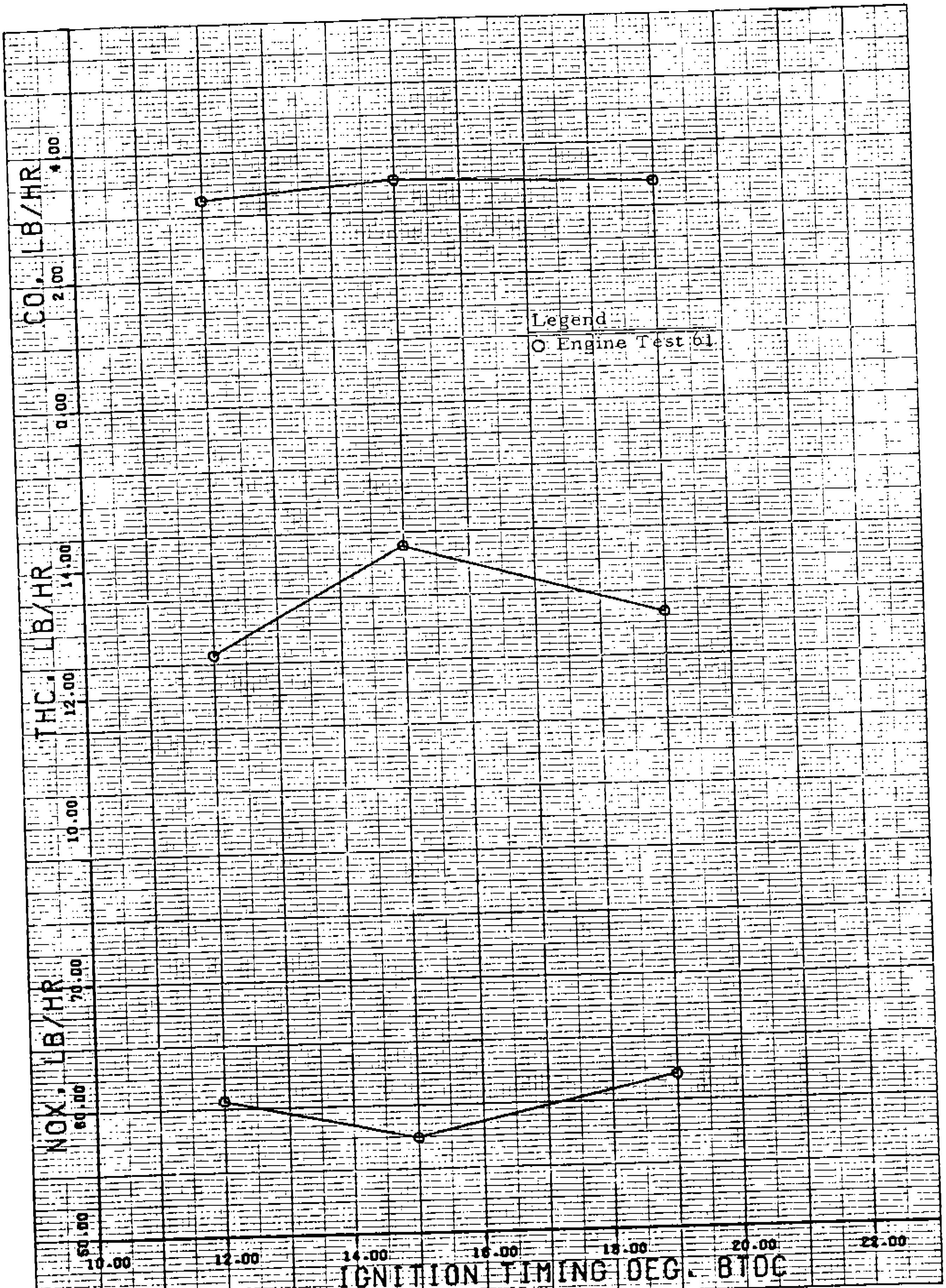


FIGURE E-111 EFFECT OF TIMING ON I-R 412-KVS LB/HR EMISSIONS

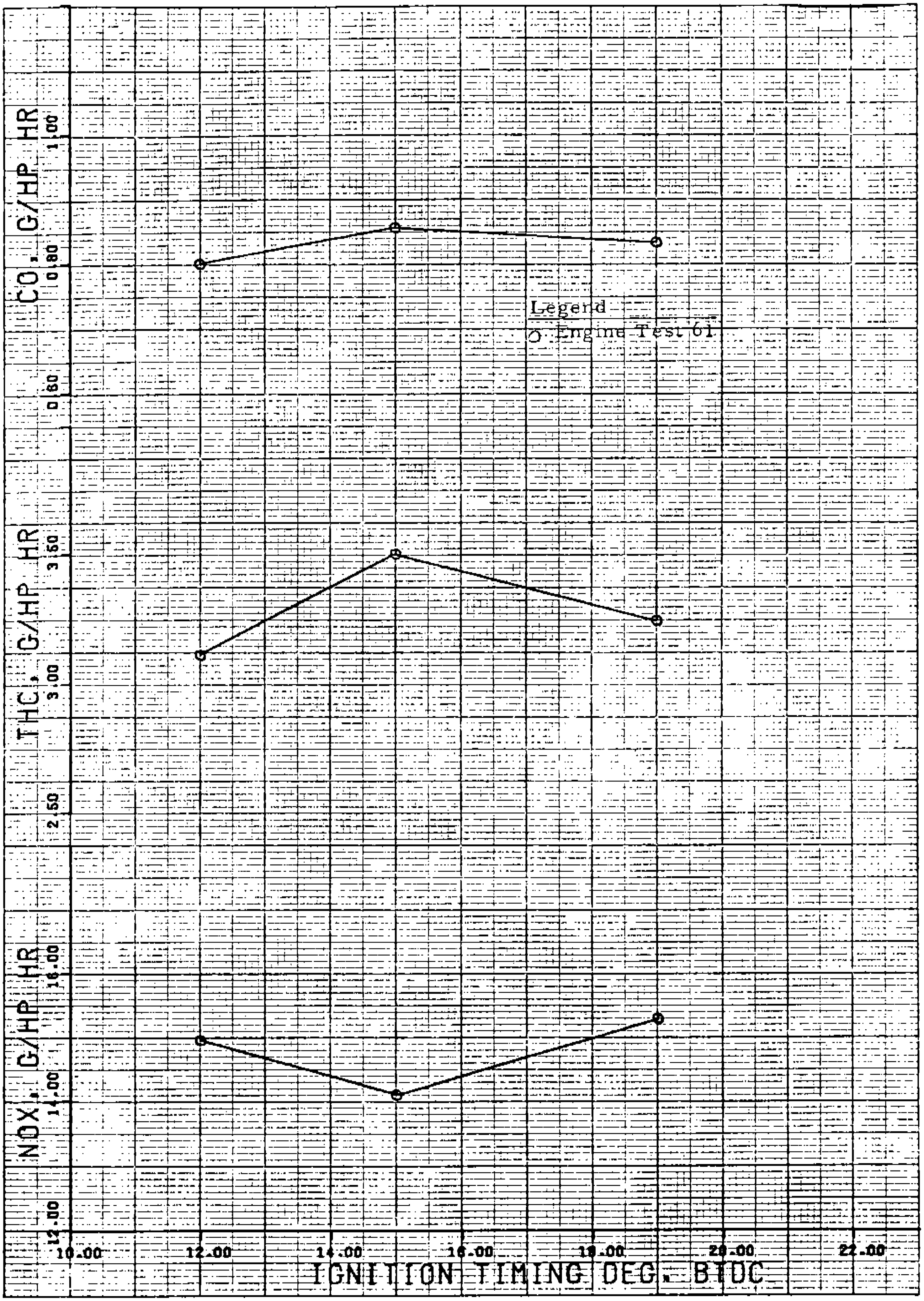


FIGURE E-112 EFFECT OF TIMING ON I-R 412-KVS G/HP-HR EMISSIONS

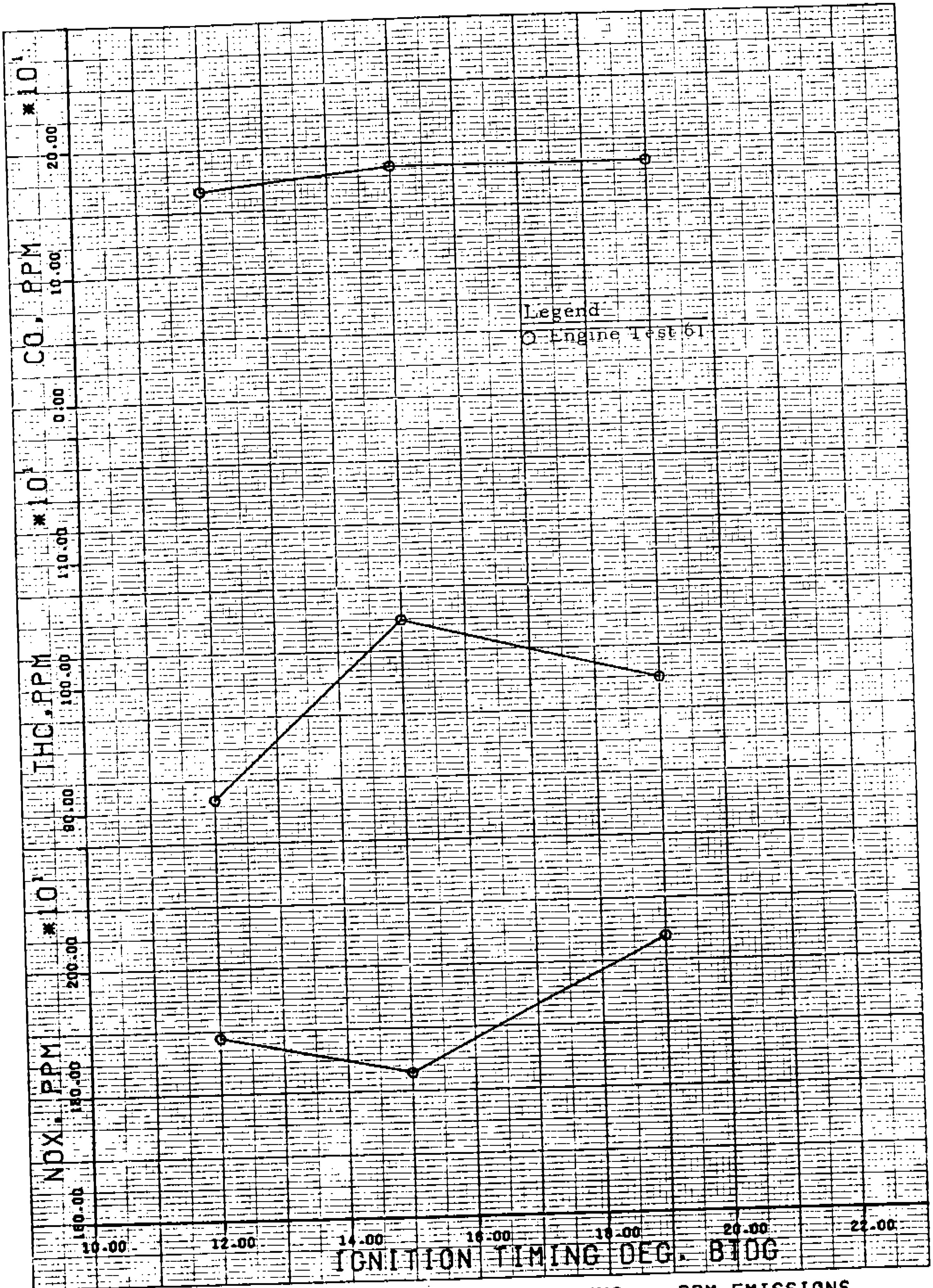


FIGURE E-113 EFFECT OF TIMING ON I-R 412 KVS PPM EMISSIONS

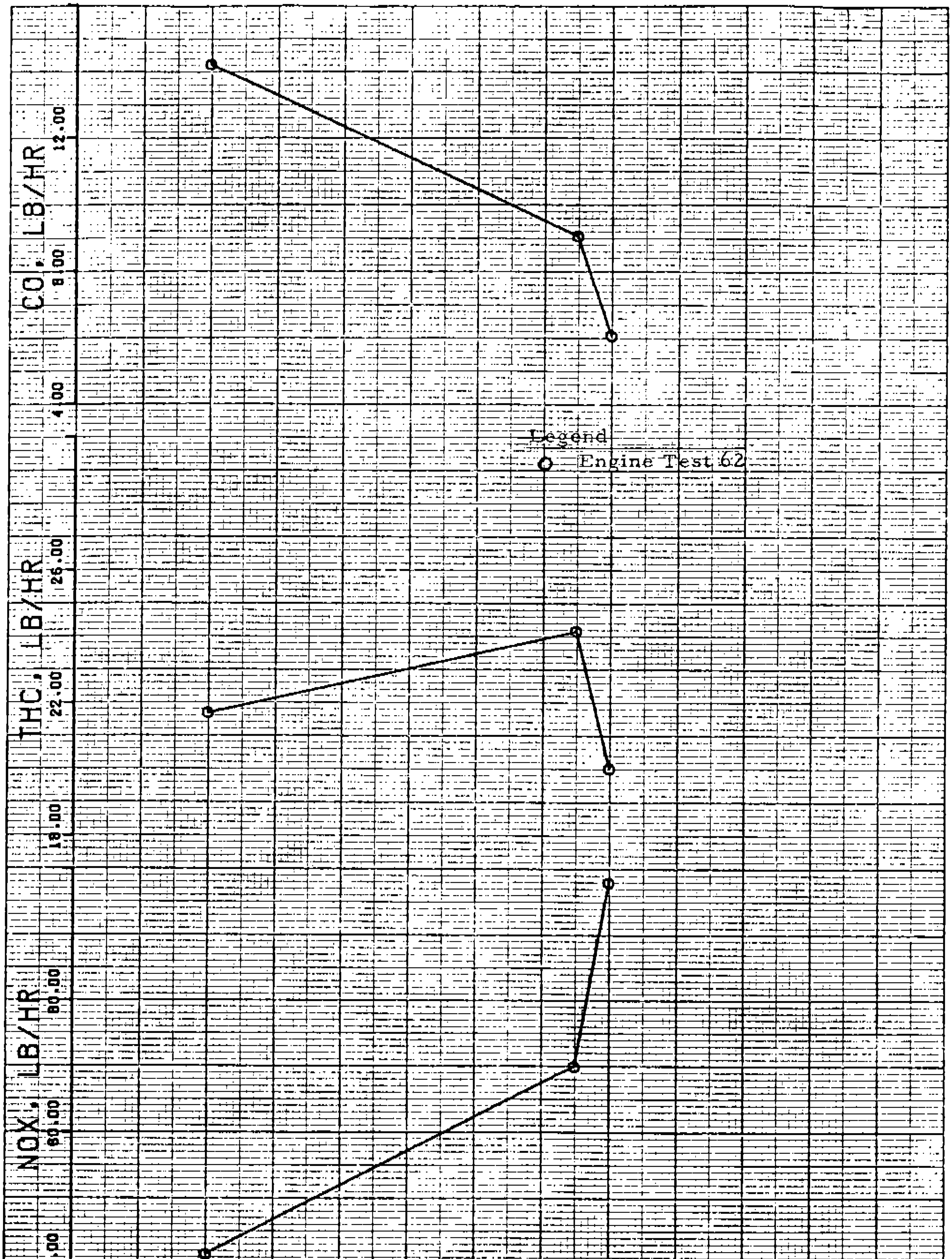


FIGURE E-114 EFFECT OF TIMING ON I-R 616KVT LB/HR EMISSIONS

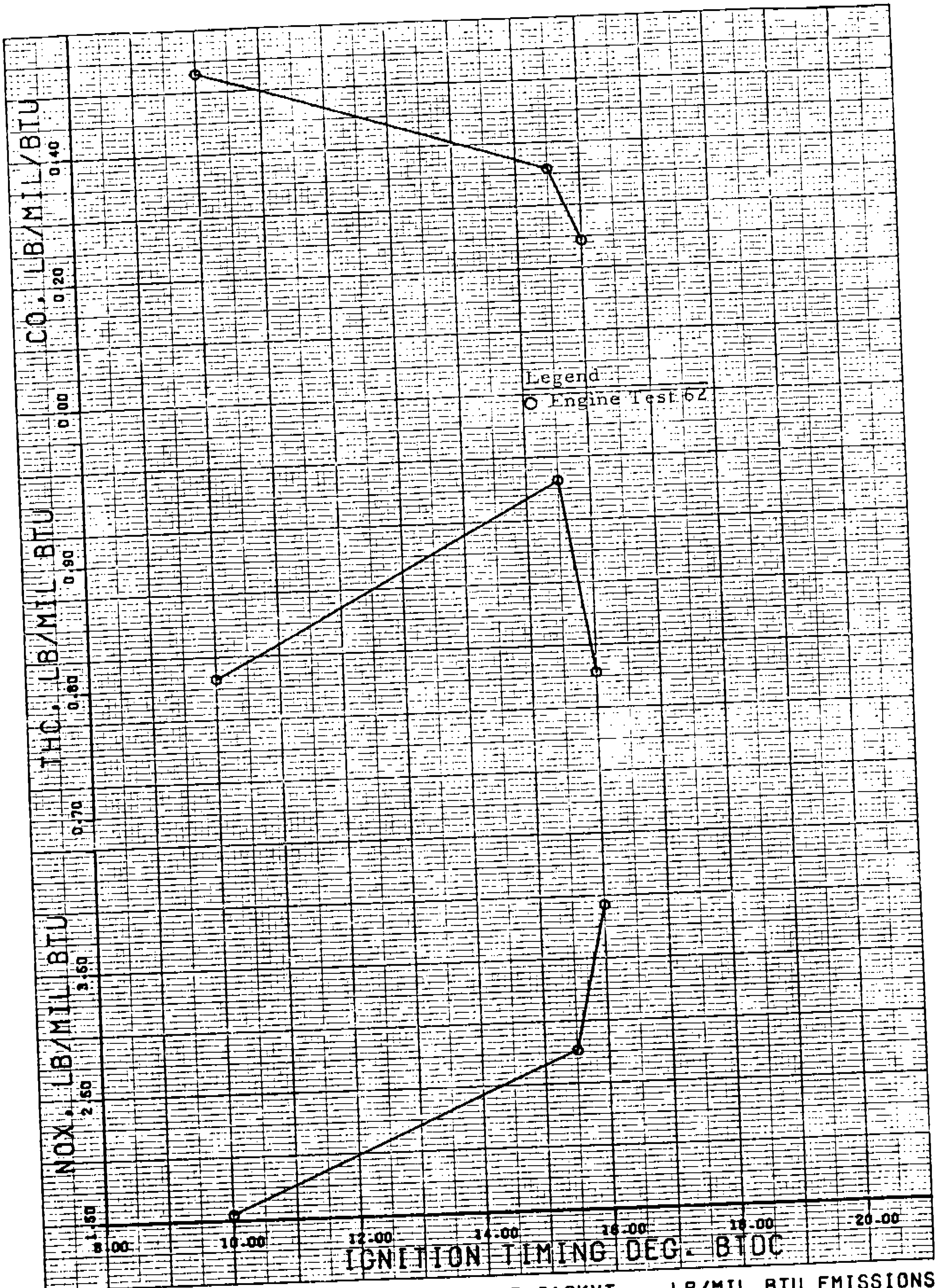
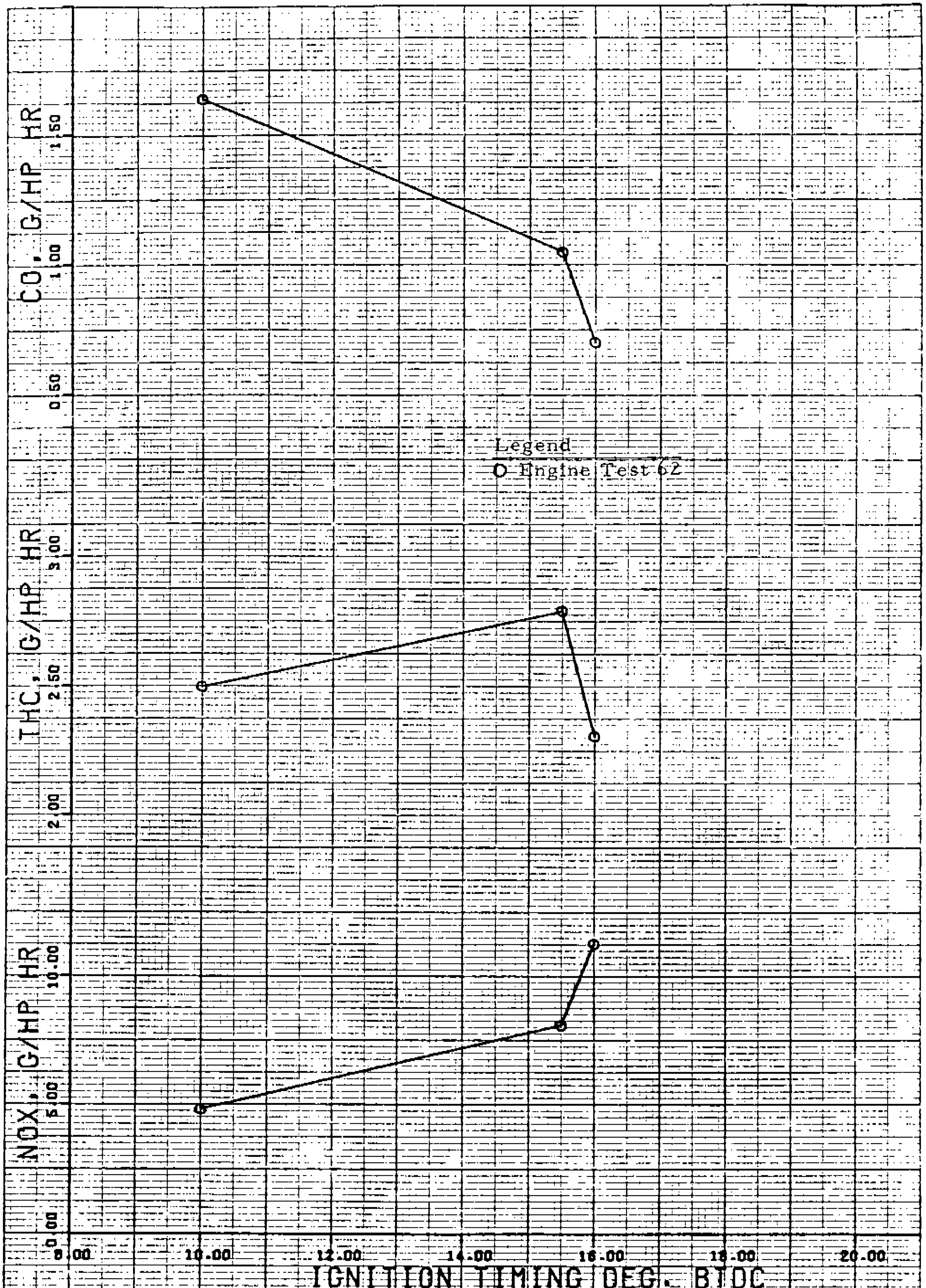
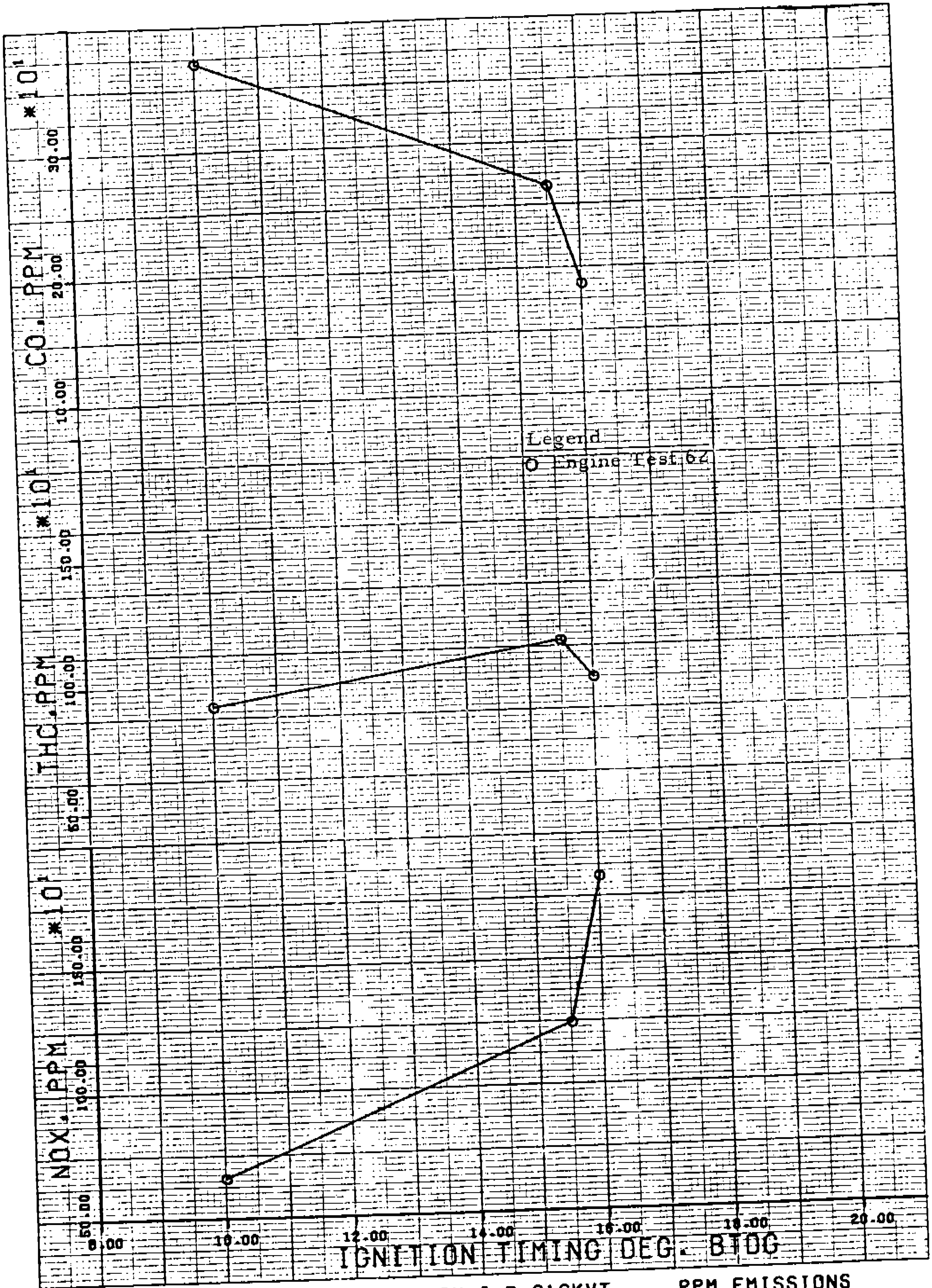


FIGURE E-115 EFFECT OF TIMING ON I-R 616KVT LB/MIL BTU EMISSIONS



FIGUREE-116 EFFECT OF TIMING ON I-R 616KVT G/HP-HR EMISSIONS



FIGUREE-117 EFFECT OF TIMING ON I-R 616KVT PPM EMISSIONS

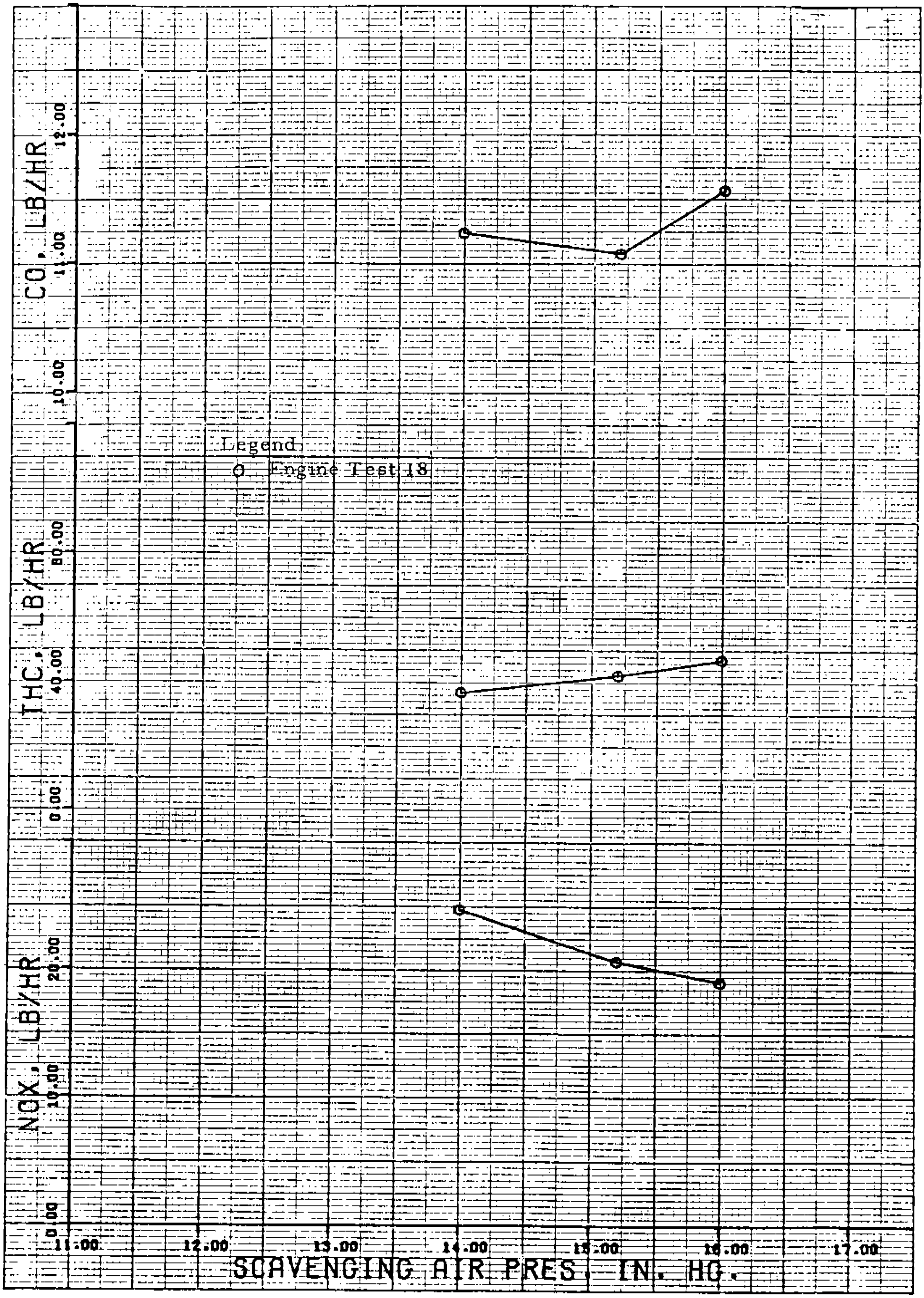
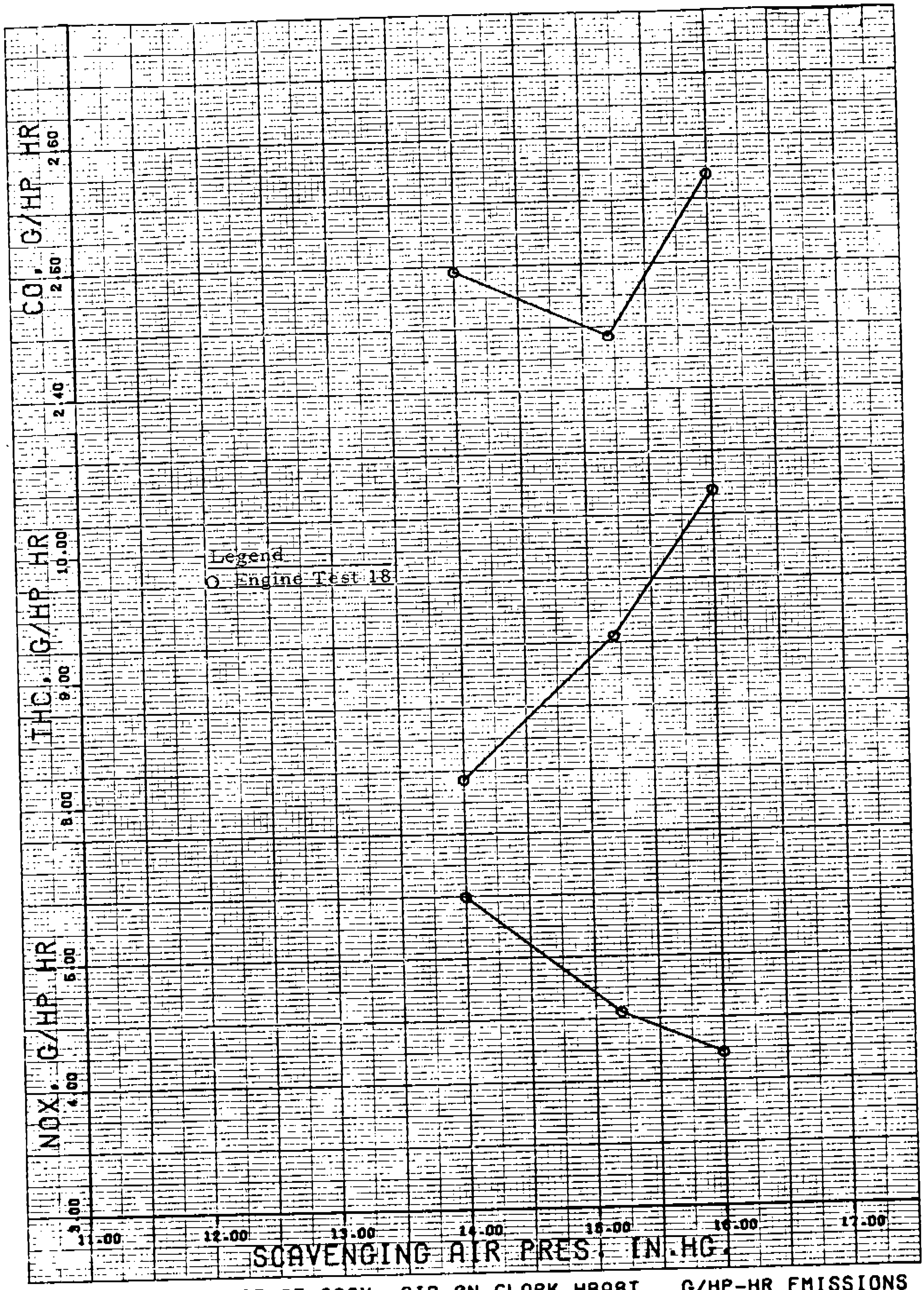


FIGURE E-118 EFFECT OF SCAV. AIR ON CLARK HBA-8T LB/HR EMISSIONS



FIGUREE-119 EFFECT OF SCAV. AIR ON CLARK HBA8T G/HP-HR EMISSIONS

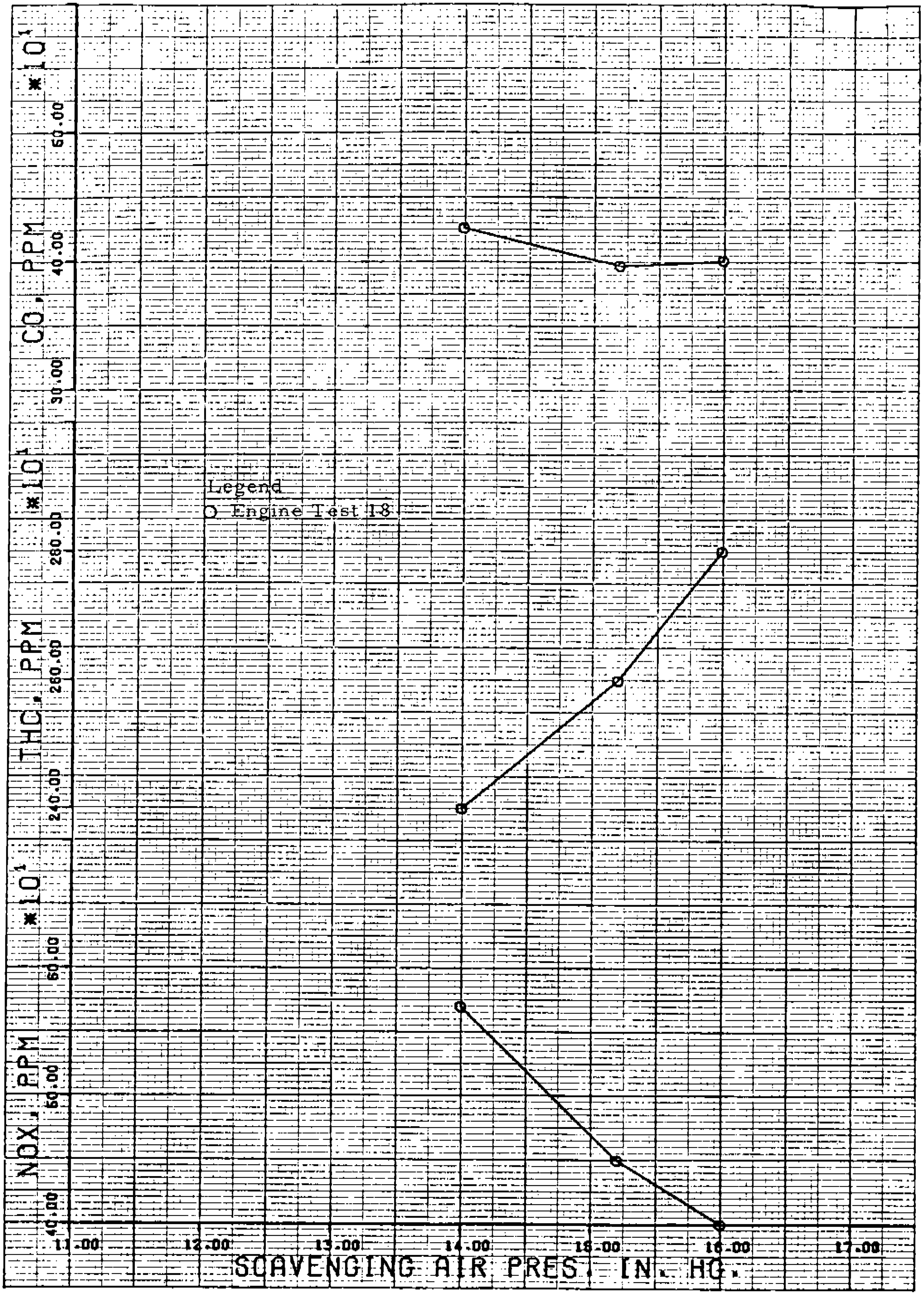


FIGURE E-120 EFFECT OF SCAV. AIR ON CLARK HBA-8T PPM EMISSIONS

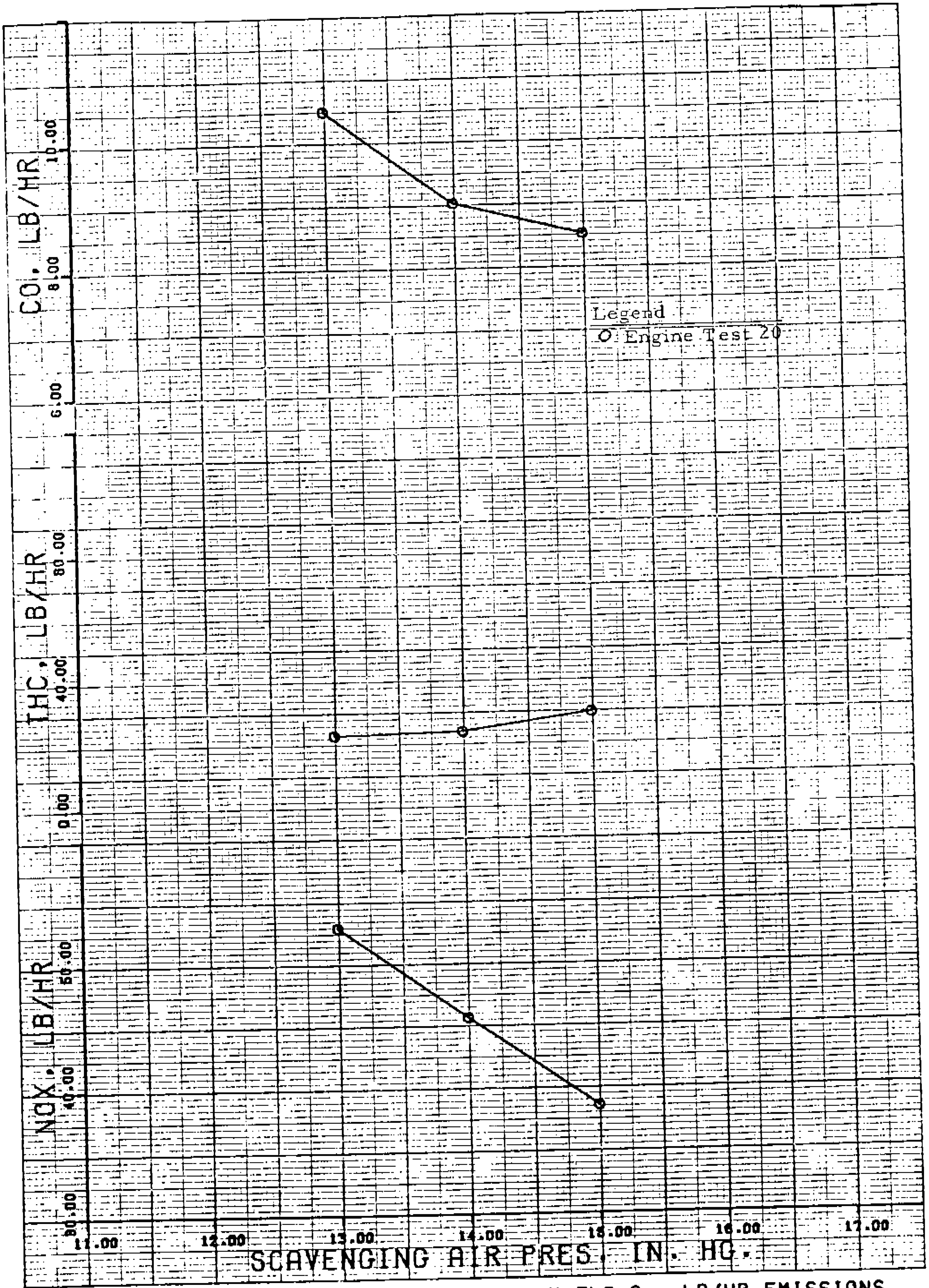


FIGURE E-121 EFFECT OF SCAV. AIR ON CLARK TLA-6 LB/HR EMISSIONS

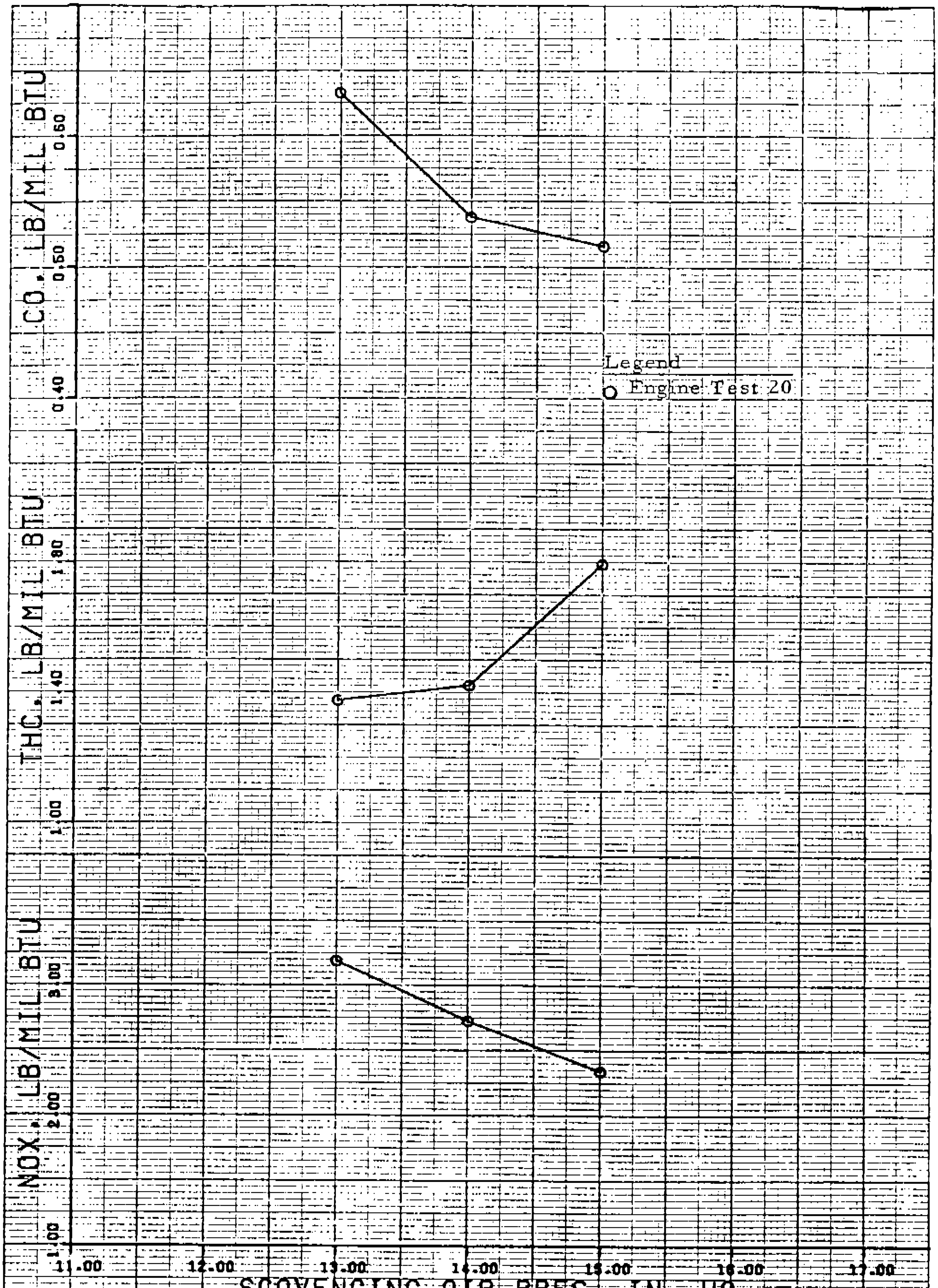


FIGURE E-122 EFFECT OF SCAV. AIR ON CLARK TLA-6 LB/MIL BTU EMISSIONS

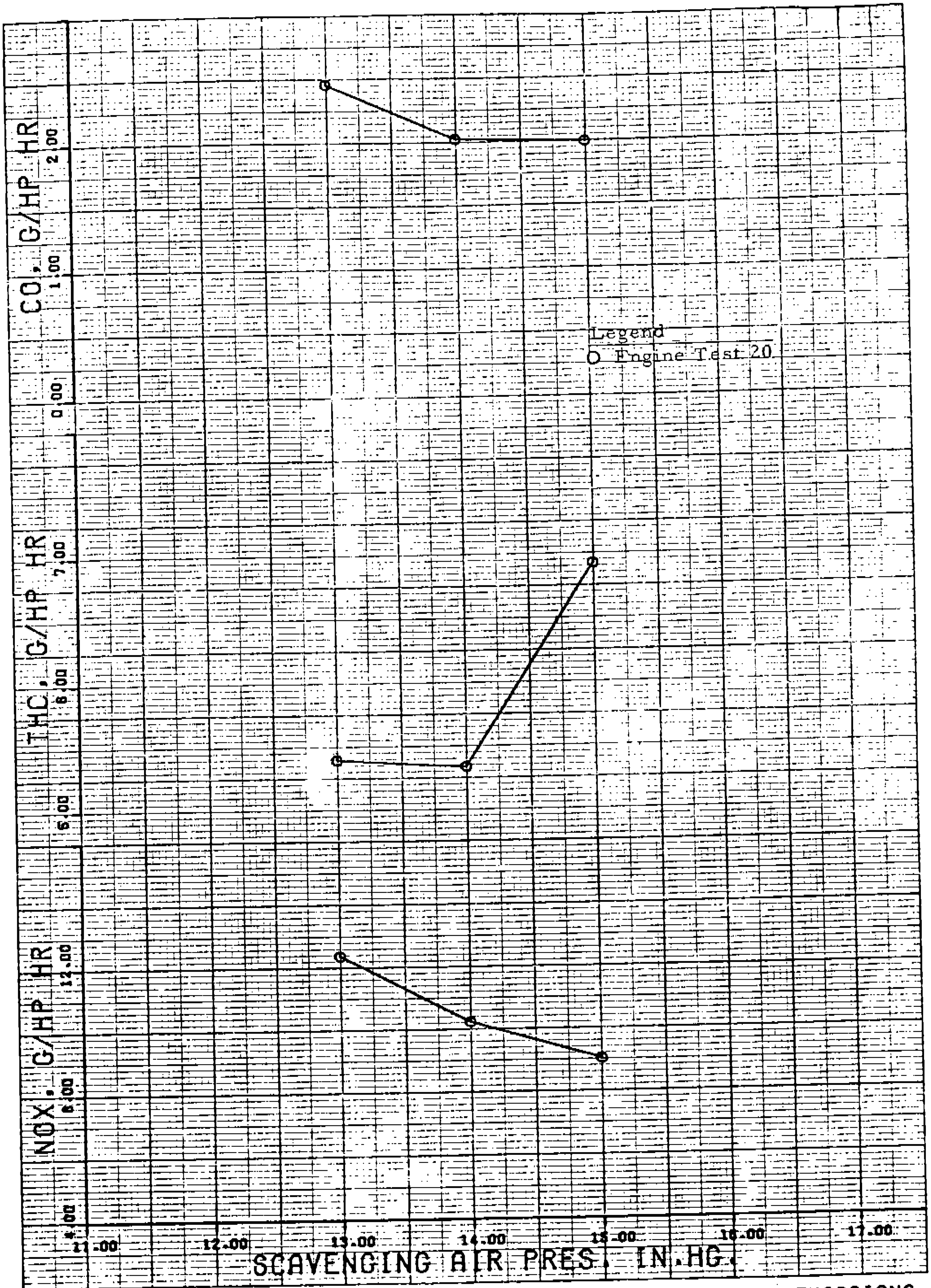


FIGURE E-123 EFFECT OF SCAV. AIR ON CLARK TLA-6 G/HP-HR EMISSIONS

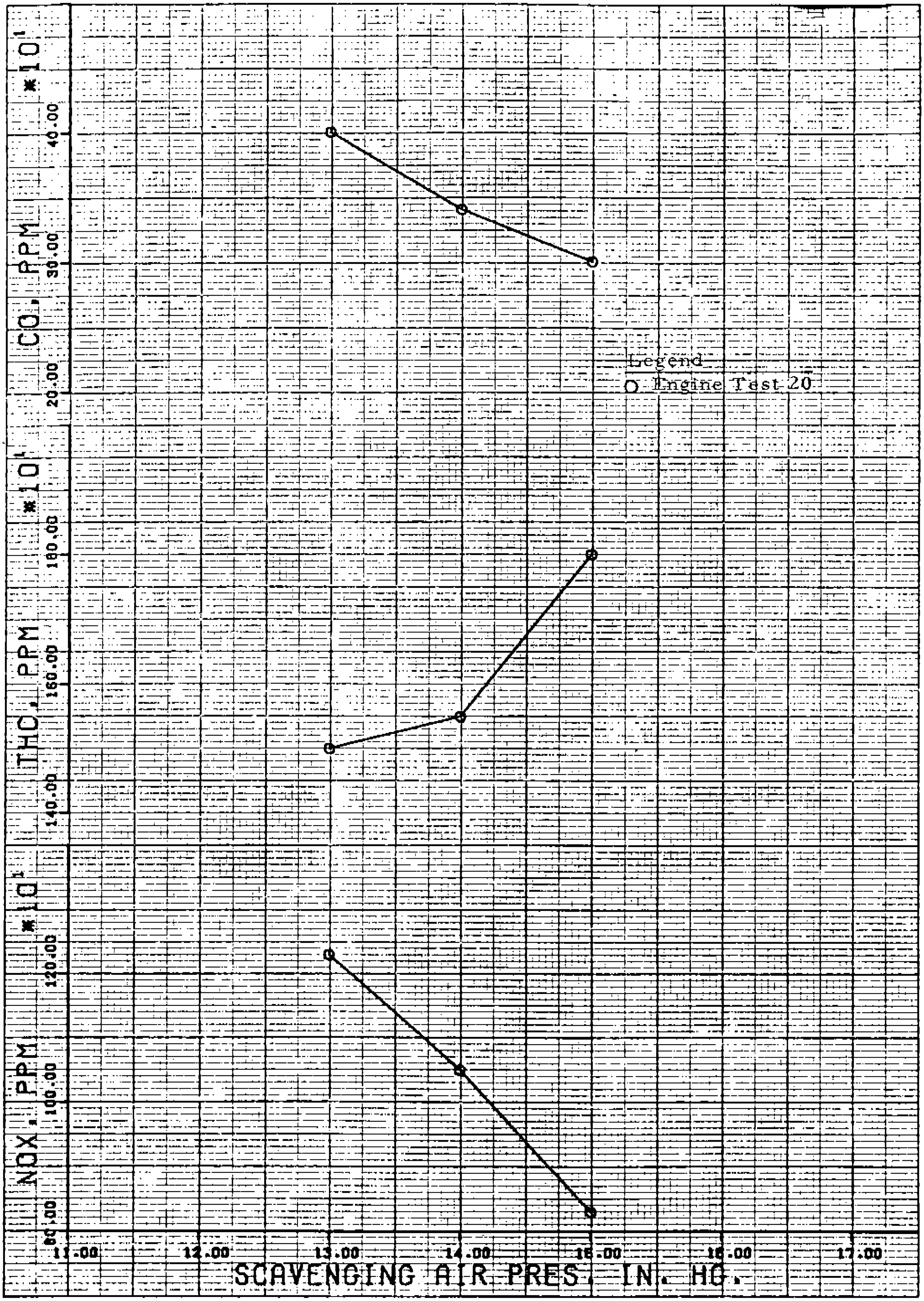


FIGURE E-124 EFFECT OF SCAV. AIR ON CLARK TLA-6 PPM EMISSIONS

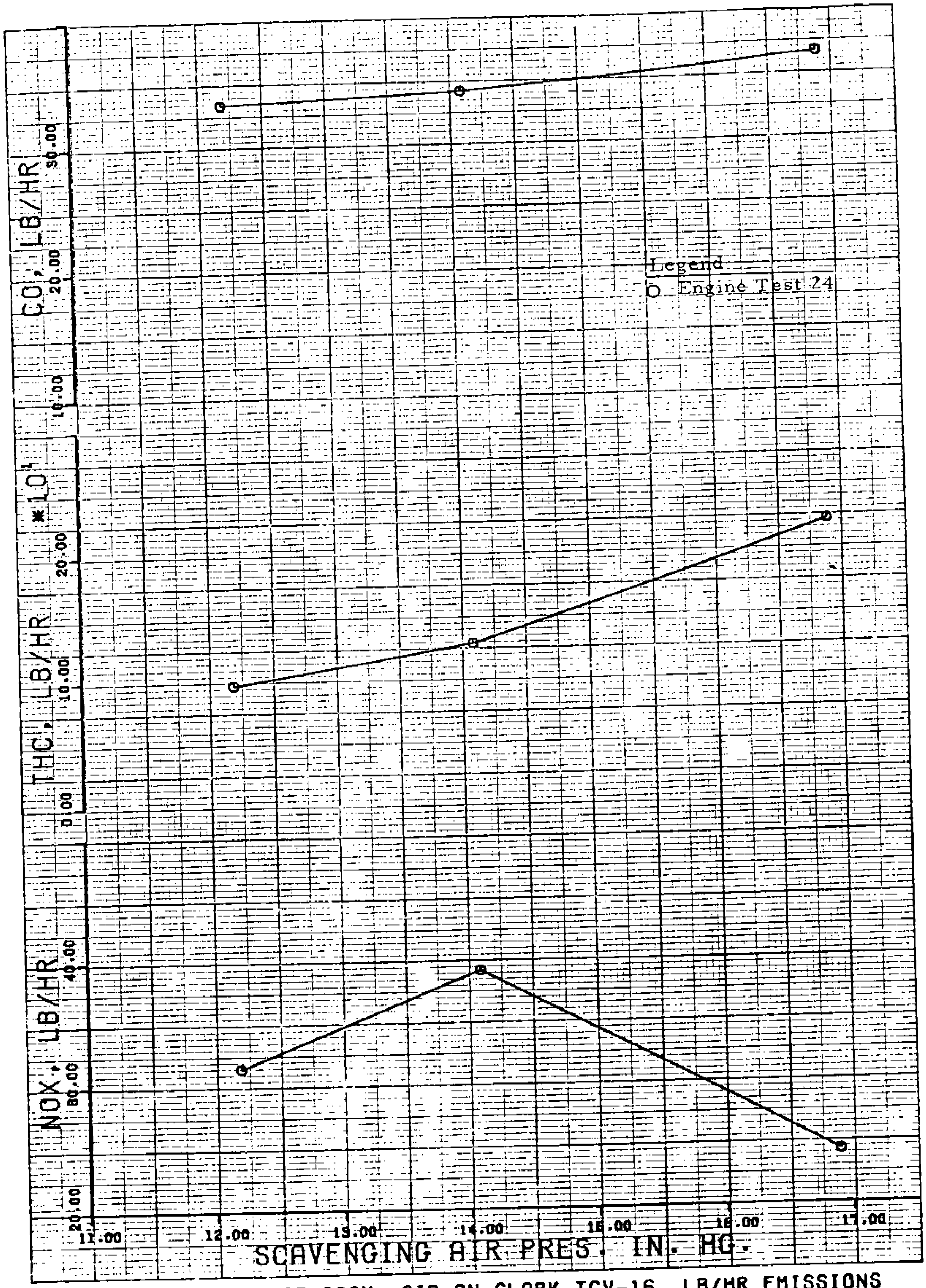


FIGURE E-125 EFFECT OF SCAV. AIR ON CLARK TCV-16 LB/HR EMISSIONS

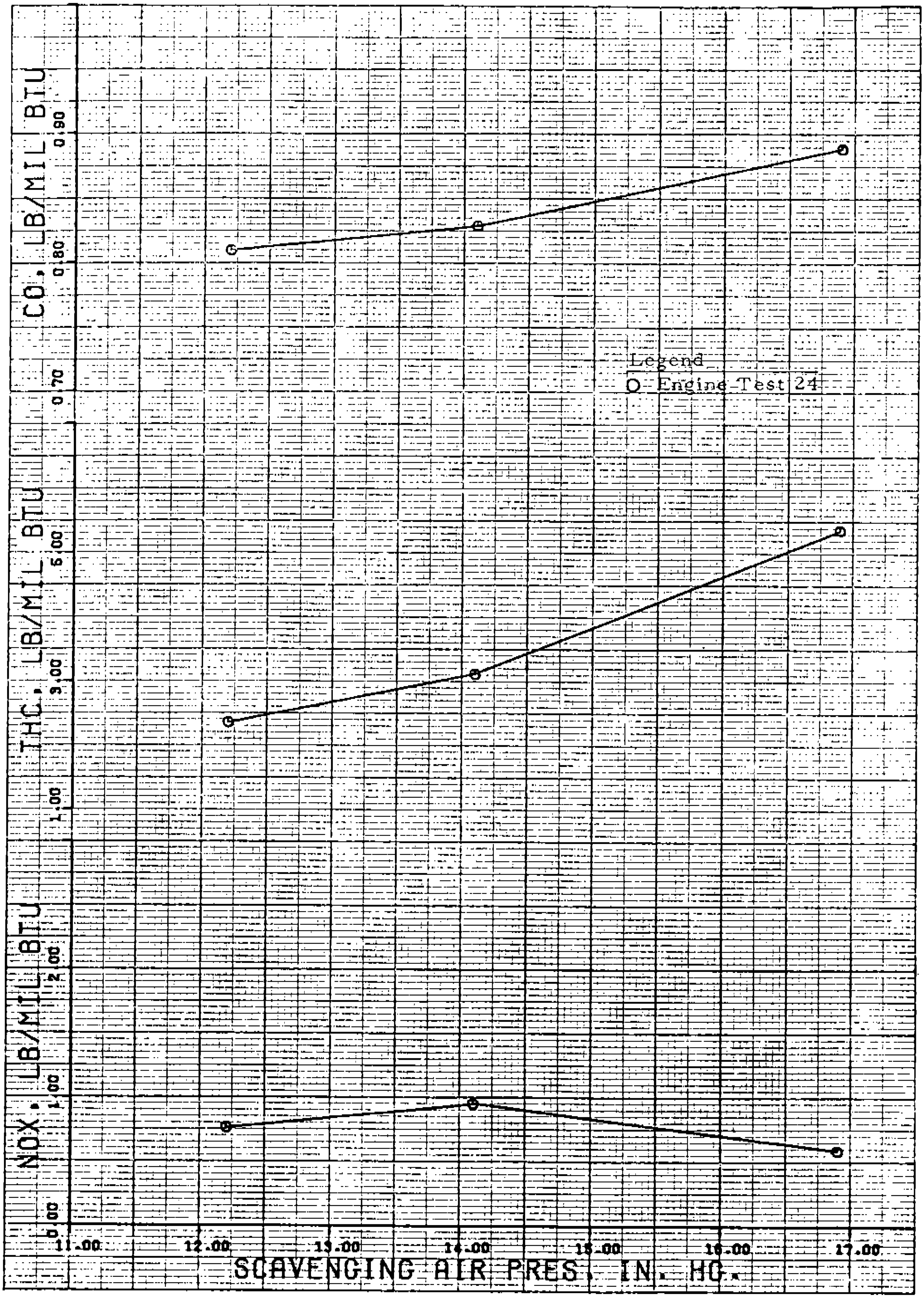


FIGURE E-126 EFFECT OF SCAV. AIR ON CLARK TCV16 LB/MIL BTU EMISSIONS

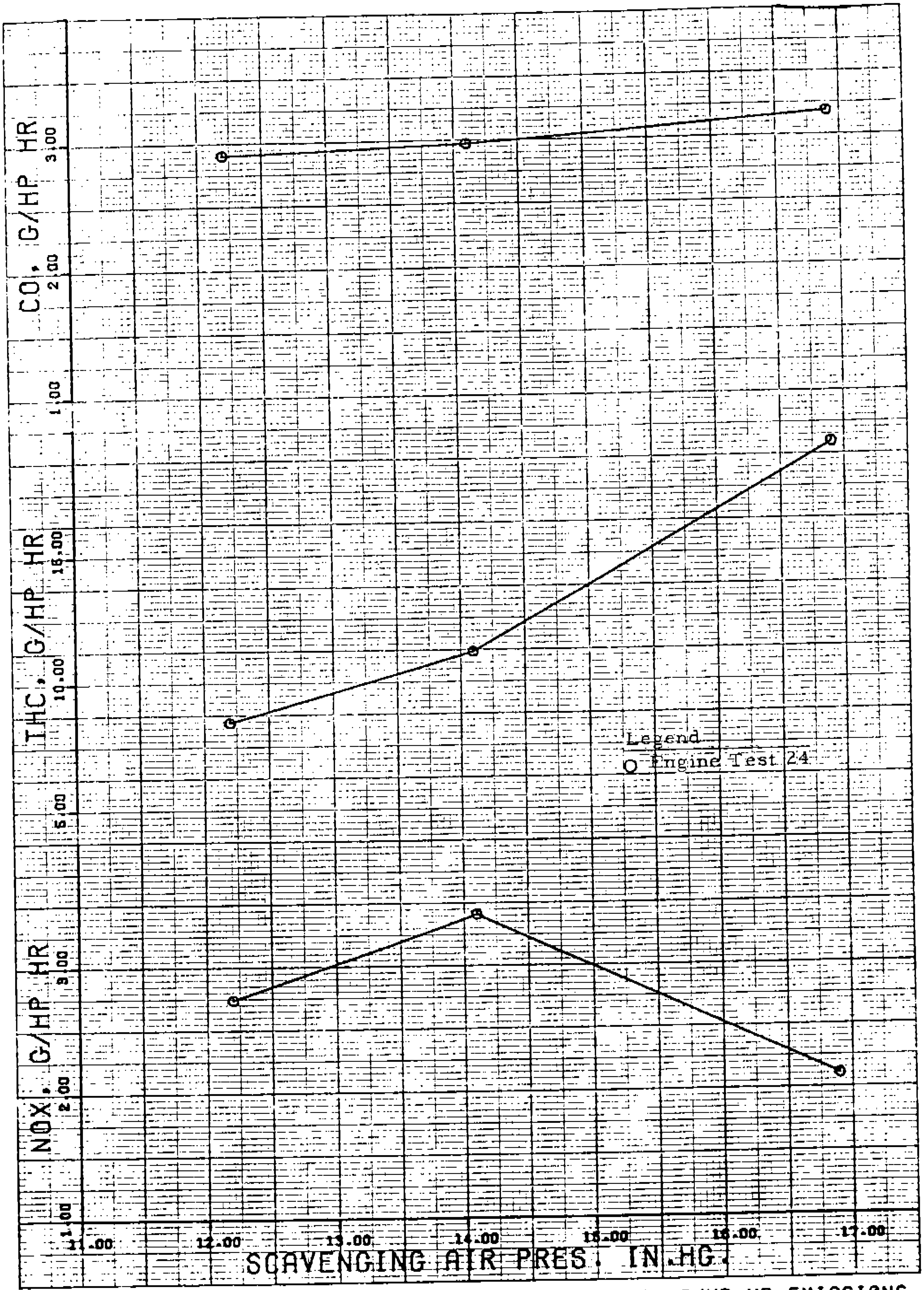


FIGURE E-127 EFFECT OF SCAV. AIR ON CLARK TCV 16 G/HP-HR EMISSIONS

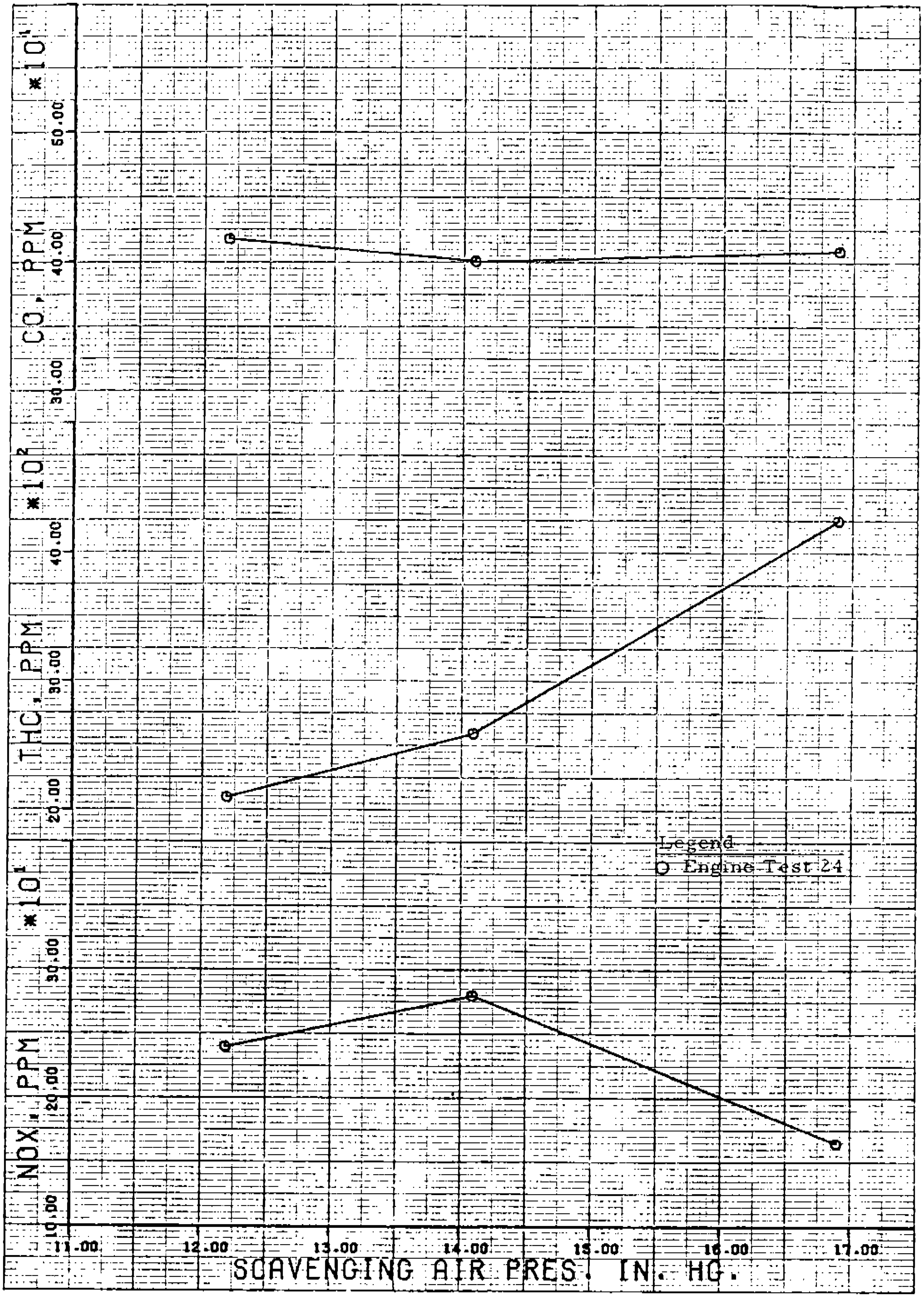


FIGURE E-128 EFFECT OF SCAV. AIR ON CLARK TCV-16 PPM EMISSIONS

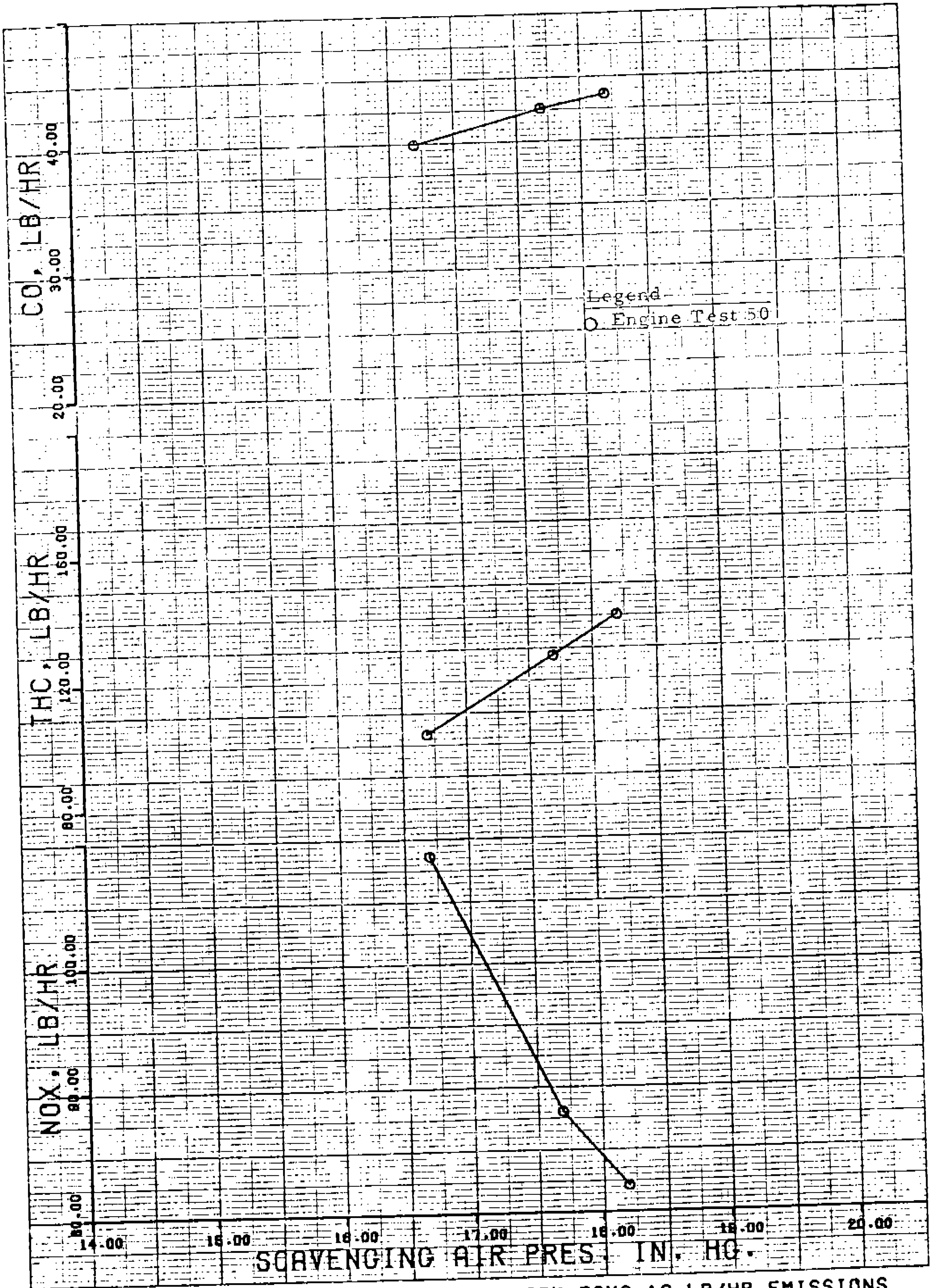


FIGURE E-129 EFFECT OF SCAV. AIR ON CLARK TCVC-16 LB/HR EMISSIONS

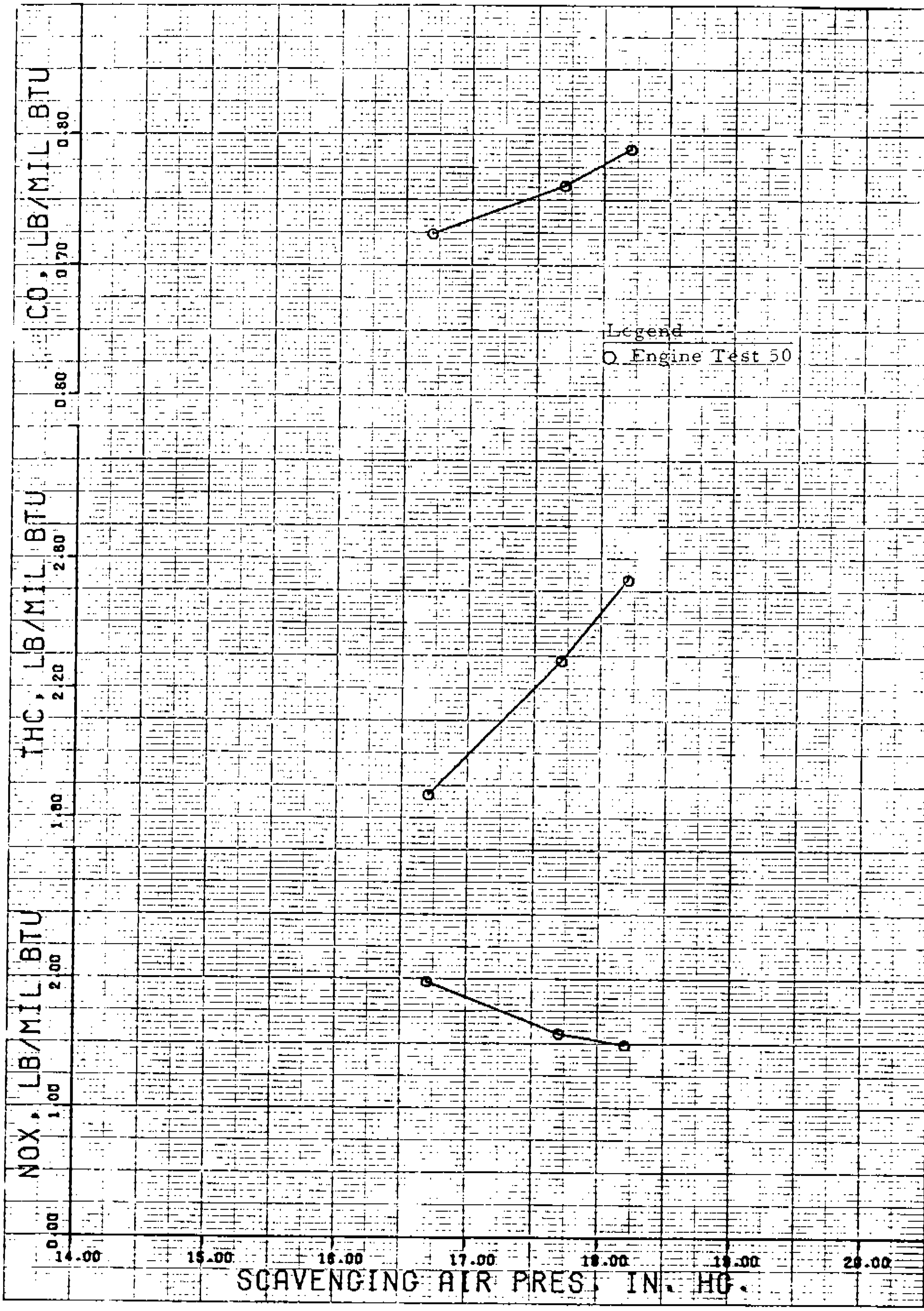


FIGURE E-130 EFFECT OF SCAV. AIR ON TCVC 16 LB/MIL BTU EMISSIONS

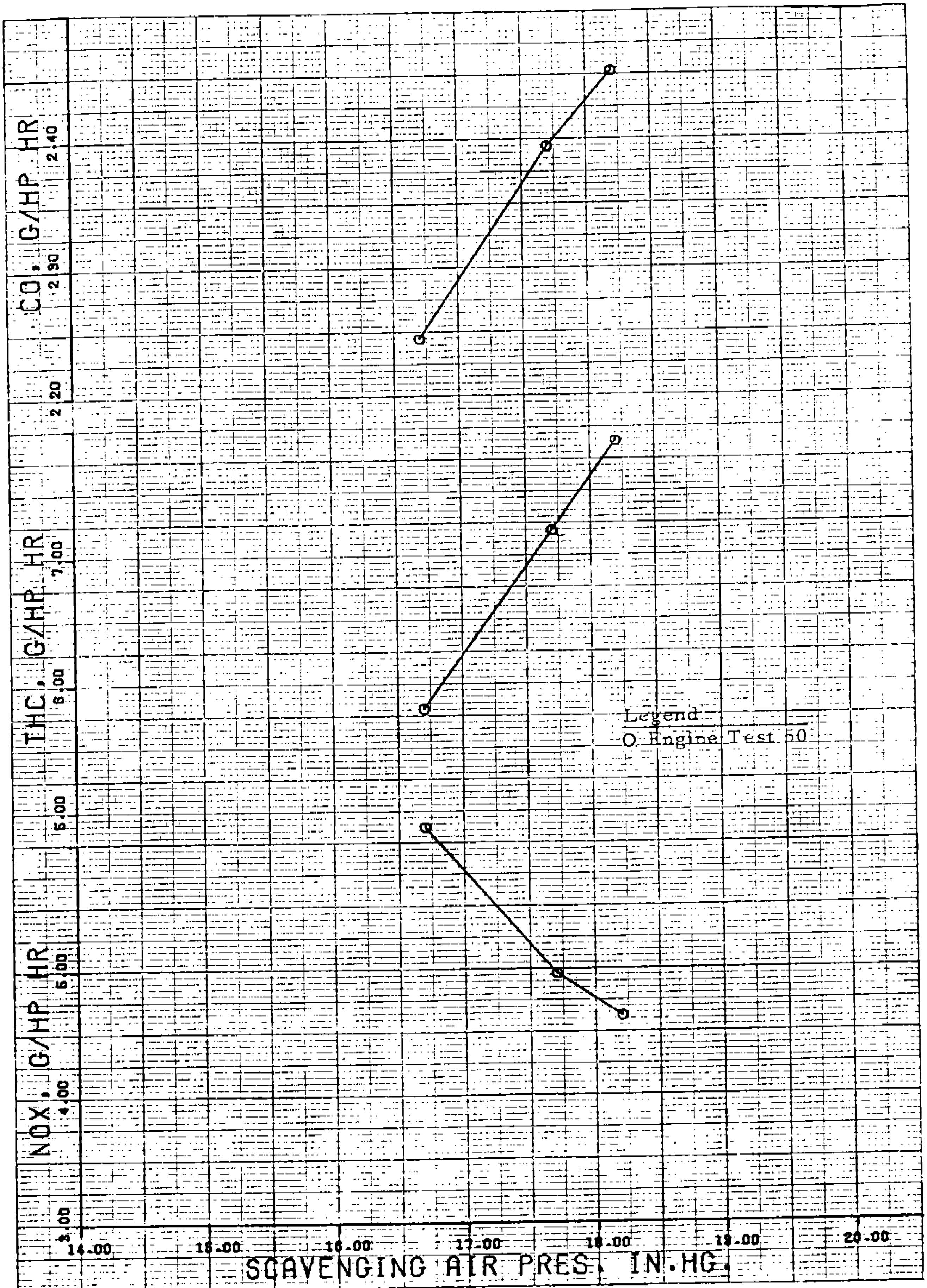


FIGURE E-131 EFFECT OF SCAV. AIR ON CLARK TCVC-16 G/HP-HR EMISSIONS

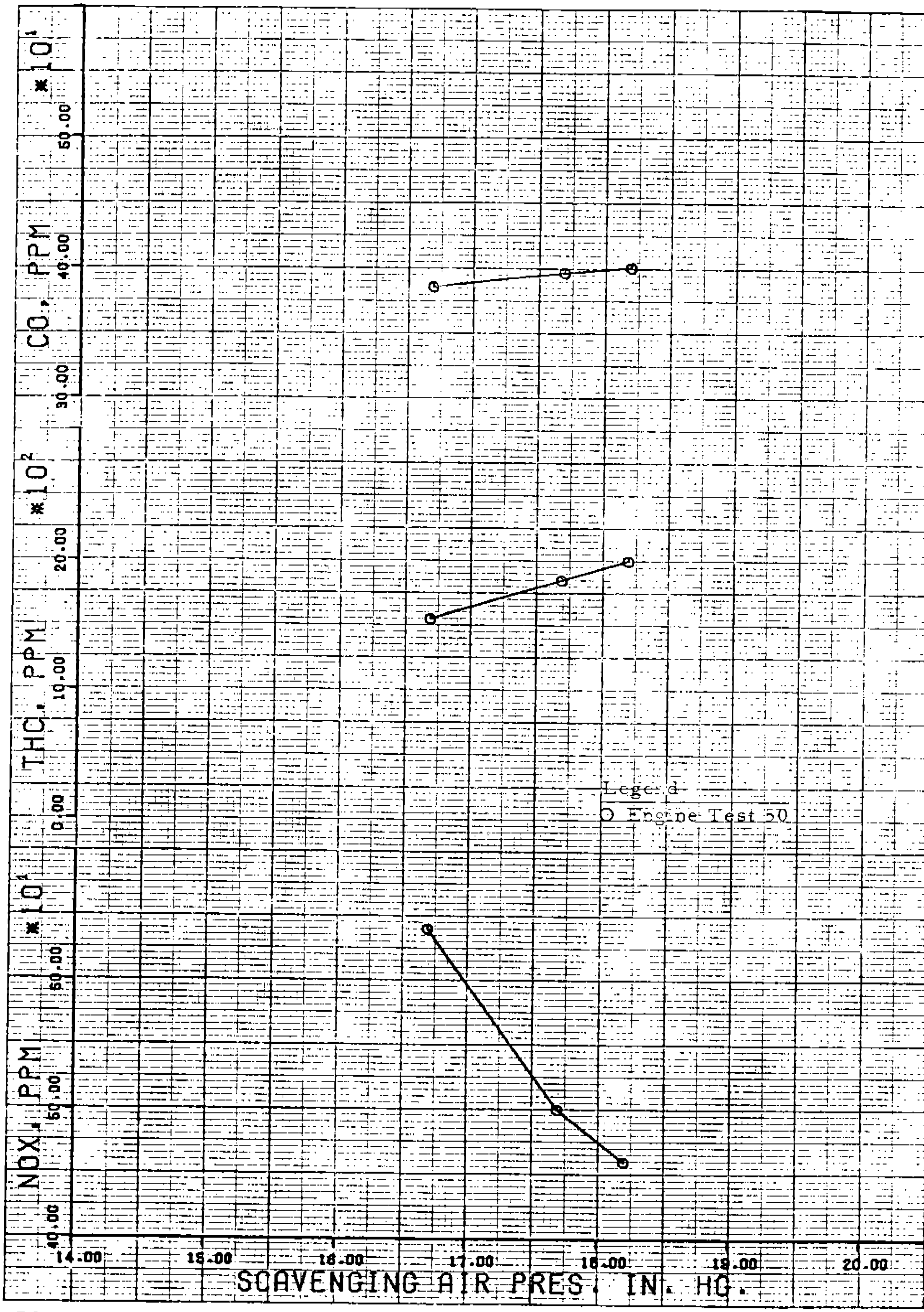


FIGURE E-132 EFFECT OF SCAV. AIR ON CLARK TCVC-16 PPM EMISSIONS

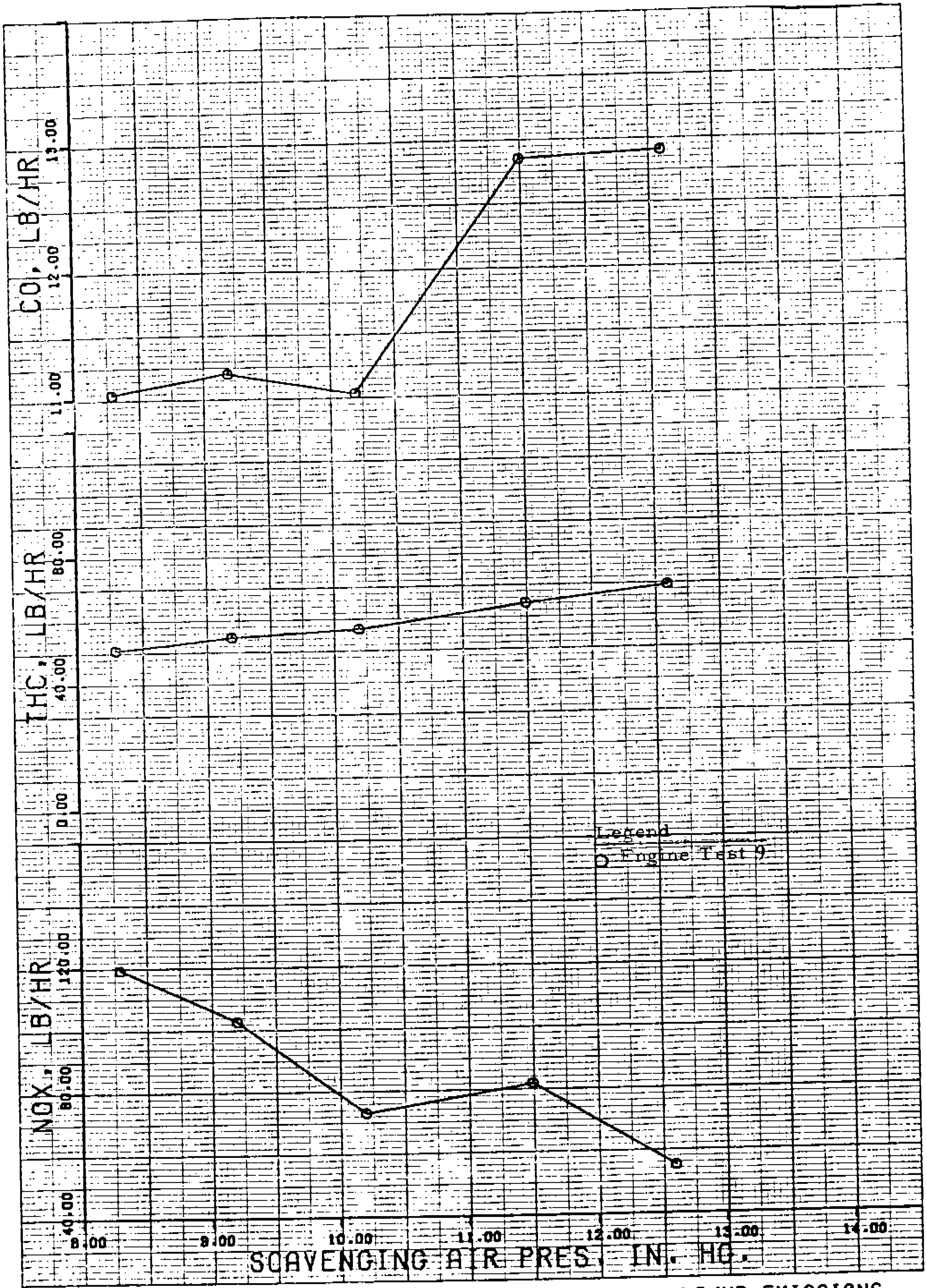


FIGURE E-133 EFFECT OF SCAV. AIR ON C-B LSV-16 SG LB/HR EMISSIONS

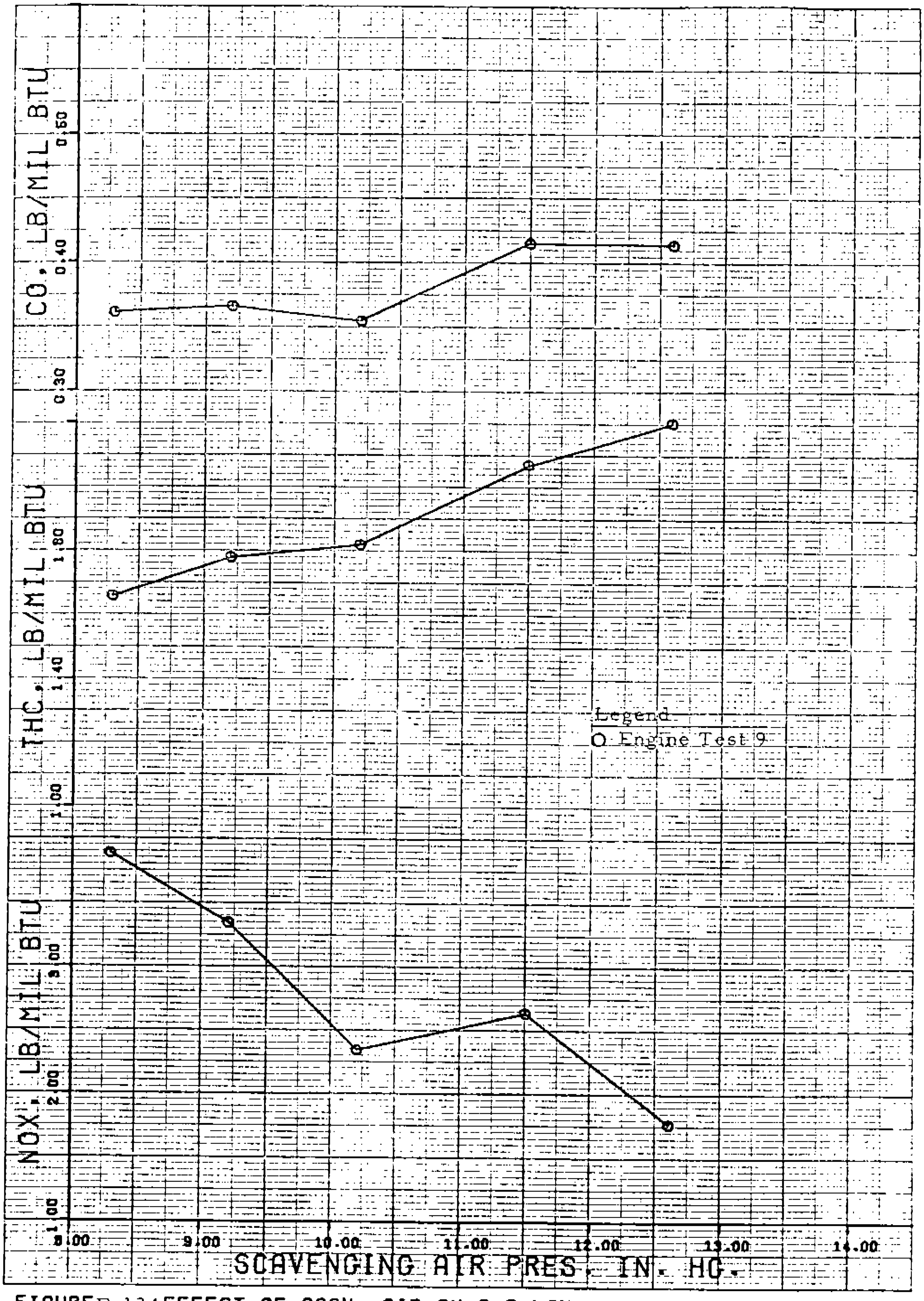


FIGURE E-134 EFFECT OF SCAV. AIR ON C-B LSV-16SG LB/MIL BTU EMISSIONS

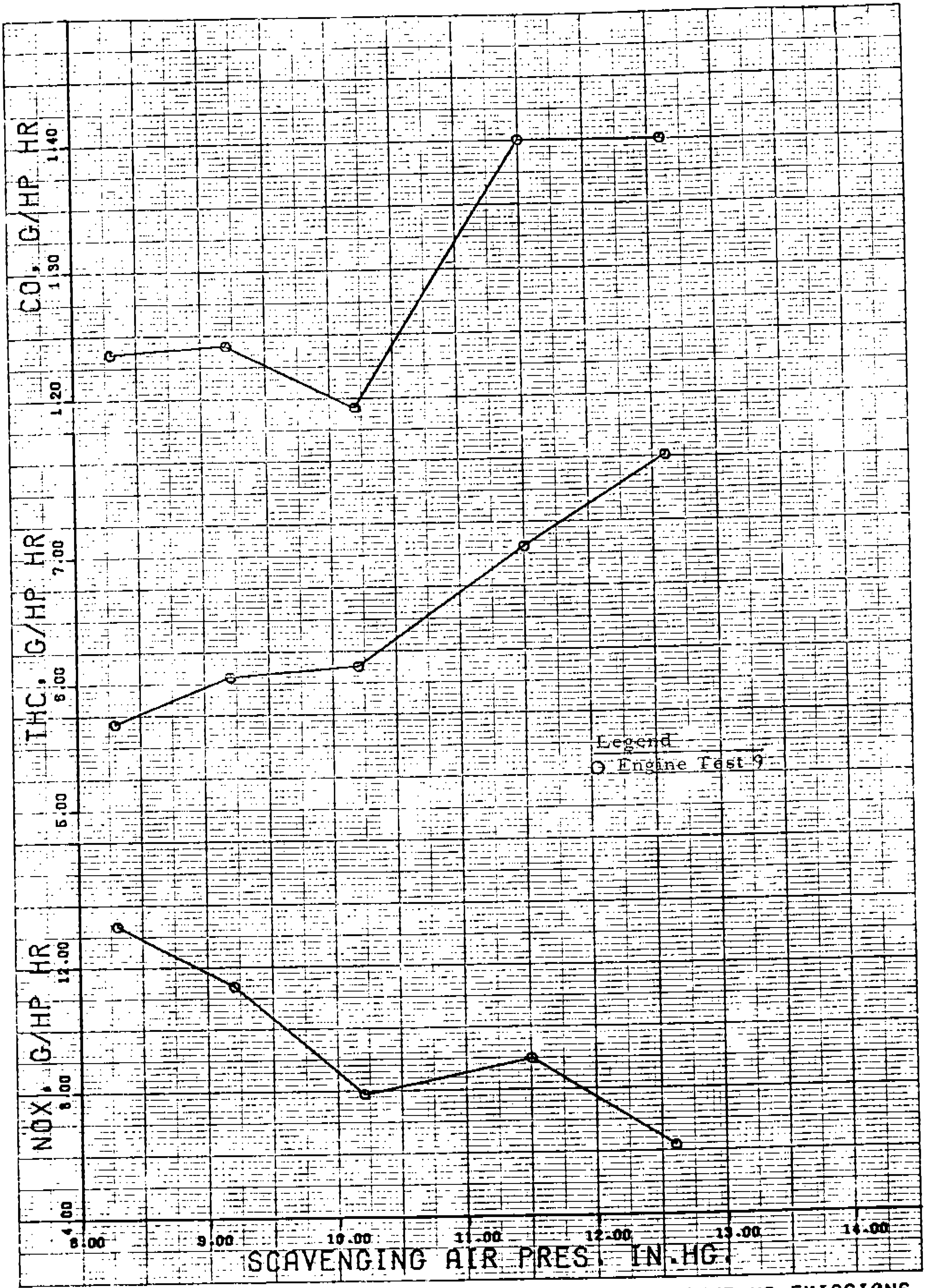


FIGURE E-135 EFFECT OF SCAV. AIR ON C-B LSV-16 SG G/HP-HR EMISSIONS

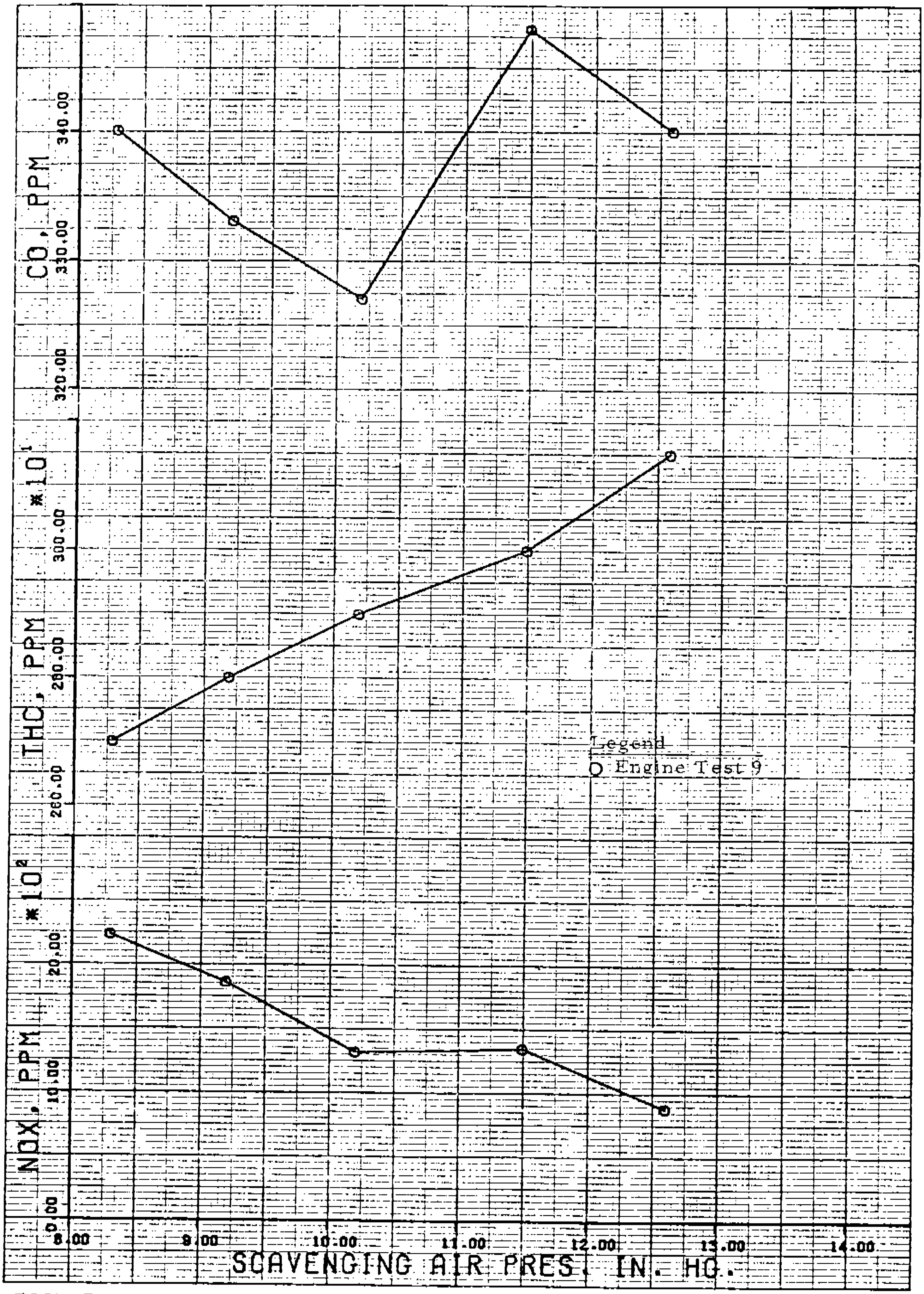


FIGURE E-136 EFFECT OF SCAV. AIR ON C-B LSV-16 SG PPM EMISSIONS

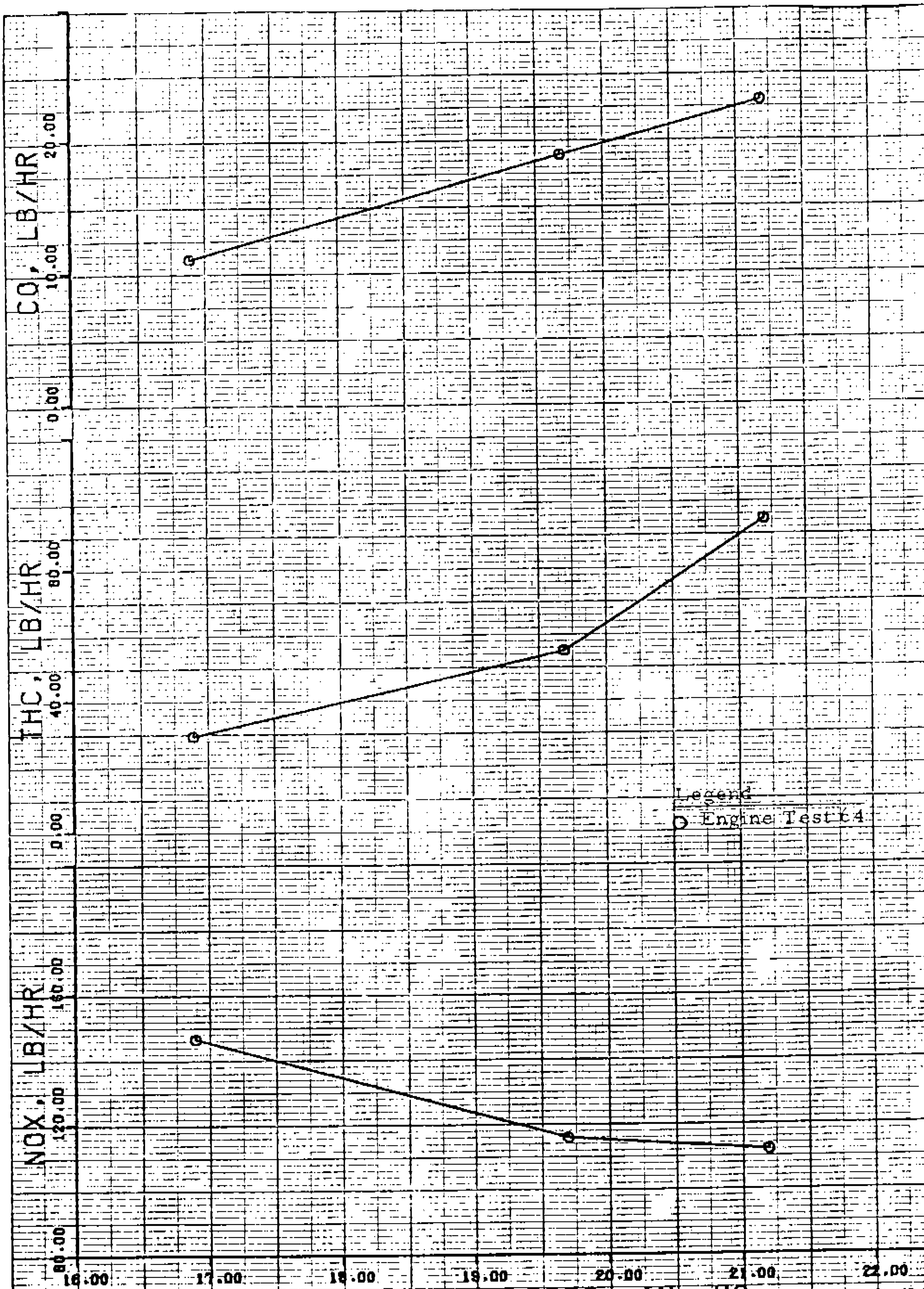


FIGURE E-137 EFFECT OF SCAV. AIR ON I-R 616KVR LB/HR EMISSIONS

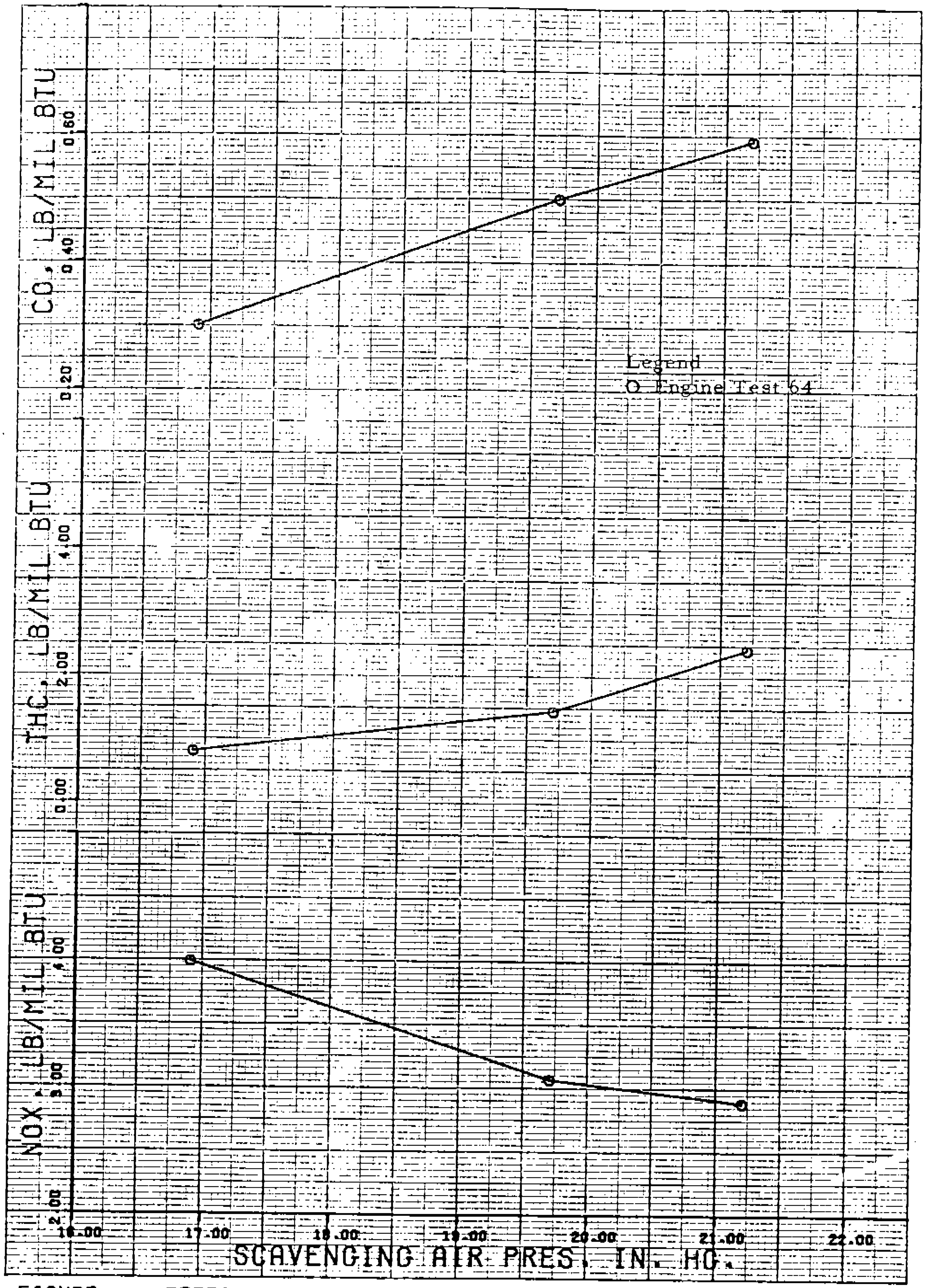
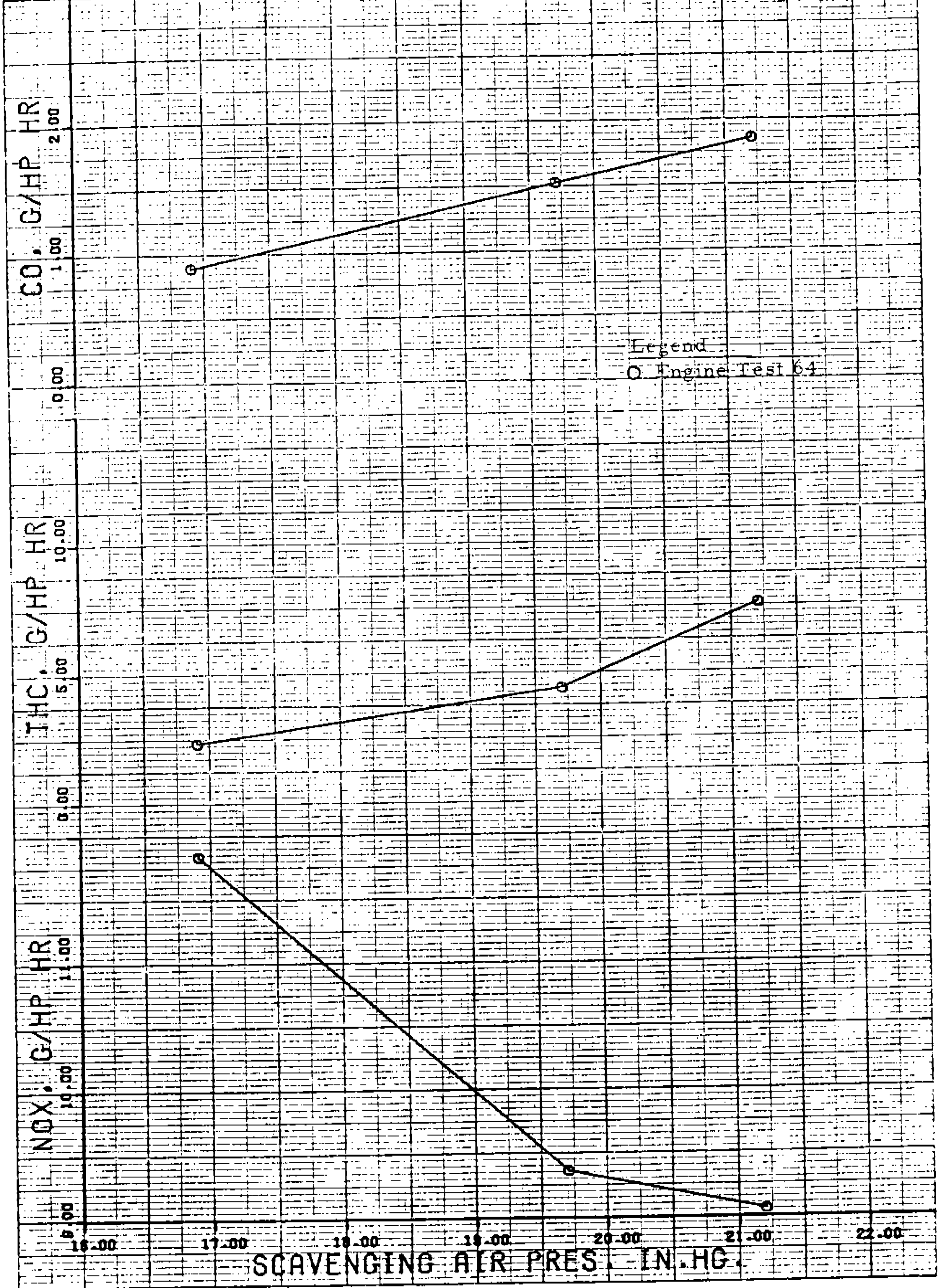
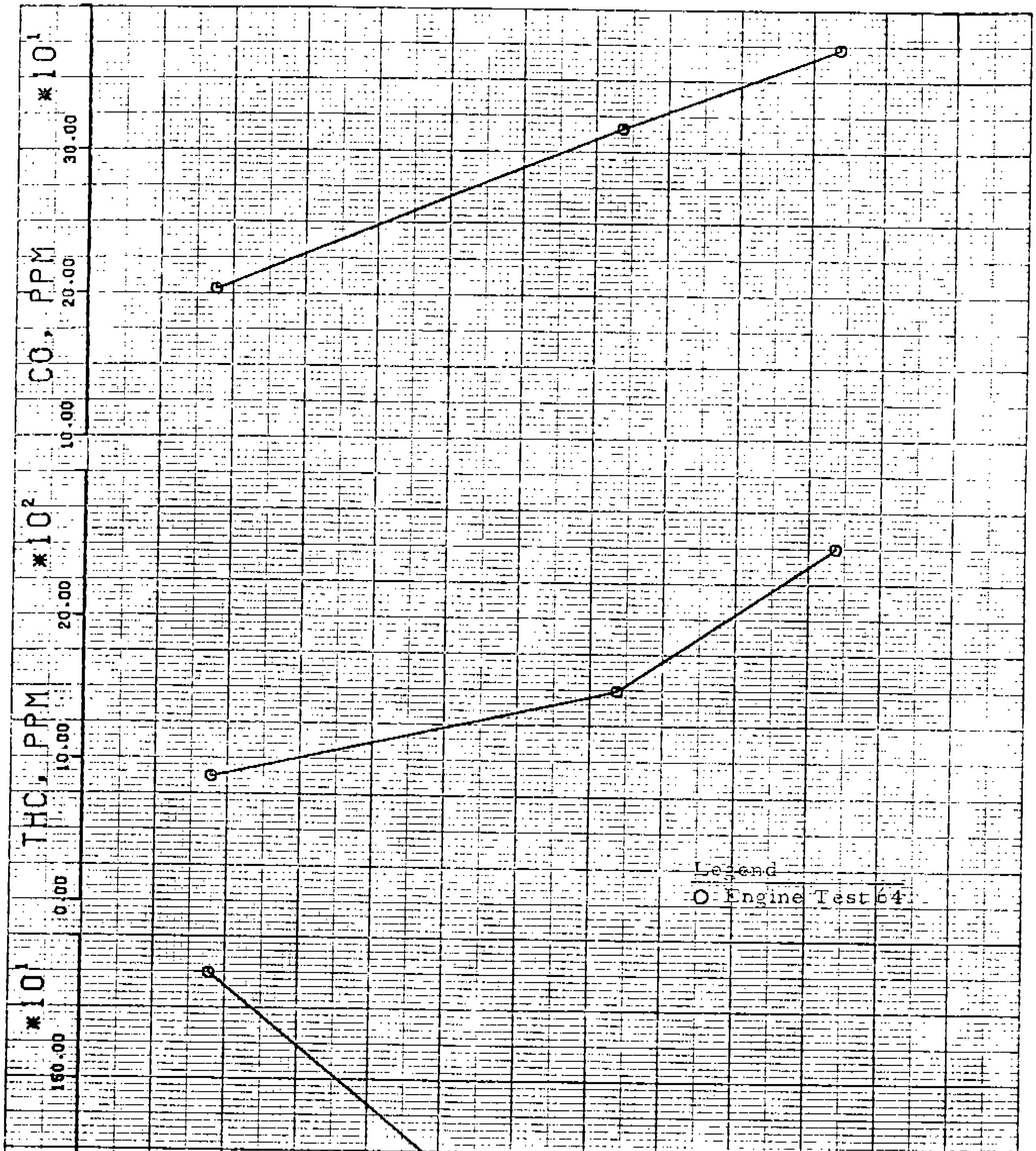


FIGURE E-138 EFFECT OF SCAV. AIR ON I-R 616 KVR LB/MIL BTU EMISSIONS



FIGUREE-139 EFFECT OF SCAV. AIR ON I-R 616KVR G/HP-HR EMISSIONS



FIGUREE-140 EFFECT OF SCAV. AIR ON I-R 616KVR PPM EMISSIONS

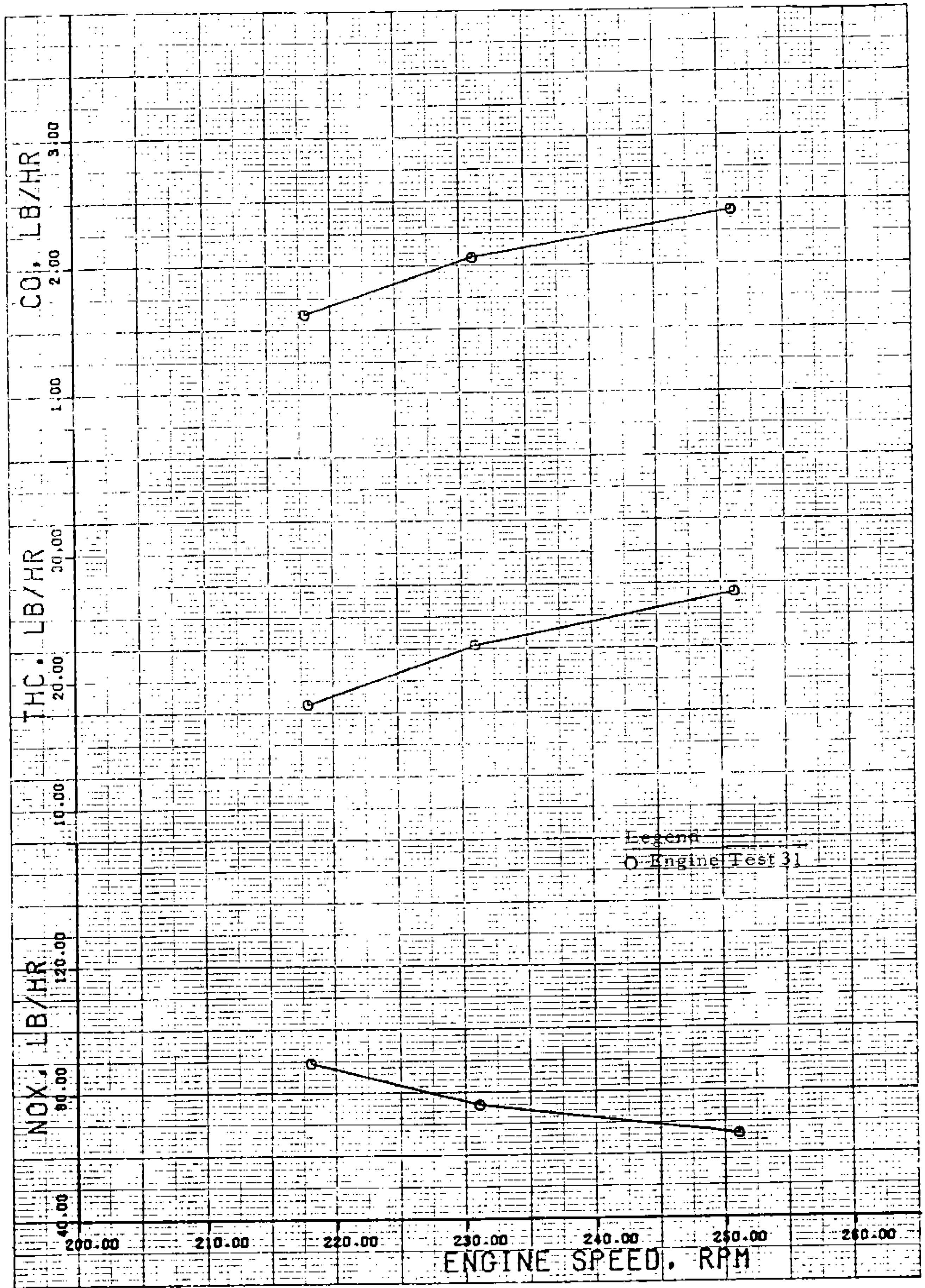


FIGURE E-141 EFFECT OF ENGINE RPM ON C-B GMW-8 LB/HR EMISSIONS

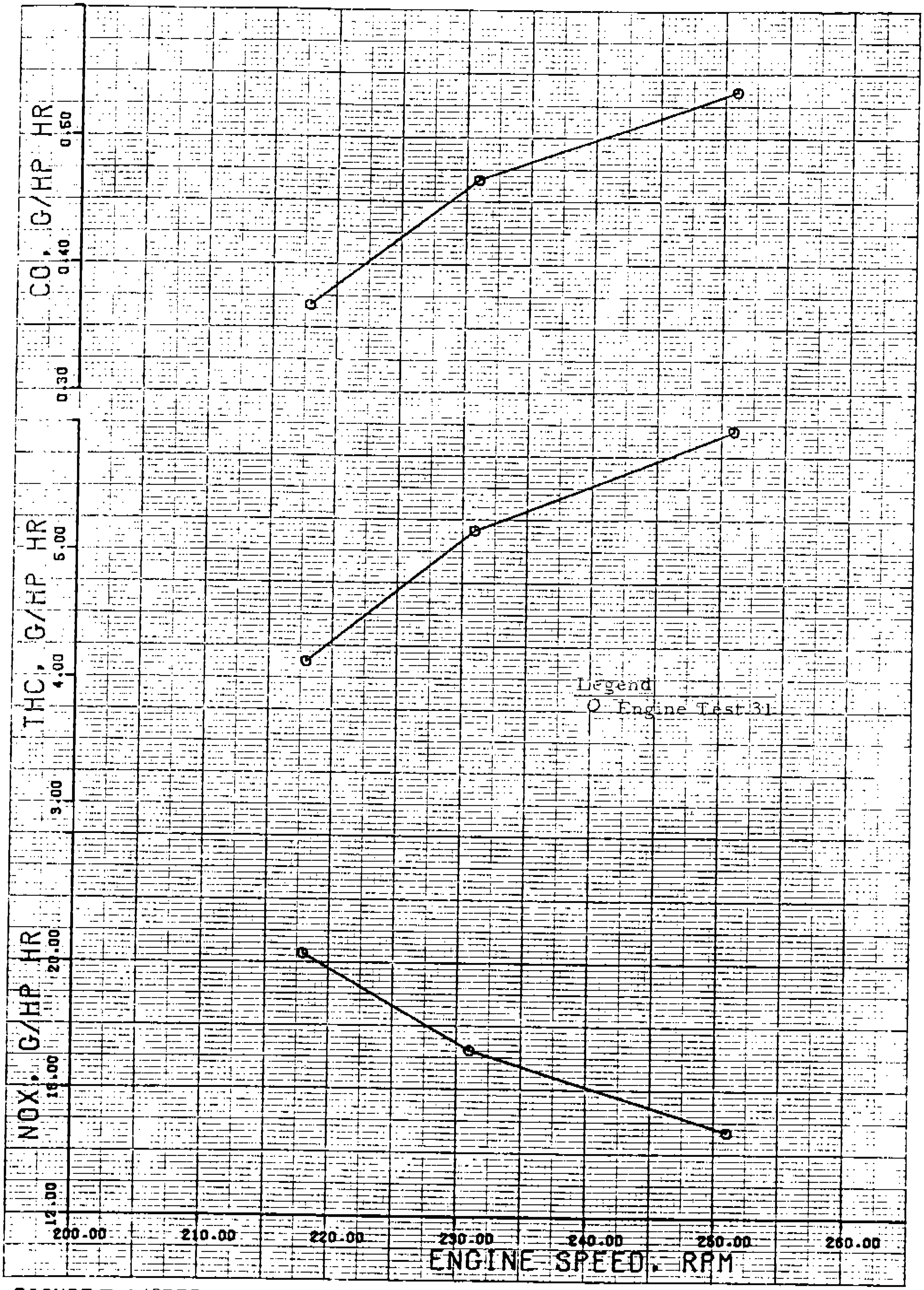


FIGURE E-142 EFFECT OF ENGINE RPM ON C-8 GMW-8 G/HP-HR EMISSIONS

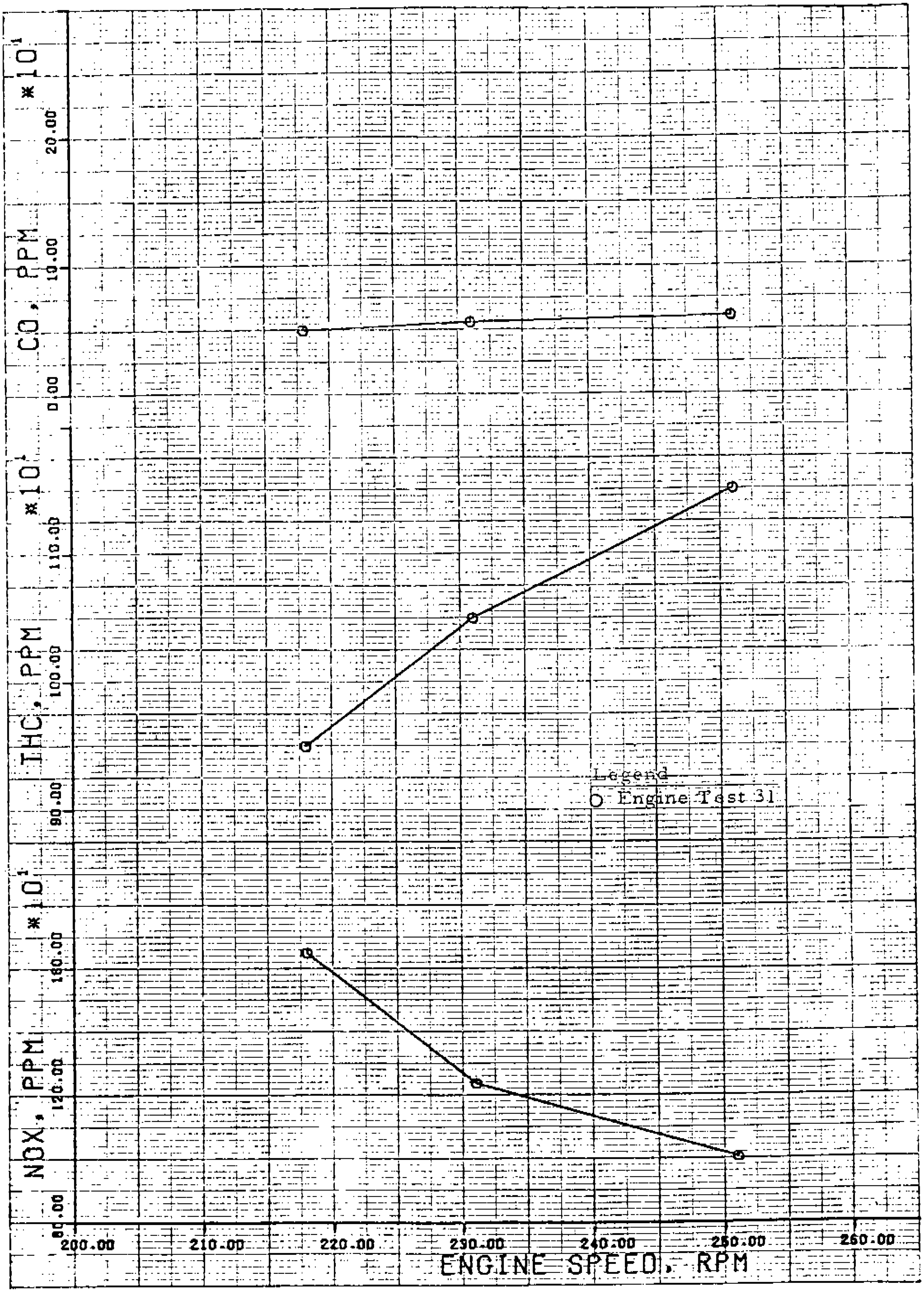


FIGURE E-143 EFFECT OF ENGINE RPM ON C-B GMW-8 PPM EMISSIONS