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1.5 Liquified Petroleum Gas Combustion

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AIR POLLUTANT
EMISSION FACTORS

April 1970

Prepared for

Department of Health, Education and Welfare
Public Health Service
Environmental Health Service
National Air Pollution Control Administration
Washington, D. C.

TRW
SYSTEMS GROUP OF TRW INC.

This report contains an updating of selected existing emission factors in addition to twenty new factors compiled for the National Air Pollution Control Administration, Division of Air Quality and Emission Data, under contract CPA-22-69-119.

1. INTRODUCTION

This report represents a compilation of the latest atmospheric emission data available for a wide variety of selected processes. One-half of the 40 processes discussed in this report involve an updating or review of existing emission factors presented in Public Health Service Publication 999-AP-42, "A Compilation of Air Pollutant Emission Factors" by R.L. Duprey. The remaining factors represent new processes for which emission factors were not previously reported. All emission factors refer to uncontrolled processes unless otherwise stated.

Information for emission factors was gathered primarily from the technical literature up to November 1969, state and local air pollution control agencies, trade and professional associations, releasable portions of data obtained by TRW in various past studies, and individual companies and persons within the various industries under study. In all cases, attempts were made to obtain some idea of the validity of the information obtained, and thus place each bit of data relative to other data in the same area. Greatest weight was given to actual measured emission data, i.e., source tests, especially when the measuring technique was known. Estimates of emissions were also made when feasible by making material balances and process loss or yield calculations.

In general, it was found that except for the combustion and incineration fields, very little new emission factor data has been made public since Duprey's work in 1967. In the metallurgical and mineral industries, additional emission data has been obtained by various companies and control equipment manufacturers. This information has not been made public, however. Some emission data was available for most of the new factors developed in this report. Frequently, however, these data were in the form of concentrations only, not quantitative emission rates. Process weight rates were also frequently not given or reported. Considerable engineering calculations were thus required in order to put these data into a form usable for emission factors. These calculations, based on material balances, combustion reactions, humidity balances, and comparisons with similar processes with available emission data, allowed one to relate the reported data with process throughputs and develop a factor which is usable until better data are made available.

Detailed information used to obtain the emission factors is generally presented in an appendix to each section. Selection of a final emission factor depended on the amount and range of data available. Where considerable data existed a direct arithmetic average was used. Values on order of magnitude greater or less than the bulk of the data were not considered in determining the arithmetic average. Where limited data were available (1 to 5 values) and the values covered a wide range, the selected factor was based on our best judgment considering the factors affecting emissions. Whenever possible, the range or variation in emission factors was reported and shown in parenthesis following the factor. This range represents the range of values used in obtaining the factor and represents the expected variation in emissions. A lack of information sometimes prevented the reporting of a reasonable factor range.

Standard statistical deviations of the emission factors were not generally reported since insufficient or only widely scattered data were available and a significant deviation could not be calculated.

All emission factors in this report were ranked according to the available data upon which they were based. A system which weighted various information categories was used to rank the final factors. These categories were: measured emission data with a total possible weight of 20, process data with a weight of 10, and engineering analysis with a weight of 10. The highest possible score for any factor was thus 40. Any factor ranking less than 20 was considered questionable and those ranked 20 or greater were considered reliable.

The emission data category rated the amount of measured emission data, i.e., stack test data available with which to develop an emission factor.

The process data category included such factors as the variability of the process and its effect on emissions, and available data on the variables. The engineering analysis category included the data available upon which a material balance or related emission calculation could be based.

The range of values for many emission factors is large. However, when the factors are applied to a large number of sources, the calculated overall emissions should approximate the true value. When applied to a single isolated source, an emission factor may yield emissions that differ considerably from the true value. Measured emission data should therefore be used, if possible, for single sources.

2. STATIONARY FUEL COMBUSTION

Particulate emissions from most types of stationary fuel combustion sources have been the subject of considerable research. However, emissions from the combustion of some of the less common fuels have not been determined to any great extent, nor have gaseous emissions been studied in any great depth. This section concentrates on some of these areas, and further quantifies some of these emissions.

Emissions from all types of fuel combustion are highly dependent on the efficiency of combustion and type of fuel. The resulting emission factors therefore cover a wide range.

Data used to determine the emission factors presented in this section were largely based on measured values or by comparison with similar combustion processes.

Anthracite coal combustion yielded the following approximate particle size breakdown (% by weight, size by microns).

Particle Size	>44	20-44	10-20	5-10	<5
% in Range	45	7	8	5	35

No particle size data was found for wood combustion emissions, the only other particulate source investigated in this section.

2.4 LIQUEFIED PETROLEUM GAS COMBUSTION

General Information

Liquefied petroleum gas, commonly referred to as LPG, consists mainly of butane, propane, or a mixture of the two, and trace amounts of propylene and butylene. This gas, obtained from oil or gas wells, or as a by-product of gasoline refining is sold as a liquid in metal cylinders under pressure. It is therefore often called bottled gas.

Butane, C_7H_{10}, boils at 31.1°F and propane, C_3H_8, boils at -43.8°F. The use of these gases is therefore limited to those areas with ambient temperatures generally higher than these, since vaporization is greatly impaired at temperatures approaching the boiling point. LP gases are graded according to maximum vapor pressure with Grade A being predominantly butane, Grade F being predominantly propane, and Grades B thru E consisting of various mixtures of butane and propane. Generally, sulfur content is less than one grain per hundred cubic feet of vapor, although variance is not uncommon. The heating value of LPG ranges from 3200 $\frac{Btu}{cf}$ for Grade A to 2500 $\frac{Btu}{cf}$[b] for Grade F.

The use of LPG has grown from 77 million gallons in 1935 to 14,466 million gallons in 1967 and is expected to top 43,500 million gallons in 1978. The largest market for LPG is presently the domestic-commercial heating market which consumed 43.0% of the 1967 total. The chemical industry and internal combustion engines consumed 37.6% and 8.0% of the 1967 total respectively. Annual utility use accounted for 97 million gallons or only 0.67% of the 1967 total, registering a decline for two straight years (1966 and 1967).[1]

This fuel is considered a "clean" fuel because of the lack of visible emissions. Gaseous pollutants such as carbon monoxide, hydrocarbons, and nitrogen oxides do occur, however.

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a) Equal to ~~337,000~~ Btu per gallon.

b) Equal to ~~308,000~~ Btu per gallon.

Wrong

Factors Affecting Emissions

The most significant factor affecting emissions is the burner design, adjustment, and venting.[2] Improper design, blocking and clogging of the flue vent, and lack of combustion air will result in improper combustion causing the emission of aldehydes, carbon monoxide, hydrocarbons, and other organics.

Nitrogen oxide emissions are a function of a number of variables including temperature, excess air, and residence time in the combustion zone. These variables in turn are a function of hydrogen to carbon ratio in the fuel and to furnace design. Since the hydrogen to carbon ratio for LPG is similar to fuel oil,[3] and combustion chamber designs are similar to natural gas fired units, a nitrogen oxide emission between that of fuel oil and natural gas combustion is probable.

The amount of SO_2 emitted is directly proportional to the amount of sulfur in the fuel.

Emissions

There have been no published results of source testing of stationary sources using LPG nor have any unpublished results been found. However, due to the similarities between LPG and natural gas, it is felt that for most emissions, the data used to compute emission factors for natural gas combustion when put on a Btu basis may be reasonably used when considering LPG. For nitrogen oxides a factor based on both fuel oil and natural gas was used. Factors based on these data as shown in the Appendix are presented in Table 2.4-1. In some instances, the sulfur content in LPG may be different than that normally found in natural gases thus affecting the amount of SO_2 produced. Therefore, a separate factor for SO_2 is presented.

Table 2.4-1. Emissions From LPG Combustion, pounds per 1000 gallons

Pollutant	Industrial Processes Furnaces		Domestic and Commercial Furnaces	
	Butane	Propane	Butane	Propane
Aldehydes (HCHO)	0.70	0.64	Neg.	Neg.
Carbon Monoxide	0.14	0.13	0.14	0.12
Hydrocarbons (CH_4)	Neg.	Neg.	Neg.	Neg.
Oxides of Nitrogen[a]	120	110	30-100[c]	30-90[c]
Oxides of Sulfur[b]	0.300S	0.335S	0.300S	0.335S
Other Organics	1.76	1.6	Neg.	Neg.
Particulate	6.3	5.8	6.7	6.1

a) Expressed as NO_2.

b) S equals sulfur content expressed in grains per 100 CF gas vapor, e.g., if the sulfur content is 0.16 grains per 100 CF vapor, the SO_2 emission would be 0.300 (for butane) x 0.16 or 0.048 lb SO_2 per 1000 gallon butane burned.

c) Use values of 30-50 for domestic units 50-100 for commercial units.
Neg. = negligible.

Reliability of Emission Factors

While there is a lack of measured emission data from LPG combustion in stationary sources, this fuel does have many of the characteristics of natural gas and the emissions are therefore similar. The factors listed in Table 2.4-1 are based on an engineering analysis of similar processes and fuels (LPG, natural gas combustion, and fuel oil combustion) and on measured emissions from natural gas and oil combustion.

An overall ranking of questionable is assigned to these factors based on the ranking in Table 2.4-2, and on the fact that the natural gas emission data itself is about 10 years old. Los Angeles County Air Pollution Control District sampling techniques were used. Further work in this area is warranted due to the lack of data, and the increased use of this fuel.

Table 2.4-2. LPG Emission Factor Ranking

Emission Data 0-20	Process Data 0-10	Engineering Analysis 0-10	Total
2	8	8	18

The major assumptions made in deriving these factors were that particulate and gaseous carbon compounds were the same as those from natural gas combustion, and nitrogen oxide emissions were between those for oil and gas combustion.

APPENDIX 2.4

Particulate, Carbon Monoxide, Hydrocarbons, and Aldehydes

The factors found in Table 4, Reference 4, are based upon pounds per million cubic feet of natural gas burned. That table was derived from the figures given in Reference 5 which assumed that 6000 cubic feet of gas is equivalent to one barrel of fuel oil. One barrel of fuel oil contains 312 lb at 18,500 Btu/lb, or 5.76 x 10^6 Btu.[5] Therefore, Duprey's emission factors are based upon pounds per 960 x 10^6 Btu.

Using the values given in Table 2.4-3; the heating value of LPG can be found on a gallon basis.

Table 2.4-3. Properties of LPG[5]

	Column				
	A	B	C	D	E
Gas	Avg. Gross Btu/CF	CF/LB	~~Avg. Specific Gravity~~	LB/GAL	Btu/1000 GAL (AxBxDx1000)
Butane	3200	6.29	~~2.02~~	~~16.75~~ 4.84	~~337 x 10^6~~ 97.4x10^6
Propane	2525	8.45	~~1.66~~	~~13.85~~ 4.24	~~308 x 10^6~~ 90.5x10^6

The emission factors shown by Duprey therefore can be converted to relate gallonage (pounds per 1000 gallons LPG burned) by multiplying each of Duprey's factors (excluding SO_2 which is treated separately herein) as follows:

GAS	MULTIPLIER
Butane	$\frac{337}{960} = 0.351$
Propane	$\frac{308}{960} = 0.321$

Duprey's table is shown below, with his column for emissions from power plants omitted:

Table 2.4-4. Emission Factors For Natural Gas Combustion (Pounds million cubic feet of natural gas burned)[4]

	Type of Unit	
Pollutant	Industrial Process Boilers	Domestic and Commercial Heating Units
Aldehydes (HCHO)	2	Neg.
Carbon Monoxide	0.4	0.4
Hydrocarbons (CH_4)	Neg.	Neg.
Oxides of Sulfur (SO_2)	0.4	0.4
Other Organics	5	Neg.
Particulate	18	19

Table 2.4-1 in the main text is based upon the values given in Table 2.4-4, with each value multiplied by 0.351 and 0.321 for butane and propane, respectively.

Sulfur Oxides

When the sulfur content, S, is expressed in grains per 100 cf of gas fuel, the weight of SO_2 given off upon complete combustion of the 100 cf is:

$$S \times \left[\frac{\text{mole. wt. } SO_2}{\text{mole. wt. } S} \times \frac{1 \text{ lb.}}{7000 \text{ grains}}\right] = S\left[\frac{32}{16} \times \frac{1}{7000}\right] = 0.000286 \text{ S lb.}$$

To determine the pounds SO_2 emitted from 1000 gal. of LPG, find the number of 100 ft.^{3} units in 100 gallons of butane and propane. Using the values shown in Table 2.4-3:

Butane: $6.29 \frac{ft^3}{lb} \times 16.75 \frac{lb}{gal} \times \frac{1000\ gal}{100\ ft^3} =$ 1050, 100 ft.^{3} in 1000 gal.

Propane: $8.45 \times 13.85 \times \frac{1000}{100} =$ 1170, 100 ft.^{3} units in 1000 gal.

Thus the weight of SO_2 emitted from combustion of 1000 gal is:

Butane: $1050 \times 0.000286\ S = 0.300\ S$

Propane: $1170 \times 0.000286\ S = 0.335\ S$

Nitrogen Oxides

For natural gas combustion in industrial furnaces, Duprey reports 214 lbs $NO_x/10^6\ ft^3$ or.214 per 10^6 Btu of fuel (1000 Btu/ft^3), and 72 lbs NO_x/1000 gallons of oil or 0.5 lbs per 10^6 Btu of fuel (142,000 Btu/gal). An average factor for LPG <u>assuming</u> NO_x emissions lie mid-way between oil and gas, would be 0.35 lbs per 10^6 Btu.

For domestic and commercial units, the natural gas NO_x factor is 0.116 NO_x per 10^6 Btu and the oil factor varies from 0.5 to 0.083 lbs per 10^6 Btu. LPG factors are therefore 0.3 to 0.1 lbs per 10^6 Btu depending on size of unit.

Butane contains 337×10^6 Btu per 1000 gals. and propane contains 308×10^6 Btu per 1000 gals. (Table 2.4-3). NO_x emissions are therefore:

	Propane lbs/1000 gal.	Butane lbs/1000 gal.
Industrial	0.35 x 308=108	0.35 x 337=118
Commercial - Domestic	0.1 x 308=30.8	0.1 x 337= 33.7

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