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Evaporation Loss In The Petroleum Industry—Causes And Control

Prepared by the Evaporation Loss Committee of the American Petroleum Institute (Reaffirmed 1973)

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FOREWORD

Evaporation loss from crude oil and its products has long been a subject of concern to the petroleum industry. Over the years, companies have studied specific loss problems and have taken numerous steps to reduce evaporation loss. Such reduction also has helped maintain product quality and promote safety.

The American Petroleum Institute took an important step to coordinate knowledge in this field when it sponsored a symposium on evaporation loss at the Thirty-second Annual Meeting in 1952. The composite viewpoint of various companies regarding probable losses from all types of storage was reported as well as a description of the conservation tanks available. The API then formed the Evaporation Loss Committee * to continue the integrated study of evaporation loss.

The purpose of this committee, representing all divisions of the industry, is to advance the basic knowledge of evaporation loss and to present methods for its control. Several bulletins will be issued as various phases of the work are completed; the ultimate aim is an evaporation-loss manual. The first publication dealing with methods for actual measurement of loss was issued in 1957 entitled *API Bulletin 2512: Tentative Methods of Measuring Evaporation Loss from Petroleum Tanks and Transportation Equipment.* The current report is the second bulletin. Other bulletins will deal with the prediction of losses from correlations developed from industry-wide test data.

The principles presented in this bulletin will aid engineers responsible for the selection and design of storage facilities. Managers who approve conservation measures will better understand the engineers' selections. Superintendents will become more aware of operation and maintenance needs.

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* The 1956-1958 membership of the API Evaporation Loss Committee is recorded in Appendix VII of this bulletin, as well as the membership of its four subcommittees.

ABSTRACT

The petroleum industry has been concerned about evaporation from crude oil and its products for many years. In 1953, the American Petroleum Institute formed the Evaporation Loss Committee to study evaporation loss and ways to control it. This bulletin, prepared by that committee, will aid superintendents, managers, and engineers in carrying out an effective loss-control program. When loss problems are adequately understood loss will be minimized.

Common sources of evaporation loss are: *a,* storage tanks—from breathing, emptying, filling, or boiling; *b,* production—from gas-oil separation and emulsion treating; *c,* refining—from treating in freely vented vessels, leaky pressure systems, sewers, ponds, and open separators; and *d,* transportation—from loading, transit, and unloading of cargo vessels and from pipelines. Also under certain conditions, such as inaccurate measurement of stock movements, a loss appears to have occured when actually there is none.

The rate of evaporation loss depends upon several factors. True vapor pressure is the force causing vaporization and, generally, loss is considered to be more or less directly proportional to it. Atmospheric and solar-heat changes cause the tank vapor space to breathe, and vapor-space volume affects the amount of breathing. Loss rate probably is less than directly proportional to vapor volume and daily atmospheric-temperature change.

For storage of petroleum and its products, the industry can choose from four basic types of tanks, fixed-roof, floating-roof, variable-vapor-space, and pressure. Each design meets specific storage needs. Selecting the most economical tank often requires careful study of the different types. For each tank, effective loss control depends upon accessories such as breather valves and automatic gages. To maintain effective control, the tank and accessories must be kept gastight. Choice of paint color is also an important factor.

The operating procedures used in production, refining, transportation, and marketing are all important in controlling evaporation loss. Prevention of leaks from glands, valves, and fittings should be common to all branches of the industry. In production, control of temperature in the gas-oil separators and in the emulsion-treating equipment is necessary. In refining, operation of treating plants, sewers, ponds, and open separators require special consideration. In transportation, careful scrutiny of the methods for loading and unloading is essential.

Control of evaporation loss requires that continued attention be given to operating procedures and maintenance of equipment. Conservation equipment sometimes becomes less effective with age and an evaluation frequently reveals that modernization would pay. These factors demonstrate the need for organized programs for loss control. Only in this way will the necessary concerted attention be given this important subject.

INTRODUCTION

Petroleum is an important natural resource and should be conserved by all practical means. The reduction of evaporation loss, in many cases, will give attractive economic return. To be most effective, conservation measures should be based upon an understanding of sources of loss, factors affecting size of loss, and means for its control.

Evaporation from tanks is a common source of loss in all branches of the industry. In earlier days, inadequate designs, construction, and materials hampered loss control. Modern tanks, however, are reasonably gastight, and the development of special conservation equipment has given industry a good selection of control measures. Each loss problem, nevertheless, requires individual analysis to determine which control measure is best suited.

Other evaporation-loss problems exist in each branch of the industry; they result from today's complex methods for producing, refining, transporting, and marketing petroleum and its products. Good operational and maintenance practices and overall programs to control stock loss are as important as good equipment. When all persons involved have an adequate understanding of and interest in the problem, evaporation loss will be minimized.

CONTENTS

EVAPORATION LOSS IN THE PETROLEUM INDUSTRY—CAUSES AND CONTROL

CHAPTER 1—SOURCES OF EVAPORATION LOSS

Evaporation loss is the natural process whereby a liquid is converted to a vapor which subsequently is lost to the atmosphere. The liquid may be unconfined or may be enclosed in a container such as an oil-storage tank. By definition, evaporation loss occurs only when the vapors reach the atmosphere.

Evaporation loss is common to all branches of the petroleum industry. Because tanks are used similarly throughout the industry, sources of loss from tanks are discussed first. Other sources of evaporation loss associated with operational features of each branch are then considered. To further emphasize true sources of loss, conditions which can falsely indicate loss are also discussed.

A. Loss in Storage

Six kinds of evaporation loss occur from petroleum in storage: breathing loss, standing-storage loss, filing loss, emptying loss, wetting loss, and boiling loss.

Breathing Loss: Vapors expelled from a tank because of the thermal expansion of existing vapors, and/or expansion caused by barometric pressure changes, and/or an increase in the amount of vapor from added vaporization in the absence of liquid-level change, except that which results from boiling, is defined as breathing loss. The term *vapor* is used herein to denote any mixture of hydrocarbon vapor and air. The term *hydrocarbon* vapor refers to hydrocarbons in the gaseous state independent of the presence or absence of air.

Breathing loss takes place in most types of tanks and occurs when limits of pressure or volume change are exceeded. Fixed-roof tanks, herein denoting ordinary storage tanks designed for only a few inches of water pressure or vacuum, suffer relatively large breathing losses. Tanks protected from a loss or gain in heat by reflective coatings, burying, insulation, or shading experience less breathing loss. Pressure tanks which operate at 2½ psig or higher, normally experience relatively little or no breathing loss. Variable-vapor-space-tank systems also normally experience little or no breathing loss. Floating-roof tanks almost eliminate vapor spaces, and little or no breathing loss occurs past the seals.

Standing-Storage Loss: Vapor from tanks, which results from causes other than breathing or change in liquid level, is defined as standing-storage loss. For floating-roof tanks, the largest potential source of standing-storage loss is attributed to an improper fit of the seal and shoe to the shell. This condition exposes some liquid surface to the atmosphere; wind affects this source of loss. Also, a small amount of vapor may permeate through the flexible membrane that seals the space between the shoes and the roof. The permeation of flexible membranes, or absorption in liquid seals, may also be a source of loss from variable-vapor-space tanks. Other sources of standing-storage loss are vapor escape from open hatches or other openings, glands, valves, and fittings.

Filling Loss: Vapors expelled from a tank as a result of filling, irrespective of the exact mechanism by which the vapors are produced, is defined as filling loss. This loss is common to all types of tanks except the floating-roof tank and closed-system pressure storage, such as for liquefied petroleum gas (LPG). It occurs when the pressure inside the tank exceeds the relief pressure. For fixed-roof tanks, the relief pressure is low, therefore the filling loss is relatively high. Filling loss from pressure and variable-vapor-space tanks is somewhat less because these tanks have added vapor-storage-capacity. The pressure tank also promotes condensation of hydrocarbon vapors during filling.

Emptying Loss: Vapors expelled from a tank after the liquid is removed is defined as emptying loss. Because vaporization lags behind the expansion of the vapor space during such withdrawal, the partial pressure of the hydrocarbon vapor drops. Enough air enters during the withdrawal to maintain total pressure at atmospheric pressure. When vaporization into the new air reaches equilibrium, the vapor volume exceeds the capacity of the vapor space. This increase in vapor volume causes the expulsion.

Emptying loss is common to all types of tanks except the floating-roof tank and closed-system pressure storage. Fixed-roof tanks are most vulnerable to this loss. Pressure tanks and variable-vapor-space tanks are less subject to this loss but will encounter it if the vapor-storage capacity is exceeded.

In the loading of transportation vessels the definition of emptying loss is restricted: The transporter considers emptying loss to be only that portion which evaporates into the vapor space of the tank during the actual withdrawal, that is, between the opening and closing of the gages.

Wetting Loss: Vaporization of liquid from a wetted-tank wall, exposed when a floating roof is lowered by withdrawal of liquid, is defined as wetting loss. This source of evaporation loss is small.

Boiling Loss: Vapors expelled from a tank as a result of boiling of the liquid is arbitrarily defined as boiling loss. Boiling loss may occur from any tank. The fixed-roof tank is more subject to this loss than the pressure tank. The earliest floating-roof tank, the pan type, is especially vulnerable to boiling loss because heat is readily conducted through the roof directly to the liquid and no vapor-storage capacity exists under the deck.

B. Loss in Production

Production entails three operations which contribute to evaporation loss: gas-oil separation, emulsion treating, and lease-tank operation.

In gas-oil separation, the oil may be rich in light components, which later are lost from the usual fixed-roof lease tank. In a recovery system, butanes and pentanes may not be completely extracted from the gas and may be lost. A true evaporation loss occurs when the gas is flared or vented. In addition to the loss in crude-oil volume, the API gravity is decreased.

In emulsion treating, heat is applied and released vapors may be vented. Also, the crude oil reaching the lease tank at elevated temperature contributes to the evaporation loss.

At the lease tank, splashing may occur as oil is introduced; in such cases vaporization and evaporation loss are accelerated. Dark-colored tanks contribute further to evaporation loss.

C. Loss in Refining

Refining involves three operations which are sources of evaporation loss: treating and blending in freely vented vessels, such as an agitator; pressure systems which may leak; and sewers, ponds, and open separators.

Use of air and agitation can result in high-evaporation loss from vessels which are not part of a closed system. Sweetening naphtha in agitators and blending volatile components in a semiopen vessel are potential examples of this source of evaporation loss.

Pressure systems, common to refineries and natural-gasoline extraction plants, may have sources of evaporation loss from leaking exchangers, glands, valves, and fittings. Hydrocarbon vapor may leak directly to the atmosphere. Also, liquid may leak and evaporate rapidly if volatile at the operating temperature. Besides outward leaks, inward leaks of air, such as at pump suctions, are sources of loss because this air becomes at least partially saturated before venting.

Sewers, ponds, and open separators are sources of evaporation loss if volatile liquids are permitted to reach them. Such liquids usually encounter high turbulence in sewers and collect in thin layers offering large exposures for evaporation. The recovered skimmings from ponds and separators require demulsification involving heat and constitute another source of loss from the recovery equipment.

D. Loss in Transportation and Marketing

Transportation includes pipeline shipments and the loading, transit, and unloading of transport vessels from which evaporation loss can occur. Pipelines are subject to loss from air eliminators used in metering systems and from leaking glands, valves and fittings, and corroded pipes.

Filling and emptying losses occur from nonpressure tankers, barges, tank cars, and trucks in much the same manner as from tanks. If tank cars and trucks are top-loaded with a short filling pipe, the undue splashing not only accelerates vaporization but also produces small droplets which may be lost by entrainment. Air inspired during loading can be an added source of evaporation loss because such air becomes at least partially saturated with hydrocarbons before it is vented; loosely connected, submerged loading spouts are sources of such inspiration.

In-transit losses from transport vessels are essentially breathing losses. Excessive heating of crude oil in marine vessels is a potential source of evaporation loss during transit.

Marketing operations entail many of the previously discussed sources of loss, particularly those discussed in Par. A, "Loss in Storage."

E. False Indications of Loss

Under certain conditions a loss appears to have occurred which actually did not. Being aware of these conditions and being able to distinguish between an "actual" and a "false" loss is important, otherwise corrective efforts may be directed toward conditions where no real improvement can result. Conversely, these conditions may balance out and cover up an actual loss, with the result that necessary corrective action is overlooked. Five such conditions are: inaccurate measurement, gravitation between tanks, inaccurate volume of supply lines, inaccurate calibration of meters, and physical changes in volume.

Inaccurate Measurement: Apparent gains or losses can result from inaccurate measurement, either of average liquid temperature, height of liquid, or incorrect calibration of containers. Other sources of error would be the failure to correct all volumes to a common temperature base by use of the unabridged Table 6, "Reduction of Volume to 60 F Against API Gravity at 60 F," of the *ASTM-IP Petroleum Measurement Tables* (1953).

Gravitation Between Tanks: Any leakage past a valve believed to close a line between two tanks results in gravitation—a loss of product in one tank results in a gain in the other tank which may not be observed.

Inaccurate Volume of Supply Lines: If the volumes of the supply lines are not known accurately, or if lines are not in the full or empty condition which is assumed, unrealistic losses or gains may be indicated.

Inaccurate Calibration of Meters: The inaccurate calibration of meters can result in apparent losses, which may be attributed incorrectly to evaporation—or in apparent gains which may conceal actual evaporation losses.

Physical Changes in Volume: Certain processing operations, such as cracking, polymerization, and the blending and separation of light and heavy stocks, result in physical changes in volume even when full correction is made for changes in temperature. For example, in a cracking process, where small molecules are produced from large ones, the products will occupy a greater volume than the charge. In a polymerization process, where large molecules are produced from small ones, the product volume shrinks. With such volume changes API gravity always changes but the total weight, before and after the volume change, is the same.

CHAPTER 2—FACTORS AFFECTING EVAPORATION LOSS FROM TANKS

The total amount of evaporation loss depends upon the rate of loss and the period of time involved. Primary factors affecting the rate of loss are: true vapor pressure of the liquid, temperature changes in the tank, tank outage, tank diameter, schedule of tank fillings and emptyings, tank condition, and type of tank. Saturation and diffusion effects are only a part of the mechanism of the loss and are classed as dependent, or secondary, variables. Although quantitative-loss relationships for the primary factors are not yet available, a fair understanding based on theory and practice can be gained by considering the mechanism of loss from fixed-roof tanks. With such understanding, the advantages of floating-roof, variable-vapor-space, and pressure-tank systems will readily be apparent.

A. True Vapor Pressure of the Liquid

True vapor pressure affects the rate of loss because it is the basic force causing vaporization. It varies with liquid composition and temperature. True vapor pressure at storage temperature is all important. For hydrocarbon mixtures, this pressure decreases with evaporation because of the change in liquid composition. True vapor pressure usually is determined from correlations relating it to Reid vapor pressure (RVP). Such relationships are illustrated in nomograph form in Appendix V.

The effect of true vapor pressure on rate of breathing loss from a fixed-roof tank involves at least two internal considerations—the saturation concentration and the diffusion and convection factor. The maximum concentration of hydrocarbons which can be present in expelled vapor, known as the saturation concentration, increases in direct proportion to true vapor pressure. It follows that if vented vapors were fully saturated, evaporation loss would increase rapidly as true vapor pressure approaches the tank relieving pressure (a boiling condition). However, another mechanism—the diffusion and convection of hydrocarbon vapor from the liquid surface through the vapor space is too slow to fully saturate it. Experience shows that vapors vented during normal breathing are usually only 80 per cent to 90 per cent saturated. Thus, the driving force to overcome resistance to diffusion factors and convection through the vapor space is one of the controlling factors. Such driving force can be looked upon as being the true vapor pressure of the liquid minus the partial pressure of hydrocarbons in the vapor space. As true vapor pressure rises, this driving force would rise in direct proportion if percentage saturation in the vapor space remains constant. Thus, both the saturation consideration and the diffusion and convection consideration suggest that actual loss is at least directly proportional to rising true vapor pressure.

Filling or emptying losses from fixed-roof tanks are directly proportional to increasing true vapor pressure because of the relationship between true vapor pressure and saturation concentration.

This concept does not apply when true vapor pressure exceeds the absolute tank pressure because boiling occurs and losses may be large. Then, the main controlling factor is heat input.

In terms of total loss over a period of time, the effect of true vapor pressure depends upon the composition of the stock. For example, two crude oils of identical true vapor pressure may weather at different rates. One crude oil may contain a relatively high per cent of volatile propane and ethane; for a specific starting loss rate, the vapor pressure will drop rapidly and the loss rate will drop shortly thereafter. The other crude oil may derive vapor pressure from relatively high concentrations of less-volatile pentanes and butanes; for the same starting loss rate, the vapor pressure will drop less rapidly but the loss rate will remain higher for a longer period. This consideration is particularly significant for newly produced crude oils at leases and pipeline storage terminals where true vapor pressures may be close to atmospheric pressure.

B. Temperature Changes in the Tank

Internal temperature changes, brought about by atmospheric and solar heat, tend to cause the tank vapor space to breathe. During the day, heat flowing through the roof and upper walls raises the vapor temperature and expands the volume. The pure thermal effect is augmented by vaporization of hydrocarbons from the tank contents during the same period. The heat input also may increase the liquid-surface temperature and accelerate vaporization. At night, reverse processes shrink the vapor and cause an intake of air.

Atmospheric and solar heat also cause forced convection in the vapor space which promotes evaporation from the liquid surface and aids in the dispersion of the hydrocarbon vapor.

Although efforts have been made to develop more precise criteria, the average daily change in atmospheric temperature is still the only accepted way to characterize atmospheric and solar-heat effects. Monthly meteorological data for various locations in the United States and Canada are presented in Appendix VI.

Theoretical considerations do not permit good estimation of how much loss will increase with increasing atmospheric temperature change; however, it probably will be somewhat less than directly proportional to the increase in atmospheric temperature change.

C. Tank Outage

The volume of most vapor spaces is directly proportional to outage—the height of the vapor space. For a fixed-roof tank, higher outage means greater loss because the larger volume will breathe more. However, when outage is increased heat input is not increased in direct proportion. Heat enters the vapor space through the tank wall, the area of which increases in direct proportion, and through the tank roof, the area of which remains unchanged. Furthermore, with added height of vapor space, resistance to transfer of hydrocarbon vapors from the liquid surface to the vent increases. Therefore, the average concentration of hydrocarbons in vented vapor should fall. Experience has confirmed that loss will increase less than directly proportional to increasing outage.

D. Tank Diameter

Tank diameter influences the volume of the vapor space and the liquid-surface conditions. Breathing is less than directly proportional to increase in vapor volume because of the less than proportional increase in area for heat transfer into the vapor space. Furthermore, increasing diameter should reduce the temperature rise of the liquid surface because the rising hot stock, in contact with the tank wall, must spread in a thinner film over the surface area. Assuming constant tank height, total breathing loss, therefore, increases at a rate less than directly proportional to tank volume.

E. Schedule of Tank Fillings and Emptyings

Over a period of time, the frequency of stock turnover and the average outage affect total loss. Operations that promote high outages may result in relatively high breathing losses. Fillings and emptyings scheduled to compensate the daily temperature changes may reduce breathing loss. The time interval between emptying and filling may have a significant effect on loss. For a system of tanks connected with vapor lines, simultaneously filling one tank while emptying another maintains the vapor-storage capacity relatively constant and filling loss is reduced.

F. Tank Condition

Tank condition is another factor affecting loss rate; however, quantitative effects cannot be predicted. Open vents result in high loss when gusty or turbulent winds cause rapid pressure changes in tanks in which volatile liquids are stored. Rapid breathing occurs as short puffs. Any hole in a tank roof, diaphragm, seal, or accessory results in the same type of loss.

Where there are two or more openings in the tank, loss is further increased. Pressure differences, which result from wind or thermal effects, cause a constant flow of air through some openings into the vapor space and an outflow of vapor through other openings.

G. Type of Tank

The type of tank or storage system will affect the evaporation loss experienced. The amount of loss depends upon the volume of the vapor space available and the pressure limitations of the equipment.

If tanks have their vapor spaces interconnected, vapor-space volume can be controlled to a limited extent by scheduling fillings and emptyings, where feasible.

If the vapor space is allowed to change volume at constant pressure, breathing loss can be practically eliminated and filling loss can be reduced. The extent of the reduction in loss is dependent upon the amount of variable vapor space provided.

CHAPTER 3—TANKS AND EQUIPMENT TO CONTROL EVAPORATION LOSS

The industry may choose from four basic types of tanks for storage of petroleum and its products: fixed-roof tanks, floating-roof tanks, variable-vapor-space tanks, and pressure tanks. Each type is designed for specific storage requirements, the actual storage problem should determine the type selected. In many instances, the most economical tank can be selected only after a detailed study comparing loss from, and the cost of different tanks. For stocks having a low true vapor pressure, less than 2 psia, the fixed-roof tank generally will be the most economical selection. For stocks of motor-gasoline range of volatility at high throughputs, the floating-roof tank generally will be the best choice, but at lower throughputs the variable-vapor-space tank generally will be better. For stocks which boil at atmospheric pressure and storage temperature, pressure tanks are best generally; however, in some cases use of the fixed-roof tanks in conjunction with a vapor-recovery system may offer more advantages.

The tendency to boil in storage is a function of vapor pressure, altitude, barometric pressure, and liquid-surface temperature. Maximum liquid-surface temperatures vary throughout the United States. For the indicated temperatures, the maximum Reid vapor pressures (RVP) of stocks which can be stored at atmospheric pressure without general boiling (but at the expense of high-loss rates) are:

Area	Maximum Liquid-Surface Temperature * (Degrees Fahrenheit)	Maximum Reid Vapor Pressure * (Pounds)
West Coast (tempered by Pacific Ocean)	80	18
	90	15.5
Gulf Coast, Atlantic Seaboard, and northern Middle West	100	13.5
	110	11.5
Mid-Continent area and arid Southwest	115	11
	120	10

* The limits must be reduced for locations at higher altitudes to account for lower barometric pressure.

Effective loss-control operation of each tank is dependent upon certain accessory items, such as breather valves and automatic gages. Continued effective operation is dependent upon a program to maintain the tank and accessories in a gastight condition.

Choice of paint color may be an important factor in reducing loss. In special instances, loss may be reduced by use of a floating plastic blanket; or, by employing insulation, a shading device, water sprays, mechanical cooling, or by burying the tank. In some cases, it may be possible to reduce loss further by specially scheduling fillings and emptyings.

A. Fixed-Roof Tanks

The minimum accepted standard for storage of volatile oils is the fixed-roof tank. It can sustain an internal pressure, or vacuum, of only an ounce or two per square inch. Being susceptible to sizable breathing and filling losses, this type of tank is used most frequently for services which cannot economically justify a conservation tank.

Design of Tank: The fixed-roof tank, the predecessor of conservation tanks, came into being during the early days of the petroleum industry. Wooden barrels were used at first, but they could not keep up with the rising flood of oil that poured from the Pennsylvania wells. As production increased, open pits and diked areas were used, but they were hazardous. Wooden tanks, caulked with oakum and held together with iron hoops, first appeared in 1861. The capacity of these tanks ranged between 500 bbl and 1,000 bbl.

The first iron tank with a wooden, gravelled roof appeared in 1864; it provided larger and safer storage. Shortly after the Civil War, bolted- and riveted-steel tanks came into use. They ranged in size up to 35,000 bbl. After 1915 capacities were increased and in 1919 the first 80,000-bbl tank was erected. The introduction of electric welding, in 1923, made possible the fabrication of welded roofs and bottoms. The welded tank was introduced in 1927.

Fixed-roof tanks built today usually are welded throughout, but many riveted tanks are still used and bolted tanks are common in the smaller sizes. Whereas the seams of welded tanks are almost inherently gastight, the seams of bolted and riveted tanks frequently require additional maintenance. In some areas, particularly on leases where corrosion is a problem, wooden roofs, which are seldom of gastight construction, are still in use. Loss from these tanks is much greater than from steel-roof tanks.

If a fixed-roof tank is found to be the best type for a particular storage problem, careful consideration should be given to the size before the final selection is made. Because the loss rate increases significantly with outage and tank diameter, the use of the smallest tank possible for the given storage requirement results in a minimum loss. For further insight as to the outage and diameter effects, refer to Chapter 2, "Factors Affecting Evaporation Loss from Tanks."

Maintenance of Tank: To maintain a gastight condition, tanks should be inspected at regular intervals and repaired as necessary. The frequency of inspections usually is determined by experience. Riveted-roof tanks, because of their greater tendency to develop leaks, should be inspected more frequently than welded-roof tanks.

When the tank is under pressure, five ways in which leaks may be detected are:

1. Observation of heat-wave-like trails of the escaping vapors.
2. Hearing the hiss of escaping vapors.
3. Smelling the vapors.
4. Use of gas testers or "sniffers."
5. Applying soap solution or linseed oil to seams.

Also, stains on the painted surfaces frequently indicate leaks.

Design of Accessory Equipment: The fixed-roof tank has several openings in roof for venting, gaging, and sampling. To maintain a gastight roof, accessory equipment of a gastight design must be provided for these openings.

The accessory for the vent opening is called a breather valve, pressure-vacuum relief valve, or conservation vent. When operating properly, this device prevents either the inflow of air or the escape of vapors until some preset vacuum or pressure is developed. Most breather valves, especially the metal-to-metal types, allow some leakage below the pressure or vacuum setting. A tight breather valve is important in reducing evaporation loss. The actual magnitude of the savings will depend upon such factors as vapor pressure of stock stored, weather conditions, paint color, and allowable working-pressure range. However, the savings realized usually will pay for the installation. The breather valve also contributes to safe operation by keeping the tank vent closed to the atmosphere most of the time.

The pressure and vacuum settings of a breather valve are dictated by the structural characteristics of the tank and should be within safe operating limits. A certain amount of pressure and vacuum beyond these settings is necessary to overcome pressure drop in order to obtain required flow. Proper size and settings can best be determined by reference to *API Std 2000: Venting Atmospheric and Low-Pressure Storage Tanks* (1968) and to the manufacturer's tank data determined in accordance with this publication. The pressure setting for vent valves to be installed on large tanks constructed in accordance with *API 12D: Specification for Large Welded Production Tanks* (1957) usually is limited to ½ oz because roof plates will start to shift when the pressure rises much above 1 oz. For small tanks, and all tanks having special structural features, the pressure range can be increased in accordance with the manufacturer's recommendations.

Breather valves should be designed to give:

1. High-flow capacity at relatively small pressure or vacuum above the setting.
2. A gastight seal.
3. Freedom from sticking or freezing.
4. Easy access to all parts for inspection and maintenance.

Diaphragm and liquid-seal valves have less leakage than metal-to-metal types. For dependable service, diaphragms should be resistant to tank vapors.

Open vents of the mushroom or return-bend type should not be used on fixed-roof tanks storing volatile oils as they permit high loss. These vents are merely hooded openings equipped with protective screens. The opening is turned down to prevent any blockage by ice or snow.

Venting accessories sometimes used are: flame arrestors, flame snuffers, and flash screens. They usually have little effect on vapor loss except when they are installed between the tank and vent valve and must be removed for cleaning.

Some vapor loss is inherent in manual gaging and sampling methods which necessitate opening a tank to the atmosphere each time these operations are performed. This loss can be minimized through the use of automatic gaging equipment, double-closure gaging locks, and a system of thermometers and sample valves in the tank shell.

Accessories which help to reduce evaporation loss from lease tanks include:

1. Pressure-vacuum thief hatch and vent-line valve.
2. Automatic-closing valve in the equalizer line which closes when the gage hatch is opened.
3. A diagonal-slotted downcomer type of fill line to minimize free fall and splashing.

Maintenance of Accessory Equipment: To maintain accessories in a gastight condition they should be inspected and restored periodically. Pallets of the metal-to-metal breather valves which become warped in service must be machined to restore a gastight fit. Defective diaphragms of diaphragm breather valves should be replaced.

Liquid-seal breather valves may be affected by dilution or loss of liquid and may have to be inspected and maintained more frequently as determined by experience. A loose fitting gage-hatch lid can be made nearly gastight by replacing the gasket or by machining the seating surface.

Flame arrestors and flash screens can become clogged with dust, rust, and ice. Such obstructions in the venting system can cause severe damage to the tank from excessive internal pressure or vacuum. These accessories should be inspected and cleaned frequently.

Choice of Paint: Tank painting is important in reducing evaporation loss as well as in preserving the tank. An adequate paint program, using reflective paints, will minimize the heat input to the tank by reducing the metal temperature of the tank.

White paint is a simple and effective means for reducing evaporation loss. The additional low cost of maintaining a clean white surface on a tank frequently has an attractive economic return. Recent data indicate that painting the tank roof and shell white, rather than gray, reduces the evaporation-loss rate by at least 20 per cent.

Use of Insulation: Insulation on the roof and shell of a storage tank tends to reduce heat input and heat loss; this tendency toward constant temperature reduces breathing loss. However, when stock at higher than normal storage temperature is added to an insulated tank, the average tank temperature increases, which in turn increases true vapor pressure and promotes a higher concentration of hydrocarbons in the vapor space. This condition may increase filling loss somewhat and breathing loss to a lesser degree. Insulation usually is expensive to install and may involve considerable maintenance. Unless moisture is prevented from entering the insulation, loss of insulation effect as well as corrosion of the tank shell may result.

Use of Shade: Shading of a storage tank from direct sunlight reduces heat input, but generally does not reduce normal heat loss. Hence, compared to a bare tank, shading provides less variation in internal temperature and, usually, results in a lower average stock temperature. Although the installation of shades generally has not been considered economical, usually the maintenance is not an expensive factor.

Use of Flexible Blanket on Liquid Surface: Evaporation loss in fixed-roof tanks can be reduced with the use of flexible blankets which float directly on the liquid surface. The blanket acts in the same manner as a floating roof. There are two types of flexible blankets: one is a foam blanket made up of plastic spheres; the other is a blanket or raft made from plastic sheeting. The latter type has not been tested extensively in this country.

The floating plastic-foam blanket consists of microscopically small, hollow, plastic, gas-filled spheres. This material has been used extensively on fixed-roof storage tanks in crude-oil service. Tests made in this country and Canada have indicated that under favorable conditions evaporation loss on crude oil can be reduced from 50 per cent to 70 per cent in working tanks and from 70 per cent to 90 per cent in static tanks. A ½-in. thickness usually is used on static tanks. A 1-in. thickness is used on working tanks to avoid breaking up the complete foam layer during filling and emptying. Gaging difficulties with the plastic foam have been minimized by the use of a portable type of gage well carried on a gage tape.

Loss of the plastic spheres can occur if tanks are pumped to low levels at high pumpout rates. The operation of mixers must be controlled to prevent the plastic spheres from being dispersed in the oil and then pumped out during emptyings.

Not enough information is available to estimate accurately the service life of the spheres. However, reports received indicate that the material has operated satisfactorily for two and one half years. The spheres should not be installed in tanks containing liquids subject to boiling; water also may damage the plastic spheres, especially, if agitation promotes contact of moisture with the spheres.

B. Floating-Roof Tanks

The floating-roof tank is an effective conservation device for stocks of motor-gasoline volatility. The basic design virtually eliminates the vapor space, which results in low losses both from breathing and filling. The exceptionally low losses from filling brought this tank into widespread use. Other advantages of this tank are excellent fire protection and corrosion resistance. Ignition may occur only in the seal area; being confined to this localized area, the fire normally is easy to extinguish. However, should the stock boil, the fire may be difficult to extinguish. Excellent protection from sour or corrosive stocks is afforded by floating roofs which are in contact with the entire liquid surface.

Design of Tank: There are three basic designs of floating-roof tanks in operation: the pan type, pontoon type, and double-deck type.

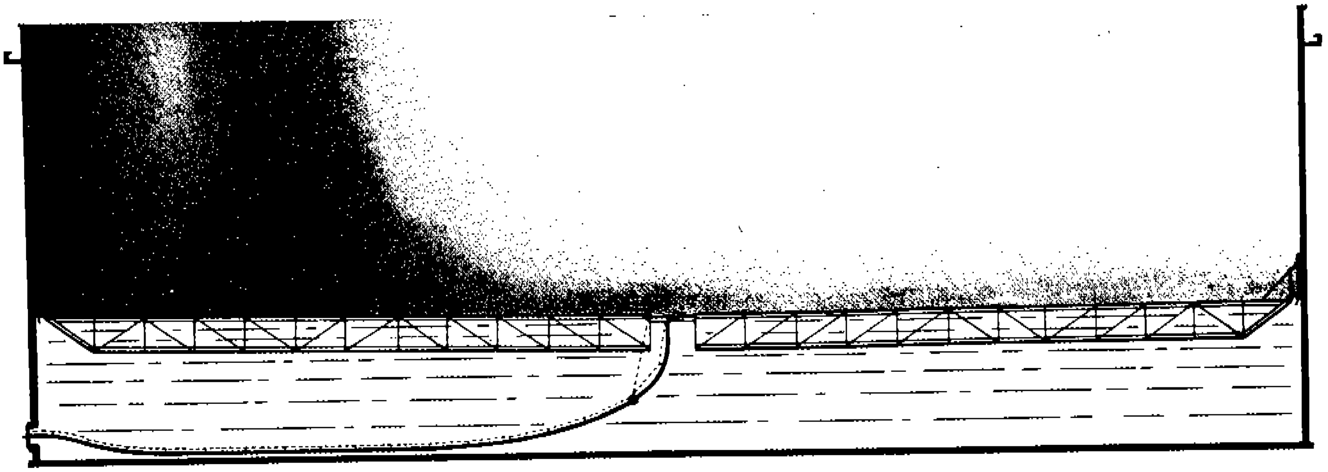
The first successful floating-roof tank, the pan type, was built in Cushing, Oklahoma, in 1922. A typical example of a pan-type floating roof in operation today is shown in Fig. 1. A single deck covers most of the liquid surface and a seal is attached to the rim of this deck. The deck slopes to the center for drainage.

This roof has three disadvantages which account for its limited use. The single deck is exposed to the sun during the middle of the day. Because the deck is held forcibly in contact with the liquid, heat is transferred directly to the liquid surface. The liquid-surface temperature rises appreciably. Sometimes the product boils and losses of gasoline and similar stocks may result. The pan roof also may tip and sink under heavy loads of water or snow, or from leaks which may develop in the deck.

The pontoon roof was developed in 1928 by adding pontoons to the pan-type roof to give it greater stability and bouyancy. Thus, the pontoon roof has a single deck over only a part of the total area, closed pontoons cover the remaining area. Pontoon-type roofs are illustrated in Fig. 2 and Fig. 3. The pontoons are arranged and compartmented to provide floating stability under heavy loads of water or snow. Enough bouyancy normally is provided so that the roof will not sink when the single-deck area leaks or the drain fails. Properly compartmented, the pontoons can be partially flooded without endangering the roof structurally.

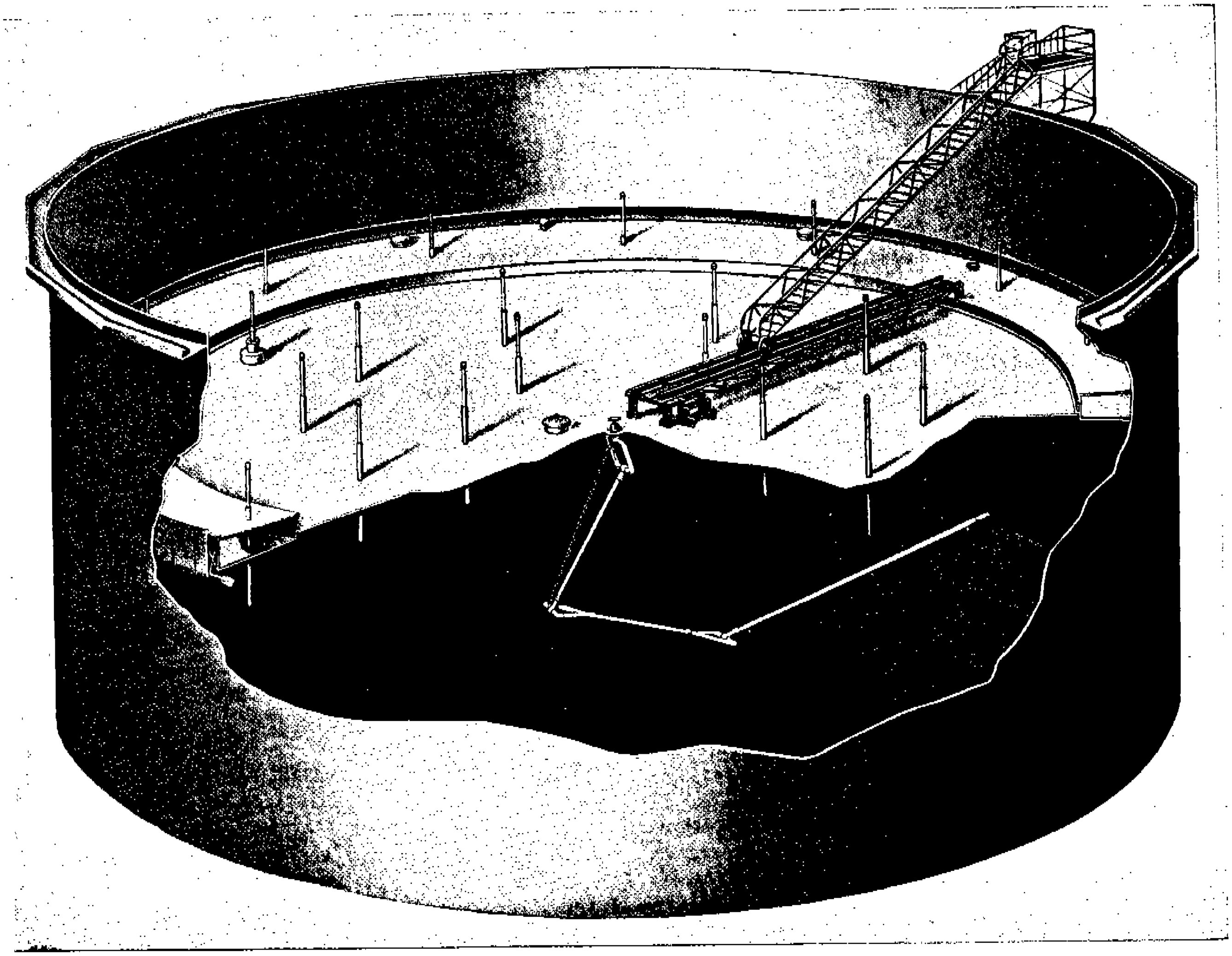
A pontoon roof having a single deck, which can rise above the liquid surface when boiling starts, provides an insulating vapor space and reduces the heat transfer from the sun to the liquid surface. Boiling losses usually will not occur with stocks in the motor-gasoline range of volatility.

In the mid 1940's the double-deck roof was offered, which in effect made the entire roof a series of pontoons, see Fig. 4. Circular and radial bulkheads divide



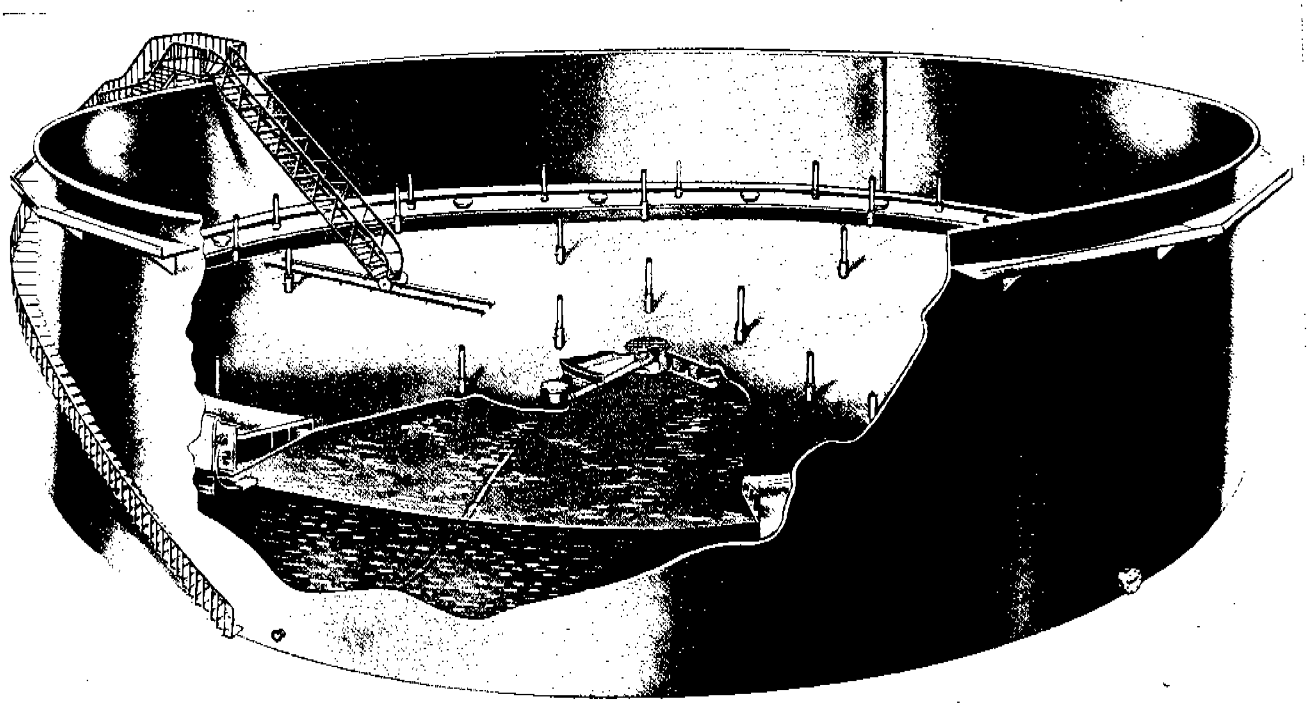
Courtesy: General American Transportation Corp.

FIG. 1—Pan-Type Floating Roof.



Courtesy: Chicago Bridge and Iron Company.

FIG. 2—Pontoon-Type Floating Roof.



Courtesy: Graver Tank and Manufacturing Company, Inc.

FIG. 3—Pontoon-Type Floating Roof.

the space between the two decks into compartments; this design can give good stability and load-carrying capacity and provides an insulating air space over the entire area. Boiling losses usually will not occur with stocks in the motor-gasoline range of volatility.

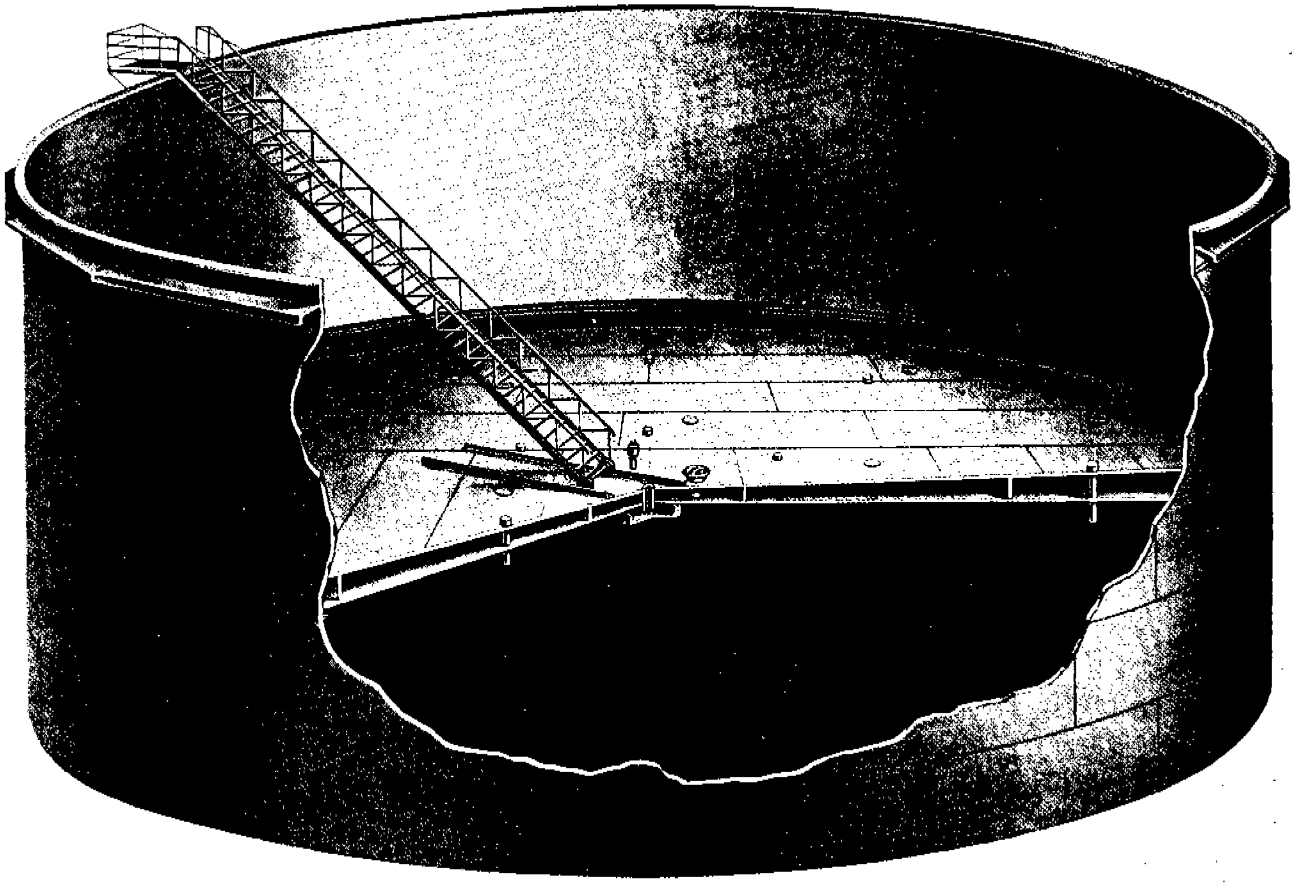
The usual seal in a floating-roof tank consists of a relatively thin-gage shoe or sealing ring supported against the tank shell around the edge of the floating roof. The bottom of the sealing ring is below the liquid surface, and the top is a few inches above the top rim of the roof. A piece of flame-retardant rubberized cloth closes the space between the sealing ring and the roof. Another type of seal consists of a flexible tube, fastened to the roof and occupying the annular space between the roof and shell. The tube, filled with a nonfreezing liquid, is held on the liquid surface and completely eliminates the vapor space. In tanks with riveted shells, abnormally high losses of the more volatile stocks occur because the rivet heads and overlapping steel plates hold the sealing ring away from the tank shell. Thus, it is advisable to use a secondary seal on riveted tanks. This type of seal consists of a strip or loop of rubber adapted to cover the slot at the top of the sealing ring. The value of a secondary seal for welded tanks is uncertain.

Maintenance of Tank: Efficient and safe operation of any mechanical device which moves intermittently requires inspection and maintenance at regular intervals; the floating-roof tank is no exception. Shoes must fit well, seals must be in good condition, the roof should be level at all times, and the breather valve and bleeder vent must operate satisfactorily.

Before the tank is put into service the opening between tank shell and shoe should be minimized by adjusting shoe springs or hangers. If the liquid surface is plainly visible between shoes and shell, after all adjustments are made, the tank may be out-of-round caused by faulty construction or uneven settling. Because this condition leads to large losses it should be corrected. Shoe fit should be checked periodically; at the same time, the above-deck hangers should be serviced to keep them in an operating condition.

The primary and secondary seals should be inspected periodically for tightness and general condition. Sections of the primary seal which have deteriorated and have weakened should be replaced. Holes that appear in sections of good material may be repaired by patching. The secondary seals are subject to considerable abrasive wear and are not amenable to patching, such worn-out seals should be replaced.

The floating position (the level) of a roof depends upon the weight of the load supported and how easily the roof can move up and down. With riveted tanks, shoes occasionally bear unevenly on the shell of the tank. Inspection for this condition should be made periodically and shoes adjusted as necessary. After every rain, drainage from the roof should be checked and any debris clogging the screened roof drains should be



Courtesy: Hammond Iron Works.

FIG. 4—**Double-Deck Floating Roof.**

removed. Although a snow load is not serious for the pontoon or double-deck roofs it can be with the pan-type roof. When more than a foot of snow accumulates on a roof of any type, it should be removed, particularly if it drifts unevenly.

Design of Accessory Equipment: Two accessories are necessary to the operation of a floating-roof tank: a breather valve for the rim space and a bleeder vent for the roof. One breather valve, sometimes two, is provided at the outer edges of all types of floating-roof tanks; it is similar in design to that used on fixed-roof tanks. The bleeder vent for the pontoon and double-deck tanks allows air trapped under the roof to escape before the roof floats and prevents a vacuum as the roof comes to rest on its supports.

Maintenance of Accessory Equipment: The following accessories should be inspected regularly and repaired as necessary: breather valves (rim vents), bleeder vents, sample and gage hatches, and any other openings from which vapors might escape.

Choice of Paint: The value of a highly reflective paint in reducing evaporation loss from floating-roof tanks is questionable. Although the floating-roof tank is a very efficient conservation device, savings effected through the use of a particular color of paint will be less than for other types of tanks. Reflective paint on the pan-type roof may be justified because it will reduce the chance for boiling. It is not so important on the pontoon and double-deck roofs because these roofs are designed to provide insulating barriers to heat transfer. Reflective paint on the shell of these tanks may be justified because it may reduce boiling in the seal area and it will help maintain a lower liquid temperature throughout the tank. Such reductions are beneficial particularly for the older riveted tanks where it is difficult to maintain a good fit between the shoes and shell.

C. Variable-Vapor-Space Tanks

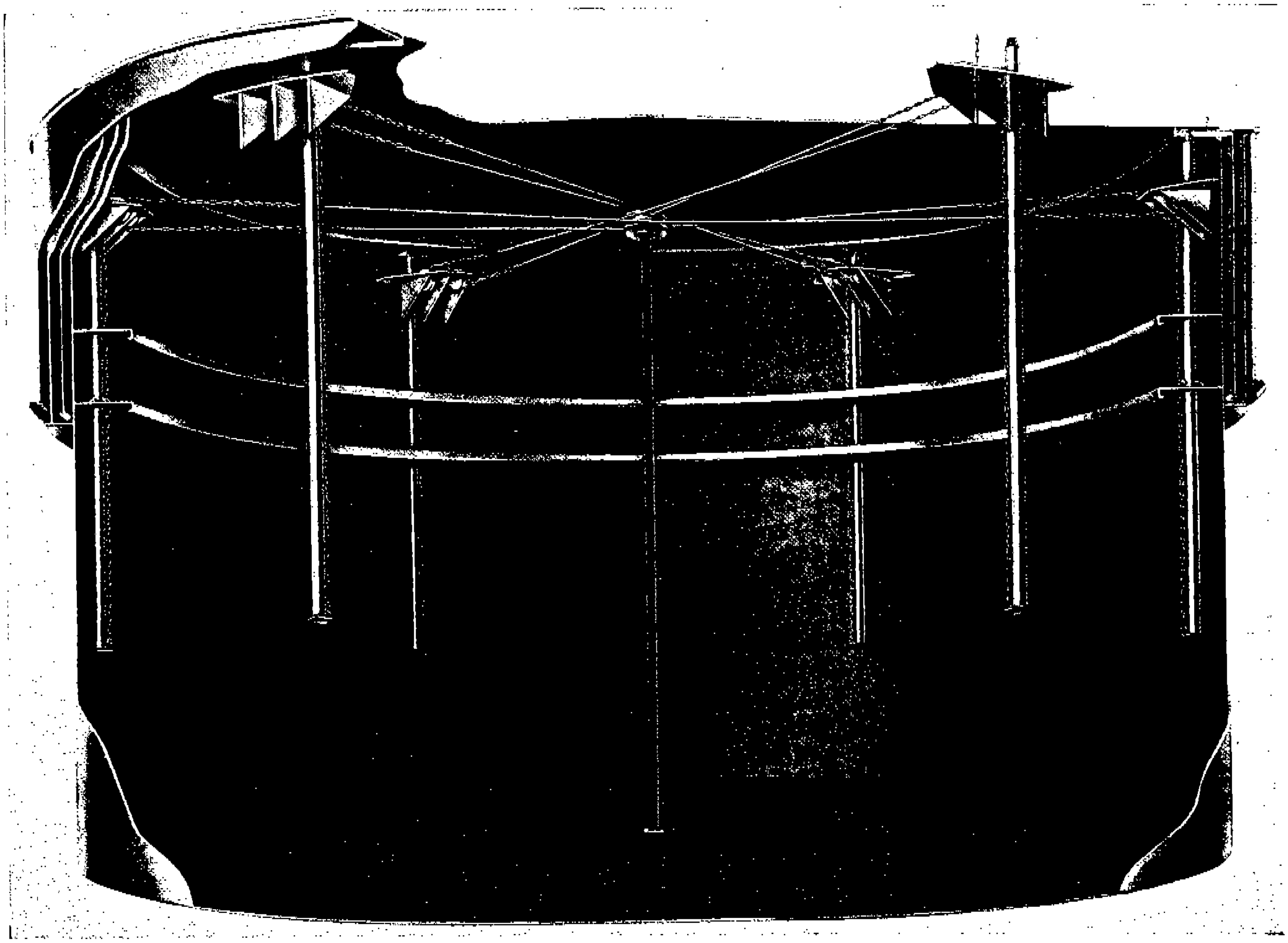
The variable-vapor-space tank is an effective conservation device particularly suited to reducing breathing losses. Expanding vapors are stored temporarily in a gasholder device and vented to the atmosphere only when the gasholder capacity is exceeded. In cooling, the vapors from the gasholder are drawn back into the tank. Variable-vapor-space capacity usually is sufficient so that one gasholder device may be used in conjunction with one or more interconnected fixed-roof tanks operating at substantially the same pressure. Filling loss is not materially reduced, except in a carefully controlled operation. However, because of the effectiveness in reducing breathing loss, this tank has been widely accepted, particularly where tank throughput is low.

Design of Tank: The first variable-vapor-space system consisted of a gasbag connected to the vapor spaces of 1, 2, or 3 fixed-roof tanks; it was introduced in the early 1920's. Later in that decade, the first lifter-roof tank was introduced. It was not until 1939, however, that the lifter- or expansion-roof tank was widely accepted. Today, two types of variable-vapor-space tanks are used—the lifter roof and the flexible diaphragm.

There are two types of lifter-roof tanks: wet-seal and dry-seal. In each type the roof is telescopic. Not being rigidly attached to the shell the roof can move up or down as the vapor above the liquid expands or contracts.

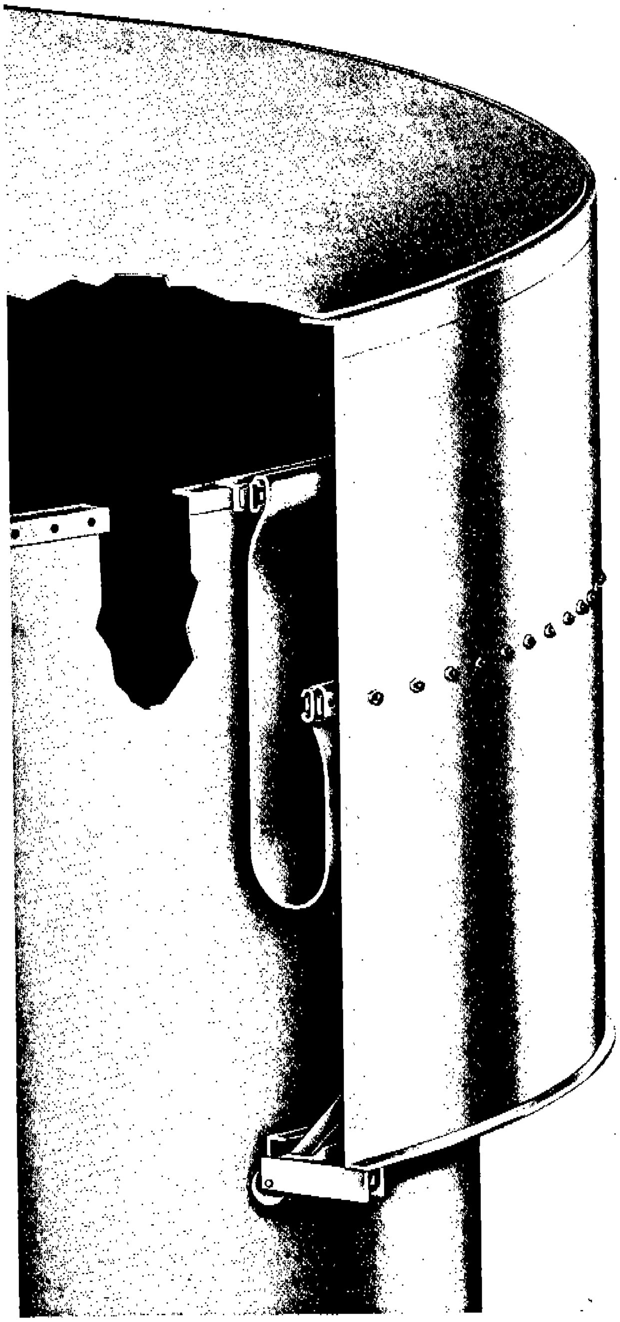
A typical design of the wet-seal lifter roof is shown in Fig. 5. The upper part of the tank is surrounded by an annular space, called a trough or launder, and contains a sealing liquid. A dip skirt extends from the roof into the liquid to provide a seal, while the roof is free to move up and down a distance of 4 ft to 10 ft or more. The seal liquid may be water, light oil, or an antifreeze solution; it should be selected in accordance with climate, solubility considerations, and tank design.

The dry-seal lifter-roof tank, shown in Fig. 6, operates similarly to the liquid-seal lifter. Instead of the liquid seal, rubberized cloth or dry seal is used to retain the vapors as the roof moves up and down. For both types of lifter roofs, the operating pressure ranges from 1½ oz to 4 oz per sq in. depending upon type, tank diameter, and height of lift. Because these pres-



Courtesy: Graver Tank and Manufacturing Company, Inc.

FIG. 5—Wet-Seal Lifter Roof.



Courtesy: General American Transportation Corp.

FIG. 6—Dry-Seal Lifter Roof.

sures control the operating pressure in the entire system, interconnected fixed-roof tanks must be designed and constructed to withstand this operating pressure plus the pressure drop in the interconnecting vapor system plus a reserve to keep the vent from leaking.

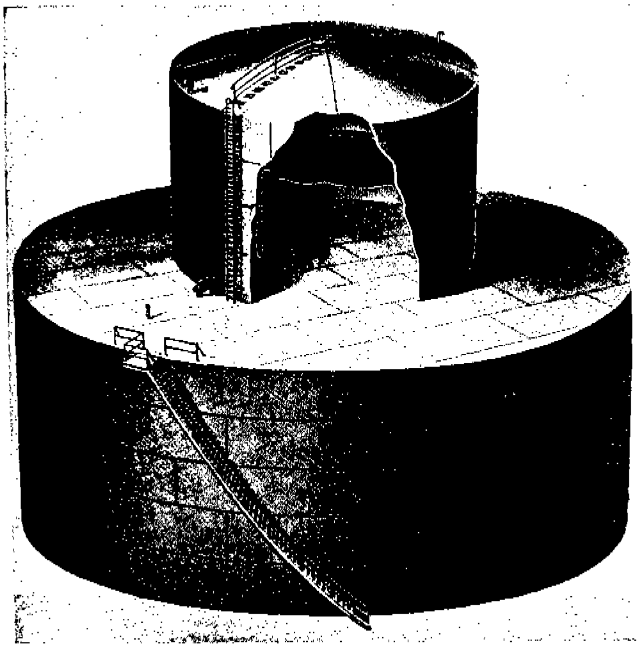
The flexible-diaphragm tank, introduced just before World War II, serves the same purpose as the lifter-roof tank by providing expansion capacity through the movement of the diaphragm. The flexible-diaphragm tanks have an advantage over the lifter-roof tanks in that the operating pressure is relatively low; therefore, it is seldom necessary to strengthen the interconnected fixed-roof tanks. Also, the lower pressure reduces the magnitude of any leaks which may develop.

There are two types of flexible-diaphragm tanks: the integral unit and the separate unit. A type of integral unit is shown in Fig. 7. This tank is essentially a fixed-roof tank with a steel shell located on the roof; a flexible diaphragm attached to the inside of the shell can expand or contract as the confined vapors change in volume. A type of separate unit is shown in Fig. 8. This gasholder is an upright cylindrical unit with a flexible diaphragm attached to the horizontal center. It may be connected to one or more fixed-roof tanks.

The diaphragm material used in dry-seal lifter roofs, flexible-diaphragm tanks, and dry-seal gasholders must have:

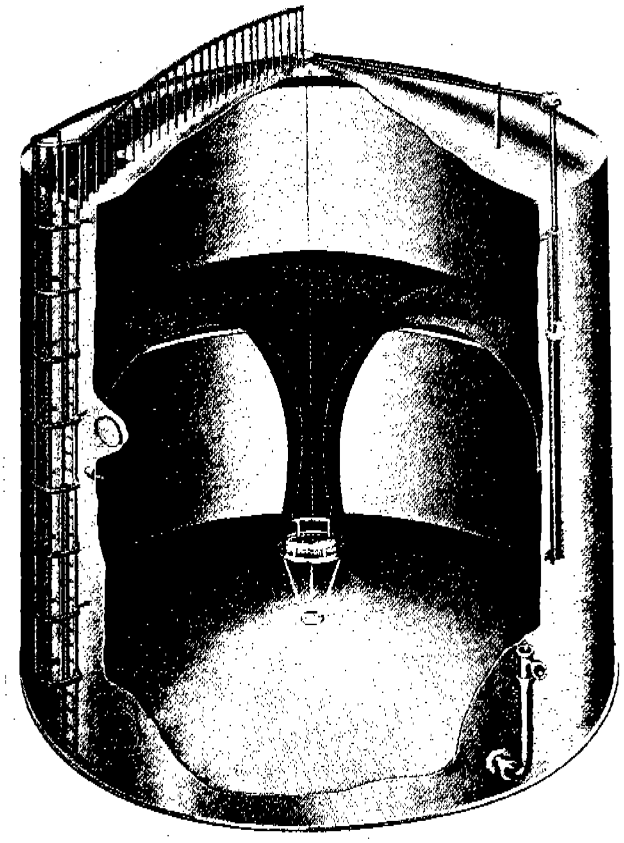
1. High strength.
2. Good chemical resistance to product and vapors in contact with it.
3. High flexibility over a wide range of temperatures.
4. Good aging properties.
5. A high degree of impermeability to vapors and to the liquid product itself when there is contact.

The interconnecting vapor lines should be of adequate diameter for minimum pressure drop. Vapor lines should be sloped to one or more low points with drains at each point for drawing off accumulated condensation. When aviation and motor gasolines are stored in the same system, it may be desirable to install



Courtesy: Hammond Iron Works.

FIG. 7—Flexible-Diaphragm Tank (Integral Unit).



Courtesy: Graver Tank and Manufacturing Company, Inc.

FIG. 8—Flexible-Diaphragm Tank (Separate Unit).

check valves in the vapor lines from the aviation tanks to protect the vapor-pressure specification of the aviation gasoline.

Maintenance of Tank: Keeping a variable-vapor-space tank or system gastight requires careful maintenance. The level of sealing liquid in the wet-seal lifter-roof tank should be checked twice a year, preferably in the spring and fall when the roof is down and the internal pressure is substantially atmospheric. Water which may have condensed in the bottom of the trough or launder should be drained to prevent freezing the dip ring of the roof. The launder should be filled with seal liquid to the design level.

Snow should not be permitted to accumulate on the lifter-roof tanks. The added pressure caused by snow at an average depth of 4 in. to 8 in., depending upon the pressure settings on the vents, will cause the pressure-vent portion of the volume-control valve to open. Also, this increased pressure will cause vents on the interconnected fixed-roof tanks to leak or open, and the entire system will become inoperative.

The flexible membrane in the diaphragm-type tank is actually a fragile material. No attempt should be made to lift the membrane by pulling up on any cable attached to diaphragm, an improper movement could easily tear it.

As a routine procedure, condensate should be drained from the connecting vapor lines to prevent clogging; if the condensate contains water, ice could be a problem during the winter months.

Design of Accessory Equipment: Breather valves are standard accessories for each tank in a variable-vapor-space system. The relief settings for the breather valves on the fixed-roof tanks are set slightly higher than those on the conservation tank. Because the variable-vapor-space capacity is not adequate to retain all vapor expelled during filling, the breather valve must accommodate vapor flow at maximum fill rate. Breather-valve equipment is described in Par. A, "Fixed-Roof Tanks."

Each type of lifter-roof tank has a volume-control valve. This valve permits vapor to escape from the conservation tank when the roof has reached its extreme upper limit of travel. This valve also allows air to enter the tank to avoid drawing a vacuum beyond 1 in. of water.

Other accessories which materially aid in reducing loss are:

1. Automatic gage and fixed thermometers.
2. Mechanical control of the vapor-line shutoff valve connected to regular gage hatch.
3. Gage wells. When gage wells are used, a manometer is needed to correct gage reading for pressure differential.

Maintenance of Accessory Equipment: Maintenance of breather valves is even more important on a variable-vapor-space system than on a fixed-roof tank alone because of elevated pressures needed on the connected fixed-roof tanks. In the event the variable-vapor-space unit is part of a multiple-tank system the leakage of one breather valve will tend to nullify the conservation effect of the entire system. Therefore, at a frequency determined to be adequate, the pallets in the lifter-roof volume-control and fixed-roof-tank breather valves should be lifted momentarily to check for binding or sticking. If a flame arrestor is used in conjunction with these breather valves, tube banks should be removed frequently and the apertures should be cleaned. During freezing weather, inspection frequency should be increased.

At a frequency determined to be adequate by experience, gage hatches, vapor piping, vapor-line valves, and diaphragms should be inspected and repaired as necessary.

Choice of Paint: Variable-vapor-space tanks frequently operate with large vapor spaces which are subject to considerable expansion and contraction effects caused by temperature changes in the vapor space. These effects on evaporation loss can be minimized by covering the tank with a heat-reflective paint. White paint is preferred.

D. Pressure Tanks

Pressure tanks are conservation devices which can withstand relatively large pressure variations without incurring a loss. Some tanks withstand only the pressure variations caused by daily temperature changes, whereas others prevent boiling of volatile stocks—stocks as volatile as propane. Therefore, pressure tanks experience little or no breathing losses. Filling losses may vary widely, depending upon product characteristics, vent-valve setting, and fill-pipe arrangement. Fill pipes arranged for filling into the vapor space (sometimes called spray filling) will greatly decrease and frequently eliminate filling loss on tanks which do not inbreathe.

Design of Tank: An early adaptation of the principle of pressure storage was the water-top roof; a 6-in. layer of water was maintained on the roof as a restraining force to the internal pressure. Later, with the application of pressure-vessel design principles, the modern pressure tanks were developed. Today, there are two classes of pressure tanks in general use: low-pressure tanks operating between 2.5 psig and 15 psig and high-pressure tanks operating up to 250 psig or higher. Low-pressure tanks can tolerate only a slight vacuum, ordinarily only 1 oz to 2 oz per sq in. but high-pressure tanks can be designed to withstand full vacuum.

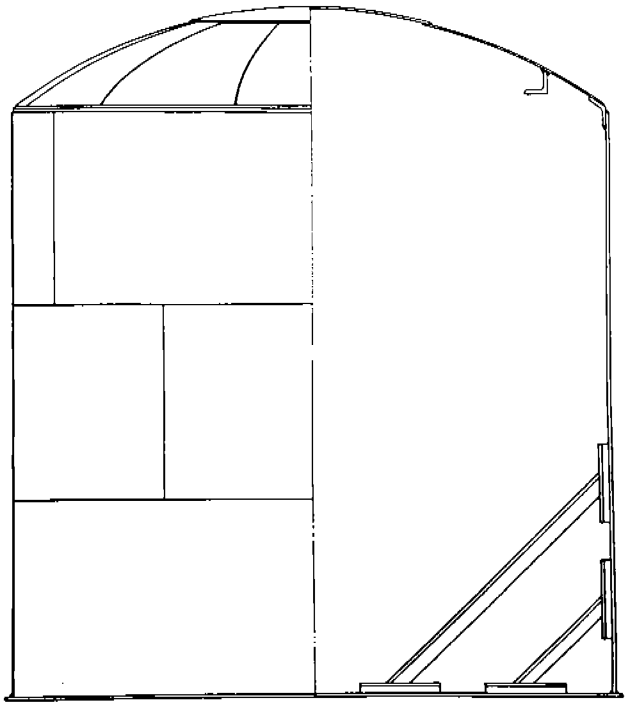
Low-pressure tanks are constructed in many shapes and sizes depending upon the operating-pressure range. The tank shown in Fig. 9 operates between 2.5 psig and 5 psig. Essentially, it is a fixed-roof tank with a flat bottom and dome roof. This tank is reinforced by means of a ring girder at the intersection of the shell and dome roof and diagonal ties between the tank bottom and the tank shell.

Another style of low-pressure tank, the noded hemispheroid, is shown in Fig. 10. This tank is designed for a pressure range of 2.5 psig to 5 psig. It consists of a cylindrical shell with curved plates in the top and bottom which may be either smooth or noded. In the plain hemispheroid there are ring girders at the intersection of the roof and shell, and the shell and the bottom, to withstand compression at these points when the vessel is subjected to internal pressure.

The noded spheroid tank, illustrated in Fig. 11, has been widely accepted for operating pressures ranging up to 15 psig; storage capacities range from 40,000 bbl to 120,000 bbl. These tanks have curved shells with internal ties and trusses and one or more nodes in the roof and bottom. Besides a ring girder and brackets around the external base of the shell, internal trusses support the curved portion of the shell and nodes in the roof. Also, a center column serves as a roof support.

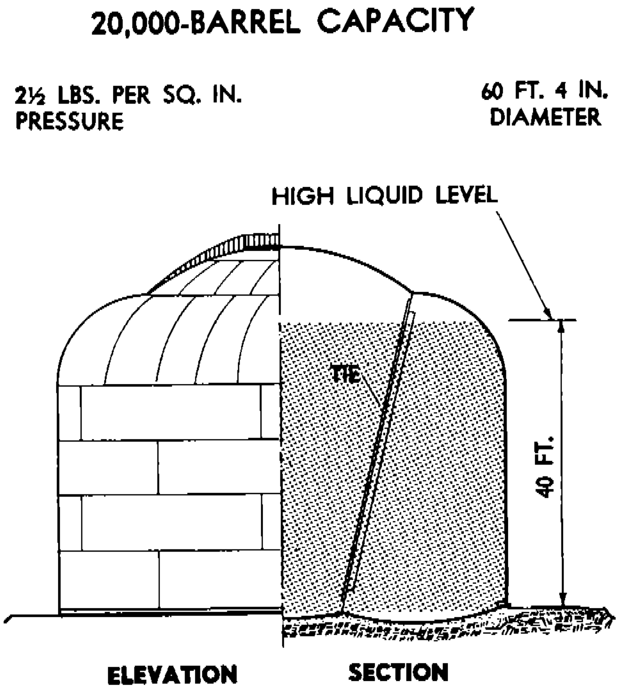
The spheroid, as illustrated in Fig. 12, is available for storage capacities ranging up to 40,000 bbl and operating pressures ranging up to 30 psig. Spheroids are smooth in appearance and have no internal framing.

The high-pressure tank is a vessel, either cylindrical, spherical, or blimp-shaped, designed for working pressures in excess of 30 psig. The maximum allowable working pressure is now limited by tank size and code requirements. For a 1,000-bbl sphere the maximum pressure is approximately 215 psig; for a 30,000-bbl



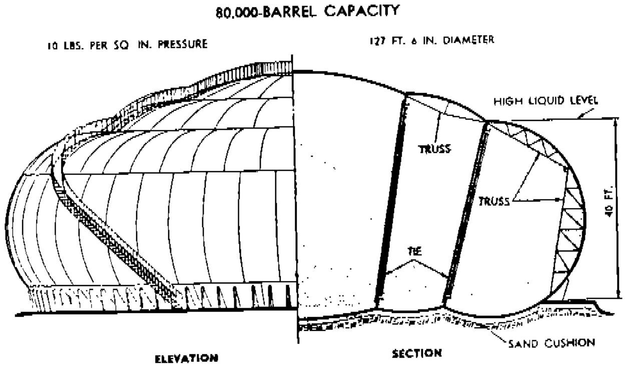
Courtesy: Hammond Iron Works.

FIG. 9—Low-Pressure Tank.



Courtesy: Chicago Bridge and Iron Company.

FIG. 10—Noded Hemispheroid.



Courtesy: Chicago Bridge and Iron Company.

FIG. 11—Noded Spheroid.

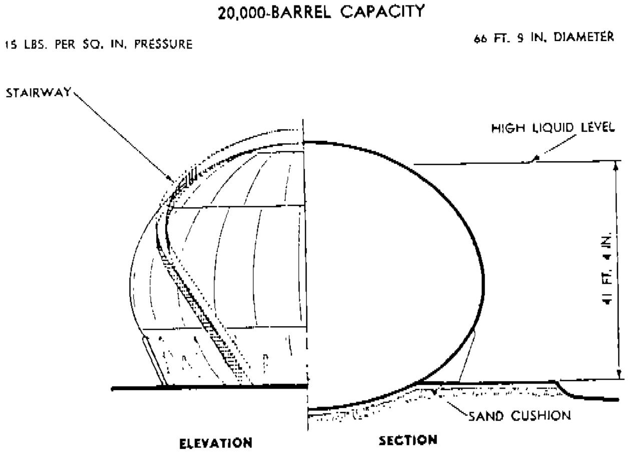
sphere, it is approximately 50 psig. These pressure limits can be increased if the vessel is stress relieved. A typical high-pressure sphere is shown in Fig. 13.

Design of Accessory Equipment: Special gastight accessories are required because of the high-pressure operations. The pressure-vacuum relief vent, and either a pressure lock or an automatic float gage are needed for normal operations. Useful auxiliary equipment may include a sampling and temperature lock on top of the tank or a series of sampling cocks and thermometers at various levels on the shell.

One style of pressure-vacuum relief vent, the still-type breather valve, is an adaptation of the safety relief valve developed for distillation columns and stills. These valves have coarse operating characteristics, which require rather high over-pressure or over-vacuum to obtain good flow.

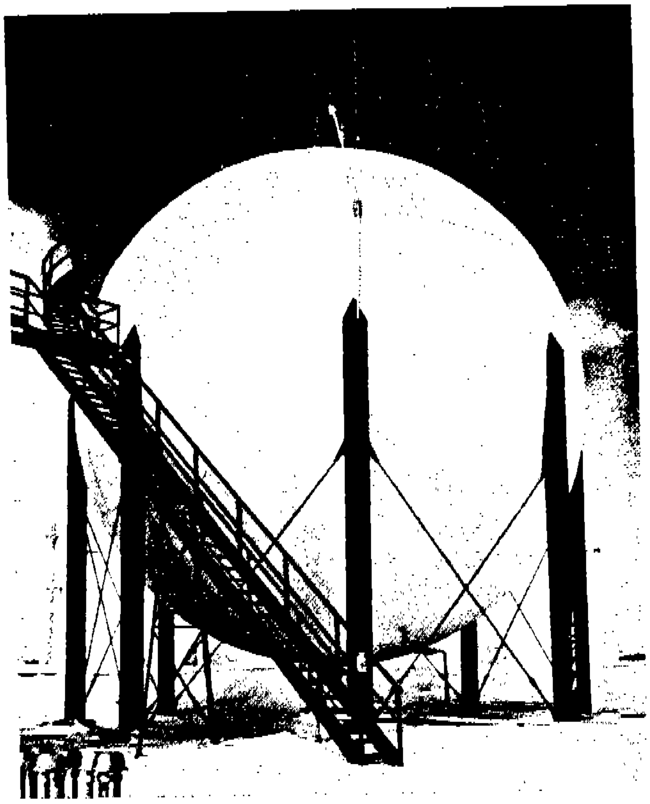
A pilot-operated pressure-relief valve is more sensitive and dependable. An integral or separate pilot valve regulates the opening and closing of a main valve. For best operation and minimum loss, the pilot-operated relief valve should be designed so that:

1. The main valve will open should the pilot valve fail.
2. Tight closure occurs at all working pressures.
3. It will be free from sticking, as a result of dust accumulation, corrosion, or other causes.
4. Free draining occurs to prevent accumulation of condensate.
5. Operation would break a film of ice which might form on the seating surface of the main or pilot valve.
6. Chatter does not occur and operation from full-open to full-close occurs with snap action and with a minimum of blowdown after relieving excess pressure.



Courtesy: Chicago Bridge and Iron Company.

FIG. 12—Spheroid.



Courtesy: Hammond Iron Works.

FIG. 13—High-Pressure Sphere.

Maintenance of Tank and Accessory Equipment: Pressure tanks should be inspected frequently to insure that tank and accessories are in gastight condition. Rupture of either the pilot or main diaphragm of a pilot-operated relief valve will cause the valve to open at a pressure below the set pressure. Valve performance should be checked periodically. Diaphragms should be inspected for cracking or other signs of deterioration and replaced as necessary. Still-type breather valves should be inspected more frequently to detect and correct freezing and sticking of pallets.

Flame arrestors should be inspected and cleaned periodically to prevent clogging with dirt or ice.

Choice of Paint: To minimize pressure variations within the tanks, they should be painted with a heat-reflective paint. Although paint color is not as critical as on fixed-roof and variable-vapor-space tanks, white paint is commonly used.

E. Vapor-Recovery Systems

Design of System: Vapor-recovery systems collect vapor from storage tanks and send it to a gas-recovery plant. These systems have sensitive pressure-vacuum controls and remove vapor as pressures build up during pumping into the tanks or during breathing. The vapor is collected, compressed, and then recovered by absorption or condensation; with lease tanks, however, the compressed gas normally is discharged into an extraction-plant gathering system. A properly designed system should eliminate most of the evaporation loss, but because of control difficulties the efficiency actually is somewhat lower.

Refinery or natural gas is sometimes used for repressuring the vapor spaces of tanks when air or a corrosive atmosphere is undesirable in the vapor-recovery system. The vapors are withdrawn from the tank as the internal pressure increases, and the repressuring gas is admitted to the tank when air normally would be drawn in. Some provision must be made to prevent collapse of the tanks when insufficient gas evolves to maintain pressure in the tanks.

Where it is uneconomical to design a tank or a storage system to operate at pressures high enough to make evaporation loss negligible, various vapor-recovery methods can be utilized. To recover vapor by condensation, one or a combination of four methods may be used:

1. Absorption may be accomplished in a suitable liquid of higher molecular weight than that of the vapors being recovered. This rich oil must be reprocessed if it is desired to separate the absorbed vapors. The liquid from which the vapors originally escaped also can be used as the absorption medium and then the enriched liquid can be returned to the storage tank without further processing. Vapor usually is absorbed under pressure.

2. Compression of the vapors, under suitable temperature conditions, will condense part or all of the vapors.

3. Cooling, alone or in combination with compression, can return vapors to the liquid state.

4. Adsorption in suitable material, such as activated charcoal or silica gel, is a means of collecting the hydrocarbon vapors if they have been mixed with noncondensables, such as air or other gases. Further processing by heat will remove the hydrocarbons from the adsorbent material; the vapors may then be condensed to the liquid state by cooling, for return to the tank.

Maintenance of System: Vapor-recovery systems require that all the tanks be kept gastight and that the instrumentation and fittings be adequately maintained.

Vapor lines should be sloped to a low spot to collect condensate. Condensed vapors and moisture should be drained periodically from each line. If vapor lines are underground, the low spot should be in a pit and it may be necessary to pump the condensate.

F. Other Ways to Control Loss

Special techniques that reduce heat input minimize evaporation loss. Before one of the techniques is used, it should be considered in relation to the specific problem; the reduction in breathing loss anticipated should be related to the cost of the technique adopted, i.e., that an economic payout be obtained.

Water Sprays: Water sprays cause cooling due to absorption of heat to vaporize the water.

Mechanical Cooling: In mechanical cooling, cooling coils or refrigeration units are used to reduce the effect of heat input. This technique is probably most commonly used for condensing vapors.

Underground Storage: In underground storage, the earth eliminates absorption or emission of radiant energy to or from the tank. Breathing effects are, therefore, greatly minimized. Accordingly, where underground storage is used for any reason, evaporation loss is minimized. Burying tanks near hot lines should be avoided.

Schedule of Tank Fillings and Emptyings: Breathing loss sometimes can be minimized where conditions permit coordinating tank filling and tank emptying with the daily breathing cycle. This is accomplished by filling during a normal period of inbreathing and emptying during a normal period of outbreathing. The compensating effects of breathing will partially cancel out filling losses. Inbreathing normally begins when the tank starts to cool in the afternoon; outbreathing normally begins when the tank starts to warm up in the morning.

Pumpings to fixed-roof tanks should be scheduled to maintain minimum average outage. If volatile stock accumulates in a group of non-interconnected tanks, only one of which is a conservation-type, this tank might be used for daily accumulation; enough stock periodically would be transferred from it to completely fill one of the fixed-roof tanks. Another method to minimize average outage is to refill a tank as soon as possible after emptying. This procedure also tends to reduce filling loss. Immediately after a tank is emptied the vapor space is lean in hydrocarbon. Refilling within a day expels vapor which is lean in hydrocarbon. A delay of three days may nullify most of the advantage.

Evaporation loss from a variable-vapor-space system can be minimized by balancing fillings and emptyings. Filling into one tank should be scheduled when vapor expansion is at a minimum or when another tank is being emptied.

Filling loss from pressure tanks can be minimized by controlling the fill rate in order to avoid pressure build up; this allows time for condensation of vapor and equilibrium is maintained. If heat of condensation cannot be dissipated as fast as condensation occurs, a rise in internal temperature will result in a higher internal pressure.

CHAPTER 4—PROCEDURES FOR CONTROLLING EVAPORATION LOSS IN OPERATIONS

Many of the operations carried out in production, refining, transportation, and marketing are potential sources of loss. Therefore, procedures which minimize evaporation loss are desirable. In production, control of temperature and pressure in the gas-oil separators and in emulsion-treating equipment is important. In refining, the operation of treating plants, and sewers, ponds, and open separators require special considerations. In transportation, the methods for loading and unloading of vessels are all-important. Marketing problems essentially are similar to those experienced in transportation.

A. Production of Crude Oil

In the production of crude oil, the methods and conditions employed in the gas-oil separation and the emulsion-treating steps will influence evaporation loss. Conservation measures should be considered for these steps to minimize loss from subsequent operations.

Gas-Oil Separation: Newly produced crude oil flows from the well to a separator through an emulsion-treating plant, and then to a lease tank. In a gas-oil separator, the hydrocarbons are divided into a gas (natural) and a liquid (crude oil and/or condensate) at the existing pressure and temperature. The phase behavior of the specific gas-oil mixture governs the distribution of the intermediate components so that any given component, such as butane, becomes distributed as a part of the gas and of the oil. In all emulsion-treating processes, the oil-gas-water mixtures go through one or more additional gas-oil separations. When the liquid enters the lease tank, another gas-oil separation occurs, normally, at a different pressure and temperature. Again, the hydrocarbons distribute themselves into a gas and a liquid phase. In these separations, some of the "crude oil components" remain with the gas and some of the gas remains, at least for a time, in solution with the crude oil. Hence, these gas-oil separations are highly important from the standpoint of possible hydrocarbon losses, and particularly with respect to possible subsequent oil losses after the oil leaves the producer's tanks.

The quantity of liquefiable vapors in the gas can be controlled in two ways. One method is to control the pressure and, where practical, the temperature of separation. This will deliver the maximum amount of these constituents to the lease tank. The other method makes use of a recovery system to process the released gases.

Loss, which results from gas-oil separation in lease tanks, can be reduced by use of the surplus wet gas to blanket the lease tanks. Such gas is at least partially saturated with the volatile components of the crude oil. The effectiveness of such a system largely depends upon a continuous supply of gas. The gas usually is supplied by crude oil in the lease tanks but may have to be augmented by gas from the separator. Such a system may be beneficial even where allowable restrictions, or heading wells, prevent continuous operation.

A vapor-recovery system may be used in two ways to minimize loss. One method is to process vapors from the separator wherein conditions are controlled to deliver a stable crude oil to the lease tanks. The other method is to process vapors from the lease tanks. Combining these two methods gives maximum recovery.

To overcome the expense of long lines of large diameter to deliver low-pressure gas to the vapor-recovery plant, the gas can be compressed at the lease. An automatic-operating compressor system is desirable because of the intermittent nature of gas release. A practical application of a gas-recovery system to lease-tank operation has been used in California for many years. In this case, a battery of tanks is manifolded to the separator gasline, which is equipped with a control valve to supply gas to the compressor whenever there are insufficient lease-tank vapors. The compressor continues to operate and does not suck air through the tank safety valves.

Emulsion Treating: Crude oil, as produced at the well, often contains water and sediment which should be removed at the lease. Materials carried along by a purely mechanical action can be separated from the crude oil by simply settling in a tank. Evaporation loss can be held to a minimum, by tieing lease gases into the settling tanks to establish air-free operation.

Crude oil containing water and sediment in an emulsion must be treated before separation. Chemicals or heat, or both, usually are used to break emulsions. Heat will increase loss from two sources as follows:

1. Raising the temperature in the heat-treating unit, it drives off larger amounts of vapor.
2. The treated crude oil is delivered to the lease tanks at a higher temperature and the evaporation rates are increased.

To some extent, the loss caused by heat treatment can be controlled. Heat must be added to raise the liquid temperature to the desired treating level. This temperature is fixed to obtain the desired emulsion-breaking action and cannot be altered to reduce evaporation except for avoiding excessive localized temperatures. This heat is dissipated in three ways:

1. As latent heat which causes vaporization in the treater.
2. As sensible heat which raises the temperature of the crude oil delivered to storage.
3. As heat lost to the atmosphere.

Heat in the outgoing treated crude oil can be minimized by cooling in heat exchange with the incoming stream. In some cases, reduced loss can justify the use of cooling coils in the stock tanks.

Treater pressure can be controlled within limits to reduce loss. There is an optimum operating pressure for each crude oil, which results in the release of the greatest amount of volatile constituents with a minimum release of the intermediate constituents.

This discussion of emulsion treating has dealt with means of delivering a maximum quantity of crude oil to the lease tanks. For lease operations at normal temperatures, when there is a vapor-recovery plant in the field, this may not be the most desirable procedure. A treater on the lease may be operated to deliver a portion of the volatile components to the recovery plant and, thus, reduce the compressor load for recovery of tank vapors.

Handling very viscous crude oils requires heat to reduce viscosity so the crude oil can be pumped economically. This situation occurs infrequently but should be discussed briefly. At the higher temperatures, these crude oils will have a greater tendency to evaporate, therefore they should be given special consideration. In applying heat, take care to avoid localized boiling. Even though the bulk of the oil is below its boiling point, local overheating can lead to a large loss.

The temperature of the oil should be kept as low as possible, consistent with the viscosity requirements. This involves an economic balance between the increased vapor loss which will result from the higher temperature operation, the value of these vapors as used or recovered, the cost of remedial measures to retard evaporation, and the savings in reduced pumping cost as a result of the lower viscosities attained at higher oil temperatures.

B. Refining

In refining, the pressure systems, treating and blending operations, and sewers, ponds, and open separators must be operated with care to minimize evaporation loss.

Pressure Systems: Some loss reduction can be achieved by maintaining pressure systems in a gastight condition. In addition, proper attention should be given to exchangers, glands, valves, and fittings to insure that they do not leak.

Treating and Blending: The major factor affecting loss from treating and blending operations is the degree of opportunity for a gas to enter the system, become saturated (partially or completely) with hydrocarbon, and leave the system. Air and other gases come into contact with hydrocarbons in treating processes in various ways. The resultant vapor issuing from the process may contain hydrocarbons in practically any degree of saturation, depending upon the intimacy and length of time in contact. Therefore, use of excessive air for treating and blending operations should be avoided. If possible, such processing vessels should be made a part of a closed system.

Sewers, Ponds, and Open Separators: Positive steps should be taken to prevent volatile liquids from reaching sewers, ponds, or open separators. This operation is best performed by isolating the individual sources of hydrocarbon entry into the sewer system. The possibility of segregating any source that contains volatile constituents should be considered.

C. Transportation and Marketing

Reduction of loss in the transportation of crude oil and its products can be achieved by the manner in which the carrier is loaded and unloaded. Control of loss also can be accomplished during the transit period between ports.

Loading Cargo Vessels, Tank Cars, and Tank Trucks: The filling lines of an oil tanker form a permanent part of its cargo piping system. The discharge nozzles are placed close to the compartment bottom and positioned to permit the flow of oil to be parallel with the bottom of the oil tanker. This arrangement minimizes the extent and duration of disturbance on the oil surface, consequently minimizing the loading evaporation loss.

Tank cars and tank trucks are either subsurface loaded or splash loaded. The latter method should be avoided because it leads to excessive loss.

For effective subsurface loading, the outlet for the loading line should be extended to the bottom of the container in order to discharge the product below the surface of the liquid soon after the start of the operation. As a result, spray loss is almost eliminated. The loading pipe for subsurface loading of tank cars is a detachable aluminum or brass spout which extends to the bottom of the car; it is connected to the loading-line outlet by a quarter-turn quick coupling. This connection should be kept gastight to eliminate drawing in air. The subsequent escape of such air will increase the evaporation loss appreciably.

For subsurface loading of tank trucks, the long downspout usually is part of a swinging counterweighted-loading-arm assembly. This system provides adequate flexibility for horizontal and vertical movements. To achieve optimum efficiency, the outlet should be kept as close as possible to the bottom of the compartment.

Installations for the recovery of vapors from loading operations have several forms, such as:

1. A system of special hoods, collecting pipelines, and a compressor to gather and deliver to a fuel system any vapor issuing from the truck hatches.

2. A system as described in item 1 but for delivery of the vapors into an existing absorption system, such as in a refinery, or into a specially built absorption unit using gasoline as the absorbing medium.

3. Recovery of the vapors by returning them to the vapor spaces in the storage tanks from which the liquid originated.

Cargo Vessels in Transit: In-transit evaporation loss can be reduced by several means. Surge and agitation with its ensuing loss can be reduced by the use of bulkheads and baffle plates. Loss because of heat absorption can be reduced by the use of insulation or reflective paints, but with products of low volatility these means usually are impractical or uneconomical. Loss caused by the escape of vapor during transit can be reduced by the use of pressure-vacuum vent valves, which is normal operation for ocean tanker and barge transportation.

Unloading Cargo Vessels, Tank Cars, and Tank Trucks: During the cargo discharge from oil tankers, evaporation of the product can be very significant if air is permitted to enter the discharge pump. Oil tankers usually are equipped with high-capacity discharge pumps which cause a high-velocity flow at the suction outlets in the tanker compartments. If the pumping rates at the time of stripping are not reduced, considerable quantities of vapor from the compartments may be drawn into the pump, resulting in inefficient operation of the pumps and, also, increased evaporation during this period. To overcome this, tankers usually are equipped with stripper pumps of smaller capacity connected to suction lines of the 6-in. size or smaller for use in discharging the last of the cargo. Excessive loss from tank cars and tank trucks during unloading is usually no problem as the discharge rates are low. However, in all unloading operations care should be taken to avoid drawing vapor into the pump.

Pipelines: A decrease in evaporation loss can be obtained by reducing the number of tanks used in pipeline operations and by reducing the frequency with which stocks are pumped into and out of tanks. A means to this end is to use a closed pipeline system with positive-displacement meters for measuring receipts and deliveries.

Controlled pumpings from lease-tank batteries into a gathering system can affect loss. Such batteries should be equipped with tank shutoff valves and pumps with speed-reducing devices to decrease the pumping rate and prevent air from being drawn into the gathering system. Special care should be taken with lease pumps operated by time clocks to avoid having a pipeline pump operate and draw air into the gathering system after available oil has been moved from the lease tank.

It is common practice to occasionally mix small percentages of butane or high-vapor-pressure natural gasolines with crude oils. These components should be added uniformly and in such a way that the specified percentage of butane or natural gasoline will not be exceeded. It is preferable to mix such components in the pipeline system while bypassing storage tanks as much as possible. Mixing should be done under sufficient pressure to avoid vaporization of the more volatile component.

The use of mechanical seals on pumps, cathodic protection of pipelines, and better housekeeping will help to reduce loss.

Marketing: Evaporation-loss problems in marketing are similar to those encountered in storage of products and in transportation.

D. Conclusion

Control of evaporation loss requires constant attention. Oil companies and tank manufacturers are constantly developing new devices and improving existing ones. Conservation equipment may become less effective with age, and an evaluation frequently reveals that modernization would be more economical. As product lines shift and product qualities change, reshuffling of tank services may reduce overall loss. Continued attention is required to maintain repair schedules and to keep desirable operating procedures in effect. Such factors demonstrate the need for organized programs for loss control.

Some type of centralized responsibility for loss control usually works best. In some situations, the control program may be only a part-time job for an engineer. In other instances, the engineer may be responsible for loss control in a specific division of the company. Some large companies have loss-control departments with broad responsibilities to insure the best handling of loss problems at all locations. Regardless of the administrative approach, some one, or some group, should be made responsible for controlling evaporation loss at each source. This will provide the necessary concerted attention that must be given to this important, economic subject related to the conservation of petroleum and its products.

APPENDIX I—DEFINITIONS AND SIGNIFICANCE OF FUNDAMENTAL TERMS

This section defines terms connected with evaporation-loss principles which govern the rate of loss.

A. Vapor Pressure of a Liquid

Vapor pressure is a measure of the force that tends to vaporize any volatile liquid, such as petroleum. Molecular motion within the liquid is responsible for this force and is related to the composition of the liquid. Smaller molecules are more active; thus, vapor pressure increases as the proportion of these low-boiling (smaller molecule) components increases. Higher temperatures also stimulate molecular motion and higher vapor pressure.

In evaporation-loss work, petroleum frequently is in contact with a vapor space. The molecules which vaporize tend to disperse throughout the vapor space. At the same time, some of the molecules in the vapor space return to the liquid. Equilibrium is established when molecules leave and return to the liquid at the same rate. At any given storage pressure, the equilibrium percentage of hydrocarbon vapor in the vapor space, essentially, is directly proportional to the vapor pressure of the liquid.

B. True Vapor Pressure of a Liquid

True vapor pressure is the vapor pressure of a liquid at a specified temperature and without its composition being changed by vaporization which occurs in most procedures used to measure vapor pressure. With mixtures, such vaporization results in a lowering of the measured vapor pressure. True vapor pressure differentiates from vapor pressures so determined.

Vaporization from a hydrocarbon mixture lowers the vapor pressure because the lighter components vaporize more readily, leaving the liquid richer in the heavier, less-volatile components. Thus, for motor gasolines and similar wide-boiling mixtures, the true vapor pressure at 100 F may be significantly higher than the Reid vapor pressure (RVP), because some vaporization is encountered during the Reid test. For a pure single component, liquid vaporization will not change the vapor pressure and true vapor pressure substantially will equal the RVP.

True vapor pressure can be estimated from correlations relating it to RVP and ASTM boiling characteristics. Charts in Appendix V illustrate such relationships for gasolines and crude oils over a wide range of temperatures. Although there is no standardized procedure for directly determining true vapor pressure, a research approach involves the testing of a gas and air-free sample in a container with an infinitesimally small vapor space. The charts in Appendix V, for gasolines, are based on true vapor pressure measurements made by this research method.

In evaporation-loss work, true vapor pressure at storage temperatures directly affects the rate of evaporation loss. Increased true vapor pressure accelerates the rate of evaporation into any tank vapor space. Also, at saturation a vapor space contains proportionately more hydrocarbon vapors as true vapor pressure rises. Both of these factors increase the evaporation loss from the tank during any specific breathing cycle or filling schedule.

C. Reid Vapor Pressure of a Liquid

Reid vapor pressure (RVP) is the absolute pressure in pounds per square inch determined at 100 F and $\frac{V}{L} = 4$ (ratio of vapor volume to liquid volume, as defined in *ASTM Designation:* D 323-56) by using apparatus and procedures as standardized under the auspices of the American Society for Testing Materials. Thus, the RVP is the vapor pressure of a sample which has had its composition changed because of the vaporization required to saturate the vapor space of the bomb. Accordingly, RVP is slightly lower than the true vapor pressure of the sample at 100 F.

Frequently, RVP is used to characterize volatility of gasolines and crude oils; it also provides the most convenient method for evaluation of true vapor pressure. Through correlation, RVP of the hydrocarbon liquid under investigation can be converted to true vapor pressure at any normal storage temperature. Charts in Appendix V relate RVP and ASTM boiling characteristics of gasolines and crude oils to true vapor pressure over a wide range of temperatures.

D. Partial Pressure of Vapor

The partial pressure of hydrocarbon vapor in a vapor space is a measure of the force exerted by hydrocarbon molecules striking the confining wall. Air molecules, usually present in evaporation-loss problems, similarly generate a partial pressure. The sum of all partial pressures equals the total pressure of the system; the partial pressure of any vapor component is proportional to its volumetric fraction of the vapor space.

In evaporation-loss work, a vapor space normally is in contact with the liquid which emits the hydrocarbon vapors. An equilibrium exists when the partial pressure of hydrocarbon vapor equals the vapor pressure of the liquid and the rates of vaporization and condensation are equal.

E. Saturation of a Vapor Space

The vapor space in a tank, with respect to a given component, is said to be saturated when equilibrium exists between that component in the vapor and the liquid phases under given conditions of temperature and pressure, and the composition of the vapor space is uniform throughout.

Degree of saturation is the percentage of saturation with respect to a given component which prevails at any given time or location under normal equilibrium conditions.

F. Diffusion in a Vapor Space

Diffusion is the molecular motion which tends to uniformly distribute any component throughout a vapor space. The rate of diffusion is highest for smaller molecules which travel fastest. Also, the rate is proportional to the distance a molecule travels before it is impeded by collision with another molecule. Thus, the total time to reach equilibrium depends upon the size of the molecules, the size of the vapor space, the temperature, and pressure.

In evaporation-loss work, diffusion is one way by which newly vaporized hydrocarbons distribute themselves throughout a vapor space in an effort to saturate it. For gasoline components at normal storage and operating temperatures, the diffusion process is relatively slow and, by itself, exerts a minor influence on evaporation loss.

G. Vaporization

Vaporization is the process whereby a liquid changes to a vapor, either with or without boiling.

H. Condensation

Condensation is the process of a vapor changing to a liquid. It is the reverse of vaporization and occurs when the partial pressure of the vapor exceeds the vapor pressure of the liquid because the liquid temperature drops or vapor-space volume decreases. However, condensation also may occur when the vapor temperature drops because of a decrease in ambient temperature. In this case, the partial pressure of the vapor and liquid droplets in the vapor space may be less than the vapor pressure of the main liquid interface.

I. Conduction

Conduction is the transfer of heat from one part of a body to another part of the same body, or from one body to another in physical contact with it; no appreciable displacement of the particles of the body occurs. Heat coming from the outside passes through the tank wall by conduction.

J. Convection

Convection is the transfer of heat by the movement and mixing of fluids induced by temperature differences. Hot gases and liquids with low density rising in a container and cold gases and liquids with higher density settling in a container represent the movement of material by convection. In addition to the movement of material caused by temperature differences (thermal convection), movement may be induced by other means, such as a pump or the wind. Heat may be transferred to or from another tank surface by convection caused by wind and is dependent upon the wind velocity. Heat may be transferred to or from the inner tank surface by thermal convection. In this process, heat is added to or taken from the material in the tank.

K. Radiation

A hot body gives off heat in the form of radiant energy. When this energy strikes another body, part is reflected and the rest is absorbed and transformed into heat. The rate at which a body absorbs radiant energy as heat is dependent upon its area-surface reflective properties, its geometrical exposure to the source, and to the temperature difference between it and the source. Heat may be transferred directly from the surroundings to the outer tank surface by radiation. The direction of heat transfer, the rate, and the amount are, of course, controlled by weather and time conditions.

APPENDIX II—DERIVATION OF BREATHING- AND FILLING-LOSS EQUATIONS [1a]

A theoretical breathing-loss equation can be derived from the ideal gas laws and from the pressure, temperature, and volume conditions in the vapor space of a tank containing a volatile liquid. An equation for filling losses can also be developed.

First, the laws governing the behavior of ideal gases must be defined. For perfect gases, the relations between pressure, volume, and temperature are defined by the law:

$$\frac{\text{(absolute pressure) (volume)}}{\text{(absolute temperature)}} = \text{constant}$$

This equation, based on Boyle's and Charles' laws, is used to analyze conditions in the vapor space of a tank.

A. Breathing Losses

For example, a tank is partly filled with a volatile liquid and equipped with a pressure-vacuum vent. In the most general case, vapor-space volume, total pressure, and temperature vary, but to different degrees. The various pressure, volume, and temperature terms used can be defined as:

P_1 = gage pressure at which tank vacuum vent opens, pounds per square inch gage.
P_2 = gage pressure at which tank pressure vent opens, pounds per square inch gage.
P_a = atmospheric pressure (standard condition of 14.7 psia).
p_1 = vapor pressure at minimum liquid-surface temperature, pounds per square inch absolute.
p_2 = vapor pressure at maximum liquid-surface temperature, pounds per square inch absolute.
t_1 = minimum average vapor-space temperature, degrees Fahrenheit.
t_2 = maximum average vapor-space temperature, degrees Fahrenheit.
V_1 = minimum volume of vapor space, cubic feet.
V_2 = maximum volume of vapor space, cubic feet.
V_{av} = volume of vapor lost by breathing, cubic feet.
I = per cent volume increase of vapor space.
G = gallons of gasoline lost in one breathing cycle.

During breathing, the temperature, volume, and pressure vary from a certain combination of minimum conditions to a certain combination of maximum conditions. All of the variables are assumed to be at minimum conditions simultaneously, and to change and arrive at maximum conditions simultaneously.

Consider the air in the vapor space of a closed container partly filled with volatile liquids. At minimum conditions, the volume of the air is V_1, and the temperature is t_1. Assuming that the vacuum vent is on the verge of opening, the total absolute pressure in the vapor space is $P_a + P_1$. The vapor pressure p_1 in the space is the vapor pressure of the stored volatile liquid at its liquid-surface temperature. The partial pressure of the air in the vapor is, therefore, $P_a + P_1 - p_1$.

Likewise, at the maximum conditions, the volume of the air is V_2, and the temperature is t_2. Assuming that the pressure-relief vent is on the verge of opening, the total absolute pressure in the vapor space is $P_a + P_2$. The vapor pressure corresponding to the maximum liquid-surface temperature is p_2. Hence, the partial pressure of the air is $P_a + P_2 - p_2$.

Then, from the laws of perfect gases as applied to the air only, the product of the partial pressure and volume of the air, divided by the absolute temperature, is constant, or:

$$\left(\frac{P_a+P_2-p_2}{t_2+460}\right) V_2 = \left(\frac{P_a+P_1-p_1}{t_1+460}\right) V_1 \qquad (1)$$

This is the general formula for the pressure-volume-temperature relationship in the vapor space of a closed system of storage of volatile liquids.

For a storage- and evaporation-saving system involving a variable vapor-space volume, equation (1) may be written:

$$\frac{V_2}{V_1} = \left(\frac{P_a+P_1-p_1}{P_a+P_2-p_2}\right)\left(\frac{t_2+460}{t_1+460}\right)$$

And by definition of I:

$$\frac{I}{100} = \frac{V_2-V_1}{V_1} = \frac{V_2}{V_1} - 1$$

Hence:

$$I = 100\left[\left(\frac{P_a+P_1-p_1}{P_a+P_2-p_2}\right)\left(\frac{t_2+460}{t_1+460}\right) - 1\right] \qquad (2)$$

This is the formula for the per cent of expansion required to prevent losses by breathing caused by temperature variation.

However, if the size of the vapor space is constant, the volume represented in this expansion is lost through the tank vents. This is the case with a fixed-roof tank at constant liquid level and not connected to a vapor-conservation system. Then, because the constant vapor-space volume equals the minimum vapor-space volume, V_1, the volume of vapor lost by breathing is:

$$V_{av} = V_1\left[\left(\frac{P_a+P_1-p_1}{P_a+P_2-p_2}\right)\left(\frac{t_2+460}{t_1+460}\right) - 1\right] \qquad (3)$$

Knowing the number of cubic feet occupied by 1 gal of liquid when it is in the form of a saturated vapor permits conversion of this vapor volume into gallons of liquid.

Avogadro's law, an important and useful concept, logically leads to an understanding of the relation be-

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[a] Figures refer to REFERENCES on p. 34.

tween molecular weight and vapor volume. This law states:

> All perfect gases at a given pressure and temperature have the same number of molecules in any given volume.

Thus, the density of a perfect gas is proportional to the molecular weight. Where *M* is the molecular weight, a pound mol or *M* pounds of perfect gas will occupy approximately 379.5 cu ft at 60 F and atmospheric pressure. Like other gas laws, Avogadro's law is approximate for real gases and vapors. For hydrocarbon vapors, *M* pounds will occupy approximately (379.5) (C) cu ft at 60 F and 14.7 psia; *C* is the compressibility factor, $C = \frac{PV}{RT}$, and may differ from unity by several per cent, and will vary with the composition of the vapor and with the true vapor pressure of the liquid.

A vapor to liquid conversion factor, number of cubic feet of saturated vapor per gallon of liquid, is derived as follows:

Let:

W = weight of 1 gal of liquid, pounds.
M = molecular weight of the hydrocarbon vapor.
C = compressibility factor.
p_v = partial pressure of the hydrocarbon in the vapor at saturation, pounds per square inch absolute.
Z = number of cubic feet of saturated vapor at 60 F and 14.7 psia, per gallon of liquid.
P = absolute pressure.
V = vapor volume.
R = gas constant.
T = absolute temperature.

Then the number of cubic feet of vapor at 60 F and atmospheric pressure containing 1 gal of liquid is:

$$\frac{379.5\ WC}{M}$$

As stated in Boyle's law, the volume of a vapor is proportional to its partial pressure, p_v, therefore:

$$Z = \left(\frac{379.5\ WC}{M}\right)\left(\frac{14.7}{p_v}\right)$$

The vapor from motor gasoline contains hydrocarbons chiefly in the range of *iso*butane, *n*butane, *iso*pentane, *n*pentane, and the hexanes, with small amounts of heavier hydrocarbons. The butanes and the pentanes are the principal components. In general, the molecular weights of the vapors from gasolines or other volatile products are unknown, this is also true as regards the equivalent weights of 1 gal of liquid. However, the value of *Z* for mixed petroleum vapors can be closely approximated by the relation:

$$Z = \frac{690-4M}{p_v} \qquad (4)$$

This relationship is applicable to 60 F gal of condensed vapor, and to vapor volumes measured at 60 F, or computed to that temperature. The molecular weight (*M*) of a petroleum vapor in equilibrium with the liquid product at 60 F can be approximated from:

Reid Vapor Pressure (Pounds)	10-Per-Cent-Point Slope				
	0	*1*	*2*	*3*	*4*
6	84	74	69	66	63
7	82	72	67	64	61
8	80	70	66	63	60
9	78	69	64	62	58
10	77	67	63	60	57
11	76	66	62	59	56
12	75	65	61	58	55
13	74	64	60	57	54
14	73	63	59	56	53
15	72	62	58	55	52
16	72	61	57	54	51

The molecular weights of petroleum vapors change with the storage temperature, and this change is independent of the Reid vapor pressure (RVP) of the product, and only depends upon the 10-per-cent-point slope. Change in molecular weight per degree change in storage temperature, $\frac{\Delta M}{\Delta t}$, as a function of 10-per-cent-point slope is:

10-Per-Cent-Point Slope	$\frac{\Delta M}{\Delta t}$
0	0.000
1	0.034
2	0.049
3	0.059
4	0.068

The molecular weight decreases as the product temperature decreases, and vice versa.

Applying the relation as expressed in equation (4) to the conditions for equation (3), where the average vapor pressure during the temperature increase is:

$$\frac{p_1+p_2}{2},$$

the average volume of vapor containing 1 gal of liquid is, therefore:

$$\frac{(690-4M)(2)}{p_1+p_2} = \frac{1{,}380-8M}{p_1+p_2}$$

The total number of gallons of gasoline lost in the vented volume of vapor then becomes:

$$G = V_1\left(\frac{p_1+p_2}{1{,}380-8M}\right)\left[\left(\frac{P_a+P_1-p_1}{P_a+P_2-p_2}\right)\left(\frac{t_2+460}{t_1+460}\right)-1\right] \qquad (5)$$

Theoretically, this expression might be used to estimate the maximum breathing loss caused by temperature change in any tank with a vapor space of fixed volume.

In equation (5), the quantity within brackets represents the theoretical expansion of the vapor expressed as a fraction of the vapor-space volume, V_1. In fixed-roof tanks, which have conservation vents with low settings, the value of this quantity usually does not exceed 15 per cent, and normally is lower.

It is possible to derive an approximate equation which is premised upon the assumption that the changes in t, p, and P are relatively small when compared with absolute values. Let Δ be used to denote these small changes and let

$$(P_1 - p_1) = (P_2 - p_2) - \Delta(P - p)$$

and

$$t_2 = t_1 + \Delta t$$

Then the quantity in brackets of equation (5) becomes:

$$\left[\left(\frac{P_a + P_2 - p_2 - \Delta(P - p)}{P_a + P_2 - p_2}\right)\left(\frac{t_1 + \Delta t + 460}{t_1 + 460}\right) - 1\right]$$

$$\left[\left(1 - \left[\frac{\Delta(P - p)}{P_a + P_2 - p_2}\right]\right)\left(1 + \left[\frac{\Delta t}{t_1 + 460}\right]\right) - 1\right]$$

$$\left[1 + \left(\frac{\Delta t}{t_1 + 460}\right) - \left(\frac{\Delta(P - p)}{P_a + P_2 - p_2}\right) - \left(\frac{\Delta(P - p)}{P_a + P_2 - p_2}\right)\left(\frac{\Delta t}{t_1 + 460}\right) - 1\right]$$

$$\left[\left(\frac{\Delta t}{t_1 + 460}\right) - \left(\frac{\Delta(P - p)}{P_a + P_2 - p_2}\right) - \left(\frac{\Delta(P - p)}{P_a + P_2 - p_2}\right)\left(\frac{\Delta t}{t_1 + 460}\right)\right]$$

The last term is the product of two small quantities and may be considered negligible. The expression becomes:

$$\left[\left(\frac{\Delta t}{t_1 + 460}\right) - \left(\frac{\Delta(P - p)}{P_a + P_2 - p_2}\right)\right]$$

$$\left[\left(\frac{t_2 - t_1}{t_1 + 460}\right) - \left(\frac{(P_2 - p_2) - (P_1 - p_1)}{P_a + P_2 - p_2}\right)\right]$$

$$\left[\left(\frac{t_2 - t_1}{t_1 + 460}\right) + \left(\frac{p_2 - p_1}{P_a + P_2 - p_2}\right) - \left(\frac{P_2 - P_1}{P_a + P_2 - p_2}\right)\right]$$

With a value of this low order, the quantity may be written with little loss of mathematical accuracy, thus:

$$\left[\left(\frac{P_a + P_1 - p_1}{P_a + P_2 - p_2}\right)\left(\frac{t_2 + 460}{t_1 + 460}\right) - 1\right]$$

$$\left[\left(\frac{t_2 - t_1}{t_1 + 460}\right) + \left(\frac{p_2 - p_1}{P_a + P_2 - p_2}\right) - \left(\frac{P_2 - P_1}{P_a + P_2 - p_2}\right)\right]$$

Then the theoretical equation for breathing loss may be expressed, with small error, thus:

$$G = V_1\left(\frac{p_1 + p_2}{1{,}380 - 8M}\right)\left[\left(\frac{t_2 - t_1}{t_1 + 460}\right) + \left(\frac{p_2 - p_1}{P_a + P_2 - p_2}\right) - \left(\frac{P_2 - P_1}{P_a + P_2 - p_2}\right)\right] \tag{5a}$$

Equation (5a) gives a clearer concept of the nature of breathing losses. Each factor and term has a definite physical meaning. V_1 is the volume of the vapor space in cubic feet. The factor $\frac{p_1 + p_2}{1{,}380 - 8M}$ is the number of gallons of liquid hydrocarbon contained in 1 cu ft of vapor. The quantity within brackets is the total theoretical expansion expressed as a fraction of the vapor-space volume. When the vapor-concentration factor $\frac{p_1 + p_2}{1{,}380 - 8M}$ is multiplied by the vapor-space volume V_1, it gives the approximate number of gallons contained in the vapor space. This, in turn, when multiplied by the quantity within brackets in equation (5a), gives the theoretical loss G, in gallons, for the breathing cycle, which is usually one day.

In the approximate equation (5a), the theoretical expansion, in brackets, is broken down into three parts. The first term, $\frac{t_2 - t_1}{t_1 + 460}$, is the expansion which results from vapor-space temperature change. The second term, $\frac{p_2 - p_1}{P_a + P_2 - p_2}$, represents the theoretical expansion which results from additional hydrocarbon evaporating into the vapor space when rising liquid-surface temperature causes an increase of true vapor pressure. The third term, $\frac{P_2 - P_1}{P_a + P_2 - p_2}$, is subtracted from the first and second terms. It represents a reduction of the total expansion which results from compression caused by an increase of the tank-gage pressure between the vacuum and the pressure-vent settings.

Thus, the mechanism of breathing is basically quite simple. Ideally, it should be possible to evaluate the several factors and terms in equation (5a) and to apply coefficients in the proper places in order to calculate breathing losses for a given combination of conditions. However, this is an enormously complicated problem. A review of published data reveals wide discrepancies in the evaluation of individual factors governing evaporation losses.

Factor $\frac{p_1 + p_2}{1{,}380 - 8M}$ of equation (5a), the approximate number of gallons per cubic foot of vapor, represents complete saturation of the vapor space and, also, equilibrium with the liquid surface at all times. It is the highest vapor concentration that can exist. Based on Orsat analyses in 80,000-bbl tanks, McCullough, *et al.*[2] report: "There appeared to be no stratification of air and vapor except for about an hour following the inhalation period." This implies a very high degree of saturation. Exhalation of saturated vapor seems a reasonable assumption because most breathing-loss tests were conducted either during standing storage or while the tanks were slowly being emptied.

One tank manufacturer gives 45 per cent as the average saturation of the vapors vented from an 80,000-bbl tank. A more nearly complete saturation probably exists, except when liquid withdrawals are rapid and the throughput is high. When the per cent of saturation is low because of very high throughput, the reduced evaporation loss usually is considered as a reduction in filling loss.

The terms $\frac{t_2 - t_1}{t_1 + 460}$ and $\frac{p_2 - p_1}{P_a + P_2 - p_2}$ are as controversial as vapor concentration. The temperatures, t_2 and t_1, are not susceptible to accurate measurement by ordinary methods. A thermometer or other temperature-sensing element does not always give a true indication of the temperature of the surrounding vapor. The transfer of heat by radiation may greatly affect the temperature reading, particularly when the roof and shell of the tank are hot and the vapor is quiescent. Also, p_1 and p_2 are difficult to evaluate because the liquid-surface temperatures, at which the true vapor pressures are desired, are obscure. The effective surface film is of molecular thickness, and no suitable means of measuring its temperature has been devised. For practical purposes, however, the effective temperature is that of the upper part of the liquid column. In addition, the problem of degree of saturation occurs again in the evaluation of the effect of p_2-p_1. The change of the average partial pressure of the vapor in the vapor space may be low when compared with p_2-p_1 at the liquid surface because of stratification or incomplete diffusion of vapors in the vapor space. Many, if not most, of the published articles neglect the second term (the effect of vapor-pressure change) as unimportant. They account for all of the expansion on the basis of temperature change, $\frac{t_2-t_1}{t_1+460}$. One reference[3] develops the formula that accounts for the vapor-pressure change and cites a short-term test on a 15,000-bbl tank with a lifter roof. Lifter-roof movement or expansion was accounted for by the assumptions:

1. Average daily vapor-space temperature change is 1¼ times the atmospheric temperature change.
2. Daily gasoline surface-temperature change is one-tenth of the atmospheric temperature change.

Smith and Harden[4] conclude that the effect of vapor-pressure change is as great or greater than the breathing effect of the vapor in the tank because of the change of vapor temperature. Thus, published data covers a wide range, evaluating $\frac{p_2-p_1}{P_a+P_2-p_2}$ from zero to an effect at least equal to the term $\frac{t_2-t_1}{t_1+460}$.

The term $\frac{P_2-P_1}{P_a+P_2-p_2}$ can be evaluated with fair accuracy. All of the variables are accurately known except p_2. The P_2 in the denominator may be neglected, inasmuch as it is small when compared with P_a. The value of p_2 may be taken as the vapor pressure of the stored liquid at its average liquid-body temperature. This will be lower than the vapor pressure at maximum liquid-surface temperature by enough to account for some incomplete saturation. In any event, a sizable error in p_2 will not seriously affect the value of the term.

B. Filling Losses

Theoretical considerations regarding filling losses are much simpler than those relating to breathing losses. Fewer variables have a direct effect on their magnitude. Basically, filling losses are caused by the displacement of vapor from the tank by the introduction of liquid into the tank. If the partial pressure of the hydrocarbon in the vapor were p_v, that is to say, the vapor is saturated, the number of cubic feet of saturated gasoline vapor per gallon of liquid would be obtained from equation (4):

$$Z = \frac{690—4M}{p_v}$$

The filling loss would be, therefore, 1 gal for every $\frac{690-4M}{p_v}$ cu ft pumped into the tank, or 1 gal for every $\frac{(690-4M)(7.48)}{p_v}$ gal pumped in. If V_L gallons were pumped into the tank, the filling loss, therefore, would be:

$$F = \frac{p_v V_L}{(690—4M)(7.48)}$$

If M is taken equal to 61, then

$$F = \frac{3p_v V_L}{10{,}000} \qquad (6)$$

Equation (6) is the basic formula for filling losses. However, experience has shown that a correction factor, K, must be applied to the equation to correct for variation in saturation caused by frequency of turnover and method of operating the tank. For practical application, equation (6) usually will take the form of:

$$F = \frac{3p\,V_L}{10{,}000}\,K$$

Where:

F = filling loss, in units of V_L.
p = true vapor pressure, pounds per square inch absolute.
V_L = volume of liquid pumped in.
K = operation factor based on experience.

REFERENCES

[1] Original breathing-loss equation derived by H. C. Boardman. See "Symposium on Evaporation Loss," *Proc. API* **32** [1] 213-81 (1952). Equations appearing herein are modifications developed by O. C. Bridgeman; see "Some Phases of the Problem of Evaluating Evaporation Losses from Petroleum Products by Means of Vapor Volume Measurements," Phillips Petroleum Co., Bartlesville, Okla., Phillips Report 1288-55R (1955).

[2] G. W. McCullough, H. R. Legatski, and H. J. Pixley, "Reducing Losses of Volatile Liquids in Atmospheric Pressure Storage," *Natl. Petrol. News* **38** [6] R122-30 (1946).

[3] H. C. Boardman, "Storage of Volatile Petroleum Products," *Petrol. Refiner* **25** [4] 109-16 (1946).

[4] S. S. Smith and G. D. Harden, "Factors Affecting Conservation of Products in Storage," *Oil Gas J.* **51** [10] 125-27 (1952).

APPENDIX III—GENERAL INFORMATION

Symbols and Abbreviations

Area	A; S	sq ft
Coefficient of expansion, volumetric	β	increase in vol per unit vol per deg temperature change
Coefficient of heat transfer:		
individual	h	Btu per (hr) (sq ft) (deg F)
overall	U	Btu per (hr) (sq ft) (deg F)
Compressibility factor	C	*PV* per *RT*
Concentration, volumetric	c	lb per cu ft; lb moles per cu ft
Conductance	$\frac{1}{R}$; C	Btu per (hr) (deg F)
Density	ρ	lb per cu ft
Diameter	D	ft
Difference, finite	Δ	
Diffusity of vapor	D_v	sq ft per hr
Film thickness, effective	B	ft
Fugacity	f	lb force per sq ft, atm
Gas constant, universal	R; R_0	
Internal energy	E	Btu; Btu per lb mole
Internal energy per unit weight	U	Btu per lb
Latent heat of evaporation	λ	Btu per lb
Length	L	ft
Mechanical equivalent of heat	J	(ft) (lb force) per Btu
Molecular weight	M	
Mole fraction in:		
liquid	x	[*Note:* x and y used to denote equilibrium value.]
vapor	y	
Mole ratio in:		
liquid	X	
vapor	Y	
Number, in general	N	No.
Partial pressure or vapor pressure	p	
Pressure, total	P	lb force per sq ft, atm
Quantity of heat transferred	Q	Btu
Radiation, intensity of	N	Btu per (hr) (sq ft)
Radius	r	ft
Rate of heat transfer	q	Btu per hr
Resistance, thermal	R	(sq ft) (deg F) per (Btu per hr)
Specific heat:	c	Btu per (lb) (deg F)
at constant pressure	c_p	Btu per (lb) (deg F)
at constant volume	c_v	Btu per (lb) (deg F)
Specific volume	v	cu ft per lb
Surface per unit volume	a	sq ft per cu ft
Surface tension	γ	lb force per ft; dynes per cm
Temperature:	t	deg F or deg C
absolute	T	deg K or deg R
Thermal conductivity	k	Btu per (hr) (sq ft) (deg F per ft)
Time	t	sec; min; hr
Volume:		
total or per mole	V	cu ft; cu ft per lb mole
liquid	V_L	gal; bbl
Weight, quantity of matter	W	lb
Width, breath	b	ft
Work	W; W_k	Btu; pcu

Conversion Factors

Multiply	By	To Obtain
Atm (atmospheres)	14.7	lb per sq in.
Atm	760	mm of Hg (32 F)
Atm	29.92	in. of Hg (32 F)
Atm	33.93	ft of water (60 F)
Atm	1,013,250	dynes per sq cm
Bbl (42 U.S. gal)	42	gal (U.S.)
Bbl	5.615	cu ft
Bbl per day	1.75	gal per hr
Bbl per day	0.234	cu ft per hr
Cm	0.3937	in.
Cm of Hg	0.1934	lb per sq in.
Cu ft	7.481	gal
Cu ft	28.32	liters
Cu ft of dry air (60 F)	0.076	lb of air
Cu ft of water (60 F in air)	62.30	lb of water
Ft	30.48	cm
Ft of water (60 F in air)	2.244	cm of Hg
Ft of water (60 F in air)	0.4326	lb per sq in.
Ft of water (60 F in air)	62.30	lb per sq ft
G per cu cm	62.43	lb per cu ft
G mol	22.414	liters at 0 C and 1 atm
Gal (U.S.)	231	cu in.
Gal (U.S.)	3.785	liters
Gal per hr	0.5715	bbl (42 U.S. gal) per day
Gal of water (60 F in air)	8.328	lb
In.	2.54	cm
In. of Hg	0.03342	atm
In. of Hg	0.4912	lb per sq in.
Lb	453.6	g
Lb-mol	379.5	cu ft vapor, 60 F and 1 atm
Lb-mol	359	cu ft vapor, 32 F and 1 atm
Liter	1,000.028	cu cm
Oz, avoirdupois	28.35	g
Oz, fluid	1.805	cu in.
Oz, fluid	29.57	cu cm
R (gas constant)	82.06	(cu cm) (atm) per (g mol) (deg K)
R (gas constant)	1,545	ft-lb per (lb-mol) (deg R)
Specific gravity 60 F / 60 F	8.328	lb per gal (in air)
Temp (deg C + 273)	1.0	abs temp, deg K
Temp (deg C + 17.8)	1.8	temp, deg F
Temp (deg F + 460)	1.0	abs temp, deg R
Temp (deg F − 32)	0.5556	temp, deg C

DEGREE FAHRENHEIT = 1.8 C +32

DEGREE CENTIGRADE = $\frac{\text{DEG F} - 32}{1.8}$

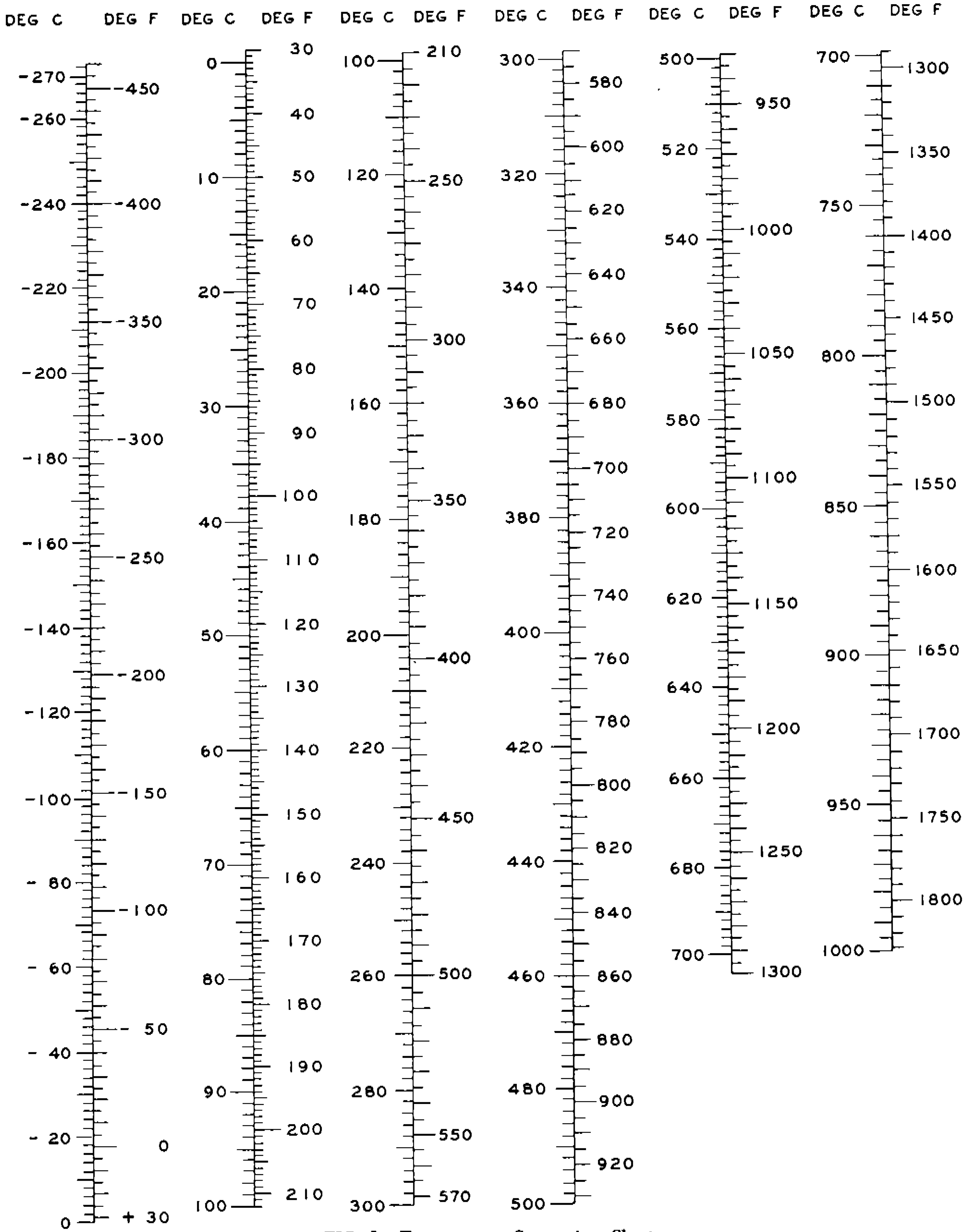


FIG. 1—Temperature Conversion Chart.

APPENDIX IV—PROPERTIES OF PURE HYDROCARBONS

TABLE 1—Properties of Pure Compounds

Name	Formula	Molecular Weight	Liquid Specific Gravity (60 F/60 F)	Normal Boiling Point (Degrees Fahrenheit)	Vapor Pressure at 100 F (Pounds per Square Inch Absolute)	Freezing Point (Degrees Fahrenheit)	Critical Temperature (Degrees Fahrenheit)	Critical Pressure (Pounds per Square Inch Absolute)	Latent Heat of Vaporization at Normal Boiling Point (Btu per Pound)
Paraffins									
Methane	CH_4	16.042	—	—258.68	—	—296.46	—115.78	673.1	219.22
Ethane	C_2H_6	30.068	—	—127.53	—	—297.89	90.32	709.8	210.41
Propane	C_3H_8	44.094	0.5077 *	— 43.73	—	—305.84	206.26	617.4	183.05
*n*Butane	C_4H_{10}	58.120	0.5844 *	31.10	—	—217.03	305.62	550.7	165.64
*Iso*butane	C_4H_{10}	58.120	0.5631 *	10.89	—	—255.28	274.96	529.1	157.51
*n*Pentane	C_5H_{12}	72.146	0.6312	96.93	15.570	—201.50	385.92	489.5	153.59
*Iso*pentane	C_5H_{12}	72.146	0.6248	82.13	20.44	—255.82	370.1	483.	147.13
*n*Hexane	C_6H_{14}	86.172	0.6640	155.73	4.956	—139.63	454.5	440.	143.95
*Iso*hexane (2-methyl pentane)	C_6H_{14}	86.172	0.6579	140.49	6.767	—244.61	436.9	440.1	138.67
2,2-Dimethylbutane (neohexane)	C_6H_{14}	86.172	0.6540	121.53	9.856	—147.77	421.2	450.7	131.24
2,3-Dimethylbutane (di*iso*propyl)	C_6H_{14}	86.172	0.6664	136.38	7.404	—199.37	440.9	455.4	136.08
*n*Heptane	C_7H_{16}	100.198	0.6882	209.17	1.620	—131.10	512.62	396.8	135.99
2,2,3-Trimethylbutane (triptane)	C_7H_{16}	100.198	0.6945	177.59	3.374	— 12.84	497.	437.2	124.20
*n*Octane	C_8H_{18}	114.224	0.7068	258.20	0.537	— 70.24	565.2	362.1	129.51
2,5-Dimethylhexane (di*iso*butyl)	C_8H_{18}	114.224	0.6980	228.39	1.101	—132.16	530.	362.	122.8
2,2,4-Trimethylpentane (*iso*octane)	C_8H_{18}	114.224	0.6962	210.63	1.708	—161.28	520.07	374.7	116.69
*n*Nonane	C_9H_{20}	128.250	0.7217	303.44	0.179	— 64.33	613.0	332.	123.74
*n*Decane	$C_{10}H_{22}$	142.276	0.7341	345.42	—	— 21.39	655.0	304.	118.68
Cetane (*n*hexadecane)	$C_{16}H_{34}$	226.432	0.7773	548.23	—	— 64.70	844.	206.	97.2
Monoolefins									
Ethene (ethylene)	C_2H_4	28.052	—	—154.68	—	—272.47	49.82	742.1	207.57
Propene (propylene)	C_3H_6	42.078	0.5220 *	— 53.86	—	—301.45	197.4	667.	188.18
1-Butene	C_4H_8	56.104	0.6013 *	20.73	—	—301.63	295.6	583.	167.94
*Iso*butene	C_4H_8	56.104	0.6004 *	19.58	—	—220.63	292.51	579.8	169.48
cis-2-Butene	C_4H_8	56.104	0.6271 *	38.70	—	—218.04	311.	600.	178.91
trans-2-Butene	C_4H_8	56.104	0.6100 *	33.58	—	—157.99	311.	600.	174.39
1-Pentene	C_5H_{10}	70.130	0.6457	85.94	19.115	—265.40	394.	586.	154.46
1-Hexene	C_6H_{12}	84.156	0.6780	146.27	6.006	—219.67	—	—	—
Cetene	$C_{16}H_{32}$	224.416	0.7850	544.77	—	+ 39.42	—	—	—
Diolefins									
Propadiene (allene)	C_3H_4	40.062	—	— 30.1	—	—213.	248.	—	—
1,2-Butadiene	C_4H_6	54.088	0.658 *	51.53	—	—213.18	—	—	—
1,3-Butadiene	C_4H_6	54.088	0.6272 *	24.06	—	—164.05	306.	628.	—
Acetylenes									
Ethyne (acetylene)	C_2H_2	26.036	—	—119. †	—	—114.	97.4	905.	—
Propyne	C_3H_4	40.062	—	— 9.80	—	—152.3	251.	—	—

Alkyl Benzenes (Aromatics)									
Benzene	C_6H_6	78.108	0.8846	176.18	3.224	+ 41.96	553.01	714.	169.34
Toluene	C_7H_8	92.134	0.8719	231.12	1.032	—138.98	609.51	590.	156.2
Ethylbenzene	C_8H_{10}	106.160	0.8718	277.14	0.371	—138.96	655.8	540.	145.7
*o*Xylene	C_8H_{10}	106.160	0.8848	291.94	0.264	— 13.33	678.3	530.	149.1
*m*Xylene	C_8H_{10}	106.160	0.8687	282.39	0.326	— 54.17	654.9	510.	147.4
*p*Xylene	C_8H_{10}	106.160	0.8657	281.03	0.342	+ 55.87	653.1	500.	146.1
*Iso*propylbenzene (cumene)	C_9H_{12}	120.186	0.8663	306.31	0.188	—140.86	685.	400.	134.3
Alkyl Cycloparaffins (Naphthenes)									
Cyclopentane	C_5H_{10}	70.130	0.7505	120.67	9.914	—136.96	461.48	654.7	167.34
Methylcyclopentane	C_6H_{12}	84.156	0.7535	161.26	4.503	—224.42	499.30	549.	147.83
Cyclohexane	C_6H_{12}	84.156	0.7834	177.33	3.264	+ 43.80	—	—	153.7
Methylcyclohexane	C_7H_{14}	98.182	0.7740	213.68	1.609	—195.87	—	—	138.9
Miscellaneous Organic Compounds									
Acetone	C_3H_6O	58.078	0.7963	133.03	7.53	—138.5	—	—	—
Chlorex	$C_4H_8Cl_2O$	143.018	—	—	—	—	—	—	—
*o*Cresol	C_7H_8O	108.134	—	—	—	—	—	—	—
*m*Cresol	C_7H_8O	108.134	—	—	—	—	—	—	—
*p*Cresol	C_7H_8O	108.134	—	—	—	—	—	—	—
Dichlorethylene	$C_2H_2Cl_2$	96.950	—	—	—	—	—	—	—
Ethyl alcohol	C_2H_6O	46.068	0.7939	172.99	2.313	—173.9	—	—	—
Furfural	$C_5H_4O_2$	96.082	—	—	—	—	—	—	—
Methyl alcohol	CH_4O	32.042	0.7962	148.12	4.63	—143.82	—	—	—
Methyl ethyl ketone	C_4H_8O	72.104	0.8103	175.26	3.16	—123.3	—	—	—
Naphthalene	$C_{10}H_8$	128.164	—	424.32	—	+176.52	—	—	—
1-Methylnaphthalene	$C_{11}H_{10}$	142.190	1.0246	472.36	—	— 23.03	—	—	—
Nitrobenzene	$C_6H_5NO_2$	123.108	—	—	—	—	—	—	—
Phenol	C_6H_5OH	94.108	—	—	—	—	—	—	—
Styrene	C_8H_8	104.144	0.9111	293.4	—	— 23.13	—	—	—
1-Methylstyrene	C_9H_{10}	118.170	0.9154	329.68	—	— 9.58	—	—	—
Trichlorethylene	C_2HCl_3	131.399	—	—	—	—	—	—	—
Miscellaneous									
Air		28.966	0.856 ‡	—318.	—	—	—221.	547.	92.
Hydrogen	H_2	2.016	0.071 ‡	—423.	—	—434.	—400.	188.	194.
Oxygen	O_2	32.000	1.140 ‡	—297.	—	—361.	—182.	730.	92.
Nitrogen	N_2	28.016	0.808 ‡	—320.	—	—346.	—233.	492.	86.
Carbon monoxide	CO	28.010	0.801 ‡	—314.	—	—341.	—218.	514.	91.
Carbon dioxide	CO_2	44.010	1.56 †	—109. †	—	—	88.	1,073.	—
Hydrogen sulfide	H_2S	34.082	0.79 ‡	— 76.	394.	—122.	213.	1,306.	236.
Sulfur dioxide	SO_2	64.066	1.46 ‡	14.	84.	— 99.	425.	1,230.	171.
Water	H_2O	18.016	1.000	212.	0.95	32.	705.	3,206.	970.
Ammonia	NH_3	17.032	0.618	— 28.	212.	—108.	271.	1,650.	589.

* At saturation pressure.
† At sublimation point.
‡ Density at boiling point, gram per cubic centimeter.

TABLE 2—Density of Light Hydrocarbons * at 60 F

Name	Formula	Molecular Weight	Pounds per Barrel	Pounds per Gallon	Pound-Moles per Barrel	Pound-Moles per Gallon	Cubic Feet of Vapor per Barrel of Liquid †
Paraffins							
Methane ‡	CH_4	16.042	87	2.07	5.42	0.1290	2,057
Ethane ‡	C_2H_6	30.068	149	3.55	4.96	0.1181	1,882
Propane	C_3H_8	44.094	178	4.23	4.03	0.0960	1,530
*Iso*butane	C_4H_{10}	58.120	197	4.70	3.39	0.0808	1,287
*n*Butane	C_4H_{10}	58.120	205	4.87	3.52	0.0838	1,336
*Iso*pentane	C_5H_{12}	72.146	219	5.21	3.03	0.0722	1,151
*n*Pentane	C_5H_{12}	72.146	221	5.26	3.06	0.0729	1,162
*n*Hexane	C_6H_{14}	86.172	232	5.54	2.70	0.0642	1,024
*n*Heptane	C_7H_{16}	100.198	241	5.74	2.40	0.0573	912
*n*Octane	C_8H_{18}	114.224	248	5.89	2.17	0.0516	822
*n*Nonane	C_9H_{20}	128.250	253	6.02	1.97	0.0469	748
*n*Decane	$C_{10}H_{22}$	142.276	257	6.12	1.81	0.0430	685
Unsaturates							
Ethylene §	C_2H_4	28.052	153	3.65	5.46	0.1301	2,072
Propylene	C_3H_6	42.078	183	4.35	4.34	0.1034	1,647
1-Butene	C_4H_8	56.104	210	5.01	3.74	0.0893	1,417
*Iso*butene	C_4H_8	56.104	210	5.00	3.75	0.0892	1,422
cis-2-Butene	C_4H_8	56.104	220	5.23	3.91	0.0932	1,486
trans-2-Butene	C_4H_8	56.104	214	5.09	3.81	0.0906	1,444
1-Pentene	C_5H_{10}	70.130	226	5.39	3.23	0.0768	1,224
1-Hexene	C_6H_{12}	84.156	238	5.65	2.82	0.0672	1,071
1-Heptene	C_7H_{14}	98.19	246	5.85	2.50	0.0595	949
1-Octene	C_8H_{16}	112.2	252	6.01	2.25	0.0535	853
1,2-Butadiene	C_4H_6	54.088	231	5.49	4.26	0.1015	1,616
1,3-Butadiene	C_4H_6	54.088	220	5.23	4.06	0.0967	1,541

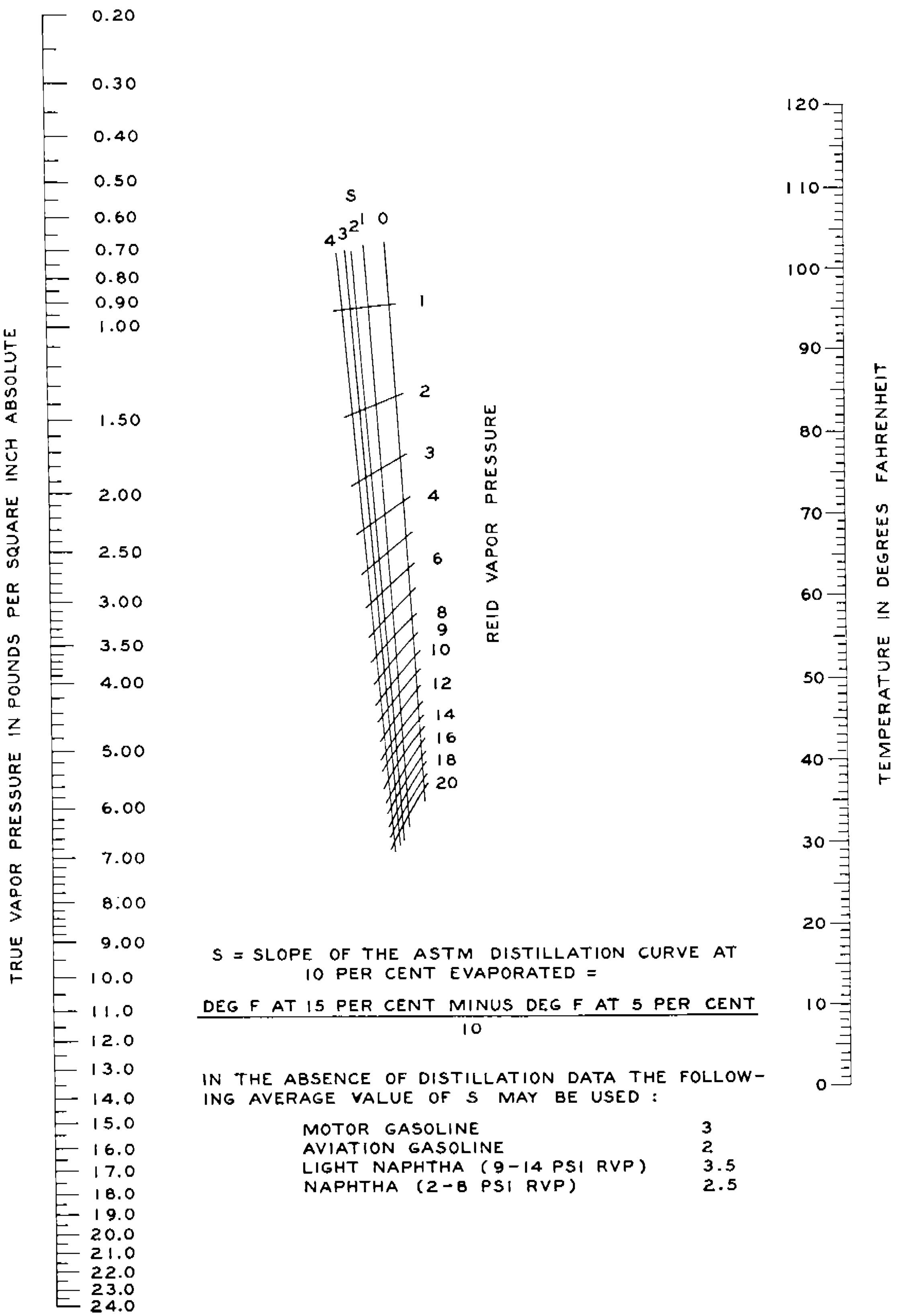
* As liquids corrected for buoyancy of air. See Table 1 for specific gravity of compounds not listed.

† At 60 F and one atmosphere as a perfect gas.

‡ Based on apparent density in solution in butane.

§ Based on ratio of densities of propylene to propane times the density of ethane.

APPENDIX V—VAPOR PRESSURE CHARTS



S = SLOPE OF THE ASTM DISTILLATION CURVE AT 10 PER CENT EVAPORATED =

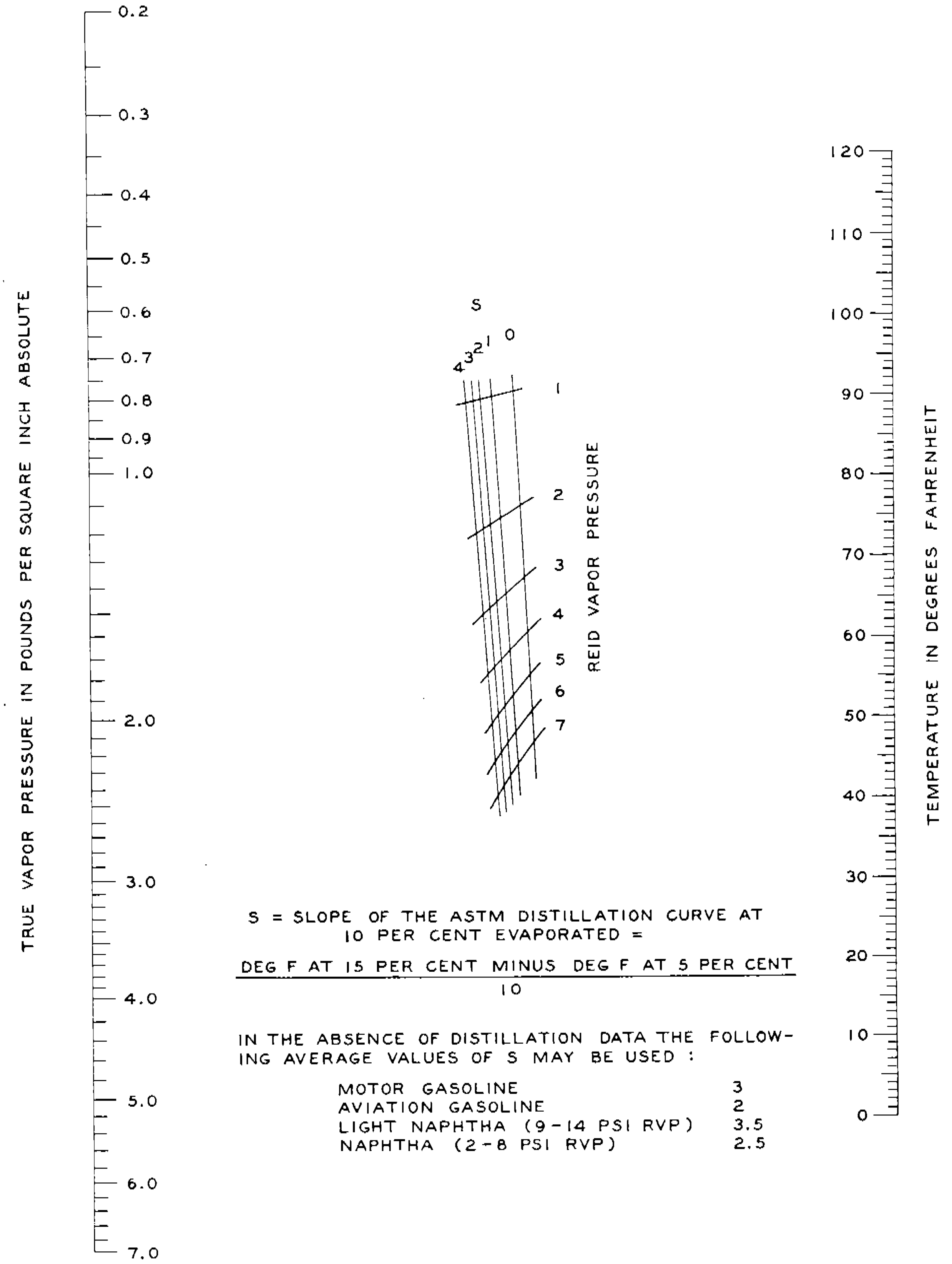
$$\frac{\text{DEG F AT 15 PER CENT MINUS DEG F AT 5 PER CENT}}{10}$$

IN THE ABSENCE OF DISTILLATION DATA THE FOLLOWING AVERAGE VALUE OF S MAY BE USED :

MOTOR GASOLINE	3
AVIATION GASOLINE	2
LIGHT NAPHTHA (9-14 PSI RVP)	3.5
NAPHTHA (2-8 PSI RVP)	2.5

Source: Nomograph drawn from data of the National Bureau of Standards.

FIG. 1—Vapor Pressures of Gasolines and Finished Petroleum Products—1 psi to 20 psi RVP.



S = SLOPE OF THE ASTM DISTILLATION CURVE AT 10 PER CENT EVAPORATED =

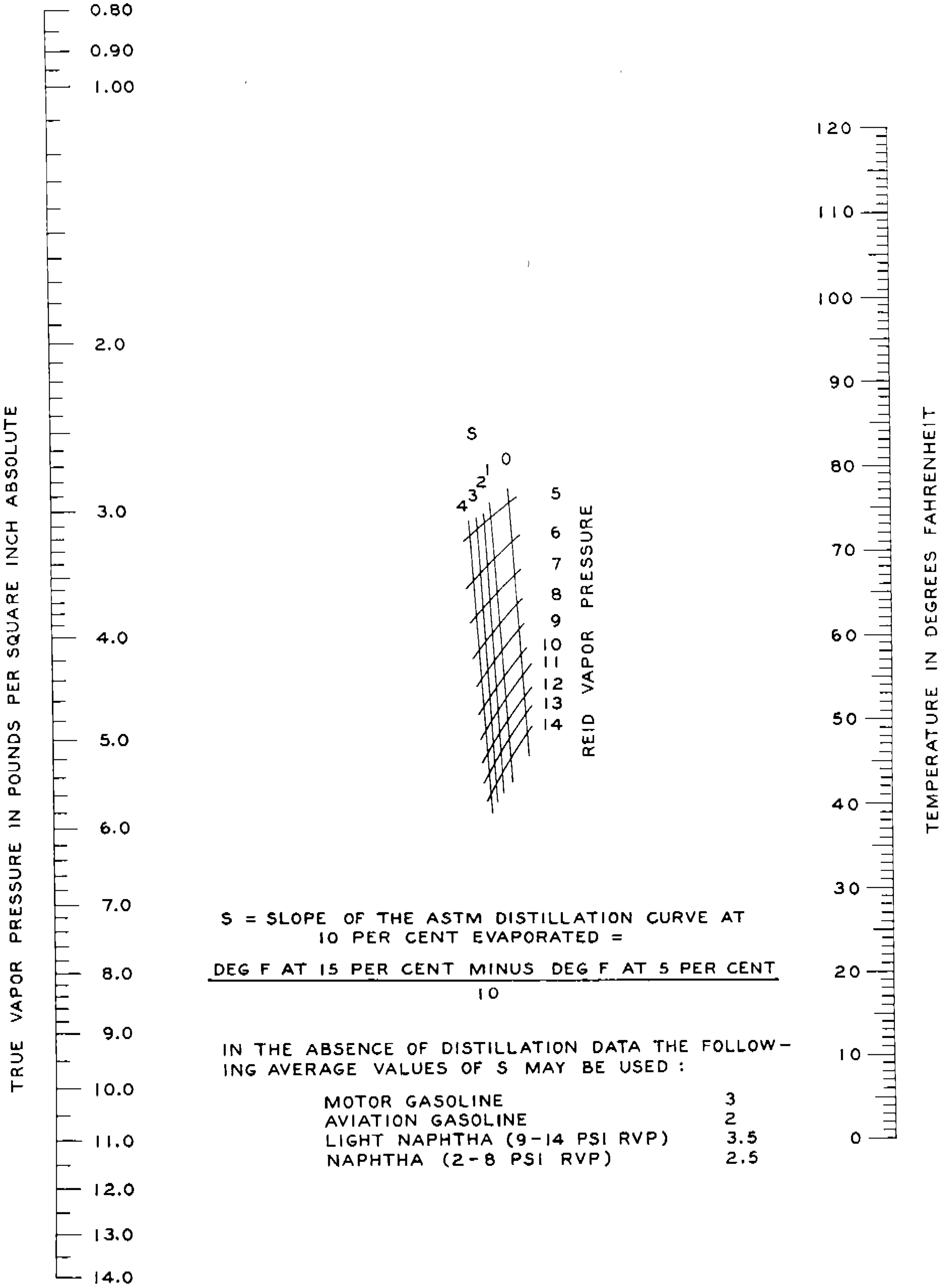
$$\frac{\text{DEG F AT 15 PER CENT MINUS DEG F AT 5 PER CENT}}{10}$$

IN THE ABSENCE OF DISTILLATION DATA THE FOLLOWING AVERAGE VALUES OF S MAY BE USED :

MOTOR GASOLINE	3
AVIATION GASOLINE	2
LIGHT NAPHTHA (9-14 PSI RVP)	3.5
NAPHTHA (2-8 PSI RVP)	2.5

Source: Nomograph drawn from data of the National Bureau of Standards.

FIG. 2—Vapor Pressures of Gasolines and Finished Petroleum Products—1 psi to 7 psi RVP.



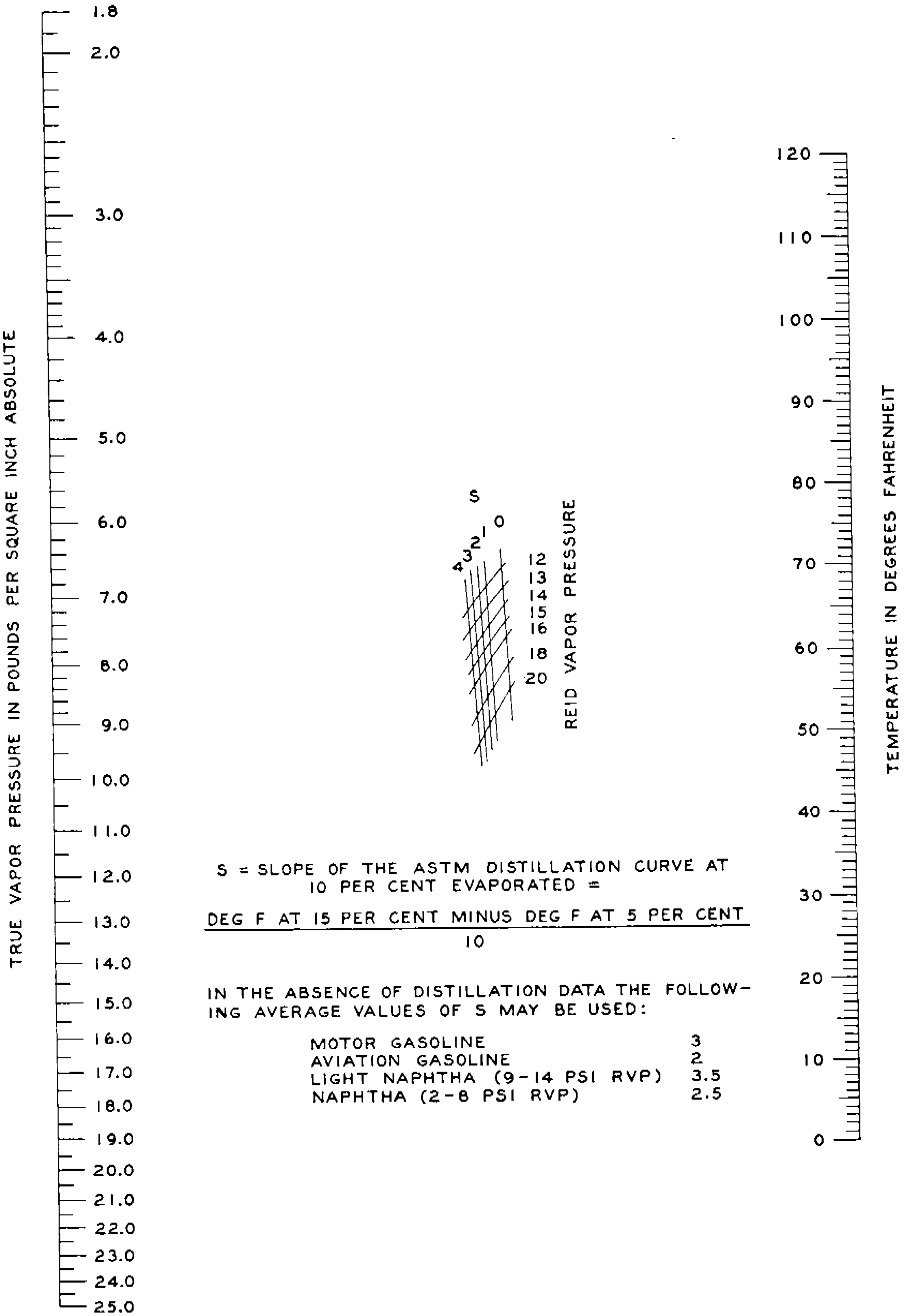
$$S = \text{SLOPE OF THE ASTM DISTILLATION CURVE AT 10 PER CENT EVAPORATED} = \frac{\text{DEG F AT 15 PER CENT MINUS DEG F AT 5 PER CENT}}{10}$$

IN THE ABSENCE OF DISTILLATION DATA THE FOLLOWING AVERAGE VALUES OF S MAY BE USED :

MOTOR GASOLINE	3
AVIATION GASOLINE	2
LIGHT NAPHTHA (9-14 PSI RVP)	3.5
NAPHTHA (2-8 PSI RVP)	2.5

Source: Nomograph drawn from data of the National Bureau of Standards.

FIG. 3—Vapor Pressures of Gasolines and Finished Petroleum Products—5 psi to 14 psi RVP.



S = SLOPE OF THE ASTM DISTILLATION CURVE AT 10 PER CENT EVAPORATED =

$$\frac{\text{DEG F AT 15 PER CENT MINUS DEG F AT 5 PER CENT}}{10}$$

IN THE ABSENCE OF DISTILLATION DATA THE FOLLOWING AVERAGE VALUES OF S MAY BE USED:

MOTOR GASOLINE	3
AVIATION GASOLINE	2
LIGHT NAPHTHA (9-14 PSI RVP)	3.5
NAPHTHA (2-8 PSI RVP)	2.5

Source: Nomograph drawn from data of the National Bureau of Standards.

FIG. 4—Vapor Pressures of Gasolines and Finished Petroleum Products—12 psi to 20 psi RVP.

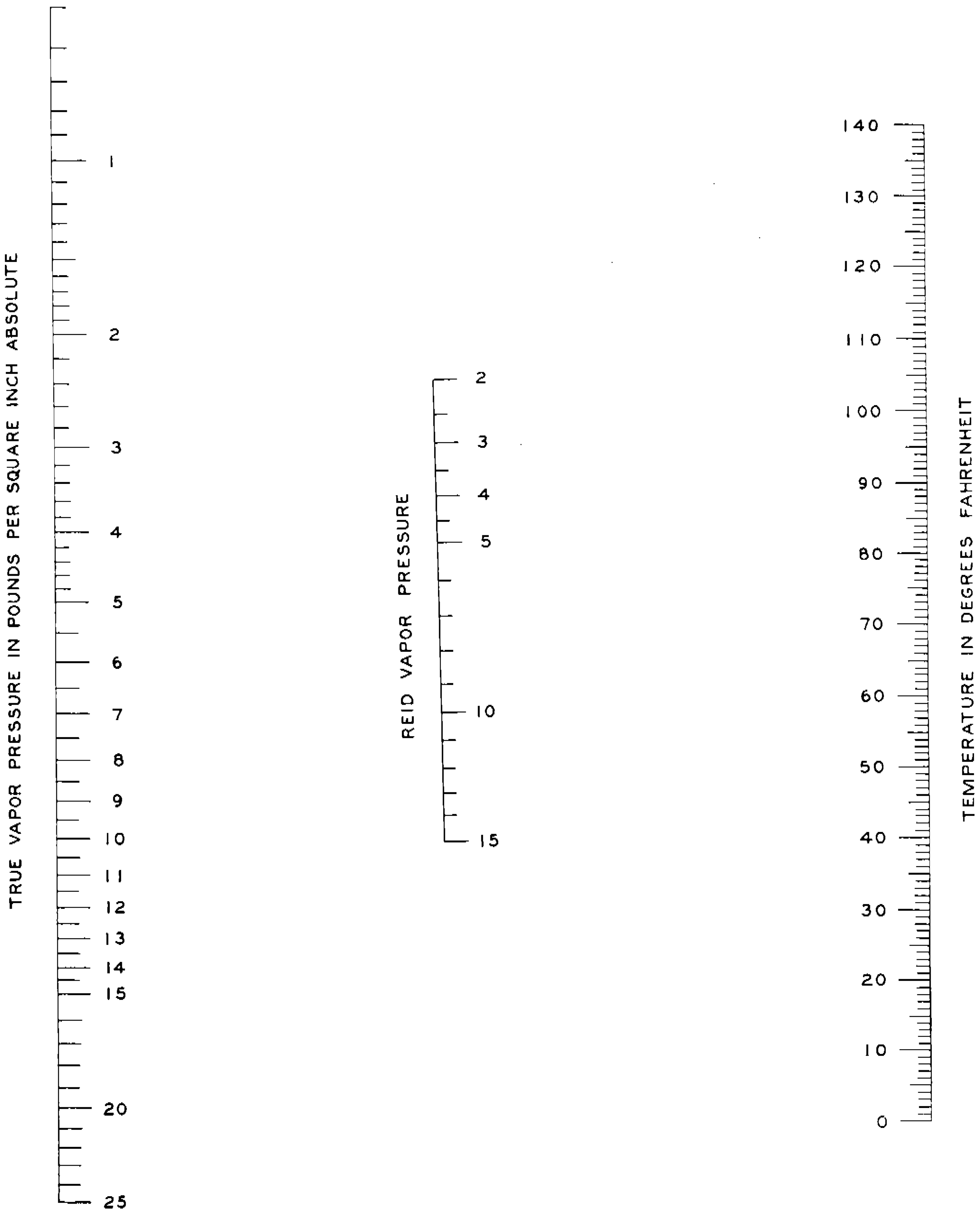


FIG. 5—Vapor Pressures of Crude Oil.

APPENDIX VI—METEOROLOGICAL DATA

TABLE 1—Solar Data, United States

Top Line: Monthly and annual duration of sunshine, expressed in hours.
Bottom Line: Total solar and sky radiation received on a horizontal plane expressed in 100 Btu's per square foot per month.

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Albuquerque	211	282	268	342	345	393	357	332	304	300	288	226	3,648
N. Mex.	302	380	518	630	730	737	754	670	545	503	346	226	6,341
Atlanta	142	203	219	240	267	347	325	317	293	253	159	140	2,905
Ga.	275	351	522	571	676	753	666	618	524	441	285	241	5,923
Bismarck	131	176	227	234	299	268	337	307	216	176	177	183	2,731
N. Dak.	181	237	415	472	662	597	675	580	403	290	196	149	4,857
Boston	128	156	260	214	214	265	343	287	225	231	182	151	2,656
Mass.	160	214	326	402	452	504	513	455	353	256	139	124	3,898
Boulder	203	260	232	292	293	358	323	328	285	253	237	227	3,291
Colo.	240	294	450	530	550	597	609	530	470	367	266	222	5,125
Charleston	182	231	245	267	311	375	346	352	279	290	229	229	3,336
S. C.	313	350	463	596	660	670	640	602	482	409	352	272	5,809
Chicago	114	155	370	184	277	319	328	255	248	140	138	103	2,631
Ill.	114	169	286	389	500	548	520	495	367	245	144	102	3,879
Columbia	170	211	239	292	334	362	392	279	289	175	197	120	3,060
Mo.	207	268	371	455	548	616	680	581	478	354	233	182	4,973
Davis	117	132	184	282	373	370	429	370	365	313	141	73	3,149
Calif.	217	300	452	615	740	770	794	702	557	428	261	155	5,991
Dodge City	197	253	257	289	241	377	371	340	333	271	258	215	3,402
Kans.	282	420	500	583	569	785	731	661	478	428	341	284	6,062
East Lansing	89	128	205	176	271	294	339	265	203	141	100	75	2,286
Mich.	143	198	296	356	427	491	525	467	355	245	139	105	3,747
El Paso	269	287	298	349	403	407	393	323	336	319	302	275	3,961
Texas	402	470	625	742	815	818	786	746	667	550	430	382	7,433
Fort Worth	131	255	213	194	237	383	337	319	341	252	243	192	3,097
Texas	260	500	532	616	696	835	795	771	677	503	423	314	6,922
Fresno	190	175	257	340	412	413	430	410	366	339	166	104	3,602
Calif.	197	294	474	616	730	766	775	696	566	439	289	194	6,036
Friday Harbor	58	63	191	164	242	198	258	136	150	119	37	62	1,678
Wash.	100	144	296	472	610	658	682	582	400	240	128	93	4,405
Gainsville	150	216	245	210	272	259	270	272	172	240	198	179	2,683
Fla.	256	327	474	568	646	562	520	456	402	368	370	240	5,188
Great Falls	107	139	190	224	294	296	406	306	261	212	137	163	2,735
Mont.	161	236	422	497	618	622	758	602	469	328	188	154	5,055
Greensboro	147	191	224	249	267	343	326	294	316	307	212	221	3,097
N. C.	245	341	453	565	653	755	710	625	550	432	241	206	5,776
Indianapolis	123	155	215	223	233	310	403	328	300	199	141	111	2,741
Ind.	155	238	379	495	580	642	690	540	470	274	192	129	4,784
Ithaca	99	117	182	210	270	281	309	201	171	133	97	56	2,126
N. Y.	143	203	287	351	482	544	570	530	428	280	144	114	4,076
Lincoln	176	212	218	267	288	367	368	263	302	163	227	187	3,038
Nebr.	216	273	384	463	555	616	634	556	455	354	244	199	4,949
Little Rock	107	207	181	235	282	373	347	356	306	216	218	145	2,973
Ark.	210	370	427	540	622	722	715	646	535	354	287	200	5,628
Madison	134	173	250	207	260	319	338	290	221	188	131	112	2,623
Wis.	173	241	354	446	538	584	600	514	389	273	167	133	4,412
Miami	259	261	313	266	252	235	285	321	276	221	248	273	3,210
Fla.	348	377	475	516	560	539	536	525	478	436	372	345	5,507
Minneapolis	115	136	197	206	251	259	281	267	147	138	118	113	2,228
Minn.	148	220	331	422	616	722	608	577	328	225	174	146	4,517

TABLE 1—(Continued)

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Nashville	159	194	166	234	204	325	316	271	274	200	183	125	2,651
Tenn.	154	225	348	455	460	580	576	520	427	339	227	148	4,459
New Orleans	160	243	239	255	268	312	246	310	261	251	215	173	2,933
La.	245	290	400	475	520	527	490	490	416	434	322	240	4,849
Newport	122	153	254	250	183	234	243	224	170	179	158	129	2,299
R. I.	171	268	365	460	562	592	594	530	422	308	208	162	4,849
New York	143	165	240	253	231	305	328	250	214	218	175	176	2,698
N. Y.	154	214	332	419	504	535	542	462	372	293	183	139	4,149
Oklahoma City	176	258	223	262	242	382	388	345	328	221	250	208	3,283
Okla.	290	395	439	522	552	789	795	746	622	447	382	318	6,297
Phoenix	266	296	306	381	410	407	387	396	361	326	302	251	4,089
Ariz.	379	456	595	720	826	825	760	730	646	542	400	337	7,216
Pittsburgh	69	85	154	212	220	274	315	247	216	119	84	47	2,042
Pa.	116	160	254	350	470	525	540	470	352	245	144	94	3,720
Put-in-Bay	90	141	223	240	291	328	340	263	231	140	145	79	2,511
Ohio	131	209	333	424	436	615	631	570	425	297	174	108	4,353
Rapid City	143	172	170	184	226	244	344	278	244	198	180	158	2,544
S. Dak.	206	289	445	515	611	668	684	620	498	379	237	184	5,336
Riverside	215	271	232	232	277	301	361	293	316	287	231	242	3,258
Calif.	285	329	450	546	610	636	667	605	520	430	310	258	5,646
Salt Lake City	122	119	200	293	342	325	394	362	304	289	247	162	3,159
Utah	194	264	405	534	634	620	720	596	484	343	202	151	5,147
San Antonio	159	236	223	220	314	316	357	339	324	273	250	221	3,232
Texas	349	364	490	537	630	686	726	690	577	484	358	302	6,193
Tampa	238	259	294	257	321	313	277	310	266	303	215	238	3,291
Fla.	392	443	592	620	690	635	570	587	502	495	405	369	6,300
Twin Falls	48	177	194	294	359	246	338	332	305	252	213	133	2,891
Idaho	188	262	407	519	641	677	692	610	495	360	216	155	5,222
Washington	157	200	241	243	231	333	367	266	261	205	139	129	2,772
D. C.	200	248	356	450	546	572	576	507	413	331	224	177	4,600

Source: U.S. Department of Commerce, Weather Bureau, Washington, D. C.

TABLE 2—Solar Data, Canada

Top Line: Monthly and annual duration of sunshine, expressed in hours.
Bottom Line: Total solar and sky radiation received on a horizontal plane expressed in 100 Btu's per square foot per month.

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Calgary	109	133	159	194	254	239	316	265	191	165	118	102	2,245
Alta.	126	196	343	498	618	609	686	572	432	252	144	103	4,579
Edmonton	79	119	169	222	253	250	303	269	188	153	98	75	2,178
Alta.	114	207	343	498	584	598	686	572	399	241	122	80	4,444
Fort William	—	—	—	—	—	—	—	—	—	—	—	—	—
Ont.	137	207	377	487	561	587	618	526	343	217	105	105	4,270
Halifax	92	111	153	165	189	199	239	212	161	137	88	89	1,835
N. S.	172	238	343	443	572	576	618	515	376	286	166	114	4,419
Kamloops	64	105	176	231	250	260	322	286	214	151	69	50	2,178
B. C.	114	181	320	454	589	620	652	538	387	229	111	86	4,281
London	—	—	—	—	—	—	—	—	—	—	—	—	—
Ont.	126	227	343	443	572	587	618	515	398	263	144	126	4,362
Montreal	76	101	145	168	205	222	243	220	169	124	70	60	1,803
P. Q.	137	258	400	465	572	609	618	515	410	275	155	137	4,551
Moose Jaw	92	121	157	210	257	273	334	290	204	159	104	87	2,288
Sask.	126	227	400	487	572	609	686	538	388	240	133	114	4,520
Ottawa	91	116	150	186	232	253	273	250	177	136	80	72	2,016
Ont.	137	227	389	498	572	609	629	515	410	240	122	114	4,462
Quebec	83	106	145	163	195	209	225	209	155	119	69	67	1,745
P. Q.	171	248	400	465	572	609	629	515	387	275	155	126	4,552
Regina	108	126	163	216	252	244	329	285	205	170	98	98	2,294
Sask.	126	227	400	487	572	609	686	538	388	240	133	114	4,520
St. John	114	123	153	160	207	200	206	204	168	145	102	99	1,881
N. B.	172	258	366	443	572	576	618	515	388	274	155	114	4,451
St. John's	—	—	—	—	—	—	—	—	—	—	—	—	—
Nfld.	149	186	320	376	515	573	572	446	343	252	122	92	3,946
Saskatoon	—	—	—	—	—	—	—	—	—	—	—	—	—
Sask.	126	217	389	498	583	609	686	538	354	229	122	92	4,443
Toronto	77	107	149	184	224	260	287	256	200	151	85	68	2,048
Ont.	126	186	343	443	549	587	606	515	387	252	144	103	4,241
Vancouver	48	82	129	178	232	226	287	268	178	112	53	39	1,832
B. C.	91	155	286	443	572	609	629	515	387	206	111	80	4,084
Windsor	—	—	—	—	—	—	—	—	—	—	—	—	—
Ont.	126	186	343	443	572	609	629	515	398	286	155	114	4,376
Winnipeg	100	131	168	204	247	252	291	263	177	127	86	78	2,124
Man.	137	238	400	498	595	609	629	538	376	228	122	103	4,473

Source: Meteorological Division of the Department of Transport, Ottawa, Ont.

TABLE 3—Average Atmospheric Temperature, Degrees Fahrenheit, United States

Top Line: Maximum.
Middle Line: Minimum.
Bottom Line: Mean.

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Albuquerque	47.3	53.0	60.8	69.8	78.6	88.5	90.6	88.5	82.1	71.1	57.7	47.4	69.6
N. Mex.	21.9	26.1	31.8	39.7	48.3	57.4	62.9	61.2	54.1	42.0	29.8	22.5	41.5
	34.6	39.6	46.3	54.8	63.5	73.0	76.8	74.9	68.1	56.6	43.8	35.0	55.6
Atlanta	51.9	54.6	62.2	70.9	79.3	86.1	87.6	86.5	82.1	71.9	60.8	52.5	70.5
Ga.	35.7	37.1	43.3	51.4	59.9	67.3	69.7	69.0	64.4	54.4	43.1	36.7	52.7
	43.8	45.9	52.8	61.2	69.6	76.7	78.7	77.8	73.3	63.2	52.0	44.6	61.6
Binghamton	33.4	33.3	43.0	55.8	68.3	77.3	81.9	79.5	73.1	61.2	47.3	35.9	57.5
N. Y.	17.3	16.1	25.2	35.8	46.2	55.0	59.5	57.3	50.9	40.5	31.8	21.2	38.1
	25.4	24.7	34.1	45.8	57.3	66.2	70.7	68.4	62.0	50.9	39.6	28.6	47.8
Bismarck	18.6	22.4	35.1	54.7	66.7	75.5	83.2	81.5	71.1	57.7	38.9	25.5	52.6
N. Dak.	—2.4	1.6	14.7	31.5	42.5	52.5	57.9	55.2	45.1	33.3	18.4	5.7	29.7
	8.1	12.0	24.9	43.1	54.6	64.0	70.6	68.4	58.1	45.5	28.7	15.6	41.2

TABLE 3—(Continued)

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Boston Mass.	36.5	36.3	44.4	54.8	66.1	75.5	80.7	78.4	71.9	62.0	50.4	39.6	58.1
	21.1	20.8	29.0	38.7	48.9	58.0	63.9	62.4	55.8	45.9	35.7	25.3	42.1
	28.8	28.6	36.7	46.8	57.5	66.8	72.3	70.4	63.9	54.0	43.1	32.5	50.1
Casper Wyo.	33.3	37.5	42.4	55.7	64.6	75.4	86.8	85.1	74.1	60.9	44.8	36.4	58.1
	12.7	16.4	20.1	31.0	38.9	47.2	55.3	53.8	43.8	34.6	23.5	17.5	32.9
	23.0	27.0	31.3	43.3	51.8	61.3	71.1	69.5	59.0	47.8	34.2	27.0	45.5
Charleston S. C.	58.5	59.8	65.7	72.4	79.9	85.8	87.9	87.3	83.1	74.9	66.0	59.2	73.4
	43.3	44.5	50.2	57.3	65.9	72.6	75.1	74.6	70.8	60.8	50.7	44.1	59.2
	50.9	52.2	58.0	64.9	72.9	79.2	81.5	81.0	77.0	67.9	58.4	51.7	66.3
Chicago Ill.	32.0	33.9	43.2	54.9	65.9	75.8	81.1	79.2	73.0	61.7	47.0	35.7	57.0
	18.0	20.1	29.2	39.6	49.4	59.7	65.8	65.0	57.9	46.8	33.6	23.3	42.4
	25.0	27.0	36.2	47.3	57.7	67.8	73.5	72.1	65.5	54.3	40.3	29.5	49.7
Cleveland Ohio	34.6	35.0	43.4	55.0	66.5	76.1	80.3	78.4	72.8	61.6	47.9	37.4	57.4
	21.0	20.7	28.2	38.5	49.8	59.8	64.4	63.3	56.6	45.9	34.8	25.2	42.4
	27.8	27.8	35.8	46.8	58.2	68.0	72.4	70.9	64.7	53.8	41.4	31.3	49.9
Columbia Mo.	39.6	42.5	53.7	65.4	74.9	84.1	89.0	87.6	80.3	69.3	54.1	42.4	65.2
	21.3	23.7	33.1	44.3	53.8	63.4	67.0	65.5	57.9	46.5	34.1	25.1	44.6
	30.5	33.1	43.4	54.9	64.4	73.8	78.0	76.6	69.1	57.9	44.1	33.8	54.9
Denver Colo.	42.9	45.0	51.2	59.9	68.8	80.1	85.7	84.4	76.7	64.9	52.6	44.6	63.1
	18.6	21.2	27.0	35.6	44.5	53.5	59.5	58.3	49.4	38.5	27.6	20.7	37.9
	30.8	33.1	39.1	47.8	56.7	66.8	72.6	71.4	63.1	51.7	40.1	32.7	50.5
Dodge City Kans.	41.9	46.4	56.0	66.9	75.2	85.6	91.1	89.8	82.0	69.9	55.8	44.8	67.1
	18.1	21.7	29.3	40.9	51.1	61.2	66.4	65.1	56.5	43.8	29.9	21.5	42.1
	30.0	34.1	42.7	53.9	63.2	73.4	78.8	77.5	69.3	56.9	42.9	33.2	54.6
East Lansing Mich.	29.8	30.4	40.6	54.2	67.6	77.3	82.3	80.0	72.5	60.6	45.3	33.2	56.1
	16.0	14.6	23.8	34.0	45.5	55.3	59.4	57.4	50.9	40.4	30.3	20.0	37.3
	22.9	22.5	32.2	44.1	56.6	66.3	70.9	68.7	61.7	50.5	37.8	26.6	46.7
El Paso Texas	57.3	62.4	69.0	77.3	85.5	94.0	93.5	91.7	86.7	77.7	65.7	57.2	76.5
	32.6	36.7	42.4	50.2	58.6	67.3	70.0	68.9	63.1	52.0	39.7	33.4	51.2
	45.0	49.6	55.7	63.8	72.1	80.7	81.8	80.3	74.9	64.9	52.7	45.3	63.9
Fort Worth Texas	56.4	59.7	68.4	75.7	82.3	91.0	94.4	95.2	88.3	78.6	66.6	57.5	76.2
	36.0	38.4	46.2	54.4	62.6	70.9	74.0	74.3	67.5	57.1	45.9	37.7	55.4
	46.2	49.1	57.3	65.1	72.5	81.0	84.2	84.8	77.9	67.9	56.3	47.6	65.8
Fresno Calif.	54.5	61.3	66.4	74.3	82.1	90.9	99.0	97.0	89.6	78.8	66.5	55.1	76.3
	37.7	41.4	44.1	48.1	53.2	59.3	64.8	63.1	58.0	50.7	42.8	38.3	50.1
	46.1	51.2	55.3	61.2	67.7	75.1	81.9	80.1	73.6	64.8	54.7	46.7	63.2
Great Falls Mont.	31.6	35.5	40.8	56.1	64.9	70.0	83.4	80.9	70.3	59.5	44.9	36.8	56.2
	13.3	15.9	21.0	33.4	42.0	48.3	55.9	53.9	46.1	38.2	27.6	20.2	34.7
	22.5	25.7	30.9	44.8	53.5	59.2	69.7	67.4	58.2	48.9	36.3	28.5	45.5
Greensboro N. C.	50.1	52.0	59.7	69.7	78.8	86.3	87.8	86.3	81.3	71.7	59.4	49.8	69.4
	30.3	30.1	36.4	45.1	54.7	63.5	66.7	65.4	59.5	46.6	36.0	29.5	47.0
	40.2	41.1	48.1	57.4	66.8	74.9	77.3	75.9	70.4	59.2	47.7	39.7	58.2
Houston Texas	62.3	65.2	71.7	77.9	84.2	90.3	92.2	92.5	88.2	81.1	70.7	63.7	78.3
	44.9	47.2	53.6	60.1	66.6	72.5	74.4	74.4	70.3	61.5	52.1	46.3	60.3
	53.6	56.2	62.7	69.0	75.4	81.4	83.3	83.5	79.3	71.3	61.4	55.0	69.3
Indianapolis Ind.	36.5	38.9	48.9	61.2	73.1	82.5	86.9	84.6	77.9	66.0	50.5	39.5	60.9
	21.4	23.1	31.7	41.9	52.8	62.3	66.1	64.0	56.9	45.8	34.0	24.6	43.8
	29.0	31.0	40.3	51.6	63.0	72.4	76.5	74.3	67.4	55.9	42.3	32.1	52.3
Lincoln Nebr.	33.5	37.2	48.7	63.0	72.7	82.8	89.1	86.7	79.0	66.7	50.1	37.6	62.3
	14.7	17.9	28.2	41.0	51.2	61.6	66.5	64.5	55.9	43.8	29.9	19.8	41.3
	24.1	27.6	38.5	52.0	62.0	72.2	77.8	75.6	67.5	55.3	40.0	28.7	51.8
Little Rock Ark.	50.4	53.9	62.6	72.0	79.2	87.5	90.6	89.9	84.2	74.1	61.3	52.2	71.5
	33.9	36.2	43.8	52.9	60.7	68.9	72.0	71.1	64.2	53.6	42.6	35.8	53.0
	42.2	45.1	53.2	62.5	70.0	78.2	81.3	80.5	74.2	63.9	52.0	44.0	62.3
Los Angeles Calif.	63.2	64.1	64.8	66.5	68.8	70.7	74.2	74.8	74.9	72.5	70.0	66.4	69.2
	43.2	45.0	46.8	50.7	53.8	57.1	60.5	60.9	59.3	54.9	48.6	45.6	52.2
	53.2	54.6	55.8	58.6	61.3	63.9	67.4	67.8	67.1	63.7	59.3	55.9	60.7
Madison Wis.	25.1	28.0	38.6	54.2	66.6	76.1	81.3	78.8	70.7	58.5	42.0	29.3	54.1
	10.3	12.9	23.8	37.2	48.8	59.0	63.9	61.8	54.0	42.5	28.7	16.8	38.3
	17.7	20.5	31.2	45.7	57.7	67.6	72.6	70.3	62.4	50.5	35.4	23.1	46.2

(*continued*)

TABLE 3—(Continued)

Top Line: Maximum.
Middle Line: Minimum.
Bottom Line: Mean.

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Miami	74.2	74.6	76.6	79.4	82.4	85.4	86.8	87.3	86.0	82.6	77.6	75.2	80.7
Fla.	62.3	61.6	64.5	68.2	71.8	74.9	76.2	76.8	75.8	72.5	66.6	63.2	69.5
	68.3	68.1	70.6	73.8	77.1	80.2	81.5	82.1	80.9	77.6	72.1	69.2	75.1
Minneapolis	22.1	25.4	38.1	55.3	67.8	77.4	83.0	80.4	71.7	59.0	40.5	27.0	54.0
Minn.	5.2	8.3	21.6	36.4	48.0	58.3	63.2	60.8	52.3	40.8	25.6	12.3	36.1
	13.7	16.9	29.9	45.9	57.9	67.9	73.1	70.6	62.0	49.9	33.0	19.7	45.1
Nashville	47.8	49.9	59.2	69.3	78.2	86.2	89.1	88.0	82.6	71.9	58.4	49.4	69.2
Tenn.	31.2	32.5	40.2	49.4	58.1	66.8	69.9	68.6	61.9	50.2	39.5	33.0	50.1
	39.5	41.2	49.7	59.4	68.2	76.5	79.5	78.3	72.3	61.1	49.0	41.2	59.7
New Orleans	63.0	65.4	71.1	77.0	83.2	88.6	89.7	89.7	86.3	78.8	69.7	63.6	77.2
La.	47.5	49.6	55.1	61.4	68.0	74.0	75.6	75.8	72.9	64.3	54.3	48.5	62.3
	55.3	57.5	63.1	69.2	75.6	81.3	82.7	82.8	79.6	71.6	62.0	56.1	69.8
New York	39.2	39.4	48.2	58.9	70.6	79.6	84.5	82.4	76.3	65.9	53.0	41.6	61.6
N. Y.	26.0	25.5	32.9	42.4	52.7	61.9	67.4	65.9	59.6	49.9	39.9	29.4	46.1
	32.6	32.5	40.6	50.7	61.7	70.8	76.0	74.2	68.0	57.9	46.5	35.5	53.9
Norfolk	49.8	50.7	57.7	66.4	75.7	83.4	86.8	84.9	79.6	69.8	59.7	51.1	68.0
Va.	34.3	34.4	40.2	48.2	57.8	66.3	70.6	70.2	65.6	55.0	44.0	36.3	51.9
	42.1	42.6	49.0	57.3	66.8	74.9	78.7	77.6	72.6	62.4	52.1	43.7	60.0
Oklahoma City	47.4	51.5	61.5	71.0	77.9	87.3	91.9	92.3	85.1	73.8	60.1	49.3	70.8
Okla.	27.8	30.3	38.8	49.3	58.0	67.2	70.9	70.3	63.1	51.7	39.1	30.4	49.7
	37.6	40.9	50.2	60.2	68.0	77.3	81.4	81.3	74.1	62.8	49.6	39.9	60.3
Philadelphia	40.6	41.4	49.9	61.0	72.3	80.7	85.0	82.6	76.7	65.9	53.5	43.1	62.7
Pa.	27.0	27.0	34.0	43.4	54.1	63.2	68.6	66.9	60.7	49.9	39.6	30.2	47.1
	33.8	34.2	42.0	52.2	63.2	72.0	76.8	74.8	68.7	57.9	46.6	36.7	54.9
Phoenix	64.9	69.1	74.6	83.0	91.6	101.3	103.8	101.7	97.8	86.9	74.9	65.9	84.6
Ariz.	37.9	41.7	46.2	52.5	59.7	68.3	76.9	75.7	68.9	56.0	44.6	38.7	55.6
	51.4	55.4	60.4	67.8	75.7	84.8	90.4	88.7	83.4	71.5	59.8	52.3	70.1
Pittsburgh	38.7	39.7	48.8	60.7	72.0	80.2	84.2	82.1	76.2	64.4	50.5	40.5	61.5
Pa.	23.6	23.5	31.1	41.0	51.6	60.4	64.5	62.8	56.7	45.6	35.4	26.8	43.6
	31.2	31.6	40.0	50.9	61.8	70.3	74.4	72.5	66.5	55.0	43.0	33.7	52.6
Portland	44.3	48.7	54.8	61.4	67.3	72.1	78.4	78.0	72.3	62.9	52.3	46.5	61.6
Oreg.	34.4	36.9	40.1	43.6	48.4	53.1	56.8	56.6	52.9	47.5	41.1	37.2	45.7
	39.4	42.8	47.5	52.5	57.9	62.6	67.6	67.3	62.6	55.2	46.7	41.9	53.7
Providence	37.5	37.3	46.0	56.5	67.6	76.6	82.0	79.9	73.2	63.2	51.0	40.1	59.2
R. I.	22.2	21.4	29.7	38.6	48.5	57.4	63.6	61.8	54.8	45.2	35.5	25.6	42.0
	29.9	29.4	37.9	47.6	58.1	67.0	72.8	70.9	64.0	54.2	43.3	32.9	50.6
Rapid City	35.0	36.3	44.0	56.4	65.8	75.5	84.8	83.4	73.8	61.7	48.2	38.0	58.6
S. Dak.	11.6	13.7	21.5	33.5	43.4	52.9	59.4	57.6	47.8	37.0	25.2	16.0	35.0
	23.3	25.0	32.8	45.0	54.6	64.2	72.1	70.5	60.8	49.4	36.7	27.0	46.8
Sacramento	52.4	58.3	63.5	69.6	76.1	84.1	90.0	89.2	84.6	75.4	63.9	53.4	71.7
Calif.	38.8	42.5	45.4	48.1	51.7	56.0	58.2	57.5	56.0	50.7	43.6	39.4	49.0
	45.6	60.4	54.5	58.8	63.9	70.0	74.1	73.3	70.3	63.0	53.8	46.5	60.4
Salt Lake City	35.7	41.7	50.6	62.3	71.7	81.4	92.1	89.7	79.5	66.2	49.4	39.5	63.3
Utah	17.0	23.6	30.1	38.1	45.0	52.2	61.5	59.9	49.9	39.9	28.1	22.1	39.0
	26.4	32.7	40.4	50.2	58.4	66.8	76.8	74.8	64.7	53.1	38.8	30.8	51.2
San Antonio	62.7	66.3	73.4	79.8	85.4	91.5	94.3	94.9	89.5	81.9	71.0	63.9	79.6
Texas	42.4	45.2	51.5	58.6	65.4	71.4	73.2	73.3	69.1	60.2	50.5	44.1	58.7
	52.6	55.8	62.5	69.2	75.4	81.5	83.8	84.1	79.3	71.1	60.8	54.0	69.2
Seattle	44.7	47.9	52.1	58.1	63.8	68.5	73.7	73.1	67.3	59.1	51.2	46.6	58.8
Wash.	35.8	37.3	39.2	42.8	47.6	51.9	55.1	55.3	52.1	47.2	41.6	38.2	45.3
	40.3	42.6	45.7	50.5	55.7	60.2	64.4	64.2	59.7	53.2	46.4	42.4	52.1
St. Louis	40.3	43.5	53.6	65.2	75.1	84.3	88.6	86.8	79.8	68.5	53.7	43.2	65.2
Mo.	24.6	27.0	36.0	47.1	57.2	66.7	71.1	69.1	61.8	50.4	37.7	28.6	48.1
	32.5	35.3	44.8	56.2	66.2	75.5	79.9	78.0	70.8	59.5	45.7	35.9	56.7
Tampa	70.5	71.7	76.2	80.7	86.0	89.0	89.5	89.8	88.4	82.9	76.0	71.1	81.0
Fla.	52.5	53.5	57.8	62.1	67.7	72.2	73.9	74.1	72.6	66.3	58.1	53.2	63.7
	61.5	62.7	67.0	71.4	76.9	80.6	81.7	82.0	80.5	74.6	67.1	62.2	72.4
Washington	45.5	47.2	55.4	66.2	75.4	83.6	87.1	84.7	78.7	69.1	56.5	45.3	66.2
D. C.	30.2	30.3	36.8	45.6	56.2	56.3	69.1	67.4	60.7	50.4	39.3	30.3	48.5
	37.9	38.8	46.1	55.9	65.8	74.5	78.1	76.1	69.7	59.8	47.9	37.8	57.4

TABLE 4—Average Atmospheric Temperature, Degrees Fahrenheit, Canada

Top Line: Maximum.
Middle Line: Minimum.
Bottom Line: Mean.

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Calgary	24	28	37	53	63	69	76	74	64	54	38	29	51
Alta.	2	6	14	27	36	43	47	45	37	29	17	9	26
	13	17	26	40	50	56	62	60	51	42	28	19	38
Edmonton	15	22	34	52	64	70	74	72	62	52	34	21	48
Alta.	—4	1	12	28	38	45	49	47	38	30	16	5	25
	6	11	23	40	51	58	62	59	50	41	25	13	37
Fort William	17	20	31	44	56	67	74	71	62	50	34	22	46
Ont.	—4	—2	10	26	37	47	52	49	44	34	19	5	27
	7	9	20	35	47	57	63	60	53	42	27	14	36
Halifax	32	31	38	47	58	68	74	74	67	57	46	35	52
N. S.	15	15	23	31	40	48	55	56	50	41	32	21	36
	24	23	30	39	49	58	65	65	59	49	39	28	44
Kamloops	28	34	48	62	71	77	84	81	70	56	41	32	57
B. C.	16	20	29	38	46	52	56	55	47	39	30	22	37
	22	27	38	50	58	64	70	68	58	48	36	27	47
London	29	29	39	54	67	77	81	79	72	58	44	33	55
Ont.	15	12	22	33	44	53	58	55	50	39	30	20	36
	22	21	30	44	55	65	69	67	61	49	37	26	46
Montreal	22	23	33	50	64	74	78	76	67	54	39	26	50
P. Q.	6	8	19	34	46	56	61	59	51	40	28	13	35
	14	15	26	42	56	65	70	67	59	47	33	20	43
Moose Jaw	13	18	30	52	66	73	80	78	66	52	34	21	49
Sask.	—5	—2	10	27	38	48	52	49	40	28	15	2	25
	4	8	20	40	52	61	66	63	53	40	24	12	37
Ottawa	21	22	33	50	66	76	81	77	68	54	38	24	51
Ont.	3	4	16	31	44	54	58	55	48	37	26	9	32
	12	24	24	41	55	65	70	66	58	46	32	17	42
Quebec	18	20	31	44	61	72	76	73	64	51	36	22	47
P. Q.	22	4	15	29	41	52	57	54	48	37	24	9	31
	10	12	23	37	51	62	57	64	56	44	30	16	39
Regina	10	13	27	50	65	73	79	77	65	52	32	16	46
Sask.	—11	—9	6	26	37	47	51	48	38	27	11	—1	22
	— 1	2	16	38	51	60	65	62	51	39	21	8	34
St. John	28	28	36	46	57	64	68	68	63	54	42	31	49
N. B.	11	12	21	31	41	49	54	54	49	40	30	17	34
	19	20	28	39	49	56	61	61	56	47	36	24	41
St. John's	30	28	33	41	51	61	69	68	61	53	43	35	48
Nfld.	18	16	22	29	35	44	51	54	47	40	32	24	34
	24	22	28	35	43	52	50	61	54	46	38	30	41
Saskatoon	9	13	27	49	64	71	77	75	63	51	31	16	46
Sask.	—11	—8	6	26	38	48	52	48	38	27	12	—2	23
	— 1	3	17	37	51	60	65	62	51	39	22	7	34
Toronto	30	30	37	50	63	73	79	77	69	56	43	33	53
Ont.	16	15	23	34	44	54	59	58	51	40	31	21	37
	23	22	30	42	53	63	69	67	60	48	37	27	45
Vancouver	40	44	50	57	63	69	74	72	66	56	48	42	57
B. C.	32	33	36	40	46	50	54	53	49	44	38	35	43
	36	39	43	48	54	60	64	63	57	50	43	39	49
Windsor	31	32	41	55	68	77	82	80	73	61	46	34	57
Ont.	16	16	24	36	46	60	61	60	53	42	31	21	39
	24	24	33	46	57	68	72	70	63	51	38	27	48
Winnipeg	7	12	27	48	65	74	79	76	65	51	30	15	46
Man.	—13	—9	5	27	40	50	55	52	43	31	14	—3	24
	— 3	2	16	38	52	62	67	64	54	41	22	6	35

Source: Climatic summaries for selected stations in Canada; Meteorological Division of the Department of Transport, Ottawa, Ont.

TABLE 5—Average Wind Speed in Miles per Hour, United States

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Albuquerque N. Mex.	6.6	8.6	9.3	10.2	9.8	11.3	9.9	8.8	8.1	7.7	7.8	6.9	8.8
Atlanta Ga.	11.5	11.9	11.8	10.8	9.3	8.2	7.8	7.4	8.3	9.4	10.6	11.1	9.8
Binghamton N. Y.	6.9	7.1	7.2	6.9	5.9	5.2	4.7	4.6	4.8	5.5	6.4	6.6	6.0
Bismarck N. Dak.	10.1	10.3	11.4	12.9	12.5	11.9	9.8	9.9	10.5	10.2	10.6	9.4	10.8
Boston Mass.	12.6	13.2	13.2	12.9	11.4	11.0	10.0	9.9	10.7	11.3	12.3	12.6	11.8
Casper Wyo.	18.2	17.0	14.8	12.8	11.5	12.1	10.4	11.1	11.1	12.3	15.0	17.0	13.6
Charleston S. C.	9.9	10.6	11.0	10.9	10.3	9.8	9.4	9.5	10.2	10.2	9.9	9.7	10.1
Chicago Ill.	11.7	11.8	12.4	12.0	10.5	9.6	8.7	8.7	9.5	10.2	11.8	11.3	10.7
Cleveland Ohio	13.0	12.5	13.3	11.2	9.6	9.0	8.1	8.5	9.8	10.0	10.7	11.7	10.6
Columbia Mo.	8.7	9.4	10.1	9.7	7.7	6.7	6.0	6.0	6.5	7.1	8.7	8.6	7.9
Denver Colo.	7.7	7.8	8.3	8.4	7.8	7.5	7.0	6.7	6.8	7.0	7.4	7.3	7.5
Dodge City Kans.	10.9	11.4	13.2	13.9	13.0	12.6	11.2	10.7	11.8	11.5	10.9	10.8	11.8
East Lansing Mich.	11.0	11.1	11.4	11.1	9.2	8.1	7.4	7.1	8.1	8.9	10.6	10.4	9.5
El Paso Texas	8.7	9.9	11.3	11.4	10.7	9.5	8.6	8.0	8.0	8.1	8.4	8.7	9.3
Fort Worth Texas	10.9	11.4	12.5	12.4	11.2	11.0	9.7	9.4	9.3	9.6	10.3	10.3	10.7
Fresno Calif.	5.4	5.8	6.4	7.4	8.3	8.6	7.8	7.3	6.6	5.6	4.9	5.0	6.6
Great Falls Mont.	17.6	16.6	14.3	14.3	12.5	12.6	11.2	11.1	12.2	14.5	16.2	17.6	14.2
Greensboro N. C.	8.3	8.7	9.5	9.2	8.0	7.2	6.7	6.4	7.0	7.3	7.7	7.6	7.8
Houston Texas	10.6	10.9	11.6	11.6	10.6	9.5	8.4	8.4	8.8	9.5	10.3	10.3	10.0
Indianapolis Ind.	11.4	11.5	11.9	11.5	10.4	9.4	8.7	8.3	9.1	9.8	11.0	11.0	10.3
Lincoln Nebr.	10.4	10.8	12.1	12.2	10.8	10.1	9.2	9.1	9.8	10.2	10.5	10.1	10.4
Little Rock Ark.	8.3	8.8	8.8	8.9	7.6	6.7	6.3	6.0	6.2	6.6	7.6	8.0	7.5
Los Angeles Calif.	5.9	6.1	6.8	6.4	6.7	6.5	6.0	5.9	5.3	5.1	5.0	5.6	5.9
Madison Wis.	11.7	11.8	13.3	12.9	11.1	10.2	8.8	8.0	9.7	10.0	11.9	11.0	10.9
Miami Fla.	13.6	13.5	14.3	14.0	12.2	11.0	10.5	10.3	12.2	13.2	12.8	13.0	12.6
Minneapolis Minn.	11.2	11.4	12.2	12.6	11.8	10.6	9.7	9.7	10.9	11.4	11.5	11.1	11.2
Nashville Tenn.	9.6	9.9	10.5	10.2	8.5	7.7	7.0	6.7	7.2	7.6	9.0	9.2	8.6
New Orleans La.	8.4	8.7	8.8	8.4	7.5	6.8	6.5	6.4	7.4	7.7	8.0	8.2	7.7
New York N. Y.	16.5	17.0	17.3	15.9	13.6	12.9	12.1	11.7	12.5	14.0	15.8	16.3	14.6
Norfolk Va.	11.9	12.1	12.8	12.2	10.9	10.1	9.6	9.5	10.0	10.7	11.2	11.3	11.0
Oklahoma City Okla.	16.5	15.7	17.2	17.0	15.1	15.2	12.1	11.4	12.6	13.6	13.8	14.8	14.6
Philadelphia Pa.	10.9	11.3	11.8	11.3	10.0	9.3	8.7	8.4	8.8	9.7	10.4	10.5	10.1
Phoenix Ariz.	4.3	4.9	5.7	5.7	5.8	5.6	5.8	5.2	4.8	4.4	4.1	4.0	5.0
Pittsburgh Pa.	11.6	12.0	12.5	11.8	10.0	9.2	8.5	8.1	8.3	9.6	11.4	11.6	10.4

TABLE 5—(Continued)

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Portland Oreg.	7.5	7.3	7.2	6.9	6.8	6.6	6.8	6.3	6.2	6.0	6.9	7.4	6.8
Providence R. I.	11.8	12.1	12.5	12.1	10.7	10.0	9.1	8.8	9.4	10.3	11.0	11.4	10.8
Rapid City S. Dak.	12.6	13.1	13.9	15.1	14.0	12.4	11.4	11.9	12.8	12.4	13.1	12.1	12.9
Sacramento Calif.	7.1	7.7	8.0	8.2	8.6	8.6	8.3	7.8	7.0	6.4	6.1	6.7	7.5
Salt Lake City Utah	7.6	8.0	9.1	9.4	9.5	9.5	9.5	9.7	9.1	8.6	7.7	7.4	8.8
San Antonio Texas	8.4	9.1	9.6	9.5	9.0	8.6	7.9	7.4	7.5	7.6	8.1	8.0	8.4
Seattle Wash.	10.3	9.8	10.1	9.4	8.9	8.4	7.9	7.3	7.5	8.4	9.4	10.5	9.0
St. Louis Mo.	11.9	12.0	12.6	12.1	11.0	10.1	9.3	9.0	9.8	10.6	11.8	11.6	11.0
Tampa Fla.	8.4	8.9	9.1	8.9	8.3	7.6	7.1	7.0	7.9	8.7	8.5	8.2	8.2
Washington D. C.	10.9	11.3	12.2	11.4	9.4	9.3	8.5	8.2	8.6	8.9	9.5	10.0	9.9

TABLE 6—Average Wind Speed in Miles per Hour, Canada

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Calgary Alta.	6.8	6.8	7.6	8.2	8.4	7.8	6.8	6.9	7.1	7.1	6.9	7.3	7.3
Edmonton Alta.	7.2	8.3	9.3	10.6	9.7	9.7	8.6	8.3	8.4	8.7	7.9	7.4	8.7
Fort William Ont.	7.9	8.3	8.9	8.8	8.7	7.9	6.8	7.1	7.9	8.9	8.8	8.3	8.2
Halifax N. S.	9.1	10.3	10.2	8.8	7.6	7.3	6.3	7.7	7.7	8.5	9.1	9.5	8.4
Kamloops B. C.	—	—	—	—	—	—	—	—	—	—	—	—	—
London Ont.	10.9	11.3	11.5	11.1	9.2	7.6	6.3	5.9	7.4	8.9	10.5	10.5	9.3
Montreal P. Q.	12.4	12.7	12.7	12.4	11.3	10.5	9.6	9.5	10.3	11.2	10.9	11.9	11.3
Moose Jaw Sask.	—	—	—	—	—	—	—	—	—	—	—	—	—
Ottawa Ont.	8.0	7.4	7.8	8.4	7.6	6.5	5.7	5.9	6.2	7.3	8.2	7.7	7.2
Quebec P. Q.	12.7	12.6	12.7	12.1	12.1	9.9	8.7	8.3	9.2	10.4	11.2	11.8	11.0
Regina Sask.	12.0	12.1	13.2	13.9	14.0	13.4	11.4	12.3	12.6	12.9	13.0	12.1	12.7
St. John N. B.	14.2	13.4	13.2	11.9	9.9	8.7	7.6	7.5	9.1	11.6	12.3	13.9	11.1
St. John's Nfld.	12.3	13.1	11.4	11.1	9.6	9.3	9.1	9.8	9.8	10.9	11.5	12.4	10.9
Saskatoon Sask.	9.5	9.3	11.1	12.6	13.0	11.4	10.2	10.6	10.2	11.7	10.8	10.2	10.9
Toronto Ont.	14.7	13.6	13.8	12.7	10.2	8.8	8.0	8.4	9.3	10.6	12.8	13.9	11.4
Vancouver B. C.	3.7	4.0	4.4	4.5	4.3	4.0	3.8	3.4	3.4	3.3	3.4	4.8	3.9
Windsor Ont.	12.1	13.4	13.7	12.4	9.6	7.2	7.5	7.0	8.1	9.7	11.5	11.4	10.3
Winnipeg Man.	11.8	11.4	12.3	13.6	13.3	12.4	10.8	11.4	12.7	13.2	13.1	12.0	12.3

Source: Climatic summaries for selected stations in Canada; Meteorological Division of the Department of Transport, Ottawa, Ont.

TABLE 7—Average Precipitation in Inches, United States

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Albuquerque N. Mex.	0.37	0.34	0.40	0.60	0.70	0.61	1.44	1.28	0.92	0.75	0.45	0.41	8.27
Atlanta Ga.	4.71	4.68	5.49	3.91	3.49	3.85	4.66	4.15	3.16	2.50	3.09	4.63	48.32
Binghamton N. Y.	2.34	2.21	2.85	2.81	3.47	3.34	3.64	3.43	3.14	2.80	2.46	2.36	34.85
Bismarck N. Dak.	0.46	0.46	0.92	1.49	2.22	3.39	2.28	1.82	1.30	0.95	0.55	0.52	16.36
Boston Mass.	3.61	3.26	3.81	3.54	3.32	3.14	3.22	3.62	3.15	3.22	3.76	3.41	41.06
Casper Wyo.	0.53	0.48	0.88	1.42	2.07	1.22	1.02	0.61	0.93	0.94	0.64	0.43	11.17
Charleston S. C.	2.81	3.20	3.39	2.73	3.21	4.62	7.19	6.50	5.19	3.12	2.23	2.85	47.04
Chicago Ill.	1.94	1.87	2.75	2.88	3.56	3.62	3.22	3.14	3.11	2.64	2.36	2.03	33.12
Cleveland Ohio	2.62	2.39	2.89	2.65	3.07	3.23	3.36	2.88	3.16	2.65	2.58	2.41	33.89
Columbia Mo.	1.92	1.80	2.95	3.75	4.75	4.83	3.28	3.97	4.39	2.86	2.32	1.83	38.65
Denver Colo.	0.45	0.55	1.09	2.01	2.31	1.38	1.56	1.38	0.99	0.99	0.64	0.63	13.98
Dodge City Kans.	0.44	0.73	0.94	1.98	2.96	3.21	2.86	2.61	1.72	1.40	0.79	0.59	20.24
East Lansing Mich.	1.87	1.81	2.50	2.82	3.61	3.43	2.57	2.82	2.92	2.47	2.26	2.03	31.11
El Paso Texas	0.45	0.40	0.33	0.29	0.36	0.62	1.70	1.54	1.16	0.82	0.46	0.51	8.64
Fort Worth Texas	1.83	2.00	2.24	3.81	4.69	3.01	2.14	2.24	2.58	2.72	2.28	2.00	31.54
Fresno Calif.	1.72	1.51	1.63	0.91	0.37	0.11	0.01	0.01	0.15	0.56	0.89	1.57	9.44
Great Falls Mont.	0.60	0.72	0.94	0.96	2.38	3.26	1.23	1.10	1.42	0.74	0.69	0.60	14.64
Greensboro N. C.	3.39	3.15	3.83	3.23	3.43	3.69	4.68	4.54	3.45	2.57	2.84	3.27	42.07
Houston Texas	3.63	2.96	3.02	3.48	4.73	4.20	4.26	3.71	3.88	3.54	3.76	4.27	45.44
Indianapolis Ind.	3.09	2.57	3.90	3.60	3.85	4.14	3.66	3.27	3.22	2.69	3.19	2.86	40.04
Lincoln Nebr.	0.71	0.98	1.35	2.52	3.83	4.33	3.57	3.48	2.83	1.83	1.22	0.84	27.49
Little Rock Ark.	4.96	3.89	4.67	5.00	4.85	3.56	3.32	3.34	3.05	2.86	4.07	4.15	47.72
Los Angeles Calif.	2.17	2.49	1.94	0.95	0.25	0.06	T	0.02	0.22	0.39	1.11	2.47	12.07
Madison Wis.	1.54	1.40	2.07	2.54	3.53	3.97	3.71	3.19	3.63	2.25	1.89	1.57	31.29
Miami Fla.	2.11	1.88	2.29	3.52	6.45	6.71	5.44	5.73	8.30	8.16	2.93	1.74	55.26
Minneapolis Minn.	0.82	0.87	1.51	2.11	3.43	4.28	3.44	3.13	3.02	1.96	1.37	0.91	26.85
Nashville Tenn.	4.98	4.14	5.16	4.13	3.77	3.79	3.98	3.38	3.19	2.44	3.42	4.06	46.44
New Orleans La.	4.55	4.46	5.50	5.33	4.77	5.78	6.79	5.96	5.39	3.37	3.74	4.78	60.42
New York N. Y.	3.53	3.42	3.85	3.41	3.46	3.44	4.31	4.38	3.67	3.50	3.22	3.39	43.58
Norfolk Va.	3.19	3.33	3.74	3.32	3.72	4.13	5.82	5.42	3.67	2.98	2.62	3.19	45.13
Oklahoma City Okla.	1.35	1.21	2.14	3.36	5.05	3.83	2.66	2.73	2.95	2.72	2.06	1.52	31.58
Philadelphia Pa.	3.36	3.15	3.53	3.30	3.52	3.54	4.20	4.65	3.29	2.81	3.09	3.15	41.59
Phoenix Ariz.	0.82	0.78	0.66	0.40	0.13	0.08	1.02	1.07	0.78	0.41	0.65	0.85	7.65
Pittsburgh Pa.	2.97	2.48	3.25	3.04	3.28	3.82	4.00	3.21	2.56	2.53	2.34	2.73	36.21

TABLE 7—(Continued)

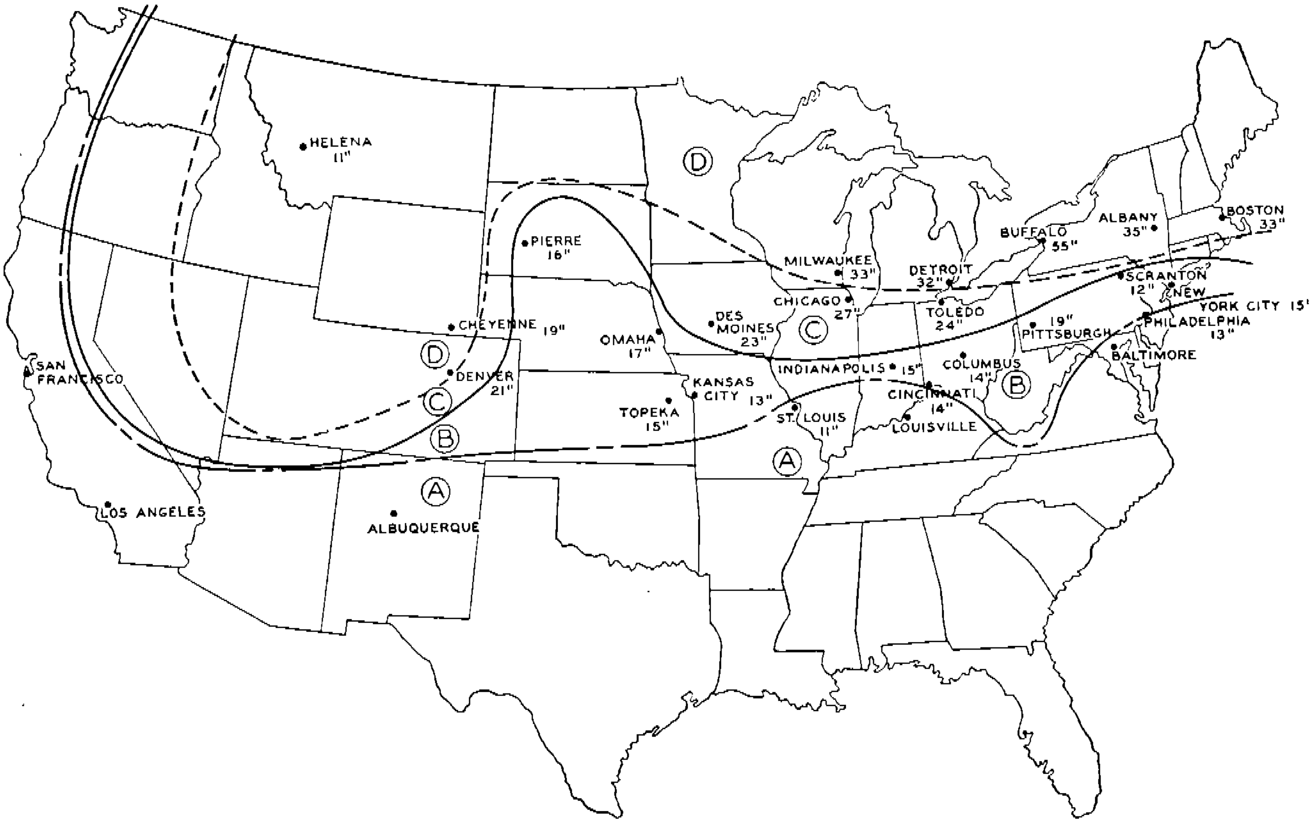
Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Portland Oreg.	6.36	5.23	4.54	2.78	2.15	1.59	0.53	0.64	1.82	3.36	6.23	7.02	42.25
Providence R. I.	3.69	3.04	3.57	3.47	3.13	2.94	3.06	3.65	3.19	2.83	3.51	3.56	39.64
Rapid City S. Dak.	0.43	0.41	1.01	1.91	3.29	3.37	2.36	1.67	1.29	1.06	0.63	0.55	17.98
Sacramento Calif	3.55	3.00	2.64	1.45	0.70	0.13	0.02	T	0.22	0.83	1.85	3.64	18.03
Salt Lake City Utah	1.31	1.16	1.60	1.72	1.30	0.97	0.66	0.93	0.64	1.25	1.27	1.23	14.04
San Antonio Texas	1.56	1.56	1.75	3.06	3.22	2.79	2.05	2.24	3.00	2.19	1.72	1.74	26.88
Seattle Wash.	4.91	3.85	3.12	2.22	1.78	1.36	0.64	0.71	1.70	2.91	4.87	5.49	33.56
St. Louis Mo.	2.30	2.42	3.49	3.74	4.36	4.38	3.43	3.54	3.21	2.86	2.79	2.44	38.96
Tampa Fla.	2.26	2.63	2.72	2.26	2.95	7.49	8.01	7.98	6.76	2.81	1.63	2.02	49.52
Washington D. C.	3.07	2.08	3.44	2.93	5.12	3.49	4.40	4.80	3.51	3.01	3.33	3.02	42.20

T = Trace.

TABLE 8—Average Precipitation in Inches, Canada

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Calgary Alta.	.51	.55	.84	.99	2.34	3.14	2.51	2.29	1.50	.69	.72	.57	16.65
Edmonton Alta.	.88	.64	.76	.88	1.85	3.06	3.32	2.35	1.33	.75	.75	.81	17.38
Fort William Ont.	.91	.76	.95	1.49	2.11	2.81	3.56	2.78	3.37	2.45	1.52	.95	23.66
Halifax N. S.	5.40	4.35	4.85	4.54	4.14	4.04	3.79	4.38	4.13	5.42	5.31	5.39	55.74
Kamloops B. C.	1.04	.74	.38	.40	.88	1.29	.99	1.07	.82	.68	.86	1.05	10.20
London Ont.	3.97	3.45	2.81	2.87	2.81	3.11	3.21	2.80	2.96	2.91	3.74	3.53	38.17
Montreal P. Q.	3.76	3.02	3.46	2.60	3.14	3.43	3.74	3.45	3.65	3.42	3.55	3.58	40.80
Moose Jaw Sask.	.68	.50	.69	.75	1.92	2.86	1.97	1.86	1.25	.91	.64	.68	14.71
Ottawa Ont.	2.93	2.17	2.77	2.70	2.47	3.52	3.39	2.56	3.23	2.93	2.98	2.58	34.23
Quebec P. Q.	3.45	2.74	3.02	2.35	3.15	3.68	4.02	3.98	3.60	3.41	3.23	3.22	39.85
Regina Sask.	.51	.35	.67	.74	1.84	3.25	2.38	1.76	1.32	.86	.60	.42	14.70
St. John N. B.	4.28	3.05	3.61	3.22	3.13	3.15	3.03	3.61	3.53	4.01	3.81	3.83	42.26
St. John's Nfld.	5.31	5.13	4.64	3.77	3.85	3.13	3.14	3.97	3.73	4.76	5.71	5.95	53.09
Saskatoon Sask.	.87	.50	.66	.72	1.42	2.57	2.41	1.94	1.46	.88	.51	.61	14.55
Toronto Ont.	2.71	2.43	2.58	2.48	2.91	2.67	2.95	2.73	2.90	2.43	2.76	2.63	32.18
Vancouver B. C.	8.57	5.79	5.03	3.34	2.84	2.45	1.22	1.69	3.63	5.78	8.28	8.76	57.38
Windsor Ont.	2.31	2.16	2.42	2.24	3.08	3.35	3.42	2.69	2.59	2.17	2.45	2.24	31.12
Winnipeg Man.	.92	.86	1.19	1.37	2.26	3.15	3.08	2.45	2.35	1.49	1.12	.95	21.19

Source: Climatic summaries for selected stations in Canada; Meteorological Division of the Department of Transport, Ottawa, Ont.



Note: Figures show maximum snow accumulation under most severe conditions.

Area A: Oil temperature seldom drops below freezing, improbable to obtain 20 in. of accumulated snow. Winter maintenance rarely required.

Area B: Although oil temperature occasionally drops below freezing, improbable to obtain 20 in. of accumulated snow. Winter maintenance rarely required.

Area C: Oil temperature occasionally drops below freezing, snow accumulation can exceed 20 in. During most severe conditions, winter maintenance occasionally required.

occasionally required. In most severe areas, vapor-balancing structures may be preferable.

Area D: Oil temperature frequently below freezing, snow accumulations can exceed 30 in. Snow removal and winter maintenance

Source: Data from the U.S. Weather Bureau.

FIG. 1—Snow and Temperature Map of the United States.

TABLE 9—Average Snowfall in Inches, Canada

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Calgary Alta.	5.0	5.4	8.1	6.4	5.2	0.3	T	0.1	2.6	4.2	7.1	5.6	50.0
Edmonton Alta.	8.3	6.3	7.0	4.1	1.9	T	—	T	0.9	3.5	6.8	7.6	46.4
Fort William Ont.	8.9	7.1	8.0	3.8	0.5	—	—	—	T	1.2	5.9	7.5	42.9
Halifax N. S.	18.9	18.8	11.9	5.7	0.1	—	—	—	—	0.2	2.7	12.5	70.8
Kamloops B. C.	9.5	6.0	1.5	0.1	—	—	—	—	T	0.5	4.7	8.6	30.9
London Ont.	23.3	22.3	11.3	3.8	0.1	—	—	—	T	0.9	10.8	19.1	91.6
Montreal P. Q.	27.7	23.3	20.1	5.5	0.1	—	—	—	T	0.9	10.9	23.8	112.3
Moose Jaw Sask.	6.7	4.9	6.3	2.7	0.7	T	—	—	0.9	2.6	5.0	6.2	36.0
Ottawa Ont.	21.5	17.3	14.4	4.4	T	—	—	—	—	0.8	6.4	17.2	82.0
Quebec P. Q.	29.3	23.1	20.8	8.7	0.5	—	—	—	T	1.8	14.4	25.1	123.7
Regina Sask.	4.7	3.4	5.4	3.0	0.6	0.1	—	—	0.6	2.3	4.8	3.9	28.8
St. John N. B.	18.8	17.2	11.5	5.4	0.1	—	—	—	—	0.2	5.1	12.8	71.1
St. John's Nfld.	—	—	—	—	—	—	—	—	—	—	—	—	—
Saskatoon Sask.	8.7	5.0	6.2	2.5	0.3	—	—	—	0.8	2.6	5.0	6.1	37.2
Toronto Ont.	16.0	15.3	10.7	2.8	0.1	T	—	—	T	0.4	4.2	12.4	61.9
Vancouver B. C.	11.5	6.4	2.7	0.3	—	—	—	—	—	0.1	2.1	5.7	28.8
Windsor Ont.	12.4	10.4	7.8	1.8	T	—	—	—	—	0.2	2.9	8.9	44.4
Winnipeg Man.	9.1	8.4	10.0	3.9	1.1	T	—	—	0.1	2.9	9.0	9.1	53.6

Source: Meteorological Division of the Department of Transport, Ottawa, Ont.
T = Trace.

APPENDIX VII—COMMITTEE MEMBERSHIP

Committee on Evaporation Loss, 1956-1958

Members

J. H. McClintock (*Chairman*)	Esso Standard Oil Co.	New York, N. Y.
E. L. Hoffman (*Vice Chairman*)	Socony Mobil Oil Co., Inc.	New York, N. Y.
E. O. Mattocks (*Secretary*)	American Petroleum Institute	New York, N. Y.
E. M. Beschwitz	Gulf Oil Corp.	Pittsburgh, Pa.
J. H. Brown	Tidewater Oil Co.	New York, N. Y.
W. H. Creel	Phillips Petroleum Co.	Bartlesville, Okla.
S. H. Dowdell	The British American Oil Co. Limited	Toronto, Ont., Canada
P. E. Frank	Sinclair Refining Co.	New York, N. Y.
T. C. Frick	The Atlantic Refining Co.	Dallas, Texas
J. P. Hammond	Amerada Petroleum Corp.	Tulsa, Okla.
D. E. Hanson	Sinclair Refining Co.	New York, N. Y.
H. M. Hart	Standard Oil Co. (Indiana)	Whiting, Ind.
R. W. Hill	Pan American Petroleum Corp.	Tulsa, Okla.
Francis Horton	The Texas Co.	New York, N. Y.
F. P. Irwin	Imperial Oil Limited	Toronto, Ont., Canada
A. W. Jasek	Humble Pipe Line Co.	Houston, Texas
O. W. Johnson	Standard Oil Co. of California	San Francisco, Calif.
K. G. Krech	The Atlantic Refining Co.	Philadelphia, Pa.
E. P. Kropp	The Standard Oil Co. (Ohio)	Cleveland, Ohio
R. T. Mapston	Richfield Oil Corp.	Wilmington, Calif.
H. S. Mount	Sun Oil Co.	Philadelphia, Pa.
K. G. Oswald	The Pure Oil Co.	Chicago, Ill.
H. C. Packard	Shell Oil Co.	New York, N. Y.
E. O. Perkins	The Texas Co.	New York, N. Y.
A. B. Stevens	General Petroleum Corp.	Torrance, Calif.
E. F. Wagner	The Atlantic Refining Co.	Philadelphia, Pa.
L. S. Wrightsman	Humble Pipe Line Co.	Houston, Texas

Subcommittee I—Methods of Testing, 1956-1958

Members

O. W. Johnson (*Chairman*)	Standard Oil Co. of California	San Francisco, Calif.
J. A. Arnold	The Standard Oil Co. (Ohio)	Cleveland, Ohio
J. M. Dempster (alternate to E. G. Ellerbrake)	The Standard Oil Co. (Ohio)	Cleveland, Ohio
E. G. Ellerbrake	Sohio Pipe Line Co.	St. Louis, Mo.
George Entwistle	Sinclair Research Laboratories, Inc.	Harvey, Ill.
H. M. Hart	Standard Oil Co. (Indiana)	Whiting, Ind.
T. W. Legatski	Phillips Petroleum Co.	Bartlesville, Okla.
D. Ray Miley	Sun Oil Co.	Toledo, Ohio
George Rezanka	Sinclair Refining Co.	East Chicago, Ind.
J. R. Spencer	Continental Oil Co.	Ponca City, Okla.
G. E. C. Wear	Esso Research and Engineering Co.	Linden, N. J.

Associate Members

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L. V. Larsen	Chicago Bridge and Iron Co.	New York, N. Y.

Subcommittee II—Correlations, 1956-1958

Members

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D. E. Bruce	Standard Oil Co. (Indiana)	Whiting, Ind.
O. W. Johnson	Standard Oil Co. of California	San Francisco, Calif.
R. W. Martz	Esso Standard Oil Co.	New York, N. Y.
C. C. Miller	The Atlantic Refining Co.	Dallas, Texas

Subcommittee II—Continued

Associate Members

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N. A. Pierson	General American Transportation Corp.	Chicago, Ill.
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Subcommittee III—Field Test Program Development, 1956-1958

Members

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J. E. Chaffin	Cities Service Pipeline Co.	Bartlesville, Okla.
J. M. Dempster (alternate to E. G. Ellerbrake)	The Standard Oil Co. (Ohio)	Cleveland, Ohio
I. T. Fritz	Sinclair Refining Co.	Marcus Hook, Pa.
H. M. Hart	Standard Oil Co. (Indiana)	Whiting, Ind.
R. W. Hill	Pan American Petroleum Corp.	Tulsa, Okla.
Francis Horton	The Texas Co.	New York, N. Y.
F. P. Irwin	Imperial Oil Limited	Toronto, Ont., Canada
F. S. Lee	Shell Oil Co. of Canada, Ltd.	Toronto, Ont., Canada
S. B. Lisle	Sohio Petroleum Co	Oklahoma City, Okla.
R. L. Meuleners	American Oil Co.	New York, N. Y.
D. Ray Miley	Sun Oil Co.	Toledo, Ohio
S. H. Pope	Gulf Oil Corp.	Houston, Texas
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R. W. Bodley	Graver Tank and Manufacturing Co.	East Chicago, Ind.
H. V. Dwight	The B. F. Goodrich Co.	Akron, Ohio
A. Fino	Hammond Iron Works	Warren, Pa.
L. V. Larsen (alternate to I. L. Wissmiller)	Chicago Bridge and Iron Co.	New York, N. Y.
W. K. Lewis	Massachusetts Institute of Technology	Cambridge, Mass.
F. V. Long	Vapor Recovery Systems Co.	Compton, Calif.
N. M. Wiseman	General American Transportation Corp.	Chicago, Ill.
I. L. Wissmiller	Chicago Bridge and Iron Co.	Chicago, Ill.

Subcommittee IV—Publications, 1956-1958

Members

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P. D. Baker	The Carter Oil Co.	Tulsa, Okla.
S. H. Dowdell	The British American Oil Co. Limited	Toronto, Ont., Canada
P. E. Frank	Sinclair Refining Co.	New York, N. Y.
D. E. Hanson	Sinclair Refining Co.	New York, N. Y.
E. L. Hoffman	Socony Mobil Oil Co., Inc.	New York, N. Y.
A. W. Jasek	Humble Pipe Line Co.	Houston, Texas
K. G. Krech	The Atlantic Refining Co.	Philadelphia, Pa.
H. S. Mount	Sun Oil Co.	Philadelphia, Pa.
O. L. Neurnberger	Shell Oil Co.	Centralia, Ill.
E. O. Perkins	The Texas Co.	New York, N. Y.
H. E. Simonson	Phillips Petroleum Co.	Bartlesville, Okla.
E. F. Wagner	The Atlantic Refining Co.	Philadelphia, Pa.
L. S. Wrightsman	Humble Pipe Line Co.	Houston, Texas

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W. F. Bland	McGraw-Hill Publishing Co., Inc.	New York, N. Y.
I. E. Boberg	Chicago Bridge and Iron Co.	Chicago, Ill.
A. A. Lummio	Graver Tank and Manufacturing Co.	East Chicago, Ind.
J. M. Suardi	Graver Tank and Manufacturing Co.	East Chicago, Ind.
J. C. Thompson	General American Transportation Corp.	New York, N. Y.

3M—Feb. 1959
3M—Jan. 1962
5C—Feb. 1970
1M—Mar. 1971
1M—June 1973
1M—Jul. 1976