Manual of Petroleum Measurement Standards Chapter 19—Evaporative Loss Measurement

Section 1A—Evaporation Loss from Low-pressure Tanks

MARCH 1962
REAFFIRMED, FEBRUARY 2006
(PREVIOUSLY API BULLETIN 2516)

American Petroleum Institute

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Measurement Coordination

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American Petroleum Institute

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ON

EVAPORATION LOSS FROM LOW-PRESSURE TANKS

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ABSTRACT

Low-pressure tanks, operating at positive pressures from just above atmospheric pressure to 15 psig, are normally used for storage of motor gasoline, pentanes, and natural gasolines having up to 30 lb RVP. Because insufficient data are available to establish equations by correlation, the loss equations presented in this bulletin are based on a theoretical study made by the API Committee on Evaporation Loss Measurement.

Using a theoretical equation, the design pressure, confirmed by experience, which will prevent breathing loss from motor fuel having a Reid vapor pressure of 14 lb calculates to be 2.5 psig. The pressure required to prevent boiling loss may be determined by use of another equation. Losses from tanks venting at pressures below the pressure required to prevent breathing may be estimated as a percent of the loss which would have attended storage in an atmospheric pressure tank.

The appropriate application of low-pressure tanks is for storage of stocks having a true vapor pressure of more than 14.7 psia, wherein working losses can theoretically be completely eliminated. In practice, working loss does occur and depends upon the rate of pump-in, dissipation of heat, and pump-out. No equations are presented for these conditions.

Because low-pressure tanks for storing stocks having a true vapor pressure of less than 15 psia are limited in number, a field test program for refinement of the breathing loss equation for those tanks is not justified. Data are needed for a wide range of pump-in rates and vessel sizes under summer conditions to establish the safe working pressure which will prevent working loss for products having a true vapor pressure of more than 15 psia.

CONTENTS

EVAPORATION LOSS FROM LOW-PRESSURE TANKS

Introduction

The term low-pressure tank, as used in this evaporation loss bulletin, refers to vessels having a maximum pressure vent setting in the range from just above atmospheric pressure to 15 psig and a vacuum vent setting normally 1 to 2 oz per sq in. The tanks are used for the storage of products, such as motor gasoline, pentanes, and natural gasolines, having a Reid vapor pressure up to 30 lb. Although a storage pressure of less than 2.5 psig may be used for some products, the type of vessel construction does not permit appreciable economy by using lower design pressures. The loss principles applying to 2.5-psig to 15-psig pressure will also apply for higher or lower working pressures than the specified range. Low-pressure tanks are constructed in many sizes and shapes, depending upon the operating pressure range. Fig. 1, 2, 3, and 4 show typical types of construction.

Pressure tanks differ from other conservation tanks in that they have neither moving parts nor a variable vapor space. The principle of operation is the same as that for the conservation vented fixed-roof tank. The basic difference is the ability of low-pressure tanks to withstand higher pressure variations. Because of this, venting loss due to boiling and breathing loss due to daily temperature changes are prevented. By increasing the tank design pressure, liquids of higher volatility may be stored without breathing loss.

The amount of loss from pressure storage tanks has been considered by users and tank manufacturers, but few data are available. Therefore, a theoretical basis has been used to estimate losses resulting from various storage conditions and types of products. Four types of losses are considered: breathing loss, boiling loss, working loss, and leakage loss. Factors are discussed that affect the performance of low-pressure tank storage.

Vent Pressure Required to Prevent Breathing Loss

Breathing loss occurs when vapors are vented from the vessel as a result of thermal expansion of the vapors in the vapor space and by the vapor pressure increase resulting from the increase in the liquid-surface temperature. No breathing loss occurs unless the pressure rise resulting from these two variables exceeds the vent setting.

For an apparent liquid-surface temperature up to 100 F, experience has shown that a pressure of 2.5 psig will substantially prevent breathing losses from motor gasolines having a Reid vapor pressure up to 14 lb. A small annual loss may result from seasonal changes in storage temperature.

By the use of equation (1) (derived in Appendix I), the theoretical pressure (P_t) required to prevent breathing losses may be calculated:

$$P_2 = 1.1(P_a + P_1 - p_1) - (P_a - p_2) \qquad (1)$$

Where:

- P_2 = gage pressure at which pressure vent opens, in pounds per square inch gage.
- P_a = atmospheric pressure (at sea level = 14.7 psia).
- P_1 = gage pressure at which vacuum vent opens, in pounds per square inch gage.
- p_1 = true vapor pressure at 90 F minimum liquid-surface temperature, in pounds per square inch absolute.
- p_2 = true vapor pressure at 100 F maximum liquid-surface temperature, in pounds per square inch absolute.

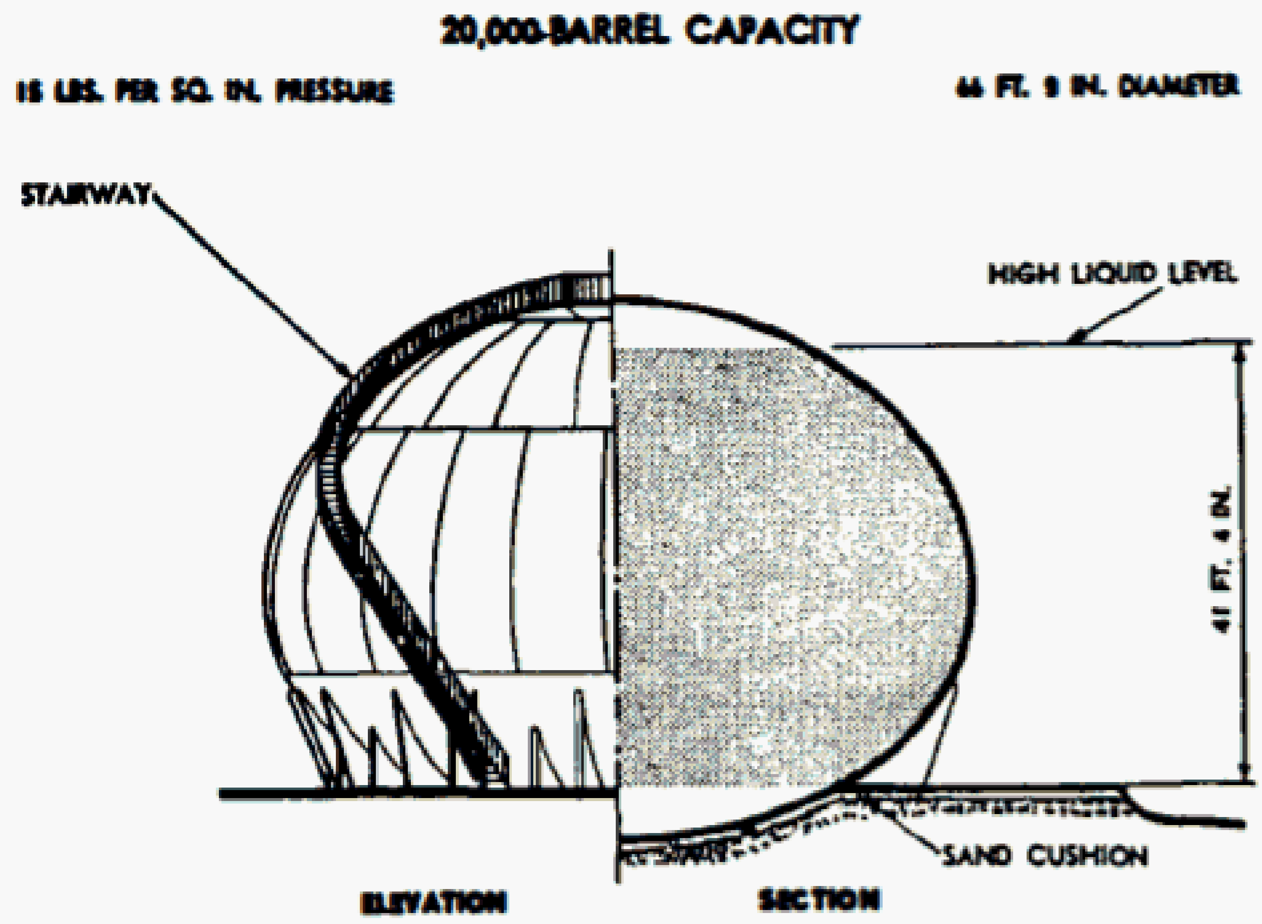
P_t has been calculated to be 2.5 psig for 14-lb-RVP gasoline, using equation (1) and sea-level atmospheric pressure. By using the temperature assumptions demonstrated to work for motor gasolines, required storage pressures may be calculated for liquids of higher volatility.

The relation in equation (1) applies only when the vapor pressure of the liquid at minimum surface temperature (p_i) is less than the absolute pressure ($P_i + P_a$) at which the vacuum vent opens. Under this condition air is always present in the vapor space. The breathing curve shown in Fig. 5 is a plot of equation (1) and gives the pressure (P_t) calculated to eliminate breathing losses for products ranging up to 17.5 psia TVP at 100 F with storage at sea-level atmospheric pressure. Products having a true vapor pressure above 17.5 psia are subjected to boiling losses; these products are discussed in a subsequent section. The Fig. 5 plot of equation (1) is for the condition where $P_i = 0.0$ psig. The value of p_i corresponding to p_t was obtained from the vapor pressure chart, Fig. 6. A range of distillation slopes was used ; i.e. S = 3 for the condition $p_t = 8$ to S = 1 for the condition $p_t = 17.5$, because the higher vapor pressure stocks tend to have a smaller slope.

Altitude will affect the required storage pressure. Adjustment of storage pressures for atmospheric pressures other than 14.7 psia may be made by substituting the proper atmospheric pressure (P_a) in equation (1). Table 1 lists the atmospheric pressure existing at various altitudes.

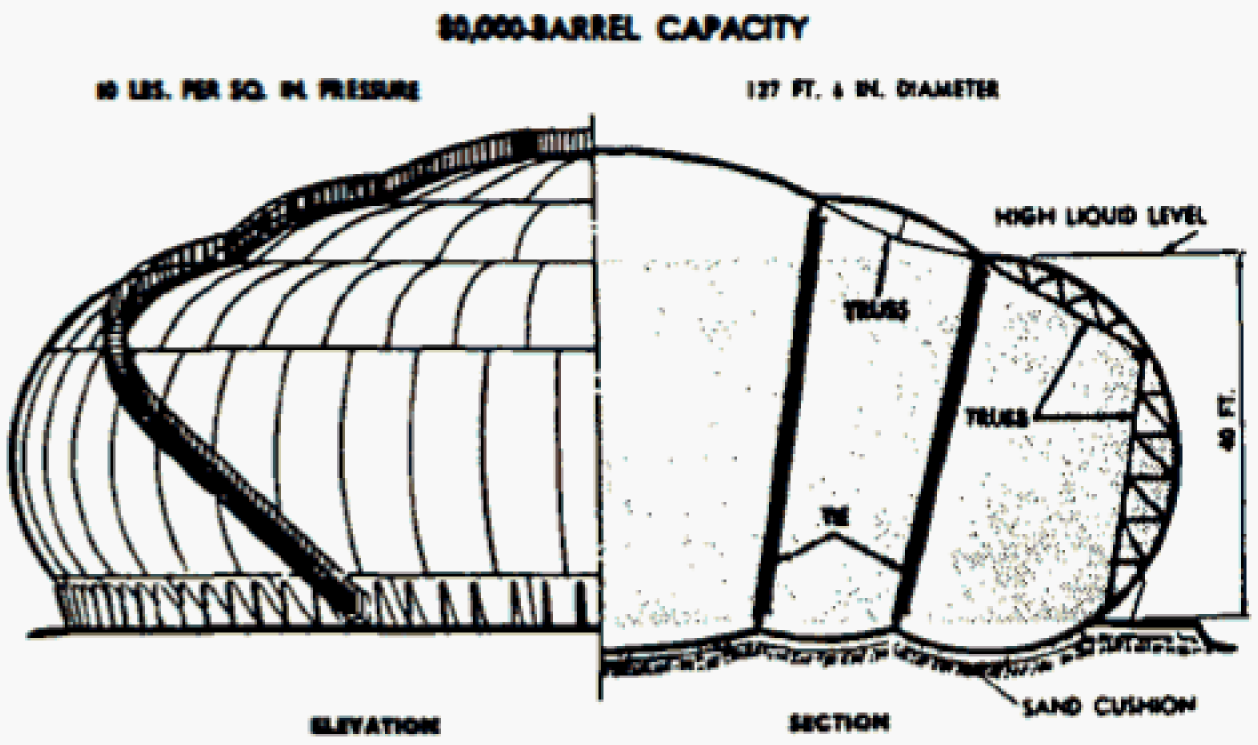
TABLE 1—Atmospheric Pressure at Altitudes Above Sea Level

Feet	Pounds per Square Inch Absolute
1,000	14.17
2,000	13.66
3,000	13.17
4,000	12.69
5,000	12.23



Courtesy: Chicago Bridge and Iron Company.

FIG. 1—Spheroid.



Courtesy: Chicago Bridge and Iron Company.

FIG. 2—Noded Spheroid.

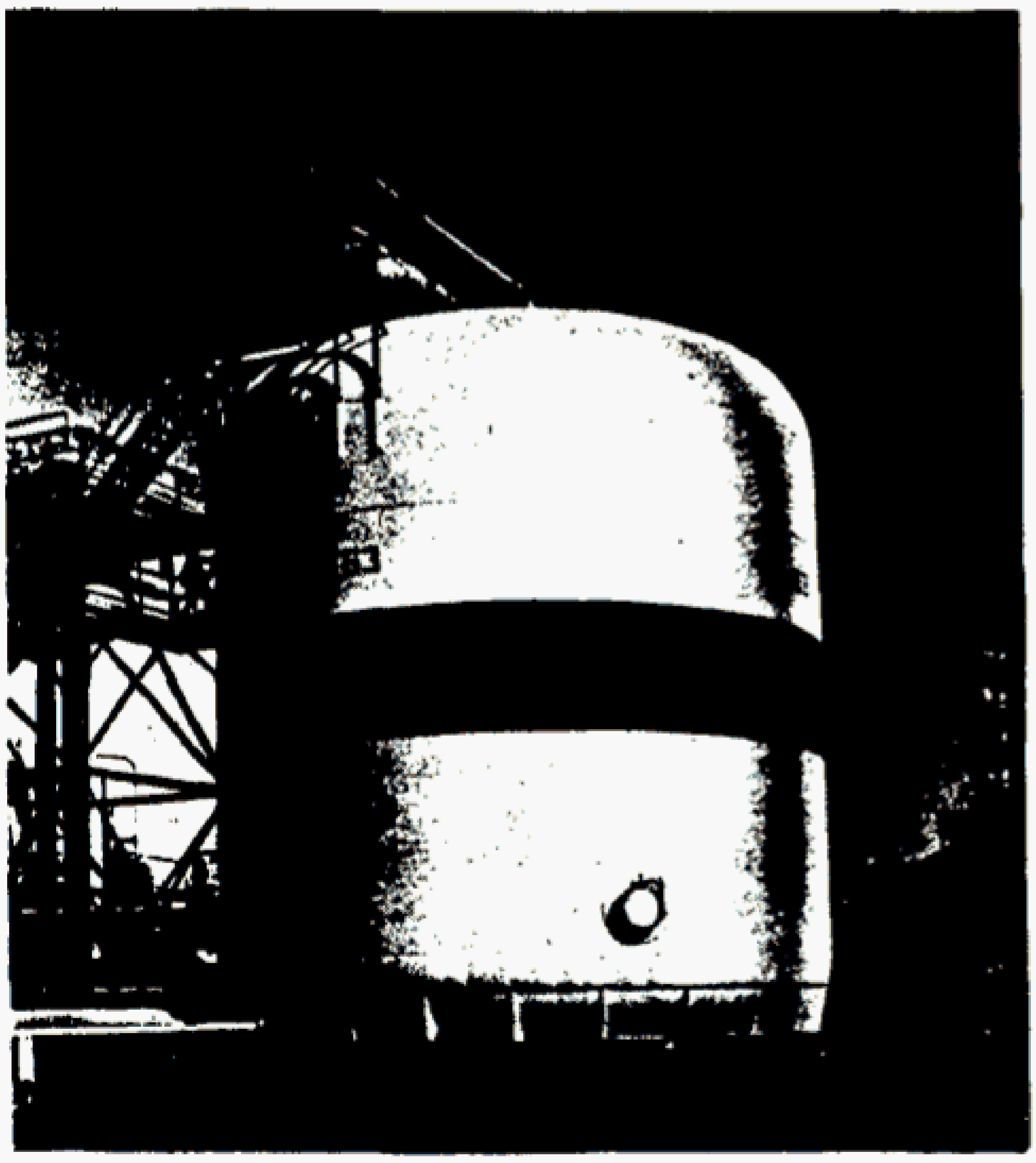
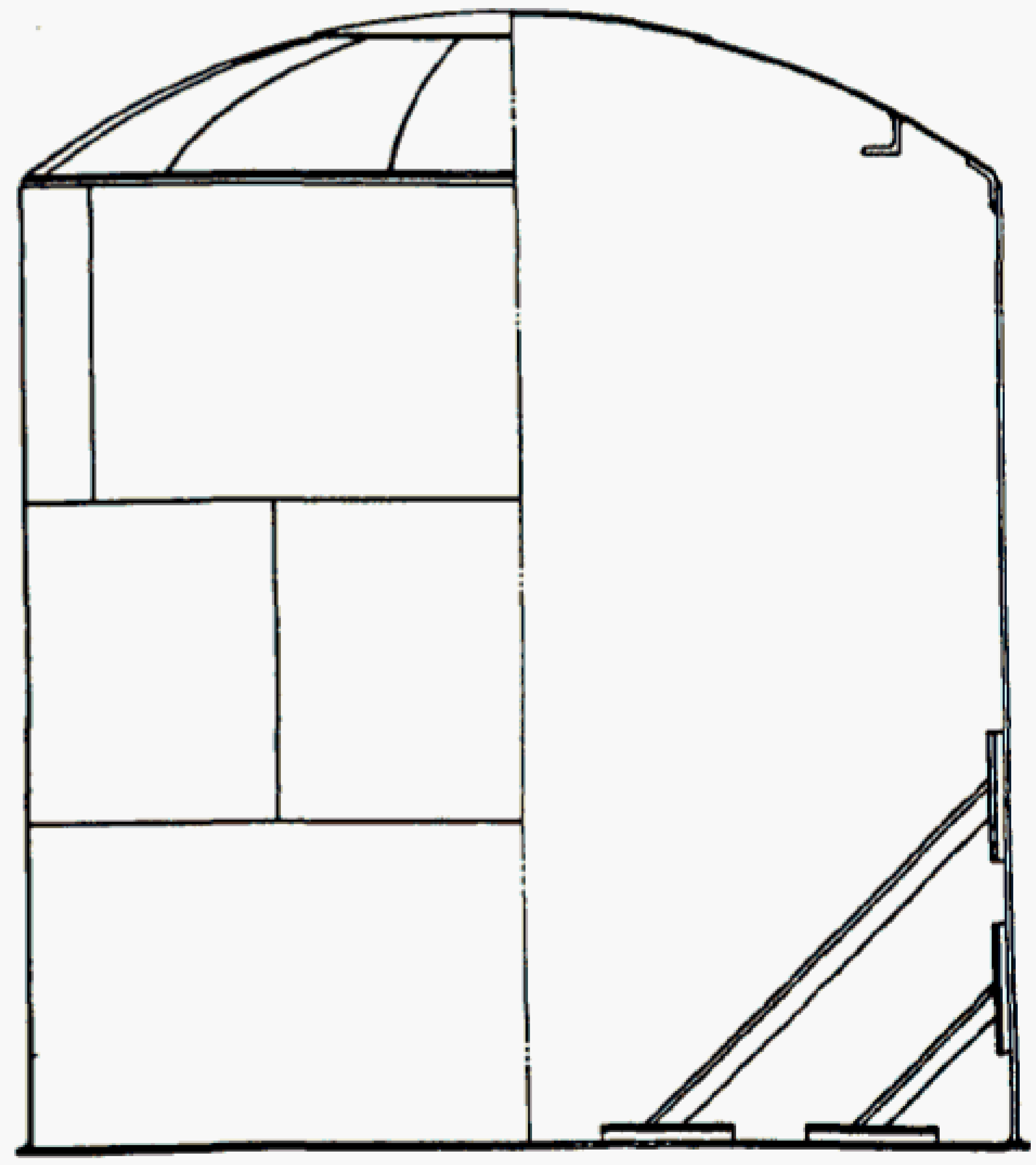


FIG. 3—Ellipsoid.



Courtesy: Hammond Iron Works.

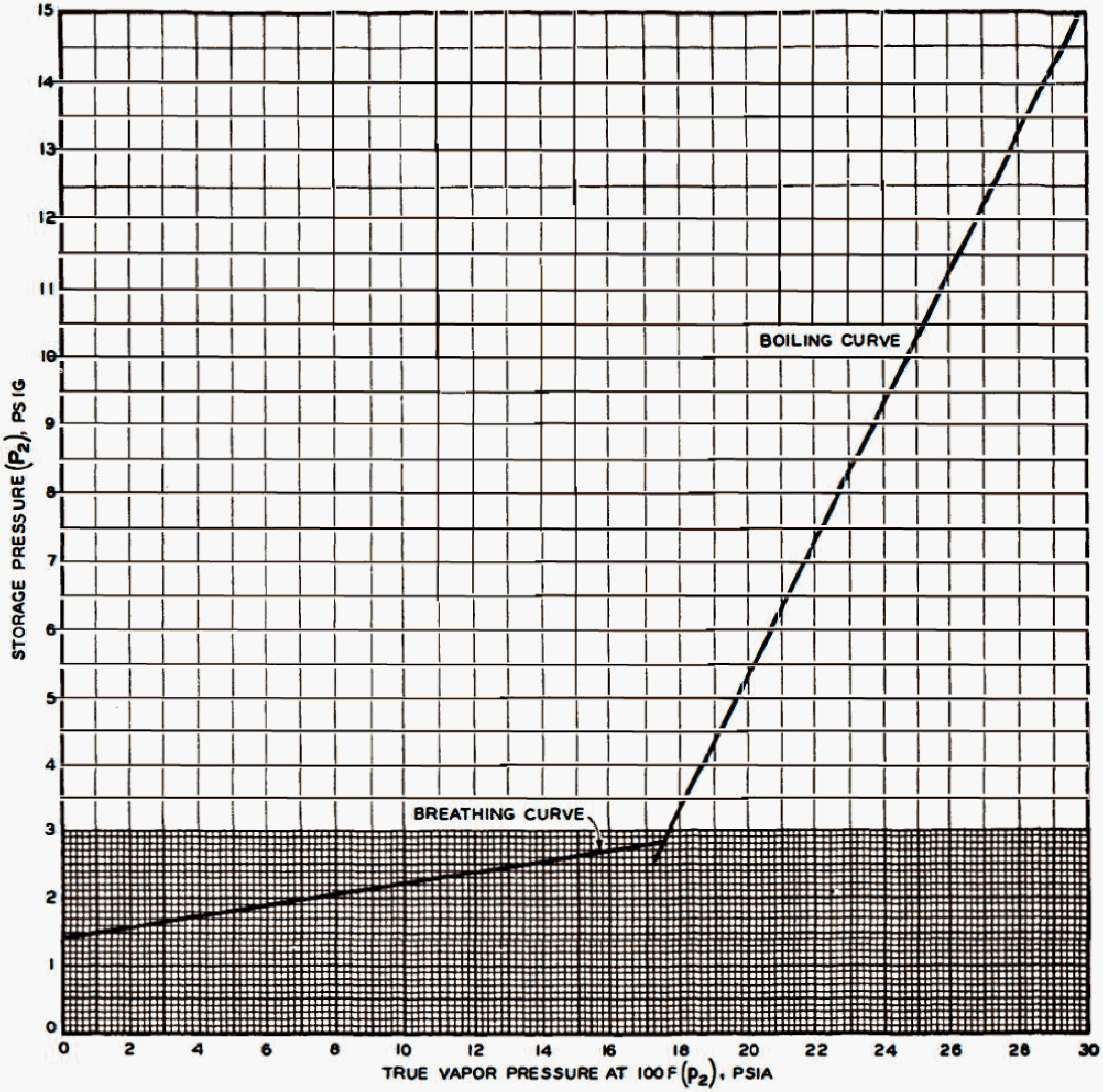
FIG. 4—Dome Roof.

Breathing Loss When Vent Pressure Is Less Than Required

A small percent of low-pressure tanks operate with a pressure vent setting below 2.5 psig—some by design and some because of corroded conditions of the vessel plating. The committee has few data upon which to develop a breathing loss correlation bridging the gap from 0 psig to 2.5 psig. No attempt has been made to develop a theoretical equation as only a few of these tanks exist and new ones are not recommended. As an approximation, it is suggested that for vent settings in the range 0 psig to 2.5 psig the breathing loss decreases from 100 percent to 0 percent of the breathing loss of an equivalent (i.e., capacity and diameter) fixed-roof tank, as shown in Fig. 7. This plot shows that each additional increment of pressure reduces the breathing loss by a progressively smaller amount. For example, the 10 oz per sq in. increment from 1 to 11 oz per sq in. reduces breathing loss 52 percent, but the 10 oz per sq in. increment from 30 to 40 oz per sq in. reduces breathing loss only approximately 3 percent.

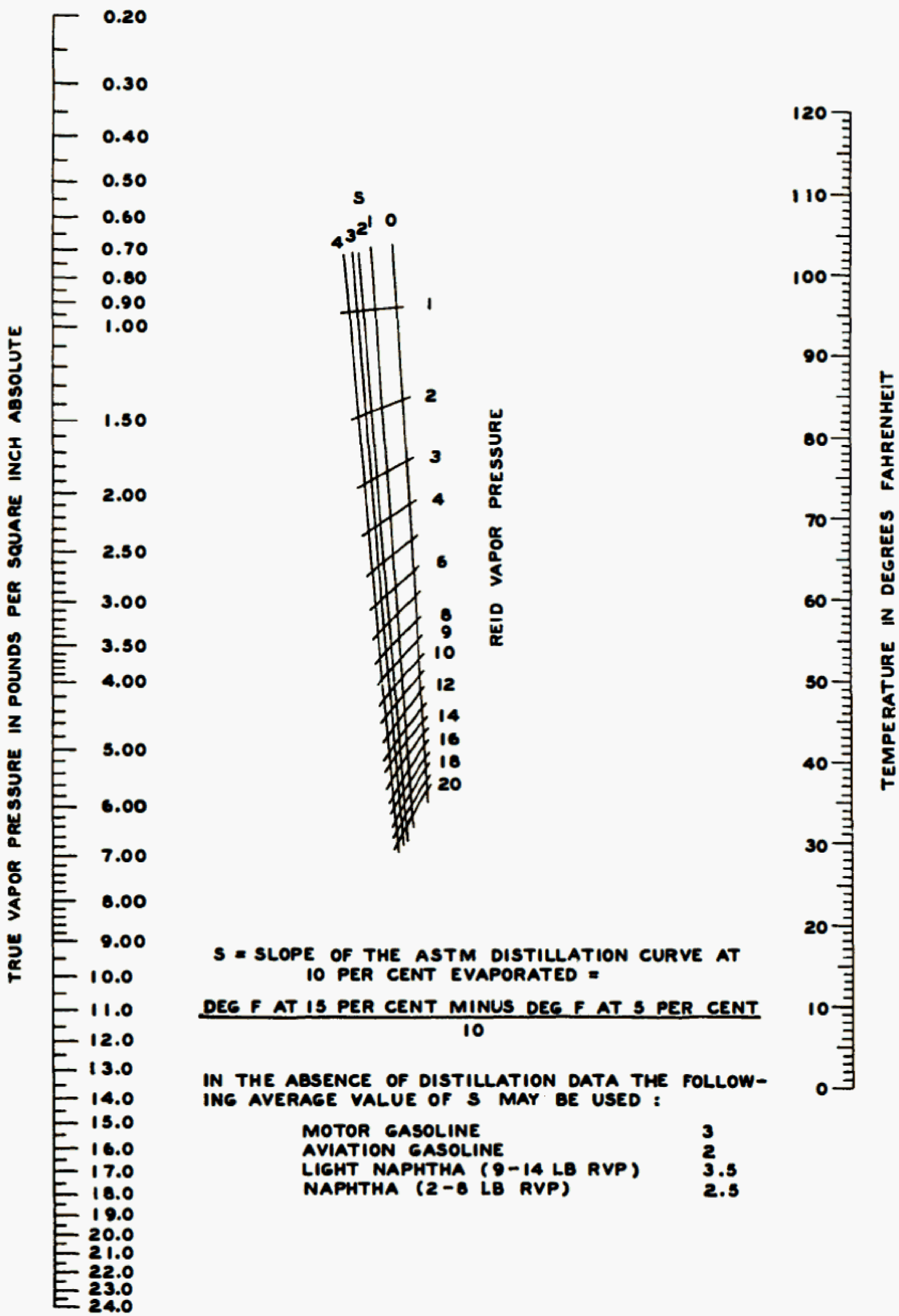
Vent Pressure Required to Prevent Boiling Loss

Boiling occurs when the temperature of the liquid surface reaches the point at which the true vapor pressure of the liquid is equal to the total pressure in the tank. Heat added to liquid in this condition will cause boiling. Boiling loss occurs when the true vapor pressure of the liquid exceeds the pressure vent setting of the tank. If p_s is equal to or exceeds the absolute pressure $(P_1 + P_a)$ at which the vacuum vent opens, air is kept out of the vapor space and the absolute tank



Note: For values of p_s between 20 and 30 psia, multiply the Reid vapor pressure at 100 F by 1.07.

FIG. 5—Storage Pressure Required to Eliminate Breathing and Boiling Losses; Based on Equations (1) and (2). Respectively.



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

FIG. 6—Vapor Pressures of Gasolines and Finished Petroleum Products, 1-Lb to 20-Lb RVP.

pressure equals the true vapor pressure of the liquid surface. The storage pressure to prevent boiling is:

$$P_2 = p_2 - P_a \qquad (2)$$

For convenience, equation (2), as well as equation (1), is plotted (for the condition when $P_a = 14.7$ psia) in Fig. 5. The minimum pressure requirements indicated in Fig. 5 have proved adequate to prevent boiling loss under usual storage conditions. In using the boiling curve shown in Fig. 5, p_t, the true vapor pressure at 100 F, may be obtained from Fig. 6 for up to 20 lb RVP. For 20 to 30 lb RVP, p_t is approximately 7 percent greater than the Reid vapor pressure at 100 F.*

Working Loss

Working loss will occur during filling if the pressure of the vapor space exceeds the vent setting and vapors are expelled. If the pressure at the start of filling is less than the pressure vent setting, the air-hydrocarbon mixture will be compressed during filling. The hydrocarbon condenses maintaining nearly a constant partial pressure. A certain fraction of vapor space may be filled with liquid before the vent opens, thus decreasing working loss. As filling continues, the total pressure eventually equals the pressure at which the relief valve opens, resulting in venting. Assuming there is no temperature change in either the liquid or the vapor during the filling period, the remaining liquid entering the tank replaces an equal volume of vapors discharged from the vent. The total amount of loss, therefore, depends on the capacity of the vapor space in the tank. Since the temperature normally does change as condensation takes place, the rate of filling and emptying can also affect the amount of loss. The unpredictable effect of these variables has made it difficult to determine the actual loss resulting from filling low-pressure tanks.

* Based on data from the chart "Vapor Pressures Vs. Temperatures for Typical Motor and Natural Gasolines," *Engineering Data Book*, p. 51, National Gasoline Supply Men's Assn., Tulsa, Okla. (1957).

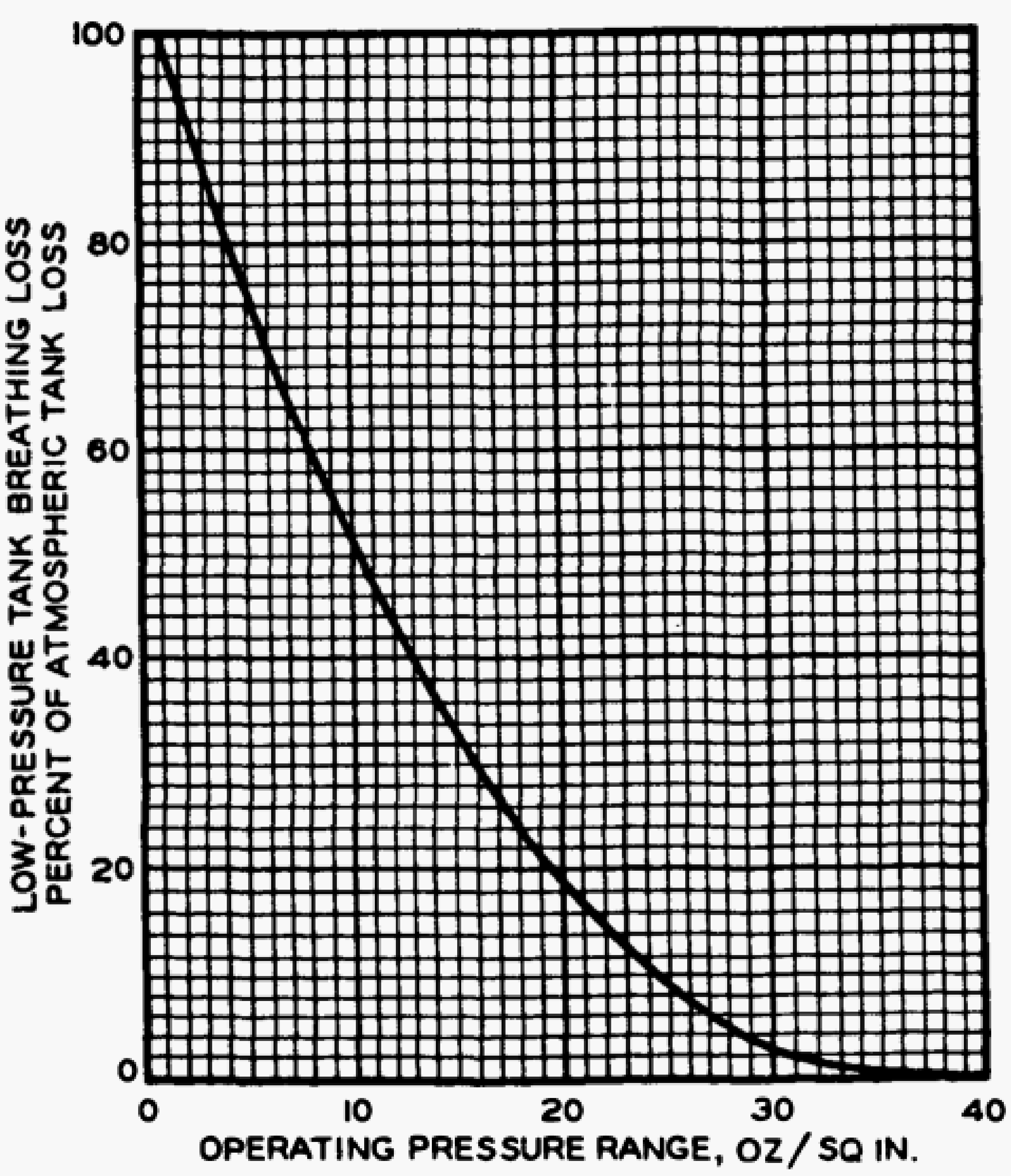


FIG. 7—Relationship for Estimating Motor Gasoline Breathing Loss from Tanks Operating at Less Than the Recommended 2.5-psig Vent Setting.

To obtain theoretical values for losses incurred during filling, two assumptions have been made:

1. The vessel is completely filled, starting with a saturated vapor space; i.e., equilibrium exists between the hydrocarbon content in the vapor and the liquid phases under given conditions of temperature and pressure.

2. Filling starts at slightly less than atmospheric pressure.

By use of these assumptions, the following working loss equation is derived in Appendix I:

$$F_v = \frac{3p_v(P_a + P_1 - p_v)}{100(P_a + P_2 - p_v)} \qquad (3)$$

Where:

F_v = working loss, percentage of volume pump-in.
p_v = true vapor pressure at liquid temperature, in pounds per square inch absolute.
P_a = atmospheric pressure (at sea level = 14.7 psia).
P_1 = gage pressure at which vacuum vent opens, in pounds per square inch gage.
P_2 = gage pressure at which pressure vent opens, in pounds per square inch gage.

For atmospheric conditions where $P_a = 14.7$ psia, equation (3) becomes:

$$F_v = \frac{3p_v(14.7 + P_1 - p_v)}{100(14.7 + P_2 - p_v)} \qquad (3a)$$

The loss indicated theoretically is correct for the assumptions that the true vapor pressure of the liquid surface is the same at both the beginning and the end of filling and that no change in vapor space temperature occurs. To the extent that the tank is not completely filled, the loss expressed as a percentage will be reduced. This favors many partial fillings rather than several complete fillings.

As liquid-surface temperature is variable and difficult to obtain, the value for p_v is based on the average temperature of the main body of the liquid. Because of the possible variables, the required pressure to prevent breathing loss from a low-pressure tank, as determined from Fig. 5, should be considered to have no pressure rise available to decrease working loss. With this condition the working loss may be determined in the same manner as for an atmospheric pressure tank, using Fig. 12 from *API Bulletin 2518: Evaporation Loss from Fixed-Roof Tanks.*

When a product is stored in a tank having a higher pressure setting than required by Fig. 5, the working loss may be estimated for this condition by use of values obtained from Fig. 5 and Fig. 8. By deducting the pressure required, as determined from Fig. 5, from the actual vent setting, the balance, designated as ΔP, may then be considered to be the effective pressure available for reducing working loss as determined from Fig. 8. Fig. 8 is based on equation (3a) except that P_s is considered to be ΔP. The loss values are representative for normal turnovers (12 per year) experienced with low-pressure storage. The values do not apply for low-pressure vessels which have rapid or frequent throughputs.

Theoretically, stocks which may be stored in the absence of air (minimum p_v equals or exceeds $P_I + P_a$) should not incur working loss. In practice, working loss does occur and depends upon the rate of filling, dissipation of heat, and vent pressure. Data are not available to determine the vent setting which would prevent working loss when air is absent.

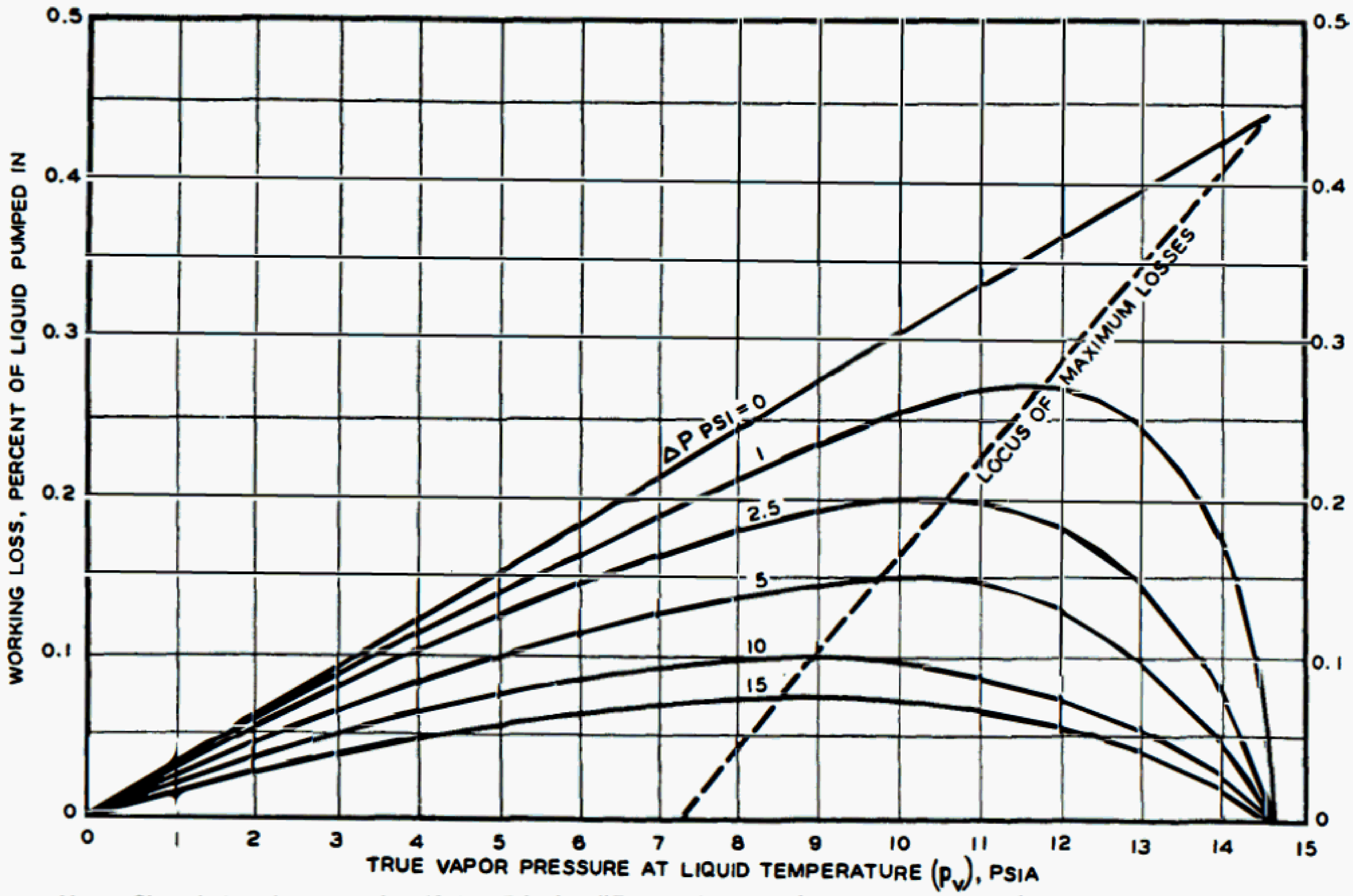
Leakage Loss

The efficiency of a low-presure vessel is directly dependent on maintaining a vapor-tight vessel. Defective operating equipment which allows vapors to escape at pressures below the vent setting results in an inefficient operating unit.

Leakage loss is not subject to estimation by means of a correlation.

Conclusion

The loss correlations are based on theory and assumed conditions. In order to correlate the theoretically calculated results with actual service, it would be necessary to obtain test data under actual operating conditions. Because of the limited use recently of low-pressure tanks for products having a Reid vapor pressure of less than 15 lb, a field test program is not warranted. In the case of products having a Reid vapor pressure from 15 lb to 30 lb, data are needed for a wide range of pump-in rates and vessel sizes under summer conditions to establish the working pressure which will effectively prevent working loss.



Note: Chart is based on equation (3a). ΔP is the difference between the pressure vent setting and the pressure required to prevent breathing loss as determined from Fig. 5 and as discussed above.

FIG. 8—Loss in Percent of Volume Pumped into Tank for Various Vent Settings.

APPENDIX I—DERIVATION OF EQUATIONS

Vent Pressure Required to Eliminate Breathing Loss

Breathing loss may be eliminated provided the proper storage pressure is used for the stored product. The storage pressure required depends upon the vapor pressure of the product and the temperature variation of the liquid surface and the vapors. The pressure rise in the vapor space may be calculated from those variables, using:

P_1 = gage pressure at which vacuum vent opens, in pounds per square inch gage.
P_2 = gage pressure at which pressure vent opens, in pounds per square inch gage.
P_a = atmospheric pressure (at sea level = 14.7 psia).
p_1 = true vapor pressure at minimum liquid-surface temperature, in pounds per square inch absolute.
p_2 = true vapor pressure at maximum liquid-surface temperature, in pounds per square inch absolute.
t_1 = minimum average vapor-space temperature, in degrees fahrenheit.
t_2 = maximum average vapor-space temperature, in degrees fahrenheit.
V_1 = minimum volume of vapor space, in cubic feet.
V_2 = maximum volume of vapor space, in cubic feet.

At minimum temperature conditions, the partial pressure of hydrocarbon in the vapor is the same as the vapor pressure of the product, p_1; therefore, the partial pressure of the air in the vapor space is:

$$P_a + P_1 - p_1$$

At maximum temperature conditions, the partial pressure of hydrocarbon in the vapor is the same as the vapor pressure of the product, p_2; therefore, the partial pressure of the air in the vapor space is:

$$P_a + P_2 - p_2$$

Assuming that the pounds of air in the system is held constant and applying the laws of perfect gases (Boyle's law and Charles' law) to the air only, the product of the air partial pressure and volume divided by the absolute temperature is constant, giving the general formula for the pressure-volume-temperature relationship in the vapor space:

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

With low-pressure tank storage the vapor space remains constant, or:

$$V_1 = V_2$$

Therefore:

$$\frac{P_a+P_2-p_2}{t_2+460} = \frac{P_a+P_1-p_1}{t_1+460}.$$

Or:

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

Application of the foregoing equation requires data on variations in the liquid-surface temperature and vapor-space temperature. Experience has shown that the following temperature conditions applied in the preceding equation have substantially prevented breathing losses from motor gasolines:

p_1 = vapor pressure at minimum liquid-surface temperature of 90 F.
p_2 = vapor pressure at maximum liquid-surface temperature of 100 F.
t_1 = minimum average vapor-space temperature at 85 F.
t_2 = maximum average vapor-space temperature at 140 F.

Substituting t_1 and t_2 in the preceding equation, a simplified equation may be written:

$$P_2 = 1.1(P_a+P_1-p_1) - (P_a-p_2) \qquad (1)$$

As an example, the minimum storage pressure required to store 14-lb-RVP product under the following conditions is:

P_1 = gage pressure at which vacuum vent opens = −0.06 psig.
P_2 = gage pressure at which pressure vent opens.
P_a = atmospheric pressure = 14.7 psia.
p_1 = true vapor pressure at minimum liquid-surface temperature of 90 F = 12.3 psia.
p_2 = true vapor pressure at maximum liquid-surface temperature of 100 F = 14.6 psia.

The true vapor pressures for the respective temperatures have been taken from the vapor pressure chart, Fig. 6, using an S value of 2.

$$P_2 = 1.1[14.7 + (-0.06) - 12.3] - (14.7 - 14.6)$$
$$= 2.5 \text{ psig}$$

Working Loss

Working loss will occur with low-pressure storage if the vapor pressure of the product is sufficiently low to draw air into the vessel or if filling is done at a rate which results in a rapid increase of pressure and subsequent venting of vapors through the relief valve.

To calculate the amount of vapor vented, it is necessary to determine the number of cubic feet occupied by 1 gal of liquid when it is in the form of saturated vapors. This derivation has been presented in Appendix II, p. 31 and 32, of *API Bulletin 2513: Evaporation Loss in the Petroleum Industry—Causes and Control.* As stated in Boyle's law, the volume of a vapor is proportional to its partial pressure, p_v, therefore:

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

Where:

Z = number of cubic feet of saturated vapor at standard conditions, 60 F and 14.7 psia, per gallon of liquid.
W = weight of 1 gal of liquid, in pounds.
C = compressibility factor.
M = molecular weight of the hydrocarbon vapor.
p_v = true vapor pressure at liquid temperature, in pounds per square inch absolute.

A reasonable average for the expression

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

is 30 because the vapor from motor gasolines contains hydrocarbon vapors, chiefly in the range of *iso*butane, *n*butane, *iso*pentane, *n*pentane, and hexane, with butane vapors as the principal components. The approximate number of standard cubic feet of vapor per gallon of liquid may then be given as:

$$Z=\frac{(30)(14.7)}{p_v}$$

$$=\frac{441}{p_v}$$

Assume the vacuum vent is on the verge of opening with a mixture of air and hydrocarbon vapor in the vapor space. As the vessel is filled, the partial pressure of the air increases. At the same time, the hydrocarbon vapor condenses, and its partial pressure remains practically constant. Eventually the total pressure may become equal to the pressure at which the pressure relief vent opens. Then as filling continues, the volume of vapor displaced through the vent is lost and will be equal to the volume of liquid pumped in after the pressure relief vent opens. Before the vent opens, a fraction of the vapor space can be filled with product by compressing the vapors. Applying Boyle's law, this fraction is equal to:

$$\frac{P_2-P_1}{P_a+P_2-p_v}$$

Where:

P_2 = gage pressure at which pressure vent opens, in pounds per square inch gage.
P_1 = gage pressure at which vacuum vent opens, in pounds per square inch gage.
P_a = atmospheric pressure (at sea level = 14.7 psia).
p_v = true vapor pressure at liquid temperature, in pounds per square inch absolute.

The preceding equation assumes the temperature remains relatively constant during the pressure change period.

Considering V_t as the initial vapor-space volume in cubic feet and considering the vessel completely filled, the cubic feet of saturated vapors displaced and lost during venting is:

$$V_1\left(1-\frac{P_2-P_1}{P_a+P_2-p_v}\right)=V_1\left(\frac{P_a+P_1-p_v}{P_a+P_2-p_v}\right)$$

As shown previously, there are approximately $\frac{441}{p_v}$ std cu ft of saturated vapors per gallon of liquid. Therefore, the number of gallons lost during the complete filling is: *

$$V_1\left(\frac{p_v}{441}\right)\left(\frac{P_a+P_1-p_v}{P_a+P_2-p_v}\right)$$

If the vessel is completely filled, 7.48 V_t gal of liquid are pumped in. The percent of loss is therefore:

$$\frac{100p_v(P_a+P_1-p_v)}{7.48(441)(P_a+P_2-p_v)}$$

And,

$$F_v=\frac{3p_v}{100}\left(\frac{P_a+P_1-p_v}{P_a+P_2-p_v}\right) \quad (3)$$

Where:

F_v = working loss, percentage of volume pump-in.

As an example, the percent of filling loss resulting from a 10-lb-RVP product in a 10,000-bbl tank for the given conditions is as follows:

p_v = true vapor pressure of liquid at 100 F = 10.5 psia (Fig. 6 with S = 3).
P_a = atmospheric pressure = 14.7 psia.
P_1 = gage pressure at which vacuum vent opens = −0.06 psig.
P_2 = gage pressure at which pressure vent opens = 2.5 psig.

$$F_v=\left[\frac{3(10.5)}{100}\right]\left[\frac{14.7+(-0.06)-10.5}{14.7+2.5-10.5}\right]$$

$$=0.2 \text{ percent}$$

Total amount of loss = (0.002)(10,000) = 20.0 bbl. This loss is based on completely filling the vessel, starting with the vapor space saturated.†

* Omission of a factor to correct tank vapors to volume at 60 F introduces a small error.

† This example is for a hypothetical condition wherein breathing loss is ignored *since fill is assumed to start with the vacuum vent on the verge of opening.* Realistically, as stated in the text on p. 9 and 10, working loss can be reduced only by that portion of pressure range which is surplus to the range required to prevent breathing loss.

APPENDIX II—COMMITTEE MEMBERSHIP

Committee on Evaporation Loss (1961)

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