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AP42 Section:	7.1
Related	11
Title:	Development of Deck Seam Factors (F_d, K_d, S_d,) "attachment V" Development of Rim Seal Loss Factors (K_r) "attachment VI" Development of Product Factor (K_c)

DEVELOPMENT OF DECK SEAM FACTORS (F_d, K_d, S_d)

The procedure used to calculate the deck seam factors (F_d, K_d, S_d) for internal floating-roof tanks, as presented in the third edition of API Publication 2519, is outlined below in Section 5.1. Section 5.2 contains the detailed calculations for the deck seam losses and Section 5.3 contains the detailed calculations for the deck seam factors. Section 5.4 outlines the derivation of the formulas used to calculate deck seam length factors (S_d).

- Calculation Procedures

The following sources of information were used in developing the deck seam factors: the API analysis of the raw data from the CBI test tank program and the descriptions of test conditions and the calendars of events contained in CBI's final report.

After an extensive review of this information, the following procedures were used to calculate deck seam factors:

Based on test tank loss data, the following calculations and assumptions were made:

- Total deck seam losses in the test tank were quantified by comparing tests in which all loss sources were sealed with tests in which all loss sources except the deck seams were sealed. Total deck seam losses were measured in Phases 1/1R and 3/3R in which bolted decks were tested. The welded deck tested in Phase 2/2R was not considered as an independent loss source; it was assumed that no losses occur from properly welded decks.

- In order to relate the total deck seam losses measured in the test tank to those from any given tank, it was assumed that deck seam losses would scale as a function of the length of the deck seam. This follows from the assumption that deck seam losses occur continuously or from discrete, localized points which are distributed along the entire length of the seam. This assumption could not be evaluated from currently available data, however, it was judged to be the most reasonable assumption which could be made, and one which would, if anything, tend to over-estimate rather than underestimate losses from various deck seam constructions. Therefore, the loss per length of seam was calculated for both Phases 1/1R and 3/3R, from the calculated total deck seam losses and the measured lengths of deck seams in each phase.

- Since the loss per seam length was not equivalent in Phases 1/1R and 3/3R, consideration was given to determining two different deck seam loss factors or to averaging the results to determine one general deck seam loss factor applicable to any bolted seam. Two deck characteristics were different for the decks in Phases 1/1R and 3/3R: the location of the deck relative to the liquid stock (one was a contact deck, the other a non-contact deck); and the construction details of the deck seams (one was of overlapping aluminum sheet construction, the other was constructed from abutting aluminum panels with a honeycombed aluminum core).

Since it was not possible to determine from the test results the relative effects on loss of the deck location as compared to the seam construction details, it was judged that only one average deck seam loss could be reported for bolted deck seams.

- Deck seam factors (F_d, K_d, S_d) were then developed from the calculated average bolted deck seam loss per length of seam and from the assumptions outlined above.

  - F_d, K_d, S_d were defined by equations relating deck seam loss to tank diameter, stock vapor pressure, and deck seam-related parameters.

Detailed Deck Seam Loss Calculations

Based on the procedures outlined above, the following presents the detailed calculations of deck seam losses. The variables used in the loss calculations are defined as follows:

E_s = loss from bolted deck seam (lb-mole/day)
E_x = loss measured in test-tank test number X (lb-mole/day)
L = length of deck seam (ft)

and a superscript on any variable denotes the test phase to which the variable applies.

Deck seam loss:

$$E_s^{1/1R} = E_{76R} - E_{77} = (0.0433) - (0.0417) = 0.0016$$

$$E_s^{3/3R} = E_{56} - E_{55} = (0.0338) - (0.0156) = 0.0182$$

Loss per length of deck seam:

$$\left(\frac{E_s}{L}\right)^{1/1R} = \frac{E_s^{1/1R}}{L^{1/1R}}, \text{ where } L^{1/1R} = 36 \text{ ft.}$$

$$= \frac{(0.0016)}{(36)} = 0.44 \times 10^{-4} \frac{\text{lb-mole/day}}{\text{ft}}$$

$$\left(\frac{E_s}{L}\right)^{3/3R} = \frac{E_s^{3/3R}}{L^{3/3R}}, \text{ where } L^{3/3R} = 89 \text{ ft.}$$

$$= \frac{(0.0182)}{(89)} = 2.04 \times 10^{-4} \frac{\text{lb-mole/day}}{\text{ft}}$$

Average loss per length of deck seam:

$$\left(\frac{E_s}{L}\right) = \frac{\left(\frac{E_s}{L}\right)^{1/1R} + \left(\frac{E_s}{L}\right)^{3/3R}}{2}$$

$$= \frac{(0.44 \times 10^{-4}) + (2.04 \times 10^{-4})}{2} = 1.24 \times 10^{-4} \quad \frac{\text{lb-mole/day}}{\text{ft}}$$

Detailed Calculations of Deck Seam Factors

Three parameters, F_d, K_d, and S_d, related to deck type and deck seam construction were developed. The variables used in this developemnt are defined as follows:

A = area of deck (ft^2) = $(\frac{\pi}{4})\ D^2$
D = tank diameter (ft)
E_d = deck seam loss (lb-mole/yr)
E_s = loss from bolted deck seam (lb-mole/day)
F_d = deck seam loss factor (lb-mole/yr)
k = factor relating deck seam loss to seam length and stock vapor pressure (lb-mole/ft yr)
K_d = deck seam loss factor per unit seem length (lb-mole/ft yr)
L = length of deck seam (ft)
P^* = vapor pressure function (dimensionless)

$$= \frac{\left(\frac{P}{P_a}\right)}{\left(1 + \left(1 - \frac{P_a}{P}\right)^{0.5}\right)^2}, \text{ where: } \begin{array}{l} P = \text{true vapor pressure (psia)} \\ P_a = \text{atmospheric pressure (psia)} \end{array}$$

S_d = deck seam length factor (ft/ft^2) = $\frac{L}{A}$

Bolted deck seam factor per unit seam length, K_d:

The following equation relates deck seam loss to the length of deck seams, the stock vapor pressure and a parameter related to the deck type and seam construction:

$$E_d = k\ L\ P^*$$

The form of the above equation is not particularly useful since the deck seam length will seldom be known. However, the deck seam length per area of the deck, S_d, can be approximately determined for various deck constructions, such that this is a more useful variable. The above equation thus becomes:

$$E_d = k \left(\frac{L}{A}\right) AP^*$$

By substitution:

$$E_d = kS_d \left(\frac{\pi}{4}\right) D^2 P^*$$

The deck seam loss factor per unit seam length, K_d, is then defined as:

$$K_d = \left(\frac{\pi}{4}\right) k$$

such that:

$$E_d = (K_d S_d D^2) P^*$$

By substitution and rearranging the above equation:

$$K_d = \frac{E_d}{S_d D^2 P^*} = \frac{E_d}{\left[\dfrac{L}{\left(\frac{\pi}{4}\right) D^2}\right] D^2 P^*}$$

$$= \left(\frac{\left(\frac{\pi}{4}\right)}{P^*}\right) \left(\frac{E_d}{L}\right)$$

To calculate an average value of K_d for bolted deck seams, use the average loss per length of deck seam calculated for bolted decks and the P^* value at the test condition of P = 5.0 psia:

$$K_d = \left(\frac{\left(\frac{\pi}{4}\right)}{(0.1036)}\right) (1.24 \times 10^{-4} \text{ lb-mole/day}) (365 \text{ day/yr})$$

$$= 0.34 \text{ lb-mole/ft yr}$$

Deck seam length factor, S_d:

By definition, S_d can be directly calculated from the following equation:

$$S_d = \frac{L}{A}$$

For cases when the length of the seam, L, is not known, S_d can be approximated from the following equations :

For decks with continuous sheet construction:

$$S_d = \frac{1}{w}$$

where: w = sheet width (ft)

For decks with panel construction:

$$S_d = \frac{l + w}{(l)\ (w)}$$

where: l = panel length (ft)
w = panel width (ft)

Deck seam loss factor, F_d:

This general loss factor is defined as that factor which relates deck seam losses to stock vapor pressure, such that F_d is defined by the following equation:

$$E_d = (F_d)\ P^*$$

From the previous discussions in 5.1 and 5.3, F_d can be specified for different deck seam types as follows:

For bolted deck seams (i.e., seams which are mechanically joined by any method):

$$F_d = K_d S_d D^2$$

For welded deck seams:

$$F_d = 0$$

For any other type of seam (e.g., adhesively - joined seams):

F_d - can not be determined from available data.

Derivation of Deck Seam Length Factor Equations

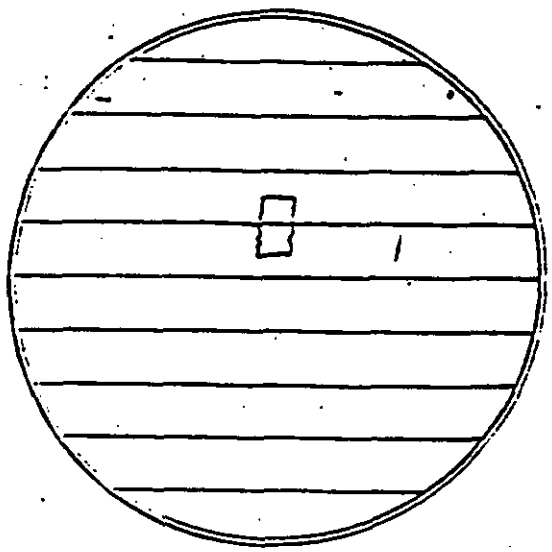
The deck seam length factor is defined as the ratio of the total length of deck seams, L, to the area of the deck, such that:

$$S_d = \frac{L}{A}$$

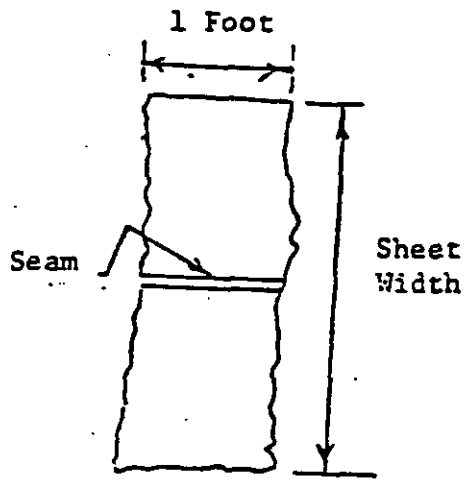
However, the deck seam length will seldom be known. Therefore, equations have been developed to calculate approximate values of the deck seam length as a function of primary characteristics of the construction of the deck. Specifically, two general deck constructions were evaluated: continuous sheet construction, with seams only along the edges of the sheets; and rectangular panel construction, with seams along each edge and perpendicular joints at the corners of each panel.

Continuous sheet construction:

As shown below, for a deck constructed from continuous sheets with seams only along the edges, an element of the deck can be chosen which is one foot wide and as long as the width of the sheet, w (ft).



DECK



ELEMENT

Thus, the area of an element, A_e, is the skin width in feet times one foot, such that:

$$A_e = (w)\ (1) = w$$

The area of the deck can be generated by moving this element along the entire length of the deck seam, L. Therefore, the area of the deck is given by:

$$A = L\ A_e = L\ w$$

The deck seam length factor, S_d, thus becomes:

$$S_d = \frac{L}{A} = \frac{L}{L\ w} = \frac{1}{w}$$

For 5 ft - wide sheets:

$$S_d = \frac{1}{5} = 0.20 \text{ ft/ft}^2$$

For 6 ft - wide sheets:

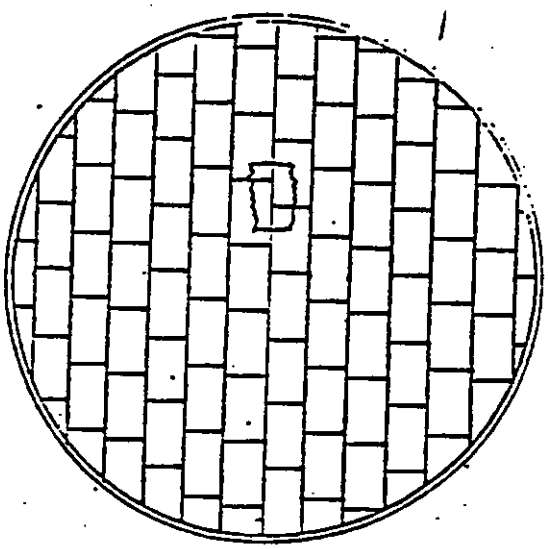
$$S_d = \frac{1}{6} = 0.167 \text{ ft/ft}^2$$

For 7 ft - wide sheets:

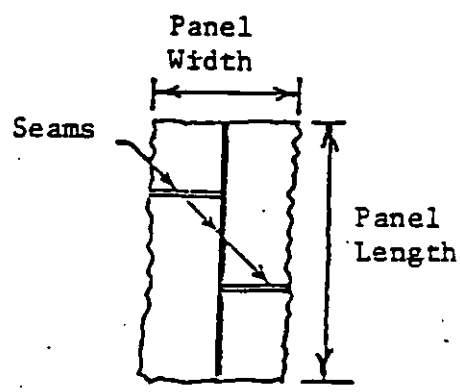
$$S_d = \frac{1}{7} = 0.143 \text{ ft/ft}^2$$

Rectangular Panel Construction:

As shown below, for a deck constructed from rectangular panels, an element of the deck can be chosen which has a width, w, and a length, l, equal to the width and length of a panel.



DECK



ELEMENT

Thus, the area of an element, A_e, is the panel width times length, such that:

$$A_e = w\ l$$

The area of the deck is equal to the area of an element times the number of elements which make up the deck, N, such that:

$$A = N\ A_e = N\ (w\ l)$$

The length of deck seam associated with each element, L_e, is equal to the element length plus the width, such that:

$$L_e = w + l$$

Thus, the total length of deck seams is equal to the seam length associated with each element times the number of elements which make up the deck:

$$L = N\,L_e = N(w+1)$$

The deck seam length factor, S_d, thus becomes:

$$S_d = \frac{L}{A} = \frac{N\,(w + 1)}{N\,(w\ 1)} = \frac{(w + 1)}{(w\ 1)}$$

For a 5 ft x 7.5 ft panel:

$$S_d = \frac{(5 + 7.5)}{(5)\ (7.5)} = 0.333\ \text{ft/ft}^2$$

For a 5 ft x 12 ft panel:

$$S_d = \frac{(5 + 12)}{(5)\ (12)} = 0.283\ \text{ft/ft}^2$$

Clearly, for both deck construction cases, the above calculations are approximate, due to the edge effects related to using a small rectangular element to generate a round deck. However, the error associated with this approximation would become significant only as the diameter of the deck becomes very small.

- DEVELOPMENT OF RIM SEAL LOSS FACTORS (K_r)

The procedure used to calculate the rim seal loss factors (K_r) for internal floating-roof tanks, as presented in the third edition of API Publication 2519, is outlined below in Section 3.1. Section 3.2 contains the detailed calculations of rim seal losses, and Section 3.3 contains detailed calculations of rim seal loss factors.

3.1 Calculation Procedure

The following sources of information were used in developing the rim seal loss factors: the API analysis of the raw data from the CBI test tank and bench test programs; the descriptions of test conditions and the calendars of events contained in CBI's final report; and some information developed during the test program which was not included in CBI's final report (but which is specifically noted in the following section).

After an extensive review of this information, the following procedures were used to calculate rim seal loss factors:

- To isolate the rim seal losses from the deck seam and fitting losses, the following calculations were made:

  - Total deck seam losses were determined for the bolted decks in Phases 1/1R and 3/3R. The welded deck in Phase 2/2R was assumed to have no loss.

  - Total residual losses measured when all loss sources (rim seals, fittings and bolted seams) were covered with a polyurethane-coated nylon fabric were quantified. This total residual loss was apportioned to the rim seal and fittings areas by the relative amount of fabric used to cover each area. (No residual loss was attributed to the deck seam area due to extensive caulking and taping of the fabric during the residual loss tests.) The residual loss is presumed to result from permeation through the polyurethane-coated nylon fabric.

  - Total deck fitting losses were determined for each phase, since different numbers and types of fittings were included in each phase. Both test tank and bench test data were used.

  - A total deck loss was calculated by summing the deck seam and fitting losses for each phase.

- Rim seal losses were then quantified for each rim seal system tested in each phase, for each seal gap condition tested. This was done by subtracting the appropriate deck and/or residual losses from the total measured loss in each test.

  - In general, only octane/propane tests were used to quantify rim seal losses. However, if no octane/propane test could be used to directly determine the loss for a given seal condition, pure octane data were used to prorate losses from one condition to another.

- Data from the first 19 tests, conducted before the inlet air duct heater was installed, were not used directly, but only indirectly, to prorate losses for conditions not tested subsequent to the installation of the heater.

- The approach taken in calculating the loss for any given condition was to use as much relevant data as possible. When the loss for a given condition could be calculated from more than one combination of measured test results, all combinations were considered and averaged.

- In Phase 1/1R, three different primary flexible wiper seals were used due to seal installation problems. The original seal was used during tests 1-12; no loss data were directly used from this seal since these tests were not temperature controlled. The first replacement seal (tests 13-34A) did not fit onto the deck as well as the second replacement seal (tests 73-77), although both seals were judged to represent acceptable commercial fit. Losses were separately analyzed for each seal.

- In those cases where losses could be directly compared for the first replacement (Phase 1) and the second replacement (Phase 1R) vapor-mounted, flexible wiper seals and the vapor-mounted, resilient filled seal (Phase 3/3R), it was observed that the loss for the resilient-filled seal was within the range of the losses from the two flexible wiper seals. Further, the losses for the liquid-mounted, resilient-filled seal (Phase 2/2R) were generally outside this range. Therefore, it was judged to be most appropriate to average all the vapor-mounted seal losses (from Phases 1/1R, and 3/3R) to quantify average losses applicable to all vapor-mounted seals.

- Rim seal losses representative of two conditions of seal fit (i.e., average and tight fit) were then calculated for vapor-mounted and liquid-mounted primary seals, with and without secondary seals.

  - Seal gap weighting factors (developed from external floating-roof tank data on the frequency of occurrence of various seal gap conditions) were determined for both average fit and tight fit (i.e., no gaps greater than 1/8 inch wide) conditions. These weighting factors were then applied to the losses calculated for each seal gap condition for the average vapor-mounted and the liquid-mounted rim seal systems.

- Rim seal loss factors (K_r) were then developed from the calculated losses for the average-fit and tight-fit cases for vapor-mounted and liquid-mounted primary seals, with and without secondary seals.

  - K_r was defined by an equation relating losses to tank diameter and vapor pressure.

Detailed Rim Seal Loss Calculations

Based on the procedure outlined above, the following presents the detailed calculations of the rim seal losses. The variables used in the calculations are defined below:

A_T = total area of sealing fabric used to cover all loss sources during some of the tests in the test tank (ft^2)
A_F = area of fabric covering the fittings (ft^2)
A_R = area of fabric covering the rim seal (ft^2)
C = correction factor used to adjust for thermocouple leakage in Phase 2 (dimensionless)
E = typical rim seal loss from average or tight-fitting rim seal systems (lb-mole/day)
E_X = loss measured in test-tank test number X (lb-mole/day)
$E_{a/b}$ = loss from rim seal system with a primary seal gap of a $inches^2/ft$ diameter and a secondary seal gap (if present) of b $inches^2/ft$ diameter
E_D = total loss from deck (lb-mole/day)
E_F = loss from fittings (lb-mole/day)
E_S = loss from bolted deck seam (lb-mole/day)
F_X = loss measured in fitting bench test number X (lb-mole/day)
R_T = total residual loss measured when all loss sources were covered with sealing fabric (lb-mole/day)
R_F = residual loss through fitting sealing fabric (lb-mole/day)
R_S = residual loss through sealing fabric covering the rim seal area (lb-mole/day)
$)_{pre}$ = subscript denoting test run prior to installation of air inlet heater in test tank
$)_{octane}$ = subscript denoting test run with octane
$)_U$ = subscript denoting fitting were ungasketed
$)_G$ = subscript denoting fittings were gasketed

and a superscript on any variable denotes the specific segment of the test phase to which the variable applies. If no superscript is used, the variable applies to both the original and repeated segments of the test phase. The following calculations are summarzed in Table 3.1. The calculated losses for each test phase are summarized in Table 3.2, and the typical rim seal losses and rim seal loss factors are summarized in Table 3.3.

Phase 1/1R Loss Calculations

Deck seam loss: assume deck seam losses in both Phases 1 and 1R are equal to those measured in Phase 1R, since same deck was used and seam loss was not directly measured in Phase 1.

$$E_s = E_{76R} - E_{77} = (0.0433 - 0.0417) = 0.0016$$

Residual losses: R_T values for Phases 1 and 1R are significantly different, which is reasonable since the sealing fabric was more extensively taped in Phase 1R than in Phase 1.

$$R_T^1 = E_{23} - E_S = (0.0714 - 0.0016) = 0.0698$$

$$R_T^{1R} = E_{77} = 0.0417$$

From measurements made during test program:

$$A_T = 114 \text{ ft}^2$$
$$A_F = 20 \text{ ft}^2$$
$$A_R = 94 \text{ ft}^2$$

Therefore:

$$R_F^1 = \left(\frac{20}{114}\right) R_T^1 = (0.175)(0.0698) = 0.0122$$

$$R_F^{1R} = \left(\frac{20}{114}\right) R_T^{1R} = (0.175)(0.0417) = 0.0073$$

$$R_R^1 = \left(\frac{94}{114}\right) R_T^1 = (0.825)(0.0698) = 0.0576$$

$$R_R^{1R} = \left(\frac{94}{114}\right) R_T^{1R} = (0.825)(0.0417) = 0.0344$$

Deck fitting losses: the column well in Phase 1 was ungasketed, whereas in Phase 1R the column well was gasketed. Assume $E_{F)G}$, applicable to Phase 1R, is equal to $E_{F)U}$, as measured in Phase 1, times the ratio of gasketed to ungasketed column well losses, as measured in the bench tests. Therefore:

$$E_{F)U} = \left(\frac{E_{24} + E_{25}}{2}\right) - \left(E_{23} - R_F^1\right)$$

$$= \left(\frac{0.1200 + 0.1080}{2}\right) - \left(0.0714 - 0.0122\right) = 0.0548$$

$$E_{F)G}^{1R} = E_{F)U}^1 \left[\frac{F_{9A}}{\left(\frac{F_{9B} + F_7}{2}\right)}\right]$$

$$= (0.0548)\left[\frac{3.38}{\left(\frac{5.07 + 4.32}{2}\right)}\right] = 0.0395$$

Total deck losses:

$$E_{D)U}^1 = E_S + E_{F)U}^1 = (0.0016) + (0.0548) = 0.0564$$

$$E_{D)G}^{1R} = E_S + E_{F)G}^{1R} = (0.0016) + (0.0395) = 0.0411$$

Rim seal losses:

Define $E_{0/-}$ as the average of $E^{1}_{0/-}$ and $E^{1R}_{0/-}$:

$$E^{1}_{0/-} = \left(\frac{E_{21A,21AR} + E_{21B,21BR} + E_{21C,21CR}}{3}\right) - E^{1}_{D)U}$$

$$= \left(\frac{0.129 + 0.102 + 0.108}{3}\right) - (0.0564) = 0.0566$$

$$E^{1R}_{0/-} = \left(\frac{E_{73A} + E_{74}}{2}\right) - E^{1R}_{D)G}$$

$$= \left(\frac{0.0628 + 0.0627}{2}\right) - (0.0411) = 0.0217$$

$$E_{0/-} = \left(\frac{E^{1}_{0/-} + E^{1R}_{0/-}}{2}\right) = \left(\frac{0.0566 + 0.0217}{2}\right) = 0.0392$$

Define $E_{gap/-}$ as the average of $E^{1}_{1/-}$ and $E^{1R}_{3/-}$, since (as shown below) the loss from the second replacement seal with a gap of 3 inches^2/ft diameter ($E^{1R}_{3/-}$) is less than the loss from the first replacement seal with a gap of 1 inch^2/ft diameter ($E^{1}_{1/-}$). (This result is not inconsistent, since with no gaps in either seal the loss from the second replacement seal was significantly less than from the first replacement seal.)

$$E^{1}_{1/-} = \left(\frac{E_{22A} + E_{22B,22BI} + E_{22C} + E_{26A} + E_{26B}}{5}\right) - E^{1}_{D)U}$$

$$= \left(\frac{0.142 + 0.173 + 0.211 + 0.117 + 0.128}{5}\right) - (0.0564) = 0.0978$$

$$E^{1R}_{3/-} = E_{75} - E_{D)G} = (0.0730) - (0.0411) = 0.0319$$

$$E_{gap/-} = \left(\frac{E^{1}_{1/-} + E^{1R}_{3/-}}{2}\right) = \left(\frac{0.0978 + 0.0319}{2}\right) = 0.0649$$

Alternatively, average losses for gaps of 1 and 3 inches^2/ft diameter can be calculated by adjusting the measured losses for each gapped primary seal tested by the appropriate ratio of measured and average losses for the no-gap cases. However, as shown below, this yields an essentially equivalent result for $E_{gap/-}$, so the above, more direct calculation was used.

$$E_{1/-} = E^{1}_{1/-}\left(\frac{E_{0/-}}{E^{1}_{0/-}}\right) = (0.0978)\left(\frac{0.0392}{0.0566}\right) = 0.0703$$

$$E_{3/-} = E^{1R}_{3/-} \left(\frac{E_{0/-}}{E^{1R}_{0/-}}\right) = (0.0319)\left(\frac{0.0392}{0.0217}\right) = 0.0574$$

$$E_{gap/-} = \left(\frac{E_{1/-} + E_{3/1}}{2}\right) = \left(\frac{0.0703 + 0.0574}{2}\right) = 0.0639$$

For all secondary seal cases, the only directly applicable data are from octane tests, both with and without a secondary seal. (All octane/propane data on secondary seals were developed prior to the installation of the inlet air duct heater. These data were judged to be useful only for comparative purposes.)

$$E_{1/0} = E_{1/-} \left(\frac{E_{1/0}}{E_{1/-}}\right) \text{ octane}$$

$$= (0.0978) \left[\frac{\left(\frac{E_{31} + E_{31A}}{2}\right) - E_{D)U,\ P=0.5\ psia}}{E_{29R} - E_{D)U,\ P=0.5\ psia}}\right]$$

$$= (0.0978) \left[\frac{\left(\frac{0.0357 + 0.0256}{2}\right) - 0.0047}{(0.143 - 0.0047)}\right] = 0.0183$$

where: $E_{D)U,\ P=0.5\ psia} = E_{D)U} \left[\frac{P^*_{p=0.5\ psia}}{P^*_{p=5.0\ psia}}\right]$

$$= (0.0564)\left(\frac{0.0087}{0.1036}\right) = 0.0047$$

Assume $E_{3/0} = E_{1/0} = 0.0183$, since for the primary seal only cases the difference in losses from one seal to another was greater than the differences of gaps from 1 to 3 inches^2/ft diameter. The 3/0 gap case is the only one for which loss was measured both before and after the heater installation. Therefore, the following losses are calculated by multiplying the loss measured before the heater installation by the ratio of losses for the 3/0 case measured both after and before the heater installation.

$$E_{0/0} = E_{0/0)pre} \left(\frac{E_{3/0}}{E_{3/0)pre}}\right)$$

where:

$$E_{0/0)pre} = E_{17} - R^1_F - E_S$$

$$= (0.0698) - (0.0122) - (0.0016) = 0.0560$$

$$E_{3/0)pre} = E_{18} - R_F^1 - E_S$$
$$= (0.110) - (0.0122) - (0.0016) = 0.0962$$

Therefore:

$$E_{0/0} = (0.0560)\left(\frac{0.0183}{0.0962}\right) = 0.0107$$

Similarly:

$$E_{3/1} = E_{3/1)pre}\left(\frac{E_{3/0}}{E_{3/0)pre}}\right)$$

where:

$$E_{3/1)pre} = \left(\frac{E_{19} + E_{19A}}{2}\right) - R_F^1 - E_S$$
$$= \left(\frac{0.134 + 0.147}{2}\right) - (0.0122) - (0.0016) = 0.1267$$

Therefore:

$$E_{3/1} = (0.1267)\left(\frac{0.0183}{0.0962}\right) = 0.0241$$

Phase 2/2R Loss Calculations

After ten tests were conducted in Phase 2, product leakage was observed through one of the deck thermocouple fittings. The leak was then sealed and a few previous tests were rerun to determine the effect of this leakage on total loss. By comparing the repeated test results, a leakage correction factor, C, was developed, which was used to correct all measured losses in tests 35 through 44.

$$C = \frac{[E_{44} - E_{45}] + \left[\left(\frac{E_{35} + E_{37}}{2}\right) - E_{48}\right]}{2}$$
$$= \frac{(0.0149 - 0.0069) + \left[\left(\frac{0.0366 + 0.0297}{2}\right) - 0.0246\right]}{2} = 0.0083$$

Deck seam loss: a welded deck was used, therefore:

$$E_S = 0$$

Residual losses: the sealing of various loss sources only occurred in Phase 2 (not in Phase 2R), therefore, only one R_T value is calculated:

$$R_T = \left[\frac{(E_{44} - C) + E_{45}}{2}\right] = \left[\frac{(0.0149 - 0.0083) + (0.0069)}{2}\right] = 0.0068$$

From measurements made during the test program:

$A_T = 116\ ft^2$
$A_F = 32\ ft^2$
$A_R = 94\ ft^2$

Therefore:

$$R_F = \left(\frac{32}{116}\right) R_T = (0.276)(0.0068) = 0.0019$$

$$R_R = \left(\frac{84}{116}\right) R_T = (0.724)(0.0068) = 0.0049$$

Deck fitting loss:

$$E_F = \frac{(E_{47} - R_R) + [E_{48} - (E_{49} - R_F)] + [E_{70} - (E_{42} - C - R_F)]}{3}$$

$$= \frac{(0.017-0.0049) + [0.0264-(0.0188-0.0019)] + [0.0202-(0.0176-0.0083-0.0019)]}{3}$$

$$= 0.0109$$

Total deck loss:

$$E_D = E_S + E_F = 0 + 0.0109 = 0.0109$$

Rim seal losses:

$$E_{0/1} = \frac{[E_{35} - C - E_D] + [E_{37} - C - E_D] + [E_{48} - E_D] + [E_{49} - R_F]}{4}$$

$$= \{[0.0366 - 0.0083 - 0.0109] + [0.0297 - 0.0083 - 0.0109] + [0.0246 - 0.0109] + [0.0188 - 0.0019]\} / 4$$

$$= \{(0.0174) + (0.0105) + (0.0137) + (0.0169)\} / 4$$

$$= 0.0146$$

$$E_{0.5/-} = E_{38} - C - E_D = (0.0334) - (0.0083) - (0.0109) = 0.0142$$

$$E_{1/-} = \frac{(E_{26} - C - E_D) + (E_{40} - C - E_D) + (E_{71} - E_D) + (E_{72} - E_D)}{4}$$

$$= [(0.0359 - 0.0083 - 0.0109) + (0.0301 - 0.0083 - 0.0109) + (0.0247 - 0.0109) + (0.040 - 0.0109)] / 4$$

$$= [(0.0167) + (0.0109) + (0.0138) + (0.0291)] / 4 = 0.0176$$

$$E_{3/-} = E_{39} - C - E_F = (0.0492) - (0.0083) - (0.0109) = 0.030$$

$$E_{0/0} = E_{41} - C - R_F = (0.0154) - (0.0083) - (0.0019) = 0.0052$$

$$E_{1/0} = \frac{[E_{42} - C - R_F] + [E_{70} - E_F]}{2}$$

$$= \frac{[0.0176 - 0.0083 - 0.0019] + [0.0202 - 0.0109]}{2}$$

$$= \frac{(0.0074) + (0.0093)}{2} = 0.0084$$

$$E_{3/1} = E_{43} - C - R_F = (0.0269) - (0.0083) - (0.0019) = 0.0167$$

Phase 3/3R Loss Calculations

Deck seam loss:

$$E_S = E_{56} - E_{55} = (0.0338) - (0.0156) = 0.0182$$

Residual losses: the sealing of various loss sources only occurred in Phase 3 (not 3R); therefore, only one R_T value is calculated:

$$R_T = E_{55} = 0.0156$$

From measurements made during the test program:

$A_T = 147\ ft^2$
$A_F = 17\ ft^2$
$A_R = 130\ ft^2$, including 60 ft^2 covering the rim plate extension seam and 70 ft^2 covering the rim seal area.

Therefore:

$$R_F = \left(\frac{17}{147}\right) R_T = (0.116)(0.0156) = 0.0018$$

$$R_{rim\ plate} = \left(\frac{60}{147}\right) R_T = (0.408)(0.0156) = 0.0064$$

$$R_{seal\ area} = \left(\frac{70}{147}\right) R_T = (0.476)(0.0156) = 0.0074$$

Deck fitting loss:

$$E_F = E_{58} - \left(E_{57} - R_F\right) = (0.0433) - (0.0345 - 0.0018)$$
$$= 0.0106$$

Total deck loss:

$$E_D = E_S + E_F = (0.0182) + (0.0106) = 0.0288$$

Rim seal losses: the loss from the rim plate extension seam was independently calculated:

$$E_{rim\ plate} = E_{57} - \left(E_{56} - R_{rim\ plate}\right)$$
$$= (0.0345) - (0.0338 - 0.0064) = 0.0071$$

This rim plate loss was considered to be part of the total rim seal loss and is implicitly included with the rim seal loss in all subsequent calculations.

$$E_{0/-} = E_{59} - E_D = (0.0536) - (0.0288) = 0.0248$$

$$E_{1/-} = \frac{\left(E_{60} - E_D\right) + \left(E_{62} - E_D\right)}{2}$$
$$= \frac{(0.0574 - 0.0288) + (0.0649 - 0.0288)}{2} = 0.0324$$

$$E_{3/-} = E_{61} - E_D = (0.0690) - (0.0288) = 0.0402$$

$$E_{0/0} = E_{52,52R} - E_D = (0.040) - (0.0288) = 0.0112$$

$$E_{1/0} = E_{53,53P} - E_D = (0.0399) - (0.0288) = 0.0111$$

$$E_{3/1} = E_{54} - E_D = (0.040) - (0.0288) = 0.0112$$

Typical Rim Seal Losses for Vapor-Mounted and Liquid-Mounted Rim Seal Systems

Since the seal gap size is not known or readily measurable for any given internal floating-roof tank, two general conditions of seal fit were defined: average and tight. To determine losses from average-fitting seal systems, gaps between the seal and the tank shell from hundreds of external floating-roof field tanks with resilient filled seals were used to determine seal gap size frequency distributions for both primary seal only and primary plus secondary seal systems. (Data from external floating-roof tanks were used because no data exist on seal gaps in internal floating-roof tanks and it was judged that seals in internal floating-roof tanks are likely to fit at least as well as those in external floating-roof tanks.) From these seal gap size distributions, factors were determined which were used to weight the loss data from seal systems with various seal gap areas to develop a typical loss which is representative of seal systems with averge fit between the seal and the tank shell.

Tight-fitting seal systems were defined as those which consistently have no gaps greater than 1/8 inch wide between the seal and the tank shell. To determine typical losses from tight-fitting primary seals only, loss data from "zero-gap" primary seals were directly used. To determine losses from tight-fitting primary plus secondary seal systems, loss data from "zero-gap" secondary seals were used, by averaging that data for both "zero-gap" and small (i.e., 1 $inch^2$/ft diameter) gap primary seals under the secondary seal.

Average-fit loss calculations:

For primary seal only, the following weighting factors and loss values for various seal gap areas were used:

$$E = (0.65)\ E_{0/-} + (0.25)\ E_{1/-} + (0.1)\ E_{3/-}$$

For primary plus secondary seal systems, the following weighting factors and loss values for various seal gap areas were used:

$$E = (0.75)\ \left[\frac{E_{0/0} + E_{1/0}}{2}\right] + (0.25)\ E_{3/1}$$

The above equations were used with the loss data summarized in Table 3.2 for vapor-mounted and liquid-mounted seal systems to calculate typical losses from average-fitting seal systems (summarized in Table 3.3).

For vapor-mounted seal systems:

With primary seal only:

$$E = (0.65)(0.032) + (0.25)(0.0487) + (0.1)(0.0526)$$
$$= 0.0382 \text{ lb-mole/day}$$

With primary plus secondary seals:

$$E = (0.75)\left[\frac{(0.0110) + (0.0147)}{2}\right] + (0.25)(0.0177)$$
$$= 0.0141 \text{ lb-mole/day}$$

For liquid-mounted seal systems:

With primary seal only:

$$E = (0.65)(0.0146) + (0.25)(0.0176) + (0.1)(0.030)$$
$$= 0.0169 \text{ lb-mole/day}$$

With primary plus secondary seals:

$$E = (0.75)\left[\frac{(0.0052) + (0.0084)}{2}\right] + (0.25)(0.0167)$$
$$= 0.0093 \text{ lb-mole/day}$$

Tight-fit loss calculations: loss data from Table 3.2 for vapor-mounted and liquid-mounted seal systems were used as shown below to calculate typical losses from tight-fitting seal systems (summarized in Table 3.3).

For vapor-mounted seal systems:

With primary seal only:

$$E = 0.032 \text{ lb-mole/day}$$

With primary plus secondary seals:

$$E = \left[\frac{(0.0110) + (0.0147)}{2}\right] = 0.0129 \text{ lb-mole/day}$$

For liquid-mounted seal systems:

With primary seal only:

$$E = 0.0146 \text{ lb-mole/day}$$

With primary plus secondary seals:

$$E = \left[\frac{(0.0052) + (0.0084)}{2}\right] = 0.0068 \text{ lb-mole/day}$$

3.3 Detailed Rim Seal Loss Factor Calculations

A parameter, K_r, related to seal type and fit was defined by the following equation:

$$E_r = (K_r D)\ P^*$$

where:

E_r = rim seal loss (lb-mole/yr)
K_r = rim seal loss factor (lb-mole/ft yr)
D = tank diameter (ft)
P^* = vapor pressure function (dimensionless)

$$= \frac{\left(\frac{P}{P_a}\right)}{\left[1 + \left(1 - \frac{P}{P_a}\right)^{0.5}\right]^2}$$

, where: P = true vapor pressure (psia)
P_a = atmospheric pressure (psia)

Rim seal loss factors, K_r, were calculated by rearranging the above equation, with the calculated rim seal losses for average and tight-fit seal systems, for vapor-mounted and liquid-mounted seals. The other variables in the equation were set by the test tank conditions during the rim seal loss tests. Therefore:

$$K_r = \frac{E_r}{D\ P^*}$$

where:

E_r = E (lb-mole/day) · (365 day/yr)
D = 20 ft
P^* = 0.1036 (at P = 5 psia)

By substituting the above values into the equation for K_r:

$$K_r = \left[\frac{365}{(20)(0.1036)}\right]\ E$$

$$= (176.16)\ E$$

The calculated values for K_r are shown in Table 3.3.

TABLE 3.1 - SUMMARY OF RIM SEAL LOSS CALCULATIONS

Description of Loss Condition	Phase 1	Phase 1F	Phase 1/1R
Rim Seal Loss, E_S			$E_{76R} - E_{77}$
Residual Loss			
Total, R_T	$E_{23} - E_S$	E_{77}	
Fittings, R_F	$(A_F/A_T)R_T^1$	$(A_F/A_T)R_T^{1R}$	
Rim seal, R_R	$(A_R/A_T)R_T^1$	$(A_R/A_T)R_T^{1R}$	
Fitting Loss			
Unguaseted, $E_{F)U}$			$\left(\frac{E_{24} + E_{25}}{2}\right) - (E_{23} - R_F^1)$
Guaseted, $E_{F)G}$			$\left[F_{9A}/\left(\frac{F_{9B} + F_7}{2}\right)\right] E_{F)U}$
Deck Loss			
Unguaseted fittings, $E_{D)U}$			$E_S + E_{F)U}^1$
Guaseted fittings, $E_{D)G}$			$E_S + E_{F)G}^{1R}$
Rim Seal Loss			
Primary seal only			
0 in^2/ft ø gap, $E_{0/-}$	$\left(\frac{E_{21A,AR} + E_{21B,BR} + E_{21C,CR}}{3}\right) - E_{D)U}$	$\left(\frac{E_{73A} + E_{74}}{2}\right) - E_{D)G}$	$\left(\frac{E_{0/-}^1 + E_{0/-}^{1R}}{2}\right)$
1 in^2/ft ø gap, $E_{1/-}$	$\left(\frac{E_{22A} + E_{22B,BI} + E_{22C} + E_{26A} + E_{26B}}{5}\right) - E_{D)U}$		$E_{gap/-} = \left(\frac{E_{1/-}^1 + E_{3/-}^{1R}}{2}\right)$
3 in^2/ft ø gap, $E_{3/-}$		$E_{75} - E_{D)G}$	
Secondary seal			
0/0 in^2/ft ø gaps, $E_{0/0}$			$E_{0/0)pre}\left(\frac{E_{3/0}}{E_{3/0)pre}}\right)^{(2)}$
1/0 in^2/ft ø gaps, $E_{1/0}$			$E_{1/-}\left(\frac{E_{1/0}}{E_{1/-}}\right)$ octane$^{(1)}$
3/1 in^2/ft ø gaps, $E_{3/1}$			$E_{3/1)pre}\left(\frac{E_{3/0}}{E_{3/0)pre}}\right)^{(3)}$

NOTES:

(1) $\left(\frac{E_{1/0}}{E_{1/-}}\right)$ octane $= \left[\frac{\left(\frac{E_{31} + E_{31A}}{2}\right) - E_{D)U,P=0.5\ psia}}{E_{29R} - E_{D)U,P=0.5\ psia}}\right]$, where: $E_{D)U,P=0.5\ psia} = E_{D)U}\left(\frac{P^*_{P=0.5\ psia}}{P^*_{P=5.0\ psia}}\right)$

(2) $E_{0/0)pre} = E_{17} - R_F^1 - E_S$

$E_{3/0)pre} = E_{15} - R_F^1 - E_S$

(3) $E_{3/1)pre} = \left(\frac{E_{19A} + E_{19A}}{2}\right) - R_F^1 - E_S$

SUMMARY OF RIM SEAL LOSS CALCULATIONS (CONT.)

Component or Loss/Condition	Phase 2/2R	Phase 3/3R
Total Rim Loss, E_S	-	$E_{56} - E_{55}$
Residual Loss		
Total, R_T	$\frac{(E_{44} - C) + E_{45}}{2}$ (4)	E_{55}
Fittings, R_F	$(A_F/A_T)R_T$	$(A_F/A_T)R_T$
Rim seal, R_R	$(A_R/A_T)R_T$	$(A_R/A_T)R_T$
Fitting Loss, E_F	$\frac{[E_{47} - R_R] + [E_{46} - (E_{49} - R_F)] - [E_{70} - (E_{42} - C - R_F)]}{3}$	$E_{58} - (E_{57} - R_F)$
Deck Loss, E_D	E_F	$E_S + E_F$
Rim Seal Loss		
Primary seal only		
0 in²/ft ϕ, $E_{0/-}$	$\frac{(E_{35} - C - E_F) + (E_{37} - C - E_F) + (E_{48} - E_F) + (E_{49} - R_F)}{4}$	$E_{59} - E_D$
1 in²/ft ϕ, $E_{1/-}$	$\frac{(E_{36} - C - E_F) + (E_{40} - C - E_F) + (E_{71} - E_F) + (E_{72} - E_F)}{4}$	$\frac{(E_{60} - E_D) + (E_{62} - E_D)}{2}$
3 in²/ft ϕ, $E_{3/-}$	$E_{39} - C - E_F$	$E_{61} - E_D$
Secondary seal		
0/0 in²/ft ϕ, $E_{0/0}$	$E_{41} - C - R_F$	$E_{52,52R} - E_D$
1/0 in²/ft ϕ, $E_{1/0}$	$\frac{(E_{42} - C - R_F) + (E_{70} - E_F)}{2}$	$E_{53,53P} - E_D$
3/1 in²/ft ϕ, $E_{3/1}$	$E_{43} - C - R_F$	$E_{54} - E_D$

NOTES:

(4) $C = \frac{(E_{44} - E_{45}) + [(\frac{E_{35} + E_{37}}{2}) - E_{48}]}{2}$

TABLE 3.2 - SUMMARY OF RIM SEAL LOSSES FROM EACH TEST PHASE

Rim Seals Conditions	Loss (lb-mole/day)					
	Phase 1/1R					
	Phase 1	Phase 1R	Combined Phase 1/1R	Phase 3/3R	Average of Phase 1/1R and 3/3R (Vapor-Mounted Seals)	Phase 2/2R (Liquid-Mounted Seals)
$E_{0/-}$	0.0566	0.0217	0.0392	0.0248	0.032	0.0146
$E_{1/-}$	0.0978	-	0.0649	0.0324	0.0487	0.0176
$E_{3/-}$	-	0.0319		0.0402	0.0526	0.030
$E_{0/0}$			0.0107	0.0112	0.0110	0.0052
$E_{1/0}$			0.0183	0.0111	0.0147	0.0084
$E_{3/1}$			0.0241	0.0112	0.0177	0.0167

TABLE 3.3 - SUMMARY OF TYPICAL RIM SEAL LOSSES AND RIM SEAL LOSS FACTORS

Seal System/Condition	Typical Losses, E (lb-mole/day)		Rim Seal Loss Factors, K_r (lb-mole/ft yr)	
	Vapor-Mounted Seal Systems	Liquid-Mounted Seal Systems	Vapor-Mounted Seal Systems	Liquid-Mounted Seal Systems
Average-fit seal system				
Primary seal only	0.0382	0.0169	6.7	3.0
Primary plus secondary seals	0.0141	0.0093	2.5	1.6
Tight-fit seal system				
Primary seal only	0.0320	0.0146	5.6	2.6
Primary plus secondary seals	0.0129	0.0068	2.3	1.2

DEVELOPMENT OF PRODUCT FACTOR (K_c)

In the external floating roof tank emissions test program comparisons of emissions from gasoline with those from octane/propane mixtures were made under equivalent test conditions These results revealed that the measured gasoline emissions could be predicted based on the octane/propane emission results by accounting for true vapor pressure (TVP) and molecular weight (M_v) differences between these products. However, similiar comparisons with crude oil revealed that even after correcting for TVP and M_v differences the emissions calculated based on octane/propane results had to be multiplied by a factor of 0.4, which we called a product factor (K_c), to be equal to the measured crude oil emissions. This observation was attributed to the mass transfer of light end components through the liquid crude oil being substantially slower than the mass transfer of the light ends from the liquid surface into the vapor phase.

Mass transfer of the propane through the octane/propane mixture to the liquid surface is naturally necessary to sustain a constant emission rate when all conditions causing the emissions remain constant. With a single component stock no mass transfer through the liquid is required to maintain a constant emission rate since the single component is always available at the surface to evaporate. If the mass transfer rate of propane through the octane/propane liquid is appreciably slower than the liquid to vapor mass transfer rate of propane then use of octane/propane emission results to predict single component emissions results could underestimate the emissions even after correcting for TVP and M_v differences.

During the internal floating roof tank emission test program several tests with each of the 3 different deck/seal combinations were conducted in which the only variable was the vapor pressure of the octane/propane mixture. In addition, several tests were conducted with the single component stocks n-hexane and n-octane. The average emissions for each of these tests, at the average TVP for the test, are given in Table B.1-1 and they are plotted in Figures B.1-1 through B.1-4. A linear regression was performed to obtain an equation for emissions from the octane/propane mixtures versus TVP, i.e. E = M(TVP) + B. The values of M, B, and the multiple correlation coefficient squared (R**2) are given in Table B.1-1. The straight lines on Figures B.1-1 through B.1-4 are based on the appropriate M and B values given in Table B.1-1.

The information presented in Table B.1-1 and in Figures B.1-1 through B.1-4 clearly shows that, in general, the single component stock emissions are either close to the value which would be predicted based on the octane/propane results or they are overestimated by the octane/propane results. As noted in Table B.1-1, considering the body of the data as a whole the most reasonable conclusion is that octane/propane emission results can be used to estimate single component emission results simply by accounting for TVP and M_v differences. Therefore the product factor (K_c) to be used when estimating single component emissions from the octane/propane derived emission estimation equations is 1.0.

TABLE B.1-1: KEY FOR FIGURES 1 THROUGH 4 AND CONCLUSION ABOUT APPROPRIATE PRODUCT FACTOR FOR PURE COMPONENTS

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* NOTE: PSIA = POUNDS PER SQUARE INCH ABSOLUTE; PM/DAY = POUND-MOLE PER DAY; C3 = PROPANE; C8 = NORMAL OCTANE; C6 = NORMAL HEXANE; TVP = TRUE VAPOR PRESSURE; ME = MEASURED EMISSIONS AT TVP FOR THE INDICATED TEST; CE = CALCULATED EMISSIONS = B + M(TVP); WHERE B AND M = THE INTERCEPT AND THE SLOPE OF THE LINES IN FIGURES 1 THROUGH 4 AS DETERMINED BY A LINEAR LEAST SQUARES REGRESSION PROGRAM. THE VALUES FOR B, M, AND THE MULTIPLE CORRELATION COEFFICIENT SQUARED, R**2, ARE GIVEN BELOW EACH SET OF DATA IN THIS TABLE. THE LINES ARE DETERMINED USING THE C3/C8 DATA ONLY; THEREFORE, THE APPARENT PRODUCT FACTOR FOR THE C6 AND C8 TESTS CAN BE DETERMINED BY THE RATIO ME/CE WHERE CE IS CALCULATED USING THE VALUES OF B, M, AND THE TVP FOR THE PRODUCT BEING CONSIDERED. THIS RATIO IS ALSO SHOWN FOR THE C3/C8 TESTS AS IT PROVIDES AN INDICATION OF WHETHER THE VALUES CALCULATED FOR THE C6 AND C8 DATA ARE SIGNIFICANTLY DIFFERENT FROM 1.

****

FIGURE B.1-1: PHASE 1, EMISSIONS VERSUS VAPOR PRESSURE (USING 1 INCH SQUARE (GAPS) PER FOOT OF DIAMETER PRIMARY SEAL DATA ONLY.)

TEST NO.	PRODUCT	TVP (PSIA)	ME (PM/DAY)	CE (PM/DAY)	PLOTTING SYMBOL	ME/CE
API-22A	C3/C8	4.22	0.116	0.122	1	0.95
API-22B	C3/C8	3.91	0.129	0.115	2	1.11
API-22C	C3/C8	3.76	0.150	0.112	3	1.34
API-26A	C3/C8	3.69	0.0814	0.111	4	0.73
API-26B	C3/C8	2.40	0.0550	0.0829	5	0.66
API-27A	C3/C8	0.727	0.0440	0.0469	6	0.94
API-27B	C3/C8	0.730	0.0288	0.0470	7	0.61
API-27C	C3/C8	0.726	0.0809	0.0469	8	1.72
API-25R	C8	0.288	0.0812	0.0375	#	2.17
API-33	C6	1.96	0.0235	0.0735	*	0.32
API-33A	C6	2.30	0.0229	0.0808	+	0.28
API-34	C6	2.35	0.0296	0.0818	$	0.36
API-34A	C6	2.37	0.0328	0.0824	@	0.40

B = 0.0313 M = 0.0215 R**2 = 0.628

FIGURE B.1-2: PHASE 1, EMISSIONS VERSUS VAPOR PRESSURE (USING 0 INCH SQUARE (GAPS) PER FOOT OF DIAMETER PRIMARY SEAL DATA ONLY.)

TEST NO.	PRODUCT	TVP (PSIA)	ME (PM/DAY)	CE (PM/DAY)	PLOTTING SYMBOL	ME/CE
API-21A	C3/C8	2.72	0.0633	0.0553	1	1.14
API-21B	C3/C8	2.68	0.0493	0.0547	2	0.90
API-21C	C3/C8	2.65	0.0514	0.0541	3	0.95
API-28	C3/C8	0.718	0.0242	0.0240	4	1.01
API-30	C8	0.295	0.0185	0.0174	8	1.07
API-32	C6	1.92	0.0173	0.0427	*	0.41

B = 0.0128 M = 0.0156 R**2 = 0.876

FIGURE B.1-3: PHASE 2, EMISSIONS VERSUS VAPOR PRESSURE (USING 1 INCH SQUARE (GAPS) PER FOOT OF DIAMETER PRIMARY SEAL DATA ONLY.)

TEST NO.	PRODUCT	TVP (PSIA)	ME (PM/DAY)	CE (PM/DAY)	PLOTTING SYMBOL	ME/CE
API-36	C3/C8	4.01	0.0211	0.0213	1	0.99
API-40	C3/C8	5.69	0.0256	0.0285	2	0.90
API-50	C3/C8	0.60	0.00513	0.00667	3	0.77
API-67	C8	0.36	0.00359	0.00563	8	0.64
API-67A	C8	0.43	0.00666	0.00593	&	1.12
API-68	C6	2.96	0.0126	0.0168	*	0.75
API-71	C3/C8	6.21	0.0326	0.0307	4	1.06
API-72	C3/C8	2.39	0.0171	0.0143	5	1.19

B = 0.00408 M = 0.00429 R**2 = 0.948

FIGURE B.1-4: PHASE 3, EMISSIONS VERSUS VAPOR PRESSURE (USING 1 INCH SQUARE (GAPS) PER FOOT OF DIAMETER PRIMARY SEAL DATA ONLY.)

TEST NO.	PRODUCT	TVP (PSIA)	ME (PM/DAY)	CE (PM/DAY)	PLOTTING SYMBOL	ME/CE
API-60	C3/C8	4.40	0.0491	0.0490	1	1.00
API-62	C3/C8	2.97	0.0355	0.0357	2	0.99
API-63K	C3/C8	0.88	0.0166	0.0164	3	1.01
API-64	C8	0.55	0.00953	0.0134	8	0.71
API-65	C6	3.28	0.0335	0.0386	*	0.87
API-65K	C6	3.33	0.0560	0.0391	•	1.43

B = 0.00832 M = 0.00924 R**2 = 1.000

	PHASE	AVERAGE PRODUCT FACTOR FOR C6	C8	AVERAGE
**********	1	0.34	2.17	1.25
* SUMMARY *	1	0.41	1.07	0.74
**********	2	0.75	0.88	0.82
	3	1.15	0.71	0.93
	AVERAGE =	0.66	1.21	0.93

CONCLUSION: CONSIDERING ALL OF THE ABOVE INFORMATION A PRODUCT FACTOR OF 1 FOR PURE COMPONENTS VERSUS A MIXTURE APPEARS TO BE A REASONABLE AND CONSERVATIVE CHOICE.

FIGURE B.1-1: PHASE 1, EMISSIONS VERSUS VAPOR PRESSURE

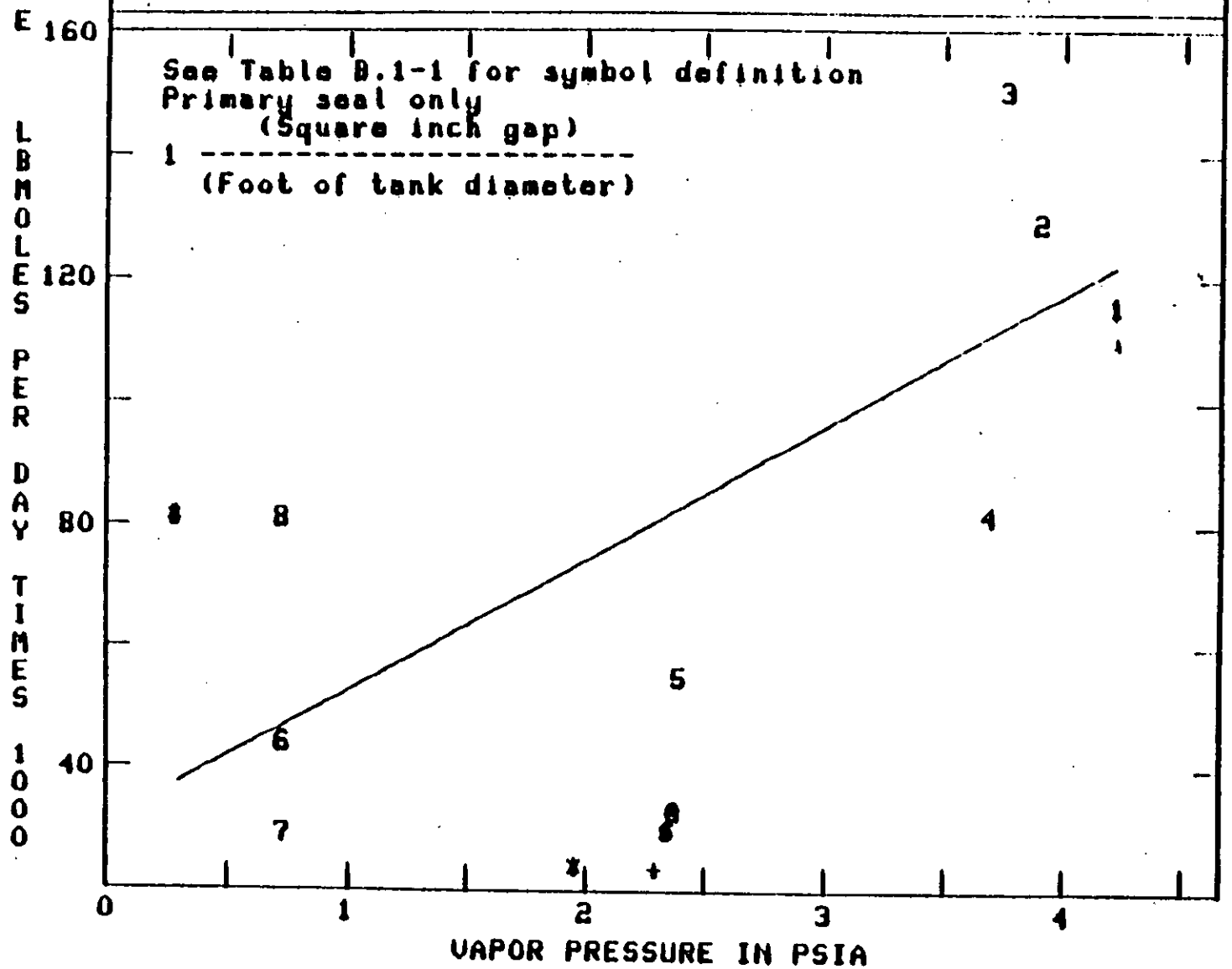

FIGURE B.1-2: PHASE 1, EMISSIONS VERSUS VAPOR PRESSURE

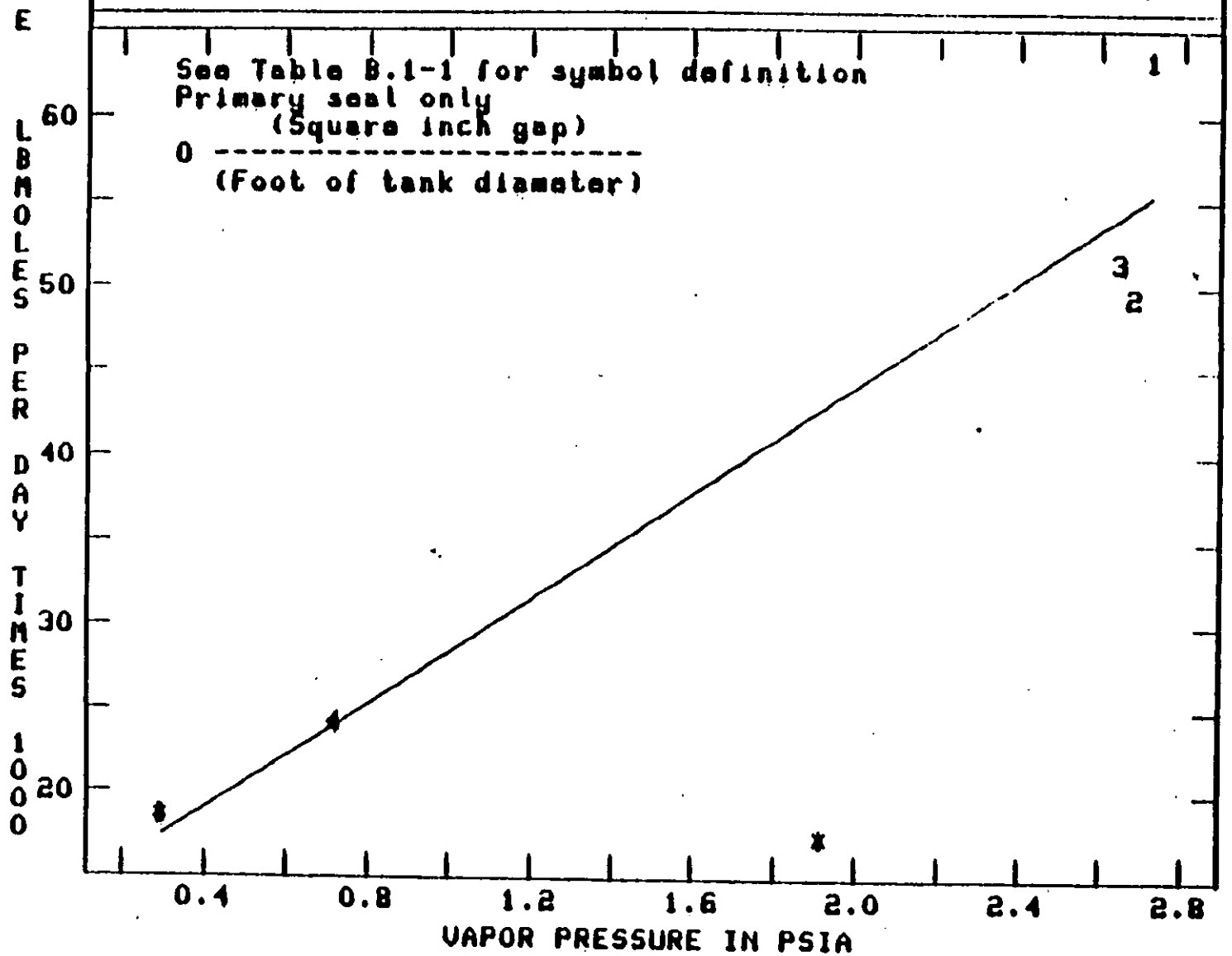

FIGURE B.1-3: PHASE 2, EMISSIONS VERSUS VAPOR PRESSURE

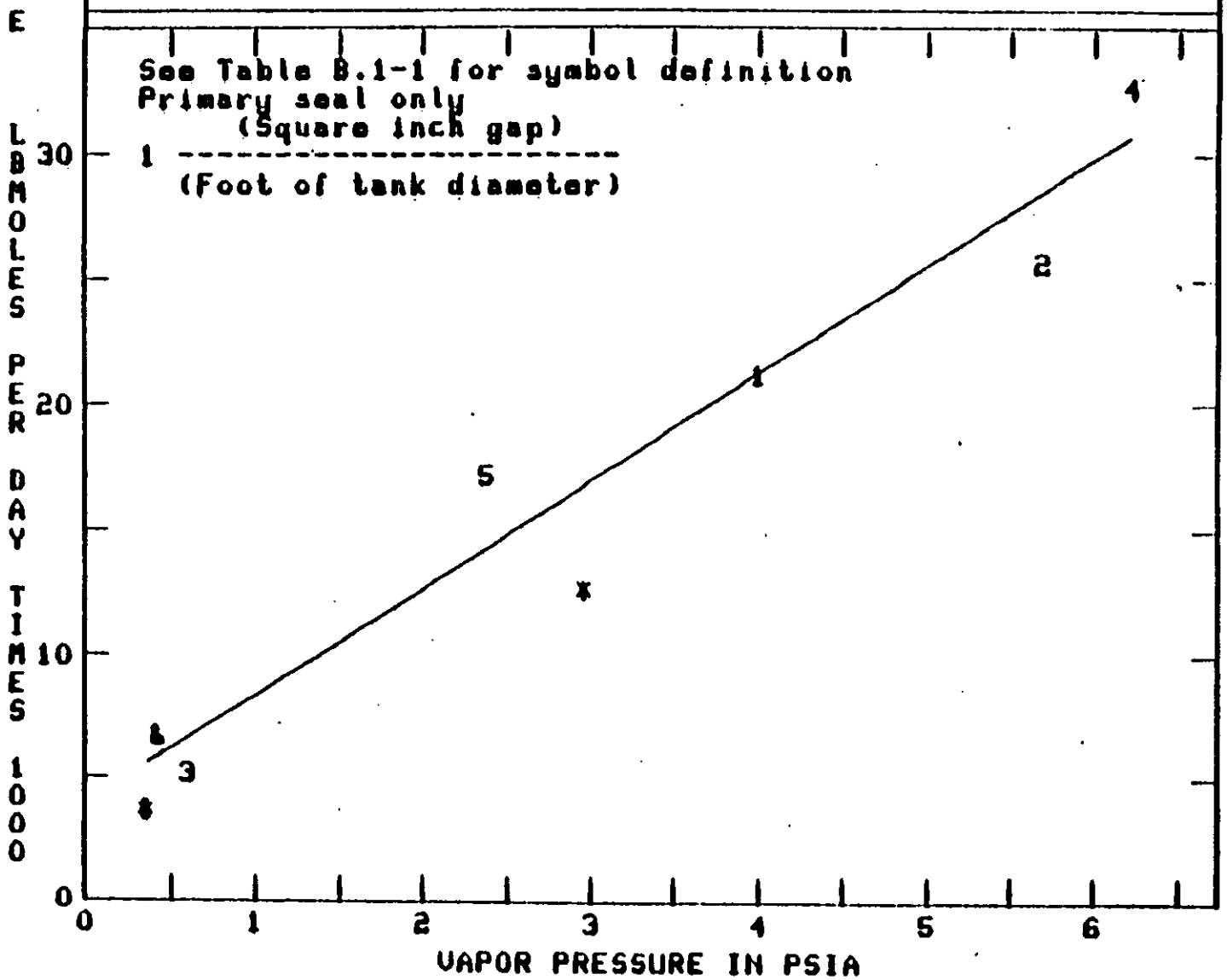
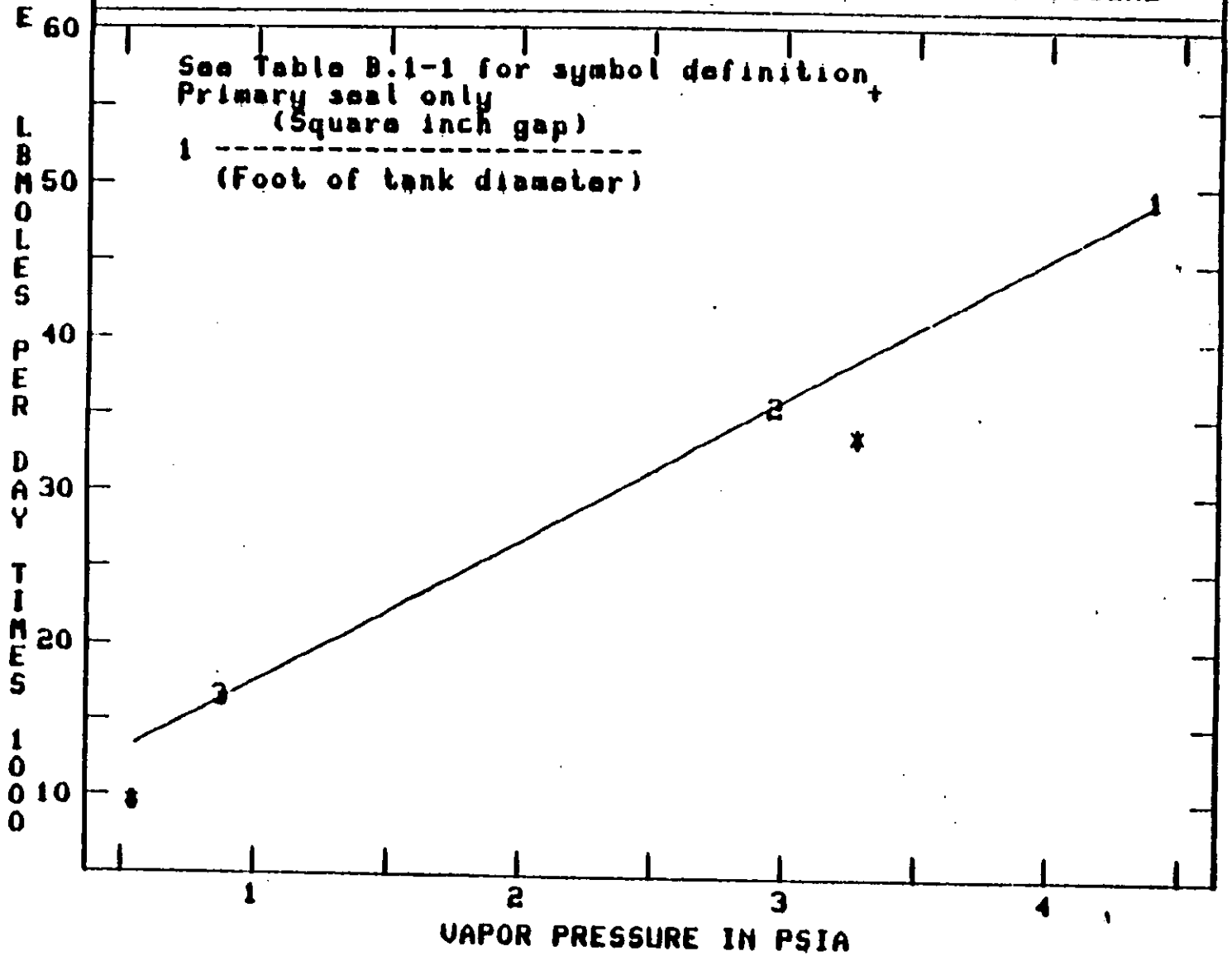
FIGURE B.1-4: PHASE 3, EMISSIONS VERSUS VAPOR PRESSURE