AP42 Section:	7.1
Related	12
Title:	Documentation File for Appendix D: Development of Diameter Function

DOCUMENTATION FILE FOR APPENDIX D
DEVELOPMENT OF DIAMETER FUNCTION

Appendix D outlines the procedures used to evaluate the appropriate diameter function for use in an equation to estimate losses from an external floating roof tank. Both aerodynamic studies of wind effects on tank losses and direct field tank loss measurements were considered. Both studies concluded that the most appropriate diameter function is direct proportionality, that is the exponent on the diameter term in the loss equation should be 1.

The aerodynamic studies are referenced in Appendix D and will not be discussed further here. This file includes a discussion of the field tanks tested; the pilot tank tests which were judged to most closely relate to the field tank conditions; the mathematical treatment of the data which resulted in plots of predicted emissions as a function of a variable diameter exponent; and a comparison with the measured field results which established the most appropriate diameter exponent.

Field Tank Tests

Three field tanks were tested for product loss. The test procedures are thoroughly described in the references given in Appendix D. These tanks were coded and are referred to in this file by the letters C, T, and P. The stock properties, tank/seal system parameters, and ambient conditions associated with each test site are given in Table 1. References for these test parameters are given in Appendix D. For Tank P, the values given in Table 1 are modified slightly from those summarized in the report referenced in Appendix D. These differences reflect the deletion of those time periods in the testing of Tank P when liquid surface boiling occurred, due to the testing of more volatile winter grade gasoline during hot summer ambient conditions. Since the loss equation in Bulletin 2517 is expressly not applicable to boiling stocks, it was necessary to delete that segment of the field test data. Table 2 presents a summary of Tank P data, showing how the modified values were calculated.

Pilot Tank Tests

Table 3 indicates the pilot tank tests which most closely relate to the field tank conditions, and includes the tank/seal conditions, stock properties, and predicted emissions evaluated at the ambient wind speed from the related field test.

For Tanks T and P, a direct comparison could be made between field and pilot tank tests. In both cases, the seal type and seal fit of the field test tanks could be matched by tested conditions in the pilot tank.

However, in the case of Tank C, the combined field test conditions of seal gap area and seal leak rate were not matched in any one or any series of pilot tank tests. Therefore, the emissions due to the large seal gap area and those due to an extremely high seal leak rate were separately estimated, then summed to predict the total emissions from the field tank.

Tank C had a very large cumulative seal gap area, which approximately related to a continuous gap of 0.5 inches in width around the entire circumference of the tank. Pilot test W6 had a seal gap of 0.5 inches in width around one-half the tank's circumference, with no gap in the other half circumference. Further, pilot tests W1, WIR, W2, and V3 all had no gaps around the entire circumference. In addition, all five pilot tests had the same shoe seal with the same leak rate of 0.032 scfm per foot diameter. By subtracting one-half of the emissions measured in tests W1, WIR, W2, and V3 from the emissions measured in test W6, and then multiplying that result by a factor of two, the seal gap conditions of field tank C could be most closely approximated.

In order to determine the incremental emissions associated with the extremely high leak rate of approximately 7.4 scfm/foot diameter measured for Tank C, a series of tests were evaluated in which the leak rate varied from 0.0085 to 25.0 scfm/foot diameter, and in which there were no measureable seal gaps. The data used to determine the leak rate for Tank C are given in Figure 1. By evaluating each of these tests at the field tank wind speed of 2.7 miles per hour, a plot was developed of pilot tank emissions as a function of seal leak rate (where the seal leak rates in scfm per foot diameter were determined at a pressure differential of 1.5 inches of water). Such a plot is attached as Figure 2. Table 4 shows the pilot tank tests used in this analysis and gives the K_s and n values determined from a regression analysis of each set of test data, as well as the calculated emissions (at a wind speed of 2.7 miles per hour) which are plotted in Figure 2. The incremental field tank emissions due to leak rate were then determined to be the difference in emissions between a leak rate of 7.4 and 0.032 scfm/foot diameter.

It is important to note that there is a high degree of uncertainty associated with the attempt to relate emissions to leak rate. As can be seen in Figure 2, the results determined from direct regression analyses of the data lend themselves to a rather subjective correlation, as is evident from the line drawn on Figure 2. Some of the tests used in this analysis had as few as two data points. For this reason, it was not possible to develop with confidence any general relationships between leak rate and emissions. However, in order to utilize the results of field Tank C in our general analysis of the diameter function, it was necessary to use such pilot tank data as were available. It was judged that the procedures used were the most reasonable that could be employed using the existing data base. Further, it was judged that since the emissions due to seal leak rate were relatively small, as compared to emissions due to the seal gap (as shown in the following section), that no major errors were introduced in the overall analysis by the use of this limited data on seal leak rate.

Mathematical Treatment of Pilot Tank Data

Following the above described procedures, pilot tank emissions could be calculated which directly related to the seal conditions and wind speed found in the field tests. In order to directly predict field tank emissions based on the pilot tank data, differences in stock vapor pressure, vapor molecular weight , and tank diameter need to be accounted for. The vapor pressure and molecular weight functions were established in the pilot tank study. Therefore, in order to determine the diameter function which provides the best match between predicted emissions based on the pilot tank data and the measured field results, predicted emissions were plotted as a function of a variable exponent on diameter. Specifically, emissions were predicted for diameter exponents of 0.8, 1.0, and 1.2. These results were then plotted as shown in Figure D-1 in Bulletin 2517.

The following summarizes these calculations. In general, predicted emissions for the field tanks are equal to the related pilot tank emissions, corrected for differences in vapor pressure, molecular weight, and diameter, as given below:

$$E_{field} = E_{pilot} \left(\frac{P^*_{field}}{P^*_{pilot}} \right) \left(\frac{M_{v(field)}}{M_{v(pilot)}} \right) \left(\frac{D^x_{field}}{D^x_{pilot}} \right)$$

where E = emissions (lb/day)
P^* = vapor pressure function defined in Appendix C
M_v = vapor molecular weight (lb/lb-mole)
D = tank diameter (ft)
x = exponent for diameter function

Tank C: Total emissions equal emissions from seal gap plus emissions due to leak rate.

(1) $$E_{SEAL\ GAP} = \left[2\ E_{W6} - 1/2\ E_{W1}, \ldots\right]\left(\frac{0.139}{0.104}\right)\left(\frac{63.2}{44.1}\right)\left(\frac{152^x}{20^x}\right)$$

$$= 2\left[4.8 - 1/2\ (1.0)\right]\ (1.92)\left(\frac{152^x}{20^x}\right)$$

$$= (16.4)\left(\frac{152^x}{20^x}\right)$$

$$E_{(x=0.8)} = 84\ \frac{lb}{day}$$

$$E_{(x=1.0)} = 125\ \frac{lb}{day}$$

$$E_{(x=1.2)} = 188\ \frac{lb}{day}$$

(2) $$E_{LEAK\ RATE} = \left[E_{7.4} - E_{0.032}\right]\left(\frac{0.139}{0.104}\right)\left(\frac{63.2}{44.1}\right)\left(\frac{152^x}{20^x}\right)$$

(where $E_{7.4}$ and $E_{0.032}$ are taken from Figure 2)

$$= \left[3.55 - 0.89\right]\ (1.92)\left(\frac{152^x}{20^x}\right)$$

$$E_{(x\ =\ 0.8)} = 26\ \frac{lb}{day}$$

$$E_{(x\ =\ 1.2)} = 39\ \frac{lb}{day}$$

$$E_{(x\ =\ 1.2)} = 58\ \frac{lb}{day}$$

(3) $E_{TOTAL}\ (x = 0.8) = 84 + 26 = 110\ \frac{lb}{day}$

$E_{TOTAL}\ (x = 1.0) = 125 + 39 = 164\ \frac{lb}{day}$

$E_{TOTAL}\ (x = 1.2) = 188 + 58 = 246\ \frac{lb}{day}$

<u>Tank T:</u>

$$E_{TOTAL} = \left[E_{PILOT}\right]\left(\frac{0.163}{0.104}\right)\left(\frac{62.7}{44.1}\right)\left(\frac{74^x}{20^x}\right)$$
$$= (3.1)\quad (2.23)\left(\frac{74^x}{20^x}\right)$$

$E_{TOTAL}\ (x = 0.8) = 20\ \frac{lb}{day}$

$E_{TOTAL}\ (x = 1.0) = 26\ \frac{lb}{day}$

$E_{TOTAL}\ (x = 1.2) = 33$ lb/day

<u>Tank P:</u>

$$E_{TOTAL} = \left[E_{PILOT}\right]\left(\frac{0.177}{0.104}\right)\left(\frac{57.3}{44.1}\right)\left(\frac{35^x}{20^x}\right)$$
$$= \left[0.32\right]\ (2.21)\left(\frac{35^x}{20^x}\right)$$

$E_{TOTAL}\ (x = 0.8) = 1.1\ \frac{lb}{day}$

$E_{TOTAL}\ (x = 1.0) = 1.2\ \frac{lb}{day}$

$E_{TOTAL}\ (x = 1.2) = 1.4\ \frac{lb}{day}$

Comparison of Predicted
and Measured Emissions

In addition to the predicted emissions plotted as function of diameter exponent in Figure D-1 in Bulletin 2517, the actual measured emissions are also shown on that figure. Based on the results shown on Figure D-1, it is clear that a diameter exponent of 1 is the function which will result in the closest match between predicted and measured emissions. Further, although there is a reasonably large 95% confidence range reported for the measured test results for two of the tests, the range of diameter exponent is from approximately 0.7 to 1.2, significantly below the previously used exponent of 1.5

Since the empirical result of an exponent of 1 was consistent with theoretical considerations and aerodynamic studies, it was judged that emissions were clearly demonstrated to be directly proportional to tank diameter.

TABLE 3

PILOT TANK TEST PARAMETERS

Test Tank:	C		T	P
Pilot tank tests:	W1, W1R, W2, V3	W6	13, 15, 16, 17, 19 20, 21, 22, 25, 31	C35, C36/38, C29
Tank properties:				
Diameter (ft)	20	20	20	20
Seal type	shoe	shoe	foam	Liquid plus weathershield
Seal mounting	standard	standard	vapor	liquid
Seal gaps (in^2/ft. dia.)	0	1/2 in. average for 50% of circumference	0	0
Seal leak rate (scfm/ft. dia.)	0.032	0.032	-	-
Stock properties:				
Average TVP (psia)	5.0	5.0	5.0	5.0
P^* function	0.104	0.104	0.104	0.104
Vapor molecular weight (lb/lb mole)	44.1	44.1	44.1	44.1
Average measured emissions (lb/day), evaluated by wind speed from Table 1	1.0	4.8	3.1	0.32

TABLE 4

TESTS RESULTS USED TO EVALUATE EFFECT OF SEAL LEAK RATE ON EMISSIONS

Pilot Tank Tests	Seal Leak Rate (scfm/ft. dia.)	Results of Regression Analyses K_s	n	Emissions at 2.7 mph Wind Speed (lb/day)
W22, W27	0.0085	1.08	1.27	0.95
W1, W1R, W2, V3	0.032	0.88	1.50	1.005
W11	0.175	0.39	2.03	0.726
W12	0.80	0.92	1.68	1.20
W17	1.50	1.32	1.78	1.93
W13	1.78	2.04	1.56	2.40
W16	2.75	1.20	1.89	1.98
W15	4.5	0.76	2.24	1.80
W14	25.0	2.32	1.89	3.77

Figure 1

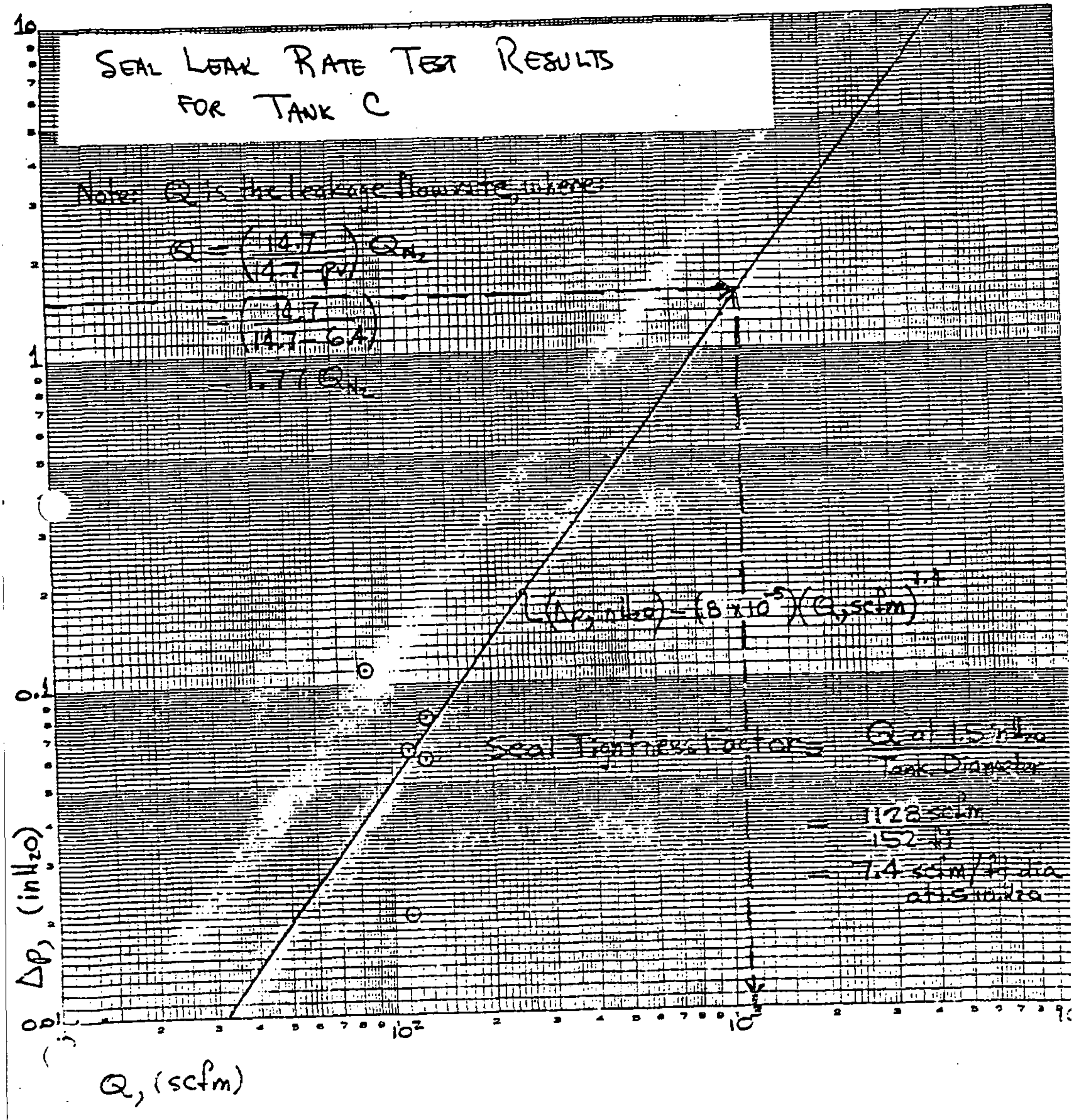
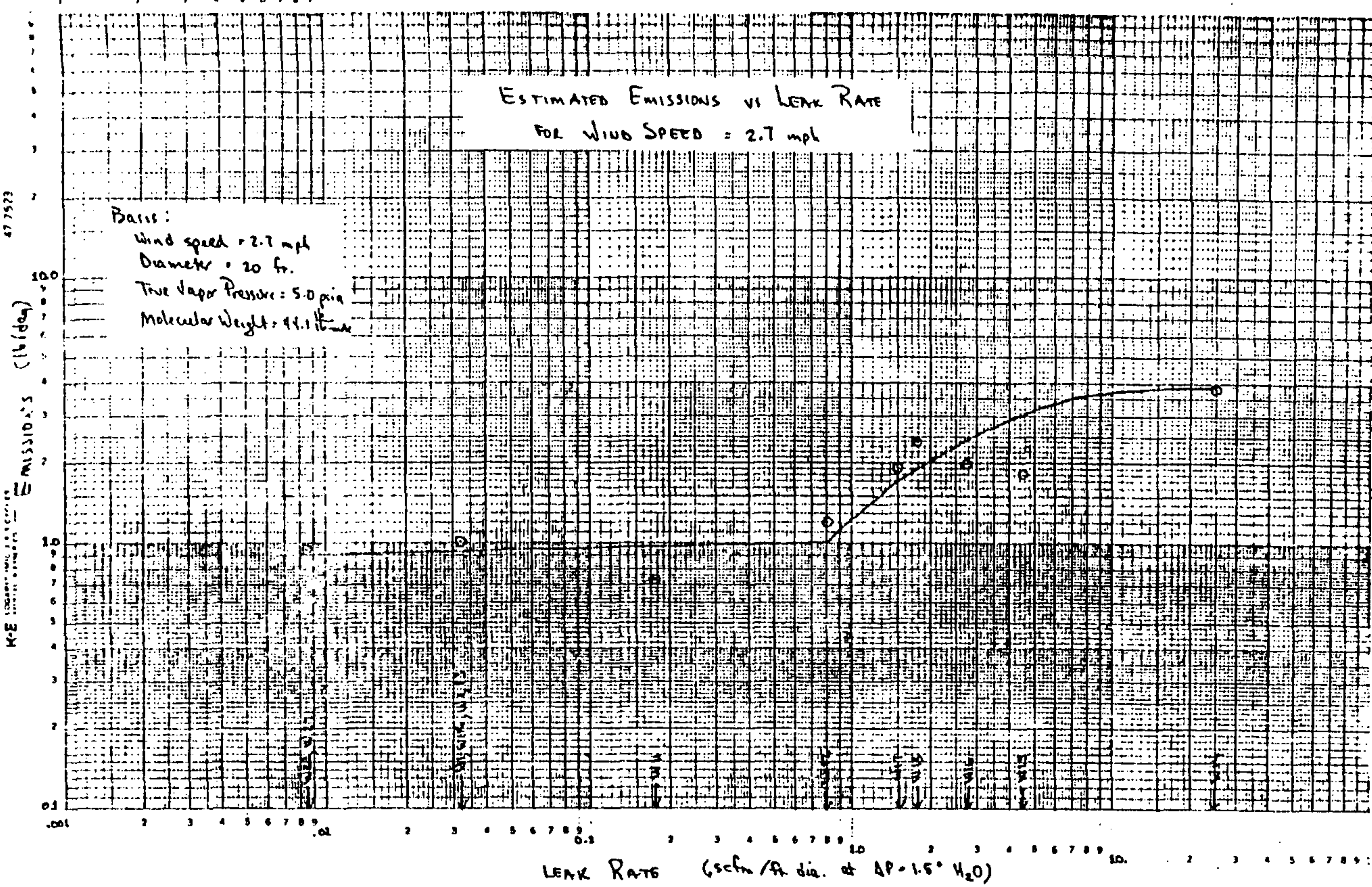

SEAL LEAK RATE TEST RESULTS
FOR TANK C
Note: Q is the leakage flowrate, where:
Q = (14.7 / 14.7 - PV) Q N2
= (14.7 / 14.7 - 6.4)
= 1.77 Q N2
(Δp, inH2O) = (8 x 10-5)(Q, scfm)
Seal Tightness Factor = Q at 1.5 inH2O / Tank Diameter
= 1128 scfm / 152 ft
= 7.4 scfm/ft dia at 1.5 inH2O
Δp, (inH2O)
Q, (scfm)
10
1
0.1
0.01
10²
10³

Fig 2


Estimated Emissions vs Leak Rate
For Wind Speed = 2.7 mph
Basis:
Wind speed = 2.7 mph
Diameter = 20 ft.
True Vapor Pressure = 5.0 psia
Molecular Weight = 44.1 lb/mole
Emissions (lb/day)
Leak Rate (scfm/ft dia. at ΔP = 1.5" H2O)
.001
.01
0.1
1.0
10.
0.1
1.0
10.0
K+E
47 7523

APPENDIX D

DEVELOPMENT OF DIAMETER FUNCTION

The API correlation for estimating evaporative losses from floating-roof tanks in the first edition of Publication 2517 [14] indicates that losses are proportional to diameter raised to the 1.5 power. However, recent aerodynamic studies [16] of wind effects on tank losses concluded that the diameter exponent should be 1 (that is, that losses are directly proportional to tank diameter).

To determine an empirical value for the diameter exponent, test programs were conducted to measure losses from field tanks varying in size from 35 to 152 feet in diameter. The 1977–79 API field test program is summarized in Reference 17; details of the testing format and program results are included in References 18, 19, 20, and 21, and results from a parallel study conducted by an independent investigator are contained in Reference 22.

Losses from the field tanks were determined by the density change method. Increases in stock bulk density were examined in two tanks tested by API [21] and one tank tested independently [22]. The increases in stock density were related to the decrease in stock volume (evaporative loss) [18–21].

Field tank seal conditions were analyzed and compared with the pilot tank data base described in Section 3. Loss predictions for the field tanks were developed from the pilot tank data. These predictions, which incorporated the gasoline stock properties and climatic conditions at the field tanks, were used to evaluate the influence of tank diameter on evaporative loss.

Field tank losses were calculated as a function of a variable exponent of tank diameter. These calculated values were plotted to determine the relationship between loss and diameter exponent, as shown in Figure D-1. Measured losses from the field tests were then compared with the predicted losses. Based on this comparison, a diameter exponent of 1 was established for the loss equation.

Data from a floating-roof tank test program sponsored by the Western Oil and Gas Association (WOGA) in 1976 [23] were evaluated in a similar manner. The WOGA tests involved 13 tanks in gasoline or volatile stock service, in which losses were measured with similar techniques. The WOGA program was the first in which sophisticated density measurement instrumentation was used. Data scatter in this developmental program was higher than in the test programs discussed above. Wind speeds at the tank sites were not measured, and less information about the seal conditions was obtained. Nevertheless, the average diameter exponent developed from the WOGA results supports the conclusion that the diameter exponent in the loss equation is 1.

The mathematical analysis and all supporting data are in the API Documentation File for Appendix D.

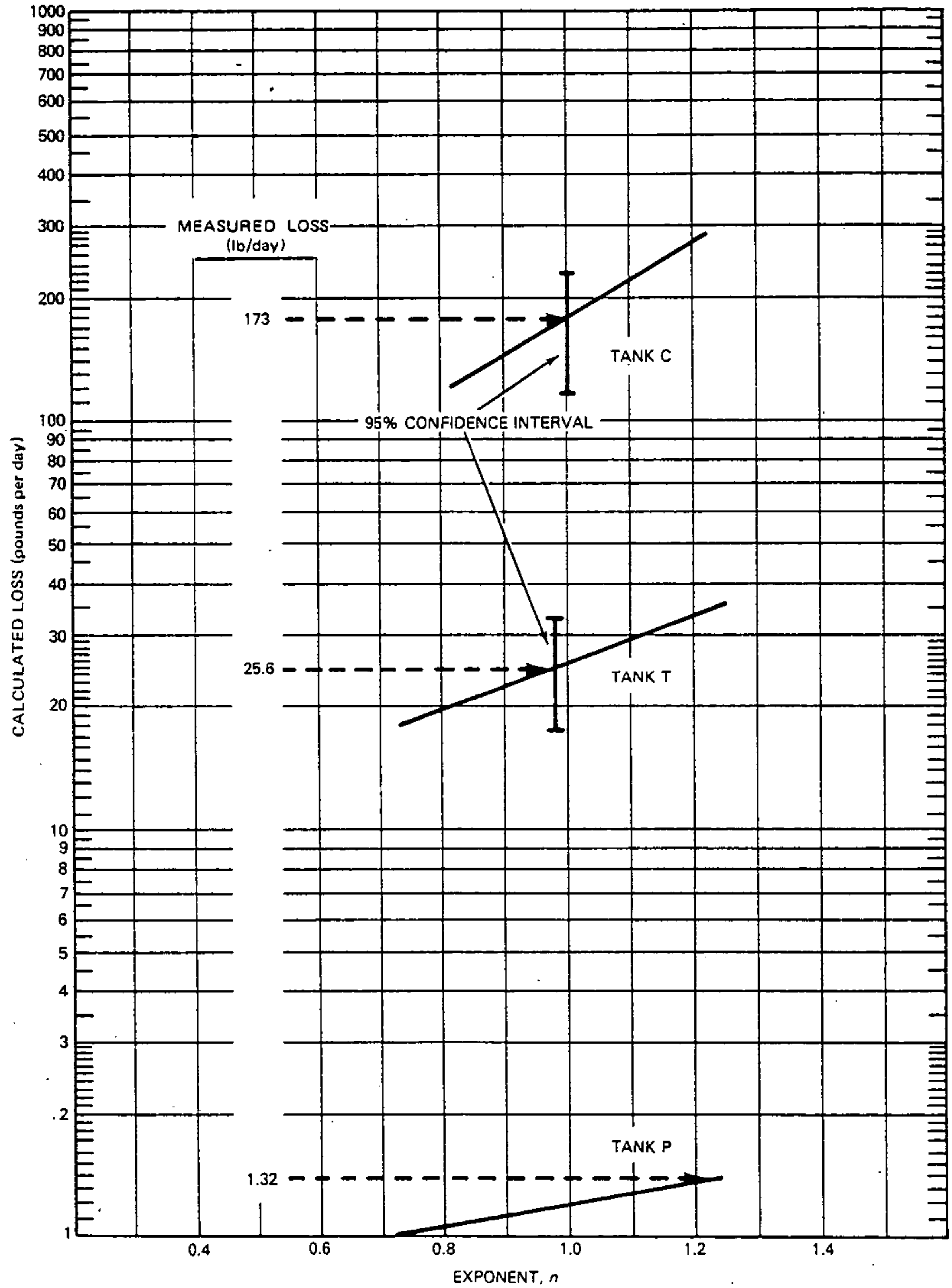


Figure D-1—Calculated Losses as a Function of Diameter Exponent