AP 42 Section 5.2: **Transportation and Marketing of Petroleum Products**

Background Documentation: **Transit Losses from Gasoline Tank Trucks**
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US EPA

FINAL VERSION

BACKGROUND DOCUMENT

TRANSIT LOSSES FROM GASOLINE TANK TRUCKS

1.0 INTRODUCTION

This document pertains only to the emission factors for transit losses from gasoline tank trucks presented in Table 4.4-3 of AP-42 and to the text that deals with these factors. The remainder of Section 4.4 was prepared by others, and the background for their calculations is found elsewhere.

2.0 THEORETICAL CALCULATIONS OF EMISSIONS

A theoretical analysis of truck transit breathing loss was made by Nichols[1] using an isothermal stirred tank as a model. Calculations were made for two situations: (1) where the tank has an open vent, and (2) where the tank has a P/V valve which prevents all venting until the valve opening pressure is reached and allows free venting thereafter.

2.1 TRANSIT WITH FULL FUEL LOADS[1, 2]

For truck transit with a full fuel load from the terminal, venting was assumed to occur until the fuel vapor space was saturated to the fuel vapor pressure. When this state is reached, no further pressure increases occur. The following equation was used to estimate losses from tanks with open vents and full fuel loads:

$$\text{gm/gal transferred} = 0.7057 \frac{V_G}{V_L} P \left[\ln\left(\frac{P - S_1 P_H^\circ}{P - S_2 P_H^\circ} \right) + \frac{P_H^\circ}{P} (S_1 - S_2) \right]$$

where V_G = vapor space volume

V_L = liquid fuel volume (same units as V_G)

P = atmospheric pressure, psia

S_1 = vapor saturation on leaving terminal, fraction of 1.00

S_2 = vapor saturation upon arrival at unloading station, fraction of 1.00

P_H° = fuel vapor pressure, psia

For losses from tanks with P/V valves and full fuel loads, the following equation was used:

$$\text{gm/gal transferred} = 0.7057\ \frac{V_G}{V_L}\ P_v \left[\ln \left(\frac{P_v - S_1^* P_H^\circ}{P_v - S_2^* P_H^\circ} \right) + \frac{P_H^\circ}{P_v} (S_1^* - S_2^*) \right]$$

where symbols are as above and

P_v = vent opening pressure, psia

S_1^* = vapor saturation at the vent opening pressure on leaving terminal, fraction of 1.00

S_2^* = vapor saturation at the vent opening pressure upon arrival at unloading station, fraction of 1.00

The constant of 0.0757 in the equations contains the assumption that the temperature is 74.1°F (534.1°R) and the mole weight of the fuel vapor is 66.7 (lb m/lb mole).

Calculations were made for both situations using the following values. Since no experimental data base was available, a series of values was used for some of the parameters in an effort to cover the entire range of reasonable values.

$\frac{V_G}{V_L}$ = 0.05, 0.10, 0.15

P = 14.7 psia

S_1 = 0, 0.2, 0.5, 0.85, 0.95

S_2 = 1.00

$P_H^\circ = 5.87$ psia

$P_V = 15.675$ psia (27 inches of H_2O)

$S_1^* = 0.1661, 0.3661, 0.6661, 1.00$

$S_2^* = 1.00$

Results are shown on the following page in Table B-1 taken from Reference 1. Calculated losses ranged from 0.0066 to 0.1717 gm/gal (0.015 - 0.379 lb/10^3 gal; 0.002 - 0.045 kg/10^3 liters) for the open vent situation, and from 0 to 0.1538 gm/gal (0 - 0.339 lb/10^3 gal; 0 - 0.041 kg/10^3 liters) for the vent valve situation.

The above calculations are based on the assumption that the tank leaks at a rate sufficient to dissipate all tank pressure during the course of a trip. Some calculations were done using information on typical leak rates available at the time,[2] which indicated that pressure within exceptionally tight tanks may not be dissipated in a 60 minute trip, although it usually is.

2.2 TRANSIST WITH VAPOR LOADS (RETURN TRIP)[1]

Theoretical values for maximum emissions were calculated by assuming that the residual fuel present in the tank after the load is delivered vaporizes immediately and so causes vapor venting from the tank at the highest initial tank pressure. The amount of vapor lost depends on the rate of leakage of the tank, which in turn determines the residual pressure in the tank when it reaches the refueling terminal. For trips of sufficient duration to permit maximum dissipation of pressure, venting losses can be calculated using the same equations that were applied to the full load case described in Section 2.1. Since no experimental data base was available, a series of values was used for each parameter in an effort to cover the entire range of reasonable values.

TABLE B.1 VENT LOSS AFTER REFUELING

OPEN VENT CALCULATION						
P = 14.7	S_1 =	0.	.2	.5	.85	.95
	V_V/V_G	.5097	.4265	.2870	.0951	.0327
GM/GAL VENTED	V_G/V_L = 0.05	.0572	.0555	.0453	.0182	.0066
	V_G/V_L = 0.10	.1145	.1110	.0906	.0365	.0132
	V_G/V_L = 0.15	.1717	.1665	.1359	.0547	.0198
IDEAL 27 IN. H_2O VENT CALCULATION						
P = 15.675	S_1^* =	.1661	.3661	.6661		
	V_V/V_G	.4050	.3217	.1822		
GM/GAL VENTED	V_G/V_L = 0.05	.0513	.0466	.0316		
	V_G/V_L = 0.10	.1025	.0933	.0633		
	V_G/V_L = 0.15	.1538	.1399	.0949		

$\frac{V_G}{V_L}$ = 1.05, 1.10, 1.15

P = 14.7 psia

S_1 = 0, 0.3261, 0.7065, 0.8152

S_2 = 0.200, 0.500, 0.850, 0.950

P_H° = 5.87 psia

P_v = 15.675 psia (27 inches of H_2O)

S_1^* = 0.1661, 0.4922, 0.8726, 0.9813

S_2^* = 0.2055, 0.5265, 0.9099, 1.000

Results are shown on the following page in Table B-2 taken from Reference 1. Venting losses ranged from 0.037 to 0.350 gm/gal (0.082 - 0.772 lb/10^3 gal; 0.010 - 0.093 kg/10^3 liters) for the open vent situation, and from 0.013 to 0.067 gm/gal (0.029 - 0.148 lb/10^3 gal; 0.003 - 0.018 kg/10^3 liters) for the vent valve situation.

In situations where residual pressure still remains in the tank, losses can be calculated from the following equation:

$$\text{gm/gal transferred} = 4.142\ (S_2^*)\ \frac{(P_v - P_R)}{P_v}\ \frac{(V_G)}{V_L}$$

where symbols are as previously defined and

P_R = residual tank pressure, psia

The constant of 4.142 contains the assumption that P_H° = 5.87 psia, M_H = 66.7 lb m/lb mole, and T = 74.1°F.

Since no experimental measurements of P_R were available, calculations were made for a wide range of theoretically possible values. Using the following values, losses were calculated from the above equation:

TABLE B.2 VENT LOSS AFTER FUEL DROP

OPEN VENT LOSS					
$P = 14.7$	$S_1 =$	.0	.3261	.7065	.8152
	$S_2 =$	.2	.5000	.8500	.9500
	$V_V/V_G =$	.0832	.0832	.0832	.0832
GM/GAL VENTED	$V_G/V_L = 1.05$	.0367	.1499	.2820	.3197
GM/GAL VENTED	$V_G/V_L = 1.10$	.0385	.1571	.2954	.3350
GM/GAL VENTED	$V_G/V_L = 1.15$	.0402	.1642	.3088	.3502
IDEAL 27 IN. H_2O VENT LOSS					
	$S_1 =$	.0000	.3261	.7065	.8152
	$S_1^* =$	.1661	.4922	.8726	.9813
	$S_2^* =$	.2055	.5265	.9009	1.000
	$V_V/V_G =$	.0159	.0159	.0159	.0112
GM/GAL VENTED	$V_G/V_L = 1.05$	.0128	.0351	.0612	.0481
GM/GAL VENTED	$V_G/V_L = 1.10$	.0134	.0368	.0641	.0504
GM/GAL VENTED	$V_G/V_L = 1.15$	.0140	.0385	.0670	.0527

$S_2^* = 1.00, 0.9009, 0.5265, 0.2055$

$P_v = 15.675$ psia (27 inches of H_2O)

P_R = 20 different values ranging from 14.7 to 15.58 psia (0.0 to 21.6 inches of H_2O)

$\frac{V_G}{V_L} = 1.05, 1.10, 1.15$

Results are shown on the following page in Table B.7 taken from Reference 1. Losses ranged from 0.011 to 0.296 gm/gal (0.024 - 0.653 lb/10^3 gal; 0.0031 - 0.078 kg/10^3 liters).

3.0 MODIFIED CALCULATIONS BASED ON EXPERIMENTAL DATA[1, 3, 4]

The theoretical calculations above covered the entire range of values for most of the parameters for which no field measurements had been made (S_1, S_2, S_1^*, S_2^*, P_v, and P_R). Subsequently, experiments were conducted to determine where typical values lay within the range of values considered theoretically. Pressure measurements were made on tank trucks while they were filled with fuel and in transit. Pressures varied widely and frequently were negative because air, originally present in the vapor space, dissolved in the freshly charged fuel. This situation is apparently typical of fuel that has been stored in floating roof tanks and is not saturated with air.

In addition, vent valves were shown to open partially rather than fully at the valve opening pressure. Vapors in tanks were found to be somewhat less than saturated (71 to 96 percent) instead of 100 percent saturated, as originally assumed, when a value of 1.00 was chosen for S_2^* in the computations shown in Table B-1 from Reference 1. Moreover, truck leakage rates were shown to be

TABLE B.7 BLOWDOWN LOSS FOR VARIOUS FUEL DROP VENT SPACE AND TANK LEAKAGE SITUATIONS

	$S_2^* = 1.0$					
P_R IN. H_2O	0.0	1.54	6.69	15.23	20.72	
GM/GAL VENTED $V_G/V_L = 1.05$	.2706	.2552	.2035	.1180	.0629	
GM/GAL VENTED $V_G/V_L = 1.10$	.2835	.2673	.2132	.1236	.0659	
GM/GAL VENTED $V_G/V_L = 1.15$	.2964	.2795	.2229	.1292	.0689	
	$S_2^* = .9009$					
ΔP_R IN. H_2O	0.0	1.8	7.12	15.35	20.75	
GM/GAL VENTED $V_G/V_L = 1.05$	.2438	.2275	.1795	.1052	.0564	
GM/GAL VENTED $V_G/V_L = 1.10$	.2554	.2384	.1880	.1102	.0591	
GM/GAL VENTED $V_G/V_L = 1.15$	.2670	.2492	.1966	.1152	.0618	
	$S_2^* = .5265$					
ΔP_R IN. H_2O	0.0	2.2	7.2	15.7	21.0	
GM/GAL VENTED $V_G/V_L = 1.05$	.1425	.1309	.1045	.0596	.0317	
GM/GAL VENTED $V_G/V_L = 1.10$	.1492	.1371	.1094	.0625	.0332	
GM/GAL VENTED $V_G/V_L = 1.15$	.1560	.1433	.1144	.0653	.0347	
	$S_2^* = .2055$					
ΔP_R IN H_2O	0.45	3.45	7.46	16.7	21.6	0.0
GM/GAL VENTED $V_G/V_L = 1.05$	.0547	.0485	.0402	.0212	.0111	.0556
GM/GAL VENTED $V_G/V_L = 1.10$	.0573	.0508	.0422	.0222	.0117	.0583
GM/GAL VENTED $V_G/V_L = 1.15$	.0599	.0531	.0441	.0232	.0122	.0609

much lower than previously supposed--possibly as little as 5 percent of the rates used in the theoretical calculations.

Based on all these findings--specifically, a tank pressure (P_V) of 14.81 psia (3 inches of H_2O), leakage that persisted for 5 minutes before the tank pressure became negative, and a leak rate of 5 percent of that used previously--the authors of Reference 3 estimated that losses from transit with full loads are 0 - 0.035 gm/gal (0 - 0.077 $lb/10^3$ gal; 0 - 0.009 $kg/10^3$ liters) rather than the 0 - 0.0172 gm/gal that was computed theoretically. These calculations were performed using a computer program that employs the same fundamental equations given in Sections 2.1 and 2.2 and also considers leakage rates expressed as equivalent orifice diameters. A complete explanation is given in References 1 and 3. A summary of the results is shown in Table 1, taken from a June 10, 1977 letter from R.A. Nichols to H.B.Uhlig of Chevron USA, Inc., San Francisco, California.[4]

Experimental tests showed that the degree of saturation of vapors in empty tankers returning to be refilled was lower than previously estimated. A value for S_2^* of 0.10 was selected by the authors of Reference 3 as more representative than the values used in the theoretical calculations. The lower tank leakage rates also reduced the losses as compared with the original estimates. A range of values from 0 to 0.166 gm/gal (0 - 0.366 $lb/10^3$ gal; 0 - 0.044 $kg/10^3$ liters) was selected rather than the 0.011 - 0.350 gm/gal estimated from the theoretical analysis.

No experiments have been attempted for the purpose of monitoring the actual hydrocarbon emissions from tank trucks as they are in transit. The losses are so small that they could not be detected by weighing (or otherwise measuring) the load at the start and end of each run. Experiments have been designed to provide values for the various parameters used to compute losses from well established theoretical principles, however.

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Table 1. TRUCK TRANSIT AND TRANSFER LEAKAGE LOSS

ΔP Loss In. H_2O	Leak Dia 5000 Gal In. O	Terminal Loss Gm/Gal	Terminal Vapor Vol%Loss	Liquid Trans. Loss Gm/Gal	Vapor Trans. Loss Gm/Gal	Loss S.S. Stage I Gm/Gal	S.S. Stage I Vol%Loss	TotLoss w/oStg I Gm/Gal	TotLoss w/stg I Gm/Gal.
0	0	0	0	0	0	.0911	2.20	0	.0911
0.5	.0528	.0002	.0037	.0001	.0016	.0915	2.21	.0019	.0934
1	.0749	.0003	.0076	.0002	.0032	.0924	2.23	.0037	.0961
2	.107	.0006	.0155	.0004	.0065	.0961	2.32	.0075	.1036
3	.131	.0010	.0232	.0006	.0097	.0994	2.40	.0113	.1107
4	.153	.0013	.0316	.0008	.0132	.1019	2.46	.0153	.1172
	.200	.0022	.0537	.0013	.0226	.1110	2.68	.0261	.1371
	.250	.0035	.0840	.0021	.0354	.1267	3.06	.0410	.1677
	.300	.0050	.1210	.0030	.0509	.1400	3.38	.0589	.1989
	.400	.0089	.2150	.0053	(.0828 .0905)	.1802	4.35	(.0970 .1047)	(.2772 .2849)
	.500	.0139	.3358	.0083	(.0828 .1415)	.2278	5.50	(.1051 .1637)	(.3328 .3915)
		ΔP = 6"		ΔP=3"H_2O	ΔP=6"H_2O				
		Q_L =600gpm		t=5min	t=60 min				
				Max*=.0351	Max*=.0828 .1657				

* Leakage rate is such that maximum losses occur.

REFERENCES

1. Nichols, R.A., "Analytical Calculation of Fuel Transit Breathing Loss." Prepared by R.A. Nichols Engineering, Corona del Mar, Ca., for Chevron USA, Inc., San Francisco, Ca., March 21, 1977.

2. California Air Resources Board (CARB), "Delivery Tank Field Results." Attachment 2 to Staff Report 77-5-1, March 15, 1977.

3. Nichols, R.A., "Tank Truck Leakage Measurements." Prepared by R.A. Nichols Engineering, Corona del Mar, Ca., for Chevron USA, Inc., San Francisco, Ca., June 7, 1977.

4. Private correspondence from R.A. Nichols of R.A. Nichols Engineering, Corona del Mar, Ca., to H.B. Uhlig of Chevron USA, Inc., San Francisco, Ca., June 10, 1977.