SECTION 4.7

OIL AND GAS PRODUCTION
CRUDE OIL PRODUCTION TANKS

(New - November 1986; Updated - September 1989)

EMISSION INVENTORY SOURCE CATEGORY
Petroleum Processing, Storage, and Transfer

EMISSION INVENTORY CODES (CES CODES) AND DESCRIPTION
310-995-1600-0000 (46458) Crude Oil Production - Tanks

METHODS AND SOURCES

The above category is used to inventory the total organic gas (TOG) and reactive organic gas (ROG) emissions from both open top and fixed roof tanks associated with oil production operations.

The information which was used to calculate tank emissions was obtained from the results of an oil production tank questionnaire developed by a group of representatives from oil production companies, air pollution control districts, and the State of California Air Resources Board. Distributed throughout Kern County in May 1984, and in other counties at a subsequently later date, this questionnaire was designed to obtain the most current data on the physical parameters of tanks used in oil production operations throughout California.

The methods used for calculating tank emissions come from the U. S. Environmental Protection Agency's AP-42 Manual.[1] In this manual, equations are developed to calculate emissions for fixed roof tanks. By assuming that open top tanks and tanks with open holes or roof openings do not have emissions greater than those for fixed roof tanks, the ARB was able to use the AP-42 equations to calculate emissions for all tanks storing crude oil in oil production fields.

The two major sources of emissions from fixed roof tanks are classified as occurring from either breathing losses or working losses. The term breathing loss refers to those emissions that result without any corresponding change in the liquid level within the tank. Most likely, these types of emissions result from hydrocarbon vapors that are released from the tank by expansion or contraction caused by changes in either temperature or pressure. Working loss, on the other hand, represents those emissions that occur due to changes in the liquid level caused by either filling or emptying the tank itself.

Detailed equations have been derived for both classifications of tank emissions. Fixed roof tank breathing losses can be calculated from the following equation: [2]

$$L_B = (2.26 \times 10^{-2}) M_V D^{1.73} H^{0.51} \Delta T^{0.50} F_P C K_C \left[\frac{TVP}{(P_A - TVP)}\right]^{0.68}$$

where:

L_B = fixed roof breathing loss (lb/yr)
M_V = molecular weight of vapor in the storage tank (lb/lb-mole)
D = tank diameter (feet)
H = average vapor space height (feet)
ΔT = average ambient diurnal temperature change (^{O}F)
F_P = paint factor (dimensionless)
C = adjustment factor for small diameter tanks (dimensionless)
K_C = product factor (dimensionless)
P_A = average atmospheric pressure at tank location (psia)
TVP = true vapor pressure at bulk liquid conditions (psia)

Slight modifications were made to the above equation by the ARB in order to more accurately reflect actual conditions as they exist in the field. The AP-42 equation does not take into account any possible control measures that might be placed on the tanks in order to reduce emissions. Realizing that such measures are common place throughout California, the ARB added a control term to the emissions calculation equation and assigned appropriate values for each type of control. Also, in order to simplify the emission calculation process, three variable terms in the AP-42 equation were assigned constant values in the revised ARB equation. Reflecting typical California data, the molecular weight of all hydrocarbon vapors (M_V) was assumed to be 60 lbs/lb-mole, the diurnal temperature change (ΔT) was assigned a value of 25^O F, while the atmospheric pressure term (P_A) was set equal to 14.7 psia. The resulting equation, as used in the ARB emissions calculation program, can be expressed as follows:

$$L_B = (6.78)(CONTROL)\, D^{1.23} H^{0.51} F_P C K_C \left[\frac{TVP}{(14.7 - TVP)}\right]^{0.68}$$

What follows is a detailed explanation of the methods used to calculate values for each of the terms remaining in the breathing loss equation.

<u>Tank Diameter (D)</u>:

The tank diameter is supplied by the companies on the survey forms submitted to the ARB. For round tanks the diameter is recorded in feet. For rectangular tanks, the equivalent diameter (in feet) is found by applying the following equation:

Equivalent Diameter = $(1.13)(\text{length x width})^{0.50}$

If the diameter as reported on the survey forms equals zero, then the corresponding breathing loss emissions are also equal to zero.

Average Vapor Space Height (H):

The average vapor space height refers to the typical height of hydrocarbon vapor that is in a tank. It is calculated by the application of the following equation:

$$H = (7.16)(\text{Capacity})/(\text{Diameter})^2 - (\text{Min} + \text{Max})/2$$

where:

Capacity = total tank capacity (barrels)
Min = minimum liquid level to which the tank is normally drawn down (feet)
Max = maximum liquid level to which the tank is normally filled (feet)

If the capacity as supplied on the tank survey form is equal to zero, or the calculated average vapor space height value is less than zero, then the breathing loss emissions are assumed to be negligible.

Paint Factor (F_p):

Vapor emissions from tanks have been found to be dependent upon the tank color, the condition of the paint itself, and whether or not there is any insulation present. The paint factor is the term that takes into account the effects that these three variables have on overall breathing loss emissions. Values of the paint factor for different conditions are tabulated below:

	CONDITION OF PAINT/PAINT FACTOR	
TANK COLOR	GOOD/F_p	POOR/F_p
Insulated Tank*	1.00*	1.15*
White	1.00	1.15
Aluminum	1.30	1.38
Black	1.50	1.50
Brown	1.45	1.45
Grey	1.30	1.38
Green	1.30	1.38
Tan	1.30	1.38
Yellow	1.20	1.25

* The values of F_p for an insulated tank are assumed to be the same as a white tank.

Adjustment Factor for Small Diameter Tanks (C):

Tank emissions have also been found to be dependent upon the size of the tank diameter, with smaller diameter tanks emitting proportionally less pollution than larger diameter ones. The breakpoint between small and large diameter tanks was set at 30 feet. At values greater than or equal to 30 feet the emissions were considered to be independent of tank diameter and the adjustment factor was set equal to 1.00. If the tank diameter was less than 30 feet, the following equation was applied to calculate the adjustment factor:

$$C = (0.0771)(\text{DIAMETER}) - (0.0013)(\text{DIAMETER})^2 - 0.1334$$

Product Factor (K_C):

It has also been determined that emissions are dependent upon the physical and chemical properties of the substance being stored in the tank itself. If the stored liquid was crude oil or wastewater (separated from crude), then $K_C = 0.65$. For any other type of liquid, $K_C = 1.00$.

Control Factor (CONTROL):

Certain types of control measures have been devised which considerably reduce theoretical tank emissions. To quantify the corresponding emissions reductions that result from the implementation of these measures, control factor terms have been developed. These terms are applied directly to the emission calculation equations in order to obtain correctly reduced emission estimates. The table below lists the seven possible types of tanks found in the tank survey along with their corresponding control factors. A control factor of 1.00 means that no emissions reductions are achieved by the use of this type of tank.

TANK TYPE	CONTROL FACTOR
1. Open top tank (no fixed or floating roof)	1.00
2. Fixed roof tank with roof openings (open vents, holes), but no vapor controls	1.00
3. Fixed roof tank with functional p.v. valve on the roof, but no open vents and no vapor controls	1.00
4. Fixed roof tank with internal floating roof	0.05
5. Fixed roof tank with vapor balance type emission control system	0.01
6. Fixed roof tank with compression, refrigeration or combustion type vapor control or recovery system	0.02
7. External floating roof tank	0.05

True Vapor Pressure (TVP):

True vapor pressure (TVP), the equilibrium partial pressure exerted by a volatile liquid, is perhaps the most difficult term in the breathing loss equation to calculate. A nomograph has been devised which relates TVP to both the reid vapor pressure (RVP) and the storage temperature (T_S).[2] From the survey forms, the RVP is the absolute vapor pressure of volatile crude oil and nonviscous petroleum liquids. Numerically, the relationship between TVP, RVP and temperature can be expressed by the following equation:

$$TVP = (RVP)e^{[C_O(IRTEMP - ITEMP)]}$$

where:

C_O	=	constant dependent upon the value of RVP
IRTEMP	=	$(1/(T_S + 459.69^O R))$
T_S	=	temperature of the stored liquid
ITEMP	=	$(1/559.69^O /R)$

The first step in calculating a value for the TVP involves determining the corresponding RVP term. In most cases, the value of the RVP was taken directly from the completed survey forms. If no RVP values for a specific tank were supplied by the companies, then other tanks on the same lease were first examined to see if they had RVP values reported for them. If so, then the average of these lease-wide values was used for the missing RVP value. The reasoning behind this decision is the belief that crude oil from the same lease and field should have roughly the same chemical properties. If no RVP values were supplied for an entire lease, then county-wide RVP numbers were used. Low, middle and high RVP values were chosen based upon typical county data. From these numbers, three corresponding values of TVP and breathing loss were calculated. The breathing loss emissions as entered into the data base were the arithmetic mean of the three calculated breathing loss numbers.

It is also necessary to determine the storage temperature of the liquid within the tank. Supplied by the companies on the survey forms, a valid range for this value was established between 90^OF and 140^OF. If the reported temperature was below this range, it was raised to 90^OF for calculation purposes, while on the other hand, if the reported value was above the acceptable range, it was lowered to 140^OF. If no temperature value was supplied on the survey forms, the ARB assigned a default temperature of 90^OF.

The value of the constant term C_O is dependent upon the given value of RVP. Values of C_O for different RVP numbers are tabulated below.

RVP	C_O
0<RVP<2	-6622.5
2<RVPA3	-6439.2
RVP = 3	-6255.9
3<RVP<4	-6212.1
RVP = 4	-6169.2
4<RVP<5	-6177.9
RVP = 5	-6186.5
5<RVP<6	-6220.4
RVP = 6	-6254.3
6<RVP<7	-6182.1
RVP = 7	-6109.8
7<RVP<8	-6238.9
RVP = 8	-6367.9
8<RVP<9	-6477.5
RVP = 9	-6587.0
9<RVP<10	-6910.5
RVP = 10	-7234.0
10<RVP<15	-8178.0
RVP > 15	-9123.2

Once C_O , T_S , and RVP have been determined, one is technically able to calculate a value for TVP. It should be noted, however, that an error was discovered in the API nomograph calculated values of TVP, such that the RVP was not equal to the TVP at 100^{O}F as should be expected, given the general definition of RVP. Through linear regression techniques, correction factors (C_F) were developed which should be added to the calculated values of TVP in order to obtain correct TVP numbers. The relation among the three values is given as follows:

$$\text{Corrected TVP} = \text{Calculated TVP} + C_F$$

The correction factor was found to be dependent upon RVP according to the following equations:

If RVP < 3: $C_F = (0.04)\,(RVP) + 0.1$

If RVP > 3: $C_F = e^{[(2.345206 \log (RVP)) - 4.132622]}$

<u>Additional Factors to be Considered in the Calculation of TVP:</u>

Some further modifications to the data were made for those cases where RVP values were supplied by the companies. These procedures were designed to correct those calculated TVP values that appeared to be slightly out of range. The changes to be made were broken down into classifications as follows:

CASE 1: The supplied RVP and temperature values were within the API nomograph ranges of 2-15 psi and 0-140^{O} F, respectively.

a) If the TVP as calculated by the algorithm was less than 14.7 psi, then this value was used in any further calculations.

b) If the TVP as calculated by the algorithm was greater than or equal to 14.7 psi, then the value of TVP was set equal to 7.0 psi.

CASE 2: The supplied RVP values are outside the API nomograph range of 2-15 psi and 0-140^{O}F respectively.

a) If the API gravity of the lease as reported on the 1982 DOG tape was less than 30 and the algorithm calculated TVP was greater than 3.5 psi, then the TVP was set equal to 3.5 psi.

b) If the API gravity of the lease as reported on the 1982 DOG tape was greater than or equal to 30 and the algorithm calculated TVP was greater than 7.0 psi, then the TVP was set equal to 7.0 psi.

Once the TVP had been determined, it was possible to solve for the breathing loss emissions, leaving only working loss emissions yet to be found. Fixed roof working losses can be calculated from the following equation[2]:

$$L_W = 2.40 \times 10^{-5} M_V (TVP) V N K_N K_C$$

where:

L_W = fixed roof working loss (lb/yr)
M_V = molecular weight of vapor in storage tank (lb/lb-mole)
TVP = True vapor pressure at bulk liquid temperature (psia)
V = tank capacity (gallons)
N = number of turnovers per year (dimensionless)
N = total annual throughput (gal)/tank capacity (gal)
K_N = turnover factor (dimensionless)
K_C = product factor (dimensionless)

Again, modifications were made to the above equation in order to more accurately reflect actual conditions as they exist in the field. The above AP-42 equation does not take into account any possible control measures that might be placed on the tanks in order to reduce emissions. Realizing that such measures are commonplace throughout California, the ARB added a control term to the emissions calculation equation and assigned appropriate values for each type of control. As in the breathing loss equation, the molecular weight of all hydrocarbon vapors (M_V) was assigned a value of 60 lbs/lb-mole. Also, the tank capacity (V) and number of turnovers per year (N) were combined together in order to obtain one variable entitled "total throughput per year" (THR). This variable was expressed in units of barrels due to the fact that oil industry sources generally report tank throughput and capacity values in these units rather than in gallons. The constant term at the beginning of the equation also had to be modified to reflect this change in units. The resulting working loss equation, as used in the ARB's emissions algorithm, can be expressed as follows:

$$L_W = (0.001)(60)(TVP)(THR)\ K_C\ K_N\ (CONTROL)$$

What follows is a detailed explanation of the methods used to calculate values for each of the terms in the working loss equation.

Throughput (THR):

The throughput is the average amount of both oil and water that are pumped through the tank in units of barrels per year. If no water enters or exits a particular tank, then the throughput is simply equal to the flow rate of oil in the tank.

If the throughput as reported on the survey forms equaled zero, then the corresponding working loss emissions were also set equal to zero. If no value of throughput was supplied on the survey forms, then the following methods were used to determine an appropriate value. If the company reported throughput values for other tanks on the same lease, then the average of these values was used. On the other hand, if the company did not report throughput values for any tank on a particular lease, then throughput values as reported on the 1982 DOG tape were averaged between the number of tanks on a lease and a given tank throughput number was calculated.

Product Factor (K_C):

It has also been determined that working loss emissions are dependent upon the physical and chemical properties of the material being stored in the tank itself. If the stored liquid was crude oil or wastewater (separated from crude), then $K_C = 0.84$. For any other type of liquid, $K_C = 1.00$.

Turnover Factor (K_N):

Working loss emissions have also been found to be dependent upon the turnover of the liquid within the tank. The turnover (N) is defined as being the annual throughput divided by the tank capacity. The turnover factor is a function of the yearly turnover according to the following relationship:

If $N < 36$ then $K_N = 1$

If $N > 36$ then $K_N = (180 + N)/6N$

True Vapor Pressure (TVP):

The methods used to calculate true vapor pressure have already been documented in the section on breathing loss emissions.

At this point, all the remaining variables in the working loss equation have been determined and it is now possible to calculate working loss emissions. Also, total tank emissions can now be evaluated as the sum of both the breathing loss and working loss emissions. Table 1 lists the total 1983 tank emissions broken down by county.

ASSUMPTIONS

Overall

1. AP-42 equations for fixed roof tank breathing and working losses are valid for all tanks storing crude oil in California.

2. There are no flashing losses from crude oil production tanks.

3. Open top tanks and tanks with holes or roof openings do not have emissions larger than the emissions calculated using AP-42 equations.

4. Crude oil from the same leases and fields have similar chemical properties.

Specific

1. The molecular weight of the hydrocarbon vapors in the tanks is 60 lbs/lb-mole.

2. The diurnal temperature change is 25^{O} F.

3. The average atmospheric pressure at the tank is equal to 14.7 psia.

4. If either the tank capacity or the tank diameter as reported on the survey forms were equal to zero, then the breathing loss emissions were set equal to zero.

5. If the value of the throughput as reported on the survey forms was set equal to zero, then the corresponding working loss emissions were also equal to zero.

6. It is assumed that an insulated tank will have emissions less than or equal to a white colored tank; therefore, we assigned the value of F_P for a white colored tank to the insulated tank.

COMMENTS AND RECOMMENDATIONS

Additional follow up of the incomplete surveys would have given a more accurate estimate of tank emissions. A new tank survey should be done for the next emission inventory. Also, the paint factor table for F_P values needs to be updated with an accurate value for insulated tanks.

CHANGES IN METHODOLOGY

In 1983 and 1987, the emissions from crude oil storage tanks were calculated by the ARB using AP-42 equations for fixed roof tank breathing and working losses. The physical and chemical properties of the tanks were obtained from the results of a survey sent to oil production companies in 1984. In 1987 the paint factor was changed for insulated tanks from zero to one.

DIFFERENCES BETWEEN 1983 AND 1987 EMISSION ESTIMATES

The 1987 emission inventory for tanks takes the data from the tank surveys and grows them to 1987. The paint factor for insulated tanks was changed between 1983 and 1987 which should reflect a small change in emissions.

TEMPORAL ACTIVITY

The emissions from storage tanks used in oil production operations are the result of expulsion of vapors into the atmosphere. The annual activity occurs primarily during the late spring, summer and early fall. Emissions are independent of weekly activity, although the daily activity occurs mostly during the daylight hours.

SAMPLE CALCULATIONS

The following example shows the calculation of fixed roof tank emissions for a hypothetical tank located in California. It has been classified as a fixed roof tank with an internal floating roof. It is painted green and is considered to be in relatively good condition. The tank contains only crude oil stored at a temperature of 95^{O} F and an RVP of 4.5 psi. The tank is 100 feet in diameter and is 50 feet tall, although it is never filled above 40 feet nor drawn below 10 feet. The tank's capacity is roughly 70,000 barrels with an annual throughput of 825,000 barrels.

Breathing Loss: Breathing loss emissions can be calculated according to the following equation:

$$L_B = (6.78)(CONTROL)\, D^{1.73}\; H^{0.51}\, F_P\; C\, K_C \left[\frac{TVP}{(14.7 - TVP)}\right]^{0.68}$$

where:

CONTROL = 0.05 (fixed roof tank with internal floating roof)

D = 100 feet (given)

$$H = \frac{7.16(Capacity)}{(DIAMETER)^2} - \frac{(MIN + MAX)}{2}$$

$$= \frac{7.16(70{,}000)}{(100)^2} - \frac{(\ 40 + 10\ )}{2}$$

= 25.1 feet

F_P = 1.30 (green tank in good condition)

C = 1.00 (tank diameter is greater than 30 feet)

K_C = 0.65 (the stored liquid is crude oil)

TVP = Calculated TVP + Correction Factor (C_F)

$TVP_{Calc} = 4.5e^{[-6177.9\ (1/559.69\ -\ 1/(95\ +\ 459.69))]}$

= 4.97 psia

$C_F = e^{[(2.345206\log(4.5))\ -\ 4.132622]}$

= 0.07 psia

TVP = 4.97 + 0.07

= 5.04 psia

$$L_B = (6.78)(0.05)(100)^{1.73}(25.1)^{0.51}(1.30)(1.00)(0.65)\left[\frac{5.04}{14.7-5.04}\right]^{0.68}$$

L_B = 2,746 lbs/year x 1 ton/2,000 lbs

L_B = 1.37 tons/year

Working Loss: Working loss emissions can be calculated according to the following equation:

$$L_W = (0.001)(60)(TVP)(THR)\ K_C\ K_N\ (CONTROL)$$

where:

CONTROL = 0.05 (fixed roof tank with internal floating roof)

TVP = 5.04 psia (from breathing loss equation)

K_C = 0.84 (the stored liquid is crude oil)

THR = 825,000 barrels/year (given)

K_N = 1.00 [Turnover (N) = 825,000/70,000 = 11.8
Since $N < 36$ K = 1.00

L_W = (0.001)(60)(5.04)(825,000)(0.84)(1.00)(0.05)

L_W = 10,478 lbs/year x 1 ton/2,000 lbs

L_W = 5.24 tons/year

Total Tank Emissions:

Total Emissions = Breathing Loss Emissions + Working Loss Emissions
= 1.37 tons/year + 5.24 tons/year
= 6.61 tons/year

REFERENCES

1. U. S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, AP-42, Section 4.3, 4th Edition.

2. Background Documentation for Storage of Organic Liquids, EPA Contract NO. 68-02-3174, TRW Environmental, Inc., Research Triangle Park, NC, (May 1981).

PREPARED BY

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Table I
1987 Area Source Emissions
Activity: Oil & Gas Extraction
Process: Tanks
Entrainment: Crude Petro-Evap
Dimn: Fugitive Tank
CES: 46458
Process Rate Unit: 1000 Barrels Produced

AB	County	Process Rate	TOG Emis. (Tons / Year)	CO Emis. (Tons / Year)	NOX Emis. (Tons / Year)	SOX Emis. (Tons / Year)	PM Emis. (Tons / Year)
NCC	MONTEREY	9987	100.20	0.00	0.00	0.00	0.00
SC	LOS ANGELES	289320	1423.30	0.00	0.00	0.00	0.00
	ORANGE	186060	916.60	0.00	0.00	0.00	0.00
	SAN BERNARDINO	0	.00	0.00	0.00	0.00	0.00
SCC	SAN LUIS OBISPO	8791	39.60	0.00	0.00	0.00	0.00
	SANTA BARBARA	0	.00	0.00	0.00	0.00	0.00
SF	SONOMA	37	.36	0.00	0.00	0.00	0.00
SJV	FRESNO	49801	1301.40	0.00	0.00	0.00	0.00
	KERN	45664976	56942.70	0.00	0.00	0.00	0.00
	KINGS	0	.00	0.00	0.00	0.00	0.00
TOTAL		46208972	60724.16	0.00	0.00	0.00	0.00

Fraction of Reactive Organic Gases (FROG): .7000
(Reactive Organic Gases (ROG) Emissions = TOG X FROG)
Fraction of PM10 (FRPM10): .9600
(PM10 Emissions = PM X FRPM10)