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ERRATUM

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Documentation File for API Manual of Petroleum Measurement Standards Chapter 19.1—Evaporative Loss From Fixed Roof Tanks [API Bulletin 2518]

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API PUBLICATION 2518 DOCUMENTATION FILE

INTRODUCTION

This document is the Documentation File to API Publication 2518, Second Edition [A7]*.

The purpose of the Documentation File is to present detailed technical information related to the development of API Publication 2518 that includes: (1) the development of theoretical equations; (2) comparisons with test data; (3) a sensitivity analysis of the loss equation; and (4) other pertinent information that was developed during the preparation of API Publication 2518.

The Documentation File is divided into two main parts: Sections A through H pertain to the standing storage loss, and Sections I through L pertain to the working loss.

The standing storage loss equation in the Second Edition [A7] is different than that in the First Edition [A6]. Sections A through H present the development of the new standing storage loss equation.

The working loss equation in the Second Edition [A7] is the same as that in the First Edition [A6]. Sections I through L contain development information that originally appeared in the First Edition.

Section R contains a list of important References that were reviewed in developing the Second Edition. These references are cited in various sections of the Documentation File.

* Numbers in brackets refer to the numbered references listed at the end of this Documentation File.

**API PUBLICATION 2518
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SECTION A

**DEVELOPMENT OF
VAPOR SPACE EXPANSION FACTOR, K_E**

**API PUBLICATION 2518
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SECTION A**

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SECTION A

NOMENCLATURE

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
A	Vapor pressure function constant	dimensionless
B	Vapor pressure function constant	OR
K_E	Vapor space expansion factor	dimensionless
n	Number of moles	mole
P	Pressure	psi
ΔP	Pressure change	psi
R	Ideal gas constant (10.731)	psia ft ³ /lbmole OR
T	Temperature	OR
ΔT	Temperature change	OR
V	Volume	ft ³
ΔV	Volume change	ft ³
y	Mole fraction in the vapor phase	mole fraction

SUBSCRIPTS

A	Air
ATM	Atmospheric
B	Breather Vent
BP	Breather Vent Pressure Setting
BV	Breather Vent Vacuum Setting
L	Liquid
LA	Liquid Average
T	Total
V	Stock Vapor
VA	Vapor Average
1	Initial Condition or Minimum Condition
2	Final Condition or Maximum Condition

A1.0 INTRODUCTION

This section of the Documentation File to API Publication 2518, Second Edition, contains a derivation of the equation for the vapor space expansion factor, K_E . This equation is derived from the ideal gas law and from the pressure, temperature and volume conditions that exist in the vapor space of a fixed-roof tank containing a volatile liquid stock.

Section A2 presents a derivation of the vapor space volume change due to thermal breathing. This derivation closely follows that originally derived by Boardman [1]* and that presented at the API "Symposium on Evaporation Loss of Petroleum from Storage Tanks" November 10, 1952 [2].

Section A3 defines the vapor space expansion factor, K_E , and develops the equation that may be used to calculate this factor.

Section A4 describes various simplifications that can be made to the equation for the vapor space expansion factor to permit ease of calculation with little loss in accuracy.

A2.0 VAPOR SPACE VOLUME CHANGE

Figure A1 is a schematic illustrating the tank vapor space thermal breathing process in a fixed-roof tank that is partially filled with a volatile liquid stock and equipped with a pressure-vacuum vent.

During the thermal breathing process, the pressure, volume and temperature vary from minimum condition 1 to maximum condition 2. At conditions 1 and 2, the total absolute pressure in the vapor space is P_1 and P_2 , respectively, where:

$$P_1 = P_{ATM} + P_{BV} \quad (A-1)$$

$$P_2 = P_{ATM} + P_{BP} \quad (A-2)$$

- Numbers in brackets refer to the numbered references listed at the end of this Documentation File.

During the thermal breathing process, the pressure, volume and temperature vary from a certain combination of values at the minimum condition to be certain combination of values at the maximum condition. At the minimum condition 1, it is assumed that all of the variables are simultaneously at their minimum values; and at the maximum condition 2, it is assumed that all of the variables are simultaneously at their maximum values. The value of the variables at the minimum condition 1 and maximum condition 2 are listed in Table A1.

Table A1 - Value of the Variables at the Minimum and Maximum Conditions

Variable	Units	Minimum Condition 1	Maximum Condition 2
Gas space total pressure	psia	P ₁	P ₂
Atmospheric pressure	psia	P _{ATM}	P _{ATM}
Gas space gage pressure	psig	P _{BV}	P _{BP}
Stock vapor pressure	psia	P _{V1}	P _{V2}
Air partial pressure	psi	P _{A1}	P _{A2}
Gas volume	ft ³	V ₁	V ₂
Gas temperature	°R	T ₁	T ₂
Liquid surface temperature	°R	T _{L1}	T _{L2}

From the ideal gas law, the total number of moles of gas, n_T , in an enclosed volume, V , at temperature, T , and pressure, P , is given by:

$$n_T = \frac{P V}{R T} \quad (A-3)$$

Assume that the gas mixture in the tank vapor space is a two-component mixture consisting air and stock vapor. The mole fraction of air, y_A , and the mole fraction of stock vapor, y_V , may be determined by Eqs (A-4) through (A-7):

$$y_A = \frac{n_A}{n_T} \quad (A-4)$$

$$y_A = \frac{P_A}{P} \quad (A-5)$$

$$y_V = \frac{n_V}{n_T} \quad (A-6)$$

$$y_V = \frac{P_V}{P} \quad (A-7)$$

The mole fraction of air, y_A , may be expressed in terms of the mole fraction of vapor, y_V , as follows:

$$y_A = 1 - y_V \quad (A-8)$$

During the thermal breathing process of the tank vapor space, the number of moles of air, n_A , in the volumes, V_1 and V_2 , is assumed to remain the same. This assumption may be expressed as follows:

$$n_{A1} = n_{A2} \quad (A-9)$$

We may substitute Eq (A-4) into Eq (A-9) to yield:

$$y_{A1} n_{T1} = y_{A2} n_{T2} \quad (A-10)$$

We may substitute Eq (A-3) into Eq (A-10) to yield:

$$y_{A1} \left(\frac{P_1 V_1}{R T_1} \right) = y_{A2} \left(\frac{P_2 V_2}{R T_2} \right) \quad (A-11)$$

Solving for V_2 and using Eq (A-8), we may write:

$$V_2 = V_1 \left(\frac{y_{A1}}{y_{A2}} \right) \left(\frac{P_1}{P_2} \right) \left(\frac{T_2}{T_1} \right) \quad (\text{A-12})$$

$$V_2 = V_1 \left(\frac{1 - y_{V1}}{1 - y_{V2}} \right) \left(\frac{P_1}{P_2} \right) \left(\frac{T_2}{T_1} \right) \quad (\text{A-13})$$

We may substitute Eq (A-7) into Eq (A-13) to yield:

$$V_2 = V_1 \left(\frac{1 - \frac{P_{V1}}{P_1}}{1 - \frac{P_{V2}}{P_2}} \right) \left(\frac{P_1}{P_2} \right) \left(\frac{T_2}{T_1} \right)$$

$$V_2 = V_1 \left(\frac{P_1 - P_{V1}}{P_2 - P_{V2}} \right) \left(\frac{T_2}{T_1} \right) \quad (\text{A-14})$$

Using Eq (A-14), the volume change due to thermal breathing, ΔV , may be determined as follows:

$$\Delta V = V_2 - V_1 \quad (\text{A-15})$$

$$\Delta V = V_1 \left[\left(\frac{P_1 - P_{V1}}{P_2 - P_{V2}} \right) \left(\frac{T_2}{T_1} \right) - 1 \right] \quad (\text{A-16})$$

We may substitute Eqs (A-1) and (A-2) into Eq (A-16) to yield:

$$\Delta V = V_1 \left[\left(\frac{P_{ATM} + P_{BV} - P_{V1}}{P_{ATM} + P_{BP} - P_{V2}} \right) \left(\frac{T_2}{T_1} \right) - 1 \right] \quad (A-17)$$

$$\Delta V = V_1 \left[\left(1 + \frac{(P_{V2} - P_{V1}) - (P_{BP} - P_{BV})}{P_{ATM} + P_{BP} - P_{V2}} \right) \left(1 + \frac{(T_2 - T_1)}{T_1} \right) - 1 \right] \quad (A-18)$$

It is convenient to define the terms ΔP_V , ΔP_B and ΔT_V as follows:

$$\Delta P_V = P_{V2} - P_{V1} \quad (A-19)$$

$$\Delta P_B = P_{BP} - P_{BV} \quad (A-20)$$

$$\Delta T_V = T_2 - T_1 = T_{V2} - T_{V1} \quad (A-21)$$

We may substitute Eqs (A-19), (A-20) and (A-21) into Eq (A-18) and expand the terms to yield:

$$\Delta V = V_1 \left[\left(1 + \frac{\Delta P_V - \Delta P_B}{P_{ATM} + P_{BP} - P_{V2}} \right) \left(1 + \frac{\Delta T_V}{T_{V1}} \right) - 1 \right] \quad (A-22)$$

$$\Delta V = V_1 \left[1 + \left(\frac{\Delta T_V}{T_{V1}} \right) + \left(\frac{\Delta P_V - \Delta P_B}{P_{ATM} + P_{BP} - P_{V2}} \right) + \left(\frac{(\Delta P_V - \Delta P_B) \Delta T_V}{P_{ATM} + P_{BP} - P_{V2}} \right) - 1 \right] \quad (A-23)$$

Since the terms $(\Delta T_V/T_{V1})$ and $(\Delta P_V - \Delta P_B)/(P_{ATM} + P_{BP} - P_{V2})$ are small, their product can be considered negligible. Thus, the product term in Eq (A-23) can be neglected. Eq (A-23) then simplifies to the following:

$$\Delta V = V_1 \left[\frac{\Delta T_V}{T_{V1}} + \frac{\Delta P_V - \Delta P_B}{P_{ATM} + P_{BP} - P_{V2}} \right] \quad (A-24)$$

A3.0 VAPOR SPACE EXPANSION FACTOR

The vapor space expansion factor, K_E , is defined as the ratio of the volume change, ΔV , to the initial volume, V_1 , as follows:

$$K_E \equiv \frac{\Delta V}{V_1} \quad (A-25)$$

Substituting Eq (A-24) into (A-25) we obtain:

$$K_E = \frac{\Delta T_V}{T_{V1}} + \frac{\Delta P_V - \Delta P_B}{P_{ATM} + P_{BP} - P_{V2}} \quad (A-26)$$

A4.0 SIMPLIFIED EQUATIONS FOR THE VAPOR SPACE EXPANSION FACTOR

Eq (A-26) may be simplified for ease of calculation. Sections A4.1 through A4.4 present various simplifications that can be made.

A4.1 Neglecting the Term P_{BP}

It should be noted that P_{BP} is small (about 0.03 psi) compared to P_{ATM} (about 14.7 psia) and can be neglected in the denominator of Eq (A-26) to yield:

$$K_E = \frac{\Delta T_V}{T_{V1}} + \frac{\Delta P_V - \Delta P_B}{P_{ATM} - P_{V2}} \quad (A-27)$$

A4.2 Replacement of T_{V1} With T_{LA}

In the first term of Eq (A-27), the minimum vapor space temperature, T_{V1} , is close to the daily average liquid surface temperature, T_{LA} , since both are absolute temperatures. Thus, for ease of calculation, we can replace T_{V1} with T_{LA} in Eq (A-27) to yield:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V - \Delta P_B}{P_{ATM} - P_{V2}} \quad (A-28)$$

A4.3 Replacement of P_{V2} With P_{VA}

For low vapor pressure stocks, the stock vapor pressure, P_V , is small compared to atmospheric pressure, P_{ATM} . Thus, we may replace the stock vapor pressure at the minimum liquid surface temperature, P_{V2} , with the stock vapor pressure at the daily average liquid surface temperature, P_{VA} , in Eq (A-28) to yield:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V - \Delta P_B}{P_{ATM} - P_{VA}} \quad (A-29)$$

Eq (A-29) appears as Eq 4 in Ref. A7.

A4.4 Use of a Simplified Equation for the Vapor Pressure Range, ΔP_V

The vapor pressure of the stock may be determined from Eq (A-30), where the vapor pressure function constants A and B must be selected for the particular stock [see Tables 4 and 5 in Ref. A7].

$$P_V = \exp [A - (B/T_L)] \quad (A-30)$$

We can determine the slope of the vapor space pressure function by taking its derivative with respect to the liquid surface temperature, T_L , as follows:

$$\frac{dP_V}{dT_L} = \frac{B P_V}{T_L^2} \quad (A-31)$$

Eq (A-31) can be written in differential form as follows:

$$\Delta P_V = \frac{B P_V}{T_L^2} \Delta T_L \quad (A-32)$$

Eq (A-32) gives the vapor pressure range, ΔP_V , in terms of the liquid surface temperature range, ΔT_L .

For most hydrocarbon liquids, the liquid surface temperature range, ΔT_L , may be related to the vapor temperature range, ΔT_V , as follows (see Eq (F-16) in Section F):

$$\Delta T_L = 0.50 \Delta T_V \quad (A-33)$$

Substituting Eq (A-33) into Eq (A-32), we obtain the following simplified equation for the vapor pressure range:

$$\Delta P_V = \left(\frac{0.50 B P_V}{T_L^2} \right) \Delta T_V \quad (A-34)$$

Eq (A-34) may be substituted into Eq (A-29) to yield:

$$K_E = \left(\frac{\Delta T_V}{T_{LA}} \right) \left[1 + \left(\frac{0.50 B}{T_{LA}} \right) \left(\frac{P_{VA}}{P_{ATM} - P_{VA}} \right) \right] - \frac{\Delta P_B}{(P_{ATM} - P_{VA})} \quad (A-35)$$

A4.5 Neglecting the Term ΔP_B

For most atmospheric storage tanks, the breather vent pressure and vacuum settings are typically +0.03 psi and -0.03 psi, respectively. Thus, the term $\Delta P_B / (P_{ATM} - P_{VA})$ is small (about 0.002 for low vapor pressure stock) compared to the term $\Delta T_V / T_{LA}$ (about 0.040 for $\Delta T_V = 20^\circ\text{F}$ and $T_{LA} = 520^\circ\text{R}$). For these cases, the last term in Eq (A-35) may be neglected to yield:

$$K_E = \left(\frac{\Delta T_V}{T_{LA}} \right) \left[1 + \left(\frac{0.50 B}{T_{LA}} \right) \left(\frac{P_{VA}}{P_{ATM} - P_{VA}} \right) \right] \quad (A-36)$$

In comparing Eq (A-36) to Eq (A-26), we can see that the calculation process is greatly simplified because it is not necessary to determine all of the variables, T_{L1} , T_{L2} , T_{LA} , P_{V1} , P_{V2} and P_{VA} , but only the variables T_{LA} and P_{VA} .

A5.0 CONCLUSION

Equation (A-29) was selected for use in calculating the vapor space expansion factor, K_E , in API Publication 2518, Second Edition [A7]. This equation was derived from the ideal gas law and from the pressure, temperature, and volume conditions that exist in the vapor space of a fixed-roof tank containing a volatile liquid stock. Equation (A-29) was developed from a more complete expression, Eq (A-26), by incorporating several simplifications that make the calculations more user friendly, with little loss in accuracy.

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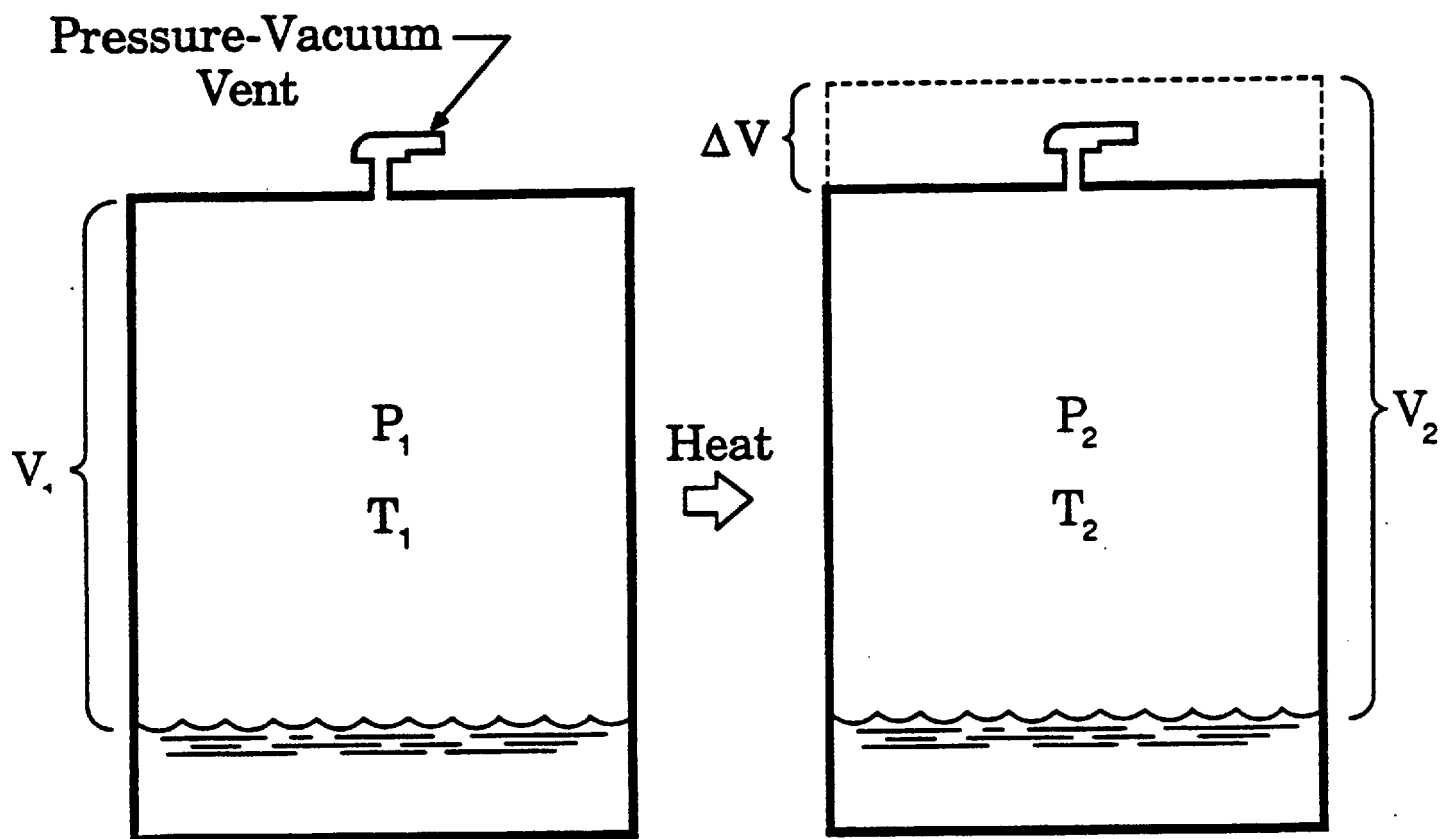


Figure A1 - Schematic of the Tank Vapor Space Heating Process and the Resulting Volume Expansion Due to Thermal Breathing

**API PUBLICATION 2518
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SECTION B

**DEVELOPMENT OF
VENTED VAPOR SATURATION FACTOR, K_S**

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SECTION B**

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SECTION B

NOMENCLATURE

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
A	Constant in the vapor pressure equation	psia
A _L	Area of the stock liquid surface	ft ²
a	Defined by Eq (B-15)	dimensionless
B	Constant in the vapor pressure equation	OR
b	Defined by Eq (B-16)	dimensionless
C _V	Average vapor concentration in the vented gas	lbm/sft ³
D	Tank diameter	ft
E	Evaporation loss	lbm/day
E _C	Evaporation loss calculated	lbm/day
E _M	Evaporation loss measured	lbm/day
H _V	Tank vapor space outage	ft
K	Overall mass transfer coefficient between the liquid surface and the vented vapor	$\left(\frac{\text{lbmole}}{\text{ft}^2 \text{ hr mole frac.}} \right)$
K _E	Vapor space expansion factor	dimensionless
K _S	Vented vapor saturation factor	dimensionless
M _V	Stock vapor molecular weight	lbm/lbmole
m _V	Moles of stock vapor vented	lbmole
P _{ATM}	Atmospheric pressure	psia
P _{VA}	Stock vapor pressure determined at T _{LA}	psia
Q	Vented gas volume outflow	sft ³ /day
R	Ideal gas law constant, (10.731)	$\left(\frac{\text{ft}^3 \text{ psia}}{\text{lbmole OR}} \right)$
RVP	Reid Vapor Pressure	psi
S	Saturation parameter, defined by Eq (B-4)	dimensionless
T _{AA}	Average daily ambient temperature	OF or OR
T _{LA}	Average daily liquid surface temperature	OF or OR
T _{VA}	Average daily vapor space temperature	OF or OR
ΔT _A	Daily ambient temperature range	OF or OR
ΔT _V	Daily vapor space temperature range	OF or OR
t _D	Time of a daily period	hr
V _V	Volume of the tank vapor space	ft ³

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SECTION B

NOMENCLATURE (Continued)

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
ΔV	Volume of gas vented during a single daily thermal breathing cycle	ft ³
y _v	Daily average stock vapor concentration in the vented vapor	mole fraction
y _v ⁰	Daily average saturated stock vapor concentration	mole fraction
ρ_G	Gas density	lbmole/ft ³

B1.0 INTRODUCTION

This section of the Documentation File to API Publication 2518, Second Edition, contains the development of the vented vapor saturation factor, K_S .

The "Vented Vapor Saturation Factor", K_S , is defined as the ratio of the daily average stock vapor concentration in the vented gas, y_v , to the stock vapor concentration, y_v^0 , in equilibrium with the stock liquid surface at the daily average liquid surface temperature.

Section B2 presents the derivation of a theoretical equation for estimating the vented vapor saturation factor that is based on an analytical model of the daily thermal breathing process.

Section B3 presents the development of a correlation for estimating the vented vapor saturation factor that is based on test data.

B2.0 VENTED VAPOR SATURATION FACTOR MODEL

B2.1 Model Description

Figure B1 is a schematic of a fixed-roof tank that is partially filled with a volatile liquid stock and equipped with a pressure-vacuum vent. During the daily thermal breathing cycle, the gas mixture in the tank vapor space is initially heated from its minimum condition to its maximum condition (see Section A of this Documentation File for additional detail). Vapor is vented from the tank vapor space when the pressure increases to the pressure setting of the pressure-vacuum vent. As the gas mixture in the tank vapor space is cooled from its maximum condition back to its minimum condition, air is admitted to the tank vapor space when the pressure decreases to the vacuum setting of the pressure-vacuum vent.

Evaporation of stock occurs from the liquid surface as the stock tries to saturate the air that was admitted to the tank vapor space. Test data indicates that there is a region at the top of the tank vapor space under the pressure-vacuum vent where there is a significant concentration gradient.

During the daily thermal breathing cycle, the moles of stock vapor that are expelled from the tank vapor space, m_V , may be estimated by Eq (B-1):

$$m_V = \rho_G \Delta V y_V \quad (B-1)$$

where the term ΔV represents the volume vented during a single thermal breathing cycle (see Section A2, Eq (A-24)).

The vented gas contains less stock vapor per unit volume than the gas near the liquid surface. The daily average stock vapor concentration in the vented vapor is y_V (unsaturated), and the daily average stock vapor concentration near the liquid surface is y_V^0 (saturated).

During the daily thermal breathing cycle, stock vapor evaporates and rises upward from the area near the liquid surface to replace the stock vapor lost as gas is vented from the tank vapor space. Stock will continue to evaporate as it tries to establish a saturation condition at the top of the tank vapor space.

The moles of stock that evaporate during a daily thermal breathing cycle may be estimated by Eq (B-2):

$$m_V = K A_L t_D (y_V^0 - y_V) \quad (B-2)$$

where K is the overall mass transfer coefficient between the liquid surface and the vented vapor.

After a series of repeated daily thermal breathing cycles where the same meteorological conditions occur, the stock vapor concentration in the vented vapor will vary during each thermal breathing cycle in a repeated manner, and the daily average stock vapor concentration in the vented vapor, y_V , will achieve a steady value. This concentration value depends upon the rate at which the stock vapor lost from the tank vapor space is replaced by stock evaporated from the liquid surface.

The steady value of the daily average stock vapor concentration in the vented vapor, y_V , may be determined by equating Eq (B-1) with Eq (B-2) and solving for y_V as follows:

$$\rho_G \Delta V y_V = K A_L t_D (y_V^0 - y_V)$$

$$y_V \left(\frac{\rho_G \Delta V}{K A_L t_D} \right) = (y_V^0 - y_V) \quad (B-3)$$

It is useful to define the saturation parameter, S , as follows:

$$S \equiv \left(\frac{\rho_G \Delta V}{K A_L t_D} \right) \quad (B-4)$$

Using this defined saturation parameter, Eq (B-3) may be written as:

$$y_V S = (y_V^0 - y_V) \quad (B-5)$$

Eq (B-5) may now be solved for y_V to yield:

$$y_V = y_V^0 \left(\frac{1}{1 + S} \right) \quad (B-6)$$

82.2 Vented Vapor Saturation Factor Definition

The vented vapor saturation factor, K_S , is defined by Eq (B-7) as the ratio of the daily average stock vapor concentration in the vented vapor, y_V , to the daily average saturated stock vapor concentration, y_V^0 .

$$K_S = \left(\frac{y_V}{y_V^0} \right) \quad (B-7)$$

When $K_S = 1$, the vented gas is completely saturated; when $K_S = 0$, the vented gas contains no stock vapor.

B2.3 Saturation Parameter

The saturation parameter, S , as defined by Eq (B-4) may be written in terms of other evaporation loss parameters. First, note Eqs (B-8) through (B-11) as follows:

$$\rho_G = \left(\frac{P_{ATM}}{R T_{VA}} \right) \quad (B-8)$$

$$A_L = \left(\frac{\pi D^2}{4} \right) \quad (B-9)$$

$$\Delta V = V_V K_E \quad (\text{see Eq (A-25) in Section A}) \quad (B-10)$$

$$V_V = \left(\frac{\pi D^2 H_V}{4} \right) \quad (B-11)$$

Substituting Eqs (B-8) through (B-11) into Eq (B-4), we obtain:

$$S = \left(\frac{P_{ATM}}{R T_{VA}} \right) \left(\frac{H_V}{K t_D} \right) K_E \quad (B-12)$$

The vapor space expansion factor, K_E , may be expressed in the following simplified form (see Eq (A-36) in Section A5):

$$K_E = \left(\frac{\Delta T_V}{T_{LA}} \right) \left[1 + \left(\frac{0.50 B}{T_{LA}} \right) \left(\frac{P_{VA}}{P_{ATM} - P_{VA}} \right) \right] \quad (B-13)$$

Substituting Eq (B-13) into Eq (B-12) and replacing T_{VA} with T_{LA} (since both are absolute temperatures), we obtain:

$$S = \left(\frac{P_{ATM}}{R T_{LA}} \right) \left(\frac{H_V}{K t_D} \right) \left(\frac{\Delta T_V}{T_{LA}} \right) \left[1 + \left(\frac{0.50 B}{T_{LA}} \right) \left(\frac{P_{VA}}{P_{ATM} - P_{VA}} \right) \right] \quad (B-14)$$

It is convenient to define the following dimensionless parameters a and b :

$$a \equiv \left(\frac{P_{ATM} H_V \Delta T_V}{R t_D K T_{LA}^2} \right) \quad (B-15)$$

$$b \equiv \left(\frac{0.50 B}{T_{LA}} \right) \quad (B-16)$$

We also know that the daily average saturated stock vapor concentration, y_V^0 , can be expressed as follows:

$$y_V^0 = \left(\frac{P_{VA}}{P_{ATM}} \right) \quad (B-17)$$

Substituting Eqs (B-15), (B-16) and (B-17) into Eq (B-14), we obtain:

$$S = a \left[1 + b \left(\frac{y_V^0}{1 - y_V^0} \right) \right] \quad (B-18)$$

B2.4 Vented Vapor Saturation Factor Development

Substituting y_V from Eq (B-6) into Eq (B-7) we obtain:

$$K_S = \left(\frac{1}{1 + S} \right) \quad (B-19)$$

Equation (B-19) shows that as the saturation parameter, S , increases, the vented vapor saturation factor, K_S , decrease toward 0. Conversely, as S decreases, the value of K_S increases toward 1.

Using Eq (B-18), the vented vapor saturation factor, K_S , may be written as:

$$K_S = \frac{1}{1 + a \left[1 + b \left(\frac{y_V^0}{1 - y_V^0} \right) \right]} \quad (B-20)$$

Equation (B-20) shows that the vented vapor saturation factor, K_S , depends upon only 3 parameters: a , b and y_V^0 .

Inserting the expressions for a , b and y_V^0 from Eqs (B-15), (B-16) and (B-17), we obtain the following final expression which contains all of the variables:

$$K_S = \frac{1}{1 + \left[\frac{P_{ATM} H_V \Delta T_V}{R t_D K T_{LA}^2} \right] \left\{ 1 + \left[\frac{0.50 B}{T_{LA}} \right] \frac{\left[\frac{P_{VA}}{P_{ATM}} \right]}{1 - \left[\frac{P_{VA}}{P_{ATM}} \right]} \right\}}$$

(B-21)

It should be noted that K_S will tend toward 1 as H_V tends toward 0. Also, K_S will tend toward 0 as P_{VA} tends toward P_{ATM} .

Insufficient information is currently available to determine the overall mass transfer coefficient, K , and thus Eq (B-21) was used only as a guide to show the dependency of K_S on P_{VA} , H_V and the other variables.

Although it is possible to improve the above simplified analysis to develop a theoretical relation for the vented vapor saturation factor, K_S , it was decided instead to develop a correlation for K_S based on actual test data, as described in Section B3. However, the above simplified analysis was used as a guide in selecting the analytical form for the correlation equation and in selecting the parameters to include in the correlation.

B3.0 VENTED VAPOR SATURATION FACTOR CORRELATION

This section summarizes the development of a correlation for estimating the vented vapor saturation factor, K_S .

Section B3.1 summarizes the saturation factors that were calculated from the API[38]*, EPA[20] and WOGA[17] test data. The API test data showed that the vented gas was near saturation conditions at all times. The EPA and WOGA Test Data, however, showed that the vented gas was not saturated, with the degree of saturation being less with increasing product vapor pressure, P_{VA} , and increasing vapor space outage, H_V .

* Numbers in brackets refer to the numbered references listed at the end of this Documentation File.

The fact that the vented gas is not saturated with stock vapor reflects the effect of mass transfer rate limitations from the liquid surface to the area below the pressure-vacuum vent. As the vapor space outage increases, the distance that the stock vapor must travel from the liquid surface to the vent is lengthened. This lengthened distance decreases the mass transfer rate and thus the concentration in the vented gas. For high vapor pressure stocks, since the amount of stock vapor lost in each daily thermal breathing cycle is larger, a higher rate of evaporation from the liquid surface is required to replenish the stock vapor that is lost. Mass transfer rate limitations, however, limit the ability of the stock to replenish the vented vapor at these higher vapor pressures and thus reduce the degree of saturation in the vented gas.

Section B3.2 presents the development of a correlation for the vented vapor saturation factor based on only the API and EPA test data. This correlation showed trends that are similar to those predicted by the theoretical analysis (see Eq (B-19)) in that the saturation factor approaches 1 as the vapor pressure or the outage approach 0, and the saturation factor becomes small as the vapor pressure or outage increase.

Section 3.3 presents the development of a correlation for the vented vapor saturation factor based on the combined set of API, EPA and WOGA test data. This correlation showed the same trends as the correlation that was based on only the API and EPA test data, but there was more scatter of the WOGA test data from the correlation.

B3.1 Summary of API, EPA and WOGA Test Data

Table B1 summarizes the 10 API tests [38] along with the calculated saturation factor, K_g . The saturation factor for the API test data are very close to 1, with an average value for the 10 tests of 0.964.

Table B2 summarizes the 15 EPA tests [20]. It was found that all of the EPA test data was suitable for use in calculating a saturation factor, with the exception of Tests EPA-4A, EPA-4B and EPA-4C. The reason for rejecting these tests is stated at the bottom of Table B2.

Table B3 summarizes the EPA test data along with the calculated saturated factor, K_s , for those tests which were selected in Table B2. Since the average liquid surface temperature was not measured during the EPA tests, the equation indicated in Note 5 at the bottom of Table B3 was used to estimate the average liquid surface temperature.

Table B4 summarizes the 44 WOGA tests [17]. Out of the total of 44 tests, 21 were found suitable to calculate a saturation factor. The reasons for rejecting the other tests is noted at the bottom of Table B4.

Table B5 summarizes the suitable WOGA test data and the calculated saturation factor, K_s . Only the crude oil tests were used to calculate a saturation factor. The vapor pressure at the daily average liquid surface temperature was calculated utilizing the equations noted at the bottom of Table B5. No such relationships were available for the distillate and fuel oil products used in the WOGA test program.

B3.2 Saturation Factor Correlation of API and EPA Test Data

In general, it was found that there was a higher quality in the API test data [38] and EPA test data [20] than in the WOGA test data [17]. The combined set of API and EPA test data were used to develop a saturation factor correlation.

Figure B2 presents the correlation, where the saturation factor, K_s , was found to be related to the product of the vapor pressure, P_{vA} , and the vapor space outage, H_v . The vapor pressure characteristics of the stock used in the EPA tests were readily known because they were single component stocks.

B3.3 Saturation Factor Correlation of API, EPA and WOGA Test Data

The correlation of the API and EPA test data shown in Figure B2 is satisfactory, but is based only on test data from fuel oil (API test data) and single component liquid stocks (EPA test data).

Although it was found that, in general, the API and EPA test data were of higher quality than the WOGA test data, it was decided to develop a single correlation which was fit to the combined set of API, EPA and WOGA test data. This combined data set includes 34 data points that extend up to a P_{VAH_V} value of about 78 psia ft. and include WOGA test data on crude oil.

Table B6 summarizes the 34 data points which were used to develop the saturation factor correlation from the combined set of API, EPA and WOGA test data.

Figure B3 is a plot of $((1/K_S) - 1)$ versus P_{VAH_V} for the API, EPA and WOGA test data. The test data were fit with a least squares linear correlation, as noted on Figure B3. The correlation coefficient, r^2 , was 0.76. Eq (B-22) is the resulting correlation.

$$K_S = \frac{1}{1 + 0.0525 P_{VAH_V}} \quad (B-22)$$

Figures B3 and B4 illustrate that the WOGA test data has more scatter in comparison to the API and EPA test data. Part of this scatter is believed to be due to the more uncertain vapor pressure characteristics of the stocks used in the WOGA tests and the fact that only a few vapor samples were taken during each WOGA test.

Figure B4 illustrates the results of the correlation developed in Figure B3, where the saturation factor is plotted versus P_{VAH_V} . The correlation indicates that the saturation factor approaches 1 as the vapor pressure or the vapor space outage approach 0. The correlation also shows that the saturation factor becomes small as the vapor pressure or the vapor space outage increase. These trends are in agreement with those that are predicted by Eq (B-21) of the theoretical analysis.

B4.0 CONCLUSION

Equation (B-22) was selected for use in calculating the vented vapor saturation factor, K_S , in API Publication 2518, Second Edition [A7]. This equation was developed from a correlation of the API, EPA and WOGA test data, and exhibits the same trends with varying P_{VA} and H_{VO} that were exhibited by Eq (B-21) of the theoretical analysis.

Table B1 - Saturation Factor, K_S , for API Test Data [38]

Test No.	Q (1) (ft ³ /day)	C _v (2) (lbm/ft ³) $\times 10^{-3}$	E (1) (lbm/day)	h _v (1) (ft)	T _{AA} (1) (°F)	T _{LA} (1) (°F)	A (1) (-)	B (1) (°R)	P _{VA} at T _{LA} (3) (psia)	h _v (1) (lbm/lbmole)	P _{VA} h _v (psia ft)	K _S (4) (-)
API-1	139	0.109	0.0152	8.85	45.4	55.3	14.348	10.082	0.00536	110.0	0.0474	1.025
API-2	157	0.108	0.0170	8.85	51.9	56.9	14.348	10.082	0.00569	110.0	0.0504	0.958
API-3	188	0.115	0.0216	8.85	52.2	58.3	14.348	10.082	0.00600	110.0	0.0531	0.967
API-4	185	0.118	0.0219	8.85	50.4	58.7	14.348	10.082	0.00609	110.0	0.0539	0.983
API-5	159	0.113	0.0179	8.85	49.2	57.8	14.348	10.082	0.00589	110.0	0.0521	0.965
API-6	78	0.101	0.0079	8.85	47.8	54.9	14.348	10.082	0.00528	110.0	0.0467	0.963
API-7	202	0.165	0.0334	8.85	54.8	65.0	9.260	7,287.2	0.00977	110.0	0.0865	0.866
API-8	210	0.239	0.0502	8.85	65.0	79.6	9.260	7,287.2	0.0142	110.0	0.126	0.884
API-9	207	0.231	0.0478	8.85	57.1	74.8	9.260	7,287.2	0.0126	110.0	0.111	0.958
API-10	185	0.238	0.0441	8.85	60.6	72.9	9.260	7,287.2	0.0120	110.0	0.106	1.033
										Average =	0.0733	0.960

Notes: (1) Measured value from test data.

(2) Calculated value. $C_v = E/Q$ (3) Calculated value. $P_{VA} = \exp[A - (B/T_{LA})]$, where T_{LA} is in °R.(4) Calculated value. $K_S = [C_v / (P_{VA} h_v / RT_{LA})]$, where T_{LA} is in °R.

Table B2 - Summary of EPA Tests [20] Selected

Test	Product Type	Insulated Tank (Yes/No)	Selected	Reasons for Rejection
EPA-1A	Isopropanol	N	Y	
EPA-1B	Isopropanol	N	Y	
EPA-2A	Ethanol	N	Y	
EPA-2B	Ethanol	N	Y	
EPA-2C	Ethanol	N	Y	
EPA-3A	Glacial Acetic Acid	N	Y	
EPA-3B	Glacial Acetic Acid	N	Y	
EPA-4A	Formaldehyde	Y	N	1
EPA-4B	Formaldehyde	Y	N	1
EPA-4C	Formaldehyde	Y	N	1
EPA-5A	Ethyl Benzene	N	Y	
EPA-5B	Ethyl Benzene	N	Y	
EPA-6A	Cyclohexane	N	Y	
EPA-6B	Cyclohexane	N	Y	
EPA-6C	Cyclohexane	N		

Reasons for Rejection: (1) Tank is insulated.

Table B3 - Saturation Factor, K_S , for EPA Test Data [20]

Test No.	Q (1) (ft ³ /day)	C _y (2) (lbm/ft ³) × 10 ⁻³	ε (1) (lbm/day)	H _y (1) (ft)	T _{AA} (1) (°F)	T _B (1) (°F)	Shell Color (1) (-)	α (3) (-)	H _H (1) (8tu/ft ² day)	T _{LA} (5) (°F)	A (1) (-)	B (1) (°R)	P _{VA} at T _{LA} (6) (psia)	M _y (1) (lbm/lbmole)	P _y H _y (psia ft.)	K _S (7) (-)
EPA-1A	3,824	3.93	15.0	27.1	65.4	70.0	White	0.17	2470	71.3	18.7687	9113.6	0.674	60.10	18.26	0.553
EPA-1B	4,248	4.06	17.2	27.1	69.1	70.0	White	0.17	2290	72.7	16.7687	9113.6	0.705	60.10	19.11	0.547
EPA-2A	1,313	4.50	5.91	11.4	77.7	70.3	White	0.17	1700	75.8	16.3801	8760.7	1.020	46.02	11.63	0.551
EPA-2B	790	4.32	3.41	11.4	75.4	71.4	White	0.17	2320	76.3	16.3801	8760.7	1.036	46.02	11.81	0.521
EPA-2C	1,435	3.59	5.15	11.4	66.3	70.4	White	0.17	1730	70.9	16.3801	8760.7	0.877	46.02	10.00	0.506
EPA-3A	9,508	2.23	21.2	26.7	62.1	69.9	Gray	0.54	1730	73.9	14.8028	8591.1	0.273	60.05	7.29	0.779
EPA-3B	18,934	2.39	45.3	26.7	65.9	69.8	Gray	0.54	2400	78.3	14.8028	8591.1	0.312	60.05	8.32	0.737
EPA-4A	25,000	1.00	25.0	27.9	70.0	149.6	Gray	0.54	2360	---	---	---	---	30.03	---	---
EPA-4B	24,000	1.00	24.0	27.9	74.0	147.1	Gray	0.54	2470	---	---	---	---	30.03	---	---
EPA-4C	22,000	1.00	22.0	27.9	78.8	143.9	Gray	0.54	1840	---	---	---	---	30.03	---	---
EPA-5A	2,526	4.50	11.4	11.9	80.5	81.7	White	0.17	2140	84.0	14.0362	8423.3	0.233	106.11	2.77	1.062
EPA-5B	3,740	3.84	14.4	11.9	78.8	80.0	White	0.17	2540	82.9	14.0362	8423.3	0.226	106.11	2.69	0.933
EPA-6A	2,965	6.75	20.0	17.8	86.7	79.0	White	0.17	1730	84.7	13.6969	7091.7	1.954	84.16	34.79	0.240
EPA-6B	3,094	5.50	17.0	17.8	80.2	78.7	White	0.17	2510	82.7	13.6969	7091.7	1.863	84.16	33.15	0.204
EPA-6C	2,980	4.82	14.4	17.8	82.0	78.7	White	0.17	2160(4)	83.0	13.6969	7091.7	1.876	84.16	33.39	0.178

- Notes:
- (1) Measured value from test data.
 - (2) Calculated value. $E = Q/C_y$
 - (3) Value determined from Table E5 in Section E of this Documentation File.
 - (4) Assumed value. Based on the average of the H_H values for the other EPA tests.
 - (5) Calculated value. $T_{LA} = 0.437T_{AA} + 0.563T_B + 0.00789Q/H_H$
 - (6) Calculated value. $P_{VA} = \exp[A - (B/T_{LA})]$, where T_{LA} is in °R.
 - (7) Calculated value. $K_S = [C_y/(P_{VA}M_y/R/T_{LA})]$, where T_{LA} is in °R.

Table B4 - Summary of WOGA Tests [17] Selected

Test No.	Product Type	RVP (psi)	Insulated Tank (Yes/No)	Vapor Outflow (sft ³ /day)	Selected (Yes/No)	Reasons for Rejection
WOGA-1A	Crude Oil	1.8	N	0	Y	
WOGA-1B	Crude Oil	1.8	N	0	Y	
WOGA-1C	Crude Oil	1.8	N	0	Y	
WOGA-2A	Crude Oil	0.8	Y	31	N	1,4
WOGA-2B	Crude Oil	0.8	Y	42	N	1,4
WOGA-3A	Distillate	---	Y	0	N	1,2
WOGA-3B	Distillate	---	Y	0	N	1,2
WOGA-4A	Crude Oil	1.3	N	0	Y	
WOGA-4B	Crude Oil	1.3	N	0	Y	
WOGA-5	Fuel Oil	---	Y	1,030	N	1,2
WOGA-6	Distillate	---	N	0	N	2
WOGA-7A	Crude Oil	3.4	N	15,300	Y	
WOGA-7B	Crude Oil	3.4	N	29,200	Y	
WOGA-7C	Crude Oil	3.4	N	15,800	Y	
WOGA-8A	Crude Oil	1.2	N	14,930	Y	
WOGA-8B	Crude Oil	1.2	N	19,220	Y	
WOGA-8C	Crude Oil	1.2	N	19,300	Y	
WOGA-9A	Crude Oil	5.3	N	4,740	N	5
WOGA-9B	Crude Oil	5.3	N	5,800	N	5
WOGA-9C	Crude Oil	5.3	N	5,800	N	5
WOGA-10A	Distillate	---	N	0	N	2
WOGA-10B	Distillate	---	N	0	N	2
WOGA-10C	Distillate	---	N	0	N	2
WOGA-11A	Crude Oil	0.1	Y	33	N	1,4
WOGA-11B	Crude Oil	0.1	Y	7	N	1,4
WOGA-12	Crude Oil	15.1	N	430	N	3
WOGA-13A	Crude Oil	0.5	N	18,300	N	4
WOGA-13B	Crude Oil	0.5	N	18,320	N	4
WOGA-14	Distillate	---	N	7,675	N	2
WOGA-15	Crude Oil	3.0	N	1,800	Y	

Table B4 - Summary of WOGA Tests [17] Selected (Continued)

Test No.	Product Type	RVP (psi)	Insulated Tank (Yes/No)	Vapor Outflow (sft ³ /day)	Selected (Yes/No)	Reasons for Rejection
WOGA-16A	Crude Oil	5.2	N	4,029	Y	
WOGA-16B	Crude Oil	5.2	N	5,857	Y	
WOGA-16C	Crude Oil	5.2	N	5,454	Y	
WOGA-17A	Crude Oil	5.5	N	17,058	Y	
WOGA-17B	Crude Oil	5.5	N	16,059	Y	
WOGA-18A	Crude Oil	0.4	N	0	N	4
WOGA-18B	Crude Oil	0.4	N	0	N	4
WOGA-18C	Crude Oil	0.4	N	0	N	4
WOGA-19A	Crude Oil	3.0	N	284	Y	
WOGA-19B	Crude Oil	3.0	N	173	Y	
WOGA-20A	Crude Oil	4.1	N	0	Y	
WOGA-20B	Crude Oil	4.1	N	0	Y	
WOGA-21A	Distillate	---	N	27,210	N	2
WOGA-21B	Distillate	---	N	25,680	N	2

Reasons for Rejection:

- (1) Tank is insulated.
- (2) Product is a distillate or fuel oil. The vapor pressure versus temperature behavior of these stock types was not well established in these tests.
- (3) The liquid sample may not be representative of the tank stock during the test.
- (4) The RVP was less than 1.0 psi, and the stock vapor pressure is, therefore, questionable.
- (5) The vented gas volume outflow, Q, appears to be in error.

Table B5 - Saturation Factor, K_S , for WOGA Test Data [17]

Test No.	Q (1) (scf/day)	C_v (1) (lbm/sft ³) $\times 10^{-3}$	E (2) (lbm/day)	H_v (1) (ft) (°F)	T_{AA} (1) (°F)	T_B (1) (°F)	Shell Color (1) (-)	Paint Condition (1) (-)	α (3) (-)	H_H (1) (Btu/ft ² day)	T_{LA} (5) (°F)	RVP (1) (psi)	A (6) (-)	B (6) (°R)	P_{VA} at T_{LA} (6) (psia)	M_v (1) (lbm/lbmole)	$P_{VA}H_v$ (psia ft)	K_S (7) (-)
WOGA-1A	0	24.0	0	6.2	55	113	Alum., Spec.	Good	0.39	1415(4)	92.0	1.8	12.25	6546	1.469	68.3	9.11	1.416
WOGA-1B	0	28.0	0	6.2	56	98	Alum., Spec.	Good	0.39	1415(4)	84.0	1.8	12.25	6546	1.234	67.0	7.85	1.976
WOGA-1C	0	22.3	0	6.2	53	90	Alum., Spec.	Good	0.39	1415(4)	78.2	1.8	12.25	6546	1.084	64.5	6.72	1.842
WOGA-2A	31	7.30	0.226	9.3	55	150	Gray, Light	Good	0.54	1415(4)	114.5	0.8	13.04	7532	0.925	41.9	8.61	1.160
WOGA-2B	42	7.30	0.307	9.3	51	150	Gray, Light	Good	0.54	1415(4)	112.8	0.8	13.04	7532	0.890	41.9	8.28	1.203
WOGA-3A	0	0.814	0	4.0	52	150	Alum., Diff.	Good	0.60	940	111.6	---	---	---	---	52.2	---	---
WOGA-3B	0	0.814	0	4.0	58	150	Alum., Diff.	Good	0.60	1310	116.0	---	---	---	---	52.2	---	---
WOGA-4A	0	4.66	0	12.4	64	55	Alum., Diff.	Poor	0.68	1415(4)	66.5	1.3	12.57	6942	0.536	67.7	6.65	0.725
WOGA-4B	0	4.66	0	12.4	59	55	Alum., Diff.	Poor	0.68	1415(4)	64.3	1.3	12.57	6942	0.507	67.7	6.29	0.763
WOGA-5	1,030	0.790	8.14	3.3	52	180	Alum., Diff.	Poor	0.68	1415(4)	131.7	---	---	---	---	124.4	---	---
WOGA-6	0	0.822	0	8.5	56	90	Peach	Good	0.34	1570	79.4	---	---	---	---	95.9	---	---
WOGA-7A	15,300	5.08	77.7	39.6	64	56	Gray, Med.	Good	0.68	1415(4)	67.1	3.4	11.64	5773	1.976	69.0	78.26	0.211
WOGA-7B	29,200	5.08	148.	39.6	66	56	Gray, Med.	Good	0.68	933	65.4	3.4	11.64	5773	1.907	69.0	75.53	0.218
WOGA-7C	15,800	5.08	80.3	39.6	62	56	Gray, Med.	Good	0.68	1415(4)	66.2	3.4	11.64	5773	1.939	69.0	76.80	0.214
WOGA-8A	14,930	5.38	80.3	37.3	62	65	Gray, Med.	Good	0.68	1780	73.2	1.2	12.64	7039	0.566	66.7	21.11	0.815
WOGA-8B	19,220	5.38	103.	37.3	64	65	Gray, Med.	Good	0.68	1415(4)	72.2	1.2	12.64	7039	0.552	66.7	20.60	0.834
WOGA-8C	19,300	5.38	104.	37.3	65	65	Gray, Med.	Good	0.68	1415(4)	72.6	1.2	12.64	7039	0.558	66.7	20.80	0.826
WOGA-9A	4,740	20.9	99.1	23.2	60	73	Gray, Med.	Good	0.68	2050	78.3	5.3	11.21	5233	4.406	55.0	102.23	0.498
WOGA-9B	5,800	20.9	121.	23.2	63	73	Gray, Med.	Good	0.68	2050	79.6	5.3	11.21	5233	4.511	55.0	104.65	0.488
WOGA-9C	5,800	20.9	121.	23.2	64	73	Gray, Med.	Good	0.68	1850	79.0	5.3	11.21	5233	4.462	55.0	103.53	0.492
WOGA-10A	0	0.311	0	3.6	58	60	Peach	Good	0.34	1415(4)	62.9	---	---	---	---	120.3	---	---
WOGA-10B	0	0.311	0	3.6	60	60	Peach	Good	0.34	1450	63.9	---	---	---	---	120.3	---	---
WOGA-10C	0	0.311	0	3.6	56	60	Peach	Good	0.34	1570	62.5	---	---	---	---	120.3	---	---
WOGA-11A	33	1.56	0.0515	2.0	54	158	Alum., Diff.	Poor	0.68	1080	118.3	0.2	14.38	9217	0.209	29.2	0.42	1.644
WOGA-11B	7	1.56	0.0109	2.0	56	158	Alum., Diff.	Poor	0.68	1415(4)	121.0	0.2	14.38	9217	0.225	29.2	0.45	1.533
WOGA-12	430	6.30	2.71	7.6	51	72	White	Good	0.17	1415(4)	64.7	0.4	13.71	8375	0.104	50.4	0.79	6.747
WOGA-13A	16,300	7.05	129.	35.8	62	92	White	Good	0.17	1400	80.8	0.5	13.49	8104	0.222	63.9	7.96	2.879
WOGA-13B	16,320	7.80	143.	35.8	61	83	White	Good	0.17	1610	75.5	0.5	13.49	8104	0.192	64.4	6.86	3.630
WOGA-14	7,675	0.185	1.42	40.1	59	65	White	Good	0.17	1415(4)	64.3	---	---	---	---	103.8	---	---
WOGA-15	1,800	24.2	43.6	2.9	73	65	White	Good	0.17	1415(4)	70.4	3.0	11.76	5926	1.787	50.6	5.18	1.522

Table B5 - Saturation Factor, K_S , for WOGA Test Data [17] (Continued)

Test No.	Q (1) (sf ³ /day)	Cv (1) (lbm/sft ³)x10 ⁻³	E (2) (lbm/day)	H _v (1) (ft)	TAA (1) (°F)	T _g (1) (°F)	Shell Color (1) (-)	Paint Condition (1) (-)	α (3) (-)	H _H (1) (Btu/ft ² day)	T _{LA} (5) (°F)	RVP (1) (psi)	A (6) (-)	B (6) (°R)	P _{VA} at T _{LA} (6) (psia)	H _v (1) (lbm/lbmole)	P _{VA} H _v (psia ft)	K _S (7) (-)
WOGA-16A	4,029	24.5	98.7	2.3	69	56	White	Good	0.17	1020	63.0	5.2	11.23	5257	3.230	63.9	7.43	0.666
WOGA-16B	5,857	24.5	143.	2.3	70	56	White	Good	0.17	984	63.4	5.2	11.23	5257	3.255	63.9	7.49	0.661
WOGA-16C	5,454	24.5	134.	2.3	64	56	White	Good	0.17	1415(4)	61.4	5.2	11.23	5257	3.132	63.9	7.20	0.685
WOGA-17A	17,058	33.9	578.	6.9	66	65	White	Good	0.17	2050	68.2	5.5	11.17	5189	3.820	52.4	26.36	0.959
WOGA-17B	16,059	33.9	544.	6.9	69	65	White	Good	0.17	1850	69.2	5.5	11.17	5189	3.892	52.4	26.85	0.943
WOGA-18A	0	1.65	0	1.8	65	67	White	Good	0.17	1415(4)	68.0	0.4	13.71	8375	0.115	21.4	0.21	3.790
WOGA-18B	0	1.65	0	1.8	59	67	White	Good	0.17	1415(4)	65.4	0.4	13.71	8375	0.106	21.4	0.19	4.080
WOGA-18C	0	1.65	0	1.8	62	67	White	Good	0.17	1415(4)	66.7	0.4	13.71	8375	0.111	21.4	0.20	3.932
WOGA-19A	284	23.1	6.56	2.5	69	63	White	Good	0.17	1415(4)	67.5	3.0	11.76	5926	1.681	53.4	4.20	1.456
WOGA-19B	173	23.1	4.00	2.5	73	63	White	Good	0.17	1415(4)	69.3	3.0	11.76	5926	1.746	53.4	4.37	1.406
WOGA-20A	0	23.2	0	4.0	61	74	Green	Good	0.59	811	72.1	4.1	11.46	5546	2.804	60.9	11.22	0.775
WOGA-20B	0	23.2	0	4.0	56	74	Green	Good	0.59	1080	71.2	4.1	11.46	5546	2.755	60.9	11.02	0.788
WOGA-21A	27,210	0.367	9.99	21.7	56	66	Black	Good	0.94	881	68.2	---	---	---	---	37.2	---	---
WOGA-21B	25,660	0.367	9.42	21.7	58	66	Black	Good	0.94	1420	72.2	---	---	---	---	37.2	---	---

- Notes: (1) Measured value from test data.
(2) Calculated value. $E = Q C_v$
(3) Value taken from Tables E3 and E5 in Section E of this Documentation File.
(4) Value determined from the average H_H measured in all of the WOGA tests.
(5) Calculated value. $T_{LA} = 0.437TAA + 0.563T_g + 0.00789Q_{HH}$
(6) Calculated values. $A = 12.82 - 0.9672 \ln(RVP)$
 $B = 7261 - 1216 \ln(RVP)$
 $P_{VA} = \exp[A - (B/T_{LA})]$, where T_{LA} is in °R.
(7) Calculated value. $K_S = [C_v/(P_{VA}H_v/RT_{LA})]$, where T_{LA} is in °R.

Table B6 - Summary of Test Data Used to Develop the Vented Vapor Saturation Factor Correlation

Test No.	K _S (-)	[(1/K _S)-1] (-)	P _V AH _v (psia ft)
API- 1	1.025	-----	0.0474
API- 2	0.958	0.0434	0.0504
API- 3	0.967	0.0338	0.0531
API- 4	0.983	0.0177	0.0539
API- 5	0.965	0.0363	0.0521
API- 6	0.963	0.0380	0.0467
API- 7	0.866	0.154	0.0865
API- 8	0.884	0.131	0.126
API- 9	0.958	0.0442	0.111
API-10	1.033	-----	0.106
EPA-1A	0.553	0.809	18.26
EPA-1B	0.547	0.827	19.11
EPA-2A	0.551	0.816	11.63
EPA-2B	0.521	0.918	11.81
EPA-2C	0.506	0.975	10.00
EPA-3A	0.779	0.284	7.29
EPA-3B	0.737	0.356	8.32
EPA-5A	1.062	-----	2.77
EPA-5B	0.933	0.0716	2.69
EPA-6A	0.240	3.17	34.79
EPA-6B	0.204	3.90	33.15
EPA-6C	0.178	4.62	33.39
WOGA-1A	1.416	-----	9.11
WOGA-1B	1.976	-----	7.65
WOGA-1C	1.842	-----	6.72
WOGA-4A	0.725	0.379	6.65
WOGA-4B	0.763	0.311	6.29
WOGA-7A	0.211	3.74	78.26
WOGA-7B	0.218	3.59	75.53
WOGA-7C	0.214	3.67	76.80
WOGA-8A	0.815	0.227	21.11
WOGA-8B	0.834	0.199	20.60
WOGA-8C	0.826	0.211	20.80
WOGA-15	1.522	-----	5.18
WOGA-16A	0.666	0.502	7.43
WOGA-16B	0.661	0.513	7.49
WOGA-16C	0.685	0.460	7.20
WOGA-17A	0.959	0.0428	26.36
WOGA-17B	0.943	0.0604	26.85
WOGA-19A	1.456	-----	4.20
WOGA-19B	1.406	-----	4.37
WOGA-20A	0.775	0.290	11.22
WOGA-20B	0.780	0.282	11.02

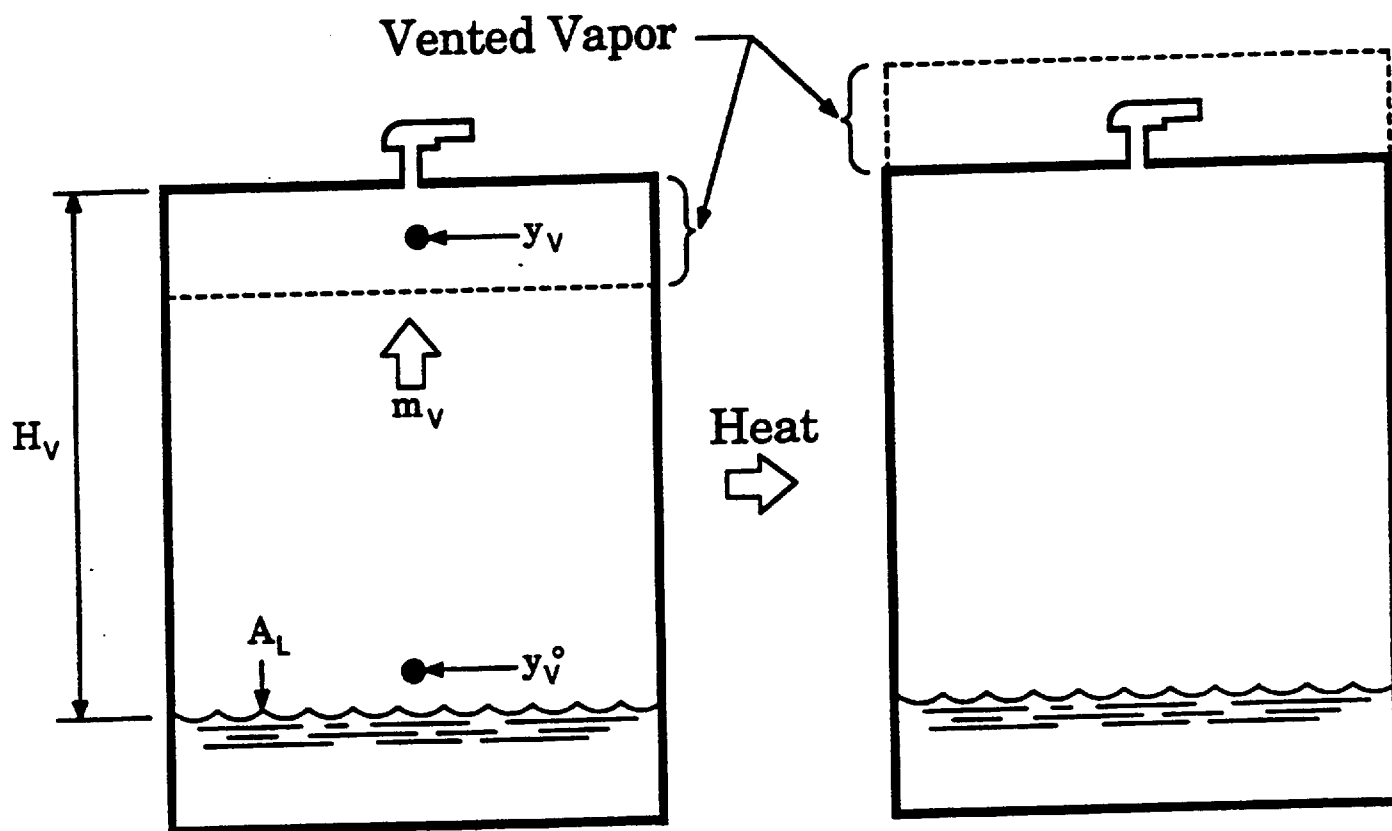


Figure B1 - Schematic of the Tank Vapor Space for the Vented Vapor Saturation Factor Analysis

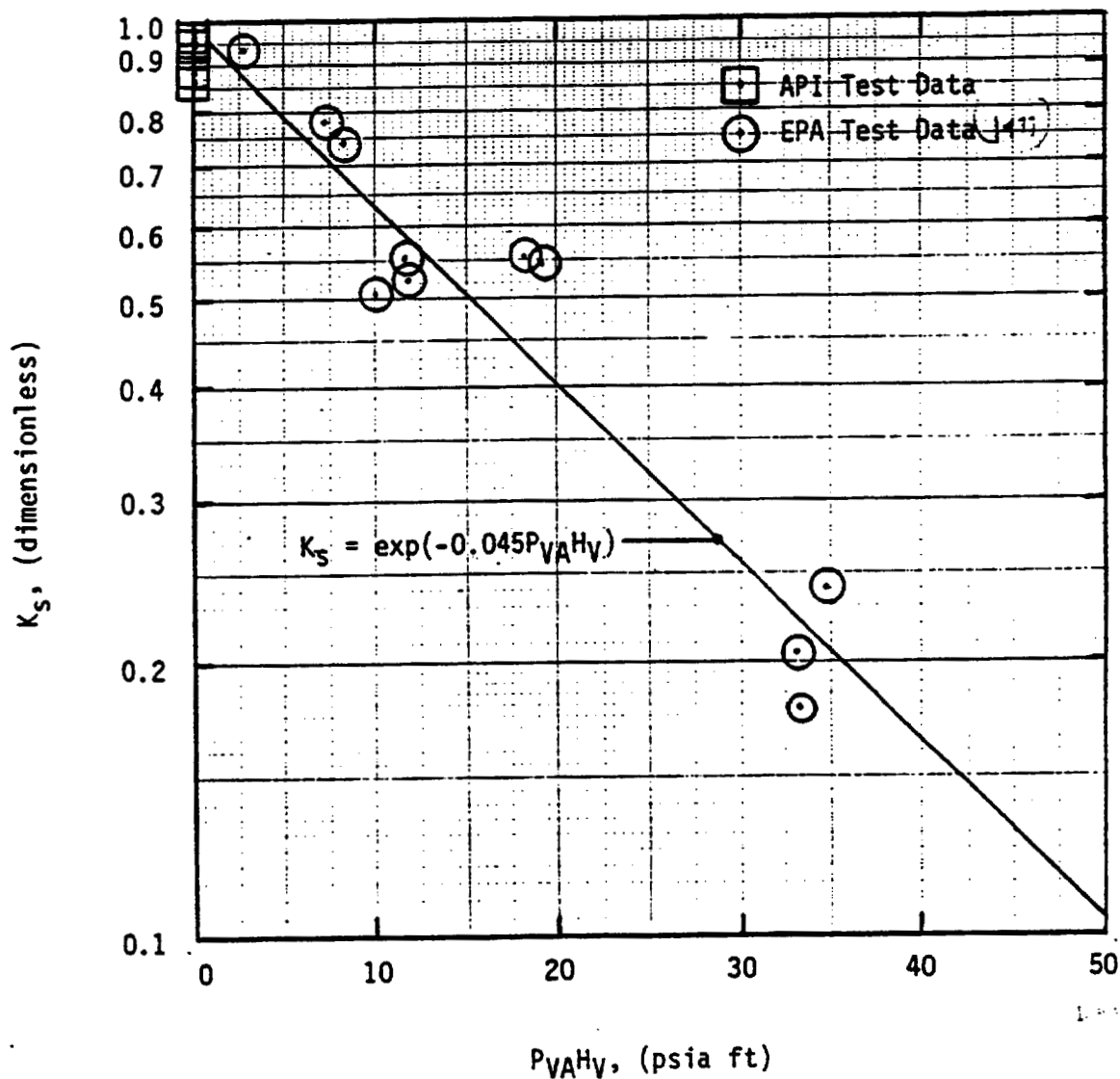


Figure B2 - Saturation Factor, K_S , Versus $P_{VA} H_V$ for the API and EPA Test Data

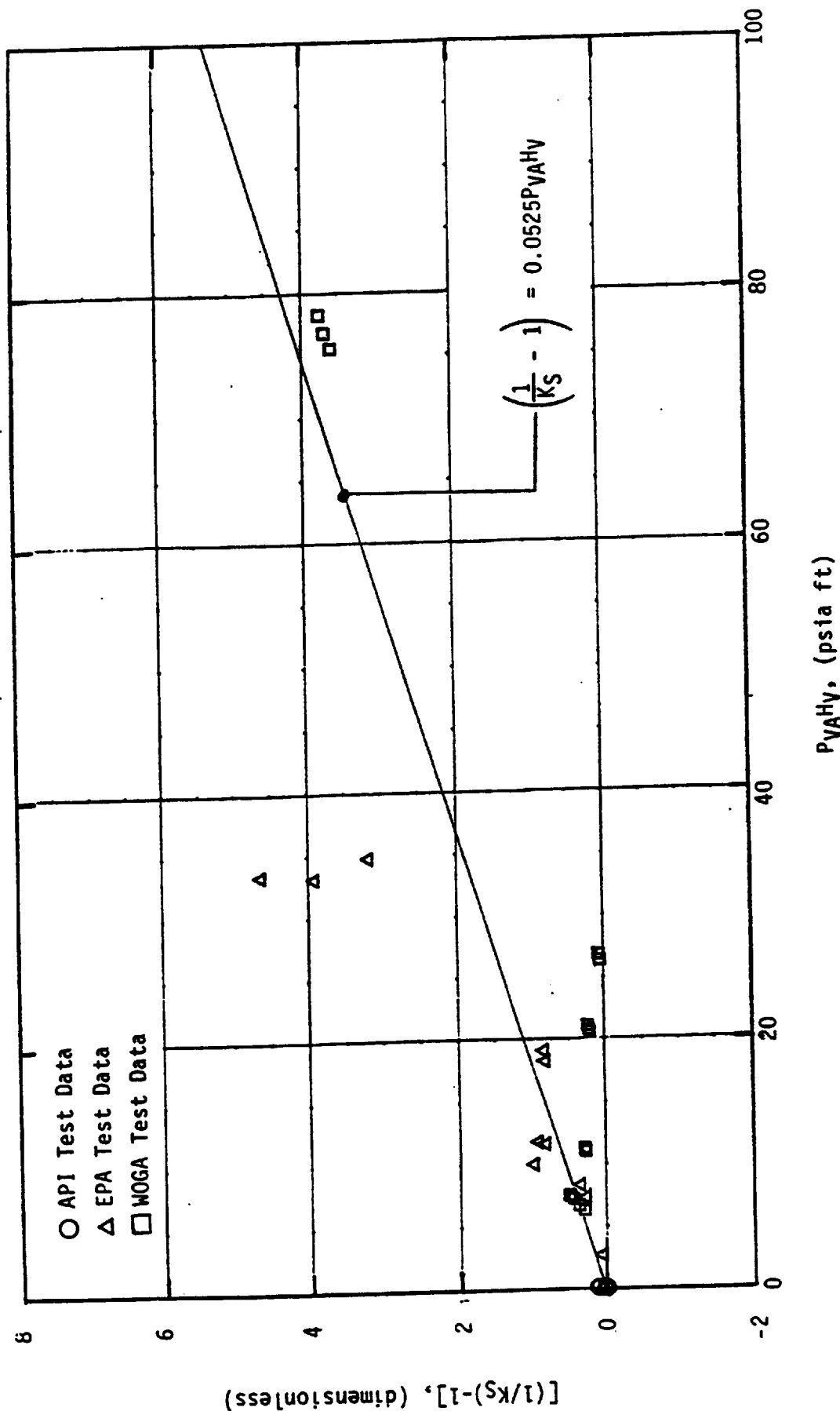


Figure B3 - Saturation Factor, K_S , Correlation

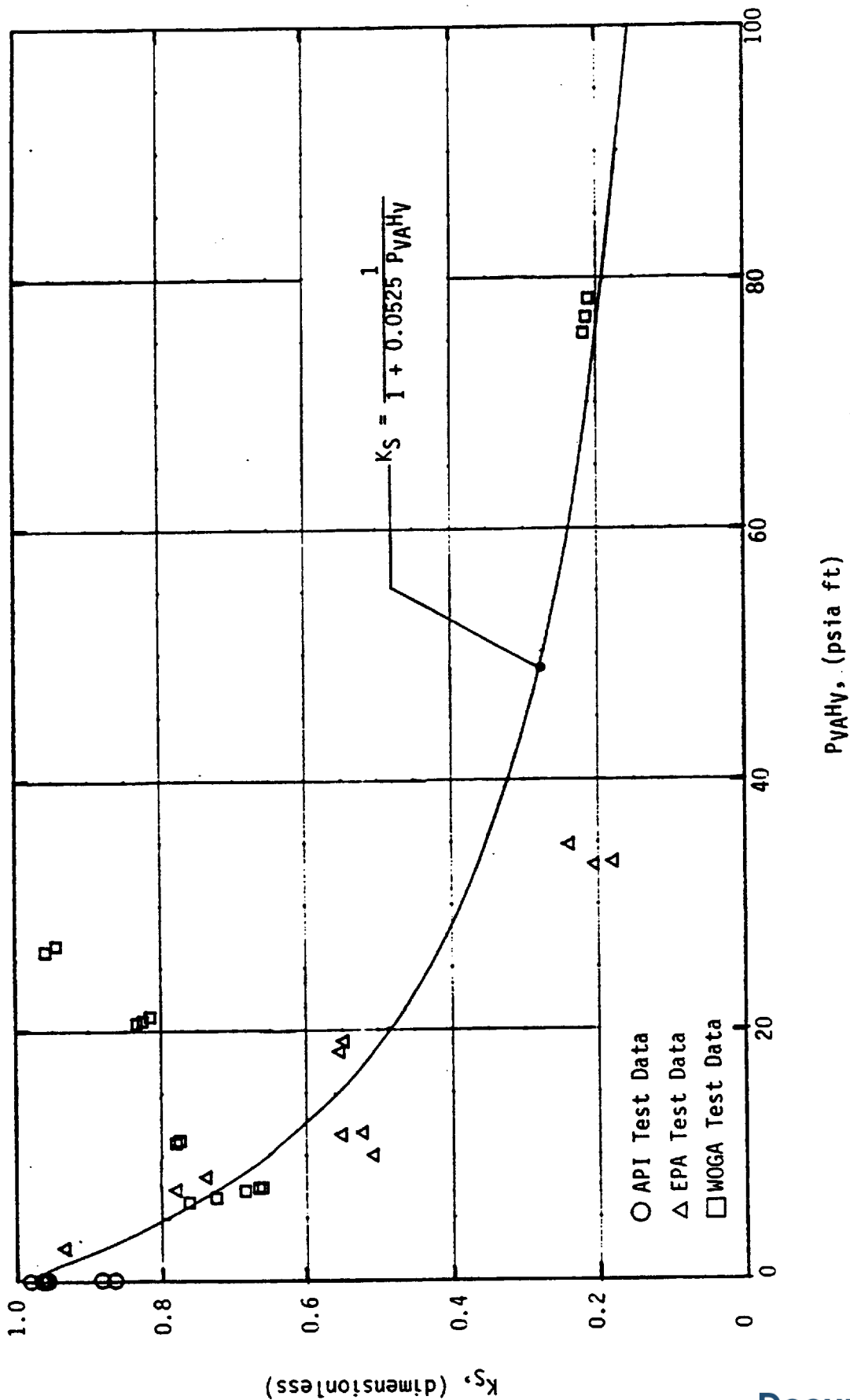


Figure 84 - Saturation Factor, K_s , Versus P_{VAHv} for the API, EPA and WOGA Test Data

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SECTION C

**DEVELOPMENT OF
VAPOR SPACE TEMPERATURE FACTOR, K_T**

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