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Oil Losses Problem in Oil and Gas Industries

Yulius Dedy Hermawan, Dedy Kristanto and Hariyadi

Abstract

Oil losses is a problem that often arises in oil and gas industries either in onshore or offshore area. There is a loss discrepancy between total quantities from shippers and measurement in the storage tanks; the total sending volume is lower than the measured volume in the mixing tank in a gathering station; this is known as oil losses. When this occurs, an agreement to determine a fair share of the losses must be made. There are two categories of oil losses, they are individual and group losses. Individual loss occurs when oil from one shipper has not been mixed yet with other oils. This includes emulsion and evaporative losses. Group loss occurs during mixing oils in the same storage tank or pipeline. Furthermore, by knowing the causes of oil losses, a way to minimize oil losses can be determined.

Keywords: Emulsion, Flash, Offset, Oil losses, Proportional, Shrinkage, Stratified

1. Introduction

Oil losses problem often arises in oil and gas industries either in onshore or offshore area. There is a loss discrepancy between total quantities from shippers and measurement in the storage tanks; the total sending volume is lower than the measured volume in the mixing tank; this is known as oil losses. When this occurs, an agreement to determine a fair share of the losses must be made. Hermawan et al. [1] have classified oil losses into two categories, they are (1) individual and (2) group losses.

1.1 Individual loss

Individual loss occurs when oil from one shipper has not been mixed yet with other oils. This includes emulsion and evaporative losses. In order to determine emulsion loss, basic sediment and water (BS and W) of oil should be measured. The net standard volume (NSV) excludes sediment, water, and free water. Evaporative loss occurs when light components are released from oil in the storage tank. This happens when the oil temperature in tank is higher than its bubble point.

1.2 Group loss

Figure 1 shows typical pipeline system and storage tank for oil gathering activity. The use of the same pipeline to transport the crude oil to a storage tank and oil mixing process either in the same temporary or final storage tank could come up the problem of oil losses. Group loss occurs during mixing oils in the same storage tank



Figure 1. Pipeline system and storage tank for oil gathering activity. (a) Pipeline System. (b) Storage Tank.

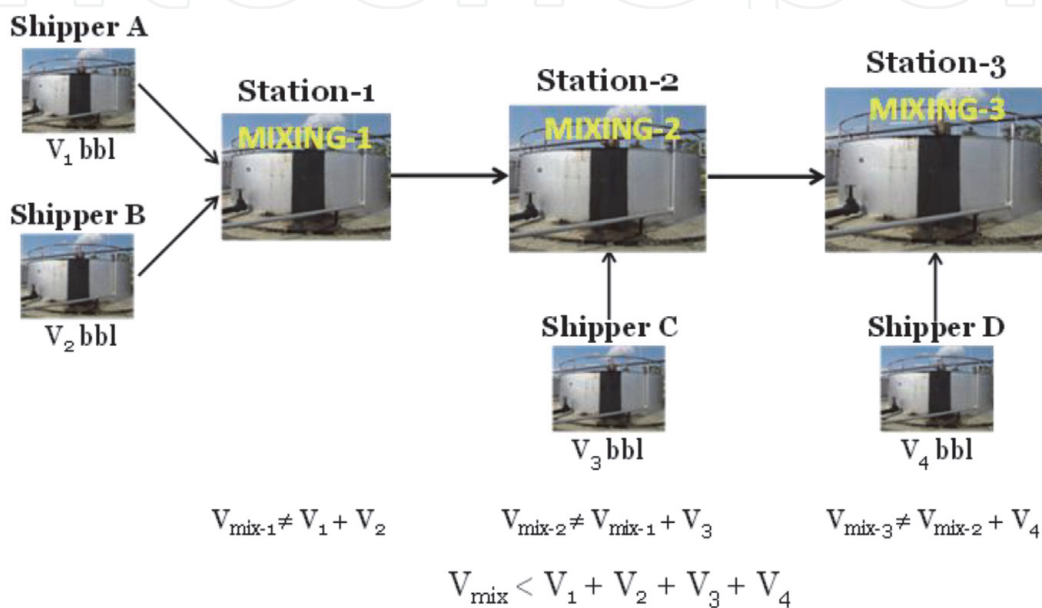


Figure 2. Typical oil mixing phenomena in gathering station.

or pipeline. Typical oil mixing phenomena in the gathering station is illustrated in **Figure 2**.

The specific characteristic which has a great effect on group loss is the specific gravity (SG) or API gravity. Petroleum can be classified based on its characteristics, for example density i.e., SG or API, (which indicates heavy oil or light oil), normal boiling point (which indicates the ease with which the oil evaporates), and viscosity (which indicates the ease with which the oil flows). There are five categories of the petroleum fluid, they are dry gas, wet gas, gas condensate, volatile oil, and black oil [2, 3]. The properties of petroleum fluids will change when they mix together in the same tank. In this case, the oil volume shrinkage occurs when two or more oils are mixed in the same storage tank. As shown in **Figure 2**, Shipper A and B undergo the mixing process 3 times, i.e., mixing in the Station-1, Station-2, and Station-3. This means that Shipper A and B will experience 3 times the volume depreciation. Shipper C and D experience the mixing phenomena twice and once, respectively. When compared to other Shippers, the volume of shrinkage for Shipper D will be less because it only experiences one mixing phenomena.

The group loss can also occur in the use of the same 3-phase-separator to separate the well stream into three phases of oil, gas, and water, as shown in **Figure 3**. The 3-phase-separator is often used in both onshore and offshore areas. In separators, gas is flashed from the liquids and free water is separated from the oil. These steps remove enough light hydrocarbons to produce a stable crude oil [4]. On the other

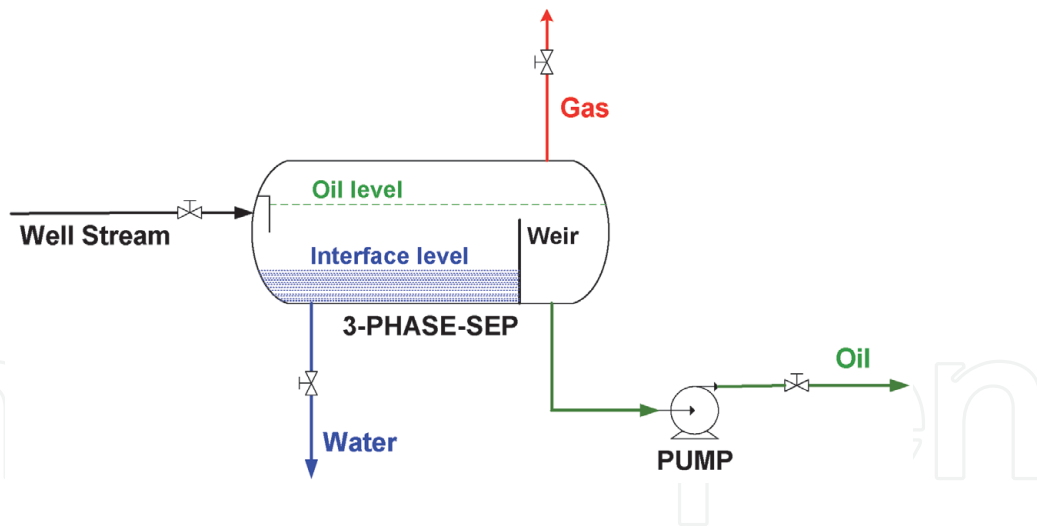


Figure 3.
 Typical 3-phase-separator in the oil and gas gathering station.

hand, setting and controlling of the interface level in 3-phase-separator must be seriously done in order to avoid oil losses due to the offset phenomena. In this case, offset means that water can overflow the weir and follow with oil to the oil storage tank, and vice versa, underflowing oil with the water stream [5].

2. Procedure of sharing oil losses

The typical block diagram of oil distribution and mixing phenomena as shown in **Figure 4** would be used as a case study of oil losses problem in the oil and gas industries. In this case, shippers are defined as the petroleum companies, both government and private companies that are members of the cooperation contract contractor. In general, the criteria for shippers are based on the type of oil produced from the oilfield for examples, heavy oil, light oil, and condensate.

When this study was carried out, the weather conditions are as follows: the air temperature varied from 26.7 to 28.7°C, and humidity varied from 71 to 82%. Climate data (from the Juanda Meteorological Station, Surabaya, Indonesia) shows an annual average rainfall of 1.969 mm/year. The ratio of the dry to wet months is

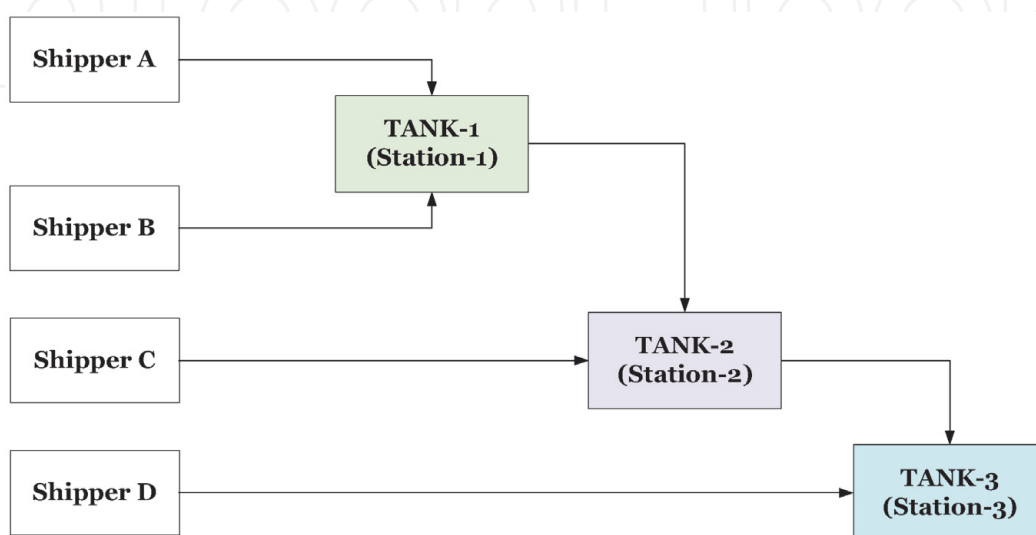


Figure 4.
 The typical block diagram of oil distribution and mixing phenomena.

0.5109 or 51.09%. The climate in the study location is relatively wet because the number of dry months is relatively the same as the number of wet months.

In this case, shipper A and B will have 3 times mixing in TANK-1, TANK-2, and TANK-3, respectively; Shipper C will have twice mixing in TANK-2 and TANK-3; while Shipper D has only once mixing in TANK-3. The tank criteria used in this case is the welded steel tank for storing petroleum at the atmospheric pressure accordance with PTK-013/PTK/II/2007, BPMIGAS, February 12, 2007, Decree of the Head of BPMIGAS: Operation and Maintenance of Petroleum Storage Tanks. Oil tank capacity depends on its production rate. In addition, the tank capacity also depends on its function, whether for temporary or final storage. TANK-1 and TANK-2 are the temporary storage tank with capacity @30,000 barrels, and Tank-3 is the final storage tank with capacity 900,000 barrels. Calculation of sharing oil losses can be determined with the following procedures.

2.1 Required data

The data required in the calculation of sharing oil losses are the gross production rate in barrel fluid per day (BFPD), the water cut (WC, %-volume), the tank's conditions (pressure and temperature), the oil specific gravity (SG_o), the formation water specific gravity (SG_w), basic sediment and water (BS&W, %-volume), and hydro carbon composition (%-mole). The required data for calculating of sharing oil losses are listed in **Tables 1** and **2**.

As shown in **Table 1**, all shippers produce fluid with different characteristic, water cut and BS&W. Shipper D produces condensate with water cut and BS&W equal to zero. All fluids are stored in the atmospheric storage tank (pressure of about 1 atm and temperature of about 30°C. Water cut is a parameter that shows the water content that is easily separated naturally from oil. While BS&W shows the amount of water and based sediment in the oil which is difficult to separate naturally. In other words, the BS&W separation can only be carried out with the aid of a separator such as a centrifuge.

Based on the water cut data, the oil rate of each shipper can be calculated. The oil rates after being separated from free water for shippers A, B, and C are 600, 1800, and 950 BOPD (barrel oil per day), respectively. But these rates are still the gross rate due to basic sediment and water content. The net standard volume (NSV) excludes sediment, water, and free water. The NSV is obtained from the gross volume minus free water and BS&W volume. In order to calculate the total sharing oil losses, the individual losses such as emulsion and evaporative losses must first be calculated.

Shipper	Production		Tank's Condition		Properties		
	Gross (BFPD)	WC (%-vol)	Press. (atm)	Temp. (°C)	SG_o	SG_w	BS&W (%-vol)
A	600	0	1	30	0.8881	1.0144	0.25
B	2000	10	1	30	0.8931	1.0135	0.25
C	1000	5	1	30	0.9043	1.0158	0.25
D*	400	0	1	30	0.8001	—	—
Total	4000						

*Shipper D produces condensate, BFPD: Barrel Fluid Per Day, WC: Water Cut in %-Vol, SG_o : Specific Gravity of oil, SG_w : Specific Gravity of formation water, BS&W: Basic sediment and water in %-Vol.

Table 1.

The required data: production rate, tank's condition, properties.

Component	Shipper			
	A	B	C	D
Metane (C1)	0.00	0.00	0.00	0.00
Etane (C2)	0.82	0.04	0.03	0.00
Propane (C3)	0.98	0.33	0.14	0.00
Butane (C4)	1.43	0.68	0.24	0.05
Pentane (C5)	1.76	1.01	0.43	30.48
Hexane (C6)	2.69	1.48	0.85	29.67
Heptane (C7)	5.04	4.17	3.11	25.85
Octane (C8)	8.37	8.15	6.88	12.37
Nonane (C9)	6.85	7.56	6.66	1.51
Decane (C10)	5.50	7.89	5.85	0.07
Undecane (C11)	4.89	5.56	6.03	0.00
Dodecane (C12)	3.00	5.49	4.88	0.00
Tridecane (C13)	3.85	6.54	5.98	0.00
Tetradecane (C14)	3.81	7.79	7.70	0.00
Pentadecane (C15)	9.22	11.06	11.83	0.00
Hexadecane (C16)	4.79	5.92	6.54	0.00
Heptadecane (C17)	7.43	6.54	7.61	0.00
Oktadecane (C18)	3.98	3.52	4.22	0.00
Nonadecane (C19)	3.12	2.61	3.44	0.00
Eicosane (C20)	2.62	1.73	2.48	0.00
Heneicosane (C21)	2.77	1.48	2.19	0.00
Docosane (C22)	2.90	1.32	1.95	0.00
Tricosane (C23)	2.99	1.28	1.89	0.00
Tetracosane (C24)	2.12	1.01	1.45	0.00
Pentacosane (C25)	1.64	1.05	1.41	0.00
Hexacosane (C26)	1.43	0.90	1.18	0.00
Heptacosane (C27)	1.56	1.01	1.18	0.00
Octacosane (C28)	1.25	1.25	1.33	0.00
Nonacosane (C29)	1.43	1.55	0.98	0.00
Triacotane (C30)	1.77	1.07	1.55	0.00
Total	100.00	100.00	100.00	100.00

Table 2.
 The required data: hydrocarbon composition (%-mole).

2.2 Calculation of emulsion correction factor

BS&W is required to calculate the emulsion losses. In this case, BS&W in oils shipper A, B, and C are taken the same 0.25%-vol (**Table 1**). The BS&W in oil of shipper D is zero since this oil is a typical condensate.

For calculation emulsion losses, the empiric emulsion equations for all shippers must be determined. The emulsion parameters (a_1, b_1, a_2, b_2) for each shipper are

shown in **Table 3**. The empiric emulsion equations and emulsion loss can be determined with following procedure:

- a. First, we make a curve of percentage of the addition of the volume of formation water (in %vol) versus the calculated SG. The first curve produces linear equation:

$$Y_1 = a_1X_1 + b_1 \tag{1}$$

where X_1 is the percentage of the addition of the volume of formation water (in %vol), Y_1 is the calculated SG, a_1 and b_1 are constants. The calculated SG is:

$$SG_{\text{calculated}} = (1 - X_w)SG_o + X_wSG_w \tag{2}$$

where X_w is water volume fraction in oil, SG_w is specific gravity of formation water, and SG_o is specific gravity of oil. The correlation between the calculated SG and the percentage of the addition of the volume of formation water for shippers A, B, and C is shown in **Figure 5**.

Shipper	$X_1 = \text{BS\&W}$ (%Vol)	$Y_1 = a_1X_1 + b_1$		$Y_2 = a_2X_2 + b_2$		$X_2 = (Y_2 - b_2)/a_2$ (%Vol)	ECF $X_1 - X_2$ (%Vol)	
		a_1	b_1	$Y_1 = Y_2$	a_2			b_2
A	0.25	0.0013	0.8881	0.8884	0.0029	0.8881	0.1121	0.1379
B	0.25	0.0012	0.8931	0.8934	0.0016	0.8931	0.1875	0.0625
C	0.25	0.0011	0.9043	0.9046	0.0016	0.9043	0.1719	0.0781
D	0	0	0	0	0	0	0	0

Table 3.
Emulsion parameters.

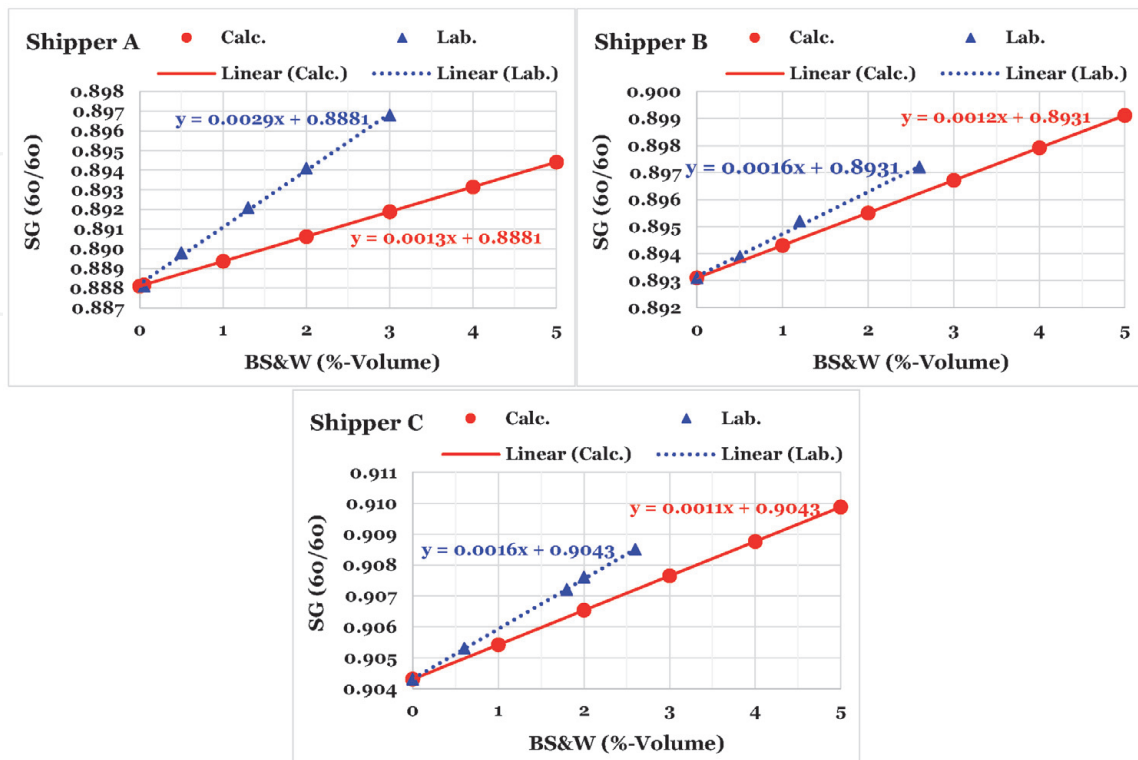


Figure 5.
Emulsion profile of Shippers A, B, and C.

- b. Simulation of oil and water emulsion is carried out by mixing of crude oil and its formation water at some levels of water volume, and the BS&W and SG of mixed oil–water are then measured.
- c. Then, the changes of BS&W and SG are plotted in a curve. This second curve results linear equation:

$$Y_2 = a_2X_2 + b_2 \quad (3)$$

where X_2 is the measured BS&W, Y_2 is the measured SG, a_2 and b_2 are constants. The correlation between the measured SG and measured BS&W for shippers A, B, and C is shown in **Figure 5**

- d. Then, the Eqs. (1) and (3) are utilized to determine the emulsion loss. The measured BS&W of oil is taken as X_1 in Eq. (1) to calculate Y_1 . The calculation result of Y_1 is then used to calculate X_2 using Eq. (3).
- e. Emulsion correction factor (ECF) in %Vol can be determined with the following equation:

$$ECF = X_1 - X_2 \quad (4)$$

The resulted ECF for all shippers are listed in **Table 3**.
 The constants of a_1 , b_1 , a_2 , and b_2 , are taken from **Figure 5**.

2.3 Calculation of evaporative correction factor

The flash calculation is usually used in the application of Vapor–Liquid–Equilibrium (VLE). Just like the name, a liquid will “flashes” or partially evaporates

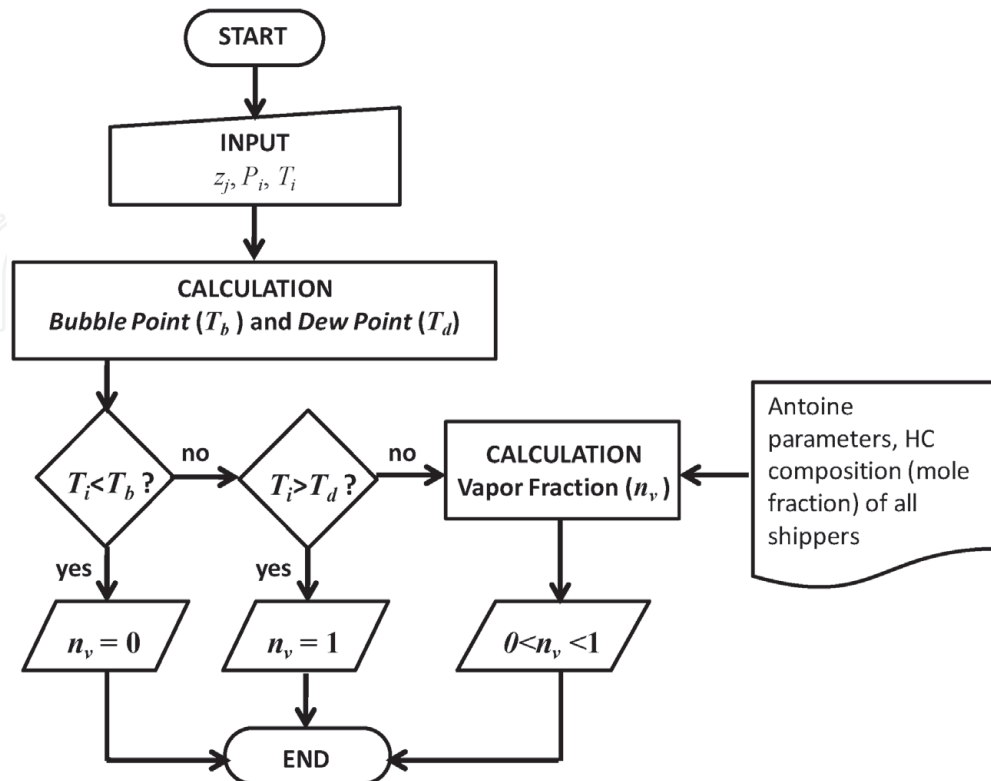


Figure 6.
 Flash Calculation algorithm [1].

Component	$P_{vap} = \exp\left(a + \frac{b}{(T+c)} + d \ln(T) + eT^f\right)$					
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>
Metane (C1)	31.35	-1307.52	0.00	-3.26	0.00	2.00
Etane (C2)	44.01	-2568.82	0.00	-4.98	0.00	2.00
Propane (C3)	52.38	-3490.55	0.00	-6.11	0.00	2.00
Butane (C4)	66.95	-4604.09	0.00	-8.25	0.00	2.00
Pentane (C5)	63.33	-5117.78	0.00	-7.48	0.00	2.00
Hexane (C6)	70.43	-6055.60	0.00	-8.38	0.00	2.00
Heptane (C7)	78.33	-6947.00	0.00	-9.45	0.00	2.00
Octane (C8)	87.00	-7890.60	0.00	-10.63	0.00	2.00
Nonane (C9)	111.98	-9558.50	0.00	-14.27	0.00	2.00
Decane (C10)	123.14	-10635.20	0.00	-15.81	0.00	2.00
Undecane (C11)	121.16	-11079.20	0.00	-15.38	0.00	2.00
Dodecane (C12)	125.19	-11737.00	0.00	-15.87	0.00	2.00
Tridecane (C13)	14.12	-3892.90	-98.93	0.00	0.00	2.00
Tetradecane (C14)	143.58	-13893.70	0.00	-18.30	0.00	2.00
Pentadecane (C15)	152.64	-14762.20	0.00	-19.55	0.00	2.00
Heksadecane (C16)	225.02	-18736.50	0.00	-30.23	0.00	2.00
Heptadecane (C17)	14.14	-4294.53	-124.00	0.00	0.00	2.00
Oktadecane (C18)	14.11	-4361.79	-129.90	0.00	0.00	2.00
Nonadecane (C19)	14.14	-4450.43	-135.50	0.00	0.00	2.00
Eicosane (C20)	196.75	-19441.00	0.00	-25.53	0.00	2.00
Heneicosane (C21)	133.88	-17129.00	0.00	-15.87	0.00	6.00
Docosane (C22)	147.40	-18406.00	0.00	-17.69	0.00	6.00
Tricosane (C23)	212.92	-21841.00	0.00	-27.53	0.00	2.00
Tetracosane (C24)	204.51	-21711.00	0.00	-26.26	0.00	2.00
Pentacosane (C25)	152.24	-19976.00	0.00	-18.16	0.00	6.00
Hexacosane (C26)	148.73	-20116.00	0.00	-17.62	0.00	6.00
Heptacosane (C27)	148.85	-20612.00	0.00	-17.55	0.00	6.00
Octacosane (C28)	285.21	-28200.00	0.00	-37.54	0.00	2.00
Nonacosane (C29)	201.65	-24971.00	0.00	-24.75	0.00	6.00
Triacotane (C30)	188.81	-22404.00	0.00	-23.36	0.00	6.00

Table 4.

Antoine parameters for hydrocarbon: T in K; P in kPa.

at a system pressure, when the liquid temperature is higher than its bubble temperature, producing a two-phase system of vapor and liquid in equilibrium [6]. Flash calculation is an integral part of process engineering calculations. Someone uses the flash calculation in order to determine the amounts (in moles) of hydrocarbon liquid and gas coexisting in a vessel at a given pressure and temperature. The flash calculation is also accomplished to determine the composition of the existing hydrocarbon phases [7].

No.	Procedure	Formula
1	Input data: vapor fraction $n_v = 0$, pressure P , and HC composition z_i of all shippers (i)	$n_{vi} = 0, P_i, z_i$
2	Calculation of vapor pressure of component j with guessed temperature T_i	$P_{vj} = \exp\left(a_j + \frac{b_j}{(T_i+c_j)} + d_j \ln(T_i) + e_j T_i^{f_j}\right)$
3	Calculation of equilibrium ratio of component K_j	$K_j = \frac{P_{vj}}{P_i}$
4	Calculation of objective function $f(n_{vi})$, where $n_v = 0$	$f(n_{vi}) = \sum_{j=1}^n y_j - \sum_{j=1}^n x_j = \sum_{j=1}^n \frac{z_j(K_j-1)}{n_v K_j - n_v + 1} = 0$
5	Repeat procedure number 2 to 4 with other value of T_i until $f(n_{vi}) = 0$	same with no. 4

Notes: i = shipper; j = component of hydro carbon.

Table 5.
 Calculation procedure of bubble point T_b [1].

No.	Procedure	Formula
1	Input data: vapor fraction $n_v = 1$, pressure P , and HC composition z_i of all shippers (i)	$n_{vi} = 1, P_i, z_i$
2	Calculation of vapor pressure of component j with guessed temperature T_i	$P_{vj} = \exp\left(a_j + \frac{b_j}{(T_i+c_j)} + d_j \ln(T_i) + e_j T_i^{f_j}\right)$
3	Calculation of equilibrium ratio of component K_j	$K_j = \frac{P_{vj}}{P_i}$
4	Calculation of objective function $f(n_{vi})$, where $n_v = 1$	$f(n_{vi}) = \sum_{j=1}^n y_j - \sum_{j=1}^n x_j = \sum_{j=1}^n \frac{z_j(K_j-1)}{n_v K_j - n_v + 1} = 0$
5	Repeat procedure number 2 to 4 with other value of T_i until $f(n_{vi})=0$	same with no. 4

Notes: i = shipper; j = component of hydro carbon.

Table 6.
 Calculation procedure of dew point T_d [1].

Flash calculation method is used to calculate evaporative loss. The three important parameters used in the flash calculation are pressure (P), temperature (T), and vapor fraction (n_v). Evaporation is indicated by the value of vapor fraction [7]. The value of vapor fraction (n_v) ranges in between 0 to 1. If the vapor fraction equals 0, the fluid is in liquid phase, if it equals 1, the fluid is in gas phase. Elseif it is in between 0 and 1 ($0 < n_v < 1$), the fluid is in mixed-liquid-vapor phase; in other words, part of light component in fluid evaporates; this causes oil loss due to flash phenomena [1].

Figure 6 shows the flash calculation algorithm. The data required in the flash calculation are hydrocarbon composition (z_i), pressure (P_i), and temperature (T_i) of each shipper fluid. The intended pressure (P_i) in this case is the fluid pressure in a storage tank. The fluids of all shippers are stored in atmospheric tanks with temperatures about 30°C (**Table 1**). The Antoine equation which is used to calculate flash correction factor (FCF, in %Vol) is taken from the equation “Anto5” in UniSim Design R451 Honeywell [8], and written as follows:

$$P_{vap j} = \exp\left(a_j + \frac{b_j}{(T + c_j)} + d_j \ln(T) + e_j T^{f_j}\right) \quad (5)$$

No.	Procedure	Formula
1	Input data: temperature T , pressure P , and HC composition z_i of all shippers (i)	T_i, P_i, z_i
2	Calculation of vapor pressure of component j	$P_{vj} = \exp\left(a_j + \frac{b_j}{(T_i+c_j)} + d_j \ln(T_i) + e_j T_i^{f_j}\right)$
3	Calculation of equilibrium ratio of component K_j	$K_j = \frac{P_{vj}}{P_i}$
4	Calculation of objective function $f(n_{vi})$ with guessed vapor fraction n_v	$f(n_{vi}) = \sum_{j=1}^n y_j - \sum_{j=1}^n x_j = \sum_{j=1}^n \frac{z_j(K_j-1)}{n_v K_j - n_v + 1} = 0$
5	Repeat procedure number 2 to 4 with other value of n_v until $f(n_{vi})=0$	same with no. 4

Table 7.
Calculation procedure of vapor fraction n_v [1].

Shipper	Bubble point T_b (°C)	Dew point T_d (°C)
A	57.91	341.60
B	131.25	330.60
C	158.48	335.28
D	61.73	92.00

Table 8.
Normal bubble and dew points of crude oils.

where $P_{vap j}$ is vapor pressure of component j (in kPa), T is temperature of system (in K), and $a_j, b_j, c_j, d_j, e_j, f_j$ are Antoine parameters for each component j and listed in **Table 4**.

The flash correction factor (FCF), in %Vol, must be calculated in order to know the oil losses due to flash phenomena. The FCF can be determined with following procedure:

- a. Inputting data: fluid pressure (P) and temperature (T) in tank, hydrocarbon composition (z).
- b. Calculations of bubble point (T_b) at the atmospheric pressure. Bubble point is saturated condition at $n_v = 0$. Calculation procedure of T_b is written in **Table 5**.
- c. Calculation of dew point (T_d) at the atmospheric pressure. Dew point is saturated condition at $n_v = 1$. Calculation procedure of T_d is written in **Table 6**.
- d. Calculation of vapor fraction n_v . As shown in **Figure 6**, n_v will equal to zero if the fluid temperature in tank (T) is less than its bubble point (T_b), this shows that the fluid is in liquid phase. The value of n_v will equal to one if T is greater than T_d , this indicates that the fluid is in vapor phase. In other case, the value of n_v is in between 0 and 1, if T is located in between T_b and T_d , this shows that the fluid is in the vapor-liquid mixture phase. **Table 7** shows the calculation procedure of n_v .
- e. Flash correction factor (FCF) can be determined by the following equation:

Shipper	Gross (barrel)	WC (%Vol)	WCV (barrel)	OFWV (barrel)	BS&W (%Vol)	ECF (%Vol)	EV (barrel)	FCF (%Vol)	VV (barrel)	TIL (barrel)	NSV (barrel)
A	600	0	0	600	0,25	0.1379	0.83	0	0	0.83	599.17
B	2000	10	200	1800	0,25	0.0625	1.13	0	0	201.13	1798.88
C	1000	5	50	950	0,25	0.0781	0.74	0	0	50.74	949.26
D	400	0	0	400	0	0	0	0	0	0	400
Total	4000		250	3750			2.69		0	252.69	3747.31

WC: Water Cut (%Vol), WCV: Water Cut Volume (barrel), OFWV: Oil Free Water Volume (barrel), BS&W: Basic sediment and water (%Vol), ECF: Emulsion Correction Factor (%Vol), EV: Emulsion Volume (barrel), FCF: Flash Correction Factor (%Vol), VV: Vapor Volume (barrel), TIL: Total Individual Losses (barrel), NSV: Net Standard Volume (barrel).

Table 9.
Total individual losses.

GROUP	$S_h (\%) = a \times L_c \times (100 - L_c)^b \times (\Delta API)^c$		
	Constant		
	<i>a</i>	<i>b</i>	<i>c</i>
TANK-1	4.86×10^{-5}	0.819	0.98
TANK-2	4.86×10^{-5}	0.819	0.60
TANK-3	4.86×10^{-5}	0.819	0.24

The constants of a, b, c are referenced from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta [9].

Table 10.
Parameters a, b, c in API 12.3 equations.

No	Procedure	Formula
1	Input data: net volume (V_{net-i}), specific gravity (SG_i) for each shipper (<i>i</i>)	V_{net-i}, SG_i
2	Calculation of $^{\circ}API_i$ for each shipper (<i>i</i>)	$^{\circ}API_i = \frac{141.5}{SG_i} - 131.5$
3	a. Calculation of the 1st total volume (V_{tot1})	$V_{tot1} = V_{net}(1) + V_{net}(2)$
	b. Calculation of the 1st %-Light component (Lc_1)	if $SG(1) < SG(2)$: $Lc_1 = \frac{V_{net}(1)}{V_{tot1}} 100$ if $SG(1) > SG(2)$: $Lc_1 = \frac{V_{net}(2)}{V_{tot1}} 100$
	c. Calculation of the 1st $\Delta^{\circ}API$ ($\Delta^{\circ}API_1$)	$\Delta^{\circ}API_1 = \text{abs}(^{\circ}API(1) - ^{\circ}API(2))$
	d. Calculation of the 1st %-shrinkage (S_{h1})	$S_{h1}(\%) = a Lc_1(100 - Lc_1)^b (\Delta^{\circ}API_1)^c$
	e. Calculation of the 1st shrinkage volume (V_{sh1})	$V_{sh1} = \frac{S_{h1}}{100} V_{tot1}$
	f. Calculation of the 1st mixed volume (V_{mix1})	$V_{mix1} = V_{tot1} - V_{sh1}$
	g. Calculation of the 1st mixed SG (SG_{mix1})	$SG_{mix1} = \frac{V_{net}(1)SG(1) + V_{net}(2)SG(2)}{V_{mix1}}$
	h. Calculation of the 1st mixed $^{\circ}API$ ($^{\circ}API_{mix1}$)	$^{\circ}API_{mix1} = \frac{141.5}{SG_{mix1}} - 131.5$
4	a. Calculation of the 2nd total volume (V_{tot2})	$V_{tot2} = V_{mix1} + V_{net}(3)$
	b. Calculation of the 2nd %-Light component (Lc_2)	if $SG_{mix1} < SG(3)$: $Lc_2 = \frac{V_{mix1}}{V_{tot2}} 100$ if $SG_{mix1} > SG(3)$: $Lc_2 = \frac{V_{net}(3)}{V_{tot2}} 100$
	c. Calculation of the 2nd $\Delta^{\circ}API$ ($\Delta^{\circ}API_2$)	$\Delta^{\circ}API_2 = \text{abs}(^{\circ}API_{mix1} - ^{\circ}API(3))$
	d. Calculation of the 2nd %-shrinkage (S_{h2})	$S_{h2}(\%) = a Lc_2(100 - Lc_2)^b (\Delta^{\circ}API_2)^c$
	e. Calculation of the 2nd shrinkage volume (V_{sh2})	$V_{sh2} = \frac{S_{h2}}{100} V_{tot2}$
	f. Calculation of the 2nd mixed volume (V_{mix2})	$V_{mix2} = V_{tot2} - V_{sh2}$
	g. Calculation of the 2nd mixed SG (SG_{mix2})	$SG_{mix2} = \frac{V_{mix1}SG_{mix1} + V_{net}(3)SG(3)}{V_{mix2}}$
	h. Calculation of the 2nd mixed $^{\circ}API$ ($^{\circ}API_{mix2}$)	$^{\circ}API_{mix2} = \frac{141.5}{SG_{mix2}} - 131.5$
5	Calculation of net-corrected-volume in tank (V_{nc})	$V_{nc} = V_{mix2}$
6	Calculation of group-shrinkage-losses in tank (V_{shg})	$V_{shg} = V_{sh1} + V_{sh2}$

*The oil mixing stratification in each tank can be seen in Table 12.

Table 11.
Calculation procedure of shrinkage volume in tanks.*

$$FCF = n_v \times 100\% \quad (6)$$

where FCF is in %Vol.

The calculation results of T_b and T_d for all shippers are listed in **Table 8**. Since the fluid storage temperatures in tanks for all shippers are lower than their bubble points, all fluids are in liquid phase. There are no evaporative losses.

2.4 Calculation of individual loss

Individual loss consists of emulsion and evaporative losses. Individual loss for each shipper is listed in **Table 9**. Shipper B produces the biggest individual loss, i.e., 201.13 barrel, due to its high water cut and BS&W. The total individual loss (TIL) is 252.69 barrel. Finally, the net standard volume (NSV) that excludes sediment, water, and free water is 3747.31 barrel. The NSV is then used to calculate the shrinkage volume factor in the group losses.

2.5 Calculation of shrinkage correction factor

A shrinkage loss is a group loss in oils mixing. The modified equation of API 12.3 is used for calculating of shrinkage losses and defined as follows:

$$S_h(\%) = a L_c (100 - L_c)^b (\Delta^\circ \text{API})^c \quad (7)$$

where a , b , and c are constants of modified API 12.3 as listed in **Table 10**, L_c is %-light component, $\Delta^\circ \text{API}$ is $^\circ \text{API}$ difference between $^\circ \text{API}$ of shipper one and other, and S_h is shrinkage volume percentage (in %Vol).

As written in McCain [10], the API gravity for each shipper is defined as follows:

$$^\circ \text{API}_i = \frac{141.5}{SG_i} - 131.5 \quad (8)$$

where $^\circ \text{API}_i$ is API gravity of shipper i , and SG_i is specific gravity ($60^\circ/60^\circ$) of shipper i . Calculation procedure of shrinkage volume in tanks is shown in **Tables 11 and 12**.

2.6 Determination of sharing oil losses

Sharing oil losses can be determined with 2 methods, they are Proportional Method, and Stratified Method [1].

(i)	Shippers' oil mix in Tank		
	TANK-1	TANK-2	TANK-3
(1)	Shipper A	TANK-1	TANK-2
(2)	Shipper B	Shipper C	Shipper D

Hermawan et al. [1].

Table 12.
 The oil mixing stratification in each tank.

Shipper	NSV (barrel)	SG	x volume fraction	x/SG	Shrinkage loss	
					Volume (barrel)	SCF (%Vol)
A	599.17	0.8881	0.1600	0.1800	0.72	0.12
B	1798.88	0.8931	0.4800	0.5375	2.14	0.12
C	949.26	0.9043	0.2533	0.2801	1.11	0.12
D	400.00	0.8001	0.1067	0.1334	0.53	0.13
Total	3747.31		1.0000	1.1311	4.49	
Net Corrected Volume in the last tank (barrel)				3742.81		
Total shrinkage loss (barrel)				4.49		

NSV: Net Standard Volume (barrel); SG: Specific Gravity; x: volume fraction; SCF: Shrinkage Correction Factor (%Vol).

Table 13.
Proportional sharing losses results.

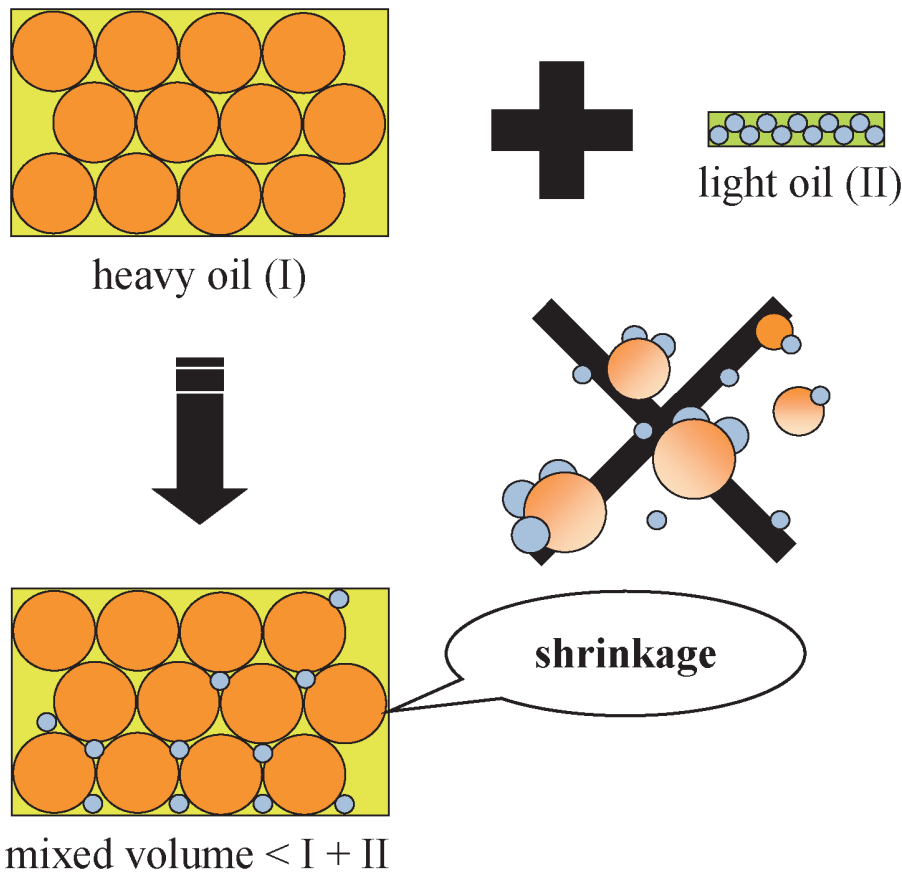


Figure 7.
Shrinkage volume illustration from mixing phenomenon of light and heavy oils [1].

2.7 Proportional method

In oil and gas industries, the proportional method is frequently utilized to determine sharing oil losses. The operator measures the total received volume of oil in TANK-3 at the last station (see **Figure 2**). This measured volume value represents the net corrected volume (NCV) which does not take into account the mixing event at the previous station.

SHIPPER			Stratified-1				Stratified-2				Stratified-3				Total Shrinkage Loss	
			(Mixing in Tank-1 of Station-1)				(Mixing in Tank-2 of Station-2)				(Mixing in Tank-3 of Station-3)					
Sending Point			Shrinkage loss		Corrected Factor		Shrinkage loss		Corrected Factor		Shrinkage loss		Corrected Factor		Vol.	SCF
Shipper	NSV (bbl)	SG	(bbl)	SCF (%)	(bbl)	SG	(bbl)	SCF (%)	(bbl)	SG	(bbl)	SCF (%)	(bbl)	SG	(bbl)	(%)
A	599.17	0.8881	0.22	0.04	598.95	0.8919	0.52	0.09	598.43	0.8954	0.11	0.02	598.32	0.8852	0.86	0.14
B	1798.88	0.8931	0.67	0.04	1798.21	0.8919	1.55	0.09	1796.65	0.8954	0.34	0.02	1796.31	0.8852	2.56	0.14
total	2398.05		0.89													
NCV Tank-1 (bbl)			2397.15													
Sub-total shrinkage loss (bbl)			0.89													
C					949.26	0.9043	0.81	0.09	948.45	0.8954	0.18	0.02	948.27	0.8852	0.99	0.10
total			3346.41		2.88											
NCV Tank-2 (bbl)					3343.53											
Sub-total shrinkage loss (bbl)					2.88											
D									400.00	0.8001	0.08	0.02	399.92	0.8852	0.08	0.02
total									3743.53		0.72		3742.81		4.49	
NCV Tank-3 (bbl)													3742.81			
Sub-total shrinkage loss (bbl)													0.72			

NSV: Net Standard Volume [barrel]; SCF: Shrinkage Correction Factor [%Vol]; SG: Specific Gravity.

Table 14.
Stratified sharing losses results.

The total shrinkage volume ($V_{sh-prop}$) is the difference volume between the total volume sent from all shippers and the net corrected volume as written below:

$$V_{sh-prop} = \sum_{i=1}^n V_i - V_{nc (TANK-3)} \quad (9)$$

where V_i is net standard volume of shipper i , and $V_{nc (TANK-3)}$ is the net-corrected-volume in TANK-3. The proportional shrinkage volume for each shipper (ξ_{prop_i}) can be calculated as follows:

$$\xi_{prop_i} = \frac{x_i (1/SG_i)}{\sum_{i=1}^n x_i (1/SG_i)} V_{sh-prop} \quad (10)$$

where x_i is volume fraction of shipper i as defined below:

$$x_i = \frac{V_i}{\sum_{i=1}^n V_i} \quad (11)$$

The proportional shrinkage correction factor (SCF_{prop_i} in %Vol) for each shipper can then be calculated as follows:

$$SCF_{prop_i} = \frac{\xi_{prop_i}}{V_i} \times 100\% \quad (12)$$

The shrinkage correction factors (SCF) with proportional method are listed in **Table 13**. The total shrinkage loss is 4.49 barrel. The SCF for each shipper is almost the same, i.e., 0,12%-Vol. When compared with other shippers, the shipper D has the highest value of SCF, i.e., 0,13%-Vol, because the oil of shipper D is categorized as condensate. Condensate which is also known as a light oil or gas oil has different characteristics with the heavy oil. The light oil has a low density with small molecular size. The molecular size of light oil is smaller than heavy oil, so it is understandable that when they mix together, shrinkage will occur geometrically as shown in **Figure 7**. This phenomenon is in accordance with the observations of Erno et al. [11], James [12], Shanshool et al. [13], and Hermawan et al. [1]. The proportional method is considered unfair since the last shipper who experienced a few mixing processes also bears losses of other upstream shippers.

Shipper	Sending Point		Mixing quantity	Shrinkage Losses			
	NSV (barrel)	SG		Proportional		Stratified	
			(bbl)	SCF (%)	(bbl)	SCF (%)	
A	599.17	0.8881	3	0.72	0.12	0.86	0.14
B	1798.88	0.8931	3	2.14	0.12	2.56	0.14
C	949.26	0.9043	2	1.11	0.12	0.99	0.10
D	400.00	0.8001	1	0.53	0.13	0.08	0.02
Total	3747.31			4.49		4.49	
<i>Net corrected volume in last tank = 3742.81</i>				barrel			

NSV: Net Standard Volume (barrel); SCF: Shrinkage Correction Factor (%Vol); SG: Specific Gravity.

Table 15.
Comparison between proportional and stratified results.

2.8 Stratified Method

The stratified method is the new method proposed by Hermawan et al. [1] where the net corrected volume (NCV) is calculated stratify from tank to tank as shown in **Tables 11** and **12**. The shrinkage volume is calculated for every mixing in the tank. Therefore, more often oil mixes with others; its volume will be more decreased.

The shrinkage volume for shippers A and B in TANK-1 is written as follows:

$$\xi_{st-Ii} = \frac{x_i(1/SG_i)}{\sum_{i=1}^n x_i(1/SG_i)} V_{shg-I} \quad (13)$$

where ξ_{st-Ii} is shrinkage volume for shipper i (A, B) in TANK-1, and V_{shg-I} is the group shrinkage volume in TANK-1. The shrinkage volume for shipper C and TANK-1 (mix A-B) in TANK-2 can be calculated with the following equation:

$$\xi_{st-IIi} = \frac{x_i(1/SG_i)}{\sum_{i=1}^n x_i(1/SG_i)} V_{shg-II} \quad (14)$$

Shipper	A	B	C	D	TOTAL
Gross rate (BFPD)	600,00	2.000,00	1.000,00	400,00	4.000,00
Water Cut, WC, (%Vol)	—	10,00	5,00	—	
Water Cut Volume, WCV, (barrel)	—	200,00	50,00	—	
Oil free-water volume, OFWV, (barrel)	600,00	1.800,00	950,00	400,00	3.750,00
Basic sediment and water, BS&W (%Vol)	0,25	0,25	0,25	—	
Emulsion Corection Factor, ECF, (%Vol)	0,1379	0,0625	0,0781	—	
Emulsion Volume, EV, (barrel)	0,83	1,13	0,74	—	2,69
Corrected Volume, CV, (barrel)	599,17	1.798,88	949,26	400,00	3.747,31
Flash Correction Factor, FCF, (%Vol)	—	—	—	—	
Vapour Volume, VV, (barrel)	—				
Net Standard Volume, NSV, (barrel)	599,17	1.798,88	949,26	400,00	3.747,31
Stratified-1					
Shrinkage Correction Factor, SCF, (%Vol)	0,04	0,04	—	—	
Shrinkage Volume, SV, (barrel)	0,22	0,67	—	—	0,89
Net Corrected Volume in Station-1	598,95	1.798,21			2.397,15
Stratified-2					
Shrinkage Correction Factor, SCF, (%Vol)	0,09	0,09	0,09	—	
Shrinkage Volume, SV, (barrel)	0,52	1,55	0,81		2,88
Net Corrected Volume in Station-2	598,43	1.796,65	948,45		3.343,53
Stratified-3					
Shrinkage Correction Factor, SCF, (%Vol)	0,02	0,02	0,02	0,02	
Shrinkage Volume, SV, (barrel)	0,11	0,34	0,18	0,08	0,72
Net Corrected Volume in Station-3	598,32	1.796,31	948,27	399,92	3.742,81

Table 16.
 Daily join report.

where ξ_{st-II_i} is shrinkage volume for shipper i (C, and mix A-B) in TANK-2, and V_{shg-II} is the group shrinkage volume in TANK-2. Finally, the shrinkage volume for shipper D and TANK-2 (mix A-B-C) in TANK-3 can be determined as follows:

$$\xi_{st-III_i} = \frac{x_i(1/S_{G_i})}{\sum_{i=1}^n x_i(1/S_{G_i})} V_{shg-III} \quad (15)$$

where ξ_{st-III_i} is shrinkage volume for shipper i (D, and mix A-B-C) in TANK-3, and $V_{shg-III}$ is the group shrinkage volume in TANK-3.

The total stratified shrinkage volume (ξ_{st-tot_i}) for shippers A and B are the summation of its shrinkage volume in TANK-1, TANK-2, and TANK-3, for shipper C is those in TANK-2 and TANK-3; while for shipper D is only once in the last tank of TANK-3.

$$\xi_{st-tot_i} = \xi_{st-I_i} + \xi_{st-II_i} + \xi_{st-III_i} \quad (16)$$

where for shipper C $\xi_{st-I_i} = 0$, and for shipper D $\xi_{st-I_i} = \xi_{st-II_i} = 0$.

The stratified shrinkage correction factor (SCF_{st_i} in %Vol) for each shipper can then be determined with the following equation:

$$SCF_{st_i} = \frac{\xi_{st-tot_i}}{V_i} \times 100\% \quad (17)$$

Table 14 shows the stratified sharing losses results. The subtotal oil losses in TANK-1, TANK-2, and TANK-3 are 0.89, 2.88, and 0.72 barrels, respectively. The stratified method produces the total oil loss of 4.49 barrels. This result is the same with the proportional result. The SCFs in TANK-1, TANK-2, and TANK-3 for each shipper are almost the same, i.e., 0.04%-Vol, 0.09%-Vol, and 0.02%-Vol, respectively. If compared with other shippers, the total SCF of shippers A and B are the biggest one, i.e., 0.14%Vol. The total SCF of shipper C is 0.10%Vol. While the total SCF of shipper D is the smallest one, i.e., 0.02%Vol.

Comparison between proportional and stratified results is shown in **Table 15**. More often oil mixes with others; its volume will be more decreased. The stratified method is therefore considered fair, since the oil volume shrinkage of each shipper is calculated according to the amount of the mixing phenomena.

3. Daily join report

A Joint Report is created when several Cooperation Contract Contractors or Shippers use shared facilities, so that a distribution mechanism for oil losses due to evaporation, emulsion, and shrinkage is required [14, 15]. Daily join report needs to be compiled to find out the distribution of oil losses for each shipper. The stratified method is chosen to determine sharing oil losses since this method gives the fair results. The daily join report for all shippers is shown in **Table 16**.

4. Sources of oil losses

Causes of oil losses that can be minimized are as follows:

- Limited number of tanks in the field (both storage and handover tanks), so this will limit the *settling time* for separation of water and sediment.

- The condition of tank that allows the loss of petroleum due to the evaporation of light component.
- Unavailability of adequate flowmeter devices, so that the measurements are made manually.
- Improper heating process operating condition.
- Improper setting of interface level in 3-phase-separator.

Inevitable oil losses are as follows:

- The presence of oil and water emulsions with a high degree of stability, so the separation of oil and water is difficult in a short time. In this case, the special demulsifier should be injected at an early stage, such as the farthest or mid oil cluster, and the wash tank inlet, in order to break the emulsion. By injecting demulsifier at the early stage, it is hoped that the oil–water turbulence in the pipe will not form a strong emulsion. If the fluid travel time from the farthest cluster to the wash tank is long enough, then midway injection of demulsifier is necessary [16].
- Shrinkage of oil volume caused by mixing two or more different characteristics of petroleum in the same pipe or tank.
- Unstable crude oil due to the evaporation of light component

5. Conclusion

A case study on oil losses in the oil and gas industries has been discussed for some shippers namely, shipper A, B, C, and D with typical diagram of oil distribution and mixing process. The individual loss includes loss due to water cut, emulsion and evaporation phenomena. The parameters of water cut (%-vol) and BS&W (%-Vol) need to be identified to calculate the net volume free of water and sediment. However, shipper D does not contribute emulsion loss because its oil is typically condensate with BS&W=0. All shippers do not produce evaporative loss, because the oil temperatures in tanks are lower than its bubble temperature.

The group loss happens during mixing oil in the same storage tank. The parameter of oil specific gravity must be determined to calculate the group loss. The oil volume will shrink when two or more oils mix together in the same storage tank. In this case, the proportional and stratified methods have been utilized to calculate the sharing oil losses. The proportional method gives almost the same of shrinkage correction factor (SCF) for all shippers. However, the proportional method is considered unfair, since the downstream shipper, e.g., shipper D, bear the losses of the upstream shippers (shippers A, B, and C). Therefore, the stratified method is considered fair for determining the sharing oil losses, since the oil loss of each shipper is calculated based on the amount of the mixing event.

According to the analysis of oil losses case study with typical oil distribution flow diagram in the oil and gas industries, the considered several ways to prevent oil losses include the following:

- Provide the adequate tanks in the field (both storage and handover tanks), so this will give enough settling time for separation of water and sediment. The

available tank should meet predetermined criteria such as material and good welding so as not to leak.

- Provide the adequate flowmeter devices to prevent measurement errors.
- Use demulsifier to solve the emulsion. The demulsifier will destroy the interfacial films that cover the water droplets, so that the water droplets can coalesce and separate from the oil. Demulsifier should be injected in several location such as the farthest and mid oil cluster, and the wash tank inlet.
- Use heating treatment to solve the emulsion. There is no standard solution for breaking the emulsion, for example, the higher the heating temperature, the faster the emulsion breaking process, and the less demulsifier required. But the heating temperature must be below the boiling temperature of the oil to avoid evaporation.
- Keep the tank operating conditions so that there is no evaporation of the light components. By maintaining low oil temperature minimizes evaporative loss from storage tank.
- Maintain the interface level in 3-phase-separator below the weir height to prevent offset.

List of abbreviation

API	American Petroleum Institute
BFPD	Barrel Fluid Per Day (barrel/day)
BOPD	Barrel Oil Per Day (barrel/day)
BS&W	Basic Sediment and Water (%-Vol)
BWPD	Barrel Water Per Day (barrel/day)
ECF	Emulsion Correction Factor (%-Vol)
FCF	Flash Correction Factor (%-Vol)
NCV	Net Corrected Volume (barrel)
NSV	Net Standard Volume (barrel)
SCF	Shrinkage Correction Factor (%-Vol)
SG	Specific Gravity
TIL	Total Individual Losses (barrel)
VLE	Vapor-Liquid-Equilibrium
WC	Water Cut (%-Vol)

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