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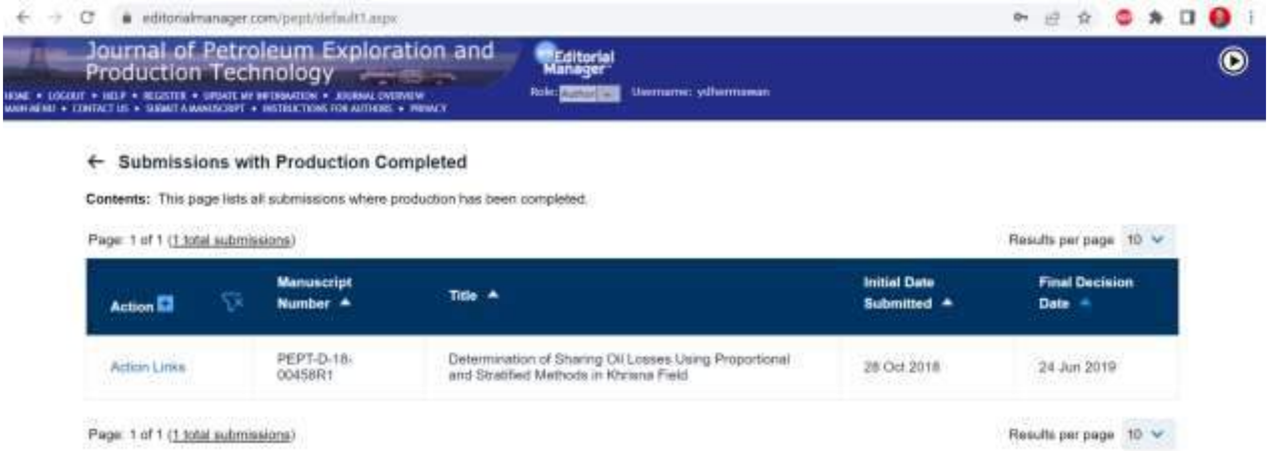
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Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field

Yulius Deddy Hermawan[1)], Dedy Kristanto[2)], Hariyadi[3)], and Wibowo[4)]
[1)] Department of Chemical Engineering, Faculty of Industrial Engineering,
[2,3,4)] Department of Petroleum Engineering, Faculty of Mineral Technology,
Universitas Pembangunan Nasional "Veteran" Yogyakarta,
Jl. SWK 104 (Lingkar Utara) Condongcatur, Yogyakarta, 55283, Indonesia
Email: ydhermawan@upnyk.ac.id and dedykris.upn@gmail.com

Abstract:

This paper discusses about the oil losses due to mixing oil phenomenon that frequently happened in the oil and gas companies. The goals of this work are to calculate the shrinkage correction volume of the mixture of two or more crude oils with different characteristics and densities and to compare between Proportional and Stratified methods for determining of sharing oil losses. The mixing of crude oil from 7 shippers in Khrisna Field would be used as a case study, and the equation of API 12.3 was chosen to calculate a shrinkage correction volume. Oils from shippers S1, S2, and S3 were first mixed together in Tank-1 of the 1st station; the mixed oil of Tank-1 was then pumped to the next station and stored in the Tank-2 and mixed with oil from shippers S4 and S5; finally, the mixed oil of Tank-2 was pumped to the final station and stored in the Tank-3 and mixed with other oil from shippers S6 and S7. The proportional method gave almost the same shrinkage percentage for all shippers, $\%S_h$ = 0.20%; while stratified method resulted $\%S_h$ in between 0.05% and 0.31%. Based on our analysis, more often oil mixed with others, its volume would be more decreased. The stratified method is therefore recommended to determine sharing oil losses since it gives a fair result.

Keywords: Oil losses, Mixing oil, Proportional, Shrinkage, and Stratified.

1. Introduction

The oil and gas fields generally produce petroleum fluid that can be classified into five categories: dry gas, wet gas, gas condensate, volatile oil, and black oil (McCain 1990.a; Whitson and Brule 2000). Since the fluids with those categories have different characteristics, i.e. densities, the properties would thus change when they are mixed together. On the other hand, in an activity of pumping of petroleum (crude oil) from shippers in the oil field to the gathering station, shippers often use the same pipeline to transport the crude oil to a storage tank. The crude oils from shippers are mixed together either in the same temporary or final storage tank. This situation comes up the problem of oil losses; there is a different volume between shipper as a sending point and gathering station as a receiving point. The study of sharing oil losses is therefore very important to be done.

Some researches or studies in field of oil losses have been done by some researchers. So far back to year 1918, Bradley, et al have studied the crude oil losses in steel and earthen storage. They classified roughly losses as occurring from evaporation, presence of sediment and water, and leakage. Several studies (Katz 1942; Erno et al 1994; Nengkoda 2011; James 2014) have discussed about prediction of crude oil shrinkage losses. Far back to year of 1942, Katz has investigated the crude oil shrinkage phenomenon by presenting methods of predicting the shrinkage from measurement made on a well of gas gravity, oil gravity, gas oil ratio, reservoir temperature and reservoir pressure. Katz (1942) pointed that the more volatile the separator liquid phase, the more impact separator conditions and shrinkage will be. In 1994, Erno et al predicted the shrinkage equation of heavy oil/condensate blend and stated that when condensate is added to heavy oil, the blended volume is less than the sum of the condensate and oil volumes. In 2011, Nengkoda has studied the role of crude oil shrinkage in heavy mix light crude in main oil pipeline and pointed that shrinkage will be very depended upon the operation pressure and temperature. In recent year 2014, James has studied shrinkage losses resulting from liquid hydrocarbon blending. James (2014) concluded that equation of API 12.3 was a valuable tool in quantifying shrinkage that occurs as a result of blending hydrocarbons of different densities. Moreover in 2011, Shanshool et al have investigated the volumetric behavior of mixtures of different oil stock. Shanshool et al (2011) concluded that volumetric shrinkage is resulted from blending hydrocarbon with gas oil, while mixing of gas oil with aromatic nature hydrocarbons, methyl-ethyl-ketone and iso-octanol were leading to high expansion effect.

The goals of this work are to calculate the oil shrinkage volume due to mixing phenomenon and to determine the sharing oil losses using proportional and stratified methods. The oil distribution of 7 shippers in Khrisna field would be taken as a case study. Since the emulsion and flash phenomenon do not occur in Khrisna field, the oil losses due to mixing phenomenon would therefore be considered. The equation of API 12.3 would be used to calculated shrinkage volume in every mixing phenomenon in tank.

2. Material and Method

2.1. Flow diagram of oil distribution

The block diagram of oil distribution and mixing phenomenon in Khrisna field is shown in **Figure 1**. As can be seen in **Figure 1**, Khrisna field has 7 shippers; they are S1, S2, S3, S4, S5, S6, and S7. Shippers S1, S2, and S3 send their oil to Station-1 and the oils are temporary stored in same tank of TANK-1. The mixed oil of TANK-1 is then pumped to the 2nd station and temporary stored in TANK-2 and mixed with other oil from shippers S4 and S5. Finally, the mixed oil of TANK-2 is pumped to the 3rd station and stored in TANK-3 and mixed with other oil from shippers S6 and S7. As shown in **Figure 1**, shippers S1, S2, and S3 have 3 times of mixing phenomenon in the tank, shippers S4 and S5 have twice, and shippers S6 and S7 have only once.

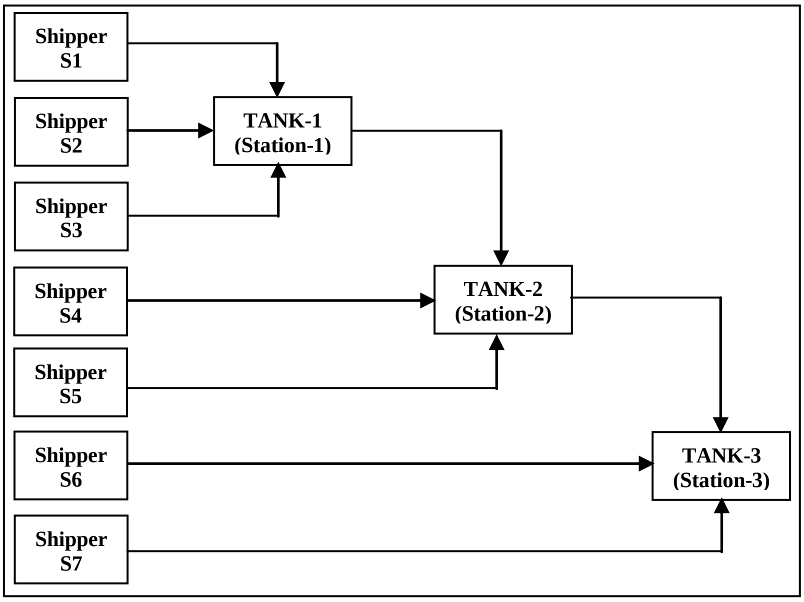

Figure 1. Block diagram of oil distribution and mixing phenomenon in Khrisna field.

2.2. Parameters input

Parameters input for calculating of oil losses are production rate, specific gravity (SG), and based sediment water (BSW). These parameters input are listed in **Table 1**. As shown in **Table 1**, all shippers send their net oil with zeros of water and BSW. The total oil rate from all shippers as sending points is 4500 barrel oil per day (BOPD). The specific gravities of all shippers vary from 0.8001 to 0.9043. Oil of shipper S7 is the lightest one with SG of 0.8001; this is typically condensate. The oil of shipper S4 is the heaviest one with its SG of 0.9043.

Table 1. Production and fluid properties of Khrisna field.

Shipper	Production			Oil Percent	Properties	
	Gross [BFPD]	Oil [BOPD]	Water [BWPD]	Volume [%]	SG (60°/60°)	BSW
S1	500	500	0	11.11	0.8881	0
S2	1200	1200	0	26.67	0.8931	0
S3	400	400	0	8.89	0.9031	0
S4	200	200	0	4.44	0.9043	0
S5	800	800	0	17.78	0.8694	0
S6	1000	1000	0	22.22	0.8912	0
S7 *)	400	400	0	8.89	0.8001	0
Total	**4500**	**4500**	**0**	100.00		

*Note *): S7 produces condensate*

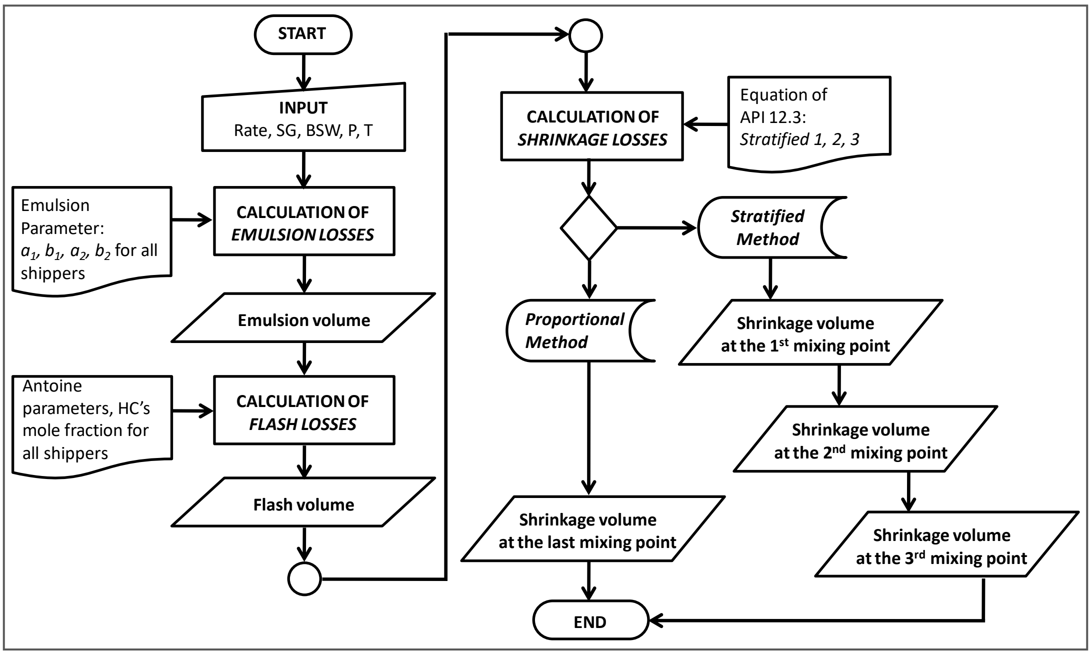

Figure 2. Calculation algorithm of sharing oil losses.

2.3. Calculation algorithm of sharing oil losses

Calculation algorithm of sharing oil losses are shown in **Figure 2**. In order to calculate the total sharing oil losses, individual losses such as emulsion and flash losses must first be calculated. Since all shippers have no BSW, all shippers have also no emulsion losses. On the other hand, the temperature conditions of all shippers are lower than its bubble points; it is understandable that all shippers have no flash losses.

After individual losses are calculated, the shrinkage losses due to mixing phenomenon are then calculated. The shrinkage volume losses are calculated based on proportional and stratified methods. The equation of API 12.3 would be used for calculating of shrinkage volume losses and defined as:

$$S_h\,(\%) = a\, L_c(100 - L_c)^b(\Delta^{o}\text{API})^c \qquad (1)$$

where:

a, b, and c are constants of API 12.3 and taken from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017) as listed in **Table 2**.

L_c is %-light component,

Δ^{o}API is ^{o}API difference (between ^{o}API of shipper one and other), and

S_h is shrinkage volume percentage (in %).

API gravity for each shipper is defined as the equation in McCain (1990.b):

$$^{o}\text{API}_i = \frac{141.5}{SG_i} - 131.5 \qquad (2)$$

where:

$^{o}\text{API}_i$ is API gravity of shipper *i*, and

SG_i is specific gravity ($60^{o}/60^{o}$) of shipper *i*.

2.3.1. Proportional method

Calculation procedures of shrinkage volume in the tanks are generally shown in **Table 3**. In proportional method, the net-corrected-volume (after through all mixings phenomenon) is directly taken from the last tank of

TANK-3 (V_{nc} of TANK-3, see procedure number 5 in **Table 3**). The total shrinkage volume of proportional method ($V_{sh\text{-prop}}$) can then be calculated as follows:

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

where:

V_i is net volume of shipper *i* (initial sending volume)

$V_{nc\,(\text{TANK-3})}$ is the net-corrected-volume in the last tank (TANK-3)

$V_{sh\text{-prop}}$ is the total shrinkage volume of proportional method

Table 2. Parameters *a*, *b*, *c* in API 12.3 equations

GROUP	S_h (%) = $a \times L_c \times (100 - L_c)^b \times (\Delta API)^c$		
	Constant		
	a	***b***	***c***
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 (2017).

Table 3. Calculation procedure of shrinkage volume in tanks *)

No	Procedure	Formula
1	Input data: net volume (V_{net-i}), specific gravity (SG_i) for each shipper (***i***)	V_{net-i}, SG_i
2	Calculation of ^{o}API$_i$ for each shipper (***i***)	$^o\text{API}_i = \frac{141.5}{SG_i} - 131.5$
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 Δ^oAPI (Δ^oAPI$_1$)	$\Delta^o\text{API}_1 = \text{abs}(\,^o\text{API}(1) - \,^o\text{API}(2))$
	d. Calculation of the 1st %-shrinkage (S_{h1})	$S_{h1}\,(\%) = a\,Lc_1(100 - Lc_1)^b(\Delta^o\text{API}_1)^c$
	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 ^{o}API (^{o}API$_{mix1}$)	$^o\text{API}_{mix1} = \frac{141.5}{SG_{mix1}} - 131.5$
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 $SG_{\text{mix1}}<SG(3)$: $Lc_2 = \frac{V_{mix1}}{V_{tot2}}100$ if $SG_{\text{mix1}}>SG(3)$: $Lc_2 = \frac{V_{net}(3)}{V_{tot2}}100$
	c. Calculation of the 2nd Δ^oAPI (Δ^oAPI$_2$)	$\Delta^o\text{API}_2 = \text{abs}(\,^o\text{API}_{\text{mix1}} - \,^o\text{API}(3))$
	d. Calculation of the 2nd %-shrinkage (S_{h2})	$S_{h2}\,(\%) = a\,Lc_2(100 - Lc_2)^b(\Delta^o\text{API}_2)^c$
	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})	$SG_{mix2} = \frac{V_{mix2}SG_{mix2} + V_{net}(3)SG(3)}{V_{mix2}}$
	h. Calculation of the 2nd mixed ^{o}API (^{o}API$_{mix2}$)	$^o\text{API}_{mix2} = \frac{141.5}{SG_{mix2}} - 131.5$
5	Calculation of net-corrected-volume in tank (V_{nc})	$V_{nc} = V_{mix2}$
6	Calculation of group-shrinkage-losses in tank (V_{shg})	$V_{shg} = V_{sh1} + V_{sh2}$

*) Notes of **Table 3** that shows the stratification of oil mix in tank are listed in **Table 4**.

Table 4. Notes of Table 3: stratification of oil mix in tank

(*i*)	**Shippers' oil mix in Tank**		
	TANK-1	**TANK-2**	**TANK-3**
(1)	Shipper S1	TANK-1	TANK-2
(2)	Shipper S2	Shipper S4	Shipper S6
(3)	Shipper S3	Shipper S5	Shipper S7

The proportional shrinkage volume for each shipper ($\xi_{\text{prop}}(i)$) can be calculated as follows:

$$\xi_{\text{prop}}(i) = \frac{x_i\left(1/_{SG_i}\right)}{\sum_{i=1}^{n} x_i\left(1/_{SG_i}\right)} V_{sh-\text{prop}} \quad \text{.......} \quad (4)$$

$$x(i) = \frac{V_i}{\sum_{i=1}^{n} V_i} \quad \text{.......} \quad (5)$$

where:

$\xi_{\text{prop}}(i)$ is proportional shrinkage volume of shipper *i*,

$x(i)$ is volume fraction of shipper *i*.

2.3.2. Stratified method

In stratified method, the net-corrected-volume is stratify calculated from tank to tank as shown in **Table 3**. The shrinkage volume is calculated for each mixing phenomenon in TANK-1, TANK-2, and TANK-3, respectively. The total oil losses for shippers S1, S2, and S3 are the summation of its shrinkage volume in TANK-1, TANK-2, and TANK-3; for shippers S4 and S5 are those in TANK-2 and TANK-3; while for shippers S6 and S7 are only once in the last tank of TANK-3.

3. Result and Discussion

3.1. Proportional results

Proportional method gives sharing oil losses results as shown in **Table 5**. As can be seen from **Table 5**, the total oil losses is 9.06 barrel and the shrinkage percentages (%-S_h) of all shippers are almost the same, ±0.20%. However, the shrinkage percentage of shipper S7 is the largest one (0.22%) since its oil is classified as condensate. Condensate is typically light oil or gas oil that has low density and small molecular size, while heavy oil has big molecular size. When condensate mixes heavy oil, hence geometrically there will be shrinkage; and this agrees with those in Erno et al (1994), James (2014), and Shanshool et al (2011).

Table 5. Sharing oil losses results with Proportional method

SHIPPER	**Sending Point**		**Individual Losses**	
	barrel	**SG**	**barrel**	**%S_h**
S1	500.00	0.8881	1.00	0.20
S2	1,200.00	0.8931	2.38	0.20
S3	400.00	0.9031	0.78	0.20
S4	200.00	0.9043	0.39	0.20
S5	800.00	0.8694	1.63	0.20
S6	1,000.00	0.8912	1.99	0.20
S7	400.00	0.8001	0.89	0.22
Total	**4,500.00**		**9.06**	
Corrected net volume in the last Tank (barrel) =				**4,490.94**
Total Losses (barrel)				**9.06**

3.2. Stratified results

Table 6 shows sharing oil losses results with stratified method. In this method, shrinkage volume of each shipper is calculated for every mixing in the tank. As can be seen from **Table 6**, the subtotal oil losses in every tank are 2.49, 4.20, and 2.38 barrels, respectively. The total oil loss in the stratified method is thus the same as in the proportional method, i.e. 9.06 barrels. The individual shrinkage percentage of each shipper in every tank is almost the same; they are 0.12%, 0.13%, and 0.05% in TANK-1, TANK-2, and TANK-3, respectively. The total of shrinkage percentages of shippers S1, S2, and S3 are larger than those in shippers S4 and S5, (0.31% vs. 0.19%); and those in shippers S4 and S5 are larger than those in shippers S6 and S7, (0.19% vs. 0.05%). This is understandable that more often oil mix with others, its volume will be more decreased.

Table 6. Sharing oil losses results with Stratified method.

SHIPPER			Stratified-1 (Mixing in Tank-1 of Station-1)				Stratified-2 (Mixing in Tank-2 of Station-2)				Stratified-3 (Mixing in Tank-3 of Station-3)				TOTAL LOSSES	
Sending Point			Individual Losses		Corrected Factor		Individual Losses		Corrected Factor		Individual Losses		Corrected Factor		Vol.	%-Sh
SHIPPER	vol (bbl)	SG	(bbl)	%Sh	(bbl)	SG	(bbl)	%Sh	(bbl)	SG	(bbl)	%Sh	(bbl)	SG	(bbl)	(%)
S1	500.00	0.8881	0.60	0.12	499.40	0.8938	0.67	0.13	498.73	0.8882	0.26	0.05	498.47	0.8810	1.53	0.31
S2	1,200.00	0.8931	1.42	0.12	1,198.58	0.8938	1.61	0.13	1,196.97	0.8882	0.63	0.05	1,196.34	0.8810	3.66	0.31
S3	400.00	0.9031	0.47	0.12	399.53	0.8938	0.54	0.13	398.99	0.8882	0.21	0.05	398.78	0.8810	1.22	0.30
total	2,100.00		2.49													
Net Corrected Vol. of Tank-1 (bbl)			2097.51													
Sub-total oil Losses (bbl)			2.49													
S4					200.00	0.9043	0.27	0.13	199.73	0.8882	0.10	0.05	199.63	0.8810	0.37	0.19
S5					800.00	0.8694	1.11	0.14	798.89	0.8882	0.42	0.05	798.47	0.8810	1.53	0.19
				total	3,097.51		4.20									
Net Corrected Vol. of Tank-2 (bbl)							3,093.32									
Sub-total oil Losses (bbl)							4.20									
S6									1,000.00	0.8912	0.52	0.05	999.48	0.8810	0.52	0.05
S7									400.00	0.8001	0.23	0.06	399.77	0.8810	0.23	0.06
								total	4,493.32		2.38		4,490.94		9.06	
Net Corrected Vol. of Tank-3 (bbl)											4490.94					
Sub-total oil Losses (bbl)											2.38					

3.3. Comparison of proportional and stratified results

Comparison results between proportional and stratified methods are listed in **Table 7**. The total sending volume is 4500 barrel, and total shrinkage volume is 9.06 barrel. Therefore, the net corrected volume in the last tank is 4490.94 barrel. The proportional method gives almost the same of shrinkage percentage, ±0.20%, whereas stratified method varies from 0.05% to 0.31% as its mixing quantity.

The proportional method is considered unfair since shippers S6 and S7 bear those losses of the upstream shippers. More often oil mixes with others, for examples oil from shippers S1, S2, and S3 pass through 3 times of mixing phenomenon, more volume shrinkage will be. Thus, the stratified method appropriates for determining of sharing oil losses in the multi mixing phenomenon.

Table 7. Comparison Results between Proportional and Stratified methods

SHIPPER	Sending Point (barrel)	SG	Mixing Quantity	Proportional (bbl)	% S_h	Stratified (bbl)	% S_h
S1	500.00	0.8881	3	1.00	0.20	1.53	0.31
S2	1,200.00	0.8931	3	2.38	0.20	3.66	0.31
S3	400.00	0.9031	3	0.78	0.20	1.22	0.30
S4	200.00	0.9043	2	0.39	0.20	0.37	0.19
S5	800.00	0.8694	2	1.63	0.20	1.53	0.19
S6	1,000.00	0.8912	1	1.99	0.20	0.52	0.05
S7	400.00	0.8001	1	0.89	0.22	0.23	0.06
Total	**4,500.00**			**9.06**		**9.06**	
***Net corrected volume* = 4,490.94 barrel**							

4. Conclusion

The sharing of oil losses in a Khrisna field has been discussed. In this work, the 2 methods i.e. proportional and stratified methods were used to determine the sharing of oil losses for 7 shippers with different amount of mixing phenomenon in the tank. According to our analysis, the proportional method gave almost the same of oil losses percentages for all shippers. However, shippers that more often mixed with others, e.g. shippers S1, S2, and S3 have 3 times of mixing phenomenon; their shrinkage volume would be larger than others. For that reason, we recommended to use stratified method to determine sharing oil losses since it gives a fair result.

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Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field

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Corresponding Author:	Yulius Deddy Hermawan, Dr Universitas Pembangunan Nasional Veteran Yogyakarta Sleman, Yogyakarta INDONESIA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Universitas Pembangunan Nasional Veteran Yogyakarta
Corresponding Author's Secondary Institution:	
First Author:	Yulius Deddy Hermawan, Dr
First Author Secondary Information:	
Order of Authors:	Yulius Deddy Hermawan, Dr
	Dedy Kristanto, Dr
	Hariyadi Hariyadi, Master
	Wibowo Wibowo, Master
Order of Authors Secondary Information:	
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Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field

Yulius Deddy Hermawan[1)], Dedy Kristanto[2)], Hariyadi[3)], and Wibowo[4)]
[1)] Department of Chemical Engineering, Faculty of Industrial Engineering,
[2,3,4)] Department of Petroleum Engineering, Faculty of Mineral Technology,
Universitas Pembangunan Nasional "Veteran" Yogyakarta,
Jl. SWK 104 (Lingkar Utara) Condongcatur, Yogyakarta, 55283, Indonesia
Email: ydhermawan@upnyk.ac.id and dedykris.upn@gmail.com

Abstract:

This paper discusses about the oil losses due to mixing oil phenomenon that frequently happened in the oil and gas companies. The goals of this work are to calculate the shrinkage correction volume of the mixture of two or more crude oils with different characteristics and densities and to compare between Proportional and Stratified methods for determining of sharing oil losses. The mixing of crude oil from 7 shippers in Khrisna Field would be used as a case study, and the equation of API 12.3 was chosen to calculate a shrinkage correction volume. Oils from shippers S1, S2, and S3 were first mixed together in Tank-1 of the 1st station; the mixed oil of Tank-1 was then pumped to the next station and stored in the Tank-2 and mixed with oil from shippers S4 and S5; finally, the mixed oil of Tank-2 was pumped to the final station and stored in the Tank-3 and mixed with other oil from shippers S6 and S7. The proportional method gave almost the same shrinkage percentage for all shippers, $\%S_h$ = 0.20%; while stratified method resulted $\%S_h$ in between 0.05% and 0.31%. Based on our analysis, more often oil mixed with others, its volume would be more decreased. The stratified method is therefore recommended to determine sharing oil losses since it gives a fair result.

Keywords: Oil losses, Mixing oil, Proportional, Shrinkage, and Stratified.

1. Introduction

The oil and gas fields generally produce petroleum fluid that can be classified into five categories: dry gas, wet gas, gas condensate, volatile oil, and black oil (McCain 1990.a; Whitson and Brule 2000). Since the fluids with those categories have different characteristics, i.e. densities, the properties would thus change when they are mixed together. On the other hand, in an activity of pumping of petroleum (crude oil) from shippers in the oil field to the gathering station, shippers often use the same pipeline to transport the crude oil to a storage tank. The crude oils from shippers are mixed together either in the same temporary or final storage tank. This situation comes up the problem of oil losses; there is a different volume between shipper as a sending point and gathering station as a receiving point. The study of sharing oil losses is therefore very important to be done.

Some researches or studies in field of oil losses have been done by some researchers. So far back to year 1918, Bradley, et al have studied the crude oil losses in steel and earthen storage. They classified roughly losses as occurring from evaporation, presence of sediment and water, and leakage. Several studies (Katz 1942; Erno et al 1994; Nengkoda 2011; James 2014) have discussed about prediction of crude oil shrinkage losses. Far back to year of 1942, Katz has investigated the crude oil shrinkage phenomenon by presenting methods of predicting the shrinkage from measurement made on a well of gas gravity, oil gravity, gas oil ratio, reservoir temperature and reservoir pressure. Katz (1942) pointed that the more volatile the separator liquid phase, the more impact separator conditions and shrinkage will be. In 1994, Erno et al predicted the shrinkage equation of heavy oil/condensate blend and stated that when condensate is added to heavy oil, the blended volume is less than the sum of the condensate and oil volumes. In 2011, Nengkoda has studied the role of crude oil shrinkage in heavy mix light crude in main oil pipeline and pointed that shrinkage will be very depended upon the operation pressure and temperature. In recent year 2014, James has studied shrinkage losses resulting from liquid hydrocarbon blending. James (2014) concluded that equation of API 12.3 was a valuable tool in quantifying shrinkage that occurs as a result of blending hydrocarbons of different densities. Moreover in 2011, Shanshool et al have investigated the volumetric behavior of mixtures of different oil stock. Shanshool et al (2011) concluded that volumetric shrinkage is resulted from blending hydrocarbon with gas oil, while mixing of gas oil with aromatic nature hydrocarbons, methyl-ethyl-ketone and iso-octanol were leading to high expansion effect.

The goals of this work are to calculate the oil shrinkage volume due to mixing phenomenon and to determine the sharing oil losses using proportional and stratified methods. The oil distribution of 7 shippers in Khrisna field would be taken as a case study. Since the emulsion and flash phenomenon do not occur in Khrisna field, the oil losses due to mixing phenomenon would therefore be considered. The equation of API 12.3 would be used to calculated shrinkage volume in every mixing phenomenon in tank.

2. Material and Method

2.1. Flow diagram of oil distribution

The block diagram of oil distribution and mixing phenomenon in Khrisna field is shown in **Figure 1**. As can be seen in **Figure 1**, Khrisna field has 7 shippers; they are S1, S2, S3, S4, S5, S6, and S7. Shippers S1, S2, and S3 send their oil to Station-1 and the oils are temporary stored in same tank of TANK-1. The mixed oil of TANK-1 is then pumped to the 2nd station and temporary stored in TANK-2 and mixed with other oil from shippers S4 and S5. Finally, the mixed oil of TANK-2 is pumped to the 3rd station and stored in TANK-3 and mixed with other oil from shippers S6 and S7. As shown in **Figure 1**, shippers S1, S2, and S3 have 3 times of mixing phenomenon in the tank, shippers S4 and S5 have twice, and shippers S6 and S7 have only once.

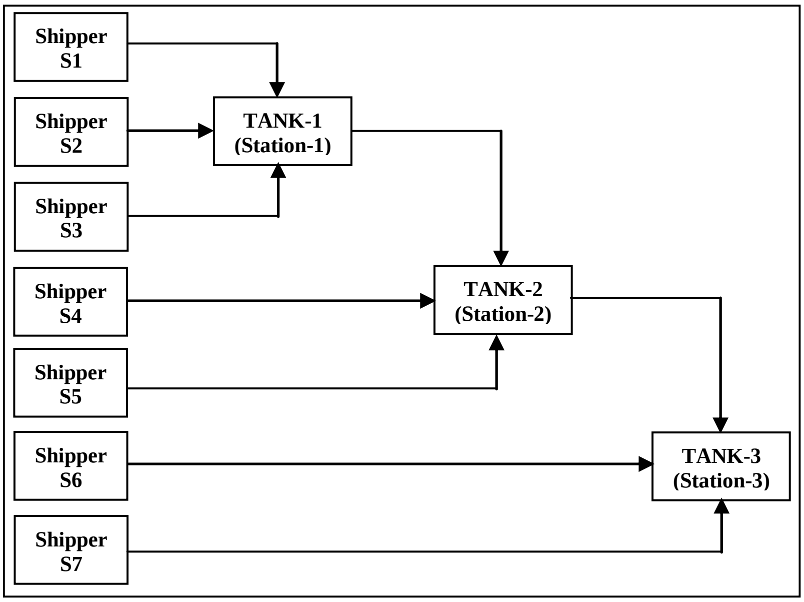

Figure 1. Block diagram of oil distribution and mixing phenomenon in Khrisna field.

2.2. Parameters input

Parameters input for calculating of oil losses are production rate, specific gravity (SG), and based sediment water (BSW). These parameters input are listed in **Table 1**. As shown in **Table 1**, all shippers send their net oil with zeros of water and BSW. The total oil rate from all shippers as sending points is 4500 barrel oil per day (BOPD). The specific gravities of all shippers vary from 0.8001 to 0.9043. Oil of shipper S7 is the lightest one with SG of 0.8001; this is typically condensate. The oil of shipper S4 is the heaviest one with its SG of 0.9043.

Table 1. Production and fluid properties of Khrisna field.

Shipper	Production			Oil Percent	Properties	
	Gross [BFPD]	Oil [BOPD]	Water [BWPD]	Volume [%]	SG (60°/60°)	BSW
S1	500	500	0	11.11	0.8881	0
S2	1200	1200	0	26.67	0.8931	0
S3	400	400	0	8.89	0.9031	0
S4	200	200	0	4.44	0.9043	0
S5	800	800	0	17.78	0.8694	0
S6	1000	1000	0	22.22	0.8912	0
S7 *)	400	400	0	8.89	0.8001	0
Total	**4500**	**4500**	**0**	100.00		

*Note *): S7 produces condensate*

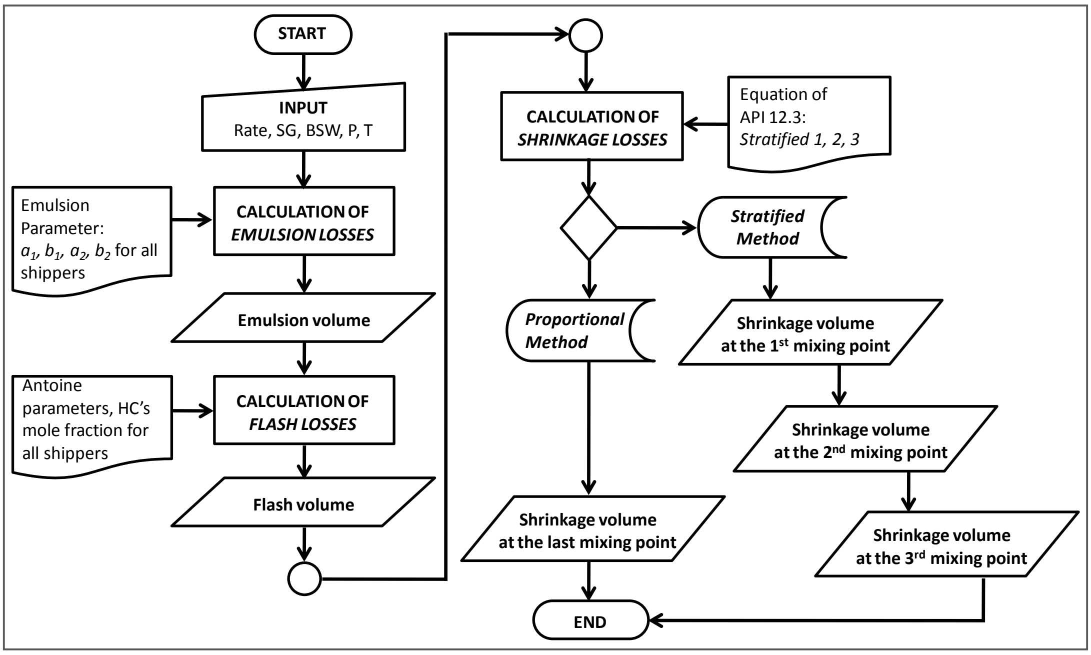

Figure 2. Calculation algorithm of sharing oil losses.

2.3. Calculation algorithm of sharing oil losses

Calculation algorithm of sharing oil losses are shown in **Figure 2**. In order to calculate the total sharing oil losses, individual losses such as emulsion and flash losses must first be calculated. Since all shippers have no BSW, all shippers have also no emulsion losses. On the other hand, the temperature conditions of all shippers are lower than its bubble points; it is understandable that all shippers have no flash losses.

After individual losses are calculated, the shrinkage losses due to mixing phenomenon are then calculated. The shrinkage volume losses are calculated based on proportional and stratified methods. The equation of API 12.3 would be used for calculating of shrinkage volume losses and defined as:

$$S_h\,(\%) = a\,L_c(100 - L_c)^b(\Delta^{o}\text{API})^c \quad \text{...} \quad (1)$$

where:

a, b, and c are constants of API 12.3 and taken from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017) as listed in **Table 2**.

L_c is %-light component,

Δ^{o}API is ^{o}API difference (between ^{o}API of shipper one and other), and

S_h is shrinkage volume percentage (in %).

API gravity for each shipper is defined as the equation in McCain (1990.b):

$$^{o}\text{API}_i = \frac{141.5}{SG_i} - 131.5 \quad \text{...} \quad (2)$$

where:

$^{o}\text{API}_i$ is API gravity of shipper i, and

SG_i is specific gravity ($60^{o}/60^{o}$) of shipper i.

2.3.1. Proportional method

Calculation procedures of shrinkage volume in the tanks are generally shown in **Table 3**. In proportional method, the net-corrected-volume (after through all mixings phenomenon) is directly taken from the last tank of

TANK-3 (V_{nc} of TANK-3, see procedure number 5 in **Table 3**). The total shrinkage volume of proportional method ($V_{sh\text{-prop}}$) can then be calculated as follows:

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

where:

V_i is net volume of shipper *i* (initial sending volume)

$V_{nc\,(\mathrm{TANK\text{-}3})}$ is the net-corrected-volume in the last tank (TANK-3)

$V_{sh\text{-prop}}$ is the total shrinkage volume of proportional method

Table 2. Parameters *a*, *b*, *c* in API 12.3 equations

GROUP	S_h (%) = $a \times L_c \times (100 - L_c)^b \times (\Delta API)^c$		
	Constant		
	a	***b***	***c***
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 (2017).

Table 3. Calculation procedure of shrinkage volume in tanks [*)]

No	Procedure	Formula
1	Input data: net volume ($V_{net\text{-}i}$), specific gravity (SG_i) for each shipper (***i***)	$V_{net\text{-}i}$, SG_i
2	Calculation of °API$_i$ for each shipper (***i***)	$^{o}\mathrm{API}_i = \frac{141.5}{SG_i} - 131.5$
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 Δ°API (Δ°API$_1$)	$\Delta^{o}\mathrm{API}_1 = \mathrm{abs}(^{o}\mathrm{API}(1) - {}^{o}\mathrm{API}(2))$
	d. Calculation of the 1st %-shrinkage (S_{h1})	$S_{h1}\,(\%) = a\,Lc_1(100 - Lc_1)^b(\Delta^{o}\mathrm{API}_1)^c$
	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 °API (°API$_{mix1}$)	$^{o}\mathrm{API}_{mix1} = \frac{141.5}{SG_{mix1}} - 131.5$
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 $SG_{\mathrm{mix1}}<SG(3)$: $Lc_2 = \frac{V_{mix1}}{V_{tot2}}100$ if $SG_{\mathrm{mix1}}>SG(3)$: $Lc_2 = \frac{V_{net}(3)}{V_{tot2}}100$
	c. Calculation of the 2nd Δ°API (Δ°API$_2$)	$\Delta^{o}\mathrm{API}_2 = \mathrm{abs}(^{o}\mathrm{API}_{\mathrm{mix1}} - {}^{o}\mathrm{API}(3))$
	d. Calculation of the 2nd %-shrinkage (S_{h2})	$S_{h2}\,(\%) = a\,Lc_2(100 - Lc_2)^b(\Delta^{o}\mathrm{API}_2)^c$
	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})	$SG_{mix2} = \frac{V_{mix2}SG_{mix2} + V_{net}(3)SG(3)}{V_{mix2}}$
	h. Calculation of the 2nd mixed °API (°API$_{mix2}$)	$^{o}\mathrm{API}_{mix2} = \frac{141.5}{SG_{mix2}} - 131.5$
5	Calculation of net-corrected-volume in tank (V_{nc})	$V_{nc} = V_{mix2}$
6	Calculation of group-shrinkage-losses in tank (V_{shg})	$V_{shg} = V_{sh1} + V_{sh2}$

[*)] Notes of **Table 3** that shows the stratification of oil mix in tank are listed in **Table 4**.

Table 4. Notes of Table 3: stratification of oil mix in tank

(*i*)	**Shippers' oil mix in Tank**		
	TANK-1	**TANK-2**	**TANK-3**
(1)	Shipper S1	TANK-1	TANK-2
(2)	Shipper S2	Shipper S4	Shipper S6
(3)	Shipper S3	Shipper S5	Shipper S7

The proportional shrinkage volume for each shipper ($\xi_{\text{prop}}(i)$) can be calculated as follows:

$$\xi_{\text{prop}}(i) = \frac{x_i\left(1/_{SG_i}\right)}{\sum_{i=1}^{n} x_i\left(1/_{SG_i}\right)} V_{s\square-\text{prop}} \quad \ldots\ldots\ldots\ldots \quad (4)$$

$$x(i) = \frac{V_i}{\sum_{i=1}^{n} V_i} \quad \ldots\ldots\ldots\ldots \quad (5)$$

where:

$\xi_{\text{prop}}(i)$ is proportional shrinkage volume of shipper *i*,

$x(i)$ is volume fraction of shipper *i*.

2.3.2. Stratified method

In stratified method, the net-corrected-volume is stratify calculated from tank to tank as shown in **Table 3**. The shrinkage volume is calculated for each mixing phenomenon in TANK-1, TANK-2, and TANK-3, respectively. The total oil losses for shippers S1, S2, and S3 are the summation of its shrinkage volume in TANK-1, TANK-2, and TANK-3; for shippers S4 and S5 are those in TANK-2 and TANK-3; while for shippers S6 and S7 are only once in the last tank of TANK-3.

3. Result and Discussion

3.1. Proportional results

Proportional method gives sharing oil losses results as shown in **Table 5**. As can be seen from **Table 5**, the total oil losses is 9.06 barrel and the shrinkage percentages (%-S_h) of all shippers are almost the same, ±0.20%. However, the shrinkage percentage of shipper S7 is the largest one (0.22%) since its oil is classified as condensate. Condensate is typically light oil or gas oil that has low density and small molecular size, while heavy oil has big molecular size. When condensate mixes heavy oil, hence geometrically there will be shrinkage; and this agrees with those in Erno et al (1994), James (2014), and Shanshool et al (2011).

Table 5. Sharing oil losses results with Proportional method

SHIPPER	**Sending Point**		**Individual Losses**	
	barrel	**SG**	**barrel**	**%S_h**
S1	500.00	0.8881	1.00	0.20
S2	1,200.00	0.8931	2.38	0.20
S3	400.00	0.9031	0.78	0.20
S4	200.00	0.9043	0.39	0.20
S5	800.00	0.8694	1.63	0.20
S6	1,000.00	0.8912	1.99	0.20
S7	400.00	0.8001	0.89	0.22
Total	**4,500.00**		**9.06**	
Corrected net volume in the last Tank (barrel) =				**4,490.94**
Total Losses (barrel)				**9.06**

3.2. Stratified results

Table 6 shows sharing oil losses results with stratified method. In this method, shrinkage volume of each shipper is calculated for every mixing in the tank. As can be seen from **Table 6**, the subtotal oil losses in every tank are 2.49, 4.20, and 2.38 barrels, respectively. The total oil loss in the stratified method is thus the same as in the proportional method, i.e. 9.06 barrels. The individual shrinkage percentage of each shipper in every tank is almost the same; they are 0.12%, 0.13%, and 0.05% in TANK-1, TANK-2, and TANK-3, respectively. The total of shrinkage percentages of shippers S1, S2, and S3 are larger than those in shippers S4 and S5, (0.31% vs. 0.19%); and those in shippers S4 and S5 are larger than those in shippers S6 and S7, (0.19% vs. 0.05%). This is understandable that more often oil mix with others, its volume will be more decreased.

Table 6. Sharing oil losses results with Stratified method.

SHIPPER			Stratified-1 (Mixing in Tank-1 of Station-1)				Stratified-2 (Mixing in Tank-2 of Station-2)				Stratified-3 (Mixing in Tank-3 of Station-3)				TOTAL LOSSES	
Sending Point			Individual Losses		Corrected Factor		Individual Losses		Corrected Factor		Individual Losses		Corrected Factor		Vol.	%-Sh
SHIPPER	vol (bbl)	SG	(bbl)	%Sh	(bbl)	SG	(bbl)	%Sh	(bbl)	SG	(bbl)	%Sh	(bbl)	SG	(bbl)	(%)
S1	500.00	0.8881	0.60	0.12	499.40	0.8938	0.67	0.13	498.73	0.8882	0.26	0.05	**498.47**	0.8810	1.53	0.31
S2	1,200.00	0.8931	1.42	0.12	1,198.58	0.8938	1.61	0.13	1,196.97	0.8882	0.63	0.05	**1,196.34**	0.8810	3.66	0.31
S3	400.00	0.9031	0.47	0.12	399.53	0.8938	0.54	0.13	398.99	0.8882	0.21	0.05	**398.78**	0.8810	1.22	0.30
total	2,100.00		2.49													
Net Corrected Vol. of Tank-1 (bbl)			2097.51													
Sub-total oil Losses (bbl)			2.49													
S4					200.00	0.9043	0.27	0.13	199.73	0.8882	0.10	0.05	**199.63**	0.8810	0.37	0.19
S5					800.00	0.8694	1.11	0.14	798.89	0.8882	0.42	0.05	**798.47**	0.8810	1.53	0.19
				total	3,097.51		4.20									
Net Corrected Vol. of Tank-2 (bbl)							3,093.32									
Sub-total oil Losses (bbl)							4.20									
S6									1,000.00	0.8912	0.52	0.05	**999.48**	0.8810	0.52	0.05
S7									400.00	0.8001	0.23	0.06	**399.77**	0.8810	0.23	0.06
								total	4,493.32		2.38		4,490.94		9.06	
Net Corrected Vol. of Tank-3 (bbl)											4490.94					
Sub-total oil Losses (bbl)											2.38					

3.3. Comparison of proportional and stratified results

Comparison results between proportional and stratified methods are listed in **Table 7**. The total sending volume is 4500 barrel, and total shrinkage volume is 9.06 barrel. Therefore, the net corrected volume in the last tank is 4490.94 barrel. The proportional method gives almost the same of shrinkage percentage, ±0.20%, whereas stratified method varies from 0.05% to 0.31% as its mixing quantity.

The proportional method is considered unfair since shippers S6 and S7 bear those losses of the upstream shippers. More often oil mixes with others, for examples oil from shippers S1, S2, and S3 pass through 3 times of mixing phenomenon, more volume shrinkage will be. Thus, the stratified method appropriates for determining of sharing oil losses in the multi mixing phenomenon.

Table 7. Comparison Results between Proportional and Stratified methods

SHIPPER	Sending Point (barrel)	SG	Mixing Quantity	Proportional (bbl)	% S_h	Stratified (bbl)	% S_h
S1	500.00	0.8881	3	1.00	0.20	1.53	0.31
S2	1,200.00	0.8931	3	2.38	0.20	3.66	0.31
S3	400.00	0.9031	3	0.78	0.20	1.22	0.30
S4	200.00	0.9043	2	0.39	0.20	0.37	0.19
S5	800.00	0.8694	2	1.63	0.20	1.53	0.19
S6	1,000.00	0.8912	1	1.99	0.20	0.52	0.05
S7	400.00	0.8001	1	0.89	0.22	0.23	0.06
Total	**4,500.00**			**9.06**		**9.06**	
***Net corrected volume* = 4,490.94 barrel**							

4. Conclusion

The sharing of oil losses in a Khrisna field has been discussed. In this work, the 2 methods i.e. proportional and stratified methods were used to determine the sharing of oil losses for 7 shippers with different amount of mixing phenomenon in the tank. According to our analysis, the proportional method gave almost the same of oil losses percentages for all shippers. However, shippers that more often mixed with others, e.g. shippers S1, S2, and S3 have 3 times of mixing phenomenon; their shrinkage volume would be larger than others. For that reason, we recommended to use stratified method to determine sharing oil losses since it gives a fair result.

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to:	Yulius Deddy Hermawan <ydhermawan@upnyk.ac.id>	
date:	Oct 29, 2018, 9:59 AM	
subject:	PEPT-D-18-00458 - Submission Confirmation	
mailed-by:	editorialmanager.com	
signed-by:	editorialmanager.com	

Dear Dr Hermawan,

Thank you for submitting your manuscript, Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field, to Journal of Petroleum Exploration and Production Technology.

The submission id is: PEPT-D-18-00458

Please refer to this number in any future correspondence.

During the review process, you can keep track of the status of your manuscript in the journal's website.

Your username is: ydhermawan
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Journal of Petroleum Exploration and Production Technology

PEPT: Your manuscript entitled Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field

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from:	**Journal of Petroleum Exploration and Production Technology (PEPT) <em@editorialmanager.com>**	**Feb 21, 2019, 2:51 AM**
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date:	Feb 21, 2019, 2:51 AM	
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Ref.: Ms. No. PEPT-D-18-00458
Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field
Journal of Petroleum Exploration and Production Technology

Dear Dr Hermawan,

Reviewers have now commented on your paper. You will see that they are advising that you revise your manuscript. If you are prepared to undertake the work required, I would be pleased to reconsider my decision.

The reviewers' comments can be found at the end of this email or can be accessed in the Editorial Manager website.

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When revising your work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript.

Please note: When uploading your revised files, please make sure only to submit your editable source files (i. E. Word, tex).

Your revision is due by 11 Apr 2019.

To submit a revision, go to the journal'd website and log in as an Author. You will see a menu item called 'Submissions Needing Revision'. You will find your submission record there.

Yours sincerely

Turgay Ertekin, PhD
Editor-in-Chief
Journal of Petroleum Exploration and Production Technology

Reviewers' comments:

Reviewer #1: The following comments need to be addressed before publication:
1) In the introduction section, define the proportional and stratified methods and explain their differences by citing appropriate references.
2) Explain the novelty of the work in the introduction section. It is not clear what is missing in the relevant literature that has been cited and discussed in the paper.
3) Are all emulsion and flash losses zero? If yes, why do you include them in the calculations? Explain.
4) Make sure all the subscripts are correct. Some of them are missing in the pdf file, such as 'h' in equations 1 and 3 in the text, and in equation 3. d in Table 3.
5) The conclusions section is short. Add more information and mention the main concluding remarks of the paper.
6) Correct the third and fourth name of co-authors. Only their last names have been mentioned
7) Review and cite the following references, as they include up to date information about hydrocarbon properties and phase behavior of oil and gas systems:

1) A smooth model for the estimation of gas/vapor viscosity of hydrocarbon fluids https://doi.org/10.1016/j.jngse.2015.07.045
2) Development of a robust model for prediction of under-saturated reservoir oil viscosity https://doi.org/10.1016/j.molliq.2016.11.088
3) Numerical simulation of mineral precipitation in hydrocarbon reservoirs and wellbores https://doi.org/10.1016/j.fuel.2018.10.101
4) Scale formation in porous media and its impact on reservoir performance during water flooding https://doi.org/10.1016/j.jngse.2017.01.019

Reviewer #2: The manuscript described a practical problem in the oil mixing process, however, significant work is required to improve the quality of the paper to make it a journal article. Some comments below:

1. The manuscript is lack of analysis for the fundamental mechanisms of why sharing oil losses happen;
2. English needs to be refined by professionals;
3. A thorough literature review on the topic under study is needed ;
4. More detailed oil properties are needed in section 2.2, for example, what are the viscosity, solution gas oil ratio, saturation pressure etc.;
5. The authors need more discussion on what's new in the manuscript. The content presented in the manuscript reads like a class report without in-depth analysis and discussion;
6. The conclusion part needs to be re-written to emphasize the new findings in the study;

__

Reminder for Revision PEPT-D-18-00458

Inbox

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date: Apr 18, 2019, 12:18 PM
subject: Reminder for Revision PEPT-D-18-00458
mailed-by: editorialmanager.com
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Please inform us if you need an extension in order to revise this paper.

We look forward to receiving your revision. Thank you.

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Journal of Petroleum Exploration and Production Technology

Re: Reminder for Revision PEPT-D-18-00458

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date: Apr 24, 2019, 8:32 AM
subject: Re: Reminder for Revision PEPT-D-18-00458
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Dear,
Editor-in-Chief
Journal of Petroleum Exploration and Production Technology

First we apologize for delay response and thank you for reminding us to revise manuscript PEPT-D-1800458.

Now we still read and review some references (recommended by one of reviewers) that not quite related with our manuscript. That's a reason why we delay to submit our revision and need an extension in order to revise our manuscript.

That's all about our information. Thank you for your attention.

Best Regards
YD Hermawan.

PEPT-D-18-00458

Inbox

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cc:	Dedy Kris <dedykris.upn@gmail.com>, Hariyadi <haryd_upn@yahoo.com>, Yulius Deddy Hermawan <ydhermawan@gmail.com>	
date:	Apr 24, 2019, 1:00 PM	
subject:	PEPT-D-18-00458	
mailed-by:	springernature.com	

Dear Dr. Hermawan,

Kindly let me know the exact tentative days required to complete the revised article online so that I could extend the due date upon the editor's confirmation.

Thank you very much.

Best regards,
Vinothini

Vinothini Panneerselvam (Ms.)
JEO Assistant
Journals Editorial Office (JEO)

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F +91 44 42197763
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from: **Yulius Deddy Hermawan** <ydhermawan@upnyk.ac.id> **Apr 24, 2019, 6:00 PM**
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cc: Dedy Kris <dedykris.upn@gmail.com>, Hariyadi <haryd_upn@yahoo.com>, Yulius Deddy Hermawan <ydhermawan@gmail.com>
date: Apr 24, 2019, 6:00 PM
subject: Re: PEPT-D-18-00458
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Dear
Vinothini,

Kindly may I know, actually how much time provided by editor for us to revise and submit our manuscript?

May we ask an extension to submit our revised manuscript until 24 June 2019?

Thank you for your cooperation and attention.

Best Regards
YD Hermawan

PEPT-D-18-00458

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cc:	Dedy Kris <dedykris.upn@gmail.com>, Hariyadi <haryd_upn@yahoo.com>, Yulius Deddy Hermawan <ydhermawan@gmail.com>	
date:	Apr 24, 2019, 7:34 PM	
subject:	PEPT-D-18-00458	
mailed-by:	springernature.com	

Dear Dr. Hermawan,

I have now forwarded your below request to the editor and would extend the due date upon the editor's confirmation.

Thank you very much.

Best regards,
Vinothini

Vinothini Panneerselvam (Ms.)
JEO Assistant
Journals Editorial Office (JEO)

Springer Nature
T +91 44 42197752
F +91 44 42197763
Vinothini.Panneerselvam@springernature.com
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date:	Apr 25, 2019, 12:15 PM	
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We look forward to receiving your revision. Thank you.

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Journal Name : Journal of Petroleum Exploration and Production Technology
Article Title : Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field
Manuscript Number : PEPT-D-18-00458

Dear Dr Hermawan,

This is to inform you that, as requested, the due date for submitting your revision entitled "Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field" has now been changed.

The new due date is: 24 Jun 2019

We look forward to receiving the revision.

With kind regards,
Springer Journals Editorial Office
Journal of Petroleum Exploration and Production Technology

Submission Revised-Manuscript PEPT-D-18-00458

Inbox

from: **Yulius Deddy Hermawan** <ydhermawan@upnyk.ac.id> **Jun 14, 2019, 6:59 AM**
to: "Journal of Petroleum Exploration and Production Technology (PEPT)" <vinothini.panneerselvam@springernature.com>
cc: Yulius Deddy Hermawan <ydhermawan@gmail.com>, Dedy Kris <dedykris.upn@gmail.com>, Hariyadi <haryd_upn@yahoo.com>, Wibowo MS <wibowo.ms@gmail.com>
date: Jun 14, 2019, 6:59 AM
subject: Submission Revised-Manuscript PEPT-D-18-00458
mailed-by: upnyk.ac.id

Dear Chief Editor,
Journal of Petroleum Exploration and Production Technology

This is to inform you that we submit our Revised-Manuscript PEPT-D-18-00458 entitled "Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field".

The attachment files include revised manuscript in (words and pdf) and the answers for reviewers' comments.

That's all about our revised-manuscript. Thank you for your nice cooperation and attention. We are looking forward to hearing from you soon.

Best regards
Yulius Deddy Hermawan
Dedy Kristanto
Hariyadi
Wibowo

Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field

Yulius Deddy Hermawan[1)], Dedy Kristanto[2)], Hariyadi[3)], and Wibowo[4)]

[1)] *Department of Chemical Engineering, Faculty of Industrial Engineering,*
[2,3,4)] *Department of Petroleum Engineering, Faculty of Mineral Technology,*
Universitas Pembangunan Nasional "Veteran" Yogyakarta,
Jl. SWK 104 (Lingkar Utara) Condongcatur, Yogyakarta, 55283, Indonesia
Email: ydhermawan@upnyk.ac.id and dedykris.upn@gmail.com

Abstract:

This paper discusses about the oil losses due to emulsion, flash, and mixing oil phenomena that frequently happened in the oil and gas companies. The goals of this work are to calculate the emulsion and vapor correction volumes, shrinkage correction volume of the mixture of two or more crude oils with different densities, and to compare between the common proportional method that usually utilized in petroleum industries and the new proposed stratified method for determining of sharing oil losses. The mixing of crude oils from 7 shippers in Khrisna Field would be used as a case study, and the equation of API 12.3 was chosen to calculate a shrinkage correction volume. Oils from shippers S1, S2, and S3 were first mixed together in Tank-1 of the 1st station; the mixed oil of Tank-1 was then transported to the next station and stored in the Tank-2 and mixed with other oils from shippers S4 and S5; finally, the mixed oil of Tank-2 was transported to the final station and stored in the Tank-3 and mixed with other oils from shippers S6 and S7. The proportional method gave almost the same shrinkage correction factor (SCF) for all shippers about 0.20%; while stratified method resulted SCF in between 0.05% and 0.31%. Based on our analysis, more often oil mixes with others its volume would be more decreased. The stratified method is therefore recommended to determine sharing oil losses since it gives a fair result.

Keywords: Emulsion, Flash, Oil losses, Mixing oil, Proportional, Shrinkage, and Stratified.

1. Introduction

Sources of oil loss in petroleum industries are emulsion, evaporative (flash), shrinkage, leakage, theft, and measurement losses, etc (Bhatia and Dinwoodie, 2004). This study focuses in oil losses due to emulsion, flash, and mixing phenomena. Human and measurement errors, leakage, and theft are excluded. Oil loss are categorized into 2 categories, they are (1) individual and (2) group losses.

1.1. Individual loss

Individual loss includes emulsion and evaporative losses. In order to determine emulsion loss, based sediment and water (BS&W) of oil should be measured. The net standard volume (NSV) excludes sediment, water, and free water. So far back to year 1918, Bradley et al have studied the crude oil losses in steel and earthen storage; they classified roughly losses as occurring from evaporation, and presence of sediment and water. Evaporative loss occurs when light components are released from oil in the storage tank. This happens when the oil temperature is lower than its bubble point. Thus, by maintaining low oil temperature minimizes evaporative loss from storage tank (Bhatia and Dinwoodie, 2004).

The goals of this work are to calculate the emulsion correction factor (ECF) and flash correction factor (FCF) that occur individually in 7 shippers of Khrisna field. The empiric equation of emulsion would be used to calculate ECF. While flash calculation with Antoine equation was chosen to calculate FCF.

1.2. Group loss

Group loss occurs during mixing oils in the same storage tank. In this study, the specific characteristic which has influence on group loss is the specific gravity (SG) or API gravity. The viscosity and gas oil ratio are excluded in calculation of group loss due to mixing phenomena in the storage tank. The oil and gas fields generally produce petroleum fluid that can be classified into five categories: dry gas, wet gas, gas condensate, volatile oil, and black oil (McCain 1990.a; Whitson and Brule 2000). Since the fluids in those categories have different characteristics, specifically SG or API, the properties would thus change when they are mixed together.

Typical oil mixing phenomena in the gathering station is illustrated in **Figure 1**. In an activity of transporting of crude oil from shippers in the oil field to the gathering station, shippers often use the same pipeline to transport the crude oil to a storage tank. The crude oils from shippers are mixed together either in the same temporary or final storage tank. This situation comes up the problem of oil losses. As shown in **Figure 1**, there is a loss discrepancy between total quantities from shippers and measurement in the storage tanks (Bhatia and Dinwoodie, 2004); the total sending volume is lower than the measured volume in the mixing tank. The study of sharing oil losses is therefore very important to be done.

Several studies (Katz 1942; Erno et al 1994; Nengkoda 2011; James 2014) have discussed about prediction of crude oil shrinkage losses. Far back to year of 1942, Katz has investigated the crude oil shrinkage phenomena and pointed that the more volatile the separator liquid phase, the more impact separator conditions and shrinkage will be. In 1994, Erno et al predicted the shrinkage equation of heavy oil/condensate blend and stated that when condensate is added to heavy oil, the blended volume is less than the sum of the condensate and oil volumes. In 2011, Nengkoda has studied the role of crude oil shrinkage in heavy mix light crude in main oil pipeline and pointed that shrinkage will be very depended upon the operation pressure and temperature. In recent year 2014, James has studied shrinkage losses resulting from liquid hydrocarbon blending. James (2014) concluded that equation of API 12.3 was a valuable tool in quantifying shrinkage that occurs as a result of blending hydrocarbons of different densities. Moreover in 2011, Shanshool et al have investigated the volumetric behavior of mixtures of different oil stock. Shanshool et al (2011) concluded that volumetric shrinkage is resulted from blending hydrocarbon with gas oil (light oil).

The goals of this work are to calculate the shrinkage correction factor (SCF) in oil mixing phenomena and to determine the sharing oil losses using the common proportional and the new proposed stratified methods. The oil distribution of 7 shippers in Khrisna field (**Figure 2**) would be taken as a case study. The modified equation of API 12.3 would be used to calculate SCF in every mixing phenomenon in tank.

2. Material and Method

2.1. Flow diagram of oil distribution

The block diagram of oil distribution and mixing phenomena in Khrisna field is shown in **Figure 2**. As can be seen in **Figure 2**, Khrisna field has 7 shippers; they are S1, S2, S3, S4, S5, S6, and S7. Shippers S1, S2, and S3 send their oil to Station-1 and the oils are temporary stored in same tank of TANK-1. The mixed oil of TANK-1 is then pumped to the 2nd station and temporary stored in TANK-2 and mixed with other oils from shippers S4 and S5. Finally, the mixed oil of TANK-2 is transported to the 3rd station and stored in TANK-3 and mixed with other oils from shippers S6 and S7. As shown in **Figure 2**, shippers S1, S2, and S3 have 3 times of mixing phenomena, shippers S4 and S5 have twice, and shippers S6 and S7 have only once.

2.2. Parameters input

Parameters input for calculating of sharing oil losses are production rate, pressure, temperature, specific gravity (SG), and based sediment water (BSW). These parameters input are listed in **Table 1**. As shown in **Table 1**, oils S1 to S6 have the same BS&W 0.1 %Vol. While shipper S7 produces condensate with BS&W equals to zero. All oils are stored in the atmospheric storage tank (pressure of about 1 atm and temperature of about 30 ^{o}C). The total oil rate from all shippers as sending points is 4500 barrel oil per day (BOPD). The specific gravities (SG) of all shippers vary from 0.8001 to 0.9043. Oil S7 is the lightest one with SG 0.8001; this is typically condensate. Oils S3 and S4 are typical heavy oil with SG around 0.90.

2.3. Calculation algorithm of sharing oil losses

Calculation algorithm of sharing oil losses are shown in **Figure 3**. In order to calculate the total sharing oil losses, individual loss such as emulsion and flash losses must first be calculated, and then the group loss in mixing phenomena is determined. Sharing oil losses would be determined by 2 methods, they are the common proportional and the new proposed stratified methods.

2.3.1. Calculation of emulsion loss

Since the net oil excludes sediment, water, and free-water, based sediment and water (BS&W) of oil has to be measured. In this study, BS&W in oils S1 to S6 are taken the same 0.1 %Vol (**Table 1**). While BS&W of oil S7 equals to zero since this oil is a typical condensate. The empiric emulsion equations are used for calculating emulsion loss. The emulsion parameters (a_1, b_1, a_2, b_2) for each shipper are shown in **Table 2**. The empiric emulsion equations and emulsion loss can be generated with following methodology:

a. Crude oil is mixed with its formation water at some levels of water volume, and the BS&W and SG of mixed oil-water are then investigated.
b. The changes of BS&W and SG are plotted in a curve. This first curve results linear equation:

   $$Y_1 = a_1 X_1 + b_1 \quad \text{(1)}$$

   where X_1 is the measured BS&W, Y_1 is the measured SG, a_1 and b_1 are constants.
c. Then, making a curve of percentage of the addition of the volume of formation water (in %Vol) versus the calculated SG. This second curve produces linear equation:

   $$Y_2 = a_2 X_2 + b_2 \quad \text{(2)}$$

   where X_2 is the percentage of the addition of the volume of formation water (in %Vol), Y_2 is the calculated SG, a_2 and b_2 are constants. The calculated SG can be found with the following equation:

   $$\mathrm{SG_{calculated}} = (1 - X_w)\mathrm{SG_{fw}} + X_w \mathrm{SG_w} \quad \text{(3)}$$

where X_w is water volume fraction in oil, SG_w is specific gravity of formation water, and SG_{fw} is specific gravity of oil free-water as defined below:

$$SG_{fw} = \frac{SG_o - X_w SG_w}{(1 - X_w)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where SG_o is specific gravity of oil that still contains water.

d. Both empiric equations are then used for calculating emulsion loss. Y_1 is found by inputting the measured BS&W of oil as X_1 in equation (1). The resulted Y_1 is then substituted in equation (2) to calculate X_2.

e. Emulsion correction factor (ECF) in %Vol is then calculated as follows:

$$ECF = X_1 - X_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

2.3.2. Calculation of evaporative loss

Evaporative loss is calculated with flash calculation method. Mass balance diagram for flash calculation method is shown in **Figure 4**. Evaporative loss depends on its operating conditions, i.e. pressure (P) and temperature (T). Evaporation is indicated by the value of vapor fraction n_v (Tarek 2007). Vapor fraction n_v ranges in between 0 to 1. n_v=0 and n_v=1 mean the fluid is in liquid and gas phase, respectively. If n_v 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.

Flash calculation algorithm is shown in **Figure 5**. Input data required in this algorithm are hydrocarbon composition (z_j), pressure (P_i) and temperature (T_i) of each shipper system. The intended pressure (P_i) is the fluid pressure in a storage tank, i.e. atmospheric pressure. **Table 3** shows the hydrocarbon composition (z_j) of each shipper. In this work, Antoine equation was chosen to calculate flash correction factor (FCF). Antoine parameters (a, b, c, d, e, f) for each hydrocarbon component are listed in **Table 4**.

The next step is the calculations of bubble (T_b) and dew point (T_d) at the atmospheric pressure. Bubble and dew point are saturated condition at n_v=0 and n_v=1, respectively. Calculation procedure of T_b and T_d are written in **Table 5** and **6**, respectively. Antoine equation used in this calculation is:

$$P_{vap\,j} = \exp\left(a_j + \frac{b_j}{(T+c_j)} + d_j \ln(T) + e_j T^{f_j}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

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**.

After calculation T_b and T_d, we calculate vapor fraction n_v. Temperature T and pressure P of fluid (system) are the input data in calculation n_v. As shown in **Figure 4**, when T is lower than T_b so n_v=0, this indicates that the fluid is in liquid phase. When T is higher than T_d so n_v=1, this means that fluid is in vapor phase. When T is in between T_b and T_d, n_v is in between 0 and 1, this means that part of light component in fluid evaporates. Calculation procedure of n_v is shown in **Table 7**. Flash correction factor (FCF) is then calculated as follows:

$$\text{FCF} = n_v \text{ x } 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

where FCF is in %Vol.

2.3.3. Calculation of shrinkage loss

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

$$S_h\,(\%) = a\,L_c(100 - L_c)^b(\Delta^{\text{o}}\text{API})^c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where a, b, and c are constants of API 12.3 that be taken from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017) as listed in **Table 8**, L_c is %-light component, Δ^{o}API is $^{\text{o}}$API difference between $^{\text{o}}$API of shipper one and other, and S_h is shrinkage volume percentage (in %).

API gravity for each shipper is defined as the equation in McCain (1990.b):

$$^{\text{o}}\text{API}_i = \frac{141.5}{SG_i} - 131.5 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

where $^{\text{o}}\text{API}_i$ is API gravity of shipper i, and SG_i is specific gravity (60$^{\text{o}}$/60$^{\text{o}}$) of shipper i.

2.3.3.1. Proportional method

Proportional method is the common method used in petroleum industries for sharing oil losses. In this method, the total received volume is measured at the last station. This measured volume is the net-corrected-volume (V_{nc}) which is directly taken from the last storage tank in the last station (TANK-3 in **Figure 2**). The total shrinkage volume ($V_{sh\text{-prop}}$) is the difference volume between the total volume sent from all shippers and the net corrected volume:

$$V_{sh-\text{prop}} = \sum_{i=1}^{n} V_i - V_{nc\,(\text{TANK}-3)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

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

$$\xi_{\text{prop}_i} = \frac{x_i\left(1/SG_i\right)}{\sum_{i=1}^{n} x_i\left(1/SG_i\right)} V_{sh-\text{prop}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

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

$$x_i = \frac{V_i}{\sum_{i=1}^{n} V_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

The proportional shrinkage correction factor ($\mathrm{SCF}_{\mathrm{prop}_i}$ in %Vol) for each shipper can then be calculated as follows:

$$\mathrm{SCF}_{\mathrm{prop}_i} = \frac{\xi_{prop_i}}{V_i} \text{ x } 100\% \quad \text{..} \quad (13)$$

2.3.3.2. Stratified method

In new proposed stratified method, the net-corrected-volume is calculated stratify from tank to tank as shown in **Table 9**. The shrinkage volume is calculated for each mixing phenomena in TANK-1, TANK-2, and TANK-3. The shrinkage volume for shippers S1, S2, and S3 in TANK-1 can be calculated with the following equation:

$$\xi_{\mathrm{st-I}_i} = \frac{x_i\left({}^{1}/_{SG_i}\right)}{\sum_{i=1}^{n} x_i\left({}^{1}/_{SG_i}\right)} V_{shg-\mathrm{I}} \quad \text{..} \quad (14)$$

where $\xi_{\mathrm{st-I}_i}$ is shrinkage volume for shipper *i* (S1, S2, S3) in TANK-1, and $V_{shg\text{-I}}$ is the group shrinkage volume in TANK-1. The shrinkage volume for shippers S4, S5, and TANK-1 (mix S1-S2-S3) in TANK-2 can be calculated with the following equation:

$$\xi_{\mathrm{st-II}_i} = \frac{x_i\left({}^{1}/_{SG_i}\right)}{\sum_{i=1}^{n} x_i\left({}^{1}/_{SG_i}\right)} V_{shg-\mathrm{II}} \quad \text{..} \quad (15)$$

where $\xi_{\mathrm{st-II}_i}$ is shrinkage volume for shipper *i* (S4, S5, and mix S1-S2-S3) in TANK-2, and $V_{shg\text{-II}}$ is the group shrinkage volume in TANK-2. Finally, the shrinkage volume for shippers S6, S7, and TANK-2 (mix S1-S2-S3-S4-S5) in TANK-3 can be calculated as follows:

$$\xi_{\mathrm{st-III}_i} = \frac{x_i\left({}^{1}/_{SG_i}\right)}{\sum_{i=1}^{n} x_i\left({}^{1}/_{SG_i}\right)} V_{shg-\mathrm{III}} \quad \text{..} \quad (16)$$

where $\xi_{\mathrm{st-III}_i}$ is shrinkage volume for shipper *i* (S6, S7, and mix S1-S2-S3-S4-S5) in TANK-3, and $V_{shg\text{-III}}$ is the group shrinkage volume in TANK-3.

The total stratified shrinkage volume ($\xi_{\mathrm{st-tot}_i}$) for shippers S1, S2, and S3 are the summation of its shrinkage volume in TANK-1, TANK-2, and TANK-3, for shippers S4 and S5 are those in TANK-2 and TANK-3; while for shippers S6 and S7 are only once in the last tank of TANK-3.

$$\xi_{\mathrm{st-tot}_i} = \xi_{\mathrm{st-I}_i} + \xi_{\mathrm{st-II}_i} + \xi_{\mathrm{st-III}_i} \quad \text{..} \quad (17)$$

where for S4 and S5 $\xi_{\mathrm{st-I}_i} = 0$, and for S6 and S7 $\xi_{\mathrm{st-I}_i} = \xi_{\mathrm{st-II}_i} = 0$.

The stratified shrinkage correction factor ($\mathrm{SCF}_{\mathrm{st}_i}$ in %Vol) for each shipper can then be calculated as follows:

$$\mathrm{SCF}_{\mathrm{st}_i} = \frac{\xi_{\mathrm{st-tot}_i}}{V_i} \text{ x } 100\% \quad \text{..} \quad (18)$$

3. Result and Discussion

3.1. Individual loss results

Individual loss includes emulsion and evaporative losses and must be determined to get the net standard volume (NSV) of all petroleum liquids. The NSV excluding sediment, water (and free water), and vapor is then used for calculating group loss in mixing phenomena. The total individual losses (TIL) including emulsion and evaporative loss is listed in **Table 11**. TIL of shipper S1 is the biggest one, i.e. 0.28 barrel. While TIL of shipper S7 equals to zero, since oil S7 is a typical condensate which has no emulsion. The total TIL and NSV resulted from the individual loss calculation are 0.96 and 4499.04 barrel, respectively.

3.1.1. Emulsion loss

By inputting BS&W=0.1% in the equation system (eq. 1 to 5), emulsion correction factor (ECF) for all shippers are found and listed in **Table 11**. The biggest and smallest ECF are given by shipper S1 and S3, respectively. The sensitivity BS&W against EFC is shown in **Figure 6**. Shipper S1 is the most sensitive compared with others, its ECF increases significantly by increasing its BS&W. While shipper S3 is not sensitive to a change in BS&W; its ECF raises slowly by increasing its BS&W.

3.1.2. Evaporative loss

In atmospheric pressure condition (about 1 atm), evaporation can happen when the fluid temperature is lower than its bubble point. The normal bubble (T_b) and dew (T_d) points resulted from flash calculation are listed in **Table 12**. Oil S7 is a typical condensate; it has the shortest span between T_b and T_d. Correlation of vapor pressure and bubble point for all shippers is shown in **Figure 7**. Since the oil temperatures in all tanks are lower than its bubble point (**Figure 7**), it is understandable that all shippers have no evaporative loss. Flash correction factor (FCF) of all shippers equal to zero. During operation in the oil gathering station, by maintaining oil temperature lower than its bubble point can eliminate evaporative loss from storage tank.

3.2. Shrinkage loss

3.2.1. Proportional shrinkage loss

Sharing oil losses resulted by the common proportional method are listed in **Table 13**. As can be seen from **Table 13**, the total shrinkage loss is 9.06 barrel and the shrinkage correction factor (SCF) of all shippers are almost the same ±0.20%. However, SCF of shipper S7 is the largest one (0.22%) since its oil is classified as condensate. Condensate is typically light oil or gas oil that has low density and small molecular size, while heavy oil has big molecular size. When condensate mixes heavy oil, hence geometrically there will be shrinkage as illustrated in **Figure 8**; and this agrees with those in Erno et al (1994), James (2014), and Shanshool et al (2011).

3.2.2. Stratified shrinkage loss

Table 14 shows sharing oil losses resulted by the new proposed stratified method. In this method, shrinkage volume of each shipper is calculated for every mixing in the tank. As can be seen from **Table 14**, the subtotal oil losses in every tank are 2.48, 4.20, and 2.38 barrels, respectively. The total oil loss in the stratified method is the same as in the proportional method, i.e. 9.06 barrels. The SCF of each shipper in every tank is almost the same; they are 0.12%, 0.13%, and 0.05% in TANK-1, TANK-2, and TANK-3, respectively. The total SCF of shippers S1, S2, and S3 are larger than those in shippers S4 and S5, (0.31% vs. 0.19%); and those in shippers S4 and S5 are larger than those in shippers S6 and S7, (0.19% vs. 0.05%). This is understandable that more often oil mixes with others; its volume will be more decreased.

3.3. Comparison of proportional and stratified results

Comparison between proportional and stratified results is listed in **Table 15**. The total NSV is 4,499.04 barrels, and total shrinkage volume is 9.06 barrel. Therefore, the net corrected volume (NCV) in the last tank is 4490.94 barrel. The proportional method gives almost the same of SCF, ±0.20%, while SCF resulted by stratified method varies from 0.05% to 0.31% depending on its mixing quantity.

The common proportional method is considered unfair since shippers S6 and S7 bear those losses of the upstream shippers (S1 to S5). More often oil mixes with others, for examples oils of shippers S1, S2, and S3 pass through 3 times of mixing phenomena, more volume shrinkage will be. Thus, the stratified method appropriates for determining of sharing oil losses in the multi mixing phenomena.

4. Conclusion

Study on oil losses due to emulsion, flash (evaporation), and mixing phenomena in a Khrisna field has been done. The oil loss is classified into 2 types, i.e. individual loss including emulsion and evaporative loss, and group loss which occurs in mixing phenomena. The individual loss must be determined to get the net standard volume (NSV). The NSV excluding sediment, water (and free water), and gas is then used for calculating group loss.

The emulsion correction factor (ECF) has been calculated for each shipper based on its BS&W. Since oil of shipper S7 is a condensate, it does not produce emulsion. According to our analysis, shipper S1 is the most sensitive to a change in BS&W, its ECF increases significantly by increasing its BS&W. While shipper S3 is not sensitive to a change in BS&W; its ECF raises slowly by increasing its BS&W.

Based on flash calculation results, all oils which are stored in tanks are the stable liquids. Since the oils' temperatures in tanks are lower than its bubble points at the normal condition (atmospheric), it is clear that all shippers have no evaporative loss. Flash correction factor (FCF) of all shippers equal to zero. Evaporative loss could be prevented by maintaining oil temperature lower than its bubble point.

In this work, the common proportional and new proposed stratified methods have been used to determine the sharing oil losses for 7 shippers in Khrisna field. According to our analysis, the common proportional method gave almost the same of shrinkage correction factor (SCF) for all shippers. However, shippers that more often mix with others, e.g. shippers S1, S2, and S3 have 3 times of mixing phenomena; their shrinkage volume were larger than others. For that reason, the new proposed stratified method is strongly recommended to determine sharing oil losses since it gives a fair result.

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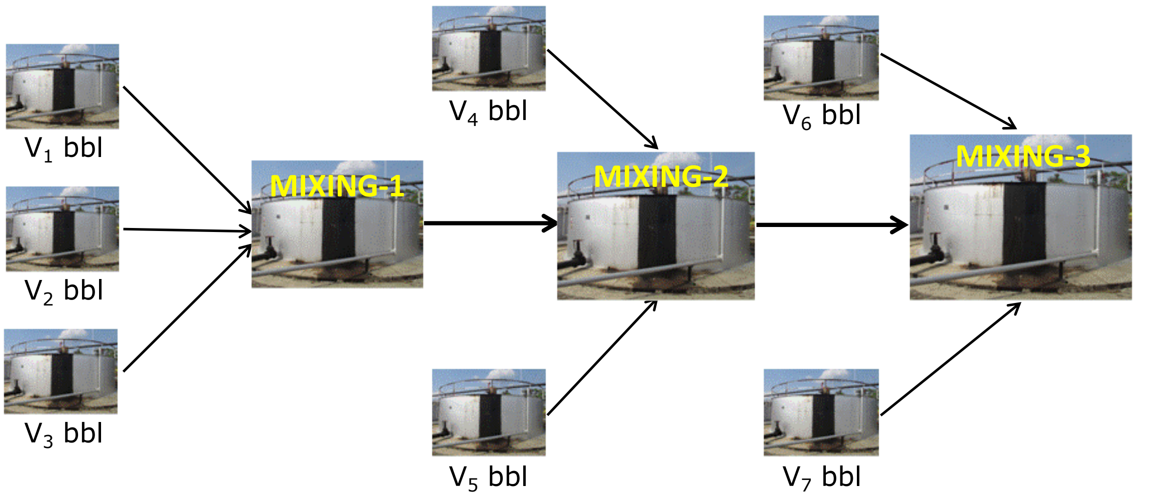

$$V_{mix-1} \neq V_1 + V_2 + V_3 \qquad V_{mix-2} \neq V_{mix-1} + V_4 + V_5 \qquad V_{mix-3} \neq V_{mix-2} + V_6 + V_7$$

$$V_{mix} < V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7$$

Figure 1. Typical oil mixing phenomena in gathering station

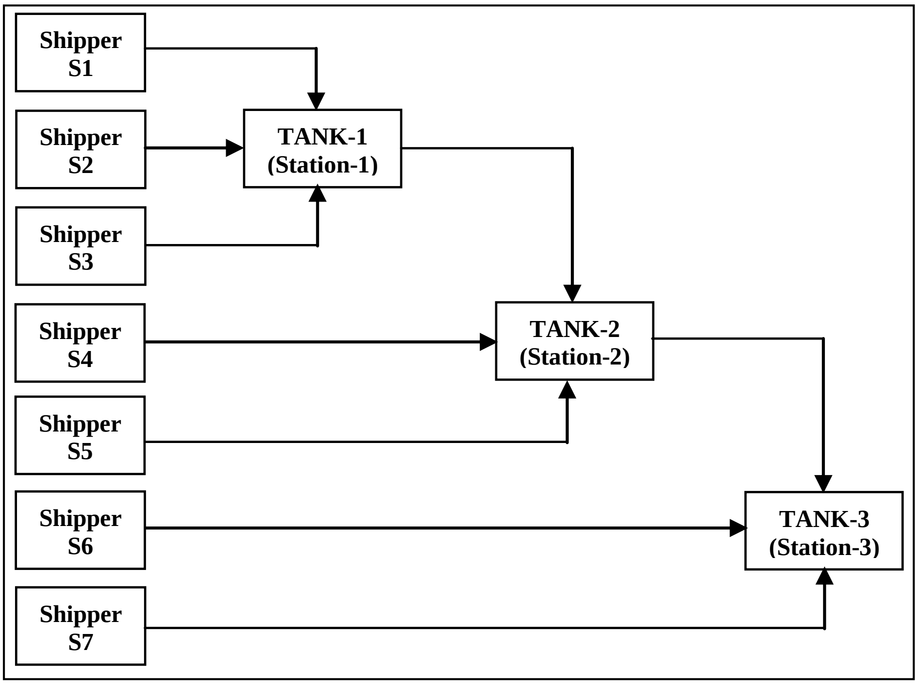

Figure 2. Block diagram of oil distribution and mixing phenomena in Khrisna field.

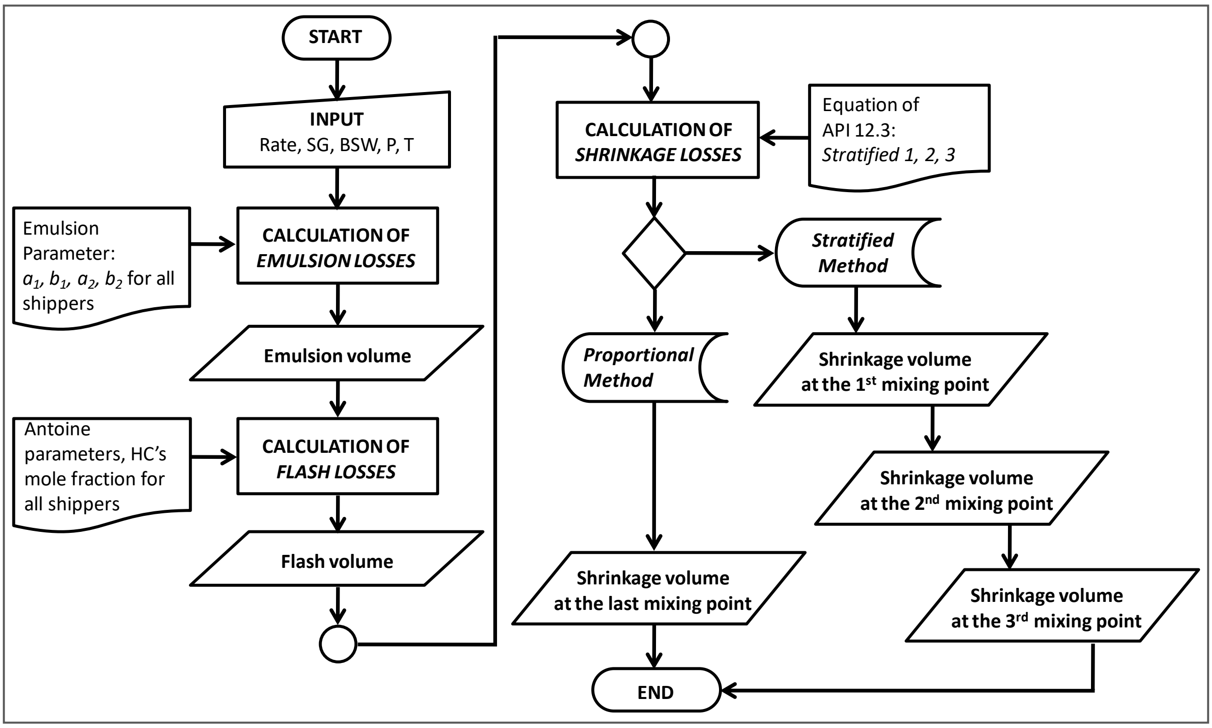

Figure 3. Calculation algorithm of sharing oil losses.

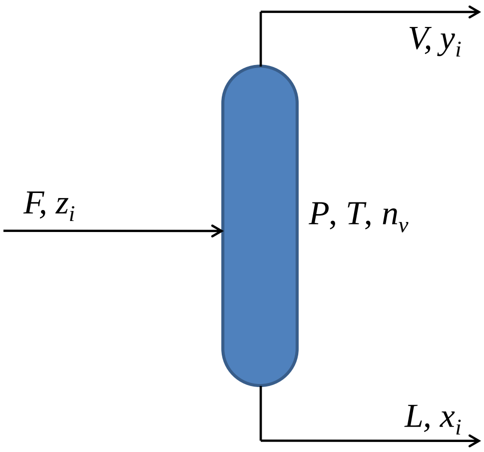

Figure 4. Vapor-liquid equilibrium for flash calculation.

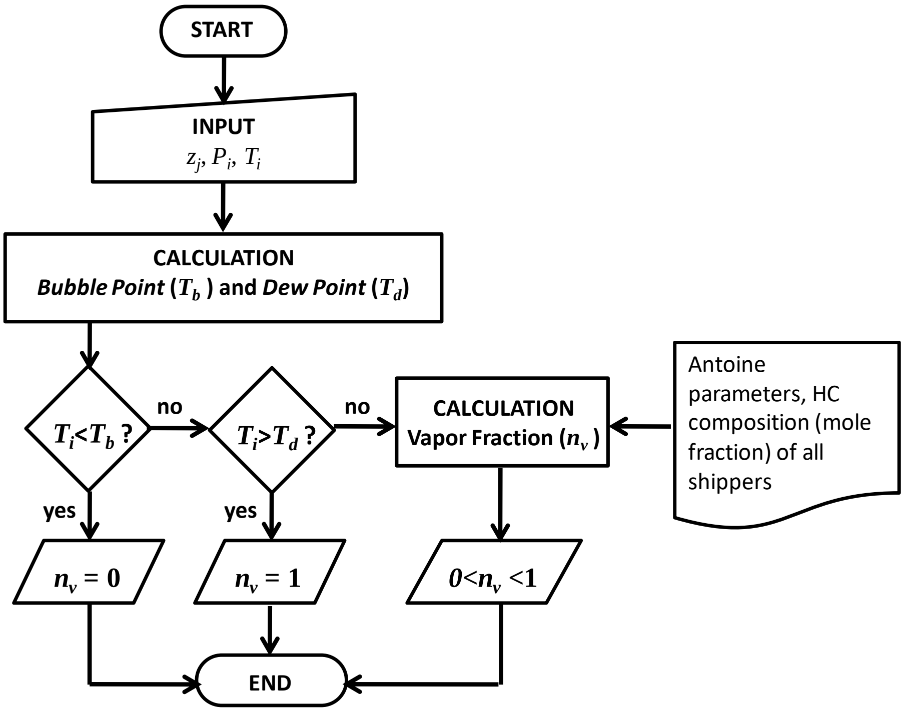

Figure 5. Flash Calculation algorithm.

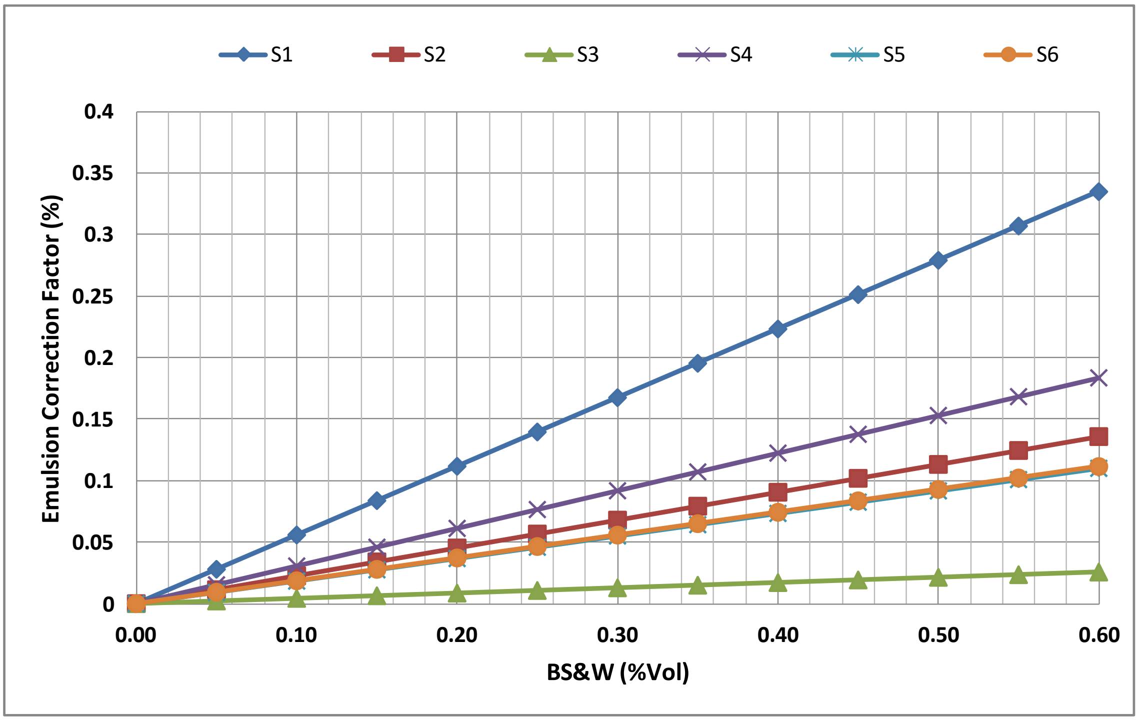

Figure 6. Sensitivity BS&W against ECF

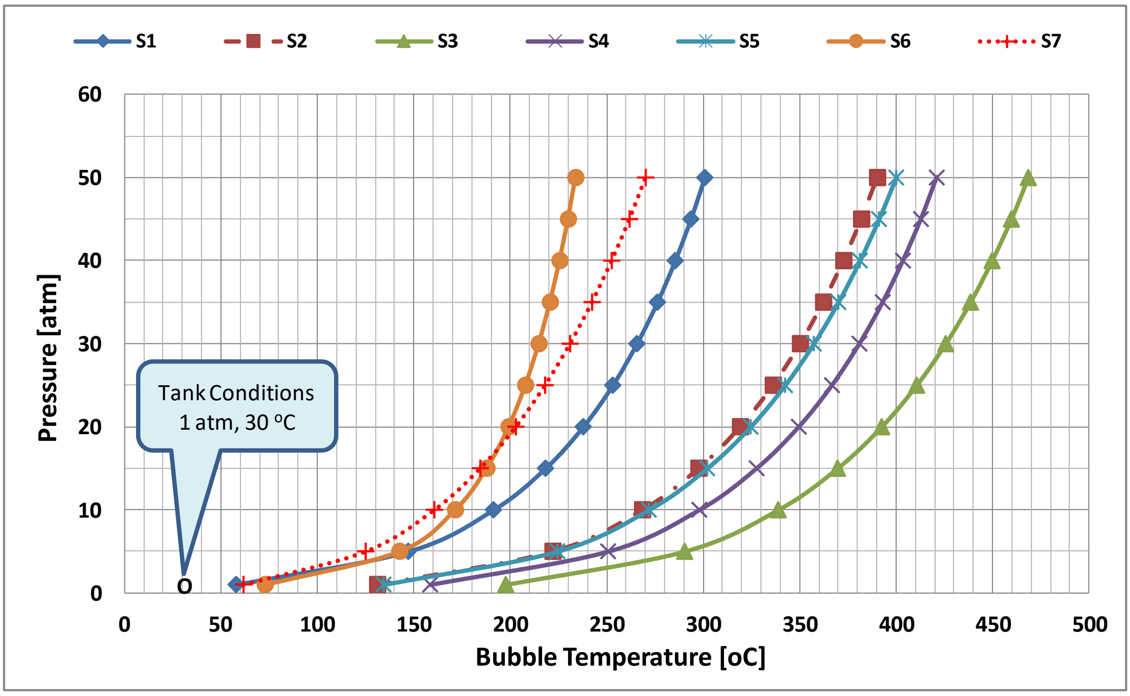

Figure 7. Correlation of vapor pressure and bubble temperature.

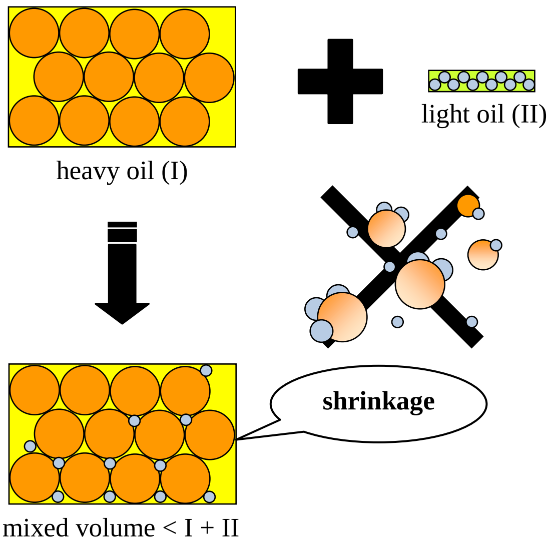

Figure 8. Illustration of shrinkage volume from mixing of heavy and light oils

Table 1. Production rate Khrisna field and its properties.

Shipper	Production			Oil Percent Volume [%]	Tank's Condition		Properties	
	Gross [BFPD]	Oil [BOPD]	Water [BWPD]		Pressure [atm]	Temperature [°C]	SG (60°/60°)	BS&W
S1	500	500	0	11.11	1	30	0.8881	0.1
S2	1200	1200	0	26.67	1	30	0.8931	0.1
S3	400	400	0	8.89	1	30	0.9031	0.1
S4	200	200	0	4.44	1	30	0.9043	0.1
S5	800	800	0	17.78	1	30	0.8694	0.1
S6	1000	1000	0	22.22	1	30	0.8912	0.1
S7 *)	400	400	0	8.89	1	30	0.8001	-
Total	**4500**	**4500**	**0**	100.00				

*Note *): shipper S7 produces condensate*

Table 2. Emulsion parameters

Shipper	X_1 = 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		
S1	0.1	0.001278	0.8881	0.888228	0.002892	0.8881	0.0442	0.0558
S2	0.1	0.001210	0.8931	0.893221	0.001564	0.8931	0.0774	0.0226
S3	0.1	0.001097	0.9031	0.903210	0.001146	0.9031	0.0957	0.0043
S4	0.1	0.001121	0.9043	0.904412	0.001615	0.9043	0.0694	0.0306
S5	0.1	0.001470	0.8694	0.869547	0.001800	0.8694	0.0817	0.0183
S6	0.1	0.001241	0.8912	0.891324	0.001524	0.8912	0.0814	0.0186
S7	0	0	0	0	0	0	0	0

The constants of a_1, b_1, a_2, and b_2, are referenced from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017).

Table 3. Hydrocarbon composition (%-mole)

Component	Shipper						
	S1	S2	S3	S4	S5	S6	S7
Metane (C1)	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Etane (C2)	0.82	0.04	0.01	0.03	0.01	0.02	0.00
Propane (C3)	0.98	0.33	0.03	0.14	0.27	0.11	0.00
Butane (C4)	1.43	0.68	0.08	0.24	0.54	0.34	0.05
Pentane (C5)	1.76	1.01	0.17	0.43	1.07	0.75	30.48
Hexane (C6)	2.69	1.48	0.26	0.85	3.45	2.53	29.67
Heptane (C7)	5.04	4.17	1.54	3.11	4.44	3.55	25.85
Octane (C8)	8.37	8.15	3.63	6.88	8.04	7.25	12.37
Nonane (C9)	6.85	7.56	4.65	6.66	7.59	6.77	1.51
Decane (C10)	5.50	7.89	5.01	5.85	6.16	5.73	0.07
Undecane (C11)	4.89	5.56	5.87	6.03	5.99	5.73	0.00
Dodecane (C12)	3.00	5.49	5.19	4.88	4.35	4.39	0.00
Tridecane (C13)	3.85	6.54	6.51	5.98	4.93	5.33	0.00
Tetradecane (C14)	3.81	7.79	8.32	7.70	5.05	6.88	0.00
Pentadecane (C15)	9.22	11.06	12.58	11.83	8.25	10.61	0.00
Heksadecane (C16)	4.79	5.92	29.37	6.54	4.22	6.00	0.00
Heptadecane (C17)	7.43	6.54	5.28	7.61	6.59	7.25	0.00
Oktadecane (C18)	3.98	3.52	2.35	4.22	2.99	3.93	0.00
Nonadecane (C19)	3.12	2.61	1.67	3.44	2.74	3.49	0.00
Eicosane (C20)	2.62	1.73	1.05	2.48	2.25	2.71	0.00
Heneicosane (C21)	2.77	1.48	0.90	2.19	2.10	2.32	0.00
Docosane (C22)	2.90	1.32	0.72	1.95	2.14	2.14	0.00
Tricosane (C23)	2.99	1.28	0.62	1.89	2.14	2.07	0.00
Tetracosane (C24)	2.12	1.01	0.58	1.45	2.09	1.64	0.00
Pentacosane (C25)	1.64	1.05	0.57	1.41	2.13	1.58	0.00
Hexacosane (C26)	1.43	0.90	0.46	1.18	1.89	1.33	0.00
Heptacosane (C27)	1.56	1.01	0.44	1.18	1.93	1.30	0.00
Octacosane (C28)	1.25	1.25	0.49	1.33	1.88	1.36	0.00
Nonacosane (C29)	1.43	1.55	0.42	0.98	1.67	1.22	0.00
Triacontane (C30)	1.77	1.07	1.23	1.55	3.13	1.62	0.00
TOTAL	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Table 4. Antoine Parameters for hydrocarbon: T in K; P in kPa

Component	$P_{vap} = \exp\left(a + \frac{b}{(T+c)} + d\ln(T) + eT^f\right)$					
	a	***b***	***c***	***d***	***e***	***f***
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

Component	$P_{vap} = \exp\left(a + \frac{b}{(T+c)} + d\ln(T) + eT^f\right)$					
	a	***b***	***c***	***d***	***e***	***f***
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
Triacontane (C30)	188.81	-22404.00	0.00	-23.36	0.00	6.00

Table 5. Calculation procedure of bubble point (T_b)

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

Notes: ***i*** = *shipper* ; ***j*** = component HC

Table 6. Calculation procedure of dew point (T_d)

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

Notes: ***i*** = *shipper* ; ***j*** = component HC

Table 7. Calculation procedure of vapor fraction (n_v)

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

Table 8. Parameters *a*, *b*, *c* in API 12.3 equations

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

The constants of *a*, *b*, *c* are referenced from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017).

Table 9. Calculation procedure of shrinkage volume in tanks *)

No	Procedure	Formula
1	Input data: net volume (V_{net-i}), specific gravity (SG_i) for each shipper (***i***)	V_{net-i}, SG_i
2	Calculation of °API$_i$ for each shipper (***i***)	$^o\text{API}_i = \frac{141.5}{SG_i} - 131.5$
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 Δ°API (Δ°API$_1$)	$\Delta^o\text{API}_1 = \text{abs}(\,^o\text{API}(1) - \,^o\text{API}(2))$
	d. Calculation of the 1st %-shrinkage (S_{h1})	$S_{h1}\,(\%) = a\, Lc_1 (100 - Lc_1)^b (\Delta^o\text{API}_1)^c$
	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 °API (°API$_{mix1}$)	$^o\text{API}_{mix1} = \frac{141.5}{SG_{mix1}} - 131.5$
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 $SG_{\text{mix1}}<SG(3)$: $Lc_2 = \frac{V_{mix1}}{V_{tot2}} 100$ if $SG_{\text{mix1}}>SG(3)$: $Lc_2 = \frac{V_{net}(3)}{V_{tot2}} 100$
	c. Calculation of the 2nd Δ°API (Δ°API$_2$)	$\Delta^o\text{API}_2 = \text{abs}(\,^o\text{API}_{\text{mix1}} - \,^o\text{API}(3))$
	d. Calculation of the 2nd %-shrinkage (S_{h2})	$S_{h2}\,(\%) = a\, Lc_2 (100 - Lc_2)^b (\Delta^o\text{API}_2)^c$
	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})	$V_{mix2} = V_{tot2} - V_{sh2}$

No	Procedure	Formula
	g. Calculation of the 2nd mixed SG (SG_{mix2})	$SG_{mix2} = \frac{V_{mix2}SG_{mix2} + V_{net}(3)SG(3)}{V_{mix2}}$
	h. Calculation of the 2nd mixed °API (°API_{mix2})	$°API_{mix2} = \frac{141.5}{SG_{mix2}} - 131.5$
5	Calculation of net-corrected-volume in tank (V_{nc})	$V_{nc} = V_{mix2}$
6	Calculation of group-shrinkage-losses in tank (V_{shg})	$V_{shg} = V_{sh1} + V_{sh2}$

*) Notes of **Table 9** that shows the stratification of oil mix in tank are listed in **Table 10**.

Table 10. Notes of Table 9: stratification of oil mix in tank

(*i*)	Shippers' oil mix in Tank		
	TANK-1	TANK-2	TANK-3
(1)	Shipper S1	TANK-1	TANK-2
(2)	Shipper S2	Shipper S4	Shipper S6
(3)	Shipper S3	Shipper S5	Shipper S7

Table 11. Individual losses

Shipper	Gross [barrel]	BS&W [%Vol]	ECF [%Vol]	EV [barrel]	FCF [%Vol]	VV [barrel]	TIL [barrel]	NSV [barrel]
S1	500	0.1	0.0558	0.2790	0	0	0.28	499.72
S2	1200	0.1	0.0226	0.2716	0	0	0.27	1199.73
S3	400	0.1	0.0043	0.0171	0	0	0.02	399.98
S4	200	0.1	0.0306	0.0612	0	0	0.06	199.94
S5	800	0.1	0.0183	0.1467	0	0	0.15	799.85
S6	1000	0.1	0.0186	0.1857	0	0	0.19	999.81
S7	400	0	0.0000	0.0000	0	0	0.00	400.00
						Total	**0.96**	**4499.04**

BS&W: Based Sediment & 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 12. Normal bubble and dew points of crude oils

Shipper	Bubble point (T_b), [°C]	Dew point (T_d), [°C]
S1	57.91	341.60
S2	131.25	330.60
S3	197.66	314.85
S4	158.48	335.28
S5	134.29	348.45
S6	72.98	338.07
S7	61.73	92.00

Table 13. Proportional sharing losses results

SHIPPER	NSV [barrel]	SG	*x*	*x*/SG	Shrinkage loss	
					Volume [barrel]	SCF [%]
S1	499.72	0.8881	0.1111	0.1251	1.00	0.20
S2	1199.73	0.8931	0.2667	0.2986	2.38	0.20
S3	399.98	0.9031	0.0889	0.0984	0.78	0.20
S4	199.94	0.9043	0.0444	0.0491	0.39	0.20
S5	799.85	0.8694	0.1778	0.2045	1.63	0.20
S6	999.81	0.8912	0.2222	0.2494	1.99	0.20
S7	400.00	0.8001	0.0889	0.1111	0.89	0.22
Total	**4499.04**			**1.1362**	**9.06**	

Net corrected volume in the last tank (barrel) =	**4489.98**
Total shrinkage loss (barrel) =	**9.06**

NSV: Net Standard Volume [barrel]; SCF: Shrinkage Correction Factor [%Vol]; SG: Specific Gravity; *x*: volume fraction

Table 14. Stratified sharing losses results.

SHIPPER			Stratified-1 (Mixing in Tank-1 of Station-1)				Stratified-2 (Mixing in Tank-2 of Station-2)				Stratified-3 (Mixing in Tank-3 of Station-3)				Total Shrinkage Loss	
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)**	**(%)**
S1	499.72	0.8881	0.60	0.12	499.13	0.8938	0.67	0.13	498.45	0.8882	0.26	0.05	**498.19**	0.8810	1.53	0.31
S2	1,199.73	0.8931	1.42	0.12	1,198.31	0.8938	1.61	0.13	1,196.69	0.8882	0.63	0.05	**1,196.07**	0.8810	3.66	0.31
S3	399.98	0.9031	0.47	0.12	399.51	0.8938	0.54	0.13	398.98	0.8882	0.21	0.05	**398.77**	0.8810	1.22	0.30
total	**2,099.43**		**2.48**													
NCV Tank-1 (bbl)			**2096.95**													
Sub-total srinkage loss (bbl)			**2.48**													
S4					199.94	0.9043	0.27	0.13	199.67	0.8882	0.10	0.05	**199.57**	0.8810	0.37	0.19
S5					799.85	0.8694	1.11	0.14	798.75	0.8882	0.42	0.05	**798.33**	0.8810	1.53	0.19
				total	**3,096.74**		**4.20**									
NCV Tank-2 (bbl)							**3,092.54**									
Sub-total srinkage loss (bbl)							**4.20**									
S6									999.81	0.8912	0.52	0.05	**999.29**	0.8810	0.52	0.05
S7									400.00	0.8001	0.23	0.06	**399.77**	0.8810	0.23	0.06
								total	**4,492.36**		**2.38**		**4,489.98**		**9.06**	
NCV Tank-3 (bbl)											**4489.98**					
Sub-total shrinkage loss (bbl)											**2.38**					

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

Table 15. Comparison between Proportional and Stratified Results

SHIPPER	Sending Point		Mixing quantity	Shrinkage Losses			
	NSV (barrel)	SG		Proportional		Stratified	
				(bbl)	SCF (%)	(bbl)	SCF (%)
S1	499.72	0.8881	3	1.00	0.20	1.53	0.31
S2	1,199.73	0.8931	3	2.38	0.20	3.66	0.31
S3	399.98	0.9031	3	0.78	0.20	1.22	0.30
S4	199.94	0.9043	2	0.39	0.20	0.37	0.19
S5	799.85	0.8694	2	1.63	0.20	1.53	0.19
S6	999.81	0.8912	1	1.99	0.20	0.52	0.05
S7	400.00	0.8001	1	0.89	0.22	0.23	0.06
Total	**4,499.04**			**9.06**		**9.06**	

Net corrected volume in last tank =	**4,489.98**	**barrel**

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

Answers for Reviewers' comments:

Reviewer #1: The following comments need to be addressed before publication:
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Revision has been accomplished

2) Explain the novelty of the work in the introduction section. It is not clear what is missing in the relevant literature that has been cited and discussed in the paper.

The novelty is the new proposed stratified method regarding sharing oil losses in oil fields (especially in Indonesia's oil field). In this study, we compare between the common proportional method and the new proposed stratified method.

3) Are all emulsion and flash losses zero? If yes, why do you include them in the calculations? Explain.

We have included the effects of the emulsion and flash in the calculation of sharing oil losses.

4) Make sure all the subscripts are correct. Some of them are missing in the pdf file, such as 'h' in equations 1 and 3 in the text, and in equation 3. d in Table 3.

Some missing has been corrected properly.

5) The conclusions section is short. Add more information and mention the main concluding remarks of the paper.

The conclusions have been revised related to the topic.

6) Correct the third and fourth name of co-authors. Only their last names have been mentioned

The name of 3rd and 4th authors are only Hariyadi, and Wibowo, respectively.

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Individual loss includes emulsion and evaporative losses. In order to determine emulsion loss, based sediment and water (BS&W) of oil should be measured. The net standard volume (NSV) excludes sediment, water, and free water.

Group loss occurs during mixing oils in the same storage tank. In this study, the specific characteristic which has influence on group loss is the specific gravity (SG) or API gravity. The viscosity and gas oil ratio are excluded in calculation of group loss due to mixing phenomena in the storage tank. Based on our explanation above, with due respect, we do not include the above recommended references in our manuscript.

Reviewer #2: The manuscript described a practical problem in the oil mixing process, however, significant work is required to improve the quality of the paper to make it a journal article. Some comments below:

1. The manuscript is lack of analysis for the fundamental mechanisms of why sharing oil losses happen;

Revision has been accomplished

2. English needs to be refined by professionals;

English has been revised by professionals.

3. A thorough literature review on the topic under study is needed ;

Literature has been revised and completed.

4. More detailed oil properties are needed in section 2.2, for example, what are the viscosity, solution gas oil ratio, saturation pressure etc.;

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The new thing in manuscript is the new proposed stratified method regarding sharing oil losses in oil fields (especially in Indonesia’s oil field). In this study, we compare between the common proportional method and the new proposed stratified method.

6. The conclusion part needs to be re-written to emphasize the new findings in the study;

The conclusion has been re-written and completed.

Best Regards
Yulius Deddy Hermawan
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Hariyadi
Wibowo

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Vinothini Panneerselvam (Ms.)
JEO Assistant
Journals Editorial Office (JEO)

Springer Nature
T +91 44 42197752
F +91 44 42197763
Vinothini.Panneerselvam@springernature.com
www.springernature.com

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Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field

--Manuscript Draft--

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Corresponding Author:	Yulius Deddy Hermawan, Dr Universitas Pembangunan Nasional Veteran Yogyakarta Sleman, Yogyakarta INDONESIA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Universitas Pembangunan Nasional Veteran Yogyakarta
Corresponding Author's Secondary Institution:	
First Author:	Yulius Deddy Hermawan, Dr
First Author Secondary Information:	
Order of Authors:	Yulius Deddy Hermawan, Dr
	Dedy Kristanto, Dr
	Hariyadi Hariyadi, Master
	Wibowo Wibowo, Master
Order of Authors Secondary Information:	
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Abstract:	This paper discusses about the oil losses due to emulsion, flash, and mixing oil phenomena that frequently happened in the oil and gas companies. The goals of this work are to calculate the emulsion and vapor correction volumes, shrinkage correction volume of the mixture of two or more crude oils with different densities, and to compare between the common proportional method that usually utilized in petroleum industries and the new proposed stratified method for determining of sharing oil losses. The mixing of crude oils from 7 shippers in Khrisna Field would be used as a case study, and the equation of API 12.3 was chosen to calculate a shrinkage correction volume. Oils from shippers S1, S2, and S3 were first mixed together in Tank-1 of the 1st station; the mixed oil of Tank-1 was then transported to the next station and stored in the Tank-2 and mixed with other oils from shippers S4 and S5; finally, the mixed oil of Tank-2 was transported to the final station and stored in the Tank-3 and mixed with other oils from shippers S6 and S7. The proportional method gave almost the same shrinkage correction factor (SCF) for all shippers about 0.20%; while stratified method resulted SCF in between 0.05% and 0.31%. Based on our analysis, more often oil mixes with others its volume would be more decreased. The stratified method is therefore recommended to determine sharing oil losses since it gives a fair result.
Response to Reviewers:	Answers for Reviewers' comments: Reviewer #1: The following comments need to be addressed before publication: 1) In the introduction section, define the proportional and stratified methods and explain their differences by citing appropriate references. Revision has been accomplished 2) Explain the novelty of the work in the introduction section. It is not clear what is

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1) In the introduction section, define the proportional and stratified methods and explain their differences by citing appropriate references.

Revision has been accomplished

2) Explain the novelty of the work in the introduction section. It is not clear what is missing in the relevant literature that has been cited and discussed in the paper.

The novelty is the new proposed stratified method regarding sharing oil losses in oil fields (especially in Indonesia's oil field). In this study, we compare between the common proportional method and the new proposed stratified method.

3) Are all emulsion and flash losses zero? If yes, why do you include them in the calculations? Explain.

We have included the effects of the emulsion and flash in the calculation of sharing oil losses.

4) Make sure all the subscripts are correct. Some of them are missing in the pdf file, such as 'h' in equations 1 and 3 in the text, and in equation 3. d in Table 3.

Some missing has been corrected properly.

5) The conclusions section is short. Add more information and mention the main concluding remarks of the paper.

The conclusions have been revised related to the topic.

6) Correct the third and fourth name of co-authors. Only their last names have been mentioned

The name of 3rd and 4th authors are only Hariyadi, and Wibowo, respectively.

7) Review and cite the following references, as they include up to date information about hydrocarbon properties and phase behavior of oil and gas systems:

1) A smooth model for the estimation of gas/vapor viscosity of hydrocarbon fluids https://doi.org/10.1016/j.jngse.2015.07.045
2) Development of a robust model for prediction of under-saturated reservoir oil viscosity https://doi.org/10.1016/j.molliq.2016.11.088
3) Numerical simulation of mineral precipitation in hydrocarbon reservoirs and wellbores https://doi.org/10.1016/j.fuel.2018.10.101
4) Scale formation in porous media and its impact on reservoir performance during water flooding https://doi.org/10.1016/j.jngse.2017.01.019

This study focuses in oil losses due to emulsion, flash, and mixing phenomena. Human and measurement errors, leakage, and theft are excluded. Oil loss are categorized into 2 categories, they are (1) individual and (2) group losses.

Individual loss includes emulsion and evaporative losses. In order to determine emulsion loss, based sediment and water (BS&W) of oil should be measured. The net standard volume (NSV) excludes sediment, water, and free water.

Group loss occurs during mixing oils in the same storage tank. In this study, the specific characteristic which has influence on group loss is the specific gravity (SG) or API gravity. The viscosity and gas oil ratio are excluded in calculation of group loss due to mixing phenomena in the storage tank. Based on our explanation above, with due respect, we do not include the above recommended references in our manuscript.

Reviewer #2: The manuscript described a practical problem in the oil mixing process, however, significant work is required to improve the quality of the paper to make it a journal article. Some comments below:

1. The manuscript is lack of analysis for the fundamental mechanisms of why sharing oil losses happen;

Revision has been accomplished

2. English needs to be refined by professionals;

English has been revised by professionals.

3. A thorough literature review on the topic under study is needed ;

Literature has been revised and completed.

4. More detailed oil properties are needed in section 2.2, for example, what are the viscosity, solution gas oil ratio, saturation pressure etc.;

This study focuses in oil losses due to emulsion, flash, and mixing phenomena. Human and measurement errors, leakage, and theft are excluded. Oil loss are categorized into 2 categories, they are (1) individual and (2) group losses.

Individual loss includes emulsion and evaporative losses. In order to determine emulsion loss, based sediment and water (BS&W) of oil should be measured. The net standard volume (NSV) excludes sediment, water, and free water.

Group loss occurs during mixing oils in the same storage tank. In this study, the specific characteristic which has influence on group loss is the specific gravity (SG) or API gravity. The viscosity and gas oil ratio are excluded in calculation of group loss due to mixing phenomena in the storage tank. Based on our explanation above, with due respect, we do not include the above recommended references in our manuscript.

5. The authors need more discussion on what's new in the manuscript. The content presented in the manuscript reads like a class report without in-depth analysis and discussion;

The new thing in manuscript is the new proposed stratified method regarding sharing oil losses in oil fields (especially in Indonesia's oil field). In this study, we compare between the common proportional method and the new proposed stratified method.

6. The conclusion part needs to be re-written to emphasize the new findings in the study;

The conclusion has been re-written and completed.

Best Regards
Yulius Deddy Hermawan
Dedy Kristanto
Hariyadi
Wibowo

Determination of Sharing Oil Losses Using Proportional and Stratified Methods in Khrisna Field

Yulius Deddy Hermawan[1)], Dedy Kristanto[2)], Hariyadi[3)], and Wibowo[4)]

[1)] Department of Chemical Engineering, Faculty of Industrial Engineering,
[2,3,4)] Department of Petroleum Engineering, Faculty of Mineral Technology,
Universitas Pembangunan Nasional "Veteran" Yogyakarta,
Jl. SWK 104 (Lingkar Utara) Condongcatur, Yogyakarta, 55283, Indonesia
Email: ydhermawan@upnyk.ac.id and dedykris.upn@gmail.com

Abstract:

This paper discusses about the oil losses due to emulsion, flash, and mixing oil phenomena that frequently happened in the oil and gas companies. The goals of this work are to calculate the emulsion and vapor correction volumes, shrinkage correction volume of the mixture of two or more crude oils with different densities, and to compare between the common proportional method that usually utilized in petroleum industries and the new proposed stratified method for determining of sharing oil losses. The mixing of crude oils from 7 shippers in Khrisna Field would be used as a case study, and the equation of API 12.3 was chosen to calculate a shrinkage correction volume. Oils from shippers S1, S2, and S3 were first mixed together in Tank-1 of the 1st station; the mixed oil of Tank-1 was then transported to the next station and stored in the Tank-2 and mixed with other oils from shippers S4 and S5; finally, the mixed oil of Tank-2 was transported to the final station and stored in the Tank-3 and mixed with other oils from shippers S6 and S7. The proportional method gave almost the same shrinkage correction factor (SCF) for all shippers about 0.20%; while stratified method resulted SCF in between 0.05% and 0.31%. Based on our analysis, more often oil mixes with others its volume would be more decreased. The stratified method is therefore recommended to determine sharing oil losses since it gives a fair result.

Keywords: Emulsion, Flash, Oil losses, Mixing oil, Proportional, Shrinkage, and Stratified.

1. Introduction

Sources of oil loss in petroleum industries are emulsion, evaporative (flash), shrinkage, leakage, theft, and measurement losses, etc (Bhatia and Dinwoodie, 2004). This study focuses in oil losses due to emulsion, flash, and mixing phenomena. Human and measurement errors, leakage, and theft are excluded. Oil loss are categorized into 2 categories, they are (1) individual and (2) group losses.

1.1. Individual loss

Individual loss includes emulsion and evaporative losses. In order to determine emulsion loss, based sediment and water (BS&W) of oil should be measured. The net standard volume (NSV) excludes sediment, water, and free water. So far back to year 1918, Bradley et al have studied the crude oil losses in steel and earthen storage; they classified roughly losses as occurring from evaporation, and presence of sediment and water. Evaporative loss occurs when light components are released from oil in the storage tank. This happens when the oil temperature is lower than its bubble point. Thus, by maintaining low oil temperature minimizes evaporative loss from storage tank (Bhatia and Dinwoodie, 2004).

The goals of this work are to calculate the emulsion correction factor (ECF) and flash correction factor (FCF) that occur individually in 7 shippers of Khrisna field. The empiric equation of emulsion would be used to calculate ECF. While flash calculation with Antoine equation was chosen to calculate FCF.

1.2. Group loss

Group loss occurs during mixing oils in the same storage tank. In this study, the specific characteristic which has influence on group loss is the specific gravity (SG) or API gravity. The viscosity and gas oil ratio are excluded in calculation of group loss due to mixing phenomena in the storage tank. The oil and gas fields generally produce petroleum fluid that can be classified into five categories: dry gas, wet gas, gas condensate, volatile oil, and black oil (McCain 1990.a; Whitson and Brule 2000). Since the fluids in those categories have different characteristics, specifically SG or API, the properties would thus change when they are mixed together.

Typical oil mixing phenomena in the gathering station is illustrated in **Figure 1**. In an activity of transporting of crude oil from shippers in the oil field to the gathering station, shippers often use the same pipeline to transport the crude oil to a storage tank. The crude oils from shippers are mixed together either in the same temporary or final storage tank. This situation comes up the problem of oil losses. As shown in **Figure 1**, there is a loss discrepancy between total quantities from shippers and measurement in the storage tanks (Bhatia and Dinwoodie, 2004); the total sending volume is lower than the measured volume in the mixing tank. The study of sharing oil losses is therefore very important to be done.

Several studies (Katz 1942; Erno et al 1994; Nengkoda 2011; James 2014) have discussed about prediction of crude oil shrinkage losses. Far back to year of 1942, Katz has investigated the crude oil shrinkage phenomena and pointed that the more volatile the separator liquid phase, the more impact separator conditions and shrinkage will be. In 1994, Erno et al predicted the shrinkage equation of heavy oil/condensate blend and stated that when condensate is added to heavy oil, the blended volume is less than the sum of the condensate and oil volumes. In 2011, Nengkoda has studied the role of crude oil shrinkage in heavy mix light crude in main oil pipeline and pointed that shrinkage will be very depended upon the operation pressure and temperature. In recent year 2014, James has studied shrinkage losses resulting from liquid hydrocarbon blending. James (2014) concluded that equation of API 12.3 was a valuable tool in quantifying shrinkage that occurs as a result of blending hydrocarbons of different densities. Moreover in 2011, Shanshool et al have investigated the volumetric behavior of mixtures of different oil stock. Shanshool et al (2011) concluded that volumetric shrinkage is resulted from blending hydrocarbon with gas oil (light oil).

The goals of this work are to calculate the shrinkage correction factor (SCF) in oil mixing phenomena and to determine the sharing oil losses using the common proportional and the new proposed stratified methods. The oil distribution of 7 shippers in Khrisna field (**Figure 2**) would be taken as a case study. The modified equation of API 12.3 would be used to calculate SCF in every mixing phenomenon in tank.

2. Material and Method

2.1. Flow diagram of oil distribution

The block diagram of oil distribution and mixing phenomena in Khrisna field is shown in **Figure 2**. As can be seen in **Figure 2**, Khrisna field has 7 shippers; they are S1, S2, S3, S4, S5, S6, and S7. Shippers S1, S2, and S3 send their oil to Station-1 and the oils are temporary stored in same tank of TANK-1. The mixed oil of TANK-1 is then pumped to the 2nd station and temporary stored in TANK-2 and mixed with other oils from shippers S4 and S5. Finally, the mixed oil of TANK-2 is transported to the 3rd station and stored in TANK-3 and mixed with other oils from shippers S6 and S7. As shown in **Figure 2**, shippers S1, S2, and S3 have 3 times of mixing phenomena, shippers S4 and S5 have twice, and shippers S6 and S7 have only once.

2.2. Parameters input

Parameters input for calculating of sharing oil losses are production rate, pressure, temperature, specific gravity (SG), and based sediment water (BSW). These parameters input are listed in **Table 1**. As shown in **Table 1**, oils S1 to S6 have the same BS&W 0.1 %Vol. While shipper S7 produces condensate with BS&W equals to zero. All oils are stored in the atmospheric storage tank (pressure of about 1 atm and temperature of about 30 ^{o}C). The total oil rate from all shippers as sending points is 4500 barrel oil per day (BOPD). The specific gravities (SG) of all shippers vary from 0.8001 to 0.9043. Oil S7 is the lightest one with SG 0.8001; this is typically condensate. Oils S3 and S4 are typical heavy oil with SG around 0.90.

2.3. Calculation algorithm of sharing oil losses

Calculation algorithm of sharing oil losses are shown in **Figure 3**. In order to calculate the total sharing oil losses, individual loss such as emulsion and flash losses must first be calculated, and then the group loss in mixing phenomena is determined. Sharing oil losses would be determined by 2 methods, they are the common proportional and the new proposed stratified methods.

2.3.1. Calculation of emulsion loss

Since the net oil excludes sediment, water, and free-water, based sediment and water (BS&W) of oil has to be measured. In this study, BS&W in oils S1 to S6 are taken the same 0.1 %Vol (**Table 1**). While BS&W of oil S7 equals to zero since this oil is a typical condensate. The empiric emulsion equations are used for calculating emulsion loss. The emulsion parameters (a_1, b_1, a_2, b_2) for each shipper are shown in **Table 2**. The empiric emulsion equations and emulsion loss can be generated with following methodology:

a. Crude oil is mixed with its formation water at some levels of water volume, and the BS&W and SG of mixed oil-water are then investigated.
b. The changes of BS&W and SG are plotted in a curve. This first curve results linear equation:

$$Y_1 = a_1 X_1 + b_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where X_1 is the measured BS&W, Y_1 is the measured SG, a_1 and b_1 are constants.

c. Then, making a curve of percentage of the addition of the volume of formation water (in %Vol) versus the calculated SG. This second curve produces linear equation:

$$Y_2 = a_2 X_2 + b_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where X_2 is the percentage of the addition of the volume of formation water (in %Vol), Y_2 is the calculated SG, a_2 and b_2 are constants. The calculated SG can be found with the following equation:

$$\mathrm{SG_{calculated}} = (1 - X_w)\mathrm{SG_{fw}} + X_w \mathrm{SG_w} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where X_w is water volume fraction in oil, SG_w is specific gravity of formation water, and SG_{fw} is specific gravity of oil free-water as defined below:

$$SG_{fw} = \frac{SG_o - X_w SG_w}{(1 - X_w)} \quad \ldots\ldots \quad (4)$$

where SG_o is specific gravity of oil that still contains water.

d. Both empiric equations are then used for calculating emulsion loss. Y_1 is found by inputting the measured BS&W of oil as X_1 in equation (1). The resulted Y_1 is then substituted in equation (2) to calculate X_2.

e. Emulsion correction factor (ECF) in %Vol is then calculated as follows:

$$ECF = X_1 - X_2 \quad \ldots\ldots \quad (5)$$

2.3.2. Calculation of evaporative loss

Evaporative loss is calculated with flash calculation method. Mass balance diagram for flash calculation method is shown in **Figure 4**. Evaporative loss depends on its operating conditions, i.e. pressure (P) and temperature (T). Evaporation is indicated by the value of vapor fraction n_v (Tarek 2007). Vapor fraction n_v ranges in between 0 to 1. n_v=0 and n_v=1 mean the fluid is in liquid and gas phase, respectively. If n_v 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.

Flash calculation algorithm is shown in **Figure 5**. Input data required in this algorithm are hydrocarbon composition (z_j), pressure (P_i) and temperature (T_i) of each shipper system. The intended pressure (P_i) is the fluid pressure in a storage tank, i.e. atmospheric pressure. **Table 3** shows the hydrocarbon composition (z_j) of each shipper. In this work, Antoine equation was chosen to calculate flash correction factor (FCF). Antoine parameters (a, b, c, d, e, f) for each hydrocarbon component are listed in **Table 4**.

The next step is the calculations of bubble (T_b) and dew point (T_d) at the atmospheric pressure. Bubble and dew point are saturated condition at n_v=0 and n_v=1, respectively. Calculation procedure of T_b and T_d are written in **Table 5** and **6**, respectively. Antoine equation used in this calculation is:

$$P_{vap\ j} = \exp\left(a_j + \frac{b_j}{(T + c_j)} + d_j \ln(T) + e_j T^{f_j}\right) \quad \ldots\ldots \quad (6)$$

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**.

After calculation T_b and T_d, we calculate vapor fraction n_v. Temperature T and pressure P of fluid (system) are the input data in calculation n_v. As shown in **Figure 5**, when T is lower than T_b so n_v=0, this indicates that the fluid is in liquid phase. When T is higher than T_d so n_v=1, this means that fluid is in vapor phase. When T is in between T_b and T_d, n_v is in between 0 and 1, this means that part of light component in fluid evaporates. Calculation procedure of n_v is shown in **Table 7**. Flash correction factor (FCF) is then calculated as follows:

$$\mathrm{FCF} = n_v \times 100\% \quad \text{(7)}$$

where FCF is in %Vol.

2.3.3. Calculation of shrinkage loss

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

$$S_{\square}\,(\%) = a\,L_c(100 - L_c)^b(\Delta^{\mathrm{o}}\mathrm{API})^c \quad \text{(8)}$$

where a, b, and c are constants of API 12.3 that be taken from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017) as listed in **Table 8**, L_c is %-light component, Δ^{o}API is ^{o}API difference between ^{o}API of shipper one and other, and S_h is shrinkage volume percentage (in %).

API gravity for each shipper is defined as the equation in McCain (1990.b):

$$^{\mathrm{o}}\mathrm{API}_i = \frac{141.5}{SG_i} - 131.5 \quad \text{(9)}$$

where $^{o}\mathrm{API}_i$ is API gravity of shipper i, and SG_i is specific gravity (60^{o}/60^{o}) of shipper i.

2.3.3.1. Proportional method

Proportional method is the common method used in petroleum industries for sharing oil losses. In this method, the total received volume is measured at the last station. This measured volume is the net-corrected-volume (V_{nc}) which is directly taken from the last storage tank in the last station (TANK-3 in **Figure 2**). The total shrinkage volume ($V_{sh\text{-prop}}$) is the difference volume between the total volume sent from all shippers and the net corrected volume:

$$V_{s\square-\mathrm{prop}} = \sum_{i=1}^{n} V_i - V_{nc\,(\mathrm{TANK-3})} \quad \text{(10)}$$

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

$$\xi_{\mathrm{prop}_i} = \frac{x_i\left(1/SG_i\right)}{\sum_{i=1}^{n} x_i\left(1/SG_i\right)} V_{s\square-\mathrm{prop}} \quad \text{(11)}$$

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

$$x_i = \frac{V_i}{\sum_{i=1}^{n} V_i} \quad \text{(12)}$$

The proportional shrinkage correction factor ($\mathrm{SCF}_{\mathrm{prop}_i}$ in %Vol) for each shipper can then be calculated as follows:

$$\mathrm{SCF}_{\mathrm{prop}_i} = \frac{\xi_{prop_i}}{V_i} \text{ x } 100\% \quad \ldots\ldots \quad (13)$$

2.3.3.2. Stratified method

In new proposed stratified method, the net-corrected-volume is calculated stratify from tank to tank as shown in **Tables 9** and **10**. The shrinkage volume is calculated for each mixing phenomena in TANK-1, TANK-2, and TANK-3. The shrinkage volume for shippers S1, S2, and S3 in TANK-1 can be calculated with the following equation:

$$\xi_{\mathrm{st-I}_i} = \frac{x_i\left({}^{1}/_{SG_i}\right)}{\sum_{i=1}^{n} x_i\left({}^{1}/_{SG_i}\right)} V_{shg-\mathrm{I}} \quad \ldots\ldots \quad (14)$$

where $\xi_{\mathrm{st-I}_i}$ is shrinkage volume for shipper *i* (S1, S2, S3) in TANK-1, and $V_{shg\text{-}\mathrm{I}}$ is the group shrinkage volume in TANK-1. The shrinkage volume for shippers S4, S5, and TANK-1 (mix S1-S2-S3) in TANK-2 can be calculated with the following equation:

$$\xi_{\mathrm{st-II}_i} = \frac{x_i\left({}^{1}/_{SG_i}\right)}{\sum_{i=1}^{n} x_i\left({}^{1}/_{SG_i}\right)} V_{shg-\mathrm{II}} \quad \ldots\ldots \quad (15)$$

where $\xi_{\mathrm{st-II}_i}$ is shrinkage volume for shipper *i* (S4, S5, and mix S1-S2-S3) in TANK-2, and $V_{shg\text{-}\mathrm{II}}$ is the group shrinkage volume in TANK-2. Finally, the shrinkage volume for shippers S6, S7, and TANK-2 (mix S1-S2-S3-S4-S5) in TANK-3 can be calculated as follows:

$$\xi_{\mathrm{st-III}_i} = \frac{x_i\left({}^{1}/_{SG_i}\right)}{\sum_{i=1}^{n} x_i\left({}^{1}/_{SG_i}\right)} V_{shg-\mathrm{III}} \quad \ldots\ldots \quad (16)$$

where $\xi_{\mathrm{st-III}_i}$ is shrinkage volume for shipper *i* (S6, S7, and mix S1-S2-S3-S4-S5) in TANK-3, and $V_{shg\text{-}\mathrm{III}}$ is the group shrinkage volume in TANK-3.

The total stratified shrinkage volume ($\xi_{\mathrm{st-tot}_i}$) for shippers S1, S2, and S3 are the summation of its shrinkage volume in TANK-1, TANK-2, and TANK-3, for shippers S4 and S5 are those in TANK-2 and TANK-3; while for shippers S6 and S7 are only once in the last tank of TANK-3.

$$\xi_{\mathrm{st-tot}_i} = \xi_{\mathrm{st-I}_i} + \xi_{\mathrm{st-II}_i} + \xi_{\mathrm{st-III}_i} \quad \ldots\ldots \quad (17)$$

where for S4 and S5 $\xi_{\mathrm{st-I}_i} = 0$, and for S6 and S7 $\xi_{\mathrm{st-I}_i} = \xi_{\mathrm{st-II}_i} = 0$.

The stratified shrinkage correction factor ($\mathrm{SCF}_{\mathrm{st}_i}$ in %Vol) for each shipper can then be calculated as follows:

$$\mathrm{SCF}_{\mathrm{st}_i} = \frac{\xi_{\mathrm{st-tot}_i}}{V_i} \text{ x } 100\% \quad \ldots\ldots \quad (18)$$

3. Result and Discussion

3.1. Individual loss results

Individual loss includes emulsion and evaporative losses and must be determined to get the net standard volume (NSV) of all petroleum liquids. The NSV excluding sediment, water (and free water), and vapor is then used for calculating group loss in mixing phenomena. The total individual losses (TIL) including emulsion and evaporative loss is listed in **Table 11**. TIL of shipper S1 is the biggest one, i.e. 0.28 barrel. While TIL of shipper S7 equals to zero, since oil S7 is a typical condensate which has no emulsion. The total TIL and NSV resulted from the individual loss calculation are 0.96 and 4499.04 barrel, respectively.

3.1.1. Emulsion loss

By inputting BS&W=0.1% in the equation system (eq. 1 to 5), emulsion correction factor (ECF) for all shippers are found and listed in **Table 11**. The biggest and smallest ECF are given by shipper S1 and S3, respectively. The sensitivity BS&W against EFC is shown in **Figure 6**. Shipper S1 is the most sensitive compared with others, its ECF increases significantly by increasing its BS&W. While shipper S3 is not sensitive to a change in BS&W; its ECF raises slowly by increasing its BS&W.

3.1.2. Evaporative loss

In atmospheric pressure condition (about 1 atm), evaporation can happen when the fluid temperature is lower than its bubble point. The normal bubble (T_b) and dew (T_d) points resulted from flash calculation are listed in **Table 12**. Oil S7 is a typical condensate; it has the shortest span between T_b and T_d. Correlation of vapor pressure and bubble point for all shippers is shown in **Figure 7**. Since the oil temperatures in all tanks are lower than its bubble point (**Figure 7**), it is understandable that all shippers have no evaporative loss. Flash correction factors (FCF) of all shippers equal to zero. During operation in the oil gathering station, by maintaining oil temperature lower than its bubble point can eliminate evaporative loss from storage tank (Bhatia and Dinwoodie, 2004).

3.2. Shrinkage loss

3.2.1. Proportional shrinkage loss

Sharing oil losses resulted by the common proportional method are listed in **Table 13**. As can be seen from **Table 13**, the total shrinkage loss is 9.06 barrel and the shrinkage correction factors (SCF) of all shippers are almost the same ±0.20%. However, SCF of shipper S7 is the largest one (0.22%) since its oil is classified as condensate. Condensate is typically light oil or gas oil that has low density and small molecular size, while heavy oil has big molecular size. When condensate mixes heavy oil, hence geometrically there will be shrinkage as illustrated in **Figure 8**; and this agrees with those in Erno et al (1994), James (2014), and Shanshool et al (2011).

3.2.2. Stratified shrinkage loss

Table 14 shows sharing oil losses resulted by the new proposed stratified method. In this method, shrinkage volume of each shipper is calculated for every mixing in the tank. As can be seen from **Table 14**, the subtotal oil losses in every tank are 2.48, 4.20, and 2.38 barrels, respectively. The total oil loss in the stratified method is the same as in the proportional method, i.e. 9.06 barrels. The SCF of each shipper in every tank is almost the same; they are 0.12%, 0.13%, and 0.05% in TANK-1, TANK-2, and TANK-3, respectively. The total SCF of shippers S1, S2, and S3 are larger than those in shippers S4 and S5, (0.31% vs. 0.19%); and those in shippers S4 and S5 are larger than those in shippers S6 and S7, (0.19% vs. 0.05%). This is understandable that more often oil mixes with others; its volume will be more decreased.

3.3. Comparison of proportional and stratified results

Comparison between proportional and stratified results is listed in **Table 15**. The total NSV is 4,499.04 barrels, and total shrinkage volume is 9.06 barrel. Therefore, the net corrected volume (NCV) in the last tank is 4490.94 barrel. The proportional method gives almost the same of SCF, ±0.20%, while SCF resulted by stratified method varies from 0.05% to 0.31% depending on its mixing quantity.

The common proportional method is considered unfair since shippers S6 and S7 bear those losses of the upstream shippers (S1 to S5). More often oil mixes with others, for examples oils of shippers S1, S2, and S3 pass through 3 times of mixing phenomena, more volume shrinkage will be. Thus, the stratified method appropriates for determining of sharing oil losses in the multi mixing phenomena.

4. Conclusion

Study on oil losses due to emulsion, flash (evaporation), and mixing phenomena in a Khrisna field has been done. The oil loss is classified into 2 types, i.e. individual loss including emulsion and evaporative loss, and group loss which occurs in mixing phenomena. The individual loss must be determined to get the net standard volume (NSV). The NSV excluding sediment, water (and free water), and gas is then used for calculating group loss.

The emulsion correction factor (ECF) has been calculated for each shipper based on its BS&W. Since oil of shipper S7 is a condensate, it does not produce emulsion. According to our analysis, shipper S1 is the most sensitive to a change in BS&W, its ECF increases significantly by increasing its BS&W. While shipper S3 is not sensitive to a change in BS&W; its ECF raises slowly by increasing its BS&W.

Based on flash calculation results, all oils which are stored in tanks are the stable liquids. Since the oils' temperatures in tanks are lower than its bubble points at the normal condition (atmospheric), it is clear that all shippers have no evaporative loss. Flash correction factor (FCF) of all shippers equal to zero. Evaporative loss could be prevented by maintaining oil temperature lower than its bubble point.

In this work, the common proportional and new proposed stratified methods have been used to determine the sharing oil losses for 7 shippers in Khrisna field. According to our analysis, the common proportional method gave almost the same of shrinkage correction factor (SCF) for all shippers. However, shippers that more often mix with others, e.g. shippers S1, S2, and S3 have 3 times of mixing phenomena; their shrinkage volume were larger than others. For that reason, the new proposed stratified method is strongly recommended to determine sharing oil losses since it gives a fair result.

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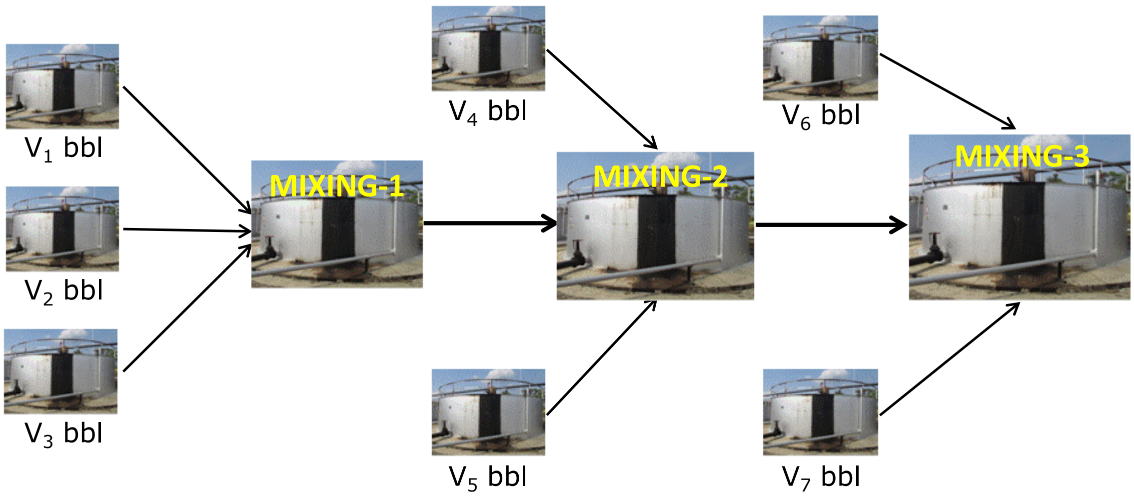

$$V_{mix-1} \neq V_1 + V_2 + V_3 \qquad V_{mix-2} \neq V_{mix-1} + V_4 + V_5 \qquad V_{mix-3} \neq V_{mix-2} + V_6 + V_7$$

$$V_{mix} < V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7$$

Figure 1. Typical oil mixing phenomena in gathering station

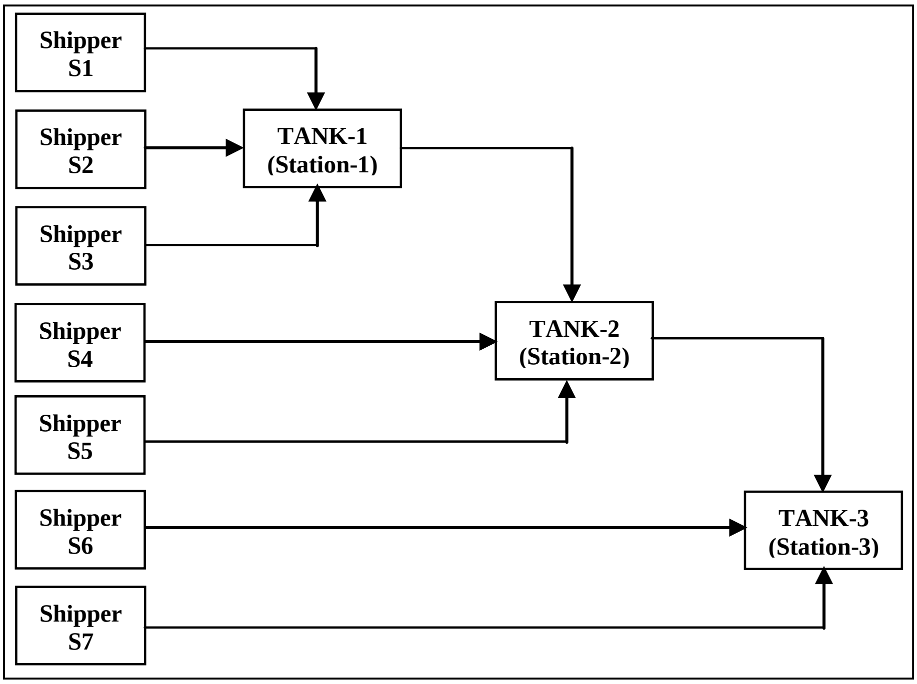

Figure 2. Block diagram of oil distribution and mixing phenomena in Khrisna field.

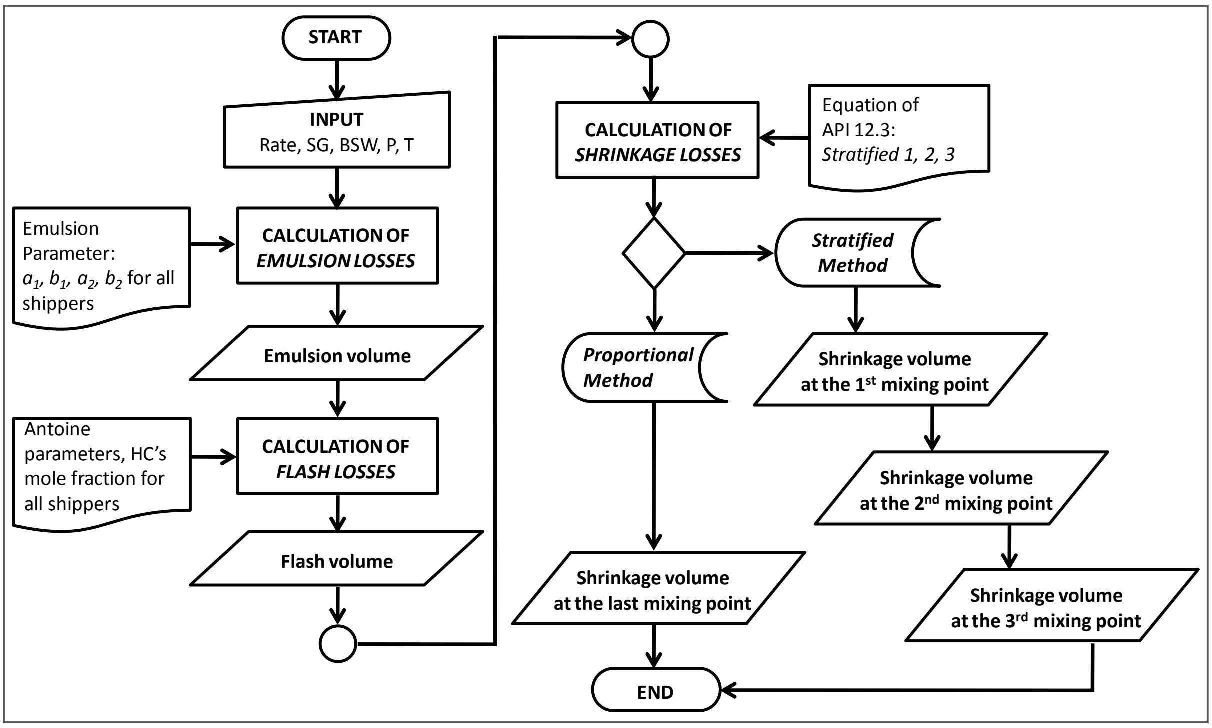

Figure 3. Calculation algorithm of sharing oil losses.

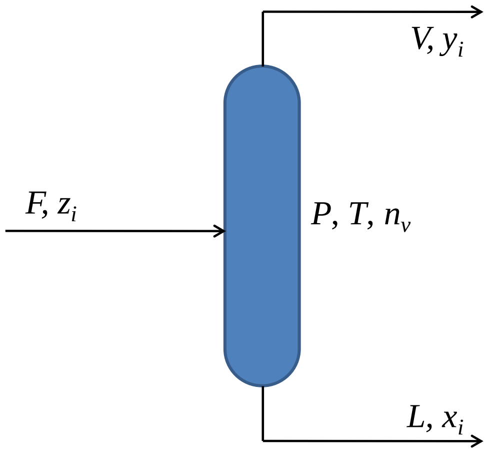

Figure 4. Vapor-liquid equilibrium for flash calculation.

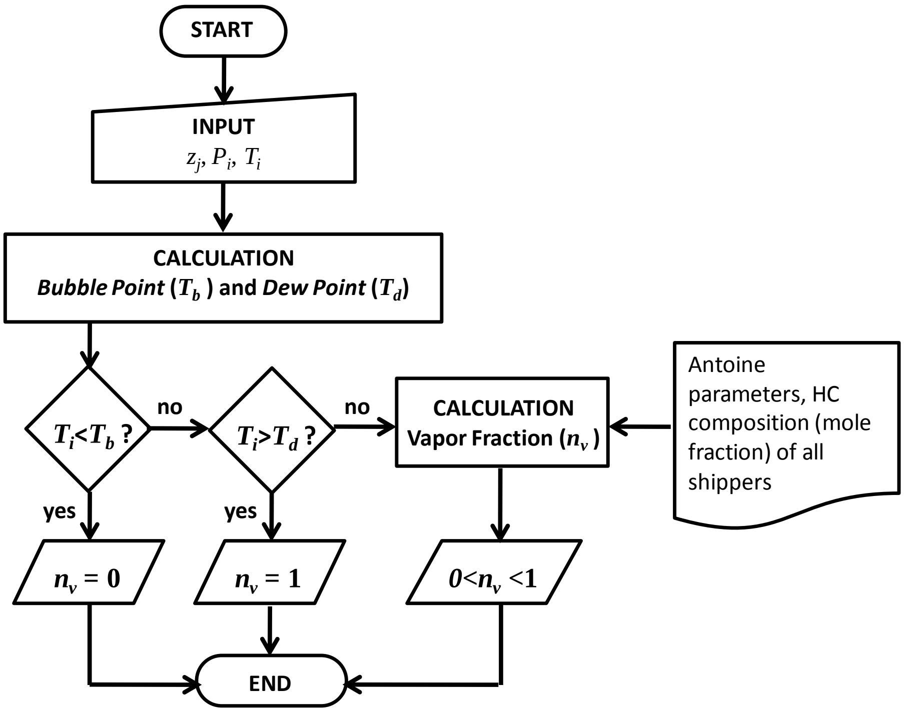

Figure 5. Flash Calculation algorithm.

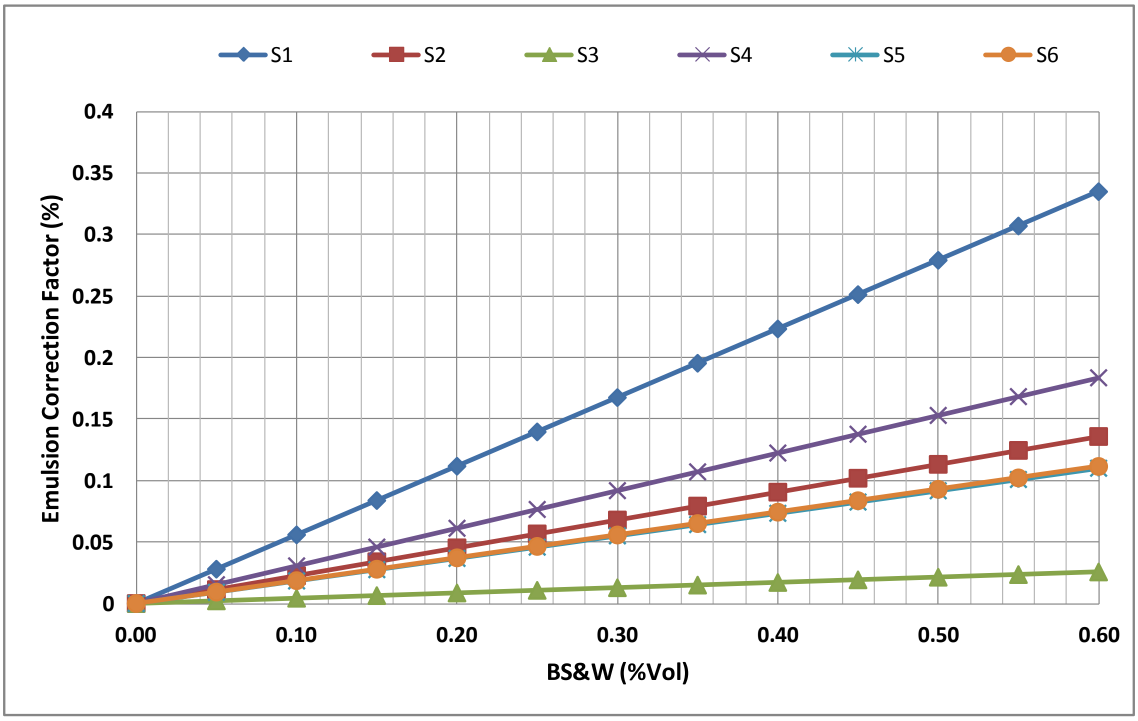

Figure 6. Sensitivity BS&W against ECF

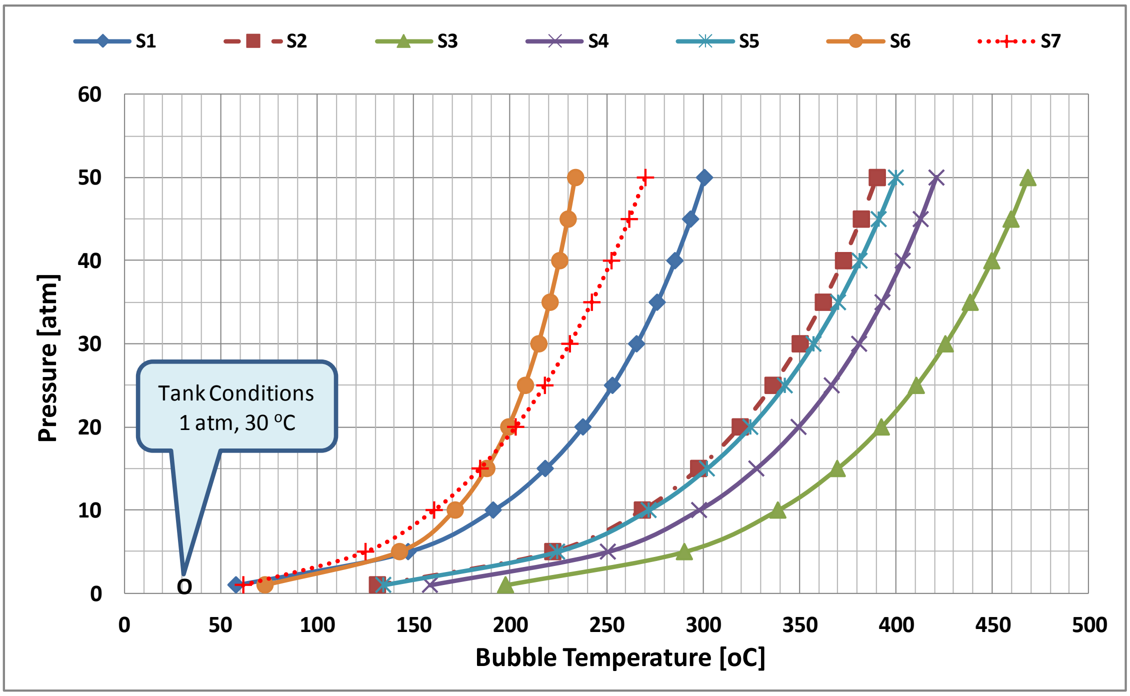

Figure 7. Correlation of vapor pressure and bubble temperature.

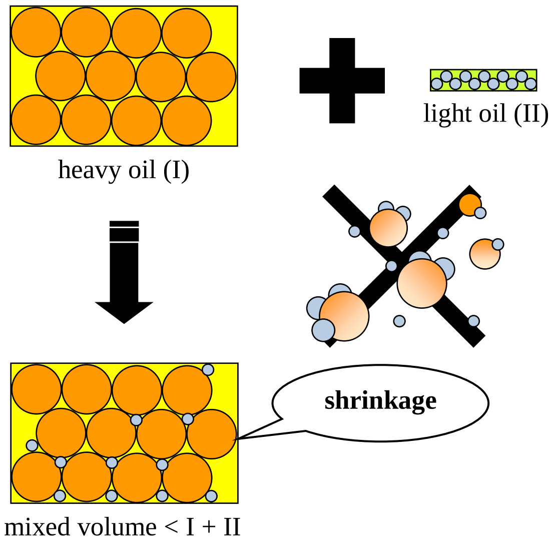

Figure 8. Illustration of shrinkage volume from mixing of heavy and light oils

Table 1. Production rate Khrisna field and its properties.

Shipper	Production			Oil Percent Volume [%]	Tank's Condition		Properties	
	Gross [BFPD]	Oil [BOPD]	Water [BWPD]		Pressure [atm]	Temperature [°C]	SG (60°/60°)	BS&W
S1	500	500	0	11.11	1	30	0.8881	0.1
S2	1200	1200	0	26.67	1	30	0.8931	0.1
S3	400	400	0	8.89	1	30	0.9031	0.1
S4	200	200	0	4.44	1	30	0.9043	0.1
S5	800	800	0	17.78	1	30	0.8694	0.1
S6	1000	1000	0	22.22	1	30	0.8912	0.1
S7 *)	400	400	0	8.89	1	30	0.8001	-
Total	**4500**	**4500**	**0**	100.00				

*Note *): shipper S7 produces condensate*

Table 2. Emulsion parameters

Shipper	X_1 = 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		
S1	0.1	0.001278	0.8881	0.888228	0.002892	0.8881	0.0442	0.0558
S2	0.1	0.001210	0.8931	0.893221	0.001564	0.8931	0.0774	0.0226
S3	0.1	0.001097	0.9031	0.903210	0.001146	0.9031	0.0957	0.0043
S4	0.1	0.001121	0.9043	0.904412	0.001615	0.9043	0.0694	0.0306
S5	0.1	0.001470	0.8694	0.869547	0.001800	0.8694	0.0817	0.0183
S6	0.1	0.001241	0.8912	0.891324	0.001524	0.8912	0.0814	0.0186
S7	0	0	0	0	0	0	0	0

The constants of a_1, b_1, a_2, and b_2, are referenced from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017).

Table 3. Hydrocarbon composition (%-mole)

Component	Shipper						
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Metane (C1)	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Etane (C2)	0.82	0.04	0.01	0.03	0.01	0.02	0.00
Propane (C3)	0.98	0.33	0.03	0.14	0.27	0.11	0.00
Butane (C4)	1.43	0.68	0.08	0.24	0.54	0.34	0.05
Pentane (C5)	1.76	1.01	0.17	0.43	1.07	0.75	30.48
Hexane (C6)	2.69	1.48	0.26	0.85	3.45	2.53	29.67
Heptane (C7)	5.04	4.17	1.54	3.11	4.44	3.55	25.85
Octane (C8)	8.37	8.15	3.63	6.88	8.04	7.25	12.37
Nonane (C9)	6.85	7.56	4.65	6.66	7.59	6.77	1.51
Decane (C10)	5.50	7.89	5.01	5.85	6.16	5.73	0.07
Undecane (C11)	4.89	5.56	5.87	6.03	5.99	5.73	0.00
Dodecane (C12)	3.00	5.49	5.19	4.88	4.35	4.39	0.00
Tridecane (C13)	3.85	6.54	6.51	5.98	4.93	5.33	0.00
Tetradecane (C14)	3.81	7.79	8.32	7.70	5.05	6.88	0.00
Pentadecane (C15)	9.22	11.06	12.58	11.83	8.25	10.61	0.00
Heksadecane (C16)	4.79	5.92	29.37	6.54	4.22	6.00	0.00
Heptadecane (C17)	7.43	6.54	5.28	7.61	6.59	7.25	0.00
Oktadecane (C18)	3.98	3.52	2.35	4.22	2.99	3.93	0.00
Nonadecane (C19)	3.12	2.61	1.67	3.44	2.74	3.49	0.00
Eicosane (C20)	2.62	1.73	1.05	2.48	2.25	2.71	0.00
Heneicosane (C21)	2.77	1.48	0.90	2.19	2.10	2.32	0.00
Docosane (C22)	2.90	1.32	0.72	1.95	2.14	2.14	0.00
Tricosane (C23)	2.99	1.28	0.62	1.89	2.14	2.07	0.00
Tetracosane (C24)	2.12	1.01	0.58	1.45	2.09	1.64	0.00
Pentacosane (C25)	1.64	1.05	0.57	1.41	2.13	1.58	0.00
Hexacosane (C26)	1.43	0.90	0.46	1.18	1.89	1.33	0.00
Heptacosane (C27)	1.56	1.01	0.44	1.18	1.93	1.30	0.00
Octacosane (C28)	1.25	1.25	0.49	1.33	1.88	1.36	0.00
Nonacosane (C29)	1.43	1.55	0.42	0.98	1.67	1.22	0.00
Triacontane (C30)	1.77	1.07	1.23	1.55	3.13	1.62	0.00
TOTAL	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Table 4. Antoine Parameters for hydrocarbon: T in K; P in kPa

Component	$P_{vap} = \exp\left(a + \frac{b}{(T+c)} + d\ln(T) + eT^f\right)$					
	a	***b***	***c***	***d***	***e***	***f***
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

Component	$P_{vap} = \exp\left(a + \frac{b}{(T+c)} + d\ln(T) + eT^f\right)$					
	a	***b***	***c***	***d***	***e***	***f***
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
Triacontane (C30)	188.81	-22404.00	0.00	-23.36	0.00	6.00

Table 5. Calculation procedure of bubble point (T_b)

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

Notes: ***i*** = *shipper* ; ***j*** = component HC

Table 6. Calculation procedure of dew point (T_d)

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

Notes: ***i*** = *shipper* ; ***j*** = component HC

Table 7. Calculation procedure of vapor fraction (n_v)

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***	$P_{v\,j} = \exp\left(a_j + \dfrac{b_j}{(T_i + c_j)} + d_j \ln(T_i) + e_j T_i^{f\,j}\right)$
3	Calculation of equilibrium ratio of component K_j	$K_j = \dfrac{P_{v\,j}}{P_i}$
4	Calculation of objective function $f(n_{vi})$ with guessed vapor fraction n_v	$f(n_{v_i}) = \sum_{j=1}^{n} y_j - \sum_{j=1}^{n} x_j = \sum_{j=1}^{n} \dfrac{z_j(K_j - 1)}{n_v K_j - n_v + 1} = 0$
5	Repeat procedure number 2 to 4 with other value of n_v until $f(n_{vi})$=0	same with no. 4

Table 8. Parameters *a*, *b*, *c* in API 12.3 equations

GROUP	S_h (%) = a x L_c x $(100 - L_c)^b$ x $(\Delta API)^c$		
	Constant		
	a	***b***	***c***
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 (2017).

Table 9. Calculation procedure of shrinkage volume in tanks *)

No	Procedure	Formula
1	Input data: net volume (V_{net-i}), specific gravity (SG_i) for each shipper (***i***)	V_{net-i}, SG_i
2	Calculation of °API$_i$ for each shipper (***i***)	$^{o}\text{API}_i = \dfrac{141.5}{SG_i} - 131.5$
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 $SG(1)<SG(2)$: $Lc_1 = \dfrac{V_{net}(1)}{V_{tot1}} 100$ if $SG(1)>SG(2)$: $Lc_1 = \dfrac{V_{net}(2)}{V_{tot1}} 100$
	c. Calculation of the 1st Δ°API (Δ°API$_1$)	$\Delta^{o}\text{API}_1 = \text{abs}(^{o}\text{API}(1) - {}^{o}\text{API}(2))$
	d. Calculation of the 1st %-shrinkage (S_{h1})	$S_{h1}\ (\%) = a\, Lc_1 (100 - Lc_1)^b (\Delta^{o}\text{API}_1)^c$
	e. Calculation of the 1st shrinkage volume (V_{sh1})	$V_{sh1} = \dfrac{S_{h1}}{100} V_{tot1}$
	f. Calculation of the 1st mixed volume (V_{mix1})	$V_{mix1} = V_{tot1} - V_{sh1}$
	g. Calculation of the 1st mixed SG (SG_{mix1})	$SG_{mix1} = \dfrac{V_{net}(1) SG(1) + V_{net}(2) SG(2)}{V_{mix1}}$
	h. Calculation of the 1st mixed °API (°API$_{mix1}$)	$^{o}\text{API}_{mix1} = \dfrac{141.5}{SG_{mix1}} - 131.5$
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 $SG_{mix1}<SG(3)$: $Lc_2 = \dfrac{V_{mix1}}{V_{tot2}} 100$ if $SG_{mix1}>SG(3)$: $Lc_2 = \dfrac{V_{net}(3)}{V_{tot2}} 100$
	c. Calculation of the 2nd Δ°API (Δ°API$_2$)	$\Delta^{o}\text{API}_2 = \text{abs}(^{o}\text{API}_{mix1} - {}^{o}\text{API}(3))$
	d. Calculation of the 2nd %-shrinkage (S_{h2})	$S_{h2}\ (\%) = a\, Lc_2 (100 - Lc_2)^b (\Delta^{o}\text{API}_2)^c$
	e. Calculation of the 2nd shrinkage volume (V_{sh2})	$V_{sh2} = \dfrac{S_{h2}}{100} V_{tot2}$
	f. Calculation of the 2nd mixed volume (V_{mix2})	$V_{mix2} = V_{tot2} - V_{sh2}$

No	Procedure	Formula
	g. Calculation of the 2nd mixed SG (SG_{mix2})	$SG_{mix2} = \dfrac{V_{mix2}SG_{mix2} + V_{net}(3)SG(3)}{V_{mix2}}$
	h. Calculation of the 2nd mixed °API (°API_{mix2})	$°API_{mix2} = \dfrac{141.5}{SG_{mix2}} - 131.5$
5	Calculation of net-corrected-volume in tank (V_{nc})	$V_{nc} = V_{mix2}$
6	Calculation of group-shrinkage-losses in tank (V_{shg})	$V_{shg} = V_{sh1} + V_{sh2}$

*) Notes of **Table 9** that shows the stratification of oil mix in tank are listed in **Table 10**.

Table 10. Notes of Table 9: stratification of oil mix in tank

(*i*)	**Shippers' oil mix in Tank**		
	TANK-1	**TANK-2**	**TANK-3**
(1)	Shipper S1	TANK-1	TANK-2
(2)	Shipper S2	Shipper S4	Shipper S6
(3)	Shipper S3	Shipper S5	Shipper S7

Table 11. Individual losses

Shipper	Gross [barrel]	BS&W [%Vol]	ECF [%Vol]	EV [barrel]	FCF [%Vol]	VV [barrel]	TIL [barrel]	NSV [barrel]
S1	500	0.1	0.0558	0.2790	0	0	0.28	499.72
S2	1200	0.1	0.0226	0.2716	0	0	0.27	1199.73
S3	400	0.1	0.0043	0.0171	0	0	0.02	399.98
S4	200	0.1	0.0306	0.0612	0	0	0.06	199.94
S5	800	0.1	0.0183	0.1467	0	0	0.15	799.85
S6	1000	0.1	0.0186	0.1857	0	0	0.19	999.81
S7	400	0	0.0000	0.0000	0	0	0.00	400.00
						Total	**0.96**	**4499.04**

BS&W: Based Sediment & 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 12. Normal bubble and dew points of crude oils

Shipper	Bubble point (T_b), [°C]	Dew point (T_d), [°C]
S1	57.91	341.60
S2	131.25	330.60
S3	197.66	314.85
S4	158.48	335.28
S5	134.29	348.45
S6	72.98	338.07
S7	61.73	92.00

Table 13. Proportional sharing losses results

SHIPPER	NSV [barrel]	SG	*x*	*x*/SG	Shrinkage loss	
					Volume [barrel]	SCF [%]
S1	499.72	0.8881	0.1111	0.1251	1.00	0.20
S2	1199.73	0.8931	0.2667	0.2986	2.38	0.20
S3	399.98	0.9031	0.0889	0.0984	0.78	0.20
S4	199.94	0.9043	0.0444	0.0491	0.39	0.20
S5	799.85	0.8694	0.1778	0.2045	1.63	0.20
S6	999.81	0.8912	0.2222	0.2494	1.99	0.20
S7	400.00	0.8001	0.0889	0.1111	0.89	0.22
Total	**4499.04**			**1.1362**	**9.06**	

Net corrected volume in the last tank (barrel) =	**4489.98**
Total shrinkage loss (barrel) =	**9.06**

NSV: Net Standard Volume [barrel]; SCF: Shrinkage Correction Factor [%Vol]; SG: Specific Gravity; *x*: volume fraction

Table 14. Stratified sharing losses results.

SHIPPER			Stratified-1 (Mixing in Tank-1 of Station-1)				Stratified-2 (Mixing in Tank-2 of Station-2)				Stratified-3 (Mixing in Tank-3 of Station-3)				Total Shrinkage Loss	
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)	(%)
S1	499.72	0.8881	0.60	0.12	499.13	0.8938	0.67	0.13	498.45	0.8882	0.26	0.05	498.19	0.8810	1.53	0.31
S2	1,199.73	0.8931	1.42	0.12	1,198.31	0.8938	1.61	0.13	1,196.69	0.8882	0.63	0.05	1,196.07	0.8810	3.66	0.31
S3	399.98	0.9031	0.47	0.12	399.51	0.8938	0.54	0.13	398.98	0.8882	0.21	0.05	398.77	0.8810	1.22	0.30
total	2,099.43		2.48													
NCV Tank-1 (bbl)			2096.95													
Sub-total srinkage loss (bbl)			2.48													
S4					199.94	0.9043	0.27	0.13	199.67	0.8882	0.10	0.05	199.57	0.8810	0.37	0.19
S5					799.85	0.8694	1.11	0.14	798.75	0.8882	0.42	0.05	798.33	0.8810	1.53	0.19
				total	3,096.74		4.20									
NCV Tank-2 (bbl)							3,092.54									
Sub-total srinkage loss (bbl)							4.20									
S6									999.81	0.8912	0.52	0.05	999.29	0.8810	0.52	0.05
S7									400.00	0.8001	0.23	0.06	399.77	0.8810	0.23	0.06
								total	4,492.36		2.38		4,489.98		9.06	
NCV Tank-3 (bbl)											4489.98					
Sub-total shrinkage loss (bbl)											2.38					

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

Table 15. Comparison between Proportional and Stratified Results

SHIPPER	Sending Point		Mixing quantity	Shrinkage Losses			
	NSV (barrel)	SG		Proportional		Stratified	
				(bbl)	SCF (%)	(bbl)	SCF (%)
S1	499.72	0.8881	3	1.00	0.20	1.53	0.31
S2	1,199.73	0.8931	3	2.38	0.20	3.66	0.31
S3	399.98	0.9031	3	0.78	0.20	1.22	0.30
S4	199.94	0.9043	2	0.39	0.20	0.37	0.19
S5	799.85	0.8694	2	1.63	0.20	1.53	0.19
S6	999.81	0.8912	1	1.99	0.20	0.52	0.05
S7	400.00	0.8001	1	0.89	0.22	0.23	0.06
Total	**4,499.04**			**9.06**		**9.06**	

Net corrected volume in last tank =	**4,489.98**	**barrel**

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

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Yulius Deddy Hermawan[1] · Dedy Kristanto[2] · Hariyadi[2] · Wibowo[2]

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Determination of sharing oil losses using proportional and stratified methods in Krisna field

Yulius Deddy Hermawan[1] · Dedy Kristanto[2] · Hariyadi[2] · Wibowo[2]

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Abstract

This paper discusses about the oil losses due to emulsion, flash, and mixing oil phenomena that frequently happened in the oil and gas companies. The goals of this work are to calculate the emulsion and vapor correction volumes, shrinkage correction volume of the mixture of two or more crude oils with different densities, and to compare between the common proportional method that usually utilized in petroleum industries and the new proposed stratified method for determining of sharing oil losses. The mixing of crude oils from 7 shippers in Krisna field would be used as a case study, and the equation of API 12.3 was chosen to calculate a shrinkage correction volume. Oils from shippers S1, S2, and S3 were first mixed together in TANK-1 of the 1st station; the mixed oil of TANK-1 was then transported to the next station and stored in the TANK-2 and mixed with other oils from shippers S4 and S5; and finally, the mixed oil of TANK-2 was transported to the final station and stored in the TANK-3 and mixed with other oils from shippers S6 and S7. The proportional method gave almost the same shrinkage correction factor (SCF) for all shippers about 0.20%, while stratified method resulted SCF in between 0.05 and 0.31%. Based on our analysis, more often oil mixes with others its volume would be more decreased. The stratified method is therefore recommended to determine sharing oil losses since it gives a fair result.

Keywords Emulsion · Flash · Oil losses · Mixing oil · Proportional · Shrinkage · Stratified

Introduction

Sources of oil loss in petroleum industries are emulsion, evaporative (flash), shrinkage, leakage, theft, and measurement losses, etc (Bhatia and Dinwoodie 2004). This study focuses in oil losses due to emulsion, flash, and mixing phenomena. Human and measurement errors, leakage, and theft are excluded. Oil loss are categorized into two categories, they are (1) individual and (2) group losses.

✉ Yulius Deddy Hermawan
ydhermawan@upnyk.ac.id

Dedy Kristanto
dedykris.upn@gmail.com

1 Department of Chemical Engineering, Faculty of Industrial Engineering, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Jl. SWK 104 (Lingkar Utara) Condongcatur, Yogyakarta 55283, Indonesia

2 Department of Petroleum Engineering, Faculty of Mineral Technology, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Jl. SWK 104 (Lingkar Utara) Condongcatur, Yogyakarta 55283, Indonesia

Individual loss

Individual loss includes emulsion and evaporative losses. In order to determine emulsion loss, based sediment and water (BS&W) of oil should be measured. The net standard volume (NSV) excludes sediment, water, and free water. So far back to year 1918, Bradley et al. (1918) have studied the crude oil losses in steel and earthen storage; they classified roughly losses as occurring from evaporation, and presence of sediment and water. Evaporative loss occurs when light components are released from oil in the storage tank. This happens when the oil temperature is lower than its bubble point. Thus, by maintaining low oil temperature minimizes evaporative loss from storage tank (Bhatia and Dinwoodie 2004).

The goals of this work are to calculate the emulsion correction factor (ECF) and flash correction factor (FCF) that occur individually in 7 shippers of Krisna field. The empiric equation of emulsion would be used to calculate ECF, while flash calculation with Antoine equation was chosen to calculate FCF.

Group loss

Group loss occurs during mixing oils in the same storage tank. In this study, the specific characteristic which has influence on group loss is the specific gravity (SG) or API gravity. The viscosity and gas oil ratio are excluded in calculation of group loss due to mixing phenomena in the storage tank. The oil and gas fields generally produce petroleum fluid that can be classified into five categories: dry gas, wet gas, gas condensate, volatile oil, and black oil (McCain Jr. 1990a; Whitson and Brule 2000). Since the fluids in those categories have different characteristics, specifically SG or API, the properties would thus change when they are mixed together.

Typical oil mixing phenomena in the gathering station are illustrated in Fig. 1. In an activity of transporting of crude oil from shippers in the oil field to the gathering station, shippers often use the same pipeline to transport the crude oil to a storage tank. The crude oils from shippers are mixed together either in the same temporary or final storage tank. This situation comes up the problem of oil losses. As shown in Fig. 1, there is a loss discrepancy between total quantities from shippers and measurement in the storage tanks (Bhatia and Dinwoodie 2004); the total sending volume is lower than the measured volume in the mixing tank. The study of sharing oil losses is therefore very important to be done.

Several studies (Katz 1942; Erno et al. 1994; Nengkoda 2011; James 2014) have discussed about prediction of crude oil shrinkage losses. Far back to year of 1942, Katz (1942) has investigated the crude oil shrinkage phenomena and pointed that the more volatile the separator liquid phase, the more impact separator conditions and shrinkage will be. Erno et al. (1994) predicted the shrinkage equation of heavy oil/condensate blend and stated that when condensate is added to heavy oil, the blended volume is less than the sum of the condensate and oil volumes. Nengkoda (2011) has studied the role of crude oil shrinkage in heavy mix light crude in main oil pipeline and pointed that shrinkage will be very depended upon the operation pressure and temperature. In recent year 2014, James has studied shrinkage losses resulting from liquid hydrocarbon blending. James (2014) concluded that equation of API 12.3 was a valuable tool in quantifying shrinkage that occurs as a result of blending hydrocarbons of different densities. Moreover, Shanshool et al. (2011) have investigated the volumetric behavior of mixtures of different oil stock. Shanshool et al. (2011) concluded that volumetric shrinkage is resulted from blending hydrocarbon with gas oil (light oil).

The goals of this work are to calculate the shrinkage correction factor (SCF) in oil mixing phenomena and to determine the sharing oil losses using the common proportional and the new proposed stratified methods. The oil distribution of 7 shippers in Krisna field (Fig. 2) would be taken as a case study. The modified equation of API 12.3 would be used to calculate SCF in every mixing phenomenon in tank.

Material and method

Flow diagram of oil distribution

The block diagram of oil distribution and mixing phenomena in Krisna field is shown in Fig. 2. As can be seen in Fig. 2, Krisna field has 7 shippers; they are S1, S2, S3, S4, S5, S6, and S7. Shippers S1, S2, and S3 send their oil to Station-1,

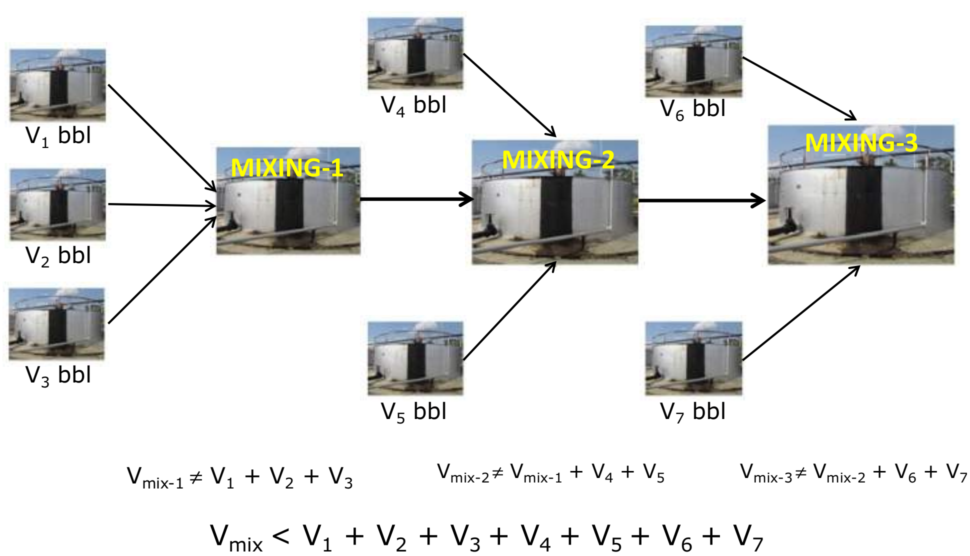

Fig. 1 Typical oil mixing phenomena in gathering station

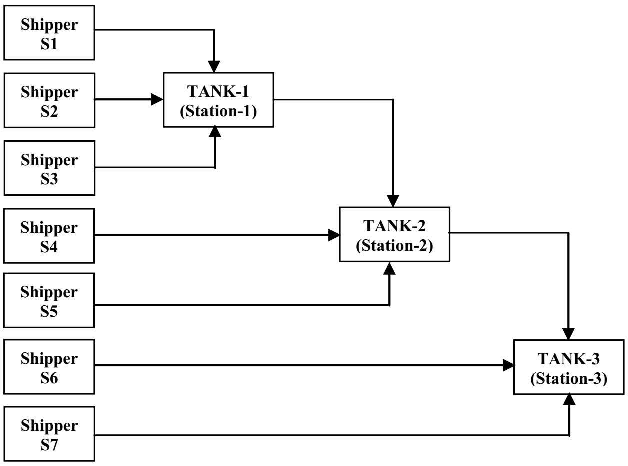

Fig. 2 Block diagram of oil distribution and mixing phenomena in Krisna field

and the oils are temporary stored in same tank of TANK-1. The mixed oil of TANK-1 is then pumped to the 2nd station and temporary stored in TANK-2 and mixed with other oils from shippers S4 and S5. Finally, the mixed oil of TANK-2 is transported to the 3rd station and stored in TANK-3 and mixed with other oils from shippers S6 and S7. As shown in Fig. 2, shippers S1, S2, and S3 have three times of mixing phenomena, shippers S4 and S5 have twice, and shippers S6 and S7 have only once.

Parameter inputs

Parameter inputs for calculating of sharing oil losses are production rate, pressure, temperature, specific gravity (SG), and based sediment water (BSW). These parameter inputs are listed in Table 1. As shown in Table 1, oils S1–S6 have the same BS&W 0.1 vol%, while shipper S7 produces condensate with BS&W equals to zero. All oils are stored in the atmospheric storage tank (pressure of about 1 atm and temperature of about 30 °C). The total oil rate from all shippers as sending points is 4500 barrel oil per day (BOPD). The specific gravities (SG) of all shippers vary from 0.8001 to 0.9043. Oil S7 is the lightest one with SG 0.8001; this is typically condensate. Oils S3 and S4 are typical heavy oil with SG around 0.90.

Calculation algorithm of sharing oil losses

Calculation algorithm of sharing oil losses is shown in Fig. 3. In order to calculate the total sharing oil losses, individual loss such as emulsion and flash losses must first be calculated, and then, the group loss in mixing phenomena is determined. Sharing oil losses would be determined by two methods, they are the common proportional and the new proposed stratified methods.

Calculation of emulsion loss

Since the net oil excludes sediment, water, and free water, based sediment and water (BS&W) of oil has to be measured. In this study, BS&W in oils S1–S6 is taken the same 0.1 vol% (Table 1). While BS&W of oil S7 equals to zero, this oil is a typical condensate. The empiric emulsion equations are used for calculating emulsion loss. The emulsion parameters (a_1, b_1, a_2, b_2) for each shipper are shown in Table 2. The empiric emulsion equations and emulsion loss can be generated with following methodology:

a. Crude oil is mixed with its formation water at some levels of water volume, and the BS&W and SG of mixed oil–water are then investigated.
b. The changes of BS&W and SG are plotted in a curve. This first curve results linear equation:

$$Y_1 = a_1X_1 + b_1 \quad (1)$$

Table 1 Production rate Krisna field and its properties

Shipper	Production			Oil Percent Volume (%)	Tank's condition		Properties	
	Gross (BFPD)	Oil (BOPD)	Water (BWPD)		Pressure (atm.)	Temperature (°C)	SG (60°/60°)	BS&W
S1	500	500	0	11.11	1	30	0.8881	0.1
S2	1200	1200	0	26.67	1	30	0.8931	0.1
S3	400	400	0	8.89	1	30	0.9031	0.1
S4	200	200	0	4.44	1	30	0.9043	0.1
S5	800	800	0	17.78	1	30	0.8694	0.1
S6	1000	1000	0	22.22	1	30	0.8912	0.1
S7[*)]	400	400	0	8.89	1	30	0.8001	–
Total	4500	4500	0	100.00				

Note [*)]: shipper S7 produces condensate

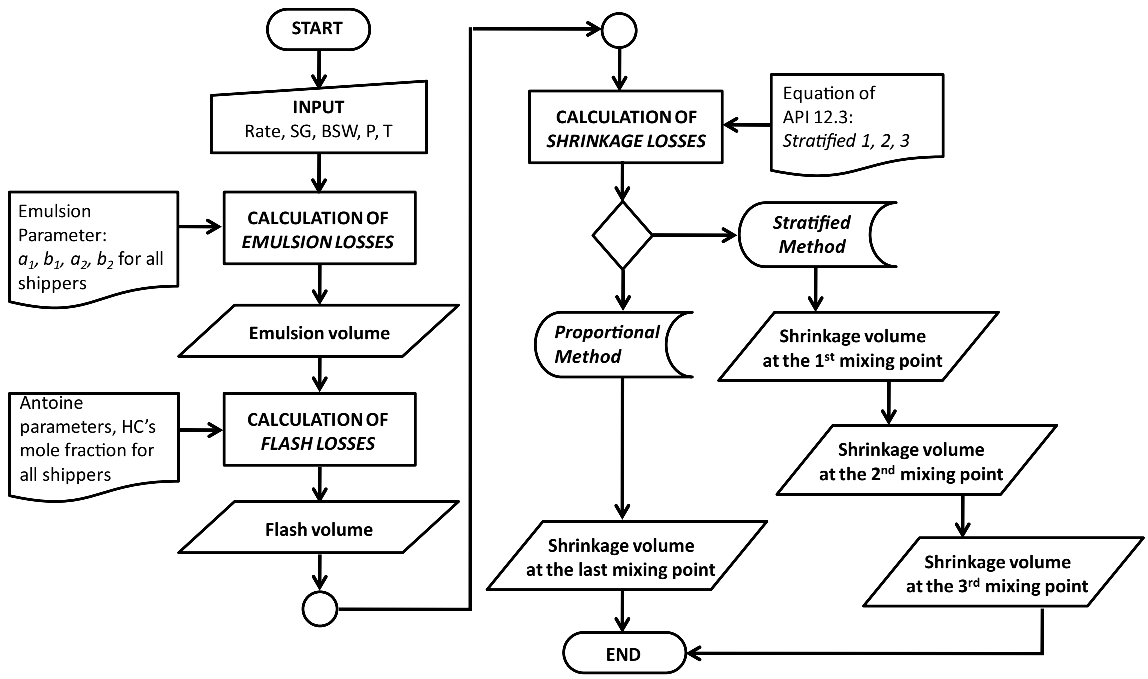

Fig. 3 Calculation algorithm of sharing oil losses

Table 2 Emulsion parameters

Shipper	$X_1=\text{BS\&W}$ (vol%)	$Y_1=a_1X_1+b_1$ a_1	b_1	$Y_1=Y_2$	$Y_2=a_2X_2+b_2$ a_2	b_2	$X_2=(Y_2-b_2)/a_2$ (vol%)	ECF X_1-X_2 (vol%)
S1	0.1	0.001278	0.8881	0.888228	0.002892	0.8881	0.0442	0.0558
S2	0.1	0.001210	0.8931	0.893221	0.001564	0.8931	0.0774	0.0226
S3	0.1	0.001097	0.9031	0.903210	0.001146	0.9031	0.0957	0.0043
S4	0.1	0.001121	0.9043	0.904412	0.001615	0.9043	0.0694	0.0306
S5	0.1	0.001470	0.8694	0.869547	0.001800	0.8694	0.0817	0.0183
S6	0.1	0.001241	0.8912	0.891324	0.001524	0.8912	0.0814	0.0186
S7	0	0	0	0	0	0	0	0

The constants of a_1, b_1, a_2, and b_2 are referenced from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017)

where X_1 is the measured BS&W, Y_1 is the measured SG, and a_1 and b_1 are constants.

c. Then, making a curve of percentage of the addition of the volume of formation water (in vol%) versus the calculated SG. This second curve produces linear equation:

$$Y_2 = a_2X_2 + b_2 \quad (2)$$

where X_2 is the percentage of the addition of the volume of formation water (in vol%), Y_2 is the calculated SG, and a_2 and b_2 are constants. The calculated SG can be found with the following equation:

$$\text{SG}_{\text{calculated}} = \left(1 - X_\text{w}\right)\text{SG}_{\text{fw}} + X_\text{w}\text{SG}_\text{w} \quad (3)$$

where X_w is water volume fraction in oil, SG_w is specific gravity of formation water, and SG_{fw} is specific gravity of oil free water as defined below:

$$\text{SG}_{\text{fw}} = \frac{\text{SG}_\text{o} - X_\text{w}\text{SG}_\text{w}}{\left(1 - X_\text{w}\right)} \quad (4)$$

where SG_o is specific gravity of oil that still contains water.

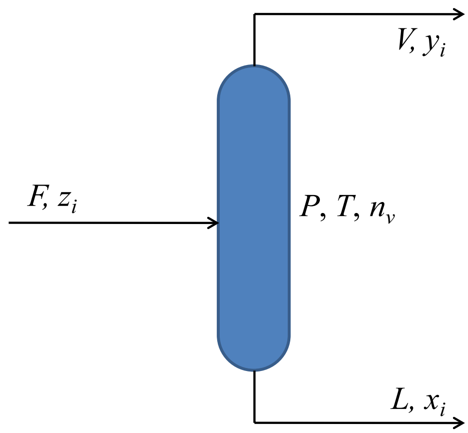

Fig. 4 Vapor–liquid equilibrium for flash calculation

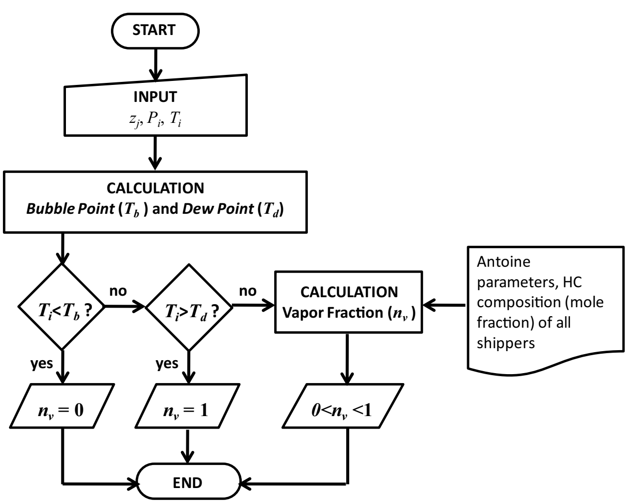

Fig. 5 Flash calculation algorithm

d. Both empiric equations are then used for calculating emulsion loss. Y_1 is found by inputting the measured BS&W of oil as X_1 in Eq. (1). The resulted Y_1 is then substituted in Eq. (2) to calculate X_2.
e. Emulsion correction factor (ECF) in vol% is then calculated as follows:

$$\mathrm{ECF} = X_1 - X_2 \tag{5}$$

Calculation of evaporative loss

Evaporative loss is calculated with flash calculation method. Mass balance diagram for flash calculation method is shown in Fig. 4. Evaporative loss depends on its operating conditions, i.e., pressure (P) and temperature (T). Evaporation is indicated by the value of vapor fraction n_v (Ahmed 2007). Vapor fraction n_v ranges in between 0 and 1. $n_\mathrm{v}=0$ and $n_\mathrm{v}=1$ mean the fluid is in liquid and gas phase, respectively. If n_v is in between 0 and 1 ($0<n_\mathrm{v}<1$), 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.

Flash calculation algorithm is shown in Fig. 5. Input data required in this algorithm are hydrocarbon composition (z_j), pressure (P_i) and temperature (T_i) of each shipper system. The intended pressure (P_i) is the fluid pressure in a storage tank, i.e., atmospheric pressure. Table 3 shows the hydrocarbon composition (z_j) of each shipper. In this work, Antoine equation was chosen to calculate flash correction factor (FCF). Antoine parameters (a, b, c, d, e, f) for each hydrocarbon component are listed in Table 4.

The next step is the calculations of bubble (T_b) and dew point (T_d) at the atmospheric pressure. Bubble and dew point are saturated condition at $n_\mathrm{v}=0$ and $n_\mathrm{v}=1$, respectively. Calculation procedure of T_b and T_d is written in Tables 5 and 6, respectively. Antoine equation used in this calculation is:

$$P_{\mathrm{vap}\ j} = \exp\left(a_j + \frac{b_j}{\left(T + c_j\right)} + d_j \ln(T) + e_j T^{f_j} \right) \tag{6}$$

where $P_{\mathrm{vap}\ j}$ 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.

After calculation T_b and T_d, we calculate vapor fraction n_v. Temperature T and pressure P of fluid (system) are the input data in calculation n_v. As shown in Fig. 5, when T is lower than T_b so $n_\mathrm{v}=0$, this indicates that the fluid is in liquid phase. When T is higher than T_d so $n_\mathrm{v}=1$, this means that fluid is in vapor phase. When T is in between T_b and T_d, n_v is in between 0 and 1; this means that part of light component in fluid evaporates. Calculation procedure of n_v is shown in Table 7. Flash correction factor (FCF) is then calculated as follows:

$$\mathrm{FCF} = n_\mathrm{v} \times 100\% \tag{7}$$

where FCF is in vol%.

Calculation of shrinkage loss

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

$$S_\mathrm{h}(\%) = aL_\mathrm{c}\left(100 - L_\mathrm{c}\right)^b (\Delta^\circ \mathrm{API})^c \tag{8}$$

where a, b, and c are constants of API 12.3 that be taken from PSME of UPN "Veteran" Yogyakarta collaborated with LEMIGAS Jakarta (2017) as listed in Table 8, L_c is %-light component, Δ°API is °API difference between °API

Table 3 Hydrocarbon composition (%-mol)

Component	Shipper						
	S1	S2	S3	S4	S5	S6	S7
Methane (C1)	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Ethane (C2)	0.82	0.04	0.01	0.03	0.01	0.02	0.00
Propane (C3)	0.98	0.33	0.03	0.14	0.27	0.11	0.00
Butane (C4)	1.43	0.68	0.08	0.24	0.54	0.34	0.05
Pentane (C5)	1.76	1.01	0.17	0.43	1.07	0.75	30.48
Hexane (C6)	2.69	1.48	0.26	0.85	3.45	2.53	29.67
Heptane (C7)	5.04	4.17	1.54	3.11	4.44	3.55	25.85
Octane (C8)	8.37	8.15	3.63	6.88	8.04	7.25	12.37
Nonane (C9)	6.85	7.56	4.65	6.66	7.59	6.77	1.51
Decane (C10)	5.50	7.89	5.01	5.85	6.16	5.73	0.07
Undecane (C11)	4.89	5.56	5.87	6.03	5.99	5.73	0.00
Dodecane (C12)	3.00	5.49	5.19	4.88	4.35	4.39	0.00
Tridecane (C13)	3.85	6.54	6.51	5.98	4.93	5.33	0.00
Tetradecane (C14)	3.81	7.79	8.32	7.70	5.05	6.88	0.00
Pentadecane (C15)	9.22	11.06	12.58	11.83	8.25	10.61	0.00
Heksadecane (C16)	4.79	5.92	29.37	6.54	4.22	6.00	0.00
Heptadecane (C17)	7.43	6.54	5.28	7.61	6.59	7.25	0.00
Oktadecane (C18)	3.98	3.52	2.35	4.22	2.99	3.93	0.00
Nonadecane (C19)	3.12	2.61	1.67	3.44	2.74	3.49	0.00
Eicosane (C20)	2.62	1.73	1.05	2.48	2.25	2.71	0.00
Heneicosane (C21)	2.77	1.48	0.90	2.19	2.10	2.32	0.00
Docosane (C22)	2.90	1.32	0.72	1.95	2.14	2.14	0.00
Tricosane (C23)	2.99	1.28	0.62	1.89	2.14	2.07	0.00
Tetracosane (C24)	2.12	1.01	0.58	1.45	2.09	1.64	0.00
Pentacosane (C25)	1.64	1.05	0.57	1.41	2.13	1.58	0.00
Hexacosane (C26)	1.43	0.90	0.46	1.18	1.89	1.33	0.00
Heptacosane (C27)	1.56	1.01	0.44	1.18	1.93	1.30	0.00
Octacosane (C28)	1.25	1.25	0.49	1.33	1.88	1.36	0.00
Nonacosane (C29)	1.43	1.55	0.42	0.98	1.67	1.22	0.00
Triacontane (C30)	1.77	1.07	1.23	1.55	3.13	1.62	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

of shipper one and other, and S_{h} is shrinkage volume percentage (in %).

API gravity for each shipper is defined as the equation in McCain Jr. (1990b):

$$^{\circ}\mathrm{API}_i = \frac{141.5}{\mathrm{SG}_i} - 131.5 \tag{9}$$

where $^{\circ}\mathrm{API}_i$ is API gravity of shipper i and SG_i is specific gravity (60°/60°) of shipper i.

Proportional method Proportional method is the common method used in petroleum industries for sharing oil losses. In this method, the total received volume is measured at the last station. This measured volume is the net corrected volume (V_{nc}) which is directly taken from the last storage tank in the last station (TANK-3 in Fig. 2). The total shrinkage volume ($V_{\text{sh-prop}}$) is the difference volume between the total volume sent from all shippers and the net corrected volume:

$$V_{\text{sh-prop}} = \sum_{i=1}^{n} V_i - V_{\mathrm{nc\ (TANK\text{-}3)}} \tag{10}$$

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

$$\xi_{\mathrm{prop}_i} = \frac{x_i\left({}^{1}/_{\mathrm{SG}_i}\right)}{\sum_{i=1}^{n} x_i\left({}^{1}/_{\mathrm{SG}_i}\right)} V_{\text{sh-prop}} \tag{11}$$

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

Table 4 Antoine parameters for hydrocarbon: T in K; P in kPa

Component	$P_{\mathrm{vap}} = \exp\left(a + \frac{b}{(T+c)} + d\ln(T) + eT^{f}\right)$					
	a	*b*	*c*	*d*	*e*	*f*
Methane (C1)	31.35	−1307.52	0.00	−3.26	0.00	2.00
Ethane (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	−10,635.20	0.00	−15.81	0.00	2.00
Undecane (C11)	121.16	−11,079.20	0.00	−15.38	0.00	2.00
Dodecane (C12)	125.19	−11,737.00	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	−13,893.70	0.00	−18.30	0.00	2.00
Pentadecane (C15)	152.64	−14,762.20	0.00	−19.55	0.00	2.00
Heksadecane (C16)	225.02	−18,736.50	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	−19,441.00	0.00	−25.53	0.00	2.00
Heneicosane (C21)	133.88	−17,129.00	0.00	−15.87	0.00	6.00
Docosane (C22)	147.40	−18,406.00	0.00	−17.69	0.00	6.00
Tricosane (C23)	212.92	−21,841.00	0.00	−27.53	0.00	2.00
Tetracosane (C24)	204.51	−21,711.00	0.00	−26.26	0.00	2.00
Pentacosane (C25)	152.24	−19,976.00	0.00	−18.16	0.00	6.00
Hexacosane (C26)	148.73	−20,116.00	0.00	−17.62	0.00	6.00
Heptacosane (C27)	148.85	−20,612.00	0.00	−17.55	0.00	6.00
Octacosane (C28)	285.21	−28,200.00	0.00	−37.54	0.00	2.00
Nonacosane (C29)	201.65	−24,971.00	0.00	−24.75	0.00	6.00
Triacontane (C30)	188.81	−22,404.00	0.00	−23.36	0.00	6.00

Table 5 Calculation procedure of bubble point (T_b)

Nos.	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	$P_{vj} = \exp\left(a_j + \frac{b_j}{(T_i + c_j)} + d_j\ln(T_i) + e_jT_i^{f_j}\right)$
3	Calculation of equilibrium ratio of component K_j	$K_j = \frac{P_{v_j}}{P_i}$
4	Calculation of objective function $f(n_{vi})$, where $n_v = 0$	$f(n_{v_i}) = \sum_{j=1}^{n} y_j - \sum_{j=1}^{n} x_j = \sum_{j=1}^{n} \frac{z_j(K_j - 1)}{n_v K_j - n_v + 1} = 0$
5	Repeat procedure number 2–4 with other value of T_i until $f(n_{vi}) = 0$	Same with no. 4

i = *shipper*; j = component HC

Table 6 Calculation procedure of dew point (T_d)

Nos.	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	$P_{vj}=\exp\left(a_j+\frac{b_j}{(T_i+c_j)}+d_j\ln(T_i)+e_jT_i^{f_j}\right)$
3	Calculation of equilibrium ratio of component K_j	$K_j=\frac{P_{v_j}}{P_i}$
4	Calculation of objective function $f(n_{vi})$, where $n_v=1$	$f(n_{v_i})=\sum_{j=1}^{n}y_j-\sum_{j=1}^{n}x_j=\sum_{j=1}^{n}\frac{z_j(K_j-1)}{n_vK_j-n_v+1}=0$
5	Repeat procedure number 2–4 with other value of T_i until $f(n_{vi})=0$	Same with no. 4

i = *shipper*; j = component HC

Table 7 Calculation procedure of vapor fraction (n_v)

Nos.	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	$P_{vj}=\exp\left(a_j+\frac{b_j}{(T_i+c_j)}+d_j\ln(T_i)+e_jT_i^{f_j}\right)$
3	Calculation of equilibrium ratio of component K_j	$K_j=\frac{P_{v_j}}{P_i}$
4	Calculation of objective function $f(n_{vi})$ with guessed vapor fraction n_v	$f(n_{v_i})=\sum_{j=1}^{n}y_j-\sum_{j=1}^{n}x_j=\sum_{j=1}^{n}\frac{z_j(K_j-1)}{n_vK_j-n_v+1}=0$
5	Repeat procedure number 2–4 with other value of n_v until $f(n_{vi})=0$	Same with no. 4

Table 8 Parameters a, b, c in API 12.3 equations

Group	$S_h\,(\%)=a\times L_c\times(100-L_c)^b\times(\Delta\text{API})^c$		
	Constant		
	a	b	c
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 (2017)

$$x_i=\frac{V_i}{\sum_{i=1}^{n}V_i} \tag{12}$$

The proportional shrinkage correction factor ($\text{SCF}_{\text{prop}_i}$ in vol%) for each shipper can then be calculated as follows:

$$\text{SCF}_{\text{prop}_i}=\frac{\xi_{\text{prop}_i}}{V_i}\times100\% \tag{13}$$

Stratified method In new proposed stratified method, the net corrected volume is calculated stratify from tank to tank as shown in Tables 9 and 10. The shrinkage volume is calculated for each mixing phenomena in TANK-1, TANK-2, and TANK-3. The shrinkage volume for shippers S1, S2, and S3 in TANK-1 can be calculated with the following equation:

$$\xi_{\text{st-I}i}=\frac{x_i\left({}^1\!/\text{SG}_i\right)}{\sum_{i=1}^{n}x_i\left({}^1\!/\text{SG}_i\right)}V_{\text{shg-I}} \tag{14}$$

where $\xi_{\text{st-I}i}$ is shrinkage volume for shipper i (S1, S2, and S3) in TANK-1 and $V_{\text{shg-I}}$ is the group shrinkage volume in TANK-1. The shrinkage volume for shippers S4, S5, and TANK-1 (mix S1–S2–S3) in TANK-2 can be calculated with the following equation:

$$\xi_{\text{st-II}i}=\frac{x_i\left({}^1\!/\text{SG}_i\right)}{\sum_{i=1}^{n}x_i\left({}^1\!/\text{SG}_i\right)}V_{\text{shg-II}} \tag{15}$$

where $\xi_{\text{st - II}i}$ is shrinkage volume for shipper i (S4, S5, and mix S1–S2–S3) in TANK-2 and $V_{\text{shg-II}}$ is the group shrinkage volume in TANK-2. Finally, the shrinkage volume for shippers S6, S7, and TANK-2 (mix S1–S2–S3–S4–S5) in TANK-3 can be calculated as follows:

$$\xi_{\text{st-III}i}=\frac{x_i\left({}^1\!/\text{SG}_i\right)}{\sum_{i=1}^{n}x_i\left({}^1\!/\text{SG}_i\right)}V_{\text{shg-III}} \tag{16}$$

Table 9 Calculation procedure of shrinkage volume in tanks

Nos.	Procedure	Formula
1	Input data: net volume ($V_{\text{net-}i}$), specific gravity (SG_i) for each shipper (i)	$V_{\text{net-}i}$, SG_i
2	Calculation of $°\text{API}_i$ for each shipper (i)	$°\text{API}_i = \frac{141.5}{SG_i} - 131.5$
3	a. Calculation of the 1st total volume (V_{tot1})	$V_{\text{tot1}} = V_{\text{net}}(1) + V_{\text{net}}(2)$
	b. Calculation of the 1st %-light component (Lc_1)	if SG(1) < SG(2): $\text{Lc}_1 = \frac{V_{\text{net}}(1)}{V_{\text{tot1}}}100$ if SG(1) > SG(2): $\text{Lc}_1 = \frac{V_{\text{net}}(2)}{V_{\text{tot1}}}100$
	c. Calculation of the 1st $\Delta°$API ($\Delta°\text{API}_1$)	$\Delta°\text{API}_1 = \text{abs}(°\text{API}(1) -° \text{API}(2))$
	d. Calculation of the 1st %-shrinkage (S_{h1})	$S_{\text{h1}}(\%) = a\text{Lc}_1\left(100 - \text{Lc}_1\right)^b\left(\Delta°\text{API}_1\right)^c$
	e. Calculation of the 1st shrinkage volume (V_{sh1})	$V_{\text{sh1}} = \frac{S_{\text{h1}}}{100}V_{\text{tot1}}$
	f. Calculation of the 1st mixed volume (V_{mix1})	$V_{\text{mix1}} = V_{\text{tot1}} - V_{\text{sh1}}$
	g. Calculation of the 1st mixed SG (SG_{mix1})	$\text{SG}_{\text{mix1}} = \frac{V_{\text{net}}(1)\text{SG}(1)+V_{\text{net}}(2)\text{SG}(2)}{V_{\text{mix1}}}$
	h. Calculation of the 1st mixed °API ($°\text{API}_{\text{mix1}}$)	$°\text{API}_{\text{mix1}} = \frac{141.5}{\text{SG}_{\text{mix1}}} - 131.5$
4	a. Calculation of the 2nd total volume (V_{tot2})	$V_{\text{tot2}} = V_{\text{mix1}} + V_{\text{net}}(3)$
	b. Calculation of the 2nd %-light component (Lc_2)	if SG_{mix1} < SG(3): $\text{Lc}_2 = \frac{V_{\text{mix1}}}{V_{\text{tot2}}}100$ if SG_{mix1} > SG(3): $\text{Lc}_2 = \frac{V_{\text{net}}(3)}{V_{\text{tot2}}}100$
	c. Calculation of the 2nd $\Delta°$API ($\Delta°\text{API}_2$)	$\Delta°\text{API}_2 = \text{abs}\left(°\text{API}_{\text{mix1}} -° \text{API}(3)\right)$
	d. Calculation of the 2nd %-shrinkage (S_{h2})	$S_{\text{h2}}(\%) = a\text{Lc}_2\left(100 - \text{Lc}_2\right)^b\left(\Delta°\text{API}_2\right)^c$
	e. Calculation of the 2nd shrinkage volume (V_{sh2})	$V_{\text{sh2}} = \frac{S_{\text{h2}}}{100}V_{\text{tot2}}$
	f. Calculation of the 2nd mixed volume (V_{mix2})	$V_{\text{mix2}} = V_{\text{tot2}} - V_{\text{sh2}}$
	g. Calculation of the 2nd mixed SG (SG_{mix2})	$\text{SG}_{\text{mix2}} = \frac{V_{\text{mix2}}\text{SG}_{\text{mix2}}+V_{\text{net}}(3)\text{SG}(3)}{V_{\text{mix2}}}$
	h. Calculation of the 2nd mixed °API ($°\text{API}_{\text{mix2}}$)	$°\text{API}_{\text{mix2}} = \frac{141.5}{\text{SG}_{\text{mix2}}} - 131.5$
5	Calculation of net corrected volume in tank (V_{nc})	$V_{\text{nc}} = V_{\text{mix2}}$
6	Calculation of group shrinkage losses in tank (V_{shg})	$V_{\text{shg}} = V_{\text{sh1}} + V_{\text{sh2}}$

This table shows the stratification of oil mix in tank listed in Table 10

Table 10 Notes of Table 9: stratification of oil mix in tank

(i)	Shippers' oil mix in tank		
	TANK-1	TANK-2	TANK-3
(1)	Shipper S1	TANK-1	TANK-2
(2)	Shipper S2	Shipper S4	Shipper S6
(3)	Shipper S3	Shipper S5	Shipper S7

where $\xi_{\text{st - III}i}$ is shrinkage volume for shipper i (S6, S7, and mix S1–S2–S3–S4–S5) in TANK-3 and $V_{\text{shg-III}}$ is the group shrinkage volume in TANK-3.

The total stratified shrinkage volume ($\xi_{\text{st - tot}i}$) for shippers S1, S2, and S3 is the summation of its shrinkage volume in TANK-1, TANK-2, and TANK-3, that for shippers S4 and S5 is the summation of its shrinkage volume in TANK-2 and TANK-3, while that for shippers S6 and S7 is only its shrinkage volume in the last tank of TANK-3.

$$\xi_{\text{st - tot}i} = \xi_{\text{st-I}i} + \xi_{\text{st-II}i} + \xi_{\text{st-III}i} \tag{17}$$

where for S4 and S5 $\xi_{\text{st}-\text{I}i} = 0$, and for S6 and S7 $\xi_{\text{st}-\text{I}i} = \xi_{\text{st}-\text{II}i} = 0$.

The stratified shrinkage correction factor (SCF_{st_i} in vol%) for each shipper can then be calculated as follows:

$$\text{SCF}_{\text{st}_i} = \frac{\xi_{\text{st}-\text{tot}_i}}{V_i} \times 100\% \tag{18}$$

Result and discussion

Individual loss results

Individual loss includes emulsion and evaporative losses and must be determined to get the net standard volume (NSV) of all petroleum liquids. The NSV excluding sediment, water (and free water), and vapor is then used for calculating group loss in mixing phenomena. The total individual losses (TIL) including emulsion and evaporative loss is listed in Table 11. TIL of shipper S1 is the biggest one, i.e., 0.28 barrel. While TIL of shipper S7 equals to zero, oil S7 is a typical condensate which has no emulsion. The total TIL and NSV resulted from the individual loss calculation are 0.96 and 4499.04 barrel, respectively.

Table 11 Individual losses

Shipper	Gross (barrel)	BS&W (vol%)	ECF (vol%)	EV (barrel)	FCF (vol%)	VV (barrel)	TIL (barrel)	NSV (barrel)
S1	500	0.1	0.0558	0.2790	0	0	0.28	499.72
S2	1200	0.1	0.0226	0.2716	0	0	0.27	1199.73
S3	400	0.1	0.0043	0.0171	0	0	0.02	399.98
S4	200	0.1	0.0306	0.0612	0	0	0.06	199.94
S5	800	0.1	0.0183	0.1467	0	0	0.15	799.85
S6	1000	0.1	0.0186	0.1857	0	0	0.19	999.81
S7	400	0	0.0000	0.0000	0	0	0.00	400.00
					Total		0.96	4499.04

BS&W based sediment & 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)

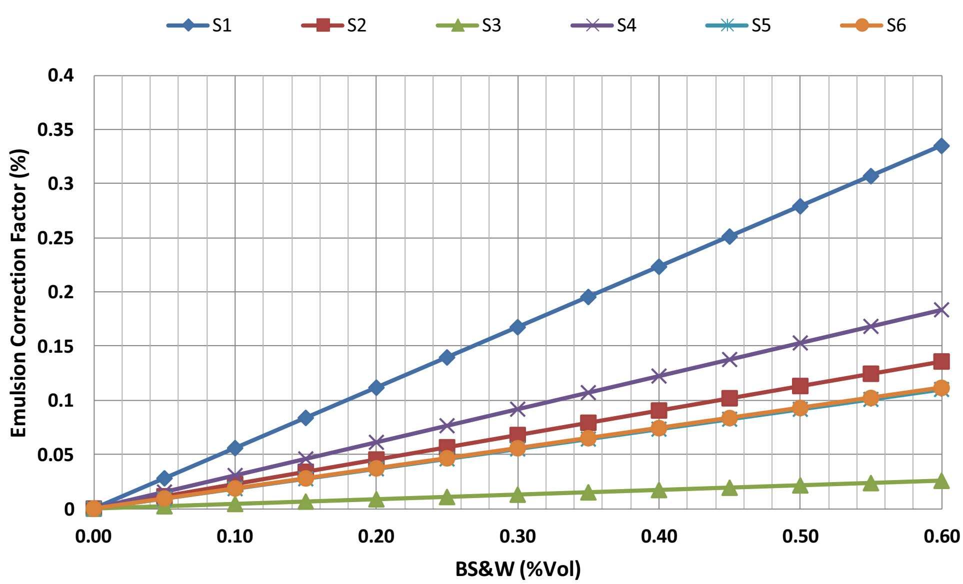

Fig. 6 Sensitivity BS&W against ECF

Table 12 Normal bubble and dew points of crude oils

Shippers	Bubble point (T_b), (°C)	Dew point (T_d), (°C)
S1	57.91	341.60
S2	131.25	330.60
S3	197.66	314.85
S4	158.48	335.28
S5	134.29	348.45
S6	72.98	338.07
S7	61.73	92.00

Emulsion loss

By inputting BS&W = 0.1% in the equation system (Eq. 1–5), emulsion correction factors (ECFs) for all shippers are found and listed in Table 11. The biggest and smallest ECFs are given by shipper S1 and S3, respectively. The sensitivity BS&W against EFC is shown in Fig. 6. Shipper S1 is the most sensitive compared with others; its ECF increases significantly by increasing its BS&W. While shipper S3 is not sensitive to a change in BS&W, its ECF raises slowly by increasing its BS&W.

Evaporative loss

In atmospheric pressure condition (about 1 atm), evaporation can happen when the fluid temperature is higher than its bubble point. The normal bubble (T_b) and dew (T_d) points resulted from flash calculation are listed in Table 12. Oil S7 is a typical condensate; it has the shortest span between T_b and T_d. Correlation of vapor pressure and bubble point for all shippers is shown in Fig. 7. Since the oil temperatures in all tanks are lower than its bubble point (Fig. 7), it is understandable that all shippers have no evaporative loss. Flash correction factors (FCFs) of all shippers equal to zero. During operation in the oil gathering station, by maintaining oil

Fig. 7 Correlation of vapor pressure and bubble temperature

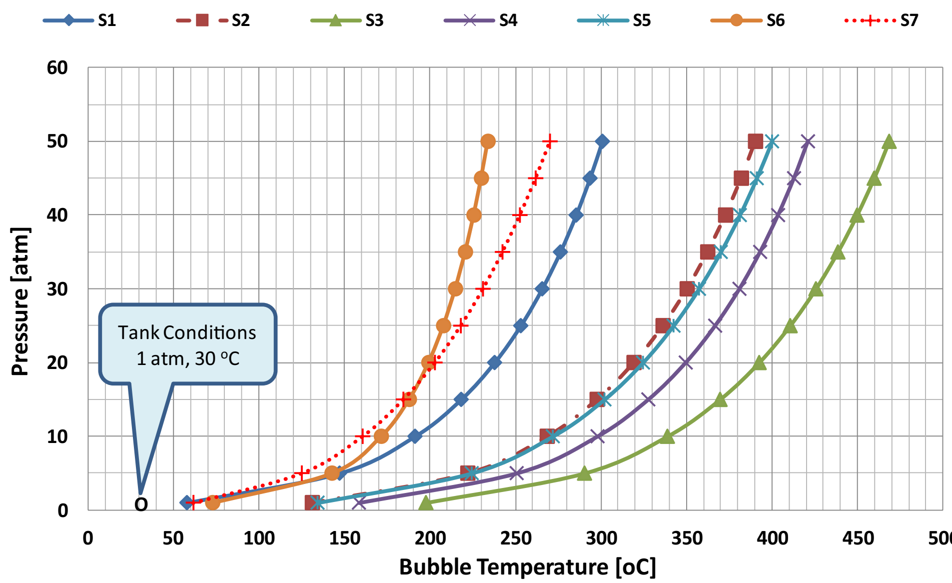

Table 13 Proportional sharing losses results

Shipper	NSV (barrel)	SG	x	x/SG	Shrinkage loss	
					Volume (barrel)	SCF (%)
S1	499.72	0.8881	0.1111	0.1251	1.00	0.20
S2	1199.73	0.8931	0.2667	0.2986	2.38	0.20
S3	399.98	0.9031	0.0889	0.0984	0.78	0.20
S4	199.94	0.9043	0.0444	0.0491	0.39	0.20
S5	799.85	0.8694	0.1778	0.2045	1.63	0.20
S6	999.81	0.8912	0.2222	0.2494	1.99	0.20
S7	400.00	0.8001	0.0889	0.1111	0.89	0.22
Total	4499.04			1.1362	9.06	
Net corrected volume in the last tank (barrel) = 4489.98						
Total shrinkage loss (barrel) = 9.06						

NSV net standard volume (barrel), *SCF* shrinkage correction factor (vol%), *SG* specific gravity, *x* volume fraction

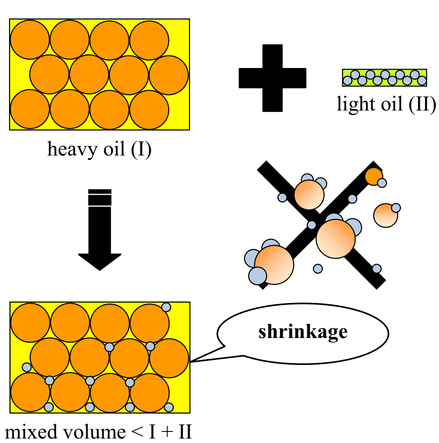

Fig. 8 Illustration of shrinkage volume from mixing of heavy and light oils

temperature lower than its bubble point can eliminate evaporative loss from storage tank (Bhatia and Dinwoodie 2004).

Shrinkage loss

Proportional shrinkage loss

Sharing oil losses resulted by the common proportional method are listed in Table 13. As can be seen from Table 13, the total shrinkage loss is 9.06 barrel and the shrinkage correction factors (SCFs) of all shippers are almost the same ± 0.20%. However, SCF of shipper S7 is the largest one (0.22%) since its oil is classified as condensate. Condensate is typically light oil or gas oil that has low density and small molecular size, while heavy oil has big molecular size. When condensate mixes heavy oil, hence geometrically there

Table 14 Stratified sharing losses results

Shipper			Stratified-1 (Mixing in TANK-1 of Station-1)				Stratified-2 (Mixing in TANK-2 of Station-2)				Stratified-3 (Mixing in TANK-3 of Station-3)				Total shrinkage loss	
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)	(%)
S1	499.72	0.8881	0.60	0.12	499.13	0.8938	0.67	0.13	498.45	0.8882	0.26	0.05	498.19	0.8810	1.53	0.31
S2	1199.73	0.8931	1.42	0.12	1198.31	0.8938	1.61	0.13	1196.69	0.8882	0.63	0.05	1196.07	0.8810	3.66	0.31
S3	399.98	0.9031	0.47	0.12	399.51	0.8938	0.54	0.13	398.98	0.8882	0.21	0.05	398.77	0.8810	1.22	0.30
Total	2099.43		2.48													
NCV TANK-1 (bbl)			2096.95													
Sub-total shrinkage loss (bbl)			2.48													
S4					199.94	0.9043	0.27	0.13	199.67	0.8882	0.10	0.05	199.57	0.8810	0.37	0.19
S5					799.85	0.8694	1.11	0.14	798.75	0.8882	0.42	0.05	798.33	0.8810	1.53	0.19
				Total	3096.74		4.20									
NCV TANK-2 (bbl)							3092.54									
Sub-total shrinkage loss (bbl)							4.20									
S6									999.81	0.8912	0.52	0.05	999.29	0.8810	0.52	0.05
S7									400.00	0.8001	0.23	0.06	399.77	0.8810	0.23	0.06
								Total	4492.36		2.38		4489.98		9.06	
NCV TANK-3 (bbl)											4489.98					
Sub-total shrinkage loss (bbl)											2.38					

NSV net standard volume (barrel), *SCF* shrinkage correction factor (vol%), *SG* specific gravity

Table 15 Comparison between proportional and stratified results

Shipper	Sending point		Mixing quantity	Shrinkage losses			
	NSV (barrel)	SG		Proportional		Stratified	
				(bbl)	SCF (%)	(bbl)	SCF (%)
S1	499.72	0.8881	3	1.00	0.20	1.53	0.31
S2	1199.73	0.8931	3	2.38	0.20	3.66	0.31
S3	399.98	0.9031	3	0.78	0.20	1.22	0.30
S4	199.94	0.9043	2	0.39	0.20	0.37	0.19
S5	799.85	0.8694	2	1.63	0.20	1.53	0.19
S6	999.81	0.8912	1	1.99	0.20	0.52	0.05
S7	400.00	0.8001	1	0.89	0.22	0.23	0.06
Total	4499.04			9.06		9.06	
Net corrected volume in last tank = 4489.98 barrel							

NSV net standard volume (barrel), *SCF* shrinkage correction factor (vol%), *SG* specific gravity

will be shrinkage as illustrated in Fig. 8; and this agrees with those in Erno et al. (1994), James (2014), and Shanshool et al. (2011).

Stratified shrinkage loss

Table 14 shows sharing oil losses resulted by the new proposed stratified method. In this method, shrinkage volume of each shipper is calculated for every mixing in the tank. As can be seen from Table 14, the sub-total oil losses in every tank are 2.48, 4.20, and 2.38 barrels, respectively. The total oil loss in the stratified method is the same as in the proportional method, i.e., 9.06 barrels. The SCF of each shipper in every tank is almost the same; they are 0.12%, 0.13%, and 0.05% in TANK-1, TANK-2, and TANK-3, respectively. The total SCFs of shippers S1, S2, and S3 are larger than those in shippers S4 and S5 (0.31% vs. 0.19%), and those in shippers S4 and S5 are larger than those in shippers S6 and S7 (0.19% vs. 0.05%). This is understandable that more often oil mixes with others; its volume will be more decreased.

Comparison of proportional and stratified results

Comparison between proportional and stratified results is listed in Table 15. The total NSV is 4499.04 barrels, and total shrinkage volume is 9.06 barrel. Therefore, the net corrected volume (NCV) in the last tank is 4490.94 barrel. The proportional method gives almost the same of SCF, ±0.20%, while SCF resulted by stratified method varies from 0.05 to 0.31% depending on its mixing quantity.

The common proportional method is considered unfair since shippers S6 and S7 bear those losses of the upstream shippers (S1–S5). More often oil mixes with others, for examples oils of shippers S1, S2, and S3 pass through three times of mixing phenomena, more volume shrinkage will be. Thus, the stratified method appropriates for determining of sharing oil losses in the multi-mixing phenomena.

Conclusion

Study on oil losses due to emulsion, flash (evaporation), and mixing phenomena in a Krisna field has been done. The oil loss is classified into two types, i.e., individual loss including emulsion and evaporative loss, and group loss which occurs in mixing phenomena. The individual loss must be determined to get the net standard volume (NSV). The NSV excluding sediment, water (and free water), and gas is then used for calculating group loss.

The emulsion correction factor (ECF) has been calculated for each shipper based on its BS&W. Since oil of shipper S7 is a condensate, it does not produce emulsion. According to our analysis, shipper S1 is the most sensitive to a change in BS&W; its ECF increases significantly by increasing its BS&W. While shipper S3 is not sensitive to a change in BS&W; its ECF raises slowly by increasing its BS&W.

Based on flash calculation results, all oils which are stored in tanks are the stable liquids. Since the oils' temperatures in tanks are lower than its bubble points at the normal condition (atmospheric), it is clear that all shippers have no evaporative loss. Flash correction factor (FCF) of all shippers equal to zero. Evaporative loss could be prevented by maintaining oil temperature lower than its bubble point.

In this work, the common proportional and new proposed stratified methods have been used to determine the sharing oil losses for 7 shippers in Krisna field. According to our analysis, the common proportional method gave almost the same of shrinkage correction factor (SCF) for all shippers. However, shippers that more often mix with others, e.g., shippers S1, S2, and S3 have three times of mixing phenomena; their shrinkage volume was larger than others. For that reason, the new proposed stratified method is strongly recommended to determine sharing oil losses since it gives a fair result.

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