

*Full Length Research Paper*

# **Effect of extended heavier hydrocarbon fraction ( $C_{n+}$ ) composition on optimum surface separation pressure and temperature**

**Juvêncio Armando Massinguil<sup>1\*</sup>, Luís Helder Lucas<sup>1</sup> and Pål Skalle<sup>2</sup>**

<sup>1</sup>Post Graduation Department, Faculty of Engineering, Universidade Eduardo Mondlane, Mozambique.

<sup>2</sup>Department of Geoscience and Petroleum, Norwegian University of Science and Technology, Norway.

Received 1 August, 2018; Accepted 12 November, 2018

Hydrocarbon fluids are made up of defined components which include  $N_2$ ,  $CO_2$ ,  $H_2S$ ,  $C_1$ ,  $C_2$ ,  $C_3$ ,  $iC_4$ ,  $iC_5$ , and  $C_6$  and undefined components known as heavier fractions ( $C_{n+}$ ) which include paraffinic, naftenic and aromatic compounds. The hydrocarbons are separated on the surface before they are sent to the market. There are several factors affecting the hydrocarbons surface separation condition which include; pressure, temperature, gas liquid flow rates, surging or slugging tendencies of the feed stream, presence of impurities such as paraffin and sands. This work is limited to the study of the effects of pressure and temperature. To obtain stabilized hydrocarbons phases optimum surface separation, pressure and temperature must be selected. Several empirical models have been developed to obtain optimum surface separation pressure and temperature. However, these models do not consider the full composition of the well stream, and the heavier fractions are most often treated as a single component. This paper presents the estimation of an optimum surface separation-pressure and temperature of crude oil while including the complete composition of the well stream and extended composition of the heavier fraction. The optimum pressure was estimated through the fluid properties such as oil formation volume factor, gas oil ratio and API gravity. Optimum pressure and temperature is the one that produces maximum liquid yield (by minimizing oil formation volume factor and gas oil ratio) of maximum quality (by maximizing API gravity). The fluid properties were predicted by phase equilibrium calculations using Peng Robinson thermodynamic Model. The optimum pressure was first estimated considering the heavier fraction as single component and second the heavier fraction was splitted in pseudo components, both including the full composition of the well stream. Ahmed splitting method was used to extend the heavier fraction composition, Kesler and Lee's correlation was applied to assign critical properties of the pseudo components. The results indicate that it is possible to estimate more accurately the optimum separation pressure by extending a composition of heavier fraction and accurate values of fluid properties were obtained.

**Key words:**  $C_{7+}$  fraction, splitting scheme, equation of state, Peng-Robison thermodynamic model, optimum separator pressure.

## **INTRODUCTION**

Hydrocarbon surface separation is an important operation in maximizing the oil and gas surface recovering.

\*Corresponding author. E-mail: [juvencio.massinguil@gmail.com](mailto:juvencio.massinguil@gmail.com). Tel: +258 845517595.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

Studying factors that affect the surface separation of hydrocarbon fluids is an important contribution in petroleum industry. To obtain stabilized hydrocarbon phases, optimum surface separation pressure and temperature must be selected. Several empirical models have been developed to obtain optimum surface separation pressure and temperature. Al-Jawad and Hassan (2010a,b) developed a group of correlations for optimum separator pressure for volatile oils using the results of theoretical correlations.

According to Ling et al. (2013), these correlations were based on data from over 6000 test runs with various independent variables. They also stated that the correlations were empirical and did not consider the full composition of the well stream but heavier fraction was included. Whinery and Campbell (1958) developed a correlation for determining the optimum second-stage separator pressure in a three-stage separation system. Al-Jawad (2010a), stated that their new method was simple and it eliminated the need for the flash vaporization calculations.

On the other hand, Ling et al. (2013) pointed out that the disadvantage of this new correlation was that the accuracy and reliability of the calculations could not be guaranteed because the temperature of the separator, the stock tank, compositions of butane and heavier components were not included. In addition, Bahadori et al. (2008) presented a methodology for optimizing separator pressures in crude oil production units. Despite that in this method, the heavier fraction composition was extended, Ling et al. (2013) also pointed out that the drawback of this method is that it requires tremendous number of trial separator and still may not be able to obtain precise optimum pressures.

According to the above-mentioned literature, neither the effect of heavier fractions nor the full composition of the well stream have been taken into consideration and the heavier fractions most often are treated as a single component. That is the reason why the present study includes these parameters by splitting the heavier fraction in pseudo components using Ahmed's splitting scheme. This study only compares to Al jawad and Hassan (2010)'s correlations, since it is the one that includes the heavier fraction composition; consequently other studies are discarded from the comparison.

### Al-Jawad and Hassan correlation

AL-Jawad and Hassan (2010) developed a correlation for estimating optimum separation pressure for heavy oils separation, one for high pressure separator in case for two stage and two for the first and second separators for three-stage separation system. In these correlations the optimum pressures have been correlated with mole percent of methane and hexane plus in the well stream, temperature of the separator and the optimum pressure of the previous separator. These equations represent

unique correlations because they are using methane and hexanes plus mole percents. The correlation of the optimum first stage pressure is formulated in Equation 1 and second stage in Equation 2.

$$(P_1)_{opt} = A(C_1\%)^{a_1} (C_6^+\%)^{a_2} T_1^{a_3} T_2^{a_4} T_3^{a_5} + a_6 \cos\left(a_7 \left(\frac{C_6^+\%}{C_1\%}\right)\right) + a_8 \quad (1)$$

$$(P_2)_{opt} = a(C_1\%)^{a_1} (C_6^+\%)^{a_2} T_1^{a_3} T_2^{a_4} T_3^{a_5} (P_1)_{opt}^{a_6} + a_7 (C_6^+\%) \cos(a_8 (C_6^+\%)) + a_9 \quad (2)$$

The correlation coefficient A of these equations equal to 0.96. Table 1 presents the values of the constants 'a' of the correlations for this system.

### The heavier fraction (C<sub>n+</sub>)

Barrufet (1998c) defined oil mixture as composed of defined and undefined components known as heavier fraction or C<sub>n+</sub> fraction. Pedersen and Christensen (2015) stated that defined components of oil mixture are N<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>S, C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, iC<sub>4</sub>, iC<sub>5</sub>, and C<sub>6</sub> while Ahmed (2007) referred that undefined components will typically contain Paraffinic, Naphthenic, and Aromatic compounds. Barrufet (1998b) also mentioned that the defined components can be quantitatively identified using chromatographic analysis, while Ahmed referred that due to the limitation of laboratory separation techniques in analyzing and characterizing the undefined components of hydrocarbon fluids these components are traditionally lumped together and categorized as the plus fraction (C<sub>n+</sub>).

Pedersen and Christensen (2015) also revealed that to perform a phase equilibrium analyses on hydrocarbon systems the physical properties for cubic equation of state (EOS) are critical pressure (P<sub>c</sub>), critical temperature (T<sub>c</sub>) and acentric factors (ω) of each component contained in the mixture. These properties have been measured and compiled for defined components.

Whitson (1982) and Sancet (2007) referred that undefined components are difficult components to be properly characterized in terms of their critical properties and acentric factors. Therefore, in this paper the phase equilibrium calculations are performed with splitted heavier fraction and assigned critical properties and acentric factor in each pseudo component.

### Splitting schemes

Ahmed (2007) defined splitting schemes as the procedures of dividing the heavier fraction into hydrocarbons groups with single carbon number (C<sub>7</sub>, C<sub>8</sub>, C<sub>9</sub>, etc) described by the same physical properties used for pure components. Imo-Jack et al. (2012) stated that heavier fraction in reservoir fluids contains different components which are impossible to identify by chemical separation techniques.

**Table 1.** Table of the coefficient of the Equation 9.

No. of carbon atoms	Condensate systems	Crude oil systems
n≤8	15.5	16.5
n>8	17	20.1

Source: Ahmed (2007).

Even if it was possible to identify them, it would not be possible to measure the critical properties and other EOS parameters for fluids heavier than C<sub>20+</sub>. Stamaki (2001) mentioned that this problem is solved practically by making approximate characterization of the heavier compounds with experimental and mathematical methods.

According to Ahmed (2007), several authors have proposed different splitting methods for extending the molar distribution behavior of C<sub>7+</sub>. Imo-Jack et al. also referred that these models are based on the assumption that there is a continuous relationship between composition and molecular weight of the pseudo components. Ahmed (2007a) and Riazi (1997) described the three main steps required for characterization of heavy end fractions:

- (i). Splitting the heavier fraction into single carbon number, with known (molar and mass) amounts and molecular weights,
- (ii). Assigning boiling point, molecular weight and specific gravity to each fraction,
- (iii). Estimating critical properties of each fraction.

Ahmed described three important requirements to be satisfied when applying any of the proposed splitting models which are presented in Equations 3 to 5. The sum of the mole fraction of the individual pseudo components is equal to the mole fraction of C<sub>7+</sub>, as expressed in Equation 3.

$$\sum_{n=7}^{n+} Z_n = Z_{7+} \quad (3)$$

The sum of the products of the mole fractions and the molecular weight of the individual pseudo components is equal to the product of the mole fraction and molecular weight of C<sub>7+</sub> as expressed in Equation 4.

$$\sum_{n=7}^n [Z_n M_n] = Z_{7+} M_{7+} \quad (4)$$

The sum of the product of the mole fraction and molecular weight divided by the specific gravity of each individual component is equal to that of C<sub>7+</sub> as expressed in Equation 5.

$$\sum_{n=7}^{n+} \frac{Z M_n}{\gamma} = \frac{Z_{7+} M_{7+}}{\gamma_{7+}} \quad (5)$$

Equations 4 and 5 can be solved for the molecular weight and specific gravity of the last fraction after splitting as:

$$\gamma_{n+} = \frac{Z_{n+} M_{n+}}{Z_{7+} M_{7+} - \sum_{n=7}^{(n+)-1} \frac{Z_n M_n}{\gamma_n}} \quad (6)$$

$$M_{n+} = \frac{Z_{7+} M_{7+} - \sum_{n=7}^n [Z_n M_n]}{Z_{16+}} \quad (7)$$

Several splitting schemes have been proposed, these schemes are used to predict the compositional distribution of the heavy plus fraction.

#### Ahmed's splitting method

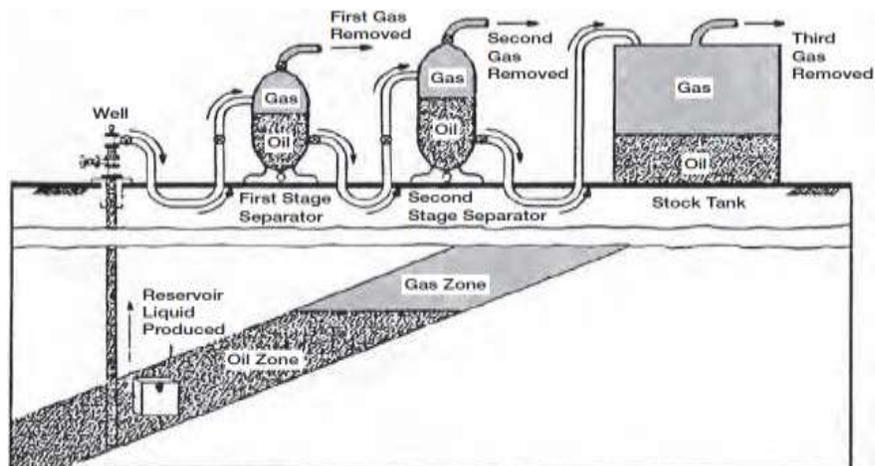
Ahmed devised a simplified method for splitting the C<sub>7+</sub> fraction into pseudo components. The method originated from studying the molar behavior of 34 condensate and crude oil systems through detailed laboratory compositional analysis of the heavy fractions. The splitting scheme is based on calculating the mole fraction, Z<sub>n</sub> at progressively higher number of carbon atoms. The extraction process continues until the sum of the mole fraction of the pseudo components are the same as the total mole fraction of the heptanes plus (Z<sub>7+</sub>).

$$Z_n = Z_{n+} \left[ \frac{M_{(n+)+} - M_{n+}}{M_{(n+)+} - M_n} \right] \quad (8)$$

Z<sub>n</sub> : mole fraction of the pseudo component with a number of carbon atoms of n (Z<sub>7</sub>, Z<sub>8</sub>, Z<sub>9</sub>),

M<sub>n</sub> = Molecular weight of the hydrocarbon group with n carbon atoms,

M<sub>(n+)+</sub> : molecular weight of the n+ fraction as calculated by the following expression:



**Figure 1.** Three stage separations.  
Source: Ahmed (2007).

$$M_{(n+1)+} = M_{n+} + S(n-6) \quad (9)$$

Where  $n$  is the number of carbon atoms and  $S$  is the coefficient of the equation with the values given in Table 1.

In this splitting method a set of physical properties proposed by Katz and Firoozabadi ( $M_n$ ), specific gravity and critical properties for the petroleum fraction  $C_6$  through  $C_{45}$  are used. After extending the composition of heavier fractions in pseudo components, critical properties and acentric factors must be assigned for the last fraction  $C_{n+}$ . In this paper Kesler and Lee's correlation was used to estimate these properties.

### Surface separation conditions

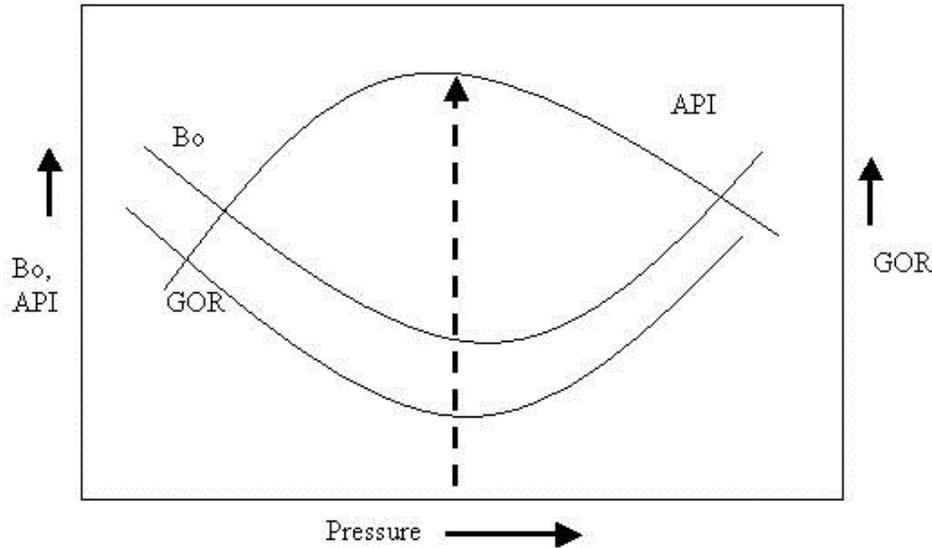
Separators are used to separate oil, water and to remove material such as entrained solid impurities from the crude oil production (Chilingar, 1969). Ling et al. (2013) explained that the separator working principle is based on the three hydrocarbon phases: vapor, liquid-oil and liquid-water with different densities, which allow them to separate when moving. Gas will be on top, water on the bottom, and oil in the middle. Each condition of pressure and temperature at which hydrocarbon phases are separated is called a stage of separation. There are different number of stage used in petroleum industry to separate oil and gas. Ling et al. (2013) also referred that the simplest system is two-stage separation consisting of one separator and one stock tank. It is most applicable for low-API-gravity oils, low gas/oil ratios (GORs), low

flowing pressures. The three-stage separation illustrated in Figure 1 is used for intermediate gravity oils, intermediate to high GOR, and intermediate well-head flowing pressures.

The four-stage separation is designed for high-API gravity oils, high GOR, and high flowing pressures. Four-stage separation is also applicable when high flowing pressure gas is needed for market or for pressure maintenance. There are several factors affecting the separation of hydrocarbon fluids, such as: temperature, pressure, gas liquid flow rates, surging or slugging tendencies of the feed streams, presence of impurities (paraffin, sand). This paper will focus on pressure and temperature effect. Furthermore, Ahmed also referred that if the separator pressure is high, large amounts of light components will remain in the liquid phase at the separator and will be lost along with other valuable components to the gas phase at the stock tank. However, on the other hand, if the pressure is too low, large amounts of light components will be separated from liquids and they will attract substantial quantities of intermediates and heavier components. Therefore optimum surface separation pressure is required. Adewumi (2017) stated that optimum separator pressure is the one that produces the maximum liquid yield (at minimum gas/oil ratio and formation volume factor) of maximum quality (by maximizing stock tank API gravity) as shown in Figure 2. Table 2 shows the typical initial values of gas oil ratio, formation volume factor and API gravity for different reservoirs fluids.

### Equation of state (EOS)

An equation of state (EOS) is used to predict the pressure, volume and temperature behavior of gas and



**Figure 2.** Optimum pressure.  
Source: Adewumi (2017).

**Table 2.** Casy study data, Pazann-Asmari Reservoir-India.

Component	Mol (%)
C <sub>1</sub>	52.510
C <sub>2</sub>	6.642
C <sub>3</sub>	4.237
iC <sub>4</sub>	0.855
nC <sub>4</sub>	2.213
iC <sub>5</sub>	1.124
nC <sub>5</sub>	1.271
nC <sub>6</sub>	2.289
CO <sub>2</sub>	0.084
H <sub>2</sub> S	1.587
C <sub>7+</sub>	27.55

The specific gravity of C<sub>7+</sub> is 0.86.

crude oil fluid. Ramdharee and Muzenda (2013) mentioned that there are many families of EOS, suitable for different purposes and substances. In petroleum engineering the most commonly used EOS are cubic polynomials.

Barrufet (1998a) stated that cubic EOSs are the simplest polynomials that can provide an adequate description of both: liquid and gas properties. They can describe the state of pure fluids and mixtures (single or multiphase) and their properties. Funjinaga and Raijo (1999) stated that cubic equations are explicit in pressure and can be written as the sum of 'b' term indicating repulsion forces and 'a' term indicating attraction forces. One of the most used EOS in petroleum engineering is

the Peng-Robinson EOS (1975). The Peng Robinson is three-parameter corresponding states model which is expressed as:

$$P = \frac{RT}{V-b} - \frac{a\alpha}{V(V+b)+b(V-b)} \quad (10)$$

Where 'a' is the attraction parameter and 'b' is the repulsion parameter defined by Equations 11 and 12 respectively:

$$a = \Omega_a \frac{R^2 T_c^2}{P_c} \quad (11)$$

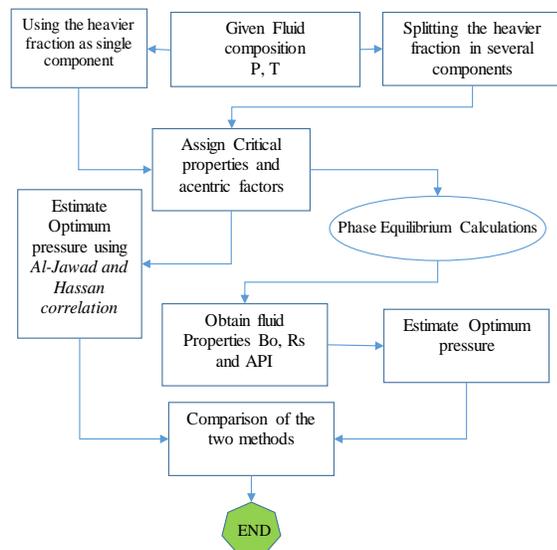


Figure 3. Summary methodology.

$$b = \Omega_b \frac{RT_c}{P_c} \quad (12)$$

$$\Omega_a = 0.45724, \Omega_b = 0.07780, \text{ and}$$

$$\alpha = \left(1 + m(1 - \sqrt{T_r})\right)^2 \quad (13)$$

with

$$m = 0.37464 + 1.5422\omega - 0.2699\omega^2 \quad (14)$$

Equation 10 can be expressed as a cubic polynomial in compressibility factor (Z) as:

$$Z^3 + (B-1)Z^2 + (A-3B^2-2B)Z - (AB-B^2-B^3) = 0 \quad (15)$$

When working with mixtures the same expressions in Equation 10 applies except that  $(a\alpha)$  and  $(b)$  are evaluated for a mixture using a set of mixing rules. The most commonly used mixing rules are: Quadratic mixing rule for 'a' :

$$(a\alpha) = \sum_{i=1}^{NC} \sum_{j=1}^{nc} x_i x_j (a_i a_j \alpha_i \alpha_j)^{0.5} (1 - k_{ij}) \quad (16)$$

Linear mixing rule for "b":

$$b_m = \sum_{i=1}^{NC} x_i b_i \quad (17)$$

The cubic expression for a mixture is then evaluated using Equation 18 for A term:

$$A = \frac{(a\alpha)_m P}{(RT)^2} \quad (18)$$

And Equation 19 for B term

$$B = \frac{b_m P}{RT} \quad (19)$$

Where 'm' refers to mixture

## MATERIALS AND METHODS

### PVT data

This study was conducted based on the data presented by Bahadori (2008). According to Bahadori, this data were collected from Pazann-Asmari, black oil Reservoir-India and is presented in Table 2. The reservoir pressure is 3700 (psig), bottom hole temperature is 208 F and molecular weight of  $C_{7+}$  = 236. The specific gravity of  $C_{7+}$  is 0.86.

In this study the optimum pressure was estimated based on the fluid properties such as oil formation volume factor, gas oil ratio and API gravity. These properties were estimated through phase equilibrium calculations using Peng-Robinson thermodynamic Model. The optimum pressure is the one that provides maximum API gravity, minimum oil formation volume factor and gas oil ratio. The optimum pressure was estimated considering the system as three stages, where the second stage was the optimization stage.

The heavier fraction was split into pseudocomponents using the Ahmed splitting method. To perform phase equilibrium calculations, critical properties and acentric factors must be assigned to the heavier fractions and pseudocomponents. Kesler and Lee's correlation was used to assign these properties. The summary of this methodology is presented in Figure 3. The phase equilibrium calculations were conducted through the VBA program, and the programming procedures are indicated in Figure 4.

## RESULTS AND DISCUSSION

The heavier fraction was extended into 2, 3 and 4 pseudocomponents, and the results of the new composition are presented in Tables 3 to 5. The maximum API gravity, minimum  $B_{osb}$  and  $R_{ssb}$  was found at  $T = 70^\circ\text{F}$ . Tables 3 to 5 present the results of extended heavier fraction, assigned critical properties, acentric factors in each new component. The last fraction is always a heavier fraction ( $C_{n+}$ ), which are  $C_{9+}$ ,  $C_{10+}$ ,  $C_{11+}$ . All the splitting constraints presented in Equation 5 to 7 were satisfied. From Table 6 it is observed that if the temperature increases, the fluid properties change, where API gravity decreases,  $B_{osb}$  and  $R_{ssb}$  increase. The optimum temperature used for pressure estimation for single and extended heavier fraction is  $70^\circ\text{F}$ . From Figures 5 to 7 it is observed that with extended heavier fraction, the API gravity changes. The API gravity values are high for single heavier

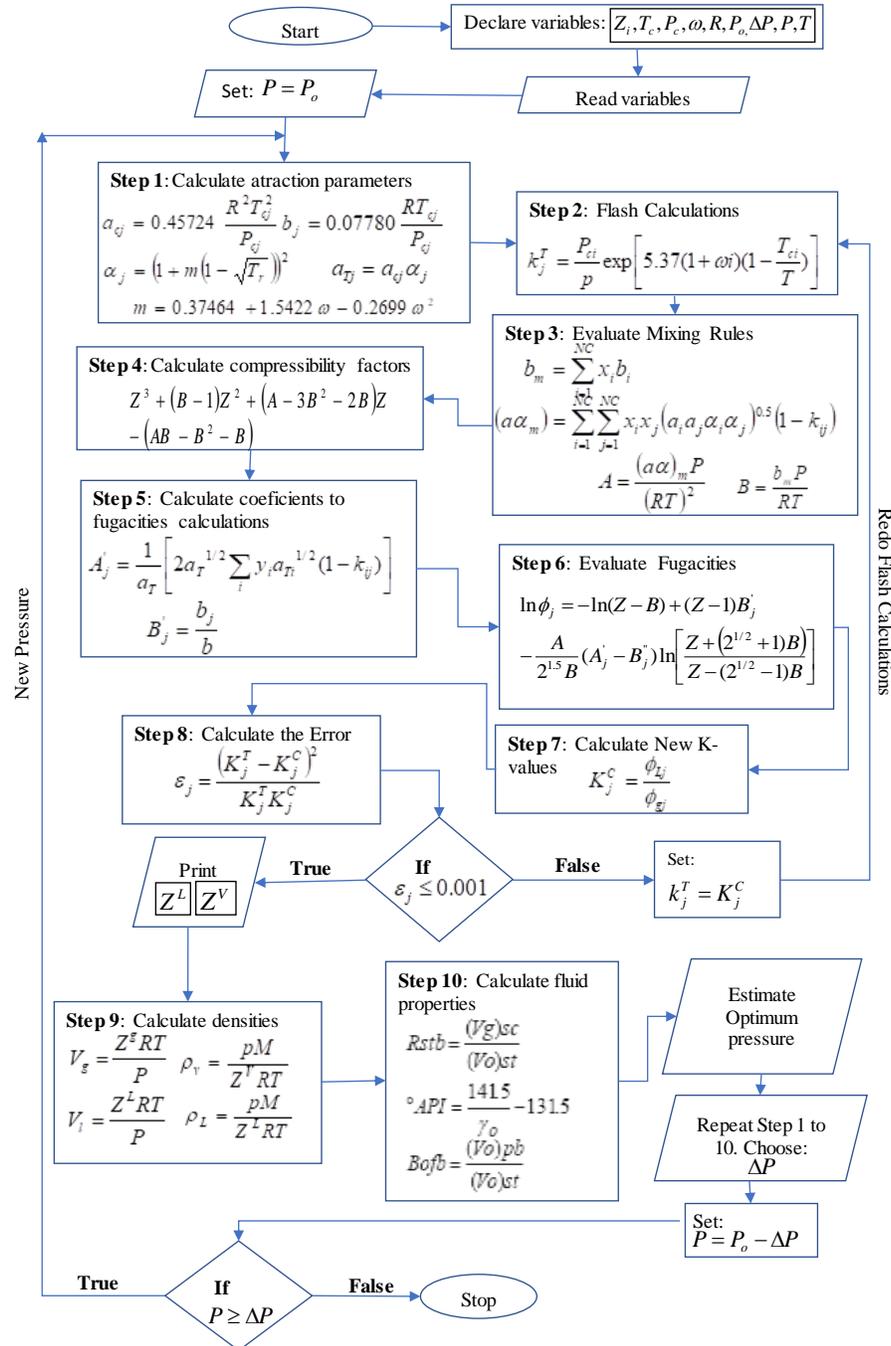


Figure 4. Optimum pressure estimation procedure.

fraction, when compared to API for extended C<sub>7+</sub> fraction, these results were compared to initial stock tank liquid gravity API, presented in Table 7, where for crude oil the values are less than 45.

In the Table 7 is observed that API gravity values obtained using heavier fraction as single component are high compared to API gravity values for extended fraction in both methods, and keep decreasing as the number of

pseudo components increases. The fluid properties predicted using the proposed methods are high when compared to properties obtained using empirical correlation. The optimum pressure predicted by the proposed method is greater compared to pressures obtained using empirical model. This shows the impact of using the full composition of the well stream and extended heavier fraction.

**Table 3.** Results of the extended C<sub>7+</sub> fraction in 2 pseudo-components.

n	$\gamma_n$	M	Mn+	Zn	ZnMn	ZnMn/ $\gamma_n$	Tc-R	Pc(psia)	$\omega_n$	Tb <sub>9+</sub> (°R)	k	$\theta$
7	0.727	96	236	0.029046	2.78845	3.22513	985	453	0.280	1304.56	12.6378	0.8424
8	0.749	107	252.5	0.025102	2.68589	3.10651	1036	419	0.312			
C <sub>9+</sub>	0.865	269	269	0.221352	59.54366	68.8685	1548.62	121.239	2.483			
			Total	0.2755	65.01800	75.2001						

**Table 4.** Results of extended C<sub>7+</sub> fraction in 3 pseudo components.

n	$\gamma_n$	M	Mn+	Zn	ZnMn	ZnMn/ $\gamma_n$	Tc-R	Pc(psia)	$\omega_n$	Tb <sub>10+</sub> (°R)	K	$\theta$
7	0.727	96	236	0.0290	2.788	3.22	985	453	0.280	1327.14	12.5899	0.8456
8	0.749	107	252.5	0.0251	2.68	3.1	1036	419	0.312			
9	0.768	121	269	0.0344	4.17	5.43	1085	383	0.348			
C <sub>10+</sub>	0.87287	296.3	296.3	0.1868	55.37	63.43	1569.53	118.349	2.481			
			Total	0.2755	65.018	75.20						

**Table 5.** Results of extended C<sub>7+</sub> fraction in 4 pseudo components.

n	$\gamma_n$	M	Mn+	Zn	ZnMn	ZnMn/ $\gamma_n$	Tc-R	Pc(psia)	$\omega_n$	Tb <sub>11+</sub> (°R)	k	$\theta$
7	0.727	96	236	0.0290	2.788	3.225	985	453	0.280	1353.66	12.5546	0.8497
8	0.749	107	252.5	0.0251	2.685	3.106	1036	419	0.312			
9	0.768	121	269	0.0389	4.718	6.143	1085	383	0.348			
10	0.782	134	296.3	0.0260	3.492	4.465	1128	351	0.385			
C <sub>11+</sub>	0.881	328.437	316.4	0.1562	51.332	58.258	1593.03	114.321	2.476			
			Total	0.2755	65.018	75.20						

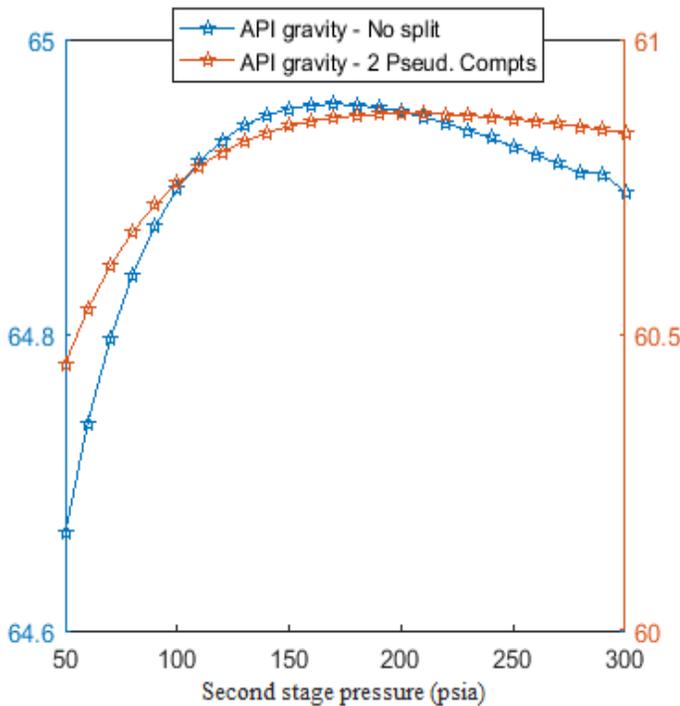
Table 7 indicates that when the number of pseudo components increases API gravity decrease with tendency to theoretical API as presented in Table 7. This is also observed in oil formation volume

factor where Figures 8 to 10 shows that increasing the number of pseudo components the oil formation volume factor increase, with tendency of predicting volatile oil when compared

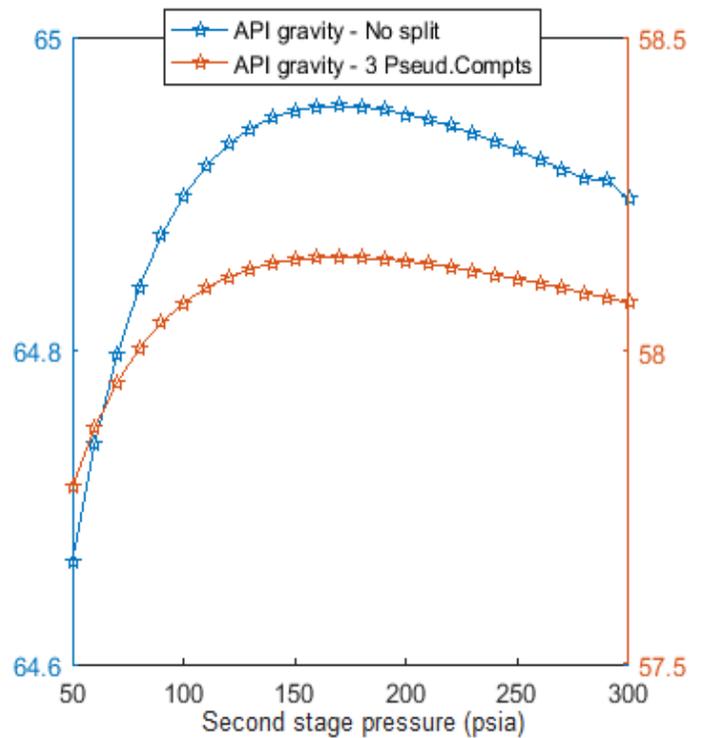
to theoretical expected properties as presented in Table 8, with values more than 2 bb\STB. This observation is also valid to gas oil ratio where Figures 11 to 13 show an increase when the

**Table 6.** Comparison of fluid properties obtained with both methods with an increment in the second stage temperature.

Second separator stage temperature (°F)	Proposed method			Al Jawad and Hassan method		
	API	Bosb(bb)\STB)	Rssb(sfc\STB)	API	Bosb(bb)\STB)	Rssb(sfc\STB)
70	64.95	1.461	892.90	64.485	1.060	35.17
85	64.91	1.463	897.23	64.456	1.061	37.30
100	64.86	1.466	901.49	64.423	1.063	39.67
115	64.82	1.469	905.84	64.386	1.065	42.22
130	64.78	1.472	910.00	64.337	1.067	45.21



**Figure 5.** Effect of splitted C7+ in API gravity for 2 pseudo components.



**Figure 6.** Effect of splitted C7+ in API gravity for 3 pseudo components.

heavier fraction is splitted into more components, and value are less than 1750 scf\STB for crude oil as presented in Table 8. So this indicates the effect of extending the heavier fractions to more components than using as single component.

The optimum second stage for single heavier fraction is presented in the Figures 14 to 20, where for maximum in API gravity, minimum in Bosb and Rssb, the optimum pressure is found at 174 psia. Similar optimum pressures estimation were made for extended heavier fraction in 2, 3 and 4 pseudo components and the results are presented in Table 7. In Table 7 is observed that the optimum pressure obtained using the heavier fraction as single component as greater compared to pressures obtained with extended fraction and keeps decreasing as fraction is continuously extended.

**Conclusion**

In this study, it is concluded that extended composition of C<sub>7+</sub> fraction affects the optimum surface separator pressure of the fluid stream. Both method showed that splitting the composition of the C<sub>7+</sub> fraction in pseudo components results in different estimated fluid properties when compared with properties estimated assuming the C<sub>7+</sub> as single component. An increment in the number of pseudo components the optimum second stage pressure changes because of changes in the fluid properties. Where accurate results are obtained when the heavier fraction is splitted in several pseudo components. Both methods showed that with an increment in second stage

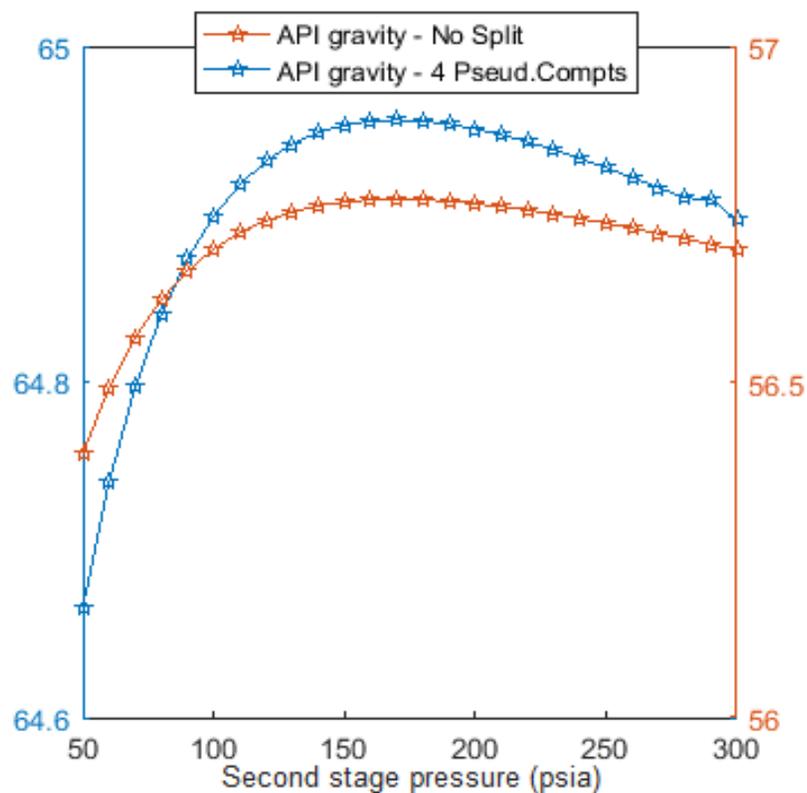


Figure 7. Effect of splitted C7+ in API gravity for 4 pseudo components.

Table 7. Comparison of the fluid properties and optimum second stage pressures obtained through the proposed method and Al jawad and Hassan method.

Splitted C <sub>7+</sub> fraction Composition	Proposed Method				Al-Jawad and Hassan Method			
	API	Bosb (bbl/STB)	Rssb (scf/STB)	Opt. Pressure (psia)	API	Bosb (bbl/STB)	Rssb (scf/ST)	Opt. Pressure (psia)
Single	64.95	1.461	892.90	174	64.48	1.060	35.17	121.08
2 Pseud.compts	60.92	1.472	918.93	170	60.32	1.061	36.20	119.62
3 Pseud.compts	58.14	1.475	924.39	166	57.46	1.061	37.03	119.09
4 Pseud.compts	56.77	1.474	922.81	159	54.81	1.062	37.80	118.89

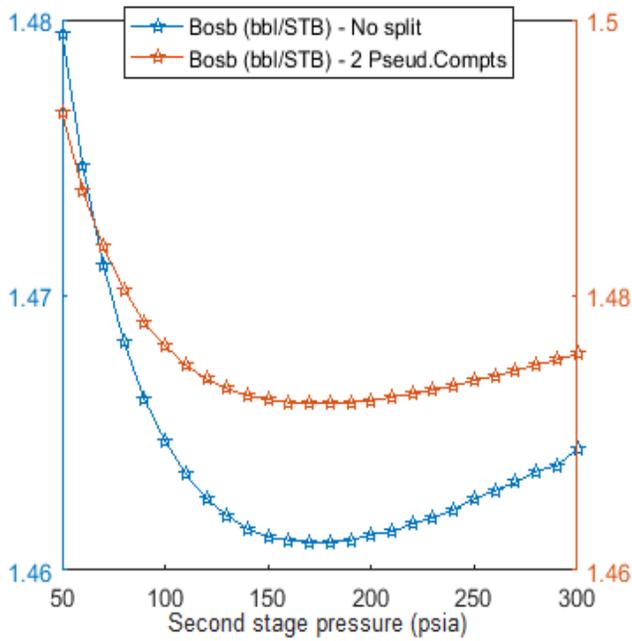


Figure 8. Effect of splitted C7+ in Bosb for 2 pseudo components.

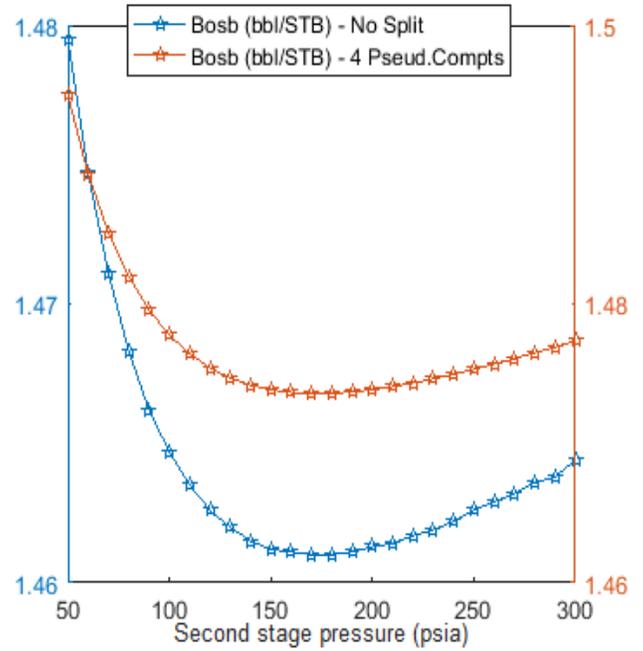


Figure 10. effect of splitted C7+ in Bosb for 4 pseudo components.

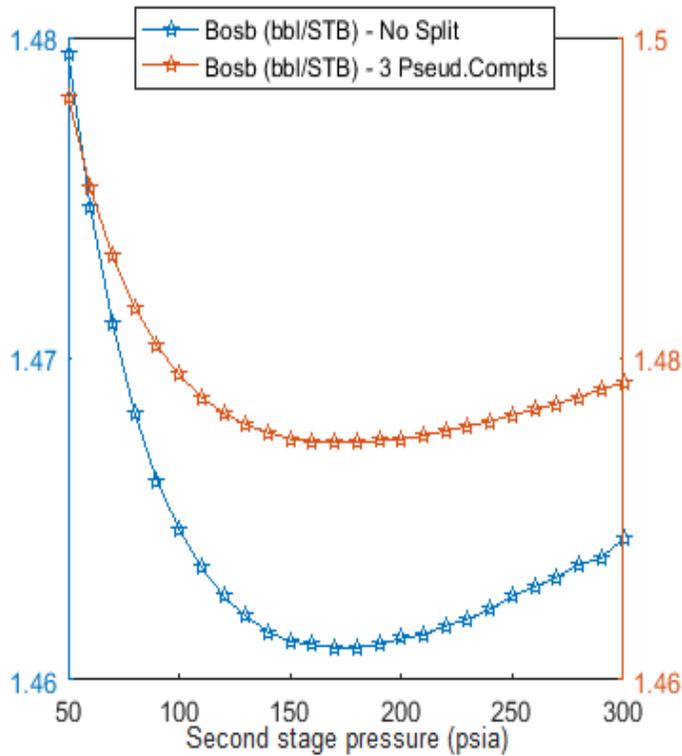


Figure 9. Effect of splitted C7+ in Bosb for 3 pseudo components.

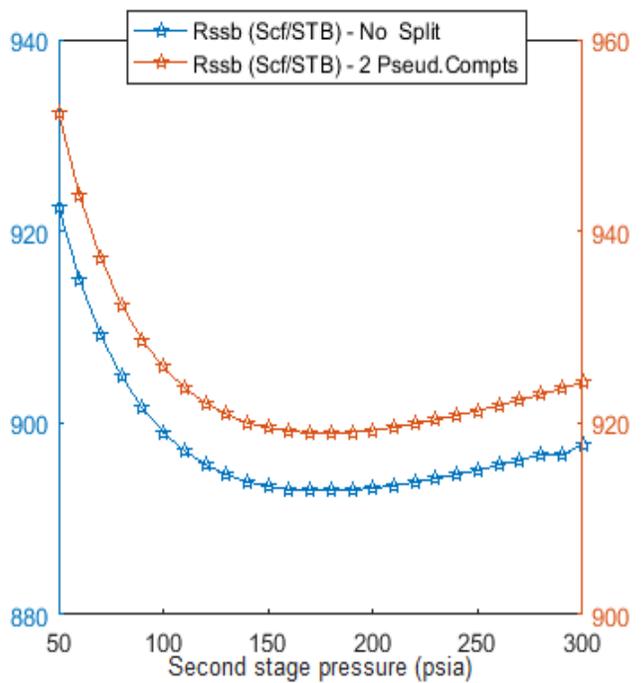


Figure 11. Effect of splitted C7+ in Rssb for 2 pseudo components.

temperature, the API gravity decrease, oil formation volume factor and solution gas oil ratio increase.

### RECOMMENDATIONS

Present study was limited to one type of reservoir fluid exposed to only a single separator test therefore more

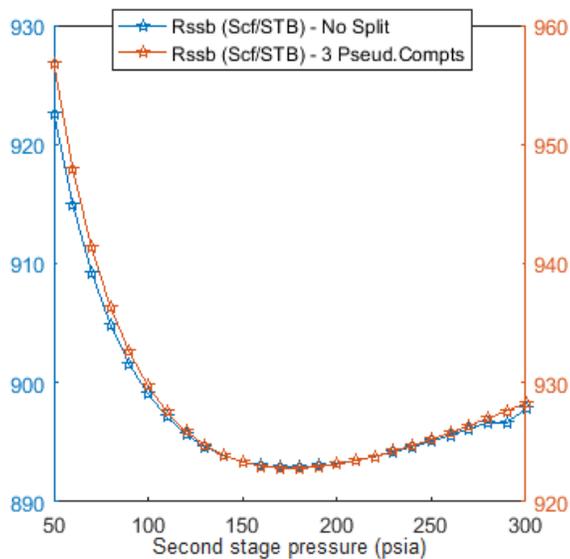


Figure 12. Effect of splitted C7+ in Rssb for 3 pseudo components.

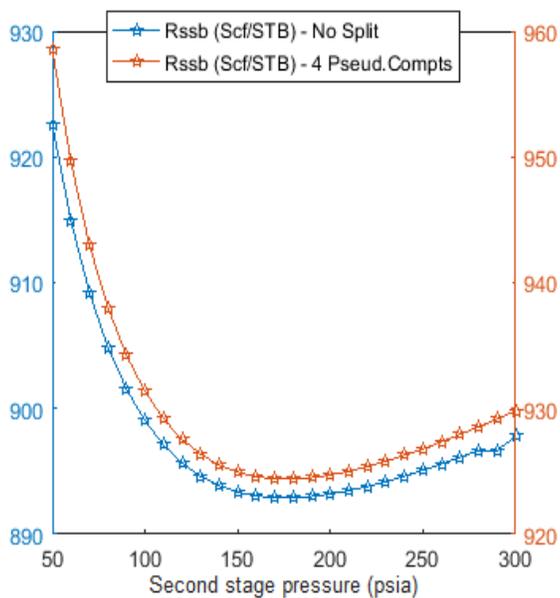


Figure 13. Effect of splitted C7+ in Rssb for 4 pseudo components.

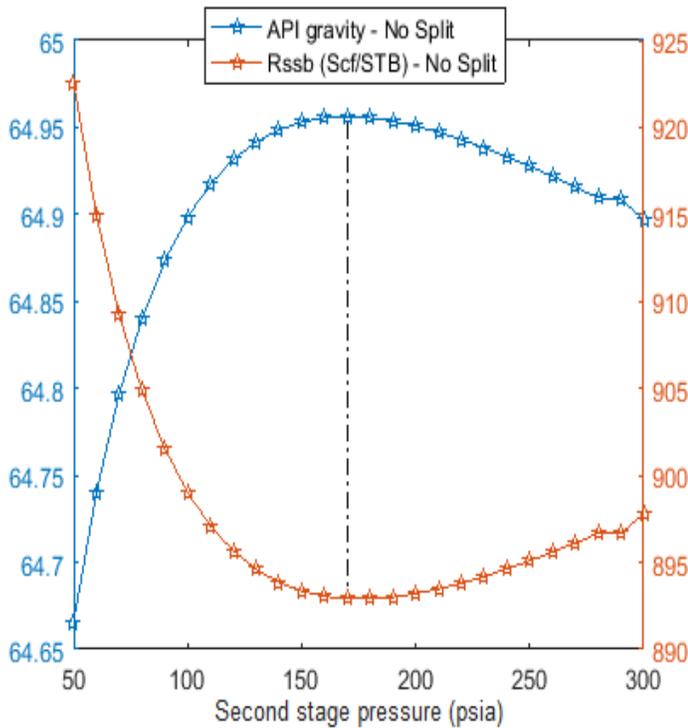
Table 8. Reservoir fluid properties.

	Black Oil	Volatile oil	Retrograde gas	Wet gas	Dry gas
Oil formation volume factor	< 2.0	>2.0	---	----	---
Initial producing gas liquid ratio (Sfc\STB)	<1.750	1750 to 3200	>3200	>1500*	100 000*
Initial stock- tank liquid gravity API	< 45	> 45	> 45	up to 70	No liquid

(McCain, 1994).\*For engineering purposes.

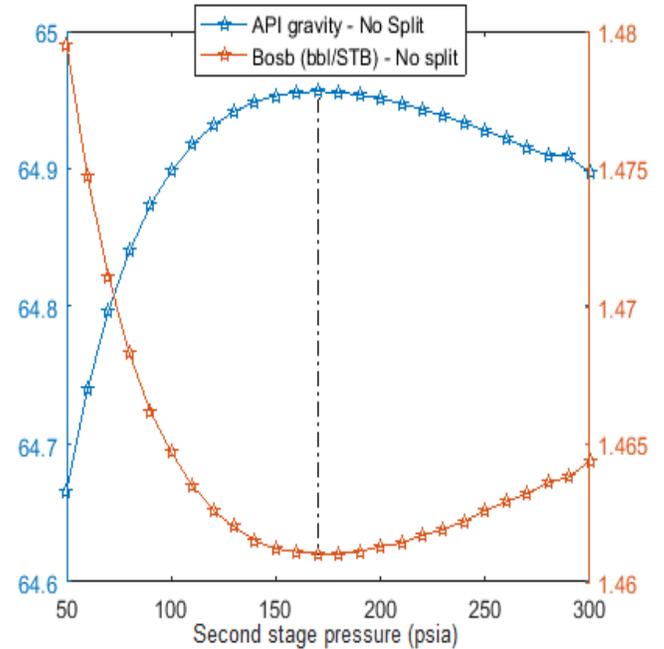
**Table 9.** Al-Jawad and Hassan correlation constants ‘a’ for equations 1 and 2.

Constant	First stage	Second Stage
a	30.82	0.23
$a_1$	0.35	-2.00
$a_2$	0.24	-0.003
$a_3$	0.91	-4.024
$a_4$	-0.21	3.27
$a_5$	-0.59	-0.44
$a_6$	-6.85	3.10
$a_7$	1.72	-0.20
$a_8$	-267.11	0.05
$a_9$	-----	20.64

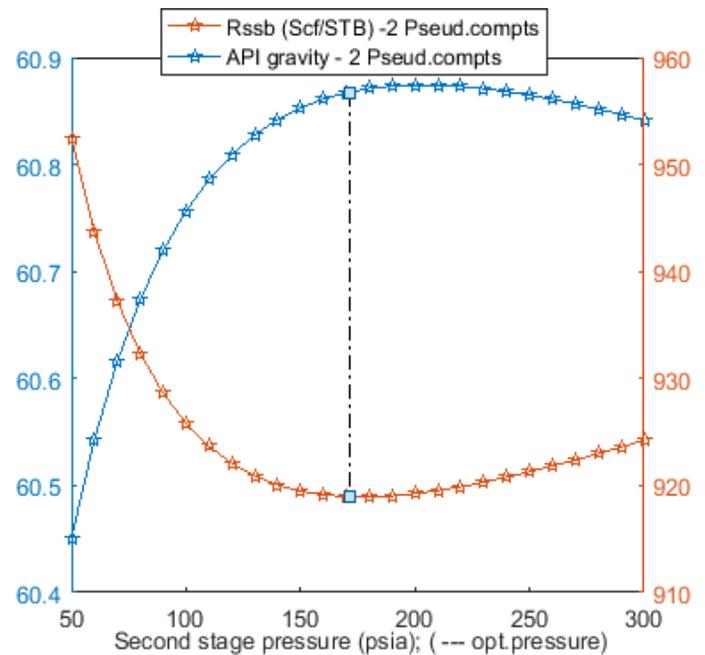


**Figure 14.** Optimum second stage pressure estimation from Rssb and API for C7+ as single component.

studies should be based in different reservoir fluids. More studies should be based on different splitting schemes techniques which can split the heavier fraction in different positions and allow more variation. In this study Ahmed’s

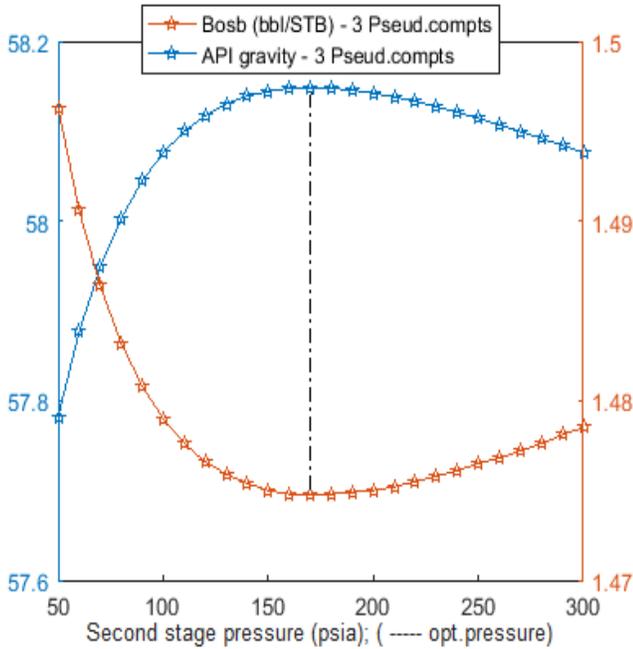


**Figure 15.** Optimum second stage pressure estimation from Bosb and API for C7+ as single component.

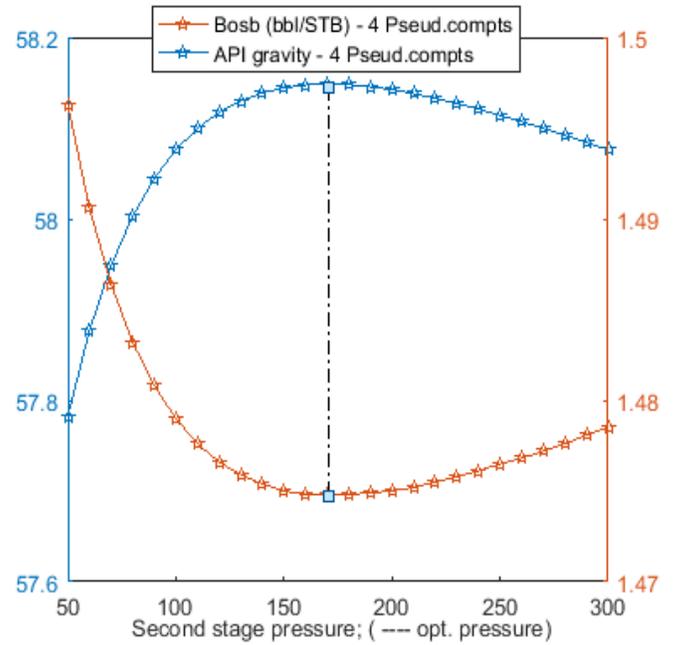


**Figure 16.** Optimum second stage pressure estimation from Rssb and API for C7+ splitted in 2 pseudo components.

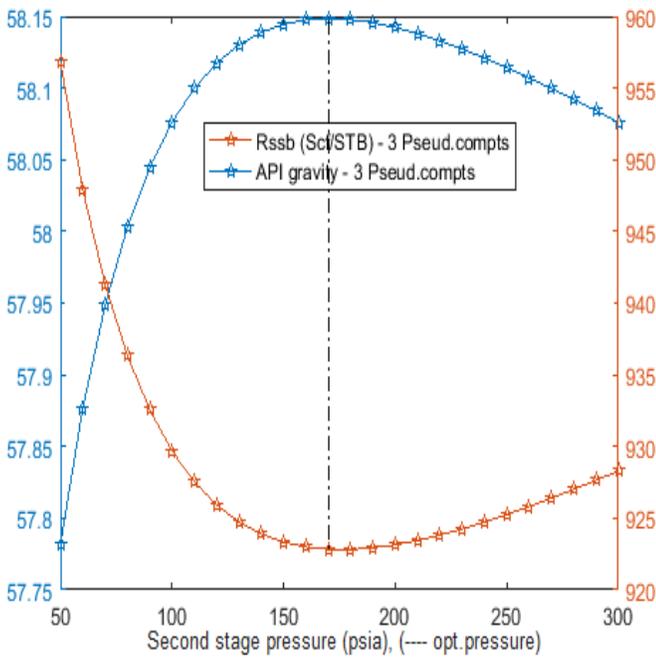
splitting scheme was the only method applied to extend the composition of the heavier fraction. We suggest performing more studies where fluid properties are obtained through laboratory PVT tests. In present



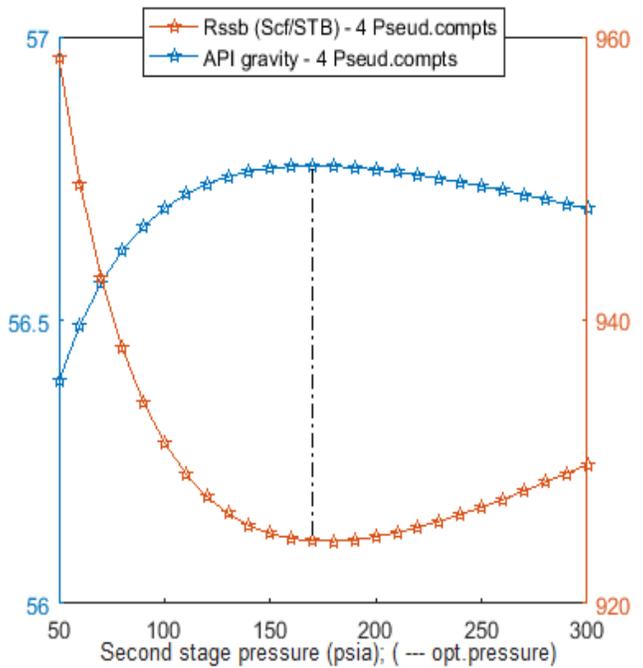
**Figure 17.** Optimum second stage pressure estimation from Bosb and API for C7+ splitted in 3 pseudo components.



**Figure 19.** Optimum second stage pressure estimation from Bosb and API for C7+ splitted in 4 pseudo components.



**Figure 18.** Optimum second stage pressure estimation from Rssb and API for C7+ splitted in 3 pseudo components.



**Figure 20.** Optimum second stage pressure estimation from Rssb and API for C7+ splitted in 4 pseudo components.

research, these properties were obtained from standard PVT experiments which are conducted through phase equilibrium simulations. It is recommended that

simulation be performed by means of commercial simulator, which are also applied and recommended by the Petroleum Industry. It is recommended to split the

heavier fraction composition in more pseudo components. In this study the heavier fractions were extended into 4 pseudo components, due to the limitation of data. Other researchers should perform phase equilibrium calculations by estimating fluid properties through different tuned equations of state. In this study, the fluid properties were estimated through the Peng Robinson EOS.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The author is grateful to professors Luis Helder Lucas and Pal Skalle for their contribution in this topic.

## Nomenclature

$z^v$ , Vapor compressibility;  $z^l$ , Liquid compressibility;  $T_b$ , True boiling point;  $T_c$ , Critical Temperature;  $P_c$ , Critical Pressure;  $(P_1)_{opt}$ , Optimum first stage separator pressure;  $(P_2)_{opt}$ , Optimum second stage separator pressure; **GOR**, Gas Oil Ratio; **API**, American Petroleum Institute; **PVT**, Pressure Volume and Temperature; **VLE**, Vapor Liquid Equilibrium; **STB**, Stock tank barrel; **EOS**, Equation of state; **VBA**, Visual Basic for Applications;  $\gamma$ , Specific gravity;  $\omega$ , Acentric factor.

## REFERENCES

- Al-Jawad MS, Hassan OF (2010a). Correlating Optimum Stage Pressure for sequential separator systems. SPE Projects, Facilities and Construction 5(01):13-16. <http://dx.doi.org/10.2118/118225-PA>
- Al-Jawad, M.S. and Hassan, O.F. (2010b). Optimum separation pressure for heavy oil sequential separation. Society of Petroleum Engineers, Abu Dhabi International Petroleum Exhibition and Conference, 1-4 November, Abu Dhabi, UAE <http://dx.doi.org/10.2118/137995-MS>.
- Adewumi M (2017). Phase Behavior of natural gas and Condensates fluids. The Pennsylvania State University of Minerals and Sciences. Retrieved March 30-2017 from [https://www.e-education.psu.edu/png520/m20\\_p3.html](https://www.e-education.psu.edu/png520/m20_p3.html).
- Ampuero JF, Castro AJ (2017). Design of Oil-Gas Separators- From Hydrocarbon Stream, National University of Engineering.
- Ahmed T (2007). On Equation of State; Anadarko Petroleum Corporation. SPE-107331.
- Alireza B, Hari BV, Saeid M (2008). Multistage Crude Oil Production Unit. Asia-Pacific Journal Chemical Engineering 3(4). <http://dx.doi.org/10.1002/apj.159>.
- Barrufet MA (1998a). A Brief Introduction to Equations of State for Petroleum Engineering Applications; Petroleum Engineer International.
- Barrufet MA (1998b). Evaluation of Standard PVT Properties from Equations of State; Petroleum Engineer International.
- Barrufet MA (1998c). Importance of the  $C_{7+}$  fraction in Phase Behavior Calculations; Petroleum Engineer International.
- Chilingar GV, Beeson CM (1969). Surface Operations in Petroleum Production. American Elsevier Publishing Company.
- Fujinaga Y, Raijo T (1999). Application of EOS for Multi-component System Containing Heavier Hydrocarbons and Impure Components; The University of Tokyo. SPE-54350.
- Imo-Jack OO, Uche IN (2012). Splitting the Heptanes-Plus Fraction of Condensate and Volatile Systems: Application of the Gamma Distribution Model. Society of Petroleum Engineers. doi:10.2118/163017-MS. Nigeria Annual International Conference and Exhibition. Society of Petroleum Engineers, 2012.
- Ling K, Wu X, Guo B, He J (2013). New Method to Estimate Surface-Separator Optimum Operating Pressures. Oil and Gas Facilities 2(03):65-76.
- Ramdharee S, Muzenda E (2013). A review of the Equations of State and their Applicability in Phase Equilibrium Modeling; International Conference on Chemical and Environmental Engineering.
- Riazi MR (1997). A continuous Model for  $C_{7+}$  fraction characterization of Petroleum fluids; Kuwait University. Industrial and Engineering Chemistry Research 36(10):4299-4307.
- McCain WD (1994). Heavy Components Control Reservoir Fluid Behavior. Society of Petroleum Engineers. Journal of Petroleum Technology 46(09):746-750.
- Pedersen KS, Christensen PL (2015). Phase behavior of petroleum Reservoir fluids. CRC press.
- Sancet GF (2007). Heavy Fraction  $C_{7+}$  characterization for PR-EOS; Buenos Aires Institute of Technology. SPE-113026-STU. Society of Petroleum Engineers
- Stamaki SK (2001). Characterization of heavy undefined fractions; Magoulas, National Technical University of Athens, Greece. SPE-64996.
- Ahmed T (2007). Equations of State and PVT analysis; Gulf Publishing Company; Houston Texas.
- Whitson CH (1982). Effect of physical properties estimation on equation-of-state predictions; SPE-11200. No. CONF-820927-. Rogaland Regional College.
- Whinery KF, Campbell JM (1958). A method for determining Optimum Second-Stage Pressure in Three-Stage Separation. Journal of Petroleum Technology, 10(04):53-54. SPE-901-G. <http://dx.doi.org/10.2118/901-G>.