C7+ Reservoir Fluid Characterisation: Modification of Lohrenz Splitting Correlation

K B Orodu1  P A L Anawe1 F A Omojola1
1Department of Petroleum Engineering, Covenant University, Nigeria.

Abstract. Petroleum reservoir fluid is commonly classified as individual components of C1 – C6 and lumped-up component of C7+. C7+ are hydrocarbon components of C7-heptane and above, that is, heavy hydrocarbons that are minimal in natural gas. De-lumping or splitting of C7+ into individual components is vital for accurate and efficient estimation of fluid properties. A number of correlations exist in literature and pressure-volume-temperature software for this. The least accurate and simple model by Lohrenz, Bray & Clark (1984) was modified in this work. Efficiency of the new model is highly comparable with existing models in the rigorous PVT systems for computing intensive and extensive natural gas properties.

1. Introduction
Equation of State (EoS) are often used to predict the phase behaviour of the reservoir fluids among other applications such as determination of equilibrium ratios, vapour pressure, bubble point, dew point, and PVT properties. However, problems occur with the C7+ fractions that exist in the fluid mixture [1]. To understand the behaviour of the reservoir fluid mixture, a proper description of the individual hydrocarbon components is required. The components are usually described in relation to molecular weight, specific gravity, mole fraction, critical pressure, critical temperature, critical volume, and acentric factor. Gas and liquid chromatography can be employed to break down the properties of the initial and intermediate components (C1 to C6) but the C7+ fractions are usually undefined.

To minimize the problem that will occur with the C7+ fractions when using EOS requires two approaches which include characterizing the C7+ fractions using correlations or adjusting the EOS parameters to correlate with the existing field data for a particular region and particularizing it to the reservoir of interest. Both approaches are rigorous techniques but being able to characterize the C7+ fractions using correlations especially when little or no PVT data is available is essential to understanding the reservoir [1]. Characterizing the C7+ fractions using correlations therefore provides a well-defined outlook of the hydrocarbon composition in the reservoir through splitting the hydrocarbon constituents into pseudo components with single carbon numbers (C7, C8, C9, etc) and lumping techniques.

In splitting the composition of the reservoir to characterize the C7+ fractions using correlations, various splitting methods exists like Pedersen et al. [2], Whitson [3], Ahmed et al. [4], Katz [5], and Lohrenz et al. [6]. In the analysis of these splitting methods, it was discovered that Lohrenz et al. [6] method was not as accurate as the other methods and the method could not predict the mole fraction of the pseudo-components beyond C40. This work addresses the problems of Lohrenz et al. [6]splitting correlation. The importance of C7+ characterization to the industry cannot be overemphasized as it serves as the building
block to understanding the nature and behaviour of the reservoir fluids for deciding the appropriate drilling and production to efficiently produce the oil and gas. For proper execution of enhanced oil recovery (EOR) especially in Nigeria where EOR is gradually gaining prominence in reservoir management, the knowledge of C\textsubscript{7+} characterization is important to understand the fluids in place through PVT analysis of EOS models and effectively plan the recovery mechanisms that will be compatible to the reservoir fluids. This study can be seen as a pool of the most widely used reservoir characterization methods as well as a modification of a particular correlation. This therefore contributes to the knowledge/research base for petroleum engineering and it can also be applicable for fluid characterization purposes.

2. Methodology

2.1. Data collection

The Data used in this work were experimental data from papers, journals, textbooks, reports from the library and internet. A total of 26 data set containing carbon number (n), mole fraction (Z\textsubscript{n}), mole fraction of C\textsubscript{6} and mole fraction of C\textsubscript{7+}. Since Lohrenz et al. [6] correlation requires only mole fraction of C\textsubscript{6} (Z\textsubscript{6}) and carbon number (n) in the prediction of mole fraction of nth component (Z\textsubscript{n}), the data set which did not contain the Z\textsubscript{6} was discarded. Therefore, 10 datasets were used in the analysis and development of the new correlation for Lohrenz et al. [6] method. The data obtained focused on mole fraction of C\textsubscript{7+} fractions of about 10 natural gas samples from different wells (Table A1 – A2). The data gathered are obtained from different parts of the world with no particular preference. This is due to the fact that the developed correlation was not intended to be location specific and will be applicable to oil and gas wells in several locations of the world. However, some of the data samples were from Niger Delta region of Nigeria. Data 10 (Table A2) is used in this work to evaluate the existing correlations for splitting C\textsubscript{7+} fractions and compare them together. Datasets (1-10, i.e. Table A1-A2) was used all together to develop the new correlation. Developing the new correlation required numerous datasets for accurate development. Using the splitting methods, the mole fraction of single carbon numbers in the C\textsubscript{7+} fraction of the naturally occurring reservoir system was calculated.

2.2. Evaluation of existing correlation

This involved the analysis of the existing correlations for splitting C\textsubscript{7+} fractions and comparison of these methods. The correlations that were evaluated are Lohrenz et al. (6], Pedersen et al. [2], Whitson [3], Ahmed et al. [4], and Katz [5]. To evaluate these correlations data 10 was chosen and the mole fraction of each carbon atom present in the reservoir fluid is calculated from the molecular weight and mole fraction of the C\textsubscript{7+} fraction of the reservoir fluid.

2.2.1 Consistency test. After all the existing correlations had been used to determine the mole fraction of each carbon number of the plus fraction in Microsoft excel, the total of the mole fractions calculated was expected be equal to the mole fraction of C\textsubscript{7+} fractions which have been predetermined by experimental approach such as chromatography for each dataset as seen in Equation (1).

\[
\sum_{n=7}^{N} Z_n = Z_{C_{7+}}
\]  

(1)

where, \( \sum_{n=7}^{N} Z_n \) is the summation of mole fraction of all carbon numbers; \( Z_{C_{7+}} \) is mole fraction of the C\textsubscript{7+} in the reservoir fluid predetermined by experimental analysis.

It was observed that Lohrenz et al. was the least accurate method for determining mole fraction by splitting of C\textsubscript{7+} fraction of reservoir fluids because the sum of mole fraction of all carbon numbers was not equal to the mole fraction of the C\textsubscript{7+}. 

2
Therefore, it required modification.

2.2.2 The evaluation process. The evaluation process involved the following steps:

1. Outlining of the molecular weight (MW) in Table A3, MW of C7+, SG of C7+ and mole fraction of C7+ (\(Z_{C7+}\)) for Data 10

2. Application of the information in step one to determine the mole fraction (\(Z_n\)) for the existing splitting methods using Microsoft excel.

3. Evaluating the existing splitting methods using the consistency test in Equation (1)

The evaluation is done for the following splitting methods.

- Lohrenz et al. [6]; \(Z_n = Z_6 e^{A(n-6)^2+B(n-6)}\) (3)
- Pedersen et al. [2]; \(Z_n = e^{A+B MW_n}\) (4)
- Whitson [3]; \(Z_n = \frac{Z_{C7+} \sum_{j=0}^{\infty} y_n e^{-y_{n+1} e^{-y_n}}}{\sum_{j=0}^{\infty} e^{(n+j) e^{-y_n}}}\) (5)
- Ahmed et al. [4]; \(Z_n = Z_{C7+} \left( \frac{MW_{n+1}+MW_{n+2}}{MW_{n+1}+MW_{n+2}} \right)\) (6)
- Katz [5]; \(Z_n = Z_{C7+} 1.38205 e^{-0.25903n}\) (7)

Step 1: The existing correlations were examined using data 10. This was used for comparison of the correlation.

Where MW and SG of C7+ for Data 10 were given as: Molecular Weight (MW) of C7+, \(MW_{C7+} = 141.25\); Specific gravity (SG) of C7+, \(SG_{C7+} = 0.797\); Mole fraction of C7+, \(Z_{C7+} = 0.0154\)

In Equation (5), the sum of mole fraction of all carbon numbers was not used in the comparison due to unavailability of some parameters required in the correlation.

Step 2: The comparison of the other methods was for Data 10 in a spreadsheet.

Step 3: The factor used as the basis of comparison was Equation (1)

From the data of the composition of a naturally occurring condensate gas system used, the \(Z_{C7+} = 0.0154\).

1. Lohrenz et al. correlation:
\[\sum_{n=7}^{N} Z_n \neq Z_{C7+}\] (8)
\[\sum_{n=7}^{N} Z_n = 0.012396035\] (9)
\[0.012396035 \neq 0.0154\] (10)

In Equation (10), the sum of mole fraction of all carbon numbers was not equal to the mole fraction of the C7+.

2. Pedersen et al. correlation
\[\sum_{n=7}^{N} Z_n \approx Z_{C7+}\] (11)
\[\sum_{n=7}^{N} Z_n = 0.015801125\] (12)
\[0.015801125 \approx 0.0154\] (13)

In Equation (14), the sum of mole fraction of all carbon numbers is approximately equal to the mole fraction of the C7+.

3. Katz correlation
\[\sum_{n=7}^{N} Z_n \approx Z_{C7+}\] (14)
\[
\sum_{n=7}^{N} Z_n = 0.01521401
\]
\[
0.01521401 \approx 0.0154
\]

In Equation (16), the sum of mole fraction of all carbon numbers is approximately equal to the mole fraction of the C\(_{7+}\).

4. Ahmed et al. correlation
\[
\sum_{n=7}^{N} Z_n = Z_{C_{7+}}
\]
\[
\sum_{n=7}^{N} Z_n = 0.015419437
\]
\[
0.015419437 = 0.0154
\]

In Equation (19), the sum of mole fraction of all carbon numbers is equal to the mole fraction of the C\(_{7+}\).

Thus from the evaluation, it was observed that Lohrenz et al. [6] was the least accurate method for determining mole fraction by splitting of C\(_{7+}\) fraction of reservoir fluids because the sum of mole fraction of all carbon numbers was not equal to the mole fraction of the C\(_{7+}\), as given by the consistency test in Equation (1), therefore the correlation required modification.

2.3. Development of the new correlation
From the preliminary evaluation process performed, the Lohrenz et al. [6] correlation does not really compare well with other methods. The choice of Lohrenz et al. [6] method is justified by the non-correspondence of the total mole fractions calculated from Microsoft Excel to the mole fraction of C\(_{7+}\) fractions based on the consistency test in Equation (1).

Development of the new Lohrenz et al. [6] correlation that provides a dependable approach to splitting of C\(_{7+}\) fractions, involved regression analysis of mole fraction and carbon numbers for datasets (Data 1-9) in Microsoft excel. Statistical parameter – R-squared was used to analyse the fitting of the data points on the line of best fit. This R\(^2\) value helps to prove the validity of the Equation of the line.

The process of development includes:
1. Regression of mole fraction (Z\(_n\)) versus Carbon number (n) for Data 1- Data 9
2. Obtaining the Equation of the line
3. Analysing the accuracy of the Equations using the R\(^2\) parameter.
   For R\(^2\) values > 90 indicates that most of the data points lie on the exponential curve of best fit, which validates the accuracy of the Equation of the line.
4. Evaluating of Variables, A and B in the new Lohrenz et al. [6] correlation.

2.4 Application of the new Lohrenz et al. [6] correlation
This involved the application of the newly developed Lohrenz et al. [6] correlation to predict the mole fractions of individual carbon atoms in the C\(_{7+}\) fractions of the reservoir fluids. A spreadsheet was used to do this. Dataset 4 and 6 were selected and the new correlation was used to determine the mole fraction of the C\(_{7+}\).

The steps involved in this analysis include:
1. Obtaining the mole fraction and carbon number from data 4 and data 6.
2. Using the new correlation to predict the mole fraction of each carbon number (C\(_7\), C\(_8\),…C\(_n\)).
3. The mole fraction deviation of the experimental data (Data 4 and Data 6) and the predicted mole fraction from the new Lohrenz et al. [6] correlation was calculated using Average Absolute Deviation (AAD).

Average absolute deviation: this is a technique used to evaluate the deviation of the calculated values to the experimental values for a given dataset, AAD is the average of the positive difference. It is given by this Equation:

\[
AAD = \frac{|experimental-calculated|}{experimental}
\]
4. The accuracy of the new correlation was analysed based on the AAD.

2.5. Comparison
The newly developed Lohrenz et al. correlation is compared with experimental data to analyse the accuracy of the correlation. The comparison method included tabular comparison and a graphical plot of experimental and calculated mole fraction and the use of deviation techniques to ascertain the percentage of deviation of the new correlation from experimental data if any.

The comparison of the newly developed Lohrenz et al. [6] correlation is done in 2 phases, namely:

1. Comparison of the new correlation with other existing methods
2. Comparison of original Lohrenz et al. [6] correlation with the new Lohrenz et al. [6] correlation.

2.5.1 Comparison of the new correlation with other existing methods. The same data (Data 10 of Table A2) used in the evaluation stage of this work was applied in a spreadsheet, where the mole fraction was predicted using the existing splitting methods and the new Lohrenz et al.. The consistency test in Equation (1) was used to compare the accuracy of the existing splitting correlations with the new Lohrenz.

2.5.2 Comparison of original Lohrenz, correlation with the new Lohrenz et al. correlation. This involved the comparison of the new Lohrenz et al. correlation with the original Lohrenz et al. correlation for splitting C7+ fraction of reservoir fluids. This was compared with experimental data (Data 8). The deviation of the predicted mole fraction from the new Lohrenz et al. correlation and the original Lohrenz et al. correlation was calculated using Average Absolute Deviation (AAD).

3. Results and discussion
The stepwise approach to the development of a new correlation for Lohrenz et al. 1984 has been outlined in Section -2.

3.1. Result of the evaluation of existing correlations

From the evaluation of the existing correlations, the mole fraction and carbon number from each existing correlations were plotted and presented in Figure 1.

Figure 1: Plot of mole fraction vs. carbon number for evaluation of the existing splitting methods
3.1.1 Summary of evaluation/comparison. From the evaluation, the following was observed:

- Ahmed et al. is the most appropriate method for determining mole fraction by splitting of C\textsubscript{7+} fraction of reservoir fluids. Since the consistency test was met.

\[ \sum_{n=7}^{N} Z_n = Z_{C_{7+}} \]  \hspace{1cm} (21)

- Pedersen et al. and Katz method are acceptable in determining mole fraction by splitting of C\textsubscript{7+} fraction of reservoir fluids. Since the consistency test was approximately met.

\[ \sum_{n=7}^{N} Z_n \approx Z_{C_{7+}} \]  \hspace{1cm} (22)

- Lohrenz et al. is the least accurate method for determining mole fraction by splitting of C\textsubscript{7+} fraction of reservoir fluids because the consistency test was not met.

\[ \sum_{n=7}^{N} Z_n \neq Z_{C_{7+}} \]  \hspace{1cm} (23)

Therefore, it required modification.

3.2. Results of the development of the new correlation

Figure 2 is the plot of that data fitted with a regression line for Data 3. The results for others are presented in Table 1.

![Figure 2: Plot of mole fraction vs. carbon number for data 3](image)

3.2.1 Summary of the result of the new correlation. The summary is presented below:

1. \( Z_6 \) is negligible: Lohrenz et al. correlation contains parameters such as mole fraction of C\textsubscript{6} (\( Z_6 \)) and carbon number (n). From the plots it was seen that \( Z_6 \) has a small to no effect on the prediction of mole fraction. This is realised from the line of best fit of the curves. Most lines did not include \( Z_6 \). This shows that \( Z_6 \) is negligible in the determination of mole fraction.

2. Statistical validation of new correlation: the R\textsuperscript{2} value is a statistical parameter to analyse the fitting of the data points on the line of best fit. From the plots the R\textsuperscript{2} values for the dataset vary from 90% < R\textsuperscript{2} < 100%. These are very high values which indicate that most of the data points lie on the exponential curve of best fit. This validates the accuracy of the Equation of the line.

Therefore, from the above plots, it is seen that the new Equation for Lohrenz et al. correlation is:

\[ Z_n = Ae^{Bn} \]  \hspace{1cm} (24)
where, A and B are variables that are reservoir specific. i.e. every reservoir has specific A and B, that can be determined via regression; n = carbon number; and \( Z_n \) = mole fraction of nth component

3.2.2 Result of the evaluation of variables A and B in the new Lohrenz et al. correlation.

This was an attempt to examine the possible link between the variables A and B in the new correlation to the mole % of C\(_{7+}\), to yield a mathematical expression. To which the A and B in the correlation can be substituted by the mathematical expression to yield a more universal/general correlation for the new Lohrenz et al. The required data to perform this is gotten from the 9-dataset used in the formulation of the correlation.

From the graph:

- For A vs Mole fraction of C\(_{7+}\) in Figure 3, there exist a relationship given by the mathematical expression as:
  \[
  y = 1.2454x^{1.0413} \tag{25}
  \]
  \[
  A = 1.2454(\%C_{7+})^{1.0413} \tag{26}
  \]
  \( R^2 \) is 0.4856
  Since the \( R^2 \) value is small, it shows that a relationship exists between variable A vs Mole fraction of C\(_{7+}\), but the relationship is not a strong one. Thus, there will be no need to substitute the mathematical expression for A.

- For A vs Mole fraction of C\(_{7+}\) in Figure 4, there exist a relationship given by the mathematical expression as:
  \[
  y = -0.0017x^2 + 0.026x - 0.29 \tag{27a}
  \]
  \[
  B = -0.0017(\%C_{7+})^2 + 0.026(\%C_{7+}) - 0.29 \tag{27b}
  \]
  \( R^2 \) is 0.0174
  Since the \( R^2 \) value is very small and negligible, it shows that no strong relationship exists between variable B vs Mole fraction of C\(_{7+}\). Thus, there will be no need to substitute the mathematical expression for B.

### Table 1: Parameters from the 9-dataset

| Data | A     | B     | Mol % C\(_{7+}\) | Regression Coefficient (\( R^2 \)) |
|------|-------|-------|-----------------|-----------------------------------|
| 1    | 0.8749| -0.252| 0.69            | 0.9083                            |
| 2    | 0.5651| -0.017| 0.57            | 0.9076                            |
| 3    | 13.553| -0.241| 13.35           | 0.9523                            |
| 4    | 5.9959| -0.361| 1.71            | 0.9859                            |
| 5    | 23.532| -0.766| 0.22            | 0.9615                            |
| 6    | 0.0317| -0.118| 0.122           | 0.9957                            |
| 7    | 0.0395| -0.195| 0.0588          | 0.9677                            |
| 8    | 0.0219| -0.263| 0.154           | 0.9915                            |
| 9    | 2.2185| -0.179| 4.43            | 0.9216                            |
3.3. Result of the application of the new Lohrenz et al. correlation

Dataset four was selected for the application of the newly developed Lohrenz et al. correlation (Equation 24) to predict the mole fractions of individual carbon atoms in the C\textsubscript{7+} fractions of the reservoir fluids. From the Table 2 it was seen that the Average Absolute Deviation (AAD) of the data is 0.1146, which is approximately 0.11. This indicates a good deviation of the mole fraction calculated by the new Lohrenz et al. from the experimental data. Thus, the new correlation is appropriate.

| carbon no (n) | mole fraction (Zn) | mole fraction of new correlation (Zn)\textsubscript{pred} | deviation (Zn - Zn, \textsubscript{pred})/Zn |
|--------------|-------------------|-------------------------------------------------------------|-----------------------------------------------|
| 6            | 0.53              | 0.479062554                                                | 0.04187489                                    |
| 7            | 0.5               | 0.333896539                                                | 0.018212                                      |
| 8            | 0.48              | 0.23718875                                                | 0.04588136                                    |
| 9            | 0.23              | 0.162200169                                                | 0.13050111                                    |
| 10           | 0.17              | 0.113050111                                               | 0.12562219                                    |
| 11           | 0.1               | 0.078793553                                                | 0.09834904                                    |
| 12           | 0.07              | 0.054917452                                                | 0.04309224                                    |
| 13           | 0.05              | 0.038276311                                               | 0.11074051                                    |
| 14           | 0.04              | 0.026677785                                                | 0.07030722                                    |
| 15           | 0.03              | 0.012959527                                                | 0.29595268                                    |
| 16           | 0.02              | 0.009032518                                                | 0.0967482                                    |
| 17           | 0.01              | 0.01                                                       |                                               |
| 18           | 0.01              | 0.01                                                       |                                               |

Mol % C\textsubscript{7+} 1.71
AAD 0.114606071
3.4. Result of comparison

3.4.1 Result of the comparison of the new correlation with other existing methods.

New Lohrenz et al. (Equation 33), Pedersen et al. (Equation 29), Katz (Equation 30) and Ahmed et al. (Equation 32) gives the sum of all mole fraction ($\sum_{n=7}^{N} Z_n$) to be approximately 0.154. In Table 3, it seen that the new correlation can predict beyond C40. The original Lohrenz et al. began non-corresponding with the other methods as observed in the Table 3. However, for the new correlation at C40 the mole fraction predictions were still accurate and corresponding to the prediction of other methods. Beyond C40, the new correlation was still corresponding likewise. The prediction stopped at C45 due to the observation of very close mole fraction prediction ($\ldots E-07$). However, the new Lohrenz et al. correlation (Equation 24) can predict beyond C45+

$$\sum_{n=7}^{N} Z_n = Z_{c7+} \quad (28)$$

$$Z_{c7+} = 0.0154$$ for this data set

From the Table 3, it was seen that:

1. Original Lohrenz et al.
   $$\sum_{n=7}^{N} Z_n = 0.012396035 \quad (29)$$
2. Pedersen et al.
   $$\sum_{n=7}^{N} Z_n = 0.015801125 \quad (30)$$
3. Katz
   $$\sum_{n=7}^{N} Z_n = 0.01521401 \quad (31)$$
4. Ahmed et al.
   $$\sum_{n=7}^{N} Z_n = 0.015419437 \quad (32)$$
5. New Lohrenz et al.
   $$\sum_{n=7}^{N} Z_n = 0.015024353 \quad (33)$$

As seen from in Figure 5 above comparing the existing splitting methods. The new Lohrenz et al. overlaps on the other methods excluding the original Lohrenz et al. This indicates that the new Lohrenz et al. correlation compares well with other splitting methods.
Figure 5: Comparison of existing splitting methods
Table 3: Comparison of new correlation with other existing methods

| S/N | GROUP | MW | MOLE FRACTION (LOHRENZ) $Z_n$ | MOLE FRACTION (PEDERSEN) $Z_n$ | MOLE FRACTION (KATZ) $Z_n$ | MOLE FRACTION (AHMED) $Z_n$ | MOLE FRACTION (NEW LOHRENZ) $Z_n$ |
|-----|-------|----|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 6   | C₆    | 84 | 0.00352533                   | 0.00364564                   | 0.00347198                   | 0.00392921                   | 0.00347462                   |
| 7   | C₇    | 96 | 0.00292379                   | 0.00280454                   | 0.00155335                   | 0.00245499                   | 0.00205337                   |
| 8   | C₈    | 107| 0.00222486                   | 0.00217570                   | 0.00159621                   | 0.00232486                   | 0.00157851                   |
| 9   | C₉    | 121| 0.00099506                   | 0.00127682                   | 0.00095082                   | 0.00104460                   | 0.00093284                   |
| 10  | C₁₀   | 134| 0.00058484                   | 0.00098224                   | 0.00047134                   | 0.00037680                   | 0.00042379                   |
| 11  | C₁₁   | 147| 0.00031538                   | 0.00075562                   | 0.00033738                   | 0.00030096                   | 0.00025278                   |
| 12  | C₁₂   | 161| 0.00015535                   | 0.00056812                   | 0.00015962                   | 0.00014604                   | 0.00015785                   |
| 13  | C₁₃   | 175| 0.00009506                   | 0.00075562                   | 0.00009508                   | 0.00009328                   | 0.00009328                   |
| 14  | C₁₄   | 190| 0.00005848                   | 0.00098224                   | 0.00004713                   | 0.00003768                   | 0.00004237                   |
| 15  | C₁₅   | 206| 0.00029237                   | 0.00280454                   | 0.00026039                   | 0.00023817                   | 0.00023817                   |
| 16  | C₁₆   | 222| 0.00022248                   | 0.00217570                   | 0.00021959                   | 0.00020533                   | 0.00020533                   |
| 17  | C₁₇   | 237| 0.00015535                   | 0.00075562                   | 0.00015962                   | 0.00014604                   | 0.00015785                   |
| 18  | C₁₈   | 251| 0.00031538                   | 0.00075562                   | 0.00033738                   | 0.00030096                   | 0.00030096                   |
| 19  | C₁₉   | 263| 0.00015535                   | 0.00075562                   | 0.00015962                   | 0.00014604                   | 0.00014604                   |
| 20  | C₂₀   | 275| 0.00009506                   | 0.00075562                   | 0.00009508                   | 0.00009328                   | 0.00009328                   |
| 21  | C₂₁   | 291| 0.00005848                   | 0.00098224                   | 0.00004713                   | 0.00003768                   | 0.00004237                   |
| 22  | C₂₂   | 300| 0.00029237                   | 0.00280454                   | 0.00026039                   | 0.00023817                   | 0.00023817                   |
| 23  | C₂₃   | 312| 0.00022248                   | 0.00217570                   | 0.00021959                   | 0.00020533                   | 0.00020533                   |
| 24  | C₂₄   | 324| 0.00015535                   | 0.00075562                   | 0.00015962                   | 0.00014604                   | 0.00015785                   |
| 25  | C₂₅   | 337| 0.00009506                   | 0.00075562                   | 0.00009508                   | 0.00009328                   | 0.00009328                   |
| 26  | C₂₆   | 349| 0.00005848                   | 0.00098224                   | 0.00004713                   | 0.00003768                   | 0.00004237                   |
| 27  | C₂₇   | 360| 0.00029237                   | 0.00280454                   | 0.00026039                   | 0.00023817                   | 0.00023817                   |
| 28  | C₂₈   | 372| 0.00022248                   | 0.00217570                   | 0.00021959                   | 0.00020533                   | 0.00020533                   |
| 29  | C₂₉   | 382| 0.00015535                   | 0.00075562                   | 0.00015962                   | 0.00014604                   | 0.00015785                   |
| 30  | C₃₀   | 394| 0.00009506                   | 0.00075562                   | 0.00009508                   | 0.00009328                   | 0.00009328                   |
| 31  | C₃₁   | 404| 0.00005848                   | 0.00098224                   | 0.00004713                   | 0.00003768                   | 0.00004237                   |
| 32  | C₃₂   | 415| 0.00029237                   | 0.00280454                   | 0.00026039                   | 0.00023817                   | 0.00023817                   |
| 33  | C₃₃   | 426| 0.00022248                   | 0.00217570                   | 0.00021959                   | 0.00020533                   | 0.00020533                   |
3.4.2 Result of the comparison of original Lohrenz et al. correlation with the new Lohrenz et al. correlation

From the Table 4:

- Average Absolute Deviation (AAD), original Lohrenz et al.
  \[ AAD = 0.66675654 \]  

  AAD is 66.7%

- Average Absolute Deviation (AAD), new Lohrenz et al.
  \[ AAD = 0.04742404 \]  

  AAD is 4.5%

The deviation of the new correlation is minimal compared to that of the original correlation. Therefore, the new correlation for Lohrenz et al. is a better option for determining the mole fraction of the \( C_{7+} \) composition of reservoir fluids.

From the graph (Figure 6), the experimental data and new Lohrenz et al. overlaps, thus indicating minimal deviation of the experimental and new Lohrenz et al. This indicates the accuracy of the new correlation for Lohrenz et al. in determining the mole fraction of the \( C_{7+} \) composition of reservoir fluids.
**Table 4: Comparison of mole fraction for experimental, original Lohrenz *et al.* and new Lohrenz *et al.***

| Carbon No (N) | Mole Fraction, Experimental (Zn)exp | Mole Fraction, Original Correlation (Zn)org | Mole Fraction, New Correlation (Zn)new | Deviation ((Zn)exp – (Zn)org) | Deviation ((Zn)exp – (Zn)new) |
|--------------|----------------------------------|---------------------------------|---------------------------------|-------------------------------|-------------------------------|
| 6            | 0.0039                           | 0.003525337                     | 0.00347463                      | 0.05890636                   | 0.07244387                   |
| 7            | 0.003746                         | 0.002923796                     | 0.003224867                     | 0.03123134                   | 0.05781657                   |
| 8            | 0.002835                         | 0.002224876                     | 0.00205338                      | 0.03723384                   | 0.04271384                   |
| 9            | 0.001623                         | 0.001553357                     | 0.00157852                      | 0.04290992                   | 0.02740707                   |
| 10           | 0.001229                         | 0.00099506                      | 0.00121347                      | 0.1903501                    | 0.01263371                   |
| 11           | 0.000993                         | 0.00058484                      | 0.00093285                      | 0.37113928                   | 0.00306201                   |
| 12           | 0.000704                         | 0.000315381                     | 0.00071712                      | 0.55201499                   | 0.01863507                   |
| 13           | 0.000532                         | 0.000156043                     | 0.00055128                      | 0.7066854                    | 0.03623964                   |
| 14           | 0.000442159                      | 7.08378E-05                     | 0.00042379                      | 0.83979105                   | 0.0415395                    |
| 15           | 0.000340696                      | 2.9505E-05                      | 0.00032579                      | 0.91339808                   | 0.04376323                   |
| 16           | 0.000262517                      | 1.12755E-05                     | 0.00025045                      | 0.95704858                   | 0.04598434                   |
| 17           | 0.000202278                      | 3.95354E-06                     | 0.00019253                      | 0.98045494                   | 0.04820282                   |
| 18           | 0.000155863                      | 1.27189E-06                     | 0.000148                        | 0.99183971                   | 0.05041867                   |
| 19           | 0.000120098                      | 3.75422E-07                     | 0.00011378                      | 0.99687404                   | 0.05263187                   |
| 20           | 0.0001075863                     | 1.431672E-07                    | 0.00012598                      | 0.99990773                   | 0.05943243                   |
| 21           | 0.00010406                     | 8.7465E-06                      | 0.00012598                      | 0.99990773                   | 0.05943243                   |
| 22           | 0.0001075863                     | 1.431672E-07                    | 0.00012598                      | 0.99990773                   | 0.05943243                   |
| 23           | 0.00010406                     | 8.7465E-06                      | 0.00012598                      | 0.99990773                   | 0.05943243                   |
| 24           | 0.0001075863                     | 1.431672E-07                    | 0.00012598                      | 0.99990773                   | 0.05943243                   |
| 25           | 0.00010406                     | 8.7465E-06                      | 0.00012598                      | 0.99990773                   | 0.05943243                   |

**Average Absolute Deviation, org** 0.66675654

**Average Absolute Deviation, new** 0.04472404

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**Figure 6 -** comparison of mole fraction for experimental, original Lohrenz *et al.* and new Lohrenz *et al.*
4. Conclusion
Characterizing the reservoir fluids, especially the C\textsubscript{7+} fractions in the mixture into well-defined compositions of distinct mole fraction, by splitting the lumped C\textsubscript{7+} fraction, via the use of correlations, is very crucial to the understanding of the behaviour of the reservoir in petroleum engineering. In this work, the existing splitting correlations were evaluated and Lohrenz et al. was discovered with least correspondence to experimental data. The correlation was modified and a new Lohrenz et al. correlation was developed for more accuracy of in the predictions of the mole fraction of the components of the C\textsubscript{7+} fractions in the reservoir fluid mixture. The following conclusions were made during the process of developing the new Lohrenz et al. correlation:

- Z\textsubscript{6} is negligible in calculating the mole fraction of reservoir fluid composition. The original Lohrenz et al. correlation contained mole fraction of C\textsubscript{6} (Z\textsubscript{6}). However, from the evaluation in this work, it is seen that Z\textsubscript{6} has a small to no effect on the prediction of mole fraction.
- It is seen that the new correlations can be used for extensive prediction of the mole fraction of reservoir C\textsubscript{7+} composition beyond C\textsubscript{40} with accuracy unlike the original Lohrenz et al. correlation which analysis ends at C\textsubscript{40}.
- The new Lohrenz et al. correlation has R\textsuperscript{2} values for the dataset varying from 90< R\textsuperscript{2} <100, which indicates the accuracy of the correlation. The deviation of the new correlation from experimental data is minimal compared to that of the original correlation. Therefore, the new correlation for Lohrenz et al. is a better option for determining the mole fraction of the C\textsubscript{7+} composition of reservoir fluids.
## 5. Appendices

### Table A1: Data 1 - 5

| Compound | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|----------|----------|----------|----------|----------|----------|
|          | Carbon Number (n) | Mole Fraction (Zn) | Carbon Number (n) | Mole Fraction (Zn) | Carbon Number (n) | Mole Fraction (Zn) | Carbon Number (n) | Mole Fraction (Zn) | Carbon Number (n) | Mole Fraction (Zn) |
| C₆H₁₄   | 6        | 0.15     | 6        | 0.1      | 6        | 1.88      | 6        | 0.53     | 6        | 0.237     |
| C₇H₁₆   | 7        | 0.13     | 7        | 0.09     | 7        | 2.73      | 7        | 0.5      | 7        | 0.129     |
| C₈H₁₈   | 8        | 0.11     | 8        | 0.12     | 8        | 3.19      | 8        | 0.48     | 8        | 0.066     |
| C₉H₂₀   | 9        | 0.09     | 9        | 0.09     | 9        | 1.66      | 9        | 0.23     | 9        | 0.02      |
| C₁₀H₂₂  | 10       | 0.12     | 10       | 0.09     | 10       | 1.26      | 10       | 0.17     | 10       | 0.007     |
| C₁₁H₂₄  | 11       | 0.07     | 11       | 0.05     | 11       | 0.86      | 11       | 0.1      | 11       | 0.004     |
| C₁₂H₂₆  | 12       | 0.05     | 12       | 0.04     | 12       | 0.65      | 12       | 0.07     | 12       | 0.004     |
| C₁₃H₂₈  | 13       | 0.03     | 13       | 0.03     | 13       | 0.61      | 13       | 0.05     | 13       | 0.22      |
| C₁₄H₃₀  | 14       | 0.03     | 14       | 0.03     | 14       | 0.52      | 14       | 0.04     | 14       | 0.004     |
| C₁₅H₃₂  | 15       | 0.02     | 15       | 0.02     | 15       | 0.46      | 15       | 0.03     | 15       | 0.02      |
| C₁₆H₃₄  | 16       | 0.01     | 16       | 0.01     | 16       | 0.28      | 16       | 0.02     | 16       | 0.02      |
| C₁₇H₃₆  |          |          |          |          |          | 0.57      |          |          |          | 0.01      |
| C₁₈H₃₈  |          |          |          |          |          | 0.2       |          |          |          | 0.01      |
| C₁₉H₄₀  |          |          |          |          |          | 0.12      |          |          |          | 1.71      |

Source: Naji [1], Orodu [7], Orodu et al. [8], Coats and Smart [9], Terek [10], Hoffmann et al. [11], Katz et al. [12]
| Carbon Compounds | Sample 6 | | Sample 7 | | Sample 8 | | Sample 9 | | Sample 10 |
|------------------|---------|---------|---------|---------|---------|---------|---------|---------|
|                  | Carbon Number (n) | Mole Fraction (Zn) | Carbon Number (n) | Mole Fraction (Zn) | Carbon Number (n) | Mole Fraction (Zn) | Carbon Number (n) | Mole Fraction (Zn) | Component | Mole fraction (Zn) |
| C$_6$H$_{14}$    | 6       | 0.0179  | 6       | 0.009   | 6       | 0.0039   | 6       | 0.54    | C$_1$     | 0.9135         |
| C$_7$H$_{16}$    | 7       | 0.01371 | 7       | 0.01141 | 7       | 0.003746 | 7       | 0.72    | C$_2$     | 0.0403         |
| C$_8$H$_{18}$    | 8       | 0.011922| 8       | 0.009197| 8       | 0.002835 | 8       | 0.88    | C$_3$     | 0.0153         |
| C$_9$H$_{20}$    | 9       | 0.01063 | 9       | 0.007412| 9       | 0.002145| 9       | 0.55    | i-C$_4$   | 0.0039         |
| C$_{10}$H$_{22}$ | 10      | 0.009479| 10      | 0.005974| 10      | 0.001623| 10      | 0.33    | n-C$_4$   | 0.0043         |
| C$_{11}$H$_{24}$ | 11      | 0.008452| 11      | 0.004815| 11      | 0.001229| 11      | 0.24    | i-C$_5$   | 0.0015         |
| C$_{12}$H$_{26}$ | 12      | 0.007536| 12      | 0.003881| 12      | 0.00093 | 12      | 0.2     | n-C$_5$   | 0.0019         |
| C$_{13}$H$_{28}$ | 13      | 0.006719| 13      | 0.003128| 13      | 0.000704| 13      | 0.21    | C$_6$     | 0.0039         |
| C$_{14}$H$_{30}$ | 14      | 0.005991| 14      | 0.002521| 14      | 0.000532| 14      | 0.18    | C$_7$     | 0.0154         |
| C$_{15}$H$_{32}$ | 15      | 0.005342| 15      | 0.002032| 15      | 0.0154  |         |         |           |                |
| C$_{16}$H$_{34}$ | 16      | 0.004764| 16      | 0.001638| 16      | 0.00086 |         |         |           |                |
| C$_{17}$H$_{36}$ | 17      | 0.004247| 17      | 0.00588 |         |         |         |         | C$_7$+     | 0.0154         |
| C$_{18}$H$_{38}$ | 18      | 0.003787|         |         |         |         |         |         |           |                |
| C$_{19}$H$_{40}$ | 19      | 0.003377|         |         |         |         |         |         |           |                |
| C$_{20}$H$_{42}$ | 20      | 0.003011|         |         |         |         |         |         |           |                |
| C$_{21}$H$_{44}$ | 21      | 0.002685|         |         |         |         |         |         |           |                |
| C$_{22}$H$_{46}$ | 22      | 0.002394|         |         |         |         |         |         |           |                |

Source: Naji [1], Orodu [7], Orodu et al. [8], Coats and Smart [9], Terek [10], Hoffmann et al. [11], Katz et al. [12]
**Table A3**: Molecular weight of pure carbon atoms

| S/N | Carbon Group | Molecular Weight (MW) |
|-----|--------------|-----------------------|
| 6   | C₆           | 84                    |
| 7   | C₇           | 96                    |
| 8   | C₈           | 107                   |
| 9   | C₉           | 121                   |
| 10  | C₁₀          | 134                   |
| 11  | C₁₁          | 147                   |
| 12  | C₁₂          | 161                   |
| 13  | C₁₃          | 175                   |
| 14  | C₁₄          | 190                   |
| 15  | C₁₅          | 206                   |
| 16  | C₁₆          | 222                   |
| 17  | C₁₇          | 237                   |
| 18  | C₁₈          | 251                   |
| 19  | C₁₉          | 263                   |
| 20  | C₂₀          | 275                   |
| 21  | C₂₁          | 291                   |
| 22  | C₂₂          | 300                   |
| 23  | C₂₃          | 312                   |
| 24  | C₂₄          | 324                   |
| 25  | C₂₅          | 337                   |
| 26  | C₂₆          | 349                   |
| 27  | C₂₇          | 360                   |
| 28  | C₂₈          | 372                   |
| 29  | C₂₉          | 382                   |
| 30  | C₃₀          | 394                   |
| 31  | C₃₁          | 404                   |
| 32  | C₃₂          | 415                   |
| 33  | C₃₃          | 426                   |
| 34  | C₃₄          | 437                   |
| 35  | C₃₅          | 445                   |
| 36  | C₃₆          | 456                   |
| 37  | C₃₇          | 464                   |
| 38  | C₃₈          | 475                   |
| 39  | C₃₉          | 484                   |
| 40  | C₄₀          | 495                   |
| 41  | C₄₁          | 502                   |
| 42  | C₄₂          | 512                   |
| 43  | C₄₃          | 521                   |
| 44  | C₄₄          | 531                   |
| 45  | C₄₅          | 539                   |

Source: Katz [12]
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