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Predicting the gas-condensate extended composition analysis

Muzher I. Almusabeh
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**PREDICTING THE GAS-CONDENSATE EXTENDED COMPOSITION
ANALYSIS**

Muzher I. Almusabeh

**Thesis Submitted to
College of Engineering and Mineral Resources
At West Virginia University
In partial fulfillment of the requirements for the degree of**

**Master of Science
In
Petroleum and Natural Gas Engineering**

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**Keywords: phase behavior prediction, heptanes plus components, equations of state,
compositional analysis**

ABSTRACT

PREDICTING THE GAS-CONDENSATE EXTENDED COMPOSITION ANALYSIS

Muzher I. Almusabeh

The objective of this study was to predict the extended composition of gas condensate fluid in order to enhance phase behavior prediction via equation of state. This research work introduces a systematic methodology to estimate the extended heptane plus composition by matching the mole fraction, the average molecular weight, the average specific gravity and the dew point pressure. For the extended method to be accepted, the averaging properties results should be within 3 % of the lab results. A number of published compositional data have been used to verify the reliability of this methodology. Four different methods are compared and analyzed, and the methods that best suit for characterization of heptane plus are discussed.

Characterization of heptane plus prediction involves determining average molecular weight, specific gravity and the dew point pressure. The first two properties are calculated. The dew point is derived from a PC version of PR-AGA software which utilizes Peng-Robison equation of state. The results using all methods are compared and discussed.

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NOMENCLATURE

a	Equation of state constant
A	Lohrenz's & Pederson's equations constant
API	American Petroleum Institute gravity
b	Equation of state constant
B	Lohrenz's & Pederson's equations constant
C	Carbon
C ₁	Methane
C ₂	Ethane
C ₃	Propane
C ₆	Hexane
C ₇₊	Heptane plus
C ₈	Octane
C ₉	Nonane
C ₁₀	Decane
C _{n+}	Plus fraction of heavier hydrocarbon
CO ₂	Carbon Dioxide
EOS	Equation of state
iC ₄	Iso-Butane
iC ₅	Iso-Pentane
GOR	Gas oil ratio
HC	Hydrocarbon
m	Equation of state parameter
MW _n	Molecular Weight of n carbon number
MW _{n+}	Molecular Weight of n plus fraction
MW _{(n+1)+}	Molecular Weight of next fraction plus of n carbon number
n	Number of Carbon
N ₂	Nitrogen
nC ₄	Normal-Butane
nC ₅	Normal –Pentane

P	Pressure
P _c	Critical pressure
PVT	Pressure, volume, temperature
R	Gas constant
S	Slopes or Coefficients of Splitting scheme
scf	Standard cubic feet
SCN	Single carbon number
SG ₇₊	Specific gravity of heptane plus fraction
SG _n	Specific gravity of n carbon number
STB	Stock tank barrel
T	Temperature
T _b	Boiling point temperature
T _c	Critical temperature
T _r	Reduced temperature
V	Total phase volume
V _m	Total phase volume of a mixture
z	Compressibility factor
Z _{two-phase}	Two phase deviation factor
Z _n	Mole fraction of SCN
Z _i	Mole fraction of component i

Greek Letters:

α	Equation of state constant
γ_{7+}	Specific gravity of heptane plus fraction
γ	Specific gravity of n carbon number
ω	Acentric factor

Subscripts:

i	Component i
n	Carbon number of hydrocarbon component
+	Plus fraction or last heavier fraction
%	Percentage

CHAPTER 1: INTRODUCTION

The gas condensate fluids are complex mixtures made up of different compounds of varied molecular properties. They are made of hydrocarbons of paraffinic, naphthenes, and aromatics. They also may contain non-hydrocarbon compounds. The heavier fractions are usually lumped as heptanes plus, have a significant effect on phase behavior prediction. The extended compositional analysis is necessary to improve the accuracy of the equation of state for predicting phase behavior. It should be estimated if the C7+ detailed analytical data does not exist. A proper description of physical properties of the heavy hydrocarbon fraction is important to predict the thermodynamics and behavior of the complex hydrocarbon (HC) mixtures by the equation of state (EOS).

It is common procedure for phase behavior prediction to use Equation of State. The EOS determines the equilibrium constants and phase behavior properties. Also, it provides continuity and smoothness of the PVT dependent fluid properties. It is important in compositional analysis to obtain satisfactory agreement between the EOS results and the measured lab data.

The Peng-Robinson equation of state (P-R EOS) is used because of its ability to provide consistency between phase behavior and densities. However, no equation of state can precisely predict the phase behavior of a hydrocarbon mixture unless the parameters of the equation of state are adjusted. In order to accurately predict the phase behavior, the parameters like molecular weight, accentric factor, critical pressure, critical temperature have to be estimated accurately. During this fine tuning process, the critical properties are adjusted by a trial and error method to arrive at a good match with the standard laboratory values. The P-R EOS has the advantage of giving improved and accurate results for liquid density, dew point and liquid yields at pipeline conditions.

CHAPTER 2: LITERATURE REVIEW

2.1 Retrograde Gas Condensate Reservoir Behavior

The hydrocarbon reservoirs are porous sections of the sedimentary crust of the earth containing groups of hydrocarbons. The hydrocarbons are a mixture of carbon components and complex molecules. The carbon components are constituting of Methane and Ethane (light fractions); Propanes, butanes, Pentanes and Hexanes (intermediates); and Heptanes and higher (heavier fractions) (Melkaveri, 2007). The complex molecules are Aromatics, Paraffinic and Naphthenic. These HC reservoirs exhibit multiphase behaviors over wide ranges of pressures and temperatures. They may occur in variety states like gaseous, liquid, solid or in various combinations of gas, liquid and/ or solid. Such ranges of conditions can be explained with the Pressure-Temperature (P-T) phase diagram as shown in Figure 1.

Figure 1: The Pressure-Temperature (P-T) Phase Diagram.

In the P-T Phase diagram (Ahmed, 2007), the area enclosed by the bubble point curve and dew point curve indicate the presence of hydrocarbons in liquid as well as gaseous state. The curves represented by the broken lines indicate the percentage of liquid hydrocarbon volume for any pressure and temperature. If the reservoir temperature, T , lies between the critical temperature, T_c and cricondentherm T_{ct} of the reservoir

fluid, the reservoir is classified as a retrograde gas condensate reservoir. This type of reservoirs is typically composed of 70 mol % of Methane, 22 mol % of Intermediates and 8 mol % of Heptane plus.

In most gas condensate reservoirs, the condensed liquid volume rarely exceeds more than 19% of the pore volume (Ahmed, 2007). It should be recognized that around the wellbore where the pressure drop is high; enough liquid dropout might accumulate to give two-phase flow of gas and retrograde liquid. The associated physical characteristics of this type of hydrocarbons are:

- GORs are between 8,000 and 70,000 scf/STB.
- Condensate gravity above 50° API.
- Stock-tank liquid is usually water-white or slightly colored.

There is a fairly sharp dividing line between oil and condensate from a compositional standpoint. Reservoir fluids that contain heptane and heavier in concentrations of more than 12.5 mol% are almost always in the liquid phase in the reservoir. Oils have been observed with heptane and heavier concentrations as low as 10% and condensates as high as 15.5%.

2.2 Equation of State

The equation of state is a thermodynamic equation describing the state of matter under a given set of physical conditions. It provides a mathematical relationship between two or more state functions associated with the matter, such as its temperature, pressure or volume. The equations of state are useful in describing the properties of fluids, mixtures of fluids and solids. They provide continuity and smoothness of PVT fluid dependent properties (Malik, 1990). They are also useful in determining the saturation pressure for reservoir fluids (Melkaveri, 2007). Moreover, they are used to find out the partial molar volume of the vapor and liquid phase's components which leading to determine the

equilibrium constants. Existing of the computer software helps in using the EOS to predict the reservoirs' phase behavior recently.

The first EOS was developed in 1873 by Van-der-Waals and that formed the basis for following equations of state developed such as Peng-Robinson, Redlich-Kwong, Soave-Redlich-Kwong and other equations of state (Van-der-Waals, 1873). The Van-der-Waals EOS successfully provided the continuity from gas to liquid state. Peng-Robinson (P-R EOS) and Soave-Redlich-Kwong (S-R-K EOS) are couple of widely used equations of state. However, in order for an EOS to predict the phase behavior, the parameters present in the EOS should be fine tuned. Fine tuning the parameters involves adjusting the critical properties. This is done usually so as to obtain a good density match.

2.2.1 Van-der-Waals EOS

Van-der-Waals (1873) added a correction factor to the ideal gas law to account the volume of the molecules and the attraction force and distance between them. The Van-der-Waals equation is the simplest EOS that uses the T_c and P_c for each component a and

b in the equation:

$$P = \frac{RT}{V-b} - \frac{a}{V^2}$$

At critical point, the values of a and b are:

$$a = \frac{27}{64} \frac{R^2 T_c^2}{P_c} = 0.421875 \frac{R^2 T_c^2}{P_c}$$

$$b = \frac{RT_c}{8P_c} = 0.125 \frac{RT_c}{P_c}$$

Where:

P = Pressure, psia.

T = Temperature, °R.

V = Volume, ft³.

R = Universal Gas Constant, 10.731 ft³psi°R⁻¹lb-mol⁻¹.

T_c = Critical Temperature, °R.

P_c = Critical Pressure, psia.

2.2.2 Redlich-Kwong EOS

Redlich and Kwong (1949) introduced a first major extension of Van-der-Waals' EOS. The simplest form of R-K EOS is:

$$P = \frac{RT}{V_m - b} - \frac{a}{\sqrt{T}V_m(V_m + b)}$$

Whereas the values of a and b are:

$$a = \frac{0.42748 R^2 T_c^{2.5}}{P_c}$$

$$b = \frac{0.08662 R T_c}{P_c}$$

2.2.3 Soave-Redlich-Kwong EOS

Soave (1972) modified the R-K EOS in order to estimate both vapor and liquid properties and the behavior of heptanes plus components by predicting molecular weight, liquid density, and boiling point. The S-R-K EOS is presented by the following equation

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

The parameter α is the dimensionless factor which becomes unity at critical pressure and is defined by the expression

$$\alpha = (1 + m (1 - T_r^{0.5}))^2$$

The parameter m is correlated with acentric factor ω and is given as

$$m = 0.480 + 1.574 \omega - 0.176 \omega^2$$

Where:

$$T_r = \frac{T}{T_c}$$

a and b are equals to the values of R-K EOS values.

ω is the acentric factor for the species.

2.2.4 Peng-Robinson EOS

The Peng-Robinson EOS was published in 1976 to overcome the weaknesses of the S-R-K EOS (Peng & Robinson, 1976; Robinson & Peng, 1978). The main advantage of the P-R EOS is that it can be used to predict the liquid density. The equation can be described as follows:

$$P = \frac{RT}{V_m - b} - \frac{a\alpha}{V_m^2 + 2bV_m - b^2}$$

At critical point, the results equal to:

$$a = \frac{0.45724 R^2 T_c^2}{P_c}$$

$$b = \frac{0.07780 R T_c}{P_c}$$

The parameter α is defined by the expression:

$$\alpha = (1 + m (1 - T_r^{0.5}))^2$$

Where m is a constant calculated by accentric factor equation as follows:

$$m = 0.37464 + 1.54226\omega - 0.26992\omega^2$$

The P-R EOS achieved goals after development are:

1. The EOS parameters are expressible in terms of critical properties and accentric factor.
2. The model provides reasonable accuracy near the critical point, particularly for calculating the compressibility factor and liquid density.
3. The EOS is applicable to all calculations of all fluid properties in natural gas processes.

2.3 Predicting the Phase Behavior of Hydrocarbon Systems Using P-R EOS

Predicting the phase behavior of the reservoir fluid needs an EOS and the extended composition analysis of the heavy fractions of the reservoir fluid. A proper description of physical properties of the heavy hydrocarbon fraction is important to predict the thermodynamics and behavior of the complex HC mixtures by the EOS. These fractions

are usually lumped as the heptanes plus group (C7+). The extended composition analysis should be estimated if the C7+ detailed analytical data does not exist. Using the extended compositional analysis improves the accuracy of the EOS in predicting the phase behavior.

The PR-AGA phase behavior package is a PC programmed version of the P-R EOS. It has a help document that allows modifying existing data files (Aminian, 1989). This software incorporates the P-R EOS using built in properties of the hexanes plus (C6+). This simulation program is capable to perform the independent equilibrium calculations which will determine the retrograde dew point pressure. Also, more major options are available in the program with more calculations can be performed. The package has an input data file generator program developed for input data preparation. The data which given by the user is stored and the program sets up an input file. The input file is then run with a command line and the program generates an output file predicting the phase behavior for the hydrocarbon system. All calculations are based on the P-R EOS.

2.3.1 The Input File for the PR-AGA Phase Behavior Package

The program starts by listing the different options that are available and allows the user to create and name a file. This is followed by a series of questions including the number of streams in the feed, number of components, number of fractions higher than C6, the correlation to be used and the type of calculations. The components present in the mixture are to be identified and assigned a title. The relative molar rate of the stream is to be entered and the mole fractions of all the components are given to the program. The pressure, temperature data at which the phase behavior is to be determined is then given to the program. At the end of the data input, a file is created and saved under a file name with all the pertinent information. The program is set to use methane interaction parameters using the density correlations. The mole fractions are next displayed followed by the pressure and temperature conditions. A typical input file is shown in Figure 2.

In some cases, it is needed to adjust EOS parameters to accurately predict the phase behavior of a complex HC mixture at reservoir conditions. These parameters are boiling

The screenshot shows a Notepad window titled 'C4C26T1n0 - Notepad'. The text content is as follows:

```

File Edit Format View Help
30 21 1 1 2 0 2
14 13 1 2 3 4 5 6 7
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
DEWPT TEST
1
RESERVOIR FLUID
100.00000
.24000 .71000 78.50000 8.22000 4.19000 1.83000 1.70000 1.16000
.61000 .90000 .70753 .40645 .31170 .15339 .10058 .06915
.04851 .03515 .02611 .01949 .01142 .01062 .00774 .00576
.00457 .00337 .00263 .00208 .00168 .00907
1
2668.00000 113.00000 4

```

The diagram uses brackets and boxes to categorize the data:

- Titles:** A bracket on the left groups rows C6 through C26.
- Components Mole Fractions:** A box is placed below the 'DEWPT TEST' section, with a bracket underneath it spanning the 'RESERVOIR FLUID' data block.
- Density Correlations:** A box is placed to the right of the 'DEWPT TEST' section, with a bracket on the right side grouping the numerical values in the 'RESERVOIR FLUID' data block.

```

1 - Notepad
File Edit Format View Help
| 15 6 1 1 2 0 2
14 13 1 2 3 4 5 6 7
C6 147.0 0.685 84.0 0.00 452.2 468.3 0.281 1.0
.1500.1000.0300.0100.0000.0000.0000.0000
C7 219.7 0.734 101.5 0.00 538.0 449.4 0.349 1.0
.1500.1000.0370.0100.0000.0000.0000.0000.0000.0000
C8 299.1 0.770 126.1 0.00 627.1 396.3 0.417 1.0
.1500.1000.0410.0100.0100.0000.0000.0000.0000.0000
C9 398.5 0.798 158.2 0.00 729.5 332.3 0.502 1.0
.1500.1000.0490.0100.0100.0000.0000.0000.0000.0000.0000
C10 503.7 0.830 203.2 0.00 834.7 275.1 0.586 1.0
.1500.1000.0490.0100.0100.0000.0000.0000.0000.0000.0000
C11 645.5 0.856 282.3 0.00 960.0 206.4 0.713 1.0
.1500.1000.0520.0100.0100.0000.0000.0000.0000.0000.0000
DEWPT TEST
1
RESERVOIR FLUID
100.00000
2.44000 .08000 82.10000 5.78000 2.87000 .56000 1.23000 .52000
.60000 .72000 1.50172 .79058 .47017 .20128 .15624
1
4076.00000 180.00000 4

```

8

2.3.2 The Output File for the PR-AGA Phase Behavior Package

The input file is then run with the help of a command with the file name. The resulting file gives out the phase behavior of all the mixtures at the requested pressures and temperatures. The output includes the physical properties, the interaction parameters, the stream mixed molar rates, the retrograde dew point pressure, reservoir temperature, total mole rate, molecular weights, densities, and other values upon requested. The values thus obtained from the program are compared with the standard laboratory values. A typical output file is shown in Figure 4.

File Edit Format View Help															

NAME	BP DEG. F	RHO G/CC	MW G/MOL	TC DEG. F	PC PSIA	W	P	N	A	CORRELATION USED					
C6	147.0	.685	84.0	452.2	468.7	.281			.00	CAVETT'S					
C7	197.5	.722	96.0	512.5	449.4	.328			.00	CAVETT'S					
C8	242.0	.745	107.0	561.5	427.0	.369			.00	CAVETT'S					
C9	279.0	.764	121.0	606.2	410.3	.399			.00	CAVETT'S					
C10	330.5	.778	134.0	659.8	374.4	.446			.00	CAVETT'S					
C11	369.0	.789	147.0	699.5	349.6	.479			.00	CAVETT'S					
***** INTERACTION PARAMETERS *****															
	CO2	N2	METH	ETHN	PROP	1-C4	N-C4	1-C5	N-C5	C6	C7	C8	C9	C10	C11
CO2	.000	.000	.150	.150	.150	.150	.150	.150	.150	.150	.150	.150	.150	.150	.150
N2	.000	.000	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100
METH	.150	.100	.000	.015	.015	.020	.020	.020	.020	.030	.035	.038	.041	.042	.044
ETHN	.150	.100	.015	.000	.000	.000	.000	.000	.000	.010	.010	.010	.010	.010	.010
PROP	.150	.100	.015	.000	.000	.000	.000	.000	.000	.010	.010	.010	.010	.010	.010
1-C4	.150	.100	.020	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
N-C4	.150	.100	.020	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
1-C5	.150	.100	.020	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
N-C5	.150	.100	.020	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C6	.150	.100	.030	.010	.010	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C7	.150	.100	.035	.010	.010	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C8	.150	.100	.038	.010	.010	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C9	.150	.100	.041	.010	.010	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C10	.150	.100	.042	.010	.010	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C11	.150	.100	.044	.010	.010	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

THE MOLAR RATE OF STREAM MIXED WAS 100.00000															
HE NORMALIZED COMPOSITION OF THIS STREAM IS .2400 .7100 78.5000 8.2200 4.1900 1.8300 1.7000 1.1600 .6100 .9000															
THE SOURCE OF THE ABOVE STREAM WAS RESERVOIR FLUID															
** THE NEW FEED COMPOSITION FROM ALL SOURCES IS **															
.240000 .710000 78.500008 8.220001 4.190000 1.830000 1.700000 1.160000 .610000 .900000 .707530 .406450															
NEWPT TEXT															
RETROGRADE DEW PT. PRESSURE DETERMINATION, INITIAL GUESS= 2682.70 PSIA															
PRESSURE 2738.80PSIA TEMPERATURE 113.00DEGREE F															
	CO2	.24000	.2145	.24000	1.1189549	.00	.00								
	N2	.71000	.3604	.71000	1.9698565	.00	.00								
	METH	78.50001	35.2327	78.50001	1.4212585	.00	.00								
	ETHN	8.22000	9.3092	8.22000	.6829941	.00	.00								
	PROP	4.19000	6.3586	4.19000	.6589492	.00	.00								
	1-C4	1.83000	3.4500	1.83000	.5304369	.00	.00								
	N-C4	1.70000	3.5578	1.70000	.4778282	.00	.00								
	1-C5	1.16000	2.9385	1.16000	.3947656	.00	.00								
	N-C5	.61000	1.6771	.61000	.3637214	.00	.00								
	C6	.90000	3.1678	.90000	.2841061	.00	.00								
	C7	.70753	3.2541	.70753	.2174272	.00	.00								
	C8	.40645	2.3830	.40645	.1705620	.00	.00								
	C9	.31170	2.2595	.31170	.1379515	.00	.00								
	C10	.15339	1.4831	.15339	.1034272	.00	.00								
	C11	.36092	4.3537	.36092	.0829000	.00	.00								

MOLE RATES 100.00000 00.0000 100.00000															
MOLECULAR WEIGHT 23.530 41.519 23.530															
DENSITY (LB/CUFT) 30.686 15.177															
HEATING VALUE (BTU/CUFT) 2375.7 1379.4															
NO. OF INTERACTIONS= 39															
THANK YOU FOR USING THIS PACKAGE															

Figure 4: The Typical Output File of the PR-AGA Phase Behavior.

2.4 Extended Compositional Analysis Methods

For an equation of state to be able to predict the phase behavior accurately, the extended composition analysis or break down of the C_{7+} is required. The heavy fractions characterization procedure has a significant effect on the prediction of the equations of state. In many cases, this heavy ends may have only few measured properties available like Average Molecular weight and Average Specific Gravity. The heavy fractions are difficult to characterize without an extended laboratory analysis. This problem can be substantially reduced by “splitting” or “breaking down” the plus fraction into a manageable number of fractions (pseudo components) for equation-of-state calculations.

An accurate description of pseudo-component compositions or Single Carbon Number (SCN) fractions is an integral part of the reservoir fluids characterization process. These data are applied with Equations of State (EOS) to evaluate gas condensate reserves and production for field development and surface facility design. Very often the required extended compositional data are unavailable experimentally and are generated from mathematical relationships called splitting schemes. Splitting schemes are included in every EOS simulation model to extend the composition of the plus fraction.

Splitting schemes refer to the procedures of dividing the heptanes-plus fractions into hydrocarbon groups with a single carbon number (C_7 , C_8 , C_9 , etc.), described by the same physical properties used for pure components (Ahmed, 2007). There are several schemes for extending the molar distribution behavior of C_{7+} in terms of mole fraction as a function of molecular weight or number of carbon atoms. The most used schemes are Katz, Lohrenz, Pedersen, Ahmed and Marching methods.

Three important requirements should be satisfied when applying any splitting model:

1. The sum of the mole fractions of the individual pseudo components is equal to the mole fraction of C_{7+} which can be expressed as following:

$$\sum_{n=7}^{n+} z_n = z_{7+}$$

2. The sum of the products of the mole fraction and the molecular weight of the individual pseudo components is equal to the product of the mole fraction and molecular weight of C₇₊. This can be expressed mathematically as:

$$\sum_{n=7}^{n+} [z_n M_n] = z_{7+} M_{7+}$$

3. 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 C₇₊. The following formula show this expression:

$$\sum_{n=7}^{n+} \frac{z_n M_n}{\gamma_n} = \frac{z_{7+} M_{7+}}{\gamma_{7+}}$$

Where:

z_{7+} = mole fraction of C₇₊,

n = number of carbon atoms,

n_+ = last hydrocarbon group in the C₇₊ with n carbon atoms,

z_n = mole fraction of pseudo component with n carbon atoms,

M_{7+}, γ_{7+} = measured molecular weight and specific gravity of C₇₊,

M_n, γ_n = molecular weight and specific gravity of the pseudo component with n carbon atoms.

2.4.1 Katz's Splitting Scheme

Katz (1983) presented an easy-to-use graphical correlation for breaking down into pseudo components the C₇₊ fraction present in condensate systems. On a semi log scale, the mole percent of each constituent of the C₇₊ fraction versus the carbon number in the fraction was plotted. The resulting relationship can be conveniently expressed mathematically by the following expression:

$$z_n = 1.38205 z_{7+} e^{-0.25903 n}$$

2.4.2 Lohrenz's Splitting Scheme

Lohrenz, Bra and Clark (1964) proposed that the heptanes-plus fraction could be divided into pseudo components with carbon number ranges from 7 to 40. The use of Lohrenz's Splitting Scheme assumes that some molar fractions beyond C6 are known in order to determine the constants A & B. They mathematically stated that the mole fraction z_n is related to its number of carbon atoms n and the mole fraction of the hexane fraction z_6 by the expression:

$$z_n = z_6 e^{A(n-6)^2 + B(n-6)}$$

Where:

A and B are constants determined such that the three above requirements are satisfied.

2.4.3 Pedersen's Splitting Scheme

Pedersen, Thomassen, and Fredenslund (1982) proposed that an exponential relationship exists between the mole fraction of a component and the corresponding carbon number. The Pedersen's Splitting Scheme was able to be used to calculate the molar fractions if some molar fractions beyond C6 are available order to determine the constants A & B. They expressed this relationship mathematically in the following form:

$$z_n = e^{(n-A)/B}$$

Where:

A and B constants determined by at least-squares fit to the molar distribution of the lighter fractions.

2.4.4 Ahmed's Extend Method

Ahmed, Cady and Story (1984, 1985) developed a simplified method for splitting the C7+ fraction into pseudo components. The only required data for the proposed method are the molecular weight and the total mole fraction of the heptanes-plus fraction. The splitting scheme is based on calculating the mole fraction, z_n , at a progressively higher number of carbon atoms. The extraction process continues until the sum of the mole

fraction of the pseudo components equals the total mole fraction of the heptanes plus (z_{7+}).

$$z_n = z_{n+} \left[\frac{M_{(n+1)+} - M_{n+}}{M_{(n+1)+} - M_n} \right]$$

Where:

M_{n+} = molecular weight of the n_+ fraction as calculated by the following:

$$M_{(n+1)+} = M_{7+} + S(n - 6)$$

Where:

S is a coefficient of the equation with the values given below.

Table 1: Ahmed Extend Method S Coefficient Values of Condensate Systmes.

No. of Carbon Atoms	S's coefficient Values
$n \leq 8$	15.5
$n > 8$	17.0

It was noticed that Ahmed Extend Method is utilizing constant set of slopes which are not true for all condensates and may ultimately lead to misleading conclusions.

2.4.5 Marching Technique

Hosein, McCain and Jagai (2008) created a four coefficient model. This model based on observation that the HC systems exhibit a molar distribution that is relative to the average molecular weight and specific gravity of the plus fraction (Hosein, 2003). It uses Ahmed procedure in all calculations with a different in the S coefficient values applied to the SCN beyond the heptane. The S 's coefficient of Marching Technique values are given in following table.

Table 2: Marching Technique S's Coefficient Values of Condensate Systems.

No. of Carbon Atoms	S's coefficient Values
$n = 8$	11.4
$8 < n < 13$	15.6
$n = 13$	11.3
$n > 13$	12.9

CHAPTER 3: THE METHODOLOGY

A methodology was developed to perform the research and achieve the objective of predicting the extended composition of gas condensate fluid. The first step was to collect data from various geographically spread fields. The second step was to examine and evaluate the accuracy of the available splitting models to bench mark the outcomes of this research. The third step was to develop a systematic methodology for splitting the heptane plus fraction. Finally, the result of this research was verified to test its applicability.

3.1 Data Collection

In this research, six samples have been used in order to evaluate various splitting schemes. These samples have laboratory extended data available which will be used to compare with results from various schemes. These samples are from various gas condensate fields from different parts of the world as discussed in the following sections:

3.1.1 Pazanan Gas Condensate Field, Iran

Pazanan reservoir at a distance of 25 km from Behbahan is situated in west of Iran with an approximate length of 60 km, width of 4-6 km and depth of 2 km (Fairouzabadi, Hekim & Katz, 1978). The discovery of the field was in 1937 and existence of hydrocarbons in 1961. At present, the field is considered as a gas condensate reservoir with a thin layer of oil column. The drilling of gas wells with the purpose of injection to the Gachsaran reservoir (Asmari formation) was started in 1974 and finally continuous gas production from gas dome of Asmari formation in 1977. The compositional analysis and the lab data of Pazanan fluid are listed in Table 3.

Table 3: Compositional Analysis & Lab Data of Pazanan Fluid.

Component	Mole Fraction
CO₂	2.44
N₂	0.08
C₁	82.1
C₂	5.78
C₃	2.87
iC₄	0.56
nC₄	1.23
iC₅	0.52
nC₅	0.60
C₆	0.72
C₇₊	3.12

Properties of Heptane Plus	
C₇₊ Molecular Weight	132
C₇₊ Specific Gravity	0.774
Dew Point Pressure	4076 psia
Reservoir Temperature	180.5 deg F

3.1.2 Rapid River 35 Gas Condensate Field, Michigan, USA

Rapid River 35 is a gas condensate field located in the Kalkaska County in northern of Michigan in USA (Katz, Herzog & Hekim, 1981). The depth of the reservoir is at 6400 ft. The field was discovered in 1973. The gas wells were started drilled in 1980 for producing from the Niagara formation. The compositional analysis and the lab data of the Rapid River 35 fluid are listed in Table 4.

Table 4: Compositional Analysis & Lab Data of Rapid River 35 Fluid.

Component	Mole Fraction
CO₂	1.15
N₂	0.14
C₁	84.15
C₂	4.79
C₃	2.56
iC₄	2.05
nC₄	1.47
iC₅	0.88
nC₅	0.37
C₆	0.61
C₇₊	1.83

Properties of Heptane Plus	
C₇₊ Molecular Weight	129
C₇₊ Specific Gravity	0.773
Dew Point Pressure	3309 psia
Reservoir Temperature	114 deg F

3.1.3 Cold Spring 12 Gas Condensate Field, Michigan, USA

Cold Spring 12 is a gas condensate field located in the Kalkaska County in northern of Michigan in USA (Katz et al., 1981). The field was discovered in 1973. Seven years later, the field was start producing from Niagara formation at depth of 6600 ft. The compositional analysis and the lab data of the Cold Spring 12 gas condensate fluid are listed in Table 5.

Table 5: Compositional Analysis & Lab Data of Cold Spring 12 Fluid.

Component	Mole Fraction
CO₂	0.001
N₂	0.79
C₁	80.099
C₂	7.46
C₃	3.70
iC₄	1.75
nC₄	1.30
iC₅	0.84
nC₅	0.39
C₆	0.84
C₇₊	2.83

Properties of Heptane Plus	
C₇₊ Molecular Weight	125
C₇₊ Specific Gravity	0.773
Dew Point Pressure	3620 psia
Reservoir Temperature	114 deg F

3.1.4 Chester 15 Gas Condensate Field, Michigan, USA

Chester 15 is a gas condensate field located in the Otsego County in northern of Michigan in USA (Katz et al., 1981). The depth of targeted formation was 6130 ft. The

field was discovered in 1970. In 1971, the field started producing from the Niagaran-pinnacle reef. The compositional analysis and lab data of the Chester 15 fluid are listed in Table 6.

Table 6: Compositional Analysis & Lab Data of Chester 15 Fluid.

Component	Mole Fraction
CO₂	0.24
N₂	0.71
C₁	78.50
C₂	8.22
C₃	4.19
iC₄	1.83
nC₄	1.70
iC₅	1.16
nC₅	0.61
C₆	0.90
C₇₊	1.94

Properties of Heptane Plus	
C₇₊ Molecular Weight	123
C₇₊ Specific Gravity	0.756
Dew Point Pressure	2668 psia
Reservoir Temperature	113 deg F

3.1.5 Khuff 4 Gas Condensate Field, Qatar

Khuff 4 is a gas condensate field of Khuff reservoir located offshore in the northwest of Qatar (Almaary, 1983). The gas field covers an area of 9700 square kilometers, of which 3700 square kilometers (South Pars) is in Iranian territorial waters and 6000 square kilometers (North Dome) is in Qatari territorial waters. The field was discovered in 1971. The field started producing in 1989 from Khuff formation at a depth of 9,400 ft. The North Field Khuff formation is a competent limestone. It is the largest single accumulation of natural gas in the world. The compositional analysis and lab data of the Khuff 4 fluid are listed in Table 7.

Table 7: Compositional Analysis & Lab Data of Khuff 4 Fluid.

Component	Mole Fraction
H₂S	0.54
CO₂	1.78
N₂	3.38
C₁	82.77
C₂	5.29
C₃	1.96
iC₄	0.42
nC₄	0.71
iC₅	0.29
nC₅	0.29
C₆	0.42
C₇₊	2.15

Properties of Heptane Plus	
C₇₊ Molecular Weight	135.6
C₇₊ Specific Gravity	0.76
Dew Point Pressure	5120 psia
Reservoir Temperature	220 deg F

3.1.6 Dakhni Gas Condensate Field, Pakistan

Dakhni (*Core laboratory report*, 1986) is a gas condensate field located about 135 km southwest of Islamabad. The field was discovered in February 1983 and came on production in the end of 1989 from Shinwari and Samanasuk formations at a approximate depth of 15900 ft. The compositional analysis and lab data of the Dakhni fluid are listed in Table no. 8.

Table 8: Compositional Analysis & Lab Data of Dakhni Fluid.

Component	Mole Fraction
H₂S	8.16
CO₂	4.44
N₂	0.72
C₁	80.51
C₂	2.67
C₃	1.15
iC₄	0.24
nC₄	0.30

iC₅	0.16
nC₅	0.13
C₆	0.22
C₇₊	1.30

Properties of Heptane Plus	
C₇₊ Molecular Weight	136.7
C₇₊ Specific Gravity	0.796
Dew Point Pressure	5668 psia
Dew Point Temperature	220 deg F

3.2 Application of the Existing Techniques

The extended compositional analysis must be calculated or estimated in the absence of the detailed analytical data. The existing splitting schemes (Katz, Ahmed and Marching) have been used to predicate the compositional distribution of the C₇₊ fraction. The results are compared in order to evaluate each scheme. All the splitting methods were test of fluid of Pazanan field. The lab results of heptane plus the Pazanan field are as following:

- Mole Fraction: $Z_{C7+} = 3.12$
- Molecular Weight: $MW_{C7+} = 132$
- Specific Gravity: $SG_{C7+} = 0.774$
- The Retrograde Dew Point Pressure = 4076 psia

All the splitting schemes are use to spitted the heptane plus to different number of components ($n = 15, 16, 17, \dots 35$) and the best results are shown. The following equations are used to calculate the mole fraction, the molecular weight and the specific gravity:

1. The mole fraction of the heptane plus:

$$Z_{C7+} = \sum_{n=7}^{n+} Z_n$$

2. The molecular weight of the heptane plus:

$$MW_{Cn+} = \frac{z_{7+}MW_{7+} - \sum_{n=7}^{(n+)-1} [z_n MW_n]}{z_{n+}}$$

3. The specific gravity of the heptane plus:

$$\gamma_{cn+} = \frac{z_{cn+}MW_{cn+}}{\frac{z_{7+}MW_{7+}}{\gamma_{7+}} - \sum_{n=7}^{(n+)-1} \frac{z_n MW_n}{\gamma_n}}$$

4. The retrograde dew point pressure is calculated by using the PC version of P-R-AGA software.

3.2.1 Application of Splitting Schemes to Pazanan Field Data

Table 9 summarizes the prediction results of applying Katz's method to predict the molar distribution of extended C_{7+} . The molar distribution of heptane-plus predicted by Katz's method with 30 components is shown in Table 12 and Figure 5.

Table 9: The Prediction Results of Katz's Method.

Splitting Method	Katz's Splitting Scheme	
Number of Components	30	
Calculated Specific Gravity	0.685	-11 %
Calculated Retrograde Dew Point Pressure	4656 psia	14 %

The prediction results of applying Ahmed's method to predict the molar distribution of extended C_{7+} are summarized in Table 10. The molar distribution of heptane-plus by this method with 30 components is shown in Table 12 and Figure 5.

Table 10: The Prediction Results of Ahmed's Method.

Splitting Method	Ahmed's Extend Method	
Number of Components	30	
Calculated Specific Gravity	0.782	1 %
Calculated Retrograde Dew Point Pressure	4198 psia	3 %

The results of applying Marching method in predicting the molar distribution of extended C_{7+} are tabulated in Table 11. The molar distribution of heptane-plus by Marching with 30 components is shown in Table 12 and Figure 5.

Table 11: The Prediction Results of Marching Technique.

Splitting Method	Marching Technique	
Number of Components	30	
Calculated Specific Gravity	0.782	1.02 %
Calculated Retrograde Dew Point Pressure	4228 psia	3.73 %

Table 12: Experimental and Predicted Extend Compositional Analysis of C_{7+} of Pazanan Field Data.

Fraction	MOLE FRACTION			
	Experimental	Katz's	Ahmed's	Marching
C7	0.75	0.70341	0.93903	0.74557
C8	0.75	0.54290	0.60366	0.82950
C9	0.49	0.41901	0.50881	0.41157
C10	0.31	0.32339	0.27522	0.28756
C11	0.22	0.24959	0.19265	0.20448
C12	0.15	0.19263	0.13987	0.11643
C13	0.12	0.14868	0.10306	0.12041
C14	0.09	0.11475	0.07796	0.08449
C15	0.07	0.08856	0.06020	0.06960
C16	0.17	0.06835	0.04665	0.05661
C17		0.05275	0.03584	0.04448
C18		0.04072	0.02741	0.03383
C19		0.03142	0.02071	0.02453
C20		0.02425	0.01591	0.01791
C21		0.01872	0.01293	0.01425
C22		0.01445	0.00982	0.00964
C23		0.01115	0.00784	0.00712
C24		0.00861	0.00633	0.00529
C25		0.00664	0.00520	0.00403
C26		0.00513	0.00427	0.00301
C27		0.00396	0.00351	0.00222
C28		0.00305	0.00293	0.00168
C29		0.00236	0.00243	0.00124
C30		0.04553	0.01775	0.00455

Figure 5: Comparison of various Splitting Scheme results for Pazanan Field Data.

3.3 Proposed (4-Coefficient) Methodology for Splitting the C_{7+}

The objective of this study as mentioned is to determine an appropriate method for splitting the heptane plus fraction into n components in the hydrocarbon systems. The existing methods for predicting the heptane plus fraction compositions have certain limitations. For that, a model has been proposed to overcome these limitations.

The model has been proposed and verified in this study on the basis of the following conditions:

1. The calculated average molecular weight of the heptanes plus based on the estimated extended analysis should match the reported molecular weight.
2. The calculated average specific gravity of the heptanes plus based on estimated extended analysis should match the reported specific gravity of the heptane plus.

3. The retrograde dew point pressure determined from estimated composite should match the reported value.

The mole fraction, molecular weight, specific gravity and the retrograde dew point pressure of heptanes plus fraction are usually provided with the detailed gas composition analysis. The proposed method here predicts the molar distribution analysis of hydrocarbon in the plus fraction from above mentioned lab data. The resulting composition can then be used to predict the thermodynamics and phase behavior of HC systems by the EOSs.

The steps of the proposed method (4-Coefficient method) are:

1. Start with Ahmed proposed values for the four coefficients as in the following table:

Table 13: S Coefficient Values of 4-Coefficient Method.

Coefficient (S)	No. of Carbon Atoms	S Coefficient Values
1	$n = 7$	15.5
2	$n = 8$	15.5
3	$n = 9$	17.0
4	$n \geq 10$	17.0

2. Knowing the molecular weight of C_{7+} fraction (MW_{7+}), Calculate the molecular weight of the octane plus fraction (MW_{8+}) by using the following equation:

$$M_{(n+1)+} = M_{7+} + S(n - 6)$$

3. Calculate the mole fraction of the heptane fraction (Z_7) by using the following equation:

$$Z_n = Z_{n+} \left[\frac{M_{(n+1)+} - M_{n+}}{M_{(n+1)+} - M_n} \right]$$

Where:

M_n = Molecular Weight of the n fraction recommended by Katz-Firozabadi shown in the Generalized Physical Properties Table (APPENDIX II).

4. Repeat steps 2 and 3 for each component in the system ($C_8, C_9, C_{10}, \dots, C_n$).
5. Calculate the average specific gravity for predicted molar distribution using the published values of molecular weights and specific gravities by Katz-Firozabadi (APPENDIX II). The average specific gravity for the predicted molar distribution is calculated as follows:

$$\overline{SG}_{C_{7+}} = \frac{\sum_{i=7}^n (Z_n \times MW_n \times SG_n)}{Z_{C_{7+}} \times \overline{MW}_{C_{7+}}}$$

Where:-

SG_n = Specific Gravity of the n fraction recommended by Katz-Firozabadi shown in the Generalized Physical Properties Table (APPENDIX II).

6. Determine the retrograde dew point pressure by using the predicted composition as input to the PC-version of the P-R-AGA program.
7. Compare the calculated average specific gravity of C_{n+} and the determined retrograde dew point pressure with the reported values given in the HC Analysis and the C_{7+} properties. If the values not close enough (within 3 %), change the values of S coefficients and repeat the steps 5 and 6 until get the best matching results.

To explain the methodology in detail, an example is shown and discussed in the following section. The data used is Pazanan Gas Condensate Sample from Iran. The results will be compared with the three previous methods that are applied.

3.3.1 Splitting Sample of Pazanan Field by 4-Coefficient Method

The published data of Pazanan gas condensate field, shown in Table 3, is used as an example to explain the 4-Coefficient methodology. Samples from the Pazanan gas condensate reservoir were taken by the Core Laboratories, from the recombination of

separator samples for experimental PVT measurements. The reservoir fluid was reported to at its dew point in the reservoir at pressure of 4076 psia and temperature of 180.5 deg F and depth of 6700 ft.

The slops suggested by Ahmed are used as first attempt. These slopes are shown in Table 13 previously in step no. 1. They are used as a starting point in order to estimate the molar distribution, specific gravity and dew point pressure. The resulting compositional analysis for 30 components is shown in Table 14. The predicted specific gravity of the C_{7+} for this molar distribution was calculated to be 0.782 and the retrograde dew point pressure was predicted to be 4198 psia.

In order to get more matching between the predicted values and the reported values, the slopes have been changed. Also, the splitting has been performed for more than number of components. Table 15 summarized the distributed compositional analysis for $n = 26$ with best results gained from changing the slops. The slopes that are used for this splitting are $S_{n=7}= 11.4$, $S_{n=8}=14$, $S_{n=7}= 16$ and $S_{n\geq 10}= 17.7$. The results show that the new predicted specific gravity is 0.781 with difference less than 1 %. The predicted retrograde dew point pressure is 4076 psia with 0 % difference. The compositional analysis for the sample with 30 components and 26 components is shown in the Figure 6.

The comparison between the proposed model and the existing splitting models is shown in Table 16. The results are presented in values comparing table and percentage comparing table. The splitting results are shown in Figure 7.

The 4-Coefficient method is applied on a different gas condensate field's sample to validate its applicability and accuracy. In the following cases, the molar distribution obtained from the 4-Coefficient method and Ahmed Extend methods (the initial slops values) are compared. Also, their results are compared and shown in tables and figures.

Table 14: The Compositional Analysis for n = 30 for Pazanan Sample using 4-Coefficient First attempt.

SCN	Mn	SGn	Mn+	zn+	MOLE FRACTION	
					4-Coefficient	Experimental
7	96	0.727	132	3.1200	0.93903	0.75
8	107	0.749	147.5	2.1810	0.60366	0.75
9	121	0.768	163	1.5773	0.50881	0.49
10	134	0.782	183	1.0685	0.27522	0.31
11	147	0.793	200	0.7933	0.19265	0.22
12	161	0.804	217	0.6006	0.13987	0.15
13	175	0.815	234	0.4608	0.10306	0.12
14	190	0.826	251	0.3577	0.07796	0.09
15	206	0.836	268	0.2797	0.06020	0.07
16	222	0.843	285	0.2195	0.04665	0.17
17	237	0.851	302	0.1729	0.03584	
18	251	0.856	319	0.1370	0.02741	
19	263	0.861	336	0.1096	0.02071	
20	275	0.866	353	0.0889	0.01591	
21	291	0.871	370	0.0730	0.01293	
22	300	0.876	387	0.0601	0.00982	
23	312	0.881	404	0.0503	0.00784	
24	324	0.885	421	0.0424	0.00633	
25	337	0.888	438	0.0361	0.00520	
26	349	0.892	455	0.0309	0.00427	
27	360	0.896	472	0.0266	0.00351	
28	372	0.899	489	0.0231	0.00293	
29	382	0.902	506	0.0202	0.00243	
30	394	0.905	523	0.0178	0.01775	

SCN	S Values
$n = 7$	15.5
$n = 8$	15.5
$n = 9$	17
$n > 10$	17

C7+ Properties:	Results	%
ZnC7+ =	3.12	0.00
MWC7+ =	131	-0.56
SGC7+ =	0.782	1.02
Dew Point Pressure =	4198	2.99

Table 15: The Compositional Analysis for n = 26 for Pazanan Sample using 4-Coefficient First attempt.

SCN	Mn	SGn	Mn+	zn+	MOLE FRACTION	
					4-coefficient	Experimental
7	96	0.727	132	3.1200	0.75038	0.75
8	107	0.749	143.4	2.3696	0.74218	0.75
9	121	0.768	160	1.6274	0.55167	0.49
10	134	0.782	180	1.0758	0.35650	0.31
11	147	0.793	202.8	0.7193	0.17321	0.22
12	161	0.804	220.5	0.5461	0.12520	0.15
13	175	0.815	238.2	0.4209	0.09208	0.12
14	190	0.826	255.9	0.3288	0.06961	0.09
15	206	0.836	273.6	0.2592	0.05378	0.07
16	222	0.843	291.3	0.2054	0.04179	0.17
17	237	0.851	309	0.1636	0.03228	
18	251	0.856	326.7	0.1313	0.02489	
19	263	0.861	344.4	0.1064	0.01901	
20	275	0.866	362.1	0.0874	0.01477	
21	291	0.871	379.8	0.0727	0.01208	
22	300	0.876	397.5	0.0606	0.00931	
23	312	0.881	415.2	0.0513	0.00751	
24	324	0.885	432.9	0.0438	0.00612	
25	337	0.888	450.6	0.0376	0.00508	
26	349	0.892	468.3	0.0326	0.03257	

SCN	S Values
$n = 7$	11.4
$n = 8$	14
$n = 9$	16
$n > 10$	17.7

C7+ Properties:	Results	%
ZnC7+ =	3.12	0.00
MWC7+ =	131	-0.94
SGC7+ =	0.781	0.92
Dew Point Pressure =	4076	0.01

Figure 6: The compositional analysis for the sample with 30 and 26 component.

Table 16: The Comparison of the Splitting methods with the proposed Methodology.

C7+ Properties	Lab Reported Results	The Splitting Methods			
		Katz Method	Ahmed Method	Marching Technique	4-Coefficient Method
Mole Fraction	3.12	3.12	3.12	3.12	3.12
Molecular Weight	132	144	131	132	131
Specific Gravity	0.774	0.685	0.782	0.782	0.781
Retrograde D. P. P.	4076	4656	4198	4228	4076

% Difference					
Mole Fraction					
Molecular Weight		8.71	-0.56	-0.05	-0.94
Specific Gravity		-11.44	1.02	1.08	0.92
Retrograde D. P. P.		14.23	2.99	3.73	0.01

Figure 7: Comparison of Various Splitting Scheme Results with the 4-Coefficient Result for Pazanan Field Data.

3.4 Verification

3.4.1 Rapid River 35 Field

The Rapid River 35 is a gas condensate reservoir in Niagran-pinnacle reef in north of Michigan State. Its initial reservoir pressure was 3485 psia with temperature of 114 deg F. The reservoir dew point pressure was 3309 psia. The C_{7+} mole fraction was 1.83. The molecular weight and the specific gravity were 129 and 0.773, consequentially. The molar distribution of the heptane plus was predicted using 4-Coefficient method for different number of components. The best splitting results are gained with 25 fractions and 15 fractions. These results are reported and compared with lab experimental and initial slops extended scheme.

3.4.2 Cold spring 12 Field

The Cold Spring 12 is a gas condensate reservoir in a Niagran-pinnacle reef in north of Michigan State. It had an initial reservoir pressure of 3453 psia and a reservoir temperature of 114 deg F. The measured reservoir dew point pressure was 3620 psia. The C_{7+} mole fraction was 2.83. The heptane plus fraction had an average molecular weight of 125 and a specific gravity of 0.773. The molar distribution of the heptane plus was predicted using the 4-Coefficient method for different number of components. The best results of number of components are ($n = 30$) and ($n = 23$).

3.4.3 Chester 15 Field

The Chester 15 is a gas condensate reservoir in a Niagran-pinnacle reef in north of Michigan State. It had an initial reservoir pressure of 3103 psia and a reservoir temperature of 113 deg F. The measured reservoir dew point pressure was 2668 psia. The C_{7+} mole fraction was 1.94. The heptane plus fraction had an average molecular weight of 123 and a specific gravity of 0.756. The molar distribution of the heptane plus was predicted using the 4-Coefficient method for different number of components. It was difficult to get good results. It was needed to lower the number of components to 12 components or even less to come closer to the reported data.

3.4.4 Khuff 4 Field

The Khuff 4 is an offshore gas condensate reservoir in north field of Khuff reservoir on the northwest tip of Qatar. Constant volume depletion at 220 deg F gave a retrograde dew point pressure of 5120 psia. The C_{7+} mole fraction was 2.15. The heptane plus fraction had an average molecular weight of 135 (estimated) and a specific gravity of 0.76. The molar distribution of the heptane plus was predicted using the 4-Coefficient method for different number of components. The best results of number of components ($n=30$) are reported and compared with other compositional analysis. The adjustment of heavy fractions critical properties such as temperature, pressure and acentric factor can reduce

the dissimilarities between the predicted and measured dew point pressure. In considering to this fact, the critical properties of the heptane plus were increased by 0.08 %

3.4.5 Dakhni Field

The Dakhni field is a gas condensate reservoir in the Potwar Region basin in northern side of Pakistan. The reported well stream analysis displayed an unusual behavior for this condensate. The reservoir temperature estimated to be 220 deg F (Calculated from Temperature-Depth relation) and a retrograde dew point pressure of 5668 psia. The C_{7+} mole fraction was 1.3. The heptane plus fraction had an average molecular weight of 136 (estimated) and a specific gravity of 0.796. The molar distribution of the heptane plus was predicted using the 4-Coefficient method for different number of components. In order to reduce the dissimilarities between the predicted and measured dew point pressure, it was necessary to adjust critical properties for heavy fractions such as temperature, pressure and acentric factor which were decreased by 60 % for this case.

Moreover, the gas reservoir depletion analysis was performed to evaluate the accuracy of the 4-Coefficient method as compare to the existing methods. The depletion calculations provide the constant volume depletion (CVD) result at series of pre-specified pressures at reservoir temperature. The outlet provides the composition of produced gas, the percentage of reservoir gas produced, the liquid volume percentage, the two phase compressibility factor, the molecular weights of heptane plus and the specific gravity of heptane plus. The calculated properties from the extended calculations were also used to aid in the comparison.

To evaluate the accuracy of the results, the laboratory determined extended composition was used with Phase Behavior Package to run similar CVD. The result of this run was used as the basis for comparing various methods. These comparisons are presented as absolute percentages of differences and then they are averaged in order to check its result against the Extended Composition CVD composition result.

Figure 8 and Table 17 summarize the results of the comparison among various techniques and Extended Composition CVD results for fraction of Heptane plus in the produced well stream. As it can be seen, the 4-Coefficient method results are closest to Extended Composition CVD results.

Figure 8: Comparison of the Heptane plus in Gas Phase.

For the percentage of the produced well stream, the 4-Coefficient method is shown the least deviation as compare to Extended Composition CVD results. These results are shown in Figure 9 and Table 17.

In comparing the Volume % liquid with the Extended Composition CVD results, the 4-Coefficient method is giving the least difference among all splitting methods with 8%. The results are drawn in Figure 10 and presented in Table 17.

Figure 9: Comparison of the Well Stream Produced.

Figure 10: Comparison of the Volume % Liquid.

The calculated 2-phase Gas Compressibility Factor (Z) is presented in Table 17. All the methods are shown close values to the Extended Composition CVD results but the 4-Coefficient is giving the least difference as it can be seen in Figure 11.

Figure 11: Comparison of the Compressibility Factor of Gas (Z) 2p.

The same conclusion was also reached for the heptane plus molecular weight and specific gravity when comparing the 4-Coefficient method and the splitting methods with the Extended Composition CVD results as illustrated in Figure 12, Figure 13 and summarized in Table 17.

For the calculated properties from the extended composition, the 4-Coefficient is presenting the least average difference from the Extended Composition CVD results with only 0.42 %. The calculated properties and the comparisons are presented in Table 17.

Figure 12: Comparison of the Molecular Weight of the Heptane plus.

Figure 13: Comparison of the Specific Gravity of Heptane plus.

Table 17: The Summary of Gas Depletion Calculations and the Absolute Difference Percentages.

Property	Pressure							ABS percentage difference			
	Psia	Experiment	Katz	Ahmed	Marching	4-Coefficient	Actual	Katz	Ahmed	Marching	4-Coefficient
Heptane plus in Gas Phase	3422.2	2.59	1.97869	2.41306	2.35712	2.47132	2.51561	21.34	4.08	6.3	1.76
	2624.7	2.01	1.37295	1.71354	1.65239	1.71239	1.69673	19.08	0.99	2.61	0.92
	1827.2	1.47	0.9211	1.16148	1.1105	1.13742	1.11748	17.57	3.94	0.62	1.78
	1232.7	1.21	0.72089	0.91476	0.86885	0.88424	0.86751	16.9	5.45	0.15	1.93
	725.2	1.2	0.69374	0.88647	0.83751	0.84931	0.83262	16.68	6.47	0.59	2
							Average=	18.32	4.18	2.06	1.68
Well Stream Produced % of Initial Pressure	4089.2	0	0	0	0	0	0				
	3422.2	11.911	13.09	13.014	13.101	12.989	12.888	1.57	0.98	1.65	0.78
	2624.7	30.766	31.456	31.491	31.577	31.531	31.531	0.24	0.13	0.15	0
	1827.2	52.054	52.006	52.227	52.269	52.269	52.285	0.53	0.11	0.03	0.03
	1232.7	68.406	67.704	68.018	68.026	68.041	68.051	0.51	0.05	0.04	0.01
	725.2	81.205	80.657	81.003	80.987	81.006	81.009	0.43	0.01	0.03	0
							Average=	0.66	0.25	0.38	0.17
Volume % liquid in Cell	4089.2	0	0	0	0	0	0				
	3422.2	1.3	5.7678	3.6251	3.7228	3.4312	2.8838	100.01	25.71	29.09	18.98
	2624.7	3.4	7.0789	5.5223	5.6071	5.5649	5.2023	36.07	6.15	7.78	6.97
	1827.2	4.6	7.2702	6.0363	6.0932	6.0884	5.788	25.61	4.29	5.27	5.19
	1232.7	4.7	6.9103	5.7834	5.8337	5.8205	5.5511	24.49	4.18	5.09	4.85
	725.2	4.4	6.3657	5.2832	5.3345	5.3108	5.0653	25.67	4.3	5.31	4.85
							Average=	42.37	8.93	10.51	8.17
Compressibility Factor of Gas (Z)	4089.2	0.893	0.87643	0.8686	0.867973	0.86732	0.86656	1.14	0.24	0.16	0.09
	3422.2	0.851	0.8435	0.8357	0.8359	0.8342	0.832023	1.38	0.44	0.47	0.26
	2624.7	0.829	0.8203	0.8138	0.8142	0.813	0.811885	1.04	0.24	0.29	0.14

	1827.2	0.833	0.8156	0.8124	0.8125	0.8119	0.811036	0.56	0.17	0.18	0.11
	1232.7	0.844	0.8176	0.8187	0.8183	0.818	0.817153	0.05	0.19	0.14	0.1
	725.2	0.834	0.8031	0.8108	0.8095	0.8097	0.808734	0.7	0.26	0.09	0.12
							Average=	0.81	0.26	0.22	0.14
Molecular Weight of C7+ from Phase	4089.2	132	143.9611	131.5018	132.0448	130.916715	128.1509	12.34	2.61	3.04	2.16
	3422.2	124	143.9611	131.5018	132.0448	130.916715	128.1509	12.34	2.61	3.04	2.16
	2624.7	116	145.6302	132.6509	133.1274	131.8521675	128.7667	13.1	3.02	3.39	2.4
	1827.2	111	148.3729	135.056	135.3974	134.0069328	130.4535	13.74	3.53	3.79	2.72
	1232.7	110	151.259	137.8627	138.0088	136.494706	132.5088	14.15	4.04	4.15	3.01
	725.2	145	153.3544	140.0122	139.9844	138.3778542	134.0931	14.36	4.41	4.39	3.2
							Average=	13.34	3.37	3.63	2.61
Specific Gravity of C7+ from Phase	4089.2	0.774	0.789966	0.776726	0.777353	0.773732201	0.772755	2.23	0.51	0.6	0.13
	3422.2	0.766	0.789966	0.776726	0.777353	0.773732201	0.772755	2.23	0.51	0.6	0.13
	2624.7	0.758	0.791586	0.778043	0.778565	0.774670971	0.773479	2.34	0.59	0.66	0.15
	1827.2	0.753	0.794109	0.780664	0.781002	0.776792921	0.775411	2.41	0.68	0.72	0.18
	1232.7	0.752	0.796639	0.783585	0.78369	0.779186886	0.777688	2.44	0.76	0.77	0.19
	725.2	0.786	0.79841	0.785738	0.785654	0.780953174	0.779393	2.44	0.81	0.8	0.2
							Average=	2.35	0.64	0.69	0.16
properties from extended calculation	ZnC7+ =	3.12	3.12	3.12	3.1	3.12		0	0	0.64	0
	MW=	132	144	131	131.9	131		8.71	0.56	0.05	0.94
	SG=	0.774	0.685	0.782	0.782	0.781		11.44	1.02	1.08	0.92
	Dew P=	4076	4656	4197.99	4227.89	4076.44		14.23	2.99	3.73	0.01
							Average=	8.6	1.14	1.37	0.47

CHAPTER 4: THE RESULTS & DISCUSSIONS

This section summarizes the result of predicting the extended compositions of gas condensate fluid for the studied fields' samples. The results include a comparison of the extended samples mole fractions, extended heptane plus specific gravity and retrograde dew point pressure. The extended compositions using 4-coefficient method are shown with the help of plots and tables for each sample.

4.1 Rapid River 35 Field

Splitting by using the suggested Ahmed's slops results in specific gravity of 0.778 with 1.1 % difference and retrograde dew point pressure of 3647 psia with 10 % difference. However, the calculated specific gravity was 0.774 and the retrograde dew point pressure was 3329 psia for splitting by 4-Coefficient method with 24 components. Also, the specific gravity was 0.772 and the retrograde dew point pressure was 3310 psia for splitting by the proposed method with 15 components. The percentage difference for this method is much less than 1 %. These results prove that the 4-Coefficient methodology can further predict the molar distribution of the heptane plus accurately. These results are summarized in Table 18 and presented in Figure 14.

4.2 Cold spring 12 Field

The initial splitting of predicted molar distribution for C_{7+} resulted in a specific gravity of 0.774 with 0.08 % difference and a retrograde dew point pressure of 3649 psia with 0.81 % difference. However, the calculated specific gravity was 0.773 and the retrograde dew point pressure was 3613 psia for splitting by 4-Coefficient ($n = 30$) components. Also, the specific gravity was 0.773 and the retrograde dew point pressure was 3620 psia for splitting by the proposed method with 23 components. Almost there are no differences for this case. The 4-Coefficient methodology compositions and results with comparing to the lab and initial extension are presented in Figure 15 and summarized in Table 19.

4.3 Chester 15 Field

The predicted molar distribution for C_{7+} initially resulted in a specific gravity of 0.771 with 1.99 % difference and a retrograde dew point pressure of 3153 psia with 18.16 % difference. However, the calculated specific gravity was 0.762 and the retrograde dew point pressure was 2810 psia for splitting by 4-Coefficient method with 12 components. Also, the specific gravity was 0.758 and the retrograde dew point pressure was 2709 psia for splitting by the proposed method with only 11 components. The compositions, results and the comparison are presented in Figure 16 and Table 20.

4.4 Khuff 4 Field

The molar distribution for C_{7+} of the Khuff 4 was predicted using initial slopes and the results were specific gravity of 0.786 with 3.38 % difference and a retrograde dew point pressure of 4260 psia with -16.80 % differences. However, the calculated specific gravity was 0.786 (3.43 % difference) and the retrograde dew point pressure was 4976 psia (-2.82 % difference) for splitting by 4-Coefficient method with 30 components. Increasing these properties by 0.08 % was in a dew point pressure of 5112 psia which is much closer to the reported value. The 4-Coefficient method compositions, results and comparison are presented in Figure 17. The results are summarized in Table 21.

4.5 Dakhni Field

The prediction of molar distribution for C_{7+} initially resulted in a specific gravity of 0.787 (-1.13 %) and a retrograde dew point pressure of 5342 psia (-5.74 %). However, the calculated specific gravity was 0.784 (-1.5 % difference) and the retrograde dew point pressure was 5430 psia (-4.2 % difference) for splitting by 4-Coefficient method with 25 components. It was necessary to adjust the critical properties for the heavier hydrocarbon fractions to achieve retrograde dew point pressure matching. For that, the critical temperatures, pressures and acentric factors were decreased by 60 %. The resulting dew point pressure was 5619 psia with 0.87 percent comparing with the reported pressure of

5668 psia. The 4-Coefficient methodology compositions and results are summarized in Table 22 and presented in Figure 18.

Table 18: Comparisons the Compositional Analysis for Rapid River 35 Field.

Constituents	Experimental	Initial Extend	4-Coefficient	
	n = 16	n = 30	n = 24	n = 15
S. G.	0.773	0.778	0.774	0.772
D. P. Pressure	3309	3647	3329	3310
THE 4 COEFFICIENTS				
n = 7		15.5	10	10
n = 8		15.5	11.75	12
n = 9		17	15	15
n > 10		17	27	19.25
SCN	MOLE FRACTIONS			
7	0.434	0.58501	0.42570	0.42570
8	0.421	0.36425	0.41681	0.42755
9	0.332	0.29873	0.40079	0.38721
10	0.2354	0.15719	0.35916	0.26224
11	0.1455	0.10792	0.05262	0.08064
12	0.1007	0.07709	0.03643	0.05698
13	0.0786	0.05597	0.02624	0.04125
14	0.0475	0.04179	0.01964	0.03083
15	0.0257	0.03189	0.01514	0.11810
16	0.0101	0.02444	0.01189	
17		0.01856	0.00944	
18		0.01403	0.00757	
19		0.01048	0.00610	
20		0.00798	0.00500	
21		0.00643	0.00422	
22		0.00484	0.00349	
23		0.00384	0.00296	
24		0.00308	0.02729	
25		0.00251		
26		0.00205		
27		0.00168		
28		0.00140		
29		0.00115		
30		0.00821		

Table 19: Comparisons the Compositional Analysis for Cold Spring 12 Field.

Constituents	Experimental	Initial Extend	4-Coefficient	
	n = 16	n = 30	n = 30	n = 23
S. G.	0.773	0.774	0.773	0.773
D. P. Pressure	3620	3649	3318	3620
THE 4 COEFFICIENTS				
n = 7		15.5	14.75	14.25
n = 8		15.5	14	14
n = 9		17	13.25	13.5
n > 10		17	13	13
SCN	MOLE FRACTIONS			
7	0.66	0.98573	0.95411	0.93243
8	0.58	0.58339	0.54034	0.56721
9	0.48	0.45850	0.35869	0.37370
10	0.35	0.23119	0.27829	0.25585
11	0.2	0.15413	0.21119	0.21187
12	0.15	0.10742	0.15085	0.15134
13	0.12	0.07629	0.10670	0.10704
14	0.09	0.05587	0.07661	0.07685
15	0.07	0.04190	0.05533	0.05550
16	0.13	0.03157	0.03856	0.03868
17		0.02357	0.02488	0.02496
18		0.01753	0.01493	0.01497
19		0.01288	0.00819	0.00821
20		0.00966	0.00460	0.00462
21		0.00771	0.00302	0.00303
22		0.00572	0.00146	0.00147
23		0.00449	0.00086	0.00226
24		0.00356	0.00052	
25		0.00289	0.00032	
26		0.00234	0.00020	
27		0.00190	0.00012	
28		0.00157	0.00008	
29		0.00129	0.00005	
30		0.00888	0.00011	

Table 20: Comparisons the Compositional Analysis for Chester 15 Field.

Constituents	Experimental	Initial Extend	4-Coefficient	
	n = 16	n = 30	n = 12	n = 11
S. G.	0.756	0.771	0.762	0.758
D. P. Pressure	2668	3153	2810	2709
THE 4 COEFFICIENTS				
n = 7		15.5	14	15.5
n = 8		15.5	15	15.5
n = 9		17	17	17
n > 10		17	17	24
SCN	MOLE FRACTIONS			
7	0.4735	0.70753	0.66244	0.70753
8	0.4775	0.40645	0.44437	0.40645
9	0.3627	0.31170	0.33013	0.31170
10	0.262	0.15339	0.15004	0.27228
11	0.1597	0.10058	0.09838	0.24203
12	0.0916	0.06915	0.25464	
13	0.058	0.04851		
14	0.0315	0.03515		
15	0.0176	0.02611		
16	0.0059	0.01949		
17		0.01442		
18		0.01062		
19		0.00774		
20		0.00576		
21		0.00457		
22		0.00337		
23		0.00263		
24		0.00208		
25		0.00168		
26		0.00135		
27		0.00109		
28		0.00090		
29		0.00074		
30		0.00498		

Table 21: Comparisons the Compositional Analysis for Khuff 4 Field.

Constituents	Experimental	Initial Extend	4-Coefficient	
	n = 20	n = 30	n = 30	+ 0.08 % CP
S. G.	0.76	0.786	0.786	0.786
D. P. Pressure	5120	4260	4976	5112
THE 4 COEFFICIENTS				
n = 7		15.5	15.5	15.5
n = 8		15.5	15.5	15.5
n = 9		17	15	15
n > 10		17	15	15
SCN	MOLE FRACTIONS			
7	0.47	0.59066	0.60481	0.60481
8	0.51	0.39915	0.40185	0.40185
9	0.35	0.38904	0.26857	0.26857
10	0.25	0.18848	0.21301	0.21301
11	0.16	0.13399	0.15607	0.15607
12	0.11	0.09864	0.11742	0.11742
13	0.09	0.07371	0.08878	0.08878
14	0.06	0.05649	0.06848	0.06848
15	0.04	0.04417	0.05364	0.05364
16	0.03	0.03470	0.04183	0.04183
17	0.02	0.02708	0.03197	0.03197
18	0.02	0.02107	0.02405	0.02405
19	0.01	0.01623	0.01764	0.01764
20	0.03	0.01269	0.01315	0.01315
21		0.01044	0.01050	0.01050
22		0.00809	0.00758	0.00758
23		0.00656	0.00585	0.00585
24		0.00536	0.00456	0.00456
25		0.00446	0.00363	0.00363
26		0.00371	0.00288	0.00288
27		0.00309	0.00227	0.00227
28		0.00261	0.00184	0.00184
29		0.00219	0.00146	0.00146
30		0.01737	0.00816	0.00816

Table 22: Comparisons the Compositional Analysis for Dakhni Field.

Constituents	Experimental	Initial Extend	4-Coefficient	
	n = 20	n = 30	n = 25	- 0.60 % CP
S. G.	0.796	0.787	0.784	0.784
D. P. Pressure	5668	5342	5430	5619
THE 4 COEFFICIENTS				
n = 7		15.5	13.5	13.5
n = 8		15.5	15.5	15.5
n = 9		17	18	18
n > 10		17	21	21
SCN	MOLE FRACTIONS			
7	0.27	0.35854	0.32380	0.32380
8	0.34	0.24041	0.28144	0.28144
9	0.24	0.21021	0.22926	0.22926
10	0.14	0.11802	0.16107	0.16107
11	0.31	0.08484	0.06751	0.06751
12		0.06301	0.04892	0.04892
13		0.04739	0.03632	0.03632
14		0.03650	0.02777	0.02777
15		0.02865	0.02174	0.02174
16		0.02256	0.01721	0.01721
17		0.01762	0.01365	0.01365
18		0.01369	0.01088	0.01088
19		0.01051	0.00865	0.00865
20		0.00819	0.00698	0.00698
21		0.00673	0.00585	0.00585
22		0.00518	0.00474	0.00474
23		0.00418	0.00395	0.00395
24		0.00340	0.00333	0.00333
25		0.00282	0.02692	0.02692
26		0.00233		
27		0.00193		
28		0.00163		
29		0.00136		
30		0.01029

Figure 14: Comparisons the Compositional Analysis for Rapid River 35 Field.

Figure 15: Comparisons the Compositional Analysis for Cold Spring 12 Field

Figure 16: Comparisons the Compositional Analysis for Chester 15 Field

Figure 17: Comparisons the Compositional Analysis for Khuff 4 Field.

Figure 18: Comparisons the Compositional Analysis for Dakhni Field.

CHAPTER 5: CONCLUSIONS & RECOMMENDATIONS

The Katz's Splitting Scheme is easy to use but it gives results with much percentage of difference when matching the reporting lab results. The specific gravity and the retrograde dew point pressure differ from the lab results by non-expected percentage, even.

Ahmed's Extend Method is good for splitting and the results are better than Katz method. The specific gravity is different in some cases by one or two percents whereas the retrograde dew point pressure had a range of differing from three to 5%.

The Marching Technique with four specified slopes gave results close to Ahmed Extend Method. This method has deviation in the results about 3 %.

The Lohrenz & Pederson methods need to have the mole fractions for more components heavier than hexane to determine the coefficients A&B. for this reason; they are excluded because there are many samples don't have these heavier components mole fractions provided.

The 4-Coefficient method gives better results comparing to the previous existing methods. Most of the results are within expected range from the reported lab results. In some cases, it is needed to change the critical properties of the heavy fractions by some percent to get retrograde pressure closer. Each case or sample has best number of splitting components which may not applicable for other sample.

The proposed method is recommended to use as splitting scheme since it provides a reliable molar distribution for heavier hydrocarbon fraction. This methodology is validated through comparison with some published data. As a result, the 4-Coefficient method provides a practical basis for studying the gas condensate reservoirs and their phase behaviors.

BIBLIOGRAPHY

- Ahmed, T. H., Cady, G. V. & Story, A. L. (1984). *An accurate method for extending the analysis of C_{7+} . Paper SPE 12916*. Rocky Mountain Regional Meeting. Casper, WY.
- Ahmed, T. H., Cady G. V. & Story, A. L. (1985). *A generalized correlation for characterizing the hydrocarbon heavy fractions. Paper SPE 14266*. Annual Technical Conference and Exhibition. Las Vegas, NV.
- Ahmed, T. H. (2007). *Equations of State and PVT Analysis: Applications for Improved Reservoir Modeling*. Houston, TX: Gulf Publishing Company.
- Almarry, J. A. (1983). Prediction of liquid recovery from a gas condensate reservoir (doctoral dissertation, Petroleum Engineering Department, COMER, WVU 1983).
- Aminian, K. (1989). *Phase equilibrium and reservoir depletion calculations on PC using PR-EO: SPE Computer Applications*. May-June.
- Bradley, H. (1987). *Petroleum engineering handbook*. Richardson, TX: SPE.
- Carsten, Slot-Petersen. (1989). *A systematic and consistent approach to determine binary interaction coefficients for the peng-robinson equation of state*”, SPE. Dansk Olie- & Gasproduktion A/S.
- Core laboratory report of Dhakni gas condensate field for oil and gas development corporation*. (1986). Pakistan.
- Firoozabadi, A., Hekim, Y. & Katz, D. (1978). *Reservoir depletion calculation for gas condensate using extended analysis in PR-EOS. Canadian Journal of Chemical Engineering*.
- Hosein, R. (2003). Optimizing the number of components in tuning the Peng-Robinson Equation-of-State for Trinidad’s gas condensates. *Paper SPE 81113, Latin*

- American and Caribbean Petroleum Engineering Conference*. West Indies, Trinidad.
- Hosein, R., McCain, W. D. & Jagai, T. (2008). *How to extend the heptanes plus fraction for gas condensate systems for use in compositional simulation*. Paper SPE 113839. 2008 SPE Europec/EAGE Annual Conference and Exhibition. Rome, Italy, 9–12 June.
- Ikoku, C. U. (1984). *Natural gas reservoir engineering*. John Wiley & Sons.
- Katz, D. (1983). *Overview of phase behavior of oil and gas production*. *Journal of Petroleum Technology*. pp. 1205–1214.
- Katz D. L., Firoozabadi, A. (1978). *Predicting phase behavior of condensate/crude oil systems using methane interaction coefficients*. *Journal of Petroleum Technology*. pp. 6721.
- Katz, D. L., Herzog, R. A., & Hekim, Y. (1981). *Predicting yield of revaporized condensate in gas storage*. SPE 10166. Proceedings of Fall SPE Annual Technical Conference. San Antonio, TX.
- Lohrenz, J., Bra, G. B., & Clark, R. C. (1964). *Calculating viscosities of reservoir fluids from their compositions*. *Journal of Petroleum Technology*. pp. 1171–1176.
- Malik, Q. M. (1990). A systematic methodology for determining gas-condensate extended compositional analysis (Master thesis, WVU, 1990).
- Melkaveri, S. R. (2007). *Compositional analysis and phase behavior prediction of heptanes plus components*. Morgantown, WV: CEMR, WVU.
- Peng, D. Y. & Robinson, D. B. (1976). *A new two constant equation of state*. *Industrial Engineering and Chemistry Fundamentals*.

- Pedersen, K., Thomassen, P. & Fredenslund, A. (1982). Phase equilibria and separation process. Report SEP 8207. Institute for Kemiteknik, Denmark. Tekniske Højskole.
- Redlich, O. & Kwong, J. N. S. (1949). *Thermodynamics of solutions v. an equation of state fugacities of gaseous solutions*. Chem. Rev. 44. pp. 233.
- Robinson, D. B., & Peng, D. Y. (1978). *The characterization of the heptanes and heavier fractions*. (Report No. 28). Tulsa, OK: GPA.
- Soave, G. (1972). *Equilibrium constant from a modified Redlich-Kwong equation of state*. Chem. Engr. Sci, 27. pp. 1197.
- Van der Waals, J. D. (1873). *On the Continuity of the Liquid and Gaseous State (doctoral dissertation)*. Universiteit Leiden. Leiden, Netherlands.

APPENDIX: GENERALIZED PHYSICAL PROPERTIES

Group	Tb, °R	SG	K	M	Tc, °R	Pc, psia	w	Vc, ft ³ /lb
C6	607	0.69	12.27	84	923	483	0.250	0.06395
C7	685	0.727	11.96	96	985	453	0.280	0.06289
C8	702	0.749	11.87	107	1036	419	0.312	0.06264
C9	748	0.768	11.82	121	1085	383	0.348	0.06258
C10	791	0.782	11.83	134	1128	351	0.385	0.06273
C11	829	0.793	11.85	147	1166	325	0.419	0.06291
C12	867	0.804	11.86	161	1203	302	0.454	0.06306
C13	901	0.815	11.85	175	1236	286	0.484	0.06311
C14	936	0.826	11.84	190	1270	270	0.516	0.06316
C15	971	0.836	11.84	206	1304	255	0.550	0.06325
C16	1002	0.843	11.87	222	1332	241	0.582	0.06342
C17	1032	0.851	11.87	237	1360	230	0.613	0.0635
C18	1055	0.856	11.89	251	1380	222	0.638	0.06362
C19	1077	0.861	11.91	263	1400	214	0.662	0.06372
C20	1101	0.866	11.92	275	1421	207	0.690	0.06384
C21	1124	0.871	11.94	291	1442	200	0.717	0.06394
C22	1146	0.876	11.95	300	1461	193	0.743	0.06402
C23	1167	0.881	11.95	312	1480	188	0.768	0.06408
C24	1187	0.885	11.96	324	1497	182	0.793	0.06417
C25	1297	0.888	11.99	337	1515	177	0.819	0.06431
C26	1226	0.892	12.00	349	1531	173	0.844	0.06438
C27	1244	0.896	12.00	360	1547	169	0.868	0.06443
C28	1262	0.899	12.02	372	1562	165	0.894	0.06454
C29	1277	0.902	12.03	382	1574	161	0.915	0.06459
C30	1294	0.905	12.04	394	1589	158	0.941	0.06468
C31	1310	0.909	12.04	404	1603	143	0.897	0.06469
C32	1326	0.912	12.05	415	1616	138	0.909	0.06475
C33	1341	0.915	12.05	426	1629	134	0.921	0.0648
C34	1355	0.917	12.07	437	1640	130	0.932	0.06489
C35	1368	0.92	12.07	445	1651	127	0.942	0.0649
C36	1382	0.922	12.08	456	1662	124	0.954	0.06499
C37	1394	0.925	12.08	464	1673	121	0.964	0.06499
C38	1407	0.927	12.09	475	1683	118	0.975	0.06506
C39	1419	0.929	12.10	484	1693	115	0.985	0.06511
C40	1432	0.931	12.11	495	1703	112	0.997	0.06517
C41	1442	0.933	12.11	502	1712	110	1.006	0.0652
C42	1453	0.934	12.13	512	1720	108	1.016	0.06529
C43	1464	0.936	12.13	521	1729	105	1.026	0.06532
C44	1477	0.938	12.14	531	1739	103	1.038	0.06538
C45	1487	0.94	12.14	539	1747	101	1.048	0.0654