

Grouping and Characterisation of Heavy Hydrocarbon Fractions for Phase Behavior Modeling of Kazakhstani Reservoir Fluids

Bolatbek Khusain

D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry, Almaty 050010, Kazakhstan
b.khusain@ifce.kz

Alfiya Khussainova

Kazakh-British Technical University, Almaty, 050000, Kazakhstan
a.khussainova@kbtu.kz (corresponding author)

Jamilyam Ismailova

Satbayev University, Almaty, 050000, Kazakhstan
j.ismailova@satbayev.university

Dinara Delikesheva

Satbayev University, Almaty, 050000, Kazakhstan
d.delikesheva@satbayev.university

Alexandr Brodskiy

Kazakh Institute of Oil and Gas, Almaty 050000, Kazakhstan
albrod@list.ru

Alexandr Sass

Kazakh Institute of Oil and Gas, Almaty 050000, Kazakhstan
aleksandr-sass@mail.ru

Abzal Kenessary

Kazakh Institute of Oil and Gas, Almaty 050000, Kazakhstan
a.kenessary@king.kz

Ranida Tyulebayeva

Kazakh Institute of Oil and Gas, Almaty 050000, Kazakhstan
r.tyulebayeva@king.kz

Adel Sarsenova

Kazakh Institute of Oil and Gas, Almaty 050000, Kazakhstan
a.sarsenova@king.kz

Tumen Darzhokov

Kazakh Institute of Oil and Gas, Almaty 050000, Kazakhstan
t.darzhokov@king.kz

Saida Samigmatova

Kazakh Institute of Oil and Gas, Almaty 050000, Kazakhstan
s.samigmatova@king.kz

Received: 26 June 2025 | Revised: 3 September 2025 | Accepted: 13 September 2025

Licensed under a CC-BY 4.0 license | Copyright (c) by the authors | DOI: <https://doi.org/10.48084/etasr.12959>

ABSTRACT

In this paper, a rigorous approach is reported for the grouping of the C7+ fraction via the gamma distribution of Whitson to create pseudo-components. The parameters of the gamma distribution were chosen to optimally match the molecular weight distribution of the original heavy end so that a representative simplification was possible. The Peng-Robinson Equation of State (EoS) was fitted to the derived pseudo-component properties and Binary Interaction Parameters (BIPs) for thermodynamic consistency. The approach was applied to a test reservoir fluid from a Kazakhstani oil field, and phase behavior was simulated for the lumped and detailed composition. The results confirmed considerable consistency in the predicted phase envelopes to demonstrate that the grouping method preserved key fluid properties. This integration of Whitson-based lumping with EoS adjustment provided sound justification for delumping and phase behavior modeling in compositional simulations as well as surface facility design.

Keywords-compositional modeling; heavy hydrocarbon fractions; lumping; phase behavior simulation; gamma-distribution

I. INTRODUCTION

Crude oil is a complex mixture of hydrocarbon and non-hydrocarbon compounds with varying molecular weights and phase behavior characteristics. Accurate modeling of such properties is important for the optimization of extraction, transportation, and refining. Compositional reservoir simulation, though, is computationally demanding when there are hundreds of components in the fluid model. To solve this issue, the heavy fraction of the fluid - typically C7+ - is commonly lumped into a limited number of pseudo-components using statistically representative methods that aim to have the least number of components but with thermodynamic precision [1].

Among these techniques, the Whitson gamma distribution approach has been particularly effective for preserving the key thermodynamic behavior while significantly reducing computational complexity. To ensure the reliability of subsequent phase behavior modeling, EoS such as the Peng-Robinson formulation was utilized, with its applicability being extremely sensitive to the characterization of the heavy fraction. When applied separately, lumping and phase modeling may lead to inconsistencies, thereby reducing the reliability of the simulation results.

The present study addresses this limitation by incorporating a gamma distribution-based lumping procedure on a Peng-Robinson EoS applied to a reservoir fluid sample from a Kazakhstani oil field, focusing on components heavier than heptane [2]. The approach is supported by a specialized code for producing pseudo-components, which was validated against field data. The novelty of this study is that it bridges the gap between lumping and phase behavior calibration with an efficient and reproducible approach to compositional modeling in under characterized oil fields lacking complex C7+ property data.

II. LITERATURE REVIEW

Modeling the phase behavior of hydrocarbon mixtures requires an acceptable representation of both light and heavy components with accuracy. The heptane-plus (C7+) fraction is particularly difficult due to its complex composition and lack of experimental data, which are typically confined to bulk properties, such as molecular weight and specific gravity. The whole inclusion of components in the C7+ fraction in compositional reservoir simulations is not feasible, as it

significantly contributes to computational demands. To avoid this issue, grouping or lumping procedures are widely deployed to reduce the number of components while preserving important thermodynamic behavior.

Strategies for representing the C7+ fraction in compositional modeling have been investigated. One of the most widely adopted approaches is the gamma distribution-based lumping method originally introduced by Whitson, which enables the construction of pseudo-components based on the molecular weight distribution of the heavy fraction [3]. This method utilizes optimized shape (γ) and shift (τ) parameters to closely match experimental molecular weight profiles and is particularly effective for defining pseudo-component boundaries and molar fractions [4]. Authors in [1] employed lumped-component Liquid Vapor Equilibrium (LVE) composition, split parameters, and EoS parameters to approximate detailed-component K -values and material balances. Their calibration between oil and gas compositions in a ternary interpretation provided specific information, but not about the projected composition trend. Authors in [5] contributed significantly to the advancement of lumping procedures by integrating lumping schemes with phase behavior calculations, establishing a structured framework for pseudo-component characterization based on thermodynamic properties and VLE conditions. Their contributions enabled consistent linkage between grouped systems and EoS parameters, laying the groundwork for modern flash calculations.

Furthermore, classical correlations remained fundamental in determining the critical temperature (T_c), pressure (P_c), acentric factor (ω), and molecular weight of hydrocarbon fractions. These correlations facilitated the estimation of component properties in cases where experimental data were limited, especially for heavier fractions (C20+ to C80+). Such correlations were indispensable for parameterizing pseudo-components and ensuring the reliability of subsequent EOS-based modeling [6].

III. METHODOLOGY

In this study, the Whitson gamma distribution model was applied to the C7+ fraction of the reservoir fluid, in order to reduce the number of components into four pseudo-components. Their properties were estimated using Watson and Kesler-Lee correlations, and they were used as inputs for EoS calibration.

The pseudo-component determines the category of the purest parts, which are connected together and also assume a single element with Single Carbon Number (SCN) [1]. The SCN groups in petroleum mixtures contain hundreds of isomers with the same number of carbon atoms and similar boiling points. It is impossible to establish the original value of the molecular weight due to the uncertainty of isomers. For instance, components with molecular mass of hydrocarbon groups M_{i-1} to M_i are combined into the i -th pseudo-component.

A. Gamma Distribution Model

The three parameter gamma distribution model is used for describing the molar distribution:

$$f(M) = \frac{(M-\tau)^{\gamma-1} \exp\left(-\frac{M-\tau}{\beta}\right)}{\beta^\gamma \Gamma(\gamma)} \tag{1}$$

where Γ is the gamma function and β is given by:

$$\beta = \frac{M_{C7+}-\tau}{\gamma} \tag{2}$$

where τ is the minimum molecular weight of the C7+ fraction, and γ controls the shape of $f(M)$.

The pseudo-component molar fractions and molecular weights are obtained using quadrature integration:

$$\sum_{k=1}^n W_k^{(n)} z_{total} = z_{total} \sum_{k=1}^n W_k^{(n)} = z_{total} \tag{3}$$

$$z_k = \sum_{k=1}^n W_k^{(n)} z_{total} \tag{4}$$

$$M_k = \frac{M_{total}}{z_{total}} \frac{1}{\Gamma(\gamma)} X^{\gamma-1} \tag{5}$$

The quadrature points are presented in Table I. The range of γ is usually from 0.5 to 2.5. To determine it, the C7+ tail was constructed, and density distribution curves with different values of γ were drawn in order to find the best match with the shape of the C7+. Figure 1 represents the mole fraction versus the molar weight according to the γ distribution.

TABLE I. QUADRATURE POINTS (CHANGE INTEGRATION PARAMETERS)

n = 2	
$X_1 = 0.5858$	$W_1 = 0.8536$
$X_2 = 0.34142$	$W_2 = 0.1464$
n = 3	
$X_1 = 0.4158$	$W_1 = 0.7111$
$X_2 = 2.2943$	$W_2 = 0.2785$
$X_3 = 6.2960$	$W_3 = 0.0104$
n = 4	
$X_1 = 0.3226$	$W_1 = 0.6032$
$X_2 = 4.5366$	$W_2 = 0.3574$
$X_3 = 6.2960$	$W_3 = 0.0384$
$X_4 = 9.3951$	$W_4 = 0.0005$

In order to construct a gamma distribution model, a program code was written. Normal alkanes from methane (C1) to hexatriacontane plus (C36+) make up the reservoir mixture that is in contact with carbon dioxide and nitrogen. The EoS parameters were the same for both groups lumped and detailed fluid. The algorithm of delumping was based on the assumption that the a and b parameters of the EoS were equal

throughout the entire calculation process. Table II presents the composition and component properties of reservoir oil.

TABLE II. COMPOSITION, COMPONENT BIPS FOR THE DETAILED MIXTURE

Component		C CO ₂ -J	C N ₂ -J
Nitrogen	N ₂	0.001482469	0
Carbon dioxide	CO ₂	0	0.001482469
Hydrogen sulfide	H ₂ S	0.000500266	0.000260939
Methane	C1	0.009224393	0.003341736
Ethane	C2	0.001082479	3.14796E-05
Propane	C3	3.0062E-08	0.001495825
Isobutane	i-C4	0.000608985	0.003982309
Butane	n-C4	0.000608985	0.003982309
Isopentane	i-C5	0.001949714	0.00680349
Pentane	n-C5	0.001949714	0.00680349
Hexane	C6	0.003631454	0.009698141
Heptane	C7	0.004903798	0.011699881
Octane	C8	0.006362749	0.013881136
Nonan	C9	0.008213005	0.016529983
Dean	C10	0.009879978	0.018836488
Undecane	C11	0.011466312	0.020978473
Dodecan	C12	0.013051527	0.023077741
Tridecan	C13	0.014516185	0.024986963
Tetradecan	C14	0.015732782	0.026553774
Pentadecan	C15	0.017194421	0.028416143
Hexadecane	C16	0.018172472	0.029651387
Heptadecane	C17	0.019107486	0.030824792
Octadecane	C18	0.019707525	0.031574208
Nonadecan	C19	0.020093274	0.032054567
Eicosane	C20	0.020360969	0.032387282
Geneicosan	C21	0.020537638	0.032606584
Docosane	C22	0.0205256	0.032591649
Triclosan	C23	0.020377209	0.03240745
Tetracosan	C24	0.020098414	0.032060959
Pentacosan	C25	0.019654135	0.031507636
Hexacosan	C26	0.019062249	0.030768182
Heptacosan	C27	0.018266207	0.029769341
Octacosan	C28	0.017373912	0.028643461
Octacosane	C29	0.016339376	0.027329183
Triacontane	C30	0.015164264	0.025823605
Gentriacontane	C31	0.013852635	0.024125314
Dotriacontane	C32	0.012408885	0.022231159
Trtriacontane	C33	0.010840641	0.020139053
Tetratriacontane	C34	0.009160367	0.017848633
Pentatriacontane	C35	0.007388789	0.015363407
Hexatriacontane plus	C36+	0.009178738	0.003314076

B. Reservoir Fluid Sample

The reservoir fluid sample was obtained from a producing oil field X in the Caspian basin, Kazakhstan. This region includes hydrocarbon accumulations, characterized by complex fluid behavior and high concentrations of acid gases (CO₂ and H₂S). Acid gas reinjection is widely practiced to maintain the reservoir pressure and reduce greenhouse emissions, which creates additional challenges for accurate phase behavior modeling. The presence of heavy fractions (C7+) in combination with acid gases requires reliable grouping and delumping procedures to ensure consistent predictions of the fluid properties under reservoir and surface conditions.

The components from C7 through C36+ were divided into four distinct groups. According to [5], based on the detailed component parameter data, the critical temperature, pressure, acentric factor, and BIPs were calculated for pseudo-components. The composition and the properties of the grouped components were assigned and organized in Tables III and IV. Figure 2 displays the phase envelopes of the lumped and detailed mixtures. As observed, the phase boundaries of the detailed and lumped mixtures for bubble points agreed, with some acceptable discrepancies for dew points [7].

TABLE III. COMPONENT COMPOSITION OF LUMPED FLUID

Component	mol (%)	mol (%wt)
N ₂	0.12	28.014
CO ₂	1.00E-03	44.01
C3	0.002	44.097
<i>i</i> -C4	2.283	58.124
<i>n</i> -C4	0.005	58.124
<i>i</i> -C5	3.096	72.151
<i>n</i> -C5	2.594	72.151
C6	4.485	86.178
C7-C11	45.007	190.86
C12-C19	27.339	264.35
C20-C29	10.73	375.15
C30-C80	4.337	508.438
Balance	100	-

TABLE IV. COMPOSITION, PROPERTIES, AND COMPONENT BIPs FOR THE LUMPED MIXTURE

Component		T _c (K)	P _c (bar)	Acentric factor	C CO ₂ -J	C N ₂ -J
Nitrogen	N ₂	126.2	33.94	0.04	0	0
Carbon dioxide	CO ₂	304.2	73.76	0.225	0	0.017
Hydrogen sulfide	C1	190.6	46	0.008	0.12	0.031
Methane	C2	305.4	48.84	0.098	0.12	0.0515
Ethane	C3	369.8	42.46	0.152	0.12	0.0852
Propane	<i>i</i> -C4	408.1	36.48	0.176	0.12	0.1033
Isobutane	<i>n</i> -C4	425.2	38	0.193	0.12	0.08
Butane	<i>i</i> -C5	460.4	33.84	0.227	0.12	0.0922
Isopentane	<i>n</i> -C5	469.6	33.74	0.251	0.12	0.1
Pentane	C6	507.4	29.69	0.296	0.12	0.08
PC-1	C7+	576.58	25.72	0.4129	0.1	0.08
PC-2	C12+	694.64	17.73	0.6844	0.1	0.08
PC-3	C20+	828.62	14.37	1.0132	0.1	0.08
PC-4	C30+	1043.0	12.43	1.1691	0.1	0.08

IV. RESULTS AND DISCUSSION

A. Equation of State Calibration

To ensure accurate phase behavior prediction after lumping, the EoS was properly tuned based on the pseudo-component parameters. For this reason, Peng and Robinson set the following tasks:

- To represent the parameters of the equation through the critical properties of the components.
- To achieve high accuracy in the region of the critical point, mainly for calculating the coefficient of super compressibility Z_c and the densities of liquid phases.

- To expand the applicability of the equation for various calculations of the properties of the liquid phase in a wide range of thermobaric conditions.

The Peng-Robinson equation developed for this purpose is given by [8]:

$$P = \frac{RT}{V-b} - \frac{a(T)}{V(V+b)+b(V-b)} \quad (6)$$

For each component, it is important to specify its molecular mass M , critical parameters of pressure P_c and temperature T_c , and the acentric factor ω [9, 10].

B. Watson Characterization Factor

The Watson characterization coefficient (K_w) describes the hydrocarbon type within a mixture, including aromatic, naphthenic, or paraffinic hydrocarbons. Typical K_w values entail:

- Aromatic hydrocarbons: 8.5 – 11
- Naphthenic hydrocarbons: 11 - 12.5
- Paraffinic hydrocarbons: 12.5 - 13.5

For the C7+ fraction, the Watson factor was calculated by:

$$K_{w,C7+} = 4.5579M^{0.15178}\gamma^{-0.84573} \quad (7)$$

In [11], a table of the relationship between the above parameters and SCN was presented, but after Watson expanded this for heavier components (C45+), he added the Watson coefficient as well as the critical parameters and acentric factors, which in turn were estimated using the Kesler-Lee correlation.

C. Properties for Heavy Fractions

The following relationships were applied to estimate the physical properties of the pseudo-components:

- Molar Weight:

$$M_i = 14n - 4 \quad (8)$$

- Specific Gravity:

$$\gamma_i = \frac{K_{wC7+}}{4.5} \frac{1}{579M_i^{0.15178}} \quad (9)$$

- Molar Concentration:

$$z_{cn} = 1.38205z_{c7+} \exp(-0.25903n) \quad (10)$$

- Boiling Point (in Rankine):

$$T_{bi} = (K_w \gamma_i)^3 = (K_{wc7+} \gamma_i)^3 \quad (11)$$

Knowing these values, the Lee-Kesler correlation was utilized to calculate the critical characteristics of the components:

$$\gamma_i, T_{bi} \rightarrow T_c, P_c, \omega \quad (12)$$

- Critical Temperature (°R):

$$T_{ci} = 341.1 + 811\gamma_i + (0.4244 + 0.1174\gamma_i)T_{bi} + (0.4669 - 3.2623\gamma_i) * 10^{-5} * T_{bi}^{-1} \quad (13)$$

- Critical Pressure (psia):

$$\ln(P_{ci}) = 8.3634 - \frac{0.0566}{\gamma_i} - \left[\left(0.242444 + \frac{2.2898}{\gamma_i} + \frac{0.11857}{\gamma_i^2} \right) * 10^{-3} \right] T_{bi} + \left[\left(1.4685 + \frac{3.648}{\gamma_i} + \frac{0.47227}{\gamma_i^2} \right) * 10^{-7} \right] T_{bi} - \left[\left(0.42019 + \frac{1.6977}{\gamma_i} \right) * 10^{-10} \right] T_{bi}^3 \quad (14)$$

- Acentric Factor:

For $\frac{T_{bi}}{T_{ci}} \leq 0.8$, then:

$$\omega_i = \frac{-\ln\left(\frac{P_{ci}}{14.7}\right) + A_1 + A_2 T_{bri}^{-1} + A_3 \ln(T_{bri}) + A_4 T_{bri}^6}{A_5 + A_6 T_{bri}^{-1} + A_7 \ln(T_{bri}) + A_8 T_{bri}^6} \quad (15)$$

where: $A_1 = -5.92714$, $A_2 = 6.09648$, $A_3 = 6.09648$, $A_4 = -0.169347$, $A_5 = 15.2518$, $A_6 = -15.6875$, $A_7 = -13.4721$, $A_8 = 0.43577$.

For $\frac{T_{bi}}{T_{ci}} > 0.8$, then:

$$\omega_i = -7.904 + 0.1352 K_{WC7+} - 0.007465 K_{WC7+}^2 + 8.359 T_{bri} + (1.408 - 0.01063 K_{WC7+}) T_{bri}^{-1} \quad (16)$$

The grouping procedure of the C7+ fraction based on the Whitson gamma distribution model was not only used to simplify the fluid composition, but also served as the basis for subsequent delumping calculations and flash modeling. The lumped pseudo-components, assigned with consistent critical properties and binary interaction parameters, enabled the calibration of the EoS and provided a reliable input for phase behavior simulations [10-14]. This integrated approach ensured that the simplified fluid model retained the accuracy required for downstream surface facility modeling and compositional reservoir analysis [15, 16].

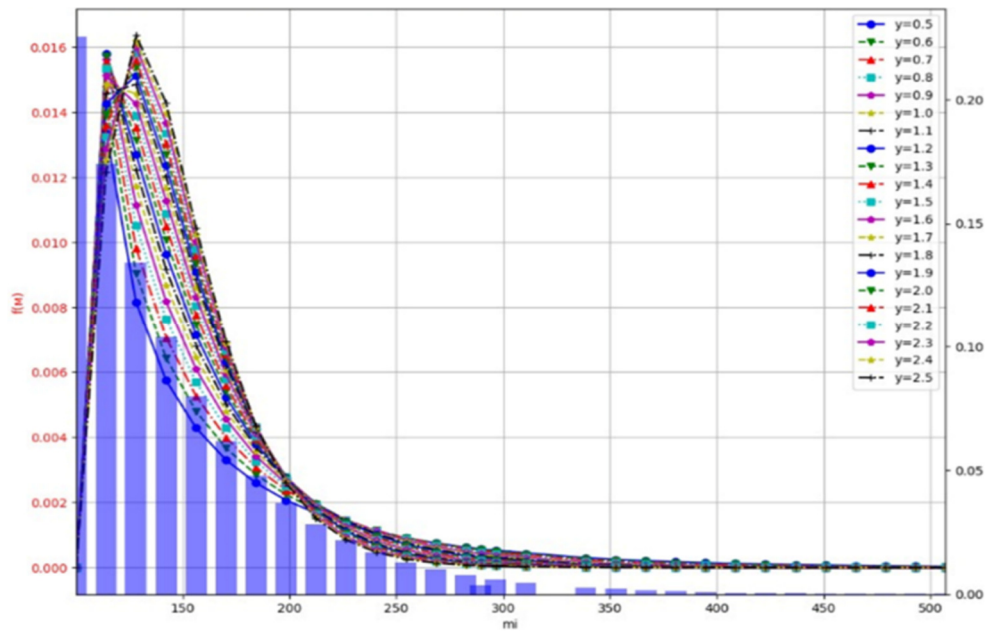


Fig. 1. Gamma distribution of C7+ tail (Sample X) with fitted $\gamma = 1$.

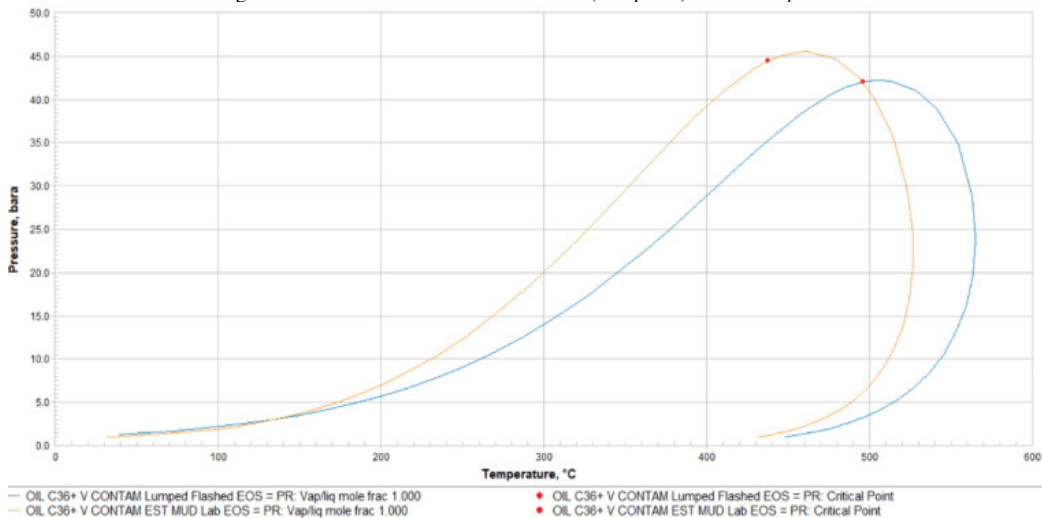


Fig. 2. Phase boundaries for the detailed and lumped mixtures.

TABLE V. CRITICAL PARAMETERS AND ACENTRIC FACTORS FOR A SAMPLE FROM THE X FIELD

Components		Tc (K)	Pc (bar)	Acentric factor, ω	Molecular weight (g/L)
Nitrogen	N ₂	126.2	33.94	0.040	28.014
Carbondioxide	CO ₂	304.2	73.76	0.225	44.01
Hydrogensulfide	H ₂ S	497.4	1.991	0.285	34.08
Methane	C1	576.1	1.949	0.067	16.043
Ethane	C2	628.8	1.920	0.198	30.07
Propane	C3	670.6	1.898	0.152	44.097
Isobutane	i-C4	670.6	1.898	0.176	58.124
Butane	n-C4	706.2	1.878	0.193	58.124
Isopentane	i-C5	706.2	1.878	0.227	72.151
Pentane	n-C5	737.6	1.862	0.251	72.151
Hexane	C6	765.9	1.846	0.296	86.178
Heptane	C7	792.0	1.833	0.337	96
Octane	C8	816.2	1.820	0.374	107
Nonan	C9	838.9	1.808	0.421	121
Dean	C10	860.3	1.796	0.482	134
Undecane	C11	880.7	1.785	0.483	147
Dodecan	C12	900.2	1.775	0.570	160.92
Tridecan	C13	918.8	1.765	0.571	174.98
Tetradecan	C14	936.7	1.755	0.660	187.93
Pentadecan	C15	954.0	1.746	0.661	205.83
Hexadecane	C16	970.7	1.737	0.750	220.12
Heptadecane	C17	986.8	1.728	0.751	236.94
Octadecane	C18	1002.5	1.720	0.828	250.96
Nonadecan	C19	1017.8	1.711	0.829	262.99
Eicosane	C20	1032.6	1.703	0.913	274.99
Geneicosane	C21	1047.1	1.695	0.914	290.99
Docosane	C22	1061.3	1.687	0.915	304.99
Triclosane	C23	1075.1	1.679	1.035	317.99
Tetracosanee	C24	1088.6	1.671	1.036	330.99
Pentacosane	C25	1101.8	1.664	1.037	344.99
Hexacosan	C26	1114.8	1.656	1.038	358.99
Heptacosane	C27	1127.5	1.648	1.039	373.99
Octacosane	C28	1140.0	1.641	1.181	387.99
Nonacosane	C29	1152.3	1.634	1.182	401.99
Triacontane	C30	1164.4	1.626	1.183	46
Gentriacontane	C31	1176.3	1.619	1.184	430
Dotriacontane	C32	1187.9	1.612	1.185	444
Tritriacontane	C33	1199.4	1.604	1.185	458
Tetratriacontane	C34	1210.8	1.597	1.151	472
Pentatriacontane	C35	1221.9	1.590	1.151	486
Hexatriacontane plus	C36+	1221.9	9.290	1.152	632.257

V. CONCLUSION

In this study, a systematic approach to streamline the compositional characterization of heavy hydrocarbon fractions (C7+) was presented using the Whitson gamma distribution model. The proposed grouping procedure adequately reduced the number of components of the reservoir fluid to facilitate faster and more efficient simulations without compromising thermodynamic accuracy. By deploying this lumping approach with a tuned Peng-Robinson Equation of State (EoS), both the phase lumped and detailed system phase behaviors were found to be in excellent agreement. Its application with Kazakhstan reservoir fluids proved its robustness and applicability for compositional modeling, delumping strategies, and surface facility design workflows. This model offered an effective method for complex fluid reservoir engineers with limited experimental data on heavy fractions.

ACKNOWLEDGMENT

The research was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. BR21882241).

REFERENCES

- [1] A. G. Schlijper and J. K. Drohm, "Inverse Lumping: Estimating Compositional Data From Lumped Information," *SPE Reservoir Engineering*, vol. 3, no. 03, pp. 1083–1089, Aug. 1988, <https://doi.org/10.2118/14267-PA>.
- [2] A. Danesh, D. Xu, and A. C. Todd, "A Grouping Method To Optimize Oil Description for Compositional Simulation of Gas-Injection Processes," *SPE Reservoir Engineering*, vol. 7, no. 03, pp. 343–348, Aug. 1992, <https://doi.org/10.2118/20745-PA>.
- [3] C. H. Whitson, "Characterizing Hydrocarbon Plus Fractions," *Society of Petroleum Engineers Journal*, vol. 23, no. 04, pp. 683–694, Aug. 1983, <https://doi.org/10.2118/12233-PA>.
- [4] C. H. Whitson, T. F. Anderson, and I. Soreide, "Application of the Gamma Distribution Model to Molecular Weight and Boiling Point Data for Petroleum Fractions," *Chemical Engineering Communications*, vol.

- 96, no. 1, pp. 259–278, Oct. 1990, <https://doi.org/10.1080/00986449008911495>.
- [5] C. Leibovici, E. H. Stenby, and K. Knudsen, "A consistent procedure for pseudo-component delumping," *Fluid Phase Equilibria*, vol. 117, no. 1–2, pp. 225–232, Mar. 1996, [https://doi.org/10.1016/0378-3812\(95\)02957-5](https://doi.org/10.1016/0378-3812(95)02957-5).
- [6] D. B. Lacerda *et al.*, "Evaluation of Different Correlation Performance for the Calculation of the Critical Properties and Acentric Factor of Petroleum Heavy Fractions," in *Recent Insights in Petroleum Science and Engineering*, London, UK: IntechOpen, 2017.
- [7] S. A. Alavian, C. H. Whitson, and S. O. Martinsen, "Global Component Lumping for EOS Calculations," in *SPE Annual Technical Conference and Exhibition*, Amsterdam, Netherlands, Oct. 2014, <https://doi.org/10.2118/170912-MS>.
- [8] D.-Y. Peng and D. B. Robinson, "A New Two-Constant Equation of State," *Industrial & Engineering Chemistry Fundamentals*, vol. 15, no. 1, pp. 59–64, Feb. 1976, <https://doi.org/10.1021/i160057a011>.
- [9] A. Danesh, *PVT and Phase Behaviour Of Petroleum Reservoir Fluids*. Amsterdam, Netherlands: Elsevier, 1998.
- [10] K. S. Pedersen, K. S. Pedersen, P. L. Christensen, J. A. Shaikh, and P. L. Christensen, *Phase Behavior of Petroleum Reservoir Fluids*, 1st ed. Boca Raton, FL, USA: CRC Press, 2006.
- [11] L. Ahmed, "Characterizing Hydrocarbon-Plus Fractions," in *Equation of State and PVT Analysis*, New York, NY, USA: Gulf Publishing Company, 2013, pp. 59–130.
- [12] W. E. Lemmon, "Thermophysical Properties of Fluid Systems," *NIST Chemistry WebBook*, 2010, <https://cir.nist.gov/crid/1573105974809840640>.
- [13] R. Kerr, "How to Measure Downhole Steam Quality Using a Thermocouple And a Non-condensable Gas," *Journal of Canadian Petroleum Technology*, vol. 38, no. 04, Apr. 1999, <https://doi.org/10.2118/99-04-02>.
- [14] W. J. Heideger and S. E. Dubois, "Mass transfer during drop formation," *AIChE Journal*, vol. 31, no. 3, pp. 483–484, Mar. 1985, <https://doi.org/10.1002/aic.690310316>.
- [15] M. A. Cremon and M. G. Gerritsen, "Multi-level delumping strategy for thermal enhanced oil recovery simulations at low pressure," *Fluid Phase Equilibria*, vol. 528, Jan. 2021, <https://doi.org/10.1016/j.fluid.2020.112850>.
- [16] B. Khussain *et al.*, "The Delumping Method as a Key Factor in obtaining a characterized Hydrocarbon Fluid using the Example of Kazakhstani Oil," *Engineering, Technology & Applied Science Research*, vol. 15, no. 1, pp. 19743–19748, Feb. 2025, <https://doi.org/10.48084/etasr.9267>.