Compositional modeling of the reservoir isn't complete without calculations of phase equilibrium and is a complex process involving many calculations. In nature, hydrocarbons don't occur as separate components, they're mainly mixtures. When modeling the reservoir composition for phase equilibrium calculations, in order to reduce computational costs, in practice, hydrocarbon mixtures are grouped into pseudo-components. The number of grouped pseudo-components varies from 4 to 10. This grouping process is called lumping. However, when crude oil comes to the surface, it's important to know its detailed composition, since mixtures grouped into pseudo-components don't allow you to know this. In this regard, modeling of the detailed composition of hydrocarbons is the main tool for understanding the detailed phase separation and design of surface facilities. In practice, this process is called delumping. In the case of this process, the detailed composition of the fluid is presented and the amount reaches up to 36 components, sometimes more. The delumping process, due to the precise separation of heavy plus fractions into carbons with single ordinal numbers (C7, C8, etc.), makes it possible to clearly recognize non-zero BIP's in the equation of state.

The new analytical approach has not previously been applied to the oils of the Caspian region, so this approach has an important role for the oil industry in the Caspian region. Analytical delumping in this paper was done to improve the PVT modeling. This paper presents the results of PVT research of Caspian oil and presents a comparison of analytical and numerical methods of delumping. As a result of the study, it was found that the analytical approach is in excellent agreement with experimental data and data from software such as PVTsim

Keywords: delumping, pseudo-component, plus fraction, BIP, EoS, PVT, K-value, Caspian oil

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PRESSURE-VOLUME-TEMPERATURE ANALYSIS OF CASPIAN OIL TO IMPROVE THE ANALYTICAL DELUMPING PROCEDURE

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1. Introduction

Hydrocarbon plus fractions are the main part of hydrocarbon fluids that are present in nature. These fractions create significant problems in the process of predicting thermodynamic properties using the equation of state (EOS). These problems get up in connection with obstacles to reliable characterization of plus fractions in view of their critical parameters and acentric coefficients.

Calculations of phase equilibrium play an essential role in modeling the composition of the reservoir, and therefore are necessary for the compilation of reservoir models. In practice, in order to speed up and facilitate calculations, the components of the heptane plus fraction are grouped into pseudo-components. When performing phase equilibrium calculations, two processes are required: lumping of the heptane plus fraction component and delumping of the heptane plus fraction. But it is important to note that the processes of lumping and delumping are interdependent, because they help to link reservoir modeling with modeling of ground facilities.

Research in the area of compositional modeling is important for oil production in the Caspian region, where calculations of phase equilibrium, clarification of composition and planning of surface structures will increase the accuracy of data and will be calibrated to local conditions.

The advantage of this method is that the delumping process can be used in combination with numerical modeling methods and laboratory measurements in order to find out how the behavior of fluid can change. The delumping process helps to obtain an accurate description of the fluid, thereby facilitating the work for reservoir engineers and software developers. Therefore, studies that are devoted to the delumping procedure are of scientific relevance, since the procedure itself is crucial for making informed decisions regarding reservoir management and field development strategies.

2. Literature review and problem statement

The phase equilibrium calculation procedure is the most expensive computational part of compositional reservoir modeling. Models of modern simulators do not permit using the entire composition of the liquid, which may consist of hundreds of components. In practice, the detailed descrip-

tion of the liquid should be abbreviated, and the number of components should be limited to a dozen pseudo-components, as a result of which individual components should be based on similar criteria. Such an abbreviation is called a grouping procedure, and then the compositional model itself is performed using grouped and simplified components [1].

The outcomes of compositional modeling, providing average values for pseudo-components in C_{7+} fractions, necessitate a reverse procedure known as ungrouping. This ungrouping process is crucial for ensuring the detailed liquid's compositional behavior, derived from flash calculation results. Its significance extends beyond mere planning to encompass the modeling of surface facilities [2].

The delumping method refers to thermodynamic processes and is directly related to the calculations of phase equilibrium. Phase equilibrium calculations play an important role not only in reservoir compositional modeling, as mentioned above, but also in the design of oil facilities located on the surface and subsurface. In the papers [3, 4], the problem of paraffin deposition on the walls of oil pipelines is considered. To solve this problem, phase equilibrium calculations are used, because they play an essential role, and the presence of a detailed description of the fluid allows you to minimize these risks.

Scientists have been developing and studying different ways to take a simplified description of a fluid and turn it into a more detailed one. They have been working on different methods to get the most accurate. To obtain the most accurate results, scientists experimented with various procedures. For example, in the study [5], known as the LSK (Leibovici-Stenby-Knudsen) algorithm, the splitting process begins by flashing the lumped system under relevant circumstances to calculate the K-values for the lumped components. The K-values of the original components can be calculated using these constants, and the Rachford-Rice equation can then be used to compute phase fractions and phase mole fractions [6]. Their method was based on the linear relation of the logarithm of the K-value with the equation of state parameters when all binary interaction coefficients are equal to zero.

The research group in the study [6] developed an analytical solution that is equivalent even with non-zero binary interaction coefficients, and modified the LSK algorithm. They reformulated the EOS parameters and fewer independent variables by using a reduction strategy. They then used the LSK algorithm with the new formulation to determine the delumped stream at a specific pressure and temperature and were able to achieve remarkably consistent results between the delumped compositions' properties and those of the original detailed fluid.

The fundamental paper [7] made a comparison between the analytical delumping, which was described in [6] and LSK delumping [5] in the reservoir simulation results. They concluded that analytical delumping provides better results with high accuracy than LSK delumping.

In synopsis, notable strides have been achieved in the realm of petroleum engineering with regard to delumping methodologies. Techniques such as the LSK algorithm have materialized as solutions to the intricate challenges associated with the simplification of fluid compositions for reservoir simulation, demonstrating promise for heightened levels of precision and efficiency. Nevertheless, extant investigations confront a multitude of constraints, encompassing difficulties in addressing non-zero binary interaction parameters (BIPs), a dependence on simplified fluid models characterized by a limited number of components, and an insufficiency in comprehensive validation utilizing authentic field data [8].

Furthermore, the regression method, notably under conditions of low BIP's values, manifests inherent limitations and yields outcomes of diminished efficacy [9]. By employing a reductionist paradigm grounded in meticulous computations of equilibrium constants (K-values) and a meticulously calibrated equation of state, the prospect of obtaining a nuanced portrayal of fluid properties becomes a tangible prospect. The imperative exists for expanded investigations into uncertainty quantification and the extended applicability of these delumping techniques across diverse reservoir typologies and environmental conditions [10].

In the case of the Caspian region and its oil fields, where acid gas injection is a prevalent practice, a meticulous fluid description is crucial for compositional modeling. Binary Interaction Parameters are integral to the phase equilibrium equations, enhancing the precision of modern models by extending them to multicomponent mixtures.

The delumping procedure for this region should favor the reduction method over the regression approach, as the latter exhibits limitations with small BIP values and yields fewer effective results. By employing the reduction method, which relies on precise calculations of equilibrium constants (K-values) and a calibrated equation of state, a detailed fluid description of the Caspian basin field can be achieved.

The choice of delumping method, particularly one rooted in the reduction approach, is poised to significantly impact the petroleum industry in the Caspian region. It will play a pivotal role in Pressure-Volume-Temperature modeling, facilities planning, and the design of systems for the gathering and preparation of hydrocarbon crudes.

The outcomes of this investigation are poised to facilitate the improvement of the aforementioned issues, given that, as of the present, the delumping algorithm remains underutilized within the Caspian region. This study thus engenders an opportunity to introduce and integrate this algorithmic approach, potentially addressing and enhancing prevailing conditions through its application in the region.

3. The aim and objectives of the study

The aim of this study is to improve the analytical method of delumping analysis, which allows us to describe the detailed composition of oil, in particular the oil of the Caspian region. This approach will help to improve the work that is aimed at modeling and construction of oil facilities.

To achieve this aim, the following objectives are accomplished:

– to conduct laboratory PVT analysis to further compare the characteristics of the fluid;

– to delump analytical compositional modeling results;

– to repeat the delumping procedure in the PVTsim software, for further comparison;

– to compare the analytical method of delumping with the results of PVTsim and laboratory analysis.

4. Materials and methods of research

4. 1. Object and hypothesis of the study

The object of this study is the delumping procedure, which will be applied in the case of oils from the Caspian region. The main hypothesis of the study states that for reliable modeling of the phase behavior necessary to de-

scribe a hydrocarbon mixture, calculations of equations are often complicated by a large number of components. The predominant challenge often lies in the complex modeling of hydrocarbon systems or the amalgamation of numerous experimentally determined fractions within the mixture. The primary assumptions of the study are effective planning of onshore facilities, which leads to more efficient design of oil facilities, reduction of their energy consumption and environmental impact, as well as economic costs.

4. 2. Experimental procedures

As noted earlier, when modeling the characteristics of fluids in oil and gas reservoirs, the equations of state (EOS) are used. The equations of state relate pressure, volume and temperature and are used to calculate the properties of all phases, ensuring the equilibrium of processes in the deposit. Compared with conventional models of fuel oil, the advantage of using EOS is that it allows you to better predict the properties of the liquid. It is possible to easily investigate the behavior of the pressure-volume-temperature (PVT) system for crude oil or liquid condensate by accurately describing it.

The main purpose of PVT tests is the result of experimental knowledge about the behavior of reservoir fluid in reservoir conditions. For the PVT research, a bottomhole oil sample was taken from the *Y* field in the Caspian region. Summary information about the oil sample is presented in Table 1.

Table 1

General information of deep-oil sample

Field	*Y*
Interval of perforation, m	1,520–1,525
	1,536–1,239
Selection point, m	1,518
Pressure of reservoir, MPa	37.92
Temperature of reservoir, K	129

In laboratory conditions, in order to study the physical and chemical composition of oil, three types of tests were carried out:

1. Flash liberation test.

2. Constant mass expansion test (CME).

The flash liberation tests and constant mass expansion test have been obtained on the PVT cell Fluid Eval G4 device (Fig. 1).

Fig. 1. The PVT cell Fluid Eval G4

Constant mass expansion (CME) test. The main purpose of the expansion test at constant mass is the result of the pressure of the bubble point. In our case, the saturation pressure for the test sample is 20.65 MPa. Table 2 contains information about the expansion test report at constant mass (CME).

Table 2

Results of constant mass expansion (CME) test

Pressure, MPa		Relative volume, V/V_b	Y-function
P_{bubble}	20.65	1.0000	0.0000
	19.40	1.0157	4.0786
	18.15	1.0354	3.8619
	16.91	1.0604	3.6452
$P_{reservoir}$	15.66	1.0924	3.4285
	14.41	1.1339	3.2119
	13.16	1.1885	2.9952
	11.91	1.2616	2.7785
	10.67	1.3619	2.5618
	9.42	1.5030	2.3451
	8.17	1.7087	2.1285
	6.92	2.0220	1.9118
	5.67	2.5291	1.6951
	4.43	3.4225	1.4784
	3.18	5.2192	1.2617
	1.93	9.8066	1.0451

Flash liberation test. The flash liberation experiment commences at the bubble point pressure, which is established through the CME (as beyond this pressure, the flash and differential experiments yield the same results). In the process of the differential liberation experiment, there is a systematic reduction of pressure in incremental steps, during which any liberated gas is efficiently separated from the oil. Importantly, each stage of pressure depletion is meticulously conducted under the rigorously controlled and uniform temperature conditions of the reservoir. Tables 3, 4 presents data relevant to the flash liberation test of oil and gas.

The main results of the differential liberation test are data on the density of oil and gas, their formation volume factors, as well as a range of properties for the removed gas at each stage gas Z-factor was measured.

Table 3

Results of flash liberation test of oil

Pressure, MPa		Oil density, g/cm^3	Oil FVF, B_{od}	R_{sd}, m^3/m^3
P_{test}	37.92	0.5753	1.8446	239.61
	36.20	0.5735	1.8503	239.61
	34.47	0.5713	1.8573	239.61
	32.41	0.5682	1.8674	239.61
	29.99	0.5637	1.8826	239.61
	27.23	0.5571	1.9047	239.61
	24.82	0.5498	1.9299	239.61
P_{bubble}	20.65	0.5346	1.9849	239.61
$P_{reservoir}$	15.86	0.5459	1.8771	192.70
	12.41	0.5601	1.7779	151.08
	8.96	0.5762	1.6461	113.28
	5.52	0.5896	1.5130	77.320
	2.07	0.6175	1.3386	38.210
	0.10	0.7044	1.0000	0.0000

Table 4

Results of flash liberation test of gas

Pressure, MPa		Gas density, g/cm^3	Z-factor	Gas FVF, Bg
$P_{reservoir}$	15.86	0.1142	0.8891	0.0080
	12.41	0.0982	0.8987	0.0103
	8.96	0.0780	0.9097	0.0135
	5.52	0.0559	0.9252	0.0225
	2.07	0.0266	0.9553	0.0566
	0.10	0.0024	0.9918	0.4543

4. 3. Analytical delumping procedure

The analytical procedure of delumping is based on the reduction method and can apply non-zero binary interaction parameters (BIP) for single components. The analytical delumping process described in the paper [6] was taken as a basis and was calibrated to the local conditions of the Caspian region.

As a result, the scientists developed a new set of variables and factors that they used to build the fugacity coefficients (reduction parameters). Since it can precisely handle scenarios with non-zero BIPs, the analytical reduction-based delumping approach consistently outperforms the earlier regression-based delumping method [6].

K-values for the detailed system are calculated by:

$$\ln K_i(Q_L,Q_V) = \Delta h_0(Q_L,Q_V) + \Delta h_\alpha(Q_L,Q_V)\alpha_i + $$

$$+\Delta h_B(Q_L,Q_V)B_i + \sum_{k=1}^{m}\Delta h_{\gamma k}(Q_L,Q_V)\gamma_{ki};$$

$$i = 1,\ nc. \quad (1)$$

Finally, the vapor mole fraction V and phase mole fractions are calculated by:

$$x_i = \frac{z_i}{1+V(K_i-1)}, \quad (2)$$

$$y_i = K_i x_i = \frac{z_i K_i}{1+V(K_i-1)}. \quad (3)$$

The vapor fraction V is determined as the solution of the Newton-Raphson equation written for the delumped K-values [5]:

$$\sum_{i=1}^{nc} = \frac{z_i(K_i-1)}{1+V(K_i-1)} = 0, \quad (4)$$

where Z_i – the total mole fraction of the component; V – molar fraction of vapor; K_i – equilibrium ratio; x_i – liquid mole fraction; y_i – vapor mole fraction.

5. Results of Pressure-Volume-Temperature analysis using various methods of delumping

5. 1. Laboratory analysis results

An oil sample from the bottom hole of oil field *Y* was obtained, and the fluid composition information was derived from a crude oil test tube. The outcomes, encompassing detailed component composition derived from laboratory PVT analysis, have been systematically documented in Table 5.

Table 5 illustrates the composition of liberated gas, reservoir fluid and stabilized oil, delineated in both mole and weight fractions across a spectrum from nitrogen (N_2) to hexatriacontane plus (C_{36+}). Remarkably, methane (C_1) emerges as the predominant constituent, constituting approximately 67 % in both weight and mole percentages within the liberated gas phase. Evidently, methane assumes a pivotal role as the principal component, commanding the highest proportion within the liberated gas composition.

Table 5

The composition of Caspian oil obtained from laboratory PVT analysis

Component		Liberated gas	Stabilized oil		Reservoir fluid	
		weight, %	mole, %	weight, %	mole, %	weight, %
Nitrogen	N_2	1.174	0	0	0.818	0.315
Carbon dioxide	CO_2	0.155	0	0	0.108	0.065
Methane	C_1	66.758	0	0	46.474	10.247
Ethane	C_2	10.361	0	0	7.212	2.980
Propane	C_3	9.266	0	0	6.450	3.908
Isobutane	iC_4	2.197	0.719	0.235	1.748	1.396
Butane	nC_4	4.275	0	0	2.976	2.376
Isopentane	iC_5	1.518	2.227	0.903	1.734	1.718
Pentane	nC_5	1.489	3.021	1.226	1.955	1.937
Hexane	C_6	0.903	6.398	3.101	2.573	3.046
Heptane	C_7	1.803	6.352	3.579	3.185	4.384
Octane	C_8	0.077	18.085	11.617	5.548	8.706
Nonane	C_9	0.019	8.604	6.205	2.627	4.629
Dean	C_{10}	0.005	7.230	5.784	2.200	4.301
Undecane	C_{11}	0.001	5.728	4.735	1.741	3.515
Dodecane	C_{12}	0.001	4.797	4.343	1.458	3.225
Tridecane	C_{13}	0	4.341	4.272	1.319	3.171
Tetradecane	C_{14}	0	3.735	3.991	1.135	2.962
Pentadecane	C_{15}	0	3.643	4.219	1.107	3.132
Hexadecane	C_{16}	0	2.816	3.515	0.856	2.609
Heptadecane	C_{17}	0	2.465	3.285	0.749	2.438
Octadecane	C_{18}	0	2.290	3.231	0.696	2.399
Nonadecane	C_{19}	0	1.942	2.872	0.590	2.132
Icosane	C_{20}	0	1.700	2.630	0.517	1.952
Heneicosane	C_{21}	0	1.542	2.523	0.468	1.872
Docosane	C_{22}	0	1.340	2.299	0.407	1.706
Triclosane	C_{23}	0	1.261	2.256	0.383	1.674
Tetracosanee	C_{24}	0	1.045	1.945	0.317	1.443
Pentacosane	C_{25}	0	0.975	1.892	0.296	1.404
Hexacosane	C_{26}	0	0.866	1.748	0.263	1.298
Heptacosane	C_{27}	0	0.766	1.611	0.233	1.196
Octacosane	C_{28}	0	0.684	1.492	0.208	1.108
Nonacosane	C_{29}	0	0.682	1.541	0.207	1.144
Triacontane	C_{30}	0	0.591	1.382	0.180	1.026
Hentriacontane	C_{31}	0	0.584	1.412	0.177	1.048
Dotriacontane	C_{32}	0	0.472	1.178	0.143	0.874
Tritriacontane	C_{33}	0	0.466	1.200	0.142	0.891
Tetratriacontane	C_{34}	0	0.400	1.126	0.100	0.836
Pentatriacontane	C_{35}	0	0.344	0.940	0.104	0.698
Hexatriacontane plus	C_{36+}	0	1.867	5.712	0.567	4.240
Balance		100	100	100	100	100

5. 2. Mathematical formulations of analytical delumping approach

Table 6 presents the empirical findings of a delumped system, founded upon an analytical methodology. The com-

putations there in were derived through the application of formulas (1) through (4). It is imperative to note that all mathematical analyses were conducted with the foundational presumption that the composite system exclusively comprises liquid and vapor phases.

Table 6

Flash on the delumped system based on the analytical method (P=0.1 *MPa*, T=303.37 K)

Component		Vapor	Liquid
		mole, %	mole, %
Nitrogen	N_2	0.861	0.312
Carbon dioxide	CO_2	0.113	0.061
Hydrogen sulfide	H_2S	0.000	0.000
Methane	C_1	48.869	10.119
Ethane	C_2	7.494	2.890
Propane	C_3	6.467	3.887
Isobutane	iC_4	1.647	1.396
Butane	nC_4	2.707	2.365
Isopentane	iC_5	0.044	1.713
Pentane	nC_5	1.399	1.932
Hexane	C_6	1.196	3.039
Heptane	C_7	3.255	4.379
Octane	C_8	5.657	8.711
Nonane	C_9	2.629	4.631
Dean	C_{10}	2.221	4.310
Undecane	C_{11}	1.745	3.509
Dodecane	C_{12}	1.427	3.225
Tridecane	C_{13}	1.320	3.171
Tetradecane	C_{14}	1.135	2.959
Pentadecane	C_{15}	1.125	3.141
Hexadecane	C_{16}	0.965	2.612
Heptadecane	C_{17}	0.811	2.435
Octadecane	C_{18}	0.745	2.401
Nonadecane	C_{19}	0.682	2.129
Icosane	C_{20}	0.619	1.952
Heneicosane	C_{21}	0.458	1.872
Docosane	C_{22}	0.499	1.706
Triclosane	C_{23}	0.483	1.674
Tetracosane	C_{24}	0.315	1.443
Pentacosane	C_{25}	0.297	1.404
Hexacosane	C_{26}	0.261	1.298
Heptacosane	C_{27}	0.310	1.196
Octacosane	C_{28}	0.202	1.108
Nonacosane	C_{29}	0.183	1.144
Triacontane	C_{30}	0.131	1.026
Hentriacontane	C_{31}	0.159	1.048
Dotriacontane	C_{32}	0.150	0.874
Tritriacontane	C_{33}	0.124	0.891
Tetratriacontane	C_{34}	0.100	0.836
Pentatriacontane	C_{35}	0.106	0.698
Hexatriacontane plus	C_{36+}	0.571	4.120
Balance		100	100

The reservoir mixture encompasses normal alkanes spanning from methane (C_1) to hexatriacontane plus, inclusive of higher alkanes (C_{36+}). This mixture interfaces with carbon dioxide and nitrogen, both non-hydrocarbon substances characterized by notably elevated hydrocarbon component ratios. The formulas described in chapter 4.2 were used to calculate the analytical method.

5. 3. Results of the PVTsim software

The outcomes of the simulation, detailed in Table 7, exhibit a notable concordance with both the analytical methodology and the experimental data.

Table 7

Delumping results obtained from the PVTsim program (P=0.1 *MPa*, T=303.37 K)

Component		Vapor	Liquid
		mole %	mole %
Nitrogen	N_2	81.870	0.120
Carbon dioxide	CO_2	0.077	0.001
Hydrogen sulfide	H_2S	0	0
Methane	C_1	0	0
Ethane	C_2	0	0
Propane	C_3	0.020	0.002
Isobutane	iC_4	9.257	2.283
Butane	nC_4	0.014	0.005
Isopentane	iC_5	3.466	3.096
Pentane	nC_5	2.190	2.594
Hexane	C_6	1.190	4.485
Heptane	C_7	1.040	9.890
Octane	C_8	0.690	14.949
Nonane	C_9	0.125	7.510
Dean	C_{10}	0.045	6.930
Undecane	C_{11}	0.015	5.728
Dodecane	C_{12}	0.005	4.830
Tridecane	C_{13}	0	4.436
Tetradecane	C_{14}	0	3.760
Pentadecane	C_{15}	0	3.938
Hexadecane	C_{16}	0	3.091
Heptadecane	C_{17}	0	2.672
Octadecane	C_{18}	0	2.488
Nonadecane	C_{19}	0	2.127
Icosane	C_{20}	0	1.830
Heneicosane	C_{21}	0	1.611
Docosane	C_{22}	0	1.386
Triclosane	C_{23}	0	1.229
Tetracosane	C_{24}	0	1.022
Pentacosane	C_{25}	0	0.922
Hexacosane	C_{26}	0	0.795
Heptacosane	C_{27}	0	0.712
Octacosane	C_{28}	0	0.619
Nonacosane	C_{29}	0	0.604
Triacontane	C_{30}	0	0.476
Hentriacontane	C_{31}	0	0.444
Dotriacontane	C_{32}	0	0.367
Tritriacontane	C_{33}	0	0.342
Tetratriacontane	C_{34}	0	0.250
Pentatriacontane	C_{35}	0	0.241
Hexatriacontane plus	C_{36+}	0	2.213
Balance		100	100

To facilitate a comparative evaluation, the delumping process was additionally executed within the PVTsim software. This software tool, specially designed for reservoir

analysis and fluid behavior, allowed for a more comprehensive assessment of fluid composition and behavior.

5. 4. Comparison of laboratory, analytical and simulation delumping methods

Fig. 2, 3 present information on comparative data of experimental analysis, analytical delumping and PVTsim delumping data. The results of analytical and numerical methods of ungrouping were confirmed by comparing the most important properties of the components with laboratory PVT data and corresponding literature data.

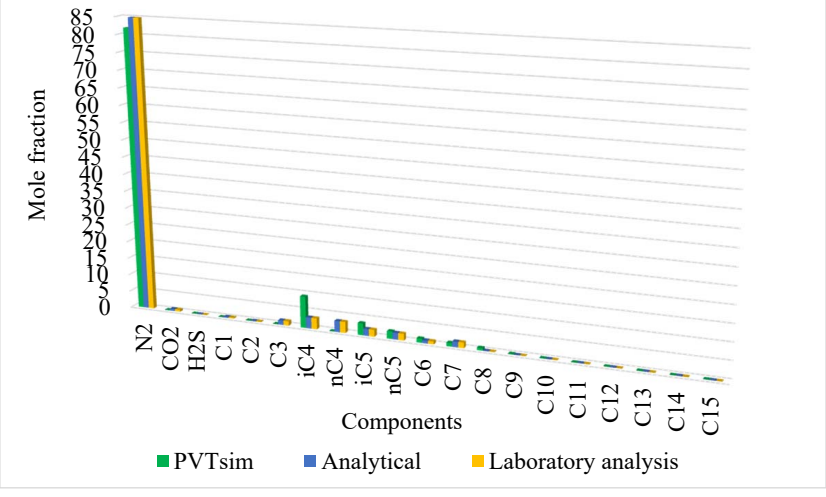

Fig. 2. The molar fraction of the vapor phase of the laboratory analyzed fluid and the delumped liquid

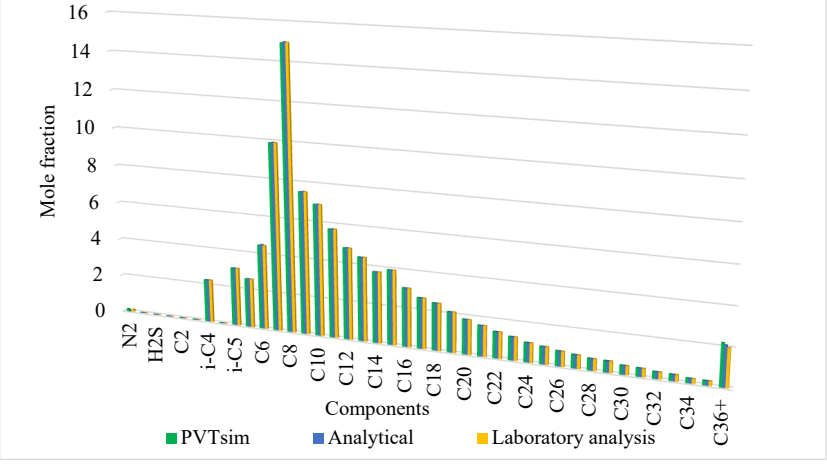

Fig. 3. The molar fraction of the liquid phase of the laboratory analyzed fluid and the delumped liquid

Manually conducted calculations utilizing the analytical delumping method closely approximate the values derived through laboratory analyses. Discrepancies become apparent in the results generated by the PVTsim software. However, upon closer examination of the empirical data presented in tables and graphical representations, a discernible and consistent trend materializes. Specifically, there is a notable convergence in the mole fraction range, characterized by a reduction in the gaseous component fraction and a concomitant augmentation in the proportion of the liquid phase, in tandem with the ascending carbon number.

6. Discussion of the obtained delumping results

An accurate description of the fluids of Caspian deposits can be obtained using the reduction method, which, in turn, is based on specific calculations of the K-value. The analytical, numerical and laboratory analysis approaches are used to retrieve the detailed fluid composition. The empirical findings derived from these methodologies have been presented in Tables 5–7, based on these data, visual comparative graphs were built. A comparative assessment of the methods used is shown in Fig. 2, 3. As a result, the implementation of the analytical delumping process makes it possible to simulate surface structures. The issue of studying the composition of oil allows us to better understand the structure and properties of the oil fluid, which, in turn, helps to apply this knowledge in all sectors of the oil and gas industry, from production to processing. The advantage of the delumping procedure is also its ability to determine the characteristics of the liquid, which tells us that delumping is an analog of PVT laboratory experiments.

The paper [6] highlights the superior accuracy of the compositional delumping approach, especially in scenarios involving non-zero Binary Interaction Parameters (BIPs). Upon comparing the LSK [5] and analytical delumping [6] methodologies, it was consistently observed that analytical delumping consistently produces better results compared to LSK delumping.

Our investigation establishes a connection with the work presented in [6], where an enhancement to the LSK approach was introduced along with an innovative analytical reduction-based delumping technique. Notably, this approach demonstrated efficacy in managing scenarios characterized by non-zero binary interaction coefficients. Our research is aligned with the overarching objective of mitigating the challenges posed by non-zero BIP's through the application of analytical delumping, underscoring its importance over regression-based methodologies [6].

Furthermore, our findings are amenable to comparison with studies such as [1], which implemented the LBW delumping approach in reservoir simulation. While [1] exhibited promising outcomes under the assumption of zero binary interaction parameters, it underscored the difficulties encountered when confronted with non-zero BIP's challenges that our research seeks to confront. The concordance observed in our investigation, particularly for heavier components, serves to affirm the viability of analytical delumping even in the presence of non-zero BIP's.

Nevertheless, it is imperative to acknowledge specific limitations inherent in this investigation. Principally, the focus of this study is centered around a particular oil sample, potentially constraining its ability to encompass the full

spectrum of behaviors exhibited in diverse oil reservoirs. The research predominantly delves into the characteristics of Caspian basin oil, necessitating an awareness that the findings may not seamlessly extrapolate to oils originating from disparate regions marked by distinct compositions and properties. Moreover, it is worth noting some disadvantage, the reliance on numerical modeling tools, such as PVTsim, inherently depends on a set of assumptions and equations of state. Any disparities between these model assumptions and real-world conditions have the potential to influence the accuracy of the results. These considerations underscore the necessity for cautious interpretation and an acknowledgment of potential constraints within the scope and applicability of our study.

The successful development of the delumping procedure in oil and gas production has the potential to revolutionize the industry by improving reservoir management practices, enhancing production optimization, and maximizing profitability for companies operating in Caspian's petroleum sector.

7. Conclusions

1. The result of the conducted laboratory Pressure-Volume-Temperature analysis provided us with a component composition of 36 components and helped us determine the percentage and molar fraction of each component in the total liquid. The component composition is crucial for engineering calculations, namely, it helps to understand how the reservoir fluid will behave over time and under various production scenarios.

2. During the study, it turned out that the method described in [6] became the most suitable, since non-zero parameters of binary interaction were used in the calculations. In addition, the analytical method we used to determine the moles of each component of the mixture was also calculated using the Rachford-Rice equation and the results have excellent consistency with experimental data. In general, analytical delumping allowed us to find out what state a particular component is in (liquid or vapor phase), and this information is valuable, because it allows to establish a connection between the reservoir and the ground structure, and subsequently is important in the strategic planning of refineries.

3. The analytical methodology elucidated within this manuscript demonstrates a commendable congruence with experimental results and outcomes derived from the PVTsim software. The observed results attest to the efficacy of the analytical approach, thereby substantiating its economic viability. The approach reduces the time required to generate composite modeling results, this could increase the productivity of the field and lead to revenue increases. In contrast to prevailing practices wherein constituents above C_{7+} are frequently amalgamated into pseudo-components, exhibiting solely mean parameter values, the imperative of discerning the intricate fluid composition is underscored, particularly in the context of designing and erecting oil facilities. The analytical technique of delumping emerges as a pivotal solution, providing detailed compositional insights into fractions above C_{7+} and thereby addressing the exigencies inherent in the planning and construction of oil structures.

4. The results indicated a strong concordance between the detailed compositions obtained via the delumping procedure and those derived from laboratory analysis, analytical method and PVTsim software with an average deviation below 5 %. This affirmation underscores the efficacy of delumping as a viable alternative method for achieving precise fluid composition assessments.

Conflict of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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