A Modified Four-Coefficient Model for Plus Fraction Characterization of a Supergiant Gas Condensate Reservoir

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Abstract

Properties and chemical composition of plus fraction in a petroleum fluid have a considerable impact on the fluid phase behavior. Understanding the trend of changes in molecular weight of successive single carbon number (SCN) groups in a plus fraction requires an accurate and reliable distribution function. Different distribution function models proposed so far may be applicable for certain types of reservoir fluids. In this work, analysis of 30 representative fluid samples in a supergiant gas condensate reservoir indicated a discontinuity in molecular weights of SCN groups at SCN=8, and SCN=13. The exponential, gamma, four-coefficient, and modified four-coefficient distribution functions were applied to these samples to predict the composition of SCN components. Results showed that the exponential distribution function does not predict the distribution of SCN composition accurately, especially in the aforementioned compositional discontinuities. Furthermore, the gamma distribution function was successful in predicting the jump in SCN=8 but failed at SCN=13. On the other hand, the modified four-coefficient model did predict the jumps in both SCN=8 and SCN=13. The overall error of calculations was 37.19%, 12.04% and 10.71% for exponential, gamma and modified four-coefficient models. Comparing four-coefficient and modified four-coefficient prediction results showed that the model parameters are strongly dependent on the fluid nature and need to be optimized based on available field data.

Keywords: Gas Condensate, plus fraction, distribution function, four-coefficient model

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Introduction

Phase behavior and thermodynamic properties of petroleum fluids are normally determined using equations of states (EOS). Proper application of EOS requires information such as physical and critical properties, acentric factor, binary interaction parameters and molecular weight of all components that exist in the petroleum fluid.

Routine separation techniques can identify some components, leaving most of them impossible to separate and characterize (Whitson and Brule, 2000). The light components, including hydrocarbon compounds up to C_6 and non-hydrocarbon components, i.e. N_2, CO_2, and H_2S are almost clearly identifiable through experimental measurements.

Other hydrocarbon compounds are usually lumped as a plus fraction (C_{7+}) to avoid further analysis of hydrocarbon components, which is limited by separation techniques, preventing extra time for reservoir production and process simulations (Danesh, 1998). Characterization of plus fraction is one of the key steps in reservoir fluid phase behavior studies. In the absence of extended compositional measurements, lumping all components into a single pseudo heavy component can cause large errors in predicting phase behavior of reservoir fluids (Ahmed, 1989). In order to characterize the plus fraction, it is first split into a number of SCN groups and then lumped into pseudo components (Pedersen and Christensen, 2007). Several techniques have been proposed for splitting heavy ends; these techniques are based on the nature of hydrocarbons that exist in the plus fraction. Pedersen et al. (1983, 1984) studied a large number of fluid samples and proposed a semilog relationship between molecular weight and composition of SCN groups for SCN>6. This relationship, also known as exponential distribution function, has been extensively implemented to characterize plus fraction of gas condensate samples (Du and Mansoori, 1987; Mansoori et al., 1989). However, Whitson (1983) observed that the mole fraction of SCN groups versus corresponding molecular weight in the plus fraction does not always follow the exponential distribution function trend, as the experimental trend shows a discontinuity at SCN=8. He proposed the three-parameter, gamma probability distribution function to predict distribution of hydrocarbons in the plus fraction. The use of variance as an adjustable parameter in this approach makes it more flexible in a wider range of components (Ahmed, 1989).

Ahmed et al. (1985) integrated the exponential and gamma distribution functions to introduce a new, linear distribution function to account for the discontinuity in SCN=8. Similar to exponential distribution function, they introduced the semilog function for composition and molecular weight of SCN groups, except for the SCN=8, which was modeled by two linear functions. Hosein et al. (2012) studied 20 petroleum and gas condensate samples and observed the discontinuity at SCN=8, 13. They extended the Ahmed et al. (1985) two coefficient model to a four-coefficient distribution function, called four-coefficient model. They reported the accuracy of predictions by four-coefficient model as AAD=7.0% for selected samples, compared to AAD% of 10.8% by Ahmed et al. (1985) model.

As stated before, all available models have adjustable parameters that can be calculated through an optimization algorithm using experimental data. It is expected that these parameters are subject to change as a function of fluid nature, composition and phase behavior. The objective of this study is to modify the parameters of the four-coefficient model and customize them using PVT data of a supergiant gas condensate field. A global optimization algorithm procedure will be introduced to include all PVT data simultaneously, rather than individual optimization followed by averaging the optimized parameters. In the next sections, field data are introduced first. Then, modeling and optimization approach is presented. Next, results of optimization approach are presented and discussed. Concluding remarks appear in the end.

Field PVT data and modeling

PVT data were collected from a supergiant gas condensate field located in the Middle East. These data were selected from among a comprehensive data set after a careful screening and quality control of sampling conditions using standard protocols. Several quality control procedures have been proposed in the literature (Drohm et al., 1988; Trengove et al., 1991; Kikani and Ratulowski, 1996; Moffatt and Williams, 1998; Cobenas and Crotti, 1999). The integrated quality control of PVT and DST data (Osfouri et al., in press) was used to select 30 valid data sets out of more than 70 available samples. The sampling depth and temperature were 8900-11300 ft and 188-220 F. Table 1 gives the average composition and range of variations for successive SCN groups. Figure 1 shows compositional analysis versus SCN for one of the samples. The decreasing trend of composition is interrupted at SCN=8, 13, same as those reported by Hosein et al. (2012).

The four-coefficient model proposed by Hosein et al. (2012) will be modified and applied to selected gas-condensate data. To test the ability of this model, results of model predictions are compared with exponential and gamma distribution functions, defined as equations (1) and (2):

$$(1)\quad \ln z_i = A + BM_i$$

$$(2)\quad F(M) = \frac{(M-\tau)^{(\alpha-1)} e^{\left(\frac{(M-\tau)}{\beta}\right)}}{\beta^{\alpha}\,\Gamma(\alpha)}$$

Table 1: Average and variance of composition of SCN groups and molecular weight of plus fraction in the data set (Osfouri et al., in press).

SCN	(%) Composition
7	0.076 ± 0.507
8	0.064 ± 0.412
9	0.056 ± 0.246
10	0.042 ± 0.241
11	0.029 ± 0.168
12	0.022 ± 0.130
13	0.023 ± 0.115
14	0.018 ± 0.086
15	0.016 ± 0.071
16	±0.012 0.050
17	0.011 ± 0.041
18	0.010 ± 0.034
19	0.008 ± 0.027
20+	0.036 ± 0.079
M_{7+}	3.213 ± 137.679

α , M and τ are model parameters that describe the distribution form, molecular weight and minimum molecular weight in the plus fraction. β is calculated by equation (3):

$$(3)\quad \beta = \frac{M_{C7+} - \tau}{\alpha}$$

M_{C7+} is the molecular weight of C_{7+} fraction, defined by equation (4):

$$(4)\quad F_i = -\exp\left(\tau/\beta\right).\left[\exp\left(-\frac{M_i}{\beta}\right) - \exp\left(-\frac{M_{i-1}}{\beta}\right)\right]$$

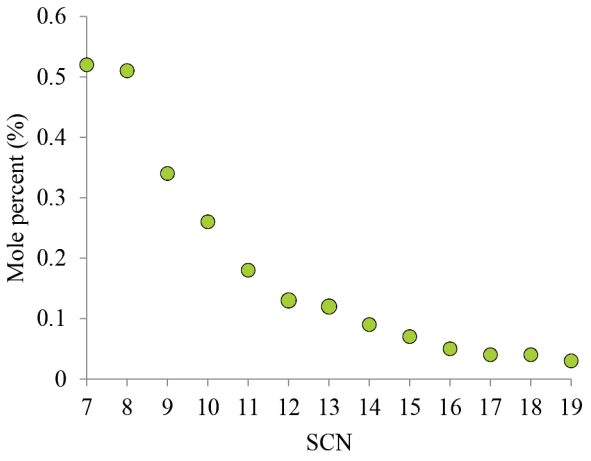

Figure 1: Mole percent distribution of pseudocomponent SCN in a gas condensate sample (Osfouri et al., in press).

The mole fraction of each pseudo SCN, z_i, is calculated by equation (5) using composition of plus fraction, z_+:

$$(5)\quad z_i = z_+ . F_i$$

The four-coefficient model divides the composition distribution of plus fraction into four distinct zones, as shown by equations (6) and (7):

$$(6)\ M_{n+} = M_{7+} + S(n-7) \quad \text{for } 7 \le SCN \le 12$$

$$(7)\ M_{n+} = M_{12+} + S(n-12) \quad \text{for } 12 \le SCN \le 19$$

Hosein et al. (2012) suggested that values of adjustable parameter S are selected from table 2 for each SCN and used equations (6) and (7) to calculate molecular weight of plus fraction, M_{n+}. Composition of each SCN pseudocomponent is calculated by equation (8), as suggested by Ahmed et al. (1985):

$$(8)\ z_n = z_{n+}\left[\frac{M_{(n+1)+}-M_{n+}}{M_{(n+1)+}-M_n}\right]$$

If the plus fraction is to be split up to SCN=20, equation (8) will be used to calculate composition of SCN=7-19, and composition of C_{20+} is calculated by mass balance, equation (9):

$$(9)\ \sum_{n=7}^{20} z_n = z_{C_{7+}}$$

Table 2: Constant for equations (6) and (7) (Hosein et al., 2012).

SCN	n=8	n<13>8	n=13	n>13
S	12.5	16	13	14.5

Results and discussion

As stated before, Hosein et al. (2012) calculated adjustable model parameters for every single sample by applying the optimization algorithm on that sample. They reported the mean or average values of adjustable parameters as the optimum model parameters for the data set. We have implemented a global optimization procedure to calculate the four model coefficients by using all PVT data simultaneously. The total average absolute deviation (TAAD), defined by equation (10), is used as an objective function:

$$(10)\ TAAD = \frac{1}{K}\sum_{j=1}^{K}\left(\frac{1}{L}\sum_{n=7}^{20}\left|\frac{z_n^{Cal}-z_n^{Exp}}{z_n^{Exp}}\right|_j \times 100\right)$$

The optimum parameters are calculated by minimizing equation (10).

K and L are the total number of experimental data sets and number of SCN groups in the plus fraction splitting. The minimization was performed using the Marquardt optimization program for minimizing TAAD (Chandler, 1985). Table (3) summarizes the S-values of the four coefficient model for 30 gas condensate data sets used in this study.

For the same data set, the exponential distribution parameters A and B were calculated as 0.981 and -0.018, and the gamma distribution parameters, α and τ, were calculated as 0.97 and 86. The molecular weight of C_{7+} for each sample is used to calculate model parameters in gamma distribution function.

Trend of plus fraction molecular weight (M_{n+}) versus SCN group can be calculated using optimized models. Figures 2 and 3 show the M_{n+} versus SCN calculated by a modified four-coefficient model for a gas condensate sample of this reservoir.

The optimized models can be used to calculate the composition of SCN groups for each sample.

For example, figure 4 compares model predictions with experimental data of SCN compositions for a gas condensate sample of this reservoir. It is clear from this figure that the modified four-coefficient model can predict experimental data very well.

Table 3: New adjusted constants of the 4 coefficient model.

SCN	n=8	n<13>8	n=13	n>13
S	13.14	14.07	12.41	13.21

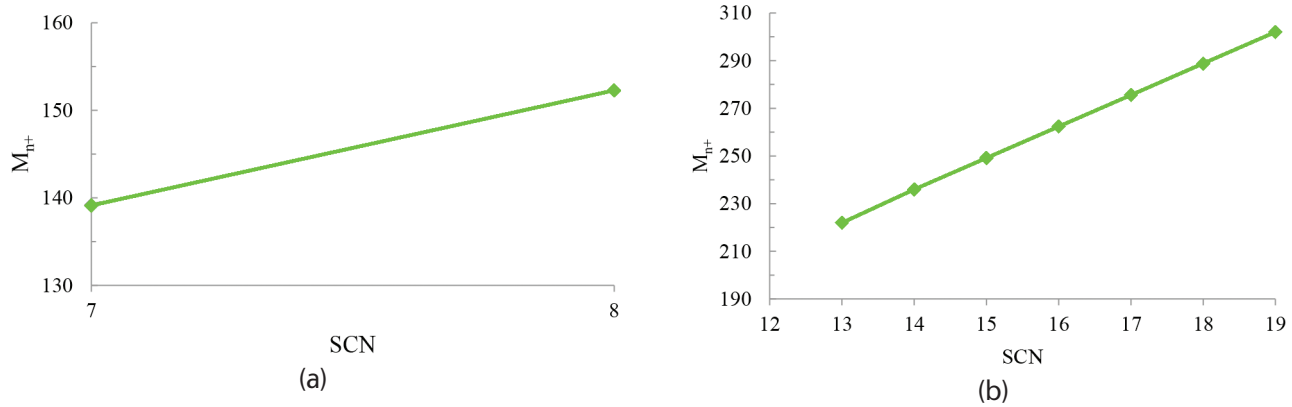

Figure 2: Changes in molecular weight of SCN=8 for one of the gas-condensate samples (a) Molecular weight between SCN=7-8 (b) Molecular weight between SCN=8-12.

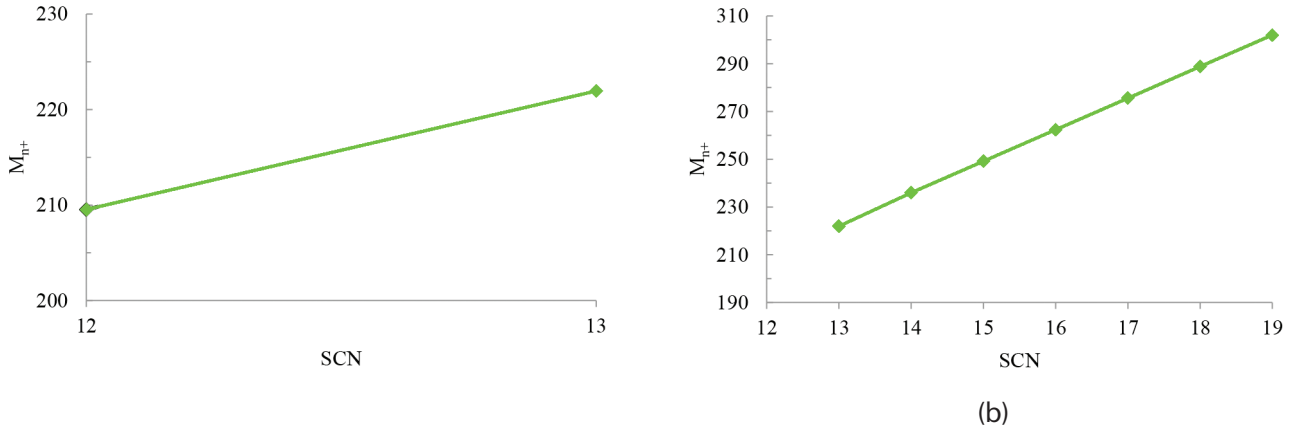

Figure 3: Changes in molecular weight of SCN=13 for one of the gas-condensate samples (a) Molecular weight between SCN=12-13 (b) Molecular weight between SCN=13-19.

Table 3 summarizes average absolute deviation (AAD%) of model predictions for all samples. According to this table, the optimized four-coefficient model (this work) has AAD% equal to 10.71, while the exponential, gamma, and original four-coefficient models give AAD% equal to 37.19, 12.04 and 16.04, respectively. According to this table, the modified four-coefficient model shows the best match with experimental data.

On the other hand, the exponential model shows large error in predicting the composition of SCN groups for all samples used in this study, although it was suggested by Mansoori et al. (1989) for gas-condensate systems.

Figure 5 compares prediction results of modified four-coefficient and optimized gamma distribution function. Both models can predict the compositional discontinuities at SCN=8; however, the gamma distribution function cannot predict second discontinuity at SCN=13, although it gives better predictions for some SCN groups.

Overall, better results are obtained by the simpler four-coefficient model modified for selected data set. This model is easier to use with less calculation complexity and requires less calculation steps.

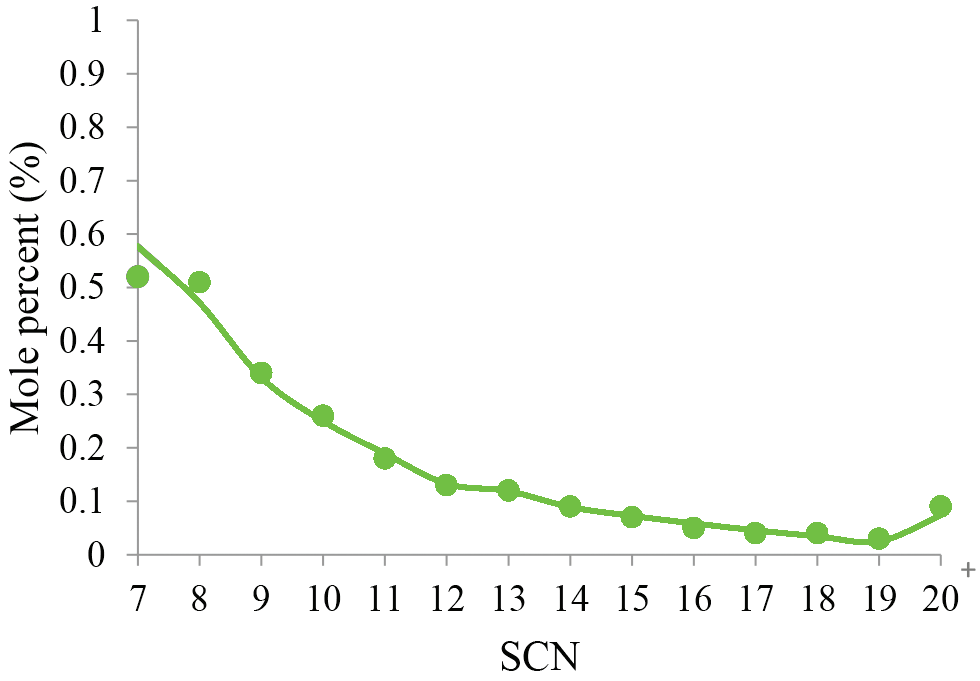

Figure 4: Comparison of modified four-coefficient model (solid line) with experimental data (black circles) for gas condensate sample.

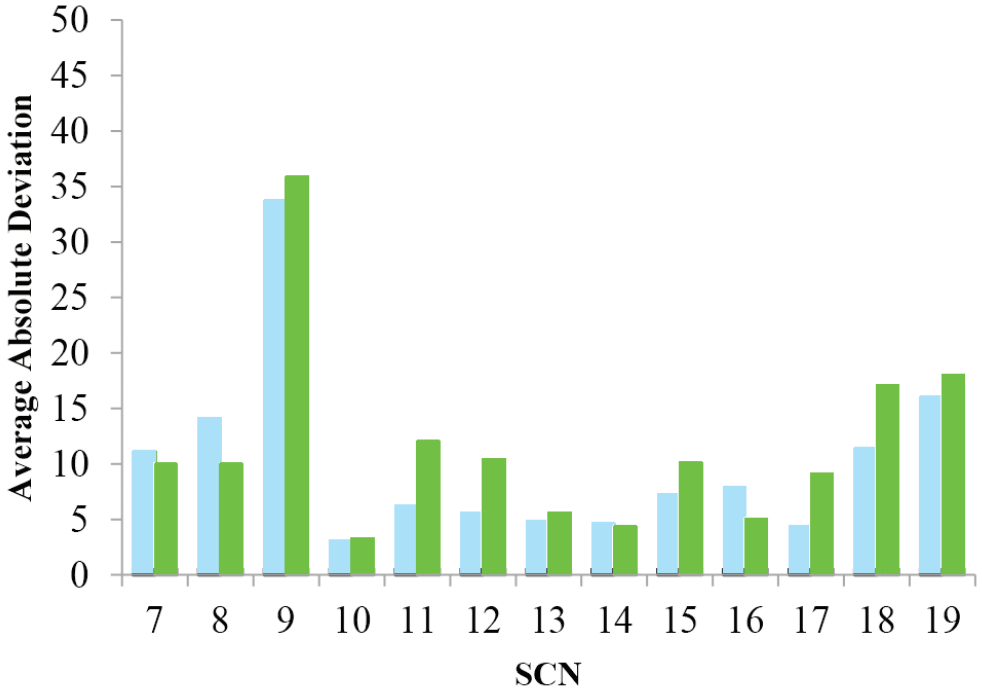

Figure 5: Average absolute deviation for composition of SCN groups in all samples. Black columns: modified four-coefficient model (this work); Grey columns: gamma distribution function

Table 4: Average absolute deviation of samples and total average deviation of different distribution functions

Sample name	Exponential	Gamma	CM 4	This work
S1	40.75	8.35	10.06	8.38
S2	34.62	6.54	10.99	5.24
S3	12.89	8.58	8.07	6.71
S4	11.55	9.68	12.30	5.87
S5	12.25	13.64	11.09	7.37
S6	16.90	10.04	14.64	9.59
S7	13.90	11.41	18.31	8.46
S8	23.29	7.04	10.79	5.94
S9	63.69	14.18	20.97	15.50
S10	15.43	10.28	15.76	11.69
S11	23.91	10.97	15.38	9.99
S12	84.82	10.12	13.03	8.97
S13	75.89	9.92	12.09	8.90
S14	34.55	17.42	25.56	14.84
S15	13.73	13.69	16.73	11.50
S16	32.86	13.63	19.98	12.71
S17	29.16	14.05	14.94	13.14
S18	22.00	13.61	15.74	12.91
S19	22.65	12.73	16.79	11.67
S20	22.65	12.47	14.46	12.66
S21	40.90	11.84	17.05	10.31
S22	30.22	11.87	14.67	10.96
S23	124.04	13.63	19.75	12.60
S24	100.58	14.08	20.10	12.94
S25	96.94	12.93	19.15	12.28
S26	22.42	12.31	16.79	11.34
S27	20.06	16.60	25.90	14.75
S28	20.63	13.72	16.19	11.70
S29	21.00	12.63	16.89	11.10
S30	31.55	13.35	16.98	11.28
TAAD	37.19	12.04	16.04	10.71

Conclusions

Gas condensate samples taken from the supergiant reservoir under study showed discontinuities or jumps in molecular weight at SCN=8, 13. Results showed that ignoring discontinuities can result in large errors when applying exponential distribution function. The gamma distribution function can predict compositional discontinuities at SCN=8 but failed at SCN=13. On the other hand, the

modified four-coefficient model was shown to successfully predict both discontinuities with the best accuracy compared to exponential, gamma, and original four-coefficient models. Results also showed that the parameters of distribution function are strongly dependent on fluid nature and better results are obtained upon optimizing the selected model using experimental field data.

NOMENCLATURE

AAD	Average Absolute Deviation
F	Distribution function
M	Molecular weight
S	Adjustable parameters of equations 6 & 7
Sn	Sample name, in table 3
SCN	Single Carbon Number
TAAD	Total Average Absolute Deviation
Z	Molar composition of SCN group
Greek Letter	
A	Distribution form
T	Minimum molecular weight in the plus fraction
Superscripts	
Cal	Calculation
Exp	Experimental
Subscripts	
+	Plus fraction
N	Number of SCN group

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ارائه مدل تصحیح شده چهار ضریبی برای مشخصه سازی جزء سنگین در یک مخزن فوق عظیم گاز میعانی

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چکیـــــــده

خواص و ترکیب برش جمعی یک سیال نفتی تأثیر قابل توجهی بر رفتار فازی سیال دارد. شناخت روند تغییرات جرم مولکولی گروه های متوالی تک کربن برش جمعی مستلزم داشتن یک تابع توزیع دقیق و قابل اعتماد است. مدل های مختلف تابع توزیع موجود برای انواع خاص سیال قابل استفاده است. در این مقاله، تحلیل ۳۰ سیال معرف یک مخزن گاز میعانی فوق عظیم نشان داد که ناپیوستگی در جرم مولکولی های گروه های تک کربن ۸ و ۱۳ است. توابع توزیع نمایی، گاما، چهارضریبی و چهارضریبی تصحیح شده بر این داده ها اعمال شد تا ترکیب گروه های تک کربن پیش بینی شود. نتایج نشان داد که تابع توزیع نمایی دقت لازم برای پیش بینی توزیع ترکیبات تک کربن به ویژه در نقاط ناپیوستگی ترکیب را ندارد. به علاوه، تابع توزیع گاما ناپیوستگی ترکیب در عدد کربنی ۸ را به خوبی پیش بینی کرد ولی دقت لازم در عدد کربنی ۱۳ را ندارد. خطای کلی محاسبات برای روش های نمایی، گاما و چهارضریبی تصحیح شده به ترتیب برابر با ۳۷,۹%، ۱۲,۰۴% و ۱۰,۷۱% بدست آمد. مقایسه نتایج پیش بینی مدل چهارضریبی و مدل چهارضریبی تصحیح شده نشان داد که متغیرهای مدل به شدت وابسته به ماهیت سیال است و بر اساس داده های میدانی موجود نیازمند بهینه سازی میباشد.

واژگان کلیدی: گاز میعانی، برش جمعی، تابع توزیع، مدل چهارضریبی