Journal of the Serbian Chemical Society
JSCS-info@shd.org.rs • www.shd.org.rs/JSCS
J. Serb. Chem. Soc. 85 (5) 687–696 (2020)
JSCS–5331
Original scientific paper

New empirical correlation for oil flowrate prediction through chokes

AMIR MASOUD FULADGAR[1]* and ZOHA VATANI[2]
[1]*Petroleum Engineering and Development Company, Tehran, Iran and* [2]*Refining Technology Development Department, Research Institute of Petroleum Industry, Tehran, Iran*

(Received 20 May, revised 11 September, accepted 27 September 2019)

Abstract: Accurate prediction of choke restricted multiphase flowrate is always interesting in oil industry in the absence of flowmeters for field production monitoring and management purposes. Also, in a producing well, choke is installed for controlling the production rate. In this research, new correlation is developed for predicting the multiphase flowrate through choke specified for one of the Iranian southern oilfields. For this purpose, 166 sets of flowrate measurement data, was gathered and filtered to 142 data sets, at the quality control step. This data was regressed to a linearized modified correlation between the measured flowrate, the wellhead pressure choke size and the producing gas liquid ratio to find the best set of correlation parameters. The resulted correlation was evaluated by determining its average relative error and root mean square error by the excluded set of test data. The evaluation indicated that new correlation could significantly improve the accuracy of flowrate predictions in contrast to previous prominent correlations.

Keywords: choke flowrate; choke correlation; critical flow; PESSAP.

INTRODUCTION

In order to control the production problems such as gas coning, water coning, asphaltene precipitation, sand production, *etc*., the optimized flowrate is particularly taken into consideration in order to determine less than maximum well production potential. For this purpose, well flowrate is restricted to a predefined limit by means of choke. Choke is a local restriction in cross sectional area of flow path, restricting flowrate by imposing pressure drop to the producing fluid.[1,2] Another benefit of the application of choke for controlling well flowrate is stabilizing the flow condition by creating sonic, or critical flow condition in its throat.[1,3] It is used not only to control and optimize production flow but also to protect surface equipment, to control and prevent undesirable flow of fluids and to provide controlled back pressure on producing fluid.[1–5] There is no specified

* Corresponding author. E-mail: Fuladgar@gmail.com
https://doi.org/10.2298/JSC190520110F

Available on line at www.shd.org.rs/JSCS/
(CC) 2020 SCS.

analytical solution to calculate pressure drop and flowrate for multiphase fluid flow through choke, but numerous models are developed to estimate choke flowrate based on fluid properties and flow condition by aiding numerical solutions. Because of the complexity of these solutions their application necessitates aiding computer programs which are not almost available at well sites in the oil industries. Then many investigators tried to find an imperial correlation capable of predicting fluid flowrate by choke size and its upstream pressure.[5] Calculation of flowrate by analytical solutions for any fluid passing through the choke can be accomplished by the application of continuity and Navier Stokes equations. But the solution for the final equation is dependent on the in-situ fluid properties passing through choke throat. For single phase flow of gas or liquid, the solution is straight forward, but for multiphase flow the equation is complex due to changing fluid properties in the choke throat by changing pressure, temperature, phase ratio, *etc*.[6] Thus many investigators attempted to find the simplest solution for calculating multiphase flowrate passing through the choke. One of the simplest approaches taken into consideration by many investigators, is developing empirical correlations predicting choke flowrate using pressure differential across the choke.

BACKGROUND

Tangren *et. al.* performed the primitive studies to predict the multiphase flowrate using empirical correlations.[7] In 1954 Gilbert developed the first empirical correlation by using 268 data set.[8] Baxandall in 1958 proposed a new correlation.[9] Ros in 1961 developed a new relationship where continuous gas stream occurs along the choke, based on Tangren works.[10]

In 1961, Achong developed the third famous empirical correlation.[11] Then in 1963 Poetman and Beck utilized Ros model by implementing it in field unit to simplify correlation and finally proposed it in graphical mode.[12] In 1969 Omana carried out some experiments in the presence of gas and water phases and presented a new correlation.[13] This correlation covers the choke size range of 4/64 to 16/64 inch. In 1972 Fortunati suggested new relationship for both subcritical and critical conditions.[14] In 1974 Ashford developed a new empirical correlation for subcritical flow.[15] Tangren *et. al.* analyzed gas liquid expansion behaviour and showed that if gas bubbles are added to the incompressible liquid under critical velocity condition, pressure changes cannot be transmitted to the choke upstream.[7] Therefore, numerous correlations were developed to predict the flowrate in chokes. These correlations mostly have the following form:

$$Q = \frac{A\,P_{\mathrm{wh}}\,Cs^{B}}{R^{C}} \tag{1}$$

where Q is the stock tank llowrate in STB d^{-1}, P_{wh} is the wellhead pressure in PSIG, Cs is the choke bean inside diameter in 1/64 inch and R is the gas to liquid ratio in Std. ft^3 STB^{-1}. Several most common prominent correlations widely cited by other investigators are listed in Table I.

Bairamzadeh *et. al.* developed a new Gilbert type correlation for the experimental data with average absolute error of 20 %.[16] Alrumah *et. al.* developed a correlation for Kuwait oilfield which is able to predict oil flowrate with R^2 of 89 %.[17] Ling in 2012 developed a new

(CC) 2020 SCS.

correlation for sonic and subsonic gas flowrate prediction in choke by modifying parameters in base correlatoins.[18] Gue *et. al.* found new correlation for oil and gas condensate fields by modifying choke discharge coefficient.[19] Recent usage of artificial intelligence in estimating oil flowrate in chokes has become very common. Al-Khalifa used artificial neural network to predict oil flowrate with average absolute percent error of less than 4 %.[20] Elhaj *et. al.* found employed different artificial intelligence including artificial neural network, fuzzy logic, support vector machine and functional network for predicting single gas flowrate.[21] Choubineh *et. al.* used a hybrid model of an artificial network with a teaching learning based optimization to predict oil flowrate in chokes.[22] R^2 of their method is equal to 0.981. Although these methods can predict flowrate with more accuracy, they cannot be employed easily, therefore developing a new correlation with flexible form is vital for oil and gas fields. Recently new correlations have been developed for choke flowrate prediction by some modifications in the main format. One of these new modifications is considering the exponent for wellhead pressure, which is claimed to reduce the prediction error of choke flowrate prediction.[23] Thus in this study, after considering various formats, in order to find the most precise new specific correlation for predicting choke flowrate in the considered Iranian oilfield, it was found out that the correlation with the following format can significantly reduce the flowrate prediction error for the considered oilfield:

$$Q = \frac{A\, P_{\mathrm{wh}}{}^{B}\, Cs^{C}}{R^{D}} \tag{2}$$

TABLE I. Emprical coefficient for Gilbert,[8] Ros,[10] Baxandall[9] and Achong[11] correlations in original oilfield unit system

Correlation	*A*	*B*	*C*
Gilbert	0.1	1.89	0.546
Ross	0.0574	2	0.5
Baxandall	0.104	1.93	0.546
Achong	0.2617	1.88	0.65

Data gathering and quality control (QC)

This case study is accomplished using surface well testing data obtained from producing oil wells in a huge oilfield located in south west of Iran. This oilfield produces more than 100000 STB d^{-1} oil from four major reservoirs with different oil properties. The main characteristic of this oilfield is provided in Table II. Wide range of actual flowrates data, measured during surface well testing operation in the field, was collected. Flowrate was measured by surge tank, P_{wh} is measured by calibrated digital gauges installed on the flow line, R is easily calculated from ratio of estimated gas flowrate in standard condition in Std. ft^3 d^{-1} to measured liquid flowrate in stock tank in STB d^{-1}. Cs is determined by the inside diameter of choke bean in 1/64 inch. Regarding that most previous similar prominent empirical correlations were derived in this oilfield unit system, it is preferred in this study to develop new empirical correlation in the same unit system to simplify comparison.

After gathering all available necessary data, a quality control was performed on all data, and invalid data diagnosed and excluded (details are given in Supplementary material to this paper). The frequency distribution of quality-controlled data based on choke size and wellhead pressure is demonstrated in histogram plots provided in Figs. 1 and 2, respectively. In

(CC) 2020 SCS.

these plots, x-axis shows districted ranges of wellhead pressure and choke size and y-axis shows count of the quality-controlled data belonging to each range of data.

TABLE II. Main characteristics of the case study oilfield

Parameter	Value
No. of oil reservoirs in the field	4
Field oil production rate, 10^3 STB d^{-1}	100
No. of producing wells	70
Reservoir area, 10^6 m^2	720
Oil density, API	19–34
STOOIP, 10^9 STB	26
Reservoir pressure, PSIA	4600–9200
Reservoir temperature, °F	71–205
GOR, Std. ft^3 STB^{-1}	290–1670
Oil viscosity, cP	0.043

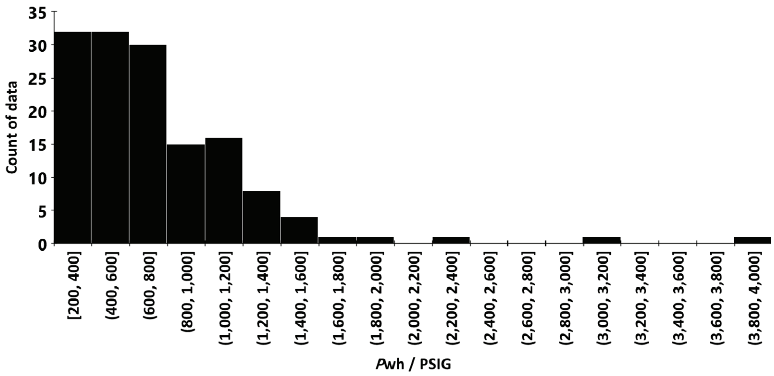

Fig 1. Frequency distribution histogram for P_{wh} (wellhead pressure) data.

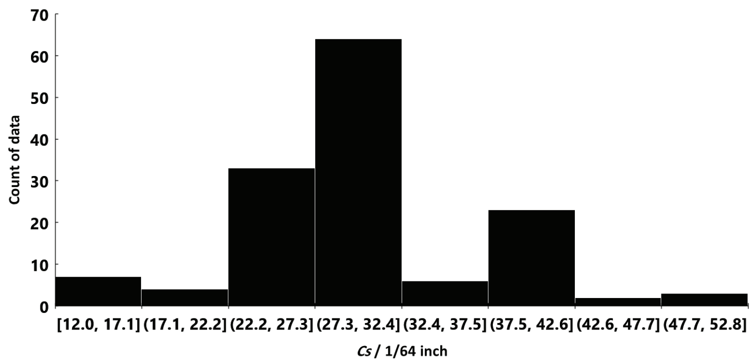

Fig 2. Frequency distribution histogram for *Cs* (choke size) data.

For the validation phase of this study around 10 % of the QC data points were extracted out. Number of data belonging to each of 4 producing reservoirs in the oilfield is categorized and provided in Table III.

(CC) 2020 SCS.

TABLE III. Data used for correlation development categorized based on reservoir

Reservoir	Count of all measured flowrate data	Count of data after QC
Reservoir S	112	98
Reservoir K	16	14
Reservoir G	23	19
Reservoir F	15	11
Total	166	142

DEVELOPMENT OF NEW SPECIFIED CORRELATION

In this study, it is aimed to develop a specified correlation for the considered Iranian oilfield based on Eq. (2) by the method of multi variable linear regression. In order to develop a more accurate correlation for flowrate prediction, with respect to the more common prominent correlations such as Baxandall,[9] Achong,[11] Ros,[10] Gilbert,[8] *etc*. at the first step, the equation was linearized. Equations 3 to 5 show the procedure of the linearizing the relationship:

$$Y_\mathrm{i} = A_0 X_1^{(A1)} X_2^{(A2)} \ldots X_\mathrm{n}^{(An)} \tag{3}$$

After linearization this equation can be rewritten as:

$$\log Y_\mathrm{i} = \log A_0 + A_1 \log X_1 + A_2 \log X_2 \ldots + A_n \log X_n \tag{4}$$

On the other hand, for this equation we can write:

$$Q = \log \mathrm{A} + B \log P_\mathrm{wh} + C \log Cs - D \log R \tag{5}$$

The purpose of analysis of multi-variable regression is to find a relationship between independent and dependent variable. In this study using linear regression on quality controlled wellhead pressure and choke size data of the considered oilfield, parameters of Eq. (2) were calculated, which are shown in Table IV. It's worth to mention that, since the quality controlled data was in the oilfield unit, it is not simple to use data in other unit system for the application of this empirical correlation.

TABLE IV. Parameters of new developed correlation based on Eq. (2)

Parameter	Value
A	0.3135
B	0.807947
C	1.740565
D	0.407676

Using above parameters, the new specified correlation for this case study, can be written in the form of Eq. (2) which is demonstrated as Eq. (6):

$$Q = \frac{0.3135\, P_\mathrm{wh}^{\,0.807949}\, Cs^{1.740565}}{R^{0.407676}} \tag{6}$$

(CC) 2020 SCS.

Also, for more convenience this correlation was provided in SI unit system as Eq. (7):

$$Q = \frac{0.000188 P_{\mathrm{wh}}{}^{0.807949}\ Cs^{1.740565}}{R^{0.407676}} \tag{7}$$

EVALUATION OF NEW CORRELATION

For evaluation of the new specified correlation, first of all, the cross plot chart of all measured data is presented *versus* the predicted data by the new correlation. The results were depicted in Fig. 3. Dispersion in data and deviation from unique slope line indicates lower precision in prediction of flowrate by correlation. The coefficient of determination for the new correlation shows a proper correlation between the measured and the predicted data. For evaluation and validation of this new specified correlation, the new correlation and previous prominent correlations were applied on the test data. The average relative error (*ARE*) was calculated by Eq. (8) and the root mean square error (*RMSE*) was calculated by Eq. (9):

$$ARE = \frac{100 \sum \left| \frac{Q_{\mathrm{m}} - Q_{\mathrm{est}}}{Q_{\mathrm{m}}} \right|}{n} \tag{8}$$

$$RMSE = \sqrt{\frac{\sum (Q_{\mathrm{m}} - Q_{\mathrm{est}})^2}{n}} \tag{9}$$

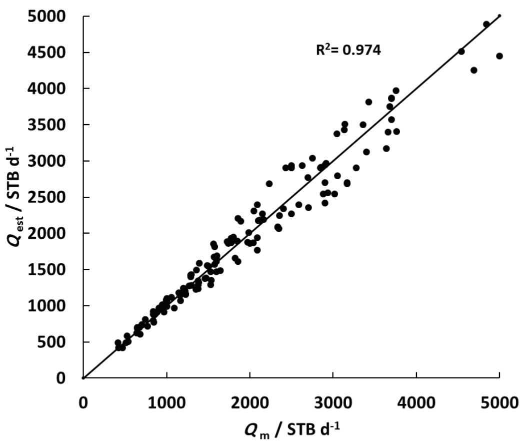

Fig. 3. Comparison between estimated and measured data.

The results show that the new relationship significantly reduces *RMSE* (Fig. 4) and *ARE* (Fig. 5) in comparison to the others.

Also, for better comparison of the new correlation with older prominent ones, 12 quality controlled measured data sets were acquired from new ongoing

(CC) 2020 SCS.

well testing operations and implemented for preparing the cross plots of measured rate and calculated rate for Achong,[11] Gilbert,[8] Baxendall,[9] Ros[10] and the new correlation which is illustrated in Fig. 6. These plots show the quality of the correlations for the prediction of flowrate.

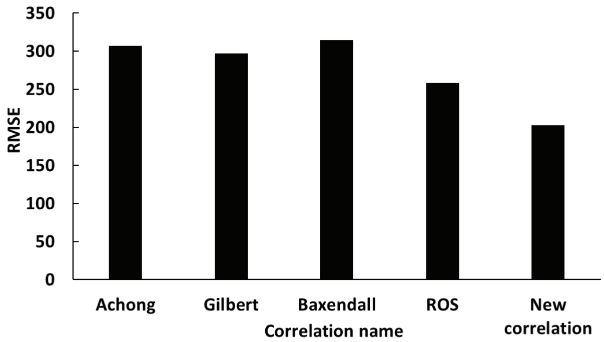

Fig. 4. RMSE for different correlations.

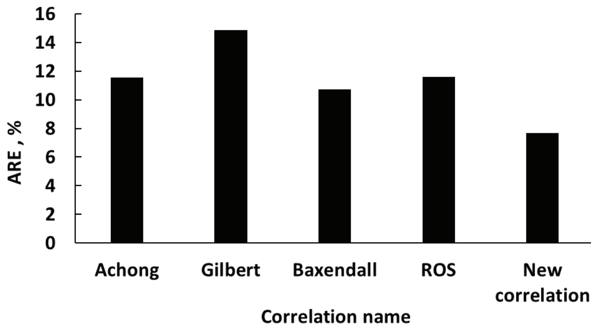

Fig. 5. ARE for different correlations.

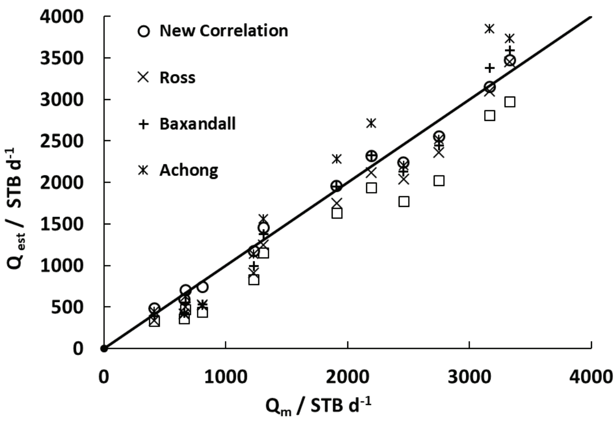

Fig. 6. Flowrate cross plot (estimated flowrate *vs*. measured flowrate) comparing new correlation with older prominent correlations.

(CC) 2020 SCS.

The precise values of *RMS* error and the average relative error for older prominent correlations *vs.* new correlation developed in this study is provided in Table V. It can be concluded that *ARE* and *RMSE* for new correlation introduced in this study is significantly lower than that of older prominent correlations.

TABLE V. Results of comparising ARE and RMSE for new correlation with older prominent correlations

Correlation	*ARE* / %	*RMSE*
Achong	11.6	306.7
Gilbert	14.9	297.1
Baxendall	10.7	314.7
Ros	11.6	258.2
New correlation	7.7	202.8

CONCLUSION

The accurate prediction of choke restricted multiphase flowrate in absence of flowmeters is always interested in the oil industry. In a producing well, choke is installed for controlling the production rate. This can be implemented to prevent water and/or gas coning, sand production, asphaltene precipitation, *etc*. Much researches has been conducted to find the best correlation between the oil flowrate and choke size. This study aims to find the best suited correlation to calculate oil flowrate through choke by means of 142 filtered and quality controlled data set. The new correlation developed for the huge Iranian oilfield, improved the precision of flowrate prediction in comparison to former prominent correlations. Regarding different sources of error influencing on flowrate measurement operations, excluding non-valid measured data significantly improved accuracy of the new correlation such that *RMS* error and average relative error for new correlation respectively was reduced to 202.8 and 7.7 %, which is significantly lower than that of the older prominent correlations.

NOMENCLATURE

QC	quality control
Q	stock tank flowrate, STB d^{-1}
P_{wh}	wellhead pressure, PSIG
Cs	choke bean inside diameter, 1/64 in
API	American Petroleum Institute
Q_{est}	estimated flowrate, STB d^{-1}
Q_m	measured flowrate, STB d^{-1}
Q_{est}	estimated flowrate, STB d^{-1}
Q_m	measured flowrate, STB d^{-1}
R	gas to liquid ratio, Std. ft^3 STB^{-1}
STOOIP	Stock Tank Oil Originally in Place
RMSE	root mean square error
ARE	average relative error, %

Available on line at www.shd.org.rs/JSCS/

(CC) 2020 SCS.

Units

STB	Stock Tank Barrel
STB d^{-1}	Stock Tank Barrel per day
Std. ft^3	Standard cubic feet
Std. ft^3 STB^{-1}	Standard cubic feet per Stock Tank Barrel
cP	g cm^{-1} s^{-1}
Stm^3 s^{-1}	Stock tank cubic meter per second
Pa=	Pascal
Std m^3 Stm^{-3}	standard meter cube gas to stock tank cubic meter liquid

SUPPLEMENTARY METERIAL

The quality-controlled data that is implemented in this study are available at http://www.shd.org.rs/JSCS/, or from corresponding author on request.

Acknowledgement. The author appreciates and acknowledge the cooperation and support of the research and development department of the Petroleum Engineering and Development Company.

ИЗВОД

НОВА ЕМПИРИЈСКА КОРЕЛАЦИЈА ЗА ПРЕДИКЦИЈУ ПРОТОКА НАФТЕ КРОЗ ЗАГУШЕЊА

AMIR MASOUD FULADGAR[1] И ZOHA VATANI[2]

[1]*Petroleum Engineering and Development Company, Tehran, Iran и* [1]*Refining Technology Development Department, Research Institute of Petroleum Industry, Tehran, Iran*

Поуздано предвиђање протока вишефазног флуида ограниченог загушењем је увек интересантно за нафтну индустрију када не постоје мерачи протока за потребе праћења у производном постројењу и управљања производњом. Такође, у производним бунарима, инсталирају се пригушења у сврху контролисања брзине производње. У овом истраживању развијена је нова корелација за предикцију протока вишефазног тока кроз загушење, специфицирана за једно нафтно поље у јужном Ирану. У ту сврху, сакупљено је 166 сетова података мерења протока, који су филтрирани на 142 сета података у кораку контроле квалитета. На основу ових података је извршена регресија којом је добијена линеарна модификована корелација која повезује измерени проток са притиском, величином сужења и односом гас–течно, при чему су одређени најбољи корелациони параметри. Извршена је провера добијене корелације одређивањем средње апсолутне грешке и стандардне девијације у односу на независтан сет података. Провера је показала да нова корелација значајно побољшава тачност предикције протока, у поређењу са претходним познатим корелацијама. Стандардна девијација нове корелације у предвиђању протока из загушења је значајно мања него код најбољих корелационих једначина које су до сада коришћене.

(Примљено 20. маја, ревидирано 11. септембра, прихваћено 27. септембра 2019)

REFERENCES

1. M. J. Moghaddasi, I. Lotfi, M. Moghaddasi, *Energy Sources, A* **37** (2015) 1340 (http://dx.doi.org/10.1080/15567036.2011.605426)
2. H. R. Nasriani, A. Kalantari, in *Proceedings of SPE Asia Pacific Oil and Gas Conference and Exhibition*, 2011, Jakarta, Indonesia, Society of Petroleum Engineers, Richardson, TX, 2011, SPE-145576-MS

Available on line at www.shd.org.rs/JSCS/

(CC) 2020 SCS.

3. L. Jin, A. K. Wojtanowicz, in *Proceedings of SPE improved oil recovery symposium*, 2010, Tulsa, OK, USA, Society of Petroleum Engineers, Richardson, TX, 2010, SPE-129663-MS
4. H. H. Al-Attar, in *Proceedings of SPE Latin American and Caribbean Petroleum Engineering Conference*, 2009, Cartagena de Indias, Colombia, Society of Petroleum Engineers, Richardson, TX, 2009, SPE 120788-MS
5. M. Ghareeb, A. Shedid, in *Proceedings of the International Petroleum Technology Conference*, 2007, Dubai, UAE, Society of Petroleum Engineers, Richardson, TX, 2007, PTC 11101-MS
6. I. Nejatian, M. Kanani, M. Arabloo, A. Bahadori, S. Zendehboudi, *J. Nat. Gas. Sci. Eng.* **18** (2014) 155 (http://dx.doi.org/10.1016/j.jngse.2014.02.008)
7. R. F. Tangren, C. H. Dodge., H. S. Seifert, *J. Pet. Explor. Prod. Technol.* **20** (1949) 637 (https://dx.doi.org/10.1063/1.1698449)
8. W.E. Gilbert, *Flowing and gas-lift well performance*, API, New York, 1954, p. 126 (https://www.onepetro.org/conference-paper/API-54-126)
9. P. B. Baxendell, R. Thomas, *SPE J.* **13** (1961) 1023 (https://dx.doi.org/10.2118/2-PA)
10. N. C. J. Ros, *Appl. Sci. Res.* **9** (1961) 374 (https://dx.doi.org/10.1007/BF00382215)
11. I. Achong, *Revised bean performance formula for Lake Maracaibo wells*, Internal Company Report, Shell Oil Co., Houston, TX, 1961
12. F. H. Poettmann, R. L. Beck, *World Oil* **184** (1963) 95 (https://dx.doi.org/10.1007/s13202-018-0532-6)
13. R. Omana, C. Jr. Houssirere, K. E. Brown, J. P. Bril l, P. B. James, R. E. Thompson, in *Proceedings of Fall Meeting of the Society of Petroleum Engineers of AIME*, 1969, Denver, CO, USA, Society of Petroleum Engineers, Richardson, TX, 1969, SPE 2682-MS
14. F. Fortunati, in *Proceedings of SPE European Meeting*, 1972, Amsterdam, Netherlands, Society of Petroleum Engineers, Richardson, TX, 1972, SPE 3742-MS
15. F. E. Ashford, *J. Petrol. Tech*. **26** (1974) 843 (https://dx.doi.org/ 10.2118/4541-PA)
16. S. Bairamzadeh, E. Ghanaatpisheh, *Science International (Lahore)* **27** (2015) 271 (http://www.sci-int.com/Search?catid=45)
17. M. K. Alrumah, M. S. Bizanti, in *Proceedings of SPE Middle East Oil and Gas Show and Conference*, 2007, Manama, Bahrain, Society of Petroleum Engineers, Richardson, TX, 2007, SPE 105103-MS
18. K. Ling, in *Proceedings of SPE Latin America and Caribbean Petroleum Engineering Conference*, 2012, Mexico City, Mexico, Society of Petroleum Engineers, Richardson, TX, 2012, SPE 151547-MS
19. B. Guo, A. S. Al-Bemani, A. Ghalambor, *J. Can. Pet. Technol.* **46** (2007) 22 (https://dx.doi.org/ 10.2118/2002-009)
20. M. Al-Khalifa, M. A. Al-Marhoun, in *Proceedings of SPE Saudi Arabia Section Technical Symposium and Exhibition*, 2013, Society of Petroleum Engineers, Richardson, TX, 2013, SPE 169597-MS
21. M. A. Elhaj, F. Anifowose, A. Abdulraheem, n *Proceedings of SPE Saudi Arabia Section Annual Technical Symposium and Exhibition*, 2015, Al-kho Bar, Saudi Arabia, Society of Petroleum Engineers, Richardson, TX, 2015, SPE 177991-MS
22. A. Choubineh, H. Ghorbani, D. A. Wood, E. Sadatshojaei, *Fuel* **207** (2017) 547 (https://dx.doi.org/10.1016/j.fuel.2017.06.131)
23. M. Babaei Khorzoughi, M. S. Beiranvand, M. R. Rasaei, *J. Pet. Explor. Prod. Technol.* **3** (2013) 279 (https://dx.doi.org/10.1007/s13202-013-0067-9).

Available on line at www.shd.org.rs/JSCS/

(CC) 2020 SCS.