CHEMICAL ENGINEERING TRANSACTIONS

VOL. 55, 2016

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors:Tichun Wang, Hongyang Zhang, Lei Tian

ISBN978-88-95608-46-4; **ISSN** 2283-9216

DOI: 10.3303/CET1655058

Research on Influence Factors and Screening Method of Tight Sandstone Oil Reservoir CO_2 Huff and Puff Based on Multi-index

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CO_2 huff and puff has been continuously considered as an import EOR method for tight oil reservoirs. However, the large number of evaluation parameters for reservoir screening has limited its application. This paper proposed a multi-index evaluation function for CO_2 huff and puff method to facilitate the reservoir screening. By the means of orthogonal experimental design, it concludes the main controlling factors for screening a tight sand oil reservoir with multi-stage fractured horizontal wells. In addition, we built a calculation model for this multi-index evaluation function with Box-Benhken experimental design method. And this model has been successfully applied to screen wells for CO_2 huff and puff of Y oilfield in Ordos.

1. Introduction

CO_2 huff and puff was considered as the substitute of steam huff and puff initially, it is an ideal way of Carbon dioxide geological storage (Bounaouara et al., 2015, Mukhopadhyay et al., 2012, Samadi and Garbolino, 2012, Zhang et al., 2016). This technique has been successfully used in various types of reservoirs, such as heavy oil reservoirs, complex fault block reservoirs and low permeability reservoirs (Liu and Lianhai, 1997; Chokejaroenrat et al., 2013; He et al., 2006; Joseph, 2012; Olenick et al., 1993; Xi, 2016). Due to complex physics, and a wide range of evaluation parameters and impact factors, the reservoir screening methods and injection-production parameter optimization have been widely noted by reservoir engineers (Mohanty et al., 2013, Shenglai et al., 2004, Uchiyama et al., 2012). For example, Petrotrin (Bybee, 2007) analyzed its impact factors and provided a screening method in the implementation of CO_2 huff and puff in Forest oilfield (Trinidad and Tobago). However, this method does not work well for tight and low permeability reservoir. Gao Huimei and her colleagues established a response surface model of CO_2 huff and puff potential evaluation for tight sandstone reservoirs. Since this model sets oil exchange ratio as its evaluation index, it cannot be used in reservoir screening for fractured reservoirs.

Chang 8 reservoir of Y oilfield belongs to southern part of Tianhuan depression of Ordos basinin regional structure. Chang 812, the major formation, has its sand body controlled by subwater distributary channels, which belongs to braided river delta front deltic subwater distributary channels. Sand thickness ranges from 4.5m to 25.1m with average value 15m. Porosity ranges from 4.4% to 14% with average porosity 10.8%. Permeability is between 0.1md to 0.64md, and the average is 0.4md. Chang 8 reservoir is a naturally fractured reservoir dominated by vertical and high angle fractures, with length between 10cm~30cm, width less than 1mm. Those fractures are mainly dominated by semi-filled and filled fractures. In general, Chang 8 reservoir is a naturally fractured sandstone reservoir with ultra-low permeability.

Please cite this article as: Li B.H., Li Y.Q., Kong D.B., Chen Y.H., Fei C.G., He Y.F., 2016, Research on influence factors and screening method of tight sandstone oil reservoir co2 huff and puff based on multi-index, Chemical Engineering Transactions, 55, 343-348
DOI:10.3303/CET1655058

This text takes Ordos Y oilfield as the research object, and analyzes the effects of geologic and injection-production parameters by multi-index orthogonal experimental design. The design incorporates the production behaviors contributed by natural fractures and multi-stage fractured horizontal wells. Finally, the screening method of CO_2 huff and puff for a tight sandstone reservoir with multi-stage fractured horizontal wells has been proposed by combining multi-index system and Box-Behnken experimental design method.

2. Multi-index integrated evaluation method

Multi-index integrated evaluation is to build a statistical index system for the research object, and analyze those indexes with certain methods and models. In general, it provides quantitative criteria for the research object, and the criteria can help reveal the mystery and underlying principles of research object.

Nowadays, most reservoir engineers evaluate the effect of CO2 huff and puff by estimating the oil exchange ratio and extra-oil production. Sometimes the stage and incremental oil recovery are also used to evaluate its effect. However, those indexes just capture one aspect for evaluating CO2 huff and puff performance, and the overall results could be opposite to the implication from those indexes. For example, there could be a case that shows high period incremental oil production but a low oil exchange ratio, or a case that has a high stage oil recovery but low oil exchange ratio is under the cutoff value. Thus, the effect of CO2 huff and puff cannot be evaluated with only one parameter, andmulti-index evaluation method should be used. This research screens and optimizes the injection-production parameters with the multi-index evaluation method. The following formula has been used in calculating the integrated index.

$$Z = \sum_i \omega_i \times f_i \tag{1}$$

Z is the integrated index; f represents individual indexes. Those individual indexes are oil exchange ratio, average period extra-oil production, stage oil recovery, incremental oil recovery and initial water content. ω is the weight of each index, and it is determined by the analytical hierarchy process. Table.1 shows the results from analytical hierarchy process.

Table 1: Weight of Indexes

Index	Ω Weight
C Oil exchange ratio	0.399
Qo Average period extra-oil production	0.369
Z_RIncremental oil recovery	0.130
R Stage oil recovery	0.073
f_w Water content	0.029

The following formula is the integrated index formula.

$$Z = 0.399C + 0.369Q_o + 0.130Z_R + 0.073R - 0.029f_w \tag{2}$$

3. Impact factor of CO_2 huff and puff

3.1 Orthogonal experimental design I

We built a dual porosity compositional model to numerically study Chang 8 reservoir. The geological model has a size of 500 m length and 300 m width with 5 vertical layers; the grid size is 10 m length X 5 m width, height corresponding to the thickness of each layer. Fractures are simulated by infilling unevenly. The effective flow conductivity of the artificial fractures is 5Dc·cm. Thermodynamic parameters of each component are tuned by PVT fitting.

According to the geological condition of Chang 8 reservoir, the variation ranges of each factor have been determined shown in Table 2. There are 13 factors and each of them has 3 values corresponding to minimum, maximum and base cases. We designed 27 experimental cases with orthogonal experimental design method. The integrated indexes value for each case has been computed based on the numerical results. Table 3 shows the 13 simulation cases and the corresponding value of each factor; the value of integrated index for each cast is listed in the last column.

3.2 Influence factors analyze

The results of orthogonal experiments show that the effect of each factor on CO_2 huff puff is different. For example, the intergraded evaluation index Z increases with the increase of oil saturation, frequency of natural fractures, layer thickness and vertical variation coefficient of frequency of natural fractures. On the other hand, Z decreases with the increase of oil viscosity, penetration ratio and the value of Kv/Kh. The relation between Z and media permeability, vertical variation coefficient of media permeability, horizontal variation coefficient of frequency of natural fractures, artificial fracture interval and formation pressure is non-uniformly varied.

A quantitative effect of each impact factor is analyzed, and the result is shown in Figure1.From high impact factors to low ones: it is oil saturation, frequency of natural fractures, oil viscosity, reservoir thickness, vertical variation coefficient of frequency of natural fractures, horizontal variation coefficient of frequency of natural fractures, vertical variation coefficient of media permeability, Kv/Kh, horizontal variation coefficient of media permeability, artificial fracture interval, initial formation pressure, media permeability and penetration ratio. The effect of oil saturation, frequency of natural fractures, oil viscosity and reservoir thickness dominates among all the factors.

Figure 2 shows the quantitative effect of each factor on the objective function of the oil exchange ratio.

From Figure 1 and 2, the order of quantitative effect of each factor is different because of different objective function. For example, the top six impact or factors of multi-index objective function are oil saturation, frequency of natural fractures, oil viscosity, reservoir thickness, vertical and horizontal variation coefficient of frequency of natural fractures. On the other hand, those of CO_2 oil exchange ratio objective function are oil saturation, frequency of natural fractures, oil viscosity, artificial fracture interval, horizontal variation coefficient of frequency of natural fractures, and vertical variation coefficient of media permeability. Since oil exchange ratio was considered as the most important factor and has a high weight when we established the Z function, the top three influential factors of those two objective functions are same.

Table 2: Analyzed impact factors and their ranges

Factors	Minimum	Base case	Maximum
Media permeability, md	0.01	0.05	0.09
Horizontal variation coefficient of media permeability	0.1	0.4	0.7
Vertical variation coefficient of media permeability	0.1	0.4	0.7
K_v/K_h	0.01	0.11	0.21
Oil saturation	0.3	0.4	0.5
Frequency of natural fractures, number of branches per meter	0.05	0.25	0.45
Horizontal variation coefficient of frequency of natural fractures	0.1	0.4	0.7
Vertical variation coefficient of frequency of natural fractures	0.1	0.4	0.7
Penetration ratio	0.1	0.15	0.2
Fracture interval	50	75	100
P/MMP	0.5	0.8	1.1
Reservoir thickness, m	5	15	25
Oil viscosity, cp	1	5	9

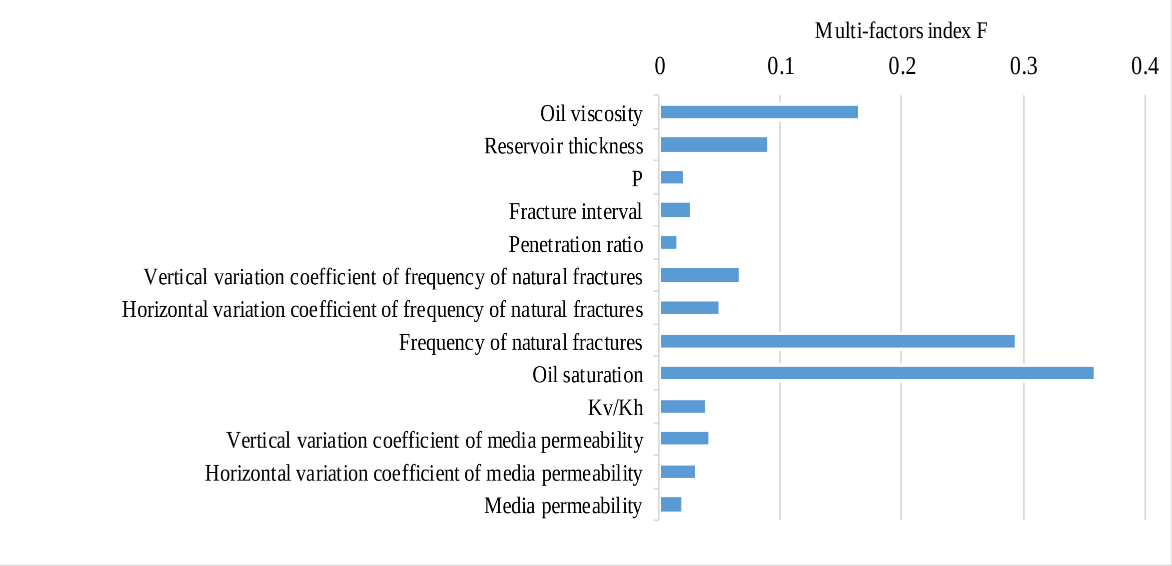

Figure 1: Quantitative effect of each factor on multi-factors index F

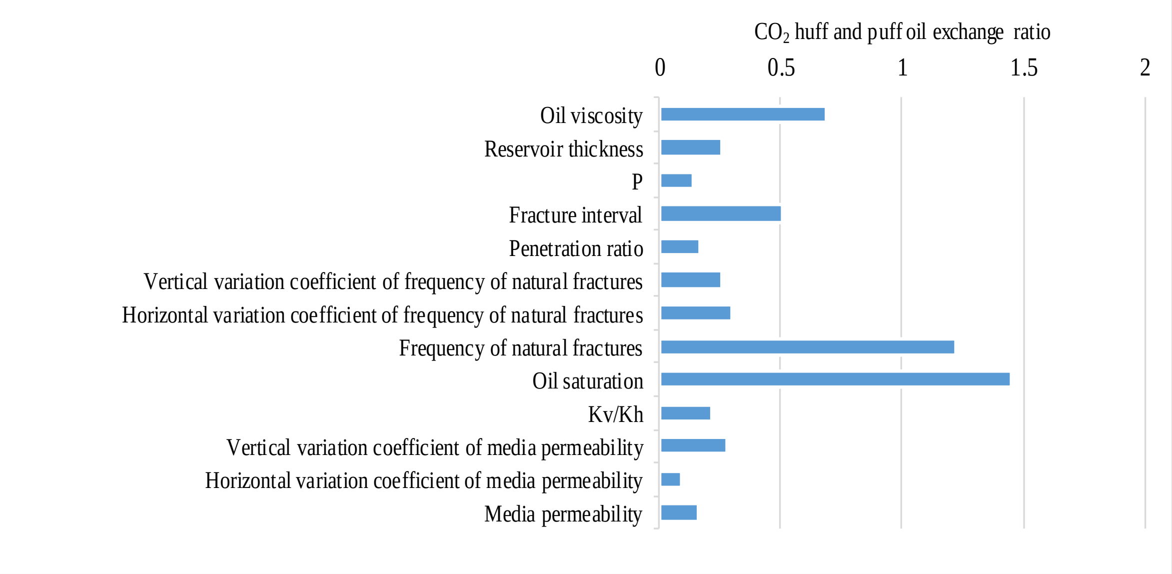

Figure 2: Quantitative effect of each factor on huff and puff oil exchange ratio

4. CO_2 huff and puff single well screening method

4.1 Box-Benhken experiment design

According to above analysis result for the impact factors, four factors, each of them having three values in its range, were considered to design 29 groups of experiments by BBD method with Design Expert 8.0. We built a typical compositional model with Eclipse and computed the value of Z under different group of experiment. Table 4 shows the factors and their ranges.

Table 4: experiment factors and their ranges

Influence factors	Factors	Range		
		-1	0	1
Oil saturation	A	0.3	0.4	0.5
Frequency of natural fractures, number of branches per meter	B	0.05	0.25	0.45
Oil viscosity, cp	C	1	5	9
Reservoir thickness, m	D	5	15	25

4.2 Establish the screening method

Table 5 and 6 shows the variance analysis and the correlation coefficients of fitting models for the relation between multi-index value and the impact factors using Design-Expert 8.0.

Table 5 shows the linear model has maximum value of F with best fitting result, and the quadratic model is the second. Table 6 presents the comparison of multiple correlation coefficients, mean square error and square of deviance of each model. Cubic polynomial model has the minimum of standard deviation, but its predicted residual sum of squares is too high. The standard deviation and the predicted residual sum of squares of linear model is larger than quadratic polynomial model as the predict value of R^2 of the linear model is smaller. Although the quadratic polynomial model has the smallest predicted residual sum of squares and small standard deviation the value of its R^2 is relatively high. Overall, the quadratic polynomial model is a better choice for screening a tight sandstone oil reservoir with multi-stage fractured horizontal wells for CO_2 huff and puff.

The following formula shows the coefficients of quadratic polynomial model to screen a tight sandstone oil reservoir with multi-stage fractured horizontal wells for CO_2 huff and puff.

$$\begin{aligned} Z = -0.38640 + 1.75110 \times A - 0.23139 \times B - 0.017842 \times C - 0.015433 \times D + 4.14746 \times A \times B - 0.17412 \times A \\ \times C + 0.038613 \times A \times D - 0.020404 \times B \times C + 0.027538 \times B \times D + 2.45189E - 0.04 \times C \times D \\ + 0.13945 \times A^2 - 1.41500 \times B^2 \end{aligned} \tag{3}$$

Accordingly, the evaluation index for reservoir screening can be computed and ranked.

Table 5: Variance analysis of the model

Sources of variation	Quadratic sum	Degree of freedom	Mean square	F	Probability >F	
Mean	3.62	1	3.62			
Linear model	1.64	4	0.41	56.17	<0.0001	
2FI	0.066	6	0.011	1.83	0.1494	
Quadratic	0.077	4	0.019	8.55	0.0010	Suggested
Cube	0.027	8	3.33E-003	3.99	0.0544	
Residual	0.005	6	8.343E-004			
Total	5.44	29	0.19			

Table 6: R^2 comprehensive analysis

Type	Standard deviation	R^2	Corrected value of R^2	Predicted value of R^2	Predicted residual sum of squares	
Linear model	0.085	0.9035	0.8874	0.8488	0.27	
2FI	0.078	0.9401	0.9068	0.8011	0.36	
Quadratic	0.048	0.9826	0.9652	0.8997	0.18	Suggested
Cube	0.029	0.9972	0.9871	0.6034	0.72	

5. Field application

There are 291 wells in Y oilfield majority area; 52 of them are easy-channeling wells that should not be considered for huff and puff because of artificial fractures. In addition, 84 wells have poor production performance therefore do not work well for single well huff and puff. Thus total 155 wells are evaluated for implementing CO_2 huff and puff. The above method is applied to the evaluation and the results show that only 51wells having promising index values for CO_2 huff and puff, one third of production wells. In conclusion, CO_2 huff and puff method should not be applied to Y oilfield.

6. Conclusion

1. A multi-index evaluation function for CO_2 huff and puff applied to tight sandstone oil reservoirs was established. This function incorporates the integrated result of oil exchange ratio, average period extra-oil production, stage oil recovery, oil recovery amplification and initial water content.
2. Based on the multi-index function and the orthogonal design method, the main impact factors for CO_2 huff and puff in a tight sandstone oil reservoir with multi-stage fractured horizontal wells have been identified. The leading factors are oil saturation, frequency of natural fractures, oil viscosity and reservoir thickness.
3. A single well screening model for CO_2 huff and puff in a tight sandstone oil reservoir with multi-stage fractured horizontal wells has been built based on the multi-index function and Box-Benchmen experimental design.

This model was successfully applied to screen wells for CO_2 huff and puff in Y oilfield, Ordos.

Acknowledgments

The authors would like to acknowledge the financial support from National Key Technology Research and Development Program (No. 2012BAC26B05) and National Science and Technology Major Project (No. 2016ZX05048-003) for this study.

Reference

Bounaouara H., Ettouati H., Ticha H.B., Mhimid A., Sautet J.C., 2015, Numerical simulation of gas-particles two phase flow in pipe of complex geometry: Pneumatic conveying of olive cake particles toward a dust burner. International Journal of Heat and Technology, 33(1), 99-106, DOI: 10.18280/ijht.330114

Bybee K., 2007, Screening criteria for carbon dioxide huff'n'puff operations. Journal of Petroleum Technology, 59, 55-59, DOI: 10.2118/0107-0055-JPT

Chokejaroenrat C., Kananizadeh N., Sakulthaew C., Comfort S., Li Y., 2013, Improving the sweeping efficiency of permanganate into low permeable zones to treat TCE: Experimental results and model development. Environmental science & technology, 47, 13031-13038, DOI: 10.1021/es403150x

He Y.F., Mei S.S., Yang Z.M., Liu L., Liu X.W. 2006, Numerical simulation analysis of the influence factors on CO_2 stimulation in Palogue Oilfield. Special Oil & Gas Reservoirs, 1, 022.

Joseph A.M.F., 2012, Effects of thermal modification by the hot oil treatment process on some physical properties of two cameroonian hardwwod species, International Journal of Heat and Technology, 30(2), 43-50.

Liu B., Lianhai L., 1997, Research on cyclic CO 2 injection for low permeability light oil reservoirs in a small complex fault block. OIL & GAS RECOVERY TECHINOLOGY, 4.

Mohanty K.K., Chen C., Balhoff M.T., 2013, Effect of Reservoir Heterogeneity on Improved Shale Oil Recovery by CO Huff-n-Puff. SPE Unconventional Resources Conference-USA, Society of Petroleum Engineers, DOI: 10.2118/164553-MS

Mukhopadhyay S., De P.R., Bhattacharyya K., Layek G.C., 2012, Slip effects on mixed convection flow along a stretching cylinder. International Journal of Heat & Technology, 30, 19-24, DOI: 10.18280/ijht.300203

Olenick S., Schroeder F., Haines H.K., Monger-Mcclure T., 1993, Cyclic CO2 injection for heavy-oil recovery in Halfmoon field: laboratory evaluation and pilot performance.

Samadi J., Garbolino E., 2012, Dynamic Analysis of Safety Performance Indicators for CO2 Capture, Transport and Storage Activities. Chemical Engineering Transactions, 26, 147-152, DOI: 10.3303/CET1226025

Uchiyama T., Fujita Y., Ueda Y., Nishizaki A., Okabe H., Takagi S., Mitsuishi H., Kawahara Y., Huy L., Phanngoc T., 2012, Evaluation of a Vietnam Offshore CO2 Huff'n'Puff Test. SPE Improved Oil Recovery Symposium, Society of Petroleum Engineers, DOI: 10.2118/154128-MS

Xi G.Q., 2016, Design of an oil pipeline nondestructive examination system based on ultrasonic testing and magnetic flux leakage, Revista de la Facultad de Ingeniería, 31(5), 132-140

Yang S.L., Liang W., He J.J., Rong G.D., 2004, Oil production enhancing mechanism and field applying result of carbon dioxide huff-puff. Journal of Xi’an Shiyou University: Natural Science Edition, 19, 23-26.

Zhang Y., Wang D., Yang J., Tian L., Wu L., 2016, Research on the Hydrate Formation in the process of Gas Phase CO2 Pipeline Transportation. International Journal of Heat and Technology, 34(2), 330-344, DOI: 10.18280/ijht.340226