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GAS-OIL RATIO CORRELATION (R_S) FOR GAS CONDENSATE USING GENETIC PROGRAMMING

КОРРЕЛЯЦИЯ ГАЗОСОДЕРЖАНИЯ (R_S) ДЛЯ ГАЗОВОГО КОНДЕНСАТА, С ИСПОЛЬЗОВАНИЕМ ГЕНЕТИЧЕСКОГО ПРОГРАММИРОВАНИЯ

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A new correlation for solution gas oil ratio (RS) for gas condensate reservoir was developed in this paper by using genetic programming algorithm of a commercial software (Discipulus) program. Matching PVT experimental data with an equation of state (EOS) model in a commercial simulator (Eclipse simulator) was used to calculate the solution gas oil ratio (RS) values used in this study. More than 1800 solution gas oil ratio (RS) values obtained from the analysis of eight gas condensate fluid PVT laboratory reports, selected under a wide range of reservoir temperature and pressure, composition and condensate yield, were used.

Comparisons of the results showed that currently published correlations of gas oil ratio (RS) for gas condensate gave poor estimates of its value,(the average absolute error for sanding correlation was 63.48 with a standard deviation equal to 0.724, the average absolute error for Glaso correlation was 61.19 % with a standard deviation equal to 0.688, the average absolute error for Vasques and Beggs correlation was 52.22 % with a standard deviation equal to 0.512, the average absolute error for Marhoun correlation was 56.34 % with a standard deviation equal to 0.519 and the average absolute error for Fattah et al correlation was 18.6 % with a standard deviation equal to 0.049).

The proposed new correlation improved extensively the average absolute error for gas condensate fluids. The average absolute error for the new correlation was 10.54 % with a standard deviation equal to 0.035. Also, the hit-rate (R2) of the new correlation was 0.9799 and the fitness variance was 0.012.

The important of the new correlation comes from being depends only on readily available production data in the field and can have wide applications when representative PVT lab reports are not available.

В данной работе представлена разработка новой корреляции газосодержания (RS) для газоконденсатной залежи с использованием алгоритма генетического программирования коммерческого программного обеспечения (Discipulus). Для вычисления значений газосодержания (RS), используемых в данном исследовании, было применено сопоставление экспериментальных PVT-данных с моделью уравнения состояния (EOS) в коммерческом имитаторе (имитатор Eclipse). Было использовано более 1800 значений газосодержания (RS), полученных из лабораторных отчетов о PVT-анализе восьми газоконденсатных флюидов, отобранных при широком диапазоне показателей температуры и давления, состава и выхода конденсата.

Сравнения результатов показали, что имеющиеся опубликованные корреляции газосодержания (RS) для газоконденсата давали некачественные определения его значения (средняя абсолютная ошибка для корреляции Standing составляла 63.48 при среднеквадратичном отклонении равном 0.724, средняя абсолютная ошибка для корреляции Glaso была 61.19% при среднеквадратичном отклонении равном 0.688, средняя абсолютная ошибка для корреляции Vasques и Beggs составляла 52.22 % при среднеквадратичном отклонении 0.512, средняя абсолютная ошибка для корреляции Marhoun составляла 56.34% при среднеквадратичном отклонении равном 0.519, и средняя абсолютная ошибка для корреляции Fattah и др. составляла 18.6% при среднеквадратичном отклонении 0.049.)

Предложенная новая корреляция значительно улучшила показатель средней абсолютной ошибки для газоконденсатных флюидов. Средняя абсолютная ошибка для новой корреляции составила 10.54% при среднеквадратичном отклонении равном 0.035. А также коэффициент детерминации (R2) новой корреляции составил 0.9799, а вероятность ошибки - 0.012.

Актуальность новой корреляции вытекает из того, что она зависит только от легкодосупных промысловых данных на месторождении, и может широко применяться при отсутствии типичных лабораторных отчетов по PVT-испытаниям.

Key words: Gas-oil ratio Correlation; PVT laboratory report; Genetic programming; Gas condensate; modified black oil simulation.

Ключевые слова: корреляция газосодержания; лабораторный отчет о PVT-анализе; генетическое программирование; газовый конденсат; модифицированная модель «блэк ойл».

Introduction

Material balance equation is a useful method of reservoir performance analysis. It is routinely used to estimate oil, and gas reserves and predict future reservoir performance. Schilthuis, in 1936, was among the first to formulate and apply material balance analysis. As time progressed, more sophisticated material balance models evolved, each striving for greater generality.

Application of two-hydrocarbon-component, zero-dimensional material balance model had been restricted to black-oil or dry-gas reservoirs. Asgas condensate reservoirs exploration increases, there has been a growing need to address this limitation.

Spivak and Dixon (1973) introduced the Modified Black Oil (MBO) simulation approach. The PVT functions for modified black oil (MBO) simulation and material balance calculations of gas condensate are (condensate-gas ratio, R_v, solution gas-oil ratio, R_s, oil formation volume factor, B_o, and gas formation volume factor, B_g). The MBO approach assumes that stock-tank liquid component can exist in both liquid and gas phases under reservoir conditions in gas condensate reservoir.

A few authors have addressed the question of how to best generate the PVT properties for gas condensate. Whitson and Torp (1983) used laboratory constant volume depletion (CVD) data to calculate "modified black oil" PVT fluid properties B_o, R_s, B_g and R_v for gas condensate fluids. Coats (1985) suggested a different approach from Whitson and Torp's (W&T) to calculate the modified black oil properties for gas condensates. Walsh and Towler (1994) suggested a new simple method to compute the black-oil PVT properties of gas condensate reservoirs. Fevang*et al.* (2000) presented guidelines to help engineers choose between MBO and compositional approaches. Fattah *et al*. (2009) presented new correlations to develop MBO PVT properties when PVT fluid samples reports are not available.

Most of the methods in the literature for generating modified black oil PVT fluid properties (B_o, R_s, B_g and R_v) for gas condensate need a combination of lab experiments and elaborate calculation procedures.

This study involves two parts: the first part includes a comparison between the different correlations used to calculate the solution gas oil ration (R_s) for gas condensate to determine the most accurate one. The second part involves the development of a new correlation to calculate R_s for gas condensate reservoir using Genetic algorithm methods. Validation of the new correlation is achieved through comparison between the new correlation value of R_s and R_s generated by Whitson and Torp method from PVT lab data.

Fluid Samples

Eight gas condensates (GC) samples are used in this study. The samples were obtained from reservoirs representing different locations and depth, and were selected to cover a wide range of gas condensate fluid characteristics. Some samples represent near critical fluids as explained by McCain and Bridges (1994**).** Table 1 presents a description of the major properties of these eight fluid samples.

EOS models in a commercial simulator (Eclipse simulator) were used to develop an EOS model for each sample in Table 1. Tuning the EOS model that matched as best as possible the experimental results of all available PVT laboratory experiments (CCE, DL, CVD, and separator tests) was constructed. The procedure suggested by Coats and Smart (1986) to match the laboratory results was followed. For consistency, all EOS models were developed using Peng and Robinson (1976) EOS with volume shift correction (3-parameter EOS).

Approach

The developed EOS model for each sample in table 1 was used to output MBO PVT properties (R_v, R_s, B_o, and B_g) at six different separator conditions using Whitson and Torp (1983) procedure. The extracting data for the MBO PVT properties involves 1836 points from the different eight gas condensate samples. The first part was to compare between the extracted R_s and the most common R_s correlations to determine the most accurate one.

The second part involved the development of a new correlation to calculate R_s for gas condensate reservoir using Genetic algorithm program.

Genetic Programming

Genetic algorithms, evolution strategies and genetic programming belong to the class of probabilistic search procedures known as Evolutionary Algorithms that use computational models of natural evolutionary processes to develop computer-based problem solving systems. Solutions are obtained using operations that simulate the evolution of individual structures through mechanism of reproductive variation and fitness based selection. Due to their reported robustness in practical applications, these techniques are gaining popularity and have been used in a wide range of problem domain. The main difference between genetic programming and genetic algorithm is the representation of the solution. Genetic programming creates computer programs as solution whereas genetic algorithm creates a string of numbers to represent the solution. Genetic programming is based on the Darwinian principle of reproduction and survival of the fittest and analogs of naturally occurring genetic operations such as crossover and mutation (Koza, 1992). Genetic programming uses four steps to solve a problem (Koza, 1997):

1) Generate an initial population of random compositions of the functions and terminals (input) of the problem

2) Execute each program in the population and assign a fitness value.

3) Create a new offspring population of computer programs by copying the best programs and creating new ones by mutation and crossover.

4) Designation of the best computer program in the generation.

Solution Gas Oil Ratio (R_s) correlations

This part presented the comparison between the common correlations used to calculate the solution gas oil ration (R_s) for gas condensate in the literature. The comparison of the Vasques and Beggs correlation (1980) with the observed R_s for gas condensate result in average absolute error was 52.22 % with a standard deviation

Table 1. Characteristics of Fluid Samples

Property	GC 1	GC 2	GC 3	GC 4	GC 5	GC 6	GC 7	GC 8
Reservoir Temperature (°F)	312	286	238	256	186	312	300	233
Initial Reservoir Pressure (psig)	14216	NA	6000	7000	5728	14216	5985	17335
Initial Producing Gas-Oil ratio(SCF/STB)	3413	4278	NA	4697	5987	8280	6500	6665
Stock Oil gravity (° API)	45.6	NA	NA	46.5	58.5	50.7	45.6	43
Saturation Pressure (psig)	5210	5410	4815	6010	4000	5465	5800	11475
Components	**Composition (Mole %)**							
CO_2	2.66	4.48	0.14	0.01	0.18	2.79	6.98	0.36
N_2	0.17	0.70	1.62	0.11	0.13	0.14	1.07	0.31
C_1	59.96	66.24	63.06	68.93	61.72	66.73	65.25	81.23
C_2	7.72	7.21	11.35	8.63	14.1	10.22	8.92	5.54
C_3	6.50	4.00	6.01	5.34	8.37	5.90	4.81	2.66
iC_4	1.93	0.84	1.37	1.15	0.98	1.88	0.85	0.62
nC_4	3.00	1.76	1.94	2.33	3.45	2.10	1.75	1.06
iC_5	1.64	0.74	0.84	0.93	0.91	1.37	0.65	0.47
nC_5	1.35	0.87	0.97	0.85	1.52	0.83	0.69	0.52
C_6	2.38	0.96	1.02	1.73	1.79	1.56	0.83	0.84
C_{7+}	**12.69**	**12.2**	**11.68**	**9.99**	6.85	6.48	8.2	6.39

equal to 0.512. Figure1 presents cross-plots for R_S (Vasques & Beggs) vs. R_S (Observed) for gas Condensate samples. The comparison of the Standing correlation (1947) results in average absolute error was 63.48 % with a standard deviation equal to 0.724. Fig. 2 shows cross-plots for Standing correlation. The comparison of the Glaso correlation (1980) results in average absolute error was 61.19 % with a standard deviation equal to 0.688. Fig. 3 displays cross-plots for Glaso correlation. The comparison of the Marhoun correlation (1988) results in average absolute error was 56.34 % with a standard deviation equal to 0.519. Figure4 presents cross-plots for Glaso correlation. The comparison of the Fattah et al correlation (2009) results in average absolute error was 18.66 % with a standard deviation equal to 0.049, which is the best correlation in the literature. Figure5 shows cross-plots for Fattah et al correlation.

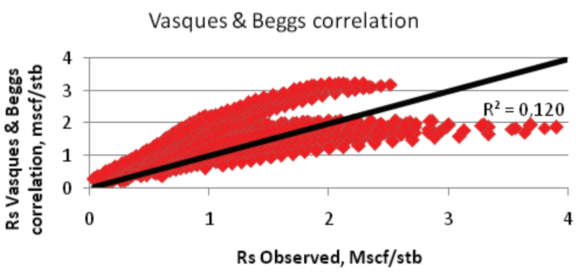

Figure 1. R_S for gas Condensate samples cross-plot for Vasques&Beggs correlation

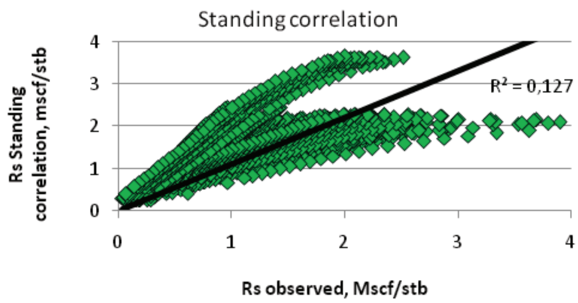

Figure 2. R_S for gas Condensate samples cross-plot for Standing correlation

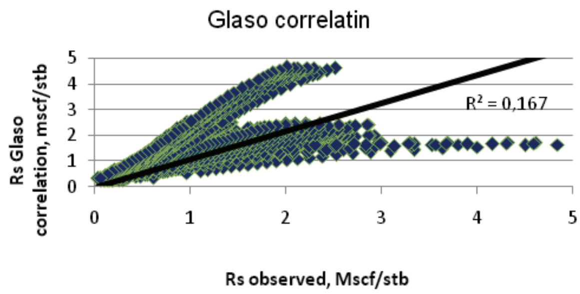

Figure 3. R_S for gas Condensate samples cross-plot for Glaso correlation

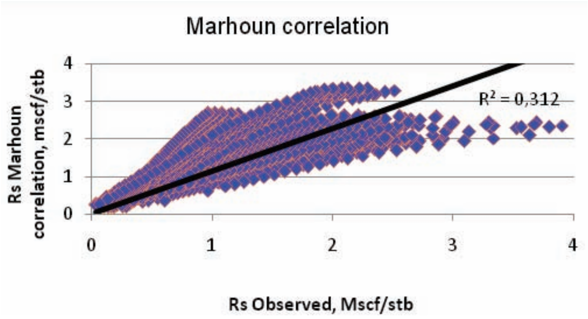

Figure 4. R_s for gas Condensate samples cross-plot for Marhoun correlation

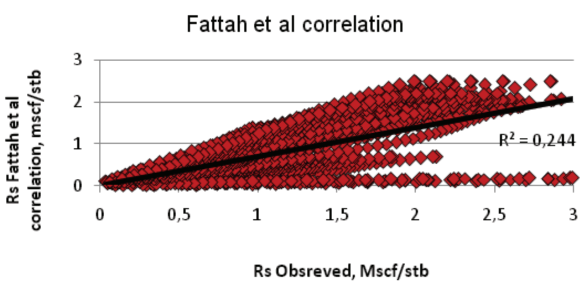

Figure 5. R_s for gas Condensate samples cross-plot for Fattah et al correlation

Developed Gas-oil ratio correlation (R_S) for gas condensate Using Genetic Program

The second part in this study involved the development of the new correlation to calculate R_s for gas condensate reservoir using genetic algorithm program. A commercial Genetic Programming system called ***Discipulus*** was used to develop the new R_S correlation (J. A. Foster, 2001, F. D. Francone, 2004). "Discipulus is a steady state genetic programming system, using tournament selection in which two pairs of individuals compete each round for reproduction. All the usual parameters can be adjusted with Discipulus: crossover rate, mutation rate, population size, instruction set, distribution of initial program sizes, termination criteria, and parsimony pressure (fitness advantages for smaller programs).", (J. A. Foster, 2001). The input data files for this software are classified into three semi-equal groups, "training data», «validation data» and «applied data». These input files include measured inputs and outputs parameters for our correlation.

The inputs parameters for our correlation are:

- Pressure (P), psi,
- Reservoir temperature (T), R°,
- API gravity of the reservoir fluid,
- Specific gravity of surface gas (SG_g)
- Specific gravity of surface oil (SG_o)

The output is the solution gas oil ratio, R_S.

Discipulus program gives different types of data and charts that show how the run in progress improved its performance. Discipulus creates thousands models (programs) from given data files that allow us to predict outputs from similar inputs and for each model (program) gives us his performance, (the hit-rate (R^2) and the fitness variance). At the end of the run, we choose the best model (program) depending on its hit-rate (R^2) and fitness variance to calculate the solution gas oil ratio; R_S. The models are creates as computer programs in Java, C++ code, or assembler program.

Figure6 shows the fitness improvement of the best genetic program for our correlation with time. The hit-rate (R^2) of the best genetic program, (the new correlation), was 0.9799 and the fitness variance was 0.012. Figs 7-9 present the match between the observed R_s and the calculated R_s for the new correlation. Each figure show that the match between all input points of the observed R_s and the calculated R_s for the same point from the best program developed by the software, the best team (During a project, Discipulus assembles the best programs into teams. The output from all of the programs that comprise a team are assembled into one collective output that is frequently better than any particular member of the team), and the selected program (almost is the best program if the default of the software is not changed). The results for our case indicated that the new correlation (best program) almost completely matches the observed R_s data. For more model validation, cross plots between observed and calculated R_s was drawn (Figure10) and the average absolute error and the standard deviation for the new correlation was calculated and equal to 10.54 % and 0.035 respectively. Table 2 summarizes the statistical comparison between the different correlations and the new correlation. From this table, we found that the new correlation is the best matched correlation.

Figure 6. The program fitness improvement with time

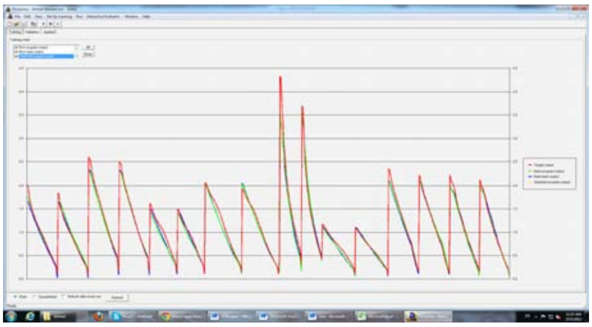

Figure 7. The observed VS calculated R_S dataformtraininginput data

Table 2. Statistical comparison of all correlations using observed data

Vas & Beggs correlation		Standing correlation		Glaso correlation		Marhoun correlation		Khaled correlation		new correlation	
AAE	SD	AAE	SD	AAE	SD	AAE	SD	AAE	SD	AAE	SD
52.2 %	0.51	63.4 %	0.73	61.2 %	0.69	56.3 %	0.52	18.6 %	0.05	10.5 %	0.035

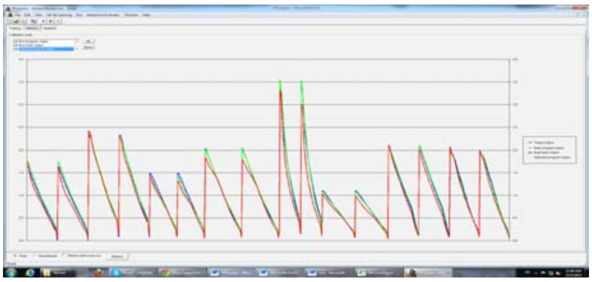

Figure 8. The observed VS calculated R_S dataform validation input data

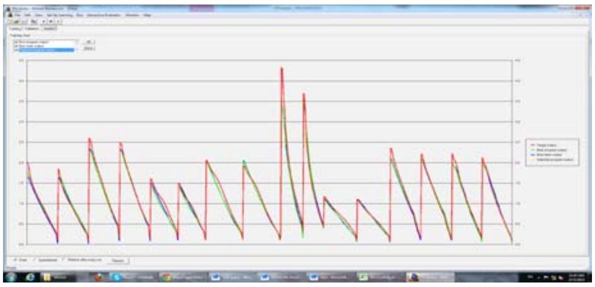

Figure 9. The observed VS calculated R_S dataformappliedinput data

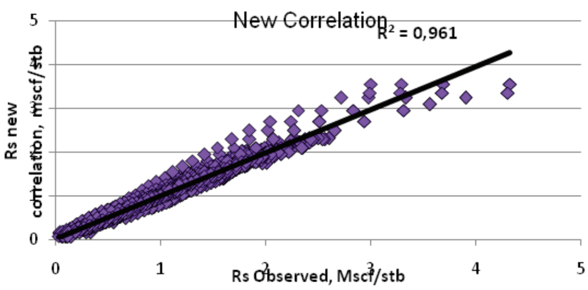

Figure 10. R_S for gas Condensate samples cross-plot for New correlation

The output C++ code of the genetic Model from the Discipulus to calculate the new $R_S$correlation was given in the appendix. This code was used with C++ compiler to develop a windows interface program to calculate R_S (Figure11). This code can be modified to generate a solution gas oil ratio array for different temperature, pressure values of a given reservoir.

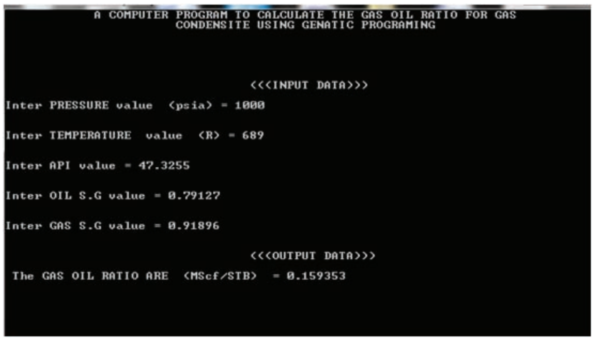

Figure 11. The windows interface of the program

The new correlation presented in this work can be used with other set of correlations to generate MBO PVT propertiesfor material balance calculation, or reservoir simulation without the need for fluid samples or elaborate procedure for EOS calculations. The application of these correlations is of particular importance especially when representative fluid samples are not available.

Conclusions

Based on work presented in this study, the following conclusions were made:

1. The comparison of the literature gas oil ratio correlations for gas condensate result in Fattah et al correlation was the best correlation to calculate gas oil ratio RS with average absolute error was 18.66 % and a standard deviation equal to 0.049.

2. New RS correlation was developed for gas oil ratio RS of gas condensates. The Discipulus software, a commercial Genetic Programming system, was used to develop the new correlation program. It is based on the concept of genetic algorithm.

3. The hit-rate (R2) of the new correlation was 0.9799 and the fitness variance for the new correlation was 0.012.

4. The comparison of the new correlation with the observed gas oil ratio RS result in average absolute error was 10.54 % with a standard deviation equal to 0.035.

Выводы

На основании работы, представленной в данном исследовании, были сделаны следующие выводы:

1. Результаты сравнения опубликованных корреляций для газоконденсата показали, что лучшей корреляцией для вычисления газосодержания RS стала корреляция Фаттаха и др. (Fattah et al), в которой

средняя абсолютная ошибка составила 18,6% при среднеквадратичном отклонении 0,049.

2. Для газосодержания RS газоконденсатов была разработана новая корреляция RS. Для разработки новой корреляционной программы было использовано программное обеспечение Discipulus, коммерческая система генетического программирования. Оно основывается на концепции генетического алгоритма.

3. Коэффициент детерминации (R2) новой корреляции составил 0,9799, а вероятность ошибки – 0,012

4. Сравнение новой корреляции с наблюдаемым газосодержанием RS показало, что средняя абсолютная ошибка для новой корреляции составляет 10,54% при среднеквадратичном отклонении равном 0,035.

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