

Theoretical and experimental analysis of constant volume depletion test and flash calculation by using a modified algorithm

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Constant volume depletion (CVD) which simulates closely the actual behavior of a gas condensate reservoir is a very important laboratory test. The results obtained from the laboratory measurements can be directly used to quantify recoveries of condensate and surface gas as a function of pressure below the dew point. The most time consuming section in simulating the compositional reservoir is flash calculation and several approaches have been suggested to speed it up. The physical properties of a fluid depend on whether the fluid is present as a single phase or splits into several equilibrium phases. Therefore to determine the number of equilibrium phases and their compositions and quantities, a flash calculation is needed in each time step. So the required calculation time increases with an increase in number of components. This paper presents the simulation of CVD test for different equation of states (EOS's) such as Peng-Robinson (PR) and Soave-Redlich-Kwong (SRK) by utilizing MATLAB program and compares the results with data obtaining from laboratory. Current study demonstrated that Saving time and money is one of the benefits of simulating the CVD test instead of laboratory procedure and the results from simulation have only small error from laboratory. This method can be equally applied to other gas condensate samples.

Key words: constant volume depletion test, gas condensate reservoir, flash calculation, equations of state model, new algorithm

1. Introduction

Gas Condensate wells behavior is unique in a sense, it is characterized by a rapid loss of well productivity. It is well known that when the flowing bottom-hole pressure drops below the dewpoint, a region of high condensate saturation builds-up in the wellbore causing lower gas deliverability, due to the reduction in gas permeability.⁵ A trustworthy estimation of the pressure depletion performance of a gas-condensate reservoir is necessary in determining reserves and appraising field-separation approaches. Currently, two approaches are being used to predict the changes in retrograde gas condensate composition and estimate the pressure depletion behavior of gas condensate reservoirs. The first approach uses the equation of states whereas the second uses empirical correlations. Equations of states (EOS) are poor predictive tools for complex hydrocarbon systems. The EOS needs adjustment against phase behavior data of reservoir fluid of known composition. The empirical correlation does not involve numerous numerical computations but

their accuracy is limited⁶ To planning future operations and investigating the economics of projects to increase liquid recovery the estimated performance is also used. Such estimations can be carried out by using the empirical data gathered by conducting constant-volume-depletion (CVD) tests on gas condensates. Suppose that retrograde liquid generating during production remains immobile in the reservoir, so these tests are carried out on a reservoir fluid sample in such a manner as to simu-

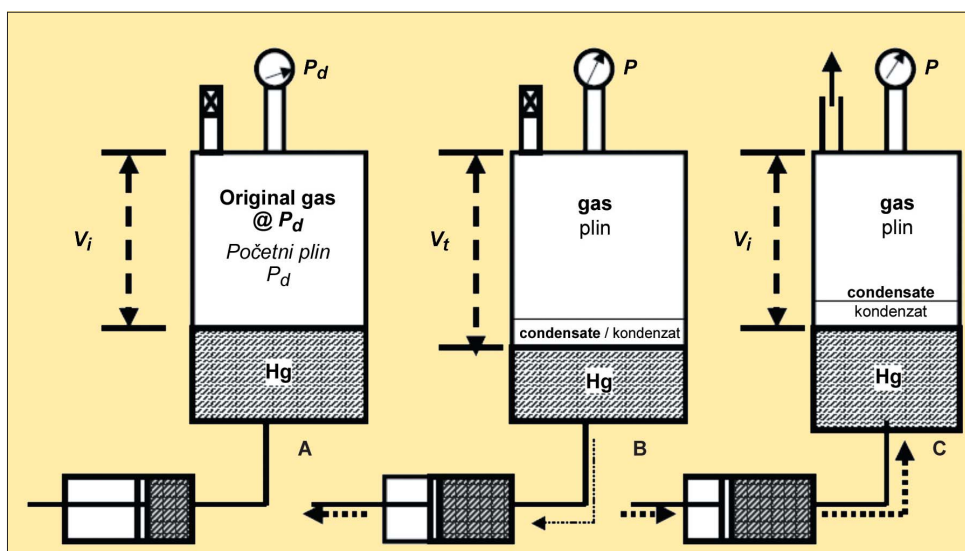
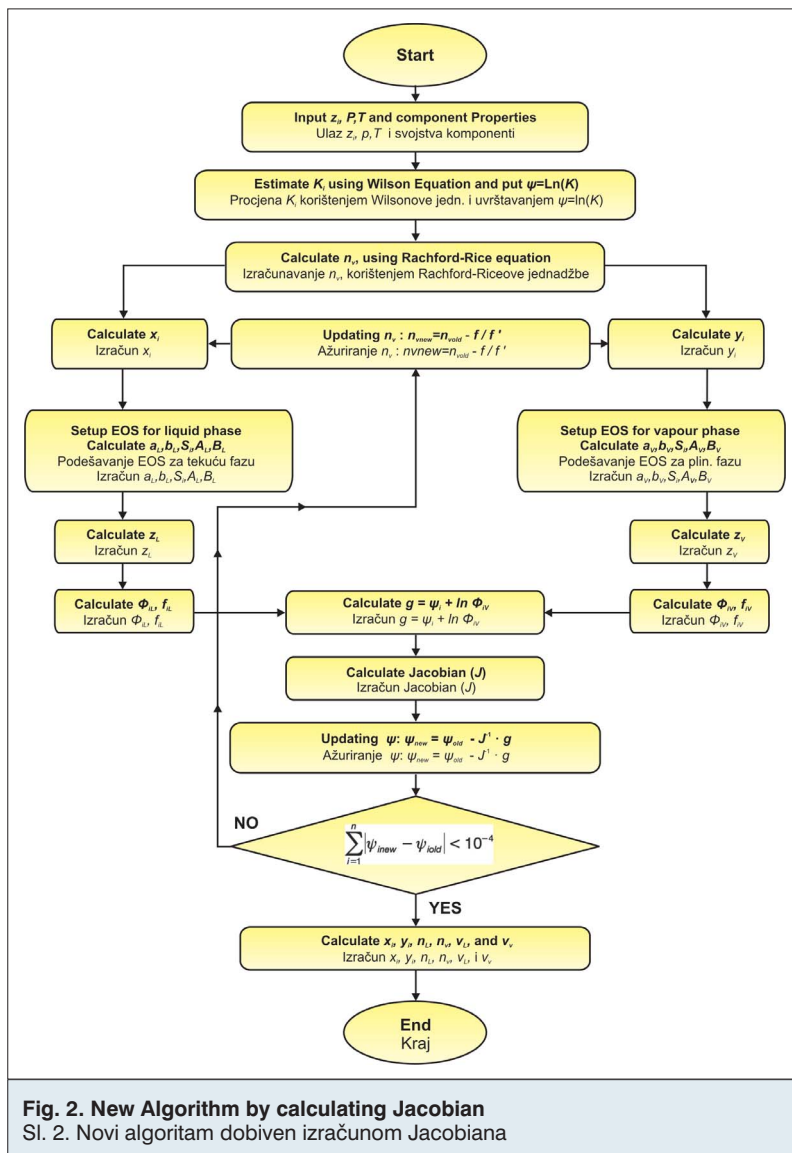


Fig. 1. A schematic illustration of the constant volume depletion test
Sl. 1. Shematski prikaz ispitivanja iscrpljivanja pri konstantnom volumenu (CVD)



late depletion of the actual reservoir. The CVD test provides five important laboratory measurements that can be used in a variety of reservoir engineering predictions:

- Dew-point pressure;
- Composition changes of the gas phase with pressure depletion;
- Deviation (Compressibility) factor at reservoir pressure and temperature;
- Recovery of original in-place hydrocarbons at any pressure;
- Retrograde condensate accumulation, that is, liquid saturation.

2. Experimental Procedure

Constant-volume depletion (CVD) experiments are performed on volatile oils and gas condensates to simulate reservoir depletion performance and compositional variation. The test supplies a diversity of important and ben-

eficial information which is used in reservoir engineering computations.

The laboratory procedure of the test is shown schematically in Figure 1.

This experimental procedure is repeated several times until a minimum test pressure is reached, after which the quantity and composition of the gas and retrograde liquid remaining in the cell are determined. The test procedure can also be directed on a volatile oil sample. In this case, the PVT cell primary contains liquid at its bubble-point pressure, instead of gas.

Flash Calculation

The determination of phase equilibrium in multi-component hydrocarbon systems is of being very interested in many different branches of petroleum engineering. EOS's have been used widely for the calculation of multi-component hydrocarbon phase equilibria. One important aspect of phase behavior computations in compositional modeling is two-phase vapor-liquid equilibrium calculation and the physical properties of a fluid in a cell or section depend on whether the fluid is present as a single phase or splits into several equilibrium phases. A flash calculation is therefore required in each time-step to determine the number of equilibrium phases and their amounts and compositions. Even with relatively few mixture components, the computation time of a compositional, transient simulation far exceeds that of a corresponding non-compositional, table-based simulation; furthermore, the computation time increases with an increased number of components.⁸ In an isothermal flash equilibrium calculation, a fluid of fixed total composition is equilibrated at a given temperature and pressure. For an equilibrium flash calculation,

the pressure, temperature, and overall mole fractions are clearly described, and the amounts of the phases and their compositions that form at equilibrium and also z factor for gas and liquid phase are computed. The thermodynamic criterion for equilibrium between the two phases is that the total Gibbs free energy should be a minimum.

3. Statement of Problem

The aim of this project is to write a MATLAB program for flash calculation; which is supposed to input pressure, temperature and composition of the fluid (z , for 3 component) and calculate K -values for each component based on 3 EOS (RK, SRK and PR). Composition of liquid and gas are also found by this program.

Algorithms

Analyses show that even with an optimized algorithm the flash computation time will typically constitute 70-80% of the total computation time required for a

Table 1. The components of the fluid which used in these simulations and other properties

| No. | Component | Composition (mol%) | T_{cs} (K) | p_{cs} (bar) | ω | MW (kg/kmol) |
|-----|------------------|--------------------|--------------|----------------|----------|--------------|
| 1 | N ₂ | 0.3243 | 126.20 | 33.94 | 0.040 0 | 28.01 |
| 2 | CO ₂ | 1.904 9 | 304.20 | 73.77 | 0.225 0 | 44.01 |
| 3 | C ₁ | 76.203 | 190.60 | 46.00 | 0.011 5 | 16.04 |
| 4 | C ₂ | 9.736 7 | 305.40 | 48.84 | 0.090 8 | 30.07 |
| 5 | C ₃ | 4.318 | 369.80 | 42.45 | 0.145 4 | 44.10 |
| 6 | iC ₄ | 0.566 7 | 408.10 | 36.48 | 0.176 0 | 58.12 |
| 7 | nC ₄ | 1.629 6 | 425.20 | 38.00 | 0.192 8 | 58.12 |
| 8 | iC ₅ | 0.450 7 | 460.26 | 33.83 | 0.227 1 | 72.15 |
| 9 | nC ₅ | 0.754 9 | 469.60 | 33.74 | 0.227 3 | 72.15 |
| 10 | CC ₅ | 0.058 0 | 511.60 | 45.09 | 0.192 3 | 70.14 |
| 11 | PC ₆ | 0.600 1 | 503.79 | 30.07 | 0.2860 | 86.18 |
| 12 | CC ₆ | 0.414 8 | 547.41 | 39.90 | 0.221 5 | 84.16 |
| 13 | PC ₇ | 0.423 9 | 536.44 | 27.60 | 0.336 4 | 100.21 |
| 14 | CC ₇ | 0.505 6 | 566.27 | 34.69 | 0.245 1 | 98.19 |
| 15 | AC ₇ | 0.306 3 | 591.70 | 41.14 | 0.256 6 | 92.14 |
| 16 | PC ₈ | 0.329 1 | 565.05 | 25.02 | 0.381 6 | 114.23 |
| 17 | CC ₈ | 0.377 5 | 594.05 | 29.74 | 0.239 1 | 112.21 |
| 18 | AC ₈ | 0.306 4 | 619.46 | 35.84 | 0.322 8 | 106.16 |
| 19 | PC ₉ | 0.263 0 | 590.64 | 23.29 | 0.423 0 | 128.25 |
| 20 | CC ₉ | 0.164 0 | 621.21 | 28.39 | 0.299 8 | 125.97 |
| 21 | AC ₉ | 0.120 8 | 644.06 | 32.08 | 0.372 5 | 120.16 |
| 22 | PC ₁₀ | 0.244 2 | 613.72 | 21.46 | 0.464 6 | 142.28 |

compositional, transient simulation. It is therefore highly desirable to be able to reduce the computation time associated with the flash calculations.⁹ We use various algorithms including the successive substitution (SS), modified successive substitution, and a new algorithm that calculate Jacobian both numerical and analytical for updating k values for defining two-phase flash.

New Algorithm

in this Algorithm (Figure 2), is calculated jacobian (J) both numerical and analytical and instead of K we update $\psi = \ln(K)$ and n_v simultaneously.

$$\psi_{new} = \psi_{old} - J^{-1} \cdot g \quad (1)$$

$$n_{vnew} = n_{vold} - f/f \quad (2)$$

Simulation of the CVD Test by EOS

When there isn't enough data for the CVD test, predictions of pressure-depletion behavior on a specific gas-condensate system can be attained by using any of the well-established equations of state to compute the phase behavior when the composition of the total gas condensate system is known. The stepwise computational procedure using the Peng-Robinson EOS as a representative equation of state now is summarized in conjunction with the flow diagram shown in Figure 3.

The components of the fluid which used in this simulation and other properties of this fluid are tabulated in Table 1.

In this part of paper the laboratory CVD test and its simulation by MATLAB was done and the data which obtain from different EOS's such as PR76 and PR78 and SRK and SRK G&D was compared.

4. Comparison of Results of Different EOS's of both MATLAB and Laboratory

The comparison of variation of gas deviation (compressibility) factor vs. pressure change by laboratory is shown in Figure 4 and by MATLAB is shown in Figure 5.

The comparison of variation of produced gas, % original mole vs. pressure change by laboratory is shown in figure 6 and by MATLAB is shown in Figure 7, and the comparison of variation of liquid volume, % original volume vs. pressure change by laboratory is shown in figure 8 and by MATLAB is shown in Figure 9.

5. Challenges

These are problems that catch so much time to solve:

- Fitting program data with laboratory data for gas produced (cum. mole % of original fluid) that are matched successfully and

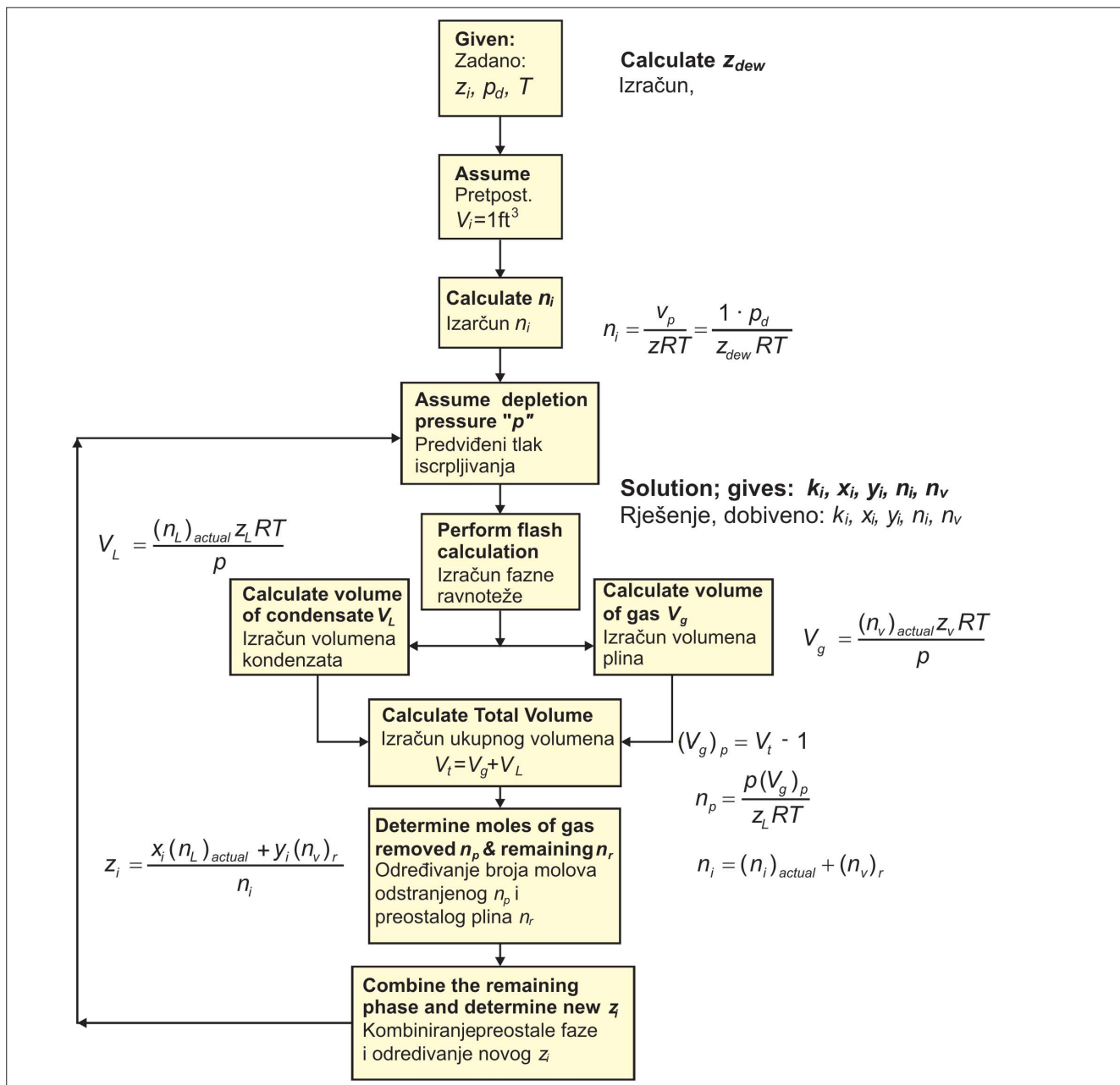


Fig. 3. Flow diagram for EOS simulating a CVD test
Sl. 3. Dijagram toka za EOS simulaciju CDV testa

- Fitting program data with laboratory data for liquid droplet (vol.% of original fluid). Although we do several works such as increasing order of error and decreasing magnitude of $\Delta \ln(\psi)$ (for numerical calculation) in order to matching them but we could not match them for a large interval.

Another problem is that if we need to use and update molar weight (MW) of component for every step of CVD calculation or not, at the end we see that it is not needed to use MW.

Setting a good initial guess for n_v and K -values because the whole three algorithms are very dependent on the first guess of this two parameters.

6. Conclusion and Recommendation

1. It seems that algorithm of Modified Successive Substitution is better than algorithms which are calculate Jacobian both analytical and numerical, because it has an exactness same as the two other algorithms but is very faster than others.
2. The CVD test provides five important laboratory measurements that can be used in a variety of reservoir engineering predictions:
 - a) Dew-point pressure.
 - b) Composition changes of the gas phase with pressure depletion.

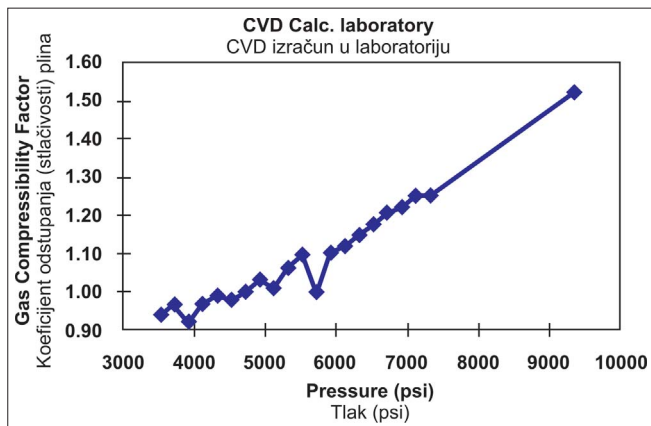


Fig. 4. The comparison of variation of gas compressibility factor vs. pressure change by laboratory

Sl. 4. Usporedba varijacija koeficijenta odstupanja (stlačivosti) plina u odnosu na promjene tlaka dobivene u laboratoriju

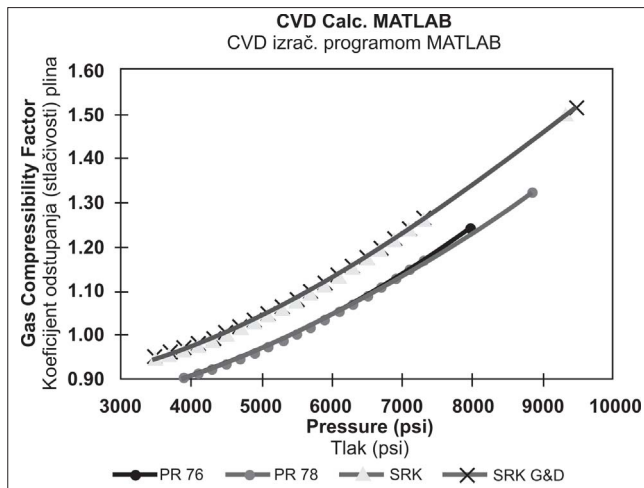


Fig. 5. The comparison of variation of gas compressibility factor vs. pressure change by MATLAB

Sl. 5. Usporedba varijacija koeficijenta odstupanja (stlačivosti) plina u odnosu na promjene tlaka izračunate programom MATLAB

- c) Deviation factor at reservoir pressure and temperature.
 - d) Recovery of original in-place hydrocarbons at any pressure.
 - e) Retrograde condensate accumulation, that is, liquid saturation.
3. CVD test is performed on a reservoir fluid sample in such a manner as to simulate depletion of the actual reservoir, assuming that retrograde liquid appearing during production remains immobile in the reservoir. we think it is a progressive step if we can simulate this test assuming that retrograde liquid is contributed in production.
 4. The importance of binary interaction coefficients in calculation was obvious, it seems that binary interaction coefficients are one of the main origins of the error (CMG also use the same binary interaction

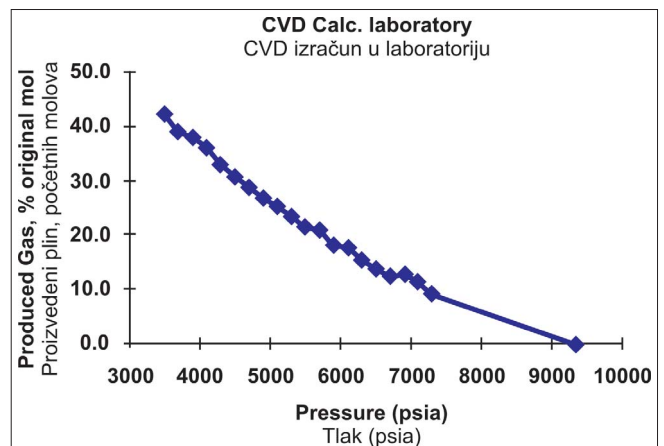


Fig. 6. The comparison of variation of produced gas, % original mole vs. pressure change by laboratory

Sl. 6. Usporedba varijacija proizvedenog plina, % početnih molova u odnosu na promjene tlaka izračunate programom MATLAB

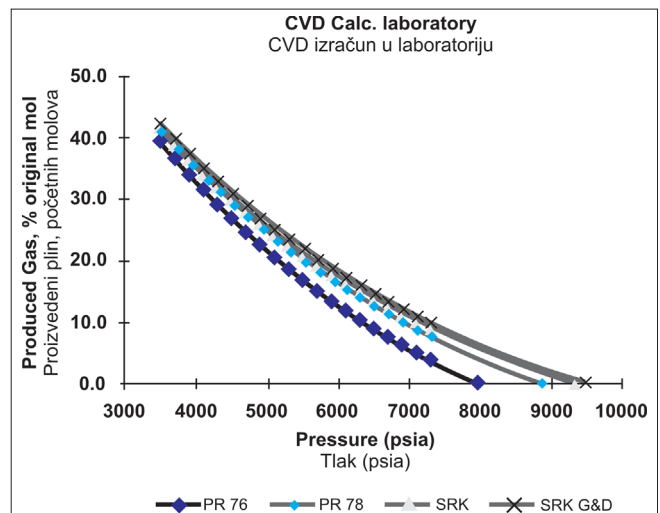


Fig. 7. The comparison of variation of produced gas, % original mole vs. pressure change by MATLAB

Sl. 7. Usporedba varijacija proizvedenog plina, % početnih molova u odnosu na promjenu tlaka izračunate programom MATLAB

coefficients for different EOS's), so we should tune EOS's for this uncertain parameters.

7. Nomenclatures

| | |
|----------|--|
| p_{wf} | Flowing bottom hole pressure |
| p_d | dew-point pressure |
| J | Jacobian |
| T_c | Critical Temperature |
| p_c | Critical Pressure |
| z | Gas Deviation (Compressibility) Factor |
| K | Equilibrium Ratio |
| n_v | Moles of Vapor |
| n_L | Moles of Liquid |
| v_v | Vapor Volume |
| v_L | Liquid Volume |

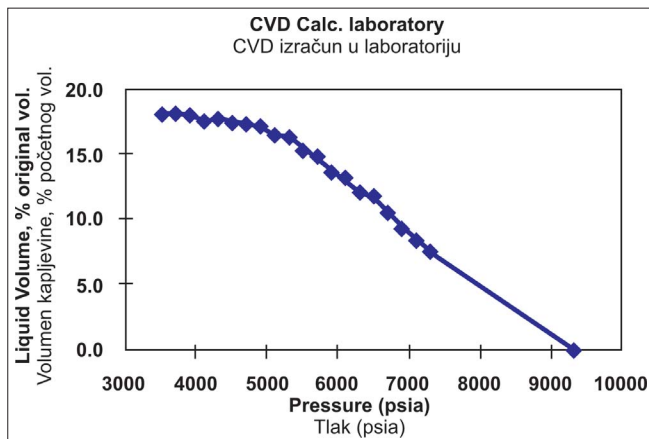


Fig. 8. The comparison of variation of liquid volume, % original volume vs. pressure change by laboratory
Sl. 8. Usporedba varijacija volumena kapljevine, % početnog volumena u odnosu na promjenu tlaka dobivene u laboratoriju

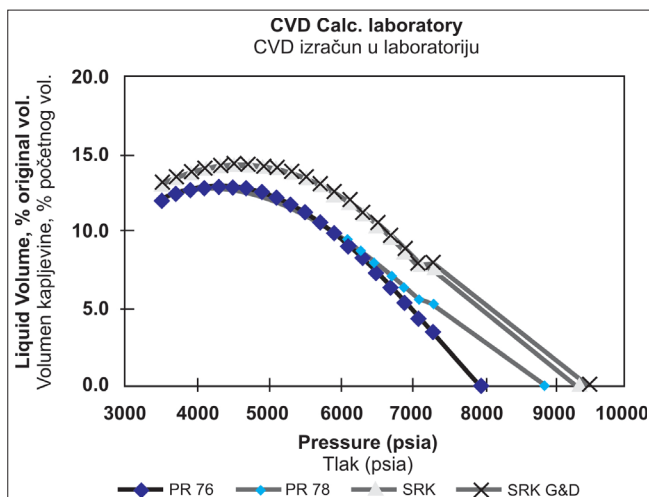


Fig. 9. The comparison of variation of liquid volume, % original volume vs. pressure change by MATLAB
Sl. 9. Usporedba varijacija volumena kapljevine, % početnog volumena u odnosu na promjenu tlaka izračunate programom MATLAB

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