Journal of Engineering and Applied Sciences 12 (22): 6045-6051, 2017
ISSN: 1816-949X
© Medwell Journals, 2017

Radius of Investigation and Radius of Desorption in CBM Reservoir

[1]Dedy Irawan, [1]Doddy Abdassah, [1]Zuher Syihab and [2]Ratnayu Sitaresmi
[1]Department of Petroleum Engineering, Institut of Teknologi Bandung, Bandung, Indonesia
[2]Department of Petroleum Engineering, Universitas of Trisakti, Jakarta, Indonesia

Abstract: Reserves estimation and classification in reservoir are important step in the CBM field development. Estimation both parameters are depend on radius of investigation and radius of desorption. This study propose semi analytical method for estimation of radius of investigation combining with radius of desorption. Desorption radius was estimated using cumulative gas production data. Cumulative water production data, fractional flow curve and sigmoid function are used to estimate water saturation distribution as a function of time and radius, this concept was used to estimate radius of investigation. Numerical model was developed to verify proposed radius of desorption and radius of investigation calculation results. Evaluation using San Juan Basin coal reservoir properties was conduct to understand and check applicability of proposed method. This proposed method can estimate radius of desorption and radius of investigation simultaneously using gas and water production rate and cumulative data. Comparison proposed method with reservoir simulation results are in very good agreement. Since, time parameter is not used in the calculation, this method is very simple in practical manner.

Key words: Radius of investigation, radius of desorption, CBM, practical manner, estimation, classification

INTRODUCTION

CBM as an unconventional resources take part as important role in energy supply. Since, there is no fluid contact in unconventional reservoir, according SPE Petroleum Resources Management System (PRMS), reserves estimation and classification in CBM reservoir development is well based (Barker, 2008). Radius of investigation and radius of desorption will be very important information in reserves classification for deterministic and probabilistic approach in CBM reserves (Elliott and Coll, 2013).

Methane desorption from coal matrix mechanism by lowering reservoir pressure are confirmed visually (Robertson, 2005). Coal seam depressurization will reduce reservoir pressure to critical desorption pressure and then adsorbed gas can release from coal and produced through cleat system to the well.

Flow regime and pressure propagation in CBM reservoir are unique. There are two transient period in CBM, pressure transient and gas desorption transient. Pressure transient period in unconventional reservoir is order-of-magnitude relatively larger since very low permeability (Xie *et al*., 2015).

Radius of investigation in conventional well already discussed for long time. Recent publication for this subject suggest rate and tools resolution as parameter in calculation (Kuchuk, 2009). Evaluation of radius investigation is fundamental to estimate how much reservoir volume is being explored for a given of a transient test or production duration period.

Adaptation of radius of investigation method applied in conventional reservoir for unconventional reservoir is proposed by Xie *et al.* (2015). Correction of radius of investigation by considering stress dependent porosity and permeability (Burgoyne and Shrivastava, 2016). Simple method for estimation of radius of desorption in CBM reservoir using gas production cumulative data proposed by Xu *et al.* (2013).

MATERIALS AND METHODS

Mathematical modeling was developed to estimate radius of investigation and radius of desorption in CBM reservoir. This method is improvement of radius of desorption estimation method were developed by Xu *et al.* (2013). Figure 1 shows conceptual illustration for radius of desorption, radius of investigation, saturation and phase distribution in CBM reservoir. These proposed approach was develop using following assumptions:

- Homogenous isotropic radial model with dual porosity system
- Under saturated reservoir and water saturation 100%
- Well produced at constant bottom hole pressure
- Pressure and desorption are still in transient period
- No stress dependent pressure and permeability

Corresponding Author: Dedy Irawan, Department of Petroleum Engineering, Institut of Teknologi Bandung, Bandung, Indonesia

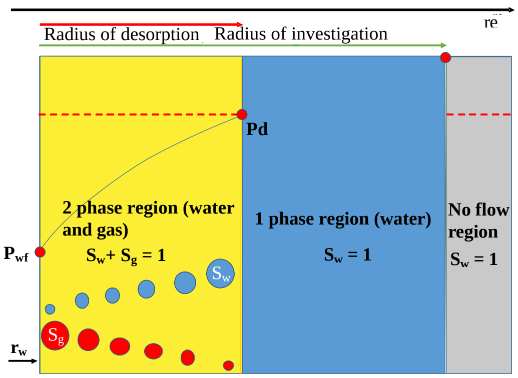

Fig. 1: Phase and radius distribution in CBM reservoir

Radius of desorption method: Desorption radius estimation method for vertical well using gas production cumulative data was developed by Xu *et al*. (2013). Xu propose P and P^2 solution to estimate pressure distribution as a function of radius:

$$P = P_{wf} + \frac{P_d - P_{wf}}{\ln(r_d/r_w)} \ln(r/r_w) \tag{1}$$

$$P^2 = P_{wf}^2 + \frac{P_d^2 - P_{wf}^2}{\ln(r_d/r_w)} \ln(r/r_w) \tag{2}$$

Total produced Gas (G_p) can be expressed as follow:

$$[\text{Gas cum pord}] = [\text{Desorbed gas}] + [\text{Gas in cleat}]$$

$$dG_p = \left[\rho_{coal}\left(\left(\frac{V_L \times P_d}{P_L + P_d}\right) - \left(\frac{V_L \times P}{P_L + P}\right)\right)\right] + \left(\frac{\varnothing . S_g}{B_g}\right) dV \tag{3}$$

Since, cleat porosity is very small, stored gas in cleat are negligible and Eq. 2 can be rearranged become:

$$dG_p = \left[\rho_{coal}\left(\left(\frac{V_L \times P_d}{P_L + P_d}\right) - \left(\frac{V_L \times P}{P_L + P}\right)\right)\right] dV \tag{4}$$

Integrating Eq. 3 for whole area, gas cumulative production can be state as:

$$G_p = 2\pi \times h \times \rho_{coal} \int_{r_w}^{r_d} \rho_{coal}\left(\left(\frac{V_L \times P_d}{P_L + P_d}\right) - \left(\frac{V_L \times P}{P_L + P}\right)\right) r \times d_r \tag{5}$$

Iteration technique used to solve radius desorption for given gas cumulative production (Eq. 5).

Radius of investigation method: Water are stored in cleat of coal with 100% saturation when water produced pressure in cleat are decreasing and propagate to entire of coal. Pressure propagation radius are equivalence to radius of investigation:

$$[\text{Water cum pord}] = [\text{Initial water volume}] - (\text{Remaining water volume}) \tag{6}$$

Proposed radius investigation method was develop by divide area in reservoir become two part, single phase region and two phase region respectively. In two phase region, produced water is estimated by calculate water saturation change:

$$W_p = \left(\frac{2\pi h \varnothing_f \int_{r_w}^{r_d} (S_w i - S_w) r \times d_r}{B_w}\right) + \left(\frac{2\pi h \varnothing_f \int_{r_d}^{r_{inv}} C_w (P_i - P) r \times d_r}{B_w}\right) \tag{7}$$

Water saturation distribution: Sigmoid function was used to estimate water saturation distribution. This function is very simple and robust:

$$f(r) = \frac{1}{(1 + e^{-r})} \tag{8}$$

Normalization procedure needed to convert radius (r_w to r_{inv}) and water saturation (Sw_{min} = Sw@well to $Sw_{max} = 1$) into Sigmoid Model. Water saturation at well was estimate using fractional flow curve:

$$f_w = \frac{1}{1 + \frac{k_{rg}\mu_w}{\mu_g k_{rg}}} \tag{9}$$

Calculation procedure for radius of desorption and radius of investigation are presented in Fig. 2 and 3, respectively

Reservoir simulation model: Reservoir simulation model input data taken from San Juan Basin coal seams (Seidle, 2011). This simulation model size was 30×1×1 grid with 320 acre well spacing. Porosity and permeability are assumed to be constant. Evaluation of pressure and desorption propagation assumed in transient period. Reservoir simulation model properties are summarized in Table 1. Reservoir simulation model and properties from San Juan Basin are shown in Fig. 4-7.

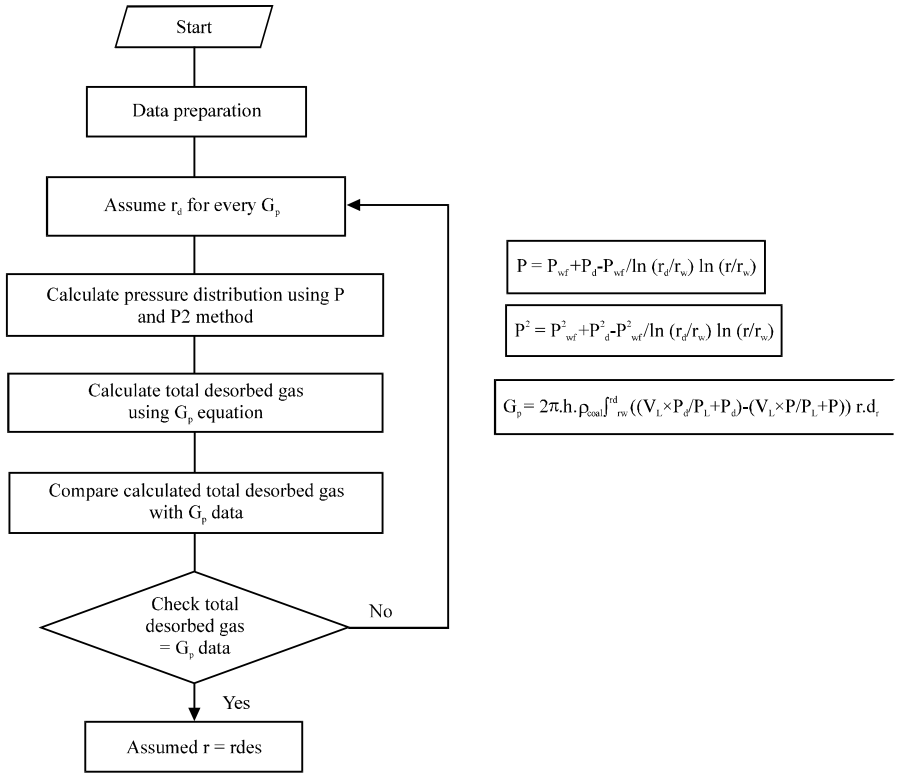

Fig. 2: Radius desorption calculation procedure (Xu *et al*., 2013)

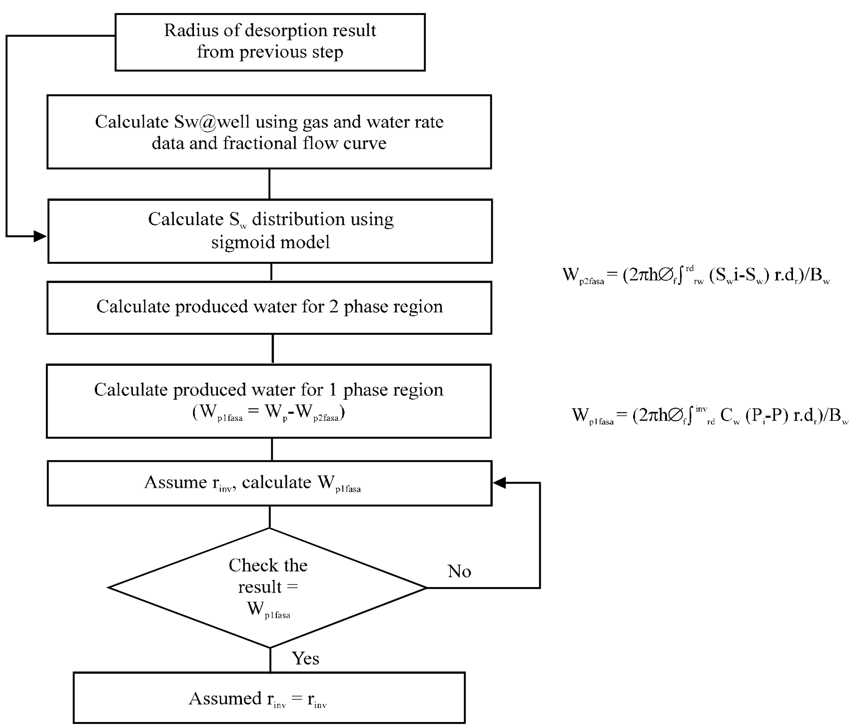

Fig. 3: Radius of investigation calculation procedure

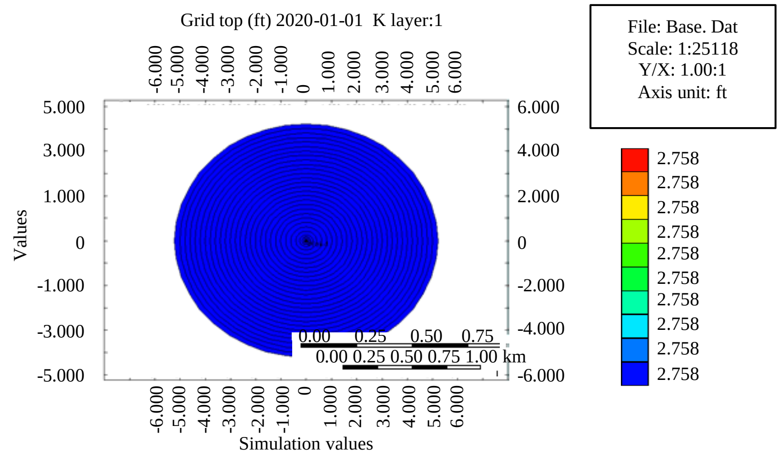

Fig. 4: Reservoir simulation model

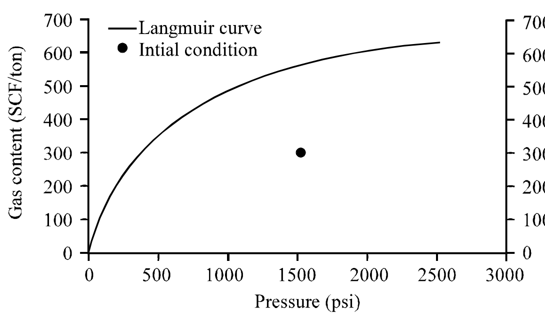

Fig. 5: Langmuir curve and initial reservoir condition

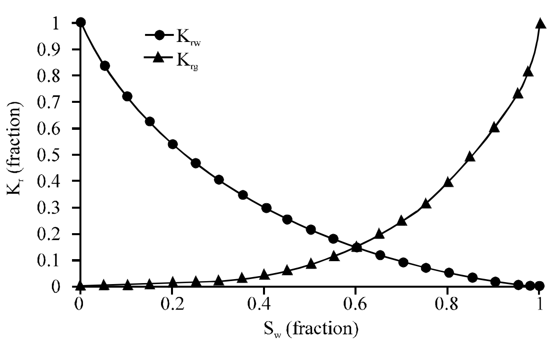

Fig. 6: Relative permeability curve (Seidle, 2011)

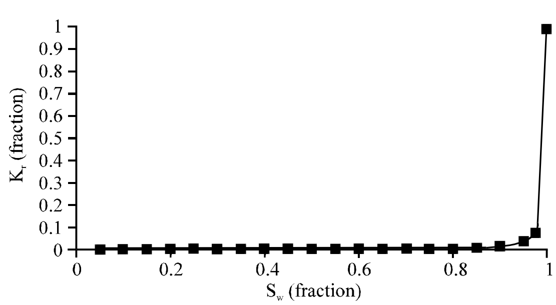

Fig. 7: Fractional flow curve

Table 1: Reservoir properties data (Seidle, 2009)

Reservior properties	Values
Porosity (fraction)	0.02
Permeability (mD)	1.2
Thickness (ft)	20
Coal density (g/cc)	1.75
Initial reservoir pressure (psi)	1537
Reservoir Temperature (°F)	120
Initial gas content (SCF/ton)	302
Langmuir volume (SCF/ton	783)
Langmuir pressure (psi)	606
Desorption time (day)	10
Gas FVF (ft^3/SCF)	9.41E-03
Gas viscossity (cP)	0.0148

RESULTS AND DISCUSSION

Important aspect in this study is defining criterion for radius of investigation and radius of desorption. Kuchuk propose pressure gauge resolution for determine radius of investigation (0.01 psi). This study propose exhibiting 0.01 gas saturation in cleat as criteria for radius of desorption. Figure 8 and 9 show cleat pressure and gas saturation distribution respectively as a function of time and distance (radius).

Radius of desorption: Proposed semi analytical model was verified by reservoir simulation result. Criterion 0.01 psi pressure alteration and 0.01 gas saturation alteration then applied for the margin. Calculation result of desorption radius using Xu *et al*. (2013) is presented in Fig. 10. These results shows in early period calculation using P^2 method give lower values compare to simulation result and later on P^2 gives very good match to the simulation rather than P method.

The result trends are slightly different from those produced by Xu *et al*. (2013) . Where the simulation result is between the calculation result using P^2 and P method.

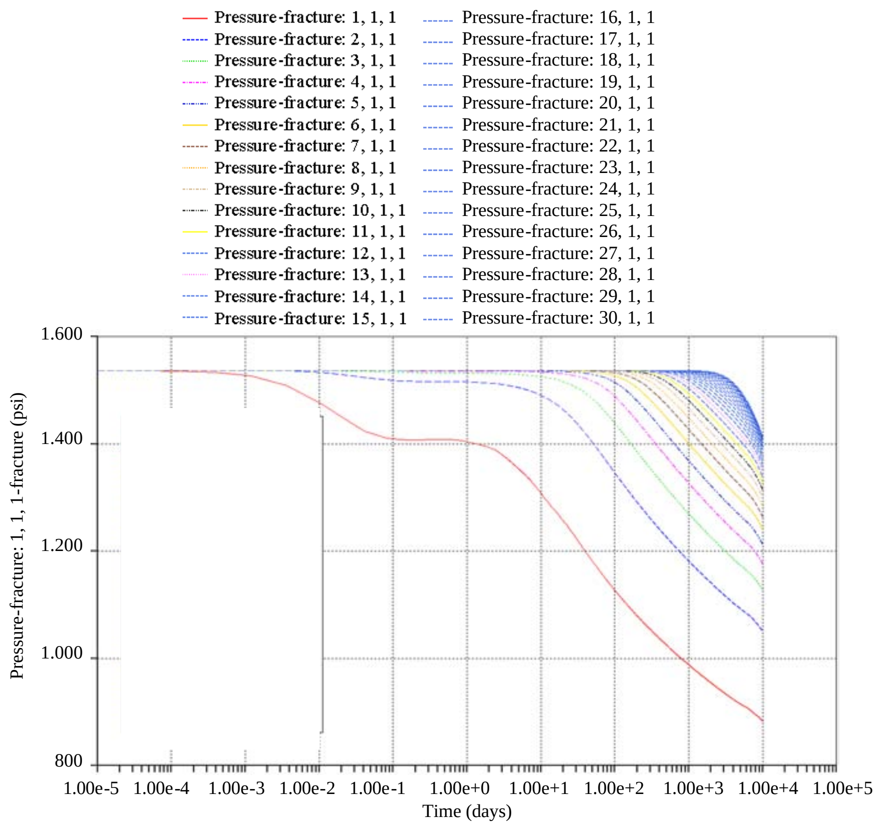

Fig. 8: Cleat pressure distribution as a function of time and distance (radius); lin320acregrid.irf

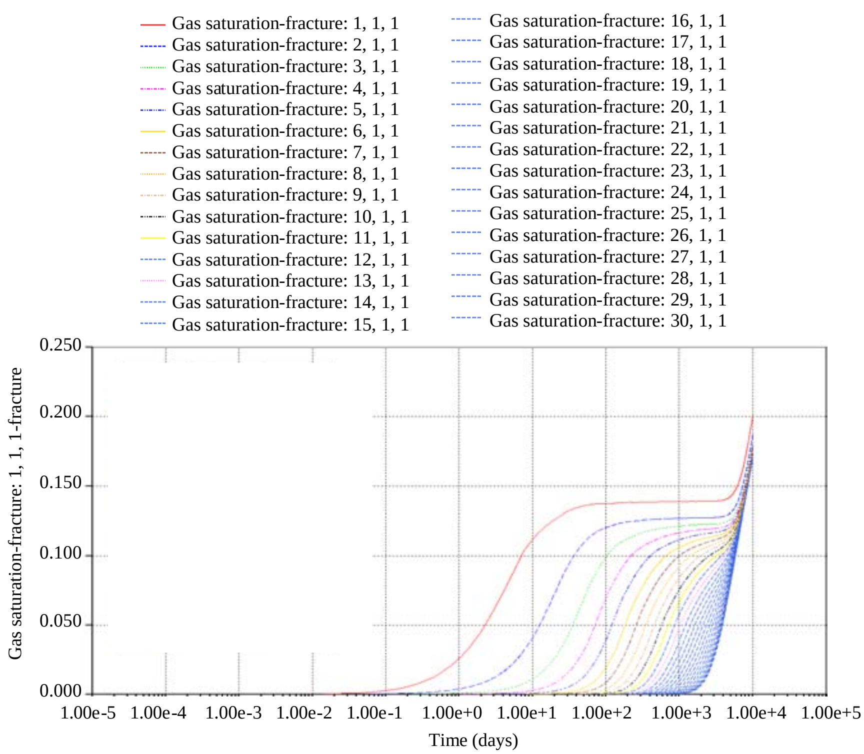

Fig. 9: Gas saturation distribution as a function of time and distance (radius); lin320acregrid.irf

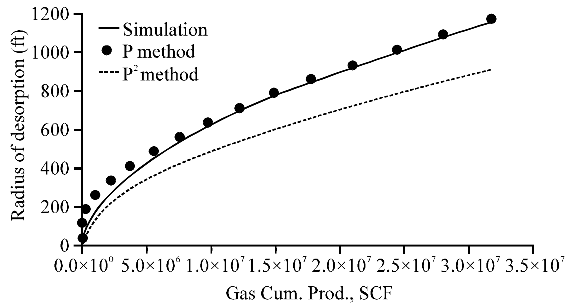

Fig. 10: Radius of desorption as a function of gas cumulative production

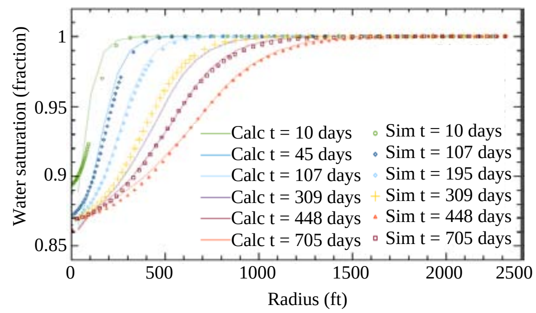

Fig. 12: Water saturation distribution as a function of time and distance (radius)

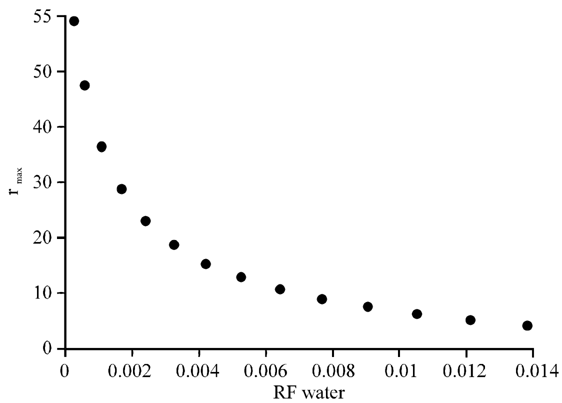

Fig. 11: r_{max} as a function of water recovery factor

This is caused by the determination of desorption margin criteria which is reflected by the emergence of gas saturation of 0.01.

Radius of investigation: The calculation procedure of the proposed method (Fig. 3), the first step is to model the water saturation distribution in cleats by using the sigmoid model. The sigmoid model used is the unsymmetrical sigmoid with the left border (r_{min}) made to be constant and the right border (r_{max}) as a function of the water Recovery Factor (RF). The r_{max} relationship as a function of RF water are attained from the simulation model. This relationship is shown in Fig. 11. By utilizing the r_{max} relationship as a function of RF water then water saturation distribution can be estimated along with increasing cumulative water production. The approximate results of the water saturation distribution compare to simulation model results are shown in Fig. 12. From this result it is seen that the water saturation distribution can be well estimated for every time and radius as a function of the cumulative water production.

The approximate radius of the investigation is carried out by determining the equivalence of a pressure change

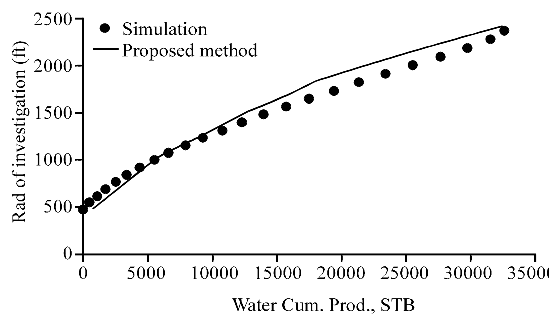

Fig. 13: Proposed method and simulation results comparison

of 0.01 psi to the contribution of water production due to pressure change in the 1 phase region. This contribution are majorly controlled by water compressibility parameter. Proposed calculation results are shown in Fig. 13. The results obtained from the proposed method indicate alignment with the results obtained from the simulation model. In the initial period the calculation using the proposed method (red line) showed slightly lower results than the results of the simulation (blue dots) whereas the mid and final periods of the proposed method result obtained slightly higher.

CONCLUSION

A combination of radius of investigation and radius of desorption estimation method has been introduced. The method can estimate radius of investigation and radius of desorption in coalbed methane reservoirs simultaneously. Proposed criteria to define radius of radius of investigation and radius of desorption will reduced subjectivity in these parameter estimation. Numerical simulation verified that estimation of radius of investigation and radius of desorption resulted from proposed method are in a good agreement.

REFERENCES

Barker, G.J., 2008. Application of the PRMS to coal seam gas. Proceedings of the International Conference on Petroleum Technology IPTC, December 03, 2008, Society of Petroleum Engineers, Perth, Australia, pp: 20-22.

Burgoyne, M. and R. Shrivastava, 2016. A practical workflow for characterizing stress-dependent behaviour of coal from changes in well productivity. J. Nat. Gas Sci. Eng., 33: 1025-1045.

Elliott, S. and C. Coll, 2013. Probabilistic and deterministic methods: Applicability in unconventional reservoirs. Proceedings of the EAGE Annual Conference on Exhibition Incorporating SPE Europec, June 10-13, 2013, Society of Petroleum Engineers, London, UK., pp: 1-12

Kuchuk, F.J., 2009. Radius of investigation for reserve estimation from pressure transient well tests. Proceedings of the SPE Conference on Middle East Oil and Gas Show, January 15-18, 2009, Society of Petroleum Engineers, Manama, Bahrai, ISBN:978-1-55563-215-1, pp: 1-21.

Robertson, E.P., 2005. Measurement and modeling of sorption-induced strain and permeability changes in coal. Ph.D Thesis, Arthur Lakes Library, Golden, Colorado.

Seidle, J., 2011. Fundamentals of Coalbed Methane Reservoir Engineering. PennWell Books, Tulsa, Oklahoma, ISBN:978-1-59370-001-0, Pages: 387.

Xie, J., C. Yang, N. Gupta, M.J. King and A. Datta-Gupta, 2015. Depth of investigation and depletion in unconventional reservoirs with fast-marching methods. SPE. J., 20: 831-841.

Xu, B., X. Li, M. Haghighi, X. Du and X. Yang *et al*., 2013. An analytical model for desorption area in coal-bed methane production wells. Fuel, 106: 766-772.