مجموعه مقالات سومین کنفرانس ملی مهندسی مخازن هیدروکربوری و صنایع بالادستی
تهران، ۲۹ خرداد ماه ۱۳۹۳ مجری: هم اندیشان انرژی کیمیا
تلفن: ۰۲۱ - ۸۸۶۷۱۶۷۶ www.Reservoir.ir

Determination of fracture network parameters using multi-rate well test data

Ali Reza Bolondarzadeh[1] (ICOFC), Bahram Soltani[2] (A.I.T.)
1- Iranian Central Oil Fields Company, Senior Coordination and Production Planning

2- Senior Research Associate, Professor Institute of Petroleum Engineering, Abadan Institute of Technology (AIT).

Abstract

The objective of this paper is to investigate the fracture parameters for oil fracture reservoirs by using multi-rate well test data. This work is based on the steady state flow of homogenous liquid through fracture network toward wells using *Kazemi* and *Warren-Root* models. Multi-rate well testing is powerful tools that could describe quantitatively the fracture networks. For constant oil production rate, if the fracture density (i.e. number of fracture) increases, then the drawdown of oil well decreases. On the other hands, by decreasing the fracture density, the drawdown increases. Therefore, the drawdown of the well could be related to the fracture network and could provide the data about the fracture reservoir characterization. This study based multi-rate well testing and two main prevailing of fracture model (i.e. Kazemi and Warren-Root) tried to obtain the fracture reservoir characterization that includes permeability of fracture and matrix, porosity of fracture, Arial fracture density, block size and fracture opening. Also, these data could be assisted to calculate the water and gas coining. Finally, the modeling was carried out for two Iranian fracture reservoirs in South. The results show very good agreement between Warren-Root model and fracture image log.

Key words: fracture parameters, fracture network, well testing, gas coning, water coning

Introduction

Naturally fractured reservoirs have recently attracted intensive research attention, because the world market is increasingly under pressure to exploit energy from unconventional sources such as naturally fractured oil and gas rock reservoirs. From field experience very high rates are obtained from fracture wells under a very limited pressure drop. The magnitude of rates or productivity index is directly associated to the presence or absence of fractures. In order to simplify the complexity of fracture networks, models based on their regular geometry have been proposed. There are several models for fracture networks. In this study the *Kazemi* and *Warren-Root* models were used. As determination of fracture parameters is very essential to analyze the fracture networks, there are several methods to obtain them. One of these methods that can be used easily is multi rate data. In some cases that enough data are not provided or to compare the results of the other methods the multi rate method can be used. If the data are obtained from well testing, the permeability Kf can be determined from the test results. Since Areal fracture density (AfD) is often determined by logging or core analysis, the porosity of fracture Φf and fracture width b may be determined by use the equations given in the table 1.

Table 1.Basic parameters of simplified models

Model Type	Velocity	A_{fD}	ϕ_f	ϕ_f	a	b
1.Slides	$V_x = 0$	1/a	b/a	$(12\ K_f\ A^2_{fD})^{0.33}$	$1/A_{fD}$	$(12\ K_f/\phi_f)^{0.5}$

2.Matches	$V_y = 0$; $V_z = 0$	1/a	2b/a	$(96\ K_f\ A^2_{fD})^{0.33}$	$1/A_{fD}$	$(24\ K_f/\phi_f)^{0.5}$
3.Matches	$V_x = 0$; $V_y = 0$	2/a	2b/a	$(48\ K_f\ A^2_{fD})^{0.33}$	$2/A_{fD}$	$(12\ K_f/\phi_f)^{0.5}$
4.Cubes	$V_z = 0$; $V_y = 0$	1/a	2b/a	$(96\ K_f\ A^2_{fD})^{0.33}$	$1/A_{fD}$	$(12\ K_f/\phi_f)^{0.5}$
5.Cubes	$V_x = V_y = 0$	2/a	2b/a	$(48\ K_f\ A^2_{fD})^{0.33}$	$2/A_{fD}$	$(12\ K_f/\phi_f)^{0.5}$
6.Cubes	$V_y = 0$	2/a	3b/a	$(162\ K_f\ A^2_{fD})^{0.33}$	$2/A_{fD}$	$(18\ K_f/\phi_f)^{0.5}$

The main input variables for this study include matrix properties such as oil viscosity, oil gravity, oil formation volume factor, reservoir thickness, well radius and drainage radius and also multi rate data from well test. Two oil fracture reservoirs from different Iranian oil fields were selected for this work. The challenge of this study is to obtain fracture parameters such as Arial fracture density, fracture permeability, fracture porosity, intensive permeability, block size and fracture opening based on Kazemi and Warren-Root models.

Kazemi Model

As illustrated in fig.1, this model reduces the fracture networks to a set of uniformly spaced horizontal matrix layers, where the set of fracture are equivalent to spaces between cylindrical slice of matrix.

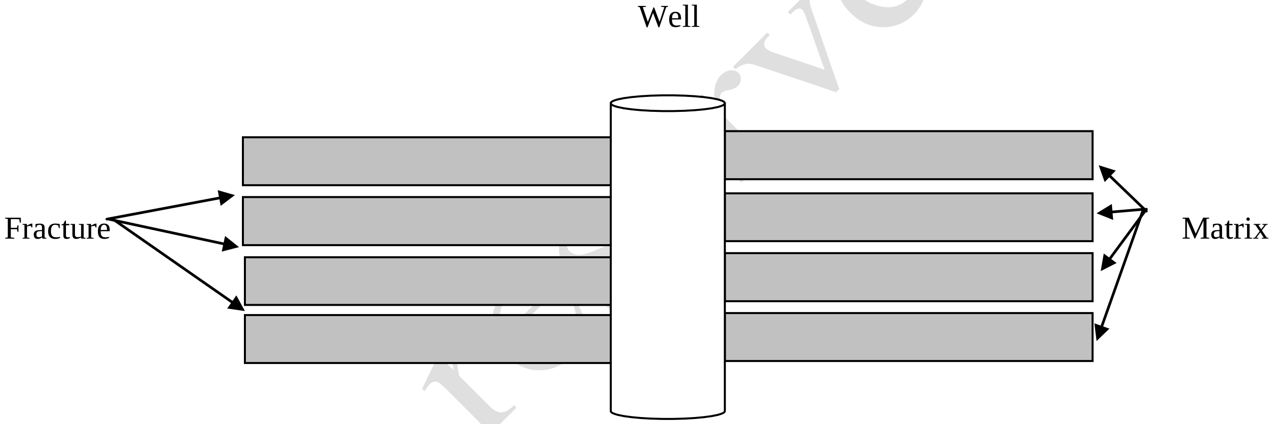


Fig.1- Kazemi Model

Warren - Root Model

In this model as shown in the Fig.2, the fractures are assumed to be constant wide, and have uniform network oriented in such a way so to be parallel to the principal direction of permeability.

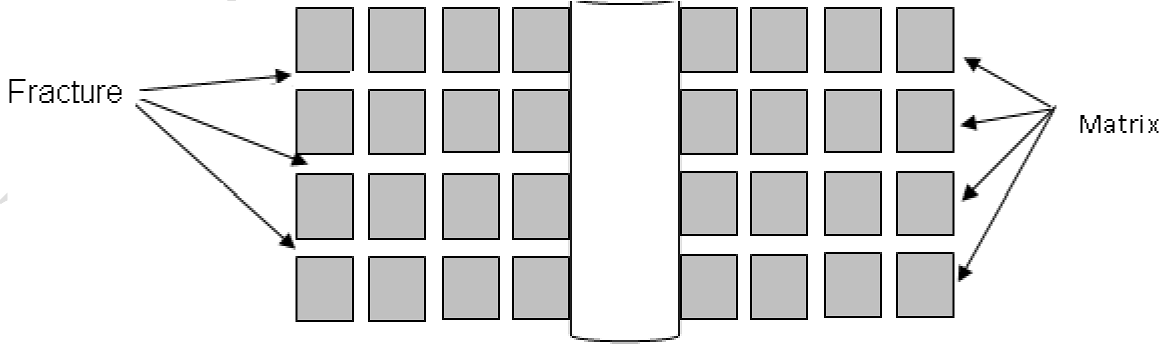


Fig.2 – Warren-Root Model

Methodology

In fracture network pressure drop can be expected to be expressed as below:

$$\Delta p = A.Q + B.Q^2 \qquad \text{(Eq.1)}$$

This corresponds to a linear flow for low rates when BQ^2 << AQ, and to turbulent flow for high rates when $B.Q^2 >> AQ$ .Both A and B depends on flow geometry and physical properties of rock and fluids. Parameter A expresses the linear proportionality between the rate and pressure drop and is associated to geometrical flow characteristics and flow resistance parameters. Parameter B represents the non-linear relationship between rate and pressure drop. It is found that B depends less on flowing geometry and more on physical characteristics of fluid (viscosity µ, mass ρ) and rock (porosity Φ and permeability k). The relationship between B vs. Φ and k depends on the turbulence factor ß. In single fracture model:

$$ß\ (1/ft) = (4.16*10^{10})/k(md)^{1.34} \qquad \text{(Eq.2)}$$

$$ß\ (1/ft) = (2.20*10^{10})/k(md)^{1.19} \qquad \text{(Eq.3)}$$

In multi-fracture model:

$$ß\ (1/ft) = (2.2*10^{9})/[k(md)*\Phi]^{1.085} \qquad \text{(Eq.4)}$$

Fig.3 presents the relation between Q and ΔP.

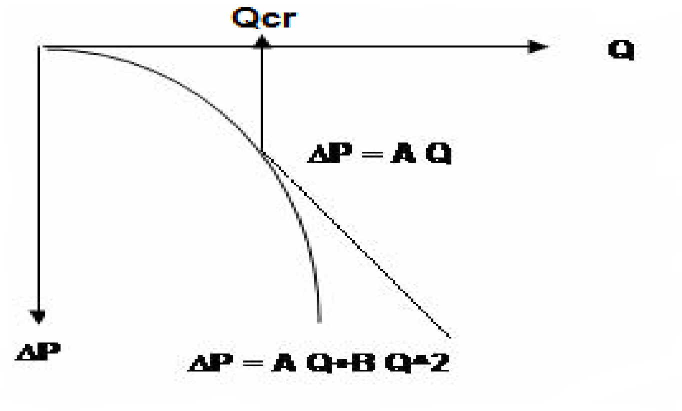


Fig.3- Production Steady state curve Q vs. ΔP of a radial symmetric flow

If it is assumed that a fracture network has certain permeability Kf and porosity Φf, based on the following equation:

$$\text{Grad } P = \mu\, V / Kf + \rho\, ß V^2 \qquad \text{(Eq.5)}$$

Based on the Eq.1 and Eq.5, the result is:

$$A = [\mu o Bo / 2\Pi\ Kf\ h]*[Ln\ re/rw + \Sigma S] \qquad \text{(Eq.6)}$$

$$B = [ß\ \rho\ Bo / 4\Pi^2\ h^2]*[1/rw - 1/re] \qquad \text{(Eq.7)}$$

If from well testing operations rates Φ and pressure drop ΔP are recorded under steady state flowing conditions the value A and B can be obtained from below Equation:

$$\Delta P/Q = A + B\ .Q \qquad \text{(Eq.8)}$$

As the Fig.4 demonstrates the straight line obtained will directly give value A as the ordinate at Q=0 and B as slope of the straight line.

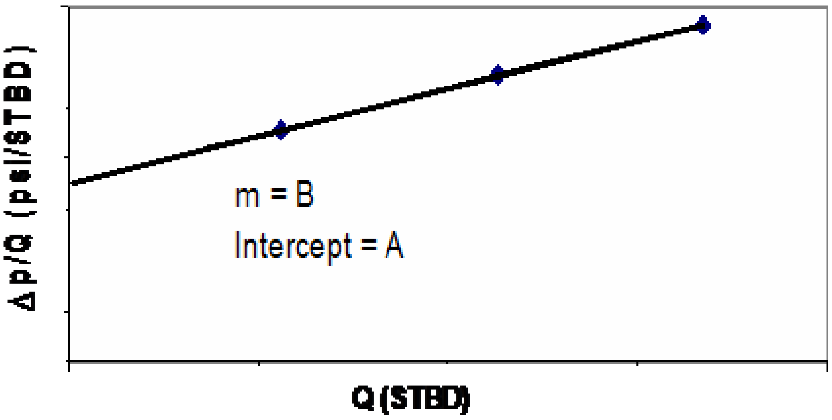


Fig.4- The relationship ΔP/Q vs. Q of a radial symmetric flow

From parameter A it is possible to evaluate the permeability. If the skin effect ΣS is neglected, Kf may be expressed as below:

$$Kf= [(\mu o.Bo.Ln (re/rw) /(6.28 h)]* 1/A \qquad (Eq.9)$$

If the fracture density (AfD= LfD) is known, the fracture porosity Φf can be expressed as a function of the productivity index PI=1/A. Based on Kazemi model the porosity Φf is obtained as below:

$$\Phi f=(12 Kf AfD^{2})^{\wedge}0.33 \qquad (Eq.10)$$

By using Warren-Root model the fracture porosity is calculated as:

$$\Phi f=(162 Kf AfD^{2})^{\wedge}0.33 \qquad (Eq.11)$$

Using Eq.7 and rw<< re, the turbulence factor ß is as below:

$$ß= [4 \Pi^{2} h^{2} rw/ \mathcal{P}o Bo] \qquad (Eq.12)$$

The intrinsic permeability of fracture Kff is as follows:

$$Kff= Kf/\Phi f \qquad (Eq.13)$$

Based on the Kazemi model the fracture width is as follows:

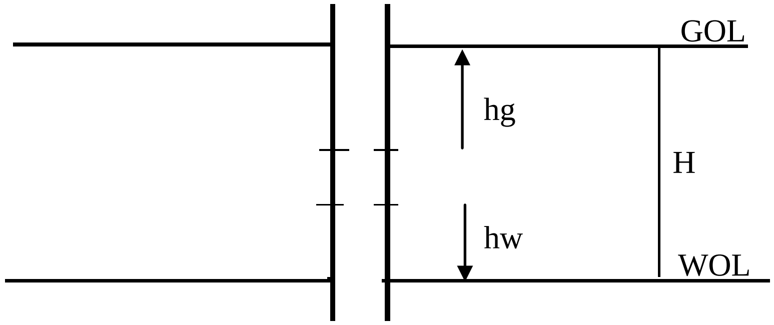
$$B= (12Kf/\Phi f)^{0.5} \qquad (Eq.14)$$

Also by using Warren-Root the fracture width is obtained as below:

$$B= (18Kf/\Phi f)^{0.5} \qquad (Eq.15)$$

Water and gas coning evaluation

In the fracture zone, either in an open hole or in a completed and perforated well, producing pays limited by two upper and lower boundaries. The Fig.5 shows the relationship between the highest fluid entry point (HFEP), lowest flow entry point (LFEP), gas-oil contacts (GOL) and water-oil contacts (WOL) in the fracture network.



If the behavior of the

granular

Porous medium based on the *Muskat's* and *Brik's* equations the critical and safe water coning height are as below:

$$h_{w,cr}=[A*Q]/[(G_w-G_o)*2.303*\text{Log}(r_e/r_o)] \qquad \text{(Eq.16)}$$

$$h_{w,safe}= [A*Q+B*Q^2]/[6.9*(G_w-G_g)] \qquad \text{(Eq.17)}$$

In order to design the well completions in the case of an oil zone bounded by a gas cap and aquifer, the critical and safe coning heights are as below:

$$h_{g,cr} = [A*Q]/[6.9(G_o-G_g)] \qquad \text{(Eq.18)}$$

$$h_{g, safe}= [A*Q+B*Q^2]/[6.9*(G_o-G_g)] \qquad \text{(Eq.19)}$$

Case study

The Asmari Formation is the major oil reservoir in Iran, and is mainly composed of carbonate entities (Limestone and Dolomite). The Asmari Formation produces almost 85 percent of total Iranian crude oil and it is one of the main known reservoirs in the world. Therefore, the study of this rock unit has been a critical subject in the past and present time. This formation is well developed in the Zagros basin, southern Iran as well as in the Persian Gulf. It is believed that the Asmari Formation has a good fracturing system, which is resulted from the Red Sea opening and movement of Arabian Plate toward Iranian platform in the Neogene geological time. One of the main products of this process is fractures. These fractures are very important in the Zagros basin for their effects in the production rate of Asmari reservoir**.** In this study two Iranian oil fracture reservoirs were analyzed to calculate the fracture parameters.

X oilfield

X Field is located in Khuzestan province, approximately 6 Km in nearest distance from the Persian Gulf, southwest Iran. In this oilfield according to well test data (table.2) ΔP/Q vs. Q was generated (fig.6).

Table 2.Well test data of X Oilfield

Q	ΔP	ΔP/Q
STBD	psi	psi/STBD
4000	440	0.110
8000	1200	0.150
11000	1870	0.170

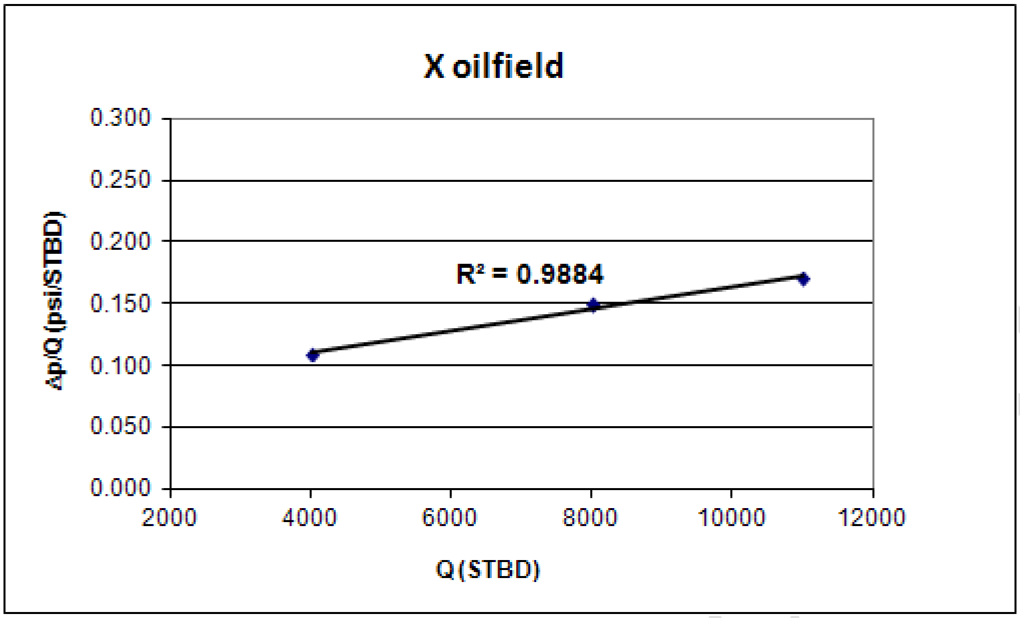


Fig.6- The relationship ΔP/Q vs. Q of a radial symmetric flow for X Oilfield

By using reservoir data (table.3) and well test data the fracture parameters were calculated (table.4).

Table 3.Reservoir data of X Oilfield

Variable	μo(cp)	Bo(Rbbl/stb)	γo	h(m)	rw(cm)	re(m)
Value	1.00	1.32	0.76	100	14.92	500.00

Table 4.Results of X Oilfield

Variable	A (psi/STBD)	B (psi/(STBD)^2)	PI (STBD/Psi)	K_f (MD)	β (1/cm)	ϕ_f	Kff (D)
Value	7.703E-02	8.649E-06	12.982	59.939	1.019E+10	1.742E-04	344.084

Comparing calculated matrix block height and fracture width with FMI logs results show good agreements between Warren-Root model and FMI logs (table.5).

Table 5.Comaring the results of X oilfield

Kazemi model		Warren-Root model		FMI log Results	
Matrix block height (cm)	Fracture Width (mm)	Matrix block height (cm)	Fracture Width (mm)	Matrix block height (cm)	Fracture Width (mm)
3.69	0.006	13.35	0.008	13.30	0.01

Y oilfield

Y oilfield is located 115 km north of Ahvaz.

In this oilfield according to well test data (table.6), ΔP/Q vs. Q was generated (fig.7). By using reservoir data (table.7) and well test data the fracture parameters were calculated (table.8). Comparing calculated matrix block height and fracture width with FMI logs results show good agreements between Warren-Root model and FMI logs (table.9)

Table 6.Well test data of Y Oilfield

Q	ΔP	ΔP/Q
STBD	psi	psi/STBD
1662	112	0.067
2496	189	0.076
4245	402	0.095

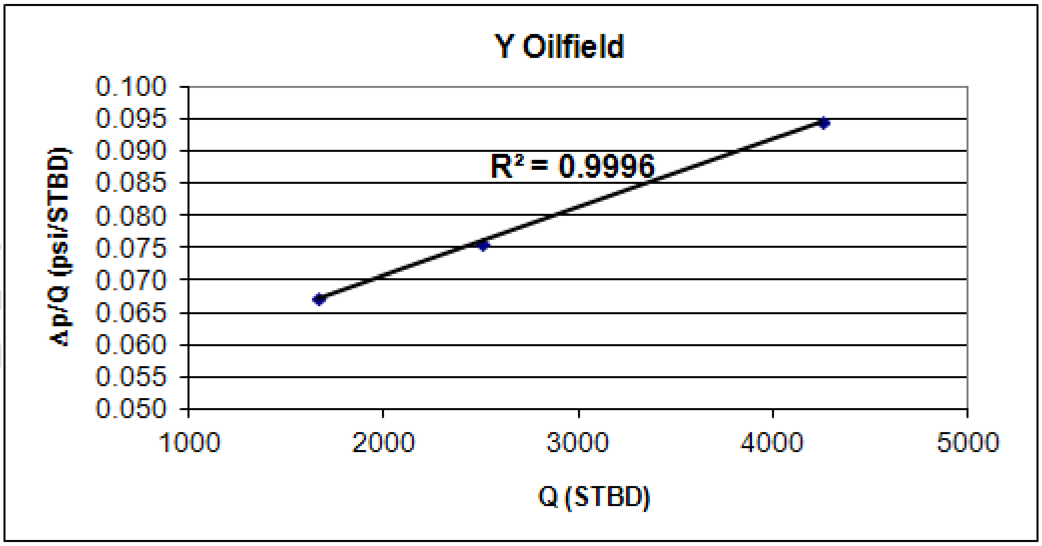


Fig.7- The relationship $\Delta P/Q$ vs. Q of a radial symmetric flow for Y Oilfield

Table 7.Reservoir data of Y Oilfield

Variable	μo(cp)	Bo(Rbbl/stb)	γo	h(m)	rw(cm)	re(m)
Value	0.611	2.47	0.858	200	14.92	305

Table 8.Results of Y Oilfield

Variable	A (psi/STBD)	B (psi/(STBD)^2)	PI (STBD/Psi)	K_f (MD)	β (1/cm)	ϕ_f	Kff (D)
Value	4.953E-02	1.062E-05	20.188	50.04	2.368E+10	9.591E-05	521.690

Table 9.Comaring the results of Y oilfield

Kazemi model		**Warren-Root model**		**FMI log Results**	
Matrix block height (cm)	Fracture Width (mm)	Matrix block height (cm)	Fracture Width (mm)	Matrix block height (cm)	Fracture Width (mm)
82.49	0.08	303.10	0.10	300	0.10

Conclusions

Mechanism of oil production in fracture reservoir depends on the fracture networks. Therefore, it is essential to identify the fracture properties in order to have more recovery from reservoir. This study tried to find fracture properties from multi-rate well testing. The fracture properties are function of fracture and matrix configuration which depends on the geological history of reservoir. The two main fracture models (i.e. *Kazemi* and *Warren-Root*) have been applied to find fracture properties. The result of modeling was compared with FMI log and good agreement has been observed. Comparing calculated matrix block height and fracture width with FMI logs results show good agreements between *Warren-Root model* and *FMI logs*.

This study found well test as powerful tools that could predict the fracture properties such as permeability of fracture and matrix, porosity of fracture, Arial fracture density, block size and fracture opening and reservoir production properties like water and gas coining. It should be kept in mind the fracture is very heterogenic feature and simplification could give the idea about the reservoir.

Nomenclature

ΔP:	Pressure drop (psi)
Q:	Flow rate (B/D)
Kf:	Fracture Parameter (md)
Kff:	The intrinsic permeability of fracture (fraction)
AfD:	Arial Fracture Density (cm) ^2
Φf:	Fracture porosity (fraction)
A:	Linear proportionality between the rate and pressure drop (Psi/STB)
B:	Non- linear relationship between rate and Q (Psi/STB)^2
ß:	Turbulence factor (1/cm)
h:	Total pay zone (m)
Bo:	Oil formation volume factor (Rbbl/Stb)
μo	Oil viscosity (Cp)
rw:	well radius (cm)
re:	External boundary radius (m)
HFEP:	Highest fluid entry point (m)
LFEP:	Lowest flow entry point (m)
hw, cr:	Critical water coning height (m)
hw,safe:	Safe water coning height (m)
hg,cr:	Critical gas coning height (m)
hg, safe:	Safe gas coning height (m)
Gw:	water gravity
Go:	Oil gravity
Gg:	Gas Gravity
a:	Matrix block height (cm)
b:	Fracture width (cm)

Acknowledgments

The work was supported by the Research & Technology department of NIOC and ICOFC

References

[1] Firoozabadi, A. and Katz D.L., 1979. An analysis of high-velocity gas flow through poros media. Jour. Petrol. Teck., February, p 211.

[2] Kazemi, H., 1969. Pressure transient analysis of naturally fracture reservoir with uniform fracture distribution. Soc.. Pet. Eng.j., p 451-458

[3] Warren,J.E. and Root, P.J., 1963. The behavior of naturally fractured reservoir. Soc. Pet.Eng. J., P 245-255.

[4] Saidi, A.M. and Martin, R.E., 1965. Application of reservoir engineering in the development of Iranian reservoirs.

[5] Van Golf-Racht, T.D. ; “ Fundamentals of fractured reservoir engineering”, Elsevier , New York, 1982, P 147-351

[6] Odeh, A.S., Jones, L.G.; “Two –Rate flow test, Variable Rate Case”, JPT (January 1974) pp.93-99, Trans. AIME, 257.

[7] Muskat, M. 1937. Homogeneous flow in porous media. McGraw Hill, New York.

[8] Romm, E.S., 1966. Fluid parallel model of fractured permeability media. PhD. Thesis, Berkely, 330 p.

[9] Moody, L, F 1944.Friction factors for the pipe Trans. ASME, vol 66, 1944.

[10] Hussein B.; ” An innovative approach to integrate fracture, well test and production data into reservoir models’, SPE 84876, University of Tulsa, 2003.