Hadhramout University Journal of Natural & Applied Sciences

Volume 15 | Issue 2 Article 6

2021

Prediction of Gas Cap Performance Using Fetkovich Model in Kharir Field

Salem Mubarak Bin-Gadeem
College of Engineering & Petroleum, Hadhramout University

Ali Salem Bin-Gadeem
College of Engineering & Petroleum, Hadhramout University

Prediction of Gas Cap Performance Using Fetkovich Model in Kharir Field

Salem Mubarak Bin-Gadeem *   Ali Salem Bin-Gadeem**

Abstract

Correlation Fetkovich is Estimate reservoir properties and compare it with that reported from the test for each well, determine ultimate gas cap recovery, determine the remaining reserves. In our paper we use an Excel sheet was developed based on the method used to match the production data and predicting the future production of Kharir-1 and Kharir-2. The best decline curve fit for the history of Kharir-1 is b = 0.00 and Kharir-2 is b= 0.2. as well as all estimated reservoir properties are in good fit with that reported from the test for each well. Ultimate gas recovery (EUR) for Kharir-2 and Kharir-1 respectively are 1968036 Mscf and 730606 Mscf which means 34.29% and 45.28% recovered from the initial gas in place. Also, the remaining reserve is 128136 Mscf of the initial gas in place in Kharir-2 whereas Kharir-1 is 8280 Mscf.

Key words: Forecasting, Reservoirs, Management, Estimated Ultimate Recovery, Fetkovich, permeability, modern, conventional, Kharir-1, Kharir-2.

Introduction:

Production forecasting and estimating remaining reserves in case of oil and gas reservoirs is a very important step in good reservoir management and safe and profitable withdrawal of oil and gas, so many forecasting approaches have been developed. One approach which has been represented best well performance and Estimated Ultimate Recovery (EUR) expectations is the Fetkovich type curve analysis method of analytical type curve matching for production data. In addition to reserves, calculated from the depletion stem (b-value) match, this analysis provides diagnostic power through the determination of reservoir permeability and wellbore skin factor. When production data fits to depletion curve b, the actual curve can be extrapolated following the trend of the type curve into the future.

Recently, decline-curve analysis has expanded to permit engineers to analyze a petroleum reservoir directly in regard to its fluid-flow characteristics and its volumetric extent using rate-time type-curves of the constant terminal pressure solution of the diffusivity equation. This analysis is of enormous value to reservoir managers whose goal is to maximize oil and gas production from a petroleum reservoir.

Reservoir extent, continuity, and flow capacity are paramount characteristics that are considered when developing models. That predicts reservoir performance while using alternative depletion strategies, such as during fluid-injection projects or enhanced recovery.

Reservoir producing conditions to which this technique can be readily applied are those whose actual bottom hole flowing pressure (BHFP) closely approximates a constant value. Most wells, however, produce with variable BHFP. The work presented here focuses on an alternative rate cumulative type-curve format whereby variable BHFP is incorporated into dimensionless variables containing both production rate and the cumulative production providing a unified approach that can be applied to any reasonable variability in the producing rate or flowing pressure history.

The proposed method, with application to single phase and multiphase flow, provides the practicing engineer a better method for decline curve analysis and therefore propagates better reservoir characterization from production data [10].

Fetkovich type curve:

Type-curve matching is an advanced form of decline analysis proposed by Fetkovich (1980). The author proposed that the concept of the dimensionless variables approach can be extended for use in decline-curve analysis to simplify the calculations. He introduced the variables for decline- curve dimensionless flow rate, q_{dD} and decline-curve dimensionless time, t_{dD} that are used in all decline-curve analysis techniques. Arps' relationships can thus be expressed in the following dimensionless forms [3]:

Hyperbolic:

$$\frac{q_t}{q_i} = \frac{1}{(1+bD_it)^{1/b}} \qquad (1)$$

In a dimensionless form:

*Department of Petroleum Engineering – Faculty of Engineering and petroleum - Hadhramout University, Mukalla –Yemen.

**Petroleum Engineer.Received on 25/12/2017 and Accepted for Publication on 8/10/2018

$$q_{Dd} = \frac{1}{(1+bt_{Dd})^{1/b}} \quad (2)$$

Where the decline-curve dimensionless variables q_{dD} and t_{dD} are defined by

$$q_{Dd} = \frac{q_t}{q_i} \quad (3)$$

$$t_{Dd} = D_i t \quad (4)$$

Exponential: $\frac{q_t}{q_i} = \frac{1}{\exp(D_i t)}$ (5)

Similarly, $q_{Dd} = \frac{1}{\exp(t_{Dd})}$ (6)

Harmonic: $\frac{q_t}{q_i} = \frac{1}{1+bD_i t}$ (7)

Or $q_{Dd} = \frac{1}{1+t_{Dd}}$ (8)

Where q_{Dd} and t_{Dd} are the decline-curve dimensionless variables, as defined by equations 3 and 4, respectively [1].

During the **boundary-dominated flow period,** that is, steady-state or semi-steady-state flowing conditions, Darcy's equation can be used to describe the initial flow rate qi:

$$q_i = \frac{0.00708\, kh\, \Delta p}{B\mu\left[\ln\left(\frac{r_s}{r_{wa}}\right)\right]-\frac{1}{2}} = \frac{kh\,(p_i - p_{wf})}{141.2B\mu\left[\left[\ln\left(\frac{r_e}{r_{wa}}\right)\right]-\frac{1}{2}\right]} \quad (9)$$

Where q = flow rate, STB/day

B = formation, volume factor, bbl/STB

μ = viscosity, cp

k = permeability, md

h = thickness, ft.

r_e = drainage radius, ft.

r_{wa} = apparent (effective) wellbore radius, ft.

The ratio r_e / r_{wa} is commonly referred to as the dimensionless drainage radius r_D:

$$r_D = r_e / r_{wa} \quad (10)$$

With

$$r_{wa} = r_w\, e - s \quad (11)$$

The ratio r_e / r_{wa} in Darcy's equation can be replaced with r_D to give

$$q_i = \frac{kh(p_i - p_{wf})}{141.2B\mu\left[\ln(r_D)-\frac{1}{2}\right]} \quad (12)$$

Rearranging Darcy's equation gives

$$\left[\frac{141.2B\mu}{kh\,\Delta p}\right] q_i = \frac{1}{\ln(r_D)-\frac{1}{2}} \quad (13)$$

It is obvious that the right-hand side of the previous equation is dimensionless, which indicates that the left-hand side of the equation is also dimensionless. This relationship thus defines the dimensionless rate q_D as follows [2]:

$$q_{Dd} = \frac{141.2B\mu q_i}{kh\,\Delta p} = \frac{1}{\ln(r_D)-\frac{1}{2}} \quad (14)$$

Recall the dimensionless form of the diffusivity equation:

$$\frac{\partial^2 P_D}{\partial r_D} + \frac{1}{r_D}\frac{\partial P_D}{\partial r_D} = \frac{\partial P_D}{\partial r_D} \quad (15)$$

Fetkovich (1980) demonstrated that the analytical solutions to these equations, the transient-flow diffusivity equation and the pseudo-steady state decline-curve equation, could be combined and presented in a family of log-log dimensionless curves. To develop this link between the two flow regimes, Fetkovich expressed the decline-curve dimensionless variables q_{Dd} and t_{Dd} in terms of the transient dimensionless rate q_D and time t_D .

Combining Equation 3 with Equation 12 gives [4]

$$q_{Dd} = \frac{q_t}{q_i} = \frac{q_t}{\frac{kh\,(p_i - p)}{141.2B\mu\left[\ln(r_D)-\frac{1}{2}\right]}} \quad (16)$$

Or

$$q_{Dd} = q_D\left[\ln(r_D) - \frac{1}{2}\right] \quad (17)$$

Fetkovich expressed the decline-curve dimensionless time t_{Dd} in terms of the transient dimensionless time t_D in this way [2]:

$$t_{Dd} = \frac{t_D}{\frac{1}{2}\left[r_D^2-1\right]\left[\ln(r_D)-\frac{1}{2}\right]} \quad (18)$$

The dimensionless time t_D gives by:

$$t_{Dd} = \frac{1}{\frac{1}{2}\left[r_D^2-1\right]\left[\ln(r_D)-\frac{1}{2}\right]}\left[\frac{0.006328t}{\phi(\mu\, c_t) r_{wa}^2}\right] \quad (19)$$

Although Arps' exponential and hyperbolic were developed empirically on the basis of production data, Fetkovich was able to give a physical basis to Arps' coefficients. Equations 4 and 18 indicate that the initial decline rate, D_i, can be defined mathematically by the following expression:

$$D_i = \frac{1}{\frac{1}{2}\left[r_D^2-1\right]\left[\ln(r_D)-\frac{1}{2}\right]}\left[\frac{0.006328t}{\phi(\mu\, c_t) r_{wa}^2}\right] \quad (20)$$

Fetkovich arrived at his unified type curve, as shown in Figure 1, by solving the dimensionless form of the diffusivity equation using the constant-terminal solution approach for several assumed values of r_D and t_{Dd} and the solution to Equation 19 As a function of t_{Dd} for several values of b ranging from 0 to 1 [10].

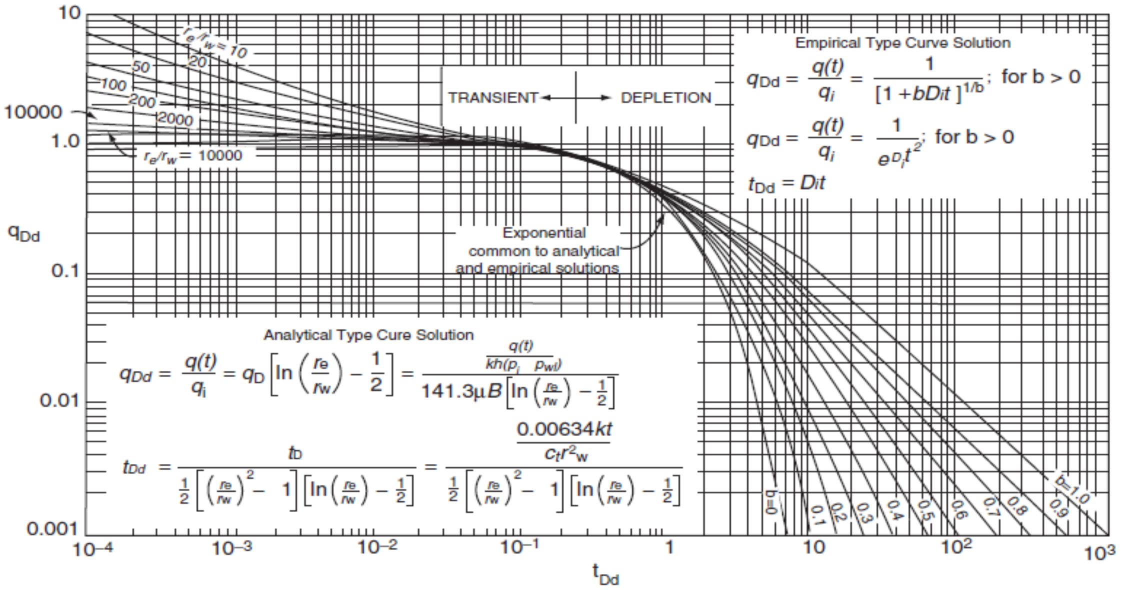


Figure 1 Fetkovich type curves [4]

Notice for Figure (1) that all curves coincide and become indistinguishable at $t_D \approx 0.3$ any data existing before a t_{Dt} of 0.3 will appear to represent exponential decline regardless of the true value of b and, thus, will plot as a straight line on a semi log scale. With regard to the initial rate qi, it is not the actual producing rate at early time; it is very specifically a pseudo steady-state rate at the surface. This pseudo-state rate can be substantially less than the actual early time transient flow rates that would be produced from low-permeability wells with large negative skins [5].

The basic steps used in Fetkovich type-curve matching of declining rate-time data are as follows:

Step 1. Plot the historical flow rate, q_t, versus time, t, in any convenient units on log-log paper or tracing paper with the same logarithmic cycles as in the Fetkovich type curve.

Step 2. Place the tracing-paper data plot over the type curve and slide the tracing paper with plotted data, keeping the coordinate axes parallel, until the actual data points match one of the type curves with a specific value of b.

Because decline type-curve analysis is based on boundary-dominated flow conditions, there is no basis for choosing the proper b values for future boundary-dominated production if only transient data are available. In addition, because of the similarity of curve shapes, unique type-curve matches are difficult to obtain with transient data only. If it is apparent that boundary-dominated (i.e., pseudo steady state) data are present and can be matched on a curve for a particular value of b, the actual curve can simply be extrapolated following the trend of the type curve into the future [6].

Step 3. From the match of the particular type curve of step 2, record values of the reservoir dimensionless radius r_e/r_{wa} and the parameter b.

Step 4. Select any convenient match point on the actual data plot (q_t and t) mp and the corresponding values lying beneath that point on the type-curve grid (q_{Dd}, t_{Dd})mp.

Step 5. Calculate the initial surface gas flow rate, q_i, at t = 0 from the rate match point:

$$q_i = \left[\frac{q_t}{q_{Dd}}\right]_{mp} \quad (21)$$

Step 6. Calculate the initial decline rate, D_i, from the time match point:

$$D_i = \left[\frac{t_{Dd}}{t}\right]_{mp} \quad (22)$$

Step 7. Using the value of r_e/r_{wa} from step 3 and the calculated value of qi, calculate the formation permeability, k, by applying Darcy's equation in one of the following three forms:

- Pseudo-pressure form:

$$k = \frac{1422T[\mathrm{In}(r_e/r_{wa}) - 0.5]q_i}{h[m(p_i) - m(p_{wf})]} \quad (23)$$

- Pressure-squared form:

$$k = \frac{1422T(\mu_g Z)_{avg}[\mathrm{In}(r_e/r_{wa}) - 0.5]q_i}{h[p_i^2 - p_{wf}^2]} \quad (24)$$

- Pressure-approximation form:

$$k = \frac{141.2(10^3)T(\mu_g B_g)[\ln(r_e/r_{wa})-0.5]q_i}{h(p_i-p_{wf})} \quad (25)$$

Where k = permeability, md

p_i = initial pressure, psia

p_{wf} = bottom-hole flowing pressure, psia

$m(p)$ = pseudo-pressure, psi^2/cp

qi = initial gas flow rate, Mscf/day

T = temperature, $°_R$

h = thickness, ft

μg = gas viscosity, cp

Z = gas deviation factor

Bg = gas formation volume factor, bbl/scf

Step 8. Determine the reservoir pore volume (PV) of the well drainage area at the beginning of the boundary-dominated flow the following expression [7]:

$$PV == \frac{56.54\ T}{(\mu_g c_t)_i[m(p_i)-m(p_{wf})]}\left(\frac{q_i}{D_i}\right) \quad (26)$$

Or, in terms of pressure squared,

$$PV = \frac{28.27(\mu_g Z)_{avg}\ T}{(\mu_g c_t)_i[p_i^2-p_{wf}^2]}\left(\frac{q_i}{D_i}\right) \quad (27)$$

With

$$r_e = \sqrt{\frac{(PV)}{\pi\ h\ \phi}} \quad (28)$$

$$A = \frac{\pi\ r_e^2}{43560} \quad (29)$$

Where PV = pore volume, ft^3

ϕ = porosity, fraction

μg = gas viscosity, cp

ct = total compressibility coefficient, psi^{-1}

qi = initial gas rate, Mscf/day

Di = decline rate, day^{-1}

re = drainage radius of the well, ft

A = drainage area, acres

Subscripts

i = initial

avg = average

Step 9. Calculate the skin factor, s, from the r_e/r_{wa} matching parameter and the calculated values of A and re from Step 8.

$$s = \ln\left[\left(\frac{r_e}{r_{wa}}\right)_{mp}\left(\frac{r_w}{r_e}\right)\right] \quad (30)$$

Step 10. Calculate the initial gas-in-place, G, from

$$G = \frac{(PV)[1-S_w]}{5.615B_{gi}} \quad (31)$$

The initial gas-in-place can also be estimated from the following relationship:

$$G = \frac{q_i}{D_i(1-b)} \quad (32)$$

Where G = initial gas-in-place, scf

Sw = initial water saturation

Bgi = gas formation volume factor at pi, bbl/scf

PV = pore volume, ft^3

An inherent problem when applying decline-curve analysis is having sufficient rate-time data to determine a unique value for b as shown in the Fetkovich type curve. It illustrates that the shorter the producing time, the more the b value curves approach one another, which leads to the difficulty of obtaining a unique match. Arguably, applying the type-curve approach with only three years of production history may not be possible form some pools. Unfortunately, since time is plotted on a log scale, the production history becomes compressed so that even when incremental history is added, it may still be difficult to differentiate and clearly identify the appropriate decline exponent b [5].

Methodology:

Available data:

The available data was taken from production reports and tests for two wells in the kharir field, block 10, Masila basin which are Kharir-1 and Kharir-2. Table (1) shows reservoir and PVT data of Kharir-1. See appendix A. the reservoir and PVT data of Kharir-2, and (A.2) respectively.

Table (1): Reservoir and PVT data of Kharir-1 [8, 9].

RESERVOIR & PVT DATA	UNITS	VALUES
Initial Reservoir Pressure, p_i	psi	1625
Flowing BHP, p_{wf}	Psi	550
Producing Thickness, h	Ft	152
Porosity,	%	8.5
Initial water Saturation, S_{wi}	%	40
Wellbore Radius, r_w	Ft	0.33
Reservoir Temperature, T	F	107
Specific Gravity,	-	0.74
Water Compressibility, c_w	1/psi	0.000006
Rock Compressibility, c_f	1/psi	0.000003
Initial z-Factor, zi	-	0.8000
Initial FVF, Bi	Rb/Mscf	1.4440
Initial Viscosity, mi	Cp	0.0162
Initial Total Compressibility, cti	1/psi	3.70E-04
Abandonment Rate, q_{abd}	Mscf/d	10
Current Cumulative Prod., Q	Mscf	722325

Procedures of calculations:

The basic steps used in Fetkovich type-curve matching of declining rate-time data are as follows [1]:

1- Excel spreadsheet was used to plot the historical flow rate, qt, versus time, t. and perform matching between historical production data and the designed type curve fig perform matching between historical production data and the designed type curve fig (1). Type curves (dimensionless) are generated by mathematical models with prescribed assumptions.

2- The purpose is to find a type curve that best matches historical production data. The process involves adjusting the values of rate match (q/q_{Dd}), and Time Match (t/t_{dD}) manually by change the values directly, until the actual data points match one of the type curves with a specific value of b.

3- From the match of the particular type curve of Step 2, record values of the reservoir dimensionless radius re/rwa and the parameter b.

4- Select any convenient match point on the actual data plot (q_t and t) mp.

5- Calculate the initial surface gas flow rate, q_i, at t = 0 from the rate match point:

$$q_i = \left[\frac{q_t}{q_{Dd}}\right]_{mp} \tag{33}$$

6- Calculate the initial decline rate, D_i, from the time match point:

$$D_i = \left[\frac{t_{Dd}}{t}\right]_{mp} \tag{34}$$

7- Using the value of re/rwa from Step 3 and the calculated value of qi, calculate the formation permeability, k, by applying Darcy's equation in the following form:

• Pressure-squared form:

$$k = \frac{1422T(\mu_g Z)_{avg}\,[\text{In}(r_e/r_{wa}) - 0.5]q_i}{h[p_i^2 - p_{wf}^2]} \tag{35}$$

Where k = permeability, md

Pi = initial pressure, psia

Pwf = bottom-hole flowing pressure, psia

Qi = initial gas flow rate, Mscf/day

T = temperature, $°_R$

H = thickness, ft.

μg= gas viscosity, cp

Z = gas deviation factor

8- Determine the reservoir pore volume (PV) of the well drainage area at the beginning of the boundary-dominated flow from the following expression [3]:
In terms of pressure squared,

$$PV = \frac{28.27(\mu_g Z)_{avg} T}{(\mu_g c_t)_i [p_i^2 - p_{wf}^2]} \left(\frac{q_i}{D_i}\right) \quad (36)$$

With

$$r_e = \sqrt{\frac{(PV)}{\pi h \phi}} \quad (37)$$

$$A = \frac{\pi r_e^2}{43560} \quad (38)$$

Where PV = pore volume, ft^3

ϕ = porosity, fraction

μg = gas viscosity, cp

ct = total compressibility coefficient, psi^{-1}

qi = initial gas rate, Mscf/day

Di = decline rate, day^{-1}

re = drainage radius of the well, ft.

A = drainage area, acres

Subscripts

i = initial

avg = average

9- Calculate the skin factor, s, from the r_e/r_{wa} matching parameter and the calculated values of A and re from step 8.

$$s = \ln\left[\left(\frac{r_e}{r_{wa}}\right)_{mp}\left(\frac{r_w}{r_e}\right)\right] \quad (39)$$

10- Calculate the initial gas-in-place, G, from

$$G = \frac{(PV)[1 - S_w]}{5.615 B_{gi}} \quad (40)$$

The initial gas-in-place can also be estimated from the following relationship:

$$G = \frac{q_i}{D_i\,(1-b)} \quad (41)$$

Where G = initial gas-in-place, scf

Sw = initial water saturation

Bgi = gas formation volume factor at Pi, bbl/scf

PV = pore volume, ft^3

Results & discussion:

Result of history match process:

Figure (2) show plot of historical flow rate, qt, versus time to find a type curve that best matches historical production data. You can notice that the actual data points match one of the type curves with a specific value of b. Figure (2) shows the actual data points match with one of the type curves with a specific value of b = 0 and flow Geometry Match, r_{eD} = 50 for Kharir#1 and Depletion Match, b = 0.2 for Kharir#2 see table (2) for the result of matching processing.

Table (2): Result of matching process

Well name / Properties	Units	KH#1	KH#2
Rate match, q/q_{Dd}	Mscf/d	415	170
Time Match, t/t_{dD}	Day	1700	10426
Flow Geometry Match r_{eD}	Ft	50	20
Depletion Match, b	-	0	0.2

Figure (3) shows the match of actual data points match with one of the type curves with a specific value of depletion, b = 0.2 and Flow Geometry Match, r_{eD}= 20 for Kharir#2 see table (2) for the result of matching processing.

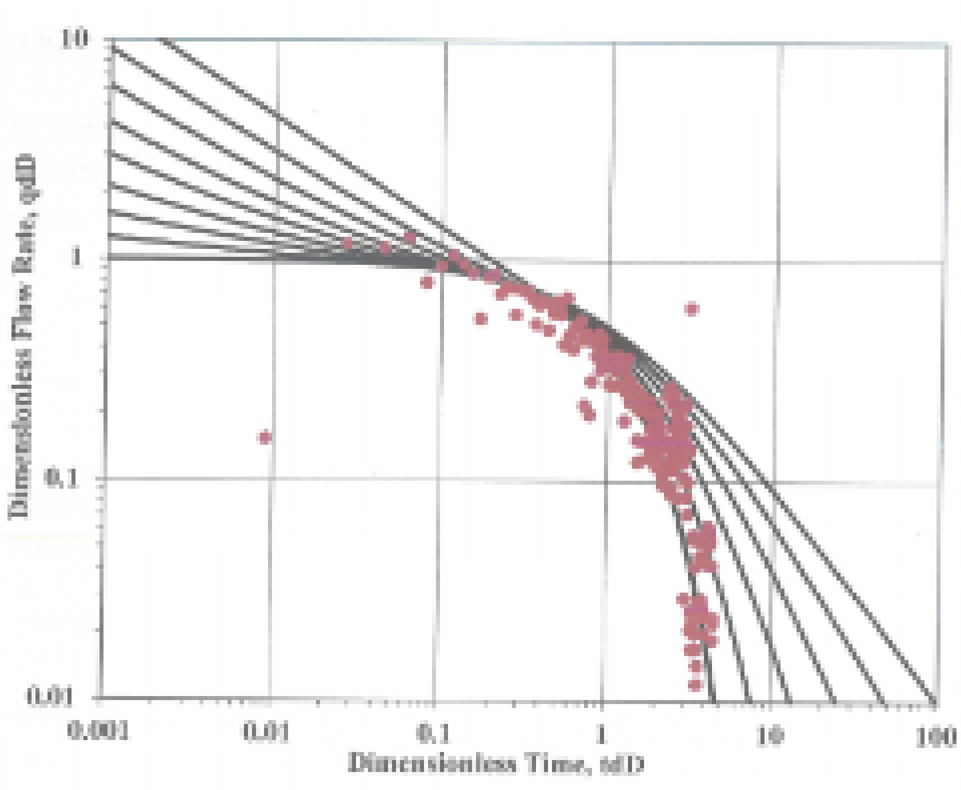


Figure (2): type-curve historical production matching of Kharir#1 well

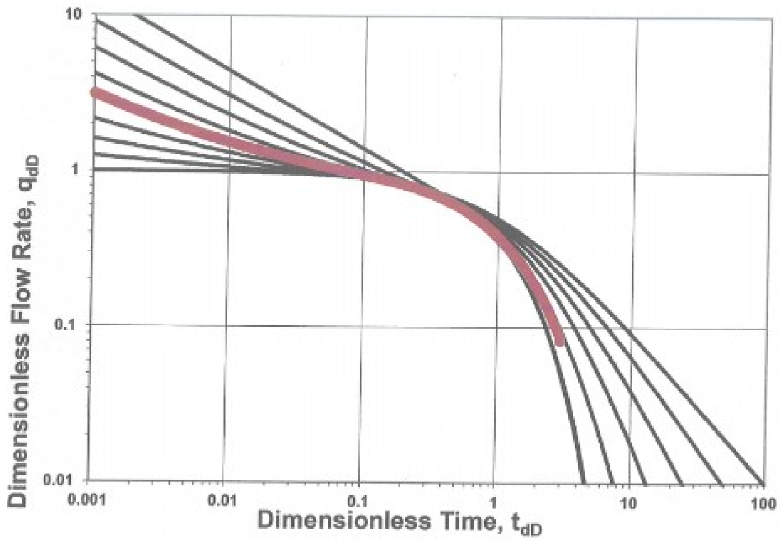


Figure (3): type-curve historical production matching of Kharir#2 well

Result of formation evaluation:

The results of type curve analysis are summarized in Table (3) for both wells Kharir#1 and Kharir#2. The match calculated average wells permeability's of 10 and 40 md respectively which are in good agreement with range of the reported field. The negative skin is consistent with perhaps only moderately effective acid treatment at completion.

Table (3): The results of type curve analysis for wells Kharir#1 and Kharir#2.

Estimated Properties	Units	Kharir#1	Kharir#2
		Rate-Time	Rate-Time
Productivity Factor, PF	Mscf/d/psi	0.577	0.151
Pore Volume, PV	MMcf	21.804	42.429
Initial Gas-in-place, IGIP	Bscf	1.614	5.706
Drainage Area, A	Acres	38.7	114.6
Equivalent Drainage Radius, r_e	Ft	732.9	1260.5
Apparent Wellbore Radius, r_{wa}	Ft	14.7	63.0
Skin Factor, S		-3.8	-5.5
Flow Capacity, Kh	D-ft	6.207	1.043
Permeability, k	D	0.04083	0.01043
Current Recovery, %IGIP	%	44.8	32.2
Current Recovery, per Acre	Mscf/acre	18644.5	16056.1

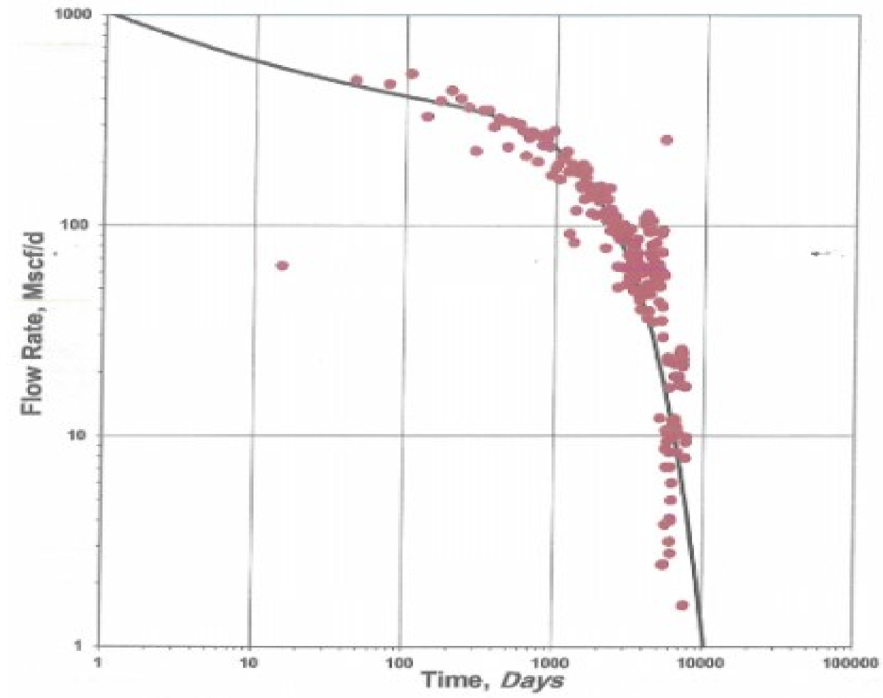
Result of forecasting:

Production forecasting were made for two wells Kharir-1 and Kharir-2 on the basis of decline match of b = 0 and b = 0.2 respectively. A recovery of 730606 Mscf and the remaining reserves 8282 Mscf is forecast for primary recovery from Kharir-1 which means 45.28% recovered from the initial gas in place see table (4).

Table (4): Final report of forecasting for Kharir-1

Last Reported Rate, (q_{last})	9.87	Mscf/d
Remaining Reserves	8281	Mscf
Estimated Ultimate Recovery (EUR)	730606	Mscf
Recovery (%IGIP)	45.28	%

It is apparent that boundary-dominated (i.e., pseudo steady state) data are present and can be matched on a curve for a particular value of b, the actual curve can simply be extrapolated following the trend of the type curve into the future.



igure (4): Kharir#1 well type-curve forecasting on real q_t vs. time

Kharir-1 production data is fit to depletion curve where b = 0, so the actual curve can be extrapolated following the trend of the type curve into the future see fig.(4), until reach the abandonment flow rate q_{abn} = 10 Mscf/d. Kharir-2 data is fit to decline b = 0.2, so extrapolate the solid curve in fig (5) into the future until the abandonment flow rate q_{abn} = 15 Mscf/d.

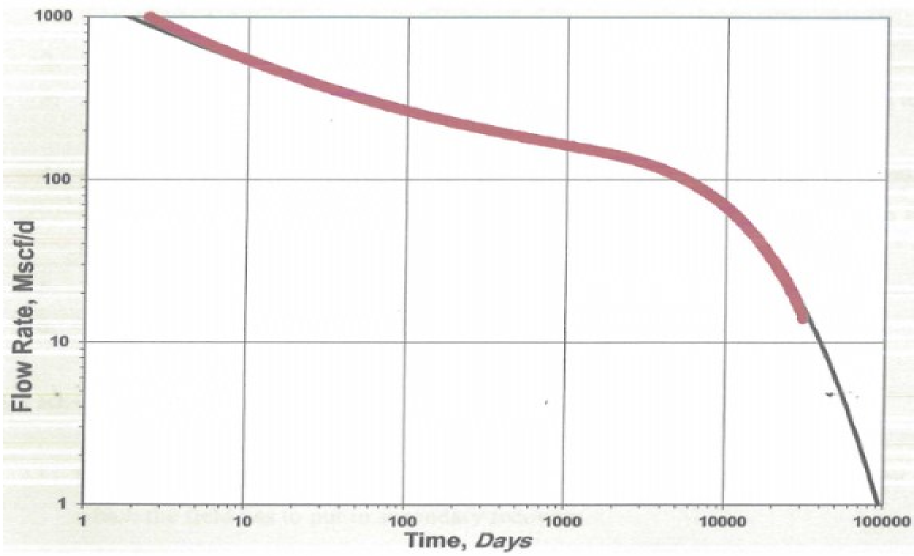


Figure (5): Kharir#2 well type-curve forecasting on real q vs. time

The results of type curve forecasting are summarized in Table (5) for Kharir-2. The math calculated well recovery of 1968036 Mscf and the remaining reserves 128136 Mscf of primary recovery which means 34.29% recovered of the initial gas in place.

Table (5): Final report of forecasting for Kharir-2

Last Reported Rate, (q_{last})	14.00	Mscf/d
Remaining Reserves	128136	Mscf
Estimated ultimate Recovery (EUR)	1968036	Mscf
Recovery (% IGIP)	34.29	%

Conclusions:

1- The decline best fit curve fit of the history for well Kharir-1 is b = 0 and Kharir-2 b = 0.2.
2- Flow Geometry Match, r_{eD} = 50 and 20 for Kharir-1, and Kharir-2 respectively.
3- All estimated reservoir properties are in good fit with that reported from the test for each wells.
4- Ultimate gas recovery (EUR) for Kharir-2 and Kharir-1 respectively are 1968036 Mscf and 730606 Mscf which means 34.29% and 45.28% recovered from the initial gas in place.
5- The remaining reserve is 8282 Mscf of the initial gas in place in Kharir-1.
6- The remaining reserve is 128136 Mscf of the initial gas in place in Kharir-2.

Nomenclature:

Q	flow rate, STB/day
B	formation, volume factors
μ	viscosity, cp
t	time, days
C_t	total compressibility coefficient, psi^{-1}
ϕ	porosity
b	Arp's decline-curve exponent
h	thickness, ft
r_e	drainage radius, ft.
r_{wa}	apparent (effective) wellbore radius, ft
k	permeability, md
Pi	initial pressure, psia
p_{wf}	bottom-hole flowing pressure, psia
m(p)	pseudo-pressure, psi^2/cp
qi	initial gas flow rate, Mscf/day
T	temperature, $°_R$
μg	gas viscosity, cp
Z	gas deviation factor
PV	pore volume, ft^3
Gp(t)	cumulative gas production at time t, MMscf
A	drainage area, acres
q_t	gas flow rate at time t, MMscf/day
S	skin factor
i	Initial
Gpa	cumulative flow rate or at abandonment, MMscf
avg	Average
G	gas-in-place, scf
Sw	initial water saturation
Bgi	gas formation volume factor at Pi, bbl/scf
Di	initial decline rate, unit day^{-1}

References:

1- Ahmed, T. reservoir Engineering handbook 4th Ed Elsevier 2010.
2- Boyun Guo, William, c. Lyons Ali Ghalambor petroleum production Engineering "A computer – Assisted Approach publisher Elsevier Science and technology Books February 2007.
3- Fetkovich, M.J. "Multipoint testing of Gas wells" SPE Mid-continent section continuing education course well test analysis, March 17 1975.
4- Fetkovich, M.J., "Decline curve Analysis using type curves, " SPE 4629 SPE Journal, June 1980,pp.1065 – 1077.
5- Fetkovich, M.J., "Decline curve Analysis using type curves: case histories "paper SPE 13169 presented at the SPE 1984 annual conf and exhib., Houston, sept, 16-19.
6- Gentry, R.W.," Decline curve Analysis "J.pet tech (Jan 1972) PP.3841.
7- Poston., S. W., and blasingame T. A., "Microcomputer Applications to Decline curve analysis "geobyte (summer 1986), PP.64-73.
8- Source of kharir oil field in Block 10-total petroleum LTD, Yemen PEPA-Yemen. 2016-2017
9- Total Final E and P Yemen East shabwa development kharir oil field. 2017
10- William, C. Lyons, Gary J. plisga Standard handbook of petroleum and Natural gas engineering second Edition Gulf professional publishing is an imprint of Elsevier 2005.

Appendices A:

Table (A.1): Reservoir and PVT data of Kharir-2

Reservoir & PVT data	**value**	**units**
Initial reservoir pressure, Pi	3000	Psi
Flowing BHP, Pwf	1500	Psi
Producing thickness, h	100	Ft
Porosity, Φ	8.5	%
Intial water saturation, Swi	30	%
Wellbore radius, rw	0.25	ft
Reservoir temperature, T	220	F
Specific gravity, ɣ	0.8764	
Water compressibility, Cw	0.000006	1/Psi
Rock compressibility, Cf	0.000003	1/Psi
Initial z-Factor, Zi	0.8148	-
Initial FVF, Bi	0.9271	rb/Mscf
Initial viscosity, Mi	0.0222	cp
Initial Total compressibility, Cti	1.98E-04	1/Psi
Abandonment rate, qabd	5	Mscf/d
Current cumulative prod, Q	1839900	Mscf

Table (A.2): The gas production history of Kharir-1 and Kharir-2

Gas cap production history of KH-1			**Gas cap production history of KH-2**		
Time	Flow rate	Cum prod	Time	Flow rate	Cum prod
(Days)	(Mscf/d)	(Mscf)	(Days)	(Mscf/d)	(Mscf)
15.2	64.2434211	1953	0.001	26237	0
45.6	488.947368	16817	0.002	20672	100
76	469.703947	31096	0.003	17613	100
106.4	525.888158	47083	0.004	15317	100
136.8	329.013158	57085	0.005	13640	100
167.2	389.671053	68931	0.006	12368	100
197.6	436.940789	82214	0.007	11220	100
228	399.934211	94372	0.008	10270	200
258.4	363.157895	105412	0.009	9568	200
288.8	225.756579	112275	0.01	8904	200
319.2	351.644737	122965	0.011	8388	200
349.6	352.960526	133695	0.012	7889	200
380	293.75	142625	0.013	7584	200
410.4	322.467105	152428	0.014	7155	200
440.8	312.434211	161926	0.015	6873	200
471.2	235.723684	169092	0.016	6633	200
501.6	310.657895	178536	0.017	6424	200
532	304.078947	187780	0.018	6239	200
562.4	303.914474	197019	0.019	6075	200
592.8	281.25	205569	0.02	6001	300
623.2	214.144737	212079	0.021	5872	300
653.6	260.756579	220006	0.022	5734	300
684	277.861842	228453	0.024	5592	300
714.4	270.361842	236672	0.025	5496	300
744.8	201.282895	242791	0.027	5349	300
775.2	267.236842	250915	0.029	5277	300
805.6	240.065789	258213	0.03	5219	300

836	270.72368	266443	0.032	5146	300
866.4	258.980263	274316	0.034	5068	300
896.8	236.578947	281508	0.035	5043	300
927.2	172.631579	286756	0.037	4980	300
957.6	281.480263	295313	0.039	4947	400
988	187.828947	301023	0.04	4916	400
1018.4	194.868421	306947	0.042	4866	400
1048.8	165.328947	311973	0.045	4821	400
1079.2	211.940789	318416	0.047	4779	400
1109.6	208.26316	324740	0.05	4740	400
1140	218.651316	331387	0.052	4712	400
1170.4	224.572368	338214	0.054	4679	400
1200.8	180.625	343705	0.057	4640	400
1231.2	91.5789472	346489	0.06	4608	500
1261.6	195.822368	352442	0.062	4580	500
1292	189.638159	358207	0.065	4546	500
Table (A.2) continue					
1322.4	83.2236842	360737	0.067	4524	500
1352.8	118.092105	364327	0.07	4493	500
1383.2	177.960526	369737	0.072	4468	500
1413.6	182.434211	375283	0.075	4436	500
1444	155.164474	380000	0.077	4417	500
1474.4	151.217105	384597	0.079	4392	500
1504.8	195.032895	390526	0.08	4385	500
1535.2	133.552632	394586	0.082	4361	600
1565.6	169.111842	399727	0.085	4332	600
1596	183.782895	405314	0.087	4314	600
1626.4	154.375	410007	0.089	4291	600
1656.8	136.546053	414158	0.09	4282	600
1687.2	144.703947	418557	0.092	4260	600
1717.6	114.605263	422041	0.095	4233	600
1748	151.907895	426659	0.098	4199	600
1778.4	148.322368	431168	0.1	4183	600
1808.8	145.657895	435596	0.103	4158	600
1839.2	112.039474	439002	0.106	4127	700
1869.6	137.171053	443172	0.108	4108	700
1900	146.217105	447617	0.111	4084	700
1930.4	130.690789	451590	0.114	4055	700
1960.8	154.177632	456277	0.116	4037	700
1991.2	142.006579	460594	0.119	4015	700
2021.6	113.782895	464053	0.122	3989	700
2052	135.493421	468172	0.126	3956	700
2082.4	142.171053	472494	0.129	3935	700
2112.8	115.690789	476011	0.132	3910	800
2143.2	78.1907895	478388	0.136	3879	800
2173.6	105.493421	481595	0.138	3859	800
2204	133.388158	485650	0.141	3835	800
2234.4	119.638158	489287	0.145	3806	800
2264.8	150.526316	493863	0.148	3787	800
2295.2	94.6710526	496741	0.15	3768	800
2325.6	119.144737	500363	0.153	3745	800
2365	115.23063	5038866	0.157	3718	900

2386.4	105.361842	507069	0.159	3700	900
2416.8	108.552632	510369	0.162	3678	900
2447.2	99.6710526	513399	0.166	3652	900
2477.6	98.0921053	516381	0.17	3620	900
2508	110	519725	0.173	3600	900
2538.4	91.1513158	522496	0.177	3576	900
2568.8	63.8815789	524438	0.181	3547	900
25992	50.8552632	525984	0.184	3528	1000
2629.6	99.3092105	529003	0.188	3506	1000
2660	86.3815789	531629	0.192	3478	1000
2690.4	97.9934211	534608	0.197	3445	1000
2720.8	98.1578947	537592	0.2	3429	1000
Table (A.2) continue					
2751.2	101.151316	540667	0.204	3404	1000
2781.6	98.75	543669	0.21	3373	1000
2812	63.2236842	545591	0.213	3353	1100
2842.4	100.526316	548647	0.217	3330	1100
2872.8	98.2894737	551635	0.222	3301	1100
2903.2	87.0065789	554280	0.226	3282	1100
2933.6	90.3947368	557028	0.23	3260	1100
2964	52.6315789	558628	0.235	3233	1100
2994.4	83.7828947	561175	0.238	3215	1100
3024.8	93.3881579	564014	0.242	3194	1100
3055.2	72.5	566218	0.247	3168	1200
3085.6	57.2368421	567958	0.25	3152	1200
3116	73.5855263	570195	0.254	3132	1200
3146.4	96.25	573121	0.259	3107	1200
3176.8	74.9013158	575398	0.265	3078	1200
3207.2	66.0197368	577405	0.269	3059	1200
3237.6	54.5394737	379063	0.273	3036	1200
3268	60.625	580906	0.279	3009	1300
3298.4	70.4605263	583048	0.287	2975	1300
3328.8	49.0131579	584538	0.291	2955	1300
3359.2	79.9671053	586969	0.297	2930	1300
3389.6	55.5605263	588655	0.3	2917	1300
3420	66.1184211	590665	0.306	3893	1300
3450.4	68.5197368	592748	0.313	2864	1400
3480.8	65.5921053	594742	0.318	2845	1400
3511.2	86.25	597364	0.323	2823	1400
3541.6	73.4539474	599597	0.33	2796	1400
3572	48.8157895	601081	0.339	2763	1400
3602.4	65.0328947	603058	0.345	2743	1500
3632.8	45.5263158	604442	0.35	2724	1500
3663.2	44.1447368	605784	0.357	2699	1500
3293.6	39.9671053	606999	0.366	2670	1500
3724	48.0921053	608461	0.371	2650	1500
3754.4	59.6710526	610275	0.378	2628	1500
3784.8	48.6184211	611753	0.386	2600	1600
3815.2	60.6578947	613597	0.391	2582	1600
3845.6	59.6052632	615409	0.398	2560	1600
3876	101.818182	617649	0.4	2553	1600
3906.4	108.347826	620141	0.407	2532	1600

3936.8	63.4193548	622107	0.415	2507	1600
3967.2	51.3461538	623442	0.425	2476	1700
3997.6	39.1935484	624657	0.432	2456	1700
4028	61.6315789	625828	0.44	2433	1700
4058.4	47	627285	0.45	2404	1700
4088.8	113.2	628417	0.458	2382	1700
4119.2	36.25	629432	0.468	2357	1800
4149.6	52.9047619	630543	0.48	2326	1800
Table (A.2) continue					
4180	93.4	631944	0.488	2306	1800
4210.4	39.1428571	633040	0.497	2283	1800
4240.8	51.8571429	633403	0.5	2276	1800
4271.2	73.75	635173	0.6	2095	2100
4301.6	47.066667	636585	0.7	1931	2300
4332	74.3793103	638742	0.8	1793	2500
4362.4	80.7222222	640195	0.9	1679	2700
4392.8	105.041667	642716	1	1586	2800
4423.2	70.6153846	644552	1.1	1505	3000
4453.6	94.2333333	647379	1.2	1433	3100
4484	59	649090	1.3	1370	3300
4514.4	34.8214286	650065	1.4	1314	3400
4544.8	61.5	651787	1.5	1265	3500
4575.2	67.4615385	653541	1.6	1221	3700
4605.6	74.1	655764	1.7	1182	3800
4636	55.0322581	657470	1.8	1147	3900
4666.4	83.0344828	659878	1.9	1116	4000
4696.8	63.6818182	661279	11061	62	1214900
4727.2	54.1034483	662848	11244	61	1226000
4757.6	51.4666667	664392	11396.5	60	1235200
4788	60.8148148	666034	11671	59	1251500
4818.4	54	667654	11854	58	1262100
4848.8	62.8148148	669850	120915	57	1275700
4879.2	51.2903226	670940	12274.5	56	1285900
4909.6	65.2173913	672440	12549	55	1301100
4940	43.3225806	673783	12762.5	54	1312600
4970.4	61.6428571	675509	130305	53	1326900
5000.8	51.44	676795	13244	52	1338000
5031.2	57.0333333	678506	13457.5	51	1348900
5061.6	12.1612903	678883	13732	50	1362700
5092	91.4090909	680894	13945.5	49	1373200
5122.4	74.5416667	682683	14274.5	48	1389000
5152.8	35.3870968	683780	14518.5	47	1400500
5183.2	94.5	684914	14823.5	46	1414500
5213.6	41.1612903	686190	15091.5	45	1426600
5244	29.5	686957	15457.5	44	1442800
5274.4	58.875	688370	15701.5	43	1453300
5304.8	254.8	690918	16061	42	1468400
5335.2	57.8888889	691960	16366	41	1481000
5365.6	0.38709677	691972	16640.5	40	1492000
5396	2.46428571	692041	17061	39	1508400
5426.4	2.3516129	692117	17335.5	38	1518900
5456.8	2.4516129	692193	17762.5	37	1534700

5487.2	2.46666667	692267	18061	36	1545500
5517.6	8.7	692528	18518.5	35	1561500
5548	10.6451613	692858	18854	34	1572900
5578.4	3.80645161	692976	19305	33	1587900
Table (A.2) continue					
5608.8	7.12903226	693197	19701.5	32	1600600
5639.2	10.4	693509	20183	31	1615500
5669.6	9.41935484	693801	20579.5	30	1627500
5700	23.6129032	694533	21000	29	1639700
5730.4	23.0714286	695179	21579.5	28	1655900
5760.8	22.516129	695877	22030.5	27	1668200
3791.2	22.6	696555	22671	26	1684800
5821.6	16.9677419	697081	23152.5	25	1696900
5852	10.8	697405	23823.5	24	1713000
5882.4	10.3225806	697725	24335.5	23	1724800
5912.8	8.38709677	697985	25061	22	1740800
5943.2	7.13333333	698199	25640.5	21	1753000
5973.6	3.16129032	698297	26244	20	1765100
6004	4.06666667	698419	27061	19	1780700
6034.4	3.96774194	698542	27732	18	1792800
6064.8	2.77419355	698628	28671	17	1808800
6095.2	4.96428571	698767	29396.5	16	1820400
6125.6	6	698953	30701.5	14	1839900
6156	11.9	699310	11854	58	1262100
6186.4	11.7419355	699674	12091.5	57	1275700
6216.8	9.86666667	699970	12274.5	56	1285900
6247.2	10.2903226	700289	12549	55	1301100
6277.6	10.7096774	700621	12762.5	54	1312600
6308	22.0666667	701283	13030.5	53	1326900
6338.4	19.16122903	701877	13244	52	1338000
6368.8	12.0666667	702239	13457.5	51	1348900
6399.2	11.9677419	702610	13732	50	1362700
6429.6	11.6774194	702972	13945.5	49	1373200
6460	11.137931	703295	14274.5	48	1389000
6490.4	10.7419355	703628	14518.5	47	1400500
6520.8	10.9666667	703957	14823.5	46	1414500
6551.2	10.7741935	704291	15091.5	45	1426600
6581.6	10.8333333	704616	15457.5	44	1442800
6612	10.3225806	704936	15701.5	43	1453300
6642.4	10.1935484	705252	16061	42	1468400
6672.8	8.36666667	705503	16366	41	1481000
6703.2	10.2903226	705822	16640.5	40	1492000
6733.6	19.1	706395	17061	39	1508400
6764	17.6129032	706941	17335.5	38	1518900
6794.4	22.0645161	707625	17762.5	37	1534700
6824.8	242142857	708303	18061	36	1545500
6855.2	25	709078	18518.5	35	1561500
6885.6	25.0666667	709830	18854	34	1572900
6916	25.3870968	710617	19305	33	1587900
6946.4	24.6	711355	19701.5	32	1600600
6976.8	24.9230769	712003	20183	31	1615500
7007.2	25.9032258	712806	20579.5	30	1627500

Table (A.2) continue					
7037.6	25.4333333	713569	21000	29	1639700
7068	25.6774194	714365	215759.5	28	1655900
7098.4	245333333	715101	22030.5	27	1668200
7128.8	23.7419355	715868	22671	26	1684800
7159.2	21.483871	716534	23152.5	25	1696900
7189.6	23.25	717185	23823.5	24	1713000
7220	21.8387097	717862	24335.5	23	1724800
7250.4	17.2666667	718380	25061	22	1740800
7280.8	17.3548387	718918	25640.5	21	1753000
7311.2	17.2666667	719436	26244	20	1765100
7341.6	17.2903226	719972	27061	19	1780700
7372	17.2608696	720369	27732	18	1792800
7402.4	17.2	720885	28671	17	1808800
7432.8	17.1612903	721417	29396.5	16	1820400
7524	7.87096774	721757	30549	15	1837700
7584.8	9.87096774	722325	30701.5	14	1839900

التنبؤ باداء انتاجية القبة الغازية باستخدام طريقة فتكوفيتش في حقل خرير

سالم مبارك بن قديم **علي سالم مبارك بن قديم**

الملخص

يستهدف البحث مقارنة مؤاشرات الخزان مع التي ذكرت في الاختبار لكل بئر، تحديد وبصورة نهائية قبة الغاز، ومن ثم تقدير الاحتياطيات المتبقية. في هذه الورقة البحثية تم إعداد ورقة أكسل لطريقة استخدامات ضبط بيانات الإنتاج مع أحد منحنيات التنبؤ لبئري خرير (1و2). حيث تم تطابق البئر (1) مع المنحنى ذات القيمة صفر، بينما البئر (2) على المنحنى ذات القيمة 0,2 الخواص المكمنية التي تم حسابها دقيقة وقريبة للقيم المعروفة مسبقا بالنسبة للبئرين. أقصى كمية من الغاز يمكن استخلاصها من القبة الغازية من البئر (1) هي 730606 ألف قدم مكعب والمتبقي هي 8280 ألف قدم مكعب، بينما في البئر (2) هي 1968036 ألف قدم مكعب والمتبقي 128136 ألف قدم مكعب.

الكلمات المفتاحية : التنبؤ، خزان، إدارة، التحسن النهائي المقدر، فتكوفتش، النفادية، حديث، تقليدي، خرير-1، خرير-2.