Sudanese Oil Field Production Performance by Nodal Analysis Technique

Fatima A. Elbrir

Abstract — The study has evaluated production performance of oil well by using nodal analysis for entire production system. The goal of this study is to analysis one of the Sudanese oil field using nodal analysis and to review the field completion strategy for the respective field. The study starts by collecting the data from oil company and takes the X Field as case study. The X field consist of 18 well and four of them were selected for the analysis namely X NW-1, X NW-2, X NW-3 and X NW-4. Operating pressure for each well are 2409, 2455, 2550 and 2420 psia, and operating flow rate are 3925.4, 1110.4, 2255.7, and 1387.2 STB/D respectively. Wellflo modeling used for this task, which permits the production optimization of oil well using the concept of nodal analysis.

Several sensitivity analyses were conducted in order to get the production forecast. If assumed that the depletion in the pressure occur within 1 year, the pressure reduced to 2000 and 1000psia for each well; as can be seen, the production reduced rapidly in XNW-2 and XNW-4. However, 1000psia the production becomes zero for the four wells.

Index Terms — Nodal Analysis, Production Performance, Wellflo Program.

I. INTRODUCTION

Nodal analysis has long been a key method used to evaluate the performance of an integrated production system [1]. It has performed in the sixties and seventies by hand calculation, using vertical pressure traverse graphs generated in-house by big oil companies [2], and define the propositions that will be used to optimize a production system, for oil and gas well. Each component of the producing system is analyzed in order to reach the desired production rate as economical as possible [3].

• Determine the fluid rate that an oil or gas well will produce, taking into account the hole geometry and the completion boundaries.

• Optimize the system to produce an objective fluid rate as economical as possible [4]. Nodal analysis provides a method to determine the flow rate at which a producing system will perform under applied condition.

The node is placed into different location. The node is classified as a functional node when a pressure exists across it and the pressure or flow rate response can be presented by some mathematical or physical function [3]. Once the node is selected, the node pressure is calculated from the both directions stared at the fixed pressures. In other words, the flow into the node equals the flow out the nod [5].

II. APPLICATION OF FIELD X NODAL ANALYSIS

A. Models and Correlations

The Wellflo computer program software was used for nodal analysis. For this study version (3.8) has been used. The computer program can conduct the nodal analysis calculations as well as (sensitivity analysis) and tested with actual field data.

Reservoir: The pressure drops across the reservoir porous media are computed by an inflow performance relationship (IPR) expressed by Vogel’s [6].

$$\frac{q_{w,\text{max}}}{q_{w}} = 1 - 0.2 \frac{p_{w}}{p_{r}} - 0.8 \left( \frac{p_{w}}{p_{r}} \right)^{2}$$

Perforation: The program computes the pressure drop across the perforations using Mc-Leod’s method [7]. The equation for the pressure losses across the perforation is as follows:

$$p_{wfr} = aq + bq^{2}$$

The coefficient a and b are define as,

$$a = \frac{3.16 \times 10^{-12} \times \beta \times \gamma \times T \times \left( \frac{1}{R_{p}} - \frac{1}{R_{c}} \right)}{L_{p} \times \mu}$$

and

$$b = \frac{1.424 \times 10^{3} \times T \times \left( \frac{L_{n}}{R_{p}} \times \frac{R_{c}}{R_{p}} \right)}{K_{r} \times L_{r}}$$

Tubing String: Hagedron and Brown correlation was used to compute the pressure drop across the tubing string.

Well Head Choke: Sechdeva, Adiatique expansion equation and Gilbert correlations used to compute the pressure losses across the wellhead choke [8].

Surface Pipeline: Hagedron and Brown correlation were used to compute the pressure drop across the surface pipeline, this equation considers slip condition and flow regime, used for all pipe size, and for all fluids.

Fluid Properties: The correlations used to build the wellflo software program to estimate the properties of the fluids are listed in Table (1). These experimental correlations are function of temperature, pressure, type of fluid (gas, oil or water), and densities of the different phase which are present in the flow.

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Fatima A. Elbrir, Sudan University of Science and Technology, Sudan.
(e-mail: fatimawael12@hotmail.com)

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B. Field X Data validation and Results

4 wells namely XNW1, XNW2, XNW3, and XNW4 were selected, all of the four well open to production in 2009. X field data represent an ideal production data which is used to verify the robustness of wellflo software program. The characteristics of the reservoir as well as the completion, production, and fluid properties, for four well are summarized in following Tables 2-6.

### Table 2: X Field Reservoir Data

| Well name | XNW-1 | XNW-2 | XNW-3 | XNW-4 |
|-----------|-------|-------|-------|-------|
| Initial pressure (psia) | 2400 | 2450 | 2500 | 2420 |
| Initial temperature (F) | 186 | 179 | 179 | 179 |
| Net pay (ft) | 84.6 | 38 | 50.5 | 49.3 |
| Porosity (fraction) | 0.21 | 0.19 | 0.24 | 0.22 |
| Permeability (md) | 2400 | 212 | 2000 | 1800 |
| Water saturation (fraction) | 0.48 | 0.44 | 0.25 | 0.29 |

### Table 3: X Field Completion Data

| Well name | XNW-1 | XNW-2 | XNW-3 | XNW-4 |
|-----------|-------|-------|-------|-------|
| Casing diameter [in.] | 6.267 |
| Perforated interval [R] | 131.2 | 55.8 | 62 | 57.4 |
| Perforation density [SPF] | 4 |

### Table 4: X Field Production Data

| Well name | XNW-1 | XNW-2 | XNW-3 | XNW-4 |
|-----------|-------|-------|-------|-------|
| Well head pressure [psia] | 390 | 265 | 235 | 280 |
| Well head temperature [F] | 164 | 130 | 155 | 143 |
| Gas oil ratio (SCF/STB) | 30 | 30 | 30 | 30 |
| Water cut % | 50 | 80 | 92 | 9 |
| Liquid production rate (STB/d) | 3925.4 | 1110.4 | 2255.4 | 1387.2 |

### Table 5: X Field Fluid Properties Data

| Well name | XNW-1 | XNW-2 | XNW-3 | XNW-4 |
|-----------|-------|-------|-------|-------|
| Specific gravity of produced gas | 0.65 |
| Oil density [API] | 37.05 | 35.11 | 39.1 | 36.06 |
| Solution gas oil ratio correlation | Glaso |
| Oil formation volume factor correlation | Glaso |
| Bubble point pressure correlation | Glaso |
| Oil viscosity correlation | Beal + chew et al |
| Gas viscosity correlation | Carr et al |
| Surface tension | Advanced |
| Water salinity (ppm) | 5878 |

### Table 6: History Match for the Four Wells

| Calculated value | Well name | Calculated value | Actual value | Comment |
|------------------|-----------|------------------|--------------|---------|
| Skin             | Xnw-1     | 8.355            | 6.1          | From well test |
|                  | Xnw-2     | 3.591            | 1.24         | From well test |
|                  | Xnw-3     | 1.59             | 2.3          | From well test |
|                  | Xnw-4     | -1.128           | -1.231       | From well test |
|                  | Xnw-1     | 18.24            | 16.32        | From well test |
|                  | Xnw-2     | 21.84            | 19.88        | From well test |
|                  | Xnw-3     | 14.11            | 11.38        | From well test |
|                  | Xnw-4     | 6.20             | 8.23         | From well test |

**Sensitivity Analysis**

Three cases were conducted to study the sensitivity of well flow rate to these cases. These cases are the pressure of the layer, the well head pressure and producing of water cut.

**Layer pressure:** The actual layer pressure of the well xnw-1 is 2400 psia. Therefore, layer pressure values of 2400, 2000 and 1000 psia are used for forecast computations for this well. The results show that when the layer pressure becomes 1000 psia, there is no operating point in well xnw-1. In other words, this well will not produce if the layer pressure decreases to 1000 Psia. Layer pressure value of 2455, 2400 and 2000 psia were used for forecast computation for well xnw-2 since the actual layer pressure of this well is 2455 psia. Simulation shows, this well has no operating point when the layer pressure became 2000 Psia. For well xnw-3 which it is actual pressure value is 2455, layer pressure values of 2455, 2400, 2000 and 1500 Psia were used. The results show that this well can produce for less than 2000 Psia layer pressure value but cannot produce if the reservoir pressure decrease to 1500 Psia. Reservoir pressure values of 2420, 2400, 2000, 1000 psia was used for well xnw-4 where the actual layer pressure value from it is 2420 psia. The well has no operation point in 2000 Psia. That means there is no flow rate at the surface and the operating of this well become uneconomic.

![Fig. 1. Sensitivity of Flow Rate With Respect to Layer Pressure for (xnw-1).](image-url)
Water Cut: In order to evaluate the viability of producing the four wells under increased water-cuts and reduced reservoir pressures, a number of sensitivity analyses were performed on the production from the four wells using WellFlo. The results summarized in Table 9. The actual water cut of the well xnw-1 is 50%. Therefore, a water cut values of 50%, 70%, and 90% are used for forecast computations for this well. The results show that when the water cut becomes 90%, the oil produced is 379 stb/d but it is reasonable comparing with other wells. Water cut value of 80%, 85% and 90% were used for forecast computation for well xnw-2 since the actual water cut of this well is 80%. Simulation shows, this well produced only 41stb/d when the water cut increasing to 90%. Well Head Pressure: The sensitivity of the four well shown in Table 8, the actual wellhead pressures of the four well are (380, 265, 235and 280 psia) respectively, different values of pressure were taken for the forecasting the four wells. The results show that the well performance improves as the well head pressure decreases. The decrease of wellhead pressure from 380 psia to 350 psia provided an increase in flow rate of about 288 b/d for the well xnw-1. However, a further decrease of well head pressure from 200 psia to 150 psia provided an increase of about 118 b/d. Moreover, the gain resulting from an eventual decrease of the well head pressure from 150 to100 psia provided an increase in flow rate of about 101 b/d, the decrease of well head pressure resulting in increasing the flow rate about 185 b/d for well xnw-3 and 174b/d flow rate was achieved for the well xnw-4.

**Table 7: Sensitivity of Layer Pressure**

| Layer Pressure Psia | Xnw-1 Gross STB/d | Xnw-2 Gross STB/d | Xnw-3 Gross STB/d | Xnw-4 Gross STB/d | Xnw-1 Oil STB/d | Xnw-2 Oil STB/d | Xnw-3 Oil STB/d | Xnw-4 Oil STB/d |
|---------------------|------------------|------------------|------------------|------------------|----------------|----------------|----------------|----------------|
| 2400                | 3964             | 1982             | 2455             | 2107.4           | 1141           | 228            | 163            | 996            |
| 2000                | 3190             | 1595             | 2400             | 1939             | 789.7          | 157            | 155            | 2400           |
| 1000                | No operating     | No operating     | 2000             | 2044             | No operating   | No operating   | 1094.8         | 927            |

**Table 8: Sensitivity of Well Head Pressure**

| Pressure Psia | Rate STB/d | Pressure Psia | Rate STB/d | Pressure Psia | Rate STB/d | Pressure Psia | Rate STB/d |
|---------------|------------|--------------|------------|--------------|------------|--------------|------------|
| 380           | 3723       | 265          | 1141       | 235          | 2107       | 280          | 1335       |
| 350           | 4011       | 200          | 1365       | 200          | 2292       | 200          | 1509       |
| 300           | 4089       | 150          | 1484       | 150          | 2379       | 150          | 1596       |
| -             | -          | 100          | 1585       | 100          | 2467       | 100          | 1678       |

**Fig. 2. Sensitivity of Flow Rate with Respect to Layer Pressure for (xnw5).**

**Fig. 3. Sensitivity of Flow Rate with Respect to Wellhead Pressure for (xnw-1).**

**Fig. 4. Sensitivity of Flow Rate with Respect to Wellhead Pressure for (xnw-3).**

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TABLE 9: SENSITIVITY OF WATER CUT

|       | Xnw-1                | Xnw-2                | Xnw-3                | Xnw-4                |
|-------|----------------------|----------------------|----------------------|----------------------|
| WC%   | Gross Sb/d | Oil Sb/d | WC%   | Gross Sb/d | Oil Sb/d | WC%   | Gross Sb/d | Oil Sb/d | WC%   | Gross Sb/d | Oil Sb/d |
| 50    | 3723       | 1982     | 80    | 1141.7    | 228      | 92    | 2226.6    | 178      | 20    | 1276.7    | 1014     |
| 70    | 3881.6     | 1164     | 85    | 1060.8    | 159      | 95    | 2248      | 112      | 50    | 981.6     | 495.8    |
| 90    | 3790.5     | 579      | 90    | 961       | 41.5     | 98    | 2270.8    | 45       | 80    | No operating point|

III. CONCLUSION

Several innovative ideas during the courses of data collection, implementation in wellflo program, history matching, and sensitivity analysis are presented the finding prove that the nodal analysis provides valuable means to help the engineer in Decisions making. Opening oil well to production always involves considerable expenses whereas a model can be run many times at lower cost to try many different possible scenarios in order to make technical and economic decisions. The wellflo program presented in this study is capable of history matching the production data as well as predicting the performance under different scenarios. The program has been validated with the help of field data. The program definitely provides a logical improvement in nodal analysis.

IV. FURTHER WORK

For future researches is better to include the difference between the inflow and outflow due to friction through the production pipes which was not considered in this study, also there are so many factors can be considered in the coming researches such as GOR, inside diameter of all well node, Roughness of all well node, effective permeability, layer thickness, wellbore radius, external radius and total Darcy skin.

NOMENCLATURE

- $P_r$ – The reservoir pressure, psia
- $P_{sep}$ – The separator pressure, psia
- $q_o$ – Inflow rate corresponding to wellbore flowing pressure, STB
- $q_o\text{ max}$ – Inflow rate corresponding to zero wellbore flowing pressure, STB/d
- $P_R$ – Average reservoir pressure, psia
$R_p$ – Radius of perforation, ft
$R_c$ – Radius of compacted zone, ft
$\mu$ – Viscosity, cp
$\gamma$ – Specific gravity, dimensionless
$K_p$ – Permeability of compacted zone, md
$L_p$ – Perforation tunnel length, ft
$T$ – Temperature, $R$
$P_{wf}$ – Bottom hole flowing pressure
$P_{wfs}$ – Sand face flowing pressure
$A_R$ – Laminar reservoir component
$K_{OR}$ – Unaltered reservoir permeability to oil
$S_d$ – Skin factor due to permeability alteration around the wellbore
$K_R$ – Reservoir permeability
$K_d$ – Alternated zone permeability
$r_w$ – Wellbore radius
$r_d$ – Alternated zone radius
$B_R$ – Turbulent reservoir component
$A_G$ – Laminar gravel-pack component
$B_G$ – Turbulent gravel-pack component
$N$ – Total number of perforation
$L$ – Gravel-pack tunnel length
$K_{GP}$ – Gravel-pack permeability
$P_{wh}$ – Wellhead pressure, psia
$R$ – Gas/liquid ratio, MCF/STB
$Q$ – Gross liquid rate, STB/D
$S$ – Choke bean size, 64th of an inch
$C$ – Constant

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