WELL PERFORMANCE ANALYSIS BASED ON FLOW CALCULATIONS AND IPR

Dr. Mohammed S. Al-Jawad
University of Baghdad
College of Engineering
Petroleum Department

Dhefaf J. S. Ottba
University of Baghdad
College of Engineering
Petroleum Department

ABSTRACT

A study has been done to analyze the total production system by developing a computer model. Every component of the production system has been programmed individually and then linked in the composite production system computer program. These components are; reservoir component, vertical component, surface choke component and finally horizontal component.

Each of the previous components are developed using various equations or models to determine the pressure loss thorough that component. In the current study the Wiggins method has been used to calculate the IPR curves. The vertical and horizontal components are developed using the unified mechanistic model of Gomez. Lage mechanistic model has been used to calculate the pressure losses through annulus. Perkins mechanistic model is used to calculate the pressure loss through surface chokes.

A filed example problem is presented to analyze the production system. This example has been used to determine the optimum system design which maximizes production rate for a set of condition.

الخلاصة

هدف الدراسة هو تحليل أدائية منظومة إنتاج متكاملة. كل جزء من منظومة الإنتاج تمت درا ستة بصورة منفصلة . ثم ربط أجزاء المنظومة كموديل متكامل. أجزاء المنظومة هي: مركبة المكمن, الجريان المتعدد الأطوار خلال الأنابيب العمودية والفراغ الحلقي, الجريان المتعدد الأطوار خلال الخانق السطحي,الجريان المتعدد الأطوار في الأنابيب الأفقية أو أنابيب الإنتاج.

كل جزء من منظومة الإنتاج تم تطويره باستخدام مختلف المعادلات والموديلات الرياضية، وذلك بإيجاد هبوط الضغط الناتج من جريان الموائع خلال كل جزء. تم استخدام طريقة(Wiggens) لحساب منحنيات (IPR) للآبار النفطية التي تنتج ماء ، ولإيجاد هبوط الضغط خلال الأنابيب العمودية والأفقية تم استخدام الموديل الميكانيكي (Gomez) حيث تمت دراسته وتقييمه مقارنة مع البيانات الحقلية ومع غيره من الموديلات وفي الفراغ الحلقي تم استخدام الموديل الميكانيكي (Lage) الذي يحسب هبوط الضغط في الفراغ الحلقي ، وقد أظهر هذا الموديل أدائية جيدة مقارنة مع البيانات الحقلية ومع بقية الموديلات .الموديل الميكانيكي ل (Perinks) تم استخدامه لحساب هبوط الضغط خلال الخانق السطحي وقد أعطى هذا الموديل أدائية جيدة مقارنة مع البيانات الحقلية ومع بقية الموديلات
.

وتضمنت هذه الدراسة تقديم مثال حقلي لتحليل أدائية منظومة إنتاج . هذا المثال استخدم لإيجاد امثل تصميم لمنظومة الإنتاج لكي تعطي أعلى معدل إنتاج و بأقل كلفة.

KEYWORDS

Well performance analysis, Production system analysis, IPR, Vertical multi-phase flow, Horizontal multi-phase flow, Choked flow.

INTRODUCTION

The objective of production system analysis can be summarized as:

- Predict the optimum flow rate for specific reservoir condition.
- Predict the pressure drop in vertical tubing and annulus, and horizontal lines.
- Predict the pressure drop through surface well head chokes.
- Determine the well head pressure and bottom hole pressure for specific well.
- Determine the proper size of tubing, flow line and surface well head chokes.

A basic requirement for well analysis is the ability to define the entire inflow performance relationship (IPR) of the well. Accurate well test data must be obtained and the proper IPR applied for successful analysis. Models for other well components can be used in addition to complete the predicted well performance.

Figure (1) shows the components that make up a detailed flowing well system. Beginning with the reservoir and proceeding to the separator, the components are: reservoir component, tubing string component (pipe and annulus), surface choke component, flow line component.

The Inflow performance relationship (IPR) of wells is an essential part of the information which is required in production well analysis. Several methods have been proposed in the literature to predict the IPR curves of a well. Brown (1984), presented a solution to calculate three-phase flow IPR curves. His method based on the combination of Vogel’s equation for the oil IPR and a constant productivity index for water. Wiggins (1994),developed a generalized equation to predict inflow performance. He used a simulator results to generate IPR curves. His method assumes that each phase can be treated separately. Brown’s method differs from generalized three-phase IPR method of Wiggins because it coupled the water and oil rates.

The use of multiphase flow- pressure drop correlation is very important for developing the vertical and horizontal components of production system. The correlation that are most widely used for vertical multiphase flow were developed by Hagedorn & Brown, Duns & Ros, Aziz & Govier. In the vertical component of production system, the fluids can flow through the annulus between the casing and the production tubing. Therefore, it is necessary to be able to predict the pressure drop in the annulus. Recently, Lage (2000) developed a mechanistic model for upward two-phase flow in vertical and concentric annulus. This model was composed of a procedure for flow pattern prediction and a set of independent mechanistic models for calculating gas friction and pressure drop in each of flow patterns. For the multiphase flow through horizontal flow line there are the correlations of Dukler et al. (1964), Eaton et al. (1967), Beggs and Brill (1973), Makherjee and Brill (1985). Gomez et al. (1999) presented a unified mechanistic model for the prediction of flow pattern, liquid holdup and pressure drop in wellbores and pipelines. This model is applicable to the entire range of inclination angles, from horizontal to upward vertical flow.

Surface choke component is represented by the critical and subcritical flow through chokes. Many correlations for multiphase flow across choke were presented. Fourtunati (1972) presented a first work to be applicable to both critical and sub-critical flow. Ashford and Pierce (1974) developed an equation for sub-critical flow through restrictions. Finally, Perkins (1990) presented a mechanistic model for the multiphase flow through chokes. His flow equations are valid for both critical and subcritical flow.

WELL PERFORMANCE ANALYSIS

Well performance analysis is a combination of various components of oil or gas wells in order to predict flow rates and to optimize the various components in the system.

RESERVOIR COMPONENT

The first component is the reservoir component, which represents by the flow through the porous media and given rise to the concept of inflow performance relationship (IPR). The IPR of an oil well relates the gross liquid well bore production rate to the bottom hole production pressure. Wiggins developed a generalized equation to predict inflow performance relationship (IPR) for three-phase flow.

The generalize IPR equations are:

$$\frac{Q_O}{Q_{O,\max}} = 1 - 0.52\left(\frac{p_{wf}}{p_r}\right) - 0.48\left(\frac{p_{wf}}{p_r}\right)^2 \quad \text{............1}$$

and,

$$\frac{Q_w}{Q_{w,\max}} = 1 - 0.72\left(\frac{p_{wf}}{p_r}\right) - 0.28\left(\frac{p_{wf}}{p_r}\right)^2 \quad \text{............2}$$

p_r = average reservoir pressure.

p_{wf} = flowing bottom-hole pressure.

Q_O = oil production rate.

$Q_{O,\max}$ = maximum oil production rate.

Q_w = water production rate.

$Q_{w,\max}$ = maximum water production rate.

VERTICAL COMPONENT

The vertical component is described by the vertical multi-phase flow in the tubing string, which is divided into two categories: (a) multi-phase through vertical pipes, (b) multi-phase flow through annuli.

In mechanistic model approach, the important variables of multiphase flow are incorporated and then coupled with appropriate laboratory and field data. The characteristic of the existing flow pattern is taken into consideration. The prediction of flow pattern represents the first step of developing mechanistic models. The other step is the development of a pressure drop model for each flow pattern to calculate the liquid holdup and pressure drop.

Many empirical correlations and mechanistic models that have been developed over the years are evaluated in this work. The Duns & Ros, Hagedorn & Brown, Aziz & Govier empirical correlations were compared with unified Gomez mechanistic model for vertical flow in pipes and with Lage mechanistic model for vertical flow in annuli.

<u>A) Multi-phase through vertical pipes (Gomez's Unified Mechanistic Model)</u>

This model has been developed to predict flow pattern, liquid hold up and pressure drop in well bores and pipelines. It is applicable to the whole range of inclination angles from horizontal to upward vertical flow. Therefore, this model can be applied to determine pressure drop in both vertical pipes and horizontal flow lines, with no need to switch among different models. The unified model consists of a unified flow patterns prediction model and separate models for determine pressure drop for the existing flow patterns. The flow patterns prediction model is based on the Barnea model, which is applicable for entire range of inclination angles. Gomez's model presents the transition mechanism for each individual boundary. The transition criteria for each flow pattern is given in the form either equations or map. Figure 2 represents the generalized flow pattern map. The transition criteria for this model, include the stratified to non-stratified, slug to dispersed bubble, annular to slug and bubble to slug flow.

The criterion for stratified to non-stratified transition is given by the following condition:

$$F^2\left[\frac{1}{(1-h_L)^2}\frac{{v_G}^2 dA_L}{A_G dA_G}\right]\geq 1 \qquad \text{.....................} 3$$

Where F is a dimensionless group,

$$F=\sqrt{\frac{\rho_G}{(\rho_L-\rho_G)}}\frac{v_{SG}}{\sqrt{dg\cos\theta}} \qquad \text{...........................} 4$$

The transition from slug to dispersed bubble occurs at high liquid flow rates, where the turbulent forces overcome the interfacial tension forces lead to dispersing the gas phase into small bubble size which can be determined from:

$$d_{\max}=\left[4.15\left(\frac{v_{SG}}{v_m}\right)^{0.5}+0.725\right]\left(\frac{\sigma}{\rho_L}\right)^{0.6}\left(\frac{2f_m{v_m}^2}{d}\right)^{-0.4} \qquad \text{.........................} 5$$

Two critical bubble diameters are considered. First is the critical diameter, below which bubbles do not deform due to agglomeration or coalescence, and this is given by:

$$d_{CD}=2\left[\frac{0.4\sigma}{(\rho_L-\rho_G)}\right]^{0.5} \qquad \text{...............................} 6$$

The other critical diameter is defined as the critical bubble size below which bubbles migrate to the upper part of the pipe and is presented by:

$$d_{CB}=\frac{3}{8}\frac{\rho_L f_m {v_m}^2}{(\rho_L-\rho_G)g\cos\theta} \qquad \text{...........................} 7$$

Therefore, the transition to dispersed bubble flow will occur when ($d_{\max} < d_{CD}$ or d_{CB}).

The bubble to slug transition occurs at low liquid flow rates. Under this condition, the turbulent forces are negligible, and gas void fraction($H_G = 0.25$)is critical. This transition is given by:

$$v_{SL}=\frac{1-H_G}{H_G}v_{SG}-1.53(1-H_G)^{0.5}\left[\frac{g(\rho_L-\rho_G)\sigma}{\rho_L}\right]^{0.25}\sin\theta \qquad \text{......................} 8$$

The condition that is given by equation (8) is satisfied in large-diameter pipes and, only for sharply inclined pipes with inclination angles between (60°) and (90°) and pipe diameter greater than that given by the following condition:

$$d \rangle 19.0096\left[\frac{(\rho_L-\rho_G)\sigma}{{\rho_L}^2 g}\right]^{0.5} \qquad \text{....................} 9$$

The Slug to annular transition is predicted by the critical velocity corresponding to the droplet model used by Taitel et al., as follows:

$$v_{SGcrit} = 3.1\left[\frac{\sigma g \sin\theta(\rho_L - \rho_G)}{\rho_G^{\;2}}\right]^{0.25} \qquad \text{.................... 10}$$

So, the annular flow exist when the superficial gas velocity (v_{SG}) is greater than the v_{SGcrit}.

After predicting the flow pattern, separate models are considered to calculate the pressure drop for the predicted flow pattern. Stratified flow model can be described best with the separate flow. The momentum force balance for the liquid and gas phases in the stratified flow are given respectively by:

$$-A_L\frac{dP}{dL} - \tau_{WL}S_L + \tau_I S_I + \rho_L A_L \sin\theta = 0 \qquad \text{.....................11}$$

$$-A_g\frac{dP}{dL} - \tau_{WG}S_G - \tau_I S_I + \rho_G A_G \sin\theta = 0 \qquad \text{.....................12}$$

Equating pressure drop in the two phases, the combination momentum equation for the two phase is obtained as follows:

$$\tau_{WL}\frac{S_L}{A_L} - \tau_{WG}\frac{S_G}{A_G} - \tau_I S_I\left(\frac{1}{A_L} + \frac{1}{A_G}\right) + (\rho_L - \rho_G)g\sin\theta = 0 \qquad \text{.............13}$$

For the slug flow pattern, average pressure gradient could be calculated from the following equation:

$$\frac{dp}{dL} = \rho_U g\sin\theta + \frac{\tau_S \pi d}{A}\frac{L_S}{L_U} + \frac{\tau_{WF}s_F + \tau_{WG}s_G}{A}\frac{L_f}{L_U} \qquad \text{................ 14}$$

The annular flow model equations are similar to stratified flow model ones, but with different geometrical configuration and the fact that the gas core in annular flow includes liquid entrainment. Momentum balance on the liquid film and the gas core are given respectively, by:

$$-\tau_{WF}\frac{S_f}{A_f} + \tau_I\frac{S_I}{A_f} - \left[\frac{dp}{dL}\right]_f - \rho_L g\sin\theta = 0 \qquad \text{.................... 15}$$

$$-\tau_I\frac{S_I}{A_C} - \left[\frac{dp}{dL}\right]_C - \rho_C g\sin\theta = 0 \qquad \text{.................... 16}$$

For the vertical flow in pipes, the bottom hole pressure calculated with the Duns & Ros, Hagedorn & Brown, Aziz & Govier correlations and with the unified mechanistic model of Gomez are compared with the measured bottom hole pressures from (50) well tests data. On the basis of the lowest absolute average percent difference and standard deviation, Duns & Ros, Aziz et. al correlation and Gomez mechanistic model are in close agreement with the measurements. In present study, Gomez mechanistic model is used to calculate the pressure losses in the vertical pipe. The values of calculated and measured bottom hole pressures are shown in fig.3 and fig 4.

B) Multi-phase through annuli (Lage's Mechanistic Model)

This model is formulated to predict the mixture behavior for upward two-phase flow in concentric annulus. The model consists of two sections; the first is a procedure for flow pattern prediction. The second section is a set of models for calculating pressure drop in each of selected flow patterns. The framework developed by Tiatel et al. (1980) is the basis for the definition of the transition criteria. Four different flow patterns were considered in the model. These flow patterns are bubble, dispersed bubble, slug and annular.

A concentric annuals needs the following geometrical parameters for definition of the properties related to fluid mechanics:

$$K = \frac{d_1}{d_2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 17$$

$$d_h = d_2 - d_1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 18$$

$$d_{ep} = d_2 - d_1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 19$$

Where:

d_1 =outside diameter of inner pipe.

d_2 = inside diameter of the outer pipe.

d_{ep} = equi-periphery diameter.

The model suggested the following equation to predict the bubble-slug transition:

$$d_{ep} \geq 19.7\left[\frac{(\rho_L - \rho_G)\sigma}{g\rho_L^{\,2}}\right]^{0.5} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 20$$

If the annulus presents an equi-periphery diameter greater than d_{ep}, the coalescence of small gas bubbles into the large Taylor bubbles is the basic transition mechanism from bubble to slug flow. The boundary between bubble and slug flow is represented by transition A in fig.5 and given by the following equation:

$$v_{SL} = \frac{1 - H_G}{H_G} v_{SG} - (1 - H_G) v_O \qquad \ldots\ldots\ldots\ldots\ldots 21$$

Dispersed bubble transition is shown in fig.5 as transition B and represented by the equation:

$$2\left[\frac{0.4\sigma}{(\rho_L - \rho_G)g}\right]^{0.5}\left(\frac{\rho_L}{\sigma}\right)^{0.6}\left(\frac{2f_m}{d_H}\right)^{0.4} v_m^{1.2} = 0.725 + 4.15\left(\frac{v_{SG}}{v_m}\right)^{0.5} \qquad \ldots\ldots \quad 22$$

The transition criterion to annular flow is based on the following equation and represented by transition D in figure 5.

$$v_{SG} = 3.1\left[\frac{(\rho_L - \rho_G)g\sigma}{\rho_G^{\,2}}\right]^{0.25} \qquad \ldots\ldots\ldots\ldots\ldots 23$$

The second section of Lage's Mechanistic Model is a set of models for calculating pressure drop in each of selected flow patterns. The total two-phase pressure gradient in bubble flow pattern consists of three components which are given by:

$$\left(\frac{dp}{dL}\right)_T = \left(\frac{dp}{dL}\right)_H + \left(\frac{dp}{dL}\right)_f + \left(\frac{dp}{dL}\right)_A \qquad \ldots\ldots\ldots\ldots\ldots 24$$

The hydrostatic pressure gradient is given by:

$$\left(\frac{dp}{dL}\right)_H = \rho_m g \sin\theta \qquad \ldots\ldots\ldots\ldots\ldots\ldots 25$$

The friction component is given by:

$$\left(\frac{dp}{dL}\right)_f = \frac{2f}{d_h}\rho_m v_m^{\;2} \qquad \text{……………………… 26}$$

Where the fanning friction factor f is a function of Reynolds number defined by:

$$\mathrm{Re} = \frac{\rho_m v_m d_h}{\mu_m} \qquad \text{…………………. 27}$$

Bubble flow is dominated by a relatively incompressible liquid phase. Consequently, the changes in the density of the flowing mixture are not very significant. It keeps the velocities nearly constant, resulting in negligible acceleration pressure. This flow pattern has been treated as a homogenous flow. Therefor, the in-situ liquid and gas velocities are equal $(v_G = v_L)$ and the gas fraction is determined as follows:

$$H_G = \frac{v_{SG}}{v_m} \qquad \text{…………………. 28}$$

The main flow parameters can be calculated using equations (24) to (27) and based on the value of H_G.

The total pressure gradient in the slug flow pattern is calculated depending on following components:
The hydrostatic pressure gradient for the slug unit is given by:

$$\left(\frac{dp}{dL}\right)_H = \rho_m g \frac{L_{LS}}{L_{SU}} \qquad \text{……………...…… 29}$$

Where $\rho_m = \rho_G H_{GLS} + \rho_L (1 - H_{GLS})$

The friction pressure drop gradient is given by:

$$\left(\frac{dp}{dL}\right)_f = \frac{2f}{d_h}\rho_m v_m^2 \frac{L_{LS}}{L_{SU}} \qquad \text{………………….. 30}$$

The acceleration pressure gradient is given by:

$$\left(\frac{dp}{dL}\right)_A = \frac{(1 - H_{GLS})}{L_{SU}}\rho_L (v_{LLS} - v_f)(v_{TB} - v_{LLS}) \qquad \text{…………….. 31}$$

For the annular flow pattern, the total pressure gradient is calculated by the following equations:

$$\frac{dp}{dL} = [H_G \rho_G + (1 - H_G)]g + \left(-\frac{dp}{dL}\right)_f \qquad \text{……………… 32}$$

Where: $\left(-\frac{dp}{dL}\right)_f$ represents the frictional losses.

$$-\left(\frac{dp}{dL}\right)_f = \frac{2f}{d_h}\rho_L \bar{v}^{2} \qquad \text{…………….... 33}$$

Where f is fanning friction factor expressed as:

$$f = 0.0380\,\mathrm{Re}^{-0.18} \qquad \text{…………….... 34}$$

Where: $\bar{v}$ is the single-phase velocity that corresponds to the liquid film flow condition.

For the multi-phase flow through annulus the bottom hole pressures are calculated using Duns & Ros, Hagedorn & Brown, Aziz & Govier correlations by substitution of hydraulic diameter (d_h) for diameter, and also calculated by Lage's mechanistic model for vertical flow in annuli. The calculated bottom hole pressure by all these methods are compared with the measured bottom hole pressure for (40) data points. All methods gave good agreement with measured data and the Lage mechanistic model gave the best one on the basis of the lowest absolute average percent difference and standard deviation. The calculated and measured values for lage's mechanistic model and Duns& Ros correlation are shown in fig.6 and fig.7 respectively.

HORIZONTAL COMPONENT

In order to select the best method to calculate the pressure drops through flow lines, the pressure calculations are carried out with Beggs&Brill, Eaton(H_L), Dukler(F_f), Mukherjee-Brill(H_L) and Beggs-Brill(F_f) correlations in addition to Gomez mechanistic model. Previous correlations have been evaluated using (55) well tests data. The statistical results indicate that all previous correlations are in close agreement with measured data but Gomez mechanistic model have shown smallest absolute average percent difference and standard deviation. Accordingly, Gomez model is chosen as the best one to calculate the pressure drop in horizontal flow lines. The calculated and measured values for Gomez mechanistic model gives the best results as shown in fig.8.

CHOKE COMPONENT

The pressure loss calculations through chokes involve two types of flow, critical and sub-critical flow. In the critical flow, the flow rate through the choke is independent of the downstream pressure when the upstream pressure is held constant. Thus the discontinuity occurs at the critical-subcritical flow boundary. The surface choke component would have to be applicable to all flow conditions both critical and sub critical. One of the few correlations, which attempt for modeling both critical and subcritical flow is the Perkins mechanistic model. To evaluate the multiphase flow through choke, the downstream pressure of (67) available subcritical data points is calculated using the correlation of Ashford & Pierce, Fortunati and the mechanistic model of Perkins. The statistical results show that the Perkins mechanistic model have smallest value of absolute percent difference and standard deviation compared with the two correlations. So that the Perkins mechanistic model is more suitable to be used in this study. Perkins mechanistic model shows good agreement with measured data and with other correlations as shown in fig.9.

COMPUTER PROGRAM OF WELL PERFORMANCE ANALYSIS

In order to analyze the total-production system, a computer program is developed which links the inflow performance relationship, vertical multiphase flow calculations, choke performance calculations and flow line calculations. Every component of the production system is programmed individually and then linked together in order to determine the pressure losses in every component and the optimum production system design for a given set of reservoir conditions and surface facility constraints.

The computer program consists of a main program which analyze the flowing well production system starting with the reservoir pressure conditions and working through the reservoir, upward through the tubing or the annulus, surface choke, flow line and finally to the separator. Various subroutines for calculating the physical fluid properties, vertical flow, horizontal flow and surface choke calculation have been developed. The physical properties correlations which are used in the computer program are listed in table 1.

EXAMPLE PROBLEM

In order to explain the application of production system analysis, results are presented for an example problem of an oil field. The example well data is presented as follows:

Initial Reservoir Pressure = 2973 Psi
Well Depth = 6560 ft
Flow Line Length = 11480 ft
Water Cut = 0%
Oil API Gravity = 18.6° API
Specific Gravity of Gas = 0.8112
Gas Oil Ratio = 525 Scf/STB
Separator Pressure = 415 Psi
Separator Temperature = 85 °F
Productivity Index = 11.9 bbl/D/Psi
Well Head Temperature = 90 °F
Bottom Hole Temperature = 150 °F
Bubble Point Pressure = 2300 Psi
Pipe Roughness = 0.0001 ft

SELECTION OF THE OPTIMUM COMBINATION OF TUBING SIZE AND FLOW LINE SIZE:

The selection of tubing size and flow line size is very important in the oil field production design. In oil wells, the pressure loss through the tubing can constitute the majority of pressure loss through the entire system. If the tubing size is undersized in well, friction loss will become excessive. If the tubing size is too large, additional pressure loss will be encountered due to liquid loading. Assume that the available flow line sizes are in the range of (2.5 to 7 inch) inside diameters and the tubing sizes are in range of (2.5 to 7 in). The large diameter of tubing size is taken when the production is from the casing. Fig.10 shows the tubing and the flow line combinations for the given data in the example. The intersection of the flow line curve and the tubing curve represent the possible flow rate for the given combination. Possible production for various tubing and flow line size combination are given in table 2. If it is desired to produce the well at 4000 STB/D as shown in Fig.10 and Fig.11, all intersections of flow line and tubing plots to the right of the vertical line through 4000 STB/D will produce the well satisfactory. The most economical combination or the optimum combination is 4-inch tubing and 5inch flow line.

SELECTION OF THE SURFACE CHOKE SIZE:

In some cases in the oil field it may be desirable to restrict the flow rate at the surface to obtain liquid production with a lower gas oil ratio. This restriction may be done by installing a surface choke on the well head. Suppose in the above example the choke sizes are varied from 32/64 inch to 144/64 inch. The results are shown in Fig.12. Fig.13 and table 3 present the effect of 3in and 4in tubing sizes for choke flow and 5 inch flow line. Fig.13 indicates that for a given wellhead pressure the flow rate through 4 inch tubing becomes significantly greater than the flow rate through the 3 inch tubing. If it desired to choke the flow rate to 3000 STB/D, then from fig.12 the required surface choke size is 48/64 inch.

CONCLUSIONS

1. Based on the available well tests data, the statistical evaluation for the pressure calculation methods for every component of production system are as follows:
   a. For the vertical flow through pipes, the evaluation of pressure loss prediction correlations and mechanistic model shows that the best correlation are the Duns & Ros correlation and Gomez mechanistic model for the data available.
   b. The evaluation of multiphase flow correlations for calculation of the pressure loss through annuals shows that the best correlations are Duns& Ros correlation and the mechanistic model of Lage.
   c. For the multiphase flow through horizontal flow lines, the evaluation of pressure loss prediction correlations and mechanistic model show that the Gomez mechanistic model gives the best results.
   d. Perkins mechanistic model for the critical and subcritical flow through chokes shows good agreement with measured data and with other correlations.

2. Flowing well performance can be greatly improved by optimum selection of tubing, flow line and well head choke size using the developed model.

REFRENCES

-Ashford, F. E., and Pierce, P. E.: (1974). " The Determination of Multiphase Pressure Drops and Flow Capacities in Down Safety Valves (Storm chokes), SPE 5161, Presented at Annual Full Meeting, Houston, Texas, Oct. Aziz, K., Govier C.W. and Fogarasi, M. "Pressure Drop in Wells Producing Oil and Gas, "J. can. Pet., July-Sept. (1972), 38-48.

Baker, D. and Swedloff, W.O., "Finding Surface Tension of Hydrocarbon Liquids," Oil and Gas J., (Jan., 1956).

Barnea, D.: "A Unified Model for Prediction Flow Pattern Transition for the Whole Range of Pipe Inclinations," Int. J. of Multiphase Flow, (1987), 1-12.

Beggs, H. D. and Brill, J. P.: "A Study of Two-Phase Flow in Inclined Pipes," J. Pet. Tech., May (1973), 607-617.

Beggs, H.D., and Robinson, J.F., "Estimating the Viscosity of Crude Oil Systems," JPT (Sept. 1975).

Brill, J.P., and Beggs, H.D., "Two-Phase Flow in Pipes" U. of Tulsa, 1975.

Brown, K. E.: "The Technology of Artificial Lift Methods", Vol. 4 Penn well published Co., Tulsa, OK (1984).

Dukler, A. E., Wichs, and Cleveland, R. G.: "Frictional Pressure Drop in Two-Phase Flow: A Comparison of Existing Correlations for Pressure Loss and Holdup. B, An Approach Through Similarity Analysis, " AIchE J., Jan. (1964),38

Duns, H. Jr. and Ros, N.C. j.: "Vertical Flow of Gas and Liquid Mixture in Wells," (1963), Proc., 6th World Pet. Congress.

Eaton, B. A., et al.: "The prediction of Flow Patterns, Liquid Holdup and Pressure Loss Occurring during Continuous Two-Phase Flow in Horizontal Pipelines, " JPT, Jun, (1967), 815.

Fortunati, F.: "Two-Phase Flow Through Wellhead Chokes," SPE 3742, Presented at SPE European Spring Meeting, Amsterdam, May (1972).

Gomez, L. E. et al.: "A Unified Mechanistic Model for Steady-State Two-Phase Flow in Well bores and Pipelines," SPE 56520, Presented at the SPE Annual Technical Conference and Exhibition held in Houston, Texas, Oct. (1999).

Gould, T.L., "Vertical Two-Phase Steam-Water Flow in Geothermal Wells," AIME, (1974).
Hagedron, A.R. and Brown, K.E.: "Experimental Study of Pressure Gradients Occurring During Continuos Two-Phase Flow in Small Diameter Vertical Conditions," J. Pet. Tech., April (1965), 475-484.
Hough, E.W., et. al., "Interfacial Tensions at Reservoir Pressure and Temperatures, Apparatus and Water-Methane Systems," AIME (1951).
Lage, A. C. And R. W. Time "Mechanistic Model for Upward Two-Phase Flow in Annuli" SPE 63127 presented at 2000 SPE Annual Technical Conference and Exhibition Held in Dallas, 1-4 October 2000.
Lee, A.L., et. al., "The Viscosity of Natural Gases," Trans. AIME (1966), 997.
Mukherjee, H. and Brill, J.: "Pressure Drop Correlations for Inclined Two-Phase Flow," J. Energy Res. Tech., December (1985).
Perkins, T. K. "Critical and Subcritical Flow of Multiphase Mixtures through Chokes" SPE 20633, Presented at the 65 th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers Held in New Orleans, Sep. 23-26 (1990).
Standing, M.B., and Katz, D.L. "Density of Natural Gases," Trans. AIME (1942), 146.
Taitel, Y. et al.: "Modeling Flow Pattern Transition for Steady Upward Gas-Liquid Flow in Vertical Tubes," AICHE J. May (1980), 345-354.
Vasquez, M.E. "Correlations for Fluid Physical Property Prediction," M.S. Thesis, U. of Tulsa (1976)
Wiggins, M. L., Russel, J. E., and Jennings, J.W.: "Analytical Inflow Performance Relationships for Three phase flow," SPE, August (1994).

NOMENCLATURE

English Symbols

A: Area, ft^2
d: Diameter, ft
F: Dimensionless group
F_W: Water cut
f: Friction factor
H_g: Gas fraction
H_L: Liquid hold up
L : Length, ft
P: Pressure, Psi
Q: Flow rate, STB/D
Re : Reynolds number
S: Perimeter ft
v: Velocity ft/sec

Greek Symbols

δ: Film thickness ft
μ: Viscosity lbm/ft.s
φ: Annular entrainment parameter
θ: Inclination angle
ρ: Density lbm/ft3
τ: Shear stress lbf/ft2
σ: Surface tension lbf/ft

<u>Subscript Symbols</u>

CB: Critical bouyncy
CD: Critical diameter
Ep: Equi-periphery
f: film
ft: Film terminal
G: Gas
GLS: Gas in the liquid slug
h: Hydraulic
L: Liquid
Ls: Liquid slug
LLS: Liquid in the liquid slug
LTB: Liquid in the Taylor bubble
S: Slug body
Sg: Superficial gas
SL: Superficial liquid

Table (1)

Fluid Physical Properties Which are Used in Computer Program

Fluid physical Property	Correlations
Gas Compressibility Factor, Z factor	Standing & Katz
Bubble Point Pressure, Pb	Vasquez & Beggs
Solution Gas Oil Ratio, Rs	Vasquez & Beggs
Oil Formation Volume Factor, Bo	Vasquez & Beggs
Water Formation Volume Factor, Bw	Gould
Oil Viscosity Below Pb	Beggs & Robinson
Oil Viscosity Above Pb	Vasquez & Beggs
Water Viscosity	Brill & Beggs
Gas Viscosity	Lee et al.
Gas-Oil Surface Tension	Baker-Swerdloff
Water- Gas Surface Tension	Hough-Rzasa

Table (2)
Possible Production Rates for Various Tubing and Flow lines Combinations

Flow Line Sizes	Tubing Sizes						
	2.5	3	3.5	4	4.5	5	6
2.5	770	–	–	–	–	–	–
3	1250	1380	–	–	–	–	–
3.5	1710	2000	2190	–	–	–	–
4	2095	2560	2780	2960	–	–	–
4.5	2380	2950	3280	3575	3700	–	–
5	2610	3300	3700	4080	4275	4350	–
6	2930	3785	4390	4820	5165	5350	5450
7	3100	4060	4810	5330	5780	6050	6270

Table(3)
Possible Choked Flow Rate

Choke Size, 1/64 inch	Tubing Size, inch	
	3	4
32/64	1625	1850
48/64	2525	3000
64/64	3030	3600
80/64	3150	3800
96/64	3230	3890
144/64	3275	3950

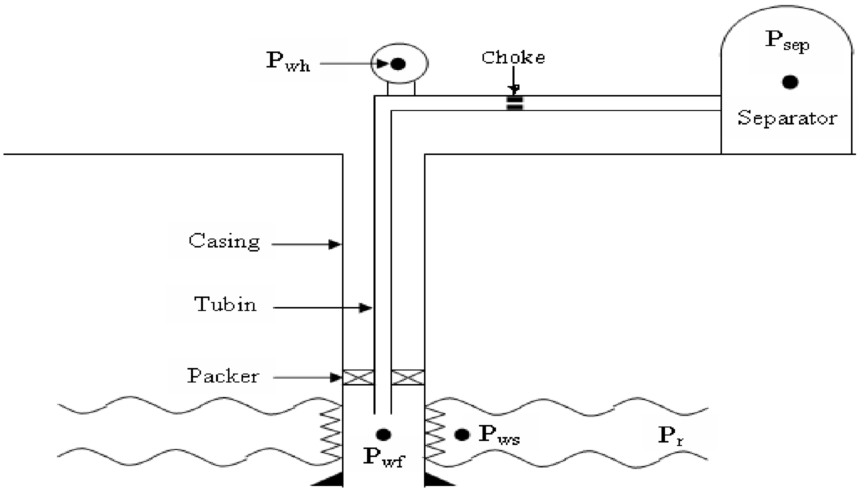


Fig .(1). Graphical Representation of a Production System

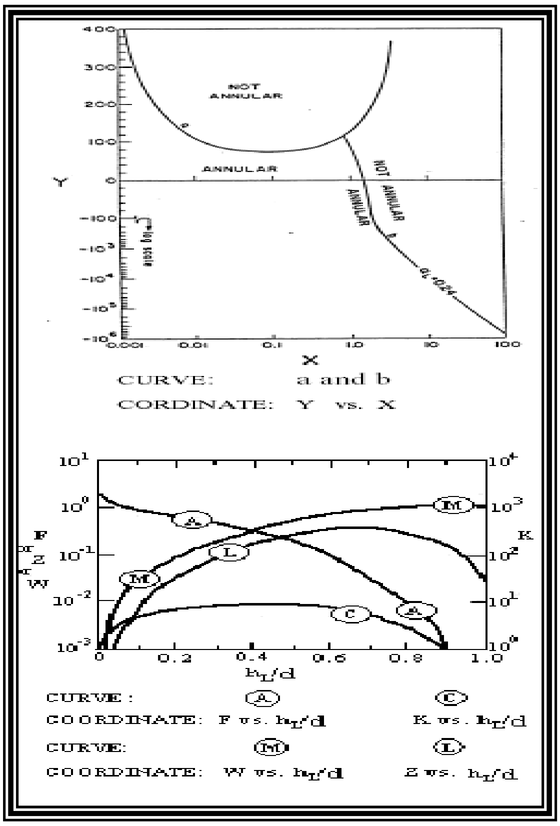


Fig.2 unified Flow Pattern Map (Barnea, 1987)

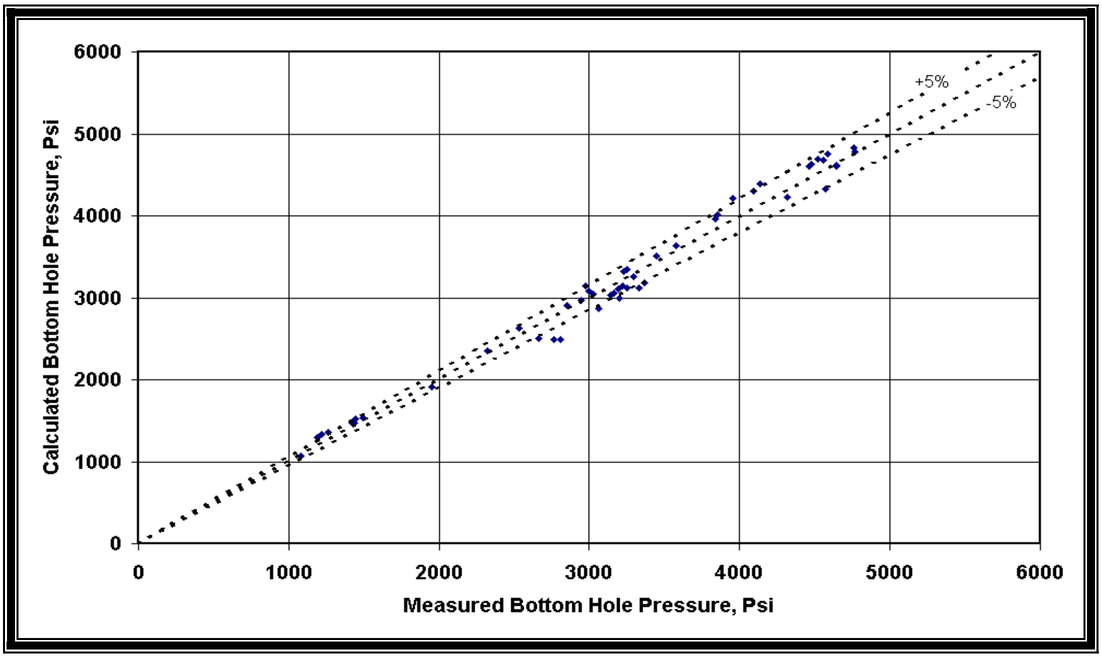


Fig.3 Calculated vs. Measured Pressure Drop in Vertical Multiphase Flow through Pipe Using Gomez Mechanistic Model.

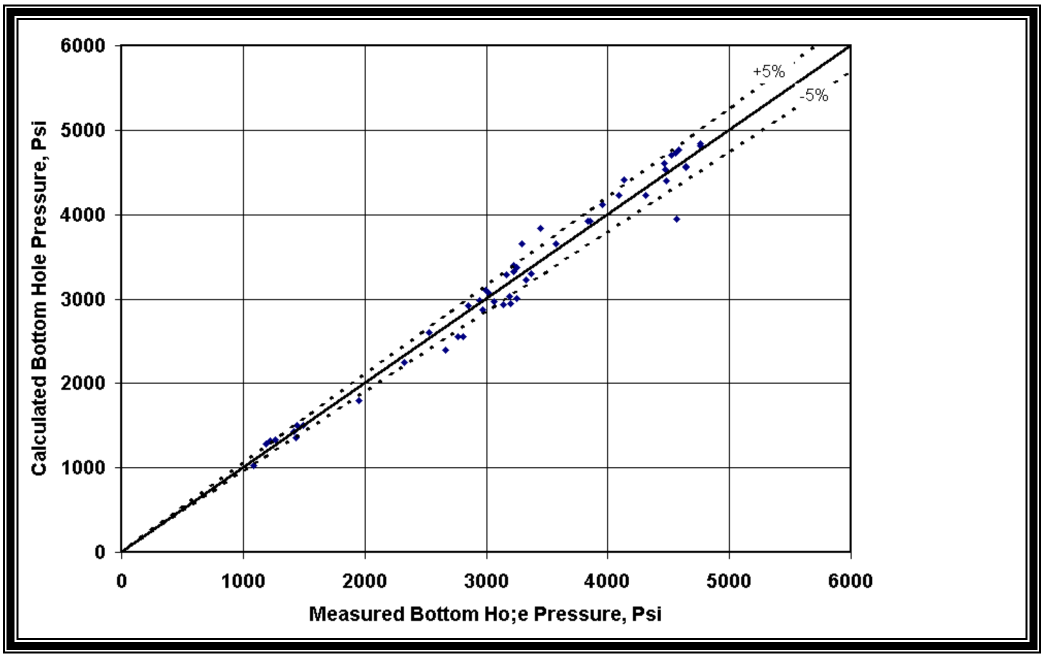
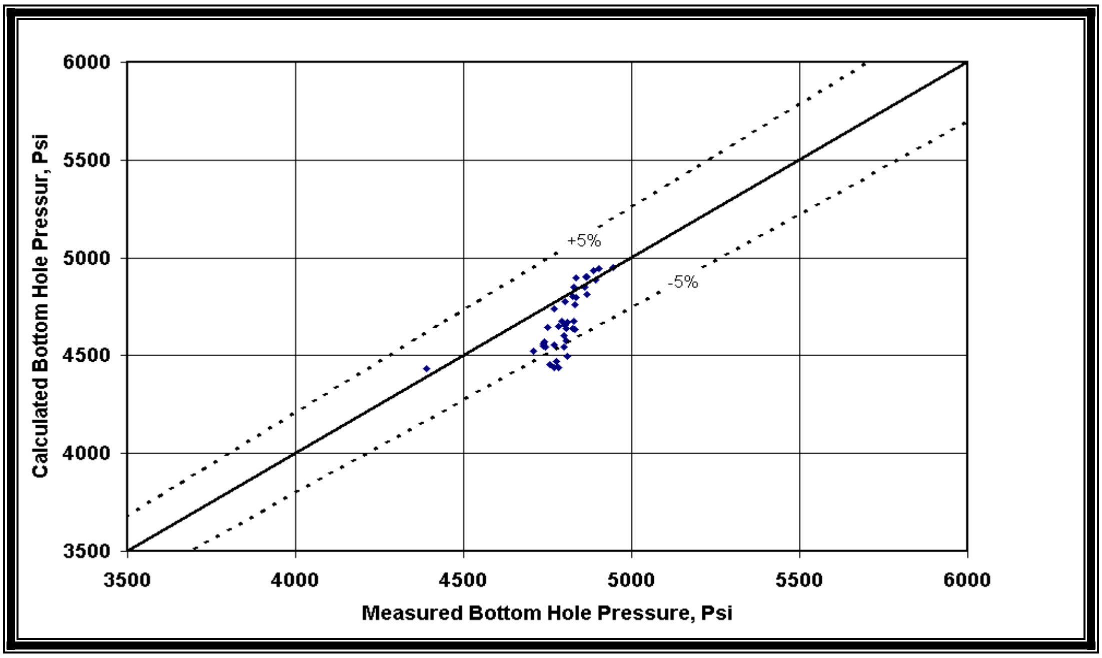
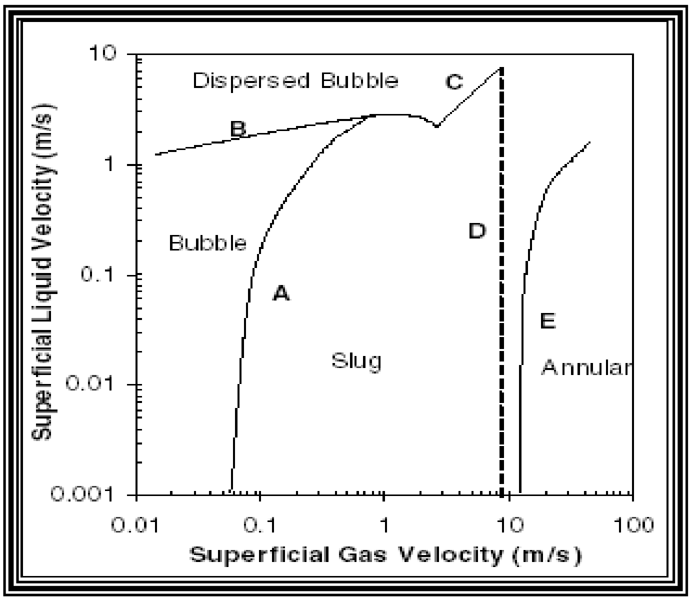


Fig.4 Calculated vs. Measured Pressure Drop in Vertical Multiphase Flow through Pipe Using Duns&Ros Correlation.

Fig.(5) Flow Pattern Map (Lage)



Fig(6) Calculated vs. Measured Bottom Hole Pressure in Vertical Multiphase Flow through annulus Using Lage Mechanistic Model.



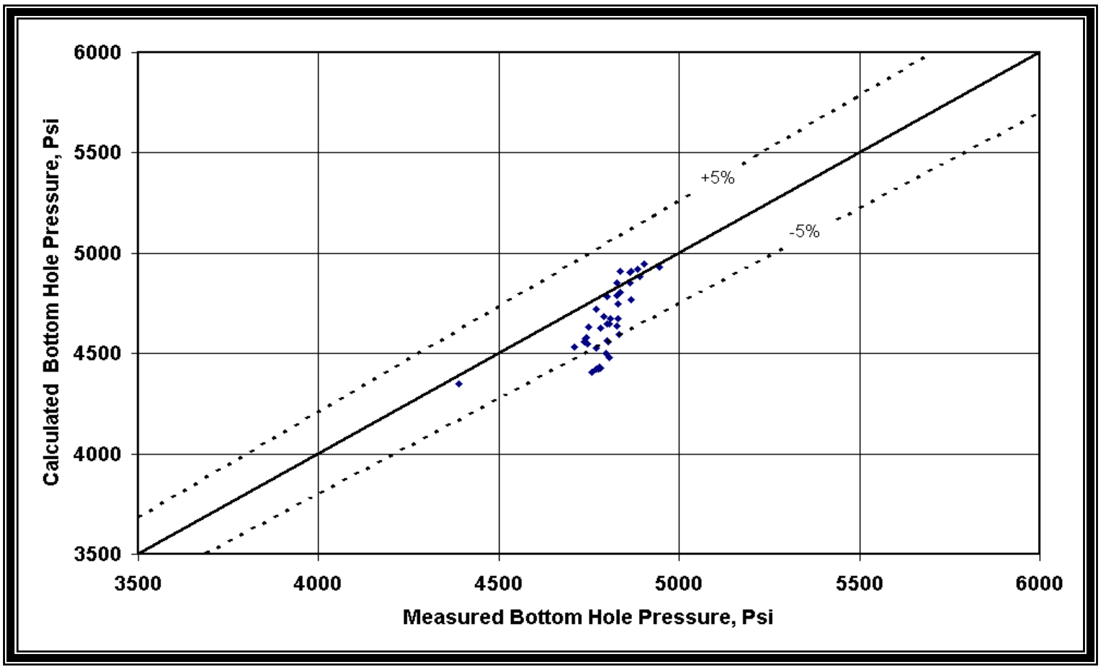
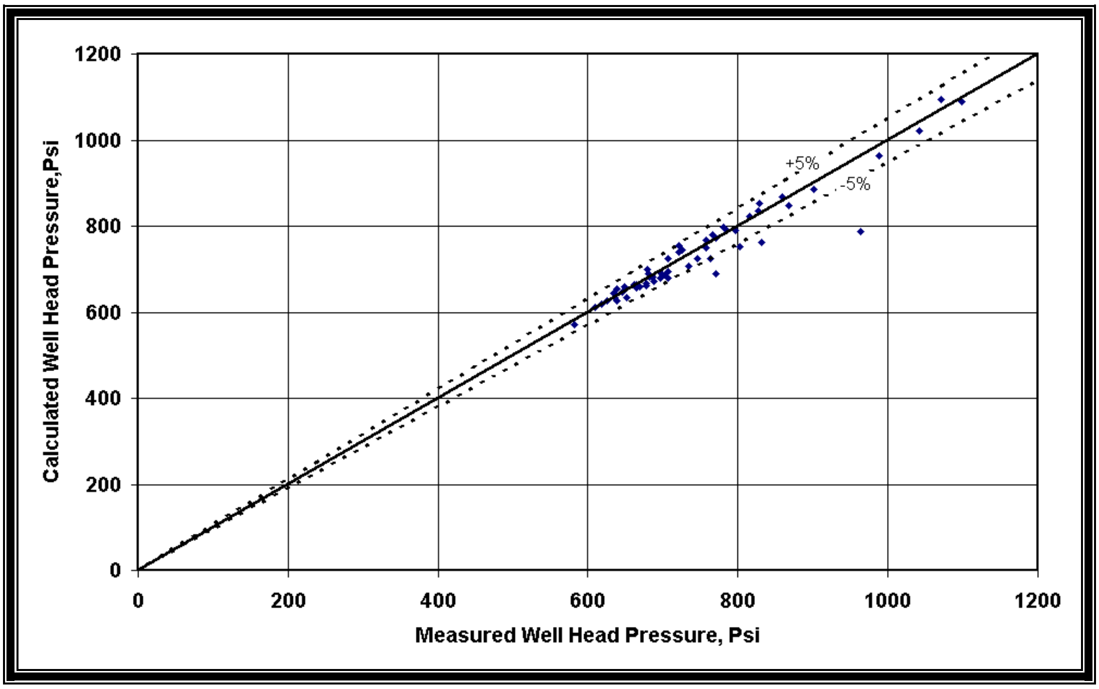


Fig.(7) Calculated vs. Measured Bottom Hole Pressure in Vertical Multiphase Flow Through annulus Using Duns&Ros Correlation.



Fig(.8) Calculated vs. Measured Well Head Pressure in Horizontal Multiphase Flow Using Gomez Mechanistic Model.

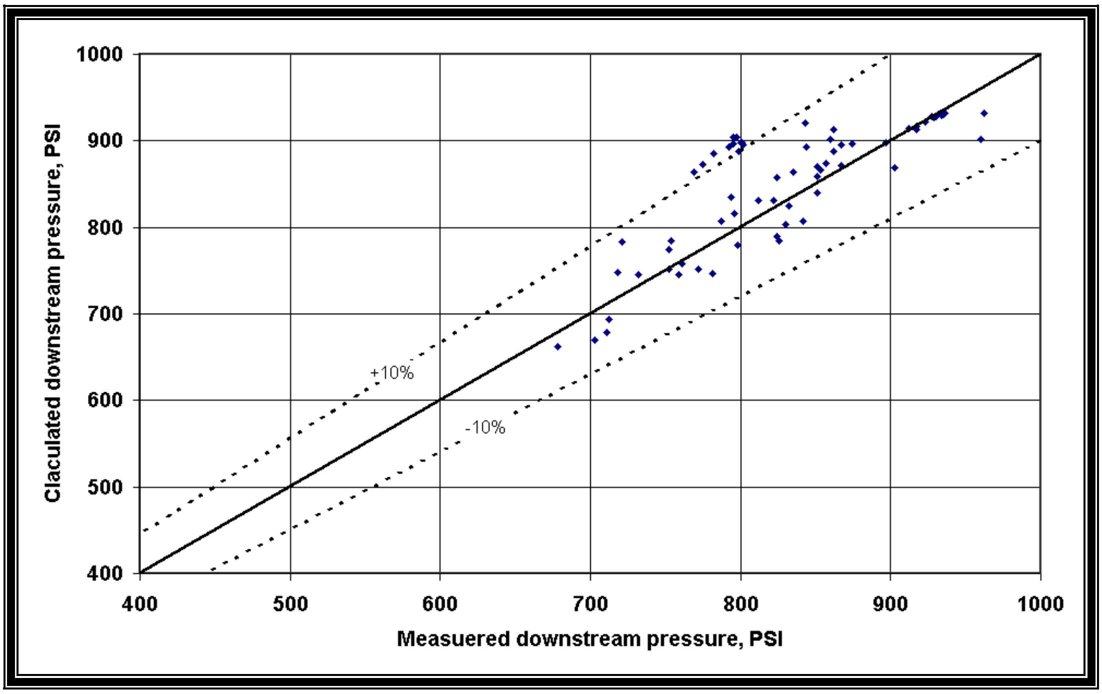


Fig.(9) Calculated vs. Measured Downstream Pressure in Choke Using Perkins Model.

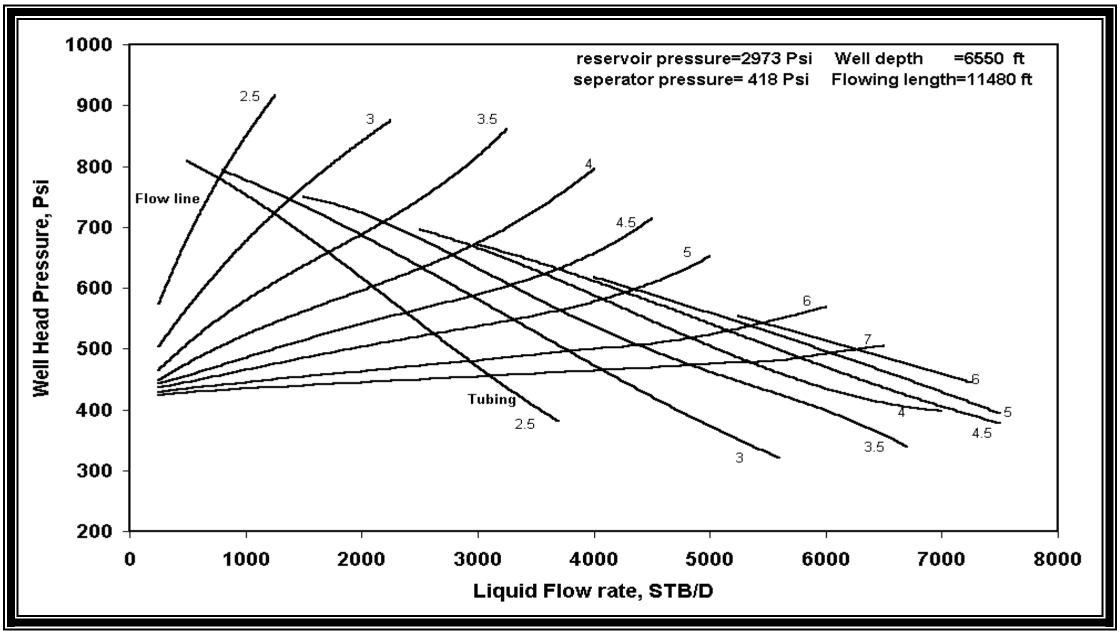


Fig.(10) Analysis Chart of Tubing and Flow Line Combinations.

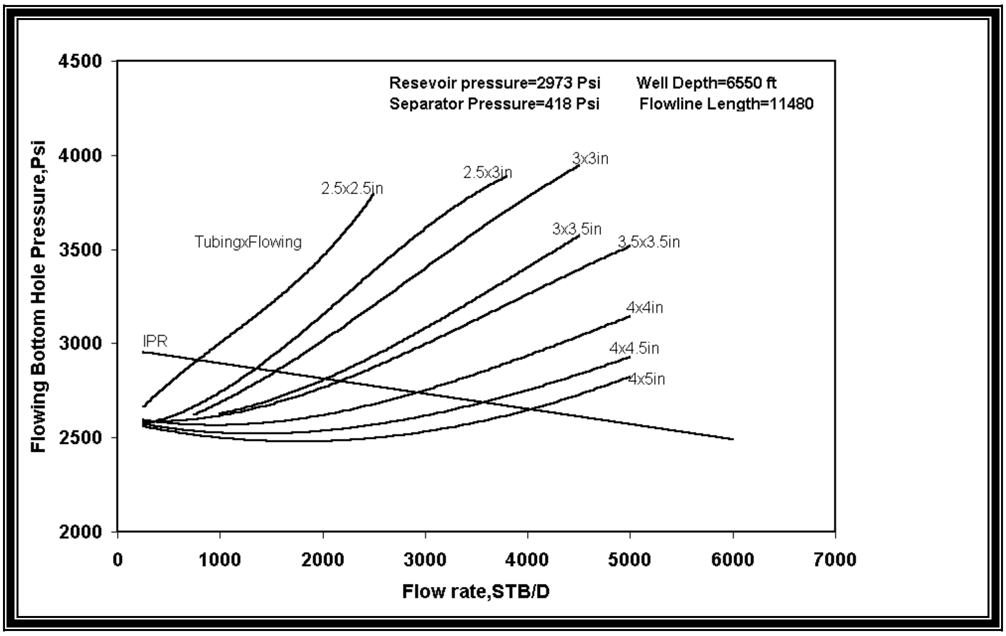


Fig.(11) Effect of Various Tubing and Flow Line Sizes Combinations.

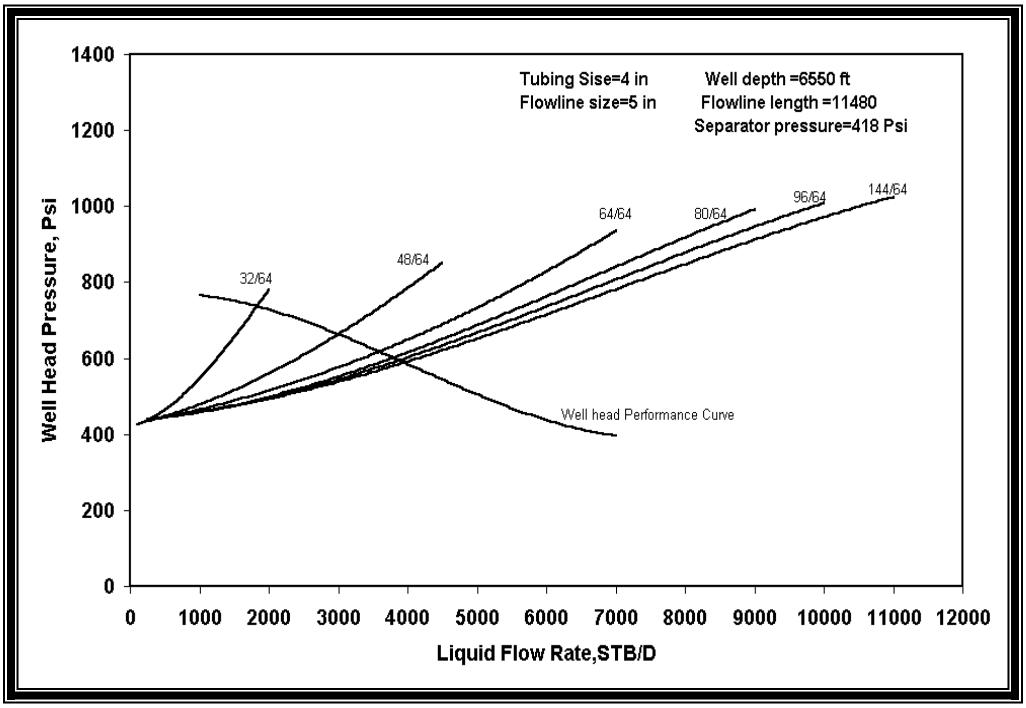


Fig.(12) Well Head Choke Performance Analysis

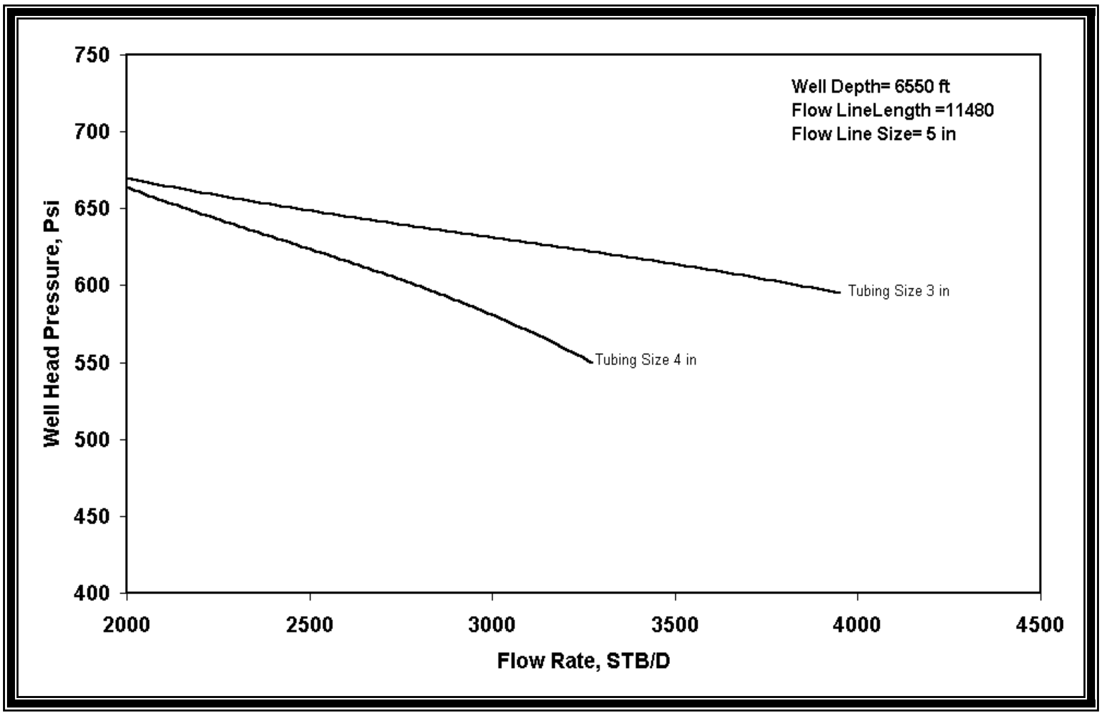


Fig.(13) Effect of tubing Size on Choked Flow Rate