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COMBINE GAS DELIVERABILITY EQUATION FOR RESERVOIR AND WELL

HASSAN DAFFALLA ELJACK

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PETROLEUM AND NATURAL GAS ENGINEERING

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WEST VIRGINIA UNIVERSITY
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ABSTRACT

COMBINE GAS DELIVERABILITY EQUATION FOR RESERVOIR AND WELL

HASSAN DAFFALLA ELJACK

A new model has been developed by combining the gas reservoir deliverability equation for a reservoir and the well flow equation.

An existing computer program was modified to determine gas production from reservoir against constant wellhead pressure.

Upon completion, a unique, simple, and user friendly model was developed, that will allow the user to predict the performance of the gas reservoir against a constant wellhead pressure.

The new model was used to generate and introduce a new set of production decline type curves, which can be utilized to forecast gas production rates under constant wellhead pressure condition.

The impact of the well tubing length and tubing size on the shape of the type curves were studied.

ACKNOWLEDGEMENTS

All Praise be to Allah, Cherisher and Sustainer of Worlds, who brought me to this world and bestowed me with life and health to complete this work. I would like to express my indebtedness and gratefulness to my academic advisor and Professor, Dr. Kashy Aminian, for his sustenance and unconditional inexhaustible supervision during my graduate program. Your support, proficient espousal, and belief always piloted my profession and made achievable what was perceived as a distant dream.

I would also like to thank Professor Sam Ameri, and Dr. Razi Gaskari for their constant encouragement and motivation during my stay at West Virginia University. I also appreciate their participation and enthusiasm to be part of my committee.

I dedicate my work to my Parents, My Brothers and Sisters, for their continuous prayer, patience and encouragement. I especially dedicate this work to two great women: my mother (Zakia) who represents the best inspiration in my life. It is like a dream coming true to achieve this degree, her unique ways of encouragement always filled my heart with joy and enthusiasm to progress ahead in life and I feel fortunate to be the special one; and also to my great and lovely wife (Zahra) for her sacrifices of her health and time to provide me with a suitable environment; her patience and encouragement was the drive for me. Thank you my mother and my wife for your entire noble up bringing and self-sacrificing love, guidance, support and encouragement that helped me with years to survive this harsh phase of life.

Finally, I dedicate this work to my kids: Manar, Mohammed and Moaiad whose smiles are the hope and whose laughs are the bright future.

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NOMENCLATURE

a= *Non*- Darcy flow coefficient, psi^2/(cp)(Mscf/D)^2.

B_g = Gas formation volume factor, RB/scf.

C = Back-pressure curve coefficient, Mst/D/psi^n.

C_A =Reservoir shape factor, dimensionless.

C_g =Gas compressibility, psi-1.

D =Decline rate, day-1.

F_{NDi} = Non-Darcy flow ratio, dimensionless.

F_{atD} =pseudo time ratio, dimensionless.

G_D =Dimensionless cumulative production.

G_i = Initial gas in place, Bcf.

G_p =Gas produced, Mscf.

h = Formation thickness, ft.

k = Absolute permeability, md.

n = Exponent of back-pressure curve, dimensionless.

P= Pressure, psia.

P_i = Initial Reservoir Pressure, psia.

Pp= Pseudo pressure, psi2/cp.

P_r = Average reservoir pressure, psia.

P_{sc} = Reservoir pressure at the standard condition, psia.

P_{tf} = wellhead pressure, psia.

P_{ts} = Shut-in pressure, psia.

P_{wf} = Bottom-hole flowing pressure, psia.

q = Flow rate, MscfD.

q_D = Dimensionless flow rate.

q_i = Initial surface gas flow rate at t=0, Mscf/D.

q_t = Gas flow rate at time t, Mscf/D.

r_e = Reservoir outer radius, ft.

r_w = Well bore radius, ft.

S = Skin factor

sc = Standard Condition.

T = Reservoir temperature, R

t_D = Dimensionless time.

t_N = Normalized time.

X_i = Dimensionless parameters.

φ = porosity, fraction.

μ_g = gas viscosity, cp.

λ = Draw-down parameter.

β = turbulence factor, 1/ft.

CHAPTER 1

INTRODUCTION

Estimation of hydrocarbon-in-place and the forecast of the gas reservoirs production are needed to determine the economic viability of the project development as well as to book reserves required by regulatory agencies. During the last 70 years, various methods have been developed and published in the literature for estimating reserves. These methods range from the basic material balance methods to decline type curve analysis techniques. They have varying limitations and are based on analytical solutions, graphical solutions. Examples of these include Arp’s decline equations, Fetkovich’s decline curves, Carter’s gas type curves, and Palacio and Blasingame`s gas equivalent decline curves. Most recently, other papers on type curves analysis, have appeared in the SPE literatures; all that reflect the important role of this area of study.

1.1 Production Type Curves:

The production type curves, which are plots of theoretical solutions to flow equations , are employed, in the absence of complete reservoir data, to predict the future production rates based on past production data. The idea of using the log-log type curves for matching and interpreting production data was first proposed by Fetkovich (1980), however, has had widespread application to analyze the pressure transient data for many years prior to that.

Fundamentally, production decline type curve is a log – log plot of a family of production type curves with dimensionless flow rate (q_D) on ordinates and dimensionless time (t_D) on abscissa.

The different curves of a family are distinguished from one another by a specific parameter. Several sets of production decline type curves have been published in past literature. Most of these type curves have bean developed based on a simplifying assumption which limits their application. There are several suggested modifications which have provided some other improvements for gas well production decline analysis. However, the modifications involve the use of new parameters which are difficult to evaluate and as a result complicate the matching process. One of the most important limitations of the previous work and development of decline type curves, is that; they were based mainly on the assumption of a constant flowing bottom hole pressure. But, from practical view, this assumption is violated; since most gas wells are produce under constant wellhead pressure and different flowing bottom hole pressures condition.

The objective of this research was to develop a set of type curves that combine formation deliverability and gas well flow equation.

CHAPTER 2

LITERATURE REVIEW

2.1 Gas Deliverability and Flow rate

Natural gas deliverability from the reservoir and the wells has been an area of continuing interest for development of production facilities as well as design and operation of storage fields. “Deliverability” of gas well relates to its ability to produce the gas into wellbore and, subsequently to the surface facilities at a particular rate. The rate of flow from a porous and permeable drainage area into a well bore is a function of the properties of both the information and the fluids; as well as the pressure gradients which is the driving force prevailing in the drainage area. Whether in production or in storage understanding of gas deliverability involves: (a) Flow near the well bore as affected by skin affect. (b) Flow into the well bore through the particular completion system and up or down through the well. (c) Flow through the gathering system that usually includes pipes, laterals, separators, dehydration, pressure regulation, metering and other equipment. (d) Field-to main-pipeline connection – usually through compressor station. During the process of flow, the system adjusts to the rate of deliverability resulting from the various components (mostly in series but sometimes in parallel). Current practice in gas well deliverability analysis involves using the laminar solution for constant terminal rate, along with a skin factor and rate proportional turbulence term added to the pseudo-pressure drop at the well bore. The gas flow through the porous media will be briefly discussed. In general, for gas flow from a reservoir, it is possible to calculate flow rate based the following equation (The Forchheimer equation):

$$-\frac{dp}{dx}=\frac{\mu}{k}v+\beta\rho v^{2} \quad \text{-------------------------------} \ (2.1)$$

The density, ρ**,** and the velocity, v, are each functions of pressure, there fore, Equation (2.2) became:

$$-\rho\frac{dp}{dx}=\frac{\mu}{k}(\rho v)+\beta(\rho v)^2 \text{ ----------------------------- (2.2)}$$

The term ρ v is the mass rate of flow and is therefore independent of pressure. By using the real gas law, we can express ρ v in the, following way:

$$\rho v=\frac{q_{sc}p_{sc}M_w}{AT_{sc}R} \text{ -- (2.3)}$$

Where:

sc = standard conditions.

Substitution of the mass flow rate expression Equation (2.3) into Equation (2.4) produces the desired universal deliverability equation:

$$\frac{M_wP}{ZRT}\frac{dp}{dx}=\frac{\mu}{k}\frac{P_{sc}M_w}{T_{sc}R}\frac{q_{sc}}{A}+\beta\frac{P_{sc}M_w}{T_{sc}R}\frac{q_{sc}}{A} \text{ ------- (2.4)}$$

Separating variables, integrating and rearranging the above equation resulting our working deliverability equation:

$$P_2^2-P_1^2=aq+bq^2 \text{ ---------------------------------------(2.5)}$$

We are now able to use Equation (2.5) to develop a reservoir, well, and surface flow line model, which can then be combined with the depletion equations developed earlier. In essence, Equation (2.5) can be applied to three different flow configurations: (a) Flow from the reservoir to the well (b) Flow from the bottom of the well to the wellhead, and (c) Flow from the wellhead to the power plant.

Each of these configurations will produce different values for their unknown constants a & b in the deliverability equation.

2.2 Production type curves review

Fetkovich[1] introduced the concept of type curve matching for production data analysis. Fetkovich combined a gas stabilized back-pressure deliverability equation, and a material balance equation to develop a set of type curves for gas well production forecasting , ignoring the gas compressibility factor.

$$q = C\left(P_R^2 - P_{wf}^2\right)^n \qquad \text{----------------------------- (2.6)}$$

$$P_R = -\left(\frac{P_i}{G_i}\right)G_p + P_i \qquad \text{--------------------------- (2.7)}$$

These curves are presented as dimensionless flow rate and the dimensionless time for various values of the exponent n and the ratio between the original shut in pressure to the constant flowing bottom pressure. Fetkovich developed a set of empirical equations for a well producing against constant backpressure. Using backpressure, Equation (2.6), he derived the following equations by setting compressibility factor z = 1.0.

$$X = \frac{P}{P_{wf}} \text{--------------------------------------} (2.8)$$

Where,

P_{wf} = constant backpressure

P = reservoir pressure.

Fetkovich[1] came out with a new plot for type curves, where he introduces the dimensionless ration Xi:

$$X_i = \frac{P_i}{P_{wf}} \text{---------------------------------} (2.9)$$

Where,

P_i = initial reservoir pressure

These curves are illustrated in, Figure 2.1 - which shows the dimensionless flow rate, q/q_i was a function of dimensionless time, $(q_i * t)/G_i$. Also, Figure 2.3 shows various values of the exponent, n ranged from 0.5 to 1.0 (laminar flow). Fetkovich[1] also showed that as X_i becomes large, his assumption became equivalent to Fetkovich assumption in which a well is producing at a constant fraction of the shut-in pressure.

The limitation of Fetkovich[1] theoretical method, is that, does not consider the change in gas properties as reservoir pressure is reduced. The value for C and n were taken as constant, where, has been shown that depends on flow rate and does not remain constant during the life of the well. The value of C depends on gas properties and varies with pressure.

Smith[2] further extended Fetkovich`s type curves, empirical method accounts for non-Darcy flow by generating a set of curves for various values of n. These values range from n = 1.0 (laminar flow) to 0.5 (Turbulent flow). The problem with this method is that having many families of curves make unique match difficult. Smith also ignore the compressibility of gas , by setting compressibility factor equal to 1, Later, Carter[3] generated a set of curves with a finite-difference reservoir model. These types curve improved the accuracy of the analysis by plotting functions that include the changes in gas properties with pressure. Thus, he considered the changes of the product μ_g C_g with the average reservoir pressure using a drawdown parameter - as show in Equation (2.24).

$$\lambda = \frac{\mu(P_i) C_g(P_i) \lfloor P_p(P_i) - P_p(P_{wf}) \rfloor}{2\lfloor (P/z)_i - (P/z)_{wf} \rfloor} \text{ -------------------- (2.10)}$$

Carter[4] introduced a new type curves for gas wells producing at constant pressure to fill the gap which existed with the Fetkovich decline curves. As shown, the λ=1.0 curve assumes a negligible drawdown effect and it corresponds to the $X_i = \infty$, on the Fetkovich type curves. But ignored no-Darcy flow effects; which limited by the fact that λ must be calculated before a match can be made and the information needed to calculate λ is not always available.

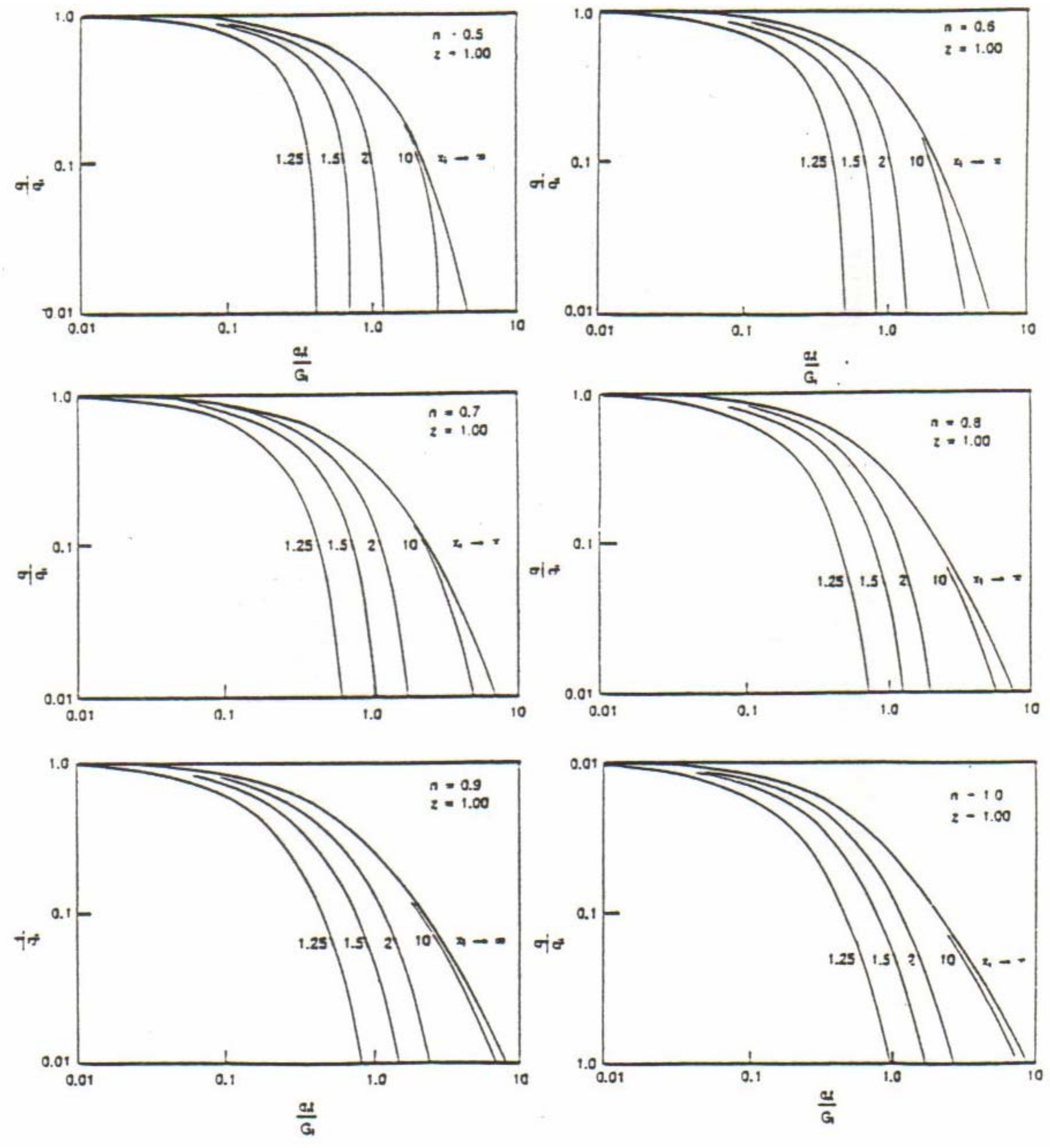


Figure 2.1: Type Curves for wells producing against back pressures with various values of n.[4]

Fraim and Wattenbarger[5] used pseudotime, first introduced by Agarwal to improve the use of Fetkovich type curves for gas. The time transformation accounts for variation of gas properties as the average reservoir declines. Their pseudo-time is different than that used by Agarwal because viscosity and compressibility are evaluated at average reservoir pressures rather that wellbore pressure. They found that, to obtain pseudo-time, value for original gas in place, G, must be assumed. The first estimate is found by matching the actual time versus rate decline curve and calculating a value of G. They showed that gas well production rates decline exponentially against the normalized time as defined in Equation (2.11).

$$t_N = \int_0^t \frac{\mu_{gi} \times C_{gi}}{\mu_g \times C_g} dt \quad \text{----------------------------------} \ (2.11)$$

Farim and Wattenbarger[6] account for variations in gas properties with pressure using pseudo-time, but they also ignore non-Darcy flow. This method has the disadvantage of requiring an estimate of gas in place and knowing the reservoir drive mechanism for the material balance equation before the pseudo-time can be calculated. As mentioned above, all these authors have neglected the impact of non-Darcy flow in their derivation. A set of more representative curves were developed by Schmidt et al, Caudle, and Aminian et al by combining the theoretical stabilized gas flow equation, Equation (2.12) and the material balance for a gas reservoir, Equation (2.13).

$$P_p(P_i) - P_p(P_{wf}) = aq + bq^2 \quad \text{---------------------} \ (2.12)$$

$$G_p = \left[\frac{P_1 / z_1 - P_2 / z_2}{P_1 / z_1} \right] \quad \text{-----------------------} \ (2.13)$$

The model accounts for non-Darcy flow and dependency of gas properties on pressure. The models previously discussed assume constant reservoir parameters and operating conditions during the entire life of the reservoir. Aminian et al[7] has discussed the violation of this assumption in practice due to changes in well spacing owing to infill drilling, back pressure changes due to compressor installation, and changes in skin factor due well stimulation.

2.2.1 Aminian et al Constant Pressure Solution

Equation (2.14) shows the analytical solution developed by Aminian et al:

$$\ln q_D + 2(1 - F_{NDi})(q_D - 1) + \frac{F_{NDi} F_{taD}}{\left[1 - \left(1 / X_i\right)\right]\lambda} \quad \text{--------------------} \ (2.14)$$

All the variables in the equations are explained and defined in Table 2.1.

The theoretical model developed to generate the type curves was based on the next assumptions:

- Pseudo steady state flow regime
- Constant well flowing pressure
- Homogeneous and isotropic formation
- High gas flow rates into wells.

The Pressure dependency of the gas properties is represented by F_{taD}, which depends on the pseudo time, and λ, which contains pseudo pressure. Pseudo pressure as defined by Equation (2.21) takes into account the variation of gas viscosity and gas compressibility.

Table 2.1: Terms included in the constant pressure solution developed by Aminian.

Parameter	**Equation**
Dimensionless Flow Rate	$q_D = \frac{q}{q_i}$ (2.15)
Non-Darcy Flow Ratio	$F_{NDi} = 1 + \frac{bq_i}{a}$ (2.16)
Darcy Flow Coefficient, $psi^2/(cp)(Mcf/D)^2$	$a = \frac{1422T}{kh\left[0.5\ln\left(\frac{10.06 Area}{C_a r_w^2}\right) - 0.75 + s\right]}$ (2.17)
Non- Darcy Flow coefficient, $psi^2/(cp)(Mcf/D)^2$	$b = \frac{3.161\times10^{-12}\beta T\gamma}{h^2\overline{\mu}\left[\frac{1}{r_w} - \frac{1}{r_e}\right]}$ (2.18)
Turbulence Coefficient, ft^{-1}	$\beta = \frac{2.73\times10^{10}}{K^{1.1045}}$ (2.19)
Pseudo time Ratio	$F_{taD} = \frac{\int_0^t \frac{dt}{\mu_g c_g}}{\frac{t}{\mu_{gi} c_{gi}}}$ (2.20)
Pseudo pressure, psi^2/cp	$P_p(P) = \int_0^p \frac{2Pdp}{\mu_g z}$ (2.21)
Dimensionless Time	$t_D = \frac{q_i t}{G_i}$ (2.22)
Drawdown parameter	$\lambda = \frac{\left[P_p(P) - P_p(P_{wf})\right]\left(\mu_{gi} C_{gi}\right)}{2\left[\left(\frac{p}{z}\right)_i \div \left(\frac{p}{z}\right)_{wf}\right]}$ (2.23)
Dimensionless Parameter, Xi	$X_i = \left(\frac{p}{z}\right)_i \div \left(\frac{p}{z}\right)_{wf}$ (2.24)

The effect of non-Darcy flow is quantified by F_{NDi}. Aminian et al,[8] concluded that the dependency of the previously discussed type curves on permeability, initial pressure and skin factor are caused by variations of this parameter.

In order to generate a type curve from Equation (2.14), it is necessary to determine F_{taD} for each point of the decline curve, which means for each pressure. Two approaches have been proposed to solve this expression. Abidi introduced the first approach known as direct method in 1991. This method solves the equation directly by utilizing polynomial approximations for F_{taD} as function of t_D. The effect of various parameters such as P_i, X_i, and k on F_{taD} was studied by plotting F_{taD} vs. t_D on log- log paper. Sets of $F_{taD} \times t_D / \lambda(1 - 1 / X_i)$, and $t_D / (1 - 1 / X_i)$ were developed in order to establish a correlation between F_{taD}, and the dimensionless time, t_D. In order to generate a type curve from these plots a polynomial regression method was used. This technique employs the least squares fit of the data by successive polynomials of order *1 to 4*, and examines the standard deviation about the regression line in each case. Thus, the type curves generated by using these correlations were compared to the type curve generated by numerical methods finding an alternative method to model Aminian et al Type curves. The second approach is the indirect method, which utilizes a stepwise method of solving material balance and deliverability equations simultaneously to determine rate versus time and converts the results to dimensionless rate and time. This method is the foundation of the computer program for generating type curves.

It has been observed that if both the non-Darcy and pressure dependency of the gas properties is ignored, $F_{taD} = 1$, $\lambda = 1.0$, and F_{NDi}, then the equation reduces to the familiar exponential decline. This is true for single-phase liquid flow.

If only the non-Darcy flow is ignored $F_{NDi}=1$, then the equation reduces to exponential decline against normalized time as suggested by Fraim and Wattenbarger[9]. Therefore, the equation is the most general and accurate form of the constant pressure pseudo-steady-state solution for single-phase gas flow.

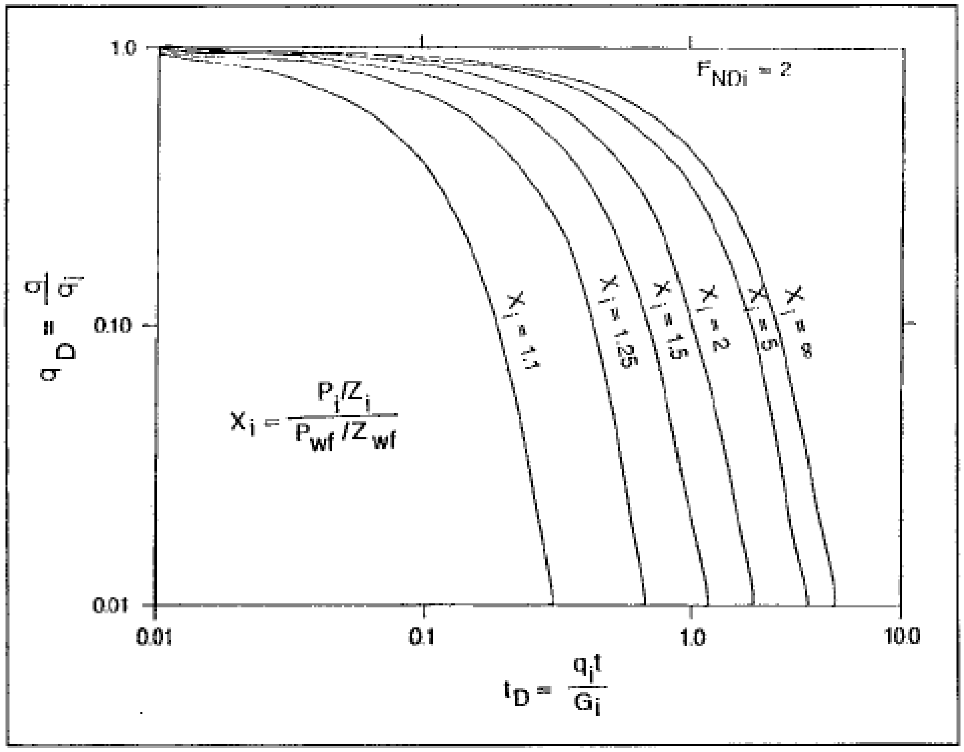


Figure 2.2 Constant back-pressure gas well production decline curves[7]

According to the number of known variables available to generate type curves, different scenarios can be analyzed. If only one of the limiting values of pressure is known, multiple sets of type curves are generated for specific values of F_{NDi} by varying X_i. Figure 2.2, shows different type curves generated by varying the values of the dimensionless parameter X_i, as defined in Equation (2.38) above and ranged here between 1.1 to infinity; for an initial pressure of 2000 psia and F_{NDi}=*2*. As is observed, X_i parameter defines the pressure drawdown exhibited by the well. As the pressure drawdown is larger the curves shift to the right due to the larger gas

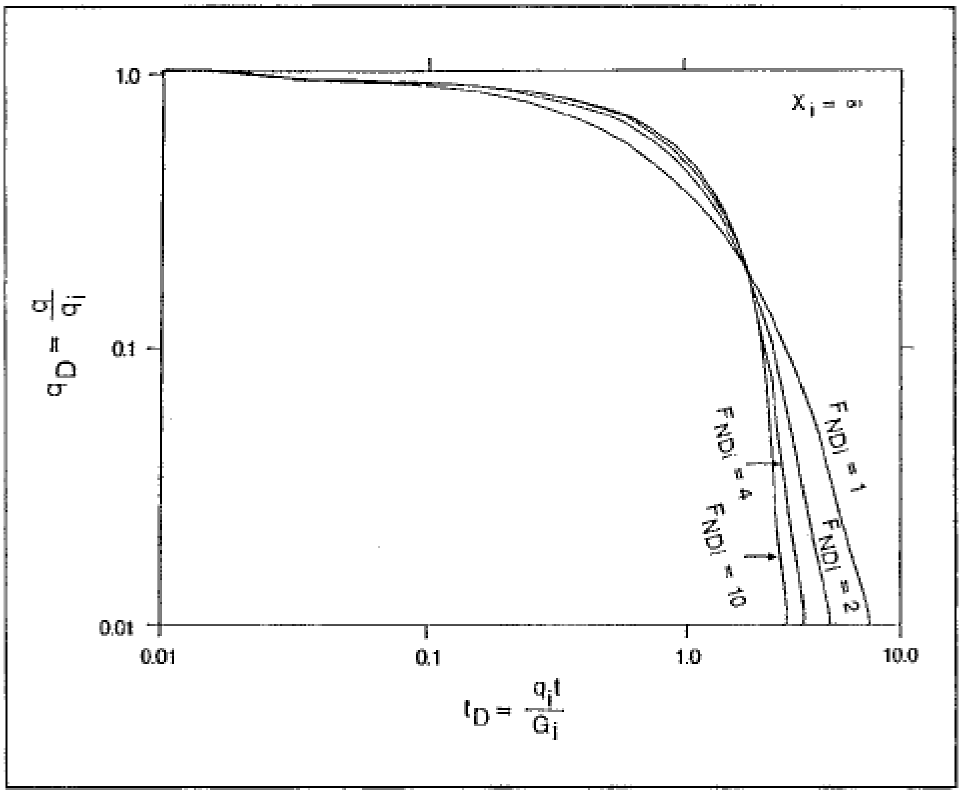


Figure 2.3 Effect of non-Darcy flow on type curves[7]

production at higher differential pressure. If the limiting values of the pressure P_i, and P_{wf} are known then λ , and X_i can be easily determined by substituting pressure values between this intervals in their respective equations.

Figure 2.3, depicts a set of type curves for P_i = 2000 psia, and P_{wf} =100. As we observed, the effect of larger F_{NDi} *(s)* results in a shift of the curves to the left side due to shorter gas production and production time. It is also the values of F_{NDi}, larger than 10 do not result in significant variations in the shape of the type curve.

These sets can be obtained either by adjusting reservoir permeability or skin factor to keep constant the F_{NDi} values. As the figure shows, the initial pressure influences the type curve only slightly when the non-Darcy effects are kept constant7. These changes are the result of variations in F_{taD} and λ given by Equations (2.34) and (2.37). Also sets of cumulative production type curve were generated as shown in Figure 2.4, was introduced by Aminian, who found that, those cumulative production type curves can enhance the matching process when the erratic rate of production data can not easily be matched to the production type curves.

Where the dimensionless cumulative production G_D is defined as of the gas cumulative production divided by the initial gas in place as follows:

$$G_D = \frac{G_p}{G_i} \text{ ---------------------------------- } (2.40)$$

Aminian et al[10] performed many simulation runs to study the effect of various reservoir parameters on the shape of the type curves. As a result, the formation permeability, the skin factor and the shape factor were found to have some effect on the curves. The effect of permeability was found to be relatively small and it is recommended that for different ranges of permeability, the type curves are generated separately.

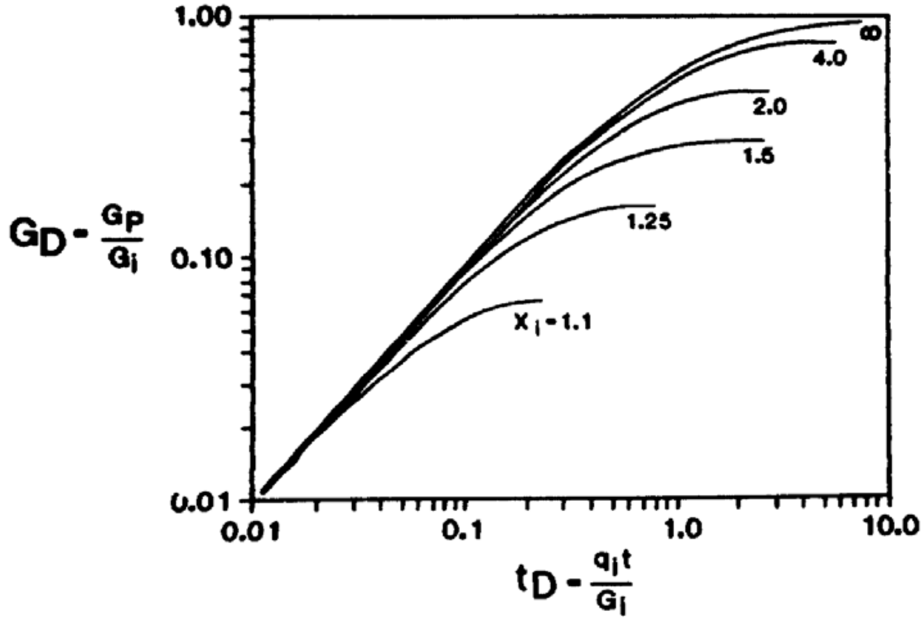


Figure 2.4 Cumul-production type curves producing against constant BP.[11]

The effect of skin factor is shown in Figure 2.6, with insignificant effects in case of a small dimensionless time values. At larger dimensionless time values skin factor makes significant change between those type curves. These changes are the result of

Non-Darcy effects, F_{NDi}; therefore, they are accounted for in the type curves. The effect of the shape factor was also found very similar to that of skin factor. Aminian type curves have limitations, that reservoir must be at pseudo-state and radial flow conditions. Wells which are dominated by linear flow and/or an unsteady flow regime should not be analyzed with these type curves.

2.2.2 Type Curve Utilization

To analyze the past production data, a log-log plot of actual production rate versus time is overlaid on different sets of type curve. The closest type curve to the production history is chosen as the match for it. As a result of these match the value of X_i, P_i, and F_{NDi} are directly obtained from the type curve. As is seen in Figure 2.7, the matched type curve differs from the plot of actual data only by a shift in coordinates. Hence, an arbitrary match point should be selected, and the two sets of coordinates are used to evaluate q_i and G_i as defined by Equations (2.41) and (2.42).

$$q_i = \left(\frac{q}{q_D}\right)_{match} \quad \text{---------------------------------} \; (2.41)$$

$$G_i = q\left(\frac{t}{t_D}\right)_{match} \quad \text{------------------------------} \; (2.42)$$

As P_i and X_i are read from the matched type curve, the value of P_{wf} is obtained from X_i relation. Knowing P_{wf}, the values of non-Darcy coefficient *b*, and Darcy coefficient *a* of the quadratic gas flow equation defined by Equation (2.26) are obtained by Equations (2.41) and (2.42).

$$a = \frac{\lfloor P_p(P_i) - P_p(P_{wf}) \rfloor}{q_i \times F_{NDi}} \text{ ----------------------- } (2.43)$$

$$b = \frac{(F_{NDi} - 1)a}{q_i} \text{ ----------------------------- } (2.44)$$

Thus, with this information gas deliverability can be calculated by substituting either P_{wf} or *q* into the quadratic equation. Gas reserves and times of production are obtained by using the material balance equation. It is essential to know X_i and F_{NDi} to generate type curves. X_i affects the position of the curve as shown in Figure 2.3, while F_{NDi} changes the shape of the curve as shown in Figure 2.4. Since X_i is available from the producing well, F_{NDi} normally will be iterated for different values and different type curves were generated. Then by superimposing the production history of a well on the top of the generated curves, a match will be made and as the result, F_{NDi} read from the matched curve. Once a match is found, q_i and Gi will be calculated using Equations (2.41) and (2.42). The deliverability coefficient , a and b were also determined using Equations (2.43) and (2.44). An example of matching process is shown in Figure 2.5.

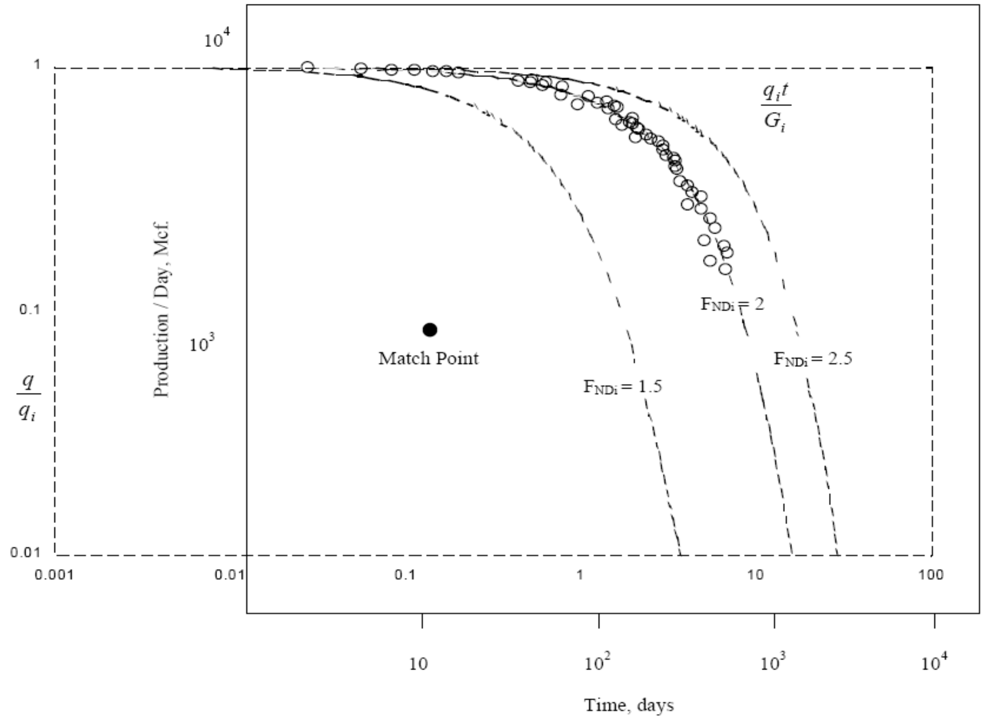


Figure 2.5 Sample of the Type Curve Matching Process[12].

2.2.3 Recent Type Curves Researches and Developments

Some of the researches and papers which have bean introduced most recently, and published through the Society of Petroleum Engineering; (SPE):

In 1999, Agarwal, Gardner, and Kleinsteiber[13], did present new production decline curves for analyzing well production data from radial and vertically fractured oil and gas wells. They combined Decline curve and Type curve analysis concepts to result in a practical tool which can more easily estimate the gas in place as well as to estimate reservoir permeability, skin effect, fracture length and conductivity.

In 2001, Zelghi, Tiab, and Mazighi[14] introduced a newly developed equation for decline curve analysis; a fitting equation was developed as an alternative for gas field data analysis; which combines both depletion and transient periods. The equation advantages: (a) Fitting with the new equation is more precise than the conventional type curve matching to obtain decline constant, D, decline exponent, and matching point. (b)The real production data can be fitted directly by the equation without using smoothing techniques. (c)The radial and pseudo-steady-state regions are determined directly from the fitting. (d) and finally, for new-developed reservoirs, production data, which may be insufficient with the conventional type curve matching, can be interpreted with new fitting developed - equation.

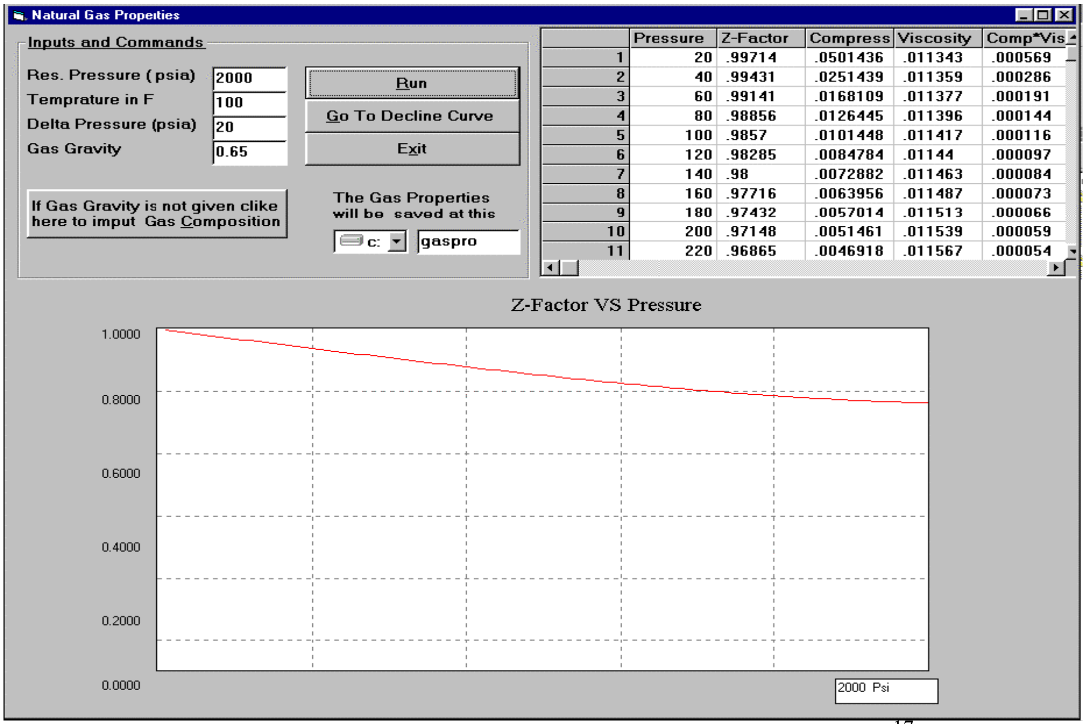
In 2001, also, Marthaendrajana and Blasingame[15] introduced a new multiwell reservoir solution to analyze single well performance data in a multiwell reservoir system. The new solution was to "couples" the single well and multiwell reservoir models, based on a total material balance of the system, and permits the estimation of total reservoir volume and flow properties within the drainage area of an individual well, where the analysis is performed using type curve.

In 2003, Partikno, Rushing & Blasingame[16] studied the methodology for decline type curve analysis using a field case of continuously measured production rate and surface pressure data obtained from a low permeability gas reservoir. The traditional type curve solutions for an infinite conductivity vertical fracture are typically inadequate - and, their new solutions for a well with a finite conductivity vertical fracture clearly show much more representative behavior. This suggests that the proposed type curves will have applications in low permeability gas reservoirs.

Therefore, even the most recent published papers still have limitation, in which most of them were based on the assumption that, some of the reservoir parameters such as bottom hole flowing pressure remain constant.

2.2.4 Computer Program

“Sfrac” is a simple analytic gas model created by Tesfasalasi, (1999)[17], that generates production decline curves of a well. The program has two parts; the first part of the program calculates the gas properties and pseudo-pressure for any pressure increment. The second part generates decline production curves and dimensionless type curves. It also prints out F_{NDi}, a, b, and G_i as part of the output. For the first part of the program, the input parameters are the initial reservoir



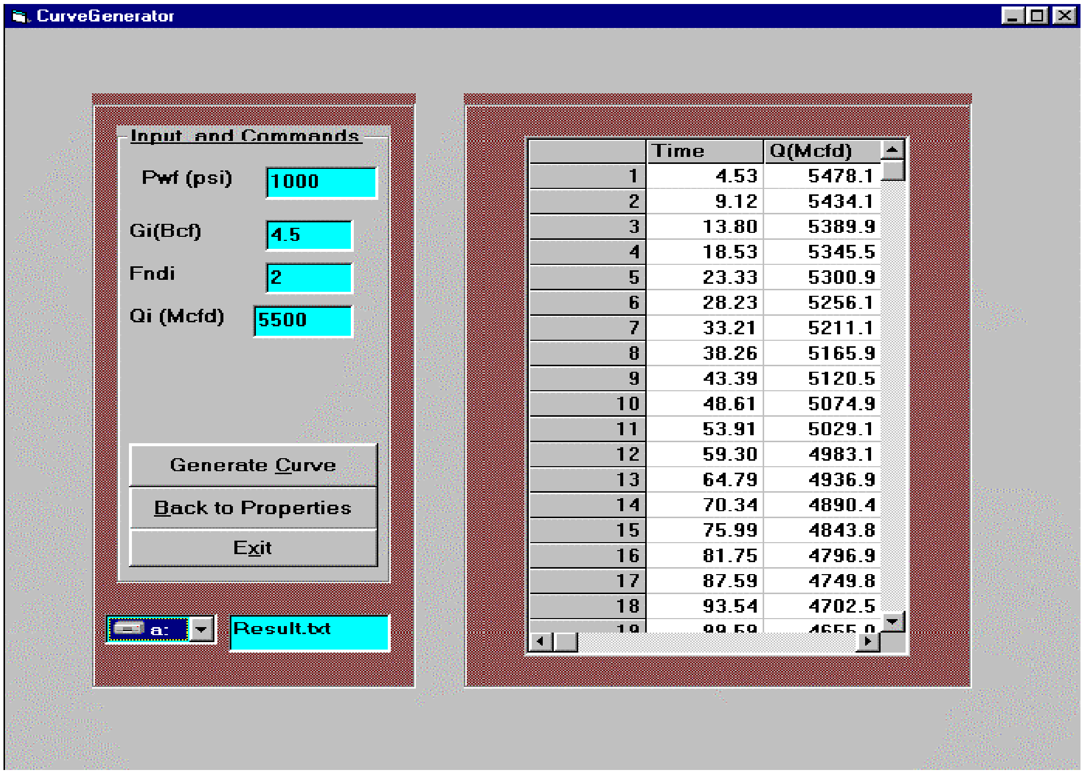
Res. Pressure (psia) 2000
Temprature in F 100
Delta Pressure (psia) 20
Gas Gravity 0.65
c: gaspro

	Pressure	Z-Factor	Compress	Viscosity	Comp*Vis
1	20	.99714	.0501436	.011343	.000569
2	40	.99431	.0251439	.011359	.000286
3	60	.99141	.0168109	.011377	.000191
4	80	.98856	.0126445	.011396	.000144
5	100	.9857	.0101448	.011417	.000116
6	120	.98285	.0084784	.01144	.000097
7	140	.98	.0072882	.011463	.000084
8	160	.97716	.0063956	.011487	.000073
9	180	.97432	.0057014	.011513	.000066
10	200	.97148	.0051461	.011539	.000059
11	220	.96865	.0046918	.011567	.000054

Figure 2.6 Sample of the Type Curve Matching Process[17]

Pressure, temperature and gas gravity or gas components. For the second part of the program, porosity, permeability, skin factor, shape factor, bottom hole flowing pressure, well bore diameter, gas saturation, and area of the reservoir are the input parameters. As shown in Figure 2.6.

Abidi[12] has worked to develop a direct method of generating type curves using polynomial regression by creating a correlation with the Armenian's general equation (26). The program was written in Fortran and it is updated to Visual Basic 5.0. The Second and third degree order polynomial equations were used depending on initial reservoir pressure. Third degree order polynomial equations were used. Abidi determined the coefficients of the polynomial equation. The input properties of the program are P_i, X_i, and F_{NDi} and the outcome of the program is a dimensionless type curve, as shown in Figure 2.7.



Pwf (psi) 1000
Gi(Bcf) 4.5
Fndi 2
Qi (Mcfd) 5500
a:
Result.txt

	Time	Q(Mcfd)
1	4.53	5478.1
2	9.12	5434.1
3	13.80	5389.9
4	18.53	5345.5
5	23.33	5300.9
6	28.23	5256.1
7	33.21	5211.1
8	38.26	5165.9
9	43.39	5120.5
10	48.61	5074.9
11	53.91	5029.1
12	59.30	4983.1
13	64.79	4936.9
14	70.34	4890.4
15	75.99	4843.8
16	81.75	4796.9
17	87.59	4749.8
18	93.54	4702.5

Figure 2.7 Sample of the Type Curve Matching Process[17]

CHAPTER 3

OBJECTIVE AND METHODOLOGY

Most of previous and recent researches, contributions and developments that had been done on production decline type curves analysis, were based mainly on the assumption that, the gas well is producing under a constant flowing bottom hole pressure; From practical point of view, was found to be untrue, most of the gas wells are currently producing under a constant wellhead pressure and a different flowing bottom hole pressures. There fore, what will happened to the production forecasting in the condition where the gas well produce against a constant wellhead pressure and different bottomhole pressures? The answer of that challenging question was the foundation of my research.

The objective of this research was to develop a new set of type curves that combine formation deliverability and gas well flow rate – using a new approach which was the assumption of constant wellhead pressure and variable bottom hole pressures.

To achieve the objective, a methodology consisting of the following steps:

(1)Generate a simple and reliable model that capable to calculate & combine the production flow rate for both gas reservoir and the well. (2)Generate and introduce a new set of dimensionless group of gas production decline type curves.(3)Study and investigate the impact of various reservoir and well parameters especially; the effect of the tubing length and tubing sizes to the shape and the behavior of the decline curves for a constant Well head pressure & various bottom hole pressures.

The methodology of this work is divided into three levels:

A-Model Development

B-Generate Production Type Curves

C-Evaluate the Impact of the Well Tubing Length & Size on the Type Curves.

3.1 Model Development

The Model was generated using “Sfrac”, which was used as a base to develop a new all that as a base to develop a new model, that capable to combine the gas deliverability equation for a reservoir and a well.

The modification to the computer program, using Visual Basic 6.0 is illustrated in a simple Flow Chart in Figure 4.1 below:

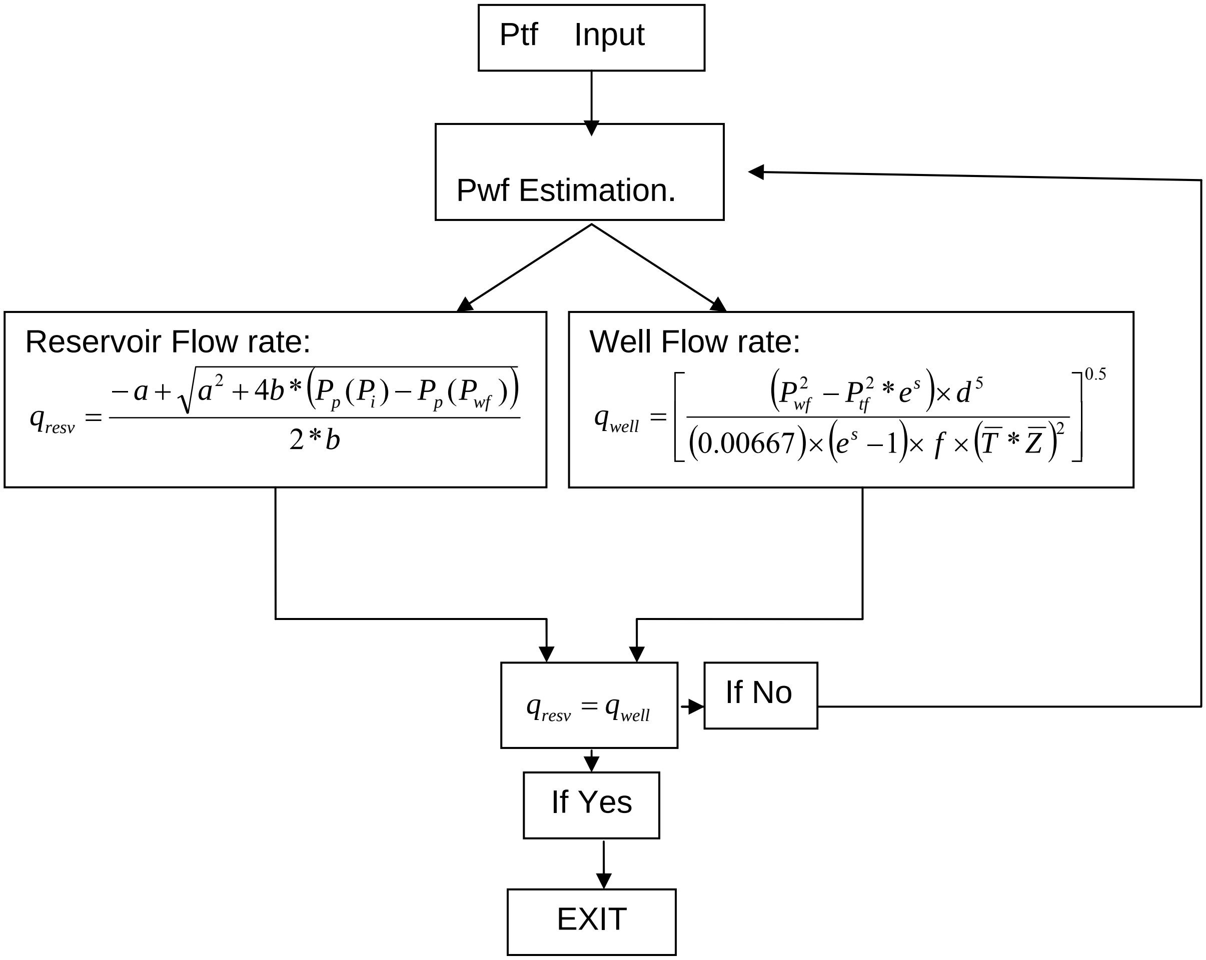


Figure 3.1: Flow Chart for Computer model modification

The combining deliverability equation procedure presented in this research is based upon the following assumptions and concepts:

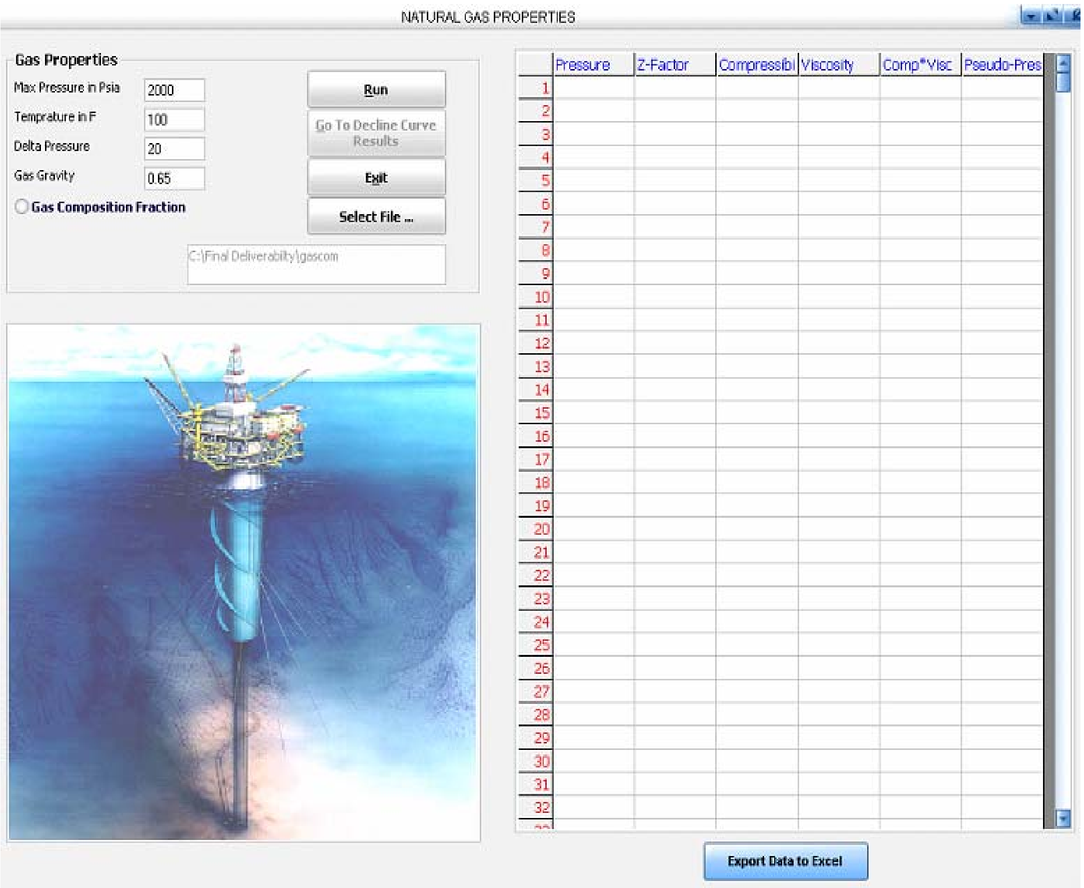
(1) The reservoir is closed volumetric reservoir.
(2) The flow regime is pseudo – steady state.
(3) Single phase gas flow.
(4) The formation is homogeneous.
(5) The system under a constant wellhead pressure

The following table summarizes the basic data that were used to generate the new model as well as the range of it:

Table 3.1 Reservoir Properties

Parameters	**Base Model Value**	**Range**
Depth	4000 ft	4000 - 8000 ft
Gas Gravity	0.65	0.65
Initial Pressure	2000 psia	2000 - 5000 psia
kh	200	10 -10000
Temperature	100 F	100 F
Tubing Diameter	2.750 inc	1.25 - 4.50
Tubing Length	4000 ft	4000 - 9000 ft
Wellhead Pressure	1000 psia	100 - 2000 psia

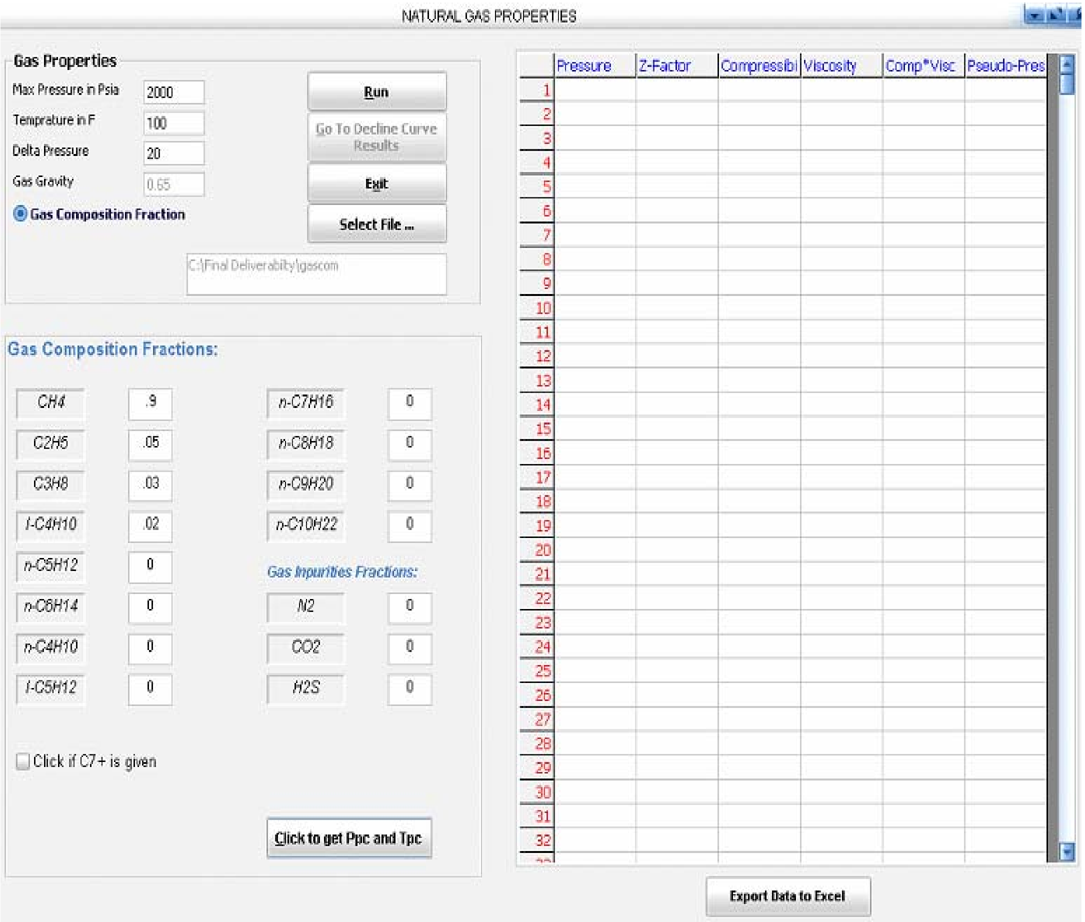
“Progress” is the new modification to the previous model “Sfrac”. The new addition focused mainly on the second phase where the program generates the type curves. Even though, the first phase was modified also, as show in Figures 3.2, & 3.3;



Max Pressure in Psia 2000
Temprature in F 100
Delta Pressure 20
Gas Gravity 0.65
C:\Final Deliverabilty\gascom

Figure 3.2: First page of the developed-software.

Beside the overall look, additional features added such as; the model was developed to allow the user to choose different external file from different location.



Max Pressure in Psia: 2000
Temprature in F: 100
Delta Pressure: 20
Gas Gravity: 0.65
● Gas Composition Fraction
C:\Final Deliverabity\gascom

CH4	.9	n-C7H16	0
C2H6	.05	n-C8H18	0
C3H8	.03	n-C9H20	0
I-C4H10	.02	n-C10H22	0
n-C5H12	0		
n-C6H14	0	N2	0
n-C4H10	0	CO2	0
I-C5H12	0	H2S	0

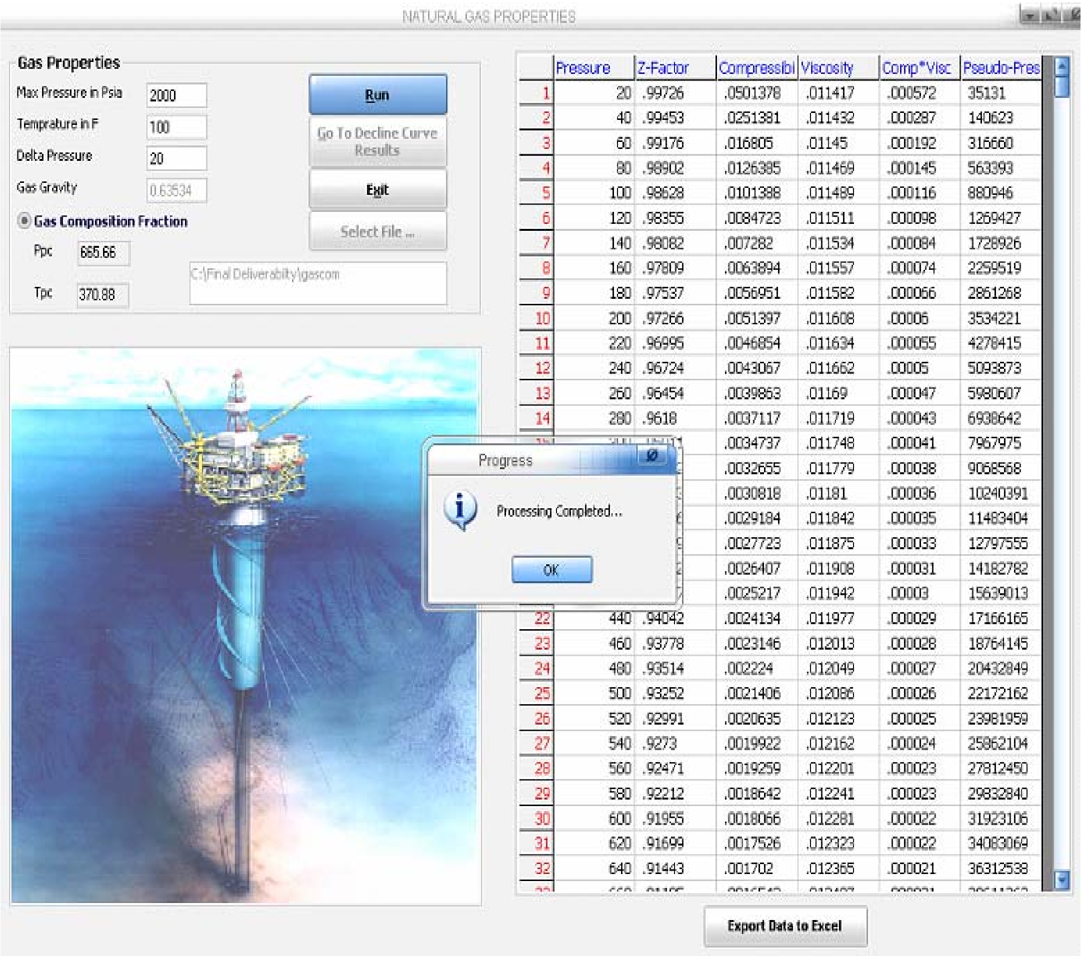
☐ Click if C7+ is given

	Pressure	Z-Factor	Compressibi	Viscosity	Comp*Visc	Pseudo-Pres
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
32						

Figure 3.3: the gas composition input window.

One of the new feature in “Progress” is that, the user will get a reminder when the system finished displaying all gas properties data in the grid table- since there is a limitation to display all data on the same page; therefore, a small window will pop – up informing the user that the process is complete, Figure 3.4.

The second phase of the model in “Progress” display the input and the result for type curve generation. On this page additional checked- box was added allowing the



Gas Properties

Max Pressure in Psia: 2000

Temprature in F: 100

Delta Pressure: 20

Gas Gravity: 0.63534

● **Gas Composition Fraction**

Ppc: 665.66

Tpc: 370.88

C:\Final Deliverabity\gascom

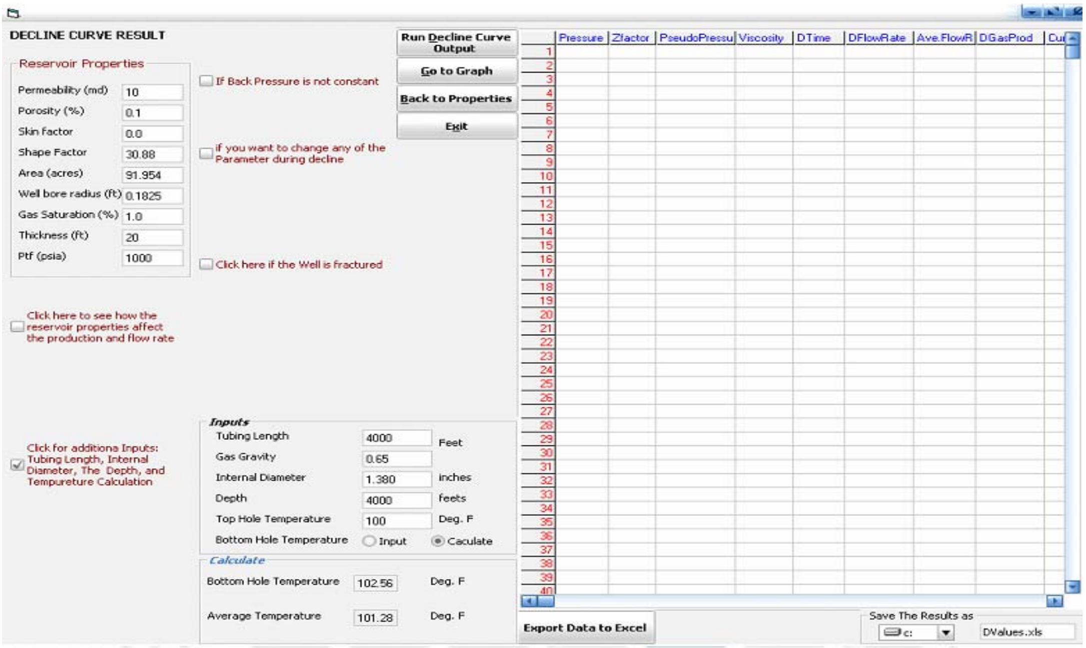
	Pressure	Z-Factor	Compressibi	Viscosity	Comp*Visc	Pseudo-Pres
1	20	.99726	.0501378	.011417	.000572	35131
2	40	.99453	.0251381	.011432	.000287	140623
3	60	.99176	.016805	.01145	.000192	316660
4	80	.98902	.0126385	.011469	.000145	563393
5	100	.98628	.0101388	.011489	.000116	880946
6	120	.98355	.0084723	.011511	.000098	1269427
7	140	.98082	.007282	.011534	.000084	1728926
8	160	.97809	.0063894	.011557	.000074	2259519
9	180	.97537	.0056951	.011582	.000066	2861268
10	200	.97266	.0051397	.011608	.00006	3534221
11	220	.96995	.0046854	.011634	.000055	4278415
12	240	.96724	.0043067	.011662	.00005	5093873
13	260	.96454	.0039863	.01169	.000047	5980607
14	280	.9618	.0037117	.011719	.000043	6938642
			.0034737	.011748	.000041	7967975
			.0032655	.011779	.000038	9068568
			.0030818	.01181	.000036	10240391
			.0029184	.011842	.000035	11483404
			.0027723	.011875	.000033	12797555
			.0026407	.011908	.000031	14182782
			.0025217	.011942	.00003	15639013
22	440	.94042	.0024134	.011977	.000029	17166165
23	460	.93778	.0023146	.012013	.000028	18764145
24	480	.93514	.002224	.012049	.000027	20432849
25	500	.93252	.0021406	.012086	.000026	22172162
26	520	.92991	.0020635	.012123	.000025	23981959
27	540	.9273	.0019922	.012162	.000024	25862104
28	560	.92471	.0019259	.012201	.000023	27812450
29	580	.92212	.0018642	.012241	.000023	29832840
30	600	.91955	.0018066	.012281	.000022	31923106
31	620	.91699	.0017526	.012323	.000022	34083069
32	640	.91443	.001702	.012365	.000021	36312538

Progress

Processing Completed...

Figure 3.4: the gas composition result displayed.

user to plug different input values for the main reservoir and well parameters; such as: system temperature, well tubing length and diameter as shown in Figure 3.5. New advantage of the new developed- model, "Progress" that, the model is capable to calculate the system average temperature automatically, by using the original formation temperature and the top hole temperature inputs, as shown in Figure 3.5.



DECLINE CURVE RESULT

Reservoir Properties

Permeability (md)	10
Porosity (%)	0.1
Skin factor	0.0
Shape Factor	30.88
Area (acres)	91.954
Well bore radius (ft)	0.1825
Gas Saturation (%)	1.0
Thickness (ft)	20
Ptf (psia)	1000

☐ If Back Pressure is not constant

☐ if you want to change any of the Parameter during decline

☐ Click here if the Well is fractured

☐ Click here to see how the reservoir properties affect the production and flow rate

☑ Click for additiona Inputs: Tubing Length, Internal Diameter, The Depth, and Tempureture Calculation

Inputs

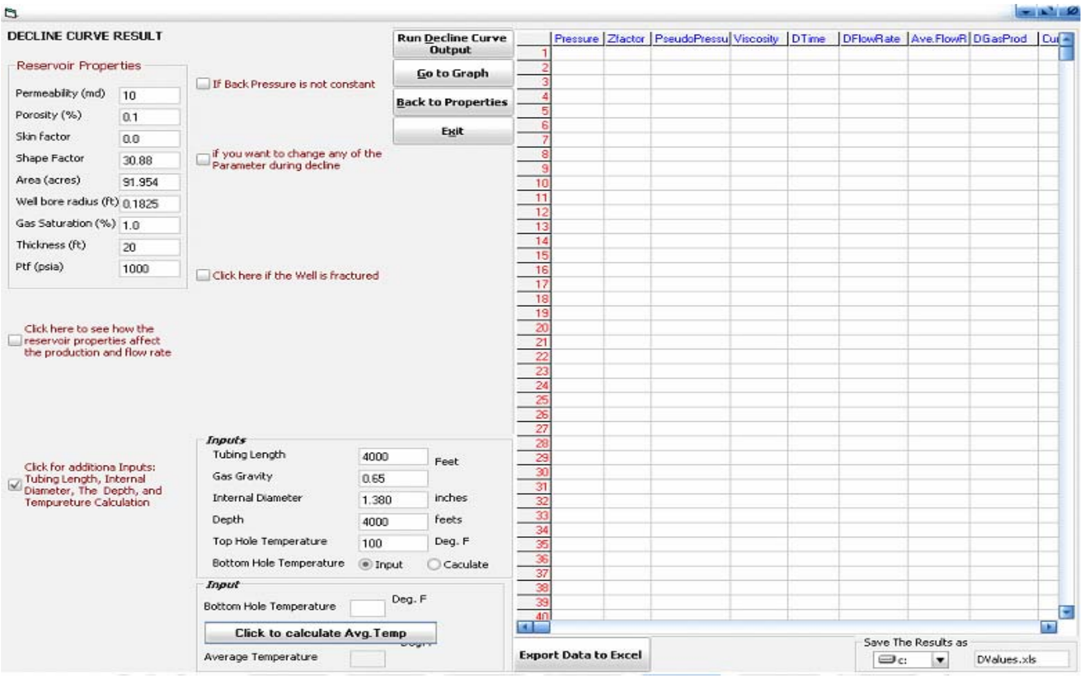
Tubing Length	4000	Feet
Gas Gravity	0.65	
Internal Diameter	1.380	inches
Depth	4000	feets
Top Hole Temperature	100	Deg. F
Bottom Hole Temperature	○ Input	● Caculate

Calculate

Bottom Hole Temperature	102.56	Deg. F
Average Temperature	101.28	Deg. F

Save The Results as c: DValues.xls

Figure 3.5: Option of calculating the average temperature automatically.



DECLINE CURVE RESULT

Reservoir Properties

Permeability (md)	10
Porosity (%)	0.1
Skin factor	0.0
Shape Factor	30.88
Area (acres)	91.954
Well bore radius (ft)	0.1825
Gas Saturation (%)	1.0
Thickness (ft)	20
Ptf (psia)	1000

☐ If Back Pressure is not constant

☐ if you want to change any of the Parameter during decline

☐ Click here if the Well is fractured

☐ Click here to see how the reservoir properties affect the production and flow rate

☑ Click for additiona Inputs: Tubing Length, Internal Diameter, The Depth, and Tempureture Calculation

Inputs

Tubing Length	4000	Feet
Gas Gravity	0.65	
Internal Diameter	1.380	inches
Depth	4000	feets
Top Hole Temperature	100	Deg. F
Bottom Hole Temperature	● Input	○ Caculate

Input

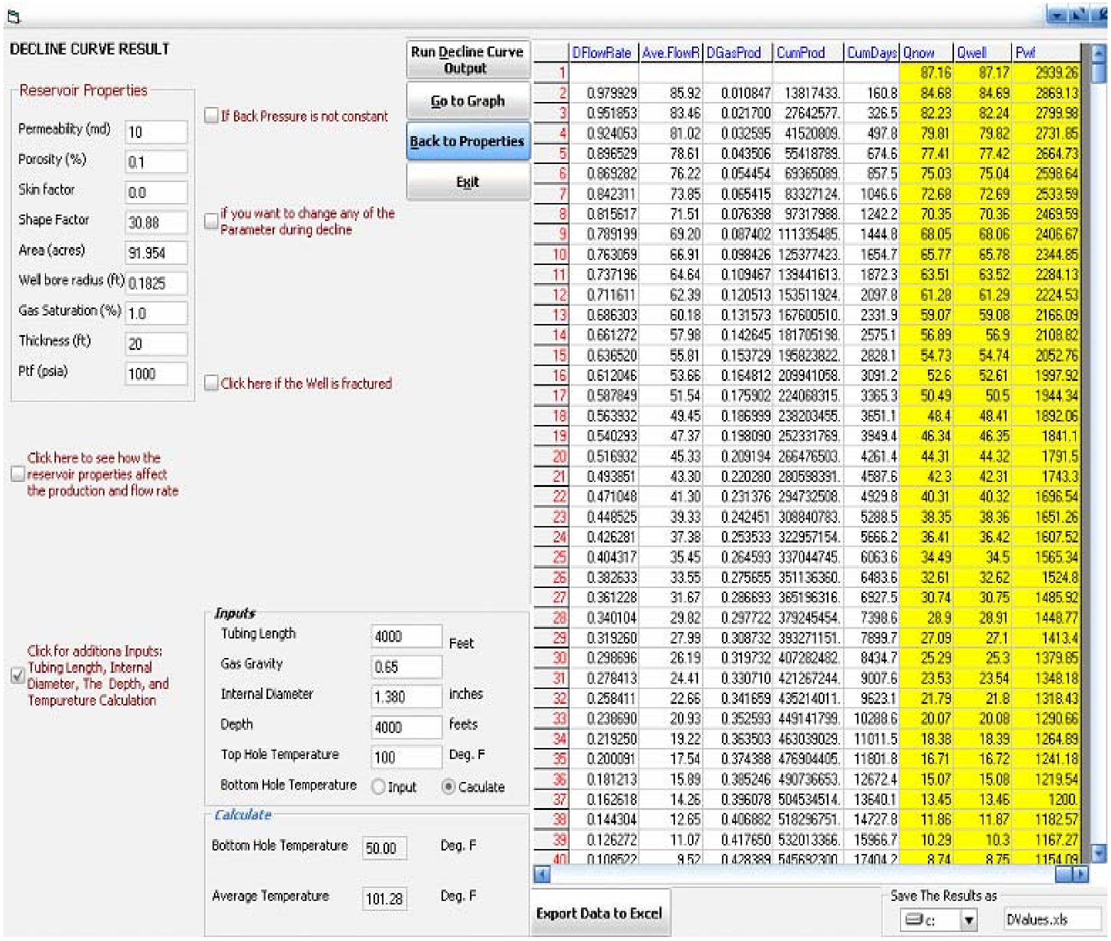
Bottom Hole Temperature		Deg. F
Average Temperature		

Save The Results as c: DValues.xls

Figure 3.6: Option of calculating the average temperature manually.

The other option for the system average temperature calculation - when the bottom hole temperature value is available, therefore, the model allows the user to manually input the value of bottom hole temperature; as shown in figure 3.6.

Finally, the most important output which are: the formation flow rates, the well flow rates, and the flowing bottom hole pressures columns were displayed in different color to distinguish them from the rest outputs; as shown in Figure 3.7.



DECLINE CURVE RESULT

Reservoir Properties

Permeability (md): 10
Porosity (%): 0.1
Skin factor: 0.0
Shape Factor: 30.88
Area (acres): 91.954
Well bore radius (ft): 0.1825
Gas Saturation (%): 1.0
Thickness (ft): 20
Ptf (psia): 1000

☐ If Back Pressure is not constant

☐ if you want to change any of the Parameter during decline

☐ Click here if the Well is fractured

☐ Click here to see how the reservoir properties affect the production and flow rate

☑ Click for additiona Inputs: Tubing Length, Internal Diameter, The Depth, and Tempureture Calculation

Inputs

Tubing Length: 4000 Feet
Gas Gravity: 0.65
Internal Diameter: 1.380 inches
Depth: 4000 feets
Top Hole Temperature: 100 Deg. F
Bottom Hole Temperature: ○ Input ● Caculate

Calculate

Bottom Hole Temperature: 50.00 Deg. F
Average Temperature: 101.28 Deg. F

	DFlowRate	Ave.FlowR	DGasProd	CumProd	CumDays	Qnow	Qwell	Pwf
1						87.16	87.17	2939.26
2	0.979929	85.92	0.010847	13817433.	160.8	84.68	84.69	2869.13
3	0.951853	83.46	0.021700	27642577.	326.5	82.23	82.24	2799.98
4	0.924053	81.02	0.032595	41520809.	497.8	79.81	79.82	2731.85
5	0.896529	78.61	0.043506	55418789.	674.6	77.41	77.42	2664.73
6	0.869282	76.22	0.054454	69365089.	857.5	75.03	75.04	2598.64
7	0.842311	73.85	0.065415	83327124.	1046.6	72.68	72.69	2533.59
8	0.815617	71.51	0.076398	97317988.	1242.2	70.35	70.36	2469.59
9	0.789199	69.20	0.087402	111335485.	1444.8	68.05	68.06	2406.67
10	0.763059	66.91	0.098426	125377423.	1654.7	65.77	65.78	2344.85
11	0.737196	64.64	0.109467	139441613.	1872.3	63.51	63.52	2284.13
12	0.711611	62.39	0.120513	153511924.	2097.8	61.28	61.29	2224.53
13	0.686303	60.18	0.131573	167600510.	2331.9	59.07	59.08	2166.09
14	0.661272	57.98	0.142645	181705198.	2575.1	56.89	56.9	2108.82
15	0.636520	55.81	0.153729	195823822.	2828.1	54.73	54.74	2052.76
16	0.612046	53.66	0.164812	209941058.	3091.2	52.6	52.61	1997.92
17	0.587849	51.54	0.175902	224068315.	3365.3	50.49	50.5	1944.34
18	0.563932	49.45	0.186999	238203455.	3651.1	48.4	48.41	1892.06
19	0.540293	47.37	0.198090	252331769.	3949.4	46.34	46.35	1841.1
20	0.516932	45.33	0.209194	266476503.	4261.4	44.31	44.32	1791.5
21	0.493851	43.30	0.220280	280598391.	4587.6	42.3	42.31	1743.3
22	0.471048	41.30	0.231376	294732508.	4929.8	40.31	40.32	1696.54
23	0.448525	39.33	0.242451	308840783.	5288.5	38.35	38.36	1651.26
24	0.426281	37.38	0.253533	322957154.	5666.2	36.41	36.42	1607.52
25	0.404317	35.45	0.264593	337044745.	6063.6	34.49	34.5	1565.34
26	0.382633	33.55	0.275655	351136360.	6483.6	32.61	32.62	1524.8
27	0.361228	31.67	0.286693	365196316.	6927.5	30.74	30.75	1485.92
28	0.340104	29.82	0.297722	379245454.	7398.6	28.9	28.91	1448.77
29	0.319260	27.99	0.308732	393271151.	7899.7	27.09	27.1	1413.4
30	0.298696	26.19	0.319732	407282482.	8434.7	25.29	25.3	1379.85
31	0.278413	24.41	0.330710	421267244.	9007.6	23.53	23.54	1348.18
32	0.258411	22.66	0.341659	435214011.	9623.1	21.79	21.8	1318.43
33	0.238690	20.93	0.352593	449141799.	10288.6	20.07	20.08	1290.66
34	0.219250	19.22	0.363503	463039029.	11011.5	18.38	18.39	1264.89
35	0.200091	17.54	0.374388	476904405.	11801.8	16.71	16.72	1241.18
36	0.181213	15.89	0.385246	490736653.	12672.4	15.07	15.08	1219.54
37	0.162618	14.26	0.396078	504534514.	13640.1	13.45	13.46	1200.
38	0.144304	12.65	0.406882	518296751.	14727.8	11.86	11.87	1182.57
39	0.126272	11.07	0.417650	532013366.	15966.7	10.29	10.3	1167.27
40	0.108522	9.52	0.428389	545692300.	17404.2	8.74	8.75	1154.09

Save The Results as: c: DValues.xls

Figure 3.7: Option to input the temperature for the wellhead pressure calculation.

3.2 Generation of Production Type Curves

The methods that had been utilized to generate Amenian's solution type curves, is initiated by solving the dimensionless time t_D and dimensionless flow rate q_D using material balance equation and deliverability equation. The goal is to utilizes a stepwise method of solving material balance and deliverability equations simultaneously to determine reservoir flow rate and match that with the well flow rate obtained from tubing deliverability equation using similar Pwf –Which is the foundation of my computer model program (that I developed and was explained previously) for combining the flow rates of the reservoir and the well in one and closely equal flow rate In order to generate a single type curve gas properties must be defined at every point of the proposed gas declines. As it was mentioned before, *Xi, FNDi*, and initial gas in place *Gi* are required to generate an individual type curve. As this information is not available to initiate type curve matching, the program iterates on these three parameters by proposing a range of K, Pwf and Gi to initiate the search. It is assumed that usual information as Pi, μ_g, and T is known. The next step is the calculation of the coefficients of the quadratic deliverability equation *a* and *b*. A pressure step of twenty psia was considered to generate the reservoir flow rate equation (Qnow), since it offers great accuracy in the process of interpolation and curve comparison. Once *a*, and *b* coefficients are identified, gas reservoir flow rate (Qnow) is obtained by solving the quadratic gas flow equation given by equation:

$$q = \frac{-a + \sqrt{a^2 + 4a\left(P_p(P_i) - P_p(P_{wf})\right)}}{2b} \quad \text{--------------------(3.1)}$$

Converting the Pseudo flowing bottom hole pressure (Pp(Pwf) to conventional flowing bottom hole pressure (Pwf) and applying that into the well deliverability equation to obtain the well flow rate (Qwell), using the following equations:

$$P_{wf} = \left[P_{tf}^2 * e^s + \frac{6.67 \times 10^{-4} * q_g^2 * f * \overline{T}^2 * \overline{Z}^2}{d^5} (e^s - 1) \right]^{0.5} \quad \text{----------(3.2)}$$

where,

$$f = \frac{0.01603}{ID^{0.224}} \quad \text{-----------------------------------(3.3)}$$

Where,

$$s = \frac{0.0375 * \gamma_g * D}{\overline{Z} * \overline{T}} \quad \text{-----------------------------------(3.4)}$$

Then the program starts comparing the values of Qnow & Qwell to math them by using the logic & techniques for adjusting the value of flowing bottom hole pressure, till the match occurs.

Finally, the output results which include the combined-flow rates and their corresponding Pwf values will export to Excel to finish generating the type curves-by the hint of other inputs data the dimensionless rate and time will be calculated to plot the type curves. The definition of those two dimensionless parameters; dimensionless flow rate (q_D) and dimensionless time (t_D) are shown in Equations (3.5) & (3.6):

$$q_D = \frac{q}{q_i} \quad \text{-- (3.5)}$$

$$t_D = \frac{t \times q_i}{G_i} \quad \text{-------------------------------------- (3.6)}$$

3.3 Impact of the Well Tubing Length & Size on the Type Curves

The final phase of this methodology was to investigate the impacts and the influences of the well tubing sizes and lengths on the shape and behavior of the type curves. As mentioned earlier, the model output was exported to Excel spreadsheet to finalize the calculation of the two dimensionless parameters ;(q_D) And (t_D) as shown in Equations (3.5) & (3.6). After that the rest of calculations were performed to evaluate the influences of the tubing lengths and sizes to the behavior of the decline curves. It is important to know that all calculations based on the new definition for X_i:

$$X_i = \left(\frac{p}{z}\right)_{tsi} \div \left(\frac{p}{z}\right)_{tf} \text{ --- } (4.5)$$

After that, we start applying different values of Tubing size and Tubing diameters while the rest of the reservoir parameters as well as the well parameters were set to be constant . By doing that a hundreds of runs and calculations will be made till a clear picture will occur. Then, by changing the values of the tubing lengths and sizes we will have a clear picture of how those two important parameters will impact and influence the shape or the position of the production decline curve.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the results obtained to predict long – term gas production based on the result of the new developed model. Several cases are discussed in this chapter to analyze different proposed scenarios. Also, results for a set of all different cases are illustrated in tables. Graphic results and gas deliverability performance are presented in appendices A and B. Using the Model "Progress" output as well as Excel spread sheet the following results were obtained after been Tested and satisfied the enclosed parameter's range.

4.1 Initial Result

The first initial result was to show impact of the dimensionless parameters, X_i, and the non – Darcy flow ratio, F_{NDi}. Figure 4.1 shows that, by changing the wellhead pressure values - X_i will have different value and according to the previous work, it was proven that, X_i affects the position of the curve.

Table 4.1, displays the data as well as the range that applicable to generate this type curves- showing the effect of the dimensionless parameters, X_i.

Table 4.1: Tubing Lengths & Sizes range data for Different Ptf

Pi	**Ptf**	**Tubing length**	**Tubing Diameter**
psia	**psia**	**ft**	**inch**
2000	**420 - 1600**	**4000 - 4300**	**2.441**

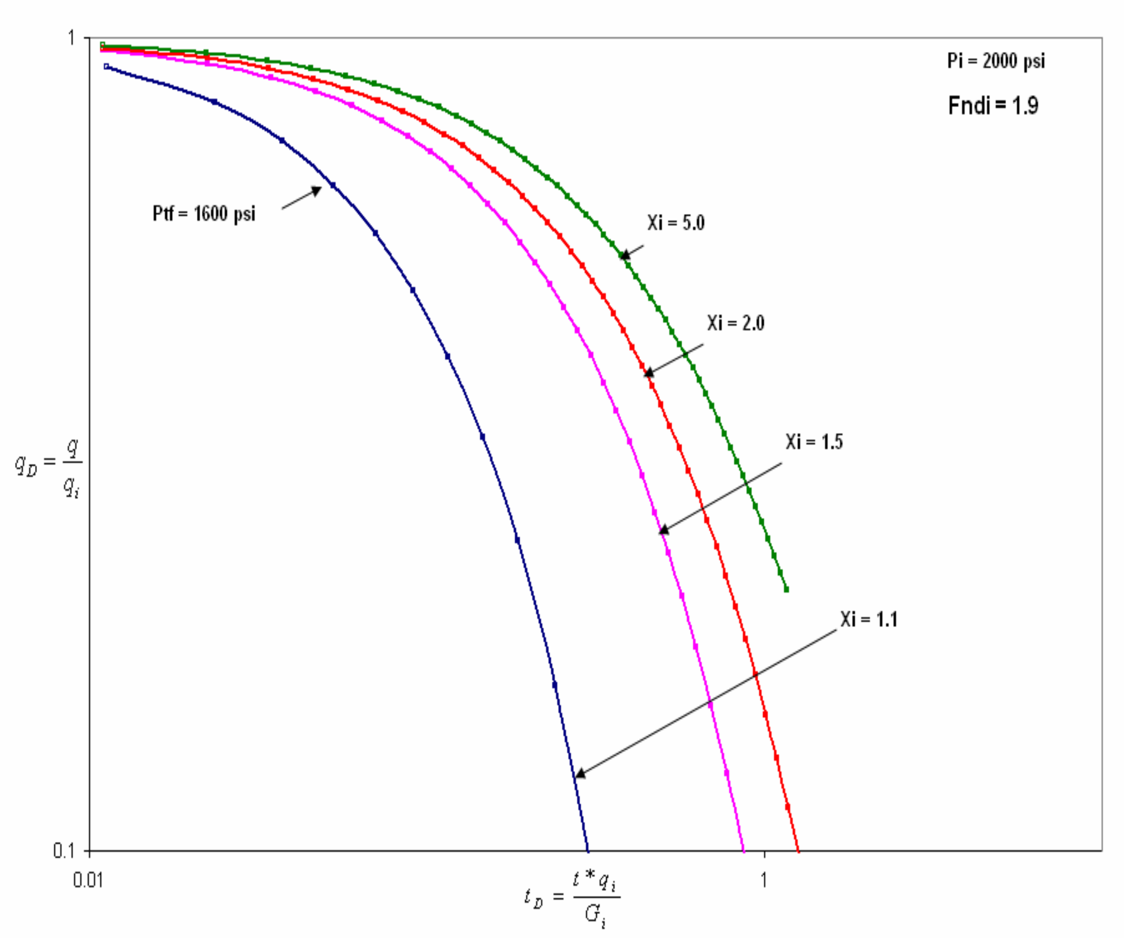


Figure 4.1: Effect of Tubing Length & Size in a different X_i values.

The second initial result was to show the impact of the non-Darcy effect on the behavior of the type curves; as mentioned before, the previous works determined that , the non-Darcy flow ratio, F_{NDi} affects the shape of the decline curve ; there fore, Figure 4.2 proved that, which reflect the successful generation of the new type curves.

Table 4.2, displays the data as well as the range that applicable to generate this type curves- showing the effect of the non- Darcy effect F_{NDi}

Table 4.2: Tubing Lengths & Sizes data for Different Fndi.

Pi	**Ptf**	**Tubing length**	**Tubing Diameter**
psia	**psia**	**ft**	**inch**
2000	**1000**	**4000**	**2.441**

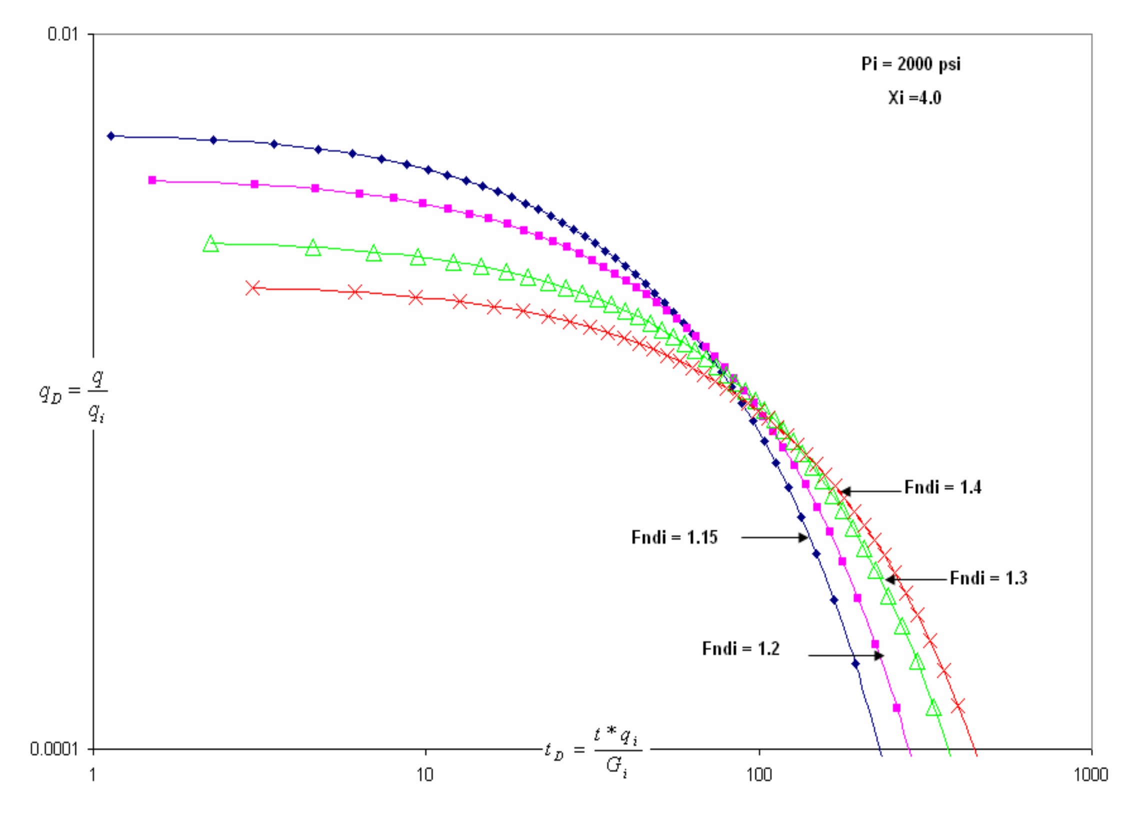


Figure 4.2: Effect of Tubing Length & Size in a different F_{NDi} values.

4.2 Effect of Tubing Length (TL)

Figure 4.3 shows the impact of the tubing length; four different curves plotted for various tubing lengths as described in table 4.3. The next three consecutive graphs show that: all curves lie on each other generating an identical single curve.

Table 4.3: Basic Data Used for Tubing Length Effect

Pi	**Ptf**	**Tubing length**	**Tubing Diameter**
psia	**psia**	**ft**	**inch**
2000	**1000**	**4000 - 4300**	**2.295**

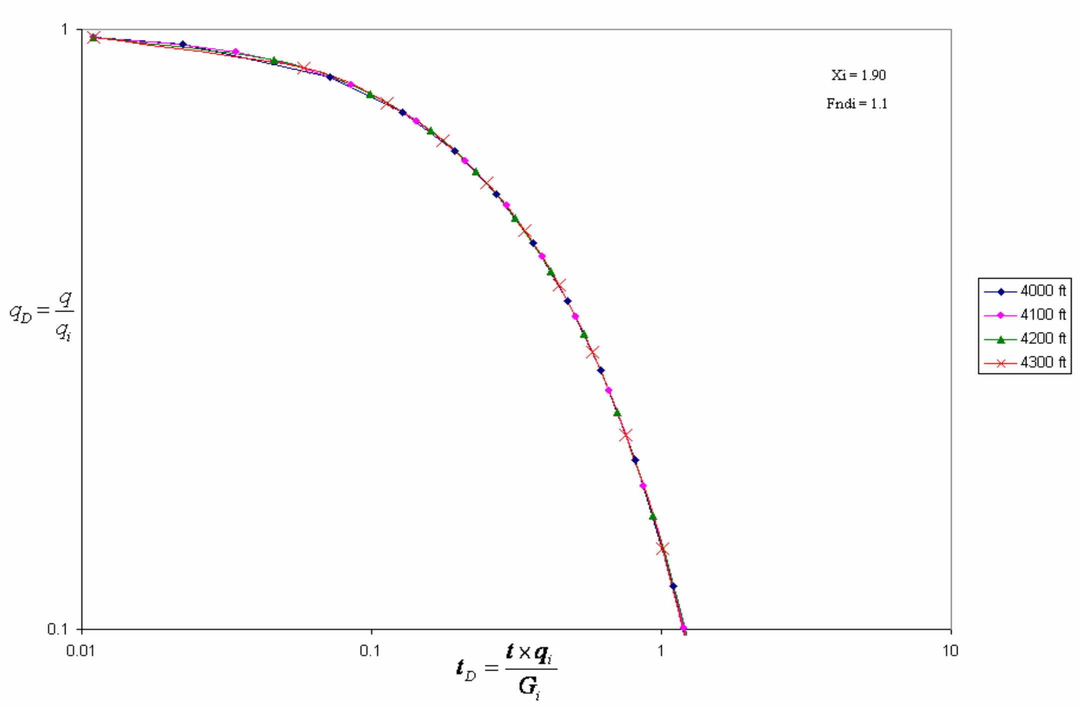


Figure 4.3: Effect of Tubing Length for F_{NDi} = 1.10.

Figures 4.4 and 4.5 below reflect the impact of tubing length, and show the type curves behavior for different values of F_{NDi} s:

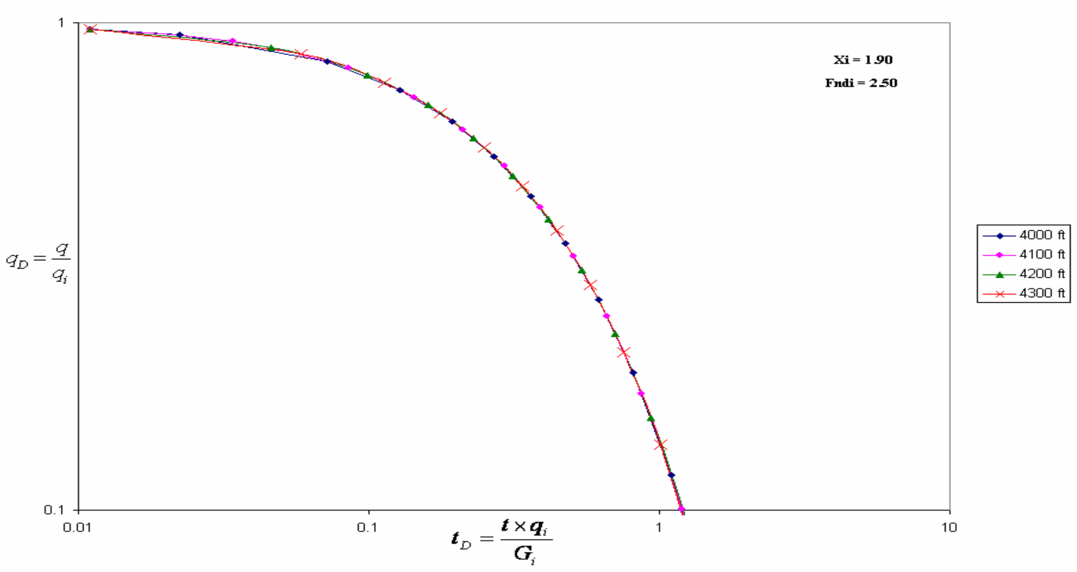


Figure 4.4: Effect of Tubing Length for F_{NDi} = 2.50.

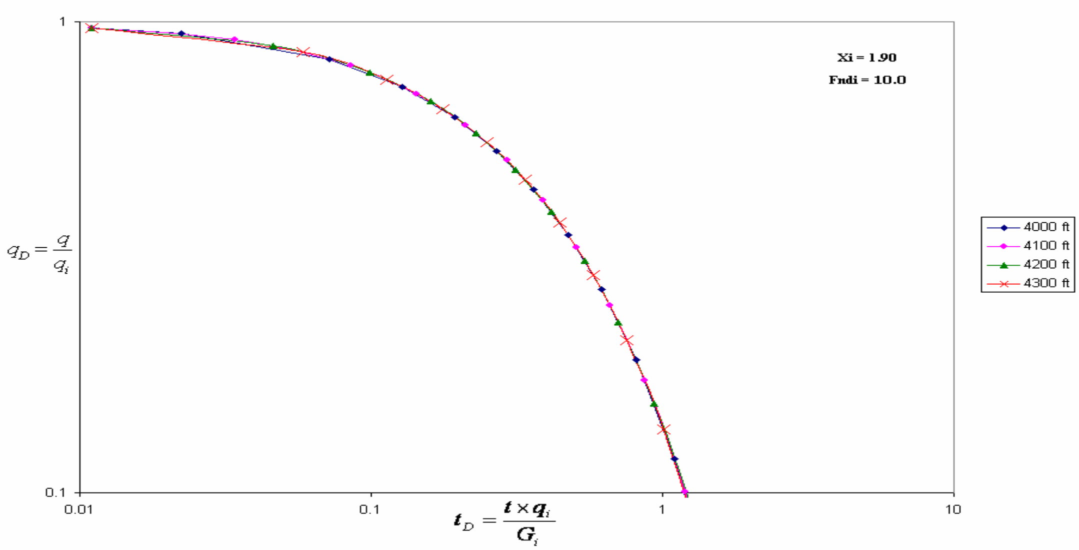


Figure 4.5: Effect of Tubing Length for F_{NDi} = 10.0.

Figures 4.6 and 4.7 below reflect the impact of tubing length, and show the type curves behavior for different values of X_i s:

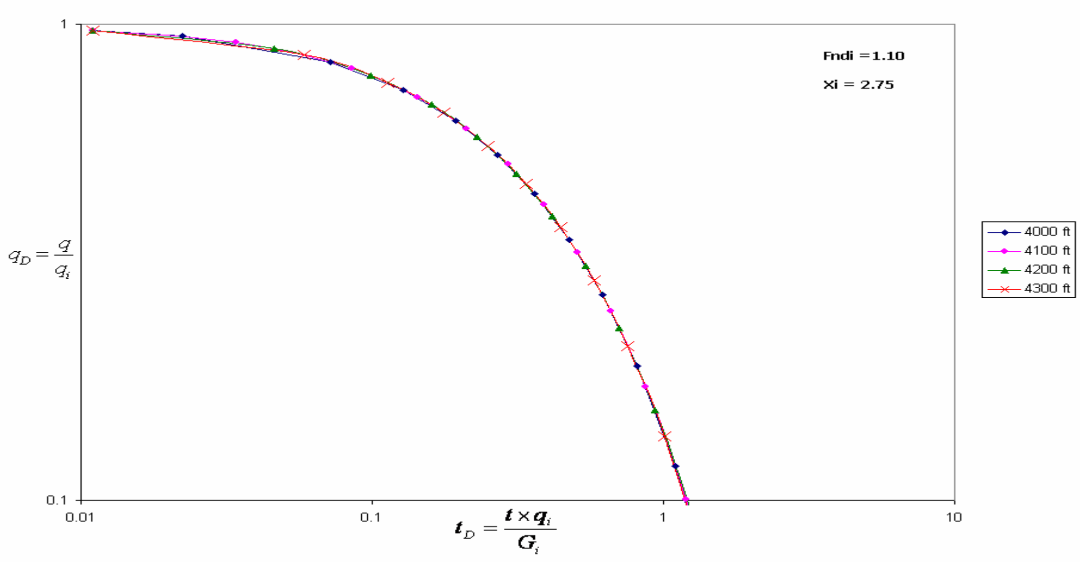


Figure 4.6: Effect of Tubing Length for $X_i = 2.75$.

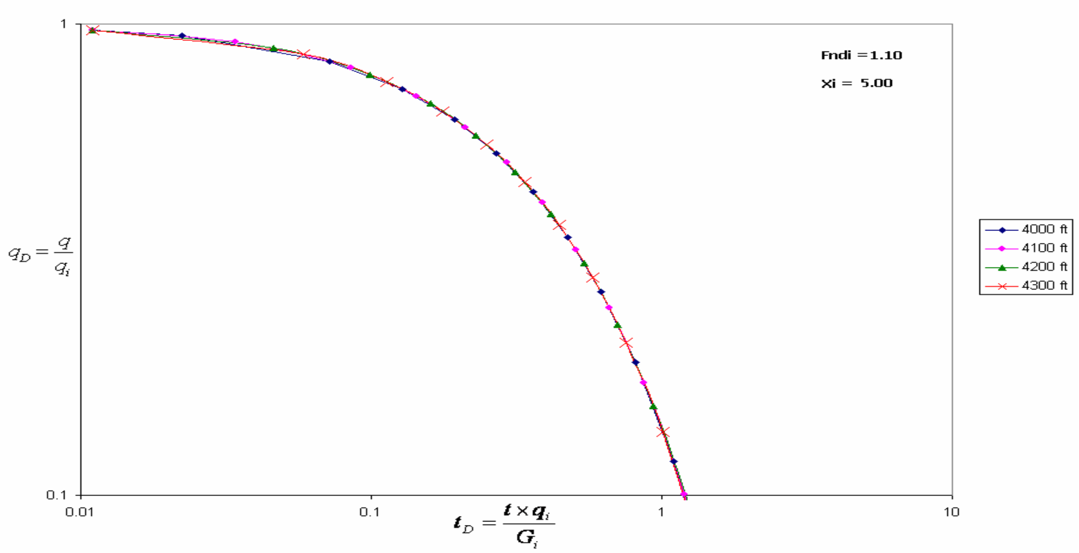


Figure 4.7: Effect of Tubing Length for $X_i = 5.0$.

4.3 Effect of Tubing Size (ID)

Figure 4.8 shows the impact of the tubing size; four different curves plotted for various tubing sizes as described in table 4.4. The next three consecutive graphs show that: all curves lie on each other generating an identical single curve.

Table 4.4: Basic Data Used for Tubing size Effect.

Pi	**Ptf**	**Tubing length**	**Tubing Diameter**
psia	**psia**	**ft**	**inch**
2000	**1000**	**4000**	**1.50 – 4.00**

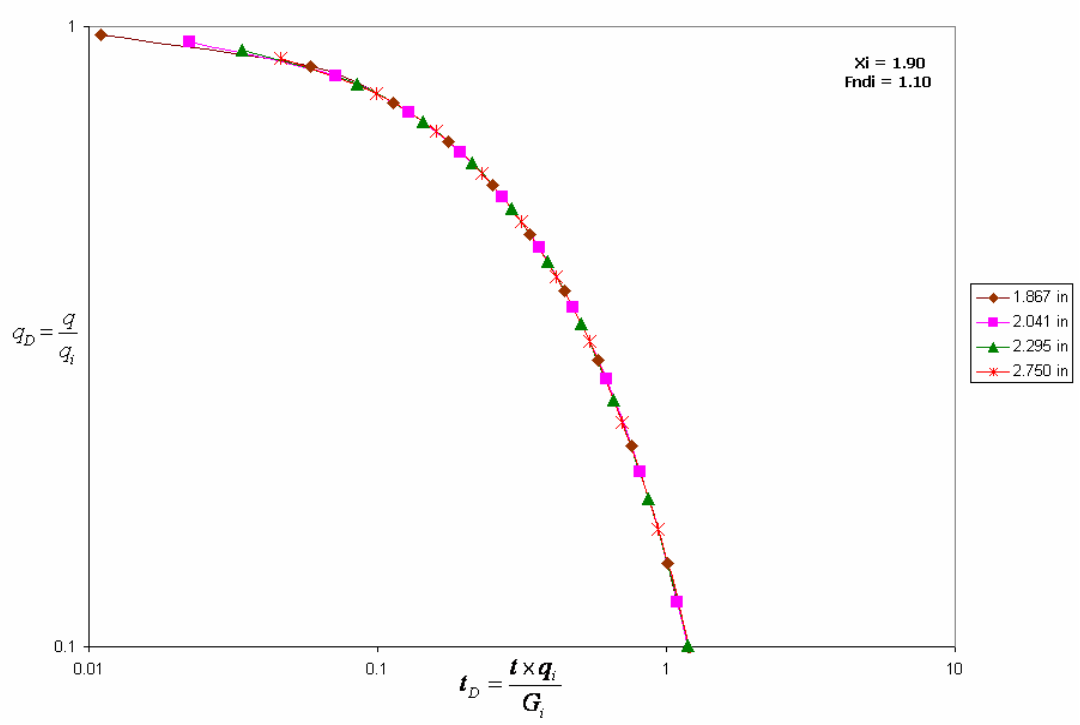


Figure 4.8: Effect of Tubing Internal Diameter for $F_{NDi} = 1.10$.

Figures 4.9 and 4.10 below reflect the impact of tubing size, and show the type curves behavior for different values of Fndis:

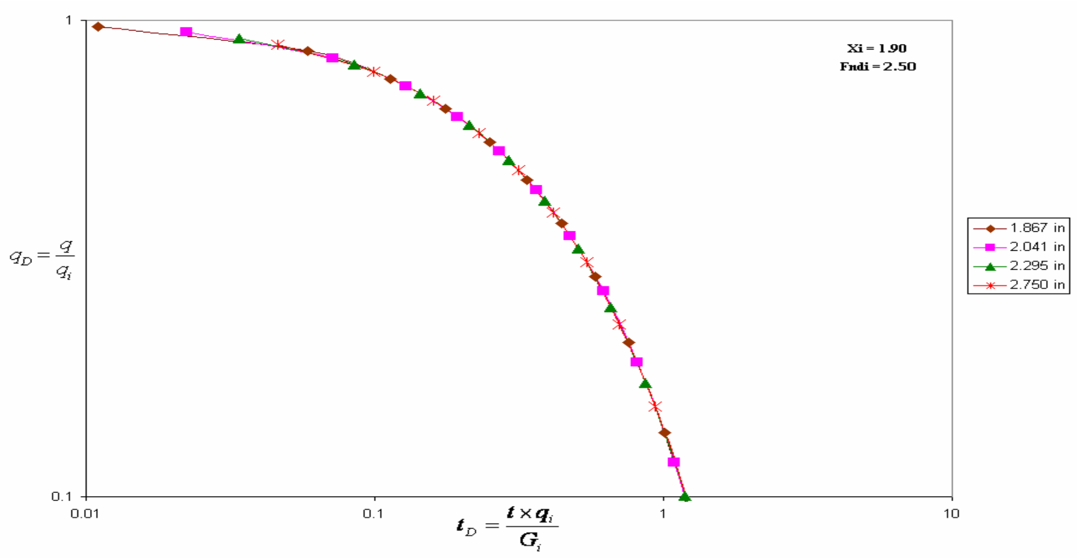


Figure 4.9: Effect of Tubing Internal Diameter for F_{NDi} = 2.50.

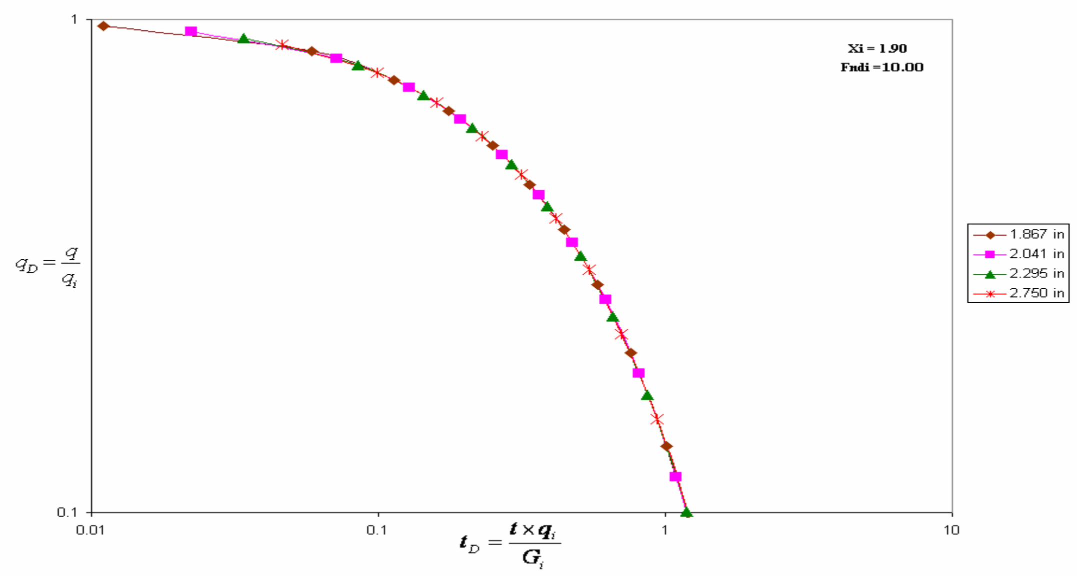


Figure 4.10: Effect of Tubing Internal Diameter for F_{NDi} = 10.0.

Figures 4.6 and 4.7 below reflect the impact of tubing length, and show the type curves behavior for different values of Xis:

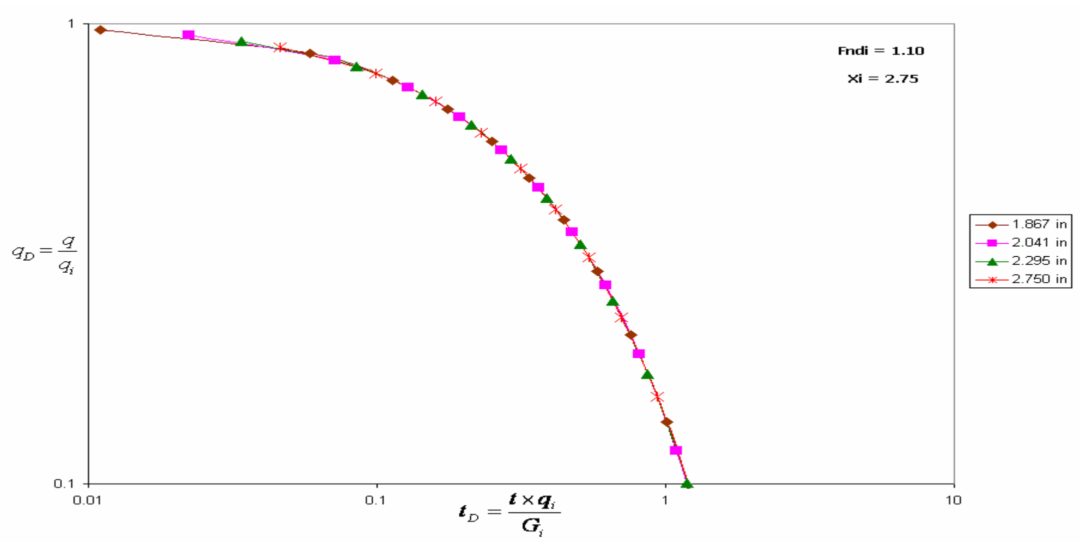


Figure 4.11: Effect of Tubing Internal Diameter for $X_i = 2.75$.

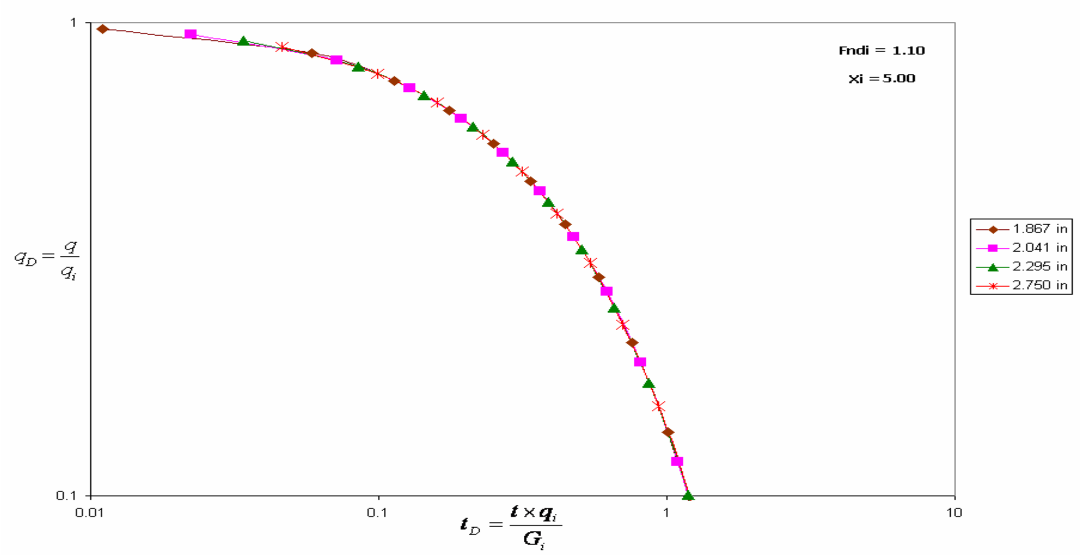


Figure 4.12: Effect of Tubing Internal Diameter for $X_i = 5.0$.

The results show that , even by changing the dimensionless parameters X_i values, (which here was redefined for the first time, as a ration between the initial shut –in pressure to the well head pressure), all different type curves lied on each other generating an identical single curve. This result obtained regardless of the length of the well tubing (TL).

Similar results will be obtained when the Tubing Size (ID) is variable-still all curves lie on each other for all scenarios.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The main focus of this research was to develop a new model for combining the gas deliverability equation for reservoir and well and using that generate and introduce a new set of type curves that could be used to evaluate and predict production data.

The research took into account all geological and reservoir data to determine the impacts of each on the production.

Based on the results, the following conclusions and recommendations were made:

-A new unique model was generated to combine the gas deliverability equation for both reservoir and the well.

-The accuracy of the new model has been tested and verified by generating hundreds of runs using different scenarios for the reservoir and the well inputs.

-A general model has been developed and utilized to generate a set of production decline curves for gas well production forecasting.

-The model was also utilized to study the decline behavior of gas wells when the Tubing length and sizes are change.

-It was found that, the decline behavior of a gas well after the tubing sizes and lengths have been changed, remained as it was.;i.e they do not make any impact on the decline curve behavior.

Recommendations:

-Development of scientific, user friendly computer tool integrating the correlations and the type curves for a condensate gas reservoir.

-The impact of fractured well to the type curve behavior.

REFERENCES

1. Fetkovich, M.J., "Decline Curve Analysis Using Type Curves," Presented SPEAIME, Las Vegas, Nevada. 1973. (SPE Serial No. 4629).

2. Smith, R. V.: “Unsteady-State Gas Flow into Gas Wells,” Jour. PetTech. (M ay 1962), pp.549.

3. Carter, R.D., "Type Curve for Finite Radial and Linear Gas Flow System: Constant-Terminal-Pressure Case," SPEJ, Oct. 1985.

4. Benjamin H. Thomas, “Predicting Gas Well performance Using Decline Curves”, Morgantown, WVU. Master thesis, 1997.

5. Fraim, M.L., Wattenbarger, R.A., “Gas Reservoir Decline-Curve Analysis Using Type Curves with Real Gas Pseudo-pressure and Normalized Time," paper SPE Serial No. 14238.

6. Gringarten, C.A., "Type-Curve Analysis: What It Can Do and Can Not Do," JPT, January 1987.

7. Aminian, K., Ameri, S., Stark, J.J., Yost II, A.B., "Gas Well Production Decline in Multiwell Reservoirs," JPT, December 1990, P.1573-1579.

8. 20. Abbit, W.E., Ameri, S., Aminian, K.,: " Polynomial Approximations for Gas ,Pseudo pressure and Pseudotime", paper SPE 23439, presented at the SPE Eastern Regional Meeting, Lexington, KY, Oct 1991.

9. Dascalescu, B.W., "Production Behavior of Gas Wells During the Unsteady State Period A Type Curve Approach," Master's Thesis, West Virginia U., Morgantown, WVU. 1994.

10. Jonathan Diazgranados, “Gas Production Forecasting Using Automatic Type Curve”, Morgantown, WV. Master Thesis, 2000.

11. Aminian, K., Ameri, S., Beg, N., Yost II, A.B., "Production Forecasting of Gas Wells Under Altered Conditions," Presented at SPE Eastern Regional Meeting, Pittsburgh, PA. September 1987.

12. Abidi, R.H., "The Effect of Pressure Dependent Gas Properties on the Performance of Gas Well," Morgantown, WV. Masters Thesis, 1992.

13. Ram **G.** Agarwal**,** SPE, David C. Gardner**,** SPE, by, Stanley William. Kleinsteiber, SPE, and Del D. Fussell**,** Amoco, "Analyzing Well Production Data Using Combined-Type-Curve and Decline-Curve Analysis Concepts" Paper SPE, published in 1999.

14. Ferhat Zelghi, Sonatrach Inc.; Djebbar Tiab, U. of Oklahoma; Mohamed Mazighi, Sonatrach Inc. "Application of Decline Curve Analysis in Gas Reservoirs Using a Newly Developed Fitting Equation**"** Paper SPE , 75532-MS, published in 2001.

15. T. Marhaendrajana, Schlumberger, and T.A. Blasingame, Texas A&M "Decline Curve Analysis Using Type Curves - Evaluation of Well Performance Behavior in a Multiwell Reservoir System" paper SPE 71517, published in 2001.

16. H. Pratikno, ConocoPhillips (Indonesia); J.A. Rushing, Anadarko Petroleum Corp.; T.A. Blasingame, Texas A&M U "Decline Curve Analysis Using Type Curves - Fractured Wells" SPE , 84287-MS, published in 2003.

17. Samson Tesfaslasie, "Automatic Type Curve Matching For Predicting Gas Wells Production", Morgantown, WVU. Master Thesis, 1999.

18. Aminian, Kashy. Natural Gas Storage, PNGE 471. West Virginia University: Spring 2007.

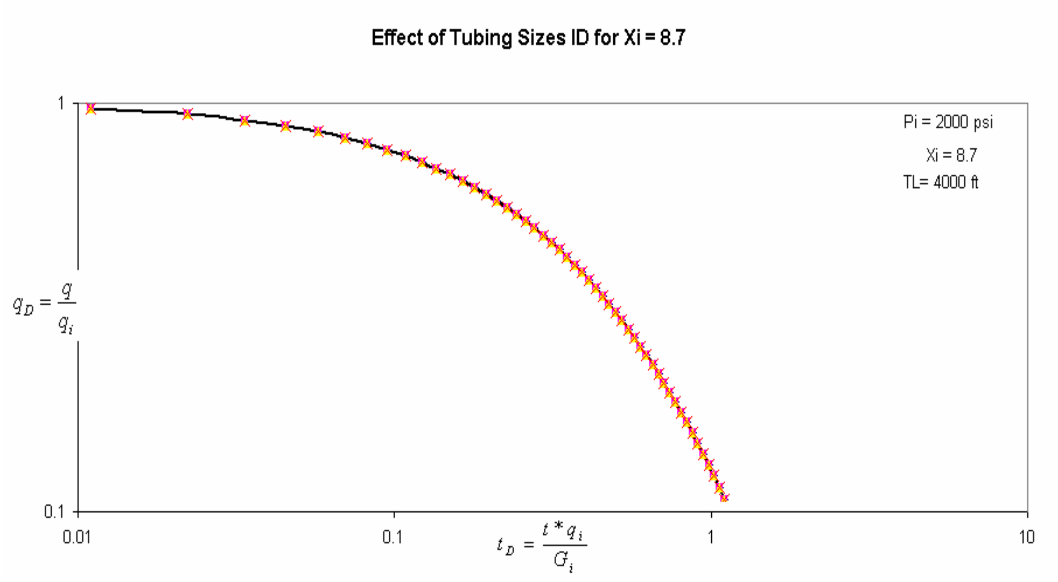
19. Aminian, Kashy. Natural Gas Engineering, PNGE 470. West Virginia University: Fall 2005.

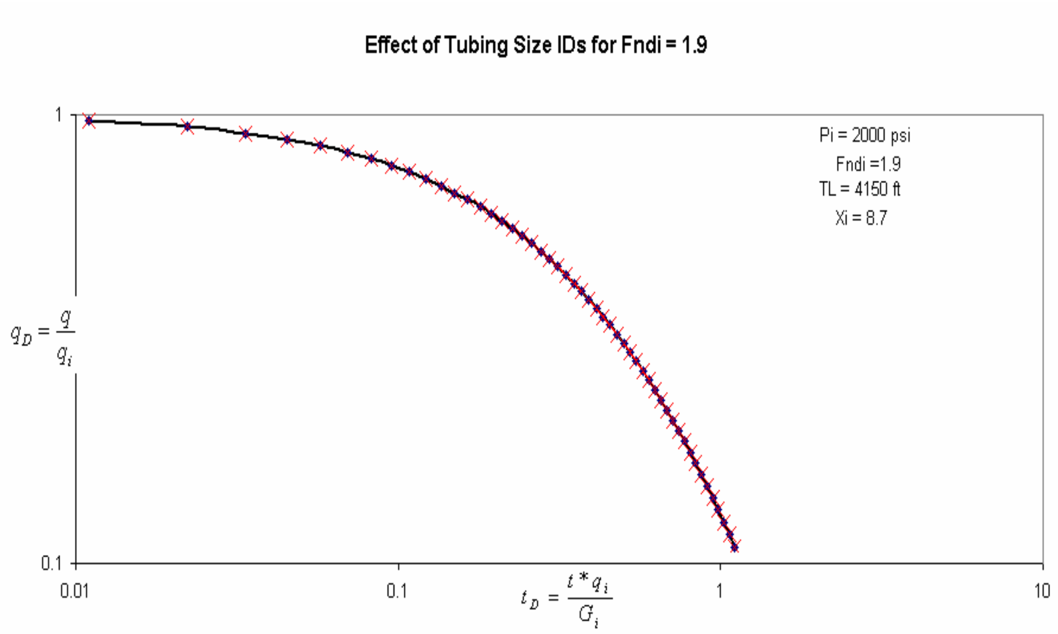
20. Aminian, K., Ameri, S., Hyman, M., "Production Decline Type Curve For Gas Wells Producing Under Pseudo Steady State Condition," paper SPE 15933, presented at 1986 SPE Eastern Regional Meeting, Columbus, OH. Nov. 12-14.

APPENDIX

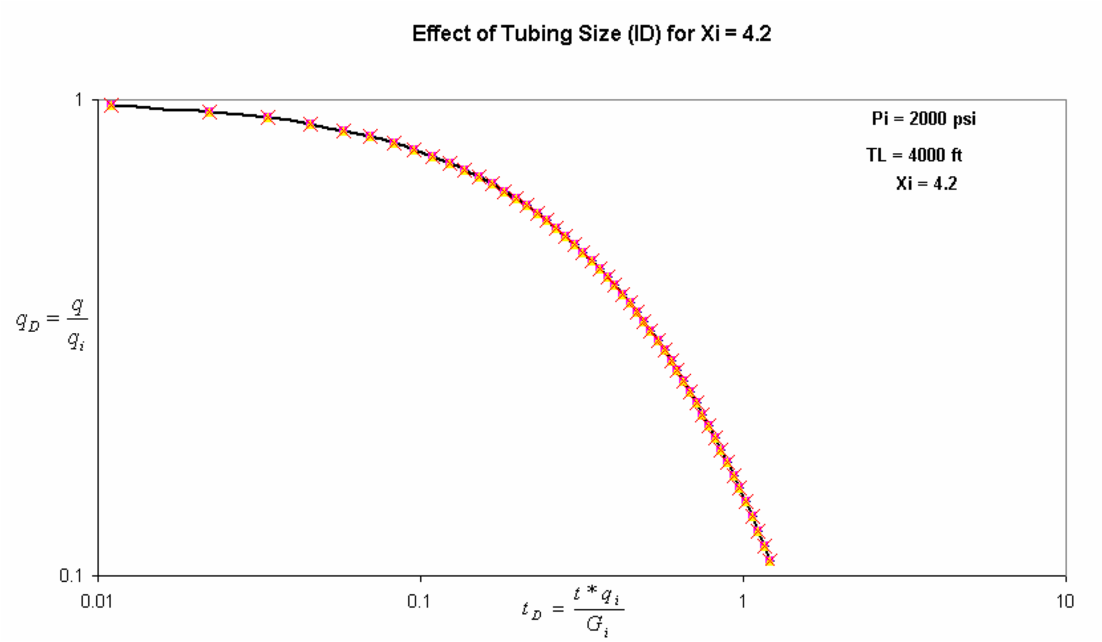
Appendix A

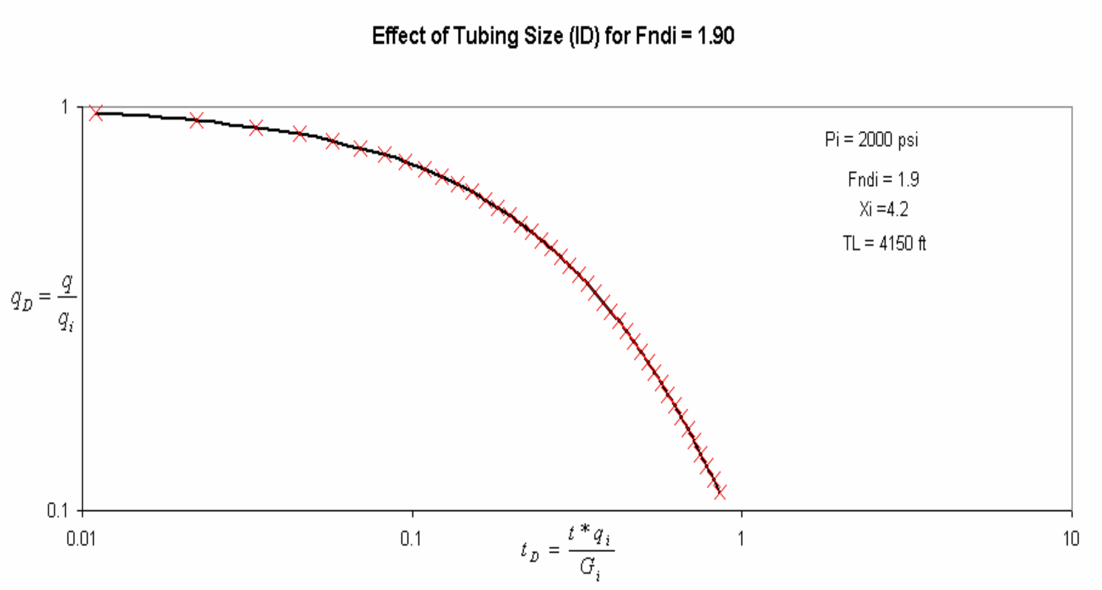
Effect of Tubing Size (ID) with Ptf = 250 psi



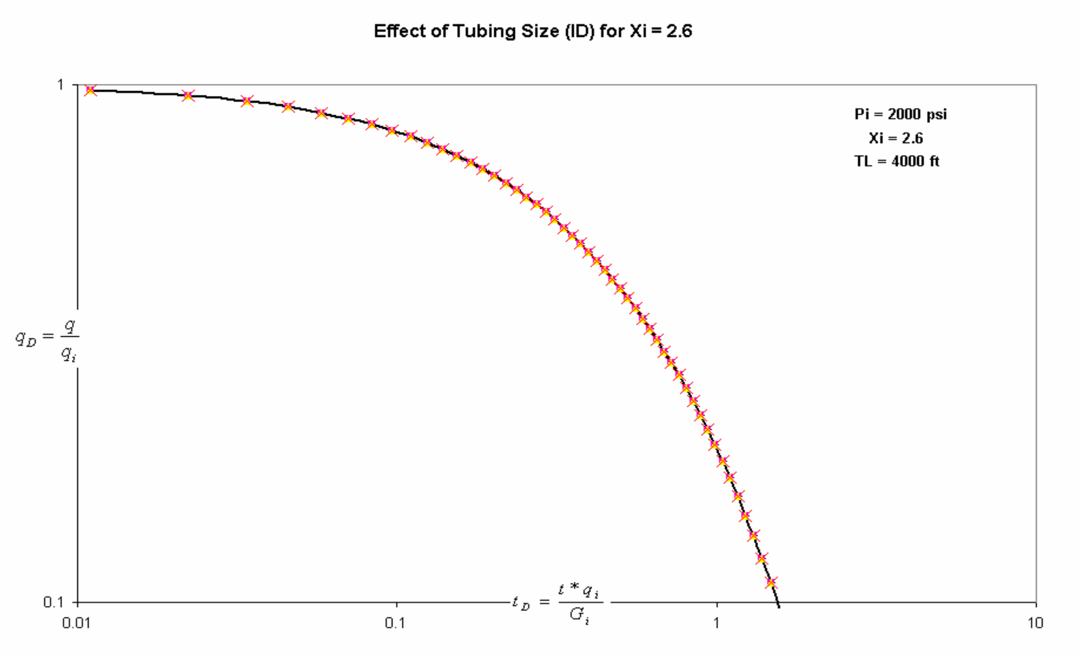


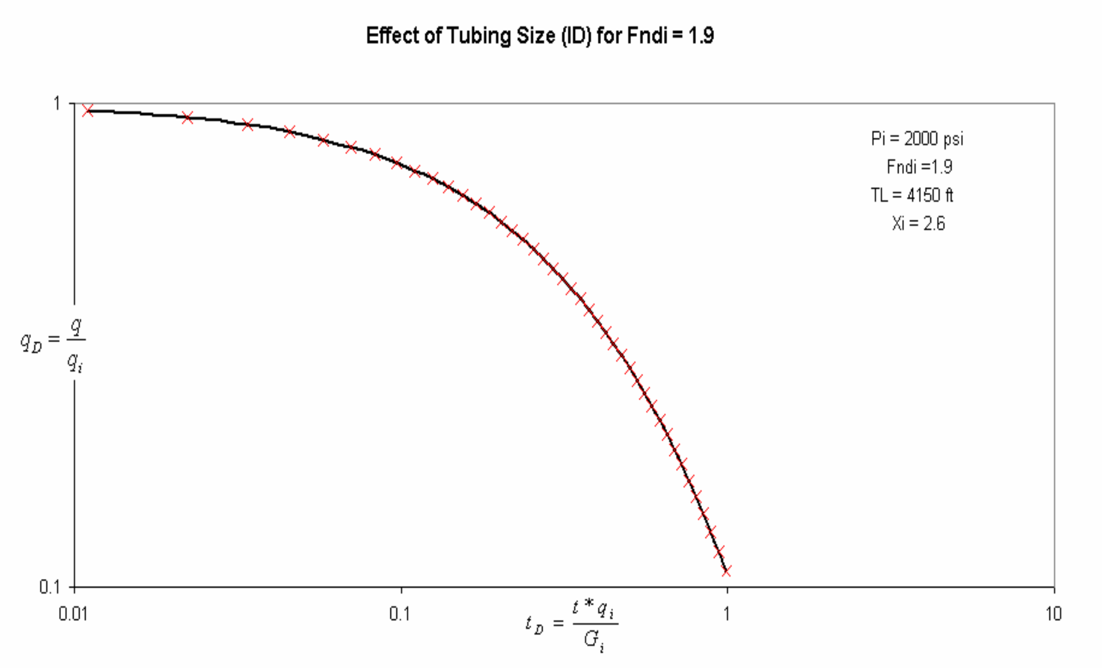
Effect of Tubing Size (ID) with Ptf = 500 psi



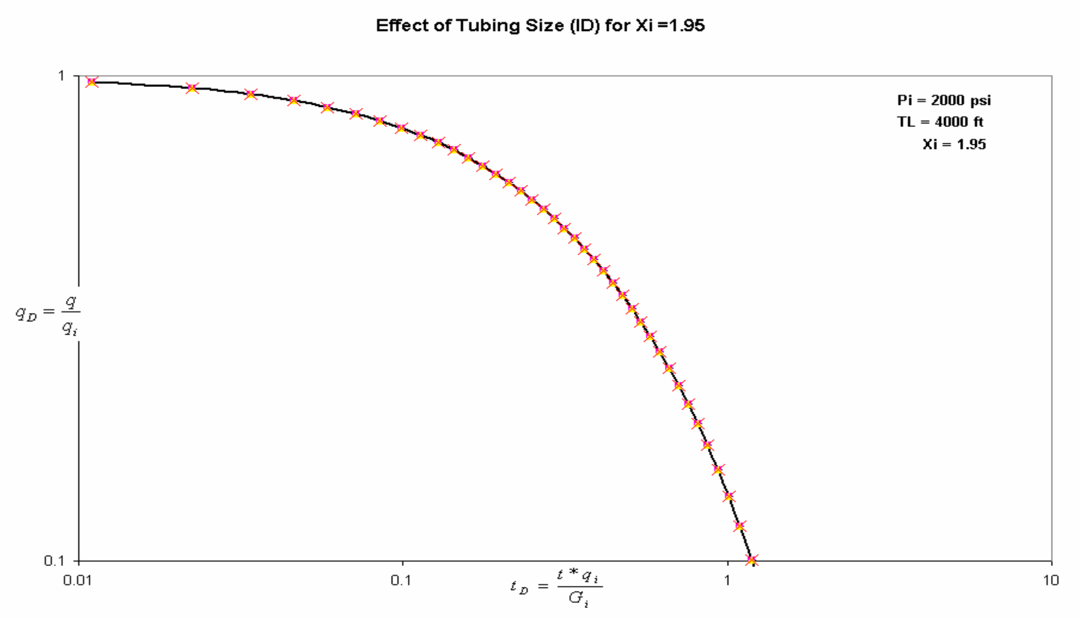


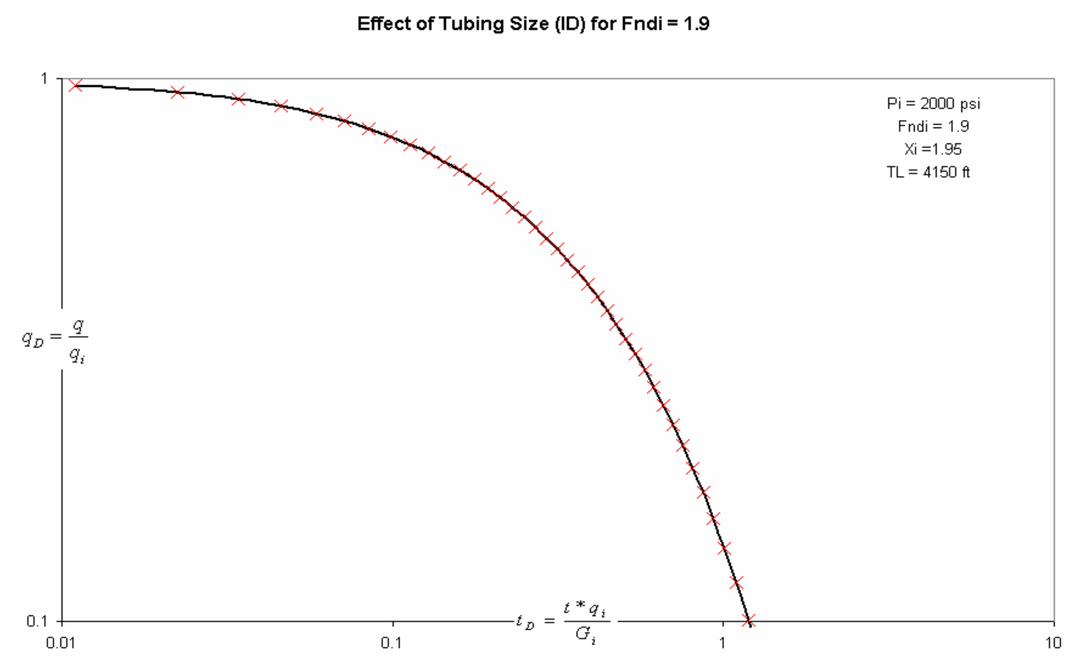
Effect of Tubing Size (ID) with Ptf = 750 psi



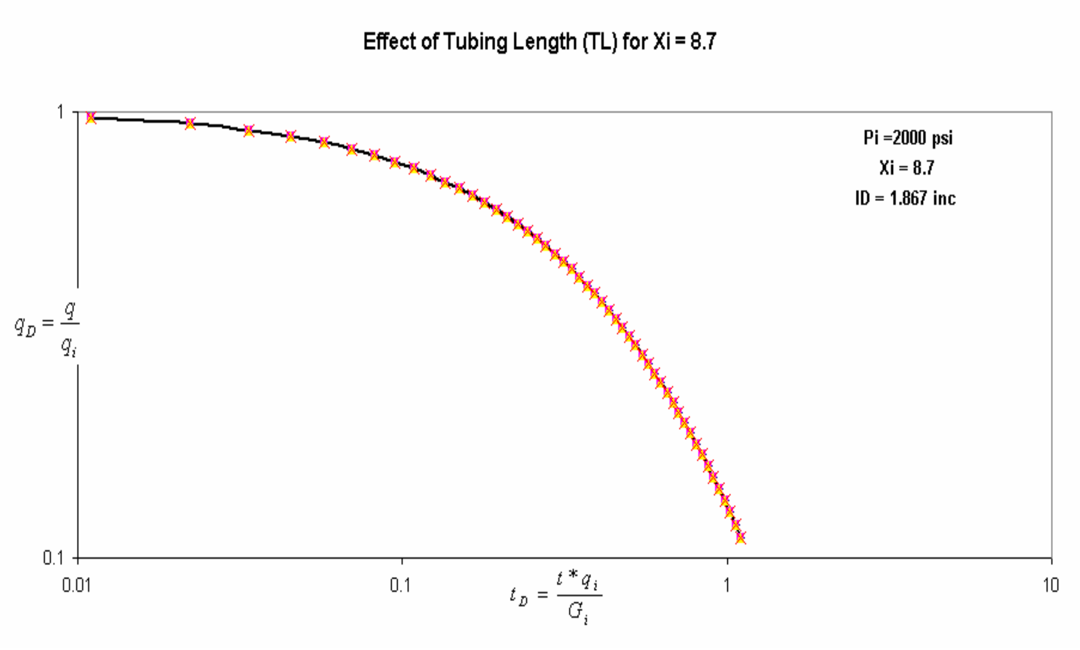


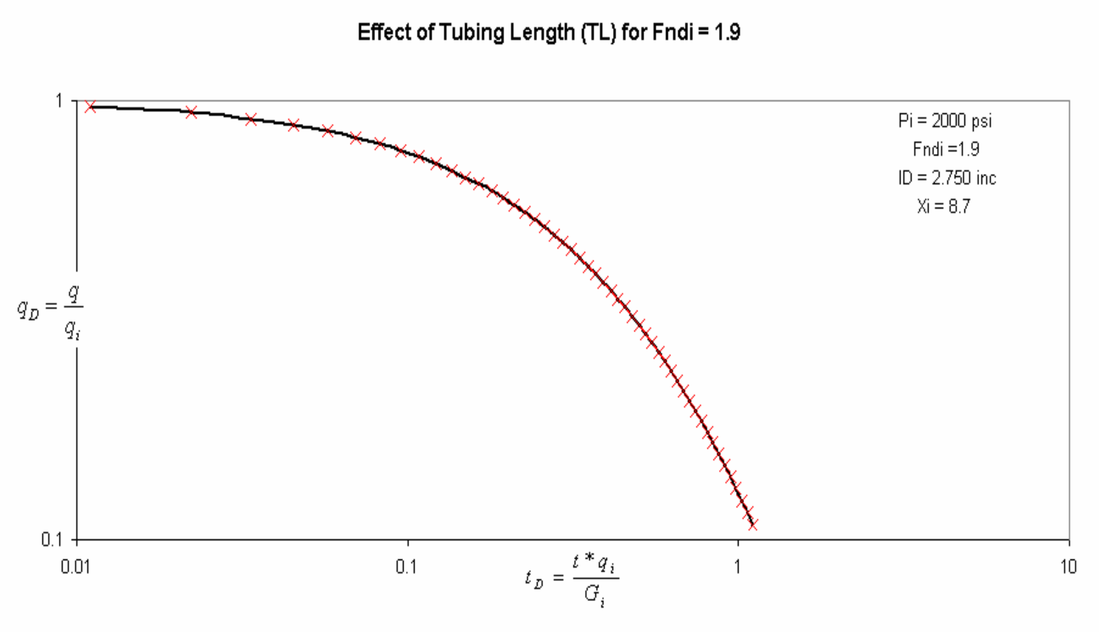
Effect of Tubing Size (ID) with Ptf = 1000 psi



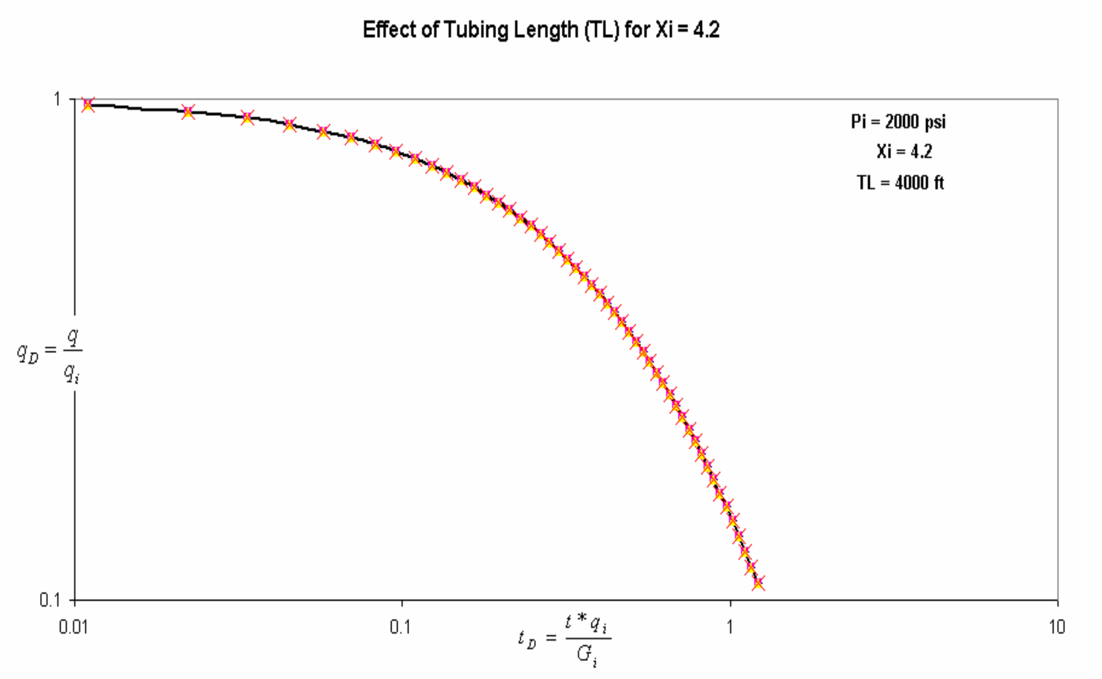


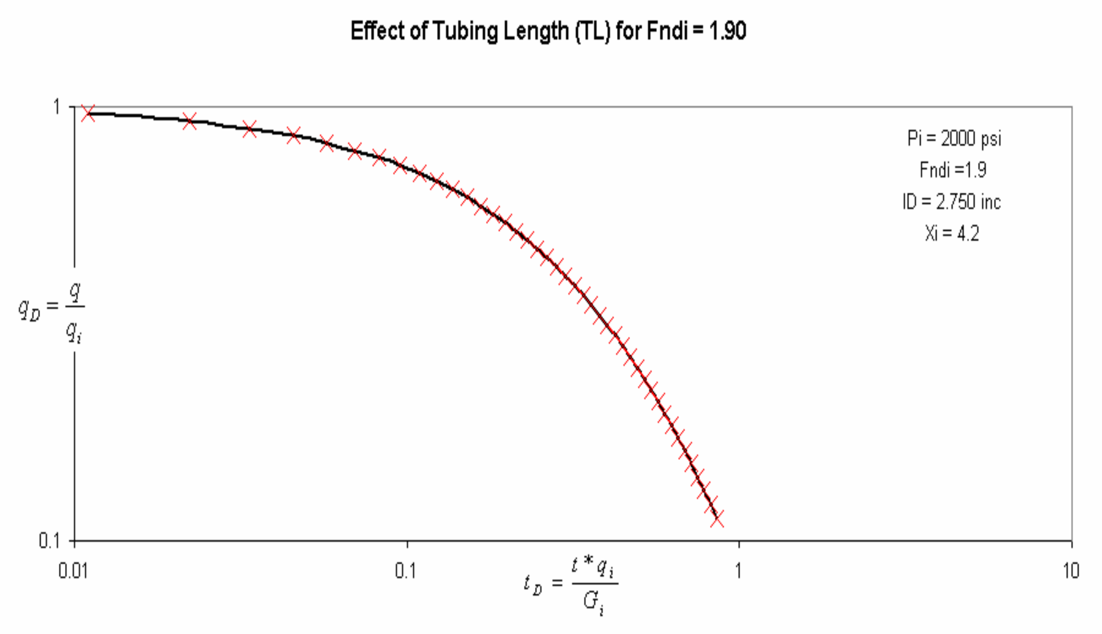
Effect of Tubing Length (TL) with Ptf = 250 psi



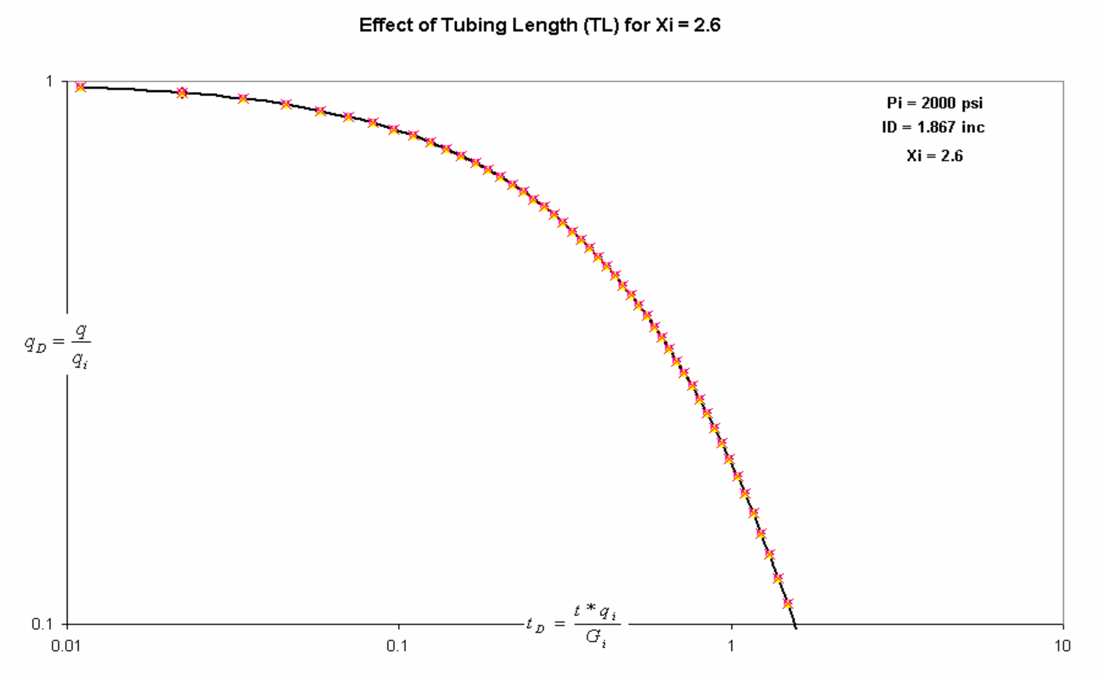


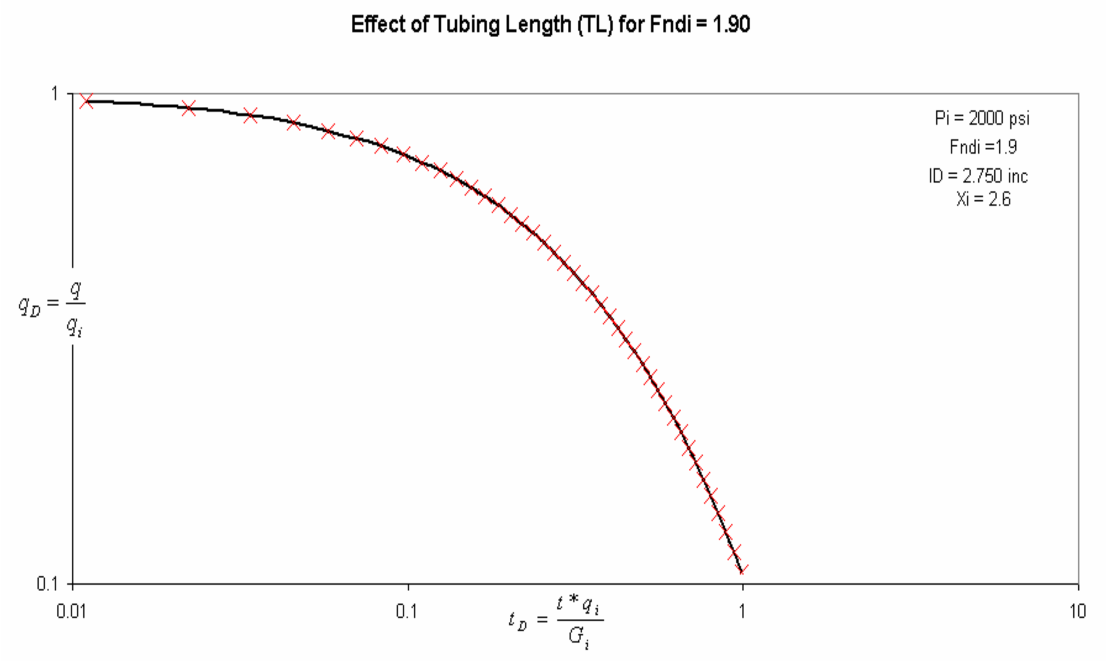
Effect of Tubing Length (TL) with Ptf = 500 psi



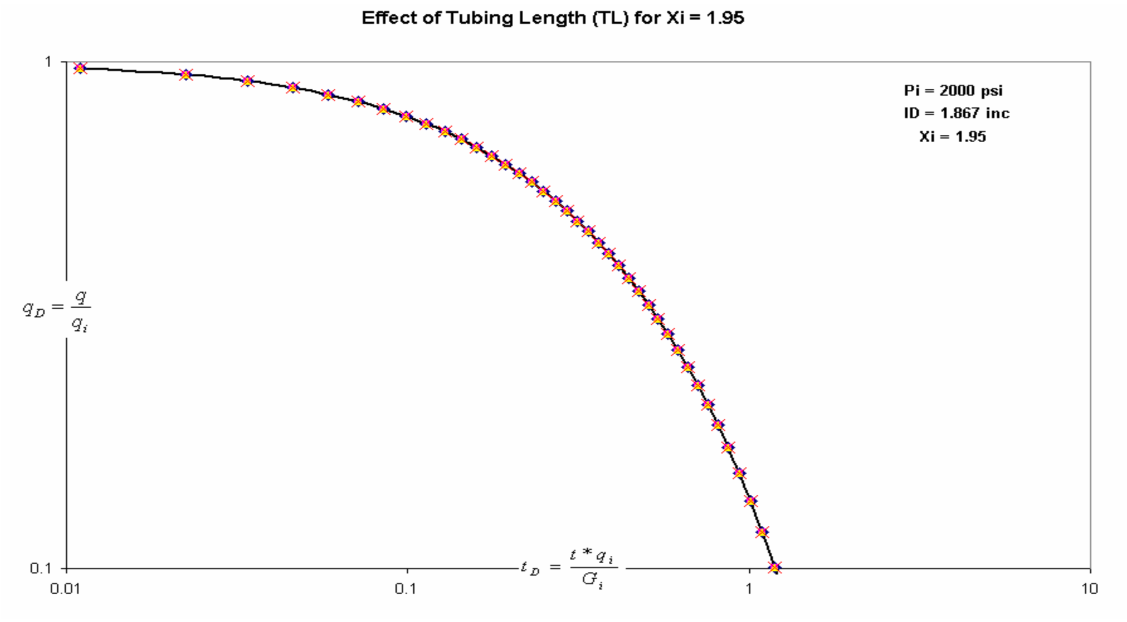


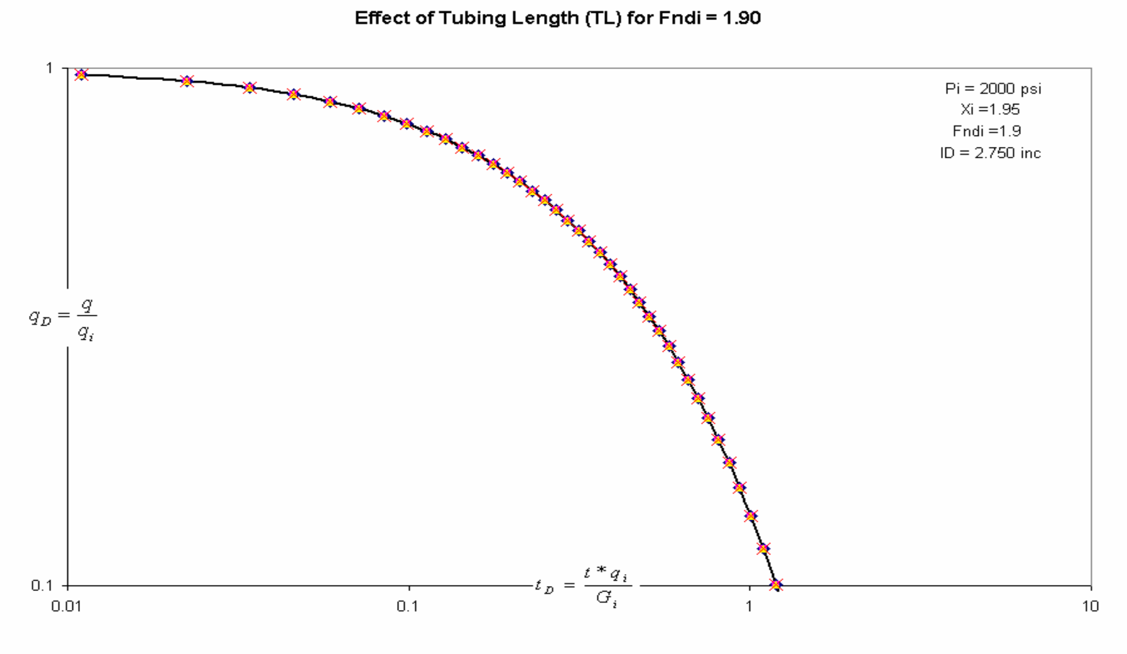
Effect of Tubing Length (TL) with Ptf = 750 psi



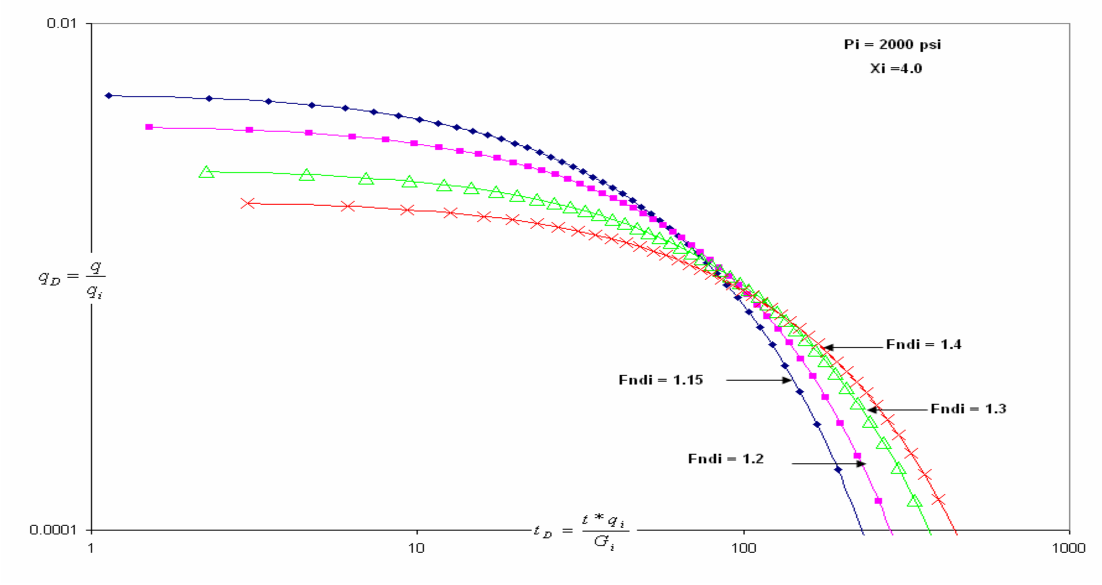


Effect of Tubing Length (TL) with Ptf = 1000 psi





Effect of Non- Darcy to the Type Curve Shape



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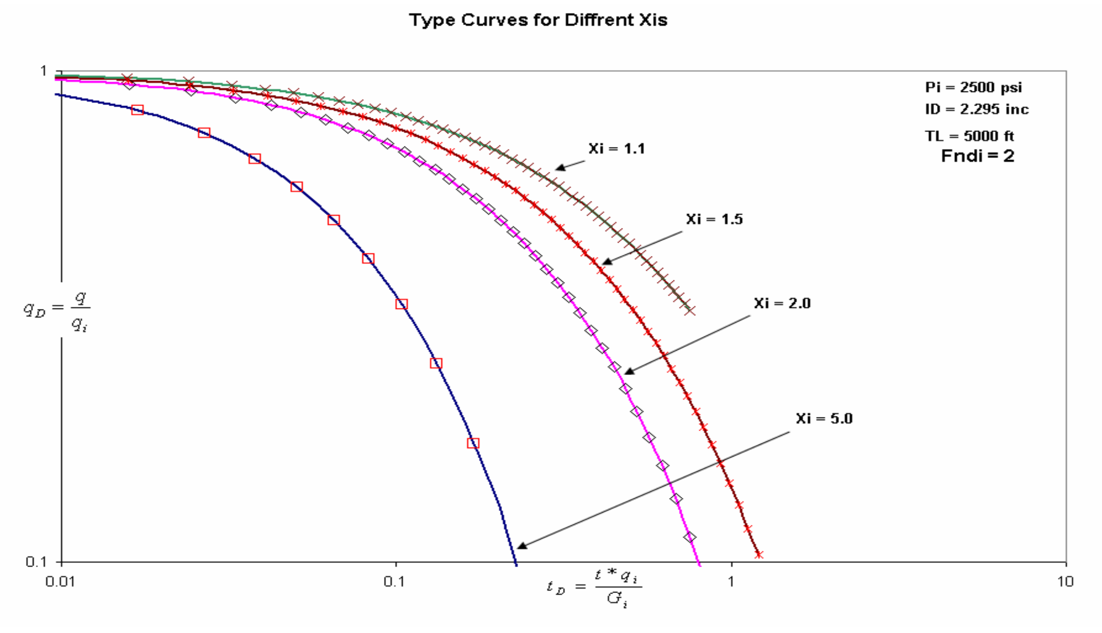

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