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Application of Couette Flow of Non-Newtonian Power-Law Fluids in dynamic surge/swab pressure prediction

[1]Mohammed Abdul Ameer Al-Humairi and [2]Faleh H. M. Almahdawi
[1] Petroleum Dept -College of Engineering
University of Misan, Iraq
[2] Department of Petroleum, College of Engineering
University of Baghdad, Iraq
dr.alhumairi@uomisan.edu.iq.

Abstract:

The displacement of drilling mud when drill pipes or casing moving, create a pressure differences in the bore hole. The displacement velocity oversees magnitude the pressure variation that can subtract or add to the hydrostatic pressure of the drilling fluid which can be create swab or surge pressure in that order. It is known that the running and pulling process of different types of pipes inside a drilling mud that occupied bore hole, lead to generate swab pressure or surge.

Forecast of surge pressure or swab pressure is of commercial status when drilling the wells somewhere the hydrostatic pressure has to be kept within specific limits to avoid the circulation lost and drilling mud influx toward the fluid of a formation. The drilling engineering have to calculate best potential ways of calculation swab pressures and surge pressure, when drilling a well, within to minimize the problems possible to happen.

The moving of pipes inside the well, is almost like a cylinder movement, concentrically located in a drilling fluid occupied outer cylinder. This occurrence can be a wide range of uses when solve some problems in chemical, petroleum, ceramic industries, and mechanical,

Key word: Non- Newtonian, surge pressure, swab pressure.

Introduction

phenomenon of Couette flowing define as two cylinders having a common axis are placed, one of the cylinders is fixed and the other one is moving with known velocity. This phenomenon represents or can be as application for the well, when consider the well wall is the fixed cylinder, while the moving cylinder represent the casing or the drill pipe. The drilling mud speed is related with the speed of moving pipes inside the borehole. Figure (1) illustrate the geometry of the phenomena.

During the drilling job, the drilling fluid movement faced when pulling and running the drill pipe or casing inside the borehole may cause momentary differences in drilling mud pressure. the variation of hydrostatic pressure of the drilling mud inside the bore hole can be expressed as

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surge pressure or swab pressure, the amount of the swab or surge pressure is a function of the inner pipe speed, the shape and geometry of the annuals, and the drilling mud properties.

Couette flow application in petroleum industry is helpful to estimate the swab pressure or surge pressure and the application of Couette flow application it can be helpful in nature and also finds its applications in mechanical productions, chemical applications. The causes of swab and surge pressures have been studied by numerous researchers since the early days of drilling.

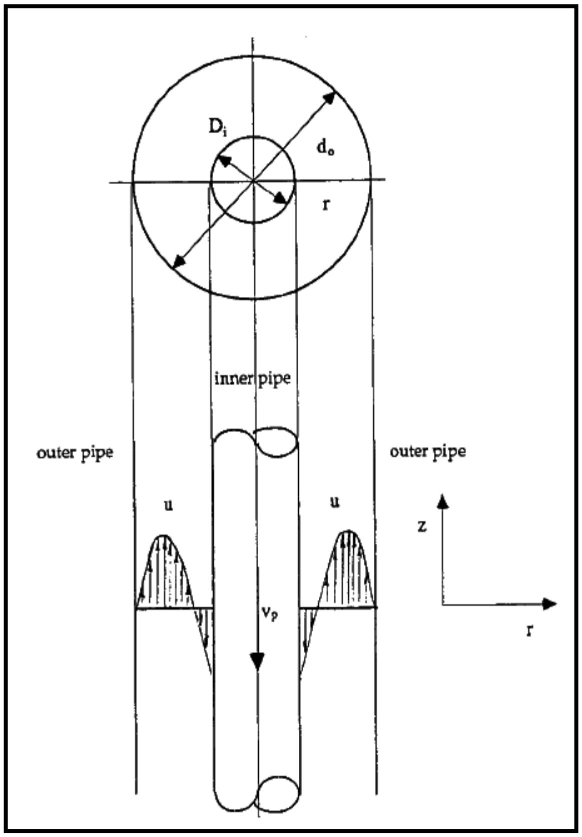

Fig. (1) Geometric Representation of a Concentric Annulus

The maximum pressure come upon pipes trips or exchange are necessary for making suitable for the well-completion discussion. The estimation of surge pressure and swab pressure, is a serious importance in oil and gas wells, which they maintain of the pressure must be within narrow limits for the pressure of pore fracture. It is also plays a main role in moving casing, mainly with narrow annular clearance.

estimation is very significant when arrangement of drilling a well. Excessive Swab pressure or surge pressure may cause fluid of the formation to entering the annulus of the well, initiating a

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endangered blow- out. The surge pressure when high may cause loss of drilling mud circulation it can happen rapidly when the formation is fractured or gradually when continuous movement of drilling mud toward the formation with high permeability.

When the drilling mud go into the created cracks in the formation that lead to a decrease in the drilling mud level, lead to a drop in the drilling mud pressure (hydrostatic pressure) inside the bore- hole. The decrease in drilling fluid pressure lets fluids of the formation to go into the well - bore, that can result to blow - out. For that especially in low clearance wellbore, tripping speed must be monitored and controlled to ensure that excessive surge or swab pressure are not generated.

Previous study

A number of researcher have developing approaches for expecting swab pressure and surges pressure when drilling wells. The Couette Flow application is to calculate pressure differences resultant from the movement of pipes inside bore- holes, which is stated for different types of pipes and borehole conformations and fluid models.

There is a basic assumption almost all of the earlier research of a constant pipes speed when moving an inner pipe inside a liquid (drilling fluid) filled bore - hole. Burkhardt (1961), Moore (1974), Canon (1934), Clerk (1955), Tao and Donovan (1955), Guckes (1975), and Yang (1993), they assume that one of the pipes was in stable movement inside the drilling fluid in the wellbore. **Lubinski** (1977) and **Mitchell** (1988) they suggest that a compressive flowing occurs, that lead to pressure variations when fixed pipe speed.

Letelier (1988) established an analytical power-law fluids model for unsteady flow in pipes. He obtained from his research profile for pressure gradient. Edwards, **Nellist**, and **Wilkinson** (1972) derived a numerical model for velocity profile for power law fluid flow in pipes

Chukwu and **Blick** (1991) realistic the theory of **Coutte** flow to present a complete practical approach to the determination of the swab pressure and surge pressure encountered when moving as a close pipe end in Non_Newtonian power law fluids. Equations were developed on the assumption of a concentric annular geometry signified by a slot. The explanation of the model was presented as a family of charts.

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Godwin A. Chukwu (1995):

In the study of "**A PRACTICAL APPROACH FOR PREDICTING CASING RUNNING SPEED FROM COUETTE FLOW OF NON-NEWTONIAN POWER-LAW FLUIDS**" , study the annular flow of non _Newtonian power law drilling fluids founded on the stable movement of the casing in a concentric wellbore annulus.

The study entails demonstration of the solutions of the equation motion in nondimensional and less difficult equation.

The pressure surge by J.A. Burkherdt formula:

J.A. Burkherdt, presents mathematical method to estimate the surge pressure, in Burkherdt_paper title, "**WELLBORE PRESSURE SURGES PRODUCED BY PIPE MOVEMENT**", J.A established a formula to estimate a surge pressure for open end and closed end pipe that is confirmed when using experimental data from the field. He assumes that the Pressure surge is (Ps) for closed end pipes and could be stated as follows,

Laminar Flow:

$$Ps = B * \mu P * Vp + \frac{\tau O}{\left(0.3 * (Dh - De)\right)} \qquad \frac{psi}{1000} ft\ of\ pipes$$

For Turbulent Flow closed pipe:

Ps = A. μp 0.21 .ρ 0.806 . Vp 1.8   Psi/1000 ft of pipe

For laminar flow - open pipe

$$p_s = \beta B \mu_p V_p + \tau_o / 0.3(D_h - D_e)$$ Psi/1000 ft of pipe

For   turbulant flow - open pipe

$$p_s = \alpha A \mu_p^{0.21} q^{0.806} V_p^{1.8}$$ Psi/1000 ft of pipe

Where the coefficient of the openings α, β are used to adjust the closed – pipe equation for open pipe.

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<u>Rudi Rubiandini R.S.,</u> "**New Formula of Surge Pressure for Determining Safe Trip Velocities**" , Bandung Institute of Technology, Indonesia:

When the casing or any pipes are moving into the well-bore, which filled with drilling mud, at high speed, it will be generating high pressure (surge pressure) and that lead to growing and increase the hydrostatic pressure of the drilling mud pressure inside the well. When dragging out pipes from the well at high velocity, it going to generate swab pressure with high value of swab pressure that going to cause reduction in drilling mud hydrostatic pressure inside the well. For that Rubiandini R.S., Bandung develop the best velocities for safe trip, when they predict the pressure of surge inside the well - hole to avoid the chance of well problem, which are loss of circulation or blow out and also keep the operating time saving factor, in limit.

Rubiandini R.S., **Bandung** study a basic equation to calculate the surge pressure value as a function of pipes speeds limitation, drilling mud properties, hole sizes and pipes dimension. The products are a basic equation to calculate the surge pressure, which is adjusted for µP, Yp, ρ mud(drilling fluid density), hole size and pipes dimension for different field conditions.

Depending on the equation of **Burkhardt**, the actual annular mud speeds (V_{ac}) can be written as,

$$V_{ac} = \left[\frac{D_p^2}{D_h^2 - D_p^2} + K \right] * V_p$$

This actual annular drilling mud speed is the mud speed, which generate viscous drag causing pressure of surge). The K value of is 0.45 in the above equation, it is a best average for K value.

when the pressure of surge is about the max. value and that occur when the pipes speed movement are at maximum speed, for that P.L. Moore presented the Maximum Actual Annular drilling fluid speed (V max) that is:

$$V_{max}=1.5 * V_{ac}$$

This value of 1.5 depend on the drilling engineer experience.

Depend on the value of V^{max}, the pressures of surge can be considered for each 1000 ft of well depth by means of pressure loss formula from Rabia Hussain for Bingham Plastic Model. The pressure loss formula inside the annular, can be written as, Critical Speeds or velocity (*Vc*):

$$V_c = \frac{(97^{*}\ PV + 97(PV^{2} + 6.2^{*}\ \rho_{mud} D_e^{2} YP)^{0.5}}{\rho_{mud}^{*}\ D_e}$$

Where:

De = Dh – OD dp (or OD collar)

If $\bar{V}$ < *Vc*, which is flow regime is laminar, for that:

$$P_s = \frac{1000^{*}\ PV\,\bar{V}}{60000 D_e} + \frac{1000 YP}{200 D_e}$$

If $\bar{V}$ > *Vc*, which is flow regime is laminar, for that:

$$Q = \frac{\bar{V}(D_h^{2} - OD_{dp}^{2})}{24.5}$$

$$p_s = \frac{8.91^{*}\,10^{-5}\,\rho_{mud}^{0.8} Q^{1.8} PV^{0.2} * 1000}{(D_h - OD)^{0.3}(D_h + OD)^{1.8}}$$

The equation for surge pressure can be written as:

A-basic formula:

$$P_s = \frac{V_p Y_p \rho_{mud}(PV + 80)}{20000(D_h - D_p)}$$

B-linear formula:

$$P_s = \frac{(V_p + 500)(PV + 33)(7Y_p)}{30000(D_h - D_p)}$$

C- Turbulent formula:

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$$P_s = \frac{(V_p - 75)(PV + 80)(\rho_{mud})[12\frac{D_p}{D_h} - 5]}{2000(D_h - D_p)}$$

Dh= diameter of hole (in)
Dp= diameter of pipe (in)
Dh-De= actual annular distance (in)
OD= outer diameter (in)
Ps= loss of pressure due to pressure surge calculated per 1000 ft (psi/1000 ft)
PV= plastic viscosity of mud (cp)
Q= flow rate of mud (gallon per min)
V = fluid velocities (average) (ft per min)
Vac= actual mud velocities in annular (ft per min)
Vc= critical speeds (ft per min)
V_{max}= max actual mud speeds in annular (ft per min)
Vp= velocities of pipe (ft per min)
YP= drilling fluid yield point (lb per 100 ft^2)
μp= plastic viscosity (cp)
ρ = drilling fluid density (lb per gallon)
τo = actual drilling fluid yield point (lb/100 ft^2)

<u>Godwin A. Chukwu:</u>

In the study of "**A Practical approach for predicting casing running speed from COUETTE flow of Non –Newtonian power law fluids**" represent the **Couette** flow behavior that exist when two co axial pipes are located such that one of them is motionless while the second pipe is moving at a exact speed. This flow specific is illustrative of drilling fluid stream in the annulus, consider the wellbore wall representing the fixed cylinder, while the casing or drill pipe is illustrative the moving cylinder, the drilling fluid speed (local speed) is dependent on the speed of the moving cylinder. On this study, magnitude of surge or swab pressure is directed by the movement of the mud properties, the annular shape and dimension, and drilling pipe or casing.

In this study, the annular flow of Non_Newtonian power -law fluids was study depend on the comparative stable moving of the casing pipe in a concentric well bore annulus.

The results from this study:

The actual fluid flow rate can be expressed as:

$$Q = {}^{\pi}\!/_{4}\,(D_i^2 - d_o^2)\bar{V}_a$$

For closed end pipes system, the fluid velocity (average speed) relative to pipe motion can be written as:

$$\bar{V}_a = \left(\frac{d_o^2}{D_i^2 - d_o^2}\right) V_p$$

The actual flow rate relative to pipe movement:

$$Q = {}^{\pi}\!/_{4}\, d_o^2 V_p$$

Maximum casing running speed at desired hole depth interval as:

$$V_{p\max} = \frac{R\left(\frac{\Delta PR}{2KL}\right)^s}{\bar{P}}$$

$$\bar{P} = \frac{R}{V_p}\left(\frac{\Delta PR}{2K\Delta L}\right)^s ---------- (A)$$

$\bar{P}$ Dimensionless pressure gradient

A group of curves of $\bar{P}$ Vs. $\alpha = d_o/D_i$ for wide range of n values can be shown in fiq.(2). For a given α and n (power law index), $\bar{P}$ can be gotten and substituted into eq. A to get the swab pressure or surge pressure.

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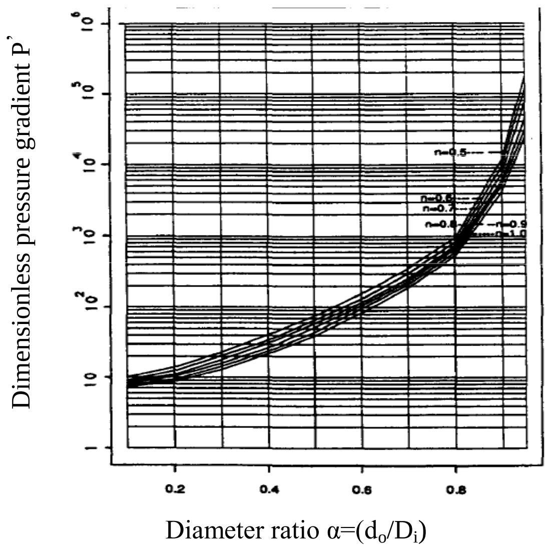

Fig.(2) Plot of Dimensionless Pressure Gradient $p^{'}$ vs. Diameter ratio d_o/D_i

R.F. Mitchell, “**Dynamic Surge / Swab Pressure Prediction**” study the dynamic swab and surge formula that extends current methods, this study consists of two analytical models, the first model is dealing with the pipes to bottom holes while the second model is dealing with coupled pipes as shown in figure 3 and 4

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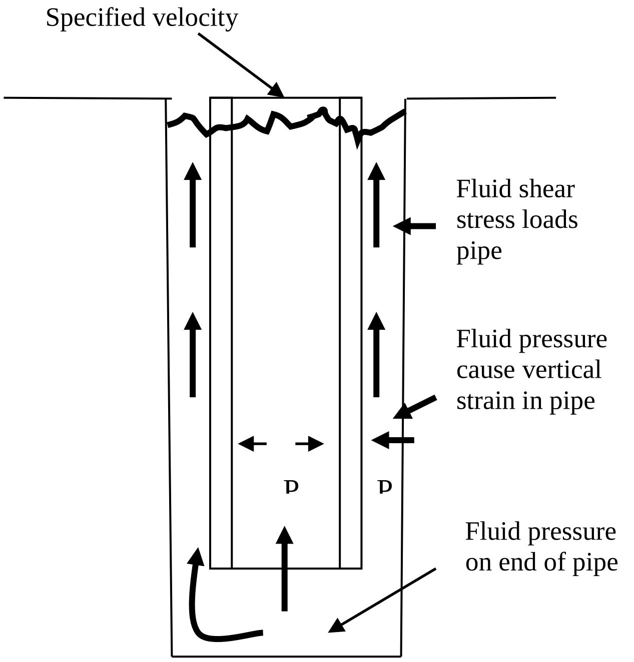

Fig (4) speed inside the pipe end is not equal to surface speed

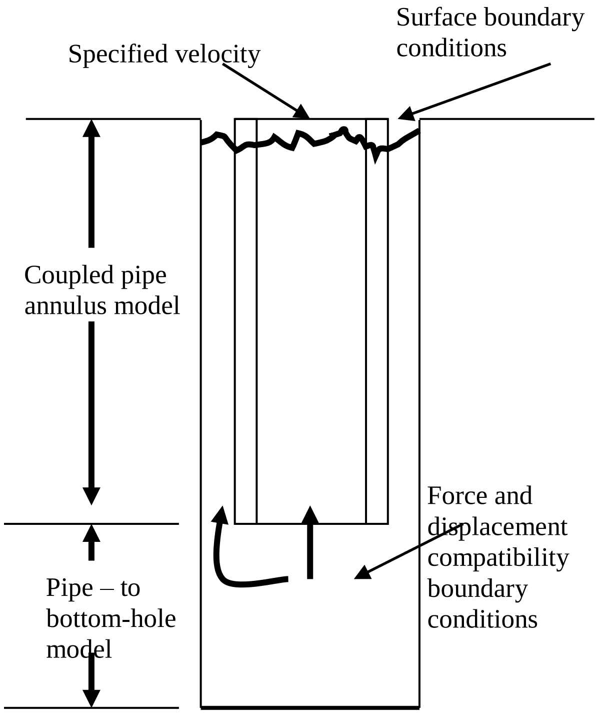

Fig (3) surge formulation flow

J.A. BURKHARDT, Humble Oil & Refining Co.:

From the field characteristic and theoretical researches, that have been done to study of surge pressure surges- transient differences in drilling fluid pressure that created by the moving of the different types of pipes inside the drilling fluid that fill the well. The pressure was recorded by using pressure gauges located at five different places inside the borehole. It’s found that the pressure peak was found when the casing speed is at maximum speed he considers that peak in pressure value is positive peak. While, the negative peaks found when the casing was lift from the slips also, when break were applied to stop the pipes movement. from the measurements and prediction theory results shows the important pressure is caused by the viscose drag of the drilling fluid flowing. By using simple graph and simple calculation steps, can be used to approximate the viscose drag surge pressure.

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In 1934, **Cannon** study the important negative peak surges pressure that may cause formation fluid to flow into the well and may cause blowout. Also Cannon study the positive peak of surge pressure during lowering the pipes.

Cardwell is the first to publish a research, that can predict the transient pressure changes. Cardwell assumption that the drilling fluid is Newtonian fluid with 300 cp viscosity and the flow regime is turbulent. Most drilling fluid consider as low viscosity and following Bingham model, But, Cardwell's results were helpful, because the results gotten were useful for field use. The results gave accurate prediction when measure the max pressure surge.

Fig (5) shows the several positive and negative pressure fluctuations produced when a single joint of casing was lowered into a mud – filled borehole. The casing – running operations were customary (1) the casing was lifted a foot **or so from the slip; (2) the added joints was lowered smoothly; (3) it was broken to a stop; and (4) it was set in the slip.**

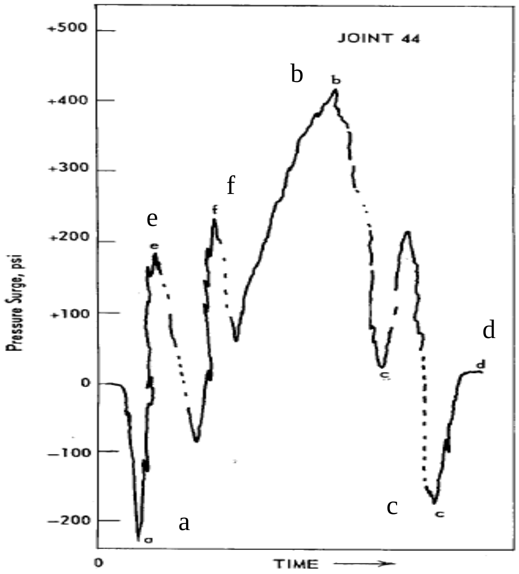

Fig (5) Typical Pressure- Surge Pattern Measured As a Joint of Casing Was Lowered Into the Wellbore.

The immediate cause of all pressure surge observed during this operation was the natural resist to flow for the drilling fluid column. Movement of mud column is related directly of the displacing string. In understanding how the pressure variation arises, it is necessary to consider the velocity and acceleration of the pipe string.

Pressure generated by inertia of the mud column.

The inertial surge component is because of the tendency of the drilling fluid column to resist a variation in motion, as described by Newtonian laws of motion. Following Clark, the inertial pressure surge component is expressed for the following:

for closed pipe string.

$$p = \frac{L\rho a_p D_p^2}{g(D_h^2 - D_p^2)}$$

For open pipe strings:

$$P = \frac{L\rho a_p (D_p^2 - D_i^2)}{g(D_h^2 - D_p^2 + D_i^2)}$$

Where a_P= pipe acceleration.

ρ=mud density.

g=acceleration of gravity.

The effective mud velocity that produced pressure surges is combination of the mud velocity due to pipe displacing mud and due to the tendency of the pipe walls to transport mud. The mud velocity due to pipe displacing the mud is simply related to the cross – sectional area of the pipe and of the annulus and the velocity of the pipe.

The velocity profile depends upon several factors, the nature of the fluid (whether Bingham or Newtonian), the geometry (annular of parallel plates) (the velocity profile for a number of different annular geometries were calculated), the type of flow (laminar or turbulent) and the pipe velocity.

The average effective annular velocity:

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$$V_{ae} = -\left(\frac{D_P^2}{D_h^2 - D_p^2} + K \right) * V_P \ {}^{ft}\!/_{\min}$$

$$N_{RE} = 15.44 \frac{(D_h - D_p) V_{ae} \rho}{\mu_p}$$

From fig.(6) a value of the friction factor f is obtained, knowing the numerical values of fluid conductance (γ) and Reynolds number (N_{RE}). And with this friction factor f, the pressure surge generated by the average effective mud velocity in the annulus resulting from the movement of closed pipe in the boreholes given by the conventional Fanning equation.

$$\frac{\Delta P}{L} = \frac{f V_{ae}^2 \rho}{9.282 * 10^4 (D_h - D_{p)}} \left({}^{psi}\!/_{ft} \right)$$

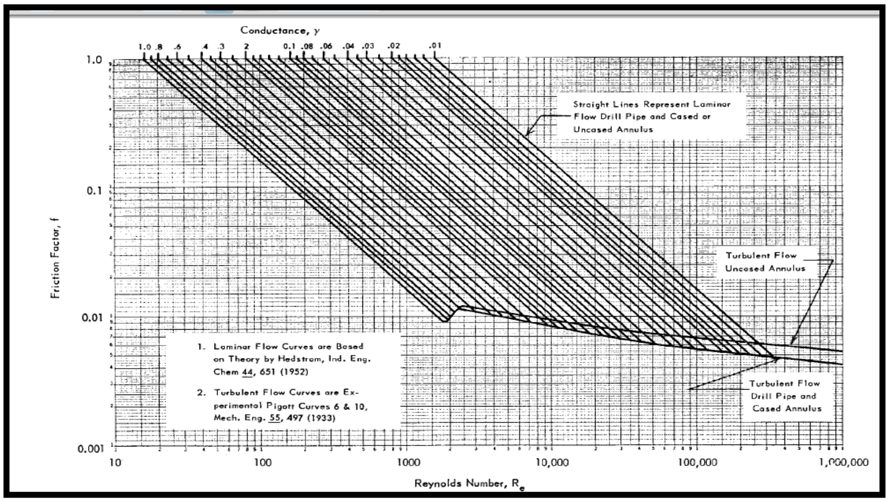

Fig (6) Modified Friction Factor – Reynolds Number Diagram for Use with Bingham Plastic

Pressure generated in the Annulus and pipe bore:

$$\frac{\Delta P}{L} = \frac{f V_{ae}^2 \rho}{9.282 * 10^4 D_i} \left({}^{psi}\!/_{ft} \right)$$

Where:

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D_i= inside diameter of pipe, in.

D_h=inside diameter of hole, in.

D_p=outside diameter of pipe, in.

f= friction factor.

P= pressure, psi.

$\Delta P/L$=pressure gradient, psi/ft.

V_{ae}=effective annulus mud velocity, ft per min.

V_p=velocity of pipes, ft per min.

γ=fluid conductance.

ρ= mud weight, lb/gal.

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