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Research Paper

A NEW APPROACH TO PRESSURE PROFILE CALCULATION OF MUD PUMPS IN DRILLING OF OIL AND GAS WELLS

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Prediction of the pressure profiles is complicated with respect to non-Newtonian behavior of the drilling fluids. Also need to use a tool that is able to estimate these parameters quickly and accurately appears to be necessary. What seems to be ample reason to develop the previous efforts is designing a software that provides a reasonable depiction of the pressure profiles with the graphical outputs in shortest possible time and minimum required input data. In this paper a software has been designed to the prediction of the pressure profiles in circulation system. The designed software is able to determine the parameters in n-points that the users ordered and will present a desired output to guide the user achieve an efficient pressure controlling through the circulating system. To design this software, all the mathematical equations have coded using MATLAB software such that divides issue into n-elements and apply calculations for these very small elements. Thus the user will be able to observe the parameters changing as point by point. In this paper, to validate the accuracy of output results we have used the real data of several wells and have shown that there is a reasonable agreement between the predicted and real data.

Keywords: Pressure profile, MATLAB, Bingham model, Power law model, Axial stress

INTRODUCTION

Proper operation of the drilling mud pumps is an important matter in the drilling science. Regarding to the parts that are involved in the mud circulating system indicates that to be desirable energy consumption efficiency the pumps energy consumption in different parts should be appropriately. Hydraulic horse power in such a system can be affected by many factors. The

most important ones are the special properties of the mud drilling flow and the inconsistency drilling mud circulation system. During the operation should pay attention on the pressure loss parameter along the circulating system. We certainly will need to know the pressure value at a certain point in the wellbore such as casing shoe points or a mud loss zone or may want to know the required pressure value for pumping a given

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value of the mud drilling at a special rate. There are various kinds of pressure as hydrostatic pressure, hydraulic pressure or impact pressure due to different mechanism. This point must be considered that the pressure at a certain point of the mud circulation system is sum of the mentioned pressures that exist on that point. Pump pressure is the pressures that are created by pump to transfer the drilling fluid from pump and flow through the wellbore until returned again to the flow line. In other words, this is the same hydraulic pressure that can be measured at a certain point in the circulating system (Baker, 1995). Kendall and Goins (1959) presented a jet-bit program to having a maximum hydraulic horse power and impact force or jet velocity. They showed conditions related to having a maximum obtainable bit horsepower in the pumps, drill string and well and also the minimum mud flow rate required to cuttings removal in their research. They also showed that the maximum achievable values were obtained for surface to total depth with proper selection of the bit nozzle sizes and using the obtained results. At the end, offered a simple graphical method of selecting the nozzle sizes and flow rates (Kendall *et al.*, 1960).

Brown and Coberly (1960) presented relations for friction loss in circular cross section parts of mud circulating system. They used correlation factors presented by different authors in their studies. They introduced equivalent diameters in annular sections to simplify calculations that take into consideration these factors. They presented obtained results as a charts that can be used for varies tubing and casing sizes (Brown *et al.*, 1960).

Shah and Zhou (2009) presented correlations to prediction of frictional pressure loss of fracturing

slurries in straight tubing and CT. Their study was based on slurry-flow tests with 1 ½ in. CT and slurries were prepared with 35 lbm/1000 gal of guar gel. Presented correlations had been verified with the experimental data and actual field CT-Fracturing data (Shah *et al.*, 2009).

Pressure drop is the amount of pressure that is required to move a fluid in a given distance. Pump pressure is sum of the pressure losses from pump to when drilling fluid is returned again to flow line. In the other word mud pressure losses must be calculate in all mud flow directions during the operation to check pump pressure. These pathways include surface equipments, stand pipe, rotary hose, swivel, kelly and inner diameter of drill string that can be include in drill pipes and collars. Then should be calculated pressure loss caused by the bit nozzles. This is the downward path of the drilling fluid to bottom hole. Then created pressure losses in annulus around the drill string must be compute in the upward path until fluid is returned again to flow lines. The analysis of these conditions is complicated with respect to non-Newtonian behavior of the drilling fluid (Baker, 1995). Of course it is important to note that will exist pressure losses due to Drag and Lift forces that are very difficult to be calculated in a long distance of circulating system (Streeter, 1985). The Drag forces created in the downward path of drilling fluid flow due to the presence of mud solids. The Lift forces will be a deterrent force in the return path of mud flow. The correlation factors always use in calculations to import effects of such forces to removed these short comings. It is understood here that applied drilling science is closely with the fluid mechanic engineering science. To have an efficient drilling program should utilize mechanical engineering science as be possible.

PRESSURE LOSS CALCULATION IN THE BINGHAM PLASTIC MODEL

Surface Equipment Pressure Loss

Equivalent lengths of drill pipes that cause the same pressure drop is selected from a table with respect to length and diameter of each the surface equipment and are added to the drill pipe length (Adam et al., 1986).

Pressure Drop Inside the Drill String

To determine mud circulating pressure drop in pipes and collars must first be determined the type of flow that passes through them. For this purpose, the critical velocity should be compute. If the mud flow velocity is less than the critical velocity, flow condition will be laminar otherwise will be turbulent condition.

$$V = \frac{Q}{2.488(ID)^2} \quad \dots(1)$$

$$V_c = \frac{108(PV) + 1.08\sqrt{(PV)^2 + 12.34(ID)^2(MW)(YP)}}{(ID)(MW)} \quad \dots(2)$$

$$\Delta P_{ds} = \frac{LV(PV)}{1500(ID)^2} + \frac{L(YP)}{225(ID)} \text{ (Laminar Flow)} \quad \dots(3)$$

$$\Delta P_{ds} = \frac{(MW)^{0.75} \times V^{1.75} \times (PV)^{1.25} \times L}{1800(ID)^{1.25}} \text{ (Turbulent Flow)} \quad \dots(4)$$

Pressure Drop in the Bit Nozzles

Much of the mud hydraulic horse power is lost during passing through the bit nozzles. Nozzles are in different sizes and should be used proper

sizes on the bit based on operation conditions and hydraulic programs.

$$\Delta P_{bit} = \frac{(Q)^Z(MW)}{1231(AT)^2(Cd)^2} \quad \dots(5)$$

$$V_n = Cd \sqrt{\frac{2(\Delta P_{bit})}{(MW)}} = 33.3585 \sqrt{\frac{(\Delta P_{bit})}{(MW)}} \quad \dots(6)$$

$$\Delta P_{bit} = \frac{(MW)(V_n)^2}{1113} \quad \dots(7)$$

Pressure Drop Through the Annular Space

Here identified the kind of flow condition with respect to V_c values.

$$V = \frac{0.408Q}{D^2 - (OD)^2} \quad \dots(8)$$

$$V_c = \frac{1.08(PV) + 1.08\sqrt{(PV)^2 + 9.26(D - OD)^2(MW)(YP)}}{(D - OD)(MW)} \quad \dots(9)$$

$$\Delta P_{ann} = \frac{L \times V \times (PV)}{1000(D - OD)^2} + \frac{L \times (YP)}{200(D - OD)} \text{ (Lamarinar Flow)} \quad \dots(10)$$

$$\Delta P_{ann} = \frac{(MW)^{0.75} \times V^{1.25} \times (PV)^{0.25} \times L}{1396(D - OD)^{1.25}} \text{ (Turbulent Flow)} \quad \dots(11)$$

Pressure Loss Calculations Using the Power Low Model

Power Low Model

$$\tau = k\gamma^n \quad \dots(12)$$

$$n = 3.32 \times \log\left(\frac{\theta 600}{\theta 300}\right) \quad \dots(13)$$

$$k = \frac{510 \times \theta 300}{(511)^n} \quad \dots(14)$$

As you know viscometers work on the different shear rates. If low shears are used for testing the value of k and n can be calculated as follows:

$$n = 0.5 \times \log\left(\frac{\theta 600}{\theta 300}\right) \quad \dots(15)$$

$$k = \frac{511 \times \theta 300}{(511)^n} \quad \dots(16)$$

The surface equipment pressure loss calculation is like the previous case and equivalent length of all surface equipment is calculated according to the table.

Pressure Drop Calculations in the Pipes

$$V_c = \left(\frac{1}{60}\right) \left[\frac{5.82 \times 10^4 \times k}{MW} \right]^{\left(\frac{1}{2-n}\right)} \left[\left(\frac{1.6}{ID}\right) \left(\frac{3n+1}{4n}\right) \right]^{\left(\frac{n}{2-n}\right)} \quad \dots(17)$$

$$\Delta P_{ds} = \frac{k \times L}{300 \times (ID)} \left[\left(\frac{96 \times V}{ID}\right) \left(\frac{3n+1}{4n}\right) \right]^n \quad \dots(18)$$

(Laminar Flow)

$$\Delta P_{ds} = \frac{(3.6033 \times 10^{-4}) \times MW^{0.8} \times V^{1.8} \times PV^{0.2} \times L}{(ID)^{12}}$$

(Turbulent Flow)

Pressure Drop Calculations in the Annular Around the Pipes

$$V_c = \left(\frac{1}{60}\right) \left[\frac{3.878 \times 10^4 \times k}{MW} \right]^{\left(\frac{1}{2-n}\right)}$$

$$\left[\left(\frac{2.4}{D-OD}\right) \left(\frac{2n+1}{3n}\right) \right]^{\left(\frac{n}{2-n}\right)} \quad \dots(20)$$

$$\Delta P_{ann} = \frac{k \times L}{300 \times (ID)} \left[\left(\frac{144 \times V}{ID}\right) \left(\frac{2n+1}{3n}\right) \right]^n$$

(Laminar Flow)

... (21)

$$\Delta P_{ann} = \frac{(7.7 \times 10^{-5}) \times MW^{0.8} \times Q^{1.8} \times PV^{0.2} \times L}{(D-OD)^3 \times (D+OD)^{1.8}}$$

(Turbulent Flow)

... (22)

Calculations related to this section are similar to given relationships in the Bingham plastic model (Adam et al., 1986).

COMPUTATIONAL ALGORITHM

The following assumptions have been considered in this study:

- 1) Drill string and casings or open holes are concentric.
- 2) The open hole intervals are quite circular shape with the ascertained diameters.
- 3) The flow is isothermal.
- 4) Boundary condition to determine Vc values are considered at $N_{Re} = 2000$.

A software has designed to prediction of the pressure profiles during the mud drilling flow through the inner diameter of pipes, bit and annular spaces until is returned to the flow line. Suppose that the available data is the physical properties of pipes, drilling fluid and the wellbore diameter versus depth. Then the computational

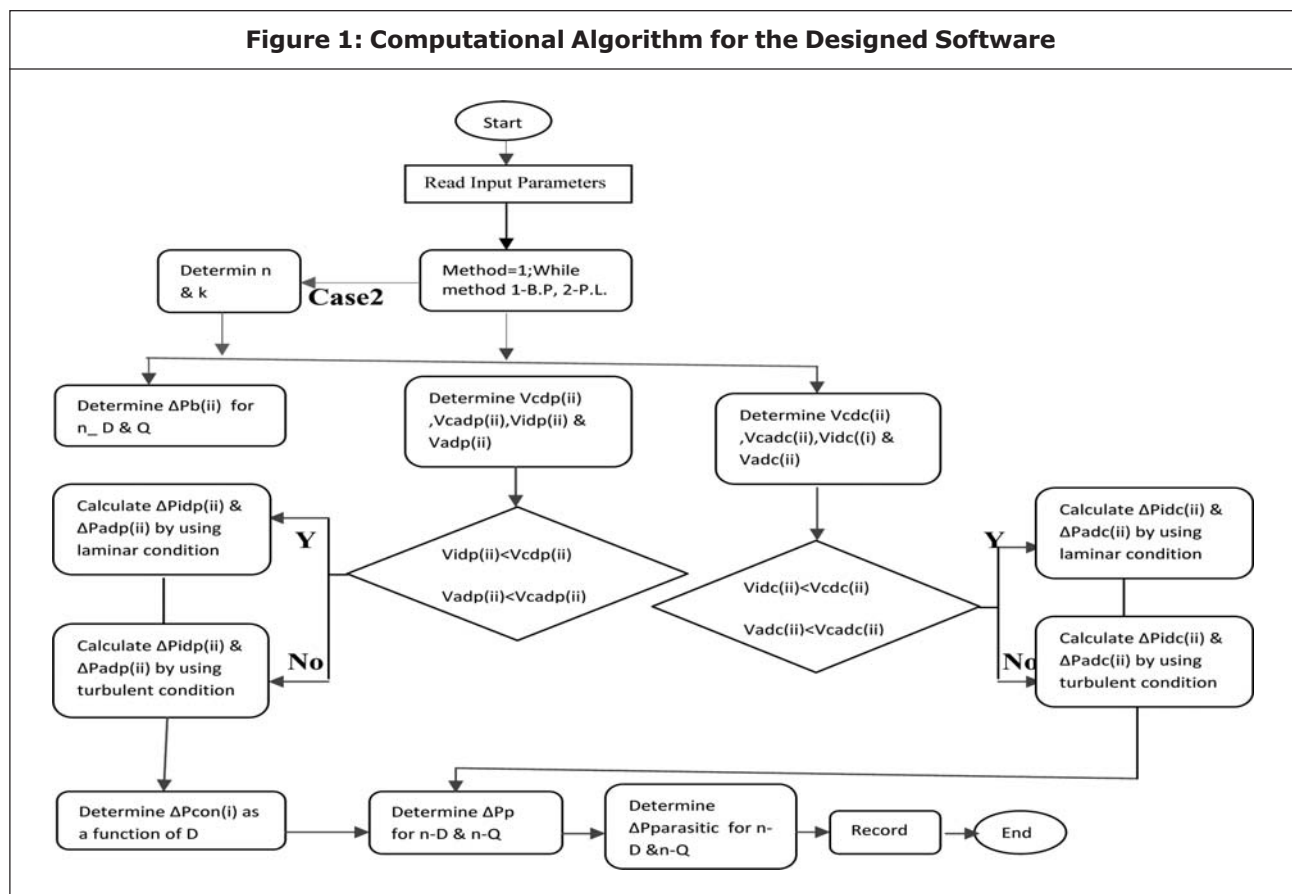
algorithm for the provided software can be summarized as Figure 1.

This software is able to consider all the parameters in n-points that the user ordered and will present a desire output for guide the users to have an efficient drilling operation. All the mathematical equations have coded via MATLAB software in the way that split the issue into the n-elements then compute the parameters for these very small elements. Hence the user will be able to observe changing in all parameters as point by point. A reason for the high calculations resolution is that the whole circulating system length are divided into very small elements and the designed software defines the flow kind for these elements with using related equations. Then applies the related equations and performs the

calculations not only at a special interval but also at the n-points in the circulation system length.

To determination of the tension force and the axial stress, the designed software first computes the hydrostatic and hydraulic pressures for all the given n-points of depths. Also determines the cross-section area of steel with respect to the number of defined elements that include various kinds of drill pipes and drill collars with the different weights. Next will compute the tension force and axial stress in the n-points of the drill string as a function of depth and will give a graphical output of results. Goins method is used to show the effect of buoyancy on buckling in this software. Goins proposed most general approaches to determination of stability force due to fluid pressure P_i inside the pipe, and pressure P_o outside the pipe (Goins, 1980).

Figure 1: Computational Algorithm for the Designed Software



FIELD STUDIES

To validate the outputs we have simulated pressure profiles for well # KSH-B-001, located in Kish gas field with the provided software. A

summary of the well characteristic are given in Table 1 and Figure 2 shows the well sketch. The software output results are presented in Figures 3 to 6.

Table 1: Kish Lower Dalan Gas Well-KSH-B-001

Bit,in	Casing	GPM	MW,pcf	PV,cp	YP,lb/100ft ²	Nozzle,in
26"	20"@260m	1000	70	20	30	3*18
17 1/2"	13 3/8"@1798m	1000	70-75	15-20	12-18	3*16
12 1/4"	9 5/8"@3314m	500	75-95	10-20	15-25	3*16
8 3/8"	7"@4174m	350	95-105	25-35	25-30	3*15-06*13
5 7/8"	TD@4803m open hole	350	95	25-35	25-30	3*13-4*12

Figure 2: The Well Sketch of K-B-001 Well

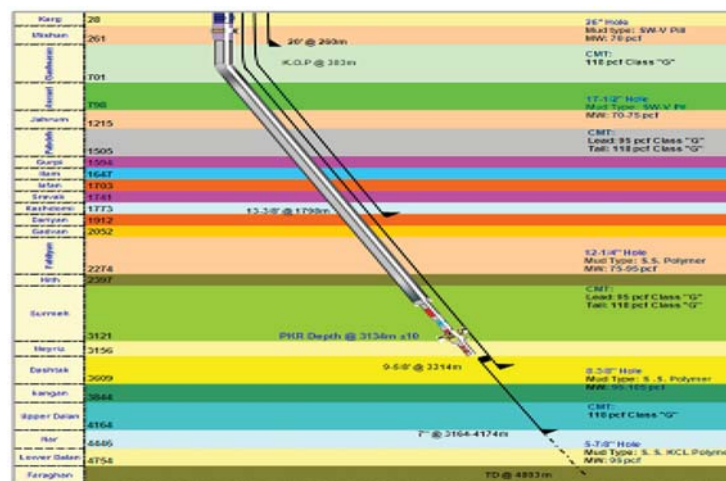


Figure 3: Prediction of the Required Pump Pressures and Parasitic Pressure Changes in all Drilling Depths

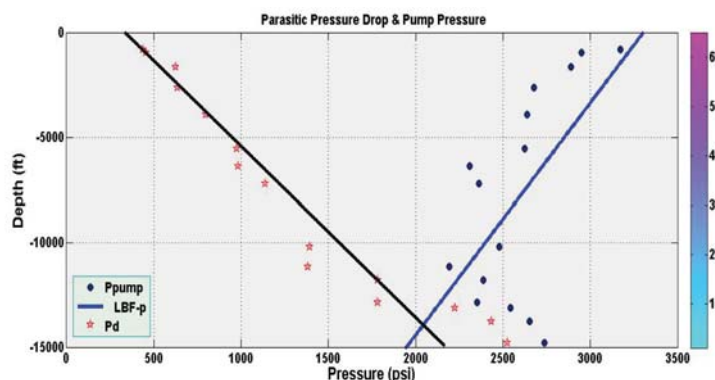


Figure 4: Prediction of Pressure Drop in the Down Path of Drilling Fluid From Surface to Bottom Hole

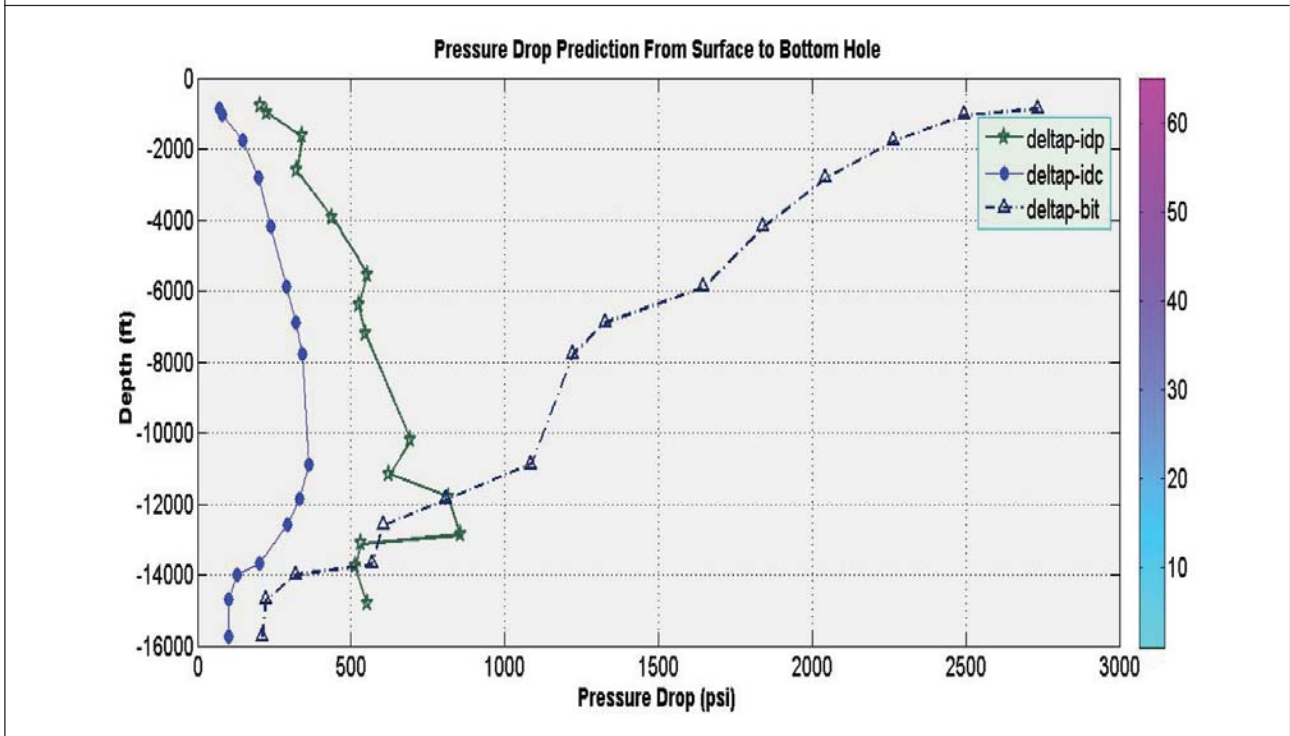
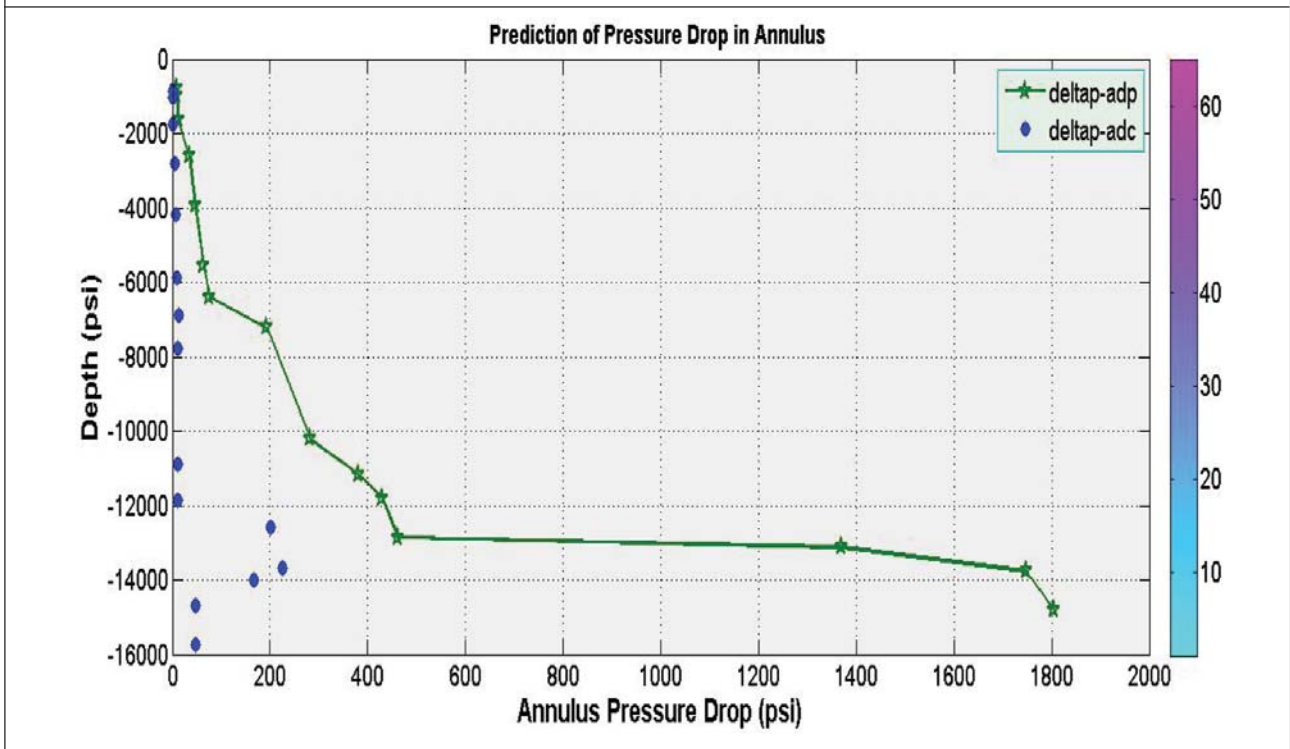
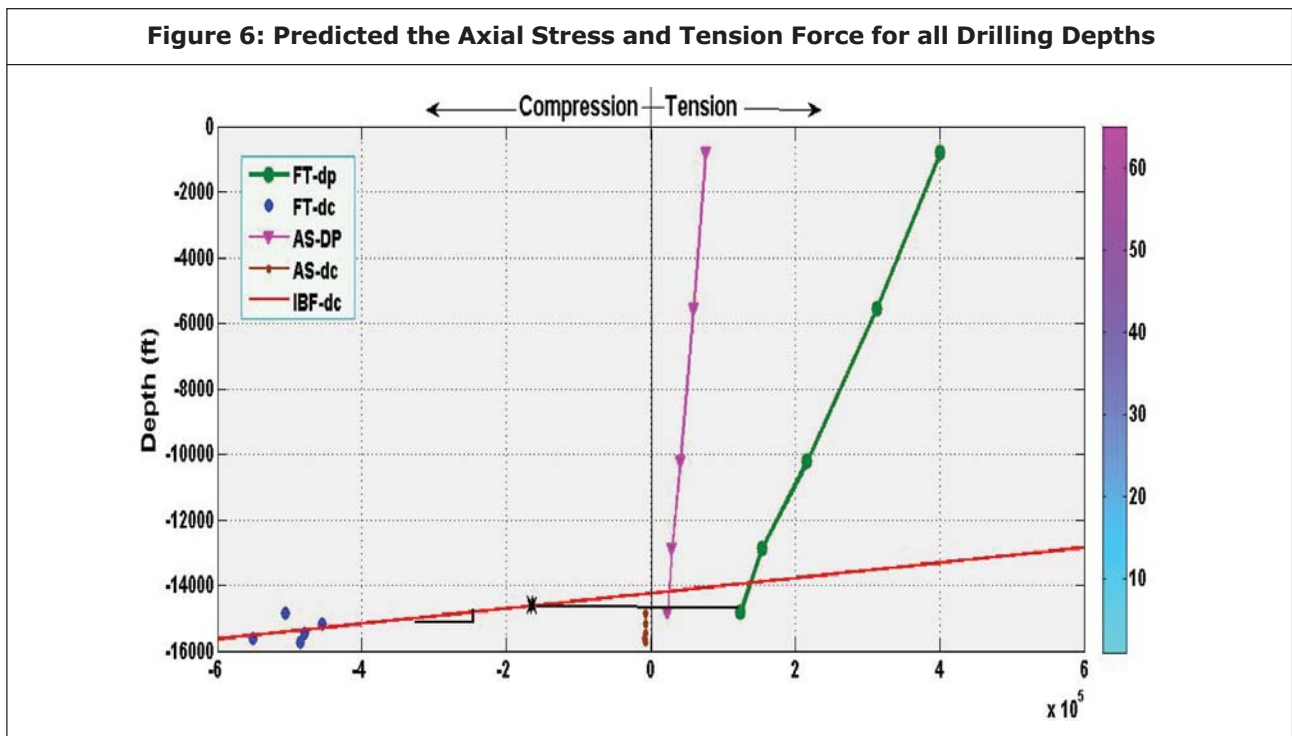


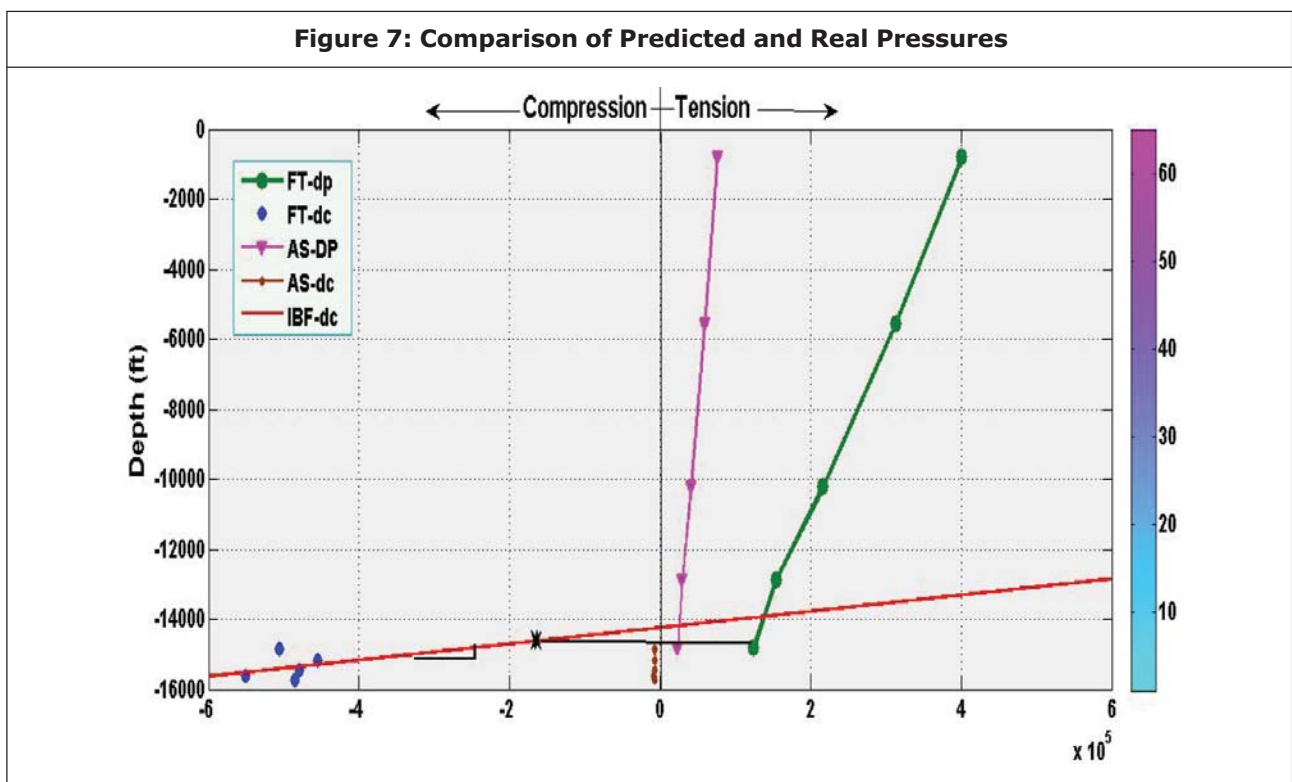
Figure 5: Prediction of the Pressure Drop in the Upward Path of Drilling Fluid From the Bottom Hole to Flow Lines





Predicted the pump pressures via the software have compared with the real data of 10 wells in Kish gas field and the absolute error obtained less

than 11.3 percent. The predicted data have compared with the real data and R^2 value is obtained to 0.8423 (Figure 7).



RESULTS

- 1) To develop the previous efforts the software has designed in this study that with the minimum required input data in the shortest possible time presents a relatively accurate approach of the operation desirable conditions as a graphical output.
- 2) Calculations in the software are performed for n-points along the wellbore or drill string lengths hence user is able to observe n-output results to have a better view of the operation desirable conditions.
- 3) By comparing the real data and predicted data from the designed software have shown that there is a reasonable agreement between them.

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Nomenclature

AT = total flow area, in ²	YP = yield point, lbf/100ft ²
Cd = nozzle discharge coefficient	ΔP_{ds} = pressure drop through drill string, psi
D = inner diameter of Casing or open hole diameter, in	ΔP_{ann} = pressure drop through annulus, psi
k = consistency index	ΔP_{bit} = pressure drop through bit, psi
L = length of pipe, ft	τ = shear stress, dyne/cm ²
MW = mud weight, PPG	γ = shear rate, sec ⁻¹
n = flow behavior index	LBF = linear best fitting
OD = outer diameter of pipe, in	<i>Subscripts</i>
PV = plastic viscosity, cp	Adc = annulus around the collars
V = flow velocity, ft/sec	Adp = annulus around the drill pipe
Idp = inner drill pipe, in	Cdc = critical drill collar
Vc = critical velocity, ft/sec	Cdp = critical drill pipe
Vn = jet velocity, ft/sec	con = connection surface equipments
	idc = inner drill collar



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