 SL, vol.10, no.1, pp.27-35, 2013

A Novel Method for the Design of Desirable Yield Point Range of Drilling Fluid

Yao Rugang[1,2], Jiang Guancheng[1,2], Li Wei[1,2], Wang Yuzhe[1,2] and Fan Jin[1,2]

Abstract: The objectives of this paper are to report a novel method for the design of desirable yield point range of drilling fluid, which take consider of the needs for drilling engineering and the principles of carry and suspend formation cuttings. The calculation model was derived using solid-liquid dynamics under certain given assumptions such as well structures, drilling fluid densities, depth, and etc., and corresponding software was developed in c#. Then, relationship between plastic viscosity and yield point has been expounded. For brevity, under the premise of no sedimentation, any one of the drilling fluid density, pump discharge, plastic viscosity and drilling fluid pump cylinder bore increases would result in the desirable yield point range turned out to be narrow. Drilling fluid pump discharge is the main cause of the decrease in the upper range of the desirable yield point range. While drilling fluid density is the main cause of the decrease in the lower range. The value of yield point is recommended a little higher than the lower range. In summary, the research will provide a useful theoretical reference for designers and field personnel, and make the regulation a clear task.

Keywords: Drilling fluid, Desirable yield point range, Solid-liquid dynamics, Model, Software.

1 Introduction

Drilling fluid technology is an important part of drilling. Regulation and control of drilling fluid rheological properties are known to be among the focuses of the drilling fluid technology. Experimental charts of desirable drilling fluid properties are clearly proposed for the field personnel [Hayatdavoudi (1989)], however, there is hardly any theory chart. To carry formation cuttings sufficiently and safe drilling,

[1] State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing, China.
[2] MOE Key Laboratory of Petroleum Engineering, China University of Petroleum, Beijing 102249, China.

drilling fluid rheological parameters such as plastic viscosity and yield point, are required within desirable limits. High plastic viscosity and yield point may cause excessive circulating pressure loss. Precise estimation of circulating pressure loss is essential in drilling and well completion operations to control formation pressures and optimize drilling and completion fluids hydraulic programs [Demirdal and Cunha (2007)]. Increase of Equivalent Circulating Density (ECD) may result in the fractured of formation, or it may result in that the needed pump pressure for circulation out of its rated pressure. What is more, a series of other emergencies is in the consequent. A lot of theoretical, field data, and experimental studies on pressure loss have been carried out [(Costa, Stuckenbruck, Fontoura and Martins (2008); Hemphill, Ravi, Bern and Rojas (2008); Johansen, Skalle, and Sveen (2003); Ozbayoglu, and Sorgun (2009); Scheid and Calcada (2009)]. Since the rated pressure of pump is certain, allowed pressure loss in circulation should be smaller than rated pressure of pump, it is possible to evaluate the upper range of the drilling fluid yield point with high precision. In addition, the maximum critical yield point is considered to be the lower range of yield point which is capable to keep solids suspending in case of pump stoppage. In other words, the plastic viscosity and yield point in circulation are required within desirable limits. This paper will take consider of the needs for drilling engineering and the principles of carry and suspend formation cuttings, in addition, the calculation model was derived using solid-liquid dynamics under certain given assumptions such as well structures, drilling fluid densities, depth, and etc., and corresponding software was developed in c#. Finally, a novel method for the design of desirable yield point range of drilling fluid was provided for designers and field personnel.

2 Assumption

To facilitate our research, and simplify our mathematical model, the microstructure of particle has not been considered. All particles are assumed spherical. And solid phase is assumed to have uniformly distributed in the physical space they share. Diameters of solid particles and drilling fluid density are assumed to be constant. In addition, allowed pressure of equipment & pipe lines are considered to be higher than that of drilling fluid pump. When come to calculations, it is assumed that all parameters have certain value except for the particular one which we are talking about.

3 Desirable yield point range

For particle in fluid, there are only two states: settlement or natural suspension status [Chen Jialang, Liu Yongjian and Yue Xiang'an (1997)]. For various reasons, such as pipe connection, log, outage time, etc., drilling fluid circulation had to be stopped temporarily or even for a long time. Therefore, it is usually required that particles in borehole could remain in suspension when drilling fluid circulation stopped. In addition, cuttings settling velocity is required below the drilling fluid velocity in annular to ensure formation cuttings are timely carried out. Meanwhile, good rheological is also very important for efficient rock-breaking. Especially, rheological parameters are expected to be desirable in case of excessively high pressures.

3.1 The lower range

In this paper, spherical particles of density of ρ_s, diameter of d_s, is considered in an unbounded fluid of density of ρ_m, the particle will experience a downwards gravitational force, G_s, and upwards buoyancy force, F_b, together with the upwards shear force T_s. When in force balance, there is,

$$G_s = F_b + T_s \tag{1}$$

And we can infer that the static shear stress τ_s, which keep the particle in suspension is

$$\tau_s = \frac{2d_s\left[\rho_s - \rho_m\right]g}{3\pi} \tag{2}$$

For different type of particles, the max $\{\tau_s(i)\}$ in equation (2) provides an estimate for the lowest value of yield point which keep particles in suspension.

For a Bingham fluid,

$$\tau = \tau_0 + \eta_{PV}\gamma \tag{3}$$

Where τ is the local shear stress, Pa. τ_o is yield point, Pa. η_{PV} is the plastic viscosity, mPa·s. and γ is the particle shear rate, s^{-1}.

When the shear stress τ in the fluid becomes larger than τ_o there is a relative flow between the particle and fluid ($v_s \neq 0$) and here is a finite particle shear rate γ that will generate an additional drag on the particle, then, there is

$$F_d = \frac{\pi}{8} C_D \rho_m (v_s)^2 d_s^2 \tag{4}$$

Where C_D is drag coefficient related to particle Reynolds number. v_s is settling velocity of particle.

When in force balance, there is

$$G_s = F_b + T_s + F_d \tag{5}$$

Then we can infer that

$$\tau_0 = \frac{2d_s\,(\rho_s\text{-}\rho_m)\,g}{3\pi} - \frac{1}{8}C_D\rho_m v_s^2 - \eta_{PV}\gamma \tag{6}$$

For different type of particles, the max $\{\tau_0\,(i)\}$ in equation (6) provided reference lowest range of yield point for a permitted settling velocity v_s. When $v_s = 0$, then, equation (6) is equal to equation (2). In other words, equation (2) is a special case of equation (6).

3.2 The upper range

The total pressure loss ΔP in circulation can be calculated by equation (7) [Chen Tinggen and Guan Zhichuan (2000)].

$$\Delta P = \Delta P_{st} + \Delta P_{an} + \Delta P_b + \Delta P_g \tag{7}$$

Where ΔP is the total pressure loss in circulation, MPa. ΔP_g is ground pipeline pressure drop, MPa. ΔP_b is bit pressure drop, MPa. ΔP_{an} is pressure drop in annular, MPa. ΔP_{st} is pressure drop in drill string, MPa.

Since the rated pressure of pump is certain, and allowed pressure loss in circulation should be smaller than rated pressure of pump, it is possible to evaluate the upper range of the drilling fluid yield point with high precision. In other words, it is the rated pump pressure that has limited the maximum value of yield point when other parameters are constant.

To ensure a safe pressure of the pump, it is necessary to adjust drilling fluid plastic viscosity and yield point to meet the critical condition that the total pressure loss in circulation is lower than the rated pressure of equipment, equation is

$$\Delta P \leq \alpha P_{rp} \tag{8}$$

Where P_{rp} is the rated pump pressure, MPa. α is safe coefficient of rated pump pressure, dimensionless, set by field technician.

Obviously, plastic viscosity and yield point which meet the critical condition of equation (8) are called the upper range of themselves.

From above, it is concluded that the value of plastic viscosity and yield point should better lies within the range determined by formula (6) and formula (8) which is named “the Desirable yield point range” by authors.

4 Application and discussion

Based on equations referred above, we developed the corresponding calculation software in c#. Newton iterative method, trial method, etc. are used in programming process to calculate the yield limits. The results are output to the excel format, and then, mapping according to these data use Excel 2010. Parameters such as the well structures, drilling fluid densities, depth, and etc. are necessary during calculation. Take a certain well as example for calculation of desirable yield point range under the premise of no sedimentation (Fig. 1∼Fig. 3). The main base data used for calculation are given in Table 1.

Table 1: Main base data used for calculation

Input parameters	Value
Well depth (m)	6684
Well diameter (m)	0.2413
Drill pipe ID (m)	0.1016
Drill pipe OD (m)	0.127
Nozzle equivalent diameter (m)	0.055902
Nozzle discharge coefficient, dimensionless	0.9
Cuttings diameter (cm)	0.5
Cuttings density (g/cm^3)	2.6
Weighting material diameter (cm)	0.02
Weighting material density (g/cm^3)	4.2
Weighting material density (g/cm^3)	4.2
Ground high pressure line length (m)	30
Ground high pressure line ID (m)	0.1086
Standpipe length (m)	30
Standpipe ID (m)	0.1086
Drilling hose length (m)	30
Drilling hose ID (m)	0.1086
Kelly bar length (m)	11.4
Kelly bar ID (m)	0.0826

Assume F-1600 drilling fluid pump was used on the well, Fig. 1 illustrates the decrease of the upper and lower limits of yield point as drilling fluid density increase under the premise of no sedimentation when well depth is 6684m, rated pressure of pump is 32.7 MPa, safe coefficient α is 0.8, pump discharge is 24.24 L/s, plastic viscosity values were 30, 60, 90 mPa·s separately. And, the value of yield point is recommended a little higher than the lower range.

Then, the upper and lower range of yield point was calculated under the condition of Φ150mm cylinder bore with different pump discharges (Q) and pump pressures (P) when other parameters are constants (Fig. 2).

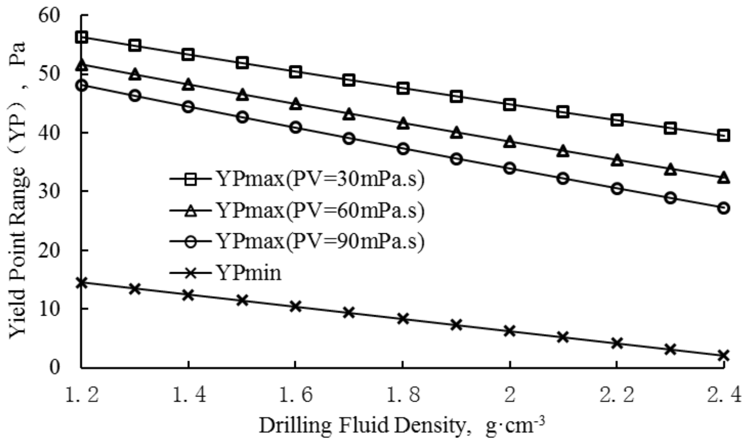

Figure 1: Desirable yield point range for different drilling fluid density.

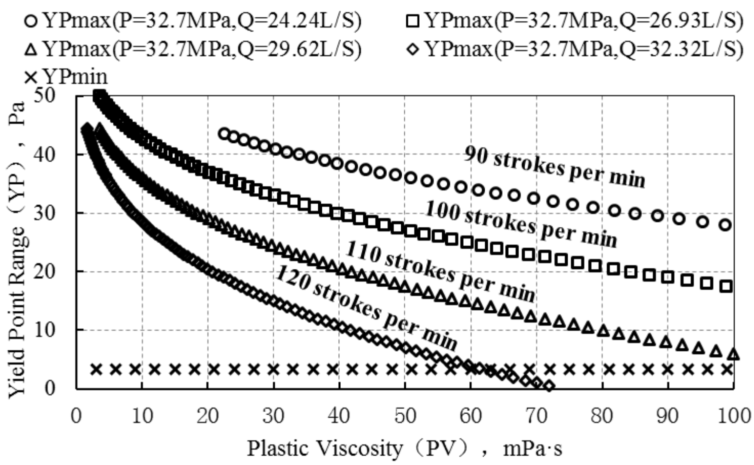

Figure 2: Desirable yield point range for different plastic viscosity under different pump discharges (or pump strokes) when cylinder bore is Φ150mm, and other parameters are constants.

Fig. 3 illustrate the desirable yield point range with different plastic viscosity under different cylinder bore when pump strokes is 90 per min, and other parameters are constants.

Fig. 2∼Fig. 3 illustrate the relationship between yield point and plastic viscosity with different pump discharges and pump pressures when other parameters are

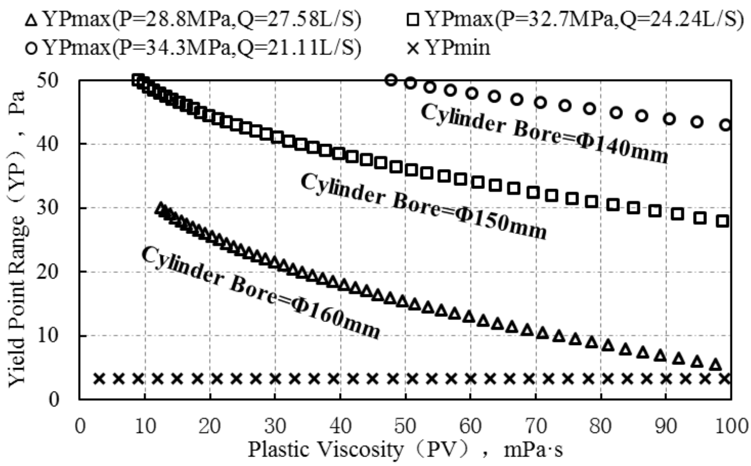

Figure 3: Desirable yield point range with different plastic viscosity under different cylinder bore when other parameters are constants.

constant. From Fig. 2 $\sim$ Fig. 3, we can infer that the upper range of yield point decrease as plastic viscosity and / or pump discharge increase, while the lower range remain unchanged under the assuming of no sedimentation. While drilling fluid density is the main cause of the decrease in the lower range. Obviously, it is recommended to use small pump discharge and large pump pressure for deep well under the permission of safe drilling. In addition, in practical, we should avoid to fracture the formation under large pump pressure.

5 Conclusion

The desirable yield point range model of drilling fluid was derived using solid-liquid dynamics under certain given assumptions in this paper with consider of the needs for drilling and the principles of carry and suspend formation cuttings. And corresponding calculation software was developed in c#. Newton iterative method, trial method, etc. are used in programming process to calculate the desirable yield point range.

The relationship between yield point and plastic viscosity with different pump discharges and pump pressures when other parameters are constant has been expounded. Any one of the drilling fluid density, pump discharge, plastic viscosity and drilling fluid pump cylinder bore increases would result in the desirable yield point range turned out to be narrow. Drilling fluid pump discharge is the main cause of the decrease in the upper range of the desirable yield point range. While drilling fluid density is the main cause of the decrease in the lower range.

This study provides a novel method for designers and field personnel to determine desirable drilling fluid plastic viscosity and yield point range with different well structures, drilling fluid densities, depth, and etc., it will provide a useful theoretical reference for designers and field personnel, and make the regulation a clear task.

Acknowledgement: The study was supported by Innovation Research Group, National Natural Science Fundation of China (Project No.: 51221003) and the Key Project of National Natural Science Fund for Petrochemical Industry (Project NO.: U1262201).

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