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Study on hydraulic characteristics of riser-less drilling lifting system

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Abstract

In this paper, by analyzing the current energy head calculation of riser-less drilling fluid recovery system mud lifting system, the influence caused by the change of drilling fluid density, water depth and solid-liquid integral number is not considered. To explore in the deep sea mud jacking system of the water depth, the impact of solid liquid integral number change to head, according to the principle of mud jacking system of double gradient and the drilling fluid flow characteristics in the line, can propose lifting pump head and the calculation method of annulus pressure, establishes the mathematical model of hydraulic lifting system, can calculate the head with the depth of the water, the changing rule of the drilling fluid density. The results have a certain guiding significance for the study of the annular pressure variation of system.

Keywords

Mud lifting system, pipeline characteristics, annular pressure, drilling fluid density.

1. Introduction

The safety density window of deep water drilling is narrow due to the action of loose sediment and sea water column, and conventional drilling is faced with a series of problems such as kick and loss of well. The emergence of riser-less drilling technology has solved the problems faced by deep water drilling. This technology has the advantages of short well construction period, deep surface casing running depth, and less drilling fluid consumption [1,2,3].Mud lifting system is an important part of riser-less drilling, among which the control system is the core technology. Riser-less drilling technology has been commercialized in foreign countries, while in China, it is still in the early stage of research and development without any successful cases. With the acceleration of exploration and development of deep-sea oil and gas resources in China, riser-less drilling technology and key equipment research and development have become an unavoidable problem.

The riser-less drilling technology is suitable for deep water and ultra-deep water surface drilling. Conventional riser-less drilling releases cuttings onto the seabed, where the drilling fluid cannot be reused, resulting in waste of drilling fluid and pollution of the Marine environment. The Norwegian riser-less drilling mud lifting system can recycle mud, effectively solve environmental problems and save drilling costs [4,5,6,7].During the operation of this system, no riser is used, the drill pipe is directly exposed to seawater, and the well is isolated from seawater by suction module. The key point of the technology is to maintain a stable balance between the inlet pressure of mud lifting pump and the static pressure of seawater, so that the wellbore annulus pressure is between the bottom pore pressure and the rupture pressure [8].

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2. Operating principle of the system

The mud lifting system is mainly composed of lifting pump, power supply module, mud return pipeline and monitoring system [9], as shown in Fig. 1.The disc pump is selected as the lifting pump. The impeller structure of the disc pump makes it have the advantages of anti-wear, non-blocking and high reliability [10], which is suitable for the requirements of mud lifting operation. The power supply module mainly includes underwater motor, frequency converter, filter, etc., which provides power for the mud lifting system. The mud return line is the passage for the mud back to the recovery tank, and it is also the attachment of the power cable and control cable of the subsea equipment. The monitoring system is the core of the mud lifting system and the center of the operation of underwater equipment. It can not only monitor and collect various operating parameters in real time, but also control the start, stop and running state between submarine lifting pump and valve, etc. The main function is to adjust the motor speed to achieve the equal of the inlet pressure of lifting pump and the static pressure of seawater.

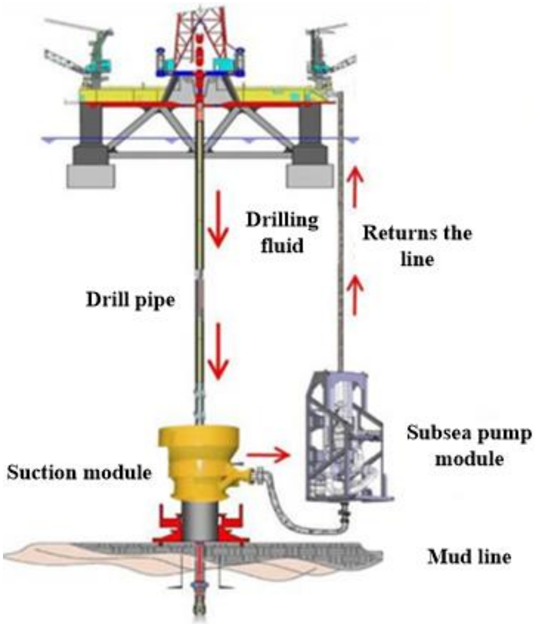

Fig. 1 Structure of mud lifting system

3. Calculation method

3.1. Lifting pipeline parameter analysis

After the water depth h of drilling operation is known according to the design requirements, the length L of the pipeline can be determined according to the Angle between the mud return pipeline and the mud line. The inner diameter of the mud return pipeline is an important parameter. The system has known the required mud return flow Q_m, and the relationship between the inner diameter D of the pipeline and the liquid velocity u_m in the pipeline is:

$$D=\sqrt{\frac{4Q_m}{\pi u_m}}$$

The normal operation of the lifting system can be guaranteed only if the velocity of fluid returning to the pipeline is greater than the settling velocity of particles. However, too high a lifting velocity will cause aggravation of pipe wear and serious heating. The appropriate lifting velocity depends on the settling characteristics of particles and is determined by the size and density of particles. Accord to the principle of fluid mechanics, solid particles are transported in the pipeline by the resistance and pressure provided by the pipeline fluid. The resistance F_d

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of solid particles in the transport liquid is proportional to the liquid density, the cross section area of particles and the square of the relative velocity of solids. Then the resistance F_d of solid particles can be expressed as:

$$F_d = C_D \frac{\pi d_s^2}{4} \frac{\rho_m}{2} \left(v - v_s\right)^2$$

Where d_s is the particle size of solid particles, m; ρ_m is the drilling fluid density, g/cm^3; v is the flow rate of drilling fluid, m/s; v_s is the velocity of solid particles, m/s; C_D is the drag coefficient. Solid particles in the process of upward transport buoyancy, particles in the liquid weight will be reduced. It is generally required to subtract buoyancy, and the gravity after subtracting buoyancy is defined as the floating weight G ', that is:

$$G' = \frac{\pi}{6} d_s^3 g \left(\rho_y - \rho_m\right)$$

When the gravity, resistance and buoyancy are in a state of equilibrium, according to the equilibrium condition Fd = G ', the settling velocity of solid particles can be calculated, namely:

$$V_0 = \sqrt{\frac{4}{3} g \frac{d_s}{C} \frac{\rho_y - \rho_m}{\rho_m}}$$

Where, ρ_y is the cuttings density, g/cm^3; G is the acceleration of gravity, m/s^2; C is the shape coefficient of solid particles, which is 0.5 for spherical shape, 0.6~0.82 for circular shape and 2.1 for irregular shape.

According to the Govier theory of solid-liquid two-phase flow theory, when solid particles move with the fluid, the minimum fluid velocity should be more than 2 times of the solid settling velocity. In the mud lifting system, considering the unstable factors, the liquid flow rate um was selected to be 3~5 times of the settling speed of solid particles to ensure that the pipeline would not be blocked.

3.2. Calculation of lifting system pressure drop

The pressure drop of the lifting system is mainly composed of local resistance loss and along the path resistance loss. The mud return line is very long, with little change in diameter or orientation, and few valves, so the local drag is relatively small and can be ignored.

In order to calculate the pressure consumption of the mud return line, the fluid flow pattern should be first judged according to the Reynolds number. The drilling mud conforms to the power law fluid, and the calculation formula of Reynolds number Re is:

$$\mathrm{Re} = \left(\frac{3n+1}{4n}\right)^{-n} \frac{\rho_m D^n u_m^{2-n}}{8^{n-1} K}$$

Where, u_m is the average flow velocity in the tube, m/s; K is the consistency coefficient of power-law fluid, MPa · Sn /cm2;N is the dimensionless flow coefficient of a power-law fluid.

When *Re*<2100, it is laminar flow, then the pressure consumption in the pipeline can be calculated as:

$$\Delta h_m = \frac{4hK}{D\sin\theta} \left[\frac{2(3n+1)u_m}{nD}\right]^2$$

Where θ is the included Angle between pipeline and submarine mud line.

When Re≥2100 is the flocculation flow, the Fanning friction coefficient F should be calculated first

$$\frac{1}{\sqrt{f}} = \frac{4}{n^{0.75}} \lg(\mathrm{Re} \cdot f^{1-0.5n}) - \frac{0.395}{n^{1.2}}$$

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After f is obtained by the iterative method, the pressure consumption of the pipeline is calculated as follows:

$$\Delta h_m = \frac{2 f \rho_m L u_m^2}{D^2} = \frac{3200 f \rho_m h}{\pi^2 D^5 \sin\theta} Q_m^2$$

The pressure loss of mud return pipeline can be calculated according to the above theoretical calculation.

3.3. Calculation of head and power of mud lifting pump

When mud pump lifting pump is used to transport solid-liquid two-phase mixture, the traditional calculation formula for the head and power of mud pump is as follows:

$$H_m = \frac{p_2 - p_1}{\rho_m g} + \frac{u_{m2}^2 - u_{m1}^2}{2g} + z_2 - z_1 + \Delta h_m$$

Where, p2 and p1 are respectively the outlet and inlet pressure of the mud return pipeline, Pa;u_{m1} and u_{m2} are respectively the average velocities of the solid-liquid mixture at the outlet and inlet of the mud return pipeline, m/s;△ hm is the pressure loss in the mud return line, Z1 and Z2 are the sea floor and surface elevation, respectively.

The solid particles in the mud have no pressure at the inlet of the lift pump. The inlet pressure of the subsea pump is equal to the static pressure of the sea water. The inlet pressure is so large that the traditional Bernoulli equation cannot be used. Considering that the solid phase has no pressure energy, according to the energy equation, continuity equation and momentum equation of the fluid, the calculation formula of the head of the subsea pump is as follows:

$$H_m = (1 - C_v)\frac{p_2 - p_1}{\rho_m g} + \frac{u_{m2}^2 - u_{m1}^2}{2g} + (z_2 - z_1) + \Delta h_m$$

Where, Cv is the volume fraction of slurry solid particles.

If the inner diameter of the mud conveying pipeline is the same and the shape of the flow cross section is the same, then ;$u_{m1} = u_{m2}$, the above equation becomes;

$$H_m = \frac{p_2 - (1 - C_v) p_1}{\rho g} + (z_2 - z_1) + \Delta h_m$$

The inlet of the mud return pipeline of the riser less drilling system is connected with the suction module by a hose. The P1 pressure is approximately equal to the static pressure of the sea bottom, and the mud return pipeline outlet reaches the platform. The pressure is required to be P2 ≥0, and the critical value of P2 is 0 for the convenience of calculation.Z2-Z1 is equal to the sum of the working water depth H and the height HP from the sea surface to the platform. The height HP from the sea surface to the platform is generally 30~40 meters. Then the formula can be simplified as:

$$H_m = [1 - (1 - C_v)\frac{\rho_s}{\rho_m}] \cdot h + H_p + \Delta h_m$$

Where, ρs is seawater density, 1.03×103kg/m3.

4. Example Verification

4.1. Influence of working water depth on system energy head parameters

The water depth of drilling is the main factor affecting the energy head of the lifting system. When the water depth increases, the pressure consumption of mud pipeline will also increase.As shown in Fig.2, when the working water depth is 1000m, the energy head required by the lifting system is approximately twice that of the working water depth of 500m.The configuration schemes of the mud lifting system designed under different parameters are different.

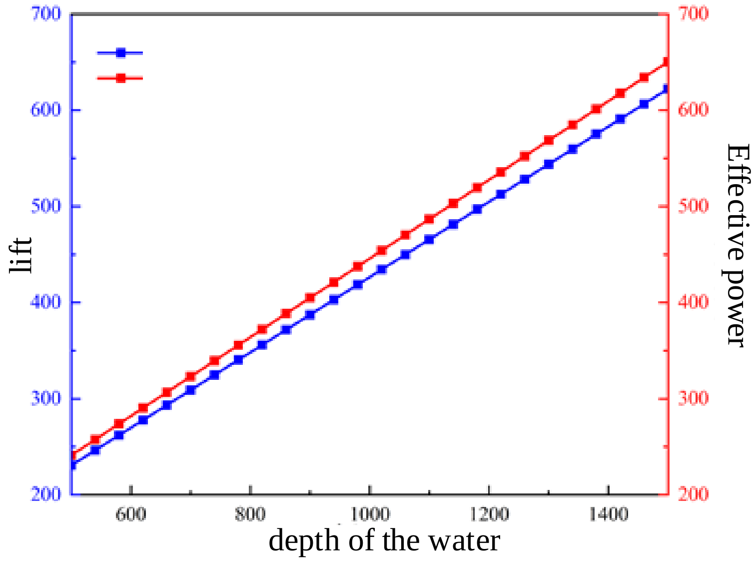

Fig.2 Influence of working water depth on system energy head

4.2. Influence of drilling fluid density on system energy head parameters

Drilling fluid density is also a very important parameter that affects the energy head of the lifting system. During deep water drilling, surface drilling fluid is generally 1.05~1.6g/cm3.During the drilling process, with the change of the bottom structure, the drilling fluid density will be adjusted accordingly. The adjustment range is generally within 0.2g/cm3, but the influence on the energy head required by the lifting system is very obvious. The influence of drilling fluid density on the system energy head is shown in Fig.3. As can be seen from the figure, when the drilling fluid density increases from 1.2g/cm3 to 1.4g /cm3, the energy head required by the system increases from 210m to 329m.When the drilling fluid density increased from 1.5g/cm3 to 1.7 g/cm3, the energy head required by the system only increased by 76m, indicating that the energy head curve required by the system was more sensitive at lower densities. The density of drilling fluid will change during drilling and production, so the maximum drilling fluid density parameter should be adopted when designing the energy head required by the system.

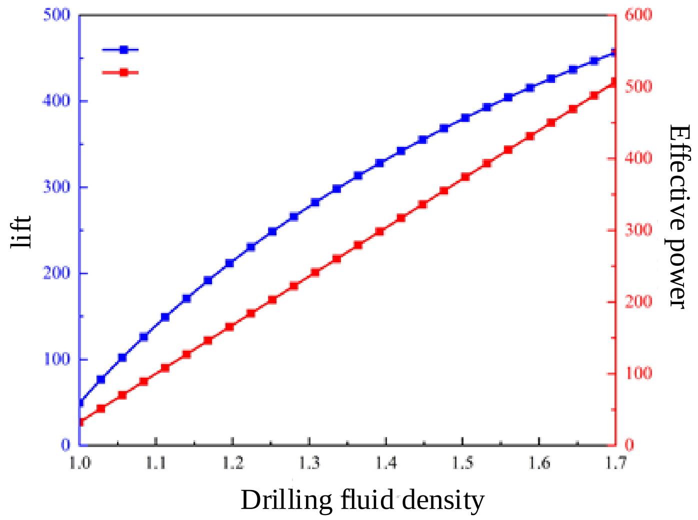

Fig.3 Influence of drilling fluid density on system energy head

4.3. Influence of solid particle volume fraction on system energy head parameters

The C_V volume fraction of solid particles in the returned mud also has a certain influence on the system energy head.At the beginning of drilling, the solid particle volume fraction Cv was approximately 0%. As the drilling depth increased, the Cv value gradually increased and the energy head required by the system also increased, as shown in Fig.4.However, the change of C_V has little influence on the energy head of the system. When designing the mud lifting system, only the maximum volume fraction of solid particles C_V is needed to design.

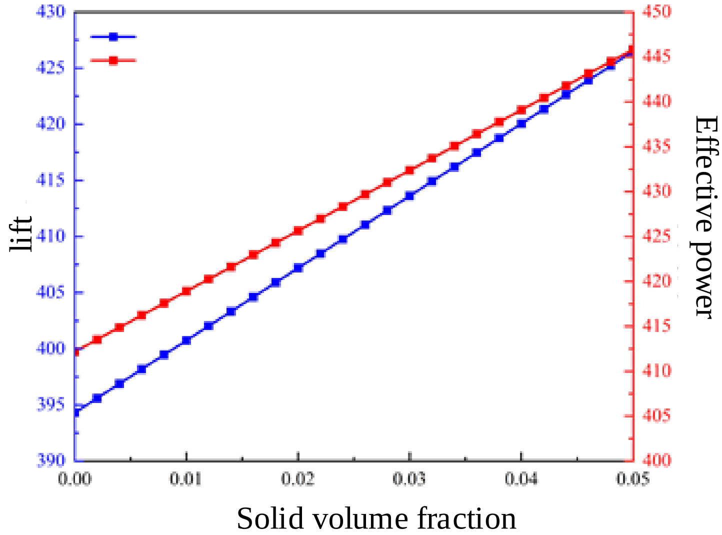

Fig.4 Effect of solid particle volume fraction on system energy head

4.4. Influence of pipeline tilt Angle on system energy head parameters

Line Angle can head to the system parameters is also there will be some impact, mud return pipeline and seabed mudline Angle theta affect the length of the return line, which can affect the drilling fluid backflow when required by the system, analyzes the theta from 50 ° ~ 90 ° effect can head for the system, as shown in fig.5, you can see tilt Angle of the system can head impact is not big, can design according to ocean conditions to calculate the lateral displacement of drill pipe, to determine the mud returns the Angle theta of pipeline and seabed mudline.

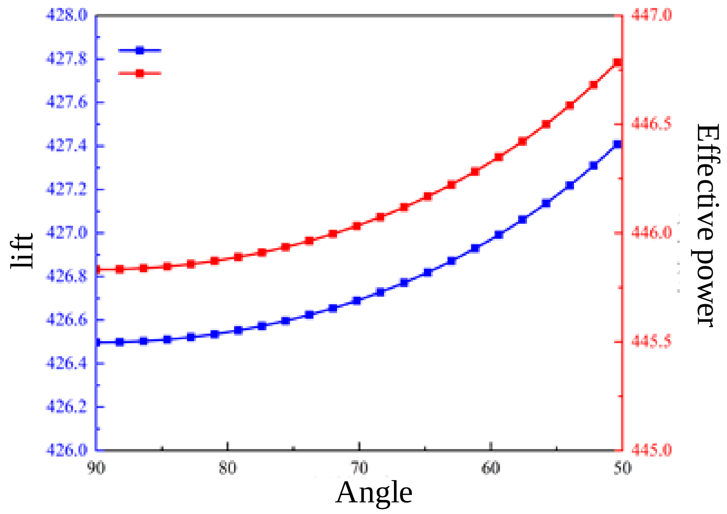

Fig.5 Influence of tilt Angle on the system energy head

5. Summary

(1) The hydraulic model including drilling fluid density, water depth, solid particle fraction and so on was established for the mud lifting control system.

(2) According to the requirements of the mud lifting control system, the energy head and effective power of the system under different parameters are analyzed

(3) The calculation results show that the drilling fluid density has the greatest influence on the system

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