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Pressure drawdown mechanism and design principle of jet pump bit

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Design principle.

Abstract. Reducing the Bottom Hole Differential Pressure (BHDP) to reduce the cutting hold-down effects can significantly improve the Rate Of Penetration (ROP). This paper analyzes the pressure drawdown mechanism of the jet pump bit, and then designs a novel annular jet pump bit. Using the hybrid grid method, key factors affecting the pressure drawdown capacity of the bit are discussed. The backflow below the reverse nozzle outlet is the main reason for the pressure drawdown capacity of the jet pump bit being reduced. The design principle of the jet pump bit is given. The axial and radial angles are 150°-180° and 60°-75°, respectively, and the bit clearance should be kept below 3 mm, preferably using the vortex-jet flow combination pressure drawdown theory, to reduce the bottom hole pressure. The bit rotation speed should be as large as possible, all of which provides the theoretical guide for its development.

1. Introduction

The BHDP is the bottom-hole hydrostatic pressure minus the formation pore pressure, which is an important factor affecting the ROP. Laboratory tests and field applications show that reducing the BHDP can significantly improve the ROP. This mainly results from two reasons: Firstly, decrease of the cuttings hold-down effect, and the cuttings being made to leave the well bottom in time to avoid repeated fragmentation, and secondly, reducing the rock crushing strength and plasticity, and improving the stress conditions of the bottom-hole to realize rock failure under tensile stress instead of under impact and shear stress.

In the drilling processes, the bottom-hole can realize near balanced or underbalanced conditions by reducing the Equivalent Circulation Density (ECD) of the drilling fluid. Thus, the cuttings hold-down effect is reduced and the stress condition of the bottom-hole is improved. Reducing the BHDP is usually realized by reducing the ECD of the drilling fluid. However, the ECD must meet the requirements of safe drilling. In recent years, scholars worldwide have undertaken much research into "how to reduce the BHDP" [1-11]. They have designed many tools, such as the vortex tool, the JHPDT, and pulsed jet tools, to reduce the BHDP, while maintaining the wellbore hydrostatic pressure. In this way, the wall of the wellbore is stable, and the bottom-hole differential pressure is reduced.

The vortex tools reduce the BHDP through the fluid vortex made from high speed rotating parts. The returning fluid from the bottom-hole is a mixture of drilling fluid and hard cuttings with different shapes. In order to increase the life of the tools, the impact resistance and wear resistance of the rotation parts must be improved, and the sealing packer needs to be good enough to prevent the cuttings from coming into its annular space, the production casing or the wall of the well bore. Using a turbine motor to drive a multi-stage pump, Bern et al. developed an ECD reduction tool that can reduce the BHDP by 2 MPa [1]. Yang et

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al. used reverse nozzles to develop a pressure drawdown joint which improves the ROP by 12% [2], and the joint developed by Du can improve the ROP by 20% [3]. Zhu et al. proposed a vortex bit to reduce the BHDP, and the reasonable axial angle, radial angle, reverse flow ratio, rotation speed, and distance between the reverse nozzle outlet and the bottom-hole surface of the vortex bit are given [4,5].

The pulsed jet tools create a cycled negative pulsed hydraulic jet to reduce the BHDP, which requires no high speed rotation parts. Because of this, it has developed quickly in recent years due to its good performance. The hydroPulse^{TM} drilling system developed by Kollé [6], the low-pressure pulse jet developed by Yang et al. [7], the suction-pulse tool used in the Shengli Oilfield [8], the hydraulic pulsed cavitating jet developed by Li [9] and the suck-in pulsed jet [10] etc. are commonly used.

The JHPDT uses the jet pump to reduce the BHDP and pump the bottom-hole mixture, needing no high speed rotation parts, but the individual power fluid is needed to drive the jet pump [11]. This paper mainly analyzes the pressure drawdown theory and structure features of the jet pump bit, studies the key points which affect its pressure drawdown capacity, and establishes its design principle, all of which offer theoretical guidance for its development.

2. Pressure drawdown mechanism of the jet pump bit

The jet pump bit reduces the hole-down pressure of the drilling fluid and increases the cutting carriage by the center jet pump designed at the bit center. The center jet pump consists of a reverse nozzle, suction pipe, throat and diffuser (Figure 1). Low pressure power fluid jets from the reverse nozzle and sucks the drilling fluid mixed with cuttings into the throat. The power fluid and the drilling fluid containing cuttings mixed together thoroughly in the throat, and exchange momentum. The drilling fluid and the cuttings, with a very high velocity and dynamic energy, at the end of the throat flow into the diffuser. The diffuser decelerates this high speed mixture, and converts part of the dynamic energy into pressure potential energy that forces the mixture upward through the annulus. The pressure of the drilling fluid jetted by the reverse nozzle is lower. The drilling fluid and the cuttings can be carried out from the bottom hole in time. So, the pressure of the bottom hole is kept at a low level and, thus, the hole-down pressure is reduced. Song et al. [12] undertook much research into the basic theory of jet pumps used in oilfields. Fan et al. [13] paid much attention to the peripheral nozzle jet pump, etc. In this paper, we do not discuss the performance equation of the jet pump.

2.1. Sun Weiliang bit

The sun bit [14] has four jet nozzles used for carrying cuttings and the cooling bit, and four reverse nozzles used for actuating the jet pump (Figure 2). The outside of the bit body is an 8 1/2″ cylinder that is arranged with many gauge teeth. The reverse and jet nozzles connect with the main flow path of the bit, and the reverse drilling fluid is determined by closing a certain number of jet nozzles. Numerical calculation and laboratory tests show that the optimal ratio of the throat diameter divided by the jet nozzle diameter is 1.8 to 2.5, which can obtain the maximum pressure drawdown value, and the maximum pressure reduced by the jet pump bit is 1.86 MPa. When the confining pressure is 10 MPa, flow rate is 30 L/s, bit clearance is 1 mm, the throat diameter is 15 mm and the reverse nozzle diameter is 8 mm. The smaller the distance is between the reverse nozzle outlet and bottom-hole surface, the better the pressure drawdown capacity. The confining pressure has little effect on the pressure

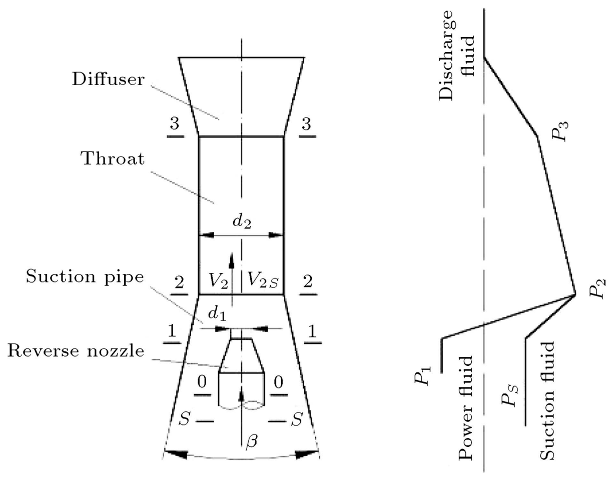


Figure 1. Pressure drawdown mechanism of the jet pump.

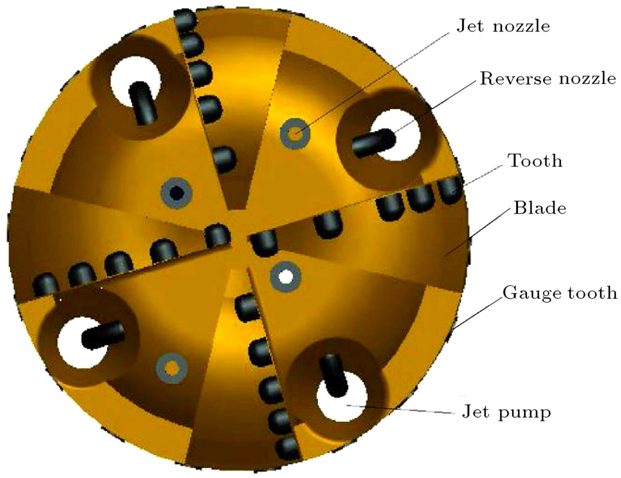


Figure 2. The structure of Sun Weiliang bit.

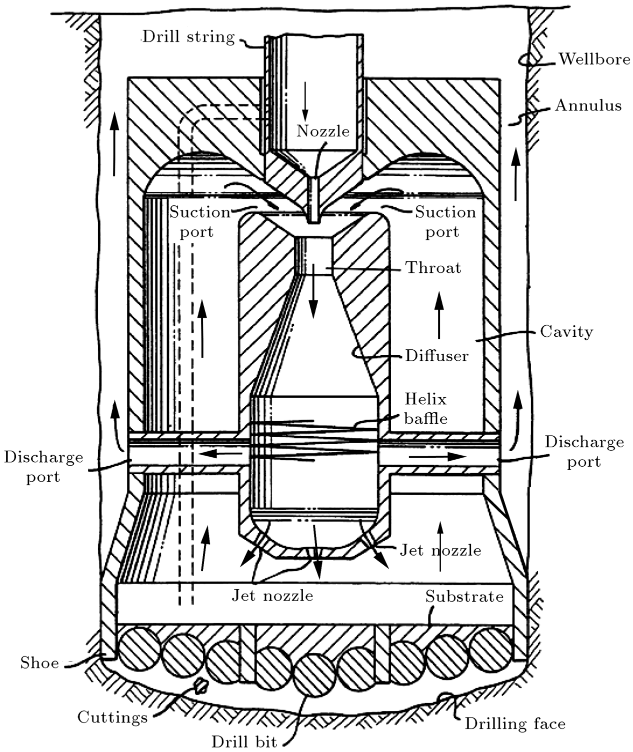


Figure 3. Underbalanced jet pump bit.

drawdown capacity. When the ratio of the reverse flow rate divided by the downward flow rate increases, the pressure drawdown value increases. Bit clearance is the major factor to affect the pressure drawdown capacity. For example, when the bit clearance is 2 mm, the BHDP is reduced by 1.22 MPa, and when the bit clearance is zero, the BHDP is reduced by 2.6 MPa.

2.2. Underbalanced jet pump bit

The underbalanced jet pump bit designed by Mueller [15] has a single jet pump which is concentric with the bit (Figure 3). The drilling fluid mixed with cuttings in the cavity is pumped into the jet pump cavity by the jet pump, then its pressure increases. The cuttings are separated by the helix baffle, and along with some of the higher pressure, they flow into the discharge ports and go out to the surface. The remaining parts of higher pressure flow downwardly through the pressure drawdown nozzle to clean the bottom-hole and carry the cuttings to the cavity. So, the reduced pressure drilling fluid can always flow back to the drilling surface. However, this bit is only in the conceptual design stage and needs further study.

2.3. Concentric nozzle jet pump bit

The external structure of the concentric nozzle jet pump bit is like a conventional three blade PDC bit or a conventional tricone bit [16] (Figure 4). This bit has three vertical cylindrical nozzles. The upper port of each nozzle is used as a reverse nozzle, while the lower port is used as a jet nozzle. The vertical nozzle is concentric with, and has a smaller diameter than, the annular chamber. Drilling fluid flows through the inlet conduit into the vertical cylinder, then, part of the fluid flows upwardly through the upper port to actuate the jet pump. The remaining fluid flows downwardly through the lower port to clean the bottom-hole surface. The upper port and the annular chamber form a jet pump to pump the bottom-hole mixed fluid through the annulus between the lower port and the annular chamber.

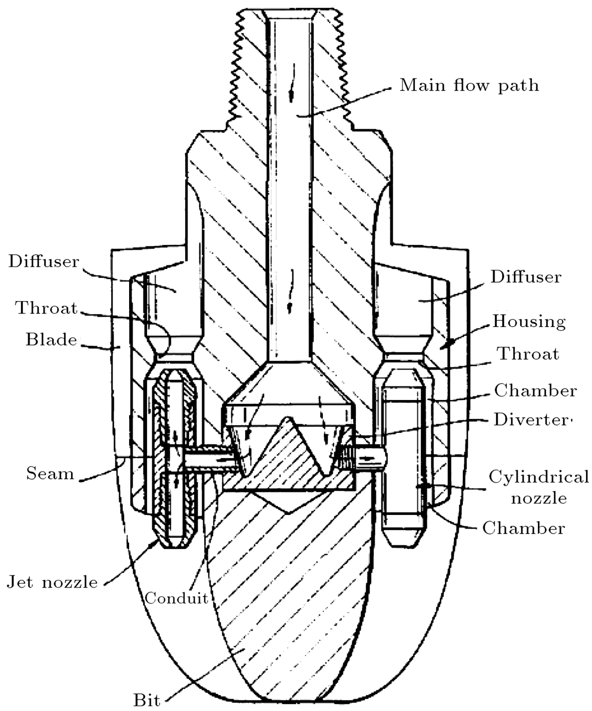
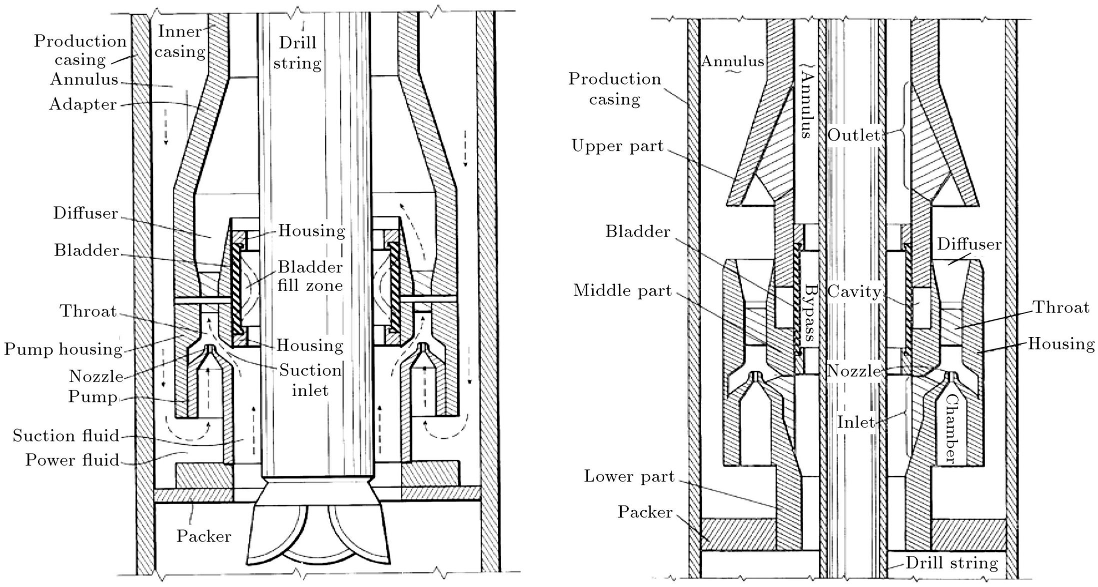


Figure 4. Concentric nozzle jet pump bit.

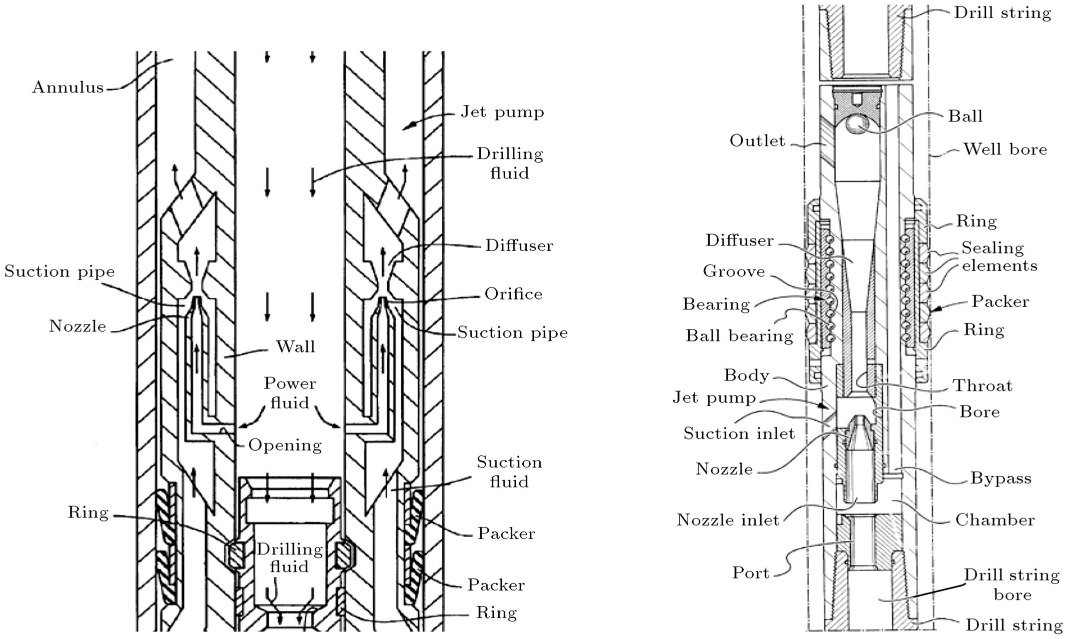
2.4. Discussion

A jet hydraulic pressure drawdown tool consists of a wellbore UBD jet pump, a jet pump joint and a jet pump bit. A casing fixing wellbore UBD jet pump uses an inner casing to provide a flow passage for the power fluid, a packer to seal the annulus between the inner casing and the production casing, and a jet pump or a helix venturi pipe to reduce the well bore pressure (Figure 5) [17-21]. A rotating wellbore UBD jet pump rotates with the drill string, while its packer needs to rotate and move vertically along the inner wall of the production casing. So, the performance of the packer is the greatest design difficulty (Figure 6) [22-26]. The jet pump joint installed on the top of the bit rotates passages for the power fluid and mixed fluid, respectively, so its structure is very complicated. Moreover, due to dimensional restrictions, the complicated stress conditions make it difficult to design. Based on a conventional bit, the jet pump bit uses inner jet pumps to reduce the BHDP. It avoids overpressure strengthening of the drill face and



(a) Independent jet pump (b) Concentric casing actuated jet pump

Figure 5. Casing fixing wellbore UBD jet pump.



(a) Packer structure (b) Packer and rolling bearing structure

Figure 6. Rotating wellbore UBD jet pump.

underpressure damage to the wellbore. The bit does not need an auxiliary assembly or trip tools, and its structure is simple.

Table 1 shows that a casing fixing wellbore UBD jet pump does not rotate with with the drill string, and does not affect the normal work of the bit and bottom-hole assembly (Figure 7) [27-29]. However, it has at least two flow drill string, but needs an inner casing to actuate it. The pressure drawdown capacity of the JHPDT is a wellbore UBD jet pump >> jet pump joint. The pressure drawdown capacity of the jet pump bit is still unknown, and requires further study.

3. Key influencing factors of the jet pump bit

3.1. The computation model of the flow fluid of the jet pump

1. **Physical model.** Currently, all jet pump bits adopt the center jet pump structure. This structure has its disadvantages: Large amounts of cutting will

Table 1. Specifications of the JHPDT.

Tools		**Rotating**	**Structure characteristic**	**Pressure drawdown capacity**	**Research**
Wellbore UBD jet pump	Casing fixing	No	Inner casing, fixing packer, jet pump or helix venturi pipe	UBD drilling for reservoir pressure as low as 0.48 g/cm^3 ECD	Structure design and methods discussion
	Rotating	Yes	Moving and rotating packer, moving packer and rolling bearing, jet pump	Unknown	Structure design
Jet pump joint	Muti-circulation	Yes	Jet pump or peripheral nozzle jet pump, fluid diverter	Unknown	Structure design
	Normal circulation	Yes	Jet pump, fluid diverter	0.45 MPa (installed directly on bit)	Laboratory water test
	Sun Weiliang	Yes	Jet pump, jet nozzle	Unknown	Laboratory water test
Jet pump bit	Underbalanced jet pump bit	Yes	Jet pump, helix baffle	Unknown	Structure design
	Concentric nozzle jet pump bit	Yes	Jet pump, vertical cylindrical nozzle	Unknown	Structure design

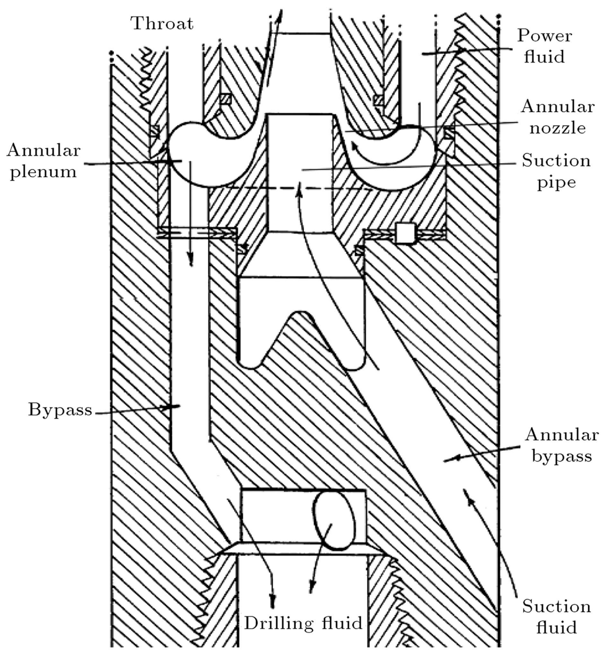


Figure 7. Jet pump joint.

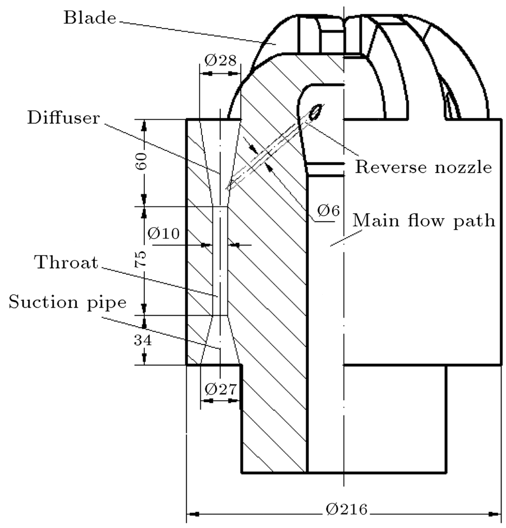


Figure 8. Peripheral nozzle jet pump bit.

block the jet pump nozzles, throats and suction pipes. Especially, bit balling occurs much more easily when the formation is mud shale, which has a high hydration expansion property. So, this kind of jet pump bit is still not used in the drilling industry, and the peripheral nozzle jet pump is taken into consideration (Figure 8). The suction pipes, throats and diffusers of the peripheral nozzle jet pump have the same axis. Several peripheral nozzles are installed at the end of the suction pipes, and there is no flow diversion of the ejecting fluid in the jet pump, which makes it particularly suitable for sucking drilling fluid with bigger solid particles. Because the flow area of the peripheral nozzle jet pump is larger than the center jet pump, a novel peripheral nozzle jet pump bit is developed. The

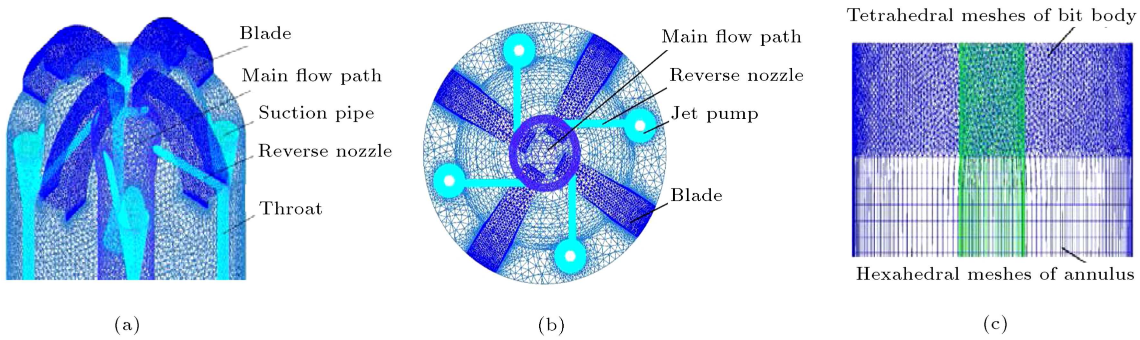


Figure 9. Mesh model of the peripheral nozzle jet pump bit.

jet pump is located at the outward range of the bit. It is easier to arrange the nozzles which are close to the drill side and it is more difficult to arrange the nozzles on the outside edge of the bit. In order to simplify the internal structure of the bit, a single-nozzle peripheral jet pump bit is introduced (Figure 9). This bit consists of 4 blades, 4 peripheral jet pumps, 4 reverse nozzles and the main flow path. To decrease the mesh number and improve the computation speed, a hybrid grid method is adopted to mesh the bottom hole flow field. The mesh process is as follows: A tetrahedral mesh is applied to the bit body (Figure 9(a) and (b)), and then, the main flow path and the annulus are meshed with the hexahedral grid. Finally, these two kinds of mesh are merged at their interface (Figure 9(c)), so that the fluid in these two kinds of mesh can pass through each other.

2. **Mathematical model.** It is supposed that the leakage of drilling fluid into the formation does not occur. The jet nozzle is not included in this bit, which means that all drilling fluid flows through the reverse nozzle. The diameter of the throat is 15 mm, and the diameter of the reverse nozzle is 6 mm. The axis equations of the reverse nozzle are expressed by the Cartesian coordinates of points A and B (Figure 10). The coordinate of point A is expressed as:

$$\begin{cases} x = R_d \cos(\theta_B + \theta) \\ \quad \theta \in [50^0, 75^0] \\ y = R_d \sin(\theta_B + \theta) \\ \quad \partial \in [135^0, 180^0] \\ Z = Z_{\min} + \cot\partial \sqrt{R_d^2 + R_h^2 - 2R_d R_h \cos\theta} \\ \quad \theta = \theta_A - \theta_B \end{cases} \tag{1}$$

The coordinate of point B is expressed as:

$$\begin{cases} x = R_h \cos\theta_B \\ y = R_h \sin\theta_B \\ Z = Z_{\min} \end{cases} \tag{2}$$

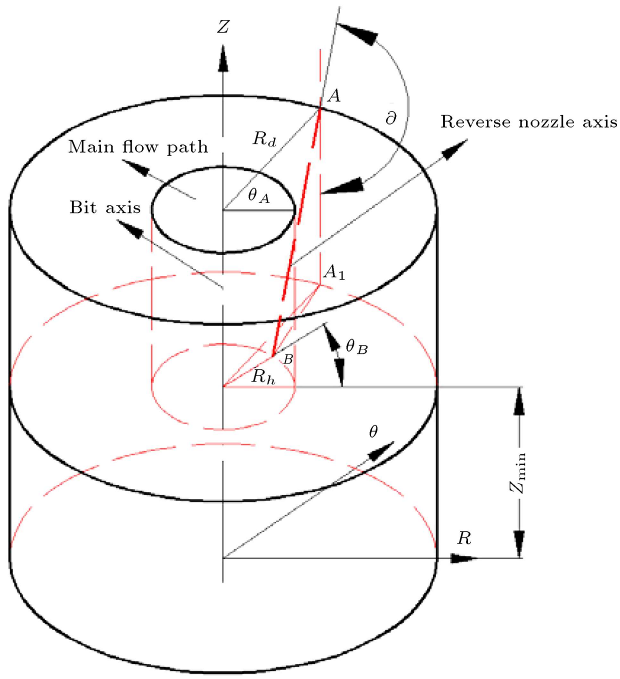


Figure 10. Reverse nozzle axis.

where ∂ is the axial angle between the reverse nozzle axis and the bit axis; θ is the radial angle between the reverse nozzle axis and the rotation direction; R_d is the radius of the reverse nozzle outlet; R_h is the radius of the main flow path of the bit; $Z_{\min}$ is the axial coordinate of the reverse nozzle inlet; θ_B is the radial angle of the reverse nozzle inlet, and θ_A is the radial angle of the reverse nozzle outlet. In this design, ∂ is 150°, and θ is 60°, confining pressure is 30 MPa, flow rate of drilling fluid is 33 L/s, and bit rotation speed is 150 rpm.

The drilling fluid streamline curvature is very big for the opposite direction of the inlet flow and the out flow of the reverse nozzle. The fluid vortex strength is stronger for the bit rotation and the existence of the radius angle θ than a conventional jet bit, so, the k-ε turbulence model may produce larger errors [30] in calculating the bottom-hole flow field of the peripheral nozzle jet pump bit. A renormalization group (RNG) method yields both scaling relations and the amplitudes of inertial-range correlation functions [31]. This makes the RNG k-ε an effective tool for turbulence modeling and simulations of the peripheral nozzle jet pump bit [32-33]. So, we adopt the RNG k-ε model as the turbulence model with the control equations as shown [34]:

$$\frac{\partial u_i}{\partial x_i}=0, \tag{3}$$

$$\frac{\partial u_i}{\partial t}+\frac{\partial (u_i u_j)}{\partial x_j}=f_i-\frac{1}{\rho}\frac{\partial p}{\partial x_i}+\nu\frac{\partial^2 u_i}{\partial x_i x_j}-\frac{\partial}{\partial x_j}\left(\overline{u_i' u_j'}\right), \tag{4}$$

where, ρ is the fluid density, kg/m^3; p is the fluid pressure, Pa; u_i is the velocity in the i direction, m/s; ρg_i is the volume force in the i direction generated by the gravity, N/m^3; $\mu=\rho C_\mu k^2/\varepsilon$ is dynamic viscosity, kg/(m.s), $C_\mu=0.09$; ε is the rate of fluid turbulent dissipation, m^2/s^3; and k is the fluid dynamic energy, m^2/s^2.

RNG k-ε model:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\eta_t\frac{\partial u_i}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\eta_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]-\rho\varepsilon, \tag{5}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t}+\frac{\partial(\rho \varepsilon u_i)}{\partial x_i}=\frac{\varepsilon}{k}C_{\varepsilon 1}\eta_t\frac{\partial u_i}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\eta_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]-\frac{\varepsilon^2}{k}\rho C_{\varepsilon 2}, \tag{6}$$

where, $c_{1\varepsilon}=1.44$; $c_{\varepsilon_2}=1.92$; σ_k and σ_ε are the Prandt1 numbers of k and ε, respectively, and their values are 1.0 and 1.3, respectively. The above equations form the closed equations to solve the flow field of the peripheral nozzle jet pump bit.

3.2. The flow field of jet pump bit

As shown in Figure 11, the velocity field of the longitudinal section can be divided into several zones: back flow, cross flow, stagnation, suction and well attachment up flow. In Figure 11, the criteria for dividing the flow field into sections are the fluid direction and fluid functions in different positions of the jet pump bit. Drilling fluid mixed with cuttings flows back from the left side of the annulus between the bit and borehole. This creates a thicker radial cross flow layer that is pumped by the peripheral nozzle jet pump when it flows below the pump, which creates a suction zone.

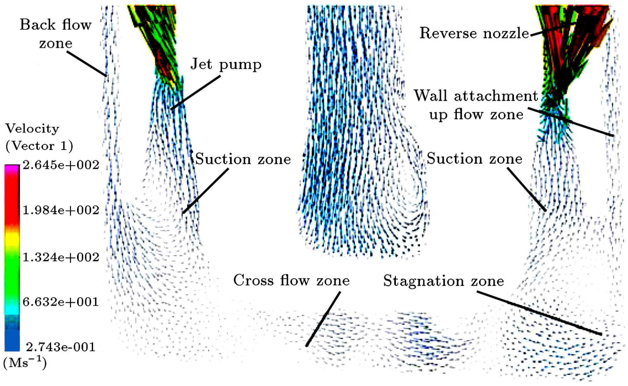


Figure 11. Velocity vector diagram of the bottom hole longitudinal section.

The fluid partially stagnates below the right side of the annulus and, on the right annulus, the fluid flows upwardly to the surface. The left and right sides of the annulus of conventional jet bit are both wall-attachment up flow zones [35] and no down flow zone, which shows that the wall-attachment up flow area is harmful for cuttings removing. The backflow zone is mainly caused by horizontal velocity, so, the axis slope angle of the upward nozzle should be increased as much as possible. Drilling fluid flows through the drilling pipe down into the main flow path, and its flow direction changes by angle ∂ after flowing into the upward nozzle, which leads to a considerable pressure loss. Bigger ∂ angle means more pressure loss, and a smaller ∂ angle increases the backflow zone. Compared to pressure loss, the influence of backflow is much more harmful for the BHDP, so, a bigger ∂ angle is recommended. The acceptable range is 150°-180°; 180° being the optimum according to simulations.

3.3. The influence of radial angle of reverse nozzle on the BHDP

When the rotation speed is 300 rpm, the maximum negative value of the BHDP is proportional to the value of angle θ, as shown in Figure 12. When θ is smaller than 60° the BHDP increases more slowly.

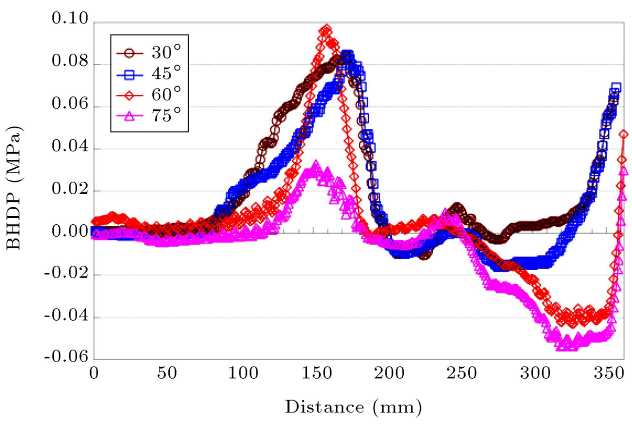


Figure 12. The BHDP and the radial angle.

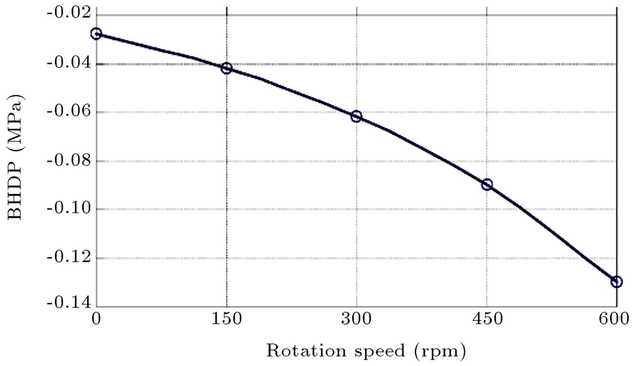


Figure 13. The BHDP and the rotation speed.

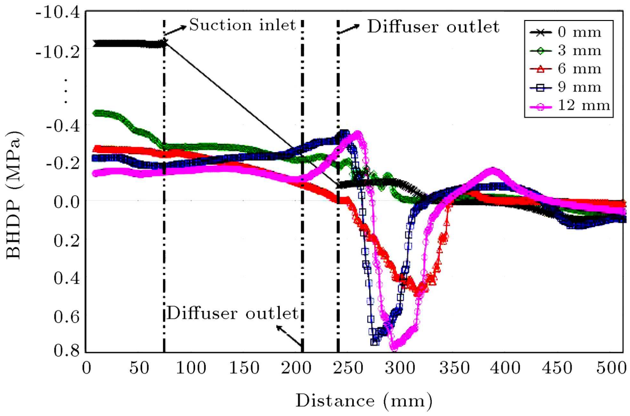


Figure 14. The BHDP of the annulus.

When it is bigger than 60° the BHDP increases rapidly. This is consistent with the recommendation value of Lamin [29].

3.4. The influence of rotation speed on the BHDP

The BHDP has a proportional relationship with the rotation speed (Figure 13), which, nevertheless, is not quadratic to the bottom negative pressure. As the rotation speed increases, the BHDP becomes much bigger.

3.5. The influence of bit clearance on annulus pressure

Figure 14 shows that when the bit clearance (the distance between the bit face and the wellbore face) is below 6 mm, the annulus pressure increases gradually to confining pressure, 30 MPa, and the velocity decreases rapidly by increasing the bit clearance. The larger the bit clearance is, the higher is the annulus pressure. When the bit clearance is above 9 mm the annulus pressure decreases gradually. The velocity tends to be unchangeable with the increasing of the bit clearance. The larger the bit clearance is, the lower the annulus pressure is, which is caused by the vortex effect of the annulus fluid. The pressure and velocity increase dramatically when the fluid flows into the annulus corresponding to the diffuser outlet.

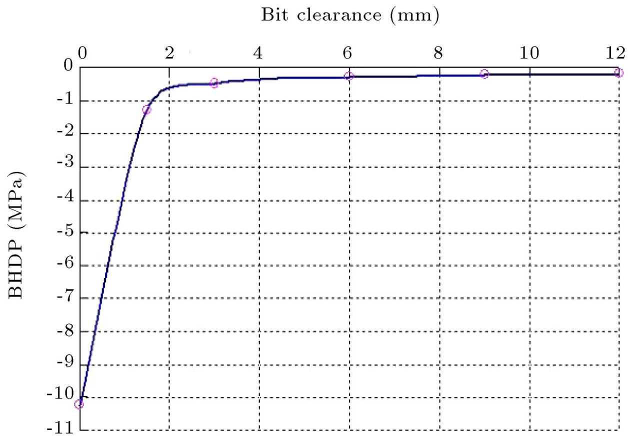


Figure 15. Bit clearance and the BHDP.

3.6. The influence of bit clearance on BHDP

Figure 15 shows that the BHDP decreases rapidly while the bit clearance increases. When the bit clearance increases from 0 mm to 3 mm, the BHDP decreases from 10.23 MPa to 0.49 MPa. With the continuing increase of the bit clearance, the BHDP decreases slowly. When the bit clearance is above 9 mm, the BHDP keeps at about 0.2 MPa. The numerical simulation agrees with the results of the experiments conducted by Sun very well [14]. So, sealing the bit clearance is a critical point in improving the performance of the jet pump bit. When the bit clearance increases, the fluid flows into the bit clearance until the flow resistance is lower than the jet pump. So, fluid flows through the throat, which greatly decreases the venturi effect; the BHDP is mainly decreased by vortex.

3.7. Discussion

The average diameter of the drilling particles is about $2 \sim 3$ mm for a peripheral nozzle jet pump bit. The diameter of the drilling particles is not a critical factor of bit balling. The shale content of the breaking rock, the drilling fluid properties and the volume are responsible for bit balling (Figure 16). If the shale content is high, the properties of the drilling fluid are poorer and the fluid volume is smaller, the bit is most probability balling. So, the jet-pump bit is preferable for drilling in rock with lower shale content.

Drilling practices show that the well-hole enlargement rate is usually 10%-15% caused by bit jump, whirl or deviate. For an 8 1/2″ bit, the wellbore enlargement value is 21.6 mm - 32.4 mm [36,37]. Jet pump bit numerical calculation results show that when the bit clearance is above 9 mm, that is, above 8.8% well-hole enlargement rate, the pressure drawdown value is kept at about 0.2 MPa (Figure 17). So, in order to put the jet pump bit in use, the critical point is how to seal the bit clearance. For the anisotropy of the formation and the complex movement of the bit, the bit clearance is always changing and is hard to be controlled, which is

Figure 16. PDC bit balling by shale.

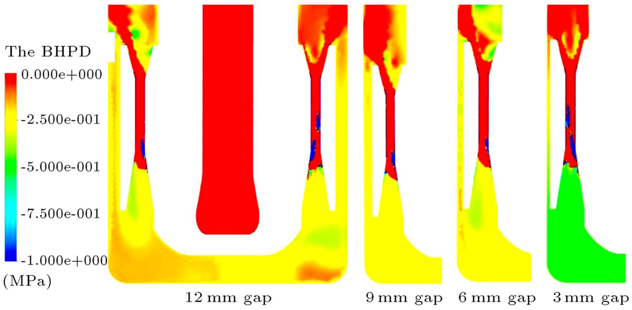


Figure 17. Pressure distribution of the bottom hole longitudinal section.

the main factor behind restriction of the jet pump bit development.

Combining the fluid vortex and jet pump pressure drawdown method can eliminate the single peripheral nozzle jet pump bit from hindering the bit clearance. Part of the high speed drilling fluid ejected from the upward nozzle rotates with the drill bit and creates a high speed swirl, which realizes negative pressure. The remaining fluid still flows through the throat of the jet pump and generates negative pressure due to the venturi effect. According to this method, a novel vortex and jet pump combination bit can be designed by keeping the blades, upward nozzle and other structures like the single peripheral nozzle jet pump (Figure 18). The throat of the jet pump is enlarged to interlink the distributary flow passage and the bit annulus.

Figure 19 shows that the backflow phenomenon of the bit flow field is weakened. The bottom-hole flow field of bits with different kinds of distance between throat and bit axes is calculated when the bit clearance is 9 mm. Figure 20 shows that the BHDP is almost axisymmetrical along the radial direction and that

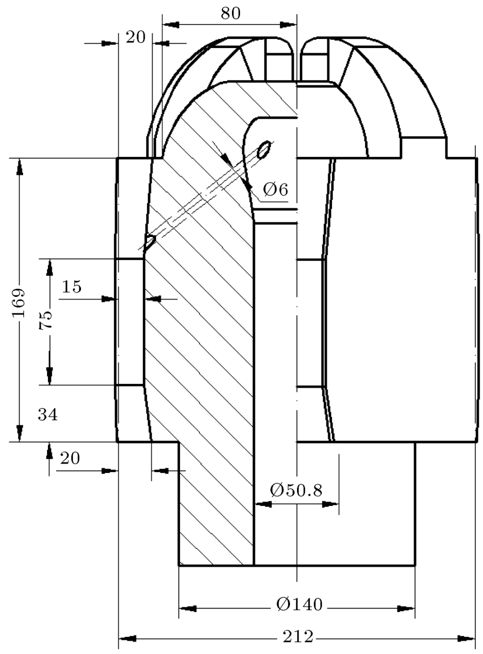


Figure 18. The vortex and jet pump combination bit.

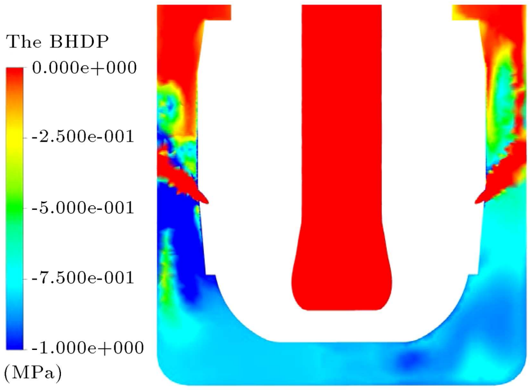


Figure 19. Pressure distribution of the bit longitudinal section.

the pressure of the left side increases slightly for the back flow of the drilling fluid. When the distance increases from 94 mm to 106 mm, the BHDP changes from −0.45 MPa to −0.88 MPa, which shows that when the flow area of the throat decreases, the venturi effect increases, and, so, the BHDP increases. When the distance increases to 110 mm, the BHDP drops to −0.4 MPa, which shows that when the distance increases to a certain value, the BHDP is caused only by a strong vortex brought about by the high speed rotation of the drilling fluid. So, an optimal parameter exists. For example, the BHDP has a maximum that is −0.88 MPa when the distance is 106 mm. In this case, the BHDP varies from −0.45 MPa to −0.88 MPa, that is, 3-4 times of the jet pump bit, which shows that the fluid vortex and jet pump combination pressure drawdown method is feasible for reducing the BHDP.

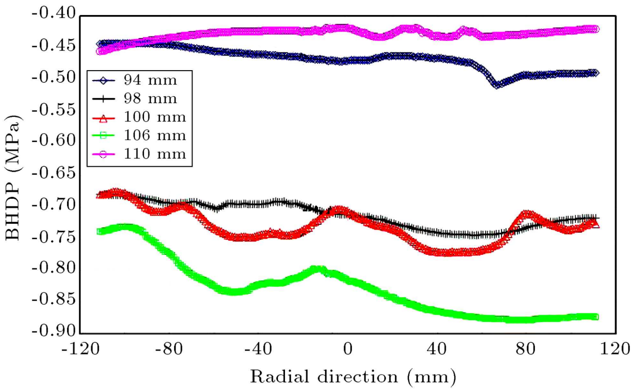


Figure 20. The BHDP along the radial direction.

4. The design principle of jet pump bit

1. The backflow zone at the bottom hole circulates downwardly with the cuttings, which leads to the precipitation of cuttings, and reduces the jet and vortex pressure drawdown effects of the upward fluid. So, reducing the backflow zone is the key point in increasing the pressure drawdown effect of the jet pump bit. The backflow zone is contributed to by the horizontal water jet, due to the axis slope angle. We recommend a bigger axis slope angle of the reverse nozzle, and the optimal ∂ value is suggested as 150° to 180°. To reduce the backflow area of the fluid, the bit clearance should be smaller than 3 mm.
2. Greater angle θ enhances the strength of the vortex generated by the reverse nozzle at the bottom hole, and, thus, increases the BHDP. However, the velocity of the drilling fluid in the axial direction is smaller, which is detrimental to cuttings carriage. So the recommended range is 60°-75°.
3. With the permission of the drilling situation, the rotation speed of the jet pump bit should be improved as much as possible.
4. The pressure drawdown effects of the vortex and jet pump combination bit vary with the distance between the axis of the throat and the drill axial. The optimal distance is 106 mm for the simulation situations of this paper. During the design of other different-size bits, this optimal distance needs to be further optimized.

5. Conclusion

When all the drilling fluid comes upwardly through the reverse nozzle and the Well-hole enlargement increases from 0 to 8.8%, the BHDP decreases from 10.35 MPa to 0.2 MPa. If the well-hole enlargement is larger than 8.8%, the BHDP keeps at about -0.2 MPa. Therefore, sealing the bit clearance and avoiding back flow is a critical point in improving the performance of the jet pump bit. The fluid vortex and jet pump combination pressure drawdown method has the potential to reduce the BHDP. The established design principle of the jet pump bit can be used for the design guidance of the jet pump bit.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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