ISSN: 2664-9640

Drilling Depth Analysis of Hydraulic Jet Radial Horizontal Well

Lang Deng [1,2], Wei Li [2, a, *], Shu Chenxu [1,2], Zou Xing [1,2]

[1]College of Mechanical and Electrical Engineering, Southwest Petroleum University, Chengdu 610500, China

[2]Key Laboratory of Oil and Gas Equipment, Ministry of Education, Southwest Petroleum University, Chengdu 610500, China

[a]82867973@qq.com

Abstract

Hydraulic jet radial drilling technology, as a new type of oil and gas field stimulation technology, is a sharp tool to increase the output of single well and realize the reduction of cost and increase of oil, and gradually becomes an effective technical means for the development of new wells and the transformation of old wells, with broad development prospects.According to the limit drilling depth and drilling speed of radial horizontal well, and based on the drilling engineering theory and the mechanism of high-pressure water jet rock breaking, the drilling mechanism of radial horizontal well system is studied, the basic mechanical relationship expression of the system is established, the dynamic equation of high-pressure hose forward drilling driven by water jet drill bit is obtained, the influence of system construction parameters and key parameters of water jet drill bit on drilling depth and drilling speed of radial horizontal well is analyzed, it is shown that the drilling speed is the maximum in the initial state of drilling, and then with the increase of drilling distance of radial horizontal well, the contact resistance between high-pressure hose and shaft wall increases gradually, and the drilling speed decreases gradually.When the limit drilling distance is reached, the drilling speed decreases to zero.

Keywords

Radial drilling technology； Rock breaking by high pressure water jet； key parameter； Drilling depth.

1. Introduction

The hydraulic jet radial drilling technology is also called the high-pressure water jet very small radius drilling technology or the ultra short radius drilling technology[1]. This technology generates high-pressure water jets through ground pressure pumps, uses high-pressure hoses to lower the water jet nozzles to the design depth of the target wellbore, and realizes the vertical to horizontal turning of the high-pressure water jet nozzles through the steering device. According to the water jet rock breaking mechanism, Realize the drilling of multiple radial horizontal boreholes along the radial side in the target formation[2-5]. According to the characteristics of hydraulic jet radial drilling technology, this technology has the advantages of simple construction equipment, simple construction technology, using high pressure water jet to break rock, no additional power, small turning radius, avoiding frequent deviation and control trajectory of horizontal wells, small construction difficulty, low drilling cost[6]. Radial drilling technology was proposed by W. Dickinson and others in 1985.After more than 30 years of continuous improvement and development, this technology has shown many advantages in the field of oil and gas reservoir development, and has achieved good application results at home and abroad, gradually become a conventional and unconventional oil and gas resources

ISSN: 2664-9640

to improve single well production, reduce costs and increase oil, with a broad development prospect[7-9].

In this paper, based on water jet theory and drilling engineering theory, firstly, according to the construction environment and hypothetical conditions of radial horizontal well, the mechanical model of radial horizontal well system is established, and the basic relations of internal dynamic and resistance of drilling system are obtained.Secondly, according to Newtonian mechanics, the motion equation of high pressure hose drilling driven by water jet drill bit of radial horizontal well system is established, and then the prediction model of ultimate extension length of radial horizontal well is obtained.Finally, the influence of key parameters such as drilling construction parameters and bit geometry on drilling distance and drilling speed is analyzed without considering geological conditions and rock stratum conditions.

2. Drilling equipment composition and construction parameters

In this paper, the drilling depth and drilling speed of radial horizontal wells are studied by taking the construction horizon well depth of 4000m as an example. Fig 1 is the composition diagram of drilling equipment. The main drilling tool adopts the coiled tubing with vehicle Ø1.5′′ (inner diameter of 30.77mm), the outer diameter of the drum is Ø3.91m, and the total length is 7857m; the upper vertical well section is the casing Ø7′′ (inner diameter of 157.1mm), and now the operating oil pipe Ø3.5′′(inner diameter of Ø75.9mm) is used, the lower part of the oil pipe is connected with special steering gear, and the lower part of the coiled oil pipe is hung with high-pressure hose. The high-pressure drilling pump pressurizes the drilling fluid, and then transmits the high-pressure potential energy to the downhole through the coiled tubing and the high-pressure hose. The high-pressure potential energy is converted into kinetic energy through the water jet drill, and the high-speed jet generated penetrates the formation with impulse work, and forms a radial horizontal wellbore under the push of the jet. Some drilling equipment parameters required for radial horizontal well construction are shown in Tab 1.

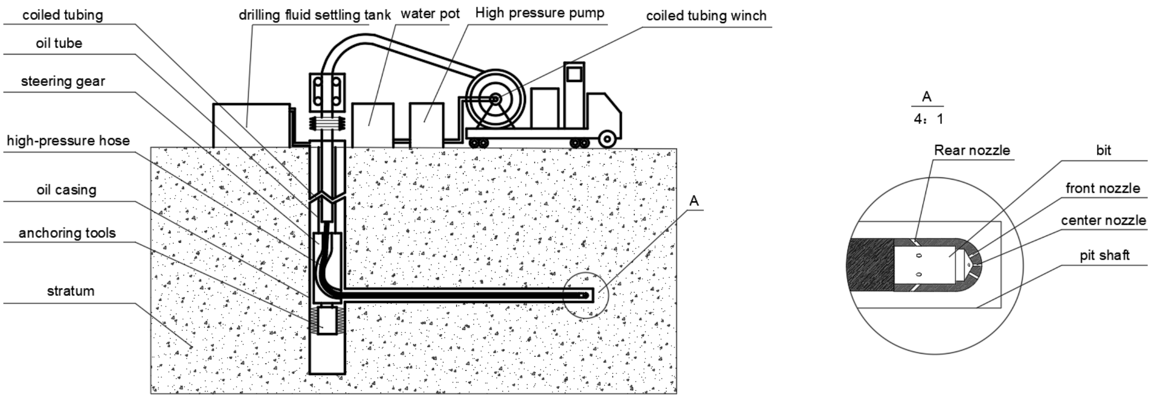


Fig.1 Composition diagram of drilling equipment for radial horizontal well

Tab.1 Drilling equipment parameter table of radial horizontal well

Construction equipment	Parameter data
Coiled tubing Ø1.5′′	external diameterØ0.0381m；internal diameterØ0.03077m；Outer diameter of roller Ø3.91m；total length 7857m
Oil casingØ7′′	external diameter Ø0.1778m；internal diameter Ø0.1571m
Oil tube Ø3.5′′	external diameter Ø0.0899m；internal diameter Ø0.0759m

Vertical well depth l_{av}	4000m
Steering gear	steering gear outer diameter Ø0.14m；height 0.4m；inner diameter of channel Ø0.026m
High pressure hose	outer diameter of high pressure steel wire wound hose Ø0.018m；internal diameter Ø0.012m,Floating weight in water m_{hp} =3.2N/m
Jet bit	The drill material is cemented carbide,$\rho_z = 1.5 \times 10^4\ kg/m^3$, $l_z = 30mm$；Impeller material is high strength alloy
Friction coefficient of open hole wellbore	$f = 0.4$
Fluid parameters	$\rho = 1 \times 10^3\ kg/m^3$；$\mu = 1.005 \times 10^3 Pa \cdot s$

3. Analysis on drilling force of radial horizontal well

In the radial horizontal well drilling system, the high-pressure drilling pump provides high-pressure fluid with certain water power. Firstly, the high-pressure fluid is transmitted to the bit through the flow in the circulation pipeline. Secondly, the high-speed jet generated by the water jet bit penetrates the formation with impulse. Finally, it flows back to the surface through the annulus and the cuttings. In the whole drilling system, the jet recoil force produced by the bit is the driving force of its forward driving. When the high-pressure fluid flows, it will inevitably produce friction with the pipe wall, bit nozzle and borehole wall. When the high-pressure hose is lowered through the coiled tubing, it will produce friction resistance with the special steering gear. The jet produced by the positive nozzle of the bit will be blocked by the bottom hole, which will produce backflow and hinder the development of the bit Sports. In order to simplify the theoretical calculation model of radial horizontal well system, the following assumptions are made in this paper：

(1) The horizontal well bore is regular cylindrical, and the bottom of the well is flat bottom, which does not take into account the irregular well case;

(2) When the water jet drill bit drives the high-pressure hose to reach the limit depth, the high-pressure hose is placed horizontally in the wellbore and is in line contact with the wellbore wall, regardless of the hose deformation, rock debris bed and surface contact;

(3) Ignore the viscous resistance of the high-pressure fluid flowing in the circulation pipeline of the whole drilling system;

(4) Only the horizontal axial stress which has great influence on drilling depth is considered.

Based on the above simplified assumptions, a theoretical calculation model for the force of the radial horizontal well system is established, as shown in Fig. 2.

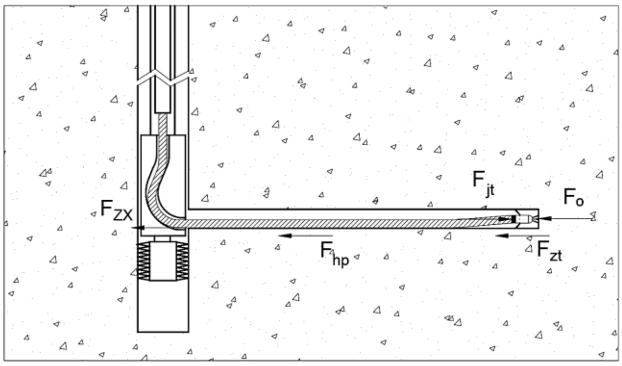


Fig. 2 Mechanical model of radial horizontal well system

The basic expression of the force relationship of the radial horizontal well system is as follows:

$$F = F_{jt} - F_{zx} - F_{hp} - F_{zt} - F_o \quad (1)$$

In that formula, is the resultant force of the radial horizontal well system in the drilling direction, N; F_{jt} is the propulsive force generated by the jet drill bit, N; F_{zx} is the frictional resistance generated by the coiled tubing when lowering the high pressure hose with the special steering gear, N; F_{hp} is the frictional resistance of the wellbore wall to the high pressure hose, N; F_{zt} is the frictional resistance of the wellbore wall to the drill bit, N; F_o is the external fluid resistance generated by the forward jet of the drill bit, N.

3.1. Calculation of bit jet impact force

Fig.3 is a calculation model of the jet impact force of the water drill, the nozzle hole of the straight rotary mixed jet drill is composed of a straight nozzle and a plurality of inclined nozzles, and the inclined nozzles are arranged at a certain angle with the axis of the drill. In general, when calculating the impact force of a straight-rotating mixed jet bit, because the nozzle hole of the bit is symmetrically distributed, in the space rectangular coordinate system, the axial impact force in the two-direction impact force on the drilling distance is less, in the process of rock breaking tunneling only plays the role of eroding the well wall and ensuring the stability of the wellbore trajectory, so this paper only to calculate the impact force in the axial direction. According to the theory of water jet and the mechanism of high pressure water jet breaking rock, the characteristics of common continuous jet are analyzed, and the basic relation of impact force of multi-hole drill jet can be deduced by comparing with small hole.

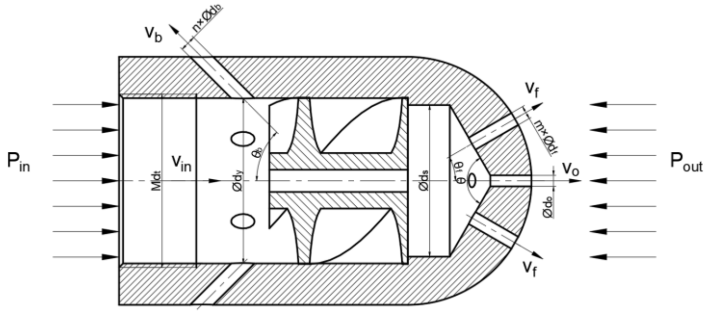


Fig.3 Computational model of direct-rotating mixed jet bit

Assuming that the internal flow of the system is steady state, ignoring the influence of fluid gravity and viscous resistance, the mass of the jet fluid flowing through the nozzle in time Δt is m. According to the momentum theorem, there are:

$$F_j \cdot \Delta t = mv_o - mv_{in} \quad (2)$$

Where, F_j is the jet impact force of single hole bit, N; Δt is the time, s; m is the mass of fluid per unit volume, kg; v_{in}、 v_o is the average velocity at the inlet and outlet of the jet bit, m/s.

By substituting $m/\Delta t = \rho Q$ into equation (2), it is concluded that:

$$F_j = \rho Q v_o \left(1 - \frac{v_{in}}{v_o}\right) \quad (3)$$

Since ${v_{in}}/{v_o} = \left({d_o}/{d_y}\right)^2 \ll 1$, the influence of its value on the calculation result can be ignored, and according to the Bernoulli equation of the small hole outflow, $v_o = \sqrt{\frac{2P_{in}}{\rho}}$, Substituting it into equation (3), the expression of jet impact force of single-hole drill bit is:

$$F_j = \rho Q v_o = \rho A_o v_o^2 = 1.57 d_o^2 P_{in} \quad (4)$$

In the process of radial horizontal well drilling, ignoring the impact of the jet drill bit by the bottom hole vortex and backflow, only consider the impact force of the nozzle jet before and after the drill bit. From equation (4), we can get the multi-hole direct-rotation mixed jet drill bit in the radial direction. The expression of the propulsion force received in the horizontal direction is:

$$F_{jt} = F_{jb} - F_{jf} = 1.57P_{in}(nd_b^2 \cos\theta_b - mCd_f^2 \cos\theta_f - Cd_o^2) \quad (5)$$

Where, F_{tj} is the propulsive force along the forward direction of the bit, N. C is the discharge coefficient, dimensionless number, in this paper, C = 0.84.

3.2. Resistance analysis of radial horizontal well system

It can be seen from formula (1) that in the radial horizontal well drilling system, the resistance in the axial direction is determined by the frictional resistance F_{zx} of the special diverter to the high-pressure hose, the frictional resistance F_{hp} of the borehole wall to the high-pressure hose, and the borehole wall surface The frictional resistance F_{zt} to the drill bit, the resistance F_{jf} generated by the forward nozzle of the drill bit, and the reflux resistance F_o generated by the forward jet are composed of these resistances. These resistances seriously affect the erosion and breaking efficiency and the tunneling depth of the water jet drill bit. In addition to the resistance generated by the forward nozzle, the sum of the remaining resistance of the drilling system is:

$$F_{rf} = F_{zx} + F_{hp} + F_{zt} + F_o \quad (6)$$

(1) Friction resistance of steering gear to hose

Fig.4 is a diagram of the $\emptyset 7''$ inside section of the steering gear used for the casing. It can be seen from the figure that the frictional resistance of the high pressure hose through the steering gear is mainly related to the bending radius R_1, bending inclination θ, straight section length L_1, steering curvature radius R and outlet section length L_2. Therefore, the frictional resistance F_{zx} of the steering gear to the high pressure hose is a function of the above parameters, and its expression is as follows:

$$F_{zx} = F_{zx}(R_1, \theta, L_1, R, L_2) \quad (7)$$

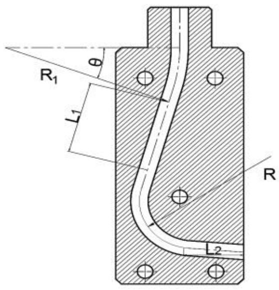


Fig.3 Schematic diagram of steering gear track section

Since the length of the oblique straight section of the steering trajectory L_1 and the length of the exit section L_2 are limited by the guide curvature radius R_1, the guide bend angle θ, the steering curvature radius R and the size of the steering gear, the friction of the high-pressure hose through the steering gear is calculated. In the resistance, only the guide curvature radius R_1, guide inclination angle θ and steering curvature radius R, which have a greater influence on the calculation result, are considered. In 2017, Hou Shihong, Wang Wenming, etc. through the trajectory design optimization and simulation analysis of the $\emptyset 7''$ casing steering gear, they believed that the guide bending rate radius R_1 and the guide bending angle θ have little effect on the steering resistance amplitude of the high-pressure hose , And use the quadratic regression method to fit the relationship between the three and the steering resistance [10]. Its expression is:

$$F_{zx} = a_1R^2 + a_2R_1^2 + a_3\theta^2 - a_4RR_1 - a_5\theta R_1 - a_6R\theta + a_7R + a_8\theta - a_9 \quad (8)$$

ISSN: 2664-9640

Where, $a_1 = -0.001938, a_2 = 0.000036, a_3 = 0.011533, a_4 = -0.001473, a_5 = -0.00056, a_6 = -0.0302, a_7 = 1.392417, a_8 = 0.2601667, a_9 = -83.216667$.

In this paper, based on previous research results, the radius of curvature of the ultra-short-radius horizontal well is less than 0.3m, the radius of curvature of the deflector is $R_1 = 0.3$m, the dip angle of guide θ=30°, and the radius of curvature R of the hole is only 0.1 When m, the steering resistance of the high-pressure hose is 23.02N calculated by formula (8). Considering that the size of the steering gear and the turning radius of curvature R are small, the high-pressure hose in radial drilling is slowly lowered to the target layer through coiled tubing, and does not directly affect the drilling depth of the horizontal well. Therefore, this paper is calculating the horizontal well Take $F_{zx} = 25$N when drilling extension length.

(2) Friction resistance of wellbore to hose

In the radial horizontal well drilling system, according to the relationship between gravity, friction coefficient and friction resistance, it can be known that the friction resistance of the well wall to the high-pressure hose F_{hp} and the contact length l_{hp} of the high-pressure hose, and the friction coefficient f of the open-hole well wall Related to the floating weight of the hose, its expression is:

$$F_{hp} = fM_{hp}gl_{hp} = fm_{hp}l_{hp} \tag{9}$$

Where, f is the friction coefficient of open hole wellbore, generally 0.23 ~ 0.5 [11-12] dimensionless; M_{hp} is the mass per unit length of high pressure hose, kg / m; m_{hp} is the floating weight per unit length of high-pressure hose, N / m; g is the coefficient of gravity, n / kg; l_{hp} is the contact length of high pressure hose, m.

(3) Friction resistance of wellbore to bit

In the radial horizontal well drilling system, when the water jet bit drives the high-pressure hose to the limit depth, it is assumed that the bit and the high-pressure hose are placed horizontally together. According to the relationship of gravity, friction coefficient and friction resistance, the friction resistance expression of the wellbore to the bit can be obtained as follows:

$$F_{zt} = fM_{zt}gl_{zt} = fm_{zt}l_{zt} \tag{10}$$

Where, M_{zt} is the mass per unit length of cemented carbide bit, kg / m; m_{zt} is the floating weight per unit length of high pressure hose, N/m; l_{zt} is the contact length of high pressure hose, m.

(4) Resistance of external fluid to bit

In the process of rock breaking and driving by water jet bit, after the forward jet erodes the broken rock, due to the block effect of bottom hole wall, some fluid will accumulate at the bottom of the well to form vortex, and the other part will form backflow to erode rock cuttings. The effect of these two parts of fluid will lead to the increase of drilling resistance of water jet bit. According to the theory of fluid mechanics, the expression of the external fluid resistance produced by the forward jet of bit is as follows:

$$F_o = \frac{\pi}{4} P_0 \left(D_n^2 - md_f^2 - d_o^2\right) \tag{11}$$

Where, P_0 is the external pressure generated by the bit forward jet flow ,Mpa, and its value is equal to the sum of ground pressure (P_{atm}) and radial drilling annular pressure loss (ΔP_{av}). D_n is the outside diameter of the bit, mm.

3.3. Drilling depth analysis of radial horizontal well

(1) Establish the motion equation of the system

According to Newton's second law, the rate of change of momentum of an object with time is equal to the sum of the forces applied to the system, and its differential expression is:

$$\sum F = m\frac{dv}{dt} \tag{12}$$

By substituting equation (5) and equation (6) into equation (1), the basic force relationship expression of radial horizontal well system is obtained as follows:

$$\mathrm{F} = F_{jt} - 25 - fM_{hp}gl_{hp} - fM_{zt}gl_{zt} - \frac{\pi}{4}P_0\left(D_n^2 - md_f^2 - d_o^2\right) \tag{13}$$

According to the analysis results of the pressure loss of the radial horizontal well drilling system [11], it can be seen that the pressure loss of the fluid in the annulus area is small, and the external pressure P_0 generated by the bit forward jet is small, so that the external fluid resistance F_o has a greater impact on the calculation results. Therefore, the influence of F_o is ignored when calculating the extension length of the water jet bit. Based on simplified assumptions and Newton's second law, a dynamic equation for the water jet bit to drive the high-pressure hose forward is established, namely:

$$\frac{d}{dt}\left(M_{hp}l_{hp}v\right) = F_{jt} - F_{zx} - fg(M_{hp}l_{hp} + M_{zt}l_{zt}) \tag{14}$$

To facilitate the calculation of equation (14), let $x = l_{hp}$ The expression can be written as follows:

$$M_{hp}\frac{d}{dx}\left[\frac{(xv)^2}{2}\right] = \left[F_{jt} - F_{zx} - fg\left(M_{hp}x + M_{zt}l_{zt}\right)\right]x \tag{15}$$

Integrate (15), when the water jet bit is the initial drill bit, the boundary conditions of the given equation are $v = 0, x = l_{zt} = 0.03m$; when the water jet bit drives the high-pressure hose to reach the limit depth, $v = 0$. From the boundary conditions, the dynamic equation of the water jet bit driving the high-pressure hose forward is obtained, and the expression is:

$$\frac{(xv)^2}{2}M_{hp} = \frac{x^2 - {l_{zt}}^2}{2}\left(F_{jt} - F_{zx} - fgM_{zt}l_{zt}\right) - \frac{x^3 - {l_{zt}}^3}{3}fgM_{hp} \tag{16}$$

Set the friction resistance between the steering gear and the high-pressure hose $F_{zx} = 25$N, the friction coefficient of the open hole wall f=0.4, the mass per unit length of the high-pressure hose $M_{hp} = 0.327$kg/m, and the mass per unit length of the water jet bit $M_{zt} = 0.38$kg/m, the length of the drill bit $l_{zt} = 0.03m$ is substituted into equation (16), and combined with equation (1), the drilling speed equation for the water jet bit to drive the high-pressure hose forward can be obtained. The expression is:

$$v^2 = \frac{(x^2 - 0.03^2)\left[1.57P_{in}\left(nd_b^2\cos\theta_b - mCd_f^2\cos\theta_f - Cd_o^2\right) - 25.04\right] - 0.86(x^3 - 0}{0.327x^2}) \tag{17}$$

(2) Calculation of drilling limit extension length

It can be seen from formula (17) that when the drilling speed v>0, the water jet bit drives the high-pressure hose to drill forward. As the drilling depth increases, the contact length between the high-pressure hose and the well wall increases, which will lead to The drag resistance of the high-pressure hose driven by the drill bit increases, so that the drilling speed v gradually decreases. When v=0, the water jet bit no longer drives the high-pressure hose to drill forward, and the radial horizontal well reaches the limit drilling depth at this time.

Substituting v=0 into equation (17), let L_{max} be the limit extension length of the water jet bit, and ignore the influence of the higher order term of the water jet bit length l_{zt} on the calculation

ISSN: 2664-9640

results, and obtain the analytical solution for the limit drilling depth of radial horizontal wells , The expression is:

$$L_{max} = \frac{1.57P_{in}\left(nd_b^2\cos\theta_b - mCd_f^2\cos\theta_f - Cd_o^2\right) - 25.044688}{0.86} \tag{18}$$

4. Influence of key parameters of radial horizontal well system on drilling performance

The drilling mechanism of water jet rock breaking is complex. According to the drilling mechanics analysis of radial horizontal well system in the previous paper, the ultimate drilling depth of radial horizontal well is mainly affected by drilling construction equipment, high-pressure hose movement resistance, bit geometry and other factors without considering geological and rock conditions. Therefore, this section is based on the construction conditions of radial horizontal well, according to equation (17) ）The influence of key parameters on drilling performance is analyzed by equation (18).

4.1. Influence of pump pressure on drilling performance

Tab.2 shows the analysis and calculation results of the influence of different pump pressures on the limit drilling depth of radial horizontal wells.The pump pressure P is 20MPa,30MPa,40MPa and 50MPa respectively, and the other drilling parameters in the system remain unchanged.When the flow in the radial horizontal well drilling system is relatively large, it can be seen from the table that with the increase of the pump pressure in the system, the greater the inlet and outlet pressure difference of the water jet bit nozzle is, the larger the jet impact force is, and the limit drilling depth of the radial horizontal well increases linearly.In combination with formula (1), formula (16) and formula (17), a relationship curve between that pump pressure and the drilling speed is obtained, as shown in Fig 5.It can be seen from the figure that the drilling speed of the high-pressure hose driven by the water jet drill bit will increase with the increase of the pump pressure.In the initial state of drilling, the drilling speed is the maximum, and then with the increase of the drilling distance of the radial horizontal well, the contact resistance between the high-pressure hose and the shaft wall increases gradually, and the drilling speed decreases gradually.When the limit drilling distance is reached, the drilling speed decreases to zero.

Tab.2 Influence of pump pressure on limit drilling depth of radial horizontal well

Pump pressure P/MPa	Recoil force F_{jb}/N	Rock breaking force F_{jf}/N	Propulsive force F_{jt}/N	Limit drilling depth L_{max}/m
20	225.14	148.54	76.6	59.95
30	337.71	222.81	114.9	104.49
40	450.28	297.08	153.2	149
50	562.85	371.35	191.5	193.56

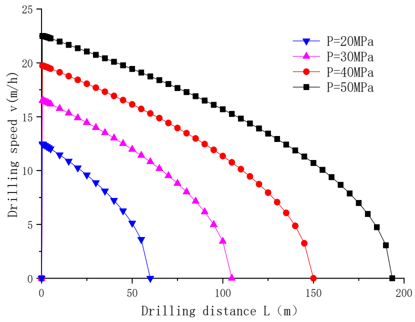


Fig.5 Relationship between pump pressure and drilling speed

4.2. Influence of bit nozzle diameter on drilling performance

(1) Influence of forward nozzle diameter on drilling performance

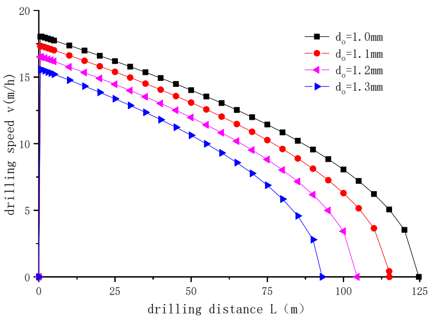
Tab.3 and Tab.4 are the analysis and calculation results of different forward nozzle diameters on the limit drilling depth of radial horizontal wells. Straight-rotation hybrid jet bit parameters: single reverse nozzle diameter d_b is 1.3mm, number of nozzles n_b is 6, and angle of inclination θ_b is 45°; single forward side nozzle diameter d_b is 1.1mm, number of nozzles n_f is 4, and angle of inclination θ_b Is 30°; the center nozzle diameter d_o is 1.2mm. Change d_f to 1.0mm, 1.1mm, 1.2mm and 1.3mm, and d_o to 1.0mm, 1.1mm, 1.2mm and 1.3mm respectively, and analyze the influence of forward nozzle diameter on drilling performance. As shown in Fig.6 and Fig.7, when the rest of the drilling construction parameters in the system remain unchanged and the flow rate in the drilling system is relatively large, under the same water jet pressure, with the increase of d_f and d_o , The equivalent diameter d_{ef} of the forward nozzle of the water jet drill bit increases, and the outlet flow rate of the forward nozzle gradually increases, causing the rock breaking force F_{jf} generated by the forward jet to increase, and the propulsion force of the entire radial drilling system will decrease. The limit drilling depth L_{max} of radial horizontal wells gradually decreases, and the drilling speed of the high-pressure hose driven by the water jet bit will decrease with the increase of d_o、 d_f.

Tab.3 Analysis of influence of central nozzle diameter on limit drilling depth

Center nozzle diameter d_o/mm	Recoil force F_{jb}/N	Rock breaking force F_{jf}/N	Propulsive force F_{jt}/N	Limit drilling depth L_{max}/m
$d_o = 1.0$mm	337.71	205.4	132.31	124.73
$d_o = 1.1$mm	337.71	213.71	124	115.07
$d_o = 1.2$mm	337.71	222.81	114.9	104.49
$d_o = 1.3$mm	337.71	232.7	105.01	92.985

Tab.4 Influence of side nozzle diameter on limit drilling depth

Side nozzle diameter d_f/mm	Recoil force F_{jb}/N	Rock breaking force F_{jf}/N	Propulsive force F_{jt}/N	Limit drilling depth L_{max}/m
$d_f = 1.0$mm	337.71	194.03	143.68	137.95
$d_f = 1.1$mm	337.71	222.81	114.9	104.49
$d_f = 1.2$mm	337.71	254.33	83.38	67.83
$d_f = 1.3$mm	337.71	288.59	49.12	27.99



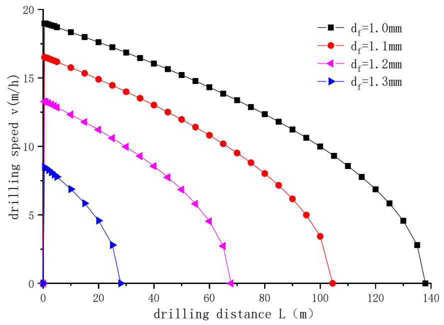


Fig.6 The relation curve of d_o and v Fig.7 The relation curve of d_{f} and v

(2) Influence of reverse nozzle diameter on drilling performance

Tab.5 shows the analysis and calculation results of different reverse nozzle diameters on the limit drilling depth of radial horizontal wells. The diameter d_{b} of the single reverse nozzle of the drill bit is 1.2mm, 1.3mm and 1.4mm respectively, and the influence of the diameter of the forward nozzle on the drilling performance is analyzed. As shown in Fig.8, the remaining drilling construction parameters and the parameters of the direct-rotation mixed jet bit in the system remain unchanged. When the flow rate in the radial horizontal well drilling system is relatively large, under the same water jet pressure, It can be seen from the figure that as d_{b} increases, the equivalent diameter d_{eb} of the reverse nozzle of the water jet drill bit increases, and the outlet flow rate of the reverse nozzle increases, causing the recoil force F_{jb} generated by the drill bit reverse jet to increase sharply. The propulsion force of the entire radial drilling system will increase sharply, the drag characteristics of the drill bit will be enhanced, the drilling speed will increase with the increase of d_{b}, and the limit drilling depth L_{max} of the radial horizontal well will also increase.

Tab.5 Influence of reverse nozzle diameter on limit drilling depth

Diameter of reverse nozzle d_b/mm	Recoil force F_{jb}/N	Rock breaking force F_{jf}/N	Propulsive force F_{jt}/N	Limit drilling depth L_{max}/m
d_b = 1.2mm	287.75	222.81	64.95	46.4
d_b = 1.3mm	337.71	222.81	114.9	104.49
d_b = 1.4mm	391.66	222.81	168.86	167.22

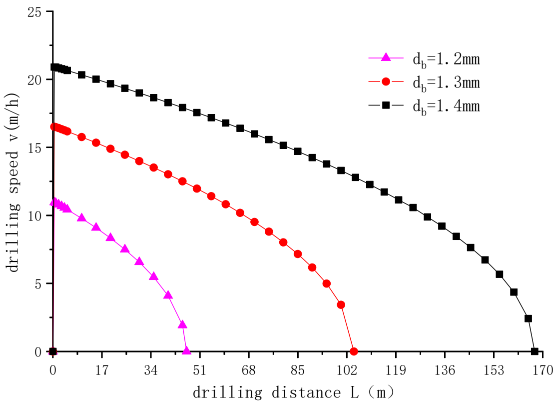


Fig.8 Relationship between reverse nozzle diameter and drilling speed

4.3. Influence of nozzle hole number on drilling performance

(1)Influence of number of positive side nozzles on drilling performance

Tab. 6 shows the analysis and calculation results of the ultimate drilling depth of radial horizontal well with different number of forward side nozzles. The number of forward side nozzles n_f of the water jet bit is 3, 4 and 5, respectively. The influence of the diameter of forward nozzles on drilling performance is analyzed. Can be seen from the table, the remainder of the system in various drilling construction parameters and straight spiral jet drilling parameters remain the same, when a relatively large radial horizontal well drilling system in the flow, the water jet pressure under the same conditions, with n_f increase, water jet drilling is the nozzle outlet flow increase, cause positive jet bit of asthenosphere F_{jf} increases linearly, erosion of rock crushing efficiency is higher, and the driving forces of the whole radial drilling system will decrease sharply, the limit of the radial horizontal well drilling depth L_{max} linearly decreasing trend. As shown in Fig.9, with the increase of n_f, the drilling speed of the water jet bit driving the high pressure hose forward will decay rapidly, and the initial drilling speed drops from 19.97m/h to 12.09m/h. Therefore, increasing the number of forward nozzles is not an effective way to increase the limit elongation length.

Tab. 6 Influence of number of positive side nozzles on limit drilling depth

Number of side nozzles n_f	Recoil force F_{jb}/N	Rock breaking force F_{jf}/N	Propulsive force F_{jt}/N	Limit drilling depth L_{max}/m
$n_f = 3$	337.71	181.35	156.36	152.69
$n_f = 4$	337.71	222.81	114.9	104.49
$n_f = 5$	337.71	264.27	73.44	56.28

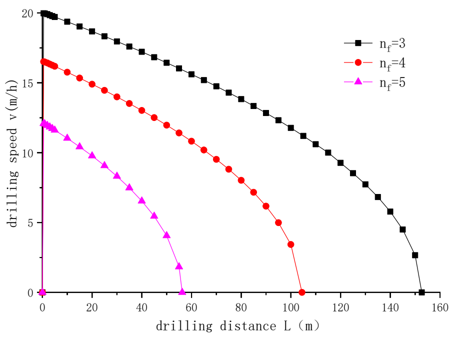


Fig.9 Relationship between number of side nozzles and drilling speed

(2)Influence of number of reverse nozzles on drilling performance

Tab.7 shows the analysis and calculation results of different numbers of reverse nozzles on the limit drilling depth of radial horizontal wells. The diameters n_b of the reverse nozzles of the water jet bit are 5, 6, 7, and 8, and the rest of the drilling construction parameters in the system remain unchanged. When the flow rate in the radial horizontal well drilling system is relatively large, Under the same water jet pressure, it can be seen from the table that as n_b increases, the outlet flow rate of the reverse nozzle of the water jet drill bit increases, causing the recoil force F_{jb} generated by the drill bit reverse jet to increase linearly. The propulsion force of the radial drilling system increases sharply, and the water jet bit has a strong drag ability to drive the high-pressure hose forward, and the limit drilling depth L_{max} 也of the radial horizontal well also increases accordingly. As shown in Fig.10, with the increase of n_b, the drilling speed of the high-pressure hose driven by the water jet bit will increase rapidly, and the initial maximum drilling speed will rise from 10.05m/h to 24.82m/h. Therefore, when the bit When the diameter d_e is constant, the number of reverse nozzles should be increased as much as possible under

ISSN: 2664-9640

the premise of ensuring the efficiency of the forward jet eroding and breaking the rock, so as to increase the limit extension length and the drilling rate of the radial horizontal well.

Tab.7 Analysis of the influence of the number of reverse nozzles on the limit drilling depth

Number of counter nozzles n_b	Recoil force F_{jb}/N	Rock breaking force F_{jf}/N	Propulsive force F_{jt}/N	Limit drilling depth L_{max}/m
$n_b = 5$	281.42	222.81	58.62	39.04
$n_b = 6$	337.71	222.81	114.9	104.49
$n_b = 7$	393.99	222.81	171.19	169.93
$n_b = 8$	450.28	222.81	227.47	235.38

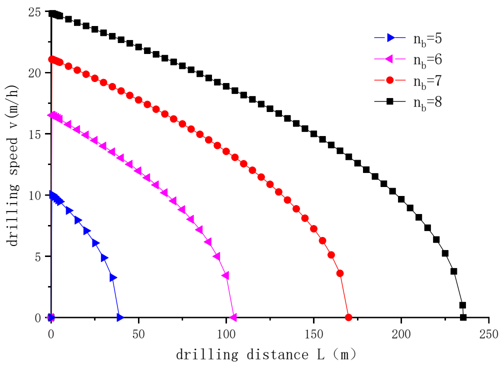


Fig.10 Relationship between number of reverse nozzles and drilling speed

4.4. Influence of bit nozzle angle on drilling performance

(1)Influence of forward nozzle angle on drilling performance

Tab.8 shows the analysis and calculation results of different forward nozzle inclination angles on the limit drilling depth of radial horizontal wells. The inclination angles θ_f of the forward nozzle of the water jet drill bit are 20°, 25°, 30°, 35° and 40°. The other drilling construction parameters in the system remain unchanged. Under the same water jet pressure, read from the table It can be seen that with the increase of θ_f, the component of the rock breaking force F_{jf} produced by the positive multiple jets gradually decreases on its axis, which increases the jet propulsion of the drill bit, and the limit drilling depth L_{max} of the radial horizontal well Increased accordingly. As shown in Fig.11. It can be seen from the figure that with the increase of θ_f, the drilling speed of the high-pressure hose driven by the water jet bit also increases. The initial maximum drilling speed increases from 15.15m/h to 18.19m/h, but this The broken pits eroded by multiple jets in the forward direction are prone to disconnection, which is not conducive to the continuous drilling of the system.

Tab.8 Analysis of influence of forward nozzle angle on limit drilling depth

Inclination angle of side nozzle $\theta_f/°$	Recoil force F_{jb}/N	Rock breaking force F_{jf}/N	Propulsive force F_{jt}/N	Limit drilling depth L_{max}/m
$\theta_f = 20°$	337.71	236.91	100.8	88.08
$\theta_f = 25°$	337.71	230.52	107.19	95.52
$\theta_f = 30°$	337.71	222.81	114.9	104.49
$\theta_f = 35°$	337.71	213.83	123.88	114.92

$\theta_f = 40°$	337.71	203.66	134.05	126.75

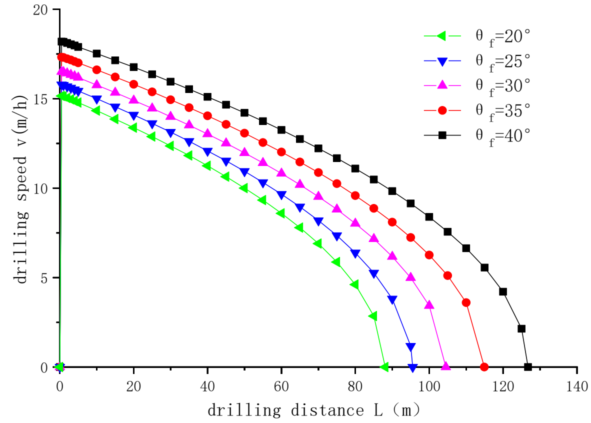


Fig.11 Relationship curve between positive nozzle angle and drilling speed

(2)Influence of reverse nozzle inclination on drilling performance

Tab.9 shows the analysis and calculation results of different reverse nozzle inclination angles on the limit drilling depth of radial horizontal wells. The inclination angle θ_b of the reverse nozzle of the water jet drill bit is 40°, 45°, 50° and 55°. The other drilling construction parameters in the system remain unchanged. Under the same water jet pressure, it can be seen from the table , With the increase of θ_b, the recoil force F_{jb} produced by the reverse jets gradually decreases on its axis, so that the jet propulsion force of the drill bit decreases, and the limit drilling depth L_{max} of the radial horizontal well also decreases accordingly. small. As shown in Figure 12. It can be seen from the figure that the drilling speed of the high-pressure hose driven by the water jet bit will decrease sharply with the increase of θ_b. In the initial state of drilling, with the increase of θ_b, the initial maximum drilling speed will increase from 18.93 The m/h dropped rapidly to 8.84m/h, and the reaming and righting ability of the reverse jet decreased. Therefore, in order to ensure the reasonable structure of the drill bit, the installation angle of the reverse nozzle should be appropriately reduced to increase the limit extension length and the drilling rate of the radial horizontal well, and to improve the stability of the drill bit during rock-breaking and tunneling in the formation.

Tab.9 Analysis of the influence of reverse nozzle angle on drilling performance

Angle of inverse nozzle θ_b/°	Recoil force F_{jb}/N	Rock breaking force F_{jf}/N	Propulsive force F_{jt}/N	Limit drilling depth L_{max}/m
$\theta_b = 40°$	365.86	222.81	143.05	137.22
$\theta_b = 45°$	337.71	222.81	114.9	104.49
$\theta_b = 50°$	306.99	222.81	84.18	68.77
$\theta_b = 55°$	273.94	222.81	51.13	30.33

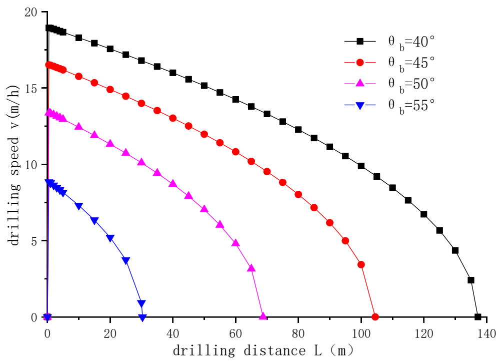


Fig12 Relationship curve between reverse nozzle inclination angle and drilling speed

5. Conclusion

(1) In the radial horizontal well drilling system, the power of the system mainly comes from the recoil force F_{jb} produced by the reverse nozzle of the water jet bit , and the rest of the forces in the system are resistances. The main resistances of the system are the friction resistance F_{hp} of the borehole wall to the high pressure hose and the impact force F_{jf} produced by the forward nozzle of the bit.

(2) By analyzing the influence of key parameters of radial horizontal well system on drilling performance, it shows that the drilling speed is the highest at the initial state of drilling, and then with the increase of drilling distance of radial horizontal well, the contact resistance between high pressure hose and wellbore increases gradually, and the drilling speed decreases gradually. When the limit drilling distance is reached, the drilling speed decreases to zero.

(3)Under the same conditions, the parameters of reverse nozzle of water jet bit have a great influence on drilling depth and drilling speed. Therefore, on the premise of ensuring the efficiency of forward jet erosion, increasing the equivalent diameter d_{eb}、 increasing the number n_b of reverse nozzle and decreasing the inclination angle θ_{b} of reverse nozzle can effectively increase the limit extension length L_{max} of radial horizontal well.

References

[1]FAN Yao, ZHANG Qun. Review of the tight radius drilling technology based on high pressure water jet [J]. Coal Geology & Exploration,2020,48(05):232-239.

[2]Zhe Huang,Zhongwei Huang. Review of Radial Jet Drilling and the key issues to be applied in new geo-energy exploitation[J]. Energy Procedia,2019,158:5969-5974.

[3]Bi Gang, Li Gensheng, Shen Zhonghou, Huang Zhongwei, Dou Liangbin. Analysis of the Application Prospect of Supercritical CO2 Radial Horizontal Drilling Technology [J]. China Petroleum Machinery, 2013,41(06):14-19.

[4]LI Jieshi. Drilling and Completion of Horizontal Well and Production Increase Technology [M]. Petroleum industry press,1992

[5]HAN Long. Research and Application of Rotary Drilling Radial Horizontal Well Technology [J]. New Technology & New Products of China, 2020(03):54-55.

[6]LIU Pingquan. Design and Operation of Descaling Device Used for Tubing String [J]. Oil Field Equipment,2018,47(01):23-27.

[7]TIAN Shouzeng, LI Gengsheng, Sheng Mao. Fracturing completion theory and method for shale gas horizontal wells [M]. Science Press,2020

[8] LI Gensheng, HUANG Zhongwei, LI Jingbin. Study of the Key Techniques in Radial Jet Drilling [J]. Petroleum Drilling Techniques, 2017, 45 (02): 1-9.

[9]CAO Youhao, WU Di, MENG Xianhui. Study on productivity influence law of radial horizontal well with hydraulic jet micro-hole [J]. Neijiang technology,2016,37(07):63-64.
[10]Hou Shihong, Wang Wenming, Ding Qingxin, Du Shuqiang, Feng Zhaojun. Optimization of Slide-way Trajectory of Whipstock for Radial Drilling[J]. China Petroleum Machinery,2017,45(09):8-13.
[11]MA Dongjun, LI Gengsheng, HUANG Weizhong, NIU Jilei, HOU Cheng, LIU Mingjuan, LI Jingbin. A model of calculating the circulating pressure loss in coiled tubing ultra-short radius radial drilling[J]. Petroleum Exploration and Developmen,2012,39(04):494-499.