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Paper

STUDY ON DOWNHOLE JET FLOW FIELD OF HIGH PRESSURE PDC BIT WITH DUAL-FLOW CHANNEL

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ABSTRACT

PDC bit with the ultrahigh pressure jet can increase rate of penetration in the deep well with the downhole boost compressor, which is one of the key techniques of increasing rate of penetration. The flow field of PDC bit with dual-flow channel can be divided into two regions: ultrahigh pressure jet flow field and lower pressure jet flow field. According to the computational fluid mechanics theory, the flow field of PDC bit was simulated, and some characteristics were discovered. Ultrahigh pressure free jet comprises of initial segment, transition segment and base segment， and Jet core is observed obvious in the flow filed, which is 7.5 times of the jet diameter, then the standoff distance was designed as 4.0 times of the jet diameter to directly break the rock. The submerged jet at lower pressure attacks the rock surface and takes the cuttings away. The flow field comprises of impact region, separation region and crossflow region, different jets interact in the bottom of well. Lower pressure jet is important to cuttings carrying and assisted rock-breaking; ultrahigh pressure jet is of significance for rock-breaking at the bottom of the well. The studies above enrich and develop the theory of ultrahigh pressure jet drilling, which plays an important role in the hydraulic structure design of high Pressure PDC Bit with dual-flow channel.

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1. INTRODUCTION

Compared with conventional PDC bit, ultrahigh pressure PDC bit with dual-flow channel has a pair of ultrahigh nozzles [1, 2] (the diameter of the nozzle is 1.8mm, as shown in **Figure 1**). The combination of the ultrahigh jet and mechanical teeth can improve the efficiency of rock-breaking, and ultrahigh pressure PDC bit with dual-flow channel [3, 4] with downhole booster is one of the key techniques of increasing rate of penetration in deep wells. Based on the computational fluid mechanics theory, the flow field of ultrahigh pressure jet and lower pressure jet is obtained by means of the numerical simulation of three dimensional flow field of the entity bit [5]; the mechanism of the rock-breaking and cuttings carrying is analyzed by means of studying the distribution of speed, pressure of ultrahigh pressure jet and lower pressure jet. The research results presented in the paper enrich hydraulic structure theory of ultrahigh pressure PDC bit with dual-flow channel, and can be used to guide the hydraulic structure design of ultrahigh pressure PDC bit with dual-flow channel.

2. NUMERICAL SIMULATION

On site，mud fluid is the usual working medium. Due to data deficiency in high shear rate about mud, water is often used as the substitute in theoretical research [6]. The flow pattern of downhole flow field of PDC bit is turbulent flow, and can be described with N-S equation[7].

2.1 Governing Equation

The κ-ε equation model can be used to calculate the turbulent flow, and the concrete form of governing equation is as follows:

$$\frac{\partial}{\partial x}\left(\rho u \phi\right)+\frac{\partial}{\partial \mathrm{y}}\left(\rho v \phi\right)+\frac{\partial}{\partial \mathrm{z}}\left(\rho w \phi\right)=\frac{\partial}{\partial x}\left(\Gamma\frac{\partial \phi}{\partial x}\right)+\frac{\partial}{\partial \mathrm{y}}\left(\Gamma\frac{\partial \phi}{\partial \mathrm{y}}\right)+\frac{\partial}{\partial \mathrm{z}}\left(\Gamma\frac{\partial \phi}{\partial \mathrm{z}}\right)+S$$

2.2 Equation Discrete Method

Semi-implicit method for pressure-linked equations is utilized to solve the equations set and finite volume method to discrete it. The governing equations are discretized with second order spatial accuracy and first order time accuracy on a non-structured mesh. The equations set are calculated with FLUENT.

2.3 The Creation of Computational Domain and the Grid

The bit’s geometrical model and the physical model of downhole flow field are set and CAD is selected to build the downhole flow field of the entity PDC bit. As shown in Figure 1, the bit has five wings, five lower pressure nozzles and two ultrahigh pressure nozzles [8, 9]. Non-structured tetrahedron mesh is used to accomplish the grid generation with Gambit; local refinement is conducted in the head of the bit and the jet fields of the nozzles. The first-floor mesh generation from the wall meets the use condition of wall function.

2.4 Boundary Conditions

Upstream side of the injector is the inlet boundary condition of the velocity(inlet mean velocity of the ultrahigh pressure nozzle is 346 m/s, inlet mean velocity of lower pressure nozzles is 80 m/s), and the annular of the flow model is the outlet boundary condition, rate of discharge equal to the inlet flow rate. The static pressure in the inlet of the nozzle is 0, and the pressure in other places is compared with the pressure in inlet.

3. JET FLOW FIELD OF ULTRAHIGH PRESSURE PDC BIT WITH DUAL-FLOW CHANNEL

The flow field of ultrahigh pressure PDC bit with dual-flow channel can be divided into two regions: ultrahigh pressure jet flow field and lower pressure jet flow field. The rock-breaking is determined by ultrahigh pressure jet flow field. The research about the structure of ultrahigh pressure jet flow field and the length of jet core is of importance for the rock-breaking feature of the bit.

3.1 The Structure of Ultrahigh Pressure Jet Flow Field

Ultrahigh pressure [10] jet flow field is studied by numerical simulation and the velocity vector diagram is given (**Figure 2**). The dotted portion is the position of half-life period of the axial velocity vector. The structure of ultrahigh pressure jet comprises of initial segment, transition segment and base segment, and jet core is observed in the flow filed. The distribution of dynamic pressure of ultrahigh pressure jet is shown in **Figure 3**. The dynamic pressure in the jet core reaches a maximum in initial segment, amount to 60 MPa, and is transformed into static pressure in transition segment and base segment[11].

3.2 The Optimization of Jet Distance of Ultrahigh Pressure Nozzle

Dimensionless distribution of velocities in jet axes is shown in **Figure 4**, which can be used to calculate the length of the jet core. The longitudinal coordinates is $\bar{u} = u/u_0$, and the abscissa is dimensionless distance $\bar{x} = l/d$. In this design condition, the length of jet core of ultrahigh pressure free jet is 7.5 times of the diameter of the jet nozzle. As the fluid passes the jet core, the dimensionless velocity in axes decays as the distance changes. The jet distance of ultrahigh pressure nozzle is designed as 4.0 times of the jet diameter to make the jet core directly break the rock.

4. THE DOWNHOLE FLOW FIELD FEATURE OF ULTRAHIGH PRESSURE PDC BIT WITH DUAL-FLOW CHANNEL

The primary functions of lower pressure jet flow field are cuttings carrying and assisted rock-breaking. The study of the structure of lower pressure jet flow field and the downhole crossflow is significant in cleaning bottom-hole in time, and avoiding bit balling and repeating cutting.

4.1 The Structure of Lower Pressure Jet Field of Ultrahigh Pressure PDC Bit with Dual-flow Channel

Contoured velocity in nozzle section of ultrahigh pressure PDC bit with dual-flow channel is shown in **Figure 5**. The streamline extends from the nozzle to the downhole rocks in the form of submerged non-free jet. Most streamlines extend laterally at the bottom, forming a crossflow region and carrying the debris up into the annular, some streamlines convolute in cuttings chute, and form the separation region [12, 13]. The existence of the separation region is not conductive to cuttings carrying. **Figure 6** is the downhole streamlined diagram through lower pressure jet nozzle of ultrahigh pressure PDC bit with dual-flow channel.

4.2 Cuttings Carrying Capacity of Crossflow in Downhole Flow Field

After the jet hits the bottom of the well, it flows along the bottom, forming a crossflow with a high velocity [14, 15]. As shown in **Figure 7**, the velocity is higher as the nozzle outlet gets closer to the bottom of the well. The crossflow gives a lateral thrust to cuttings at the bottom, and takes them away from their original positions and moves forward laterally with the drilling fluid, and turn to the outlet due to the limitations of the wall.

4.3 The Pressure Feature of Ultrahigh Pressure PDC Bit with Dual-flow Channel

The pressure caused by the ultrahigh pressure jet reaches the maximum at the center of impact region, up to 60MPa, is far higher than the pressure in other positions. The maximum pressure at bottom of the well caused by the lower pressure jet reaches 2Mpa.

In the process of drilling, the lower pressure jet (**Figure 8**) hits the downhole rocks and the dynamic pressure is transformed into static pressure (**Figure 9**). Because of the static pressure, pressure gradient is formed at the bottom, under which the cuttings carrying are accomplished. In the low rock strength formation, fractures are generated because of the effect of the mechanical teeth, and the lower pressure jet can play an assisted role.

After the ultrahigh pressure jet flows out of the nozzle, the jet core hits the bottom directly, forming a big impact tension (**Figure 10**), and the dynamic pressure is transformed into static pressure on the wall (**Figure 11**). The impact region coming into being, the pressure decays laterally. When the impact pressure exceeds the cracking pressure, the fluid of the ultrahigh pressure jet will push into rock microcracks and fractures, causing water wedge and making microcracks and fractures expanded, and the rock strength will drop considerably and the rock-breaking efficiency of bit will be enhanced.

5. CONCLUSIONS

- The structure of ultrahigh pressure jet comprises of initial segment, transition segment and base segment.
- Jet core is observed in the flow field, which is 7.5 times of the jet diameter, and the standoff distance is designed as 4.0 times of the jet diameter.
- The downhole flow field of ultrahigh pressure PDC bit with dual-flow channel is consisted of the impact region, the separation region and the crossflow region.
- The maximum velocity and dynamic pressure in the downhole field are both in outlet of ultrahigh pressure jet nozzle. Lower pressure jet is important to cuttings carrying and assisted rock-breaking; ultrahigh pressure jet is of significance for rock-breaking at the bottom of the well.

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NOMENCLATURE

$\phi = 1$ Continuity Equation;

$\phi = u, v, w$ Components momentum equation in rectangular Cartesian coordinate system;

$\phi = k, \varepsilon$ Turbulent kinetic energy and turbulent dissipation equation.

u, v, w Components velocity in rectangular Cartesian coordinate system.

k turbulent kinetic energy.

ε turbulent dissipation.

u_0 the maximum velocity in axes.

Γ viscosity factor

s the source item.

l the distance of the dot in axes from the outlet of the nozzle.

d the diameter of the outlet of nozzle.

GRAPHICS

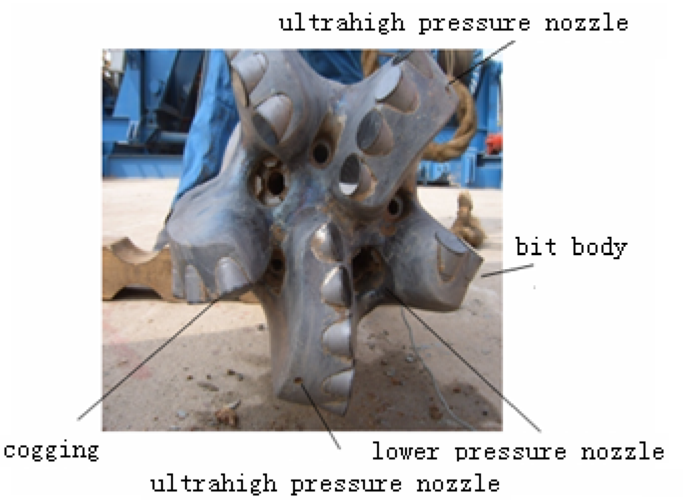

Figure 1. Ultrahigh Pressure PDC Bit

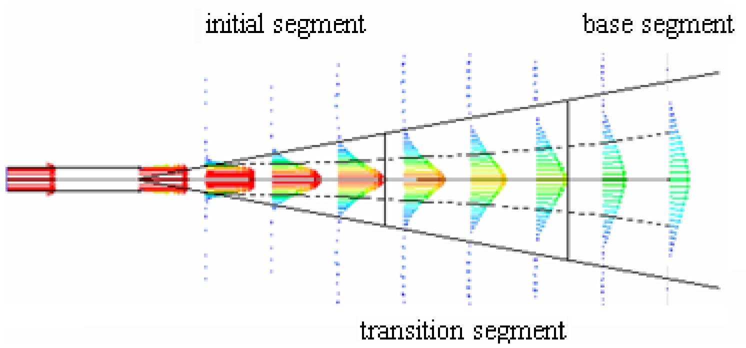

Figure 2. Structure of Ultrahigh Pressure Jet

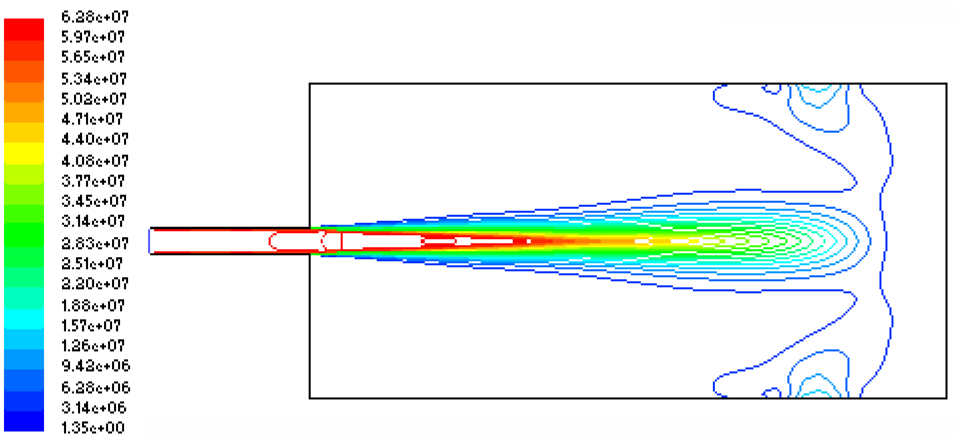

Figure 3. Pressure Contour Map of Ultrahigh Pressure Jet (Pa)

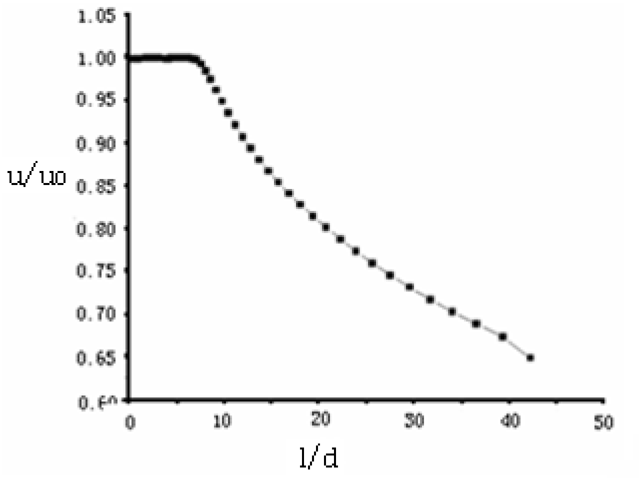

Figure 4. The Length of Jet Core

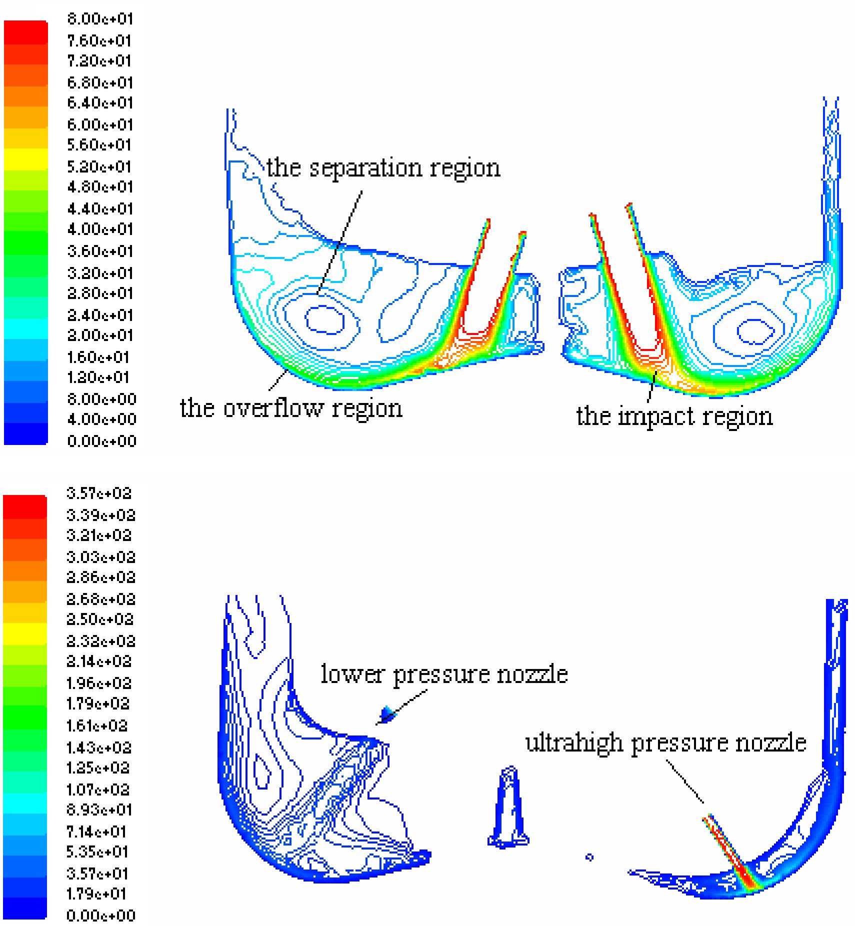

Figure 5. Velocity Contour Maps of Downhole Flow Field

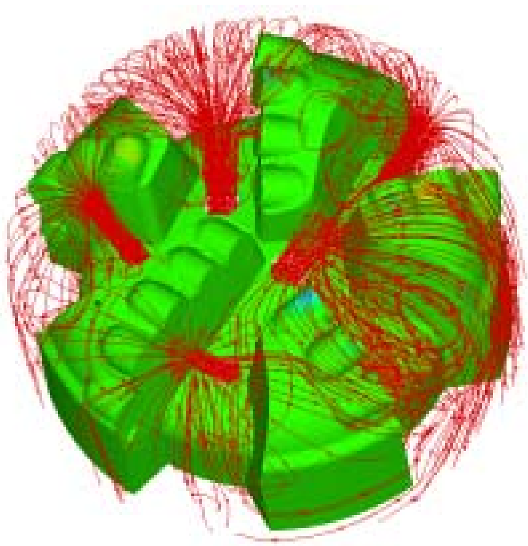

Figure 6. Streamlines of Ultrahigh Pressure PDC Bit

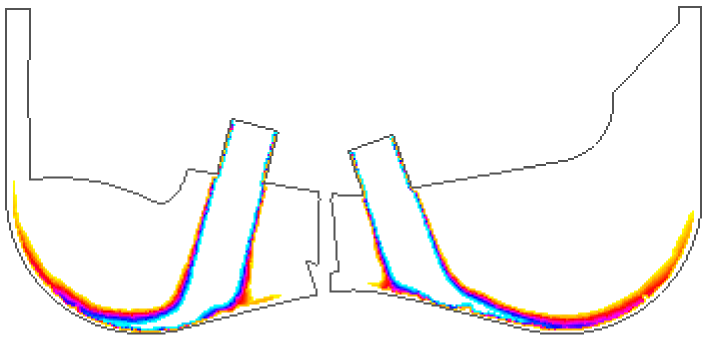

Figure7. The Crossflow Region

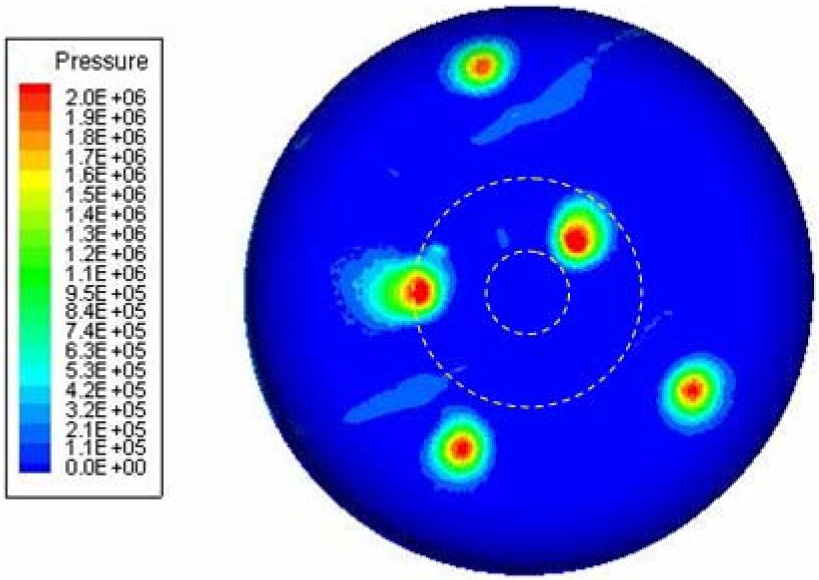

Figure 8. Distribution of Lower Pressure（Pa）

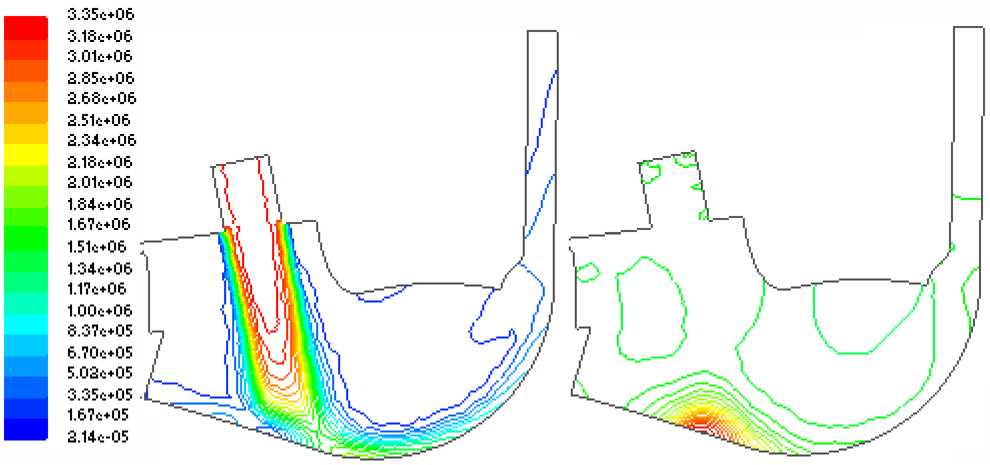

Figure 9. Dynamic Pressure and Static Pressure of Lower Pressure Jet (Pa)

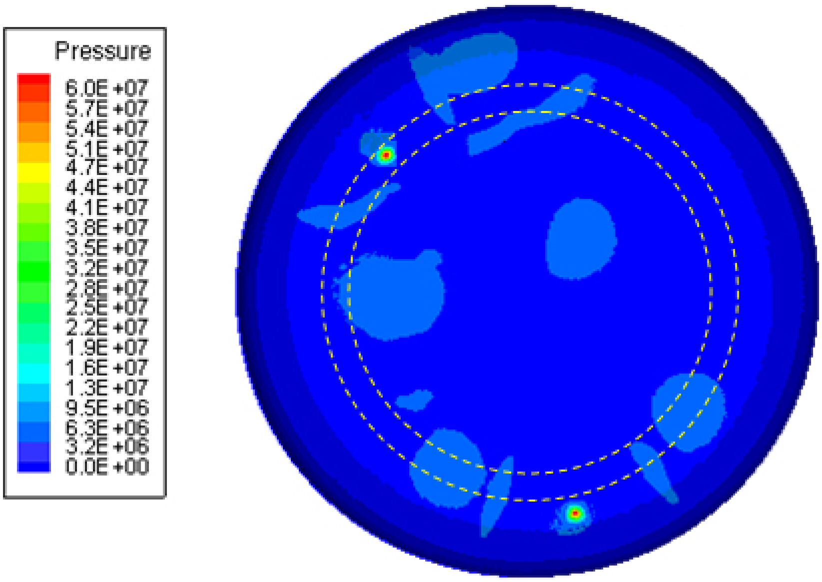

Figure10. Distribution of Ultrahigh Pressure （Pa）

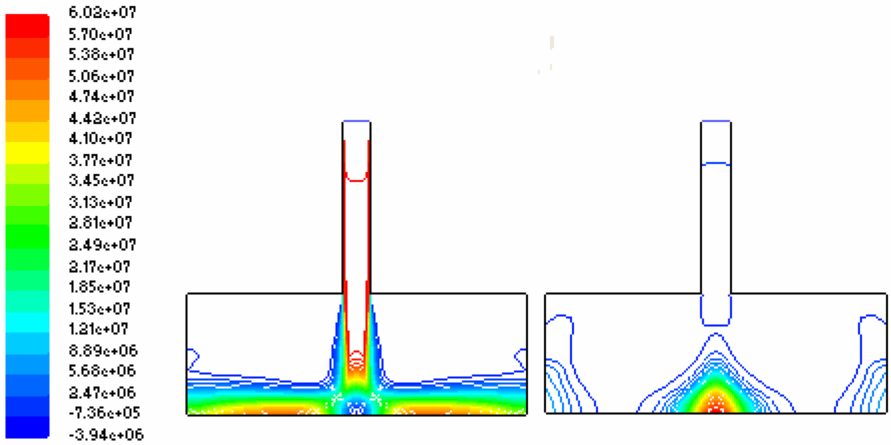

Figure11. Dynamic Pressure and Static Pressure of Ultrahigh Pressure Jet (Pa)