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Drill Bit Performance Investigation Using Computational Fluid Dynamics

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ABSTRACT

Drilling tools are extensively used in mining and quarrying industries. Even though working environments may be different for different drilling tools application, the basic working principle has extensive similarity. The markedly different physical properties of the drilled substance (rock, soil), the depth of drilling, the rotating speed of the drill and the overall performance characteristics of the air compressor are the main parameters which affect the performance effectiveness of the drill bit. It is fairly difficult to carry out detailed experimental investigations to predict the effects of all these parameters on drill bit performance. Hence it is advisable to use the state of the art fluid dynamics simulation package Computational Fluid Dynamics (CFD) to establish parametric interdependence. The CFD software is used due to its ability to substantially reduce the lead times and costs of new designs and its flexibility to study systems where controlled experiments are difficult to carry out. In addition, CFD also gives opportunity to study systems under hazardous conditions and yields fairly in-depth details.

Keywords: Computational Fluid Dynamics, Drill Bit, Velocity Ratio, Static Pressure

INTRODUCTION

Computational simulations can be used to understand the flow field in the vicinity of a drill bit in operation and quantify its effectiveness. Using the CFD simulations, the interdependence of parameters like exhaust air flow rate, supply pressure, the geometrical set up of the drill bit, the drill bit rotational speed, the sold/liquid hold up distance and the particles size effects can be established. Extensive research has been carried out to evaluate the performance of drill bits using computational fluid dynamics (Watson et. al., 1997, Bilgesu et. al., 2002 and Wells et. al., 2008). These studies are fairly limited in their scope. The scope of this study is to investigate the flow characteristics around the drill bit during its operation and analyze the effects of air flow rate and the drill bit rotational speeds on the flow filed characteristics.

MODELLING AND SIMULATION

To analyse the performance of the drill bit, a commercial CFD package has been used. The main steps in CFD analysis that has been carried out are summarized in fig. 1. The model of the drill bit was developed using commercial CAD software and the geometry has been imported into the CFD package as shown in fig. 2.

The computational domain and mesh are shown in fig. 3. The simulations have been carried out on a drill bit with a diameter of 115.6mm and length of 300mm. The complete flow domain of the model has the dimensions of 120 mm x 300 mm. The drill bit has two air vents each of 18mm diameter and each making an angle of 20 degrees with the centre line. To get fairly accurate results, three dimensional modelling has been carried out. After considering the mesh independence analysis, the minimum mesh size selected was 0.54mm and maximum mesh size selected was 2.7mm. Tetrahedral and hybrid volume meshes have been used for meshing the flow domain. The model has 7.5 million mesh elements. The inlet of the computational flow domain has been assigned mass flow boundary condition and two different values of 0.176kg/s and 0.132 kg/s have been used.

Pressure outlet boundary condition has been used at the outlet. The drilled hole in the rock has been assumed as a stationary wall with no-slip condition and the drill bit has been assigned rotating wall boundary condition in order to accurately predict the flow phenomena within the computational domain. To examine the performance of the drill bit two sets of cases have been investigated. Firstly, the effect of air flow rates (0.176kg/s and 0.132kg/s) through the drill bit has been investigated at a constant drill bit rotational speed of 45rpm. Secondly, keeping the air flow rate constant at 0.176kg/s, the drill bit speed has been varied (45rpm, 60rpm and 75rpm). The boundary conditions and the solver settings being used for simulating the solution have been summarized in table 1.

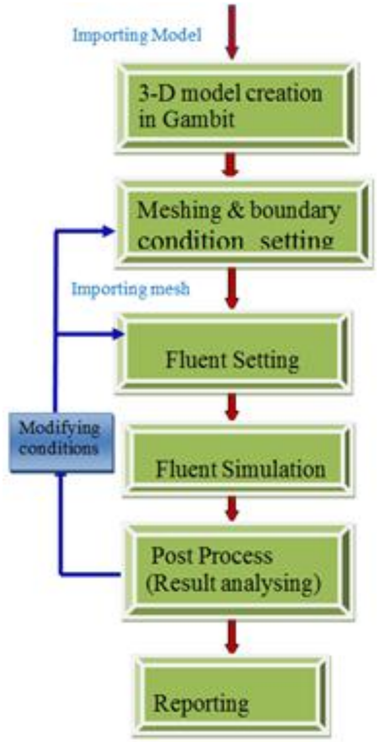


Fig. 1 CFD Analysis steps in Drill bit performance Optimization

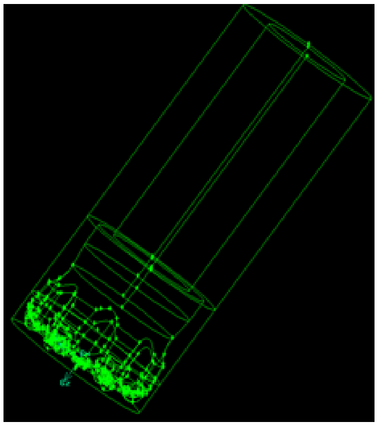


Fig. 2 The Drill Bit model

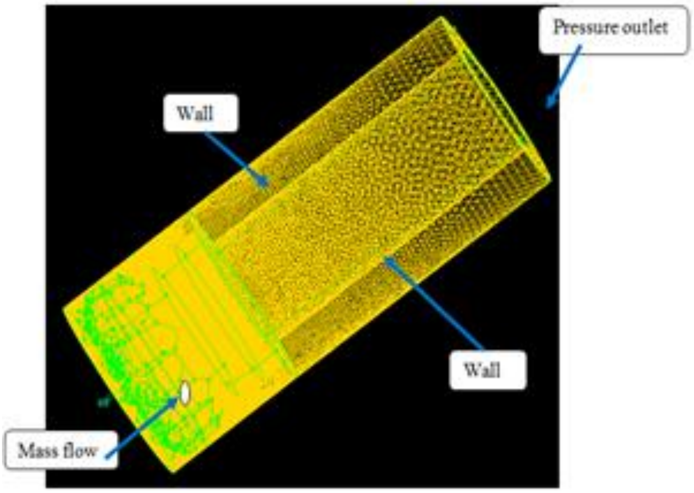


Fig. 3 Mesh and boundary conditions of the drill bit in Gambit

Table 1 Simulation operating parameters

Parameters	Description	Remarks
Solver	Density Based	
Gradient Option	Green – Gauss Node Based	Unstructured Tetrahedral/Hybrid Mesh
Viscous Model	k – ε	
Discretisation	Second Order Upwind	
Material	Air	Ideal Gas
Inlet Boundary Conditions	Mass Flow	0.176kg/s per air vent, 0.132kg/s per air vent at: • Pressure = 1.62 mPa • Temperature = 298 K
Outlet Boundary Condition	Pressure Outlet	Zero Pa Gauge
Drill-Hole in Rock	Stationary Wall	
Drill Bit	Rotating Wall	
Drill Bit's Rotational Speed	45, 60 and 75 rpm	

RESULTS AND DISCUSSION

In order to establish the performance characteristics of the drill bit, two parameters have been varied in the simulations i.e. the drill bit rotational speed and the air mass flow rate. The operational air mass flow rates of 0.176kg/s and 0.132kg/s and the rotational speed of 45rpm of the drill bit have been selected for simulating the model under consideration. The drill bit performance has also been investigated by varying the rotational speeds to 60rpm and 75rpm at a constant air flow rate.

Figure 4 depicts the velocity magnitude at the interior of the computational model i.e. between the drill bit and the rock hole. It can be clearly seen that at the base of the drill bit the flow is non-uniform due to the presence of insert button and the flute. To investigate the uniformity of the flow in the interior, XZ plane has been generated and the velocity vector magnitudes on that plane have been shown in fig. 5. Figure 5 depicts that the flow in the interior is fairly uniform.

To investigate the effects of the buttons, air flute and tapered-geometry of the drill bit, an in-depth analysis of the flow has been carried out at the bottom section of the drill bit. The effects have been investigated along five radial directions at the drill bit bottom corresponding to different angular positions as illustrated in fig. 6. The results as shown in fig. 7 show that the drill bit buttons have considerable effect on the air flow field. It can be seen that the velocity of air reduces in the outward radial direction. Another important section of the drill bit is the tapered section. In all angular directions the velocity of the air reduces at the edge of the tapered outward section. Figure 7(a) shows that higher velocity magnitudes exist in radial direction at an angle of 45 degree. This is due to the effects of the proximity of air flutes and relatively less effected of the drill bit buttons. The minimum velocity exists at 0 degree angular position. This may be due to the combined effects of the drill bit buttons, both on the left and right sides. This clearly highlights that the velocity field is not axisymmetric and considerable non-uniformity is present.

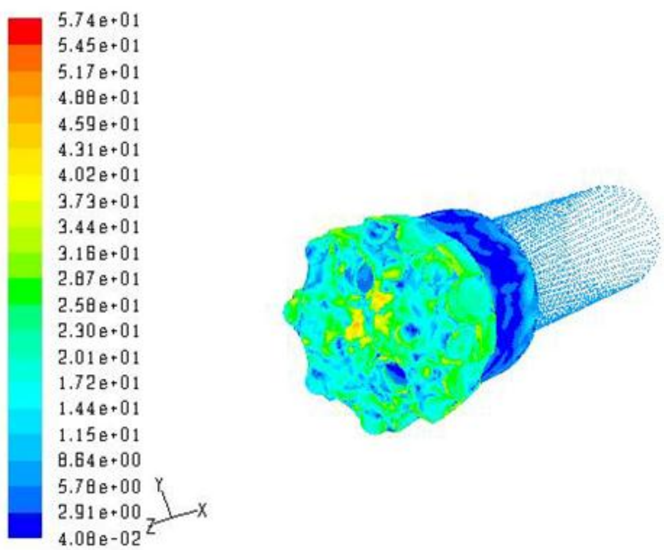


Fig. 4 Velocity vectors field at drill bit surface (45rpm, 0.176kg/s)

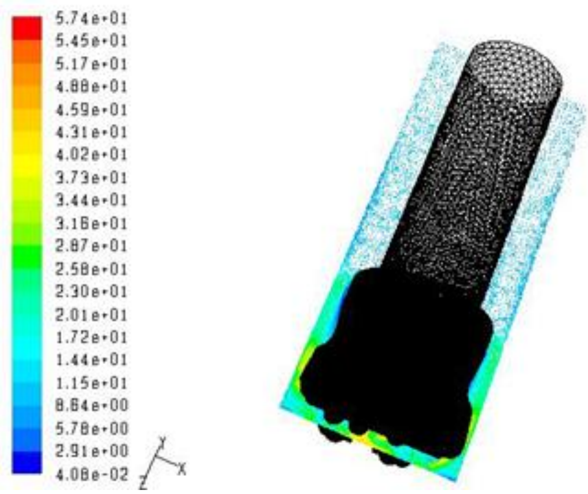


Fig. 5 Velocity Vectors on XZ plane (45rpm, 0.176kg/s)

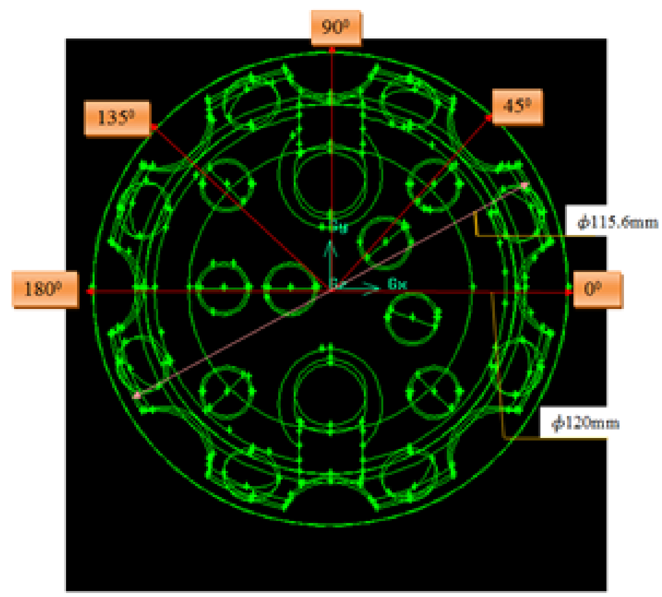
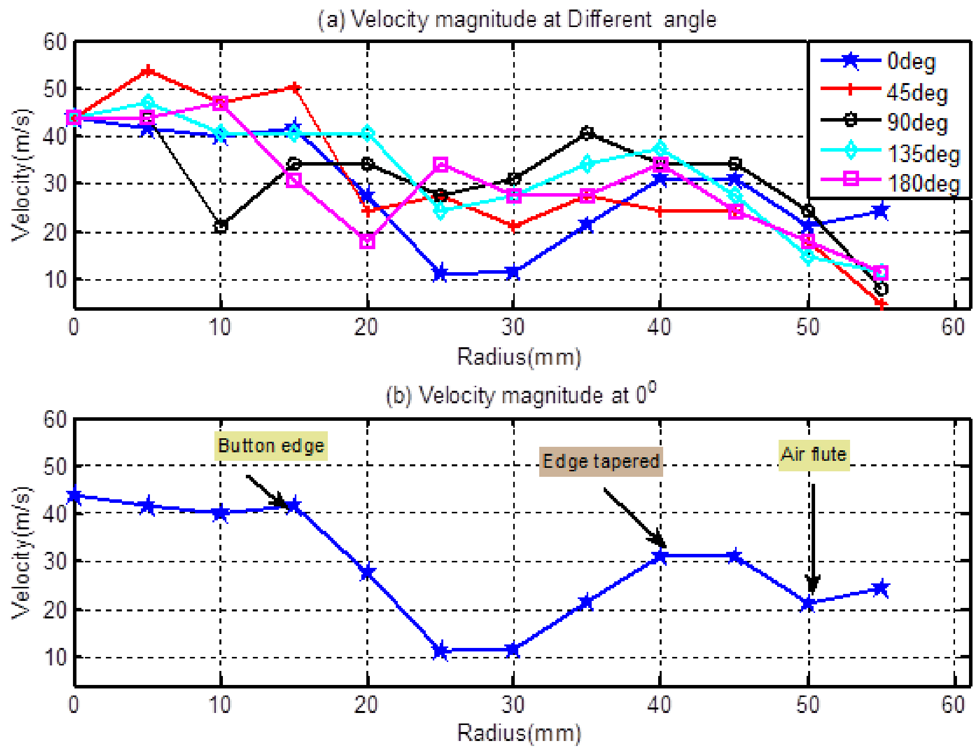
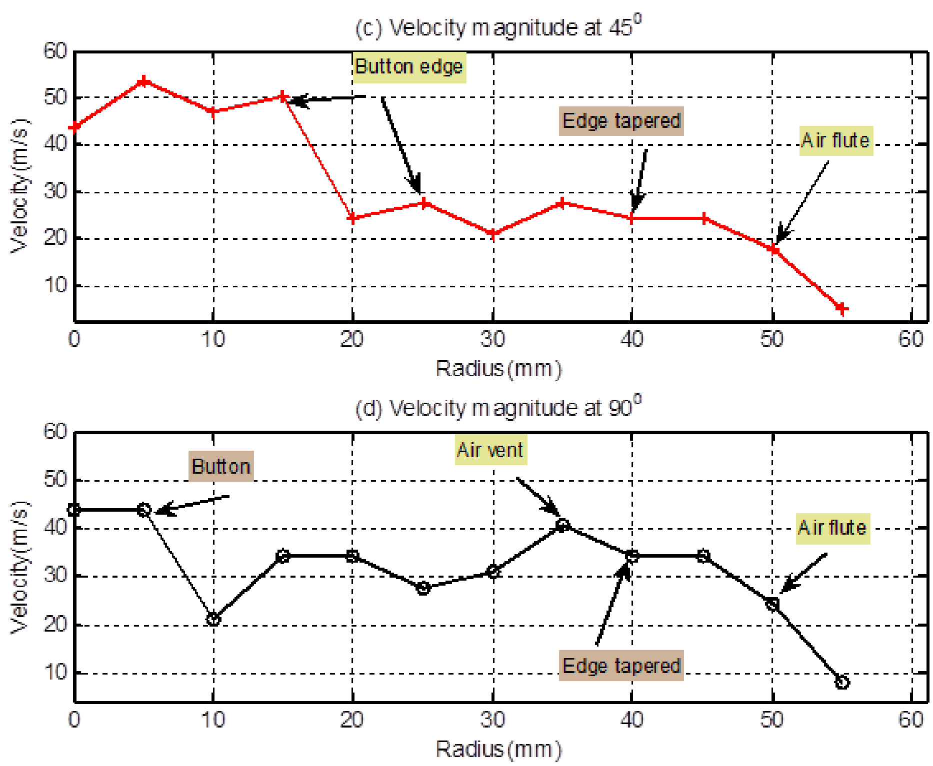


Fig. 6 The drill bit bottom section and angular setting


(a) Velocity magnitude at Different angle
0deg
45deg
90deg
135deg
180deg
Velocity(m/s)
Radius(mm)
(b) Velocity magnitude at 0^0
Button edge
Edge tapered
Air flute
Velocity(m/s)
Radius(mm)


(c) Velocity magnitude at 45^0
Button edge
Edge tapered
Air flute
Velocity(m/s)
Radius(mm)
(d) Velocity magnitude at 90^0
Button
Air vent
Air flute
Edge tapered
Velocity(m/s)
Radius(mm)

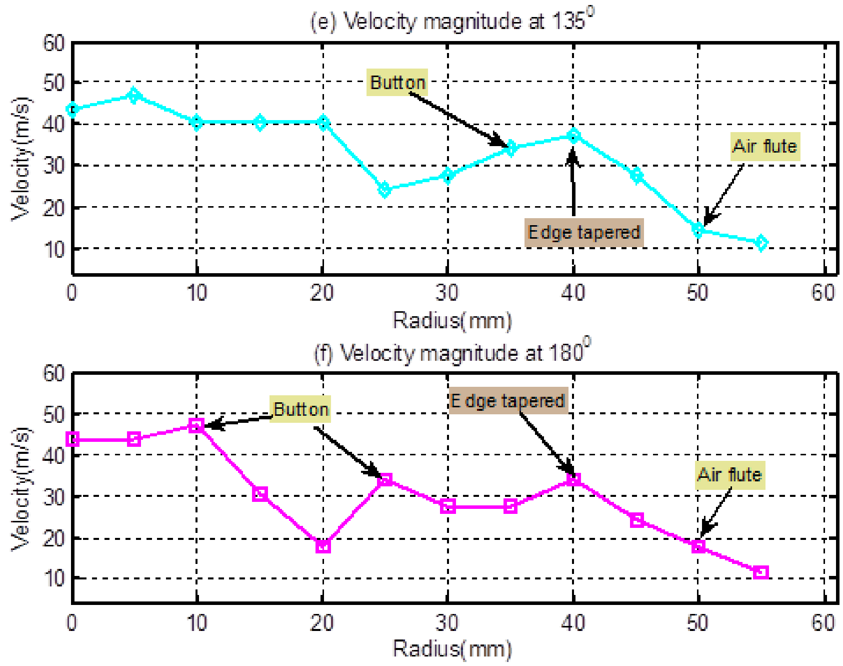
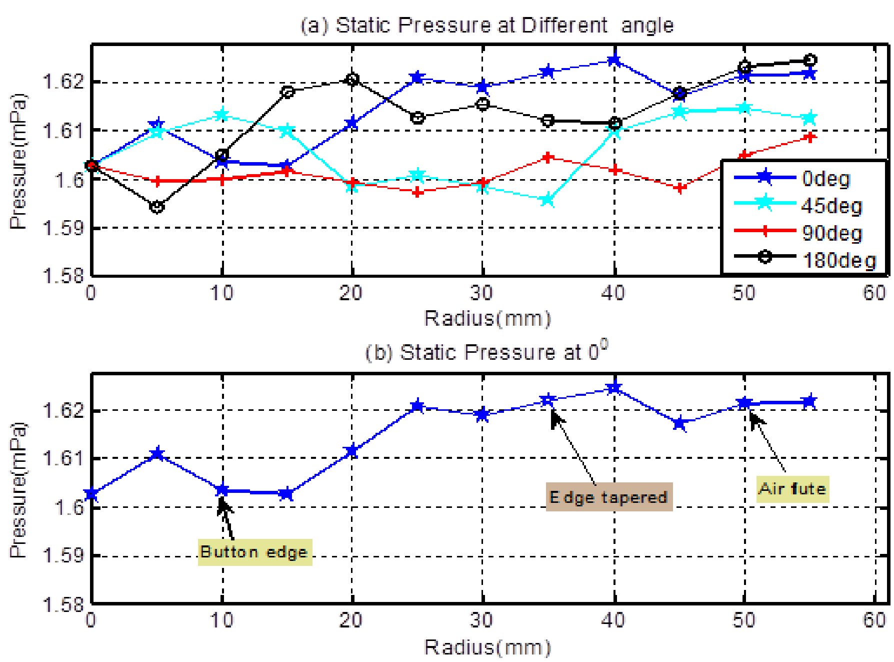


Fig.7 Velocity of the air flow at 0°, 45°, 90°, 135° and 180°

The effects of the buttons, air flute and tapered geometry of the drill bit on the static pressure of the flow at the bottom section of the drill bit (fig. 8) has also been analysed. The effects have been investigated along four radial directions of 0 degree, 45 degree, 90 degree and 180 degree. The maximum and the minimum pressures occur at 0 degree and 45 degree respectively.



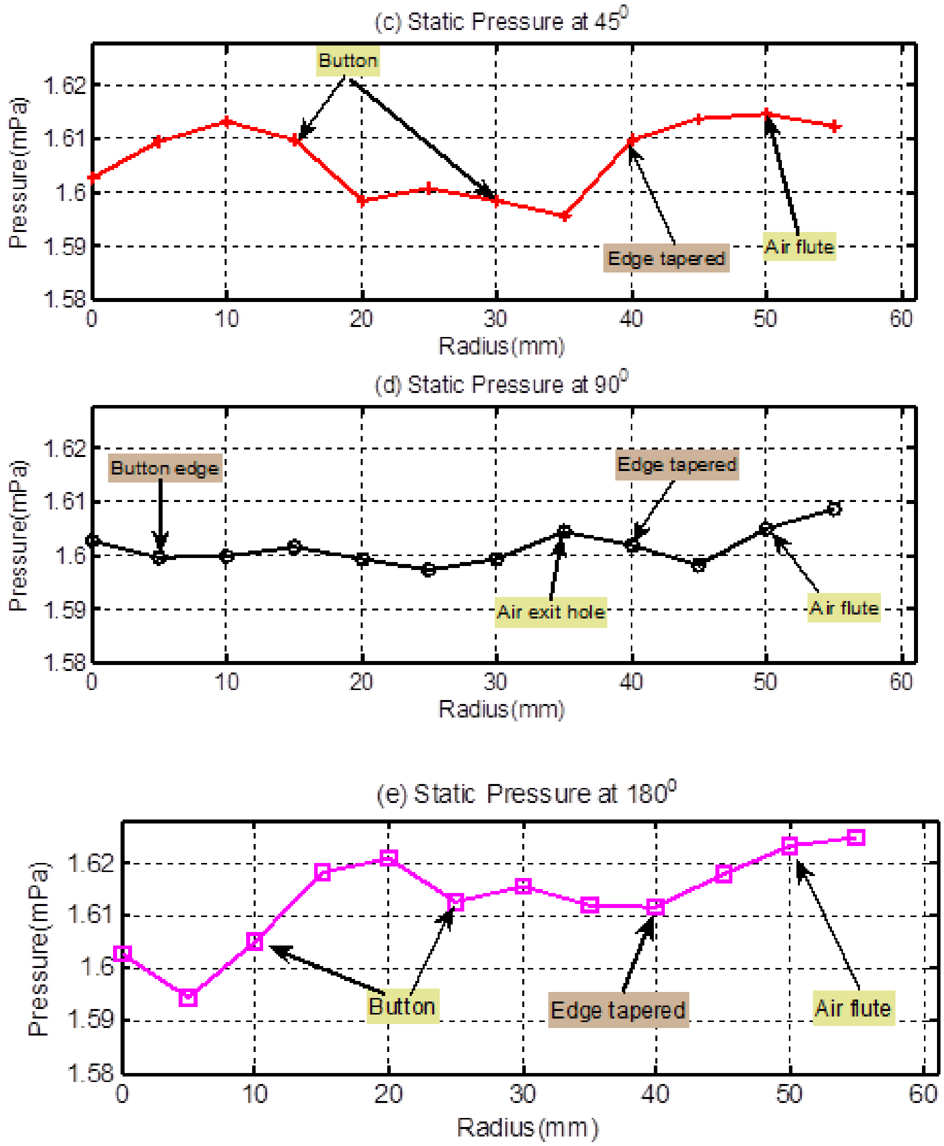


Fig. 8 Static pressure of the air flow at 0°, 45°, 90° and 180°

The effect of air flow rate variation on static pressure field at various heights from the bottom surface is shown in fig. 9. The figure depicts that when air flow rate increases the static pressure decreases. The static pressure also varies with the distance from the bottom. Near the bottom of the drilled cylindrical rock-hole surface, the static pressure has higher value. The static pressure then reduces sharply to its minimum point at which velocity is highest because of convergence effects. The minimum static pressure point is at 16 mm from the bottom surface of the drilled cylindrical rock-hole. The insert button and the air guidance exist at this point.

The static pressure increases again to attain peak value at the end of the drill bit air flute; approximately at 90mm. Finally, it attains its maximum value at 100mm. Figure 10 shows the effect of air mass flow rate on velocity in the drill bit. The air has maximum velocity of 37m/s at 16mm from the drilled rock bottom. The percentage change in the static pressure, due to air flow rate effects, is depicted in fig. 11(a). It can be seen that the magnitude of the change is insignificant and limited to a maximum of 0.35%.

However, the effects of air flow rate change on the drill bit flow velocity shows a maximum change of 19% (fig. 11(b)).

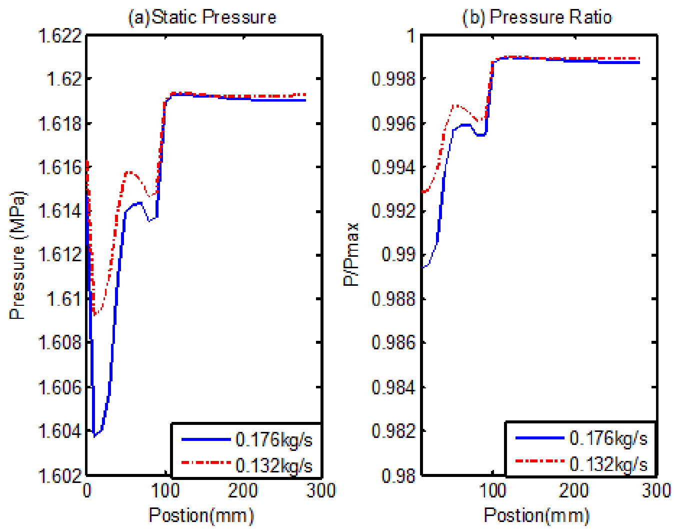


Fig. 9 Static pressure at various air flow rates

Figure 12 shows the effects of air flow rate on velocity of air flow at different positions inside the drilled rock hole. It can be seen that when the air flow rate increases the velocity of the air increases. Similar to the static pressure, the velocity of air varies with the geometrical features of the drill bit.

The effects of air flow rate on the air velocity in the radial direction of the drill bit bottom have been investigated and the results are shown in fig. 12. It can be seen that 0.176kg/s of air flow rate has resulted in higher velocity in the radial direction at 25mm radius of the drill bit. 0.132kg/s mass flow rate shows 40% velocity increase in between 25mm and 35mm radial sections of the drill bit.

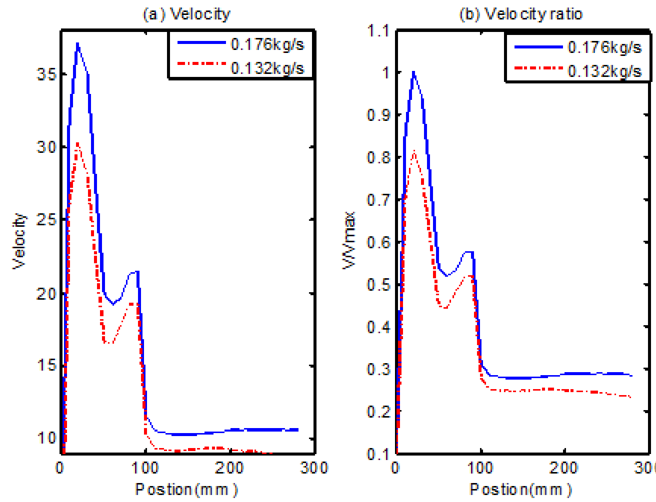


Fig. 10 Velocity at various air flow rate

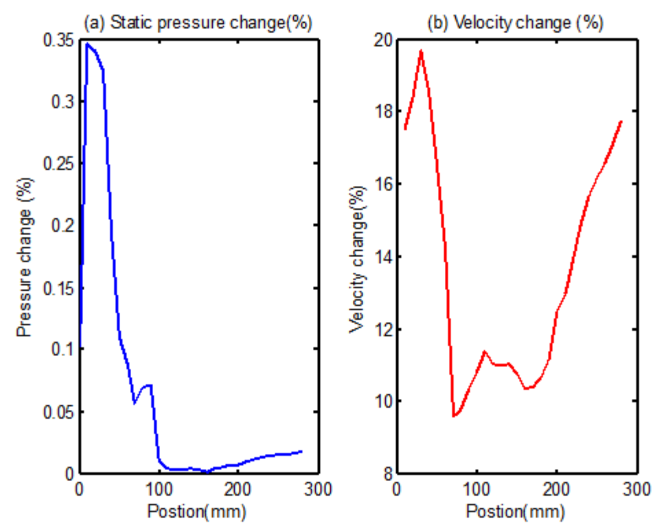


Fig. 11 The percentage change of static pressure and velocity for various air flow rate

The effects of the rotational speed on the static pressure are presented in fig. 13. The figure depicts that the drill bit rotational speed effects on the static pressure are insignificant. Figure 14 shows the velocity magnitudes of air in the drilled rock-hole at speeds of 45rpm, 60rpm, and 75rpm. It can be seen that changing the drill bit rotational speed does not show any significant change in the velocity magnitude of the air flow.

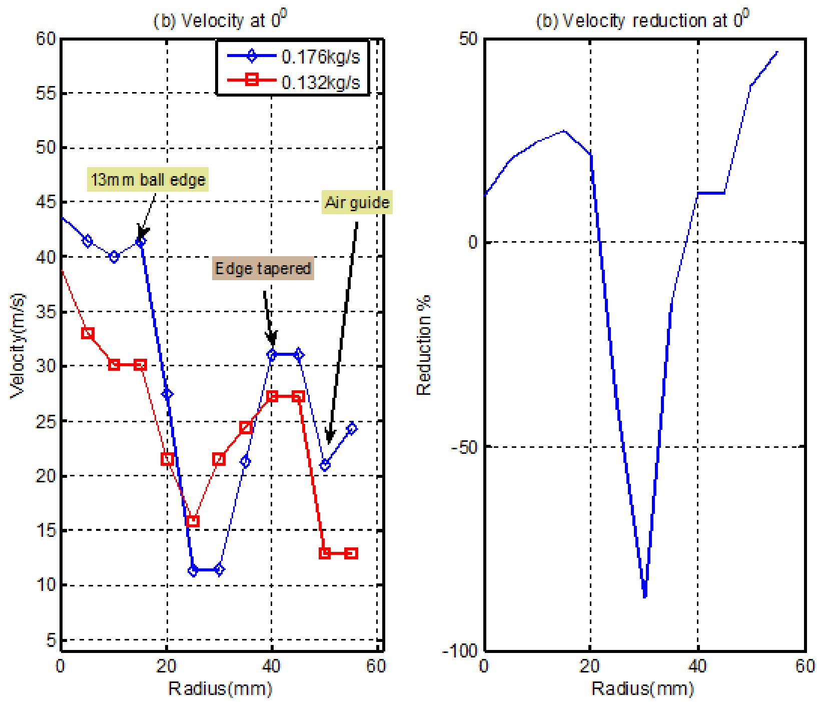


Fig. 12 Effects of air flow rate on the air velocity magnitude at 0 degree

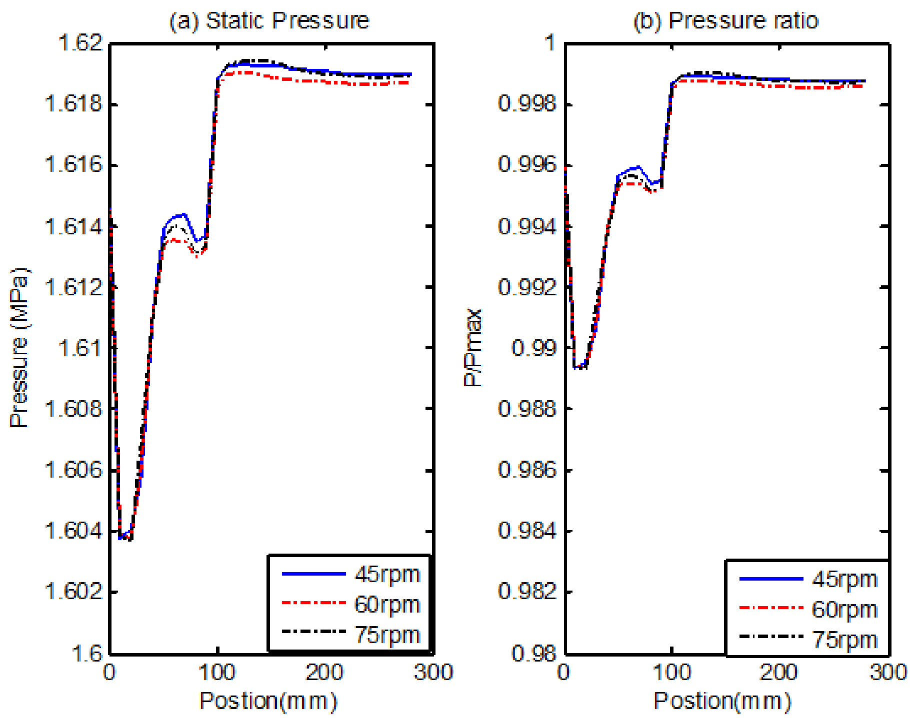


Fig. 13 Static pressure at different drill bit rotational speed

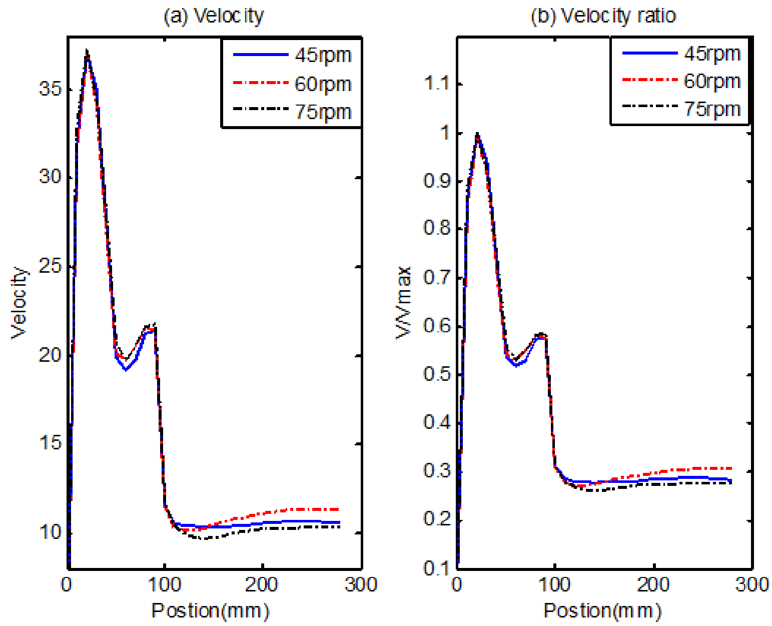


Fig. 14 Velocity at different drill bit speed

CONCLUSION

CFD analysis has been carried out to investigate the performance of the drill bit by varying air flow rate vales and drill bit rotational speed. The following conclusion can be drawn from the investigations:

1. The drill bit buttons, air flute and the tapered geometry have significant effects on the drill bit performance and further investigations are required to quantify it.

2. The pressure is not significantly affected by the air flow rate and the geometry. By changing the air flow rate by 25%, the static pressure changed only by 0.35%. However, the air flow rate changes have significant effect on the velocity of the air. By changing the air flow rate by 25%, the air velocity changes by a maximum of 20%.

3. The variations in the drill speed do not show any significant effects on both the static pressure and the magnitude of the velocity of air moving in drilled rock-hole field. The simulations can now be carried out using multiphase flow approach to evaluate the effectiveness of brill bit geometry in maintain smooth flow of the material.

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