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EFFECT OF HOLE SHAPE ON ROUGHNESS FRICTION FACTOR IN PERFORATED AND SLOTTED HORIZONTAL BOREHOLES USED FOR OPENCAST MINE DEWATERING

Abstract. Horizontal boreholes were adapted for using in mine dewatering systems. Efficient and economically sound application of this new method of dewatering requires using perforated or slotted pipes as filters when installing casing. Pressure drop along a horizontal borehole is a major factor that affects the borehole performance. The pressure drop is caused by four separate effects: wall friction, perforation roughness, inflow acceleration, and mixing effects. This paper is devoted to studying the effects of these two former factors in perforated or slotted pipes. Numerical analysis was carried out using different types of perforation holes and slots. The simulation model was constructed using ANSYS Fluent 14.5 software. The results showed that at high Reynolds number, roughness friction factor values in perforated pipes with circular holes are significantly higher than those in slotted pipes with axially elongated slots and slotted pipes with perpendicular (to pipe axis) slots.

Keywords: perforation roughness, horizontal filters, dewatering, opencast mines.

Introduction

Horizontal directional drilling (HDD) method has been tested in mining industry for dewatering opencast mines [1, 2]. This technique was adapted based on its successful application in oil production and utility construction fields. Efficient and economically sound application of this new method of dewatering requires using perforated or slotted pipes as filters during casing installation [3, 4]. However, these filters must have appropriate mechanical strength and hydraulic characteristics. As for hydraulic performance, the flow pressure drop through the horizontal filter plays an important role and significantly affects the dewatering system productivity. This paper addresses the first phase of the study on the pressure drop of flow through the horizontal filters without inflow through the walls: the effect of perforation roughness.

The effect of perforation roughness and inflow through the walls was thoroughly studied by other researches [5–8]. However, these works were mostly devoted to studying effects of circular perforation hole size and density. This paper focuses on the hole shapes in different filter pipes studied using numerical analysis. These pipes had different hole shapes, but constant hole sizes (areas) and ratio of hole area to the whole pipe surface area (opening area) and the same size. In the simulation study, pipes of inner diameter of 50 mm, the wall thickness of 4 mm, and perforated/slotted length of 920 mm were used. The perforated/slotted area share ranged 2 %-3 % to 5 %. The hole shapes were as follows: Circular Perforated Hole (CPH), Axial Slotted Hole (ASH), and Perpendicular Slotted Hole (PSH). The of hole width varied from 1.5 mm, 2 mm to 3 mm. The Reynolds number changed between 10,000 and 80,000 with the increment of 10,000. There was no flow through the perforation holes or slots.

Simulation technique

To calculate the flow pressure drop through the different perforated/slotted pipes, an academic finite volume code ANSYS Fluent 14.5 was employed. In the numerical simulations the SIMPLE, standard k-ε turbulent model, was used, which previously proved to have good agreement with experimental results [9]. The fluid used was presented by water entered the pipes at temperature of 25°, constant density of ρ = 998.2 kg/m^3, and viscosity of μ = 0.001 kg⁄ms. Besides, no-slip boundary condition along the isothermal walls was assumed. The inlet Reynolds number ranged from 10,000 to 80,000. The pipes were assumed to be hydraulically smooth in nonperforated or non-slotted areas. Two initial conditions were considered: the inlet mass flow and the outlet pressure.

The pipes were uniformly perforated or slotted at different hole sizes, shapes (i.e. CPH, ASH, and PSH), and different ratios of opening area to non-perforated area. These pipes had 2, 3 and 5 percent of the opening share (i.e. the ratios of 0.02, 0.03, and 0.05). The hole width varied from 1.5mm, 2mm to 3mm. A total of 27 pipes were used in the simulation. The configurations of the simulation model and the computational meshes of flows in the pipes are shown in Fig. 1 and Fig. 2, respectively. The flows in the pipes were discretized within ANSYS Meshing environment before solving using the Fluent solver. In the computation process, symmetries were used to reduce computational time and resource consumption.

Results: Effect of Hole Shape on Roughness Friction Factor

The simulation results showed that flows in pipes with different hole shapes demonstrated different pressure drops. It can be seen in Fig. 3, Fig. 4, Fig. 5, and Fig. 6 that the friction factors tend to have lower values than those in common pipes at low Reynolds number (approx. 15,000 for the ASH hole pipes and PSH hole pipes, and 15,000–35,000 for CPH hole pipes).

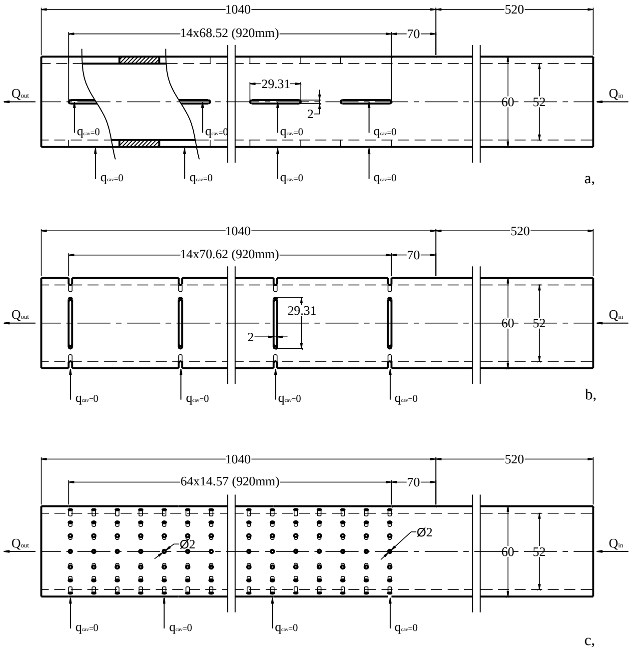

Fig. 1. Configurations of the simulation model

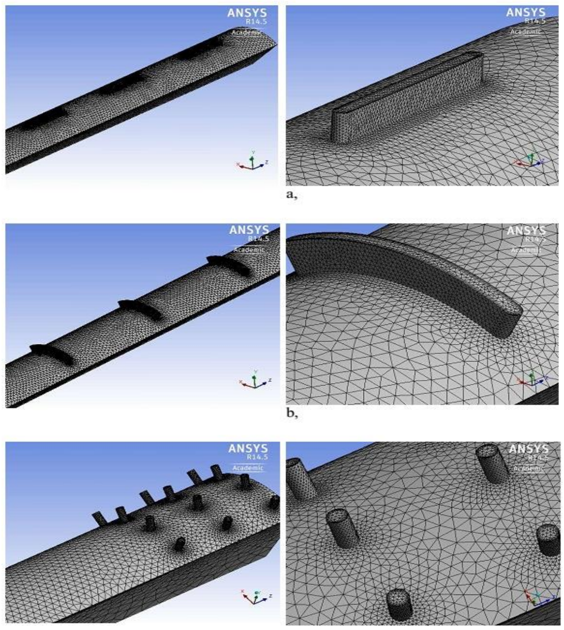

Fig. 2. Computational meshes of flows in pipes: *a* – ASH hole pipes; *b* – PSH hole pipes; *c* – CPH hole pipes

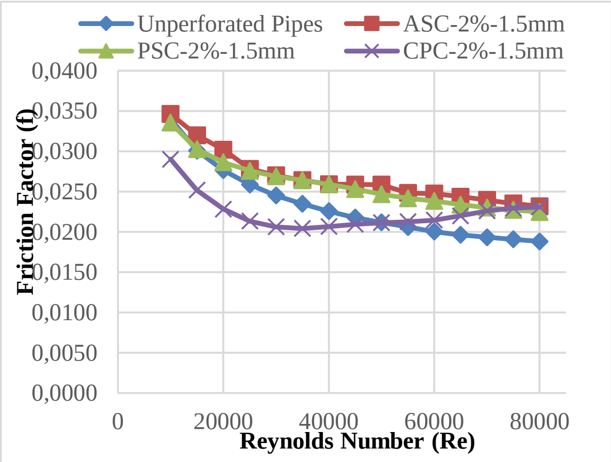

Fig. 3. Friction factors in pipes with 2 % hole area share, 1.5 mm hole size

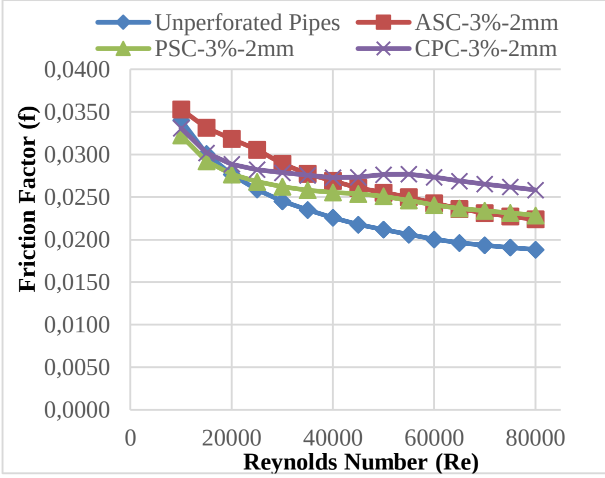

Fig. 4. Friction factors in pipes with 3 % hole area share, 2 mm hole size

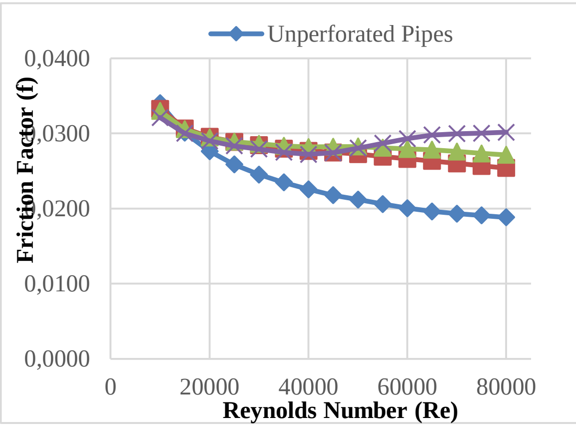

Fig. 5. Friction factors in pipes with 5 % hole area share, 3 mm hole size

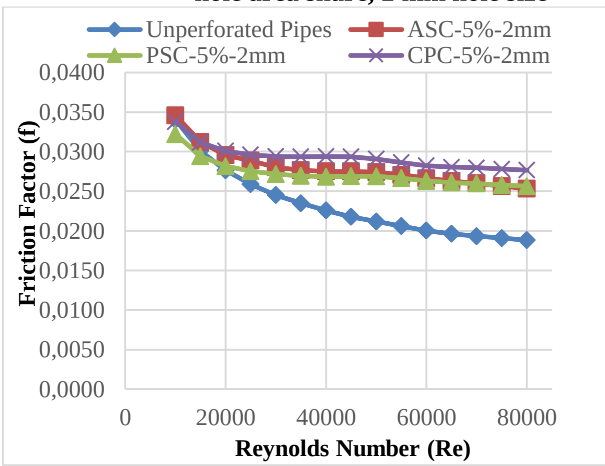

Fig. 6. Friction factors in pipes with 5 % hole area share, 2 mm hole size

This effect can be explained by lesser contact area between the flow and the pipe's wall. The phenomenon of decreasing friction factor at low Reynolds number seemingly took place solely for the pipes with 1.5mm CPH hole size, at any hole area share (2 %, 3 %, and 5 %).

When Reynolds number increases, the pipes with different hole shape demonstrate different trends. The friction factor for the ASH hole and PSH hole pipes decreases with increasing Reynolds number. The rate of the decrease is slower than in common pipes. Generally, the friction factor is 18%-36% higher compared that in nonperforated pipes. In contrast, friction factor in the CPH hole pipes showed the increase with increasing Reynolds number from 35,000 to 65,000. Further the values of friction factor started to decrease. On the whole, at high Reynolds number, friction factor in the CPH hole pipes was 18 %–60 % higher as compared to common pipes and 0 %–18 % higher than that in the ASH and PSH hole pipes. The magnitude of the differences also depends on the hole size. When the hole size increased, the difference in the roughness friction factor increased too.

Conclusions

The numerical simulation results showed that when flow rate through borehole pipe is high (i.e. Re > 50,000), the flow in the CPH hole pipes is characterized by the highest roughness friction factor values and the largest pressure drop. Meanwhile, the ASH hole pipes demonstrated slightly lower values of roughness friction factor compared to the PSH hole pipes. These results are of utmost importance for investigation of more complicated situation where inflow through holes exists.

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