Numerical Simulation of Foam Flow in Annulus With Wellbore Heat Transfer

SUN Shihui[a],*; YAN Tie[a]; BI Xueliang[a]; XING Yunlong[b]

[a] Petroleum Engineering College, Northeast Petroleum University, Daqing, China.
[b] China Oilfield Services Co. LTD, Tianjin, China.
*Corresponding author.

Abstract

In the study of hydraulic parameters in foam drilling, most foam hydraulic models were built based on the assumption that wellbore temperature was equal to formation temperature. But energy exchange takes place among annular foam fluid, formation and drill string, there may be a discrepancy between wellbore temperature and formation temperature. The effects of heat transfer on foam flow in annulus were investigated by numerical simulation in this paper. Simulation results show that due to the influence of temperature on pressure, the changes of annular pressure are transient. And foam fluid density, viscosity and other physical parameters are change with pressure. During foam fluid transports the solid particles from bottom to surface, solid particles accelerate and foam decelerates. When high solid particles concentration zone is reached, foam velocity decreases to a minimum value, and then increases due to the decrease of solid particle concentration. When cuttings velocity increases to a certain value, cuttings transport with a constant velocity.

Key words: Heat transfer; Foam drilling; Annulus pressure; Foam velocity; Numerical simulation

INTRODUCTION

A number of studies have been conducted to investigate foam fluid rheology, foam stability, hydraulic model and cuttings carrying capacity of foam drilling using laboratory measurements and theoretical results at home and abroad, and some valuable achievements were achieved[1-4]. In the study of hydraulic parameters in foam drilling, most foam hydraulic models were built based on the assumption that wellbore temperature is equal to formation temperature[5-7]. However, foam quality of stable foam is within a certain range from 55% - 96%. Because of its large gas content, foam physical parameters are sensitive to temperature. And energy exchange takes place among annular foam fluid, formation and drill string while foam circulating along wellbore. Besides, mechanical energy and internal energy can be converted to one another. Therefore, there may be a discrepancy between wellbore temperature and formation temperature[8-9]. If the effect of heat transfer on foam flow was ignored, the calculation of bottomhole pressure, minimum cuttings transport velocity, minimum gas injection rate and other key parameters were easier to cause prediction errors. Based on heat transfer and multiphase flow, the effect of heat transfer on flow laws in annulus during foam drilling was studied using numerical simulation method in this paper.

1. PHYSICAL MODEL

Because the flow of foam fluid in the wellbore is complex, for the convenience of research, the following assumptions were made: i) foam fluid is 1-dimensional unstable flow; ii) heat conduction between drillpipe and annular is steady state; formation far from well and borehole wall is transient conduction; iii) heat loss in annular and formation is radial; axial heat transfer of wellbore, thermal radiation and cuttings effects are ignored.

The diagram of the physical model is shown in Figure 1. And hexahedral mesh is applied for the flow domain in annulus, as shown in Figure 2.
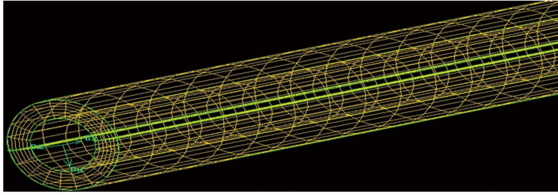

Figure 1
Physical Model of Wellbore

Figure 2
Annular Grid Structure

2. RESULTS AND DISCUSSIONS

Annular temperature contours of gas and solid phase are shown in Figures 3 and 4[10]. In foam drilling, heat transfer takes place among annulus fluid, borehole wall and drill pipe. And convection transfer is conducted among gas, liquid, and solid in annular. As shown in figures, in the same well depth, the closer to the symmetrical axis, the faster solid phase temperature increases, and the faster gas phase temperature reduces. This is because heat transfer coefficient between gas phase and solid phase where closer to the axis is larger, heat transfer quantity is large. Near wellbore zone, if the temperature of foam drilling fluid is lower than that of wellbore, heat transfer from wellbore to annular. However, due to the resistance of the wall, heat transfer efficiency near wellbore is relatively low.
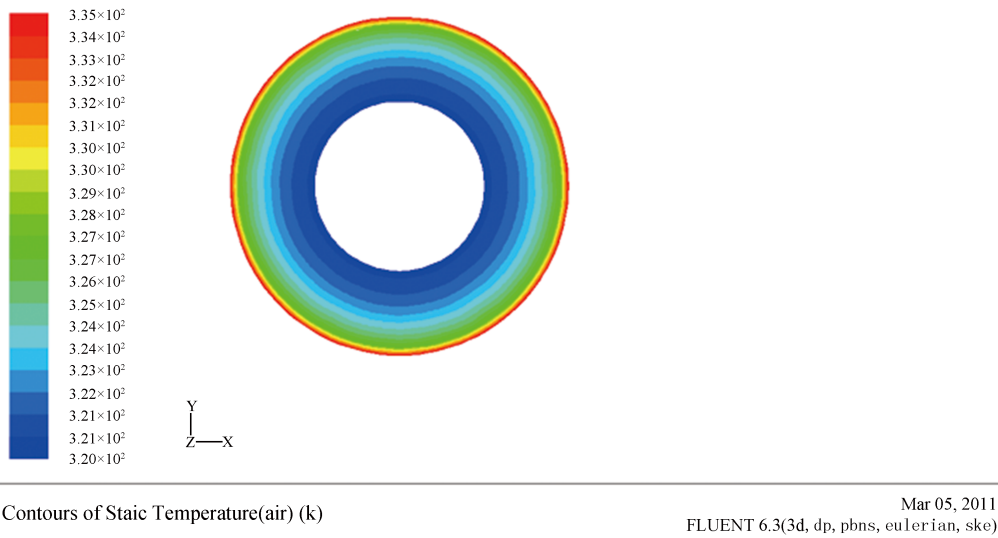

Contours of Staic Temperature(air) (k)

Mar 05, 2011
FLUENT 6.3(3d, dp, pbns, eulerian, ske)

Figure 3
Annular Temperature Contours of Gas Phase

Contours of Static Temperature(sand)(k)

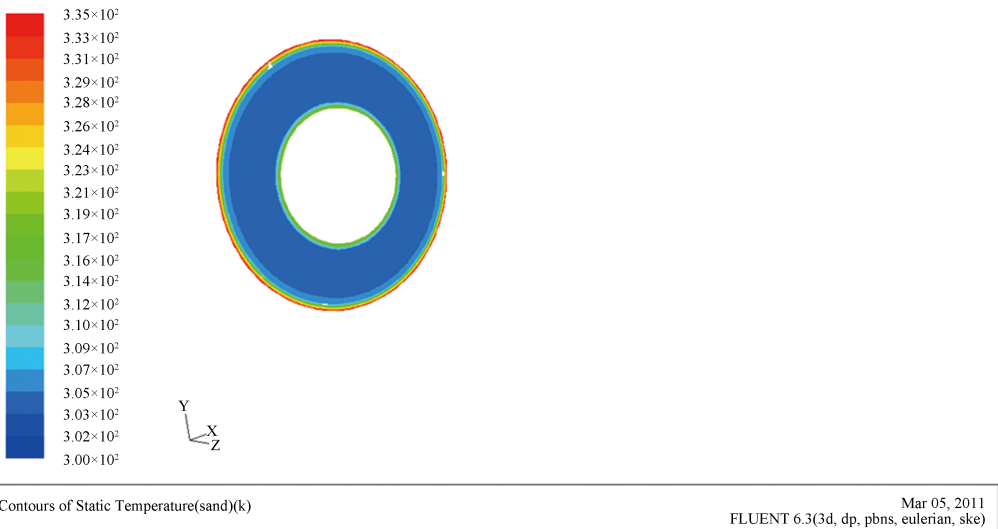Mar 05, 2011
FLUENT 6.3(3d, dp, pbns, eulerian, ske)

Figure 4
Annular Temperature Contours of Solid Phase

Axial pressure contours are shown in Figure 5. As the figure shows, annulus pressure increases with well depth. Both heat transfer among the wellbore, annulus fluid and drill pipe and convection heat transfer among multiphase flow phases are taken into account, the temperature of annulus fluid appears transient changes. And due to the influence of temperature on pressure, the changes of annular pressure are transient, as shown in Figure 6.

Hence, foam fluid density, viscosity and other physical parameters changes. At low pressures, foam density increases rapidly. However, at high pressure, the trend shows slight. This is because annular pressure increases as well depth increases, repulsive forces between gas molecules will rapidly increase to a maximum. It will be difficult to compress gas phase in foam, and the change of foam density is relatively slow.
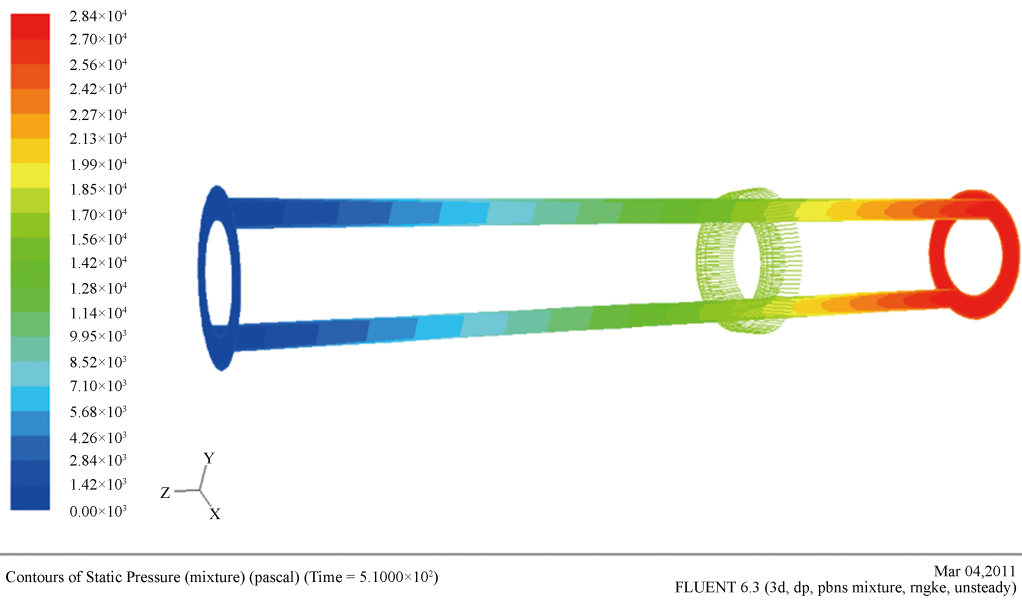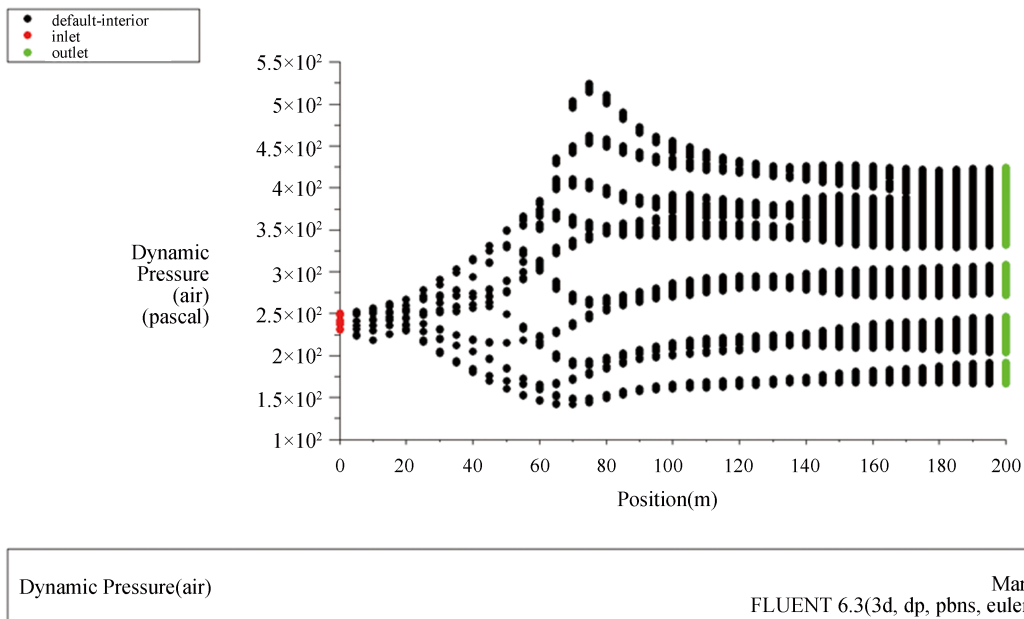

Figure 5
Annular Pressure Contours

Figure 6
Dynamic Pressure Curve of Gas Phase

Contours of solid volume fraction and gas volume fraction are shown in Figures 7 and 8. As shown in Figure 7, solid particles, gas and liquid phase are circulating from bottom to surface, solid particles first accelerates due to particles velocity is smaller than that of gas phase, under the action of radial pressure and turbulent kinetic energy, particles gather to the center of the annular gradually, where forms a high concentration zone.

However, Figure 8 shows the trend of gas volume fraction just opposite to that of cuttings. Under the friction of wellbore and the drag effect of solid particles, gas velocity reduces, high concentration zone near wellbore.
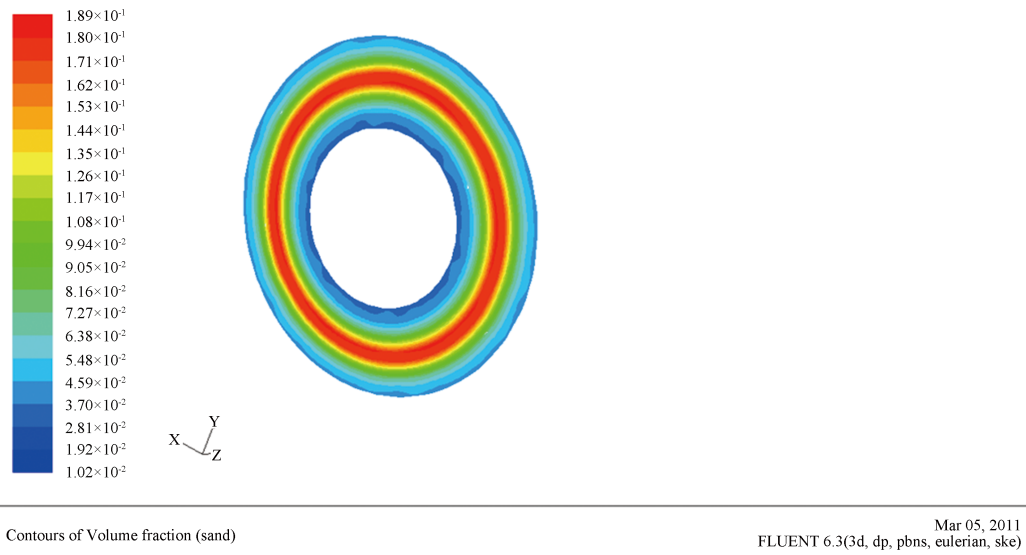

Contours of Volume fraction (sand)

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FLUENT 6.3(3d, dp, pbns, eulerian, ske)

Figure 7
Contours of Solid Volume Fraction

Contours of Volume fraction (air)

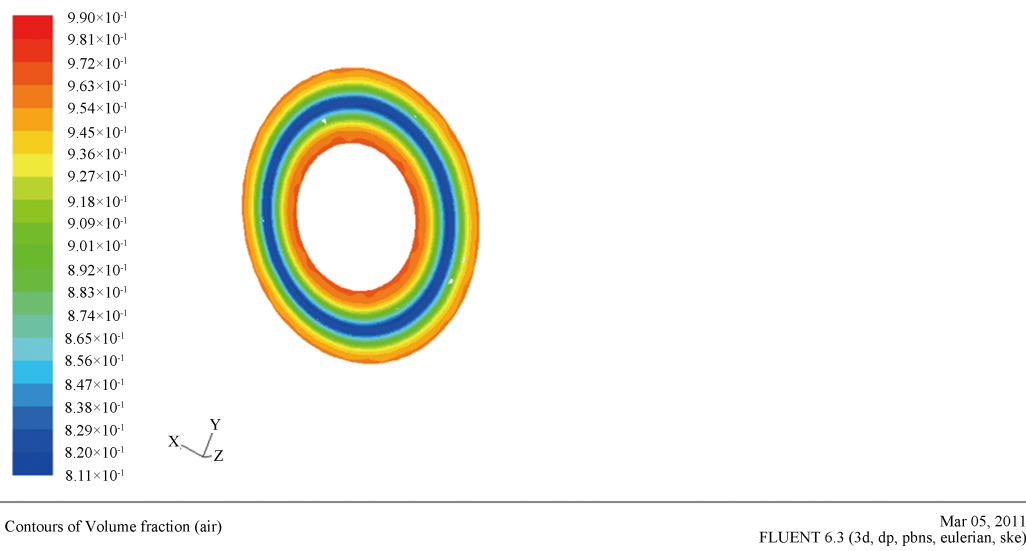Mar 05, 2011
FLUENT 6.3 (3d, dp, pbns, eulerian, ske)

Figure 8
Contours of Gas Volume Fraction

Velocity magnitude of gas and cuttings velocity curve is shown in Figures 9 and 10. During foam fluid transports the solid particles from bottom to surface, solid particles accelerate and foam decelerates. When high solid particles concentration zone is reached, foam velocity decreases to a minimum value. With the decreases of solid particle concentration, the amount of solid particles carried by foam is also decreased, and foam velocity could be increases. When cuttings velocity increases to a certain value, velocity between different phases will not change obviously, a constant velocity is reached. Since annulus fluid is affected by the friction from wellbore, the velocity of wellbore is lower than that of center.
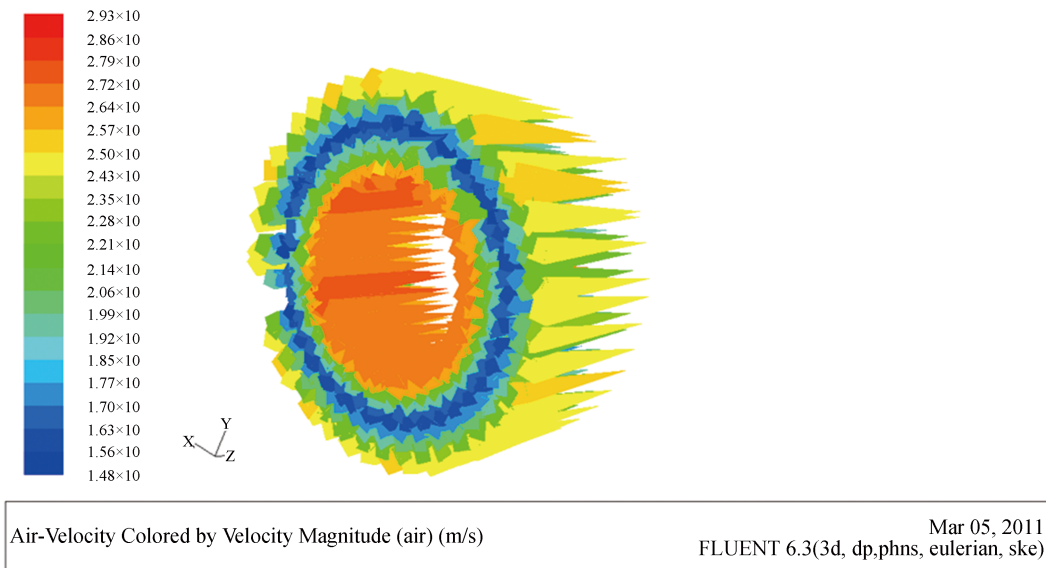
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Air-Velocity Colored by Velocity Magnitude (air) (m/s)	FLUENT 6.3(3d, dp,phns, eulerian, ske)

Figure 9
Velocity Magnitude of Gas

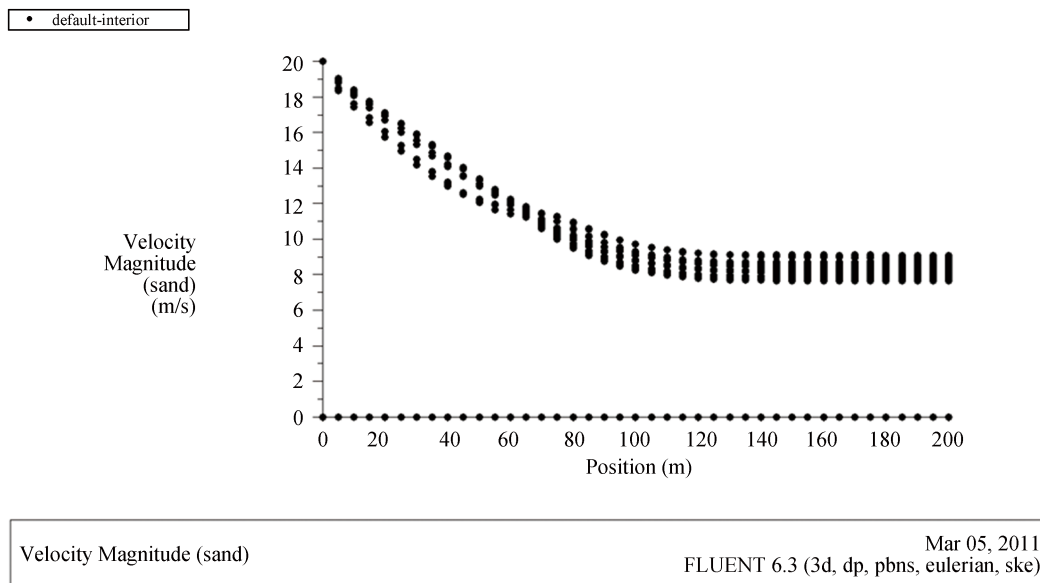|	Mar 05, 2011
Velocity Magnitude (sand)	FLUENT 6.3 (3d, dp, pbns, eulerian, ske)

Figure 10
Cuttings Velocity Curve

CONCLUSION

(a) In the same well depth, the closer to the symmetrical axis, the faster solid phase temperature increases, and the faster gas phase temperature reduces. Near wellbore zone, due to the resistance of the wall, heat transfer efficiency is relatively low.

(b) Due to the influence of temperature on pressure, the changes of annular pressure are transient. And foam fluid density, viscosity and other physical parameters are changes with pressure. At low pressures, foam density increases rapidly. However, at high pressure, because of repulsive forces between gas molecules, the trend shows slight.

(c) Solid particles high concentration zone is in the center of annular. However, high concentration zone of gas near wellbore.

(d) During foam fluid transports the solid particles from bottom to surface, solid particles accelerate and foam decelerates. When high solid particles concentration zone is reached, foam velocity decreases to a minimum value, and then increase due to the decrease of solid particle concentration. When cuttings velocity increases to a certain value, cuttings transport with a constant velocity.

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