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A Study on the Rotating Flow in an Annulus

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ABSTRACT

Lift forces acting on a fluidized particle play a central role in many importance applications, such as the removal of drill cuttings in horizontal drill holes, sand transport in fractured reservoirs, sediment transport and cleaning of particles from surfaces. An experimental and numerical investigation is conducted to study a solid-liquid mixture upward-transporting hydraulically by Newtonian fluid and non-Newtonian fluid such as sodium carboxymethyl cellulose(CMC) solution by weight in a slim hole concentric annuli with rotation of the inner cylinder. Annular fluid velocities varied from 0.2 m/s to 2.0 m/s under the actual drilling operational condition. Macroscopic behavior of solid particles, averaged flow rate, and particle rising velocity are observed. For both waater and CMC solutions, the higher the concentration of the solid particles are, the larger the pressure gradients become. Also, CMC solutions have been observed to provide better capability to mobilize and transport particles. The mean diameter of particles was 0.1 cm and a material density of 2.55 g/cm^3 were used in the experiment.

INTRODUCTION

Among the various industrial unit operations involved with multi-phase systems, agitation of solid-liquid systems is quite commonly encountered such as catalytic reactions, drilling operation of oil well, etc. Although there are many industrial applications of solid-liquid flows in technology, the available knowledge about particle flows is not complete due to the difficulties encountered in analyzing these complex systems.

Rotating flows in annular passages are important, since they have many engineering applications in bearings, rotating-tube heat exchangers and, especially, annulus flows of mud in case of slim hole drilling of oil well.

When an oil well is drilled, it is necessary to transport the cuttings up to the ground. To this end, fluid is pumped through the center of drill pipe and back up to the ground through the annular gap between the drill pipe and the drilled hole. The fluid is viscous, non-Newtonian, and will typically have gel strength. The annulus flow might be laminar or it might be turbulent, depending on the situation.

Therefore, numerous mathematical and empirical models for the prediction of cuttings transport in horizontal and directional wells have been developed by several researchers. A detailed study reveals that the cuttings transport characteristics change with an increase in wellbore angle. Tomren et al. and Ford et al. carried out experimental study on cuttings transport in inclined annulus and observed the existence of different layers that might occur during the mud flow and cuttings in an annulus.

Interests have been growing in the interaction between particle and local flow structure in two-phase particulate flow. Pigot discussed the application of Stoke's law for laminar flow and Rittinger's formula for turbulent flow to drilled particle settling velocity calculation. He concluded that high fluid viscosity was not necessary, suggesting that laminar flow in the annulus would lead to more efficient cleaning. For trouble-free operation, he also recommended that the volumetric cuttings concentration in the annulus be kept less than 5 percent.

Sifferman et al. found that annular velocity and fluid rheological properties are the most important factors influencing the transport ability of a fluid. Other variables such as particle size, drill pipe rotation, drill pipe eccentricity have only moderate effects on carrying capacity in their study.

NOMENCLATURE

dP/dz	[Pa/m]	Axial Pressure loss
D_h	[m]	Hydraulic diameter
D_1	[m]	Diameter of inner cylinder
D_2	[m]	Diameter of outer cylinder
Re_p	[-]	Particle Reynolds number
v_z	[m/s]	Velocity in the z-direction

Special characters

η	[-]	Radius ratio
μ	[Pa·s]	Absolute viscosity
ρ	[kg/m^3]	Density of fluid