THRESHOLD SHEAR STRESS FOR TRANSPORTE OF PARTICLES BED IN ANNULAR FLOW

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Abstract. *The flow in the annular space between two stationary concentric cylinders with an imposed axial flow was studied using numerical simulation with the k - ε turbulence model. This study considers the similar flow geometry to in the experiments carried out by Loureiro et al. (2006), where the bottom of the annular space was considered a plate parallel to axis of inner cylinder. The objective of this work was to numerically estimate the threshold shear stress necessary to start the erosion process in a sediment bed. In addition, the purpose of this study was to investigate the influence of the height bed on the flow structure with an imposed axial flow. The results showed that the velocity field and bed shear stress increase with the decreasing of the gap region on the annular space.*

Keywords*: annular flow, erosion shear stress, horizontal wells, turbulence model*

1. INTRODUCTION

The study of the mechanism for cleaning the bed of particles in drilling wells plays an important role in the process of the oil gas production. Several studies have been made to determine the optimum cleaning efficient conditions when vertical well are used. However, in drilling horizontal wells, more serious problems appear than drilling vertical wells (Gaurina-Medimurec et al., 1996). The major problems of an inefficient cleaning of wells are: excessive torque of the column of drilling, pipe stucking, mechanical locking of the column and difficulties in the operations of cementing and casing-loogging. This could cause a significant increase in the cost of the drilling process (Azar and Sanchez, 1997).

Some factors influences the efficient cleaning in horizontal wells are axial velocity of the fluid in annular space and erosion shear stress. Although both axial velocity of the fluid and erosion shear stress affect the efficient cleaning, they affect in a different manner. The axial velocity is the main parameter that causes the transport and suspension of the sediment particles. The erosion shear stress it is necessary for initiate the erosion and removes sediment from the bed surface. The eccentricity and rotational velocity of the column of drilling; penetration rate; rheology and density fluid; inclination angle of wells and; particle size, shape and density also affect the efficient cleaning.

The precise mechanisms that govern the erosion and cleaning of particles of a sediment bed are still not completely understood because of the complex physical processes that are involved. However, experimental studies carried out by Loureiro and Siqueira (2006a) and Loureiro et al. (2006b) have been used to clarify that shear stress at the interface of the sediment bed is an important controlling parameter.

In this work, an axial flow between two stationary concentric cylinders of a horizontal well partially obstructed of phase 12¼” was simulated using standard k - ε turbulence model. The main goal of this case study it was to predict numerically the erosion shear stress of a sediment bed in an annular space. In order to obtain the results it was carried out a series of three-dimensional (3-D) numerical simulations using techniques of computational fluid dynamics (CFD). Six cases with different bed heights were simulated and analyzed, where the bottom of the annular space was considered as a parallel plate to the axial radius.

2. NUMERICAL METHODS AND BOUNDARY CONDITIONS

Based on experiments performed out by Loureiro et al. (2006a), numerical simulations were employed to investigate the 3-D axial flow in an annular space partially obstructed. The main motivation was to determine the shear stress applied to a bed of gravel simplified by a rigid and fixed obstruction.

The numerical simulations of the axial flow were performed by using the 6.12.16 version of the FLUENT code. In this work, the standard k - ε turbulence model was used to investigate the 3-D axial steady flow in the annular space. The Navier-Stokes equations were solved numerically for turbulent flow in annular space on parallel computers. The parallelization of turbulent flow was run on a 5-node Linux cluster.

The flow transport equations for the proposed flow were discretized using a Control Volume Method (Patankar, 1980). The SIMPLE algorithm from Patankar (1980) was used in order to obtain the velocity-pressure coupling, and the Power Law discretization scheme was used for equations of mass, momentum, turbulent kinetic energy and dissipation turbulent rate.

The geometry of the investigated problem was a concentric annular space with inner cylinder, of radius R_{in} = 0.0825 m, outer cylinder, of radius R_{out} = 0.157 mm, and length to 6.0 m. Six cases with different bed heights were considered

to study the field variables, i.e., velocity and wall shear stress, with the following bed ration: : H/R_{out} = 0.119; H/R_{out} = 0.237; H/R_{out} = 0.296; H/R_{out} = 0.356; H/R_{out} = 0.356; H/R_{out} = 0.415; and H/R_{out} = 0.525, where H is the height of the sediment bed.
The mesh used for discretization of the problem was not structured and uniform. Table (1) presents the heights of bed obstruction and the quantity of cells for each geometry built in this work

Tabela (1) Geometry and mesh information.

Geometry	Height of bed [mm]	H/R	Nodes
I	0.018625	0.119	2,560,000
II	0.037250	0.237	2,560,000
III	0.046530	0.296	2,560,000
IV	0.055875	0.356	2,560,000
V	0.065188	0.415	2,880,000
VI	0.830000	0.529	2,560,000

2.1 Boundary Conditions and Wall Functions

2.1.1 Upwind Boundary

At the inlet of the computational domain the boundary condition considered was a constant mass-flux. In this case, in all the numerical simulations it was considered that liquid water enters uniformly throughout the annular space, with mass flux equal to 31.545×10^{-3} kg/s.

It was also specified an intensity of turbulence equal to 10 % and a length scale of turbulence equal to 0.0745 m, which corresponds to the scale of larger vortex that can be formed within the computer field ($R_{out} - R_{in}$) .

2.1.2 Downwind Boundary

At the outlet, tangential gradients were set to zero.

2.2.3 Bottom and cylinder walls

At the bottom and both the inner and outer cylinder boundaries were considered as contour of wall. On the wall, no-slip condition for the velocity components was used. In this case, the wall functions were set.

3. METHODOLOGY

In this work, it was established a typical flow in a horizontal well, in order to perform numerical simulations of an axial flow in the annular space and to estimate the shear stress in the bed, where there are sediment particles. In this case, the following assumptions were made:

(I) The flow in the annular space was assumed to be turbulent due to the constant fluid flow rate imposed at the inlet equal to 31.545×10^{-3} kg/s.

(II) The fluid was assumed to be incompressible and the flow to be steady state.

(III) The bed of gravel was considered without surface roughness, that is, smooth wall as a first approach to solving the problem.

(IV) The inner and outer cylinders were stationary.

(V)The fluid used in the axial flow, liquid water, is Newtonian and low viscosity. Although such characteristics are not applicable to the drilling fluids, main objective of this work is to present a methodology for assessing the cleaningness of a horizontal well with different heights of the sediment bed.

(VI) The calculation of shear stress on the sediment bed it was performed using of shear stress equation on the *zy* direction, since the other components of tension do not have influence on the drag of the particles present in sediment bed, the flow only presents v_z the component of velocity.

4. RESULTS

4.1 Velocity profiles

The velocity field of the flow was obtained for each computational domain, considering the following fluid flow rate at inlet of 31.545×10^{-3} kg^3/s. To demonstrate the fully development of the velocity field, axial velocity was taken, v_z, along the radial coordinate of the annular space, located on the vertical axis of symmetry for various positions. Figure (1) shows the velocity profiles for each geometry, where it was possible to see that the full development of the flow occurs at $z = 4.0$ m. Figure (1) also presents the velocity profiles in the gap region of the Bed I to Bed VI.

It can be see from the Fig. (1), the velocity along the radial coordinated of the annular space increases with the increase in bed height, considering the same mass flux at inlet. This fact is due to the decrease of gap region that provides an increase in average velocity, in order to keep the conservation of mass. The increase in velocity will provide a greater axial flow gradient of the velocity near the walls of the annular space, and in the region near the sediment bed.

For Beds I to VI, in the gap region, it was possible to note that the velocity along the radial coordinated in the annular space decreases with the increase in sediment bed, as expected. This effect occurs in the light of greater restriction of flow in the region of annular blocked, as shown in Fig. (1).

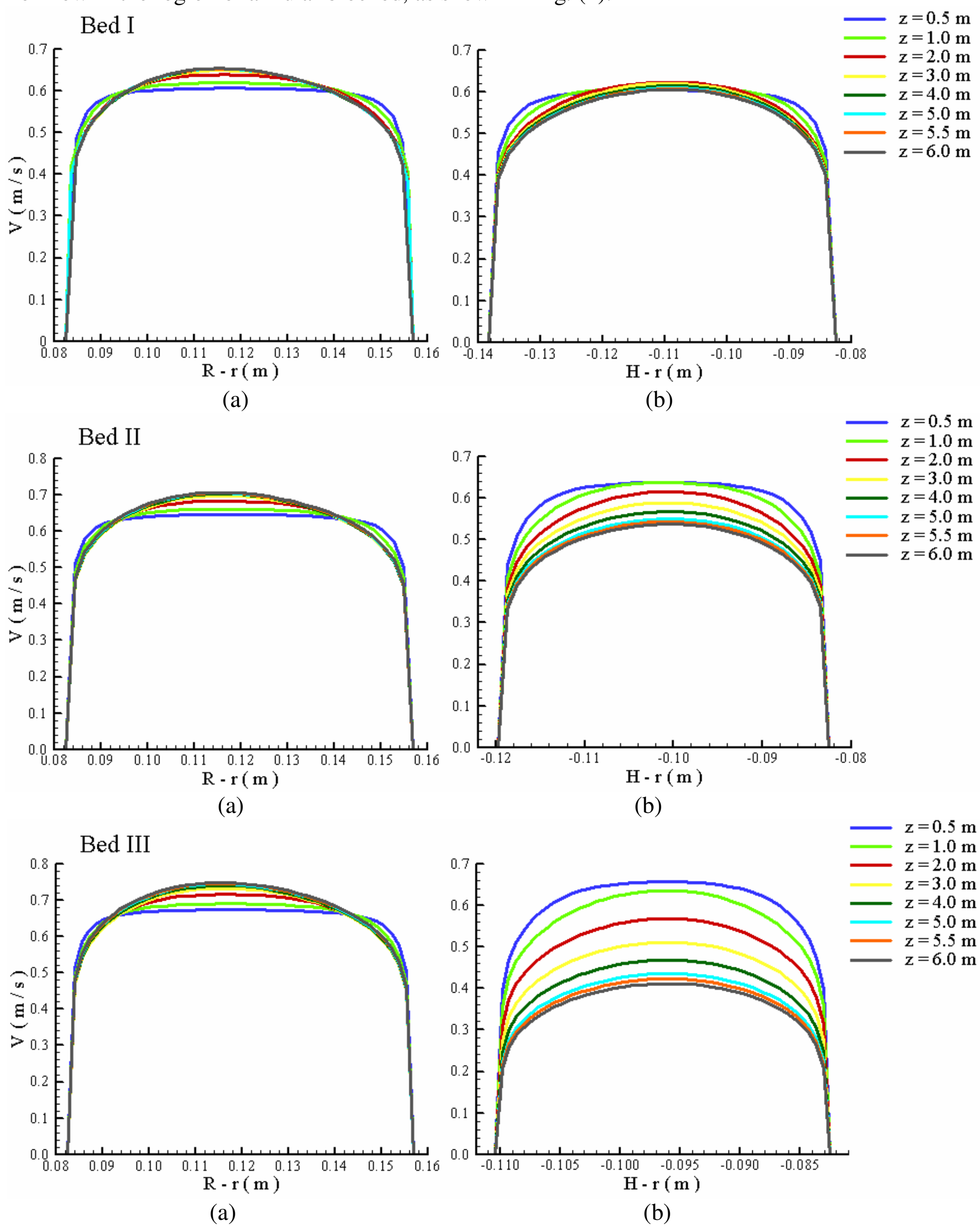

Figure 1. Axial velocity profiles, v_z, in the radial coordinate: (a) R – r e (b) gap region.

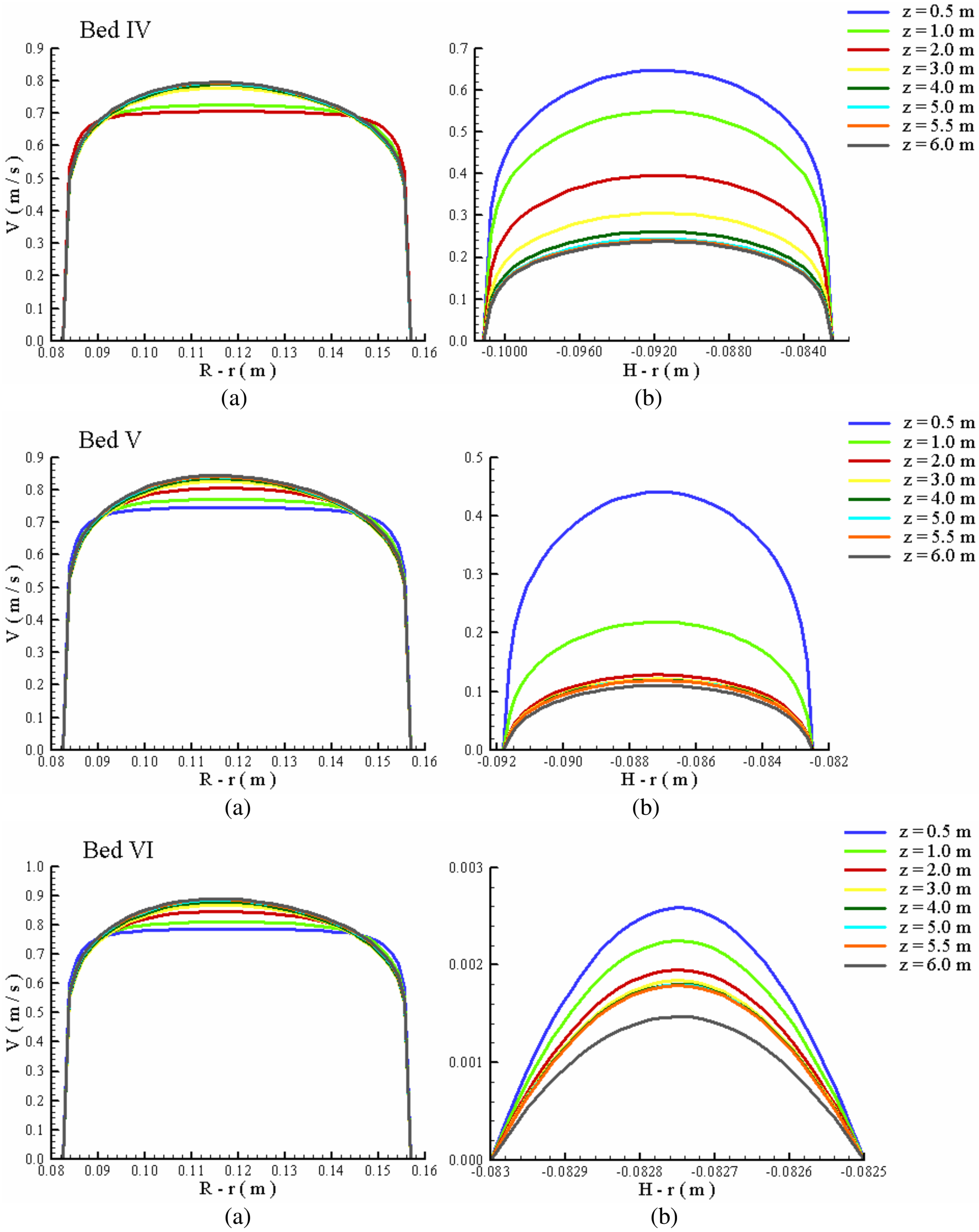

Figure 1 (Cont.). Axial velocity profiles, v_z, in the radial coordinate: (a) R – r e (b) gap region.

4.2. Countor stream of velocity in the *r* - θ plane

Figure (2) shows the estimated velocity field for six bed height configurations in the axial coordinated at z = 5.5 m. The velocity field in the r - θ plane showed the change in the flow with increasing obstruction of annular space. From this estimated velocity field, it was qualitatively possible to verify the increased of the velocity with increasing obstruction in the most distant regions of obstruction. The problem appears to be symmetrical around a line of vertical symmetry due to two concentric cylinders which were considered stationary.

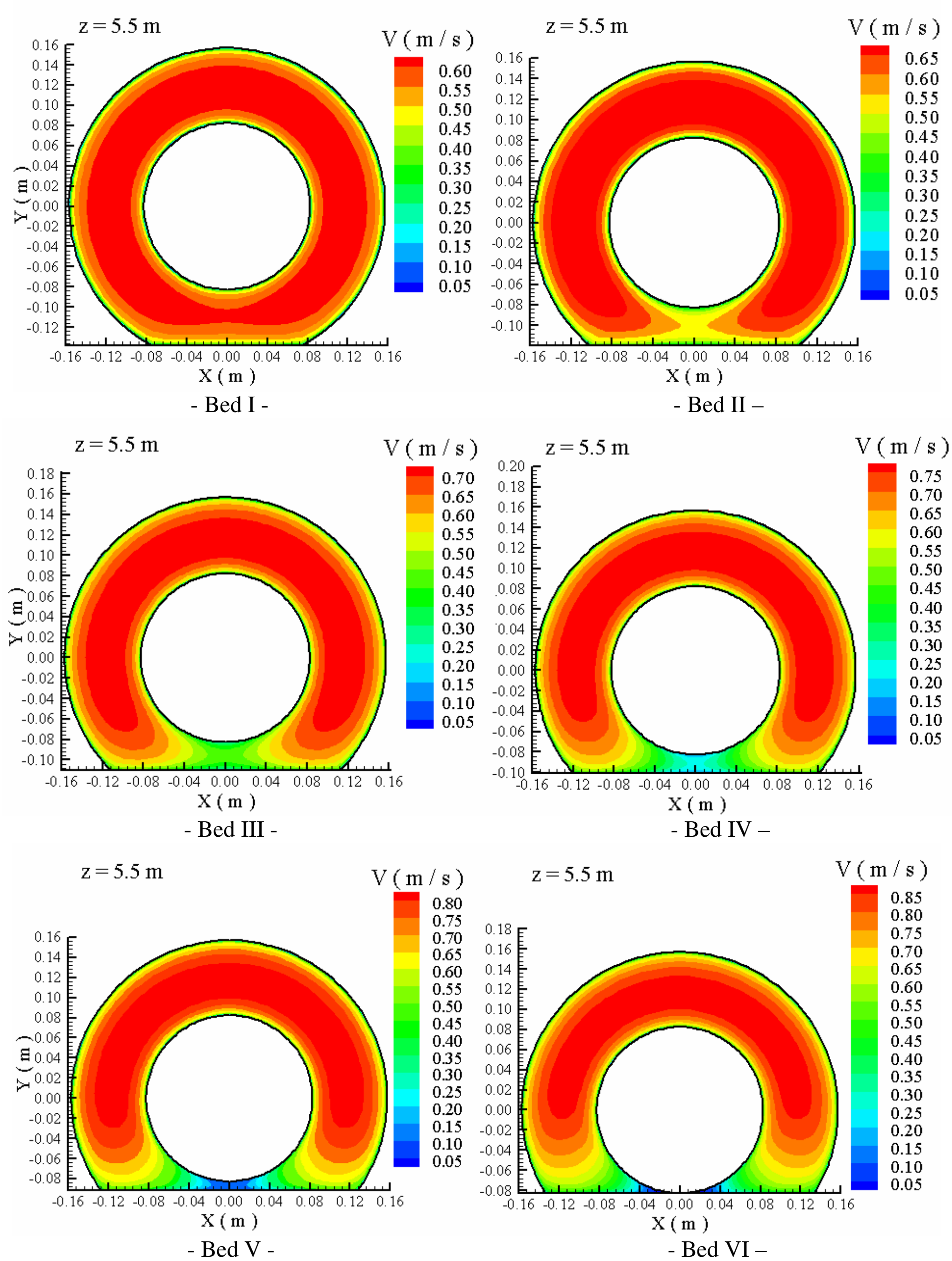

Figure 2. Axial velocity countor, v_z, in the axial coordinate at the z = 5.5 m for the different geometry of the sediment bed.

4.4.3 Shear Stress

Figure (3) shows the shear stress profiles for six bed height configurations in different positions of axial coordinates. In this study the erosion shear stress was defined as the minimum applied bed shear stress required to initiate erosion and removing the particles from the bed surface. The shear stress that acts on a bed surface was a function of the flow in the in annular space (velocity and flow regime), as well as the fluid viscosity, the dimensions of the annular space, superficial roughness, and the height of the sediment bed. Due to the vertical symmetry of the problem studied, the results of the shear stress profiles on the sediment bed showed in Figure (3) to only one side, that is, for the coordinated x negative.

The results indicate that the turbulent flow has become fully developed at z = 5.0 m, as shows in Fig. (3). This flow behaviour can be attributed to the constant mass flux at inlet of the computational domain for the seven cases tested and that the surface roughness was considered null for all conditions of contour of the wall.

It was possible to note that a significant variation in the shear stress profiles at the bottom of computational domain occurred, in the region of fully developed turbulent flow (z = 5.0 m), as a shows Fig. (3). The increases in shear stress were probably due to the increased of the bed ratio (H / R_{out}), on which the sediment bed was formed hypothetically through the depositing of the particles on the bed surface.

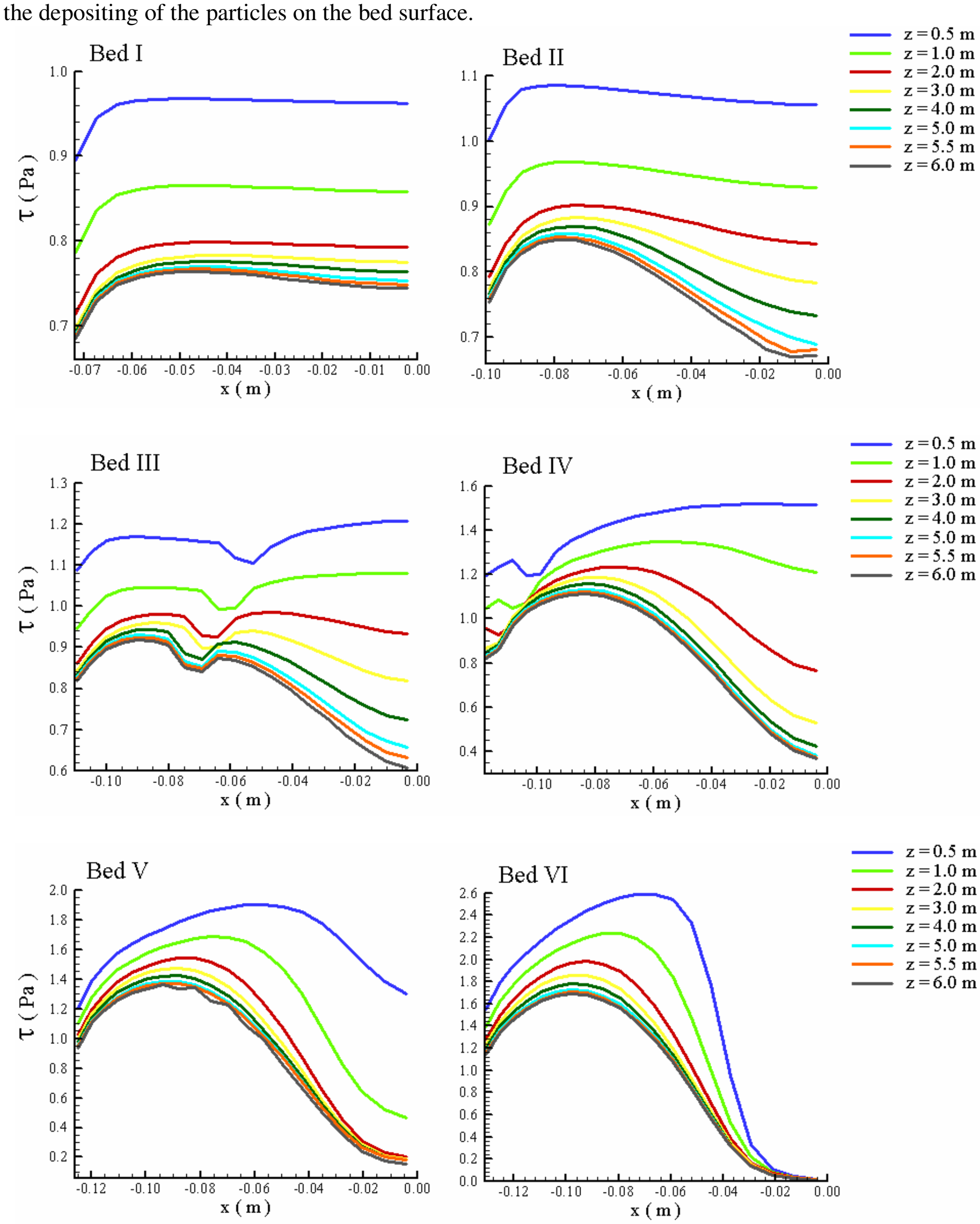

Figure 3. Shear stress profiles for six sediment bed for the different axial coordinates.

In the case of Bed I (H / R_{out} = 0.119), the numerical results showed that the shear stress on the sediment bed in the coordinate axial at z = 5.0 m, has its maximum point in the symmetry of the bed surface, due to the greater height of the gap region, i.e., the bed height that blocks the annular space.

From Bed II (H / R_{out} = 0.237) to Bed VI (H / R_{out} = 0.529), the shear stress profiles on the bed presented a shift from the point of maximum tension of region of the symmetry to a region closer to the outer wall of the cylinder. This was due to the fact that shear stress increased with the decreasing of the gap region.

The shear stress in the region also presented a decrease of symmetry as the obstruction of the annular space increased, Bed I to Bed VI. This decrease in shear stress was maximum in the case of Bed VI, in which the value of the tension got close to zero; as to the obstruction occupied almost all the annular space region. In addition, the lower velocity in this region was due to the low intensity when compared to other regions of the obstructed space. In contrast, shear stress increases in the region near the maximum point as the obstruction of annular space increased.

5. CONCLUSION

In the present investigation, an imposed axial flow in annular space between two concentric cylinders stationary, it was analyzed numerically using a commercial CFD code FLUENT. Analysis was carried out for six bed heights configurations.

The numerical results showed that both axial velocity field in annular space and the erosion shear stress on the sediment bed increased with decreasing of the gap region.

This study was conducted using liquid water. That is not the most common practice for drillings operations, but it was observed that the methodology can be use the tool useful in the estimating horizontal wells cleaning processes in different situation. It is important to note that the shear stress plays an important role in the processes of the bed erosion.

The literature shows that the fluid flow rate have an effect on the carrying capacity of drilling fluids. Additional research is needed on the effects of fluid flow rate on efficiency cleaning.

The results of the present study may be useful in the procedures of depositing sand in the gravel pack and External Casing Packers (ECPs).

6. ACKNOWLEDGEMENTS

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