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SEPARATION PROCESS WATER/OIL USING CYCLONIC SEPARATOR: MODELING AND SIMULATION

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Abstract. *During oil production it is common the appearance of water, be connate or injected into oil reserves that are often discarded directly into the environment. However, this disposal must meet the specifications regulated by the Board of Control of the environment that, in the case of Brazil, limits on monthly average of less than 29 mg / L, with a maximum daily 42 mg / L. Several separation equipments water/oil have been developed and used for this purpose, and that many of them have dimensions that prevent use at oil rigs. However, they have been used compact equipments that require little space and have a separation efficiency ranging between 60 and 90% depending on working conditions. In this respect, the present study aims to evaluate numerically separation device water/oil with operating principle similar to the hydrocyclone called cyclonic separator. This in turn presents a cylindrical body with two tangential inlets and two outlets on the opposite side, one tangential and another axial. All simulations were performed using the commercial package Ansys CFX using the particle model to describe the two-phase flow water/oil and the turbulence model RNG k-ε. Was evaluated the influence of the velocity of inlet of the mixture into the process of separating water/oil and the dynamic of flow, using the field of pressure, flow lines, tangential velocity profiles and oil concentration. It was found that the increase of the velocity of feed accelerates the separation water/oil, producing a higher efficiency of the equipment, among the conditions evaluated.*

Keywords: *Produced water, separation, CFX,*

1. INTRODUCTION

Hydrocyclones are equipments used for solid-liquid and liquid-liquid separation of different densities. Because they have no moving parts, these equipments offer one of the cheapest modes of separation from the point of view of operating and investment (LUNA and FARIAS NETO, 2011).

These devices are basically provided with a cylindrical part coupled to a conical region. In cylindrical section has a tangential inlet of mixing. The outlet tube located axially at the top of the cylindrical region of the equipment allows the outlet of fluid of lower density, called *overflow*. The conical part has a bottom hole, responsible for directing the fluid of higher density, called underflow (MORAES, 2004, FILGUEIRAS, 2005, SILVEIRA, 2006).

According to Farias *et al.* (2011), the geometric dimension of each part of the hydrocyclone, as well as the angle of the conical part, are important variables in the separation process, being directly related to the capacity and the power rating of these equipments (Figure 1: Schematic drawing of the hydrocyclone (FARIAS *et al.,* 2005)).

Despite the high efficiency, these devices, in most situations, don't reach the specifications of environmental agencies that restricting the disposal of oily water at a concentration of oil below monthly average of less than 29 mg / L, with a maximum daily 42 mg / L (LUNA and FARIAS NETO, 2011). Aiming to improve the efficiency in the separation of fluids with different densities, the proposal of this study was to manufacture a device, called cyclonic separator, showing the main characteristics of the hydrocyclone, but with changes in conventional geometry.

2. METHODOLOGY

2.1. Description of the problem

The cyclonic separator, illustrated in figure 1, is composed of a main cone provided with two tangential inlets and two outlets, being one tangential and another axial. In the cylindrical section, near the tangential inlets was introduced a tapered stem, in order to direct the flow of oil to the axial outlet.

In order to numerically analyze the behavior of fluids inside the cyclonic separator was created a structured mesh of 300,000 control volumes using ICEM CFD.

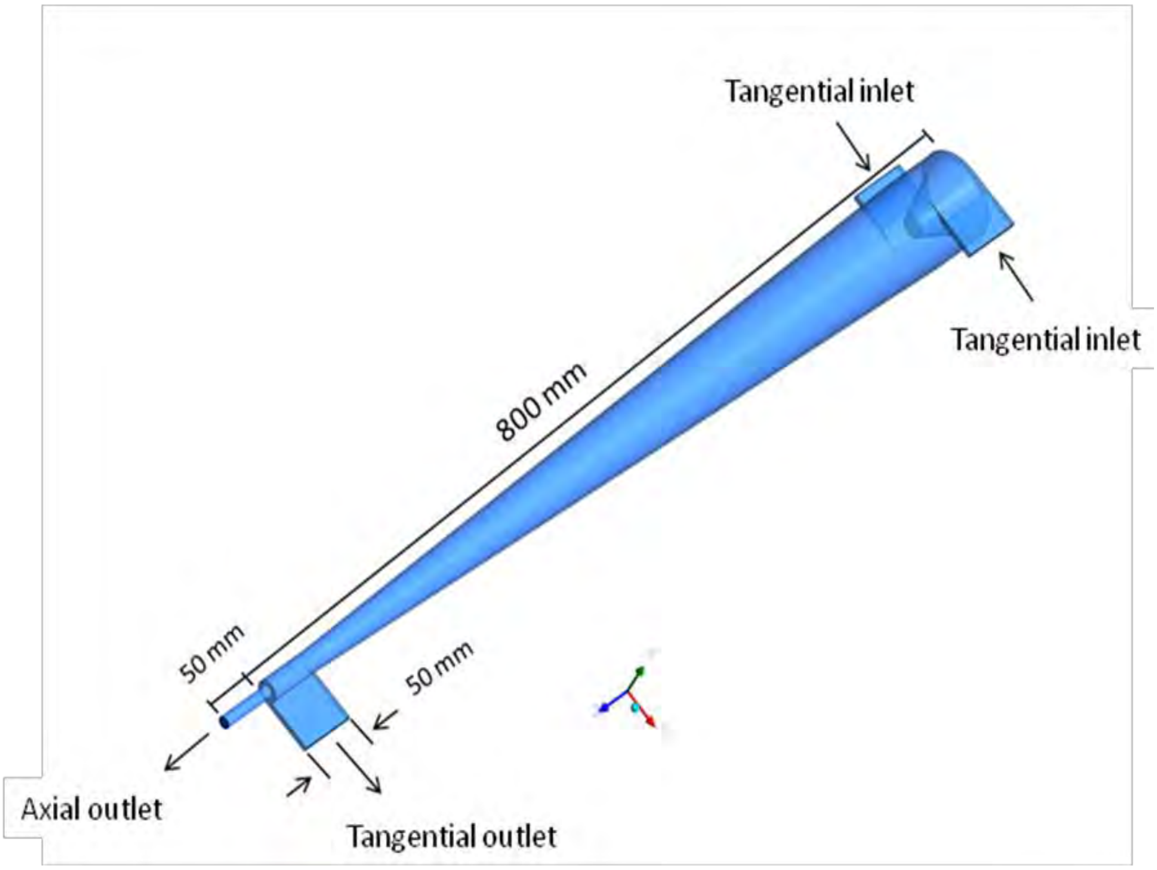

Figure 1: Representation of Cyclonic Separator

2.2. Mathematical Modeling

The mathematical representation of the multiphase flow inside the cyclone separator was based on the Eulerian-Eulerian approach. In this model are assumed that the equations of momentum are solved for each one of the presents, continuous and dispersed phases and coupling between the phases is given by the interfacial transfer. It has also adopted the following considerations:

a. Newtonian fluid and incompressible;
b. Isothermal flow in steady state;
c. The walls of the equipment are static;
d. Just interfacial drag forces are considered.

With these considerations, the equations of conservation of mass and momentum are reduced to:

- Equation of Conservation of Mass

$$\nabla \cdot \left(f_\alpha \rho_\alpha \vec{U}_\alpha \right) = 0 \qquad (1)$$

where the subscript α represents the phase involved in water and oil two-phase mixture, f, ρ, and $\vec{U}$ are the volume fraction, density and the velocity vector, respectively. For α phase, the velocity vector is given by $\vec{U_\alpha} = (u, v, w)$ (MANUAL CFX, 2011).

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- Equation of Conservation of Momentum

$$\nabla\cdot\left[f_\alpha\left(\rho_\alpha\vec{U}_\alpha\otimes\vec{U}_\alpha\right)\right]=-f_\alpha\nabla p_\alpha+\nabla\cdot\left\{f_\alpha\mu_\alpha\left[\nabla\vec{U}_\alpha+\left(\nabla\vec{U}_\alpha\right)^T\right]\right\}+S_{M\alpha}+M_\alpha \qquad (2)$$

where p is the pressure, $S^{M\alpha}$ represents the term of external forces acting on the system per unit volume, M_α describes the interfacial drag force on the α phase due to interaction with the β phase defined by:

$$M_\alpha=\frac{3}{4}\frac{C_D}{d_p}f_\beta\rho_\alpha\left|\vec{U}_\beta-\vec{U}_\alpha\right|\left(\vec{U}_\beta-\vec{U}_\alpha\right) \qquad (3)$$

where d_p is the diameter of particle and C_D is the drag coefficient, which was assumed to equal 0.44.

2.4. Boundary Conditions

The following boundary conditions were used:

a. Input condition: oil volumetric fraction, f_o equal to 5% and input flow, Q, equal to 4.5, 6.3, 9.0 m^3/h.
b. Output condition tangential and axial: static pressure equal to 2.1 bar.
c. Wall condition: Was adopted the non-slip condition, $U_x = U_y = U_z = 0$

The physic-chemical properties of water and oil that were used in this study are presented in Table 1:

Table 1: Physical properties of the fluid under study

Properties		Fluids	
		Water	Oil
Densities	(Kg/m^3)	997	868.7
Viscosity	(Pa.s)	8.889×10^{-4}	0.985
Molecular Weight	(g/mol)	18.05	873.00
Diameter of the oil droplet	(mm)	–	0.05
Surface tension	(N/m)	0.01	

In Table 2 are shown the studied cases, varying the concentration of oil in the inlet of cyclone separator.

Table 2: Cases studied

Cases	Flow on Inlet, W (m^3/h)	Volumetric Concentration on Inlet, f_o (%)
Case 01	4.5	5
Case 02	6.3	5
Case 03	9.0	5

The numerical experiments were performed by Server Dual Quad-Core Intel Xeon Processor E5430 of 2.66GHz with 8GB of memory RAM present at the Laboratory of Computational Fluids and Thermal (LCTF) and at the Research Laboratory of Fluid Dynamics and Imaging (LPFI) of Academic Units of Mechanical Engineering and Chemical Engineering at the Federal University of Campina Grande. The processing of simulations occurred in a time of 3 days/simulation.

3. RESULTS AND DISCUSSION

The numerical results obtained with simulations for the cases described in Table 2, using Cyclonic Separator, are analyzed by field pressure, flow lines, profiles of tangential velocity and concentration of oil inside the equipment.

Figure 2 shows the behavior of the flow lines for oil and water inside the cyclonic separator for different inlet flow rates (4.5; 6.3; 9.0 m^3/h). It is observed the presence of two distinct fluid streams, both with spiral shape, similar to what

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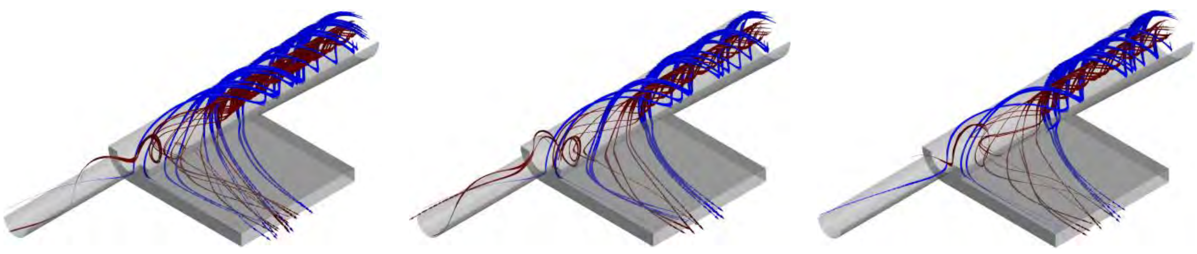
is observed in traditional hydrocyclones, as can be seen in several studies in the literature, for example, the work of Barbosa (2011). Notice also that the spiral flow of water tends to happen near the wall of the equipment, while the oil flows on the center, due the differences between fluid densities and drag and centrifugal forces. Also in Figure 2, it is observed that the flow behavior depends on the feed rate. The higher is the inlet rate, the faster oil tends to flow in the center of the equipment, increasing, possibly, the separation efficiency. In contrast, the oil tends to be driven to the tangential outlet, which can spoil the final result.

(a) (b) (c)

Current water Current oil

Figure 2: Flow line inside the cyclonic separator for different inlet flow (a) 4.5 m^3/h; (b) 6.3 m^3/h and (c) 9.0 m^3/h

Aiming to analyze in detail this behavior in collecting fluid, is shown in Figure 3 the flows of water and oil featured in outlets. Verifying that there is influence on the tangential output on the flows lines of oil and water. View clearly that the oil flow located in the center of the cyclonic separator is deformed due to the pressure drop caused by the tangential outlet, causing a mixing zone at the end of the equipment. Still, in Figure 3, it is observed that the oil flow which runs a tangentially outlet tends to increase with the input flow.



(a) (b) (c)

Current water Current oil

Figure 3: Flow line in the cyclonic separator outputs for different input flows(a) 4.5 m^3/h; (b) 6.3 m^3/h and (c) 9.0 m^3/h

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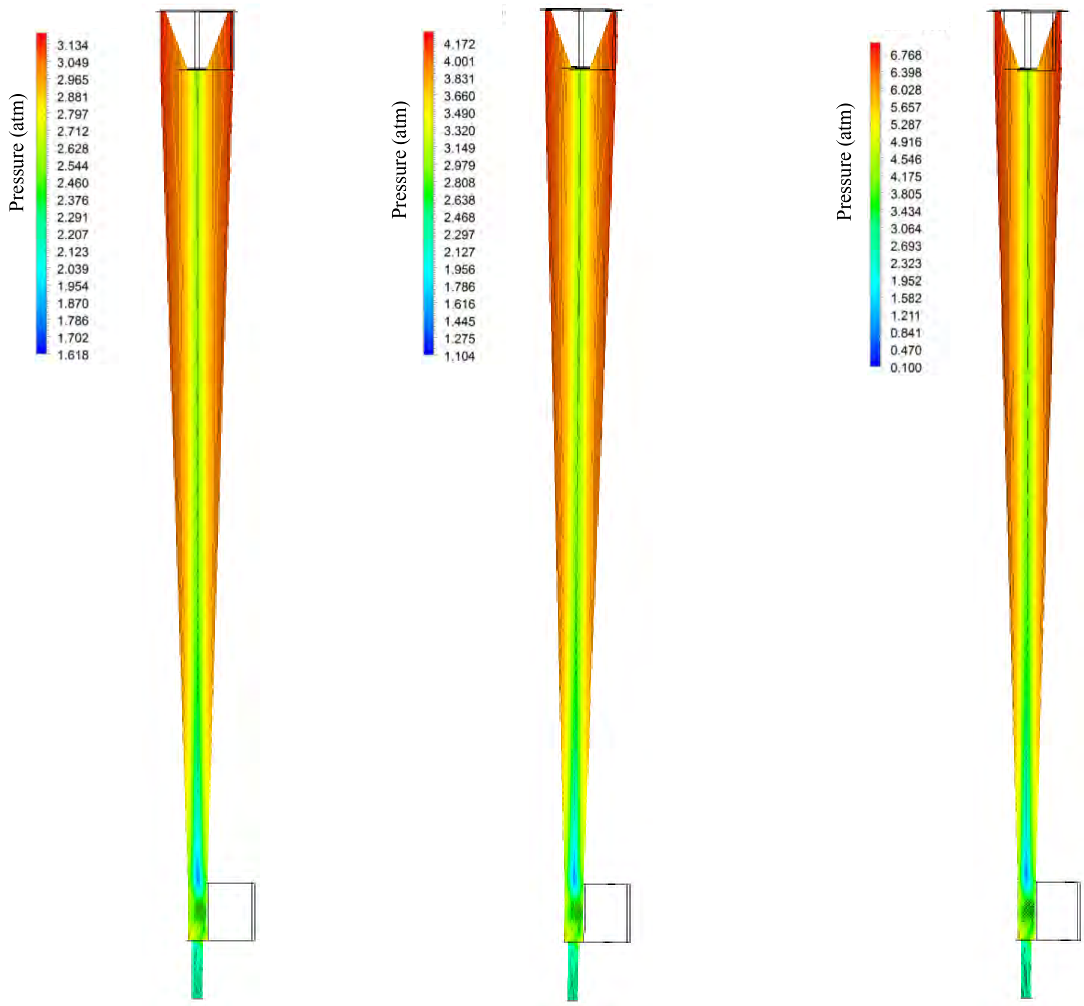
In Figure 4 are illustrated the distributions of pressure on the plane representing a longitudinal section, xy plane, passing through the central axis of the cyclonic separator. These figures show that the pressure decreases radially towards the center from the wall of the separator. Similar behavior was observed in hydrocyclones (Souza *et al*., 2011; Farias *et al*., 2011; Barbosa, 2011), as well as cyclonic separators Luna and Farias Neto (2011), Silva and Farias Neto (2012). It was also observed that the higher the flow, or input velocity, the higher the loss in the device.



(a) (b) (c)

Figure 4: Representation of the pressure field on the xz planes (a) 4,5 m^3/h; (b) 6,3 m^3/h e (c) 9,0 m^3/h

In Figure 5 are represented the tangential velocity profiles of four axial positions 50, 200, 500 and 700 mm. It is possible to notice that the tangencies velocities increase with the increase of input flow, and that the amplitude of the tangential velocity increases along the cyclonic separator. Similar behavior was obtained by Barbosa (2011) to analyze the process of separating water/oil using a hydrocyclone.

Luna and Farias Neto (2011) studying a cyclonic separator with cylindrical body found a reduction in turbulent intensity due to the angular movement along the device. In this study, it was observed that with the use of a conical body the angular movement is maintained throughout the separator. This fact is ratified by maintaining nearly constant the velocities tangencies.

All analyzed results show a significant increase in separation efficiency with increased of input velocity. This fact can be explained by the increase of input flow, which is converted into angular momentum.

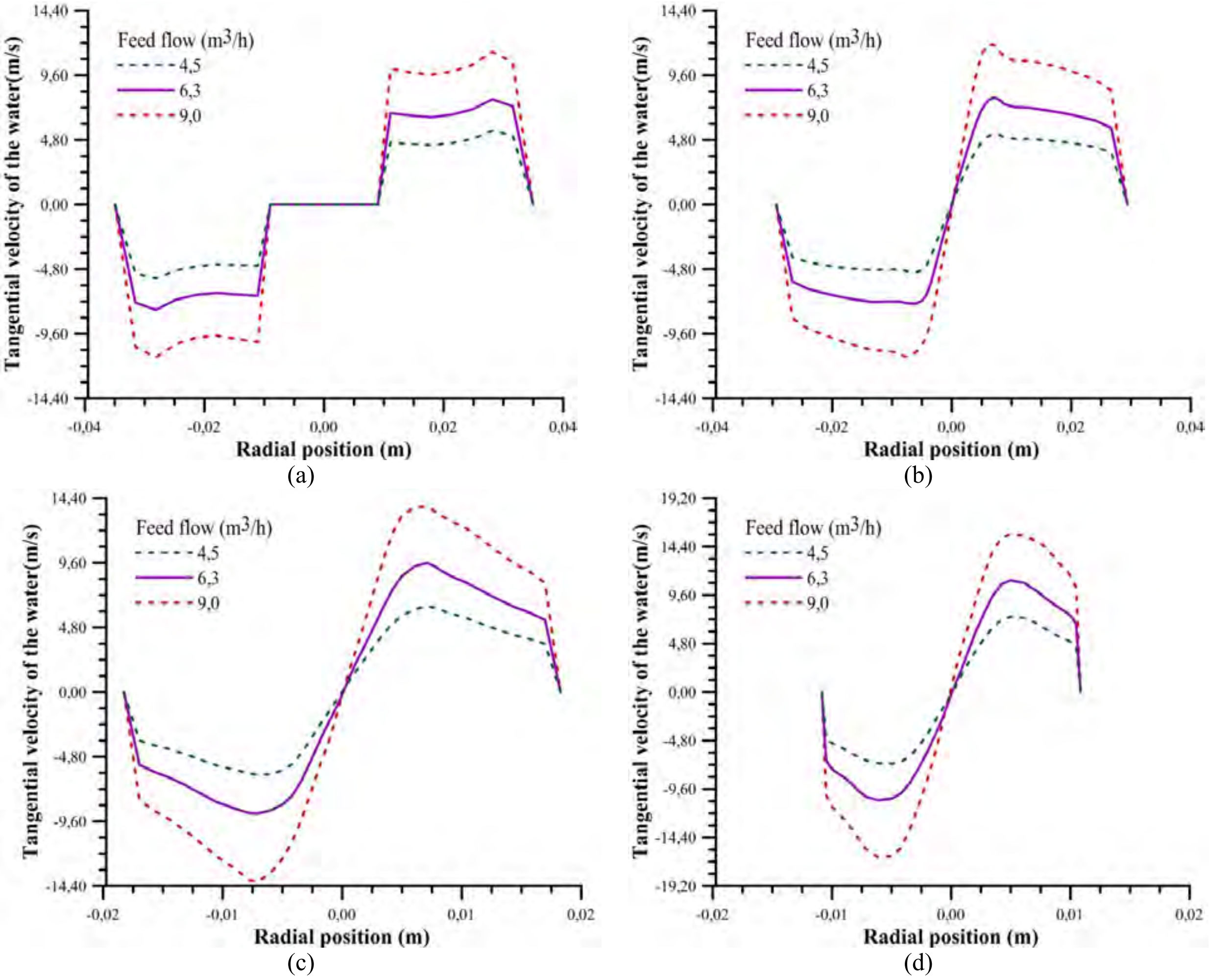


Figure 5: Analysis of the influence of rate of input into the tangential velocity profile (a) 50 mm; (b) 200 mm; (c) 500 mm e (d) 700 mm

In Figure 6, are represented the profiles of the volume fraction of oil for three feeding flows (4.5; 6.5; 9.0 m/s) at four axial positions in the cyclonic separator (50, 500, 700 and 775 mm). It is noticed that the cyclonic separator tends to concentrate the oil in the center of the equipment since the start of the flow, as can be seen in Figure 6a, the axial position of 50 mm, and thus follows by the other positions, being deformed in the axial position 775 mm. In Figure 6d, it is possible to notice that the oil core formed in the central region of the separator is broken as a result of the action of the tangential fluid outlet leading, thus, to a reduction in the efficiency of the separation water/oil.

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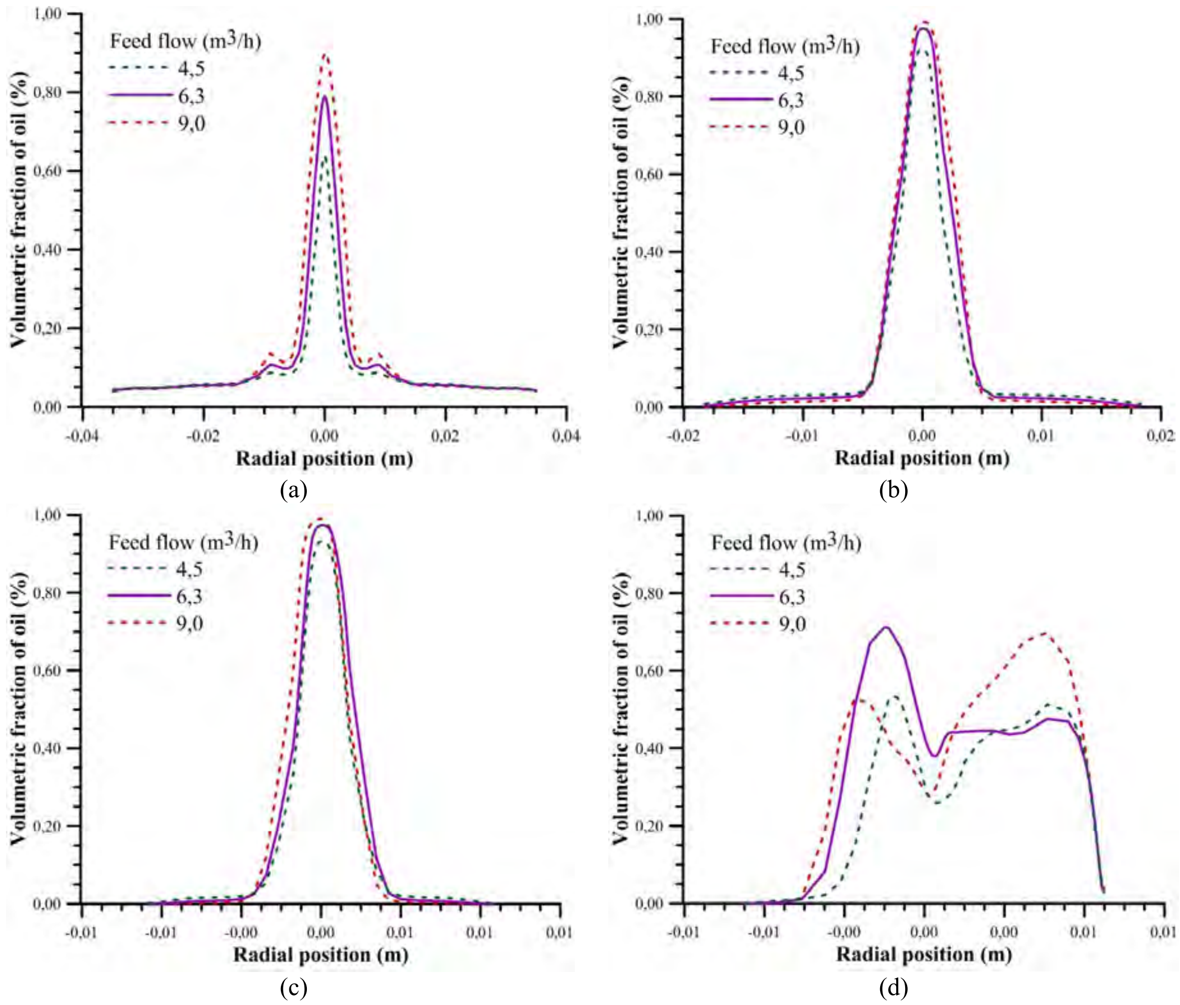

Figure 6: Analysis of the influence of input flow in equipment efficiency (a) 50mm; (b) 500 mm; (c) 700mm e (d) 775mm

Conclusions

Based on the numerical results of simulation of the separation process water/oil using the cyclonic separator can be concluded, under the conditions evaluated that:

- It was possible to notice a three-dimensional behavior of flow inside the cyclonic separator;
- The increase in the concentration of oil in the feeding affected the behavior of the distribution of the tangential velocity inside the equipament;
- Must be improved the form of collection of separated fluid to avoid the mixing zone at the end of the separator.

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