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THE EFFECT OF TEMPERATURE ON THE SEPARATION EFFICIENCY OF WATER/OIL MIXTURES IN A HYDROCYCLONE

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Abstract. *The petroleum, after it be extracted from reservoir, needs to be treated before going to refinery. This occurs because the petroleum do not exists alone. In fact, along the well there is a mixture of hydrocarbon flowing, beyond water, sand and other chemicals substances. In oil platforms there are equipments to treat the oil, and these equipments needs to have smalldimensions because there is not a sufficient space to do this treatment. Between the machinery, this work highlights the cyclonic separator, which is in the final process of the treatment. Among the different equipments, the mixture that feeds is a emulsion and has a bigger volume part of water and a small part of oil. The objective of this work is study numerically the influence of the temperature in the separation of oil and water using a cyclonic separator, which has two inlets and two outlets. All simulations were performed using the commercial package Ansys CFX. Were used the particle model to describe the water/oil two-phase flow and the turbulence model RNG k-e standard. From the results was concluded that the temperature interferes greatly in the oil separation efficiency until the value of 60º. Above this value, there is no interference.*

Keywords: *petroleum, cyclonic separator, numerical simulation, temperature.*

1. INTRODUCTION

According to Habibian *et al.* (2007), hydrocyclones are very important for their use in separation of liquid–liquid, solid–liquid and gas–liquid phases in large scales. This separation occurs due to the action of centrifugal force in the mixture. A conventional cyclone has a conical body connected to a cylindrical body at the bottom, and a feed duct tangentially connected to the tapered portion. The taper region terminates at the underflow orifice, which is the internal diameter of the discharge point.

About solid-liquid separation, Habibian *et al*. (2007) studied the use of hydrocyclones to separate *Saccharomyces serevisiae* 5209 from a prepared media. The hydrocyclone with 15mm internal diameter was used for cell separations. This equipment were studied for decrease the production costs in general. The hydrocyclone separated the microbial cells successfully. The better separation efficiency were achieved with a volumetric flow rate of about 112 cm^3/s. Vieira *et al*. (2007) studied a solid–liquid separation using a filtering hydrocyclone, wich consist of a hydrocyclone whose conical section is replaced by a conical filtering wall.

In the petrochemical industry, the hydrocarbon mixture goes through a separation process components. The oil should go to the refinery with a big purity and the water should be discarded at the lowest possible concentration of oil. The cyclonic separator is contained in the oily water treatment system.

Several authors has studied the oil separation efficiency of oily water with equipment such as cyclone. Hashmi *et al*. (2004) studied a hydrocyclone patented by a Canadian company, where the device is intended for the treatment of oily waters. This paper, describes experimental investigations and hydrocyclone efficiency during transient flow rates. Husveg *et al.* (2007) described the performance of a deoiling hydrocyclone during variable flow rates, emphasizing the importance of having adequate operational control in fulfilling hydrocyclones performance criteria.

Others authors studied the cyclonic separator involving the flow of three phases: oil, water and sand. According to Wang *et al*. (2006), during the daily operation of many oil fields throughout the world, sand particles are required to be separated from liquid mixture because they could cause many troubles, including erosion, solids accumulation, and even equipment blockage, etc. Sousa Neto and Medronho (2004) justify the use of cyclones because they have advantages in economy, simplicity of construction and hability to work at high temperatures and pressures. For all that, they have high potential for separation of produced sand. In their work were used three differents models of cyclones, in order to choose the one that has a higher separation efficiency. Wang *et al.* (2006) studied the separation of sand particles from a mixture of water and oil. Among the various results, stands out the fact that separation process efficiencies of small particles are more sensitive to the changes of parameters, including inlet velocity, oil/water ratio and the number of hydrocyclones.

Thus, this paper aims to study new water-oil separation equipment, similar to the hydrocyclone, using the commercial package ANSYS CFX 12.1. The influence of the temperature in the separation of an oil and water mixture was investigated using the cyclone shown by de Luna *et al.* (2015).

2. MATERIALS AND METHODS

2.1 Description of the problem

The water/oil separation process is conducted using a cyclonic separator. Differently from traditional cyclonic separators, this new separator consists in a conical main body provided with two tangential inlets and two concentric outlets of different radius, like shown in the Figure 1.

2.2 Computational domain

On the representative domain was built a hexahedral mesh with 300,000 control volumes, using tools available in ICEM CFD software, as shown in Figure 2.

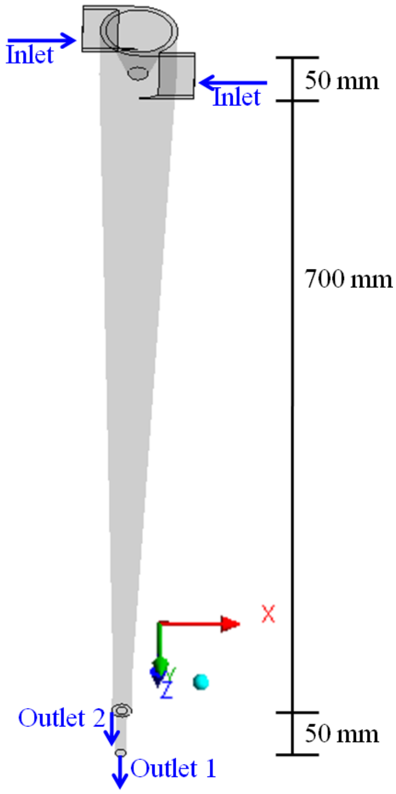

Figure 1. Geomety of the cyclonic the separator proposed in this work

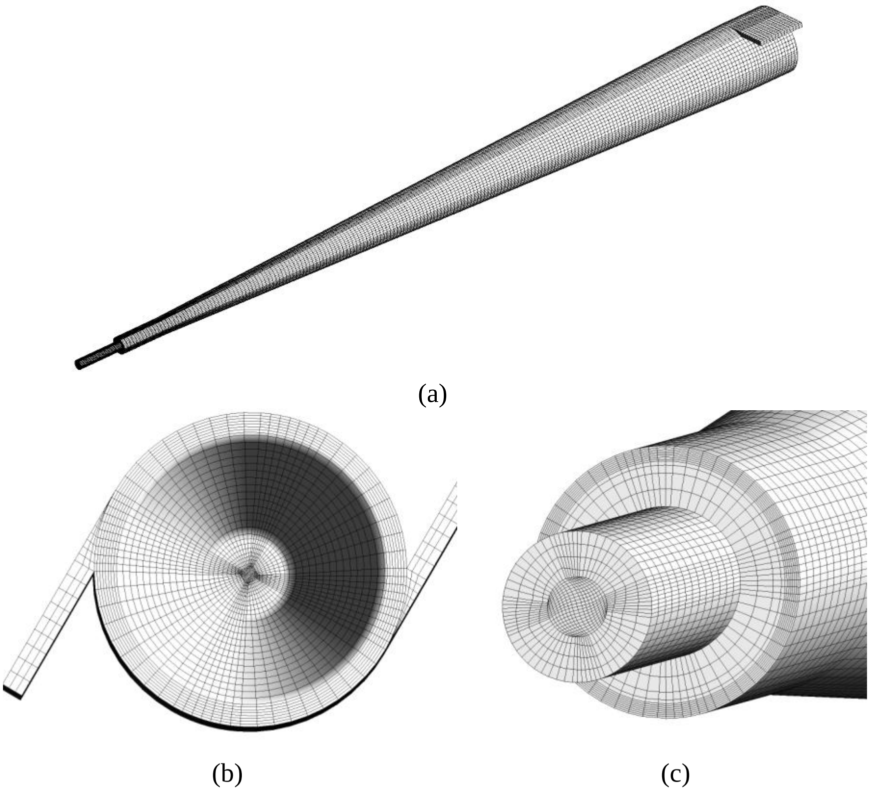

Figure 2. Numerical grid (a) Cyclone, (b) Details of the Inlet, and (c) Details of outlet

2.3 Mathematical modeling

The mathematical representation of the multiphase flow inside the cyclonic separator was based on the Eulerian-Eulerian approach, which assumes that all the equations are solved for each phase, continuous and dispersed. Coupling between the phases is given by the interfacial transfer. It has been also adopted the following considerations:

- Newtonian and incompressible fluid;
- Steady state and non isothermal flow;
- The walls of the equipment are static;
- Turbulent flow;
- Water is the continuous phase and oil is the dispersed phase;
- Interfacial drag forces are considered;

- There is no heat and mass sources.

The equations of mass, momentum and energy conservation are given, respectively, by:

$$\nabla \cdot \left(f_\alpha \rho_\alpha \overrightarrow{U_\alpha} \right) = 0 \tag{1}$$

$$\nabla \cdot \left[f_\alpha \left(\rho_\alpha \overrightarrow{U_\alpha} \otimes \overrightarrow{U_\alpha} \right) \right] + f_\alpha \nabla p_\alpha - \nabla \cdot \left\{ f_\alpha \mu_\alpha \left[\nabla \overrightarrow{U_\alpha} + \left(\nabla \overrightarrow{U_\alpha} \right)^T \right] \right\} - \overrightarrow{S_{M\alpha}} - \overrightarrow{M_\alpha} = 0 \tag{2}$$

$$\nabla \cdot \left[f_\alpha \left(\rho_\alpha \overrightarrow{U_\alpha} h_\alpha - \lambda_\alpha \nabla T_\alpha \right) \right] = 0 \tag{3}$$

where the subscript α represents the phase, $\vec{U}$, ρ, p, μ, S_M, h, λ and T are, respectively, the velocity, density, pressure, fluid viscosity, source term, enthalpy, thermal conductivity and temperature. The parameters $\overrightarrow{M_\alpha}$ is the sum of interfacial forces, in which only the drag forces are considered, defined as follows:

$$\overrightarrow{M_\alpha} = \frac{C_D}{4} \frac{3 f_\beta}{d_\beta} \rho_\alpha \left| \overrightarrow{U_\alpha} - \overrightarrow{U_\beta} \right| \left(\overrightarrow{U_\beta} - \overrightarrow{U_\alpha} \right) \tag{4}$$

where β represents the dispersed phase, d_β is the average diameter of phase β, f_β is the volume fraction of phase β and C_D is the drag coefficient of Schiller-Naumann.

With the presence of a turbulent flow inside the device, the mass, momentum and energy equations aren't able to adequately predict the oscillations arising from this phenomenon. So, it is necessary to use a suitable turbulence model.

Barbosa (2011) showed that the RNG κ–ε turbulence model was the best representative of the flow inside a traditional hydrocyclone. The RNG κ–ε model is classified as a model of two equations. The connect transport equations for describe the turbulent characteristics of the flow are the turbulent kinetic energy k, which is defined as the variance of the fluctuations in speed, and the turbulent dissipation rate ε, which is defined as the rate at which the fluctuation dissipates, which are defined, according CFX Manual, as follows:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho U_j k\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k - \rho\varepsilon + P_{kb} \tag{5}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho U_j \varepsilon\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_{\varepsilon RNG}}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{\varepsilon}{k}\left(C_{\varepsilon 1RNG} P_k - C_{\varepsilon 2RNG}\rho\varepsilon + C_{\varepsilon 1RNG} P_{\varepsilon b}\right) \tag{6}$$

where:

$$C_{\varepsilon 1RNG} = 1,42 - \frac{\eta\left(1 - \frac{\eta}{4,38}\right)}{\left(1 + \eta^3 \beta_{RNG}\right)} \tag{7}$$

and

$$\eta = \sqrt{\frac{P_k}{\rho\varepsilon C_{\mu RNG}}} \tag{8}$$

The values of the constants of the equations of generation and dissipation of turbulence for the RNG k-ε model are: $C_{\varepsilon 2RNG} = 1.68$; $\sigma_{\varepsilon RNG} = 0.7179$; $\beta_{RNG} = 0.012$ and $C_{\mu RNG} = 0.085$.

The water/oil separation efficiency inside the cyclonic separator were determined in two ways. Moraes (2004) presents an equation for efficiency given by Equation 9.

$$E = \left[\frac{(C_f - C_o)}{C_f} \right] \times 100\% \tag{9}$$

where E is the efficiency of separation, C_o and C_f are the proportion between the oil mass flow rate in outlet 2 and mass flow rate of the mixture in the inlet of the cyclonic separator. Husveg *et al.* (2007) used the Equation 10 to determine the separation efficiency.

$$E' = \left[1 - \left(\frac{K_o}{K_f} \right) \right] \times 100\% \tag{10}$$

where E' is the efficiency of separation, K_o and K_f are the concentrations of oil in the outlet 2 and in the inlet, respectively. The unit of concentrations is kg of oil/m³ in mixture.

2.4 Boundary conditions

The following boundary conditions were used:

- Inlet: Volumetric flow rate, Q = 6.3 m^3/h and oil volumetric fraction (f_o) of 5%.
- Outlet: Static pressure equal to 2.1 bar on the outlets 1 and 2.
- Wall: No slip conditions.

The physical and chemical properties of water and oil are shown in Table 1. The viscosities of the water and oil varies with temperature and are defined by Equations 11, 12 and 13.

Table 1. Fluid data used in all simulation

Parameters	Fluid at 20°C	
	Oil	Water
Density [kg/m³]	860*	997***
Specific heat [J/kg.K]	2092**	4181,7***
Thermal Conductivity [W/m.k]	0.143*	0.6069***

Source: *Xu *et al.* (2010);**Cunha (2010); ***Manual CFX 12.1

$$\mu_{water} = \frac{2.185}{\left(40.12 + 0.0051547 T_F\right) T_F - 1000} \tag{11}$$

$$\mu_{oil} = 10^{-5} \exp\left\{ \exp\left[11.7613 - 2.099 \ln\left(T_F\right) \right] - 1.05 \right\} \tag{12}$$

$$T_F = 1.8 T_F - 459.67 \tag{13}$$

where T_F is the temperature in Fahrenheit degrees and T_K is the temperature in Kelvin. Equations are valid in the range approximately from 295 K to 500 K.

The studied cases are described in Table 2

Table 2. Studied cases

Case name	Temperature of the inlet flow
Case A	20°C
Case B	40°C
Case C	60°C
Case D	80°C

3. RESULTS AND DISCUSSION

The numerical results of the simulations for the cases described in Table 2 are analyzed by flow lines, pressure field, velocity profiles, and oil concentration field within the cyclonic separator.

Figure 3 illustrates the streams of water and oil in highlighted outlets. It is verified a higher concentration of oil in the outlet 1 and a larger amount of water in the outlet 2, for all cases studied. Similar behavior was verified in all studied cases.

For hydrodynamic analysis, transverse lines were used, shown in Figure 4, with their respective distances from the top of the cyclonic separator (0.1, 0.5 and 0.7 m).

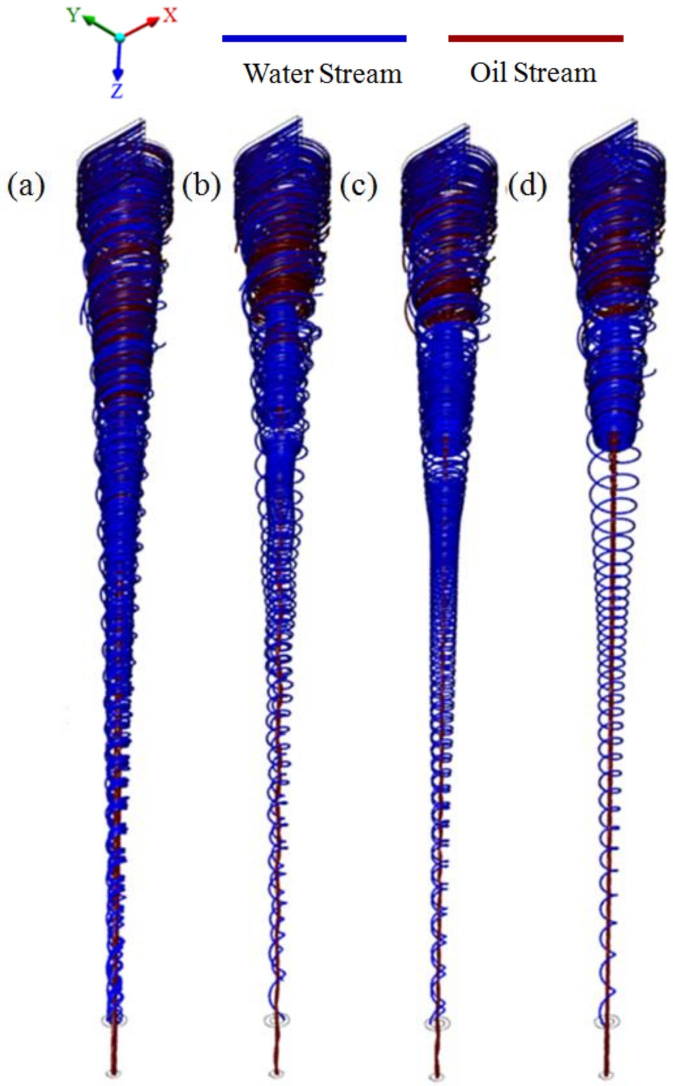

Figure 3. Flow lines for different intlet fluid mixture temperatures (a) 20°C, (b) 40°C, (c) 60°C and (d) 80°C.

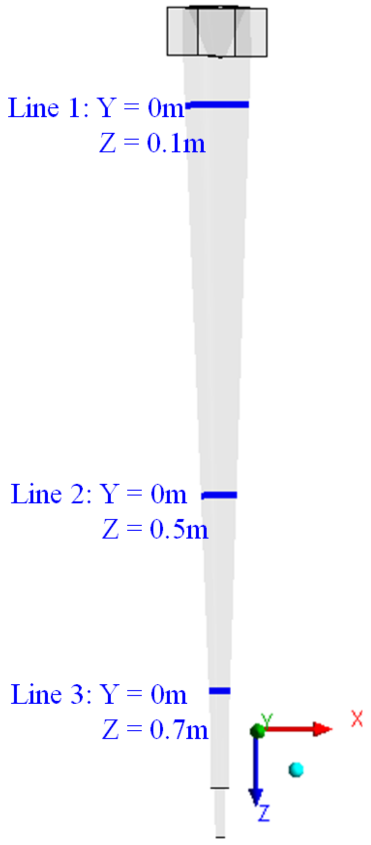

Figure 4. Location of regions under study.

Figure 5 shows the oil tangential velocity profile on the lines positioned in the regions represented in the Figure 4. Firstly, you should note that for each line there is a behavior of the tangential velocity. Beyond it, note that the amplitude of tangential velocity is influenced significantly by the increase in feed mixture temperature. The exception occur in a temperature of 60°C, where the influence of the temperature in velocity practically ceases to exist.

Using the lines, the pressure distribution as a function of temperature was analyzed within the separator (Figure 6). Note that from 20 to 40°C and from 40 to 60°C there is a significant variation on the pressure, but from 60 to 80°C the temperature do not disturb the pressure profile.

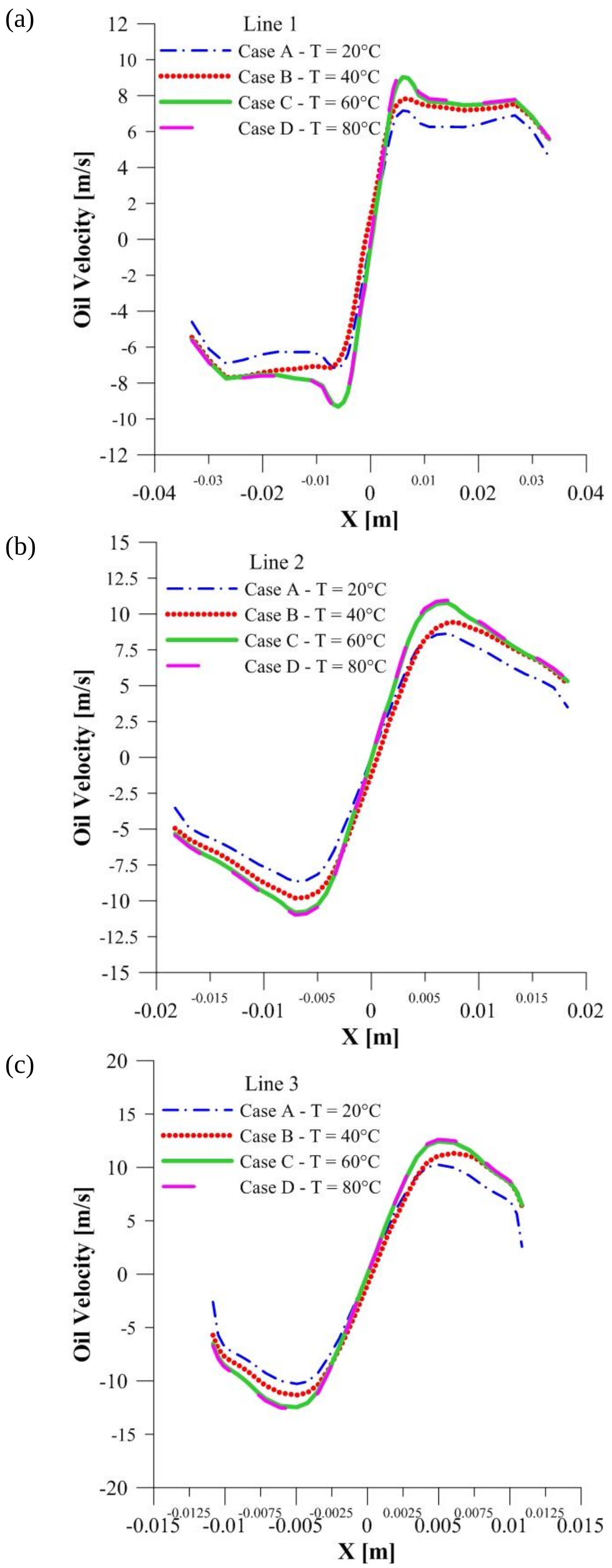

Figure 5. Oil tangential velocity as a function of the radial position in (a) Line 1, (b) Line 2 and (c) Line 3.

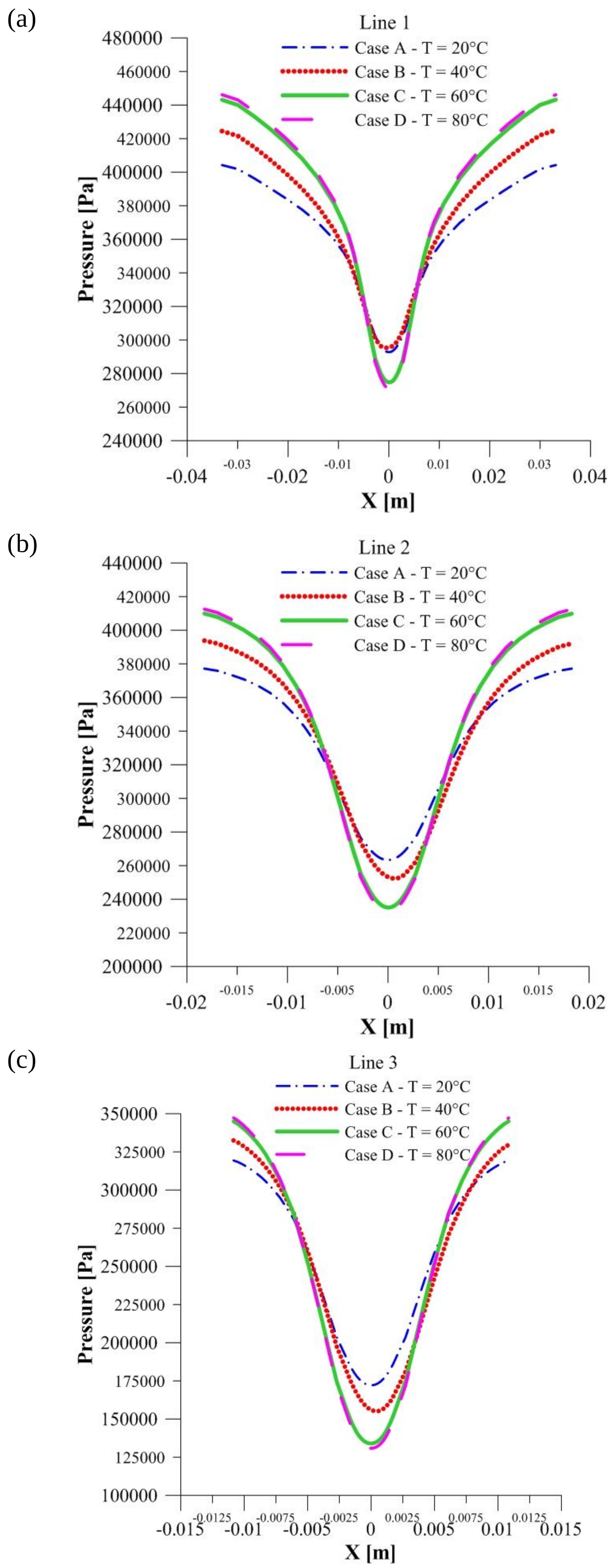

Figure 6. Pressure profile as a function of the radial position in (a) Line 1, (b) Line 2 and (c) Line 3.

The separation efficiency was calculated using equations 9 and 10. Figure 7 shows the efficiency values as a function of the fluid mixture temperature at the inlet.

The results show that the efficiency values obtained with the two mathematical equations were different. Higher values were obtained when using equation 10 (efficiency E') for all studied cases. Note that the efficiency increase until 60°C, reaching a maximum value around 99.8%.

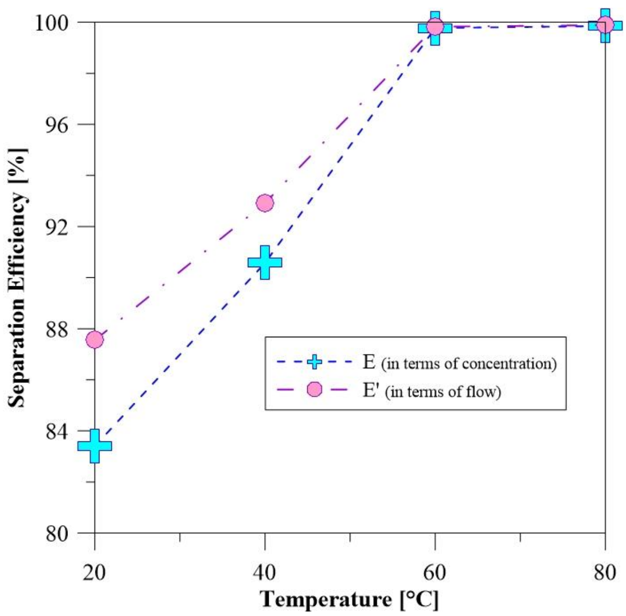

Figure 7. Water /oil separation efficiency as a function of the inlet temperature.

4. CONCLUSIONS

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

- The oil tends to flow in the central region of the equipment, until be collected at the outlet 1;
- The oil velocity profile, the pressure profile and the separation efficiency are greatly influenced by varying the temperature at the inlet of the equipment;
- From the moment when the mixture of fluids reaches a temperature of 60 degrees, it is noted that the temperature increase do not interfere more in the tangential profile of speed and pressure. So, the maximum temperature for work with separation is 60 ºC;
- The highest separation efficiency value (≈ 99,8%)was obtained in the fluid mixture temperatures of 60°C and 80°C.

5. ACKNOWLEDGEMENTS

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