Mechanics and Mechanical Engineering
Vol. 21, No. 2 (2017) 243–251

Flow of a Nanofluid in an Inter Blade Canal of a Centrifugal Pump

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Received (11 January 2017)
Revised (16 January 2017)
Accepted (11 February 2017)

The use of centrifugal pumps in the hydraulic transport of nano–fluids poses major problems for the rational choice of the type of pump capable of working with a nanoparticle concentration difference in a base fluid . In this context, the objective of this work is to study the internal flow in an inter blading canal of a centrifugal pump for pumping fluid nano Al_2O_3/water to various concentrations. And this through the ANSYS - CFX software, based on the finite volume method. The turbulence of the flow in the inter–blade canal is taken into account using the k–ε model. The results obtained show that the addition of nanoparticles in the nano fluid has an appreciable effect on the flow velocity, pressure and shear stresses.

Keywords: nano–fluid (Al_2O_3/water), inter–blade canal, turbulence k—ε model.

1. Introduction

At the present time, the hydraulic conduct of the solid liquid mixture by centrifugal pumps is widely applied in various fields of industry; mining, chemical and agriculture. The choice of centrifugal pumps for any transportation system depends mainly on past experience and the characteristics of the pump operating in clear water. Many researchers have proven that the performance of the pump depends on the behavior of the solid liquid mixture. General conclusions drawn from most researchers such as Riezes (1976) [1],Sellgren Vappling (1989) [2], Wilson (1997) [3], F. NI, Vlasblom (2002) [4], J.J Vocaldo (1973) [5], Cave (1976) [6] and Geoff Moore (2003) [7] is that the expanded height and the yield decreases while the power supplied increases with increase of the density of the mixture. Generally, the variables that directly affect pump performance (yield, height gauge, ... etc) are: the concentration of the nanoparticles, the physic mechanical properties of the fluid namely; the density, shape and size of the nanoparticles, the distribution of nanoparticles as well as the design of the pump elements (wheel, volute, ...) and the flow regime within the pump. These researchers have tried to correlate their experimental data pumps trials with some of these variables and showed correlations to estimate the performance of centrifugal pumps operating in mixture based on the determined characteristics for clear water. In this present work, we will study the flow of nano-fluid in centrifugal pumps. Is desired to see the influence of the of nanoparticles (Al_2O_3) in the base fluid (water) on the properties of the internal flow in the inter–blade canal of a centrifugal pump.

2. Nanofluid properties

The addition of nanoparticles in the base fluid changes its physical properties. In this case we use the one phase model which consider the nanofluid as continuous medium with different physical properties that those of the base fluid.

Assuming that the solid nanoparticles of Al_2O_3 are well dispersed in water, one can then calculate the physical and thermal properties of the nanofluid keeping in mind that for each physical property there are many correlations, the following equations were chosen:
The dynamic viscosity:

$$\mu_{nf} = (199.21\phi^2 + 4.62\phi + 1)\mu_l \tag{1}$$

where: l is base fluid (water), nf is nanofluid, s is nanoparticles.
Thermal conductivity:

$$\lambda_{nf} = \left(125.62\phi^2 + 4.82\phi + 1\right)\lambda_l \tag{2}$$

Density:

$$\rho_{nf} = (1-\phi)\,\rho_l + \phi\rho_s \tag{3}$$

Specific heat:

$$Cp_{nf} = (1-\phi)\ Cp_l\ + \phi\ \mathrm{Cp_s} \tag{4}$$

Coefficient of expansion:

$$\beta_{nf} = (1-\phi)\ \beta_l\ + \phi\ \beta_\mathrm{s} \tag{5}$$

where: Cp is specific heat, β is coefficient of expansion, λ is thermal conductivity and ϕ is volume fractions of nanoparticules.

3. Configuration studied

The internal flow of the nanofluid is studied according to the configuration given in (Fig. 1) in order to see the effect of the nature of the fluid on the flow parameters (velocity, pressure gradient and shear stresses). This configuration is made of a number of periodical surfaces upper and lower ceiling belt the input and output of inter–blade canal and blade. The walls of the configuration are assumed to be undeformable and not subjected to sliding.

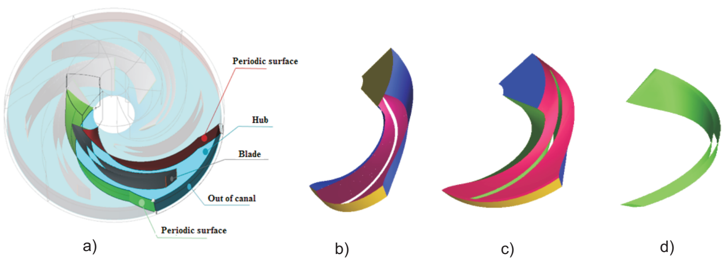

Figure 1 Inter–blade canal configurations: a) impeler, b) hub and the walls of the configuration, c) inter–blade channel, d) blade

4. Elaboration of the mesh of the inter–blade canal

The meshing of the inter–blade canal must meet the geometrical and physical criteria and also takes into consideration the conditions linked to the study (such as the direction of the flow, the boundary conditions and the interface definitions. . . etc). The mesh of the canal has been constructed using ANSYS ICEM–CFD code; it is a tetrahedral structure type of mesh as shown in (Fig. 2).

5. Simulation

The computational domain is defined by the CFX-pre module of ANSYS-CFX code. The internal flow is assumed to be tridimensional and turbulent (k–ε) model and stationary of incompressible fluid with an inlet pressure of 101325 Pa and an output flow rate of 163.8kg/s. The calculation of these parameters based on Navies- Stocks and conservation equations is also carried out by ANSYS code.

The rotational periodicity type of the interface is selected. The rotational velocity of the canal is 1740 rev/min. For the solver a scheme of diffusion of high precision is defined with an average residual of 10^{-4}. The method of finite volume combined with pressure velocity coupled algorithm is used as a numerical method for solving Reynolds equations.

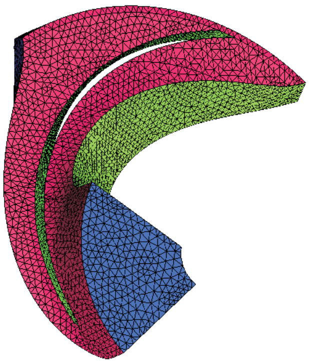

Figure 2 Mesh of the inter–blade channel

The load has been modeled as shown in (Fig. 3).

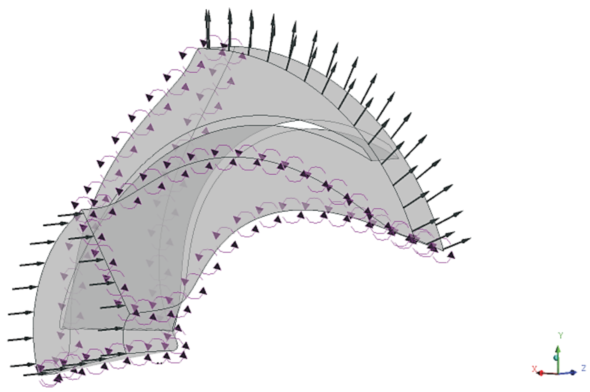

Figure 3 Boundary conditions

6. Determination of nanofluid properties

The nanofluid Al_2O_3/water is determined from Al_2O_3 and water properties. The calculated properties of nanofluid Al_2O_3/water for different volume fractions are presented in the following table:

7. Results and discussion

The results of pressure gradient, the magnitude of the velocity, velocity vector and the shear stresses are grouped in order to make a comparison. For each nanofluid concentration, the corresponding evolutions of these parameters are illustrated in (Fig. 4 to Fig. 8).

Table 1 Properties of different Nanofluid

Property	Water	AL_20_3	Nanofluid1	Nanofluid2	Nanofluid3
Volume fractions of nanoparticules: ϕ			0.01	0.04	0.09
Specific heat: Cp [$\mathrm{Jkg}^{-1}\mathrm{K}^{-1}$]	4179	765	4047.005	3214.455	3336.9
Density: ρ [kgm^{-3}]	997.1	3970	1026.829	1264.661	1443.035
Thermal conductivity: λ [$\mathrm{Wm}^{-1}\mathrm{K}^{-1}$]	0.613	40	0.630739	0.786	0.9206312
Coefficient of expansion: β [K^{-1}]	$21\mathrm{x}10^{-5}$	$0.85\mathrm{X}10^{-5}$	0.000201	0.000153	0.0001798
Dynamic viscosity: μ[Pa s]	0.001003	-	$1.028\mathrm{x}10^{-3}$	$1.228\mathrm{x}10^{-3}$	$1.3791\mathrm{x}10^{-3}$

7.1. *Evolution of the pressure gradient*

From Figure 4, it is found that the complex shape of the canal creates a geometric asymmetry that affects the pressure field. The pressure gradient decreases at the intrados and varies from a parabolic manner at the suction face of the blade. The pressure distribution is not identical and not equal in all passages of inter-blade canal. Note also that the discontinuity between the two curves of the lower and upper inter-blade canal represents the thickness of the blade. From the pressure gradient of the curves obtained along the path along the X axis, it is observed that there is a significant difference between the four types of fluids. The higher the concentration of nanoparticles increases over the pressure gradient decreases. while addition is deduced nanoparticles in a fluid increases the viscosity and therefore the pressure loss in the system.

7.2. *Evolution of the velocity*

The impeller of centrifugal pump transmits to the nanofluid a rotational movement which gives different velocities along the blade. The velocity of the nanofluid inside the pump is an important parameter for the computation of the characteristics of the centrifugal pump and it is also used to evaluate the erosion of the mobile parts. The theoretical studies in this domain have shown that the performance of the pump working with nanofluid changes compared to those working with water as well as the appearance of supplementary losses of charge due to the presence of nanoparticles. (Fig. 5) and (Fig. 6) represent the magnitude of the velocity and the velocity vector respectively. They show a decrease in velocity with increasing nanoparticule concentration. The magnitude of the velocities decreases due to the wall geometry of the inter-blade canal which presents a curvature form and also the

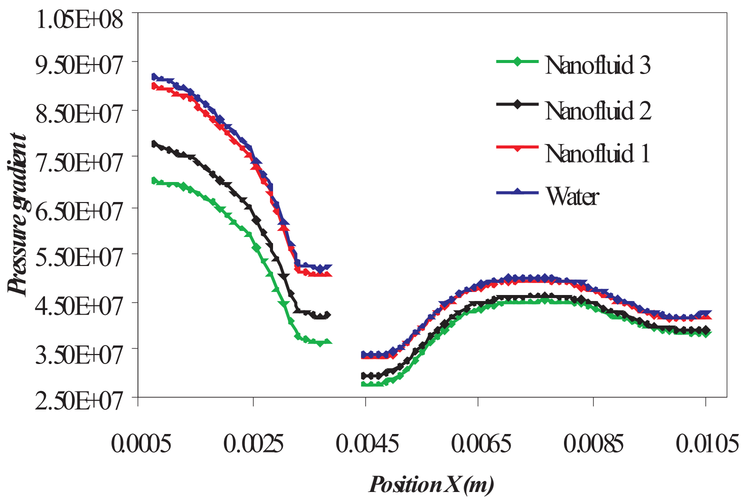

Figure 4 Evolution of pressure gradient at position x

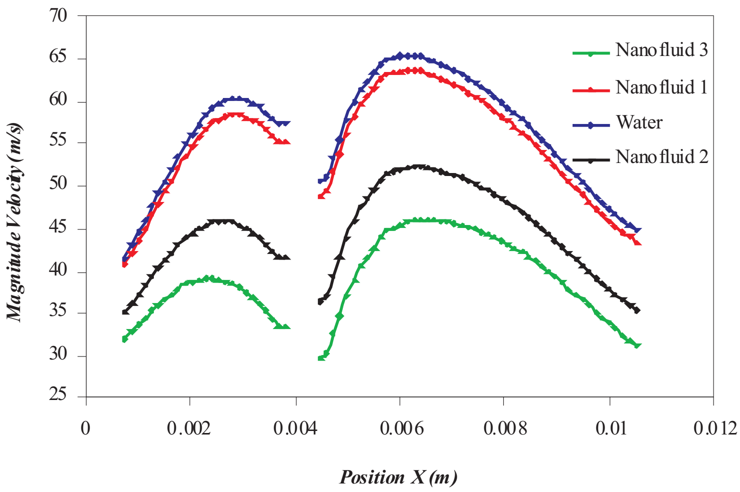

Figure 5 Evolution of magnitude velocity with respect to position (x)

boundary layer which is a thin layer of nanofluid which is influenced by the contact with the wall. The action of the mutual forces between the blades and the nanofluid it is that which determines the values of the velocity of the flow. Moreover, since the velocity values in (Fig. 6) are positives this implies that there is no recirculation phenomenon in the four case studies.

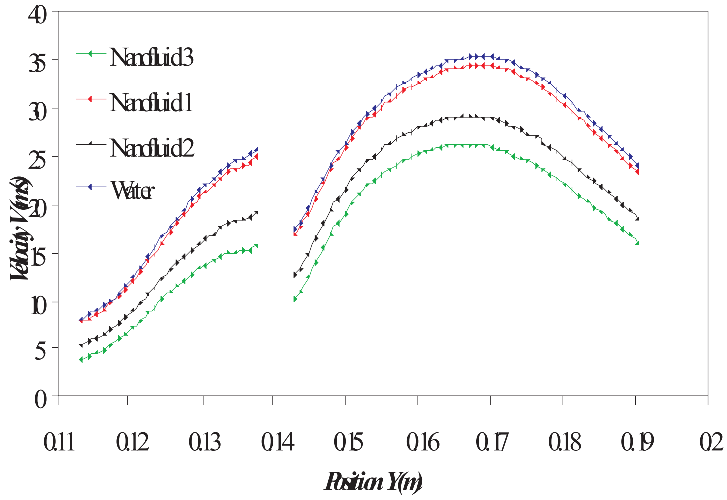

Figure 6 Evolution of velocity with respect to position (y)

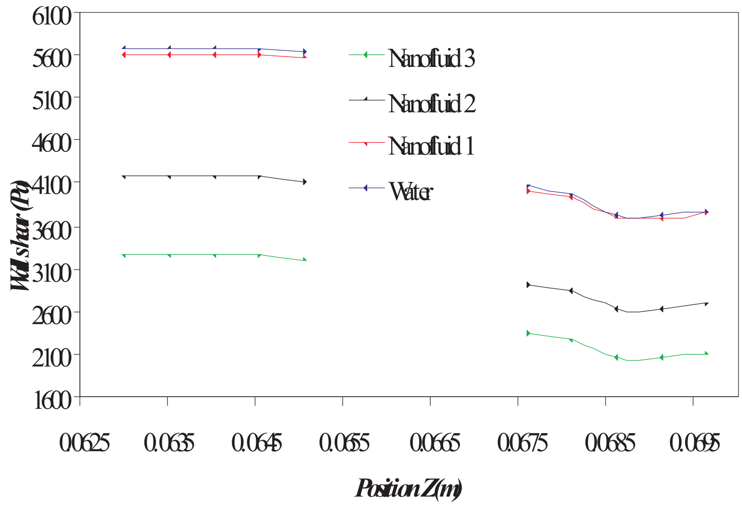

Figure 7 Evolution of shear stresses at position (Z)

7.3. *Evolution of shear stresses*

The variation of the shear stresses along the path in the Z direction of the canal for different nanoparticles concentrations are presented in (Fig. 7). The four curves have the same profile. The shear stresses for the two levels intrados and extrados of the blade diminish with increasing nanoparticles concentration. According to the contours of the shear stress distribution given in (Fig. 8), they are not uniformly distributed. The shear stress is a fundamental dynamic factor in rheology. During shear motion, two successive layers in contact with each other move relatively with respect to each other. It appears at the interface of the friction forces acting tangentially to the surface of these layers. So if these shear stresses are high, the nanofluid tends to damage the walls of the blade. From these findings, it follows that the higher the viscosity of nano fluid increases and consequently the velocity gradient decreases, the shear stress decreases.

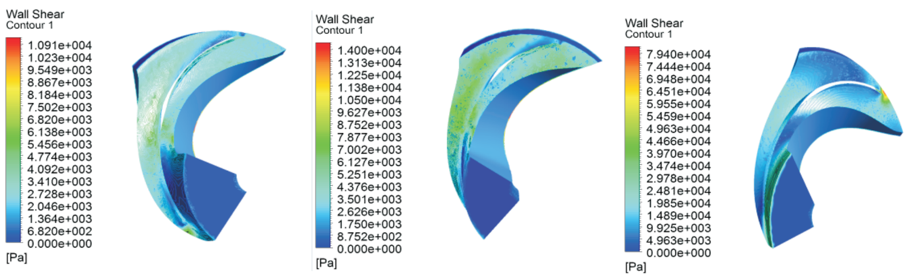

Figure 8 Shear stresses contours: a) Nanofluid3, b) Nanofluid2, c) Nanofluid1

8. Conclusion

The numerical results show that the concentration of nanoparticles (Al_2O_3) in the base fluid (water) has a significant effect on the speed of flow , pressure and shear stresses . We deduce that the speed of the nanoparticles within the pump is a very important parameter for the calculation of the characteristics of centrifugal pumps and for evaluating the erosion of the moving parts. The performance of pumps operating in nano fluid change compared to those in water, and the appearance of additional pressure losses due to the presence of nanoparticles. The increase in additional pressure losses in the wheel causes the decrease in the discharge head generated by the pump.

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