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Nano-fluid turbulent flow analysis using computational fluid dynamics

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Abstract: Given that the use of nano-fluids has increased in heat exchangers and since the flow regime in heat exchangers is often turbulent, justifying the effectiveness of using nano-fluids requires studying the nano-fluids turbulent flow. Analysis of nano-fluids steady flow, containing water-based fluid and aluminum oxide nanoparticles AR, AF and AK, has performed in developing and fully developed turbulent flow, in the pipe with a diameter of 150 mm and a length of 30 m by Gambit and Fluent software. After examining the independence of numerical results from the network, the results of numerical modeling were compared with the experimental results and given the consistency of numerical results with existing relationships, created model was used to study the nano-fluids flow. In this study, the impact of the type of nanoparticles on the parameters of nano-fluids flow in turbulent flow regime has been thoroughly investigated. Of the three aluminum oxide nanoparticles of AR, AF and AK, the nano-fluid, containing the aluminum oxide nanoparticles of AF, has the greatest coefficient of friction, pipe wall shear stress, the viscous drag force and pressure drop and nano-fluids, containing aluminum oxide nanoparticles AR, has the lowest ones.
Key words: *Nano-fluid, Pipe, Tturbulent flow, Simulation*

1. Introduction

With the development of modern technology in various industries, increasing heat transfer, reducing the time of heat transfer, downsizing the heat exchangers and increasing energy and fuel efficiency are the serious needs. Cooling has raised as one of the most important challenges in energy savings and increased productivity of many industries [1]. The first serious obstacle in compressing the heat transfer devices and making them efficient is the common weak heat transfer properties of fluids. Cooling systems are one of the main concerns of factories and industries such as microelectronics [10]. With the advancement of technology in industries such as microelectronics in which fast and large operations occur at very high speeds (several GHz) at the scale smaller than a hundred nanometers, using the engines with high power and heat load becomes of prime important. So, the use of improved and developed cooling systems is inevitable. Optimizing existing heat transfer systems, in most cases, has been done by increasing their level which always leads to the increase in the size of the devices. So, to overcome this problem, the new and efficient cooling systems are required. Given that justifying the effectiveness of using nano-fluids requires studying the nano-fluids turbulent flow in the pipe (as a common geometry), the parameters of nano-fluids in pipe has been studied numerically and the impact of different parameters such as volume fraction of nanoparticles, type of nanoparticle, type of base fluid, Reynolds number of flow and volumetric flow rate on the flow of nano-fluids has been investigated fully[2]. If the nano-fluid is used in cooling systems, the capability of these systems will be increased in terms of reducing energy consumption and increasing their efficiency due to the better heat transfer properties of nano-fluids, such as thermal conductivity and convection heat transfer coefficient, than common fluids of heat transfer such as water or ethylene glycol. So, the use of nano-fluids reduces the costs due to reduced energy consumption and will lead to a more efficient implementation of a cooling project [9].

Kim et al. (2009) had performed the experiments with nano-fluids, containing aluminum oxide nanoparticles, in calm and turbulent regimes and showed that the mechanism of improving heat transfer is different for

two regimes. Delay and disruption in the thermal boundary layer in calm region increases the heat transfer while in turbulent regime, increased thermal conductivity increases the heat transfer [5].
Perumal Kumar and Rajamohan Ganesan (2012), had studied the increased thermal transfer in turbulent flow in circular tube by the use of CFD and found that adding mili- or micro-size particles to the fluid one of the best used technique in improving the heat transfer rate. Although this technique seems simple, but, it has some practical problems such as high pressure drop, fouling, erosion, By dispersing nano-size particles in a base liquid or generally, using nanoparticles, these problems can be overcome. Nanoparticles increase the heat transfer. Nano fluids have higher pressure drop and viscosity than base fluid [6].

1-2- Thermo-physical properties of nano fluids

Given that suspension nano fluid is composed of nanoparticle and base fluid, its thermo-physical properties are the combination of nanoparticle properties and base fluid's properties. In this study, following equations were used to calculate thermo-physical properties of nano fluid [15].

1-2-1- The density of nano fluids

ρ_{nf} indicates the density of nano fluid which estimated by eq(1). [7]:

$$\rho_{nf} = (1 - \Phi)\rho_{bf} + \Phi\rho_p$$

$\rho_{bf}\rho_p$ and ρ_p are the density of base fluid and the density of nanoparticles, respectively and is the volume fraction.

1-2-2- The viscosity of nano fluids

μ_{nf} is the viscosity of nanofluid which estimated by eq.(2) [3]:

$$\mu_{nf} = \mu_{bf}(1 + a\Phi)$$

$\mu_{bf}$is the viscosity of base fluid and is constant. Einstein considered a equal to 2.5 in his proposed equation to calculate the viscosity of nano fluids. For nano fluids, it is greater than 2.5 because nanoparticles have more volume in suspension than the microparticles. Using the experimental results by Chan et al. [12], for three aluminum oxide nanoparticles AR, AK and AF, a has been estimated equal to 4.9407, 3.5573 and 15.4150, respectively.

1-3- Calculation of thermo-physical properties of nanofluids

In this study, three aluminum oxide nanoparticles (AR, AF and AK) were used that are different in terms of surface, size and shape [4].
The reasons of choosing aluminum oxide can be summarized as follows:

- Metal oxides such as aluminum oxide, are chemically more stable than metals in suspension.
- Aluminum oxide nanoparticles show good stability in different PH in suspension.
- Nanoparticles, containing aluminum oxide, have high heat transfer.
- Aluminum oxide is harmless to humans and animals so that it has been used in cosmetics and disinfection of water.
- Nanofluids containing aluminum oxide nanoparticles have excellent stability without any additive.

Table 1 shows the physical properties of aluminum oxide nanoparticles.

Table1. Physical properties of aluminum oxide nanoparticles [15]

Aluminum oxide	**AK**	**AR**	**AF**
Company	Degussa	N&A Materials	
Size(mm)	43	27-43	7
Shape	Spherical	Spherical	bar
Surface	Hydrophobic	hydrophilic	hydrophilic
Density (kg/m^3)	3970	3970	3970

1-3-1- The density of nano fluids

Eq1 was used to calculate the density of nano fluids. Figure(1) shows the density of nano fluids in terms of different volume fractions:

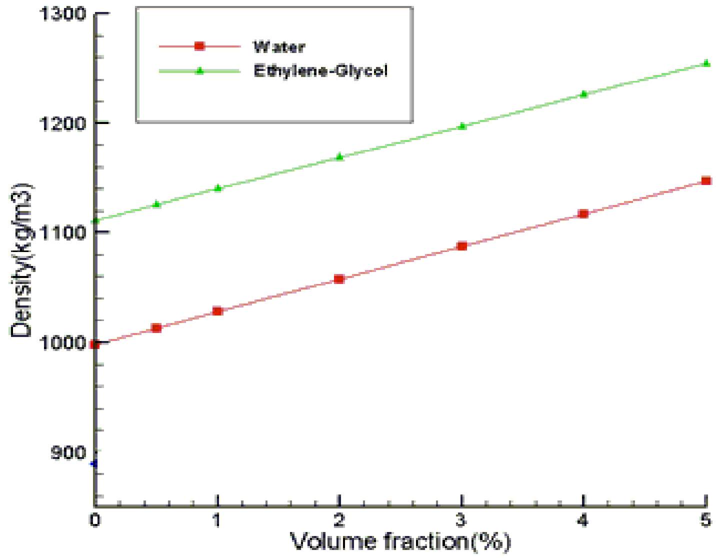

Figure1. The density of nano fluids containing various base fluids

Given figure1, it is observed that the density of nano fluids is more than base fluid and it increases by increasing volume fraction of nanoparticle, because all of the nanoparticle used in this study are of aluminum oxide, so, figure1 represents the density of all nano fluids containing various base fluids [14].

1-3-2- The viscosity of nanofluids

To obtain the viscosity of nano fluids, eq2 was used. Figure(2) shows the viscosity of nano fluids consisting of water-based fluid and nanoparticles of AR, AF and AK.

Figure2. The viscosity of water- aluminum oxide (AR, AF and AK) nano fluids

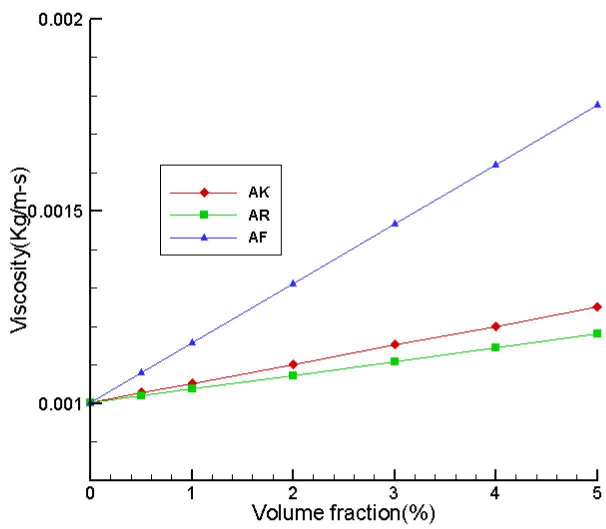

Figure2. The viscosity of water- aluminum oxide (AR, AF and AK) nano fluids

As shown in figure2 the nanoparticle of AF increases the viscosity more than two other nanoparticles and the nanoparticle of AK has higher viscosity than the nanoparticle of AR in suspension. Given the eq.7 the value of a is maximum for aluminum oxide nanoparticle of AF and minimum for the aluminum oxide nanoparticle of AR and given this equation, there is a direct relationship between a and the viscosity of nano fluids, so, the nano fluid containing aluminum oxide nanoparticle of AF has the highest viscosity and the nano fluid containing the aluminum oxide nanoparticle of AR has the lowest one [13].

2. Material and methods

Preprocessor software of Gambit was used to produce the geometry of a pipe with a diameter of 150 mm and a length of 30 m. gambit software is a comprehensive integrated preprocessor software for CFD analysis. Given that there is an axial symmetry in the problem, two-dimensional geometry was considered. After generating the geometry, meshing the solution field was performed by the use of tetrahedral elements. A non-uniform network with the non-uniformity coefficient of 1.1 was used to chop the network near the wall, because, severe gradients occur quickly in the wall of pipe. Applied boundary conditions were the boundary conditions of velocity inlet, pressure outlet and upper wall. In addition to axial asymmetry in a proposed geometry, the boundary of axis is assigned to the lower boundary of pipe because of reducing the computing costs, so, only half of the problem was analyzed in software. Figure (3) shows the created network in Gambit software:

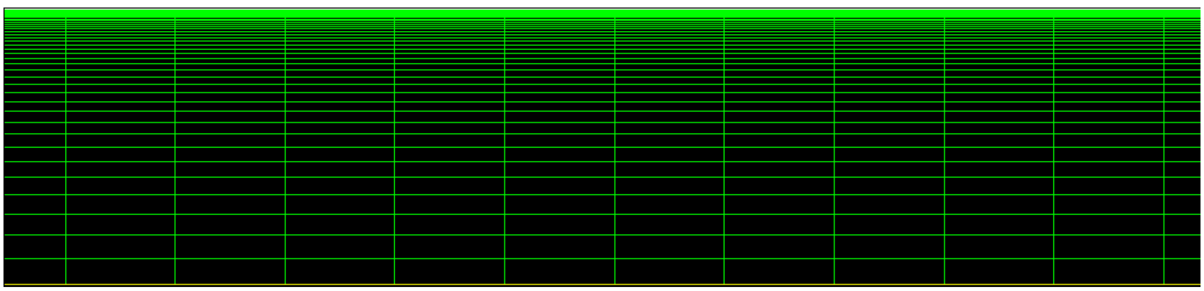

Figure3. Network created in Gambit software

2-1- Choosing a stress-speed communication method

In FLUENT software, the following algorithms exist to express the stress-speed communication [11]:

- SIMPLE
- SIMPLEC
- PISO
- FSM

Generally, in a permanent mode, the methods of SIMPLE and SIMPLEC are used. In this study, the algorithm of SIMPLE was used for pressure-speed communication

2-2- Impact of the type of nanoparticles

In this part, inlet velocity is uniform and 0.53589 m/s and outlet pressure is atmospheric pressure.

2-2-1- Impact of the type of nanoparticles on the friction coefficient

In order to evaluate the impact of the type of nanoparticles on the friction coefficient, three types of aluminum oxide nanoparticle of AR, AF and AK were used. Volume fraction of nanoparticles was 2% and the base fluid was water. Figure (4) shows the friction coefficient in using the nano fluids containing water-based fluid and aluminum oxide naboparticles of AR, AF and AK with the volume fraction of 2%.

Figure4.The impact of the type of nanoparticles on friction coefficient in the pipe

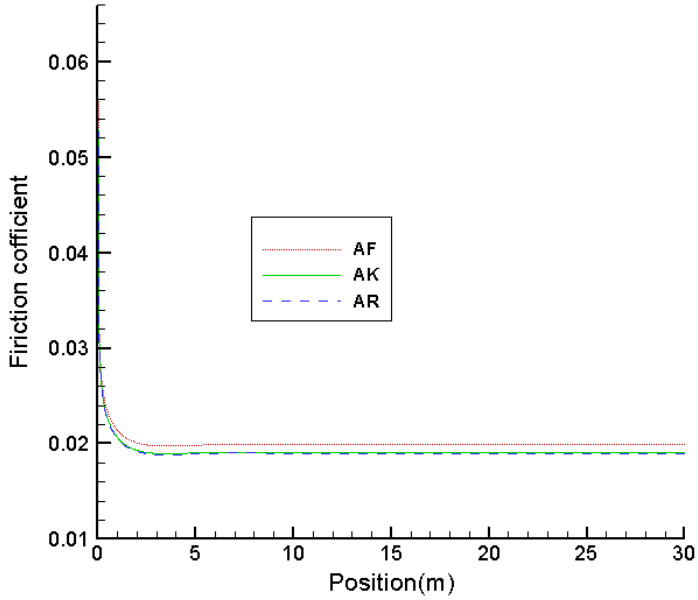

Figure4. The impact of the type of nanoparticles on friction coefficient in the pipe

As can be seen in figure 2-2, the nano fluid containing the nanoparticle of AR has the greatest friction coefficient and the nanoparticle of AR has the lowest. Its reason can be further viscosity of nano fluid containing the aluminum oxide nanoparticle of AF.

2-2-2- The impact of the type of nanoparticles on shear stress of the pipe's wall

To evaluate the impact of the type of nanoparticles on shear stress of the pipe's wall, three types of aluminum oxide nanoparticle of AR, AF and AK were used. Volume fraction of nanoparticles was 2% and the base fluid was water. Figure (5) shows the created shear stress in the wall of pipe in using the nano fluids containing water-based fluid and aluminum oxide naboparticles of AR, AF and AK with the volume fraction of 2%.

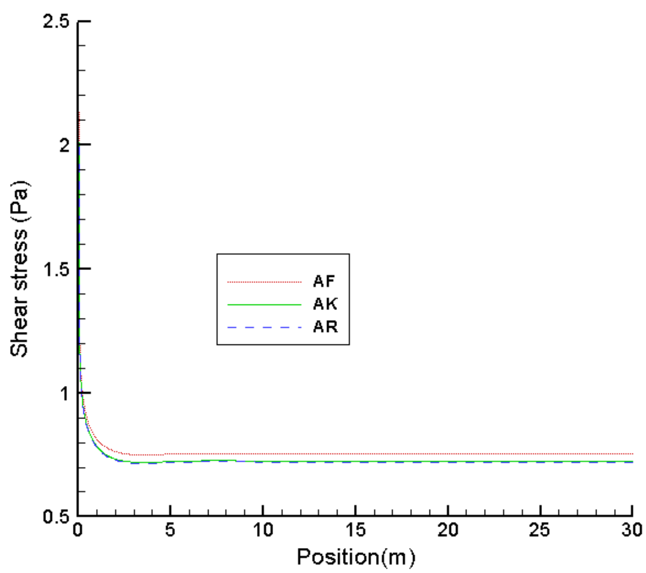

Figure5. The impact of the type of nanoparticles on shear stress in the pipe

As can be seen in figure 2-2, the highest shear stress in the pipe wall was observed in using nano fluids containing nanoparticle of AF and the lowest one was observed in using nano fluids containing nanoparticle of AR.

2-2-3- The impact of the type of nanoparticles on pressure

To investigate the impact of the type of nanoparticles on pressure, three types of aluminum oxide nanoparticle of AR, AF and AK were used. Volume fraction of nanoparticles was 2% and the base fluid was water. Figure (6) shows the created pressure drop between the inlet and outlet of pipe in using the nano fluids containing water-based fluid and aluminum oxide naboparticles of AR, AF and AK with the volume fraction of 2% in the pipe.

Figure6. The impact of the type of nanoparticles on pressure in the pipe

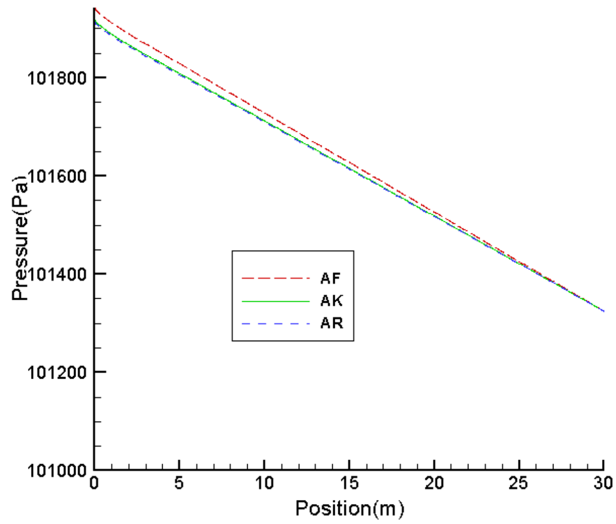

Figure6. The impact of the type of nanoparticles on pressure in the pipe

As shown in figure (6), the nano fluid containing the nanoparticle of AF creates the highest pressure drop and the nanoparticle of AR creates the lowest.

2-2-4- The impact of the type of nanoparticles on viscous drag force of the pipe wall

In table 6-3, the impact of the type of nanoparticles on viscous drag force of the pipe wall were investigated. Volume fraction of nanoparticles was 2% and the base fluid was water.

Table 2. The impact of the type of nanoparticles on viscous drag force of the pipe wall

Type of nanoparticle	AF	AR	AK
Viscous drag force of pipe wall (N)	10.80007	10.313886	10.372993

As can be seen in table (2), the nano fluid containing the nanoparticle of AF creates the largest viscous drag force (10.80 N) in the pipe wall and the nanoparticle of AR creates the least one (10.31N). The reason can be further viscosity of nano fluids containing nanoparticle of AF.

2-3- Impact of using nano fluid on the development of the velocity field

To investigate the impact of using nano fluid on the development of the velocity field, the speed of the centerline of the pipe for the base fluid was compared with the speed of the centerline of the pipe for the

water-aluminum oxide (AF) nano fluid with volume fraction of 2% and 4%. Figure 5-2 shows the comparison of speeds along the pipe length:
Figure7. Impact of using nano fluid on the development of the velocity field

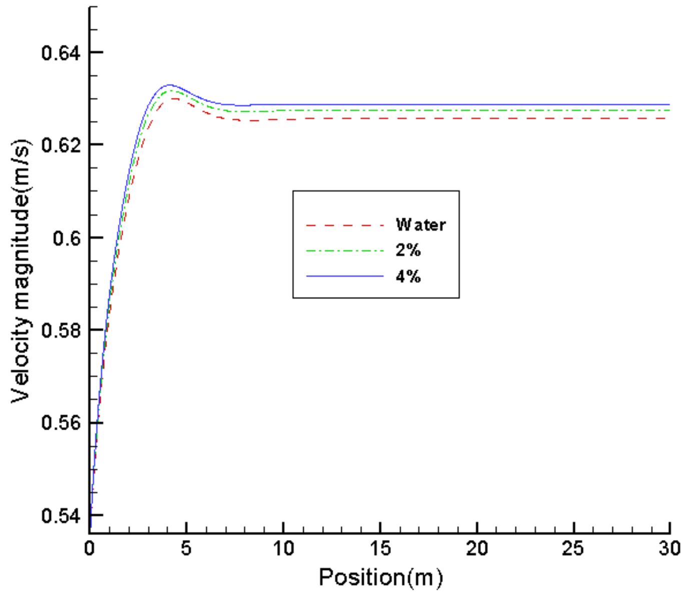

Figure7. Impact of using nano fluid on the development of the velocity field

As can be seen in figure (7), using nano fluids has no significant effect on the development of the velocity field, though the speed rate increases with increasing volume fraction of nanoparticles.

3. Conclusion

In recent research, the flow of nano fluids containing the water –based fluid and aluminum oxide nanoparticles of AR, AF and AK in turbulent flow regime in the pipe was investigated by the use of net producing software of Gambit and computational fluid dynamics software of FLUENT. After examining the independence of numerical results from the network, the numerical results of friction coefficient were compared with the experimental results of Petukhov's equation and the comparison showed the consistency of numerical results with it. In this study, the impact of different parameters such as type of nanoparticle and type of base fluid on the friction coefficient, shear stress of pipe wall, viscous drag force of wall and pressure drop have been investigated fully. Using water-based fluid with the lowest friction coefficient and shear stress in fully developed area, the nano fluid containing aluminum oxide nanoparticles of AF has the greater pressure drop, friction coefficient and shear stress due to further viscosity. Also, in comparison with two other nanoparticles, it creates greater viscous drag force (10.80) in the pipe wall and the nano fluid containing aluminum oxide nanoparticles of AR has the lower pressure drop, friction coefficient and shear stress due to lower viscosity and creates smaller viscous drag force (10.31). So, the use of nano fluids containing aluminum oxide nanoparticles of AR is preferred compared to other nanoparticles. The use of nano fluids has no significant impact on the development of velocity field. Generally and by considering the costs of pumping nano fluids, use of water-based fluid and aluminum oxide nanoparticles of AR has greater economic benefits.

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