Computational Analysis of Nanofluids in Heat Exchanger

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Abstract. In this paper is study the performance of heat exchangers by using computational analysis method. In past decade's years, many researchers had discovered that nanofluids have a brilliant efficient in the heat transfer process. They believes that applied the nanofluids in the heat transfer equipment would bring a better enhancement compare with the conventional cooling fluids. In the literature journals, the authors have specified focused on the thermal conductivity, specific heat, density, and viscosity of nanofluids. They believes these are the most significant factors of the working fluids that would influence the efficiency of heat exchanger. In this study, an imitated real-life marine transport used of shell and tube heat exchanger to be analyzed. The shell and tube sides of heat exchanger will be filled with Water or nanofluids and Water or seaWater in respectively. The nanofluids will be assumed as single-phase nanofluids with variant of volume fraction of copper and alumina. The computational result of Water at the shell and tube sides will be used as validation of data compared with the technical performance specification given by the supplier. Further, the efficiency of different volume fraction of nanofluids and the optimum of volume fraction of nanofluids in this system would be discussed in the simulation results.

Introduction

In recent years, many researches are concerned on the studied of applied nanofluids in the heat transfer equipment. Hence, the nanofluids has reputed that it having a better heat transfer rate compared with the common coolants such as Water, ethylene glycol, and mineral oil.

Nanofluids are the newly fluids that mixed of two substances of liquid and solid with the size of range from 1nm to 100nm. The idea of invented of the nanofluids are helping the heat transfer process of the common coolants that widely used in the heat transfer equipment industrial. Therefore, the base-fluids of the nanofluids would be secured with its potential of good in heat transfer rate. The nano-sized of solid particles will be the enhancement mechanical properties of the nanofluids.

Many researchers have mentioned that the heat transfer of the nanofluids is relatively depends on the thermal conductivity and viscosity that could be leaded by increase the volume fraction/concentration or the selected materials of the nano-particle or base-fluids. [1, 2, 3] A single-phase model of nanofluids will be considered due to the limitation of computational analysis and lack of experimental results in the past studied.

There are several types of heat exchanger in the industrial market that had been studied in the past literature. Trisaksri et al. [4] and Mare et al. [5] has highlighted that most of the manufacturer are likely to extend on the features on the equipment in order to improve the heat transfer. In fact, a good heat exchangers shall qualified with the conditions of low cost, light-weight, small occupied area and efficient. In order to getting better efficient without compromise the other conditions, the only solution will be substituted the operational fluids with nanofluids.

A marine transport used heat exchanger will be imitated in the scale of one-to-one in the computational software - SolidWorks 2012. Follow by the technical specification that given by the manufacturer, the key parameters of inlet temperature and pressure for the shell and tube sides will be input. The analysed output will be utilised as the comparison of the validation and studied of the improvement after applied the nanofluids at the shell side.

Research Methodology

Thermal Conductivity for Nanofluids

In the recent years, many researchers have developed different types of models. The new models are reference from the ancient models such as Maxwell, Hamilton-Crosser, Wasp and Bruggmen. In this studied, Hamilton-Crosser model will be applied in this studied due to the model has considered nano-particle shape factor and flexibility for changes of shape. The nanoparticle with spherical shape will be assumed in this studied. The nanopartocle shape factor is 3 will be used. The Hamilton-crosser formulae are as follow: -

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{np} + (n-1)k_{bf} - (n-1)(k_{bf} - k_{np})\phi}{k_{np} + (n-1)k_{bf} + \phi(k_{bf} - k_{np})} \qquad (2.1)$$

Based on the equation (2.1), the thermal conductivity of nanofluids is tabulated in table 2.1. The applied thermal conductivity of copper and alumina are 401 W/m.K and 237 W/m.K in respectively with the Water based fluid of 0.609 W/m.K.

	Thermal Conductivity (W/m.K)	
Type of Fluids	Copper (Cu)	Alumina (Al_2O_3)
Water*	0.6090	0.6090
Water + 0.5% nanoparticle	0.6181	0.6181
Water + 2.5% nanoparticle	0.6556	0.6555
Water + 5% nanoparticle	0.7047	0.7044
Water + 7.5% nanoparticle	0.7564	0.7559
Water + 10% nanoparticle	0.8110	0.8103
Water + 12.5% nanoparticle	0.8686	0.8677

Table 2.1 Thermal Conductivity of the Basefluids* and Nanofluids.

Dynamic Viscosity for Nanofluids

The dynamic viscosity will be using Brinkmann model. Since, it hasthe properties of applied on many material criteria. Theirs is one of the common model that developed by Einstein are cited from the Brinkmann model. However, the Eistein model could not applied on this studied due to it has the limited for the volume fraction lesser than 0.05. Due to the applied volume fraction in this project are larger than 0.05. Hence, Eistein model will not be considered in this studied. The Brinkmann formulae is derive as:-

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\phi)^{2.5}} \qquad (2.2)$$

Based on the equation (2.2), the dynamic viscosity of nanofluids is tabulated in table 2.2 with applied dynamic viscosity of Water of 0.315 Pa.s with the portion of the Water.

	Dynamic Viscosity (Pa.s)	
Type of Fluids	Copper (Cu)	Alumina (Al_2O_3)
Water*	0.3150	0.3150
Water + 0.5% nanoparticle	0.3190	0.3190
Water + 2.5% nanoparticle	0.3356	0.3356

Water + 5% nanoparticle	0.3581	0.3581
Water + 7.5% nanoparticle	0.3828	0.3828
Water + 10% nanoparticle	0.4099	0.4099
Water + 12.5% nanoparticle	0.4398	0.4398

Table 2.2 Dynamic Viscosity of the Basefluids* and Nanofluids.

Density for Nanofluids

The density of nanofluids will be considered in the sum of the percentage of nano-particle and fluids. A simply equation will be formed:

$$\rho_{nf} = (1-\phi)_{\rho bf} + \phi\rho_{np} \tag{2.3}$$

Based on the equation (2.3), the density of nanofluids is tabulated in table 2.3. The applied density of copper and alumina are 8940 kg/m3 and 3960 kg/m3 in respectively with the Water based fluid of 1000 kg/m3.

	Density (kg/m^3)	
Type of Fluids	Copper (Cu)	Alumina (Al_2O_3)
Water*	1000.0	1000.0
Water + 0.5% nanoparticle	1039.7	1014.8
Water + 2.5% nanoparticle	1198.5	1074.0
Water + 5% nanoparticle	1397.0	1148.0
Water + 7.5% nanoparticle	1595.5	1222.0
Water + 10% nanoparticle	1794.0	1296.0
Water + 12.5% nanoparticle	1992.5	1370.0

Table 2.3 Density of the Basefluids* and Nanofluids.

Specified Heat of Nanofluids

The heat capacity will be applied the same formulae as density with multiple of its specific heat at constant pressure. This is applied for the solid and fluids. The formulae are written as below:-

$$(\rho C_p)_{nf} = (1-\phi)(\rho C_p)_{bf} + \phi(\rho C_p)_{np} \tag{2.4}$$

Based on the equation (2.4), the density of nanofluids is tabulated in table 2.4. The applied density of copper and alumina are 385 J/kg.K and 773 J/kg.K in respectively with the Water based fluid of 4184 J/kg.K.

	Specific Heat (J/kg.K)	
Type of Fluids	Copper (Cu)	Alumina (Al_2O_3)
Water*	4184.00	4184.00
Water + 0.5% nanoparticle	4020.67	4117.45
Water + 2.5% nanoparticle	3475.55	3869.58
Water + 5% nanoparticle	2968.43	3595.69
Water + 7.5% nanoparticle	2587.49	3354.98
Water + 10% nanoparticle	2290.85	3141.75
Water + 12.5% nanoparticle	2053.32	2951.56

Table 2.4 Specific Heat of the Basefluids* and Nanofluids.

In the previous section, a comparison of the actual technical specification data and the simulation results data has been shown in Table 2.5. It has successful proved that the efficiency with minimum differences about 0.1155 and temperature difference between the simulation and technical specification are within ±5K. However, the nanofluids has not been proven in the actual running, but it could be estimated with this reliable computational study.

Description	**Technical Specification**	**Simulation Result**
Shell Water Inlet Temperature, K (°C)	353.15 (80)	353.15 (80)
Shell Water Outlet Temperature, K (°C)	346.45 (73.3)	343.22 (70.07)
Tubes Water Inlet Temperature, K (°C)	313.15 (40)	313.15 (40)
Tubes Water Outlet Temperature, K (°C)	321.45 (48.3)	324.11 (50.96)

Table 2.5 Comparison data between Technical Specification and Simulation Result

Simulations Result

With all the information of the mechanical properties of the nanofluids has been calculated in the previous chapter, the simulated result has plotted the graph of basefluids and nanofluids' temperature along the travel along the shell side in the conditions of freshwater and seawater filled in the tubes of the heat exchanger as shown in Figure 3.1 and 3.2.

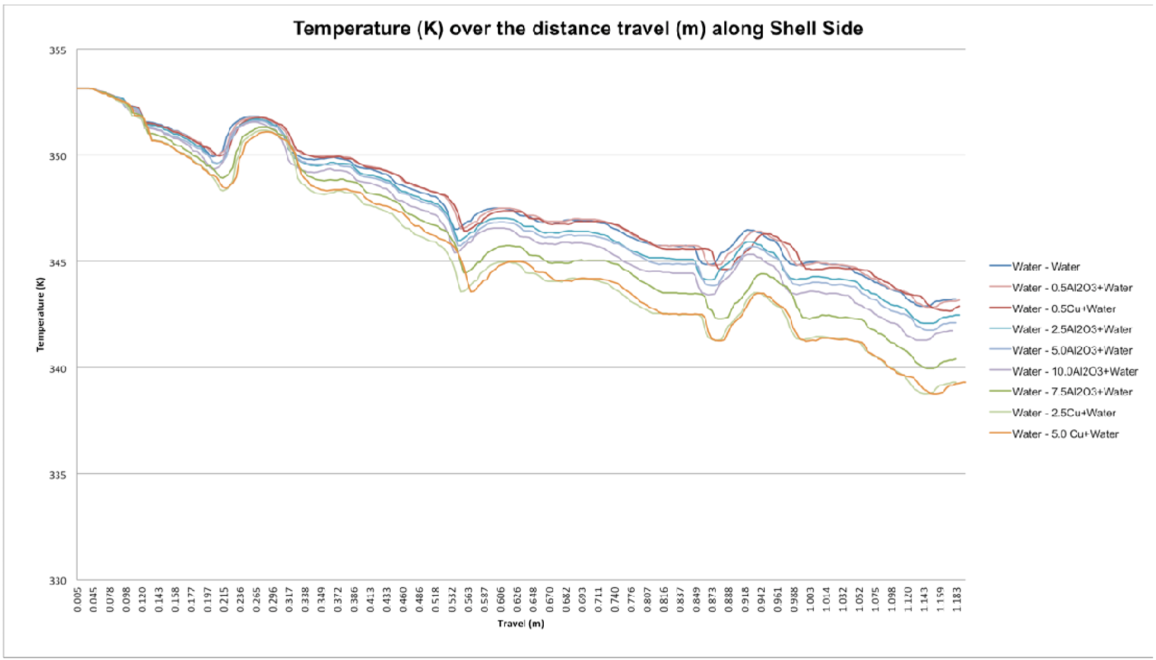

Fig. 3.1 Temperature of Water and Nanofluids flows along the core of shell while the tubes side filled with FreshWater

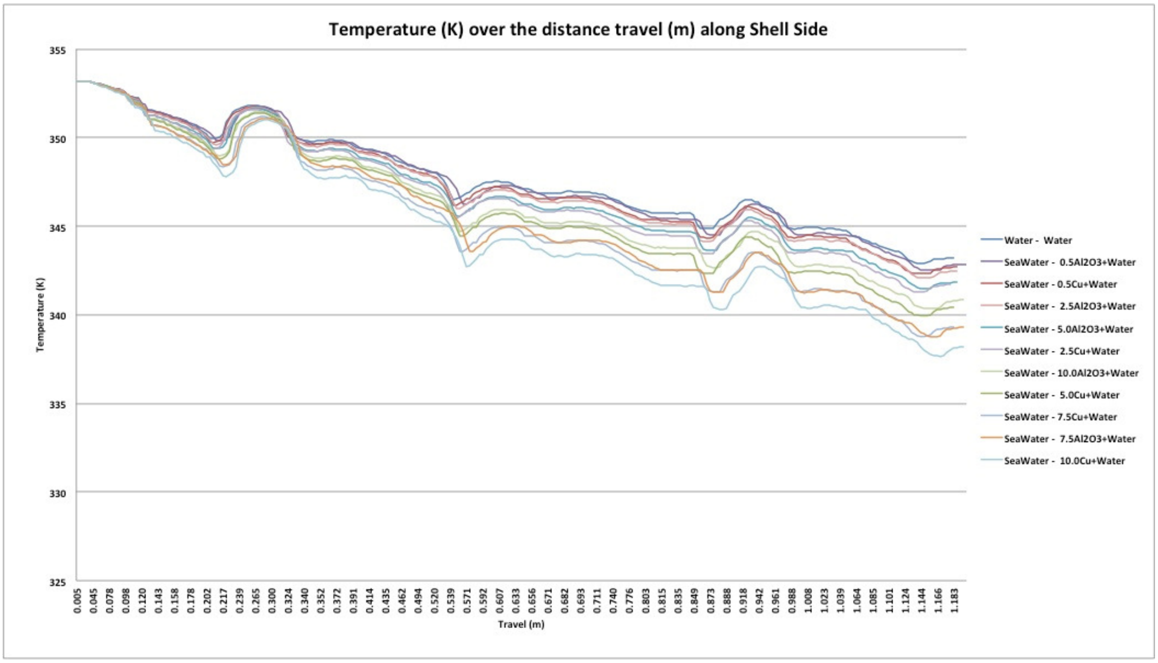

Fig. 3.2 Temperature of Water and Nanofluids flows along the core of shell while the tubes side filled with SeaWater.

Based on the Outlet Temperature in the Figure 3.1 and 3.2, the information has been used to tabulate in the Table 3.1 and 3.2. From the Table 3.1 and 3.2, it is shown that the variant of volume fraction of nanofluids at the shell side will lead different percentage of improvement regardless the tubes side are filled with seawater or freshwater.

Type of Fluids	Volume Fraction (%)	Inlet Temperature @ Shell (K)	Outlet Temperature @ Shell (K)	Percentage of Improvement (%)
Water – Water *	0%	353.15	340.03	
Water – 0.5% vol. Cu/Water	0.5%	353.15	339.97	0.46%
Water – 2.5% vol. Cu/Water	2.5%	353.15	334.43	42.68%
Water – 5.0% vol. Cu/Water	5.0%	353.15	334.03	45.73%
Water – 7.5% vol. Cu/Water	7.5%	353.15	336.85	24.24%
Water – 0.5% vol. Al_2O_3/Water	0.5%	353.15	339.94	0.69%
Water – 2.5% vol. Al_2O_3/Water	2.5%	353.15	339.52	3.89%
Water – 5.0% vol. Al_2O_3/Water	5.0%	353.15	339.24	6.02%
Water – 7.5 vol. Al_2O_3/Water	7.5%	353.15	336.67	25.61%
Water – 10.0 vol. Al_2O_3/Water	10.5%	353.15	338.01	15.40%

Table 3.1 Percentage of Improvement compared with the Nanofluids and Technical Specification *.

Type of Fluids	Volume Fraction (%)	Inlet Temperature @ Shell (K)	Outlet Temperature @ Shell (K)	Percentage of Improvement (%)
Water – Water *	0%	353.15	340.03	
SeaWater - 0.5% vol. Cu/Water	0.5%	353.15	340.17	0.46%
SeaWater - 2.5% vol. Cu/Water	2.5%	353.15	338.77	11.30%
SeaWater – 5.0% vol. Cu/Water	5.0%	353.15	338.03	17.03%
SeaWater – 7.5% vol. Cu/Water	7.5%	353.15	336.9	25.77%
SeaWater – 10.0% vol. Cu/Water	10.0%	353.15	336.09	32.04%
SeaWater – 12.5% vol. Cu/Water	12.5%	353.15	337.73	19.35%
SeaWater – 0.5% vol. Al_2O_3/Water	0.5%	353.15	340.35	0.00%
SeaWater – 2.5% vol. Al_2O_3/Water	2.5%	353.15	339.46	5.96%
SeaWater – 5.0% vol. Al_2O_3/Water	5.0%	353.15	339.29	7.28%

Table 3.2 Percentage of Improvement compared with the Nanofluids and Technical Specification *.

From the table 3.1 and 3.2, the inlet fluid temperature and the outlet fluid temperature at the shell have been used to present in the percentage of improvement. The percentage of improvement are stipulated as:-

$$percentage\ of\ improvement = \frac{\Delta Tnanofluids}{\Delta T_{tech.spec}} \times 100\% \qquad (3.1)$$

With the percentage of improvement, the Figure 3.3 and 3.4 has been plotted. From the Figure 3.3 and 3.4, it shown that the percentage of improvement from the copper water-based nanofluids will be significantly higher than alumina water-based nanofluids. Further, the Copper water-based nanofluids are efficiency improve while the seawater filled in the tubes compare to the alumina water-based nanofluids. In the figure 3.3, it is shown that the alumina water-based nanofluids is optimum when the volume fraction is 7.5% vol. regardless the tubes filled with seawater or fresh water. However, in the figure 3.4, the copper water-based nanofluids has shown the optimum volume fraction at the 3% and 10% when tubes filled with freshwater and seawater respectively. Comparing to the improvement by using different volume fraction of variant nanofluids, the copper (Cu) contains are required lesser volume fraction than than Alumina (Al_2O_3) to achieved better performance.

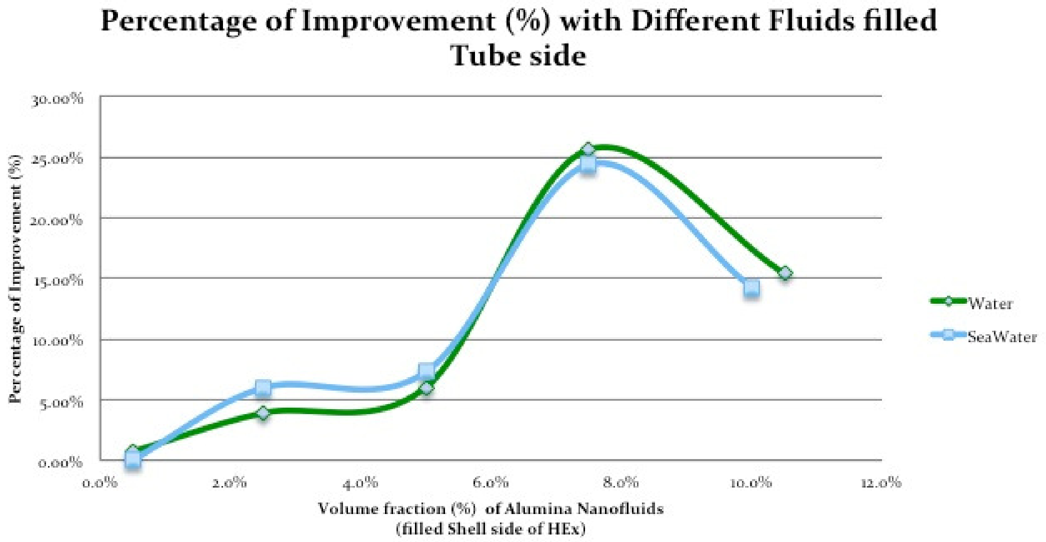

Fig. 3.3 Percentage of Improvement over variant volume fraction of Alumina Nanofluids filled in Shell side with condition of Fresh Water and Sea Water filled in the Tube side.

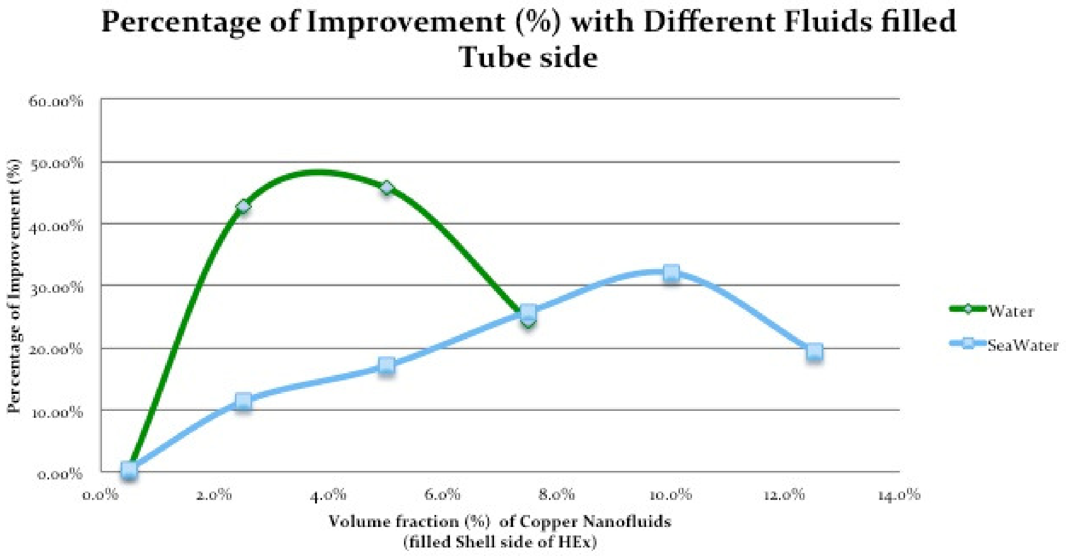

Fig. 3.4 Percentage of Improvement over variant volume fraction of Copper Nanofluids filled in Shell side with condition of Fresh Water and Sea Water filled in the Tube side.

Conclusions

In this paper, the computational investigation shown that the efficiency of heat exchanger is validated by the technical specification with the tolerance of ±5°C. In the general results, the nanofluids has significantly showed their performance in the studied heat exchanger. The application of nanofluids has showed the enhancement the heat transfer in the heat exchanger in this present study. A further research work for the same area is required to determine the optimum volume fraction (%) of nanofluids with smaller interval gap in order to achieve the accuracy and precision. Besides, a validation process of the simulation result with the real life experimental with different types of nanofluids is highly recommended.

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