Mathematical Modelling of Engineering Problems
Vol. 9, No. 4, August, 2022, pp. 1073-1078
Journal homepage: http://iieta.org/journals/mmep

Numerical Investigated to Improve Heat Transfer in a Pipe Using Nanofluid

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https://doi.org/10.18280/mmep.090425

Received: 31 May 2022
Accepted: 16 August 2022

Keywords:
heat transfer, nanofluid, pipe, copper, carbon nanotubes

ABSTRACT

A numerical analysis demonstrates the significance of utilizing nanoparticles to enhance heat transfer in pipes. This research examines the addition of nanomaterials to used metal at concentrations of 1%, 5%, and 10%. Copper is utilized as the pipe material, while carbon nanotubes serve as the nanomaterial. The analysis was conducted with the ANSYS/FLUENT 16 enthalpy–porosity formulation. The results of this study indicate that the use of nanoparticles increases heat transfer, and that the more the percentage of nanomaterials, the more pronounced the improvement in heat transfer through the tube, as the inclusion of 10% nanomaterials greatly improves heat transfer. This study can be utilized to enhance heat transmission in air conditioners.

1. INTRODUCTION

The world has recently seen a trend toward employing modern electronic means and everything else that is relevant to the development that has taken place in the recent period. this trend has been a recent phenomenon. We take note of the interest in heat transfer as an essential component in a wide variety of scientific applications, and we take note of the significant impact that heat transfer has on a wide variety of elements of life, such as the following: (electronics, x-rays, optical devices, cooling devices, etc.). The exponential growth of these devices and technologies through miniaturization, data storage, and optimization of the operating rate has led to serious problems in the thermal management of these devices [1-3]. This growth has been driven by factors such as data storage, operating rate optimization, and miniaturization. It is generally agreed that low thermal conductivity is the single most important reason why there is a pressing need to boost thermal conductivity; consequently, in order to accomplish this goal, it is necessary to either work toward using materials that already have a high thermal conductivity or to improve the existing materials [4]. Because this was such an important topic, researchers devoted close attention to it and put in a lot of effort to determine the most effective strategies for enhancing the features of thermal energy transfer [5-8]. Understanding and being familiar with the mechanism of heat transfer is essential for the design of numerous and extensive applications across all commercial, industrial, and home appliance fields [9-11]. Solar energy, air conditioning, the oil and gas sector, energy generation, and electronic refrigeration are a few examples of these uses. The importance of heat transfer and the major effects it has on a wide range of applications in human existence are important. The most major methods used by researchers to increase heat transfer are the insertion of fins to increase heat transfer or the increase in material surface area to increase the region to which heat is transmitted [12, 13]. It also entails improving heat transmission from carrier fluids by altering the fluids to enable quick heat acquisition and loss [14-18]. Adding nanomaterials to heat transfer compounds and enhancing the ability to lose and gain heat at high speeds are two of the most important recent ways for boosting heat transfer. Nanomaterials have brought about an artificial revolution in a number of different industries, the most significant of which is the heat transfer industry due to the significance of this industry and its influence on other industries [19-23]. Metals are also improved to increase their thermal conductivity by improving thermal conductivity by adding nanomaterials [24-30]. In this work, we try to improve heat transfer by adding nanomaterials to the metal (copper) to increase thermal conductivity and thus increase heat transfer through it. The numerical study paves the way for an experimental study showing the importance of using nanomaterials in improving heat transfer.

2. METHODOLOGY

2.1 Governing equations

In order to finish the pipeline CFD study, it is extremely vital to set up the operating circumstances and make any necessary adjustments to the governing equations (momentum, continuity, and energy). Where is the two-dimensional form, the temporal mean, and the incompressible Navier-Stokes equation, and the energy equation These equations, when applied to some systems, can be expressed as:

Continuity equation

$$\frac{\partial p_{nf}}{\partial t}+\nabla.\left(p_{nf}\right)V=0 \tag{1}$$

Momentum equation

$$\frac{\partial\left(p_{nf}\nu\right)p_{nf}}{\partial t}+\nabla.\left(p_{nf}\right)V=-\nabla P+\mu\nabla^{2}V+p_{nf}g \tag{2}$$

Energy equation

$$\frac{\partial}{\partial t}\left(p_{nf} H\right)+\nabla.\left(p_{nf} VH\right)=\nabla.\left(K_{nf} \nabla T\right) \tag{3}$$

2.2 Preparation of nanofluids

Nanoparticles used in nanofluids range in size from 1 to 100 nm and different shapes such as nanospheres (spherical), nano reefs, nano boxes, nanoclusters and nanotubes. This study using carbon Nanotubes In certain proportions to explain their effect on heat transfer and thermal conductivity and their importance in many applications. Using Eq. (5) [14, 31], you can figure out how many grams of nanoparticles you need to make nanofluid with a certain concentration by volume.

$$\phi=\frac{V_{np}}{V_{np}+V_{bf}} \tag{4}$$

$$m=P_{np} V_{np} \tag{5}$$

where, $Ø$: volume concentrations, V_{np}: volume of nanoparticles, V_{bp}: volume of base fluid, ρ_{np}: density of nanoparticle (g/cm^3), m: mass of nanoparticle in gram. In this investigation, a volume concentration of 0.5% was employed.

The thermal conductivity of nanofluids is influenced both by the nanoparticle material and the base fluid (de-ionized water). Maxwell's model is responsible for introducing the concept of thermal conductivity.

$$K_{nf}=\frac{K_p+2K_{bf}+2\varphi\left(K_p-K_{bf}\right)}{K_p+2K_{bf}-\varphi\left(K_p-K_{bf}\right)} K_{bf} \tag{6}$$

where, K_p is Thermal conductivity of nanoparticles, K_{bf} is Thermal conductivity of the base fluid.

The density of nano-fluid is introduced by Pak and Cho's equation

$$p_{nf}=\phi p_p+(1-\phi) p_{bf} \tag{7}$$

where, ρ_p is the density of nanoparticles, ρ_{bf} is the density of the base fluid.

The specific heat of nano-fluid is introduced by Xuan and Roetzel's equation

$$\left(C_p\right)_{nf}=\frac{(1-\varphi)\left(PC_p\right)_{bf}+\varphi\left(PC_p\right)_p}{\varphi p_p+(1-\varphi) p_{bf}} \tag{8}$$

It is referred to as transient conduction when the mode of thermal energy transfer occurs whenever there is a period of time during which temperatures vary at any location within an object. Alterations in temperature can also take place internally in an object if, for example, a new heat source or sink is added all of a sudden, which causes the temperature in the area immediately surrounding the source or sink to fluctuate over time.

$$\frac{\partial}{\partial t}\left(p_{nf} H\right)+\nabla.\left(p_{nf} VH\right)=\nabla.\left(K_{nf} \nabla T\right) \tag{9}$$

Thermal conductivity, specific heat capacity, and density are three examples of thermal parameters that have the potential to influence conduction and convection. Accurate thermal property data are necessary for any model that involves heat transmission. When nanomaterials are added to a copper tube, the thermal characteristics can then be computed, as indicated in Table 1.

Table 1. Thermal properties of the material [32-34]

Properties	Copper	CNTs	1% Nano fluid	5% Nano fluid	10% Nano fluid
ρ kg/m³	8978	1.3	8888	8529	8080
K W/ (m. K)	387.6	4000	396	433	482
C_P J/Kg. K	381	686	381	381381	381

3. PHYSICAL MODEL

The physics model of the pipe in (Figure 1) shows the two-dimensional pipe is 0.7 m inner diameter and 1m outer diameter, made in copper add the carbon nanotube in certain proportions to improve heat transfer through the tube. The choice of the large size of the tube clearly illustrates the heat transfer and indicate the importance of adding nanomaterials.

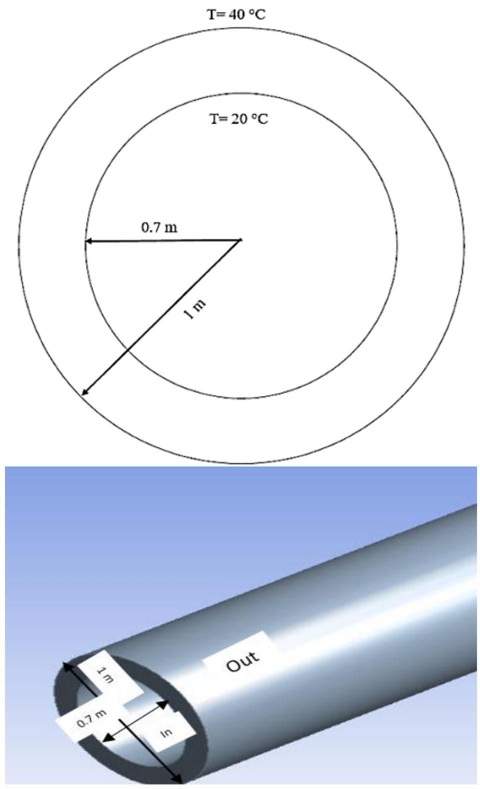


Figure 1. Configuration of the physical model

4. BOUNDARY CONDITIONS

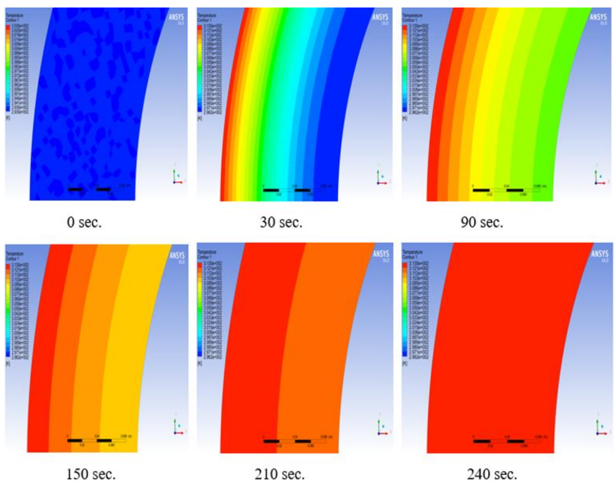
The modelled as a 2-D, initially, unsteady, laminar, incompressible, and The distribution of the studied mesh is (18,652) nodes. As the external temperature of the pipe is 40°C and the internal temperature of the pipe is 20°C and this difference is to clearly show the heat transfer.

5. RESULTS AND DISCUSSION

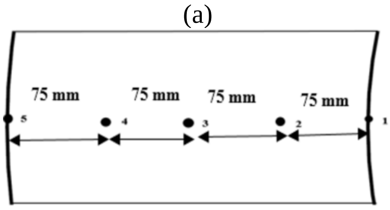
This study, show the importance of using nanomaterials to improve heat transfer. Where we numerically study heat transfer without using nanomaterials and then add nanomaterials with certain ratios to explain the effect of using nanomaterials and the importance of this in many applications.

5.1 The cell without nanomaterials

The heat transfer depends on the thermal conductivity of each material and therefore copper is considered one of the materials with high thermal conductivity. In Figure 2 we note the heat transfer inside the cell and large cell size was chosen to illustrate this transfer. Table 2 shows the heat transfer according to the points shown in the attached figure to show the heat transfer inside the cell and compare it when adding nanomaterials.



(a)



(b)

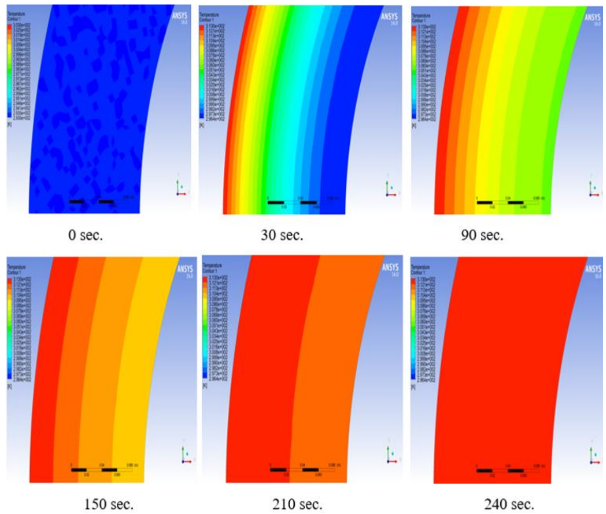
Figure 2. (a) Heat transfer in the cell without nanomaterials, (b) The locations of the points inside the cell

Table 2. Temperatures at the locations shown inside the cell

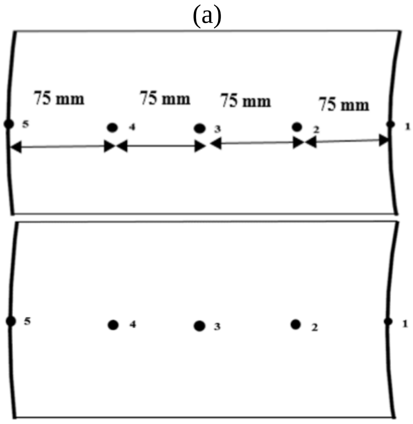
Time (sec.)	1	2	3	4	5
0	293	293	293	293	293
60	301.7	302.38	304.92	308.67	313
120	308.19	308.45	309.55	311.15	313
180	310.94	311.06	311.52	312.21	313
240	312.12	312.17	312.37	312.66	313

5.2 The cell with nanomaterials by 1%

The addition of nanomaterials helps to improve heat transfer, and to clarify this, nanomaterials were added by 1%, where we notice in Figure 3 that the heat transfer improved slightly because the added percentage is very low, and therefore heat transfer is similar when using materials without nanomaterials. Table 3, which shows the temperatures in different places inside the metal, where we notice a small difference in temperatures compared to when nanomaterials are not used.



(a)



(b)

Figure 3. (a) Heat transfer in the cell with nanomaterials by 1%, (b) The locations of the points inside the cell

Table 3. Temperatures at the locations shown inside the cell

Time (sec.)	1	2	3	4	5
0	293	293	293	293	293
60	302.07	302.66	305.15	308.79	313
120	308.44	308.69	309.73	311.25	313
180	311.1	311.21	311.64	312.27	313
240	312.21	312.25	312.43	312.69	313

5.3 The cell with nanomaterials by 5%

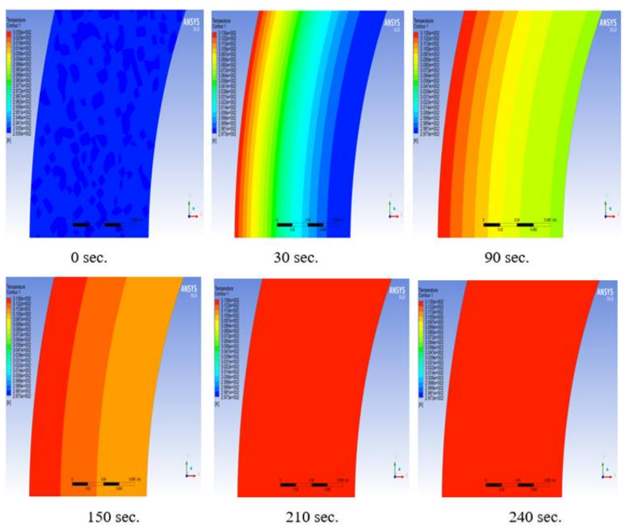


Figure 4. Heat transfer in the cell with nanomaterials by 5%

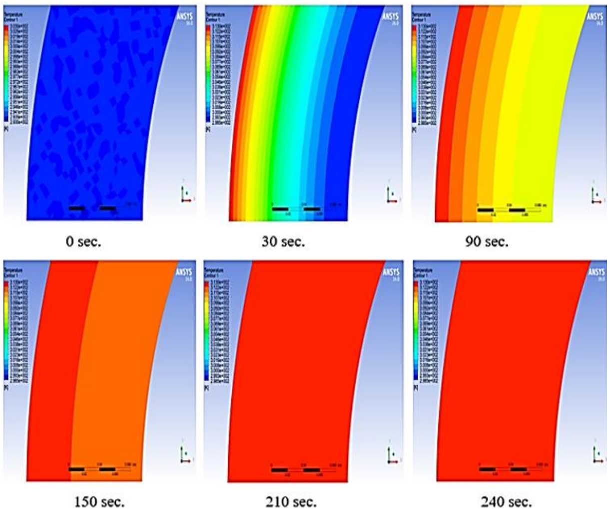
When adding nanomaterials by 5%, we notice a clear improvement in heat transfer, which shows the importance of using these materials. In Figure 4, we notice better heat transfer inside the metal, as it shows the importance of using nanomaterials in improving heat transfer. In Table 4, we notice that the temperatures are higher than the first and second cases, and this clearly shows the importance of using nanomaterials in improving heat transfer.

Table 4. Temperatures at the locations shown inside the cell

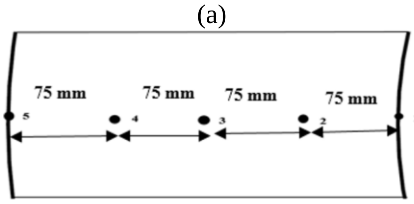
Time (sec.)	1	2	3	4	5
0	293	293	293	293	293
60	303.31	303..83	306.01	309.23	313
120	309.42	309.62	310.42	311.61	313
180	311.68	311.75	312.05	312.49	313
240	312.21	312.54	312.65	312.81	313

5.4 The cell with nanomaterials by 10%

When adding 10% nanomaterials, we notice very clearly the effect of their use in improving heat transfer, and this is very important because improving heat transfer has a very large impact in many applications. In Figure 5 we notice the heat transfer within the materials used, where the figure shows this transfer is better and faster than the previous cases. Table 5 shows the better temperatures and the reason is the use of nanomaterials in a greater proportion, which shows the importance of using these materials in improving heat transfer.



(a)



(b)

Figure 5. (a) Heat transfer in the cell with nanomaterials by 10%, (b) The locations of the points inside the cell

Table 5. Temperatures at the locations shown inside the cell

Time (sec.)	1	2	3	4	5
0	293	293	293	293	293
60	304.84	307.29	307.15	309.87	313
120	310.46	310.6	311.18	312.03	313
180	312.21	312.25	312.43	312.69	313
240	312.75	3012.76	312.85	312.9	313

5.5 Comparison of cases

In this study, we numerically study the importance of using nanomaterials in improving heat transfer. We note that heat transfer improves dramatically in increasing the proportion of nanomaterials. In Figure 6, a comparison between the cases that have been studied, where the figure shows the importance of adding nanomaterials and its effect on heat transfer in Figure 7, a comparison between the temperatures in the middle of the figure, where we notice the increase in temperatures when increasing nanomaterials.

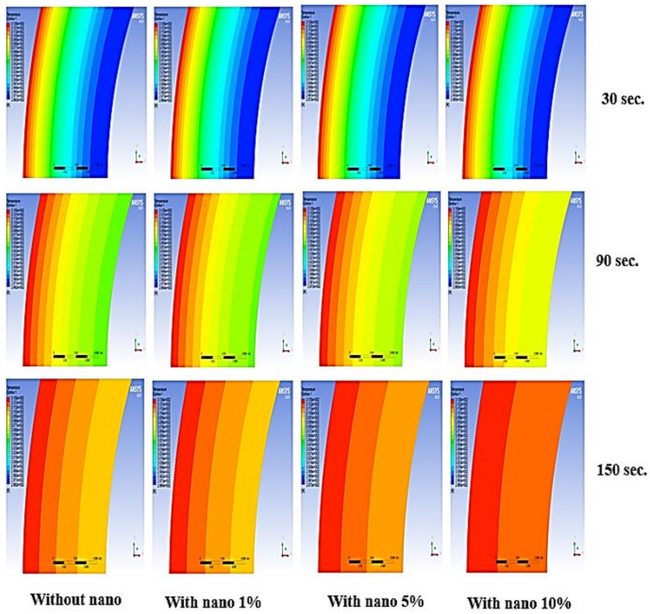


Figure 6. Comparison of cases

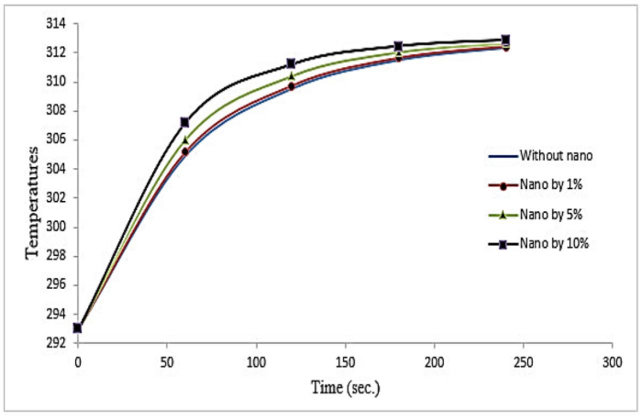


Figure 7. Comparison of temperatures between states in the middle of the metal

6. CONCLUSIONS

In this work, we study the importance of using nanomaterials in improving heat transfer. The use of nanomaterials in certain proportions has been studied to show their effect on heat transfer. The study was conducted using an enthalpy–porosity formulation (ANSYS/FLUENT 16 software). In this study, copper was used as a material to show heat transfer to it, and carbon nanotubes were added at 1%, 5%, and 10% to illustrate the importance of using these materials in improving heat transfer. From the results of the study, we note that increasing the percentage of nanomaterials added to copper improves heat transfer. The study showed that the addition of nanomaterials by 10% significantly improves heat transfer, as practical experiments can be conducted on the study and used in many applications.

ACKNOWLEDGMENT

This work was supported by the College of Engineering and the Department of Construction and Projects within the Presidency of Karbala University.

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NOMENCLATURE

D	Dimeter, m
H	Enthalpy, J. kg^{-1}.
t	Time, s^{-2}
T_{in}	Temperature inner, °C.
T_{out}	Temperature inner, °C.
C_p	Specific heat, J.kg^{-1}. K^{-1}

Greek symbols

ϕ	Volume concentration
K	Thermal conductivity, W.m^{-1}. K^{-1}
μ	dynamic viscosity, Pa. s
ρ	Density, kg. m^{-3}

Subscripts

nf	Nanofluid
bf	Base fluid