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Pressure drops of h-BN/DCM and SiO_2/DCM nanofluids

h-BN/DCM ve SiO_2 nanoakışkanlarının basınç düşümlerinin incelenmesi

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Pressure Drops of h-BN/DCM and SiO_2/DCM Nanofluids

Highlights

- *The pressure losses and flow behaviors of several nanofluids in pipes of various diameters are investigated.*
- *It was found out that the trend of variation for the pressure drop curve for nanofluids is similar to that of water.*
- *In terms of pressure drop, the transition region for both water and nanofluids is much more sensible to the changes in Reynolds number.*
- *The increment in pipe diameter causes the pressure drop between the fluids to get larger.*
- *The transition region from laminar boundary layer to turbulent boundary layer is the longest in DCM and shortest in water.*

Graphical Abstract

The current study presents the investigation of the flow characteristics and pressure heads of h-BN & DCM, SiO2 & DCM nanofluids at various pipe diameters by using numerical methods.

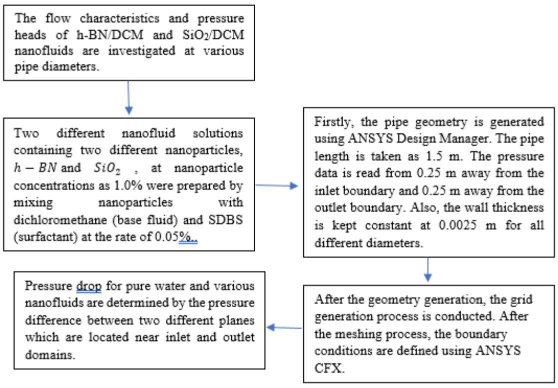

Figure. The graphical summary of the study

Aim

In the present study, the flow characteristics and pressure heads of nanofluids are investigated at various pipe diameters by using numerical methods.

Design & Methodology

After the modelling of the geometry, the grid generation was conducted, follwed by the analyses in CFX. The results were invesigated in terms of pressure drops and flow behaviours.

Originality

Although nanofluids have been located in the center of many thermal and thermodynamic analyses, the scientific research about the energy losses caused by their increased viscosity compared to the base fluids have remained insufficient. This study investigates the pressure losses of several nanofluids and their behaviors in a pipe.

Findings

The trend of variation for the pressure drop curve for nanofluids is similar to that of water. In terms of pressure drop, the transition region for both water and nanofluids is much more sensible to the changes in Reynolds number. Also, it was seen that the viscosity, density and heat transfer coefficient have a direct effect on the obtained pressure drop, independent from the type of fluid investigated and pressure drop is directly affected by the viscosity of the nanofluids. as the pipe diameter increases, the boundary layer thickness decreases and the pipes with smaller diameters have higher performance indexes than that with larger diameters.

Conclusion

The highest increment in pressure drop was in SiO2-DCM which has the largest viscosity of 0.00056 kg/ms and the smallest increment in pressure drop is in DCM which has the lowest viscosity with 0.000413 kg/ms for a constant pipe diameter.

Declaration of Ethical Standards

The authorof this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

h-BN/DCM ve SiO2/DCM Nanoakışkanlarının Başınç Düşümlerinin İncelenmesi

Araştırma Makalesi/Research Article

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ÖZ

Sunulan çalışmada, sayısal yöntemler kullanılarak h-BN/DCM ve SiO2/DCM nanoakışkanlarının akış karakteristikleri ve basınç düşüleri, farklı boru çaplarında incelenmiştir. Kullanılan boru çapları 0,0127 m, 0,0254 m, 0,0381 m, 0,0508 m ve 0,0762 m'dir. Nanoakışkanların hazırlanmasında dikolorometan (DCM) baz akışkan olarak kullanılmış, ve heksagonal bor nitrür ve silika, baz akışkana %1 oranında karıştırılmıştır. Her ne kadar nanoakışkanlar günümüzde birçok termal ve termodinamik analize konu olmuş olsa da, baz akışkana kıyasla viskozitelerindeki artışın sebep olduğu enerji kayıpları ile ilgili araştırmalar yetersiz kalmıştır. Bu çalışma sonucunda da sabit boru çapında basınç düşümünün en yüksek 0,00056 kg/ms ile en yüksek viskoziteye sahip SiO2/DCM nanoakışkanında, en düşük basınç düşümünün de en düşük viskoziteye sahip DCM'de olduğu görülmüştür.

Anahtar Kelimeler: Basınç düşüşü, heksagonal bor nitrür, silika, hesaplamalı akışkanlar dinamiği.

The Investigation of Flow Characteristics and Pressure Drops of h-BN/DCM and SiO_2 Nanofluids

ABSTRACT

The present study is about the investigation of the flow characteristics and pressure heads of h-BN & DCM and SiO2 & DCM nanofluids at various pipe diameters by using numerical methods. The pipe diameters are 0.0127 m, 0.0254 m, 0.0381 m, 0.0508 m, 0.0762 m. Dichloromethane (DCM) was used as base fluid in nanofluid preparation. Hexagonal boron nitride and silica were mixed into the base fluid by 1% when obtaining the nanofluids. Although nanofluids have been located in the center of many thermal and thermodynamic analyses, the scientific research about the energy losses caused by their increased viscosity compared to the base fluids have remained insufficient. This study investigates the pressure losses of several nanofluids and their behaviors in a pipe. It was found out that the highest increment in pressure drop was in SiO2-DCM which has the largest viscosity of 0.00056 kg/ms and the smallest increment in pressure drop is in DCM which has the lowest viscosity with 0.000413 kg/ms for a constant pipe diameter.

Keywords: Pressure drop, hexagonal boron nitride, silica, computational fluid dynamics.

1. INTRODUCTION

Today, nanofluids or nanoparticle containing fluids are widely used throughout the world serving various purposes in a wide range of industries such as; heat pipes [1-7], heat exhangers [8-11], and solar systems [12-15]. Their augmented fluid properties in terms of heat transfer coefficient, viscosity, and thermal conductivity results in the widespread utilization of these fluids.

One of the nanofluids used in this study, hexagonal boron nitride (h-BN), which is white in color, non-toxic and slippery, looks very similar to alumina. The density of the specified nanofluid, 2.27 g/cm3, is the lowest throughout the ceramic materials. Although the crystal structure is similar to the graphite, the major difference between h-BN and graphite is that h-BN is white in color and its electrical conductivity is higher. Besides being an inert material, it does not mix into chemical reactions it is highly resistant when exposed to high temperatures. Moreover, it has a stable behavior when faced with thermal shocks, it has high thermal conductivity and flawless electrical insulation.

In the present study, two different nanofluid solutions containing two different nanoparticles, h-BN and SiO_2, at a concentration of 1.0% were analyzed in a pipe having different diameters by using DCM as the base fluid. Dichloromethane was selected as a base material as it has a boiling temperature about 40°C and it is possible to monitor the bubble formations. Therefore, it has the advantage of providing to easily observe the effects of nanoparticle addition into the base fluid and illustrating the augmentation in heat transfer, even at low temperatures..

2. MATERIAL and METHOD

2.1. Properties of Nanofluids

Table 1 represents the density and dynamic and kinematic viscosity values of DCM and the utilized nanofluids at room temperature. It is clear that adding

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nanoparticles inside dichloromethane, that is to say increasing the nanoparticle concentration, results in an increased viscosity. The viscosities of the nanofluid solutions were higher than that of base fluid. When the rate of increment of viscosity for nanofluid solutions came into question, the solution of silica nanoparticles was more viscous than hexagonal boron nitride nanoparticles. The reason to this result was thought to stem from the solubility of the nanoparticles into the base fluid. In order words, silica nanoparticles dissolved more inside DCM compared to hexagonal boron nitride nanoparticles.

Table 1. Viscosities and densities of DCM and utilized nanofluid solutions

Fluid	Concentration Rate (%)	Density (ρ) (g/cm^3)	Viscosity (μ) (mPa.s)	Kinematic viscosity (ν) (mm^2/s)
DCM	-	1.318	0.41	0.311
h-BN / DCM				
	1.0	1.282	0.51	0.398
SiO_2 / DCM				
	1.0	1.255	0.56	0.446

2.2. Numerical Analysis Method

In the presented study, the pressure differences at the inlet and outlet of a pipe are determined at different Reynolds numbers (varying from 1000 to 100000) for five different pipe diameters. The pipe diameters are 0.0127 m, 0.0254 m, 0.0381 m, 0.0508 m, 0.0762 m.

Firstly, the pipe geometry is generated using ANSYS Design Manager. The pipe length is taken as 1.5 m. The pressure data is read from a distance of 0.25 m from the inlet boundary and from 0.25 m from the outlet boundary. Also, wall thickness is kept constant at 0.0025 m for all different diameters.

After the geometry generation, the grid generation process is conducted. The same meshing procedure is applied to all diameters. It is checked if the results are dependent on the generated solution grid and obtained that increasing the element number higher than 400000 does not change the mesh quality significantly and no vital differences in terms of flow parameters are observed for higher element numbers (the differences are below 0.1% in terms of pressure). For a qualified mesh, it is known that the average skewness value should be kept under 0.33 (ANSYS Fluent User's Guide). The skewness vs. percent mesh volume is given in Figure 1.

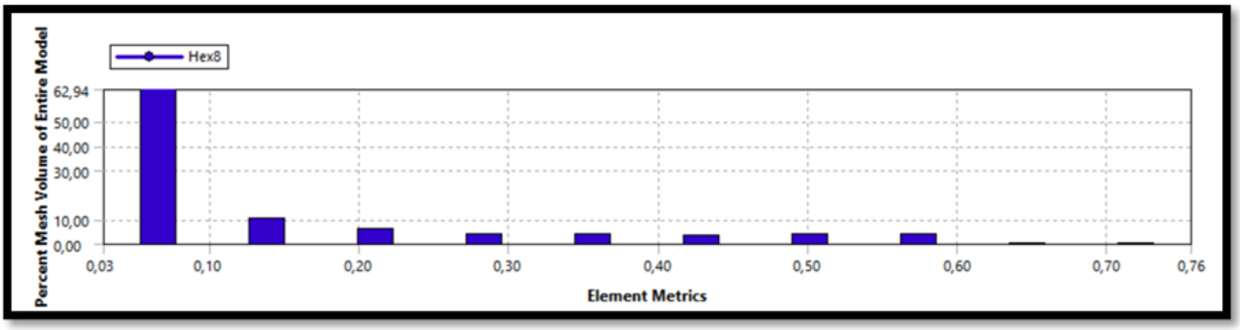

Figure 1. The skewness vs. percent mesh volume

It can be seen from Figure 5 that approximately 63% percent of the mesh volume has a skewness value of 0.03 whereas the maximum skewness obtained is 0.76, which exists at a volume nearly 0%. The generated mesh structure is given in Figure 2.

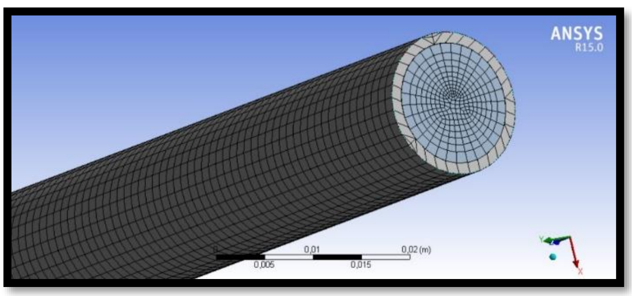

Figure 2. The generated solution grid

After the meshing process, the boundary conditions are defined using ANSYS CFX. Three boundary conditions are defined in the present case; inlet, outlet and wall. Inlet boundary type is selected as normal speed, which is calculated using the Reynolds Number chosen for each specific case. The outlet boundary type is chosen as static pressure and is kept constant for all cases at zero, as the pipe is opened to the atmosphere. The reference pressure is taken as 1 atm, and the wall has nothing specified other than a no-slip boundary condition. The turbulence model is chosen as k-ε which is commonly used in CFD analyses to simulate the flow characteristics for turbulent flows, especially for nonrotating problems. Also, the specified model has an easy convergence behavior if it is implemented in a suitable case. The residual target is chosen as 10-6 to ensure that the problem converges and reveals accurate results. Also, a monitor point in terms of velocity located at approximately at the middle section is applied to check that the case converges. The obtained value of the residuals and the monitor point at the end of the solution stage are given for a random case in Figure 3 and Figure 4, respectively.

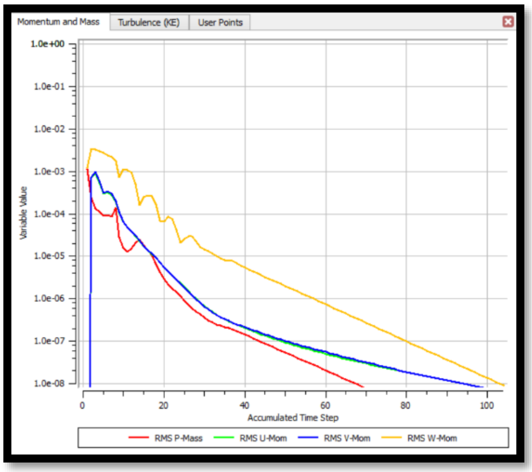

Figure 3: The residuals at the end of the solution

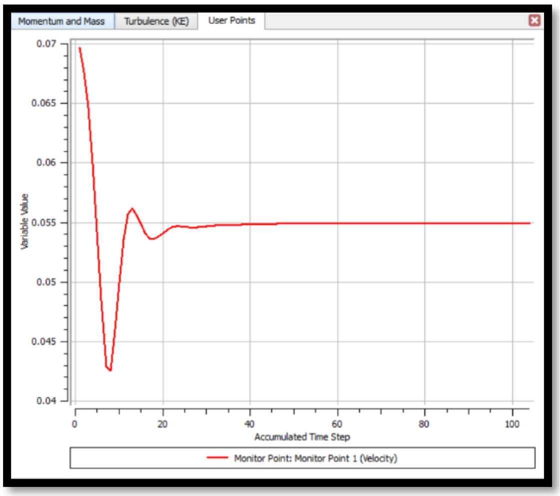

Figure 4. The monitor point (velocity) at the end of the solution

3. RESULTS and DISCUSSION

3.1. Pressure Drops

Pressure drop values for pure water and various nanofluids are determined by the pressure difference between two different planes which are located near inlet and outlet domains. Figs. 5-9 represents the variation of pressure drop for increasing Reynolds numbers at different diameters.

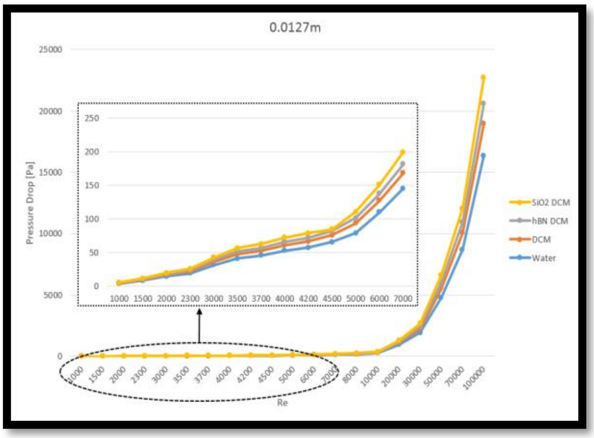

Figure 5. The alteration of pressure drop for increasing Reynolds numbers at 0.0127 m diameter

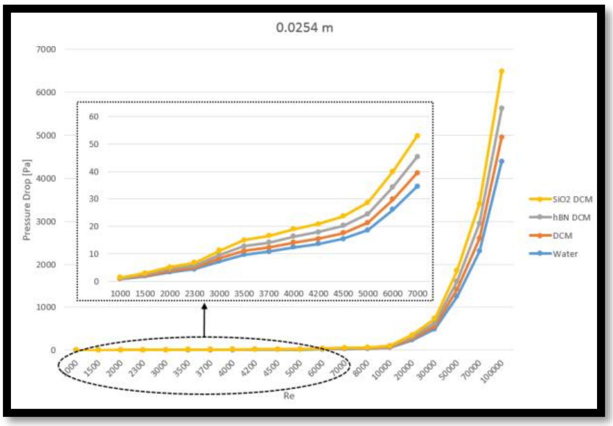

Figure 6. The alteration of pressure drop for increasing Reynolds numbers at 0.0254 m diameter

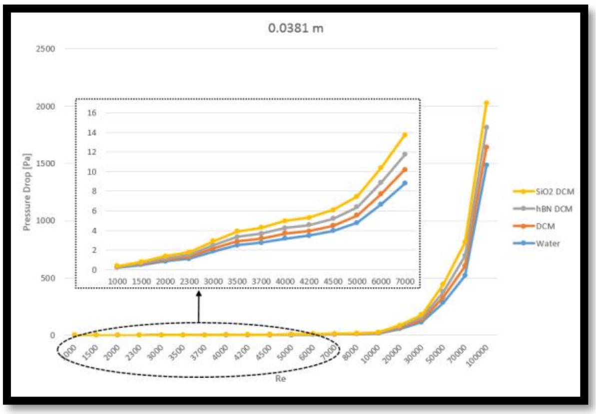

Figure 7. The alteration of pressure drop for increasing Reynolds numbers at 0.0381 m diameter

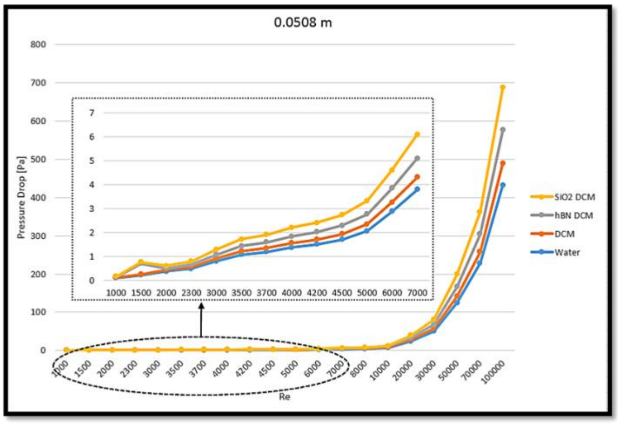

Figure 8. The alteration of pressure drop for increasing Reynolds numbers at 0.0508 m diameter

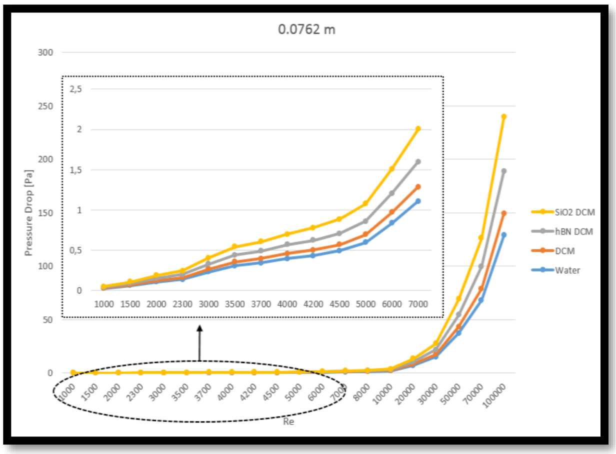

Figure 9. The alteration of pressure drop for increasing Reynolds numbers at 0.0762 m diameter

It is obvious from the above figures that the trend of the pressure drop curve for the nanofluids is not different from that of water despite the fact that the pressure drop amounts of water is much higher than that obtained from the nanofluids. It can be deducted from Figure 9 that the transient region for water and nanofluids is much more sensible to any change in Reynolds Number in terms of pressure drop. In addition, it can be told that viscosity, density and the heat transfer coefficient of the working fluid has a direct effect on the amount of the obtained pressure drop. Although the densities of DCM and SiO2-DCM are equal, they have different pressure drops. This is due to the difference in their viscosities and heat transfer coefficients. For a diameter of 0.0127 m, the pressure drop of water increased by 30.4%, the pressure drop of DCM increased by 30.51%, the pressure drop of hBN-DCM increased by 31.08% and the pressure drop of SiO2-DCM increased by 32% with the increment of Reynolds Number from 2000 to 2300. As a result, one can say that the pressure drop is directly related to the viscosity of the nanofluids. The amount of increment in pressure drop is the highest in SiO2-DCM which has the largest viscosity of 0.00056 kg/ms and the smallest increment in pressure drop is in DCM which has the lowest viscosity with 0.000413 kg/ms. Furthermore, to compare the results depending on the pipe diameters, it can be said that with the increment in the diameter, the pressure drop differences between the fluids gets bigger and the pressure drop values in the laminar and transition region decreases. This is due to the decrement in velocity caused by the increased pipe diameter.

Figures 10, 11, 12, 13 and 14 represent the velocity contours of hBN-DCM, SiO2-DCM, DCM and water for a constant Reynolds number of 10000 for the diameters of 0.0127 m, 0.0254 m, 0.0381 m, 0.0508 m and 0.0762 m, respectively.

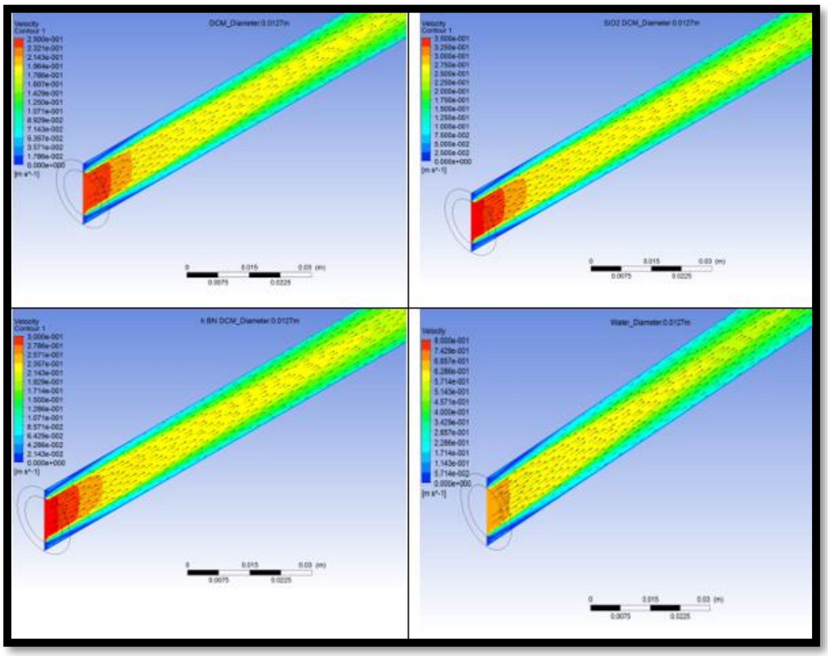

Figure 10. Velocity contours of the nanofluids and water in terms of pipe diameter (d=0.0127m =1/2")

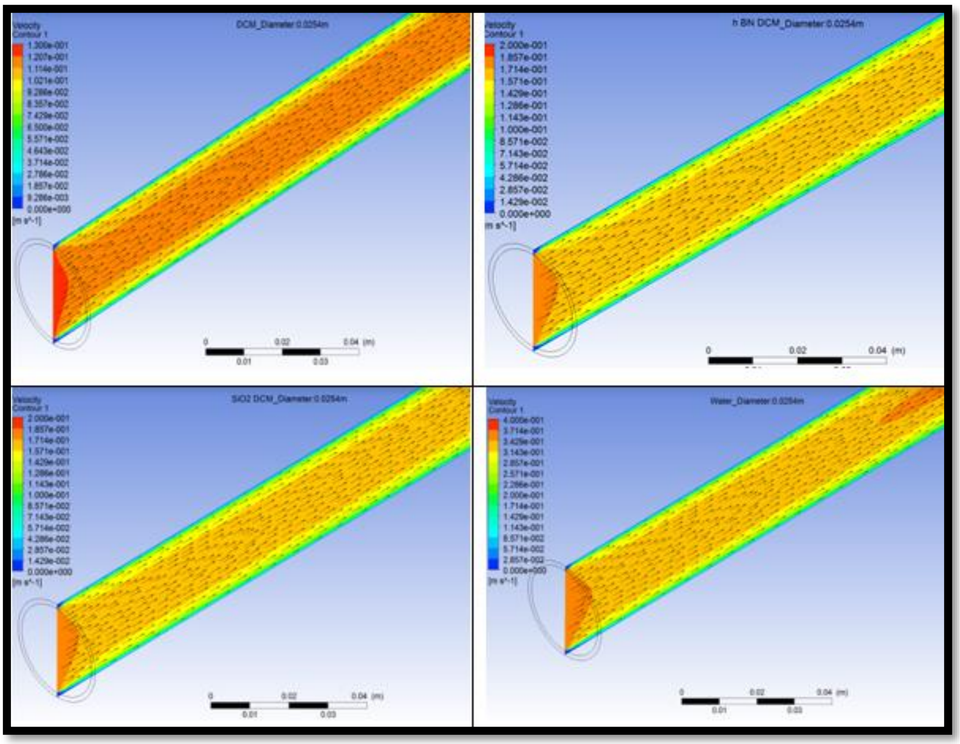

Figure 11. Velocity contours of the nanofluids and water in terms of pipe diameter (d=0.0254m =1")

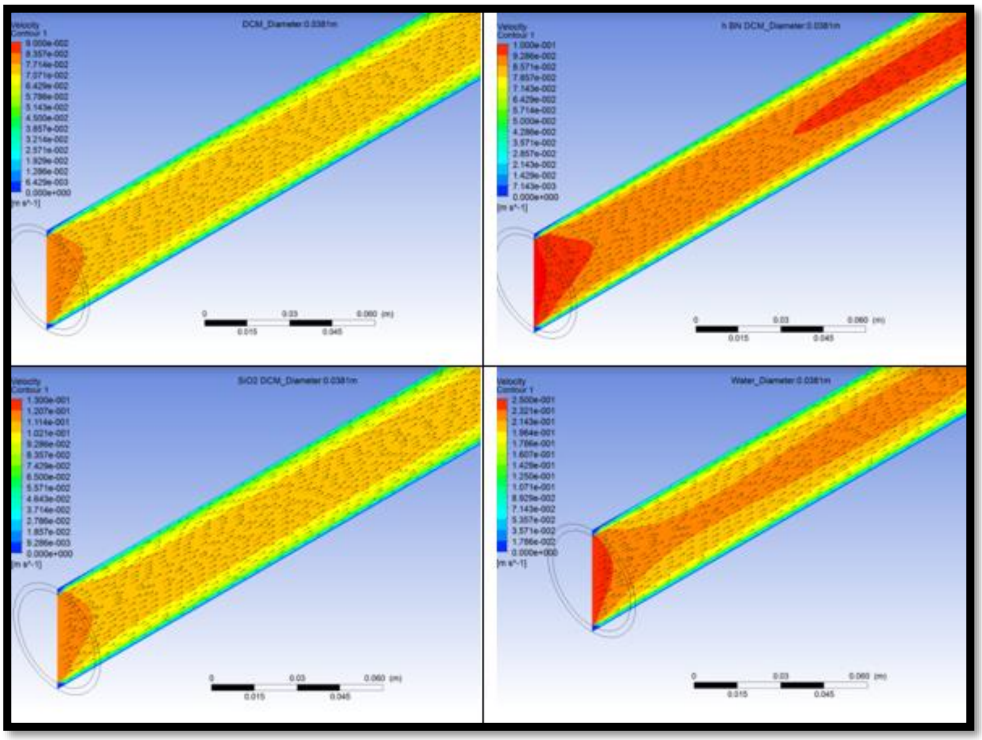

Figure 12. Velocity contours of the nanofluids and water in terms of pipe diameter (d=0.0381m =1½")

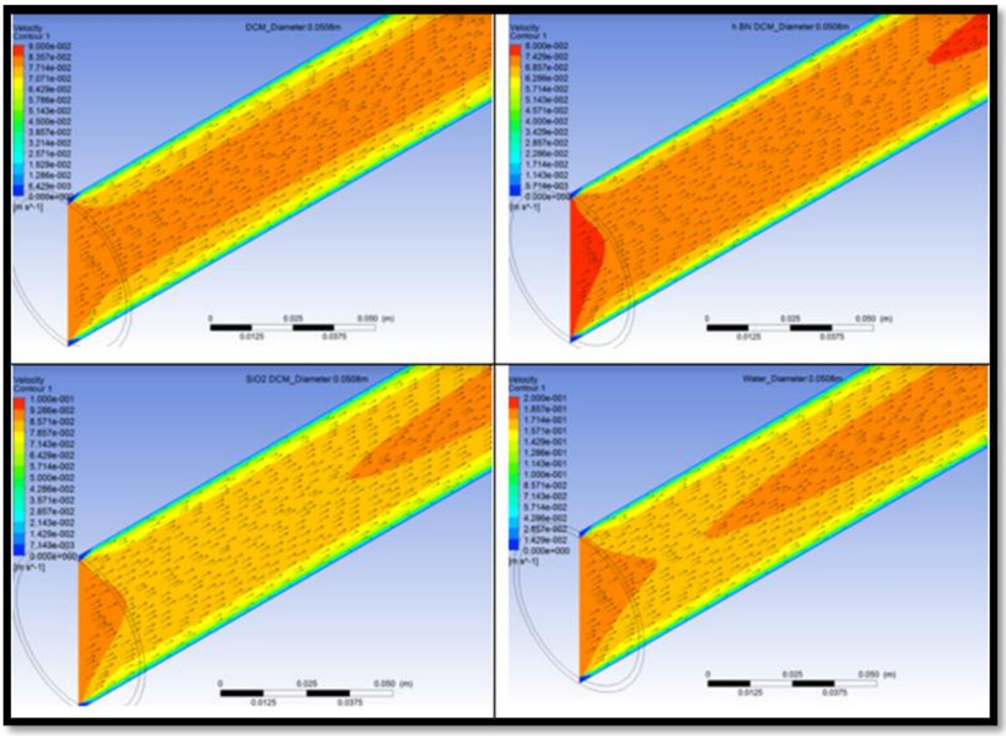

Figure 13. Velocity contours of the nanofluids and water in terms of pipe diameter (d=0.0508m =2")

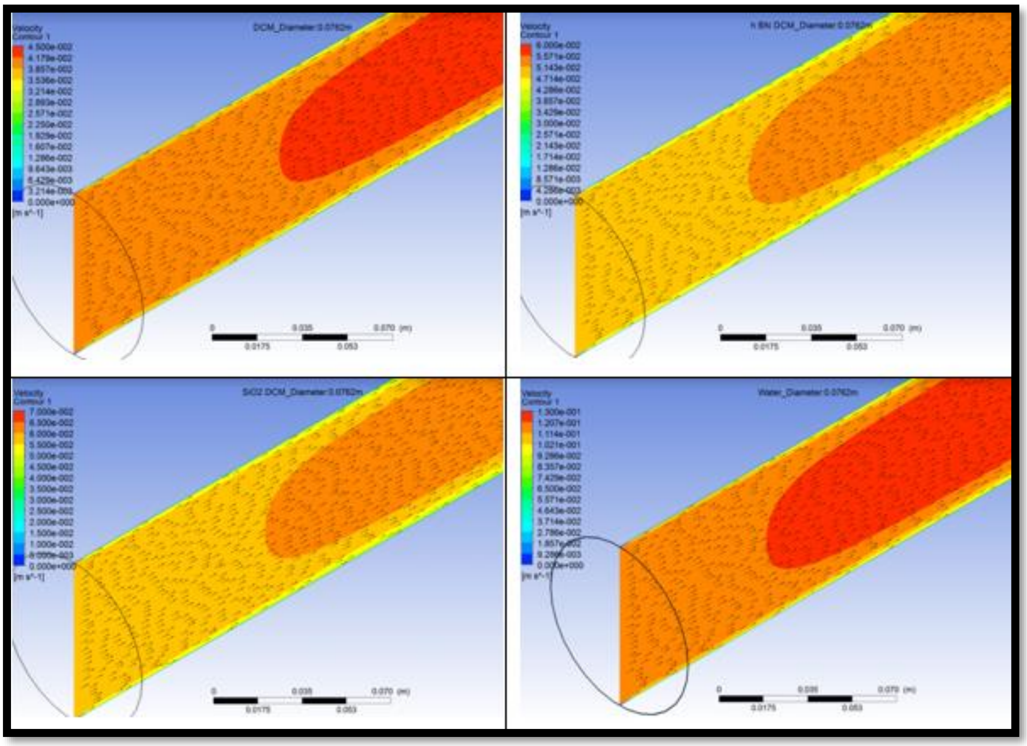

Figure 14. Velocity contours of the nanofluids and water in terms of pipe diameter (d=0.0762m =2½")

The transition from laminar boundary layer to turbulent boundary layer is the longest in DCM and the shortest in water and the boundary layer thickness is also the greatest in DCM as it has the lowest velocity, for all cases. If the diameters are compared, it is clear that the boundary layer thickness gets smaller as the diameter increases and the transition from laminar to turbulent boundary layer the longest at 0.0127 m.

3.2. Performance Index

It is known that the main advantage of nanofluids is that they have higher thermal conductivities [16]. When small particles are added to the base fluid, the viscosity of the nanofluid increases, which also causes an increment in the pressure drop values [17]. In contrary, depending on the weight percentage of the nanofluid, the increment in heat transfer coefficient can end up in a slight decrement in pressure drop. Therefore, viscosity becomes prominent for the determination of the feasibility of the nanofluid for that specific application. To determine the optimum conditions for that application, heat transfer coefficient, viscosity and pressure drop must be taken into consideration [18]. For this purpose, the performance index parameter is defined which is given in Eq 1 [19].

$$\varepsilon = \frac{\frac{h_{nf}}{h_{bf}}}{\frac{\Delta P_{nf}}{\Delta P_{bf}}} \tag{1}$$

Here, h_{nf} is the heat transfer coefficient of the nanofluid and hbf is that of base fluid, and ΔP represents the pressure drop values. If the attained performance index is above one, it is feasible to use a nanofluid; because it has a greater role compared to pressure drop for heat transfer and so, utilization of the nanofluid leads to an improvement in thermal performance. For the present case, DCM was utilized as the base fluid as mentioned previously for the calculations.

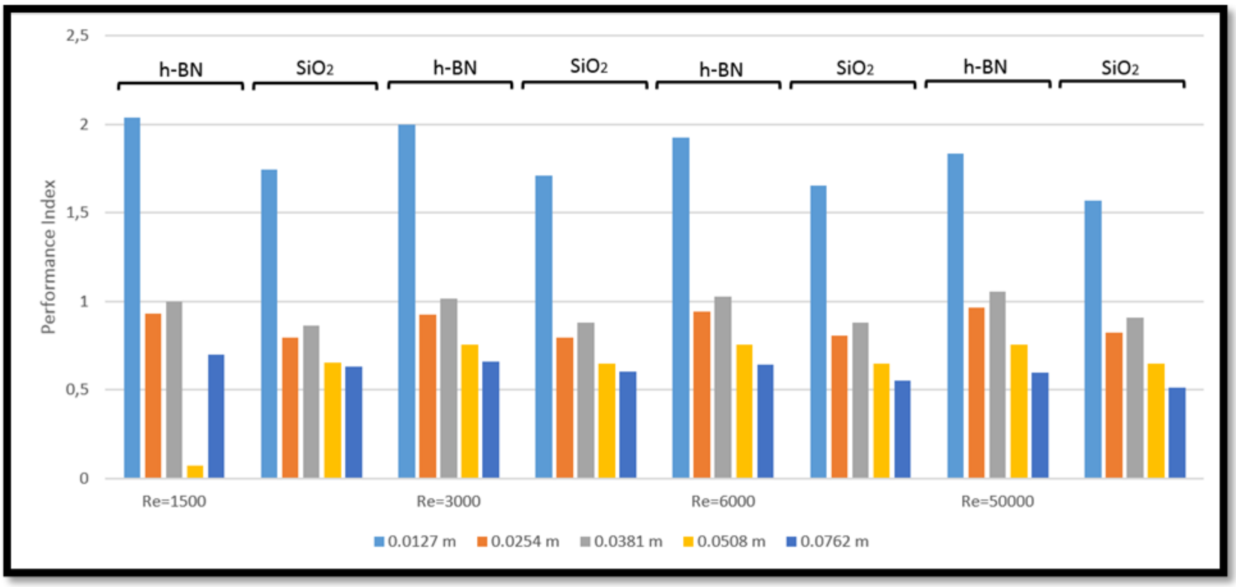

Figure 15. Performance index of nanofluids depending on Reynolds number for various diameters

When Figure 15 is examined, it can be deducted that the smaller diameters have higher performance indexes. For the diameter of 0.0762 m, none of the flow rates have a performance index higher than 1; therefore, it is not feasible to use the specified nanofluids. However; for the diameter of 0.0127 m, both nanofluids have performance indexes higher than 1 for all flow rates.

4. CONCLUSION

The present study investigates the pressure losses of several nanofluids and their behaviors in pipers of various diameters using numerical methods. The used pipe diameters for the analyses are 0.0127 m, 0.0254 m, 0.0381 m, 0.0508 m, 0.0762 m. Dichloromethane (DCM) was used as base fluid in nanofluid preparation. Hexagonal boron nitride and silica were mixed into the base fluid by 1% when obtaining the nanofluids. The pressure drop values for water and the utilized nanofluids are determined by the pressure difference between two different planes located near the inlet and outlet domains.

It was found out that the trend of variation for the pressure drop curve for nanofluids is similar to that of water. However, the only significant difference is that the pressure drop amounts of water are much higher than that of nanofluids, i.e. the order of the pressure drops vary.

In terms of pressure drop, the transition region for both water and nanofluids is much more sensible to the changes in Reynolds number. Also, it was seen that the viscosity, density and heat transfer coefficient separately directly affect the amount of pressure drop, independent from the fluid investigated and pressure drop is directly related to the viscosity of the nanofluids. In other word, the nanofluid with the largest viscosity (SiO2 – DCM) has the highest increment in pressure drop and vice versa for DCM.

When comparing the pipe diameters, it can be said that the increment in pipe diameter causes the pressure drop between the fluids to get larger and the pressure drop values in laminar and transition regions decreases. This result is due to the decrement in velocity caused by the increased pipe diameter. Also, from the obtained results it can deducted that as the pipe diameter increases, the boundary layer thickness decreases and the pipes with smaller diameters have higher performance indexes than that with larger diameters.

Finally, the transition region from laminar boundary layer to turbulent boundary layer is the longest in DCM and shortest in water and the boundary layer thickness of DCM is the greatest, as it has the lowest velocity compared to other fluids in the same pipe diameter.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Zeynep AYTAÇ: Perofrmed the experiments and analyse the results. Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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