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HEAT TRANSFER EFFICIENCY USING NANO FLUIDS: A COMPARATIVE ANALYSIS OF EXPERIMENTAL AND SIMULATION DATA

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1 INTRODUCTION

This chapter presents a comprehensive overview of heat exchangers, Nano fluids, and the Ansys 2021 R1 software, followed by a detailed explanation of the study objectives. The subsequent subsections provide an in-depth discussion of each aspect covered in this chapter.

According to Gugulothu et al., (2017) Maintenance of heat exchanger's is one of the most challenging tasks in the industry today. Much work has been done in recent years to develop cost-effective strategies to improve the performance of heat exchanger's. [1]

According to Akurek et al. (2018) in recent years, researchers have tried to produce smaller and lighter heat exchanger's. Many industries use common heat transfer fluids such as ethylene glycol, water, and oil. Due to their poor thermal properties, liquid heat transfer fluids have lower thermal conductivity than solids, which limits their efficiency and compactness in engineering equipment.

Various techniques may be employed for the purpose of enhancing the efficiency of heat transfer. Conventional heat transfer involves solid particles suspended in liquids such as polymers, metals, and non-metallic particles. Although they improve thermal performance, millimeter or even micrometer particles cannot be used in many applications. Since its viscosity is low, the flow channels are quickly clogged, which leads to a rapid settling of particles and a drop in fluid pressure. To solve these problems, the scattering of nanometer-sized particles can be used. Instead of these particles, a base fluid containing Nano particles ranging in size from1 to 100 nm is used for this specific purpose. These suspensions, known as Nano fluids, are among the latest innovations and are used in many industries. These properties of Nano fluids make them useful in various fields, such as electrical engineering, chemistry, automotive, heating and cooling systems, microelectronics, and others. [2]

1.1 Nano fluids

According to Vijayan et al. (2019) Nano fluids are a relatively new type of fluid engineered to improve heat transfer properties. [3] They are made by dispersing tiny particles, known as nanoparticles, into a base fluid such as water, oil, or ethylene glycol. These nanoparticles, which range in size from 1 to 100 nanometers, can be made from various materials, including metals, oxides, carbides, and carbon-based materials.

1.2 ANSYS 2021 R1

This is the latest version of leading engineering simulation software that provides comprehensive tools for modeling, simulating, and analyzing various engineering challenges. This release introduces several enhancements and new features aimed at improving simulation accuracy, efficiency, and user experience, making it an indispensable tool for engineers and designers across multiple industries.

1.3 Research objectives

The following research tasks of the planned research work:

a) Evaluation of various Nano fluid and solvent combinations in comparison to conventional fluids.

b) Ranking of different alternatives based on their performance.

2 LITERATURE REVIEW

2.1 Purpose

The objective of this literature review is to analyze the existing research on the application of Nano fluids in heat transfer systems, focusing on the comparison of various nanoparticles and base fluids. Nano fluids, which are formed by dispersing nanoparticles in base fluids, have gained significant attention due to their enhanced thermal conductivity and potential to improve the performance of cooling and heating systems. This review aims to provide a detailed understanding of the role of Nano fluids in enhancing heat transfer efficiency.

The review covers the following key areas:

- Basic Properties and Characteristics: It includes a detailed study of the fundamental properties of Nano fluids, such as thermal conductivity, viscosity, and stability, which directly influence heat transfer performance.
- Performance Comparison: It highlights the comparative study of different nanoparticles like metals, metal oxides, and carbon-based materials, along with base fluids like water, ethylene glycol, and oils, to understand their impact on heat transfer applications.
- Theoretical and Experimental Studies: This section reviews various theoretical models and experimental research that describe the heat transfer enhancement mechanism in Nano fluids.
- Practical Applications: The practical use of Nano fluids in different heat transfer systems such as cooling systems, solar energy systems, and industrial applications is also discussed.
- Challenges and Limitations: This part focuses on identifying major challenges in the use of Nano fluids, such as stability issues, high cost, and environmental impact, which need to be addressed for their large-scale adoption.

The overall purpose of this review is to provide a comprehensive understanding of the current progress in nanofluid-based heat transfer applications and identify areas that require further research for practical implementation.

3 METHODOLOGY

The methodology for this research began with identifying the problem through a comprehensive literature review, focusing on the comparative analysis of Nano fluids for heat transfer applications. We selected a shell and tube heat exchanger with specific dimensions from Labvision Technologies, Ujjain, M.P., and prepared nanofluid mixtures by dispersing nanoparticles at a 5% volume concentration in two base fluids. The experimental procedure involved passing these mixtures through the heat exchanger while circulating hot water in the shell, with exit temperatures measured across five trials for each combination. To validate these experimental findings, we modeled the heat exchanger in Ansys R21 software, replicating the experimental conditions. The simulation results were then compared with experimental data to rank the Nano fluids based on their thermal performance, ensuring the accuracy and reliability of our conclusions.

3.1 Experimental setup used in Research Work

The experimental setup comprises two primary subsystems: the heating subsystem and the shell-and-tube heat exchanger. The heating subsystem is designed to generate hot water for the experiment, which flows through the outer tube of the shell-and-tube heat exchanger. The cooling subsystem, incorporating a tube heat exchanger, cools the hot water using Nano fluids to maintain a stable inlet temperature within the system loop.

The shell-and-tube heat exchanger, a crucial component of the system, features a shell with a diameter of 1 meter and a length of 4 meters. Various Nano fluids, with water and ethylene glycol as base fluids, are utilized to flow inside the tube of the heat exchanger to analyze the resultant temperature differences.

4 PROBLEM FINDING AND SOLUTION

The research methodology began with an in-depth literature review to identify the research problem, focusing on the comparative analysis of Nano fluids for heat transfer applications. For the experimental study, a shell and tube heat exchanger with specified dimensions was procured from Labvision Technologies, Ujjain, M.P. Nano fluid mixtures were formulated by dispersing nanoparticles into two different base fluids, maintaining a fixed volume concentration of 5%. During the experimentation, the prepared Nano fluids were passed through the heat exchanger, while hot water was circulated in the shell, and the exit temperatures were recorded over five trials for each combination. To validate the accuracy of experimental results, a virtual model of the heat exchanger was developed using Ansys R21 software, ensuring that the simulation conditions closely matched the experimental setup. The simulation results were then compared with the experimental data, allowing the performance of different Nano fluid combinations to be evaluated and ranked based on their heat transfer efficiency. This systematic approach ensured reliable results, providing a clear understanding of the thermal performance of the tested Nano fluids.

4.1 Problem Finding

Based on the survey of literature the following problem was formulated:

"Comparative Analysis of Nano Fluids used for Heat Transfer Applications"

4.2 Solution of Found problem

Following steps were undertaken in order to solve the research problem:

1. Experimentally, and by
2. Simulation

Here we are going to validate the value of simulation by experimental results

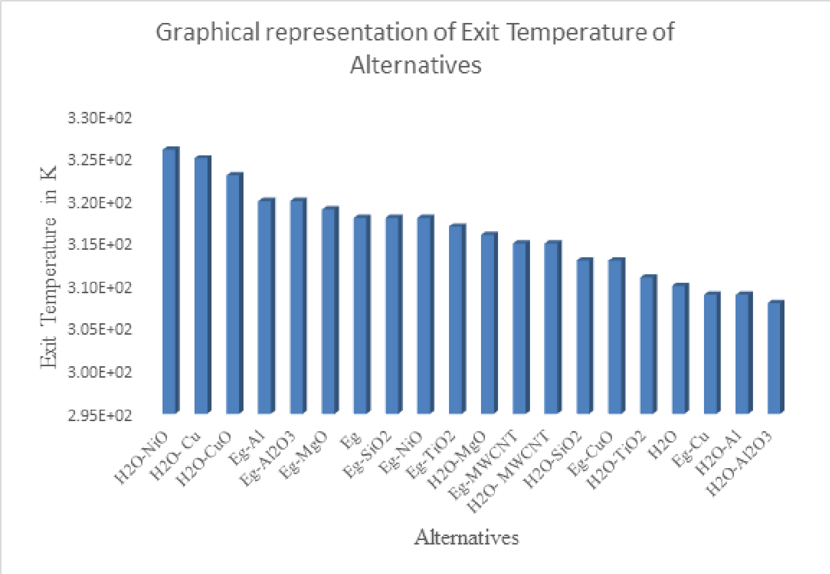
5 RESULTS AND DISCUSSION

In this chapter we are discussing about result obtain in experimental and simulation both

5.1 Experimental Results

Table 5.1: Exit Temperature

S.No	Alternatives	Exit Temperature (K)Experimentation Approach	Exit Temperature (K)Experimentation Approach
1.	H_2O-NiO	325.77	3.26E+02
2.	H_2O- Cu	324.65	3.25E+02
3.	H_2O-CuO	322.79	3.23E+02
4.	Eg-Al	320.30	3.20E+02
5.	Eg-Al_2O_3	320.17	3.20E+02
6.	Eg-MgO	319.39	3.19E+02
7.	Eg	317.59	3.18E+02
8.	Eg-SiO_2	318.05	3.18E+02
9.	Eg-NiO	317.62	3.18E+02
10.	Eg-TiO_2	316.75	3.17E+02
11.	H_2O-MgO	315.5	3.16E+02
12.	Eg-MWCNT	315.08	3.15E+02
13.	H_2O- MWCNT	314.94	3.15E+02
14.	H_2O-SiO_2	313.37	3.13E+02
15.	Eg-CuO	312.78	3.13E+02
16.	H_2O-TiO_2	310.77	3.11E+02
17.	H_2O	310.18	3.10E+02
18.	Eg-Cu	309.33	3.09E+02
19.	H_2O-Al	308.77	3.09E+02
20.	H_2O-Al_2O_3	307.75	3.08E+02

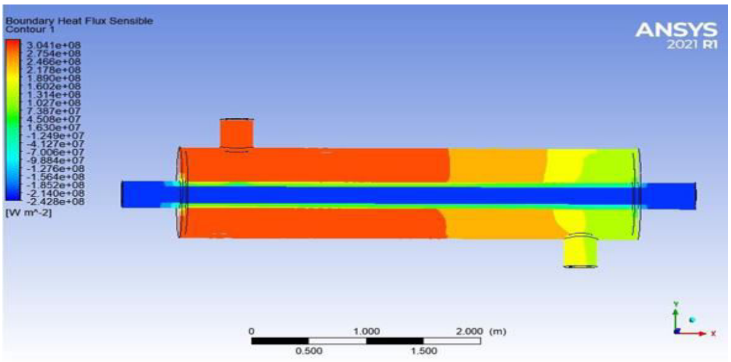


Graph 5.1: Maximum Exit Temperature for Different Alternatives

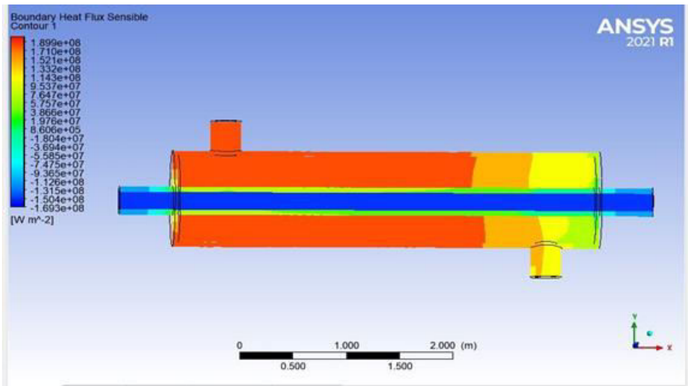
Graph 5.1 Shows that the combination of H_2O-NiO shows the maximum temperature 3.26E+02K, and scores rank 1. In the similar manner the rank obtained by the combination H_2O- Cu shows the rank 2 with the value of temperature as 3.25E+02K. Proceeding in the same manner, one can find that the Nano fluid H2O-CuO scores rank 3 with the value of maximum temperature is equal to 3.23E+02K. For rank 4 two alternatives, namely, Eg-Al2O3 and Eg-El appear, as they scored the value of temperature as 3.20E+02K. For rank 5, the Nano fluid Eg-MgO seems to be suitable as it scores the value of maximum temperature equals to 3.19E+02K. In the similar manner, for rank 6 the Nano fluid Eg, Eg-SiO_2 and Eg-NiO scores temperature equals to 3.18E+02K. For rank 7, the Nano fluid Eg-TiO_2, scores the value of temperature equals to 3.17E+02K, Appears at rank 7 and with the value of temperature equal to 3.54E+02K, H2O-MgO at rank 7. At rank 8, the combination of Eg-MWCNT and H_2O- MWCNT appears with the temperature value of 3.15E+02K, Combination H_2O-SiO_2 and Eg-CuO scores rank 9 with the value of temperature to 3.13E+02K. For rank 10, alternatives, H_2O-TiO_2 appear with value of temperature equal to 3.11E+02K. In the similar manner, the alternatives, H_2O scores the rank 11 with value of temperature equal to 3.10E+02K. For rank 12 the combination of Eg-Cu and H_2O-Al seems to be suitable with the value of maximum temperature equal to 3.09E+02K. and finally for rank 13, alternatives, namely ethylene H_2O-Al_2O_3 with the value of maximum temperature equal to 3.08E+02K.

5.2 Simulation Results

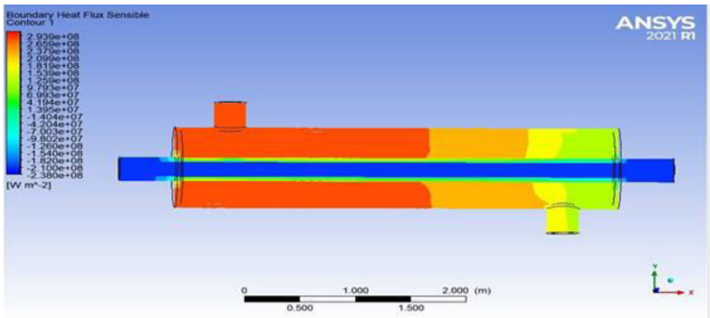
This Figures 5.1 Represents the results obtained for maximum heat flux.



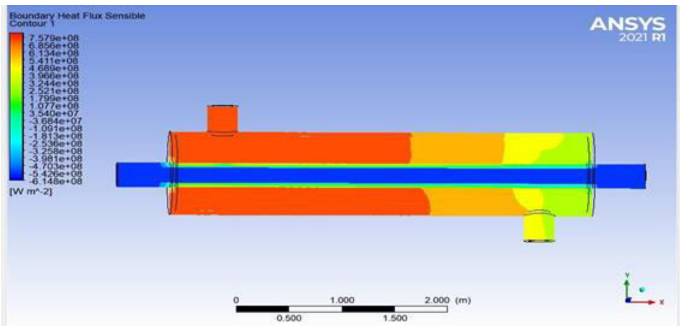
a) H_2O-SiO_2



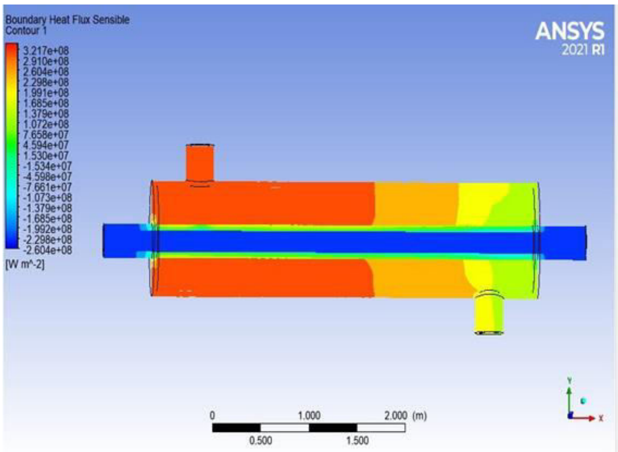
b) EG-SiO_2



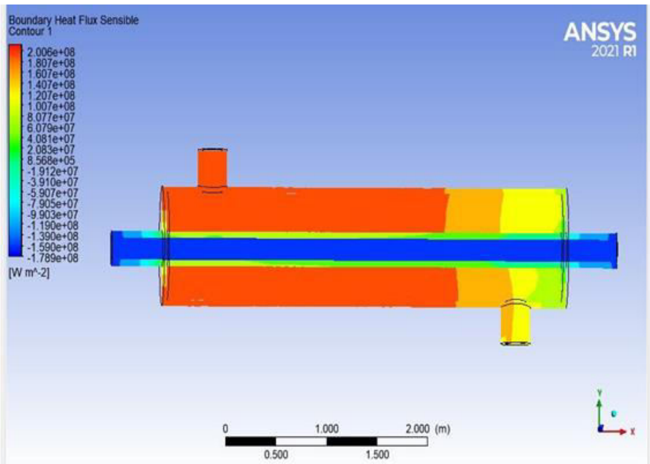
c) H_2O-MVCNT



d) EG-MVCNT



e) H_2O-Al



f) EG-Al

5.3 Validation of Results

For the purpose of validation of results, experimental approach was used, under which, a shell and tube exchanger of the same dimensions was tested, with different Nano fluids, and the results were recorded as follows:

Table 5.3: Validation of Results

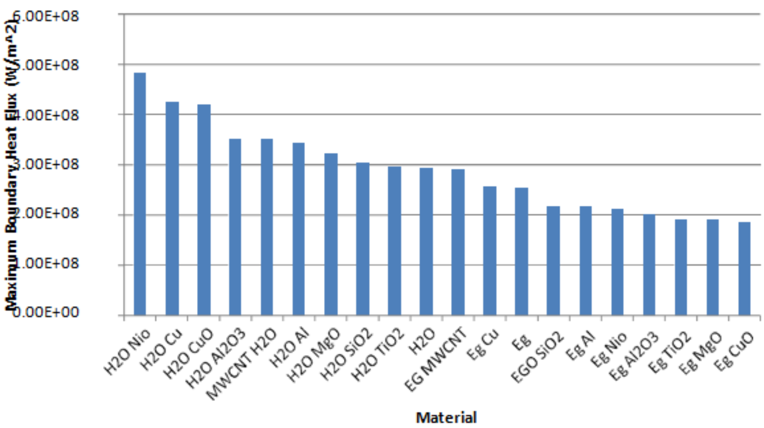
S. No	Alternatives	Exit Temperature (K)Simulation Approach	Exit Temperature (K)Experimentation Approach	Percentage Error (%)
1	H_2O-NiO	3.58E+02	3.26E+02	9.35
2	H_2O- Cu	3.57E+02	3.25E+02	9.38
3	H_2O-CuO	3.57E+02	3.23E+02	10
4	Eg-Al	3.56E+02	3.20E+02	10.65
5	Eg-Al_2O_3	3.56E+02	3.20E+02	10.65
6	Eg-MgO	3.56E+02	3.19E+02	10.96
7	Eg	3.54E+02	3.18E+02	10.71

8	Eg-SiO_2	3.54E+02	3.18E+02	10.71
9	Eg-NiO	3.52E+02	3.18E+02	10.14
10	Eg-TiO_2	3.52E+02	3.17E+02	10.46
11	H_2O-MgO	3.52E+02	3.16E+02	10.77
12	Eg-MWCNT	3.50E+02	3.15E+02	10.52
13	H_2O- MWCNT	3.50E+02	3.15E+02	10.52
14	H_2O-SiO_2	3.50E+02	3.13E+02	11.16
15	Eg-CuO	3.49E+02	3.13E+02	10.87
16	H_2O-TiO_2	3.48E+02	3.11E+02	11.22
17	H_2O	3.47E+02	3.10E+02	11.26
18	Eg-Cu	3.46E+02	3.09E+02	11.29
19	H_2O-Al	3.45E+02	3.09E+02	11
20	H_2O-Al_2O_3	3.45E+02	3.08E+02	11.33

For validation, we found that Kumar et al. (2019) observed that increasing the tube length significantly enhances heat transfer efficiency, resulting in a 12% improvement in exit temperature when the tube length was extended by 25% and Gupta et al (2020) studied CFD analysis showing that as the tube diameter increases, the heat transfer rate improves, but only up to a certain point. A 10% increase in diameter led to a 5% improvement in the heat transfer rate.

5.4 Discussion

This Graph 5.2 Shows the details of maximum heat flux obtained for different alternatives as well asthe rankings of materials.



Graph 5.2: Maximum Boundary Heat Flux for Different Alternatives

Graph 5.2 Shows that the combination of H2O-NiO shows the maximum value of heat flux, 4.83E+08 W/m^2, and scores rank 1. In the similar manner the rank obtained by the combination H2O-Cu shows the rank 2 with the value of maximum heat flux as 4.24E+08 W/m^2. Proceeding in the same manner, one can find that the nanofluid H2O-CuO scores rank

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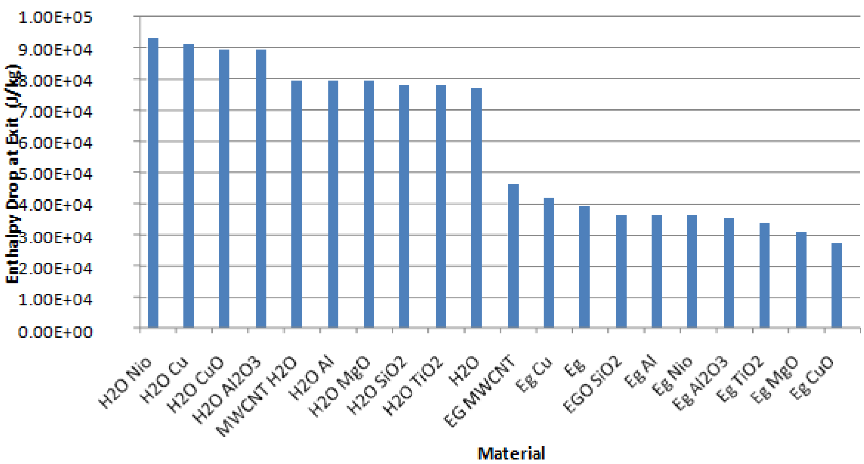
3 with the value of maximum heat flux is equal to 4.19E+08 W/m^2. For rank 4 four alternatives, namely, A2O-Al2O_3 and H2O-TiO2 appear, as they scored the value of maximum heat fluxes as 3.53E+08 W/m^2. For rank 5, the nanofluid H2O-MgO seems to be suitable as it socres the value of maximum heat flux equals to 3.43E+08 W/m^2. In the similar manner, the nanofluid H2O-Al scores heat flux equals to 3.22E+08 W/m^2. For rank 7, the nanofluid H2O-SiO2, scores the value of heat flux equals to 3.04E+08 W/m2. Water appears at rank 8 with the value of heat flux equals to 2.96E+08 W/m^2. At rank 9, the combination H2O-MWCNT appears with the heat flux value of 2.94E+08 W/m^2, whereas the combination of ethylene glycol-copper appears at the rank 10 with the value of heat flux equals to 2.90E+08 W/m^2.

Combination of ethylene glycol-NiO scores rank 11 with the value of heat flux equals to 2.58E+08 W/m^2, whereas the alternative ethylene glycol-CuO obtains rank 12 with heat flux equals to 2.54E+08 W/m^2. For rank 13, two alternatives, ethylene glycol-TiO2 and ethylene glycol-al2O3 appear with values of heat fluxes equal to 2.18E+08 W/m^2. In the similar manner, the combination of ethylene glycol-MgO scores the rank 14 with heat flux value of 2.13E+08 W/m^2. For rank 15 the combination of ethylene glycol-aluminum seems to be suitable with the value of maximum heat flux equals to 2.01E+08 W/m^2. For rank 16, two alternatives, namely ethylene glycol-SiO2 and ethylene glycol appear with the value of maximum heat flux equal to 1.90E+08 W/m^2, and finally for rank 17, the alternative ethylene glycol-MWCNT appears with the maximum heat flux is equal to 1.86E+08 W/m^2.



Graph 5.3: Enthalpy Drop at Exit for Different Alternatives

Graph 5.3 shows the values of exit enthalpy drops for different Nano fluids, which in turn, describes their rankings for the criterion. It may be found that the alternative H2O-Nio scores the rank 1 with the enthalpy drop is equal to 9.30E+04 J/kg. Proceeding in the similar manner, for the rank 2, the alternative H2O-Cu with exit enthalpy drop of 9.10E+04 seems to be appropriate. For rank 3, two alternatives, namely H2O-CuO and H2O-Al2O3 appear with the value of exit enthalpy drop equal to 8.90E+04 J/kg. Similarly, the 3 alternatives, namely H2O-MWCNT and H2O-Al and H2O-MgO appear at the rank 4 with exit enthalpy drop equals to 7.90E+04 J/kg. For rank 5, alternatives H2O-SiO2 and H2O-TiO2 appear with exit enthalpy drop equals to 7.80E+04 J/kg. Proceeding in the similar manner, for rank 6 water seems to be appropriate with the exit enthalpy drop of 7.70E+04 J/kg, and for rank 7, the alternative ethylene glycol-MWCNT seems to be appropriate with the value of exit enthalpy drop equals to 4.60E+04 J/kg.

6 CONCLUSION

The present research work focused on investigating the application of various combinations of Nano fluids and base fluids in a heat exchanger to enhance its thermal performance. For this study, ten different types of nanoparticles were utilized with two base fluids, namely water and ethylene glycol, maintaining a fixed volumetric concentration of 5%. The study primarily aimed to evaluate three thermal properties: maximum heat flux, enthalpy drop at the outlet, and exit temperature. In the final stage of the research, a statistical approach using relative standard deviation was applied to obtain a consistent set of results, which were further validated through experimental analysis.

The key conclusions derived from the research are as follows:

a) Among all the tested combinations, the nanofluid consisting of H2O-NiO demonstrated the best thermal performance, making it the most suitable alternative for heat exchanger applications.

b) Water was identified as the most effective base fluid for heat exchangers, as it showed superior thermal performance in most of the tested combinations.

The findings from this research provide valuable insights into selecting appropriate Nano fluids and base fluids for improving heat exchanger efficiency.

6.1 Limitations of the Research

The limitations of this research work can be identified from the following points:

a) The study was conducted using a limited range of materials, which restricts the scope of the research;

b) The research was confined to a specific volumetric concentration of Nano fluids in base fluids, limiting the possibility of exploring different concentration levels; and

c) Only a selected set of thermal properties, such as maximum heat flux, enthalpy drop, and exit temperature, were considered, which limits a comprehensive thermal performance analysis.

Thus, the findings of this research are based on specific conditions, and further investigations with a broader range of materials, concentrations, and thermal properties are recommended to achieve more generalized results.

6.3 Future Scope of the Research

The future scope of this research work can be outlined as follows:

a) Future studies may focus on exploring a wider variety of nanoparticles to gain a more comprehensive understanding of their impact on heat transfer performance;

b) Further research can be conducted by considering a broader range of volumetric concentrations of nanoparticles in base fluids to analyze their influence on thermal efficiency; and

c) Expanding the scope of research by incorporating a larger set of thermal properties may provide more accurate and detailed insights into the performance of Nano fluids in heat exchangers.

Such extended research can contribute to a deeper understanding of Nano fluids and their potential applications in enhancing heat transfer efficiency.

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