A COMPARATIVE ANALYSIS OF NANOFLUIDS FOR HEAT TRANSFER ENHANCEMENT: EXPERIMENTAL VS. SIMULATION RESULTS

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1 INTRODUCTION

This chapter provides an overview of heat exchanger's, nanofluids, Ansys 2021 R1 Software and ends with a breakdown of the study objectives, details of which are Provided in the further subsections.

Nivedini et al (2020) state that the industry mainly uses thermal energy for its heating and cooling systems [1]. Many industrial applications require high heat transfer (Karuppasamy et al., 2019) [2].

Gugulotu et al. (2017) state that methods to improve heat transfer have been developed in recent decades and are now widely used in heat exchanger's in industrial, chemical and automotive industries. In many industrial processes, the working fluid is heated or cooled by heat exchanger's. They can be used for heat recovery from superheated steam cooling in engine cooling systems, oil cooling, air conditioning and refrigeration systems, dairy and chemical industries, pharmaceutical industries, and refineries. They significantly reduce production costs by eliminating the use of an external heat source [3]. Cupradit et al. (2021) state that heat exchangers are used to efficiently transfer heat from one fluid (gas or liquid) to another [4]. The term heat exchanger has become a buzzword in heating engineering as it is essential for many industries that need to reduce their heating bills (Chourasia et al., 2020) [5].

1.1 Research objectives

The following research tasks of the planned research work:

a) Comparison of different combinations of nanofluids and solvents with conventional fluids
   - Investigation of thermal properties of a heat exchanger with nanofluids.

b) Ranking of different alternatives.
   - Ranking of nanofluids in regards to their suitability in the heat exchanger.
   - Investigations on best basefluid.

2 LITERATURE REVIEW

2.1 Purpose

The purpose of this literature review is to critically analyze the current state of research on nano fluids in heat transfer applications, with a focus on comparing different types of nanoparticles and base fluids. Nano fluids, colloidal suspensions of nanoparticles in base fluids, have emerged as promising alternatives to conventional heat transfer fluids due to their superior thermal conductivity and potential to improve efficiency in cooling and heating systems.

This review will explore several key areas:

- Fundamentals and Properties: Examination of the fundamental characteristics of nanofluids, including thermal conductivity, viscosity, and stability, to understand how these properties influence heat transfer.
- Comparative Analysis: Analysis of various types of nanoparticles (e.g., metallic, oxide, carbon-based) and base fluids (e.g., water, ethylene glycol, oils) used in nanofluids, highlighting their performance differences in heat transfer applications.
- Theoretical and Experimental Insights: Review of theoretical models and experimental studies that explain the mechanisms behind heat transfer enhancement in nanofluids.
- Practical Applications: Evaluation of the use of nanofluids in real-world heat transfer systems, such as cooling systems, solar thermal applications, and industrial processes.
- Challenges and Limitations: Identification of the main challenges associated with the use of nanofluids, including issues related to stability, cost, and environmental impact.

3 METHODOLOGY

The methodology for this research began with identifying the problem through a comprehensive literature review, focusing on the comparative analysis of nanofluids 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 nanofluids based on their thermal performance, ensuring the accuracy and reliability of our conclusions.

4 PROBLEM FINDING AND SOLUTION

In my comprehensive literature survey spanning the last two decades, I identified several research gaps in the analysis of nanofluids for heat transfer applications. Among the numerous issues uncovered, I have selected a specific problem that I aim to address through a combination of experimental investigation and simulation using ANSYS R21 software. This chapter elaborates on the formulation of the problem and outlines the methodologies for solving it. The subsequent sections detail the experimental setup, the simulation framework, and the integration of findings from both approaches. This dual approach not only seeks to provide a robust solution to the identified problem but also aims to enhance our understanding of nanofluids' thermal properties. The results from this research are expected to contribute significantly to the optimization of nanofluids in practical heat transfer systems, thereby addressing a critical gap in the existing body of knowledge.

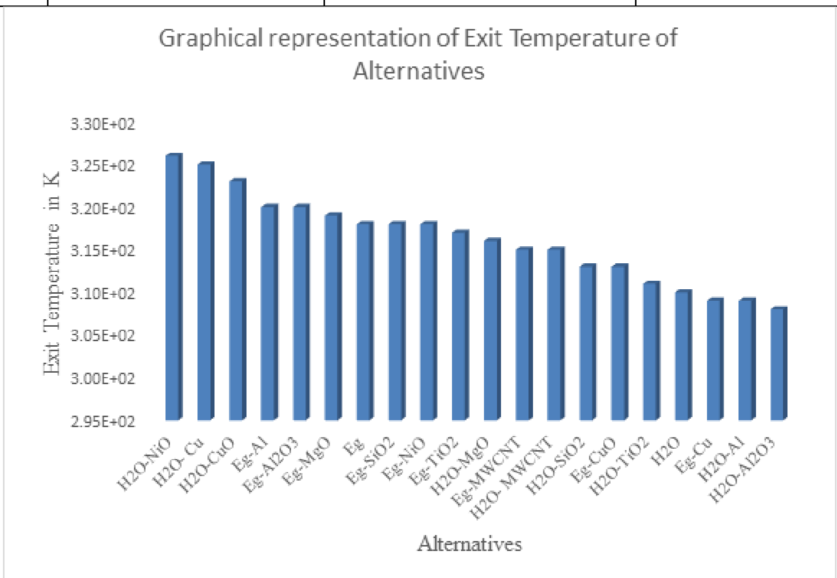
5 RESULTS AND DISCUSSION

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



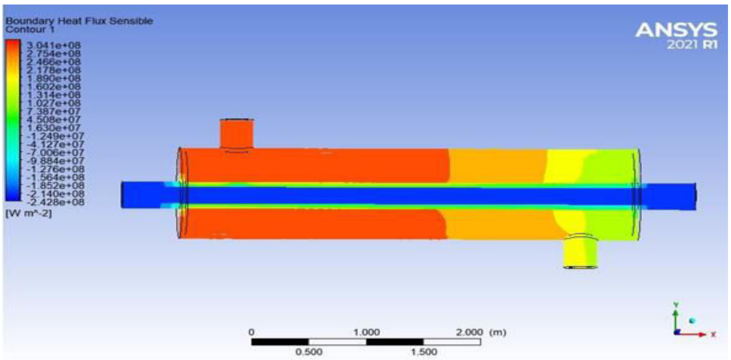
Graph 5.1: Maximum Exit Temperature for Different Alternatives

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

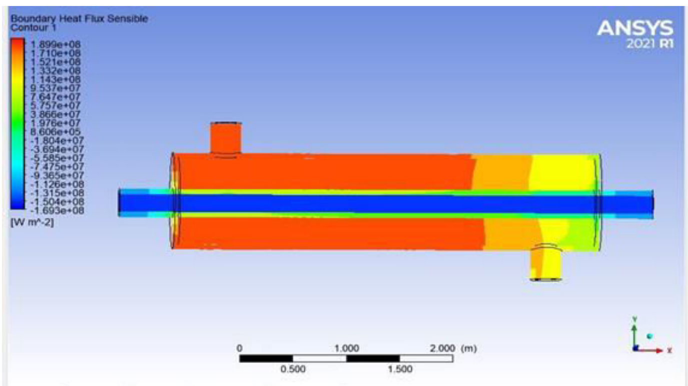
H_2O- Cu shows the rank 2 with the value of temperature as 3.25E+02K. Proceeding in the same manner, one can find that the nanofluid H2O-CuO scores rank 3 with the value of maximum temperature is equal to 3.23E+02K. For rank 4 two alternatives, namely, Eg-Al2O_3 and Eg-El appear, as they scored the value of temperature as 3.20E+02K. For rank 5, the nanofluid Eg-MgO seems to be suitable as it socres the value of maximum temperature equals to 3.19E+02K. In the similar manner, for rank 6 the nanofluid Eg, Eg-SiO_2 and Eg-NiO scores temperature equals to 3.18E+02K. For rank 7, the nanofluid 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



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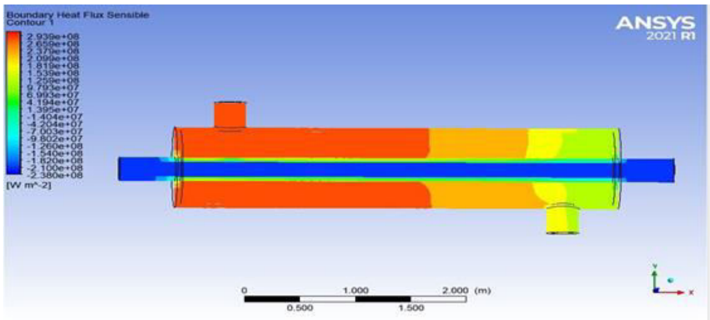
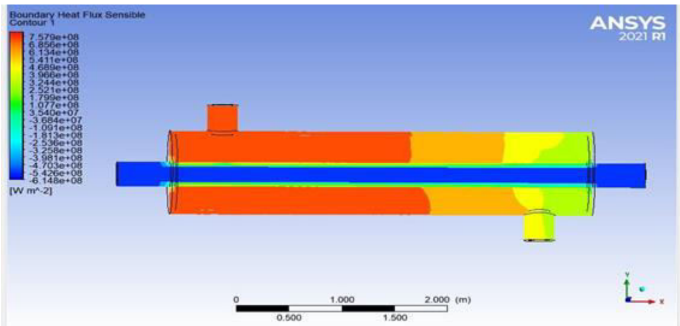
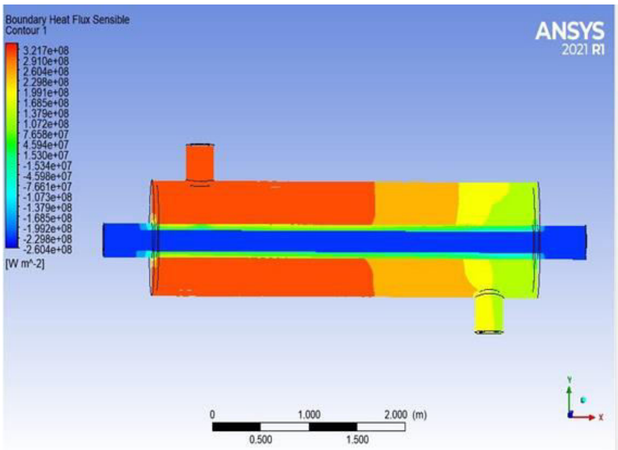
b) EG-SiO_2



c) H_2O-MVCNT



d) EG-MVCNT



e) H_2O-Al

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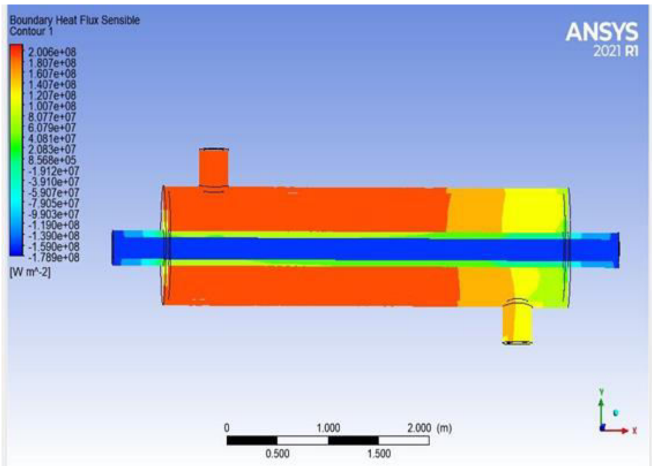


f) EG-Al

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 nanofluids, and the results were recorded as follows:

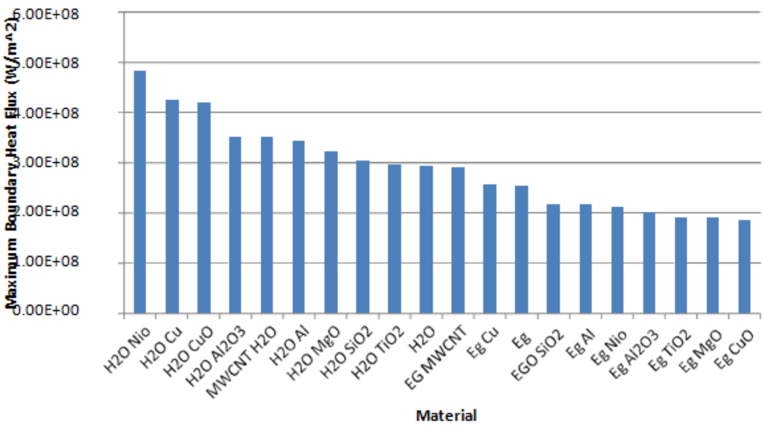
Table 5.3: Validation of Results

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) [93] 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) [94] 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

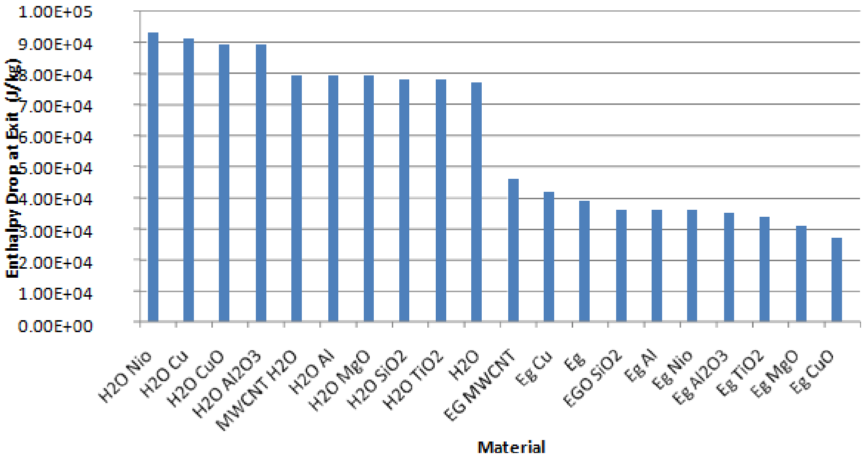
This Graph 5.2 Shows the details of maximum heat flux obtained for different alternatives as well asthe rankings of materials.



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 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.

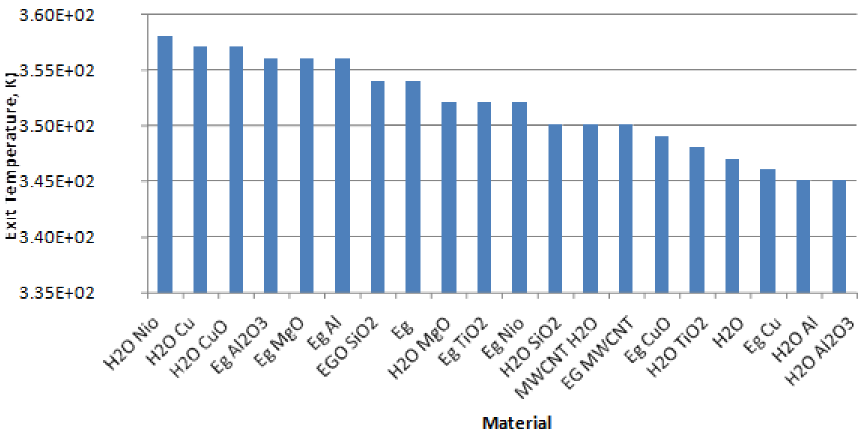
Combination of ethylene glycol-NiO scores rank 11 with the value of heat flux equals to 2.58E+08 W/m^2, whereas the alternative ethylene glycol-CuO obtains rank 12 with heat flux equals to 2.54E+08 W/m^2. For rank 13, two alternatives, ethylene glycol-TiO2 and ethylene glycol-al2O3 appear with values 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 nanofluids, 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.

For the rank 8, the alternative ethylene glycol-copper seems to be appropriate with the value of exit enthalpy drop equals to 4.20E+04 J/kg. For the rank 9, pure ethylene glycol secures the rank with exit enthalpy drop is equal to 3.90E+04 J/kg. For rank 10, three alternatives, namely ethylene glycol-SiO2, ethylene Glycol-Al and ethylene glycol-NiO seem to be appropriate with the values of exit enthalpy drops equal to 3.60E+04 J/kg. Proceeding in the similar manner,



Graph 5.4: Exit Temperatures for Different Alternatives

For rank 11, the alternative ethylene glycol-Al2O3 scores exit enthalpy drop of 3.50E+04 J/kg, for rank 12, the alternative ethylene glycol-TiO2 scores the exit enthalpy drop of 3.40E+04 J/kg, for the rank 13, ethylene glycol-MgO scores exit enthalpy drop of 3.10E+04 J/kg and the last alternative, ethylene glycol-CuO appears at rank 14 with the exit enthalpy drop of 2.70E+04 J/kg.

Graph 5.4 shows the values of exit temperatures for different alternatives. The alternative H2O- NiO scores the rank 1, showing the maximum value of the exit temperature of 3.58E+02K. For rank 2, two alternatives namely H2O-Cu and H2O-CuO appear with the exit temperatures of 3.57E+02 K. Proceeding in the similar manner, for rank 3, three alternatives ethylene glycol- Al2O3, ethylene glycol-MgO and ethylene Glycol-Al appear with the exit temperatures of 3.56E+02 K. Similarly, for the rank 4, two alternatives namely ethylene glycol-SiO2 and pure ethylene glycol appear with the exit temperature of 3.54E+04 K, and for the rank 5, three alternatives, namely H2O-MgO, ethylene glycol-TiO2 and ethylene glycol-NiO appear with the exit temperatures of 3.52E+02 K.

Proceeding in the similar manner, for rank 6, again three alternatives namely H2O-SiO2, H2O- MWCNT and ethylene glycol-MWCNT appear with the exit temperatures of 3.50E+02 K. For rank 7, alternative ethylene glycol-NiO appears with the exit temperature of 3.49E+02 K. For the rank 8, the alternative H2O-TiO2 with the exit temperature of 3.48E+02 K seems to be appropriate. Water scores rank 9 with the exit temperature of 3.47E+02, whereas the alternative ethylene Glycol-Cu scores rank 10 with the exit temperature of 3.46E+02 K. Finally, the alternative H2O-Al2O3 scores rank 11 with the exit temperature value of 3.45E+02 K. Table 5.3 Shows the rankings scored by different alternatives on different criteria.

Table 5.4: Rankings of Alternatives on Different Criteria

S. No	Alternative	Criteria and Rankings					
		Maximum Heat Flux (W/m^2)	Rank	Enthalpy Drop at Exit (J/kg)	Rank	Exit Temperature(K)	Rank
1.	Eg	1.90E+08	16	3.90E+04	9	3.54E+02	4

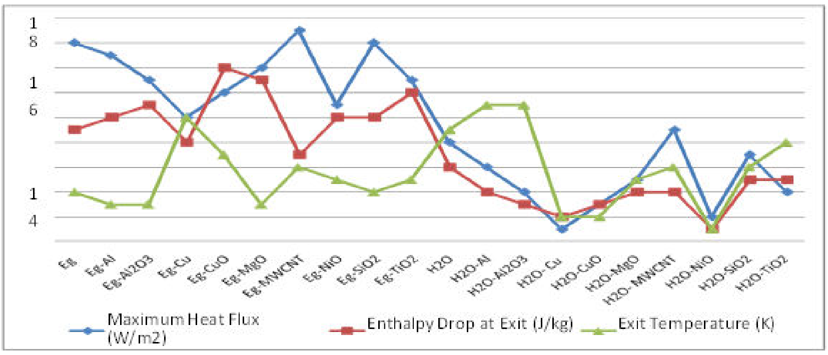
2.	Eg-Al	2.01E+08	15	3.60E+04	10	3.56E+02	3
3.	Eg-Al2O3	2.18E+08	13	3.50E+04	11	3.56E+02	3

Table 5.4: Rankings of Alternatives on Different Criteria (Countinue…)

4.	Eg-Cu	2.90E+08	10	4.20E+04	8	3.46E+02	10
5.	Eg-CuO	2.54E+08	12	2.70E+04	14	3.49E+02	7
6.	Eg-MgO	2.13E+08	14	3.10E+04	13	3.56E+02	3
7.	Eg-MWCNT	1.86E+08	17	4.60E+04	7	3.50E+02	6
8.	Eg-NiO	2.58E+08	11	3.60E+04	10	3.52E+02	5
9.	Eg-SiO2	1.90E+08	16	3.60E+04	10	3.54E+02	4
10.	Eg-TiO2	2.18E+08	13	3.40E+04	12	3.52E+02	5
11.	H2O	2.96E+08	8	7.70E+04	6	3.47E+02	9
12.	H2O-Al	3.22E+08	6	7.90E+04	4	3.45E+02	11
13.	H2O-Al2O3	3.53E+08	4	8.90E+04	3	3.45E+02	11
14.	H2O- Cu	4.83E+08	1	9.10E+04	2	3.57E+02	2
15.	H2O-CuO	4.19E+08	3	8.90E+04	3	3.57E+02	2
16.	H2O-MgO	3.43E+08	5	7.90E+04	4	3.52E+02	5
17.	H2O- MWCNT	2.94E+08	9	7.90E+04	4	3.50E+02	6
18.	H2O-NiO	4.24E+08	2	9.30E+04	1	3.58E+02	1
19.	H2O-SiO2	3.04E+08	7	7.80E+04	5	3.50E+02	6
20.	H2O-TiO2	3.53E+08	4	7.80E+04	5	3.48E+02	8

Table 5.4: Rankings of Alternatives on Different Criteria

This Graph 5.5 Shows the above rankings in a graphical manner.



Graph 5.5: Graphical Representation of Rankings of Alternatives on Different Criteria

But, it may be found from the above analysis that there were significant variations in the rankings scored by different alternatives on the criteria maximum heat flux, and enthalpy drop at exit and exit temperature. It was also found that the difference in rankings scored by alternatives on criteria enthalpy drop at exit and exit temperature is more than that of maximum heat flux. So therefore, in order to get common rankings of alternatives, a statistical technique, relative standard deviation, which is defined as the percentage of ratio of standard deviation and average, was used, which yielded the following results. According to the concept or relative standard deviation, the criterion with the minimum value of relative standard deviation value was considered for the final ranking of alternatives.

Table 5.5: Relative Standard Deviation for Different Criteria

S. No	Criteria	Relative Standard Deviation	Remark
1.	Maximum Heat Flux	29.680	**Preferred Criterion for Ranking**
2.	Enthalpy Drop at Exit	41.510	**Preferred Criterion for Ranking**
3.	Exit Temperature	1.1960	**Preferred Criterion for Ranking**

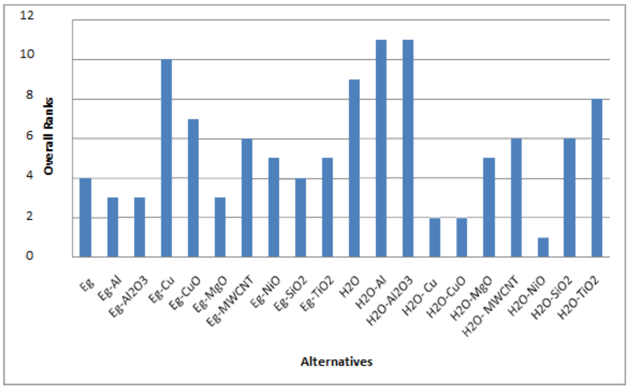
On the basis of above results, the criteria exit temperature was selected for the final ranking of alternatives, which may be verified by considering the working concept of the device that, which tells that maximum exit temperature for the hot fluid is necessary for the successful operation of a heat exchanger.

Table 5.6: Overall Rankings of Alternatives

S. No	Alternatives	Exit Temperature (K)	Overall Rank
1.	H2O-NiO	3.58E+02	1
2.	H2O- Cu	3.57E+02	2
3.	H2O-CuO	3.57E+02	2
4.	Eg-Al	3.56E+02	3
5.	Eg-Al2O3	3.56E+02	3
6.	Eg-MgO	3.56E+02	3
7.	Eg	3.54E+02	4
8.	Eg-SiO2	3.54E+02	4
9.	Eg-NiO	3.52E+02	5
10.	Eg-TiO2	3.52E+02	5
11.	H2O-MgO	3.52E+02	5
12.	Eg-MWCNT	3.50E+02	6
13.	H2O-MWCNT	3.50E+02	6
14.	H2O-SiO2	3.50E+02	6
15.	Eg-CuO	3.49E+02	7
16.	H2O-TiO2	3.48E+02	8
17.	H2O	3.47E+02	9
18.	Eg-Cu	3.46E+02	10
19.	H2O-Al	3.45E+02	11
20.	H2O-Al2O3	3.45E+02	11

Table 5.6: Overall Rankings of Alternatives

This Graph 5.6 Shows the graphical representation of Results.



Graph 5.6: Graphical Representation of Overall Ranking of Alternatives

In this manner, overall ranking for the alternatives were obtained.

From the obtained results, water may be considered as the best alternative base fluid. It can also be found that yet the base fluid water has appeared at ranks 1 and 2, but most of the upper ranks are scored by ethylene glycol, and therefore its contribution cannot be neglected.

Present chapter gives the results obtained as well as discussion made about the research. Conclusion of the research work, as well as limitations and future scope of the research will be presented in upcoming chapter.

6 CONCLUSION

Present research work was based on the investigations on the application of different combinations of nanofluids and base fluids to a heat exchanger. For this purpose, ten types of nano-particles were employed with two base fluids, namely, water and ethylene glycol with 5 percent volumetric concentration, and three thermal properties, namely, maximum heat flux, enthalpy drop at exit and temperature, were calculated. In the last step of research work, a statistical technique, relative standard deviation, was also employed to get a unique set of results, along with the validation of result using experimentation approach. The following points represent the conclusion of the research work:

a) The nanofluid H_2O-NiO may be considered as the best alternative for the heat exchanger application; and
b) H_2O may be considered as the best base fluid for the heat exchanger application.

6.1 Limitations of the Research

The limitations of the research work may be found out from the following points:

a) During the research work, a limited number of materials are used which shows its limitations;
b) It is also limited to a particular concentration of nano fluids in base fluids; and
c) A limited set of thermal properties is used in the research work, which also shows a limitation of the research work.

6.3 Future Scope of the Research

The following points represent the future scope of the research work:

a) A detailed research work based on a broader set of nano-particles may be initiated;
b) An extensive research work consisting a broader range of volumetric concentrations of nanoparticles may be initiated; and
c) A broader research work, consisting of a greater set of thermal properties may be called.

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