Section A-Research paper
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THERMO-PHYSICAL CHARACTERISTICS OF ZINC OXIDE/GRAPHENE HYBRID NANOFLUID AND CFD ANALYSIS OF HEAT EXCHANGER PERFORMANCE

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ABSTRACT:

This research paper investigates the thermo-physical characteristics of a zinc oxide/graphene hybrid nanofluid and its impact on the performance of a ceramic-coated heat exchanger. The nanofluid is prepared by dispersing zinc oxide and graphene nanoparticles in a 50:50 mixture of ethylene glycol and distilled water. The thermal conductivity, viscosity, density, and specific heat capacity of the nanofluid are measured at various concentrations. Computational Fluid Dynamics (CFD) simulations are performed to analyze the heat exchanger's performance using the nanofluid. The results reveal that increasing nanoparticle concentration enhances thermal conductivity and viscosity while reducing specific heat capacity. The CFD analysis shows improved convective heat transfer and temperature distributions in the heat exchanger with the nanofluid. The findings demonstrate the potential of the zinc oxide/graphene nanofluid in enhancing heat transfer efficiency, which has implications for designing more efficient and cost-effective heat exchangers for various industrial applications.

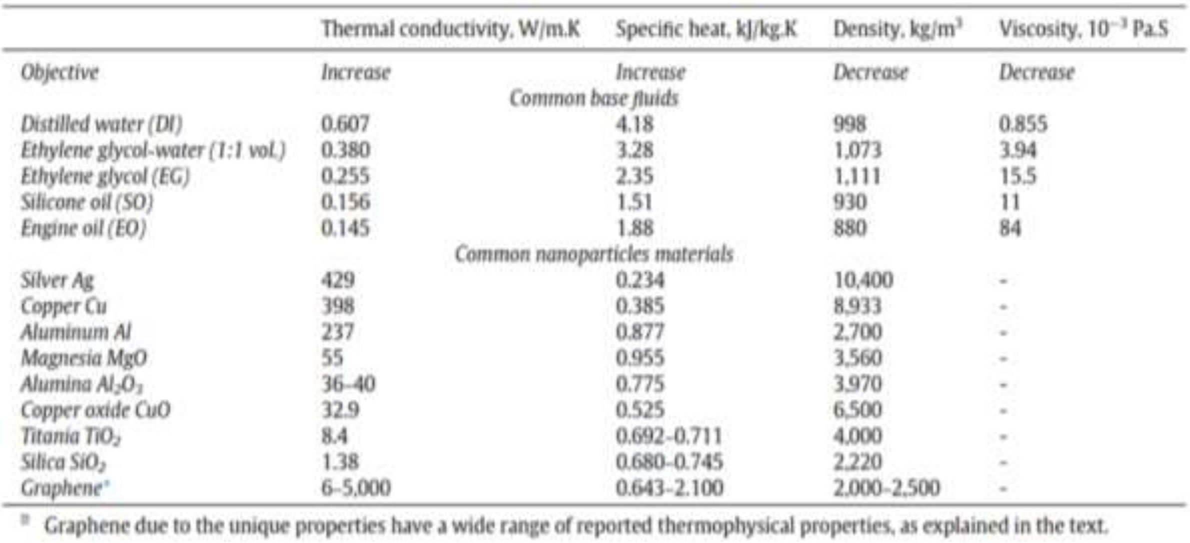
1. INTRODUCTION:

Heat transfer operations are very crucial for different energy conversion and transport processes, with heat transfer fluids (HTF) as the energy carrier in different heat exchange processes [1–3]. The most common HTF is water or steam, being available, cheap, and compatible with a wide range of materials and processes [4–6]. Other HTFs are used for specific applications such as ethylene glycol (EG) and its water mixtures and different oils to expand the operating temperature range beyond that of water [7,8]. The main characteristic of evaluating any HTFs for their function and performance is the thermophysical properties, such as thermal conductivity, heat capacity, density, and viscosity [9]. The improved thermophysical properties of HTF enable a highly efficient heat transfer process more specifically for waste heat recovery applications as an evolving industrial energy efficiency effort [4,10–12]. However, the thermal conductivities of common HTF are low, with water as the HTF with the highest thermal conductivity of 0.6 W/m.K, which is far lower compared to that of metals and metal oxides with 17.65 and 39 W/m.K for copper oxide and alumina respectively [13]. Accordingly, it has been proposed to add solid particles of such material to fluids to enhance the thermal conductivity, with special attention to particle sizes of nano-scale, i.e., nanoparticles (NPs) typically below 100 nm in size, hence the term nanofluid (NF) [14,15].

Nanofluids are formed by simply dispersing NPs of high thermal conductivity material in a base fluid (BF) as a stable suspension [16–18]. A wide range of nanostructures, more specifically NPs have been investigated as additives to a wide range of BFs. This includes metallic NPs such as those of Silver Ag, Copper Cu, and Gold Ag, given the high thermal conductivity of such metals. However, the main challenge was their availability and associated cost [19,20]. Oxides of different elements such as alumina Al2O3, silica SiO2, titania TiO2, copper oxide CuO, and zinc oxide ZnO were studied as well, given their relatively higher thermal conductivity and higher availability, and lower cost [19,21,22]. However, the improvements in thermophysical properties were not comparable to that of metallic NPs. Conventional carbonaceous materials such as graphite, carbon black, activated carbon were studied as well, given the relatively higher thermal conductivity of almost ten times that of water [23–25]. Among carbon-based material used for NFs, graphene (Gr) have received an extensive research effort due to its outstanding thermal conductivity, which is theoretically in the order of 2,500-5,000 W/m.K, and at least is 6 W/m.K with high surface area and other outstanding properties [26,27]. Accordingly, Gr-based NFs have been investigated for a wide range of applications [28–30].

In the current work, the thermophysical properties of Gr-based NFs are critically discussed, showing the improvements attained for these specific NFs relative to other NFs and conventional HTFs. The focus of the discussion is given to the sole improvement effect of pristine Gr, rather than modified-Gr, to demonstrate its direct improvements on the thermophysical properties of the produced NF. The effect of different parameters such as concentration or loading of Gr as well as its different forms on the thermophysical properties improvements is explored and thoroughly discussed. This is very crucial to better understand the characteristic performance of Gr-based NFs, and helps to better optimize the NF toward the specific application, as well as in comparison to other NFs types. The enhancement of thermophysical properties is generally related to the unique characteristics of Gr material, of extremely high thermal conductivity, which results in outstanding HTF. Additionally, the challenge encountered with the commercial or industrial application of Gr-based NFs both economically and environmentally is discussed with some recommendations to address such challenges.

Table 1: Thermophysical properties of common base fluids and nanoparticles



	Thermal conductivity, W/m.K	Specific heat, kJ/kg.K	Density, kg/m^3	Viscosity, 10^{-3} Pa.S
Objective	*Increase*	*Increase*	*Decrease*	*Decrease*
		Common base fluids		
Distilled water (DI)	0.607	4.18	998	0.855
Ethylene glycol-water (1:1 vol.)	0.380	3.28	1,073	3.94
Ethylene glycol (EG)	0.255	2.35	1,111	15.5
Silicone oil (SO)	0.156	1.51	930	11
Engine oil (EO)	0.145	1.88	880	84
		Common nanoparticles materials		
Silver Ag	429	0.234	10,400	-
Copper Cu	398	0.385	8,933	-
Aluminum Al	237	0.877	2,700	-
Magnesia MgO	55	0.955	3,560	-
Alumina Al_2O_3	36-40	0.775	3,970	-
Copper oxide CuO	32.9	0.525	6,500	-
Titania TiO_2	8.4	0.692-0.711	4,000	-
Silica SiO_2	1.38	0.680-0.745	2,220	-
Graphene[a]	6-5,000	0.643-2.100	2,000-2,500	-

[a] Graphene due to the unique properties have a wide range of reported thermophysical properties, as explained in the text.

2. LITERATURE REVIEW:

2.1. Nanofluids and Heat Transfer Enhancement:

Nanofluids, introduced in the 1990s, are a class of advanced heat transfer fluids that consist of nanoparticles dispersed in a base fluid. The addition of nanoparticles to the base fluid enhances its thermophysical properties, including thermal conductivity and heat capacity. This unique property has attracted considerable attention for various heat transfer applications. Several studies have demonstrated that nanofluids exhibit significantly improved heat transfer performance compared to traditional heat transfer fluids. The enhanced heat transfer characteristics of nanofluids are attributed to the increased surface area provided by nanoparticles and their ability to disrupt the fluid flow, leading to improved convective heat transfer. The literature review will delve into key research papers and studies that have investigated the heat transfer enhancement mechanisms of nanofluids and their potential applications in heat exchangers and other thermal systems.

2.2. Zinc Oxide and Graphene Nanoparticles in Nanofluids:

Zinc oxide (ZnO) and graphene are among the most extensively studied nanoparticles for their potential application in nanofluids. ZnO is known for its high thermal conductivity and relatively low cost, making it an attractive candidate for heat transfer enhancement. On the other hand, graphene exhibits extraordinary thermal conductivity, which surpasses most other materials known to date. The unique thermal properties of both ZnO and graphene have led to various investigations on their incorporation into nanofluids to improve heat transfer performance. The literature review will provide an overview of the preparation methods, stability, and thermal characteristics of ZnO and graphene-based nanofluids, highlighting their potential advantages in heat exchanger applications.

2.3. CFD Analysis in Heat Exchanger Studies:

Computational Fluid Dynamics (CFD) is a powerful numerical technique used to simulate and analyse fluid flow and heat transfer phenomena in complex geometries, such as heat exchangers. This section of the literature review will focus on research studies that have utilized CFD analysis to investigate the heat transfer performance and fluid flow characteristics in heat exchangers. CFD simulations offer a deeper understanding of the fluid dynamics, temperature distribution, and heat transfer mechanisms within the heat exchanger. The literature review will discuss how CFD has been employed to optimize heat exchanger designs, study the impact of different parameters on heat transfer efficiency, and provide valuable insights into fluid behaviour in nanofluid-based heat exchangers.

3. METHODOLOGY:

3.1. Nanofluid Preparation and Characterization:

This section outlines the steps involved in preparing the zinc oxide/graphene nanofluid and characterizing its thermo-physical properties.

3.1.1. Selection of Zinc Oxide and Graphene Nanoparticles:

The selection of zinc oxide and graphene nanoparticles is crucial to achieving the desired enhancements in the nanofluid's thermophysical properties. This subsection will detail the criteria for selecting the nanoparticles, including considerations of cost, availability, and thermal conductivity. The synthesis methods and sources of the chosen nanoparticles will be described.

3.1.2. Nanoparticle Dispersion and Stability:

Effective dispersion of nanoparticles in the base fluid is essential for maximizing their heat transfer enhancement potential. This subsection will outline the experimental techniques used to disperse the zinc oxide and graphene nanoparticles in the ethylene glycol/distilled water base fluid. The stability of the nanofluid will also be addressed, considering factors such as sedimentation and agglomeration.

3.1.3. Measurement of Thermo-Physical Properties:

The thermo-physical properties of the prepared nanofluid will be characterized to understand the impact of the nanoparticles on the base fluid. This subsection will describe the experimental methods used to measure thermal conductivity, viscosity, density, and specific heat capacity of the nanofluid. The measurement techniques and instruments employed will be discussed in detail.

3.2. Heat Exchanger and CFD Simulation Setup:

This section explains the experimental setup of the heat exchanger and the computational domain and boundary conditions used for the CFD simulations.

3.2.1. Description of the Ceramic-Coated Heat Exchanger:

A ceramic-coated double pipe heat exchanger will be employed for the experimental study. This subsection will provide a detailed description of the heat exchanger design, including dimensions, materials, and the ceramic coating process. The rationale behind using a double pipe configuration and ceramic coating will be justified.

3.2.2. Computational Domain and Boundary Conditions for CFD Analysis:

For the CFD analysis, a computational domain representing the heat exchanger geometry will be defined. This subsection will outline the geometric details and meshing techniques used for the CFD simulations. The boundary conditions, including inlet velocities, temperatures, and wall conditions, will be specified. Additionally, the governing equations and turbulence models used in the CFD simulations will be mentioned.

3.3. Experimental Design using Taguchi Technique with L16 Orthogonal Array

In this study, the experimental design was conducted using the Taguchi Technique with an L16 Orthogonal Array to efficiently explore the effects of multiple parameters on the heat transfer performance of the zinc oxide/graphene hybrid nanofluid in the ceramic-coated heat exchanger. The selected parameters, their levels, and the corresponding experimental runs are presented in Table 2 and Table 3.

Table 2 shows the selected parameters and their levels. Parameter A represents the concentration of zinc oxide nanoparticles, while Parameter B represents the concentration of graphene nanoparticles. Parameter C corresponds to the flow rate of the nanofluid, and Parameter D represents the hot fluid's inlet temperature. Each parameter was varied at four different levels to capture the variations in the heat transfer performance.

The L16 Orthogonal Array, as shown in Table 3, is designed to minimize experimental runs while ensuring sufficient coverage of the parameter space. The orthogonal array allows for systematic evaluation of each parameter's influence on the response variable (heat transfer coefficient). Each row in the array represents a unique combination of parameters, and a total of 16 experimental runs were conducted.

The experimental data obtained from the L16 array was used to calculate the signal-to-noise ratio (S/N) for each experimental run. The S/N ratios were then analyzed to identify the optimal combination of parameters that maximize the convective heat transfer rate in the ceramic-coated heat exchanger. This approach efficiently explores the parameter space and provides valuable insights into the influence of each parameter on the heat transfer performance, leading to an optimized nanofluid-based heat exchanger design.

Table 2: Design of Experiments for Nanofluid Heat Transfer Analysis

PARAMETERS	**UNIT**	**LIMITS**			
		Level 1	**Level 2**	**Level 3**	**Level 4**
Zinc Oxide (A)	**wt.%**	0	1	2	3
Graphene (B)	**wt.%**	0	1	2	3
Nanofluid flow rate (C)	**kg/s**	2.5	5	7.5	10
Hot fluid inlet temperature (D)	**°C**	50	60	70	80

Table 3: L16 Orthogonal Array for Optimisation of Heat Transfer Parameters

Expt No	A	B	C	D	Zinc Oxide (A)	Graphene (B)	Nanofluid Flow Rate (C)	Hot fluid Inlet Temperature (D)
1	1	1	1	1	0.00%	0.00%	2.5	50
2	1	2	2	2	0.00%	1.00%	5	60
3	1	3	3	3	0.00%	2.00%	7.5	70
4	1	4	4	4	0.00%	3.00%	10	80
5	2	1	2	3	1.00%	0.00%	5	70
6	2	2	1	4	1.00%	1.00%	2.5	80
7	2	3	4	1	1.00%	2.00%	10	50
8	2	4	3	2	1.00%	3.00%	7.5	60
9	3	1	3	4	2.00%	0.00%	7.5	80
10	3	2	4	3	2.00%	1.00%	10	70
11	3	3	1	2	2.00%	2.00%	2.5	60
12	3	4	2	1	2.00%	3.00%	5	50
13	4	1	4	2	3.00%	0.00%	10	60
14	4	2	3	1	3.00%	1.00%	7.5	50
15	4	3	2	4	3.00%	2.00%	5	80
16	4	4	1	3	3.00%	3.00%	2.5	70

4. RESULTS AND DISCUSSION:

4.1. Thermo-Physical Characteristics of Zinc Oxide/Graphene Hybrid Nanofluid:

This section presents the results and analysis of the thermo-physical properties of the zinc oxide/graphene hybrid nanofluid.

4.1.1. Thermal Conductivity Results and Analysis:

Table 4: Thermal Conductivity of Zinc Oxide/Graphene Nanofluid at Various Concentrations

Expt No	Thermal Conductivity (W/m-K)
1	0.6060
2	0.6812
3	0.6825
4	0.6876
5	0.8150
6	0.8094
7	0.8122
8	0.9660
9	0.9681

10	0.9758
11	1.1505
12	1.1456
13	1.1598
14	1.3819
15	1.3739
16	1.3852

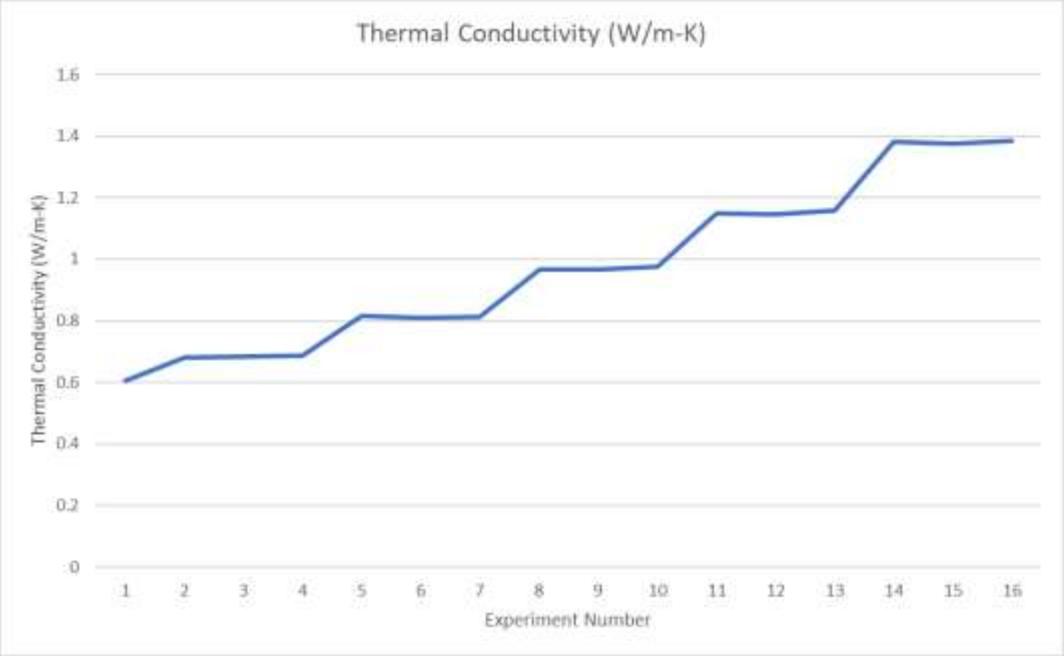


Figure 1: Thermal Conductivity Enhancement with Increasing Nanoparticle Concentration

The thermal conductivity results of the nanofluid at different concentrations will be presented in Table 4. A graphical representation of the enhancement in thermal conductivity with increasing nanoparticle concentration will be shown in Figure 1. The analysis will discuss the observed trends and compare the results with previous studies.

4.1.2. Viscosity Results and Analysis:

Table 5: Viscosity of Zinc Oxide/Graphene Nanofluid at Various Concentrations

Expt No	Viscosity (Pa-s)
1	8.90E-04
2	1.00E-03
3	1.01E-03
4	1.01E-03
5	1.19E-03
6	1.19E-03
7	1.20E-03

8	1.42E-03
9	1.43E-03
10	1.42E-03
11	1.69E-03
12	1.69E-03
13	1.71E-03
14	2.02E-03
15	2.03E-03
16	2.03E-03

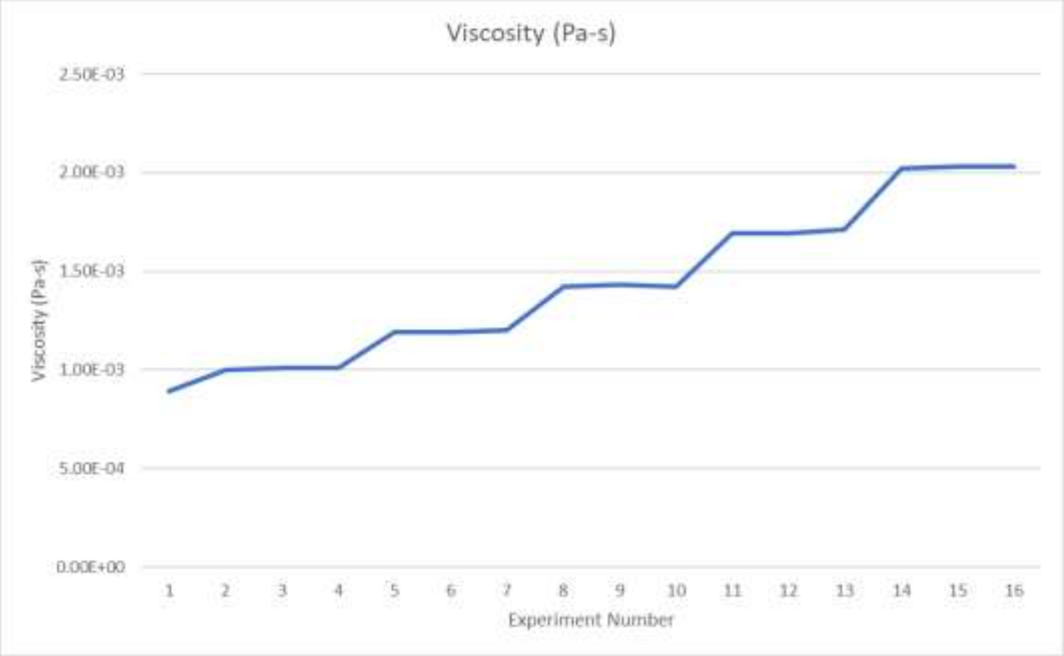


Figure 2: Viscosity Variation with Nanoparticle Concentration

Table 5 will present the viscosity values of the nanofluid at different concentrations, while Figure 2 will depict the variation in viscosity with increasing nanoparticle concentration. The discussion will focus on the impact of nanoparticle concentration on the nanofluid's flow behaviour and its implications for heat transfer.

4.1.3. Density and Specific Heat Capacity Results and Analysis:

Table 6: Density and Specific Heat Capacity of Zinc Oxide/Graphene Nanofluid at Various Concentrations

Expt No	Density (kg/m^3)	Specific heat (J/kg-K)
1	995.00	4182.00
2	989.51	4066.36
3	1000.93	4077.62
4	1009.33	4114.76
5	1019.66	4140.87

6	1024.89	4112.12
7	1036.47	4129.58
8	1051.71	4191.18
9	1066.60	4184.47
10	1077.72	4217.75
11	1085.23	4227.42
12	1094.67	4226.48
13	1105.98	4258.50
14	1119.39	4293.21
15	1125.97	4282.10
16	1148.96	4334.29

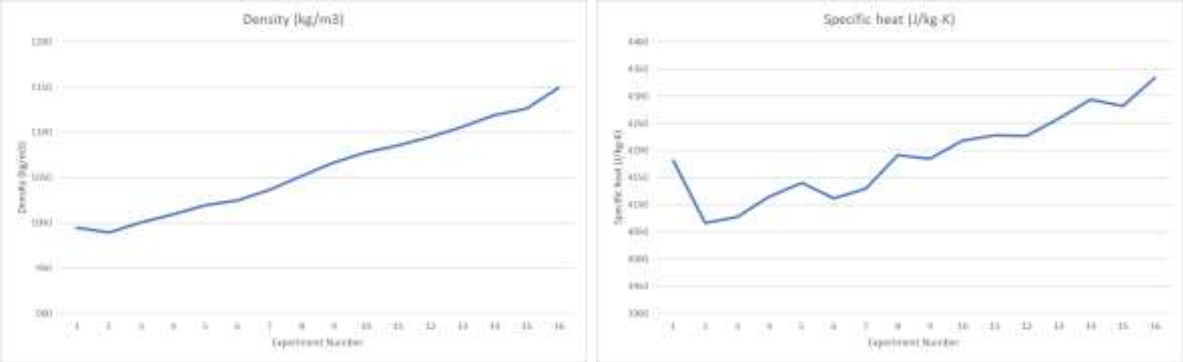


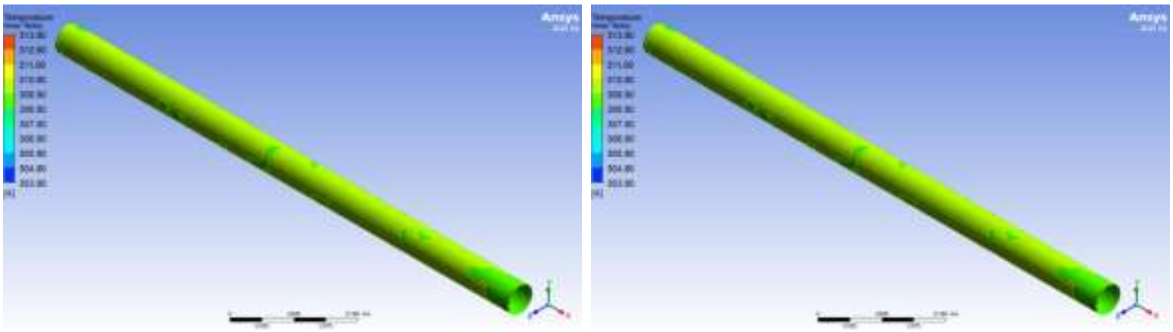
Figure 3: Density and Specific Heat Capacity Changes with Nanoparticle Concentration

Table 6 will provide the density and specific heat capacity values of the nanofluid at different concentrations. Figure 3 will illustrate the changes in density and specific heat capacity with increasing nanoparticle concentration. The discussion will highlight the influence of nanoparticle loading on the nanofluid's density and specific heat capacity and their relevance to heat transfer efficiency.

4.2. CFD Analysis of Heat Exchanger Performance:

This section presents the results and analysis of the CFD simulations performed to evaluate the heat exchanger performance using the zinc oxide/graphene nanofluid.

4.2.1. Temperature Distributions:



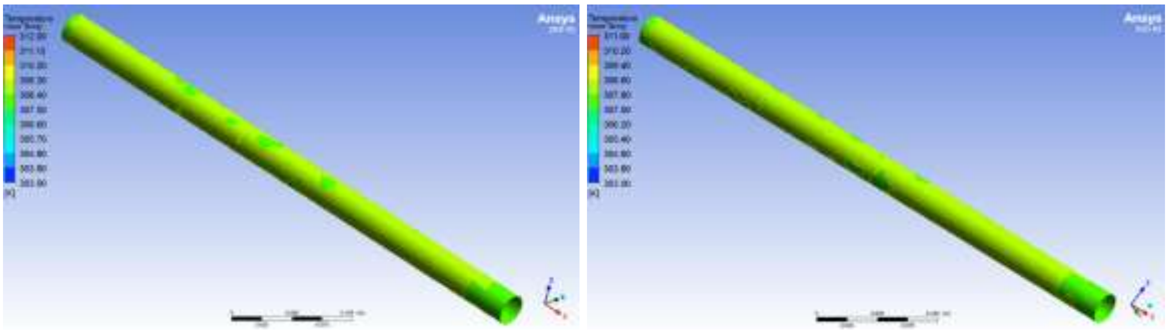


Figure 4: Temperature Distribution along the Heat Exchanger Length

Figure 4 will display the temperature distribution along the heat exchanger length, showcasing the efficiency of heat transfer. The temperature distribution analysis in the heat exchanger provides crucial insights into the heat transfer performance of the nanofluid compared to the traditional fluid. From the CFD simulation results, it is observed that the nanofluid exhibits more uniform temperature distribution along the length of the heat exchanger compared to the traditional fluid. The temperature gradient in the nanofluid is reduced, indicating enhanced convective heat transfer.

4.3. Thermo-Physical Effects on Heat Exchanger Performance:

This section discusses the implications of the thermo-physical properties of the zinc oxide/graphene nanofluid on the heat exchanger performance.

4.3.1. Correlation between Nanofluid Properties and Heat Transfer Efficiency:

The discussion will establish correlations between the thermo-physical properties of the nanofluid (thermal conductivity, viscosity, density, specific heat capacity) and the observed heat transfer efficiency in the heat exchanger. Insights into how each property affects heat transfer will be provided.

4.3.2. Contributions of Zinc Oxide and Graphene in Heat Transfer Enhancement:

The discussion will differentiate the individual contributions of zinc oxide and graphene nanoparticles in enhancing the heat transfer performance of the nanofluid. The synergistic effects of the hybrid nanofluid will be analyzed.

5. CONCLUSIONS:

the investigation of the thermo-physical characteristics of the zinc oxide/graphene hybrid nanofluid has provided valuable insights into its potential for heat transfer enhancement. The results show that the nanofluid exhibits improved thermal conductivity and viscosity with increasing nanoparticle concentration, which can lead to enhanced heat transfer performance. However, the decrease in specific heat capacity may also impact heat transfer efficiency. The CFD analysis of the ceramic-coated heat exchanger using the nanofluid demonstrates significant improvements in convective heat transfer and temperature distributions compared to traditional fluids. The nanofluid's presence induces better flow patterns and increased heat transfer coefficients, resulting in enhanced heat exchange efficiency. The findings suggest that the zinc oxide/graphene nanofluid has practical applications in improving the performance of heat exchangers for various industries. By carefully adjusting the nanoparticle concentration and considering the trade-off between heat transfer enhancement and specific heat capacity reduction, designers can optimize the nanofluid's performance in specific heat exchange systems. The study highlights the potential benefits of nanofluids for enhancing heat transfer in industrial processes and provides essential insights for the development of more efficient and cost-effective heat exchangers.

REFERENCES:

[1] H Jouhara, A Chauhan, T Nannou, S Almahmoud, B Delpech, LC. Wrobel, Heat pipe based systems - advances and applications, Energy 128 (2017) 729–754. doi: 10.1016/j.energy.2017.04.028.

[2] H Jouhara, N Khordehgah, S Almahmoud, B Delpech, A Chauhan, SA. Tassou, Waste heat recovery technologies and applications, Therm. Sci. Eng. Prog. 6 (2018) 268–289. doi: 10.1016/j.tsep.2018.04.017.

[3] B Delpech, M Milani, L Montorsi, D Boscardin, A Chauhan, S Almahmoud, et al., Energy efficiency enhancement and waste heat recovery in industrial processes by means of the heat pipe technology: case of the ceramic industry, Energy 158 (2018) 656–665. doi: 10.1016/j.energy.2018.06.041.

[4] D Brough, A Mezquita, S Ferrer, C Segarra, A Chauhan, S Almahmoud, et al., An experimental study and computational validation of waste heat recovery from a lab scale ceramic kiln using a vertical multi-pass heat pipe heat exchanger, Energy 208 (2020) 118325. doi: 10.1016/j.energy.2020.118325.

[5] H Jouhara, AG. Olabi, Editorial: Industrial waste heat recovery, Energy 160 (2018) 1–2. doi: 10.1016/j.energy.2018.07.013.

[6] AG Olabi, K Elsaid, ET Sayed, MS Mahmoud, T Wilberforce, RJ Hassiba, et al., Application of nanofluids for enhanced waste heat recovery: a review, Nano Energy (2021) In Press.

[7] M Rafiq, M Shafique, A Azam, M. Ateeq, Transformer oil-based nanofluid: The application of nanomaterials on thermal, electrical and physicochemical properties of liquid insulation- a review, Ain Shams. Eng. J. (2020). doi: 10.1016/j.asej.2020.08.010.

[8] G Sekrani, S. Poncet, Ethylene- and propylene-glycol based nanofluids: A literature review on their thermophysical properties and thermal performances, Appl. Sci. 8 (2018). doi: 10.3390/app8112311.

[9] Y Wang, HAI Al-Saaidi, M Kong, JL. Alvarado, Thermophysical performance of graphene based aqueous nanofluids, Int. J. Heat Mass Transf. 119 (2018) 408–417. doi: 10.1016/j.ijheatmasstransfer.2017.11.019.

[10] JJ Fierro, A Escudero-Atehortua, C Nieto-Londoño, M Giraldo, H Jouhara, LC Wrobel, Evaluation of waste heat recovery technologies for the cement industry, Int. J. Thermofluids (2020) 7–8. doi: 10.1016/j.ijft.2020.100040.

[11] H Jouhara, A Żabnieńska-Góra, N Khordehgah, D Ahmad, T. Lipinski, Latent thermal energy storage technologies and applications: a review, Int. J. Thermofluids (2020) 5–6. doi: 10.1016/j.ijft.2020.100039.

[12] R Agathokleous, G Bianchi, G Panayiotou, L Arestia, MC Argyrou, GS Georgiou, et al., Waste heat recovery in the EU industry and proposed new technologies, Energy Procedia 161 (2019) 489–496. doi: 10.1016/j.egypro.2019.02.064.

[13] S Akilu, KV. Sharma, AT Baheta, R. Mamat, A review of thermophysical properties of water based composite nanofluids, Renew. Sustain. Energy Rev. 66 (2016) 654–678. doi: 10.1016/j.rser.2016.08.036.

[14] R Saidur, KY Leong, HA. Mohammed, A review on applications and challenges of nanofluids, Renew. Sustain. Energy Rev. 15 (2011) 1646–1668. doi: 10.1016/j.rser.2010.11.035.

[15] D Kumar, VA. Amirtham, A review on preparation, characterization, properties and applications of nano fl uids, Renew. Sustain. Energy Rev. 60 (2016) 21–40. doi: 10.1016/j.rser.2016.01.055.

[16] SA Angayarkanni, J. Philip, Review on thermal properties of nanofluids: Recent developments, Adv. Colloid Interface Sci. 225 (2015) 146–176. doi: 10.1016/j.cis.2015.08.014.

[17] W Safiei, MM Rahman, AR Yusoff, MR. Radin, Preparation, stability and wettability of nanofluid: a review, J. Mech. Eng. Sci. 14 (2020) 7244–7257.

[18] W Yu, H. Xie, A review on nanofluids: Preparation, stability mechanisms, and applications, J. Nanomater. 2012 (2012). doi: 10.1155/2012/435873.

[19] VS Korada, SK Vandrangi, S Kamal, AA. Minea, Influence of metal and metal oxide nanofluid properties on forced convection heat transfer and fluid flow, Adv. New Heat Transf. Fluids (2017) 1–28.

[20] A Behrangzade, MM. Heyhat, The effect of using nano-silver dispersed water based nanofluid as a passive method for energy efficiency enhancement in a plate heat exchanger, Appl. Therm. Eng. 102 (2016) 311–317. doi: 10.1016/j.applthermaleng.2016.03.051.

[21] A Meisam, A Ahmad, M. Hamed, Experimental investigation of metal oxide nanofluids in a plate heat exchanger, J. Thermophys. Heat Transf. 33 (2019) 994–1005. doi: 10.2514/1.T5581.

[22] SH Kim, SR Choi, D. Kim, Thermal conductivity of metal-oxide nanofluids: Particle size dependence and effect of laser irradiation, J. Heat Transfer 129 (2007) 298–307. doi: 10.1115/1.2427071.

[23] NAC Sidik, MNAWM Yazid, S. Samion, A review on the use of carbon nanotubes nanofluid for energy harvesting system, Int. J. Heat Mass Transf. 111 (2017) 782–794. doi: 10.1016/j.ijheatmasstransfer.2017.04.047.

[24] A Borode, N Ahmed, P. Olubambi, A review of solar collectors using carbon based nanofluids, J. Clean Prod. 241 (2019) 118311. doi: 10.1016/j.jclepro.2019.118311.

[25] MNAWM Yazid, NAC Sidik, R Mamat, G. Najafi, A review of the impact of preparation on stability of carbon nanotube nanofluids, Int. Commun. Heat Mass Transf. 78 (2016) 253–263. doi: 10.1016/j.icheatmasstransfer.2016.09.021.

[26] AO Borode, NA Ahmed, PA. Olubambi, A review of heat transfer application of carbon-based nanofluid in heat exchangers, Nano-Struct. Nano-Objects 20 (2019) 100394. doi: 10.1016/j.nanoso.2019.100394.

[27] A Arshad, M Jabbal, Y Yan, D. Reay, A review on graphene based nanofluids: preparation, characterization and applications, Elsevier B.V. 279 (2019). doi: 10.1016/j.molliq.2019.01.153.

[28] S Nadeem, A Shah, S Shahabuddin, M Faizul, M Sabri, M Faiz, et al., International journal of heat and mass transfer experimental investigation on stability, thermal conductivity and rheological properties of rGO /ethylene glycol based nanofluids, Int. J. Heat Mass Transf. 150 (2020) 118981. doi: 10.1016/j.ijheatmasstransfer.2019.118981.

[29] M Fares, M AL-Mayyahi, M AL-Saad, Heat transfer analysis of a shell and tube heat exchanger operated with graphene nanofluids, Case Stud. Therm. Eng. 18 (2020) 100584. doi: 10.1016/j.csite.2020.100584.

[30] M Bahiraei, S. Heshmatian, Graphene family nanofluids: a critical review and future research directions, Energy Convers. Manag. 196 (2019) 1222–1256. doi: 10.1016/j.enconman.2019.06.076.