International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Thermal Performance Comparison of FPC Based Solar Thermal Water Heaters Using Hybrid Nanofluids (Composite Al_2O_3 & Cuo-Water-Based) to Single Nanofluids for Varied Volume Fractions

Harshit Kumar Joshi [1], Dr. Gourav Purohit [2]

[1]M.Tech Scholar (Thermal Engineering), [2]Associate Professor
[1, 2]Department of Mechanical Engineering, Aravali Institute of Technical Studies, Udaipur, Rajasthan, India

Abstract
This study compares the thermal performance of Flat Plate Collector (FPC) based Solar Thermal Water Heaters (STWH) employing hybrid nanofluids, namely Al_2O_3-CuO-water, to single nanofluids such as Al_2O_3-water and CuO-water. Combining Al_2O_3 with CuO nanoparticles in water for varied volume fractions of Nanoparticlesenhances thermal conductivity, specific heat, and heat transfer efficiency. Numerical simulations using ANSYS Fluent Software, based on the Finite Volume Method (FVM) Modelling, show that hybrid nanofluids improve the overall thermal performance of solar thermal water heaters more effectively than single nanofluids, indicating a promising solution for efficient energy utilization in solar thermal applications.

Keywords: Solar Thermal Water Heater (STWH), Hybrid Nanofluids (NFs), Nanoparticles (NPs), Al_2O_3, CuO, Thermal Performance Analysis,Renewable Energy Technologies, Thermal Conductivity, Nanoparticle Concentration (NPC),Flat Plate Collector (FPC),Nanotechnology in Solar Systems

1.0 Introduction

The growing need for renewable energy has resulted in considerable developments in solar thermal systems. Solar thermal water heaters (STWHs) have grown in popularity due to their ease of use, low cost, and high energy efficiency. However, improving the thermal performance of STWHs remains an important topic of study in order to optimize their value we are using Flat Plate Collector (FPC) based STWH for study.

Nanofluids, or nanoparticle suspensions in a base fluid, have emerged as a promising alternative for improving heat transfer rates. Although single nanofluids like Al_2O_3-water and CuO-water have been widely investigated, hybrid nanofluids, which combine two or more types of nanoparticles, have synergistic effects that can further improve thermal characteristics.

This research analyses the thermal performance of FPC based STWHs utilizing compositeAl_2O_3-CuO-water hybrid nanofluids and compares them to single nanofluids like Al_2O_3-water and CuO-water for varied volume fractions of NPsusing ANSYS Fluent Software.

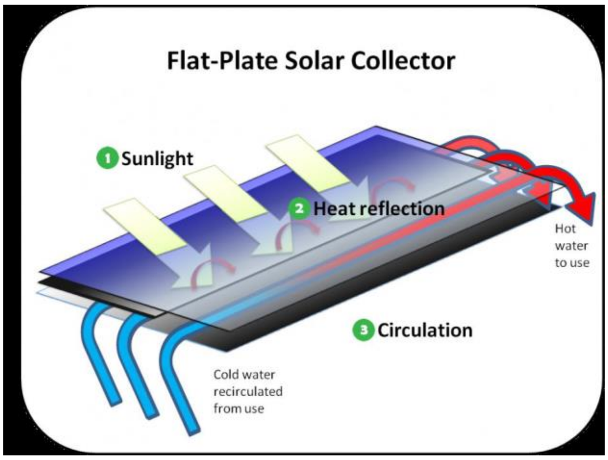


Figure 1 : Diagrammatic representation of Solar Thermal Flat Plate Collector

2.0 Methodology

2.1 Numerical Modelling

- **Software:** The simulations were performed using ANSYS Fluent. The governing equations for fluid flow and heat transmission were solved using the Finite Volume Method (FVM).
- **Geometry and Mesh:** A 3D model of a flat-plate solar water heater was built, which included an absorber plate, glass cover, and fluid flow channels. A structured mesh was employed to enhance numerical stability and precision.

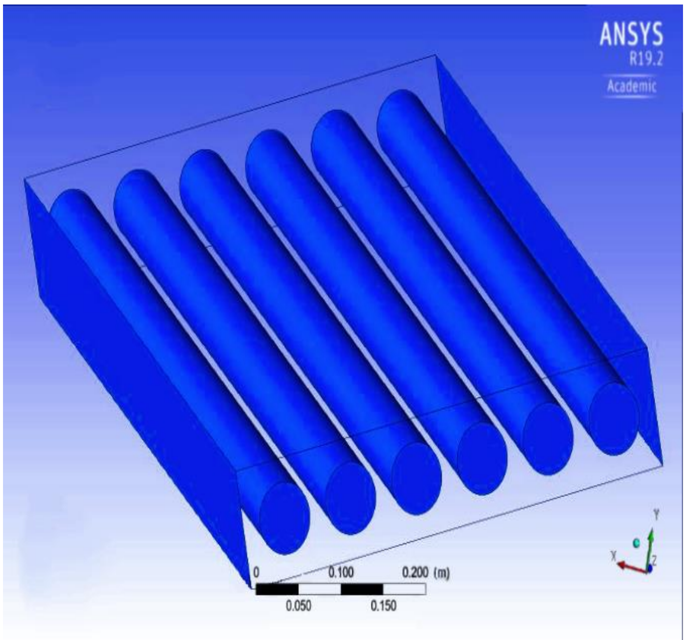


Figure 2 : Geometry of FPC

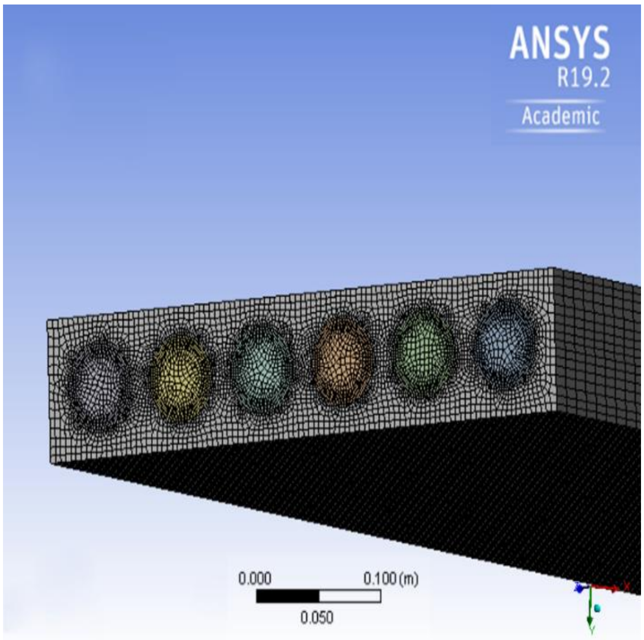


Figure 3 : Meshing

- **Boundary Conditions:** A constant heat flow of 1000 W/m² was delivered to the absorber plate to imitate solar irradiation. The working fluid's input temperature was fixed at 300 K, and the flow velocity was uniform.

2.2 Nanofluid Properties

- **Hybrid Nanofluid Composition:** Al_2O_3 and CuO nanoparticles were mixed at a 1:1 volume ratio. The thermophysical characteristics (thermal conductivity, specific heat, and viscosity) were determined using proven empirical correlations.
- **Single Nanofluids:** We compared the characteristics of Al_2O_3-water with CuO-water.

2.3Raw Specifications of Solar Thermal Collector's Design Conditions

Solar thermal water heater capacity	60-70 Litres/day
Minimum attaining temperature of heated water	60-80°C (expected)
Collector's Inclination based on location: Banswara, Rajasthan	23°-27° (According to UNDP and MNRE date handbook)
Absorber plate	
Absorber / Collector area	1 m^2 (Experimental), 2-4 m^2 (Domestic)
Collector's Shape	200cm X 50cm (Rectangular)
Covering	Low-iron tempered flat glas, 4-6 mm thick

Thickness	0.2-0.5 mm
Cover's Transmissivity	90-95 %
Absorptivity	91-96 %
Emissivity	0.06-0.15 (Etched copper)
Tubes	
Number	6, (6-12 depending on the collector size)
Outside Diameter	60-70 mm
Thickness	2-3 mm
Inside Diameter	45-54 mm
Tube Clearance	20 mm
Tube and Side walls Clearance	20 mm
Insulation	
Back Insulation Thickness	20-30 mm
Side Insulation Thickness	15-20 mm
Thermal conductivity	0.04-0.06 W/m-K (for glass-wool material)
Thermal conductivity	385-400 W/m-K (Copper)
Depth of whole assembly	100 mm (excluding insulation)

2.4 Governing Equations The following equations were solved:

ContinuityEquation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho v = 0$$

For Steady Flow

$$\frac{\partial \rho}{\partial t} = 0$$

$$\nabla \cdot \rho v = 0$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

MomentumEquation:

$$\int \rho \frac{Dv}{Dt} d = \sum F$$

X-momentum equation

$$\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right)\rho = -\frac{\partial \rho}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

Energy Equation:

$$\rho c_p\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = \lambda\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)$$

2.5 Thermo-physical Properties

2.5.1 Thermal Conductivity (k_{nf}): Maxwell's model for nanofluids:

$$\frac{k_{nf}}{k_b} = \frac{k_p + 2k_b - 2\emptyset(k_b - k_p)}{k_p + 2k_b + \emptyset(k_b - k_p)}$$

where:

- k_b: thermal conductivity of the base fluid (water)
- k_p: thermal conductivity of nanoparticles (Al_2O_3)
- $\emptyset$: volume fraction of nanoparticles

2.5.2 Density (ρ_{nf}):

$$\rho_{\mathrm{nf}} = \varphi\rho_{\mathrm{np}} + (1 - \varphi)\rho_{\mathrm{bf}}$$

where:

- ρ_{np}: density of nanoparticles
- ρ_{bf}: density of the base fluid

2.5.3 Specific Heat Capacity ($C_{p,nf}$): Pak and Cho's model:

$$C_{p,nf} = \frac{\phi\rho_p C_{p,p} + (1 - \phi)\rho_f C_{p,f}}{\rho_{nf}}$$

where:

- $C_{p,p}$: specific heat of nanoparticles
- $C_{p,f}$: specific heat of the base fluid

3.0 Results and Discussion

3.1 Known Thermal Properties of Nanofluids

Phase/NPs	Thermal Conductivity (W/m-k)	Density (kg/m^3)	Specific heat (J/kg-K)	Viscosity (Pa-Sec.) at 25°C
Water at 25°C	0.607	997.2	4182	0.0008904
Al_2O_3	36	3970	765	-
CuO	20	6500	540	-
Al_2O_3&CuO	**1.50782**	**1010**	**4100**	-

3.2 Determined Thermo-physical Characteristics of composite Al_2O_3-Water Nanofluid for varied volume fraction of NPs

NFs (NPC volume %)	Thermal Conductivity (W/m-k)	Density (kg/m^3)	Specific heat (J/kg-K)
0.1	0.6147	999.97	4168.89
0.2	0.6165	1002.95	4155.86
0.5	0.6217	1011.87	4117.22
1.0	0.6305	1026.73	4054.32
1.25	0.6349	1034.16	4023.55
1.5	0.6393	1041.60	3993.22
2.0	0.6483	1056.46	3933.83

3.3 Determined Thermo-physical Characteristics of composite CuO-Water Nanofluid for varied volume fraction of NPs

NFs (NPCvolume %)	Thermal Conductivity (W/m-k)	Density (kg/m^3)	Specific heat (J/kg-K)
0.1	0.6147	1002.50	4158.39
0.2	0.6164	1008.01	4135.03
0.5	0.6214	1024.51	4066.47
1.0	0.6300	1052.03	3956.98
1.25	0.6342	1065.79	3904.35
1.5	0.6385	1079.55	3853.07

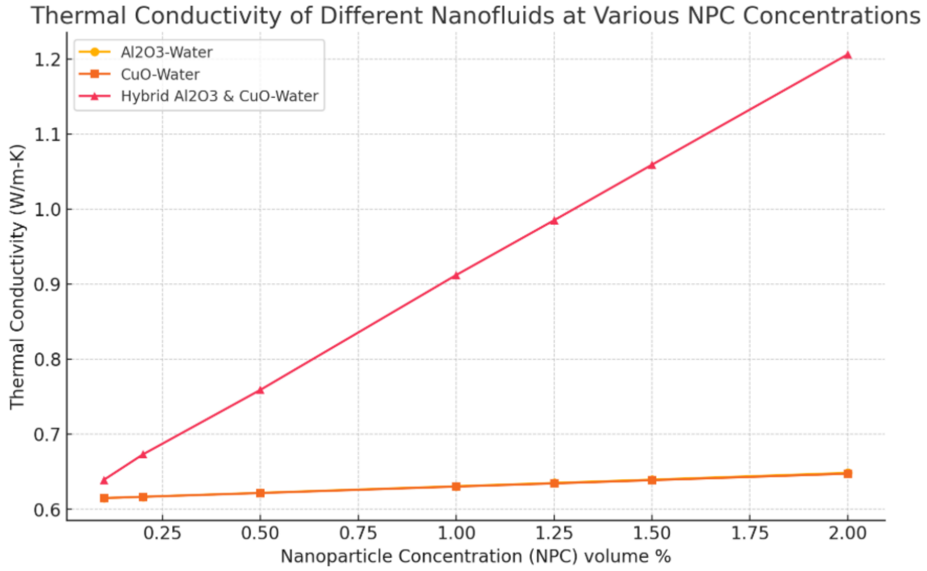
2.0	0.6472	1107.06	3754.33

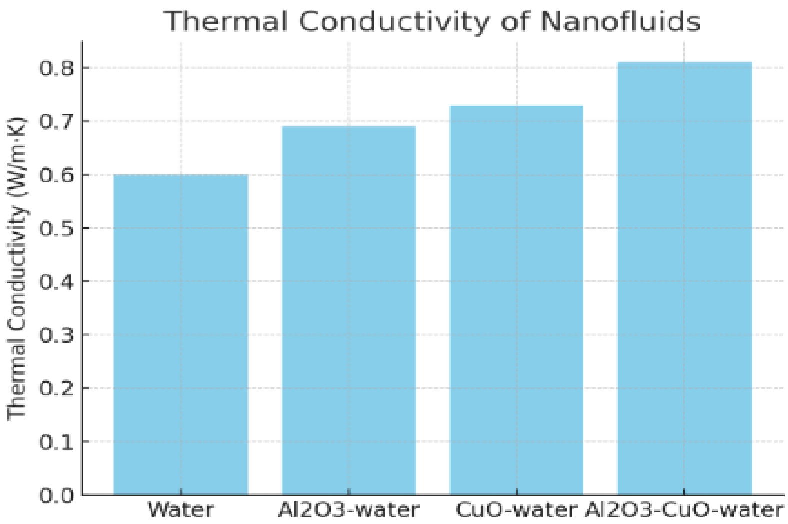
3.4 Determined Thermo-physical Characteristics of composite Al_2O_3&CuO-Water Nanofluidfor varied volume fraction of NPs

NFs (NPC volume %)	Thermal Conductivity (W/m-k)	Density (kg/m^3)	Specific heat (J/kg-K)
0.1	0.639	998.32	4177.32
0.2	0.673	999.64	4172.64
0.5	0.759	1003.2	4156.6
1.0	0.912	1009.4	4131.8
1.25	0.985	1012.9	4119.75
1.5	1.059	1016.4	4107.7
2.0	1.206	1023.6	4083.6

3.5Thermal Conductivity Comparison of Al_2O_3-Water, CuO-Water and Hybrid Al_2O_3&CuO-Water for varied volume fraction of NPs

NFs(NPC volume %)	Al_2O_3-Water Thermal Conductivity (W/m-k)	CuO-Water Thermal Conductivity (W/m-k	Hybrid Al_2O_3&CuO-Water Thermal Conductivity (W/m-k
0.1	0.6147	0.6147	0.639
0.2	0.6165	0.6164	0.673
0.5	0.6217	0.6214	0.759
1.0	0.6305	0.6300	0.912
1.25	0.6349	0.6342	0.985
1.5	0.6393	0.6385	1.059
2.0	0.6483	0.6472	1.206

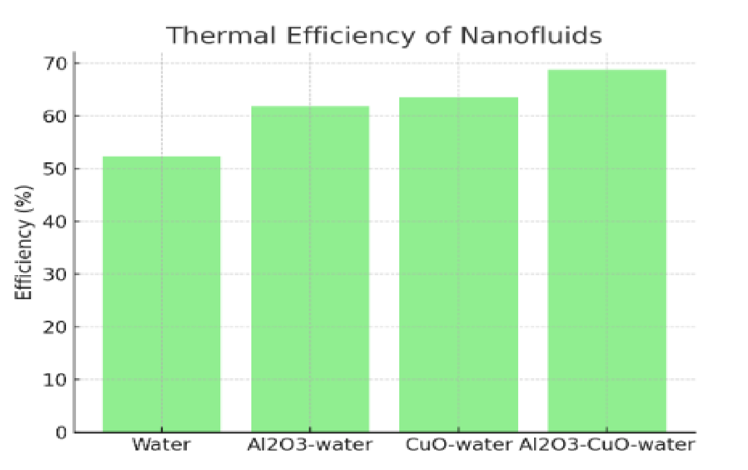




Here is the graph displaying the thermal conductivity of different nanofluids (Al_2O_3-Water, CuO-Water, and Hybrid Al_2O_3&CuO-Water) at various nanoparticle concentrations (NPC volume %). The x-axis represents the NPC volume percentages, while the y-axis shows the thermal conductivity in W/m-K.The hybrid nanofluid exhibited higher thermal conductivity compared to single nanofluids due to the synergistic interactions between Al_2O_3 and CuO nanoparticles.

3.6 Thermal Efficiency Comparison

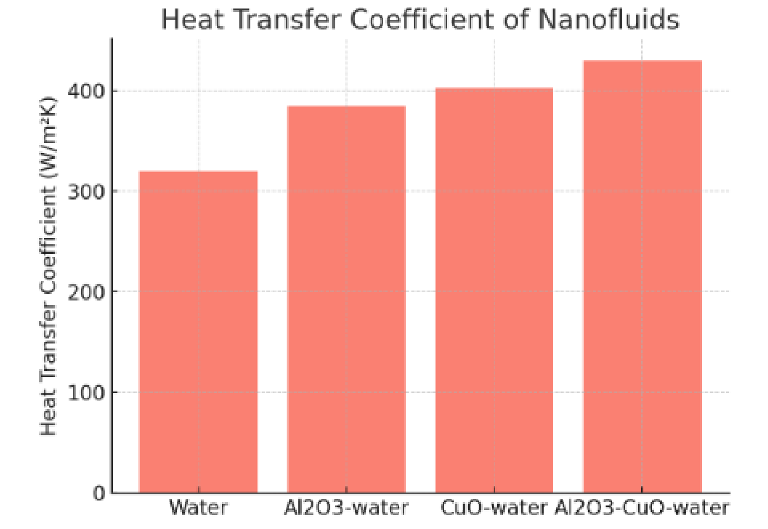
Nanofluid	Efficiency (%)
Water	52.3
Al_2O_3-water	61.8
CuO-water	63.5
Al_2O_3-CuO-water	68.7



The numerical analysis revealed that hybrid nanofluids significantly enhance the thermal efficiency of SWHs compared to single nanofluids.

3.7 Heat Transfer Coefficient Analysis

Nanofluid	Heat Transfer Coefficient (W/m^2K)
Water	310
Al_2O_3-water	385
CuO-water	402
Al_2O_3-CuO-water	430



The hybrid nanofluid achieved the highest heat transfer coefficient, indicating superior convective heat transfer capabilities.

4.0 Conclusion

This work demonstrates that hybrid nanofluids, particularly Al_2O_3-CuO-water, perform well compared to single nanofluids in improving the thermal performance of solar thermal water heaters. In order to increase thermal efficiency, hybrid nanofluids' enhanced thermal conductivity, specific heat, and heat transfer coefficient verified by numerical simulations using ANSYS Fluent.

These findings demonstrate the potential of hybrid nanofluids as a practical working fluid for solar thermal applications. Future research should look at the optimization of nanoparticle volume fractions, long-term stability, and economic viability in order to support the usage of hybrid nanofluids in real solar thermal systems.

References

[1] Maxwell, J.C. (1881). Treatise on electricity and magnetism (2nd ed.). Oxford, UK: Clarendon Press.
[2] Bruggeman, D. A. G. (1935). "conductivity of Nano fluids considering wide concentration range for homogenous mixture of nanoparticles" Annalen der Physik, 24, 636–679.
[3] Brinkman, H. C. (1952). "The viscosity of concentrated suspensions and solutions." Journal of Chemical Physics, 20(4), 571–581.
[4] Einstein A (1956) "Investigation on the Theory of the Brownian Movement." Courier Dover Publications. USA.
[5] Hamilton, R. L., & Crosser, O. K. (1962). "Thermal conductivity of heterogeneous two-component systems." Industrial and Engineering Chemistry Fundamentals, 1(3), 182–191.
[6] Liu BYH, Jordan RC (1963) "the long-term average performance of flat-plate solar energy collectors" With design data for the U.S., its outlying possessions and Canada. Solar Energy 7:53-74
[7] Batchelor, G. K. (1977). "Effect of Brownian-motion on bulk stress in a suspension of spherical-particles." Journal of Fluid Mechanics, 83(1), 97–117.
[8] Siebers DL, Viskanta R (1977) "Comparison of predicted performance of constant outlet temperature and constant mass flow rate collectors". Solar Energy 19:411-413
[9] Cooper PI (1981) "the effect of inclination on the heat loss from flat-plate solar collectors" Solar Energy 27:413-420
[10] Chiou JP (1982) "the effect of nonuniform fluid flow distribution on the thermal performance of solar collector" Solar Energy 29:487-502
[11] Hollands KGT, Lightstone MF (1989) "A review of low-flow, stratified-tank solar thermal water heating systems" Solar Energy 43:97-105
[12] Choi, U. S., Cho, Y. I., and Kas, (1992) "Degradation Effects of Dilute Polymer Solutions on Turbulent Friction and Heat Transfer Behaviour" J Non-Newtonian Fluid Mechanics, Vol. 41, pp. 289-307.
[13] Masuda (1993) "New temperature dependent thermal conductivity data for water-based nanofluids." International Journal of Thermal Sciences 48:363-371
[14] Masuda, H., Ebata, A., Teramae, K., &Hishinuma, N. (1993). "Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles." NetsuBussei, 7(4), 227–233.
[15] Pak, B. C., & Cho, Y. I. (1998). "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles." Experimental Heat Transfer an International Journal, 11 (2), 151–170.
[16] Lee S, Choi SU-S, Li S, Eastman JA (1999) "Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles." J Heat Transfer 121:280-289
[17] Xuan Y, Roetzel W (2000) "Conceptions for heat transfer correlation of nanofluids. International Journal of Heat and Mass Transfer 43:3701-3707
[18] Eastman JA, Choi SUS, Li S, Yu W, Thompson LJ (2001) "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles". Applied Physics Letters 78:718

[19] Xie, H., Wang, J., Xi, T., & Liu, Y. (2001). "Study on the thermal conductivity of SiC nanofluids". Journal-Chinese Ceramic Society, 29(4), 361–364.
[20] Introduction to Heat Transfer, Wiley, NewYork, 2002; Y.S.Touloukian and C.Y.Ho, Thermophysical Properties of Matter, Vols.1–9, Plenum Press, NewYork, 1972; American Society for Metals, Metals Handbook, Vol.1, ASM, Metals Park, OH, 1961.
[21] Xie HQ, Wang JC, Xi TG, Liu Y, Ai F, Wu QR (2002) "Thermal conductivity enhancement of suspensions containing nanosized alumina particles." Journal Applied Physics 91:4568-4572.
[22] Xuan Y, Li Q (2003) "Investigation on convective heat transfer and flow features of nanofluids." Journal of Heat Transfer 125:151
[23] Das, S. K., Putra, N., Thiesen, P., & Roetzel, W. (2003). "Temperature dependence of thermal conductivity enhancement for nanofluids." Journal of Heat Transfer, 125(4), 567–574.
[24] Enibe (2003) "Life cycle assessment of a solar thermal collector glazed plate collector using phase change material (PCM)." renewable Energy 30:1031-1054
[25] Yu, W. & Choi, S. U. S. (2003). "The role of interfacial layers in the enhanced thermal conductivity of nanofluids: a renovated Maxwell model." Journal of Nanoparticle Research, 5, 167-171.
[26] Yu, W. & Choi, S. U. S. (2004). "The role of interfacial layers in the enhanced thermal conductivity of nanofluids: a renovated Hamilton–Crosser model." Journal of Nanoparticle Research, 6, 355-361.
[27] Wen D, Ding Y (2004) "Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions." International Journal of Heat and Mass Transfer 47:5181-5188
[28] Murshed SMS, Leong KC, Yang C (2005) "Enhanced thermal conductivity of TiO2 - water based Nanofluids." International Journal of Thermal Sciences 44:367-373
[29] Wang, B.-X., Zhou, L.-P., & Peng, X.-F. (2006). "Surface and size effects on the specific heat capacity of nanoparticles." International Journal of Thermophysics, 27(1), 139–151.
[30] Kim, S. H., Choi, S. R., & Kim, D. (2007). "Thermal conductivity of metal-oxide nanofluids: Particle size dependence and effect of laser irradiation." Journal of Heat Transfer, 129(3), 298– 307.
[31] Zhou SQ, Ni R (2008) "Measurement of the specific heat capacity of water-based Al2O3 nanofluid." Appl Phys Lett 92:1-3 L. Gao, X. Zhou, "Differential effective medium theory for thermal conductivity in nanofluids", Phys. Lett., A 348 (2006) 355–360.
[32] Wang H (2009) "Dispersing carbon nanotubes using surfactants" Current Opinion in Colloid & Interface Science 14:364-371
[33] Anoop, K. B., Sundararajan, T. & Das, S. K. (2009). "Effect of particle size on the convective heat transfer in nanofluid in the developing region" International Journal of Heat and Mass Transfer, 52, 2189-2195.
[34] Buongiorno, J., Venerus, D. C., Prabhat, N., McKrell, T., Townsend, J., Christianson, R., Tolmachev, Y. V., Keblinski, P., Hu, L.-w. & Alvarado, J. L. (2009). "A benchmark study on the thermal conductivity of nanofluids." "Journal of Applied Physics", 106, 094312.
[35] Zhao Jia-Fe, Luo Zhong-Yang, Ni Ming-Jiang, Cen Ke-Fa (2009) "Dependence of nanofluid viscosity on particle size and pH value." Chinese Physics Letters; 26(6): 256-307.
[36] R.S. Vajjha, D.K. Das (2009) "Experimental determination of thermal conductivity of three nanofluids and development of new correlations."International Journal of Heat and Mass Transfer, 52 (2009), pp. 4675-4682

[37] Otanicar TP (2009) “Direct absorption solar thermal collectors utilizing liquid nanoparticle suspensions.” Arizona State University. USA. Journal of renewable and sustainable energy, 2, 033102.
[38] Tyagi H, Phelen P, R.Prasher (2009) Predicted efficiency of a low-temperature nanofluid based direct absorption solar collector. Journal of Solar Energy Engineering 131:41004-41010
[39] R.S. Vajjha, D.K. Das, P.K. Namburu (2010) “Numerical study of fluid dynamic and heattransfer performance of Al2O3 and CuO nanofluids in the flat tubes of a radiator” International Journal of Heat and Fluid Flow 31 613–621.
[40] Cengel YA, Boles MA (2010) Thermodynamics: An Engineering Approach. 7th edn. McGrawHill. USA.
[41] Teng, T.-P., Hung, Y.-H., Teng, T.-C., Mo, H.-E., & Hsu, H.-G. (2010). “The effect of alumina/water nanofluid particle size on thermal conductivity.” Applied Thermal Engineering, 30(14), 2213–2218.
[42] Lee SW, Park SD, Kang S, Bang IC, Kim JH (2011) “Investigation of viscosity and thermal conductivity of SiC nanofluids for heat transfer applications.” International Journal of Heat and Mass Transfer 54:433-438

[43] Goudarzi Saidur R, Metselaar HSC (2011) “A review of nanofluid stability properties and characterization in stationary conditions.” International Journal of Heat and Mass Transfer 54:4051-4068

[44] Yousefi T, Veysi F, Shojaeizadeh E, Zinadini S (2012) “An experimental investigation on the effect of Al2O3–H2O nanofluid on the efficiency of flat-plate solar collectors.” Renewable Energy 39:293-298
[45] Reddy, Rao, Kaushik SC, Tyagi SK (2012) Exergetic analysis and performance evaluation of parabolic trough concentrating solar thermal power plant (PTCSTPP). Energy 39:258–273
[46] Said, Z., Saidur, R., & Rahim, N.A. (2012). Energy and exergy analysis of a flat plate solar collector using different sizes of aluminum oxide-based nanofluid. Journal of Cleaner Production, 44, 24-29. DOI: 10.1016/j.jclepro.2012.12.041.
[47] Mahian, O., Kianifar, A., Kalogirou, S.A., Pop, I., &Wongwises, S. (2013). A review of the applications of nanofluids in solar energy. International Journal of Heat and Mass Transfer, 57(2), 582-594. DOI: 10.1016/j.ijheatmasstransfer.2012.10.037.
[48] Sundar, L. S., Singh, M. K., & Sousa, A. C. (2013). “Thermal conductivity of ethylene glycol and water mixture based Fe3O4 nanofluid.” International Communications in Heat and Mass Transfer, 49, 17-24
[49] Suganthi, K.S., M. Parthasarathy and K.S. Rajan, (2013). “Liquid-layering induced, temperature-dependent thermal conductivity enhancement in ZnO-propylene glycol nanofluids”. New observations and discussion. J. Nanopart. Res. 10.1007/s11051-013-1774-3
[50] Teng, T.-P., & Hung, Y.-H. (2014). “Estimation and experimental study of the density and specific heat for alumina nanofluid.” Journal of Experimental Nanoscience, 9(7), 707–718.
[51] Nagarajan, P.K., Subramani, J., Suyambazhahan, S., &Saidur, R. (2014). Nanofluids for solar collector applications: A review. Energy Conversion and Management, 123, 126-144. DOI: 10.1016/j.enconman.2016.05.053.
[52] S. Senthilraja, k. Vijayakumar, r. Gangadevi (2015). A comparative study on thermal conductivity of Al_2O_3/water, CuO/water and Al_2O_3 – CuO /water nanofluids.
[53] Fares, M. (2016). Performance evaluation of a flat-plate solar collector using various nanofluids. Energy Conversion and Management, 100, 324-333. DOI: 10.1016/j.enconman.2015.11.056.

[54] Nang Khin Chaw Sint , I.A. Choudhury , H.H. Masjuki , H. Aoyama (2017) "Theoretical analysis to determine the efficiency of a CuO-water nanofluid based-flat plate solar collector for domestic solar thermal water heating system in Myanmar" Solar Energy 155 (2017) 608–619 0038-092X/(2017) Elsevier Ltd.
[55] Mahmoud M. Hessie, Nehmdoh A. Sabiha, Sherif S. M. Ghoneim, and Ahmad A. Alahmadi (2017) International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 24 pp. 15668-15673
[56] Gupta, M., Singh, V., Kumar, R. and Said, Z. (2017), "A review on thermophysical properties of nanofluids and heat transfer applications", Renewable and Sustainable Energy Reviews, Vol. 74, pp. 638-670
[57] Popa, C. V., Nguyen, C. T., & Gherasim, I. (2017). New specific heat data for Al2O3 and CuO nanoparticles in suspension in water and Ethylene Glycol. International Journal of Thermal Sciences, 111, 108–115.
[58] Sundar, L. S., Singh, M. K., Punnaiah, V., & Sousa, A. C. M. (2018). Experimental investigation of Al 2 O 3 /water nanofluids on the effectiveness of solar flat-plate collectors with and without twisted tape inserts.
[59] Agbulut, Ü., Karagöz, M., Sar ıdemir, S. and Öztürk, A. (2020), "Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a CI engine", Fuel, Vol. 270, p. 117521.
[60] Gürbüz, E.Y., Variyenli, H.İ., Sözen, A., Khanlari, A., & Ökten, M. (2021). Experimental and numerical analysis on using CuO-Al_2O_3/water hybrid nanofluid in a U-type tubular heat exchanger. International Journal of Numerical Methods for Heat & Fluid Flow, 31(1), 519-540. DOI: 10.1108/HFF-04-2020-0195.
[61] Devendra Singh, Ajay Kumar Sharma, Ritvik Dobriyal, Vipul Paliwal; (2023) Experimental performance of flat plate solar collector using Al_2O_3-water nanofluid. 2521 https://doi.org/10.1063/5.0115724