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Geometrical Analysis of the Thermal Conductivity of Nanofluids Using Different Models

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Abstract

Nanofluids (NF) have recently emerged as pioneers of standard heat transfer fluid augmentation or potential replacement. The potential for NFs to be employed in a wide range of technical applications, ranging from renewable energy to nanomedicine, have become one of today's most investigated issues. The widespread use of warmth to move liquids in modern applications emphasizes their critical role in the effectiveness of the system. The various methods for determining the thermal conductivity of NFs are explained. Using hypothetical thermal conductivity (TC) models like Hamilton and Crosser, Jeffrey, Maxwell, Davis, and Bruggeman, the heat conductivity of Water, Liquid Sodium, and Ethylene Glycol possessing unique concentrations for Copper, Aluminum and Silver nanoparticles are investigated in this study. As a result, this study provides an overview of the most significant achievements and contentious discoveries in the field of NFs thermal conductivity. The findings reveal that when nanoparticles are fixed, the thermal conductivity of nanofluids increases.

Keywords

Thermal Conductivity, Nanoparticles, Nanofluids, Maxwell model, Suresh and Davis models, Bruggeman model

1. Introduction

Nanofluids are a fresh type of homogeneous mixtures of low-centralization nanoparticles and common liquids/oils created for dramatically enhancing their warm and hostile to wear execution [1]. The millimeter-scaled molecule scatterings have a number of drawbacks, including sedimentation, part disintegration, clogging, and unwanted pressing factor drop, all of which can be avoided by using nanofluids, which are created by uniformly scattering nanoparticles.

By avoiding basic concerns such as obstructions, precipitation, and disintegration, nanoparticles have a simple fluidized measure. By avoiding basic concerns such as obstructions, precipitation, and disintegration, nanoparticles have a fluidized measure that is simple [2] [3]. The TC of the regular working liquid of warmth transmission frameworks is thought to be an important factor in increasing the efficiency of heat transfer. A lot of scientists have recently claimed that the TC of nanofluid has improved as a result of trial concentrating [4]. The TC was examined by Duangthongsuk et al. and consistency of Titanium dioxide nanoparticles centralizations ranging from 0.2 to 2 microns. The findings reveal that as the volume concentration of nanoparticles raises, so does the TC of nanofluids and falls as the temperature rises [5]. Sharp edges, platelets, round and hollow, blocks, and circular form nanoparticles were studied by Alawi et al. to see how they affected the TC of metallic oxide nanofluids. The best warmth transfer enhancement is found in nanofluids containing spherical nanoparticles, next came barrel-shaped nanoparticles, blocks, sharp edges, and platelets shapes, in that order [6]. One study found that the heat conductivity of a graphene oxide-based nanofluid made of deionized water and ethy-

lene glycol and a weight component for 0.10% and a temperature of 25°C-45°C resulted in a 6.67-10.47% improvement [7]. The heat conductivity of carbon nano tube-polyalpha Olefin oil nanofluid of percentage of 1% was investigated by Choi et al. and it was also discovered a TC improvement of 160%.

Another study found that the heat conductivity of Poly Ethylene Glycol on CuO Nanoparticles-fluid having a proportion of 4% and found a 20% improvement in heat conductivity [8].

Aluminum, Silver, and Copper nanoparticles have thermal conductivities of 237 W/mK, 429 W/mK, and 400 W/mK, in that order, while Water, Ethylene glycol, and Liquid Sodium have thermal conductivities of 0.605 W/mK, 0.252 W/mK, and 76 W/mK, in that order [9] [10].

The heat conductivity of Ethylene glycol, Water and Liquid Sodium possessing different centralizations of Aluminum, Silver, and Copper nanoparticles is evaluated in this study by theoretical and observational TC model as an example Maxwell model and the findings are presented and debated [11].

2. Nano Fluids Preparation

The main step in the nanofluids test investigations is to arrange the nanofluids. Both the one-step and two-step preparation processes are both important methodologies for nanofluid planning. The following is a brief discussion of the nanofluid preparation method.

Single-step preparation process: The one-step preparation procedure displays the single-step mixing of nanofluids. For nanofluid arrangement, a few single-step approaches have been demonstrated. Akoh et al. developed a single direct advance dissipation approach [12]. VEROS (Vacuum Evaporation onto a Running Oil Substrate) is the name of this cycle. Regardless, isolating nano-particles from liquid structures was difficult. Eastman et al. created a customized VEROS process in which Cu fume is densely packed into nanoparticles by contacting it with low-fume-pressure ethylene glycol in a stream by reducing copper sulphate. $5H_2O$ with $NaH_2PO_2.H_2O$ in ethylene glycol under microwave illumination, Zhu et al. developed a single advanced chemical interaction for the design of Cu nanofluids [13]. This technology also works well for delivering silver nanofluids that are based on mineral oil. To create Copper oxide, Cu_2O. and Cu based nanofluids with various dielectric fluids, Lo et al. created a vacuum-based decreased circular segment nano-particle combination. To supply an electric circular segment between 6,000 and 12,000°C, which liquefies and disintegrates a metal pole in the area where the curve is produced, a suitable force source is required. The disintegrating metal is dense, and deionized water scatters it to generate nanofluids. [14]. The one-venture blend process has the advantage of limiting nano-particle aggregation. The main challenge is that such a cycle is only practicable with lone low fume pressure liquids. Figure 1 shows a one-venture planning measure (substance interaction) for nanofluids.

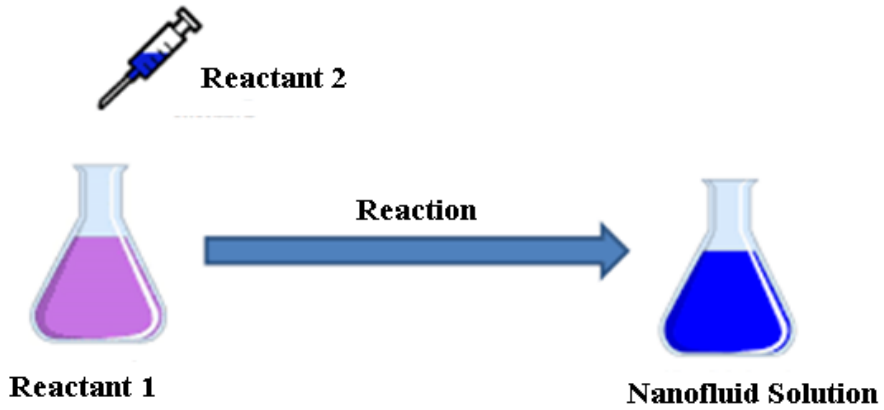

Figure 1. Single-step Preparation Process of nanofluids.

Two-step preparation process: By combining base liquids with economically accessible nanoparticles obtained through various mechanical, physical, and material courses like processing, crushing, and sol-gel and fume stage techniques, the two-step preparation procedure is widely employed in the blend of nano-fluids. Mixing Nano particles with liquids is usually done with an ultrasonic vibrator or a higher shear blending device. To reduce molecular agglomeration, it is necessary to use ultrasonication or blending multiple times.

Murshed et al. used a similar technique to arrange TiO 2-water Nano suspension [15]. Xuan et al. developed nanofluids of both water and transformer oil using commercially available Cu nanoparticles. Kim et al. made an application of a

two-step technique to create CuO dispersed ethylene glycol nanofluids without stabilizers using a two-step strategy. Union of carbon nanotube-based nanofluids can also be accomplished via a two-step method. Pyrolysis is used to release single-walled and multi-walled carbon nano-tubes, which are then balanced in base liquids with or without the usage of surfactants [16] [17]. A few authors suggested that preparing nanofluids including oxide nanoparticles in two steps is more reasonable than preparing nanofluids containing metallic nanoparticles in one stage. As the powders effectively total due to solid vander Walls power among nanoparticles, consistency is a big challenge that fundamentally identified with this activity. Despite these drawbacks, this cycle is still widely used as the most profitable method of producing nanofluids. Figure 2 depicts the most well-known two-step method [18].

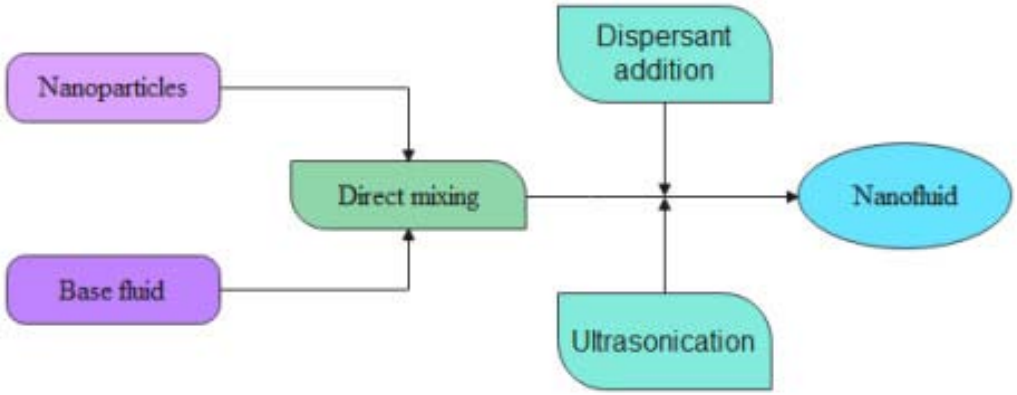

Figure 2. Two-step preparation process of nanofluids.

3. Thermal Conductivity of Nanofluids

To predict the successful TC of nanofluids, a variety of speculative and specific forms have been presented. To estimate the heat conductivity of blends and composites, the most prominent models such as Effective Medium Theory and the Maxwell model (Equation 1) are usually utilized [19]. Molecule scattering is acknowledged in the Maxwell heat conductivity model for the low molecule volume region of round nanoparticles. Collaborations between particles, nano particle size, and the temperature of the base liquid are ruled out.

$$\frac{k_{eff}}{k_f} = \frac{k_p + 2k_f + 2\varphi(k_p - k_f)}{k_p + 2k_f - \varphi(k_p - k_f)} \tag{1}$$

The Shape aspect is important in determining the powerful heat conductivity of liquid including round, and hollow nanoparticles, is used to develop the Hamilton and Crosser (Equation 2) model. Where n relies upon molecule shape and$\frac{K_s}{K_l}$, n $= \frac{3}{\varphi}$for$\frac{K_s}{K_l}$>100, n=3 for different cases. By considering the architecture and condition of nanoparticles, the compelling TC of both consistent and spasmodic stages is determined using this approach [20].

The Maxwell, Hamilton, and Crosser models were modified to create the majority of additional static TC models [21].

$$\frac{k_{eff}}{k_f} = \frac{k_p + (n-1)k_f - (n-1)\varphi(k_f - k_p)}{k_p + (n-1)k_f + \varphi(k_f - k_p)} \tag{2}$$

To anticipate the compelling thermal conductivity, the Jeffrey model (Equation 3) was devised by considering the collaboration between two haphazardly spread nanoparticles in a liquid medium [22].

$$\frac{k_{eff}}{k_m} = 1 + 3\beta\nu + (3\beta^2 + \frac{3\beta^2}{4} + \qquad \frac{9\beta^3}{16}\frac{\alpha+2}{2\alpha+3} + \cdots\cdots)\nu^2 \tag{3}$$

In the Davis model, connection of distributed circular in the liquid environment is addressed for measuring the TC of nanofluids, similar to Jeffrey's TC model, which has large request terms due to pair communications of haphazardly spread circles [23].

$$\frac{k_{eff}}{k_f} = 1 + \frac{3(\alpha-1)\varphi}{(\alpha+2)-(\alpha-1)\varphi}[\varphi + f(\alpha)\varphi^2 + \qquad 0(\varphi)^3] \tag{4}$$

The model Bruggeman (from equation no 5) is utilized to foresee the viable TC of the parallel combination of uniform round and arbitrarily scattered nanoparticles [24].

$$\frac{k_{eff}}{k_f} = \frac{1}{4}[(3\varphi - 1)\frac{k_p}{k_f} + (2 - 3\varphi) + \frac{k_f}{4}\sqrt{\Delta}] \quad (5)$$

where,

k_{eff} is the effective TC of nanoparticles (W/mk)

k_f is the TC of base fluids (W/mk)

k_p is the TC of the particle

φ is the volume fraction of the particles, n is the empirical shape factor given by $n = \frac{3}{\varphi}$, and φ is the sphericity. For spherical and cylindrical particles, the values of sphericity (φ) are 1 and 0.5 respectively.

The TC of nanoparticles at rates ranging from one to eight is determined using the methodology in Equations 1-5 [25] [26]. The TC of ethylene glycol, water, and liquid sodium possessing silver, aluminum and copper is presented separately in the tables below.

Table 1 shows the TC of water possessing 1-8 percent aluminum nanoparticles, as well as an analysis of the consequences by hypothetical TC models [27].

Table 1. TC of nanofluids (Water + Aluminum)

Nano Particle Percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	0.6231	0.6222	0.6238	0.6218	0.6218
2	0.6456	0.6434	0.6318	0.6478	0.6372
3	0.6628	0.6658	0.6564	0.6634	0.6608
4	0.6800	0.6864	0.6810	0.6812	0.6814
5	0.6917	0.6991	0.6998	0.7074	0.7028
6	0.7049	0.7194	0.7113	0.7304	0.7487
7	0.7224	0.7288	0.7229	0.7663	0.7845
8	0.7436	0.7476	0.7436	0.7916	0.8257

At room temperature, aluminum nanoparticles have a TC of 237 W/mK, while water has a TC of 0.605 W/Mk [28].

Water's TC when aluminum nanoparticles are used as a component of the nanoparticle fixation between 1% and 8% is shown in Table 1. The TC of aluminum nanofluids rises linearly as the nanoparticle focus increases. The TC of the nanofluid is improved by taking into account the presence of interfacial layers of nanoparticles according to the interfacial layer concept [29].

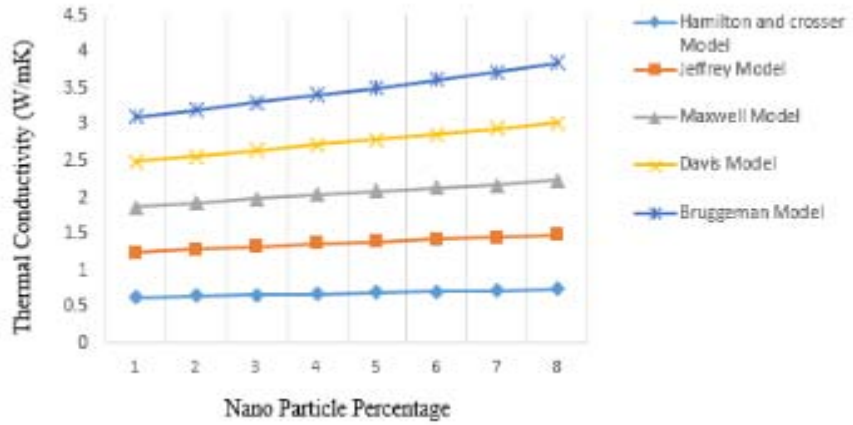

Figure 3. Thermal Conductivity of Nanofluids (Aluminium +Water).

Table 2 shows the TC of water with 1-8 percent silver nanoparticles, as well as the correlation of consequences by hypothetical TC models

Table 2. TC of nanofluids (Water + Silver)

Nano Particle percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	0.6231	0.6226	0.6232	0.6224	0.6224
2	0.6474	0.6492	0.6418	0.6442	0.6418
3	0.6654	0.6652	0.6574	0.6672	0.6678
4	0.6802	0.6842	0.6798	0.6884	0.6812
5	0.6911	0.6955	0.7045	0.7145	0.7034
6	0.7044	0.7171	0.7158	0.7352	0.7473
7	0.7290	0.7219	0.7269	0.7778	0.7845
8	0.7489	0.7427	0.7402	0.7935	0.8219

At room temperature, Silver nano-particles have a TC of 429 W/mK, whereas Water has a TC of 0.605 W/mK. Table 2 shows the TC of Silver nano-particle-containing water as a function of nano-particle concentrations ranging from 1 to 8%. Silver nano-fluids' TC rises in a linear relationship with nano-particle concentration [30].

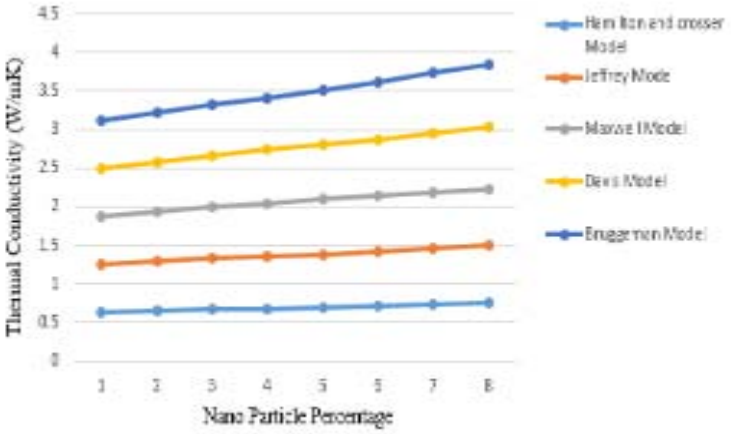

Figure 4. Thermal Conductivity of Nanofluids (Silver + Water).

Table 3 shows the TC of water with 1-8 percent copper nanoparticles, as well as the correlation of consequences by hypothetical TC models [31].

Table 3. TC of nanofluids (Water + Copper)

Nano Particle percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	0.6217	0.6273	0.6223	0.6210	0.6274
2	0.6374	0.6438	0.6355	0.6424	0.6356
3	0.6482	0.6678	0.6472	0.6692	0.6514
4	0.6552	0.6874	0.6802	0.6856	0.6878
5	0.6858	0.6998	0.7000	0.7111	0.7187
6	0.7084	0.7148	0.7158	0.7347	0.7453
7	0.7267	0.7234	0.7269	0.7714	0.7891
8	0.7468	0.7411	0.7402	0.7979	0.8211

Copper nanoparticles have a TC of 400 W/mK, whereas water has a TC of 0.605 W/mK at ambient temperature. Water's TC when copper nanoparticles are used as a component of the nanoparticle fixation between 1% and 8% is shown in Table 3. With the fixation of nanoparticles, the TC of Copper nanofluids rises linearly.

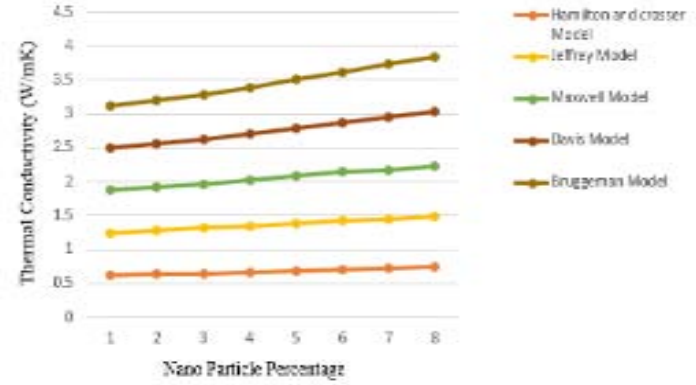

Figure 5. Thermal Conductivity of Nanofluids (Copper + Water).

Table 4 shows the TC of Ethylene glycol with 1-8% aluminum nanoparticles, as well as a comparison of data obtained using theoretical TC models.

Table 4. TC of nanofluids (Ethylene glycol + Aluminum)

Nano Particle percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	0.2560	0.2534	0.2592	0.2518	0.2542
2	0.2658	0.2674	0.2644	0.2619	0.2686
3	0.2774	0.2782	0.2716	0.2734	0.2714
4	0.2866	0.2814	0.2802	0.2856	0.2828
5	0.2903	0.2921	0.2911	0.2913	0.2955
6	0.3078	0.3023	0.3015	0.3165	0.3176
7	0.3134	0.3145	0.3124	0.3276	0.3386
8	0.3256	0.3253	0.3254	0.3394	0.3554

Aluminum nanoparticles have a TC of 237 W/mK at ambient temperature, while Ethylene glycol has a TC of 0.252 W/mK. The TC of Ethylene glycol incorporating aluminum nanoparticles as a component of nanoparticle fixation between 1% and 8% is depicted in Table 4. The TC of aluminum nanofluids increases in direct proportion to the amount of nanoparticles fixed [32].

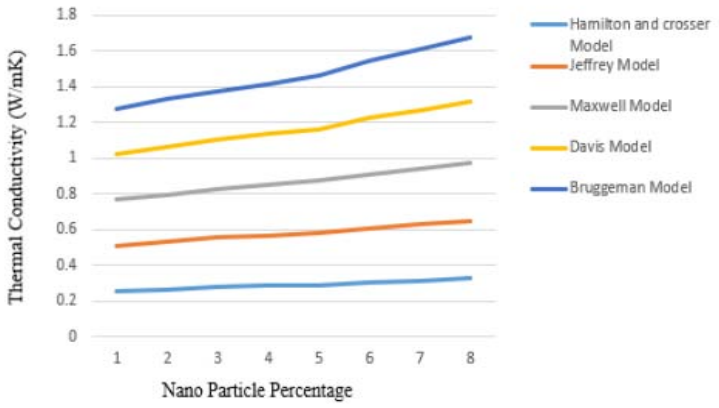

Figure 6. Thermal Conductivity of Nanofluids (Aluminium + Ethylene glycol).

Table 5 shows the TC of Ethylene glycol with 1-8 percent Silver nanoparticles, as well as the analysis of data using hypothetical TC models [33].

Table 5. TC of nanofluids (Ethylene glycol + Silver)

Nano Particle percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	0.2546	0.2558	0.2596	0.2578	0.2512
2	0.2610	0.2694	0.2652	0.2692	0.2632
3	0.2757	0.2714	0.2718	0.2744	0.2744
4	0.2812	0.2838	0.2864	0.2872	0.2872
5	0.2966	0.2967	0.2981	0.2916	0.2911
6	0.3015	0.3073	0.3077	0.3122	0.3123
7	0.3119	0.3115	0.3179	0.3232	0.3318
8	0.3293	0.3222	0.3285	0.3343	0.3535

At normal temperature, Silver nanoparticles have a TC of 429 W/mK, while Ethylene glycol has a TC of 0.605 W/mK. In Table 5, the TC of Ethylene glycol with Silver nanoparticles as a component of nanoparticle fixation between 1-8% is shown. The TC of Silver nanofluids rises in a straight line with the focus of nanoparticles.

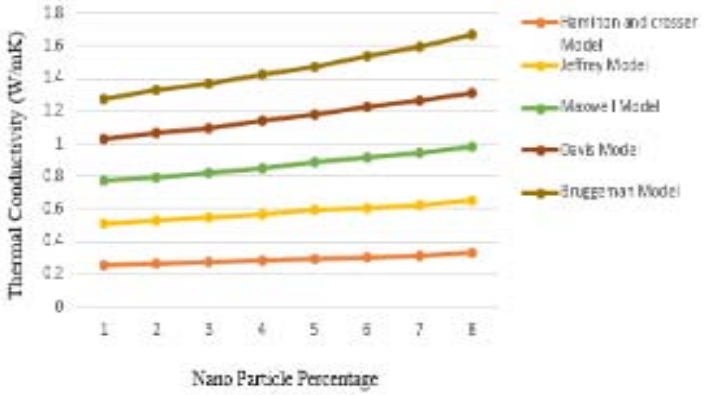

Figure 7. Thermal Conductivity of Nanofluids (Silver+ Ethylene glycol).

The TC of Ethylene glycol with 1-8 percent Copper nanoparticles is shown in Table 6, along with an analysis of the consequences by hypothetical TC models [34].

Table 6. TC of nanofluids (Ethylene glycol + Copper)

Nano Particle percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	0.2582	0.2568	0.2594	0.2584	0.2508
2	0.2644	0.2686	0.2654	0.2618	0.2614
3	0.2716	0.2732	0.2768	0.2726	0.2738
4	0.2856	0.2872	0.2882	0.2846	0.2814
5	0.2991	0.2955	0.2917	0.2936	0.2919
6	0.3097	0.3067	0.3067	0.3119	0.3138
7	0.3189	0.3123	0.3108	0.3281	0.3352
8	0.3278	0.3253	0.3201	0.3367	0.3546

Copper nanoparticles have a TC of 400 W/mK, whereas Ethylene glycol has a TC of 0.252 W/mK at ambient temperature. The TC of Ethylene glycol with Copper nanoparticles is depicted in Table 6 as a component of nanoparticle focus in the range of 1-8%. With the fixation of nanoparticles, the TC of Copper nanofluids rises linearly.

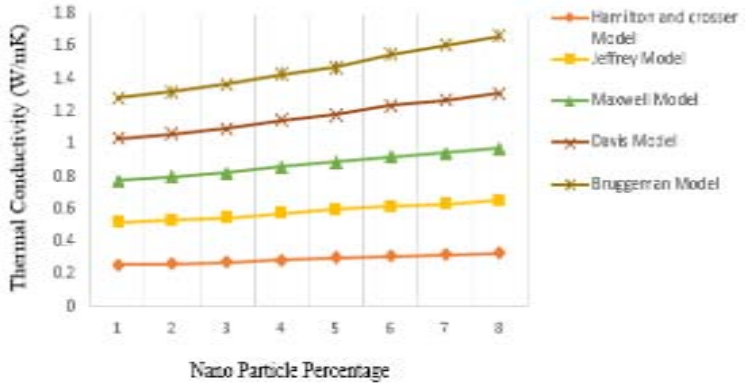

Figure 8. Thermal Conductivity Nanofluids (Copper + Ethylene glycol).

The TC of sodium with 1-8 percent aluminum nanoparticles is provided in Table 7, along with an assessment of outcome by theoretical TC models

Table 7. TC of nanofluids (liquid Sodium + Aluminum)

Nano Particle percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	76.947	78.302	76.947	76.957	73.380
2	77.903	79.275	77.903	77.941	74.565
3	78.866	80.271	78.866	78.955	75.757
4	79.838	81.240	79.838	79.997	76.960
5	80.817	82.330	80.817	81.070	78.174
6	81.806	83.387	81.806	82.175	79.399
7	82.802	84.466	82.802	83.312	80.635
8	83.807	85.560	83.807	84.482	81.880

Aluminum nanoparticles have a TC of 237 W/mK at ambient temperature, whereas liquid sodium has a TC of 76 W/mK. Table 7 shows the TC of liquid Sodium with Aluminum nanoparticles as a component of nanoparticle fixation between 1% and 8% [35]. The TC of Aluminum nanofluids rises in lockstep with the focus of nanoparticles.

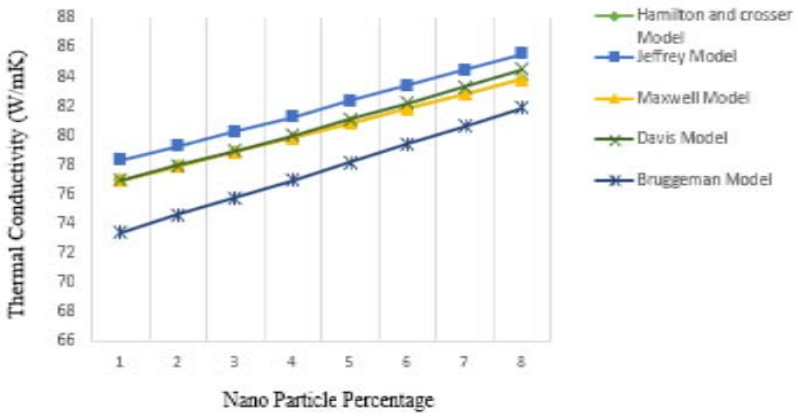

Figure 9. Thermal Conductivity of Nanofluids (Aluminium + Liquid Sodium).

The TC of sodium with 1-8 percent silver nanoparticles is provided in Table 8, along with an assessment of outcome by theoretical TC models.

Table 8. TC conductivity of nanofluids (Liquid Sodium + Silver)

Nano Particle percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	76.58798	80.18	77.39373	77.40	75.026
2	77.16693	81.624	78.80461	78.86	76.598
3	77.73706	83.068	80.23296	80.36	78.208
4	78.29857	84.588	81.67909	81.91	79.85
5	78.85165	86.108	83.14334	83.51	81.549
6	79.39649	87.628	84.62606	85.17	83.281
7	89.16223	89.604	86.1276	86.88	85.05
8	91.16763	90.896	87.64831	88.65	86.872

Silver nanoparticles have a TC of 429 W/mK at ambient temperature, while liquid sodium has a TC of 76 W/mK. Table 8 shows the TC of liquid Sodium with Silver nanoparticles as a component of nanoparticle application between 1% and 8%. The TC of Silver nanofluids rises in lockstep with the nanoparticle concentration [36].

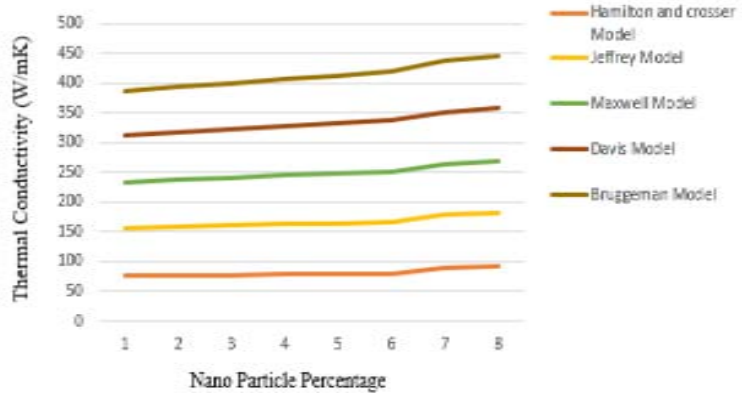

Figure 10. Thermal Conductivity of Nanofluids (Silver + Liquid Sodium).

The TC of Sodium with 1-8 percent Copper nanoparticles is presented in Table 9, along with a judgment of outcome utilizing theoretical TC models [37].

Table 9. TC of nanofluids (Liquid Sodium + Copper)

Nano Particle percentage	Hamilton and Crosser Model	Jeffrey Model	Maxwell Model	Davis Model	Bruggeman Model
1	77.346	79.98	77.346	77.3597	74.852
2	78.708	81.37	78.7083	78.7635	76.381
3	80.086	82.76	80.0867	80.2130	77.944
4	81.481	84.23	81.4817	81.7097	79.543
5	82.893	85.70	82.8936	83.2555	81.179
6	84.322	87.21	84.3226	84.8519	82.852
7	85.769	88.75	85.7692	86.5009	84.563
8	87.233	90.31	87.2335	88.2041	86.312

Copper nanoparticles have a TC of 400 W/mK, whereas liquid sodium has a TC of 76 W/mK at ambient temperature. Table 9 shows the TC of liquid Sodium incorporating Copper nanoparticles as a nanoparticle focus element between 1-8%. Copper nanofluids' TC rises in lockstep with nanoparticle fixation.

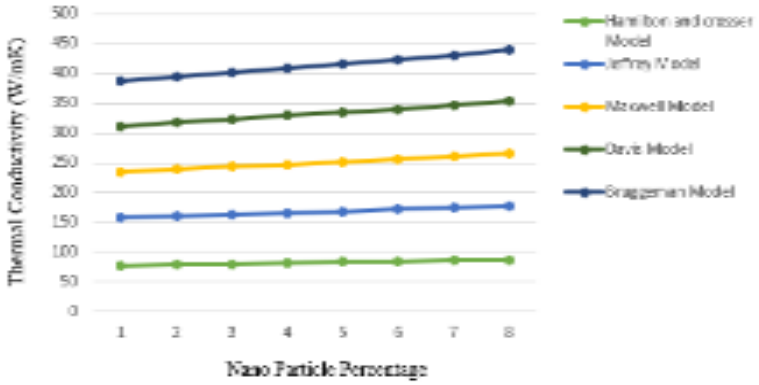

Figure 11. Thermal Conductivity of Nanofluids (Copper+ Liquid Sodium).

4. Conclusion

The findings suggest that nanofluids containing modest concentrations of nanoparticles have significantly greater heat conductivity than basic liquids. The amount of molecule volume, the dimension and condition of nanoparticles, the kind of base liquid and nanoparticles, the pH value of nanoliquids, and the TC of nanofluids is affected by the sort of molecule that covers them all. The most accurate model for nanofluid TC is currently lacking. It is clear from the preceding graphs and tables that the Maxwell model exhibits some common variations in comparison to other models. Suresh and Davis models have greater TC values, Suresh's model, alternatively, has a much greater TC value than the other models. In comparison to Suresh and Davis models, the Bruggeman model provides slightly higher TC. The Hamilton and Crosser models are more similar to the Jeffrey model in terms of attributes.

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