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Selection of nanofluid for heat transfer applications from existing models of thermal conductivity

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ABSTRACT

Nanofluids are gaining much importance over the past decade due to their enhanced thermal conductivity, specific heat, cooling capacity, electrical conductivities. Novel properties of nanofluids are yet to be explored to the highest potential applications. One of the prominent applications of nanofluids is in thermal conduction. The presence of nanoparticle in a fluid can enhance the thermal conductivities by several orders of magnitude (100-250).Experimental techniques involved in measuring thermal conductivity are transient hot wire method, steady state technique, and temperature oscillation technique, but suffer from drawbacks arising during measurement. Theoretical models are also proposed by Maxwell, Hamilton Crosser, Yu and Choi, Koo and Kleinstreuer, and Kumar. The present paper deals with identification of the best combination of nanoparticle and fluid by making use of existing models.

Keywords: *Nanofluids; Heat transfer; Thermal conductivity; Nanoparticles; Existing models.*

INTRODUCTION

Heat transfer is crucial in evaporators, condensers, optical devices, microelectronic devices and automobiles. The conventional way to increase cooling rates is by use of microchannels, fins which provide extended surface. [1] Owing to size limitation of device an alternative approach of cooling was by the use of nanofluids. The term nanofluid was proposed by Choi in 1995 of the Argonne National Laboratory, U.S.A [2]. The idea behind the development of nanofluid is to improve the heat transfer coefficient and to minimize the size of heat transfer equipment for conversion of material and energy. Donzelli [3] showed that a particular class of nano fluids can be used as a smart material working as a heat valve to control the flow of heat.

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The observed advantages of nanofluids over heat transfer fluids with micron sized particles include better stability and lower penalty on pressure drop, along with reduced pipe wall abrasion, on top of higher effective thermal conductivity [4].

Nanofluids are combination of nanoparticle and a suitable fluid. Nano particles are more efficient than micro particles with respect to stability, flow resistance and erosion. Thus nanofluids are next generation heat transfer fluids which pave miniaturization of existing heat exchanger systems .The development of nanofluids is hindered by lack of agreement between results, poor suspensions, and lack of theoretical understanding of mechanisms [5]. Experimental measurement of thermal conductivity is possible by Transient Hot wire method [6] ,Steady state parallel Technique [7] Temperature Oscillation technique [8]. The above methods of measurements have their own limitations and range of accuracy. On the other hand, many models also exist for theoretical investigation of thermal conductivity of nanofluids. The first proposed model was by Maxwell [9]. The model was modified by Hamilton and crosser accounting for the shape of nanoparticles [10]. Further models was proposed by Yu and Choi [1], Wang [11], Koo ,Kang and Kleinstreuer [12] Kumar[13] .In addition to this analytical models are also proposed by Chandrasekar [14]. Here an attempt to verify the primary models Maxwell and Hamilton crosser model is performed.

EXPERIMENTAL

Computational methods-Heat transfer models

The Maxwell model is used to calculate the effective thermal conductivity of colloidal suspensions with particle size in the range of mili to micro. It has the limitations, that it is applicable only to spherical shape particles. Hamilton–Crosser is the modification of Maxwell model with the inclusion of empirical shape factor n=3/ψ for spherical and cylindrical shaped particles. Where ψ is the sphericity and defined as the surface area of sphere with the volume equal to that of the particles. The above two models can be considered as primary models and other models complicated as they require details of particle interactions, critical radius of nanoparticle, interfacial layer dependence, which are not available for a given particle and fluid as a standard data. Thus selecting the best nanofluid is easily possible with respect to above two models.

The nanofluid is a mixture consisting of a continuous base fluid component called a matrix and a discontinuous solid component called particles. The properties of the nanofluid depends on the details of their microstructures, such as component properties, component volume concentrations, particle dimension, particle geometry, particle distribution, particle motion, matrix-particle interfacial effects. It is impossible to measure the properties of nanofluids unless all the details of the microstructure are known completely. One way to avoid this problem is to attempt to determine upper and lower bounds on the effective properties from partial statistical information on the sample in the form of correlation functions. Using two such equations we tried to find the effective thermal conductivity of copper and iron nanofluids.

Maxwell and Hamilton-crosser model

The variation of effective thermal conductivity of nanofluid to thermal conductivity of base fluid ratio with volume fraction is studied with the help of Maxwell model and Hamilton-Crosser model.

Maxwell model:

$$\frac{Keff}{Kf} = 1 + \frac{3(\frac{Kp}{Kf}-1)\emptyset}{\left(\frac{Kp}{Kf}+2\right)-(\frac{Kp}{Kf}-1)} \tag{1}$$

Hamilton-crosser model:

$$\frac{Keff}{Kf} = \frac{Kp+(n-1)Kf-(n-1)\emptyset(Kp-Kf)}{Kp+(n-1)Kf+\emptyset(Kf-Kp)} \tag{2}$$

Where

- K_{eff} - Effective thermal conductivity of nanofluid
- K_f - Thermal conductivity of base fluid
- K_p - Thermal conductivity of nanoparticles
- Φ - Volume Fraction
- n - Form factor

- n=3 – spherical shaped particles
- n=6 – cylindrical shaped particles

RESULTS AND DISCUSSION

The commonly used base different nanofluids selected for heat transfer applications are water, ethylene glycol and propylene glycol. Here the nanoparticles selected are copper and Iron as they can be prepared with ease and are also good thermal conductors. Using the above two models, the variation of effective thermal conductivity of nanofluid to thermal conductivity of base fluid ratio with volume fraction is studied for the following six combinations

- Iron-water nanofluid
- Iron-ethylene glycol nanofluid
- Iron-propylene glycol nanofluid
- Copper-water nanofluid
- Copper-ethylene glycol nanofluid
- Copper-propylene glycol nanofluid

Based on the equations (1) and (2) the thermal conductivity of the different nanofluids is tabulated. (Tables 1-6) and the graphical change is represented from Figures 1-6. Table 7 gives a comparative increased for all nanofluids selected.

Iron and water

Table 1. Thermal conductivity for iron water nanofluid

Volume Fraction (%)	K WATER W/mK	K Fe W/mK	Maxwell model	Hamilton Crosser (n=3)	Hamilton Crosser (n=6)	% increase in K_{eff} / K_f of n=6 from n=3
0.1	0.613	33	1.313551035	1.27398644	1.591970463	21.19593528
0.2	0.613	33	1.70029479	1.65611238	2.313536752	36.06680241
0.3	0.613	33	2.189245978	2.139225374	3.212487049	46.73942905
0.4	0.613	33	2.82709015	2.769453533	4.36339798	54.34237143
0.5	0.613	33	3.694052405	3.626064051	5.889464811	59.43100328
0.6	0.613	33	4.940610256	4.857737701	8.009835987	62.12240133
0.7	0.613	33	6.885946465	6.779846129	11.15562076	62.00562718
0.8	0.613	33	10.34644798	10.19902843	16.30787561	57.61810856
0.9	0.613	33	18.22136006	17.97991216	26.28515043	44.25460196
1	0.613	33	53.83360522	53.16693855	53.83360522	7.91932E-14

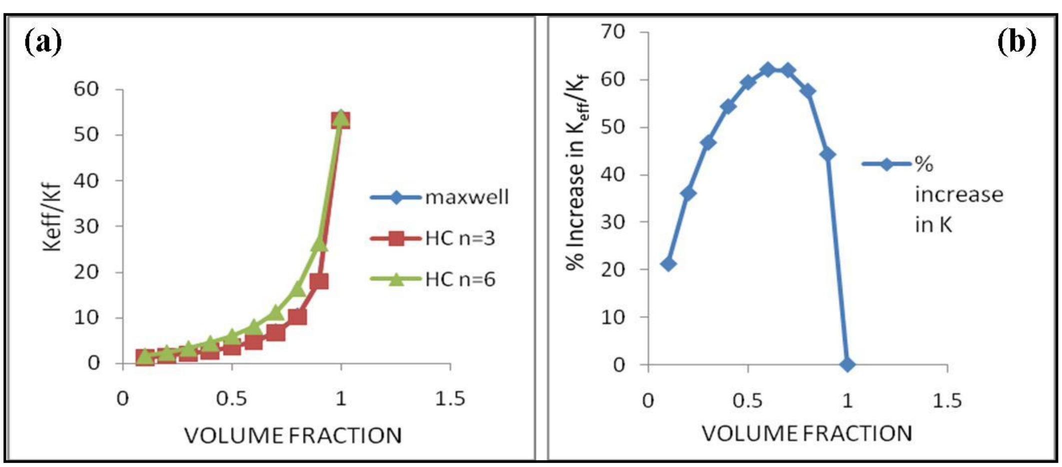

Fig. 1. a) Volume fraction Vs K_{eff} / K_f . b) Volume fraction Vs % increase in K_{eff} / K_f

Iron and Ethylene Glycol

Table 2. Thermal conductivity for iron ethylene glycol nanofluid

Volume Fraction (%)	K EG W/mK	K Fe W/mK	Maxwell model	Hamilton Crosser (n=3)	Hamilton Crosser (n=6)	% increase in K_{eff} / K_f of n=6 from n=3
0.1	0.258	33	1.324802095	1.307739619	1.633393303	23.29338161
0.2	0.258	33	1.728474169	1.709340097	2.416298988	39.79375747
0.3	0.258	33	2.243713439	2.221935222	3.408739793	51.92402617
0.4	0.258	33	2.924188999	2.898918665	4.707830814	60.99611947
0.5	0.258	33	3.864566929	3.834470691	6.481667504	67.72041014
0.6	0.258	33	5.248896963	5.211696514	9.048672566	72.39188785
0.7	0.258	33	7.488703924	7.44000906	13.09403198	74.85044288
0.8	0.258	33	11.73156342	11.66109472	20.41129391	73.98613616
0.9	0.258	33	22.83770565	22.71024159	37.66517357	64.92538329
1	0.258	33	127.9069767	127.2403101	127.9069767	-1.11103E-13

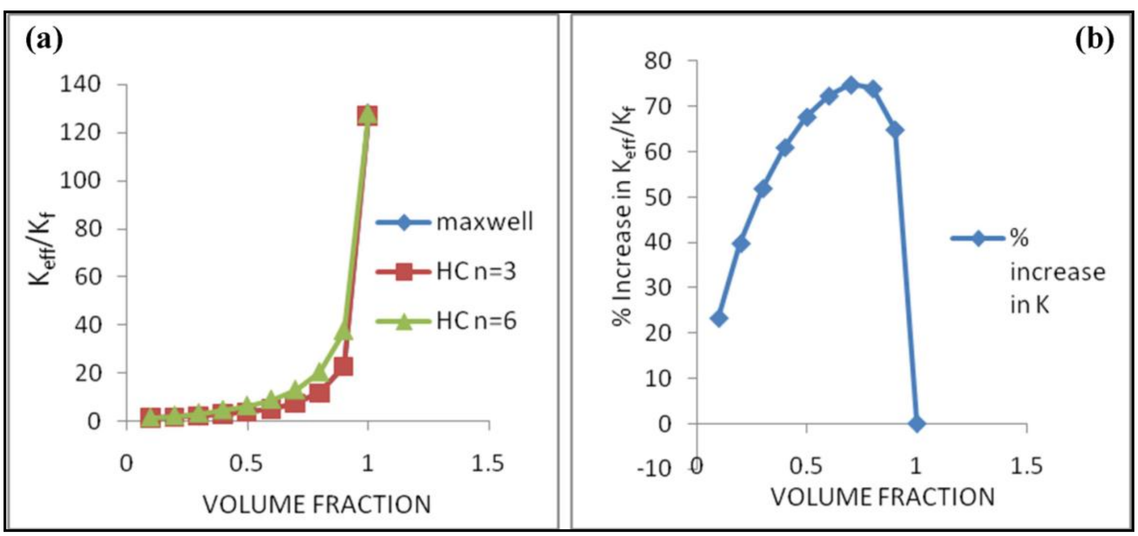

Fig. 2. a) Volume fraction Vs K_{eff} / K_f . b) Volume fraction Vs % increase in K_{eff} / K_f

Iron and Propylene Glycol

Table 3. Thermal conductivity for iron propylene glycol nanofluid

Volume Fraction (%)	K PG W/mK	K Fe W/mK	Maxwell model	Hamilton Crosser (n=3)	Hamilton Crosser (n=6)	% increase in K_{eff} / K_f of n=6 from n=3
0.1	0.147	33	1.328434754	1.318637595	1.647356132	24.00730459
0.2	0.147	33	1.737623207	1.726621613	2.45129655	41.07181238
0.3	0.147	33	2.261522905	2.248979226	3.476450117	53.72164084
0.4	0.147	33	2.956234369	2.941645826	4.828686304	63.33908954
0.5	0.147	33	3.92156514	3.904135171	6.694254268	70.70363564
0.6	0.147	33	5.35388965	5.332243672	9.433938046	76.20718137
0.7	0.147	33	7.700201031	7.671648749	13.85005448	79.86614146
0.8	0.147	33	12.24525073	12.20332021	22.15964898	80.96525318
0.9	0.147	33	24.8046051	24.72570646	43.57101721	75.65696782
1	0.147	33	224.4897959	223.8231293	224.4897959	2.40551E-13

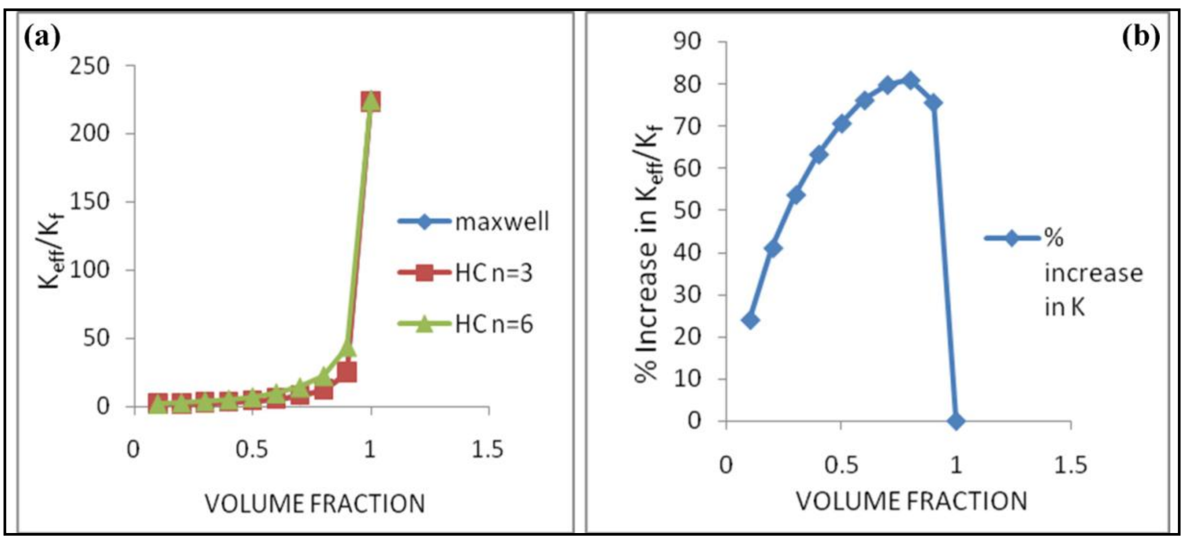

Fig. 3. a) Volume fraction Vs K_{eff} / K_f b) Volume fraction Vs % increase in K_{eff} / K_f

Copper and water

Table 4. Thermal conductivity for copper water nanofluid

Volume fraction (%)	K WATER W/mK	K Cu W/mK	Maxwell model	Hamilton Crosser (n=3)	Hamilton Crosser (n=6)	% increase in K_{eff} / K_f of n=6 from n=3
0.1	0.613	400	1.331636623	1.328243201	1.659914195	24.65218866
0.2	0.613	400	1.745707932	1.741892761	2.482929419	42.23051712
0.3	0.613	400	2.277312205	2.272955571	3.538038453	55.36027272
0.4	0.613	400	2.98476837	2.97969116	4.939533978	65.49136702
0.5	0.613	400	3.972624763	3.966541377	6.89148922	73.47445661
0.6	0.613	400	5.448788258	5.441201333	9.797458038	79.80985081
0.7	0.613	400	7.894184461	7.88410679	14.58304081	84.73144226
0.8	0.613	400	12.72994405	12.71494094	23.94355122	88.08842466
0.9	0.613	400	26.81149513	26.78214933	50.44642304	88.15221905
1	0.613	400	652.5285481	651.8618815	652.5285481	8.71125E-14

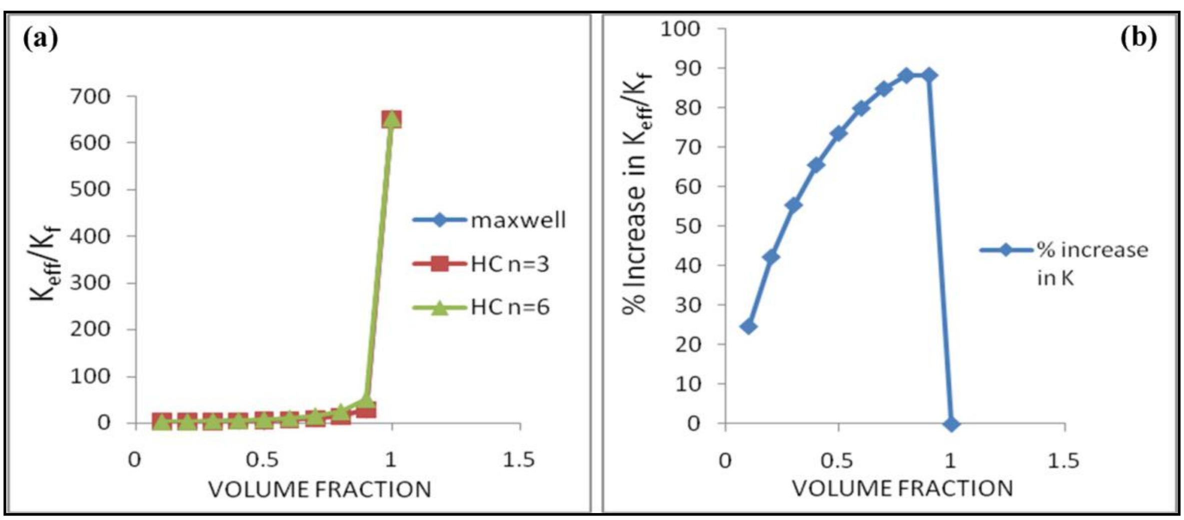

Fig. 4. a) Volume fraction Vs K_{eff} / K_f b) Volume fraction Vs % increase in K_{eff} / K_f

Copper and Ethylene Glycol

Table 5. Thermal conductivity for copper ethylene glycol nanofluid

Volume fraction (%)	K EG W/mK	K Cu W/mK	Maxwell model	Hamilton Crosser (n=3)	Hamilton Crosser (n=6)	% increase in K_{eff} / K_f of n=6 from n=3
0.1	0.258	400	1.332617744	1.331186564	1.66381044	24.85279049
0.2	0.258	400	1.748189149	1.746579505	2.492774045	42.59178107
0.3	0.258	400	2.28216772	2.28032876	3.557281334	55.87291426
0.4	0.258	400	2.993566598	2.991422131	4.974348905	66.16797193
0.5	0.258	400	3.988427322	3.985855616	6.953887171	74.35160802
0.6	0.258	400	5.478322134	5.475110599	9.913704251	80.96241892
0.7	0.258	400	7.955110583	7.950835401	14.82158646	86.31527875
0.8	0.258	400	12.884939	12.87854672	24.5441271	90.48694837
0.9	0.258	400	27.48714299	27.47447985	52.98681187	92.76944094
1	0.258	400	1550.387597	1549.72093	1550.387597	-1.02659E-13

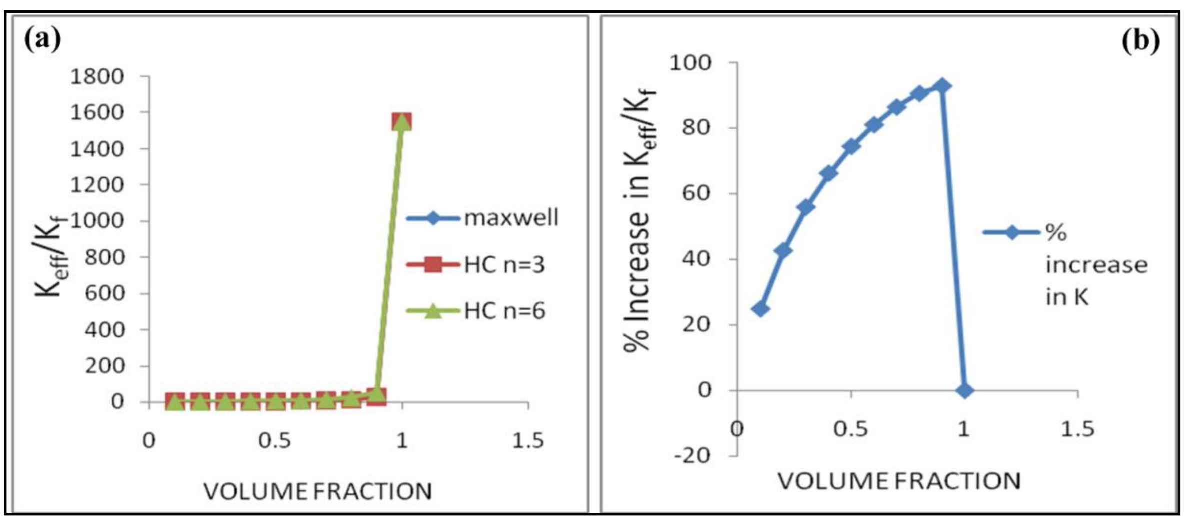

Fig. 5. a) Volume fraction Vs K_{eff} / K_f b) Volume fraction Vs % increase in K_{eff} / K_f

Copper and Propylene Glycol

Table 6. Thermal conductivity for copper propylene glycol nanofluid

Volume fraction (%)	K PG W/mK	K Cu W/mK	Maxwell model	Hamilton Crosser (n=3)	Hamilton Crosser (n=6)	% increase in K_{eff} / K_f of n=6 from n=3
0.1	0.147	400	1.33292535	1.332109383	1.665036728	24.91597732
0.2	0.147	400	1.74896745	1.748049627	2.495875477	42.70565629
0.3	0.147	400	2.283691728	2.282642994	3.563351047	56.03467857
0.4	0.147	400	2.996330394	2.995107192	4.98534846	66.38180053
0.5	0.147	400	3.993397133	3.991929829	6.973646534	74.62942708
0.6	0.147	400	5.487626432	5.485793311	9.95064145	81.32869597
0.7	0.147	400	7.974359805	7.971917882	14.89781352	86.82143622
0.8	0.147	400	12.9341886	12.93053241	24.73819024	91.26201885
0.9	0.147	400	27.70546402	27.69819152	53.83456945	94.31029711
1	0.147	400	2721.088435	2720.421769	2721.088435	-5.68207E-13

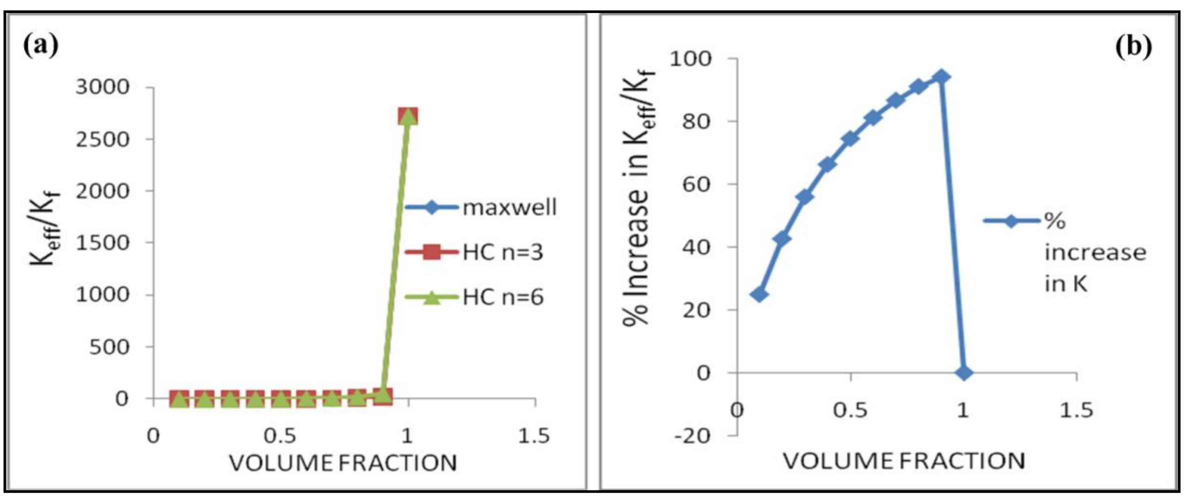

Fig. 6. a) Volume fraction Vs K_{eff} / K_f b) Volume fraction Vs % increase in K_{eff} / K_f

Comparison of thermal conductivity of nanofluids

NANOFLUIDS	% increase in K_{eff} / K_f ratio	% increase in K_{eff} / K_f ratio
	VOLUME FRACTION = 0.1%	VOLUME FRACTION = 0.9%
Cu-Water	24.6522	88.1522
Cu-EG	24.8528	92.7694
Cu-PG	24.91598	94.3103
Fe-Water	21.1951	44.2546
Fe-EG	23.2934	64.9254
Fe-PG	27.0073	75.6569

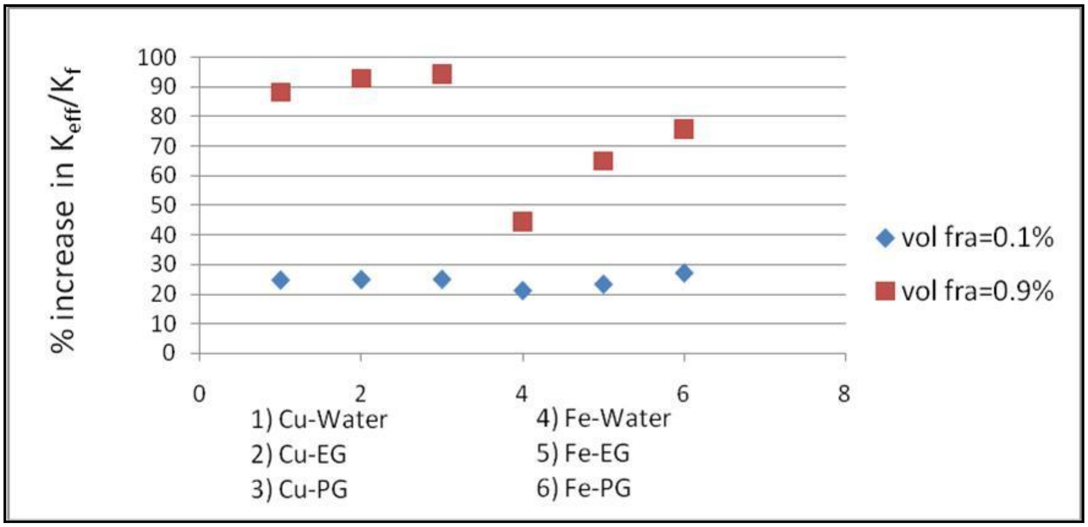

Fig. 7. Nanofluids Vs % increase in K_{eff} / K_f ratio

CONCLUSIONS

Variation of thermal conductivity of nanofluid to the thermal conductivity of base fluid ratio with volume fraction is studied for iron and copper nano particles with Water, Ethylene Glycol and Propylene Glycol as base fluid.

- Propylene Glycol based nanofluids showed maximum value of Keff/Kf and %increase in Keff/Kf ratio of around 80-90% for 0.8% volume fraction.
- In all the cases the results of Maxwell model coincides with the Hamilton-crosser n=3 value.
- In all the cases Keff/Kf value for Hamilton-Crosser n=6(cylindrical) is greater than Hamilton-Crosser n=3(spherical) value because of larger surface area of the cylindrical nanoparticles than the spherical nanoparticles.
- The percentage increase in Keff/Kf ratio is not identical for all nanofluids at all volume fractions.
- At volume fraction of 0.1% Fe-Propylene glycol nanofluid showed maximum increase in Keff/Kf ratio while at the volume fraction of 0.9% Cu-Propylene glycol nanofluid showed maximum increase in Keff/Kf ratio.

List of symbols

ψ	sphericity	m^2
K_{eff}	Effective thermal conductivity of nanofluid	W/mK
K_f	Thermal conductivity of base fluid	W/mK
K_p	Thermal conductivity of nanoparticles	W/mK
Φ	Volume Fraction	
n	Form factor	
K_{water}	Thermal conductivity of water	W/mK
K_{Fe}	Thermal conductivity of iron nanoparticles	W/mK
K_{EG}	Thermal conductivity of ethylene glycol	W/mK
K_{Cu}	Thermal conductivity of copper nanoparticles	W/mK
K_{PG}	Thermal conductivity of propylene glycol	W/mK

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