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# A review on heat transfer enhancement in NEILS for solar applications

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## ABSTRACT

Harvesting solar energy has been the keen focus of study among researchers all over the globe. In the current scenario of fast depleting non-renewable resources, efforts have to be made for maximum utilization of available solar radiations. The present review studies NEILS as one of the front runner as suitable HTF for solar collectors due to their impeccable thermal properties and the various possible reasons for enhancement in heat transfer properties of NEILS.

## Nomenclature

IL – Ionic Liquids
NEILS – Nano Enhanced Ionic Liquids
Cp – Specific Heat
K – Thermal Conductivity
$V_T$ – Thermopheretic Velocity
r – radius
HTF – Heat Transfer Fluid
[C4mim][NTf2] - 1 – butyl – 3 – methyl imidazolium bis {(trifluoromethyl)sulfonyl} imide
[C4mpyrr][NTf2] - N - butyl – N - methyl pyrrolidinium bis {trifluoromethyl) sulfonyl} imide

## Introduction

The shortage of fossil fuels and environmental considerations has been a source of motivation to the researchers to use alternative energy sources such as solar energy. Therefore, it is essential to enhance the efficiency and performance of the solar thermal systems. Utilizing nanofluids [1] as well as nano enhanced ionic liquids (NEILS) as an advanced kind of liquid mixture with a small concentration of nanometre-sized solid particles in suspension is a relatively new field, which is less than two decades old. The aim of this review paper is the investigation of the nanofluids' applications in solar thermal collector systems. Subsequently, some suggestions are made to use the nanofluids in different solar thermal systems such as photovoltaic/thermal systems, solar ponds, solar thermoelectric cells, and so on.

In solar any solar devices, the solar radiations are allowed to fall on a dark absorbing surface which absorbs part of radiations falling on it. The absorbed radiations are then transferred to a heat transfer fluid usually air or water. Besides water several non-conventional fluids such as ethylene glycol, molten salts etc. are being used as heat transfer fluids which have got their own advantages as well as disadvantages. The efficiency of solar collectors and hence in turn the efficiency of solar devices depend mostly on the thermal properties of the heat transfer fluid such as heat capacity, conductivity and heat transfer coefficient etc. The following table gives an idea of the physical properties of various heat transfer fluids used.

**Table 1. Properties of various Heat transfer fluids (HTFs)**

| Sl. No. | HTF | Thermal Conductivity K (W/m°C) | Specific Heat $C_p$ (KJ/Kg°C) |
|---|---|---|---|
| 1 | Air | 24 to 29<br>(0°-100°C) | 1.0<br>(0°-100°C) |
| 2 | Water | 0.56 to 0.68<br>(0°-120°C) | 4.2<br>(0°-120°C) |
| 3 | Ethylene Glycol<br>$C_2H_4(OH)_2$ | 0.24 to 0.26<br>(0°-100°C) | 2.29 to 2.7<br>(0°-100°C) |
| 4 | Ionic Liquids | 0.124<br>(0°-325°C) | 1.5 – 1.25<br>(0°-325°C) |
| 5 | Therminol V P | 0.137 - 0.07<br>(12°-400°C) | 1.52 to 2.76<br>(12°-400°C) |

## Nanoparticles & Nanofluids

Nano particles are particles of size varying from 1nm to 100nm. Nano materials have unique mechanical, optical, electrical, magnetic, and thermal properties. Nanofluids are synthesised by adding nano particles to traditional heat transfer fluids such as water, ethylene glycol, ionic liquids etc. When suspended uniformly, the nano particles can bring about dramatic changes to the thermal properties of conventional heat transfer fluids, particularly enhancing their properties to several times. The word nanofluid was first used by Choi in 1995[2].The concentration of nanoparticles should be preferably less than 1%. CuO, ZrO2, $Al_2O_3$, $Fe_3O_4$, $TiO_2$, MWCNTs are some of the nano particles used for synthesis of nanofluids.

## NEILS

NEILS (Nano Enhanced Ionic Liquids) are nanofluids with ionic liquids as base fluids and suspended nano particles. The term ionic liquids (IL's) were first used by R. M. Barrer at 1943. ILs are the group of salts, which consist of organic cations (imidazolium, pyrazolium, triazolium, thiazolium, oxazdium, pyridinium, pyridazinium, pyrimidinium, pyrazinium) and organic or inorganic (halogen, fluorinated) anions and are liquid at room temperature [3].

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The experiments conducted by various researchers show that ionic liquids have low thermal conductivity than water. Ionic liquids have low melting points resulting in higher liquidous range and it decreases with increase in cation size. They are stable at high temperatures also. This is the main characteristic of choosing ionic liquids since they can work over a wide range varying from –2°C to 200°C. The viscosity is preferably less than 100cP.

Most conventional fluids have some advantages as well as certain disadvantages leading to limiting their application to certain fields. Since metals normally have high thermal properties when compared to liquids, the thought arise to enhance thermal conductivity of liquids by adding suspended solid particles to them. This led to the concept of nanofluids. Studies have proved that adding particle concentrations from 1 to 5% the thermo-physical properties of liquids may be increased upto 20%. Experiments conducted by Yang [4] proved that a 1.8% of $Al_2O_3$ in water/ethylene glycol enhanced 32%. $Al_2O_3$ has shown less augmentation when compared to other nanoparticles. By changing conventional heat transfer fluids ti ionic liquids still further enhancement in properties could be expected.

## Synthesis of Nanofluids

A nanofluid can be synthesized by simply mixing a nano-powder in the base liquid followed by strong agitation in order to prevent the coagulation of nano particles. Sometimes a stabilizing agent may also be added to prevent re-agglomeration of nano particles on a long time basis. But the stabilising agent may affect the properties of nano fluid. The agglomeration of nanoparticles may cause corrosion of pipes through which the fluid flows. Experiments conducted by T C Paul [5] prepared nanofluids using 1 – butyl – 3 – methyl imidazolium bis {(trifluoromethyl)sulfonyl} imide ([C4mim][NTf2]) and N - butyl – N - methyl pyrrolidinium bis {trifluoromethyl) sulfonyl} imide ([C4mpyrr][NTf2]) with 1% $Al_2O_3$ are measured. It has been found that the effect of particle volume fraction has an asymptotic relationship with the collector efficiency. The increase in particle fraction more than 1.8 to 2% doesn't bring about much variation in efficiency (Fig. 1). It might be due to increase in other fluid parameters such as viscosity.

## Enhancement of Properties

### Thermal Conductivity

Wang et al. [6] was first to propose new static and dynamic mechanisms behind enhanced thermal transport in nanofluids. They attributed enhanced conductivity to the microscopic motions of nanoparticles and fluids, which are induced by microscopic forces acting on a nanoparticle such as the van der Waals force, the electrostatic force resulting from the electric double layer at the particle surface, the stochastic force that gives rise to the Brownian motion of particles, and the hydrodynamic force.

Xuan and Li [7] suggested several possible mechanisms for enhanced thermal conductivity of nanofluids, such as the increased surface area of nanoparticles, particle–particle collisions, and the dispersion of nanoparticles. Keblinski et al. [8] proposed four possible microscopic mechanisms for the anomalous increase in the thermal conductivity of nanofluids: Brownian motion of the nanoparticles, molecular-level layering of the liquid at the liquid–particle interface (clustered nanoparticles provide local percolation-like paths for rapid heat transport and increase the effective nanoparticle volume fraction), the ballistic rather than diffusive nature of heat conduction in the nanoparticles, and the effects of nanoparticle clustering.

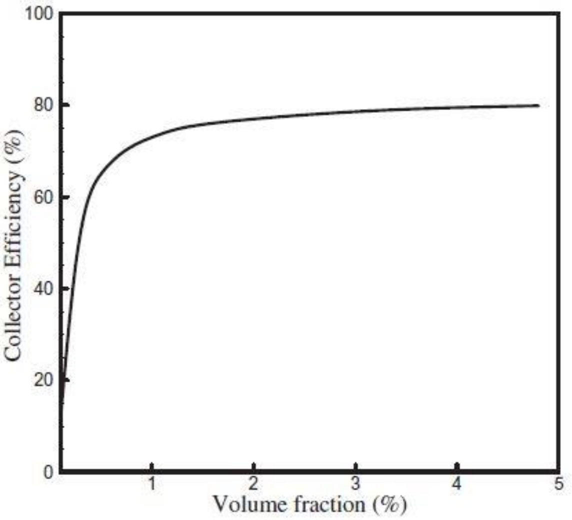

**Fig. 1 Variation of collector efficiency with Volume fraction of nano particles**

Jang and Choi [9] developed for the first time a dynamic model that takes into account convection induced by a single Brownian nanoparticle. They derived a general expression for the thermal conductivity of nanofluids involving four modes of energy transport i) collision between the base fluid molecules (thermal conductivity of the base fluid). ii) Thermal diffusion in nanoparticles in fluids (thermal conductivity of suspended nanoparticles). iii) Collision between nanoparticles due to Brownian motion iv) thermal interactions of dynamic nanoparticles with base fluid molecules.

### Specific Heat

Shin and Banarjee [10] have suggested three modes for enhancement in specific heat of nanofluids. 1. Mode 1: the specific heat is enhanced due to higher specific surface energy of the surface atoms of the nanoparticles, as compared to the bulk material. The surface energy is higher because of the low vibration frequency and higher amplitudes of the vibrations at the surface of the nanoparticles. (2) Mode 2: the enhancement of the specific heat can also be due to additional thermal storage mechanisms due to interfacial interactions between nanoparticles and the liquid molecules, which act as virtual spring-mass systems. This interfacial effect is present due to the extremely high specific surface area of the nanoparticles. (3) Mode 3: a third mechanism is liquid layering. Solid like liquid layers adhering to the nanoparticles are more likely to have an enhanced specific heat due to a shorter intermolecular mean free path compared to the bulk fluid.

### Enhancement in Heat transfer

Yang reported that nanoparticle concentration, material, temperature, and base fluid affected the heat transfer coefficient. Another phenomenon suggested for unusual enhancement is thermophoresis. The solid particles suspended in a fluid experience a force in the direction opposite to the temperature gradient imposed and as a result they tend to diffuse under this force.

The thermophoretic velocity can be given by

$$V_T = -\beta \frac{\mu}{\rho} \frac{dT}{T}$$

Where proportionality factor $\beta = 0.26 \frac{k}{2k+k_p}$ ; k and $k_p$ are thermal conductivity of medium and particles respectively [11].

## Theoretical Prediction – Maxwell's Model

### Thermal Conductivity

Before conducting experimental analysis, the theoretical enhancement in thermo-physical properties of NEILS may be predicted using Maxwell's Mean Field Theory [12]. The properties of heterogeneous mixtures were investigated and published by James Clark Maxwell a century ago. If the interactions among particles are ignored, for a very dilute dispersion of spherical particles with radius $r_p$ and field temperature T, the governing equation for steady state is Laplace Equation:

$\Delta^2 T(r) = 0$

Consider a large sphere with radius $r_0$ consisting of all such spheres dispersed in the medium and being surrounded by the medium. If $k_p$, km are the thermal conductivities of the particle and medium respectively, by superposition principle, the Temperature T outside the sphere $r_0$ at a distance $r \gg r_0$ will be

$$T(r) = \left(-1 + \frac{k_p - k_m}{2k_m + k_p}\frac{v_p r_0^3}{r^3}\right) G.r$$

From the above equation, the effective thermal conductivity of mixture, $k_e$ can be found as

$$k_e = k_m + 3v_p \frac{k_p - k_m}{2k_m + k_p - v_p(k_p - k_m)} k_m$$

For low particle volume fractions the term $v_p(k_p - k_m) \approx 0.$

## Heat Capacity

The heat capacity of NEILs can be predicted by using the equation, $C_{p_{NEIL}} = \frac{v_n \rho_n C_{p_n} + v_{IL} \rho_{IL} C_{p_{IL}}}{v_n \rho_n + v_{IL} \rho_{IL}}$ where $\mathbf{C_{p_n}}, \mathbf{C_{p_{IL}}}, \mathbf{C_{p_{NEIL}}}$ are the specific heats of nanoparticles, ILs and NEILs respectively; $\mathbf{v_n}, \mathbf{v_{IL}}$ are the volume fractions of nanoparticles and ILs respectively; $\boldsymbol{\rho_n}, \boldsymbol{\rho_{IL}}$ are the densities of nanoparticles and ILs respectively.

## Experimental Analysis

### Thermal Conductivity

Thermal Conductivities of ILs ([C4mim][NTf2] and [C4mpyrr][NTf2]) and NEILS were measured by T.C.Paul[5] using a Pro Thermal Property Analyser (Mfd. By Decagon, USA). The analyser works on the principle of transient hot wire method. The expansion of wire when a stipulated current is passed is measured using a thermo-resistor which gives a measureable value for thermal conductivity of medium in which the probe is inserted. Fig. 2 to 5 gives the results.

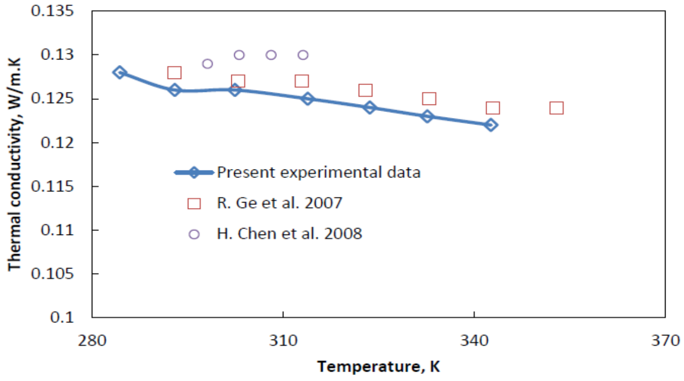

**Fig. 2 Thermal Conductivity versus Temperature of [C4mim][NTf2]**

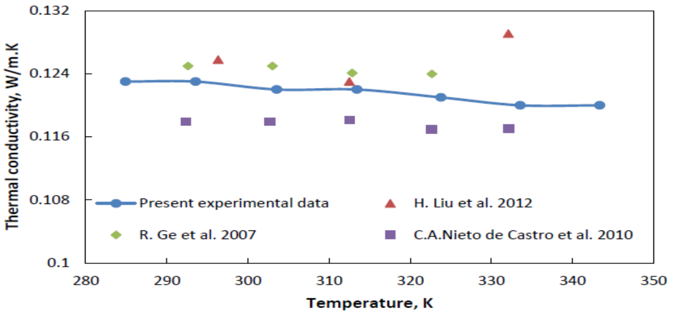

**Fig. 3 Thermal Conductivity versus Temperature of [C4mpyrr][NTf2]**

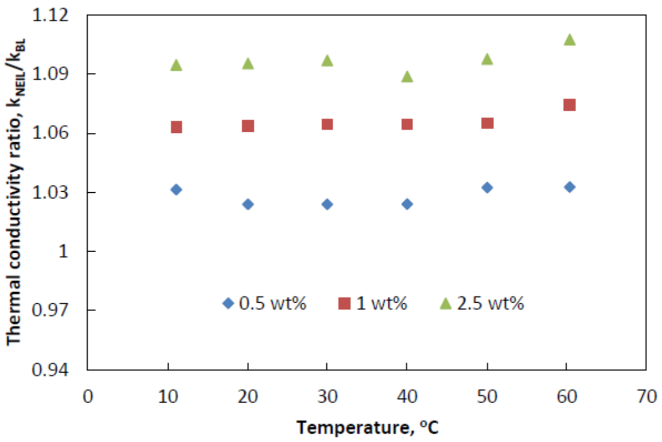

**Fig. 4 Thermal Conductivity of NEIL versus Temperature of [C4mim][NTf2]**

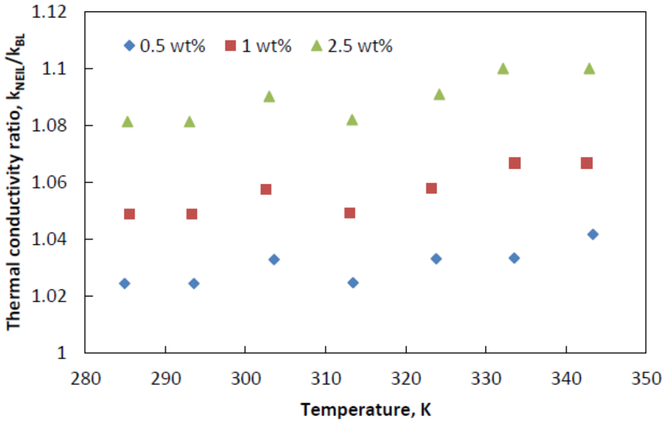

**Fig. 5 Thermal Conductivity of NEIL versus Temperature of [C4mpyrr][NTf2]**

### Heat Capacity

T C Paul[5] studied the variations in Heat capacity of IL's and NEILS for different particle fractions. The results are below. He used differential scanning calorimetr (Mfd. By TA Instruments Inc.). The experiments were conducted within the temperature range 25-345°C and he found that within the measured temperature range heat capacity increases almost linearly with temperature. The results can be compared in Fig. 6 – 9.

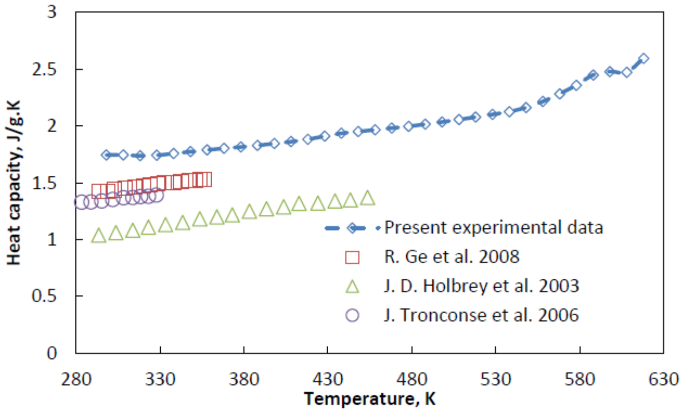

**Fig. 6 Heat Capacity versus Temperature of [C4mim][NTf2]**

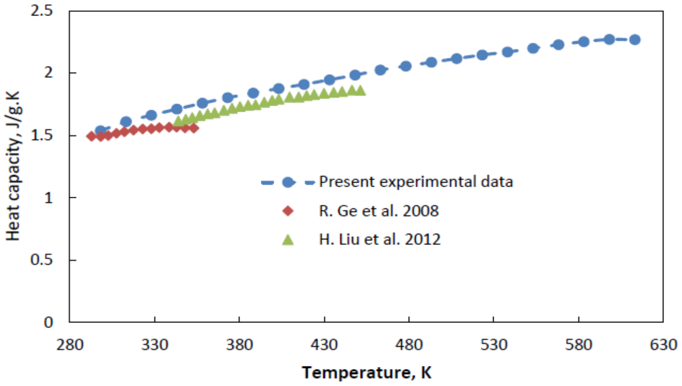

**Fig. 7 Heat Capacity versus Temperature of [C4mpyrr][NTf2]**

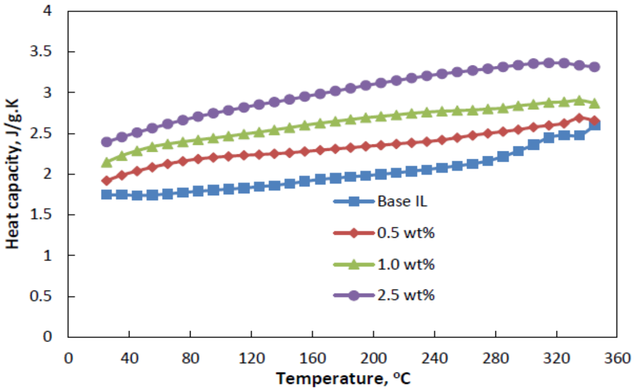

**Fig. 8 Heat Capacity of NEIL versus Temperature of [C4mim][NTf2]**

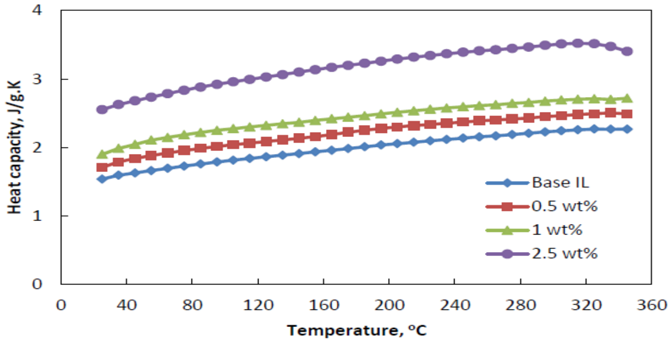

**Fig. 9 Heat Capacity of NEIL versus Temperature of [C4mpyrr][NTf2]**

## Heat Transfer Coefficient in Forced Convection

The forced heat transfer coefficient for ILs and NEILS were experimentally found by T C Paul[5] using a test setup as shown below (Fig. 10).

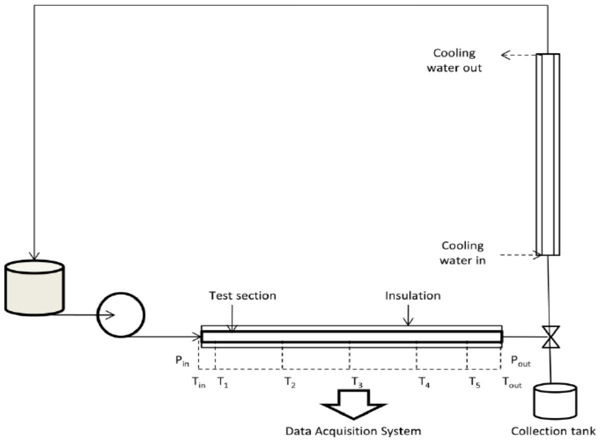

**Fig 10. Fabricated setup for Forced heat transfer coefficient**

The measurements from thermocouples T1-T5 and pressure transducers were fed to a data acquisition system (Mfd. By National Instruments) interfaced to a computer using *Labview* software. The local temperatures and local heat transfer coefficients for both ILs and NEILs were found using conventional heat transfer relations. The forced heat transfer coefficient of NEILs were found to be significantly high than base liquids (Fig. 11). The experiment was conducted at various Reynolds numbers.

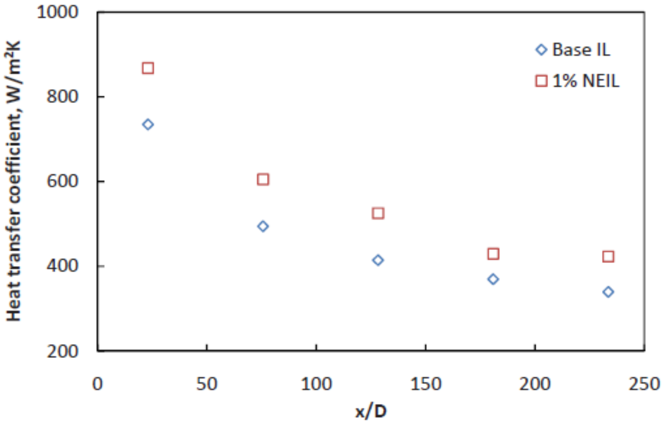

**Fig 11. Heat transfer coefficient Vs x/D for NEILs and ILs**

## Results and discussions

The experiments conducted by T C Paul [5] can be summarized as below:

1. Heat Capacity - enhanced the heat capacity by ~23%.
2. Thermal Conductivity – an enhancement in conductivity of NEILS by 5-6% than base ionic liquids.
3. Forced Heat transfer coefficient - heat transfer coefficient of NEILs were found to be significantly high than base liquids.

## Conclusions

The investigation done by various researchers and specialy in NEILS by T C Paul [5] has showed an enhancement in thermal transport properties of nanofluids and NEILS.

## Future Scope

The interest of ionic liquids as heat transfer fluids (HTFs) has been increasing in recent years because of their thermophysical properties. Enhanced thermophysical properties can be achieved by dispersing small amount of nanoparticles into the base liquid. In the present research, thermal conductivity, heat capacity and heat transfer behaviour under forced convection of IL's and nanoparticle enhanced ionic liquids (NEILs) was investigated. However there is a broad scope to work within on the NEILs to assess the fluids in solar thermal applications. Suggestions for future research are as follows:

1. In the forced convection thermal performance there needs to be more exploration of specific mechanism of heat transfer enhancement of NEILs. Nanoparticle size and shape effect also need to be explored. Future research would study the effect of particle morphology on thermal performance of NEILs and find a specific particle size and shape for maximum enhancement.
2. Cost analysis can be performed by considering a small capacity power plant. The study can give a comparison of NEILs with the currently used heat transfer fluid.
3. Introduction of twisted pipes has shown enhancement in heat transfer of nanofluids. Effect of twisted tape inserts in further enhancing can be studied and modelled using simulation software.

## References

[1] Taylor, R.A., et al., Small particles, big impacts: A review of the diverse applications of nanofluids, Journal of Applied Physics, Volume 113, Issue 1, Pages 011301-19

[2] U.S. Choi, Enhancing thermal conductivity of fluids with nanoparticles, ASME FED 231 (1995) 99–103.

[3] Rogers R. D. and Seddon, K. R., 2003. Ionic liquids–solvents of the future? Science 302, 792–793.

[4] Ying Yang, George Zhang, Z., Eric Grulke, A., William Anderson, B., Gefei Wu, 2005. Heat Transfer properties of nanoparticle-influid dispersions (nanofluids) in laminar flow, International Journal of Heat and Mass Transfer 48, p. 1107-1116.

[5] NEILS as working fluid for next generation solar collectors – 5th BSME International conference on Thermal Engineering – Titan C Paul, AKM M Morshed, Jamil A Khan.

[6] Wang, X., X. Xu, and S.U.S. Choi (1999). Thermal conductivity of nanoparticle–fluid mixture, *J. Thermophys. Heat Transfer*, 13 (4): 474–480.

[7] Xuan, Y., and Q. Li (2000). Heat transfer enhancement of nano-fluids, *Int. J. Heat Fluid Flow*, 21: 58–64.

[8] Keblinski, P., S. R. Phillpot, S. U. S. Choi, and J. A. Eastman (2002). Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids), *Int. J. Heat and Mass Transfer*, 45: 855–863.

[9] Jang, S. P., and S. U. S. Choi (2004). Role of Brownian motion in the enhanced thermal conductivity of nanofluids, Appl. Phys. Lett., 84: 4316–4318.

[10] Shin, D., and Banerjee, D., 2011, “Enhancement of Specific Heat Capacity of High-Temperature Silica-Nanofluids Synthesized in Alkali Chloride Salt Eutectics for Solar Thermal-Energy Storage Applications,” Int. J. Heat Mass Transfer, 54(5–6), pp. 1064–1070.

[11] McNab, G. S., and Meisen, A., 1973, “Thermophoresis in Liquids,” J. Colloid Interface Sci., **44**(2), pp. 339.

[12] Maxwell, J.C., 1904. A Treatise on Electricity and Magnetism, second ed. Oxford University Press, Cambridge, pp. 435–441.