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Nanofluid Augmented Cooling of Solar Thermoelectric Refrigerator - An Experimental Study

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***Abstract* - The performance of heat transfer enhancing is used thermoelectric refrigeration devices with nanofluid in a minichannel heat exchanger is experimentally investigated. The thermoelectric cooler (TEC 1- 12708T125) with a ΔT_{max} of 125 °C is used to haul out heat from the refrigeration, which is operated on solar battery energy system. The designed evaporator section normally operates with the heating power range on nearly 300W which is calculated as the input power to the thermoelectric module. The aluminium oxide - water based nanofluid with volume concentrations of 0.1% is use as the coolant to remove the heat from the hot body of the test section. The flow is operated on forced convection system. The result showed 40 % enhancement in the coefficient of performance (COP) of thermoelectric module for 0.1% of nanoparticle volume concentration. So the combination in solid state and liquid (nanofluid) of refrigeration system and solar energy is promising cooling techniques for future applications.**

1. INTRODUCTION

Cooling of heat flux removal from evaporator in refrigeration system is one of the foremost critical challenges faced by current technology industries. Power consumption is another major problem to unease run the compressor as well as air and water cooled condenser. Due to observe the above problem refrigerator is supposed to self-defrost approximately four times in every 24 hour period. If one of the components in the self-defrosting system fails, the refrigerator continues to try to cool. But, such devices consume more power, thus, increases heat dissipation per unit area. The inadequate thermal management in these devices forces them to work at higher temperatures. The efficiency in the performance of such devices is poor at rich operation temperatures, which raises challenges in its cooling. The latest electronic devices need a cooling system with very high heat indulgence capability. The nanoparticle dispersed liquids (nanofluids) have been recommended as a promising option for various heat transfer applications, enhancement of thermal conductivities and heat transfer coefficients. A number of studies have been reported on the thermal and heat transfer characteristics of various nanofluids in the recent past [1–3]. Baby and Ramaprabhu experimentally investigated the thermal conductivity of graphene - water nanofluid at very low volume concentrations [4]. The workshop held on "Thermal Challenges in Next Generation Electronic Systems (THERMES 2007)" concentrated on the critical issues and research needs for high heat flux applications. Different forms of liquid cooling systems from adaptive cooling technique to heat pipe spreaders and miniature pipe flows have been used for versatile applications from small electronic systems to military electronics, and space related systems [5]. Wang et al. showed that sufficient cooling capabilities may be provided by the TEC's in order to increase the power densities of the computer chips [6]. Ghanbarpour et al. experimentally analyzed the thermal conductivity of Al_2O_3 water nanofluids and observed 87% enhancement at 293 K for 50 wt. % [7]. Godson et al. experimentally studied the thermal conductivity of silver-water nanofluids. A minimum and maximum enhancement of 27% and 80% at 0.3 vol. % and 0.9 vol.% are respectively observed at an average temperature of 70 °C. [8] Thermoelectric cooling employs a solid-state device that works based on Seedbeck, Peltier, Joule, and Fourier effects for pumping the heat away from a heat source, without any moving parts. Thermoelectric modules consist of a series of p-type and n-type semiconductor element junctions that are sandwiched between ceramic plates. The ceramic plates control the flow of electrical current into the device that is being cooled, but allows the heat to pass through easily. The passage of current causes electrons in the n-type material to move toward the hot end, and holes in the p-type material also move toward the cold end. Both the electrons and holes carry thermal energy. So, the result net flow of heat from the cold end to the hot end, where the heat is rejected. The principles of the various effects will not be repeated here for the sake of brevity and can be obtained [9–13]. Xie et al. numerically investigated a minichannel heat sink with the bottom size of 20 x 20 mm for thermal resistance maximum allowable heat flux and pressure drop. A nearly optimized configuration of heat sink was found which can cool a chip with heat flux of 256 W/cm^2 [14]. Dai et al. proposed a general threshold to subdivide a flow in a smooth or a rough micro- and mini-channel in terms of relative roughness. It is concluded that when the relative roughness is less than 1%, the roughness had little effect on flow characteristics, while for the relative roughness is larger than 1%, the friction factor and critical Reynolds number deviates from the prediction values [15]. F. Katiraei and J. R. Aguero expected widespread adoption of solar generation by customers on the distribution system significant challenges to system operators both in transient and steady state operation, from issues including voltage swings, sudden weather-induced changes in generation, and legacy protective devices designed with one-way power flow in mind [16]. ERCOT

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regulations require that distribution system operators (DSO) on their system to maintain at least a 0.97 lagging power factor for the maximum net active power supplied from a substation transformer at its distribution voltage terminals to the distribution system [17]. Nnanna et al.experimentally investigated the performance of thermoelectric module with nanofluid heat exchanger. The nanofluid used Al_2O_3–water with volume fraction between 0% and 2%. It was found that the temperature difference between the hot and cold side was almost zero for nanofluid and greater than zero for water for the chip powers of 28.3, 49.6 and 78.5 W. The average thermal contact resistance was 0.18 and 0.12 °C/W respectively observed for deionized water and nanofluid. The COP was between 1.96 and 0.68 for optimum range of current, 1.2 and 4.1 A [18]. Naphon and Wiriyasart studied the performance of a liquid cooling system using small scale heat sinks in the presence and absence of thermoelectric modules for CPU cooling applications. The de-ionized water was used as the coolant. It was reported that the effect of channel width, coolant flow rate, heat sink material, and operating conditions of PC on the thermal field in CPU. Authors also observed a significant improvement in cooling after using the thermoelectric system [19]. Chang et al. experimentally investigated the performance of an air cooled thermoelectric module. The input current was around 6A or 7A. The results showed that the performance of the heat sink was further increased by the TEC under certain heat load conditions. It was also stated that the limit of this device was around 57W and it was not suitable for high temperatures. The TEC were not only used to cool electronic devices but also as a thermoelectric refrigerator [20]. Paisarn et al. investigated the liquid cooling in the mini- rectangular fin heat sink with and without thermoelectric for the Central Processing Unit (CPU). The results showed that the liquid cooling in the heat sink with thermoelectric cooling of CPU had a significant effect when compared without thermoelectric for the same conditions and operating temperature. It was also reported that the significance came with a penalty of increased energy consumption [21]. Joshua et al. mathematically analyzed and simulated a model of coolant rail thermoelectric coolers with enhanced nanoparticles for different cooling configurations. The results of the simulated system maintained low computer chip temperatures [22]. David et al. simulated and analyzed the effect of nanofluid with thermoelectric module on computer chip temperature. They compared to numerical result of convective heat transfer coefficient and simulation result of convective heat transfer coefficient. It was found that simulation results showed only a variation of 0.4%, of peak computer chip temperature. It was also reported that cooling performance provided by the nanofluid augmented thermal management system, would not be possible with traditional air-cooled heat sinks which remain limited to the ambient temperatures [23]. From the literature review, it is clear that thermal and heat transfer performance of micro and minichannel heat sinks with and without nanofluids are done by many. From the results of their works it is clear that the nanofluid enhances the performance of the cooling systems. However, the combination of thermoelectric cooling of refrigeration with nanofluid as the working fluid in a minichannel heat exchanger for using it in the real time refrigeration cooling applications remains undone. Hence, in the present work, a nanofluid cooled eight minichannel heat exchanger with thermoelectric cooler is considered for cooling the refrigeration system. The heat is varied from 26W to 416W for cooling the refrigerator. The effect of power input, mass flow rate, volume concentration, heat abosorption (Qc) and heat rejection (Qh) on the COP of the thermoelectric cooler and the heat transfer and pressure drop characterization of minichannel heat exchanger are experimentally studied in this paper.

2. EXPERIMENTATION

2.1 Experimental Setup and configurations

The major components of the solar thermoelectric refrigerator included thermoelectric module, solar cells, aluminum test section, circuit boards (Voltage regulator), mini-channel, rotameter, pump and heat exchanger. The Figure 2.1 shows the proposed experimental test facility and illustrates all the components as connected together in testing the operation of the thermoelectric module. In these connection sixteen thermoelectric modules was used to the design of the refrigerator. The electrical power generated by the solar cells was supplied to the thermoelectric refrigerator by means of the photovoltaic effect. The mini-channel heat exchanger was used to enhance and increase the rate of heat transfer from the hot surface of the thermoelectric module so the heat will be discarded outside of the refrigerator. In order to maintain the efficiency of the thermal module, nanofluid was used to efficiently reject the heat from the hot side of the module to ambient surroundings.

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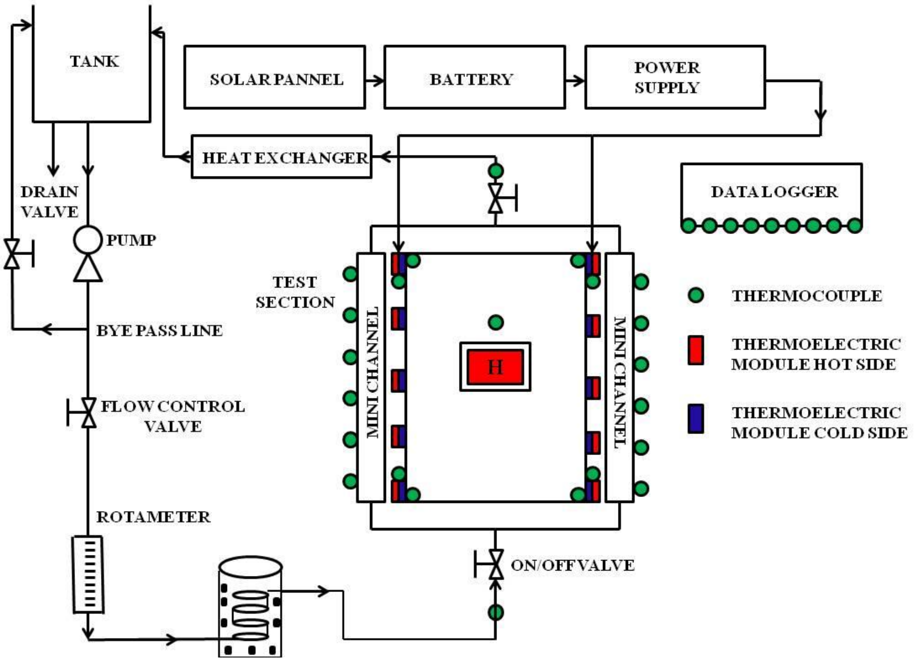

Figure 2.1 Proposed experimental test facility for solar thermoelectric refrigeration

It was planned to manufacture a prototype refrigerator which has a base of 120 x 80 mm and height of 160 mm. Eight units of the thermoelectric module will be placed on one side of the refrigerator and the other eight will be placed in the opposite side of the refrigerator. This arrangement of the modules on the opposite long two sides of the refrigerator is selected in order to enhance heat transfer by convection through the water inside the cabinet of the refrigerator. In addition, 8 mini-channel heat exchangers will be used with nanofluid as the coolant to increase the heat dissipated from the hot side of the modules and to reject the extra heat to the ambient surroundings. The test section (Figure 2.1) consists of a 2mm thickness of aluminum sheet which has a base of 120 mm by 80 mm and a height of 160 mm dimension of box was fabricated. The below arrangement of mini channel both side covered the aluminum box filled with water. Eight T-type thermocouples were fixed on both sides on mini channel along with respective distance. A double pipe heat exchanger was fixed in the path of the nanofluid for attaining steady state easily. The outer tube is made of acrylic material (25mm diameter, 0.75m long) and a submersible pump was provided inside the cold water tank. The DC power supply was given to the diodes using capacitors and regulators. Capacitors are provided for controlling the voltage and regulator required for power can be adjusted. For the working of pump and stirrer motor are all also connected with the Battery Energy Storage System. It consists of a data logger which was connected to the computer for direct measurement. All the T-type thermocouples are connected to the data logger and the reading can be stored automatically in the computer.

2.2 Nanofluid Preparation

Preparing a stable and durable nanofluid is a prerequisite optimizing its thermal properties. Therefore many combinations of material might be used for particular applications, namely nanoparticles of metals, oxide, nitrides, metal carbide, and other non-metals with or without surfactant molecules which can be dispersed into fluids such as water ethylene glycol or oils. In this study aluminum oxide – water nanofluid was prepared using two step methods. The amount of particle mixed, size and shape and dispersion quality determines the properties and behavior of the dispersion. If the dispersion is of not in proper proportion then fusion of particles, layer formation, adhesion to the walls may cause problem. Therefore the particle dispersion process in the liquid plays a major role for suspension. In this method, dry nanoparticles were first produced, and then dispersed in a suitable liquid congregation. The particles will clog and sediment at the bottom of the container. Thus making a homogeneous dispersion by two step method remains a challenge. However there exist some techniques to minify this problem lie high shear and ultrasound. Also addition of surfactant to the nanofluid will increase its stability. In the study water was used as the base liquid to make the nanofluid. Dry aluminum oxide nanoparticles are first dispersed in water. To avoid agglomeration and sedimentation of nanoparticles ultrasonication was done. Preparing a homogeneous suspension is still a technical challenge due to strong Van der Waals interactions between nanoparticles always favoring the formation of aggregates. To obtain stable nanofluids, some methods are recommended, such as physical or chemical treatment. In order to produce required particle volume fractions, dilution with water followed by a stirring action is effected by ultrasonicator. The desired volume concentrations used in this study is Φ 0.1% (3.9876 grams).

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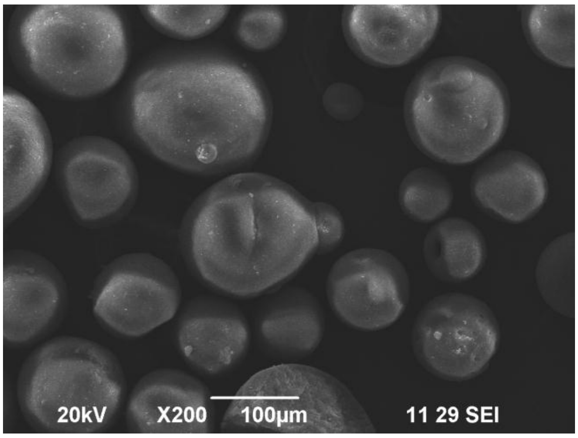

Fig.2.2 Microscopic Study on Al_2O_3particle

2.2.1 Nanofluid Properties

The thermo physical properties used for nanofluid were calculated from water and nanoparticle properties at average bulk temperature using following correlation for density, specific heat and thermal conductivity [10].

$$\rho_{nf} = \varphi\rho_p(1-\varphi)\rho_w \quad (1)$$

$$[\rho Cp]_{nf} = \varphi(\rho Cp)_p + (1-\varphi)[\rho Cp]_w \quad (2)$$

$$k_{nf} = k_w(1+7.47\varphi) \quad (3)$$

2.3 Battery Energy Storage System

Battery Energy Storage System consists of a battery bank, control system, power electronics interface for ac-dc power conversion, protective circuitry, and transformer to convert the BESS output to the transmission or distribution system voltage level. The one-line diagram of a simple BESS is shown in Fig. 2.3 note that a BESS is typically connected to the grid in parallel with the source or loads it is providing benefits to, whereas traditional uninterruptible power supplies (UPS) are installed in series with their loads. The power conversion unit is typically a bi-directional unit capable of four-quadrant operation, meaning that both real and reactive power can be delivered or absorbed independently according to the needs of the power system, up to the rated apparent power of the converter. The solar photovoltaic cell manufactured by Udhaya Semiconductors Coimbatore, model USP 36 Sl.No 12162.

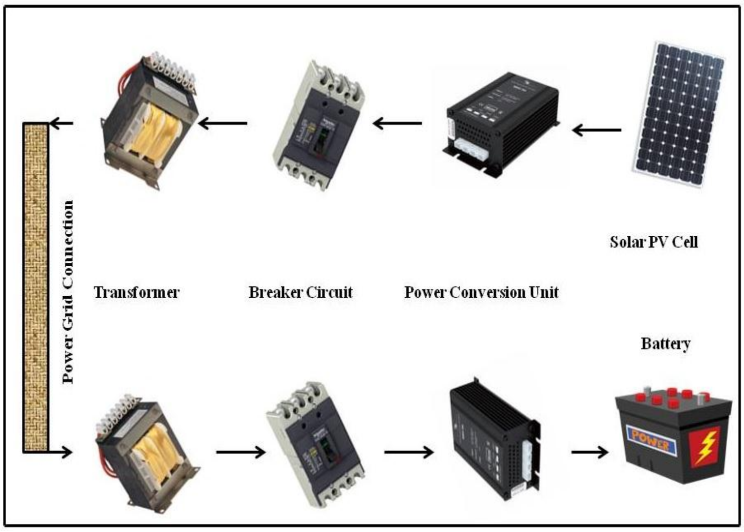

Fig2.3 Parallel Grid Connection of Battery Energy Storage System

The battery bank consists of many batteries connected in a combination series-parallel configuration to provide the desired power and energy capabilities for the application. Units are typically described with two numbers, the nameplate power given in MW, and the maximum storage time given in MWh. The BESS described in this paper is a 1.5/1 unit, meaning it stores 1 MWh of energy, and can charge or discharge at a maximum power level of 1.5 MW. In renewable energy applications, it is common to operate a BESS under what is known as partial state of charge duty (PSOC) [24], a practice that keeps the batteries partially discharged at all times so that they are capable of either absorbing from or discharging power onto the grid as needed.

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3. METHODOLOGY

3.1 Electrical Circuit

The DC power supply was given to the diodes used by capacitors and regulators. Capacitors were provided for controlling the voltage and regulator required for power can be adjusted. Thermoelectric module power was taken by above the circuit connection (Fig.3A) the capacitors and regulators were connected parallel to the diode front and back side of circuit connection in Fig 3B and Fig 3C shown below.

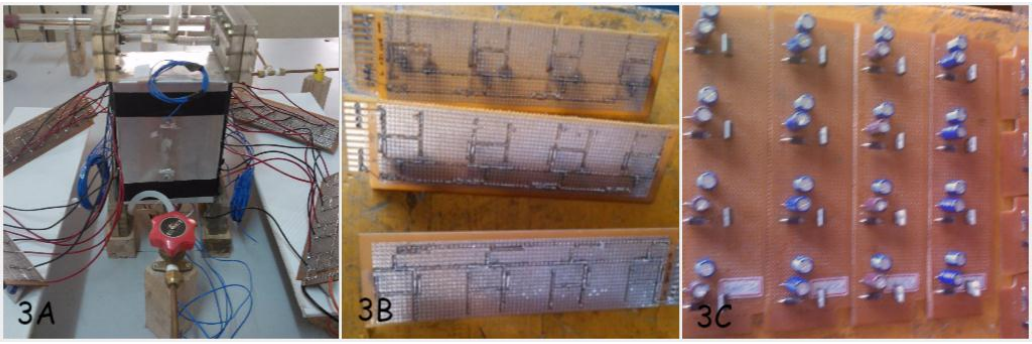

Fig3.1 Circuit Connected through TEC Module using Electric Circuit

3.2 Thermoelectric Module (TEC 1- 12708T125)

The selection of the thermoelectric cooler (TEC) plays an important role in this area. The selection of the TEC involves certain basic calculations as it is required in the conventional system. The calculation depends upon the load given, the area which is to be cooled, the maximum power supplied.

The important parameters to select the TEM are, $\Delta T_{max}, I_{max}, V_{max}$ and Q_{max}.

$$\Delta T_{max} = \frac{1}{2} Z T_C^2 \quad (4)$$

$$I_{max} = \frac{S_M}{R_M}[T_h - \Delta T_{max}] \quad (5)$$

$$V_{max} = S_M \Delta T_{max} + I_{max} R_M \quad (6)$$

$$Q_{max} = S_M T_c I_{max} - \frac{1}{2} I_{max}^2 R_M \quad (7)$$

Thus the basic required parameters are calculated and according to which the thermoelectric modules selected. With the help of the calculated ΔT_{max}, I_{max}, and Q_{max} values the thermoelectric module is selected. The TE module selected for our test facility is listed below.

V_{max} = 15.2 V
ΔT_{max} = 65°c
L×W×H = 40×40×3.9 mm
I_{max} = 8A

With the selected thermoelectric module the tests are carried out and the co-efficient of performance is found out where the,

$$COP = \frac{Q_C}{Q_P} \quad (8)$$

$$Q_c = 2N\left[sIT_c - \frac{1}{2} I^2 \frac{\rho}{G} - k G \Delta T\right] \quad (9)$$

$$Q_p = VI \quad (10)$$

With the calculated basic parameters the investigation is done and the experimental results were tabulated. Thus the experimental results were compared with the existing correlation of generalized chart for a single stage (TEC 1- 12708T125) module.

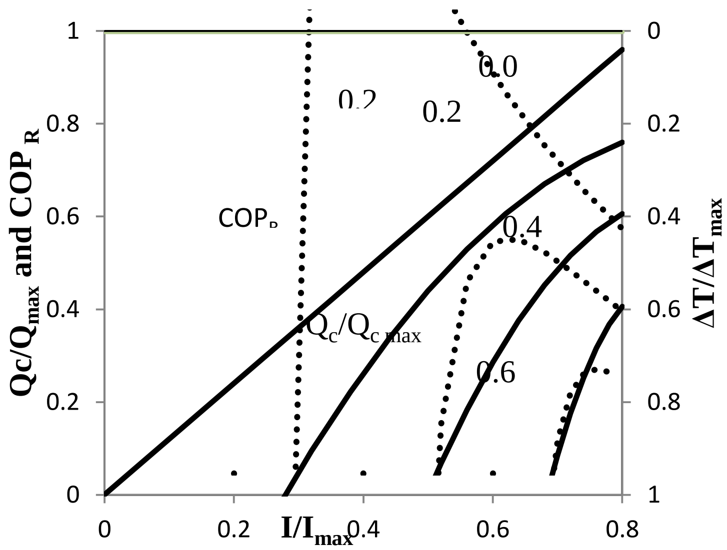

Fig3.2 Generalized Charts for a single stage (TEC 1- 12708T125) module.

The heat transfer performance of nanofluid through minichannel was defined in terms of the convective heat transfer coefficient calculated as follow:

$$h = \frac{q}{T_w(x)-T_f(x)} \quad (11)$$

Where 'x' represents perpendicular distance from the entrance of the test section 'q' is the heat flux in W/m2, 'T_w' is the measured wall temperature, and 'T_f' is the fluid temperature decided by following energy balance:

$$Tf = \frac{Tin+Tw}{2} \quad (12)$$

The mass flow rate can be calculated using the relation,

$$m = \frac{Re\times D\times\mu\times\pi}{4} \quad (13)$$

Where 'Re'- Reynolds number

'D' – Inner diameter of the copper inch tube(4mm)

'μ' – Fluid dynamic viscosity.

The refrigeration effect of nanofluid through mini channel was defined in terms of cooling rate and COP calculated as follow:

$$Qc = \frac{m\times Cp\times\Delta T}{\Delta t} \quad (14)$$

Where 'm'- mass flow rate

'C_p'- Specific heat

'ΔT' – Cabin Temperature Difference

'Δt' – Time period in sec

$$COP = \frac{Qc}{Qin} \quad (15)$$

Where Q_c – Cooling rate (or) refrigeration effect in Watts.

Q_{in} – Input of power through thermoelectric module in Watts.

$$R = \frac{\Delta T}{Qin} \quad (16)$$

Where ΔT – Temperature difference in thermoelectric module cold and hot side

4. RESULTS AND DISCUSSION

4.1 Performance of Temperature & Resistance using water instead of 0.1vol %

The experiments are carried out using water and aluminum oxide – water nanofluid, the following governing parameters: Reynolds's number is 400, the power supply Q_{in} between 26W to 416W, the particle volume fraction 0.1%. The enhancement in heat transfer coefficient, coefficient of performance, temperature difference in cabin, resistance and cold, hot side temperature of thermoelectric module using water and nanofluid. The comparisons of water and nanofluid results are discussed below:

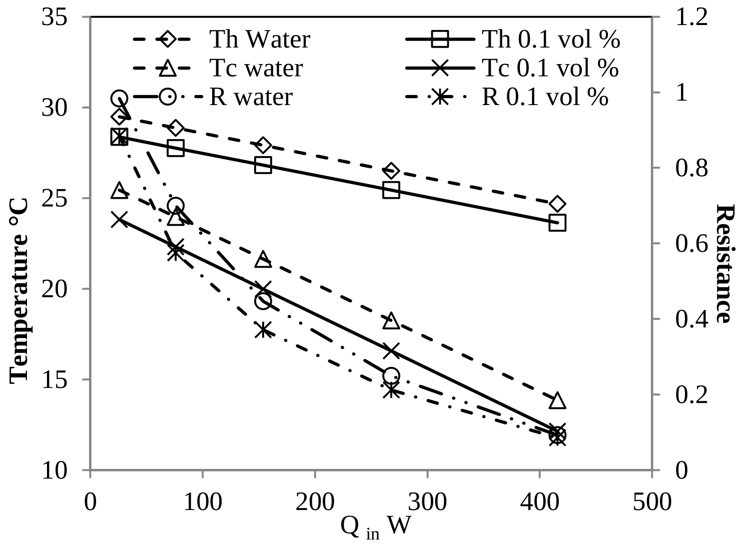

Figure 4.1. Plot between power supply with respect of resistance and temperature

The temperature difference and resistance with respect of power supply plotted in figure 4.1 shown. When compared cold side of the thermoelectric module using water instead of 0.1% volume fraction nanofluid, the heat absorbed rate is increased. At the same time the power supply increases the heat transport also increases. At the 26 W to 416 W given power supply the cold side of thermoelectric module enhancement 8.5% is observed.

4.2 COP as function of Cabin

Fig. 4.2(a) and 4.2 (b) represent variation of cabin temperature as a function power supply and time. A temperature drop of 12°C in cabin temperature is achieved after 20 min of cooling, at an input power range of 26W to 416W to the thermoelectric modules when water is used as the coolant in the minichannel. The temperature drop in cabin temperature is increased to 15 °C when the alumina–water nanofluid with volume concentration of 0.1% is used as coolant in the minichannel. A maximum drop of 22% in cabin temperature is achieved. The drop of heat content from the liquid cabin is considered as the heat input at the cold side of the thermoelectric cooler.

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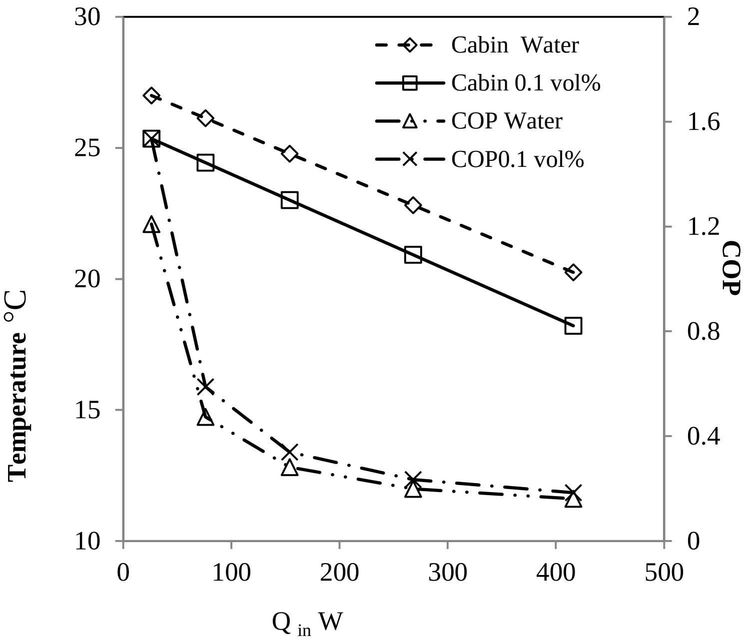

Fig4.2(a) Variation of COP as function of Input power

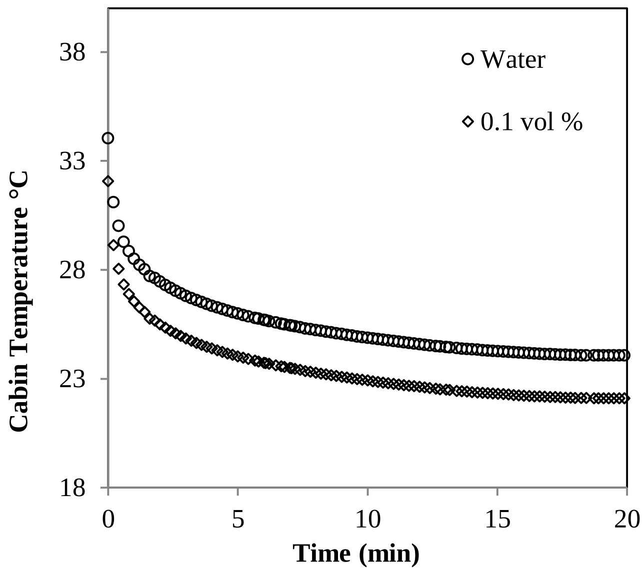

Fig4.2 (b) Variation of Cabin Temperature as function of Time

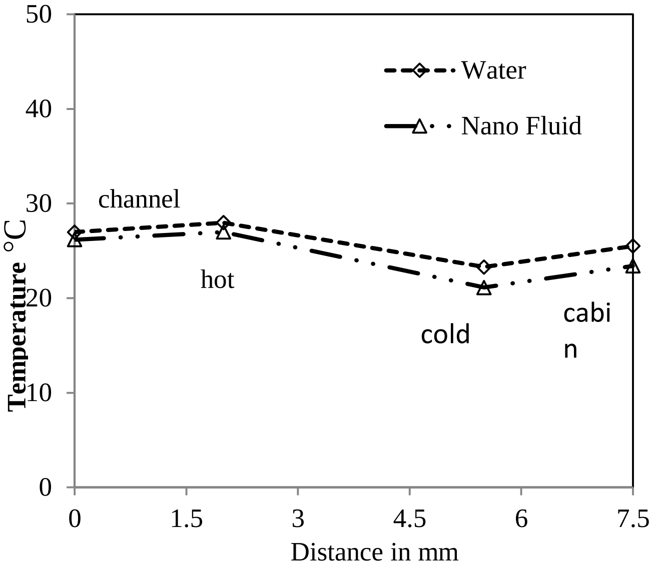

Fig4.2 (c) Temperature Profile with respect of distance (Channel to Cabin)

Fig 4.2(c) It is clearly seen that there is a variation of temperature range with respect of distance, when temperature drop in cold body, the nanoparticle size and volume increased. This result shown that the heat absorbed and heat rejection on thermoelectric module with minichannel heat exchanger for 0.1 volume concentration nanofluids lower than water. The addition of nanoparticles enhances the thermal conductivity of the nanofluids. However, the enhancement in the thermal conductivity of nanofluid is lesser compared to the enhancement in the heat transfer coefficient. So, it is clear that the enhancement in the thermal conductivity of the nanofluid is not the only reason for the enhancement in heat transfer coefficient. Generally, the nanofluid is assumed to be either as single phase or two phase mixture.

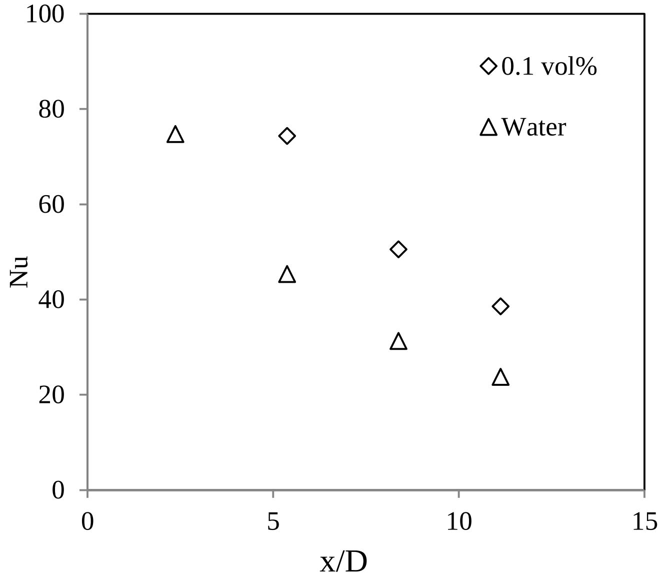

Fig4.3 Plot between distance ratio and Nusslet number

Fig 4.3 presents the plot between distance ratio and Nusslet number; it has been found to improve the nusslet number difference in around 17 units in mini channel heat exchanger is used water instead of nanofluid. For distance in mini channel temperature difference is low the average heat transfer coefficient is more. If the temperature difference is more the heat transfer coefficient is very less. The same trend applicable Nu number also.

4.4 Comparison of water and 0.1vol% fraction (Varying power supply)

The comparison of water and nanofluid (volume fraction) temperature with respect of time shown in Fig 4.4 . The power taken from direct current source to cool the cabin with respect of time taken to obtained the steady state. When the input of power 27 W is given to thermoelectric module, the cabin temperature obtained

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steady state difference in 26.9°C to 25.3°C with respect of water and nanofluid. Similarly 77W is given in thermoelectric module the cabin temperature obtained steady state up to 26.1°C to 24.4°C 154 W is given to thermoelectric module the cabin temperature obtained in steady state up to 24.7°C to 23.0°C, 268 W is given in thermoelectric module the cabin temperature obtained in steady state up to 22.08°C to 20.9°C and finally 416 W given to thermoelectric module the cabin temperature steady state obtained up to 20.24°C to 18.21 °C.

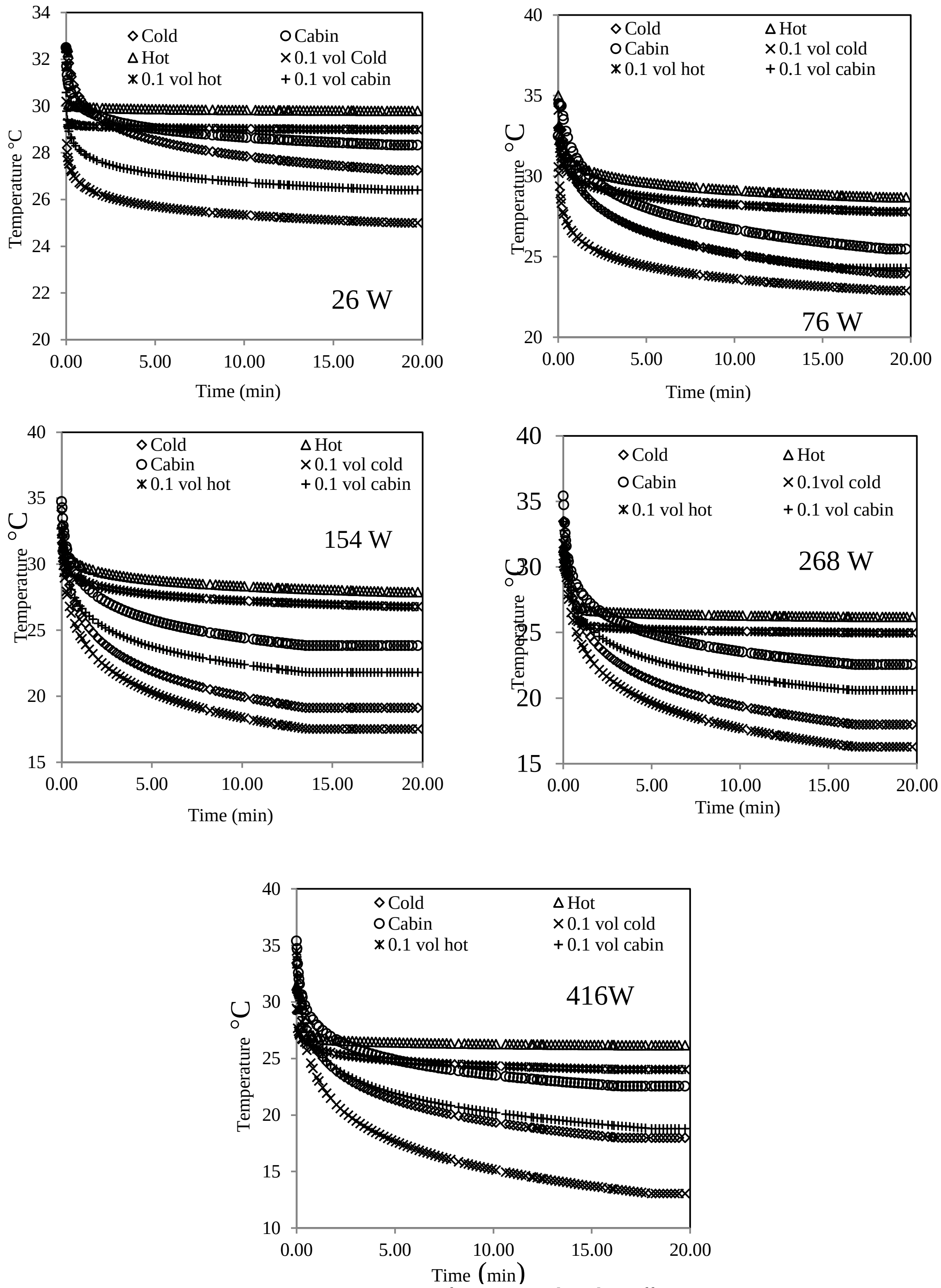

Fig 4.4 comparison of Varying Load Cooling Efficiency

5. CONCLUSION

This study is to improve the coefficient of performance at forced convection condition, the water and Al_2O_3 nanofluid passed through a mini channel and heat transport rate is investigated experimentally in variation of 26W to 416W. It has been shown that a nanoparticle presence in enhancing the cabin temperature. The use of

Al_2O_3 nanoparticle 0.1% of volume concentration induces gradually decreasing the cabin temperature by nearly 20% at forced convection system. The results shown at a 20 minutes dc input power 27 W of thermoelectric module, the cabin temperature obtained steady state difference between 26.9°C to 25.3°C with respect of water and 0.1volume concentration nanofluid. Similarly 76W of thermoelectric module the cabin temperature difference 26.1°C to 24.4°C, 154 W to thermoelectric module the cabin temperature from 24.7°C to 23.0°C, 268 W in thermoelectric module the cabin temperature from 22.08°C to 20.9°C, and finally 416 Watt given to thermoelectric module the cabin temperature steady state obtained up to 20.24°C to 18.21 °C.

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LIST OF SYMBOLS USED

Q_{in}	Power input
ρ_{nf}	Density of Nanofluid
ρ_p	Density of Particle
ρ_w	Density of Water
φ	Particle Volume Concentration
k_w	Thermal conductivity of water
k_{nf}	Thermal conductivity of nanofluid
k_p	Thermal conductivity of particle
h	Heat transfer coefficient
Q_c	Cooling rate
$[C_p]_{nf}$	Specific heat of nanofluid
$[C_p]_p$	Specific heat of particle
$[C_p]_w$	Specific heat of water

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