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Experimental Analysis of Ice Plant Using EG-Water Mixture Based Nanofluids (Al_2O_3) with Different Particle Sizes and Volume Concentrations

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ABSTRACT

For ice plant ethylene glycol, propylene glycols, sodium chloride are widely used as secondary refrigerants. However, due to poor thermal conductivity of secondary refrigerants the heat transfer performance of these refrigerants is restricted. Much research is today carried out with phase changing secondary refrigerant. An innovative way of improving the thermal properties of these secondary refrigerants is to suspend nanometer sized metallic or non metallic solid particles in them. Such fluids are called secondary refrigerant based nanofluids.

In the present work experimental analysis of ice plant has been investigated using EG-Water mixture based nanofluids (Al_2O_3) as a secondary refrigerant with different particle sizes (15nm & 60nm) and volume concentrations (0.1-2%). An experimental ice plant test rig is designed and constructed for this purpose. The performance of the test rig is measured in terms of coefficient of performance, efficiency of the system, refrigerating effect, production capacity and number of hours required for ice production. The experimental data of coefficient of performance of the test rig is validated with standard secondary refrigerant based test rig. The result shows that for both EG-Water mixtures based nanofluids i.e. Al_2O_3-15nm &60nm as a secondary refrigerant and R134a as a primary refrigerant, COP of the system increase with increase in volume concentration of nanoparticle in EG-Water mixture. For 15nm particle size Al_2O_3 nanofluid as a secondary refrigerant COP of the system found to be better than for 60nm particle size Al_2O_3 nanofluid as a secondary refrigerant.

Keywords— **Al_2O_3 nanoparticle, coefficient of performance, production capacity , refrigerating effect, secondary refrigerant.**

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I. INTRODUCTION

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surrounding. The aim is to freeze ice, cool some product or space. The basis of modern refrigeration is the ability of liquids to absorb enormous quantities of heat as they boil and evaporate. One of the important applications of refrigeration is in ice plant. Ice plant is used for producing refrigeration effect to freeze potable water in standard cans placed in rectangular tank which is filled by brine. Brines are secondary refrigerants and are generally used where temperature is required to be maintained below the freezing point of water i.e. $0^{\circ}C$. Brine is a solution of a salt in water. It may be noted that when a salt is mixed in water, then the freezing temperature of the solution becomes lower than that of the water. This is due to the fact that the salt while dissolving in water takes off its latent heat from the solution and cools it below the freezing point of water. The mass of the salt in the solution is known as concentration of the solution. As the concentration of the solution increases its freezing point decreases. The point, at which the freezing temperature is minimum, is known as eutectic temperature and the concentration at this point is known as eutectic concentration. A typical phase diagram for aqueous solutions is shown in Fig.1. The curves of the freezing points show that in many cases the solution of the two constituents has a lower freezing point than either substance individually. The diagram shows the possible phases and mixtures that can exist at various concentrations and temperatures. Assume that the brine is a solution of saltand water. If the brine at temperature A has a concentration M, the brine remains a liquid until the temperature drops to B.

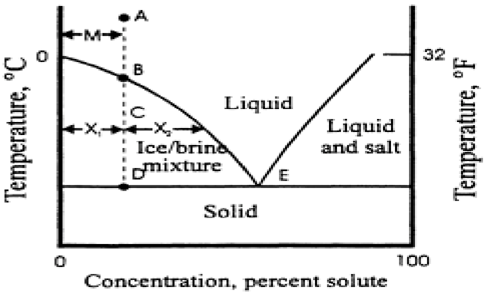

Fig.1 Phase diagram of an aqueous secondary coolant

Further cooling to C results in slush, which is a mixture of ice and brine. The brine at C has concentrated itself by freezing out some of its water into ice. Cooling the solution below D solidifies the entire mixture. Point E is called the eutectic point and represents the concentration at which the lowest temperature can be reached with no solidification.

The brines commonly used are calcium chloride ($CaCl_2$), sodium chloride i.e. common salt (NaCl), and glycols such as ethylene glycol, propylene glycol etc. For ice plant ethylene glycol, propylene glycols, sodium chloride are widely used as secondary refrigerants. However, due to poor thermal conductivity of secondary refrigerants, the heat transfer performance of these refrigerants is restricted. An innovative way of improving the thermal properties of these secondary refrigerants is to suspend nanometer sized metallic or non-metallic solid particles in them. Such fluids are called secondary refrigerant based nanofluids. Nanofluids are suspensions of solid nanoparticle in base fluid with sizes generally less than 100nm. Nanofluid technology becomes a new challenge for the heat transfer fluid since it has been reported that the thermal conductivity of nanofluid enhances at a very low volume fraction as explained by Choi et.al. [2] and also observed an increase up to approximately two times in the thermal conductivity of the fluid with the addition of a nanoparticle less than 1% volume concentrations. Most of the metallic or non-metallic solid particles have thermal conductivity higher than those of the secondary refrigerants or convection fluids. Therefore, high heat transfer performance may be obtained when such particles are dispersed in conventional secondary refrigerants.

A nanoparticles suspension is considered as a three phase system including the solid phase (nanoparticles), the liquid phase (fluid media) and the interfacial phase, which contributes significantly to the system properties because of their extremely high surface to volume ratio in nanofluid. The review showed that the thermal conductivity of Al_2O_3 nanofluid increases with the increase in the Al_2O_3 nanoparticle concentrations in the base fluids.[1]-[8]. This study would be useful in the field of secondary refrigerants.

II. OBJECTIVES OF EXPERIMENT

1. To prepare the nanofluid with different concentrations.
2. To design and fabricate the ice plant model.
3. To determine the performance of the ice plant when EG+ water mixture is used as seconadary refrigerant. (i.e. determining production capacity of the ice plant and actual & theoretical COP of the system and energy consumption).
4. To investigate the effects of nanofluid used with different particle sizes and volume concentrations in the commercial EG + water mixture based secondary refrigerants by analyzing the performance of the ice plant (i.e. determining production capacity of the ice plant and actual & theoretical COP of the system and energy consumption).
5. To compare the performance evaluation parameters of ice plant for both secondary refrigerants.

III.LITERATURE REVIEW

Conventional heat transfer fluids such as water, ethylene glycol, engine oil are widely used in thermal systems. However, due to poor thermal properties of conventional heat transfer fluids, the heat transfer performance of these fluids is restricted. An innovative way of improving the thermal properties of conventional fluids is to suspend nanometer sized metallic or non-metallic solid particles in them. Such fluids are called nanofluids [1]. Since most solid particles have thermal conductivities higher than those of the conventional heat transfer fluids, high heat transfer performance may be obtained when such particles are dispersed in conventional fluids. The more common base fluids that have been used to develop nanofluids are water, ethylene glycol and engine oil. The common nanoparticles that have been used are Al_2O_3, TiO_2, CuO, Al, Cu and CNT (Carbon nanotubes). Over the last 15 years, several researchers have studied thermal properties and heat transfer performance of nanofluids. Among the thermal properties, thermal conductivity is by far the most studied property since it is expected to have the biggest impact on the heat transfer coefficient of the fluid. A literature survey shows that water-Al_2O_3 nanofluids have been widely investigated. Lee et al. [2] measured an increase of 1.44% for water- Al_2O_3 nanofluids with a particle volume concentration of 0.3%. Chandrasekhar et al. [3] obtained an enhancement of approximately 10% in the thermal conductivity of water- Al_2O_3 nanofluids at 3% particle volume concentration. Das et al. [4] showed that the thermal conductivity of nanofluids increases with increasing temperature as well as with increasing concentration. They observed an increase of 2% in the thermal conductivity at 21 ºC and an increase of 10.8% at

51ºC for water-Al2O3 nanofluids at 1% volume concentration of nanoparticles. The corresponding increase in the thermal conductivity at 4% volume concentration of nanoparticles was 9.4% and 24.3% at 21ºC and 51ºC respectively. Duangthongsuk and Wongwises [5] investigated water-TiO_2 nanofluids and found an increase of 3-7% in thermal conductivity for volume concentrations ranging between 0.2% and 2%. Choi et al. [6] chose to investigate transformer oil based nanofluids and observed that the thermal conductivity increases by more than 20% over the base fluid for a 4% volume concentration of Al_2O_3. Several researchers have studied convective heat transfer performance of nanofluids under turbulent flow conditions. Duangthongsuk and Wongwises [7] studied heat transfer performance of water- TiO_2 nanofluids flowing in a horizontal double tube heat exchanger under turbulent flow conditions. Their results showed that, at 1% particle volume concentration, the heat transfer coefficient for the nanofluid was approximately 26% more than that obtained for the base fluid. However, at 2% particle volume concentration, the water- TiO_2 nanofluid showed approximately 14% lower heat transfer performance as compared to that for the base fluid. Farajollahi et al. [8] measured heat transfer characteristics of water- Al_2O_3 and water- TiO_2 nanofluids flowing in a shell and tube heat exchanger under turbulent flow conditions. The experimental results for both nanofluids showed that the heat transfer characteristics of nanofluids significantly improve with Peclet number. Pak and Cho [9] experimentally studied the heat transfer performance of water- Al_2O_3 and water-TiO_2 nanofluids. Their results showed that the Nusselt number of a nanofluid increases with an increase in the Reynolds number as well as with an increase in the particle concentration up to 3%. However, at 3% particle concentration, the heat transfer coefficient for the nanofluid was 12% lower than that for the base fluid at a given Reynolds number. They proposed a correlation for the determination of the heat transfer coefficient based on their results. Xuan and Li [10] determined convective heat transfer and flow characteristics for water-Cu nanofluids flowing in a straight tube under laminar and turbulent flow conditions. Addition of nanoparticles in the base fluid showed 39% enhancement in heat transfer coefficients for nanofluids. Xuan and Li [10] proposed their own heat transfer correlation for calculating the heat transfer coefficient of a nanofluid. Y. Xuan, Q. Li [11] discusses the physical phenomenon of heat transfer in the nanofluid. Y. Xuan, W. Roetzel [12] is investigated the mechanism of heat transfer enhancement of the nanofluid. Based on the assumption that the nanofluid behaves more like a fluid rather than a conventional solid-fluid mixture. R.L. Hamilton, O.K. Crosser, [13] gives the theoretical model of thermal conductivity of heterogeneous two-component systems. L.D. Landau, E.M. Lifshitz [14] discussed the heat diffusion through the nanofluid with the theoretical model. J.R. Henderson, F. van Swol [15] discussed the interface between a fluid and a planar wall by theory model and simulations of a hard sphere fluid at a hard wall. C.-J. Yu, A.G. Richter, A. Datta, M.K. Durbin and P. Dutta [16] Molecular layering in a liquid on a solid substrate has been discussed with the help of an X-ray reflectivity study. G.H. Geiger, D.R. Poirier [17] study the heat transfer by considering heat get transfer by phonon, by propagating the lattice vibration. Sandipkumar Sonawane [18] has done an experimental investigation of thermo-physical properties and heat transfer performance of Al_2O_3-Aviation Turbine Fuel nanofluids.

J.J. De Groot, J. Kestin, H. Sookiazian [19] describe the high precision Instrument measure thermal conductivity of gases and discussed theory about transient heat wire apparatus. D. Yoo, K.S. Hong, H. Yang [20] studied effect of volume concentration on the thermal conductivity of nanofluids for the applications of heat transfer fluids. Durairajan A. [22] a briefly overviewed the historical evolution of nanofluid concept, possible synthesis routes, level of improvements reported, theoretical understanding of the possible mechanism of heat conduction by nanofluid and scopes of application. Cabello et al. [23] had studied about the effect of operating parameters on COP, work input and cooling capacity of single stage vapour compression refrigeration system and found a great influence on energetic parameters due change in suction pressure, condensing and evaporating temperature. Cabello et al. [24] also studied experimentally the effect of condensing pressure, evaporating pressure and degree of superheating on the single stage vapour compression refrigeration system using R22, R134a and R407C and found that mass flow rate is greatly affected by change in suction conditions of compressor due to refrigeration capacity depend on mass flow rate through evaporator. They also observed that for higher compression ratio R22 gives lower COP than R407C.Jiang et al. [25] observed that thermal conductivity of nanofluids also depends upon the nanoparticles size and temperature. Wang et al. [26] conducted experimental study of the boiling heat transfer characteristics of R22 refrigerant with Al2O3 nanoparticles and observed that the nanoparticles enhanced the refrigerant heat transfer characteristics with reduced bubble sizes that moved quickly near the heat transfer surface. J.P.Yadav et. al. [30] had studied the vapour refrigeration cylce and fabricated an ice plant model. They calculated various performance parameters of the fabricated ice plant model.

IV. SAMPLE PREPARATION

Preparation of nanofluids is the first key step in experimental studies with nanofluids. To prepare nanofluids by suspending nanoparticles into base fluids, proper mixing and stabilization of the particles are required. Al_2O_3 nanoparticle is shown in Fig 2.

A) Synthesis And Preparation Methods For Nanofluids-

Nanofluids are not just dispersion of solid particles in a fluid. The essential requirements that a nanofluid must fulfill are even and stable suspension, negligible agglomeration of particles, no chemical change of the particles or fluid, etc.

Nanofluids are produced by dispersing nanometer scale solid particles into base liquids such as water, ethylene glycol, oil, etc.

Fig 2. Al_2O_3 nanoparticle

In the synthesis of nanofluids, agglomeration is a major problem. There are mainly two techniques used to produce nanofluids: the single-step and the two-step techniques [21].

*1]Two Step Technique :*Two-step method is the most widely used method for preparing nanofluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method are first produced as dry powders by chemical orphysical methods. Then, the nanosized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Two step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled up to industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications.

*2] Single Step Technique :*The single step simultaneously makes and disperses the nanoparticles directly into a base fluid. This technique is best for metallic nanofluids. Various methods have been tried to produce different kinds of nanoparticles and nano suspensions. The initial materials tried for nanofluids were oxide particles, primarily because they were easy to produce and chemically stable in solution. Various investigators have produced Al_2O_3 and CuO nanopowder by an inert gas condensation process and found to be 2–200 nm-sized particles. The major problem with this method is its tendency to form agglomerates and its unsuitability to produce pure metallic nanopowder. The problem of agglomeration can be reduced to a good extent by using a direct evaporation condensation method .

B) Preparation of Nanofluid-

A series of trials are performed to determine the exact timing of the ultrasonication for the particle remains suspended for stipulated timing. A two-step method is used to produce Al_2O_3–EG +water mixture nanofluids of Al_2O_3 nanoparticles from 0.1 to 3 vol.% without any surfactant. The two- step method used in this study can be divided into two stages. The first stage is to mix Al_2O_3 nanoparticles with a nominal particle size of 15 ± 5 nm in EG +water mixture. The Al_2O_3 nanoparticles used in the present work were manufactured and supplied by Alfa Aesar India pvt. Ltd. The specifications of the nanoparticle of 15nm size are given below.

Properties of Al_2O_3 nanoparticle

15±5nm Al_2O_3 nanoparticle, 99.98% (metals basis), predominantly gamma phase, 0.01-0.02 Micron Powder, Quantity: 500g, Appearance: powder, Colour: White, Smell: odourless, Density at 20°C: 3.965g/cm^3, Melting point: 2045°C, Boiling point: 2980°C, Manufacturer/ Supplier: Alfa Aesar A Johnson Matthey Company.

*1] Volume Fraction (∅) of A Sample:*To prepare Al_2O_3-EG +water mixture based nanofluid of different volume fraction (∅), take the reference of basic formulae of fluid mechanics. First we take the density of nanoparticle .Density of the Al_2O_3 nanoparticle (15nm) is 3.97g/cm^3. Samples are prepared in the 3lit of EG +water mixture. So from that we found out the mass of nanoparticle equivalent to the 0.1, 0.3,0.5, 1, 2 vol.%. The calculations as follow,

$$\text{Density of nanoparticle } (\rho) = \frac{\text{Mass of nanoparticle (m)}}{\text{Volume of nanoparticle (v)}} \quad \ldots 1$$

As given in specification the Density of Al_2O_3 are 3.965g/cm^3 ≈ 3965kg/m^3 and to calculate the volume fraction in terms of mass for 3lit of EG +water mixture, volume of nanoparticle becomes v= 3×10^{-3} m^3

∴ Eq. (1) becomes

$$3965 = \frac{\text{Mass of nanoparticle (m)}}{3 \times 10^{-3}} \quad \ldots 2$$

So, Mass of nanoparticle= 11.895kg

It means that, 100% volume fraction (∅) required 11.895kg of nanoparticle for the 3lit of EG +water mixture. Like that, for 0.1 volume% required 11.895gm ≈ 12gm of nanoparticle. So that, for 0.3, 0.5, 1, 2 vol.% required 36, 60, 120, 240gm of Al_2O_3 nanoparticle, respectively.

Since ultrasonic vibration breaks down agglomerates in the mixture, the next stage is to homogenize the mixture using ultrasonic vibration at sound frequencies of 34 ±3 kHz, by using the ultrasonicator cleaner.

*2] Ultra Sonicator:*Sonication is the act of applying sound energy to agitate particles in a sample, for various purposes. Ultrasonic frequencies (>20 kHz) are usually used, leading to the process also being known as ultrasonication or ultra-sonication. In the laboratory, it is usually applied using an ultrasonic bath or an ultrasonic probe, colloquially known as a sonicator..

Sonication is commonly used in nanotechnology for evenly dispersing nanoparticles in liquids.

Fig 3: Ultrasonic cleaner

The ultrasonicator used to prepare the nanofluid shown in Fig.3 has following specification:

Tube No.	Fluid Description	Sonication Time	Remark
1	nf 15nm 0.1 vol.%	5hr	Particle remains suspended in base fluid for more than 24 hr.
2	nf 15nm 0.3 vol.%	5hr	Particle remains suspended in base fluid for more than 24 hr.
3	nf 15nm 0.5 vol.%	6hr	Particle remains suspended in base fluid for more than 24 hr.
4	nf 15nm 1 vol.%	6hr and 30 min	Particle remains suspended in base fluid for more than 24 hr.
5	nf 15nm 2 vol.%	7hr	After 12 hr particle get agglomerated at the bottom of test tube.
6	nf 60nm 0.1 vol.%	5hr	Particle remains suspended in base fluid for more than 24 hr.
7	nf 60nm 0.3vol.%	5hr	Particle remains suspended in base fluid for more than 24 hr.
8	nf 60nm 0.5vol.%	6hr. and 30min	Particle remains suspended in base fluid for more than 24 hr.
9	nf 60nm 1 vol.%	7hr	Particle remains suspended in base fluid for more than 24 hr.
10	nf 60nm 2 vol.%	7hr. and 30min	After 12 hr particle get agglomerated at the bottom of test tube.

1. Ultrasonicator Power: 120W
2. Tank size: 250×150×100mm (L×H×W)
3. Tank capacity: 3 Liter. (Approx.)
4. Tank Material: SS 304, 18G
5. Frequency: 34 ± 3 KHz
6. Transducer: PZT sandwich type
7. Input Supply: 230 volt, 1 phase, 50Hz
8. Timer: Mechanical

In lab, 5 different samples with 15nm and 60nm particles (0.1, 0.3,0.5, 1, 2 vol.%) are prepared by sonicating them at different time as shown in the TABLE I. Five different test tube containing nanofluid sample with no. 1 to 5 are for 15nm nanoparticle and 6 to 10 are for 40nm naoparticle as shown in Fig. 4 .

After sonicating we get the homogenous mixture a shown in the Fig 5. As the time passes nanoparticle are try to agglomerate and then settled at the bottom of the test tube a shown in the Fig 6. Thus we prepare the 5 different nanofluid samples with 15nm & 40 nm nanoparticles in the lab successfully.

Fig 4. Preparation of nanofluid at different concentration.

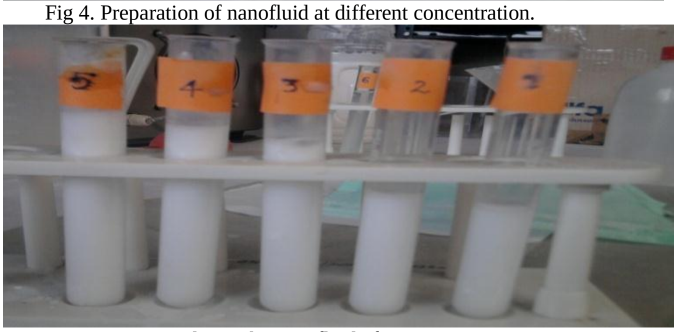

Fig 5. Indicate the nanofluid after sonication

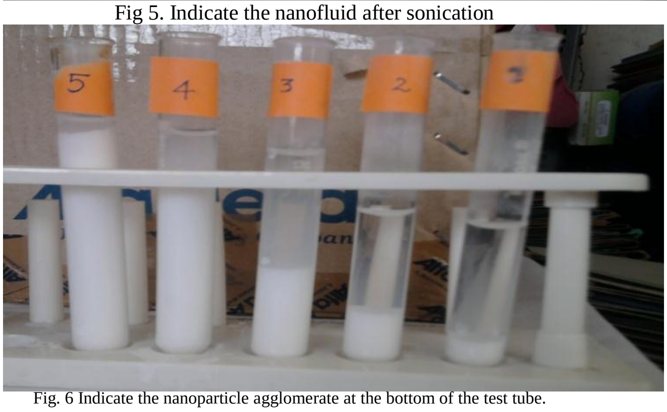

Fig. 6 Indicate the nanoparticle agglomerate at the bottom of the test tube.

V.EXPERIMENTAL SETUP

commonly used to form ice in production process. The indirect method of cooling is used for ice production see Fig.7. The brine is cooled first in the evaporator and then it is circulated around the can of ice which contains water. The heat is extracted from water through the can and is given to the brine. The brine is circulated around the can till the water is converted into the ice. The can is lifted and the ice is taken out.The brine tank for refrigeration mode consists of an insulated stainless steel tank in which evaporator tubes are fixed. The tubes are made of refrigerated grade annealed copper tubes

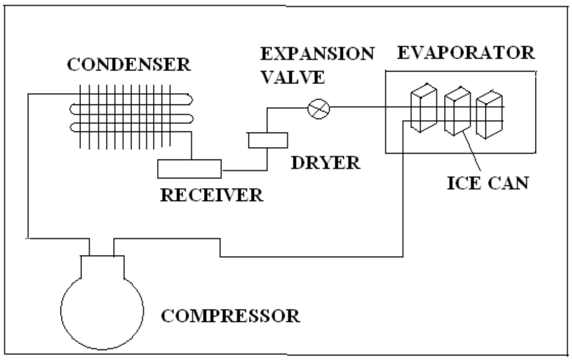

Fig.7 Schematic layout of ice plant test rig

This is a direct type evaporator. Adequate safety devices such as HP/LP cut-outs, heating thermostat and overload protection for compressor are incorporated to prevent any malfunctioning of the given system.

TABLE I
TECHNICAL SPECIFICATION OF ICE PLANT

Sub Title	Parameter of Model	Description
Refrigeration System	Compressor	Hermetically sealed, Make:Kirloskar.
	Condenser	Forced convection air cooled
	Condenser fan	Axial flow type
	Drier/Filter	Molecular sieve type
	Expansion device	Thermostatic expansion valve and /or capillary tube
	Evaporator	Direct expansion type copper coil
	Accumulator	Copper/MS shell suction line
	Refrigerant	R-134a & R-290
	Secondary Refrigerant	Ethylene glycol + water mixture
Controls & Indications	HP/LP cut out	Danfoss make
	Temperature Indicator	Digital temperature indicator
	Pressure Indicator	Dial type pressure guages-2 nos.
	Temperature Control	By digital thermostat
	Input power	0.9 kW
	Rated current	0.4 amp
	Operating switches	Main switch and piano type switchesfor compressor and heater
	Indicating lamps	Provided for compressor and heaters
	Energy meter	
	Brine tank	Stainless steel:SS-304 tank with proper insulation

A) Experimental Equipment and Instrumentation

Experimental setup consists of following components:

1. Thermocouples
2. Voltmeter
3. Ammeter
4. Multi point temperature indicator
5. HP & LP pressure guage
6. Round-tube condenser
7. Coil type evaporator
8. Flow meter of water
9. Flow meter of refrigerant(R134a)
10. Control panel
11. Two side fan
12. Water Motor
13. Hermatically sealed compressor

1) Thermocouples:

It is use to measure the temperature of refrigerant at inlet and outlet from condenser, compressor and evaporator. It is also used to measure ambient temperature and exit temperature from condenser. There are twelve numbers of thermocouples are as follows:

Refrigerant temperature: T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9

Ambient temperature : T_{10}

Exit air temperature : T_{11} and T_{12} (Condenser exit)

These twelve thermocouples are connected to multi point temperature indicator to measure the temperature at different locations.

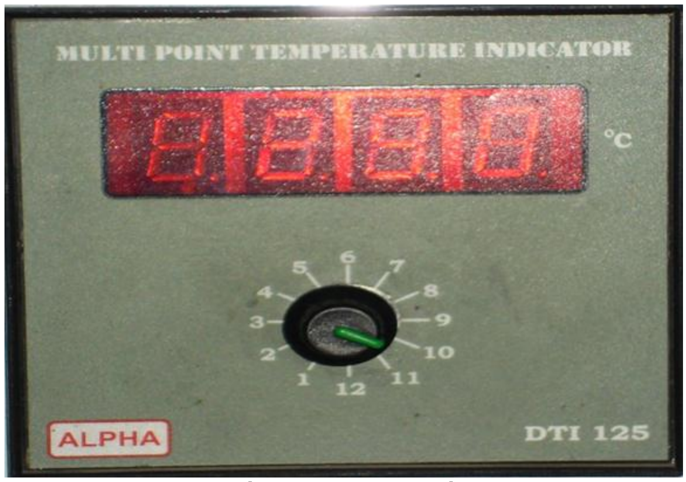

Fig.8 Multi point temperature indicator

The specification of each thermocouple which are used in the present study are:

T1: Refrigerant inlet temperature to Condenser in ^{0}C

T2: Refrigerant outlet temperature from condenser in ^{0}C

T3: Inlet temperature to evaporator

T4: Outlet from evaporator

T5: Bath temperature evaporator

2) Round Tube Condenser:-

In Round type condensers, the circulation of air over the condenser surface is maintained by using a fan or a blower. These condensers normally use fins on air-side for good heat transfer. The fins can be either plate type or annular type. The red colour tubes indicate inlet and blue colour shows outlet of refrigerant from condenser. Actual view of round tube condenser shown in Fig.9

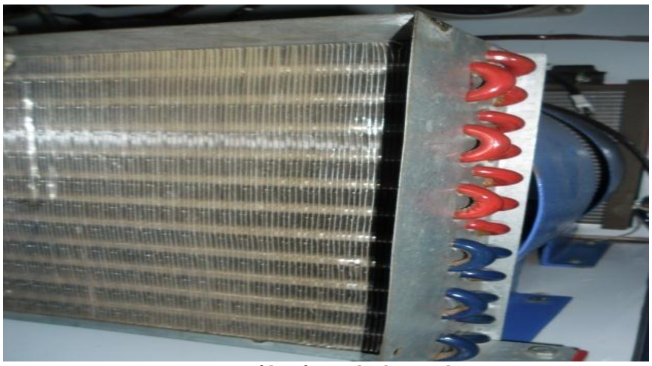

Fig. 9 Profile of round tube condenser

The specification of Round tube condenser:
Diameter of refrigerant tube: 09 mm
Length of round tubes: 3600 mm
Number of round tubes: 36
Round tube: 12" *12" * 4 rows
Fins material: Aluminium
Refrigerant tube material: Copper

3) *Control panel***:**

It consists of ON/OFF switch, pressure indicators (H.P and L.P), multi point temperature indicator, energy meter of heater, and energy meter of compressor.

Fig.10 Control panel

4) *Pressure gauges:*

Direct indication of the operating conditions of a compressor is by pressure gauges at suction, discharge and oil delivery. Such gauges are mounted on or near the compressor. Since the pressure losses along the discharge and suction lines are comparatively small on most systems, these pressures will also approximate to the conditions in the condenser and evaporator, and the equivalent saturation temperatures will be the condensing and evaporating temperatures. See Fig.11

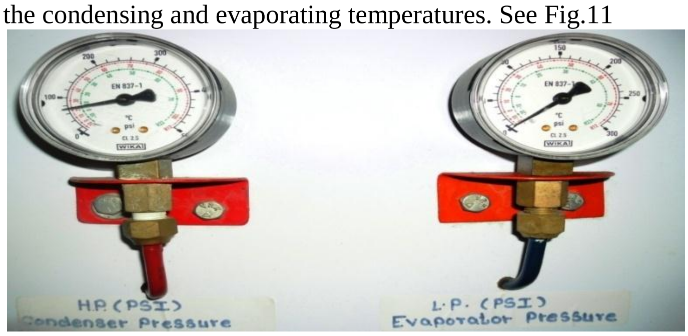

Fig. 11 HP & LP Gauges

5) *Evaporator:*

The purpose of the evaporator is to receive low-pressure, low temperature fluid from the expansion valve and to bring it in close thermal contact with the load. The refrigerant takes up its latent heat from the load and leaves the evaporator as a dry gas. The charge from expansion device enters in evaporator bath and absorbs the heat from brine solution. Charge from evaporator again enters to compressor at a evaporator pressure (LP).

Specification of evaporator:
Refrigerant tube diameter: 9mm
Circular coil tube diameter: 200mm
Length of the tube: 600 mm
Volume capacity of brine solution: 3 litre
Evaporator type: Wound coil
Evaporator coil material: Copper

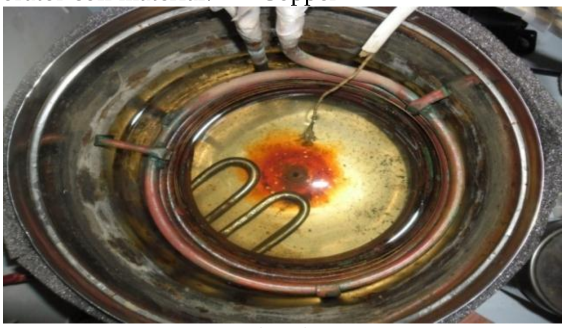

Fig. 12 Profile of evaporator

6) *Hermetically Sealed Compressor:*

In hermetic compressors, the motor and the compressor are enclosed in the same housing to prevent refrigerant leakage. The housing has welded connections for refrigerant inlet and outlet and for power input socket. As a result of this, there is virtually no possibility of refrigerant leakage from the compressor. Similarly the compressor also gets heated-up due to friction and also due to temperature rise of the vapor during compression. In Open type, both the compressor and the motor normally reject heat to the surrounding air for efficient operation. In hermetic compressors heat cannot be rejected to the surrounding air since both are enclosed in a shell. Hence, the cold suction gas is made to flow over the motor and the compressor before entering the compressor. This keeps the motor cool. The cooling rate depends upon the flow rate of the refrigerant, its temperature and the thermal properties of the refrigerant. Hermetically sealed compressors give satisfactory and safe performance over a very narrow range of design temperature and should not be used for off-design conditions. The COP of the hermetic compressor based systems is lower than that of the open compressor based systems since a part of the refrigeration effect is lost in cooling the motor and the compressor. However, hermetic compressors are almost universally used in small systems such as domestic refrigerators, water coolers, air conditioners etc, where efficiency is not as important as customer convenience (due to absence of continuous maintenance). See figure 5.8.

Compressor: Hermetically sealed type
Capacity: 1/3 T

Fig.13 Profile of evaporator

VI. PERFORMANCE EVALUATING PARAMETERS OF ICE PLANT

The purpose of this work is to investigate the effects of nanofluid used in the commercial ethylene glycol based secondary refrigerants by analyzing the performance of the ice plant (i.e. determining production capacity of the ice plant and actual and theoretical COP of the system) and compare these data with the reference values obtained when pure ethylene glycol water solution is used in ice plant. This work is purely experimental work going to perform on the set up of ice plant. The outcomes of the work will be used for undergoing project on ice plant.The performance evaluation parameters of ice plant are as follows:

A) Actaul COP of The Plant:

1) Refrigerating Effect (RE) –

RE=Sensible heat of water(I) + Latent heat of ice(II) + Sensible heat of ice(III)

RE= I + II + III

Where,

I) Sensible heat of water = $m.C_{p.}\Delta T$

Where,

m=mass of water filled in cans (Kg),

C_p= specific heat of water (4.187 kJ/KgK),

ΔT=temperature difference of water in °C

= initial temperature of water – freezing point of water

II) Latent heat of ice = $m.h_{fg}$

Where ,

m= mass of ice formed (Kg),

h_{fg}= laltent heat of ice=335kJ/Kg

III) Sensible heat of ice = $m.C_{p.}\Delta T$

Where ,

m= mass of ice formed (Kg),

C_p= specific heat of ice (2.1 kJ/KgK),

ΔT=temperature difference in °C

= temperature of ice – temperature of ethylene glycol

2) *Work done*:

Compressor work=final EMR – initial EMR

3) Coefficient of performance (COP):

$$COP = \frac{\text{Refrigerating Effect}}{\text{Work done}}$$

4) *Total Capacity of the plant:*

$$Capacity\ of\ the\ plant = \frac{24\ \text{hrs X quantity of ice formed}}{\text{Time required (hrs)}}$$

5) *Theoretical COP of The Plant:*

From the pressure enthalpy chart theoretical COP of the ice plant can be obtained.

6) *Plant Efficiency:*

$$\eta = \frac{\text{Actual COP of the plant}}{\text{Theoretical COp of the plant}}$$

7) *Tonnes of Refrigeration:*

$$TR = \frac{\text{Refrigerating Effect}}{\text{Time Required for ice production X 60 X 210}}$$

VII.EXPERIMENTATION

For the analysis ice plant set up is built to find various parameters.The measurement parameters are actual coefficient of performance, theoretical coefficient of performance, total capacity of the ice plant, compressor work, plant efficiency, time required for ice production and tonnes of refrigeration. From various operating conditions the data obtained from ice plant system using EG + water as a secondary refrigerant was compared with system using EG+ water +nanoparticles with various volume concentrations. Primary refrigerant used is R134a (Tetrafluoroethane) and for secondary refrigerant nanoparticles used are 15nm and 60nm dispersed in EG + water mixture.

A) OPERATIONAL INSTRUCTION-

Connect the two plugs to main. Before ON the supply, conform that all the switches on panel are off position. Put ON the condenser fan switch & wait for 2 - 3 minutes. Now switch ON the solenoid valve switch & the compressor switch. The refrigeration flow will start. This can be confirmed on the sight glass. Now the ammeter, voltmeter will show the current & voltage for compressor. Note down the time for 10 revolutions of energy for compression. After some time we will see that the Temperature of water in the evaporator slowly goes down & reaches steady state.

After the steady state note down the readings as follows:

1. HP Condenser pressure in PSI = PSI
2. LP Evaporator Pressure in PSI = PSI
3. Condenser Inlet Temperature in ^{0}C = T1
4. Condenser Outlet Temperature ^{0}C = T2
5. Evaporator Inlet Temperature in ^{0}C = T3
6. Evaporator Outlet Temperature ^{0}C = T4
7. Temperature of secondary refrigerant ^{0}C= T5
8. Initial energy meter reading = in kW-hr.
9. Final energy meter reading = in kW-hr.

B) OBSERVATION TABLES-

The readings of pressure, temperature, flow rate obtains during experimentation were recorded in below tabulate form.

1. Reaings of ice plant using R134a as a primary refrigerant and EG +Water as a secondary refrigerant.:

SR. NO.	Time (am)	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	8.45	26	25	-8	21	19	85	15	22.72	22.8
2	9.15	30	31	-1	25	14	85	15		
3	9.30	36	28	-2	18	0	84	13		
4	10.30	42	23	-5	8	-2	84	14		
5	11.00	37	23	-6	7	-2	83	14		
6	11.45	36	22	-6	7	-2	83	14		

2. Readings of ice plant using R134a as a primary refrigerant and EG +Water+0.1% Al_2O_3(15nm) as a secondary refrigerant.:

SR. NO.	Time (am)	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	8.45	26	29	-8	20	18	105	42	24	24.041
2	9.20	32	30	-4	22	12	108	38		
3	9.50	34	29	-5	17	6	109	39		
4	10.20	35	28	-4	12	1	108	39		
5	10.45	36	27	-4	8	-2	105	38		
6	11.10	36	28	-5	7	-3.3	105	40		

3. Readings of ice plant using R134a as a primary refrigerant and EG +Water+0.3% Al_2O_3(15nm) as a secondary refrigerant.:

SR. NO.	Time (am)	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	2.00	28	27	-6	22	21	110	44	23.5	23.542
2	2.30	34	30	-4	23	16	110	45		
3	3.00	35	32	-3	18	7	112	45		
4	3.30	36	27	-2	9	-1	114	47		
5	4.00	40	28	-5	7	-2	115	47		
6	4.30	38	26	-6	8	-3	115	48		

4. Readings of ice plant using R134a as a primary refrigerant and EG +Water+0.5% Al_2O_3(15nm) as a secondary refrigerant.:

SR. NO.	Time (am)	T1	T2	T3	T4	T5	HP	LP	EMR Initia	EMR Final
1	9.00	30	24	-5	24	17	99	10	26.1643	26.2
2	9.30	32	25	-3	26	11	100	11		
3	10.00	35	26	-4	16	8	101	12		
4	10.30	38	27	-6	10	-1.1	102	14		
5	11.00	39	28	-7	10	-2.5	104	15		
6	11.25	40	28	-7	9	-3.4	104	15		

5. Readings of ice plant using R134a as a primary refrigerant and EG +Water+1% Al_2O_3(15nm) as a secondary refrigerant.:

SR. NO.	Time	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	11.00	26	24	-4	23	16	98	10	26.58	26.6148
2	11.30	28	26	-3	25	10	100	12		
3	12.00	27	25	-2	19	5	102	14		
4	12.30	32	26	-4	12	-1.6	104	15		
5	1.00	37	27	-6	8	-3.6	104	15		
6	1.25	39	27	-6	8	-3.6	104	15		

6. Readings of ice plant using R134a as a primary refrigerant and EG +Water+2% Al_2O_3(15nm) as a secondary refrigerant.:

SR. NO.	Time	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	1.00	30	26	-9	18	15	105	44	27.053	27.086
2	1.30	33	29	-8	20	8	108	46		

3	2.00	35	30	-6	17	2	110	47		
4	2.30	38	32	-5	7	-1.9	114	47		
5	3.00	41	37	-7	9	-4	115	48		
6	3.15	41	37	-7	9	-4	115	48		

7. Readings of ice plant using R134a as a primary refrigerant and EG +Water+0.1% Al_2O_3(60nm) as a secondary refrigerant.:

SR. NO.	Time	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	9.00	27	26	-9	22	19	100	37	28.06	28.135
2	9.30	31	32	-4	26	13	101	38		
3	10.00	37	27	-2	19	0	104	38		
4	10.30	43	26	-5	8	-1.8	104	39		
5	11.30	37	23	-7	8	-2.1	105	39		
6	12.00	37	23	-7	8	-2.1	105	40		

8. Readings of ice plant using R134a as a primary refrigerant and EG +Water+0.3% Al_2O_3(60nm) as a secondary refrigerant.:

SR. NO.	Time	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	10.00	28	25	-8	21	18	102	37	28.5	28.57
2	10.30	26	24	-7	16	12	105	38		
3	11.00	27	23	-8	10	10	106	39		
4	11.30	29	24	-6	-2	0	105	39		
5	12.00	34	21	-5	8	-2	105	40		
6	1.00	36	22	-6	7	-2.2	105	40		

9. Readings of ice plant using R134a as a primary refrigerant and EG +Water+0.5% Al_2O_3(60nm)as a secondary refrigerant.:

SR. NO.	Time	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	1.30	29	24	-6	22	16	99	9	29.04	29.108
2	2.00	30	25	-8	16	12	101	10		
3	2.30	32	26	-5	10	10	100	13		
4	3.15	36	25	-2	4	2	102	14		
5	3.45	38	23	-5	6	-1.8	104	15		
6	4.30	39	23	-8	8	-2.2	104	15		

10. Readings of ice plant using R134a as a primary refrigerant and EG +Water+1% Al_2O_3(60nm)as a secondary refrigerant.:

SR. NO.	Time	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	1.30	29	27	-7	20	20	110	40	23.04	23.1
2	2.00	32	30	-4	24	15	110	44		
3	2.30	35	28	-3	17	-1	112	46		
4	3.00	36	25	-2	7	-1	113	47		
5	3.30	42	24	-5	6	-2	115	48		
6	4.30	35	23	-5	6	-2.2	115	48		

11. Readings of ice plant using R134a as a primary refrigerant and EG +Water+2% Al_2O_3(60nm)as a secondary refrigerant.:

SR. NO.	Time	T1	T2	T3	T4	T5	HP	LP	EMR Initial	EMR Final
1	9.00	29	26	-5	23	15	100	39	29.58	29.08
2	9.30	36	28	-6	16	10	103	42		
3	10.00	38	24	-8	14	8	105	44		
4	10.30	38	23	-6	12	0	110	46		
5	11.00	39	24	-5	10	-1.1	115	48		
6	11.40	40	25	-7	8	-2.8	115	48		

VIII.RESULTS AND DISCUSSION

The experimental data obtained from the set up is presented in the previous chapter. On the basis of the experimental data following graphs are plotted showing experimental analysis of the ice plant using EG + Water based nanofluid (Al_2O_3) with different particle sizes and volume concentrations.

The refrigerating effect verses Al_2O_3 (15nm & 60nm) nanoparticles volume concentration in EG +Water mixture graph is shown in Fig.14. For all the volume concentrations of nanoparticles it can be seen from the Fig.14 that the refrigeratig effect goes on increasing. Due to the presence of nanoparticles in the secondary refrigerant heat transfer rate got increase. Because of this the compressor work of the system got decrease as shown in Fig. 15. Also the no. of hours required for ice production also decreased because of high rate of heat transfer between primary refrigerant and secondary refrigerant see Fig.16.

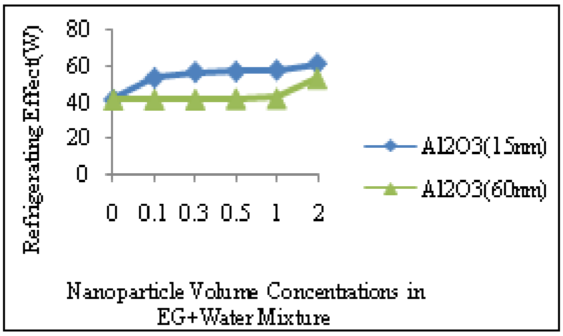

Fig.14 Effect of nanoparticle on refrigerating effect

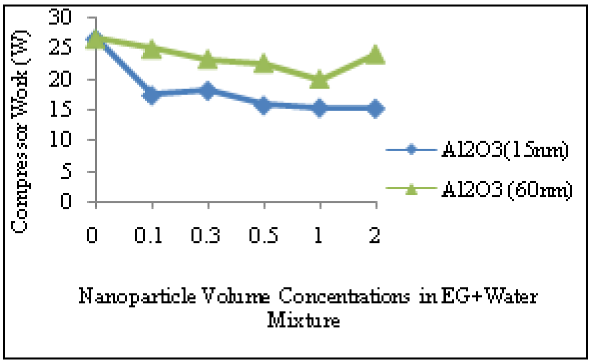

Fig.15 Effect of nanoparticle on compressor work

The tonnes of refrigeration of the system also increased. For 2% of volume concentration of Al_2O_3 nanoparticle in EG+ water mixture the TR of the system is large as compared to other concentrations see Fig.17. The coefficient of performance of the system also get improved. The advatages of adding nanoparticles in secondary refrigerant are to reduce the power consumption of the compressor and increase the refrigerating effect. Because of this actual COP of the system increased see Fig.18.

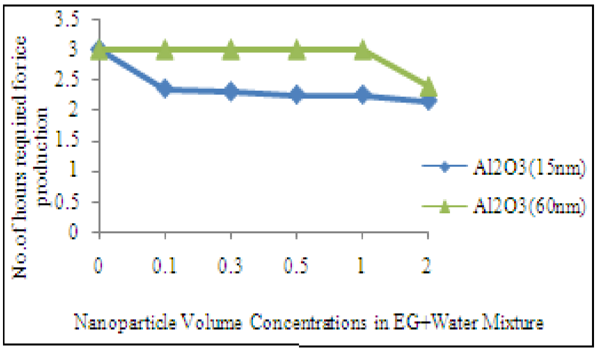

Fig.16 Effect of nanoparticle on no. of hours required for ice production

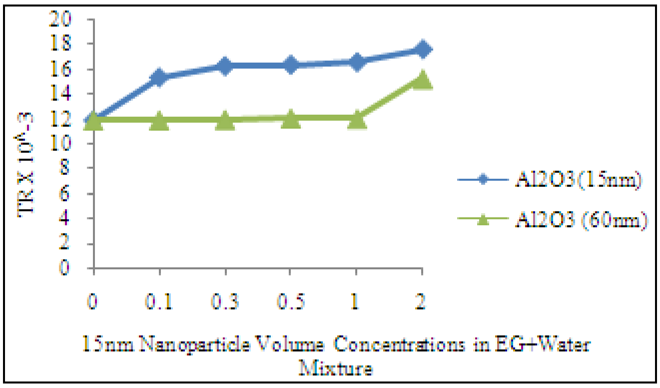

Fig.17 Effect of nanoparticle on TR of the plant

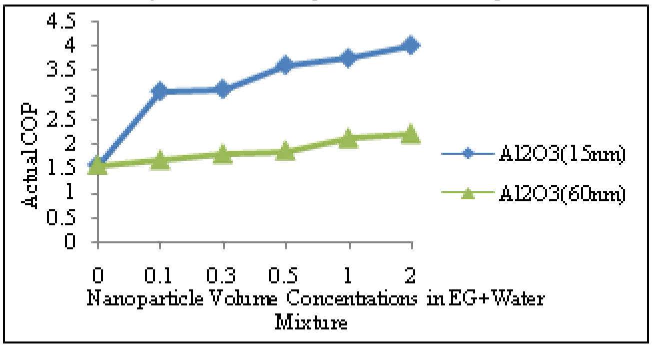

Fig.18 Effect of nanoparticle on actual COP of the plant

IX.CONCLUSION

Extensive experimental studies have been conducted to evaluate the performance of ice plant using EG+water mixture based nanofluid (Al_2O_3) with different particle sizes (15nm and 60nm) and volume concentrations (0.1% to 2%). The refrigerating effect, compressor work, no. of hours required for ice production,tonnes of refrigeration and actual coefficient of performance of the ice plant test rig have been investigated. The following conclusions can be drawn from this study.

1. The R134a primary refrigerant and EG+water based nanofluid (Al_2O_3) as a secondary refrigerant in the Ice plant test rig worked normally.
2. The refrigerating effect of the system is higher with higher particle volume concentrations. It increases sharply due to nanoparticle concentration compared to temperature effects.
3. The power consumption of the system reduces by 42% for Al_2O_3 (15nm) nanoparticle with 2% volume concentration and 25% for Al_2O_3 (60nm) nanoparticle with 1% volume concentration. This is because of the higher heat transfer coefficient of nanofluids.
4. The actual coefficient of performance of the ice plant test rig also increases when EG + water secondary refrigerant is replaced by EG+ water mixture based nanofluid as a secondary refrigerant. Hence we observed that, the actual COP of the system increases rapidly from 0.1 to 2 vol.% particle concentration. In 15 nm, 0.1 to 2 vol.% concentration of the nanofluid percentage enhancement of actual COP is more than 60nm particle size fluid. This rapid increase in the thermal conductivity can possibly be attributed to nanoparticle clustering. Nanoparticle clustering is a phenomenon in which nanoparticles randomly get aligned to other nanoparticles and are held together by weak forces of attraction. The clusters thus formed are regions of low thermal resistance since energy can rapidly move within the cluster in the form of heat.

Moreover ,more experimentation is needed to used nanofluids as a secondary refrigerant in the ice plant test rig. It is important to note that, there will be unknown effects on the evaporator performance because of the nanofluid. Neverthless, the present work would help the researchers working in this area to carry out some experimental studies.

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