Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 6, Issue 1; January-March, 2019, pp. 23-26

http://www.krishisanskriti.org/Publication.html

First and Second Law Analysis of Scraped Surface Ice Slurry Generator

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Abstract—*The present study reports the experimental comparison of antifreezes Propylene Glycol (PG) and Mono Ethylene Glycol (MEG) at different concentrations in a scraped surface ice slurry generator. The aqueous solution of Antifreezes, (PG) and (MEG) with water at different weight percentages 10%, 20%, 30% and 35% of Antifreezes and 90%, 80%, 70% and 65% of water respectively were subjected to the freezing process. The results show that at different concentrations of antifreezes (PG and MEG), total energy balance is same. It is observed that COPcarnot reduces with increase in concentrations of antifreezes (PG and MEG), COPcarnot is higher using PG as comparison to MEG. It is also observed that work carnot increases with increase in concentrations of antifreezes (PG and MEG), work carnot is slightly higher using MEG as comparison to PG. Actual compressor power requirement increases with increase in concentrations of antifreezes (PG and MEG), actual compressor power requirement is slightly higher using MEG as comparison to PG.*

1. INTRODUCION

The ice slurry is normally the ice crystals distributed in water or an aqueous solution where different substances are added to achieve reduction in freezing point, viscosity, corrosion behavior, agglomeration and increase in heat carrying capacity and thermal conductivity of the fluid phase. Ice slurry has a great potential for the future due to wide range of industrial applications, ranging from comfort cooling and commercial refrigeration to industrial production processes and medicine. An important application of an ice slurry system is in the milk production where high peak loads are to be adjusted [1].Ice slurry is a phase-changing secondary fluid consisting of both a liquid state fraction and a solid–state fraction. The solid-state fraction is composed of fine ice particles. The main purpose of using ice slurry is to take advantage of the stored cooling energy (in terms of latent heat) in the ice particles when they melt. The ice particles are in the range of 0.1 to 1 mm in diameter. The same aqueous solutions that are used for single-phase secondary fluids are of interest for use as ice slurry. Ice slurry refers to a homogenous mixture of small ice particles and carrier liquid. The liquid can be either pure fresh water or a binary solution consisting of water and a freezing point depressant. Sodium chloride, ethanol, ethylene glycol and propylene glycol are four most commonly used freezing point depressants in industry [2]. Depending on the type of additive and additive concentration, the operating temperature for ice slurry can be chosen from 0 to at least -35ºC [3]. When water freezes out after the temperature of the fluid has passed below the freezing point, the concentration of the additive increases in the liquid-phase. The increased additive concentration implies that the freezing point of the remaining liquid-phase is further lowered and in order to freeze out more ice the temperature of the fluid has to be further lowered below the current freezing point of the liquid. The result is that the fluid has no definitive freezing point but rather a freezing range. Thus by plotting the freezing point as a function of the additive concentration, one obtains a freezing point curve. as a function of the additive mass concentration of different freezing point depressants. The lowering of the temperature of the ice slurry is independent of the effect of the latent heat from the phase change, but dependent on the sensible heat of the fluid. Since it is the advantage of the latent heat in ice slurry that is desired, one desires a fluid where the latent heat dominates. To minimize the influence of the sensible heat, a fluid with a relatively low first derivative of the freezing point curve (flat freezing point curve) is to be preferred [2]. In the present experimental study 'scraped surface ice slurry generator has been designed, developed and fabricated with a focus on collection of experimental data related to ice crystallization mechanism in the microscopic scale, and heat transfer and fluid mechanics involving agitation and phase change in the macro scale for the ice slurry production.

2. DEVELOPMENT OF ICE SLURRY TEST RIG

In the present experimental study 'scraped surface ice slurry generator' of 5 litre capacity has been designed, developed and fabricated (Fig.1) with a focus on collection of experimental data related to ice crystallization mechanism in the microscopic scale, and heat transfer and fluid mechanics involving agitation and phase change in the macro scale for the ice slurry production [4].

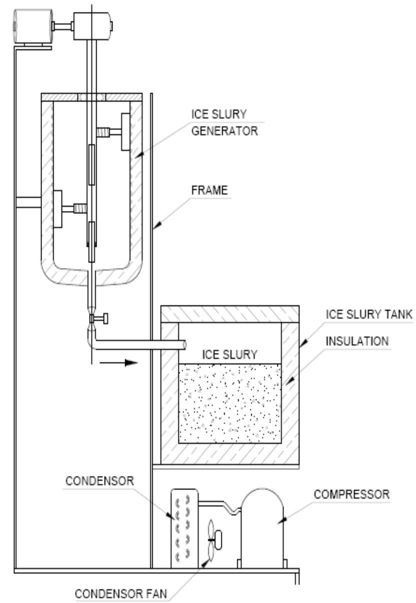

Fig. 1: Schematic diagram of Ice Slurry system

The main components of ice slurry circuit are: Scraped surface ice slurry generator with a scraper, condensing unit, pump and a storage tank. The scraped surface ice slurry generator consists of a circular shell and coil type heat exchanger cooled by an evaporating refrigerant flowing in a spiral shape coil around the outer shell side. The inner cooled surface of the shell is scraped by spring loaded rotating blades to prevent crystal depositions. This scraping action is required to prevent the formation of an ice layer on the ice generator walls. Turbulence is mechanically induced into the ice slurry flow by the action of the rotating scraper blades mounted in the centre of the generator, thus greatly enhances the heat transfer rates and thus facilitating the production of a homogeneous ice slurry mixture. This unit supplies the refrigerant to the coil of the ice slurry generator (referred as evaporator in the refrigeration cycle) where evaporating refrigerant at lower pressure withdraws heat from the binary solution which is finally converted into ice slurry. Experimental studies have been performed using water and various depressants such as propylene glycol, methyl alcohol, ethyl alcohol in different proportions. Performance studies have been conducted for wide range of operating variables.

3. FORMULATION

In this research study, the formulation of [5] has been taken which represents the First-law and second-law energy balance. The mass flow of refrigerant is the same through all components, so it is only computed once through the evaporator. Each component in the system is analyzed sequentially, beginning with the evaporator. Equation (6) is used to perform a first-law energy balance on each component, and Equations (11) and (13) are used for the second-law analysis. In continuation to our previous works [6,7] 'Development of Scraped Surface Ice Slurry Generator' and 'Effect of antifreeze mass fraction on ice slurry generation in a scraped surface ice slurry generator' experiments were carried out. Actual vapor compression refrigeration system operating steadily differ from the ideal cycles in many respects. Pressure drops occur everywhere in the system except in the compression process. Heat transfers between the refrigerant and its environment in all components. The actual compression process differs substantially from isentropic compression. The working fluid is not a pure substance but a mixture of refrigerant and oil. All of these deviations from a theoretical cycle cause irreversibility's within the system. Each irreversibility requires additional power into the compressor.

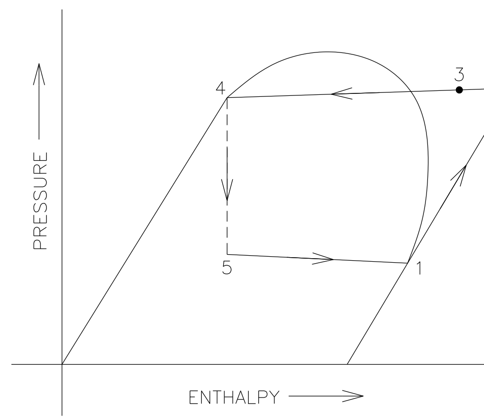

Fig. 2: Pressure-enthalpy diagram of this system

4. EXPERIMENTAL DATA COLLECTION

An air-cooled, direct-expansion, single-stage mechanical vapor compression refrigeration system of scraped surface ice slurry generator uses R-134a and operates under steady conditions. A pressure-enthalpy diagram of this system is shown in Fig.2. Pressure drops occur in all piping, and heat gains or losses occur. Power input is compressor power. The following performance data are obtained for 35% MEG concentration:

Ambient air temperature = 32.4°C

Ice slurry temperature = –14.7°C

Compressor power input = 0.09325 kW

Mass flow rate of refrigerant = 0.00193 kg/s

Refrigerant pressures and temperatures are measured at the five locations shown in Fig.2. Thermodynamic properties of the refrigerant are computed by a mathematical model developed using Matlab neglecting the dissolved oil. The energy transfers to the refrigerant in each component of the system is computed and the second-law irreversibility rate in each component is determined.

5. RESULTS AND DISCUSSIONS

The aqueous solution of Antifreezes, Propylene Glycol (PG) and Mono Ethylene Glycol (MEG) with water at different weight percentages 10%, 20%, 30% and 35% of Antifreezes and 90%, 80%, 70% and 65% of water respectively were subjected to the freezing process. The coolant temperatures were measured with RTD. Recorded temperatures of aqueous solution of Antifreezes (PG and MEG) at various concentrations are plotted (Fig.3) with respect to total energy balance for PG and MEG respectively. With antifreeze PG, the lowest ice slurry temperatures achieved are -2.9 ^{0}C, -6.4 ^{0}C, -11.0 ^{0}C and -13.9 ^{0}C at 10%, 20%, 30% and 35% concentrations respectively, whereas with antifreeze MEG, lowest ice slurry temperatures achieved are -3.4 ^{0}C, -7.1 ^{0}C, -11.9 ^{0}C and -14.7 ^{0}C at 10%, 20%, 30% and 35% concentrations respectively. COPcarnot vs. antifreeze mass fraction, work carnot vs. antifreeze mass fraction and actual compressor power requirement vs. antifreeze mass fraction are plotted shown in Fig. 4, Fig. 5 and Fig. 6 respectively.

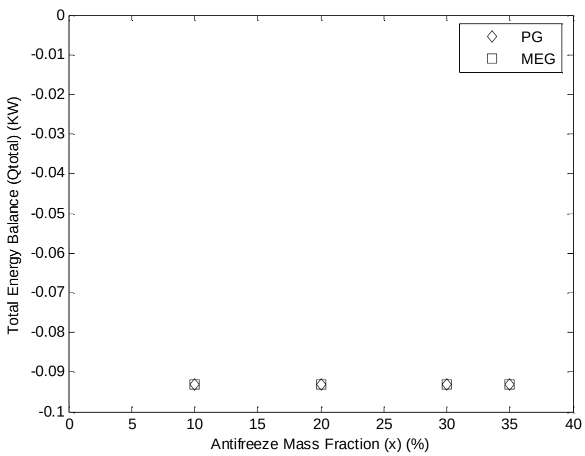

Fig. 3: Total energy balance Vs Antifreezes (PG and MEG) at various concentrations

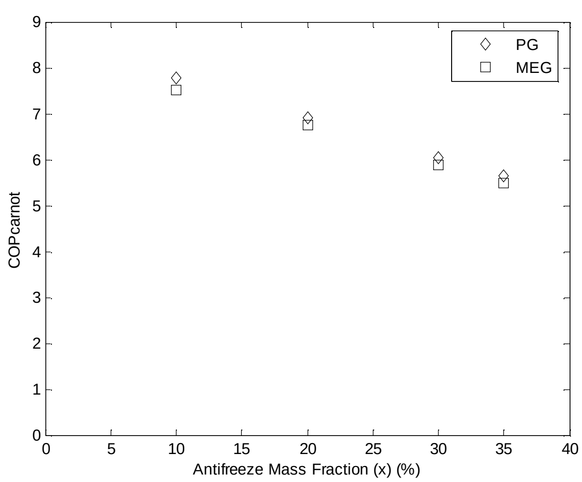

Fig. 4: COPcarnot Vs Antifreezes (PG and MEG) at various concentrations

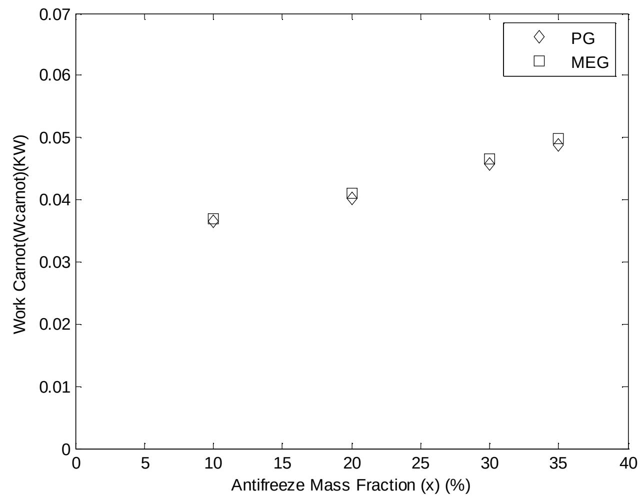

Fig. 5: Work carnot Vs Antifreezes (PG and MEG) at various concentrations

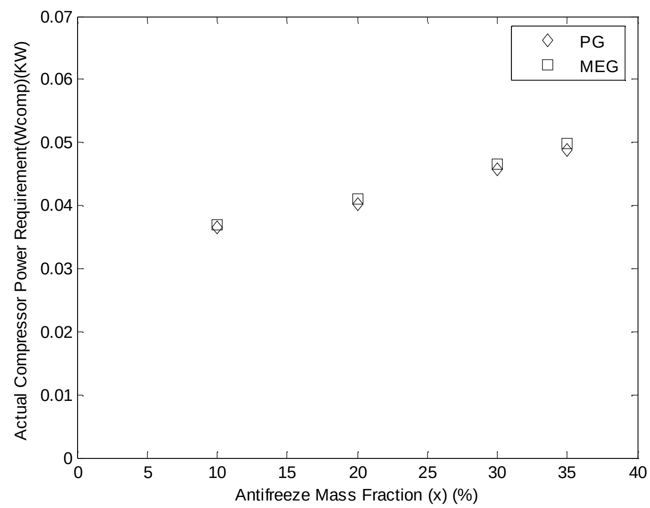

Fig. 6: Actual compressor power requirement Vs Antifreezes (PG and MEG) at various concentrations

6. CONCLUSION

From the present experimental data it can be concluded that at different concentrations of antifreezes (PG and MEG), total energy balance is same (Fig.3). It is observed that COPcarnot reduces with increase in concentrations of antifreezes (PG and MEG), COPcarnot is higher using PG as comparison to MEG (Fig.4). It is also observed that work carnot increases with increase in concentrations of antifreezes (PG and MEG), work carnot is slightly higher using MEG as comparison to PG (Fig.5). Actual compressor power requirement increases with increase in concentrations of antifreezes (PG and MEG), actual compressor power requirement is slightly higher using MEG as comparison to PG (Fig.6).

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