

Research Article

Experimental Performance Evaluation of Ice Slurry Refrigeration System using PG & EG Depressants**Arshlaan. Siddiqui^{1,*}, Jatin Gupta², Aabhaas Bhatiya³, Ujjwal Sahu⁴, Atul Singh⁵, Manish Mangla⁶ and Vaibhav Jain⁷**¹⁻⁶Student, Department of Mechanical Engineering, Maharaja Agrasen Institute of Technology, 110086, New Delhi, India⁷Associate Professor, Department of Mechanical Engineering, MaharajMaharaja Agrasen Institute of Technology, 110086, New Delhi, India

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Abstract: The use of certain types of depressants is one of the primary contributors to global warming and ozone depletion, the demand for effective and sustainable cooling systems has increased the use of ice slurry as a promising substitute in a variety of applications. But there is still much work to be done to produce ice slurry effectively. To improve the formation of ice crystals, the process, and overall system effectiveness, this study report presents an experimental examination of a mechanical scraper ice slurry generator using ethylene glycol, and propylene glycol as depressants at three different percentages, namely 10%, 18%, and 25%. The study comprises the measurement of several parameters at various state points, such as mass flow rate, pressure, temperature, and enthalpy, as well as the computation of performance parameters, the link between slurry temperature and time, and a comparison of the system's coefficient of performance (COP) at various concentrations. In this study, a -14.8°C temperature was attained for a 25% volume-by-volume aqueous solution of ethylene glycol, representing the lowest temperature recorded on our system.

Keywords: Coefficient of Performance, Depressants, Mass Flow Rate, Pressure, Temperature.

1. Introduction

Some commonly used conventional refrigerants have been linked to ozone depletion and greenhouse gas impact over the past few decades. Because of this, the refrigeration industry has been working consistently to find alternative refrigerants with good physical and thermodynamic qualities as well as fewer harmful environmental implications. In parallel, research has been conducted on using secondary refrigeration loops to reduce the number of refrigerant installations. In these loops, the heat transfer fluid is often water or an aqueous solution, which can be substituted to increase system efficiency with dysphasic secondary refrigerants like ice slurries. Ice slurries are an example of dysphasic secondary refrigerants that can increase system effectiveness. The ice slurry typically consists of ice crystals dispersed in water or an aqueous solution with various compounds added to reduce the freezing point, increase heat carrying capacity, and improve corrosion behavior as well as agglomeration. Due to its many industrial uses, including those for comfort cooling, commercial refrigeration, industrial manufacturing processes, and medicine, ice slurry has a bright future. In the production of milk, where large peak loads must be regulated, an ice slurry system has essential applications [1].

A phase-changing secondary fluid called an ice slurry contains both a liquid and a solid fraction (made up of tiny ice particles). The major objective of employing ice slurry is to utilize the latent heat of cooling that is stored in the ice particles (0.1 to 1 mm in size) during melting.



The four most often used freezing point depressants [2] in the refrigeration sector are sodium chloride, ethanol, ethylene glycol, and propylene glycol. The operating temperature [3] for ice slurry can be set between 0 °C and -35 °C depending on the type of additive and additive concentration. Qin et al. [4] conducted a thorough investigation into the length of time needed for ice to cover an unscrapped cooling surface, the thermal response of the supercooled solution at the beginning of phase change, the heat transfer coefficient on the scrapped surface with/without phase change, and the growth kinetics of an ice film spreading along the cooling surface. The process of freezing aqueous solutions, in which water is extracted as solid ice, requires continuous heat extraction. The process of freeze concentration in a scrapped surface heat exchanger revealed three typical steps of heat-transfer patterns, including chilling, nucleation, and crystallization [5]. Qin et al. [6] achieved an analytical solution by combining the Laplace and inverse transform with the initial condition of ice nucleation.

Vaessen et al. [7] have studied the heat transmission processes in two types of eutectic crystallizers. In crystallizing circumstances with increasing scraping speeds, both rising and falling heat transfer rates have been reported. Differences are due to solid composition and geometrical crystallizer features [8]. Broader engineering knowledge on fluid flow and heat transfer properties, however, is needed before ice slurries can gain broader acceptance. A scrapped surface heat exchanger employed for the freezing of water-ethanol mixtures and aqueous sucrose solutions was the subject of an experimental research [9]. It was determined how different parameters affected how much heat transferred. When a 10 weight percent sugar solution was frozen in a scrapped-surface heat exchanger (SSHE) in the lab, its heat transfer coefficient and power consumption were determined. According to experimental findings [10], ice formation increased the heat transmission coefficient by three to five times compared to no ice development. Inada and Modak [11] looked into how poly vinyl alcohol (PVA) affected ice crystal size growth in isothermal ice slurries. A innovative method to totally prevent the growth of ice crystal size in isothermal ice slurries is to use PVA, which has thermal hysteresis. A novel kind of sensor for in-line antifreeze readings According to Ayel et al. [12], mass fraction in aqueous solutions is described. Its operating principles are based on taking advantage of the temperature increase that occurs when an undercooled solution freezes. In order to comprehend the properties of ice slurries utilized in ice thermal energy storage systems, Kumano et al. [13] looked into the latent heat of fusion of ice in aqueous solutions.

A new thermal storage substance for ice storage called an emulsion is the topic of the investigation by Matsumoto et al. According to the findings, one emulsion was a W/O kind, whilst the other was an O/W type. The two emulsions' adaptation to ice storage was finally evaluated, and it was determined that the W/O type emulsion could generate a high performance ice slurry. The performance of various frequently used organic and inorganic ice slurry secondary refrigerants is compared in a study by Guilpart et al. [15]. This research was based on thermophysical evaluations done at various operating temperatures. Accurate freezing point data and more fundamental thermophysical property data at low concentrations are required for ice slurry applications [16]. Hawlader et al. [17] created an analytical model to forecast the development of ice around the injected super-cooled coolant droplets, which involves phase shift and layer-to-layer heat transfer. Li et al. [18] proposed theoretical and practical studies on a unique ice slurry making device using inner waste heat. A liquid dehumidification process and an evaporative super cooling procedure are the two main processes that make up this system. For the purpose of creating PCM slurries that have the potential to be used for cooling applications,

Lu and Tassou [19] explored various types of phase change materials. Baccar and Abid numerically modelled the heat transfer from a jacketed wall of a scraped-surface heat exchanger (SSHE). [20] to use the three-dimensional variant of the Navier-Stokes and energy equations to analyze the hydrodynamic and thermal behavior under varied operational and geometrical situations. The outcomes demonstrate that a heat exchanger's performance can be significantly impacted by its geometrical and operational factors. The performance of heat transmission would be enhanced by a higher frequency of the scraped film, which is influenced by an increase in the number of scrapers. Radial dispersion decreases and a rigid-body rotation occurs when there are more than four blades. Grandum et al. [21] have researched the crystal surface topography and the growth pattern associated with the potential for crystal growth. It was discovered that the crystal's size and structure are substantially influenced by the super cooling of the liquid that surrounds it between a transition temperatures.

Dumont et al. [22] conducted an experimental research of a scraped surface heat exchanger (SSHE) utilizing visual observations and the electrochemical approach in order to analyze the wall shear rates and explore the transition between laminar and vortex flows. It was discovered that the flow patterns in an SSHE differ considerably from those seen in an annular space under the identical circumstances. Zhang et al. [23] used a bubbling device to reduce ice adherence to the cooling wall in an experimental dynamic ice production system. The experimental dynamic ice manufacturing device used an air compressor to produce air bubbles, and for this reason, it had a vertically positioned ice slurry producer. The air bubbles were found to be successful at preventing ice from sticking to the cooling wall, although the air compressor's air blowing rate needs to be maximized. Lasvignottes et al.'s [24] experiment showed that it is possible to make ice slurry out of super-cooled water. This technology is a promising replacement for current technologies because it does not require additional mechanical energy to operate. To manage the super-cooled degree at the evaporator's exterior, the design must be extremely precise. A little amount of additive was added to a 90 percent water silicone oil mixture to create a functional fluid, and the functional fluid was then cooled while being stirred to create ice slurry. Based on the findings of earlier investigations, Matsumoto et al.'s new ice formation method [25] for ice storage showed that the ice slurry could be continuously created for 10 hours.

To enhance the performance of the current system, experiments were conducted under various operating settings, and an ideal working condition was identified. Kousksou et al. [26] developed a physical model to examine the non-isothermal freezing kinetic in ice slurry systems. To make use of ice slurry more widely, Matsumoto et al. [27] suggested utilizing it to store meals in the cold. The "harvest method" was utilized to test a novel ice slurry containing the food ingredient trehalose. When a high viscosity fluid is present, heat exchangers supplemented by a mechanical agitation device that has the ability to "scrape" the exchange surface can significantly improve heat transmission. In this instance, fluid properties, heat transfer circumstances, exchanger and agitator geometry, and agitation techniques all play a significant role in the efficiency of heat transfer [28]. The experimental examination of the flow patterns inside the SSHE under isothermal and continuous flow conditions is the main goal of Yataghene et al.'s work [29]. The foundation for additional experimental investigations of mixing and heat exchange mechanisms is the analysis of experimental flow pattern data. The heat transmission phenomenon of melting slurry ice was investigated by Thongwik et al. an outside copper helical coil surface. The experimental results demonstrate that a high heat transfer coefficient of the

slurry ice at the heated helical coil surface is attained with small coil diameter, high mass flow rate of circulating water, and low ice fraction. The equilibrium thermodynamic approach serves as the foundation for the majority of ice slurries crystallization models.

Another method of simulating the phase shift was done by Che'gnimonhan et al. [31], who presented the results of simulations based on the classical nucleation theory and crystal growth along with global Nakamuratype kinetics connected with the one-dimensional nonlinear heat equation. Ice storage is an excellent way to potentially reduce the energy consumption of air conditioning systems. The traditional method of making ice slurry from super-cooled water suffers from ice block instability and is significantly reliant on electricity. Li et al. [32] suggested a unique ice slurry-producing technology that makes use of internal waste heat. This new approach can increase efficiency and lessen the strain on electric power as compared to the conventional one. Current ice generators' fundamental crystallization processes and heat transport mechanisms are not fully understood. Stamatiou et al. [33] show heat transfer data in a prototype small ice generator to clarify the heat transfer mechanisms. Pascuala et al. [34] investigated the turbulent fluid flow and associated solid particle behavior in close proximity to the heat-exchanging surface of a scraped heat exchanger crystallizer. The major objective was to create scraper designs that successfully scrape off particles that nucleate, develop, and stick to the heat exchanger surface while improving heat transmission by disrupting the thermal boundary layer. The Ultrasonic Doppler Method (UDM) has been applied by Vurnoz et al. [35] to the process of ice slurry generation by direct injection of a refrigerant into an aqueous solution. The main objective of this work has been to investigate the fluid dynamic behavior of evaporating refrigerant drops in an immiscible fluid and the approach taken has been to evaluate how suitable the UDM technique is for such investigations. Pronk et al [36] performed a dynamic simulation of an experimental set-up in order to predict heat transfer coefficients in a fluidized bed ice slurry generator.

A comparison between experiments and results from simulations pointed out that both models overestimate heat transfer coefficients and that crystallization does not affect the heat transfer process significantly. The latter phenomena may be explained by the crystallization occurring in the fluidized bed's center rather than close to the wall. Mouneer et al. [37] conducted an experimental comparison of a super-cooling ice slurry generator type and a conventional scraped surface type. Koji et al. [38] created a new technique for generating ice slurries without the need to deposit an ice layer on a cooled surface. As previously mentioned, a recent review of the literature reveals that there are primarily six methods for producing ice slurries: (i) mechanical scraper method (also known as harvest method), (ii) fluidized bed method, (iii) direct injection method, (iv) vacuum freezing method, (v) oscillatory moving cooled wall method, and (vi) super-cooling water. An essential factor in the system selection process is the investment and running costs of each of these methods. The refrigerant evaporates in a double-wall cylinder when using a mechanical scraper. The water or aqueous solution passes through the interior space, which is enclosed by the inner cylinder, and ice crystals are produced. The ice that is forming on the cooling surface is scraped with a rotating tool with sharp edges. In comparison to ice slurry generator, the scraped surface generator has a high surface area for the production of ice crystals. Liquid-solid fluidized bed heat exchangers are used in the fluidized bed method to generate the ice slurry. The refrigerant is directly injected into the water domain in the direct injection method. The refrigerant is directly injected into the water domain in the direct injection method. Refrigerant liquid enters through nozzles, typically at the base of the generator, and begins to evaporate. Growing droplets and bubbles climb to the top of the water-containing

column by buoyancy. Alcohol solution and clear water have been used to study the vacuum freezing technique.

The chilled surfaces on which the ice layers are formed are subjected to an oscillating motion in the oscillatory moving cooled wall method, and the vibration produced by the oscillatory motion removes the ice layers. The ice slurry is created using the standard shell and tube design in the super-cooling water method; however the freezing process must be started under control to modify the produced ice concentration without clogging the system. Because of the high investment costs of commercially available (only imported) ice slurry generators, ice slurry systems for industrial applications have not yet been widely adopted in developing nations. The goal of this study is to design and construct a small-scale scraped-surface ice slurry generator test rig using small- and medium-sized business manufacturing techniques, as well as to gather experimental data to understand ice crystallization mechanisms at the microscopic level and heat transfer and fluid mechanics involving agitation and phase change at the macro level for the production of ice slurry using propylene glycol (PG) and molybdenum (Mo). In order to investigate the potential for the creation of a future big capacity ice slurry producing machine, experimental data on a prototype have been gathered varying solute concentrations in a solution

2. Experiment Details

The scraped surface ice slurry generator works on the vapor compression refrigeration cycle it mainly consists of 4 parts

1. Compressor
2. Evaporator
3. Condenser and
4. Expansion valve.

The evaporator coil is coiled around a hollow cylinder and insulation is done on the outer surface to ensure no heat loss. When the refrigerant flows the temperature of the evaporator drops which further drops the temperature of the aqueous solution filled inside the hollow cylinder. when a layer of Ice starts to deposit at the inner surface of the cylinder scraper motor starts and scraps the layer of ice, the process continues until the ice slurry of the required concentration and temperature is achieved

2.1 Type of ice slurry generation methods

The literature review conducted recently [4] indicates that ice slurry generation commonly employs 6 methods namely

1. Oscillatory moving cooling wall method
2. Vacuum freezing method
3. Direct injection method
4. Super cooling water method
5. Fluidized bed method and
6. Mechanical scraper method.

Among all the methods mentioned above the most evolved and commonly recognized method is the Mechanical scraper method. The mechanical scraper method is also known as the harvest method

2.2 Working

The scratched ice slurry generator contains a circular heat exchanger in a shell and tube, cooled in it on the side of the outer shell with evaporation, and scrubbed on its inner side by loads loaded with rotating blades or orbital sticks to prevent any crystals from entering the cooler at the top. This scrubbing action is required to prevent the formation of ice layers on the walls of the ice generator, which would not introducing additional thermal resistance and also possible significantly reduce heat transfer. The continuous accumulation of ice layer on the walls of the ice generator would be finally blocking the rotation of the scraper blades and the cause cold ice slurry generator. To block cracking of the walls of the ice generator, solutes were added concentration under eutectic concentration to press the cold point of the solution but otherwise affects the thermal energy in heat transfer. The turmoil is automatically introduced into the flow of ice slurry by the action of rotating scraper blades mounted on the center of the heating system, thus greatly increasing the temperature transfer rates facilitate homogeneous production of ice slurry mixture. A cooler refrigerator unit, including compressor, condenser and expansion device (such as heat exchanger valve or capillary tubes), usually provides a refrigerator on the side of the ice generator shell, also called evaporator in refrigeration cycle. As the refrigerator evaporates at low pressure using an external pipe slurry generator, emits heat from its surroundings, cools close the non-binary solution (glycol dilute or inorganic brine solution) flows into the internal ice pipe generator. Using this cooling process, ice slurry produced on the side of the ice slurry generator tube. The refrigerator unit may use excess liquid or full of water program type depending on application; however, it it has been reported that refrigeration systems are flooded can cause a buildup of lubricating oils in side of the evaporator due to the low temperatures involved and so on reduce heat transfer rates . At the exit of evaporator, a refrigerator of high enough temperature vapor produced from this indirect heat exchange process, repressed and re-stressed with high pressure to continue the refrigeration cycle.

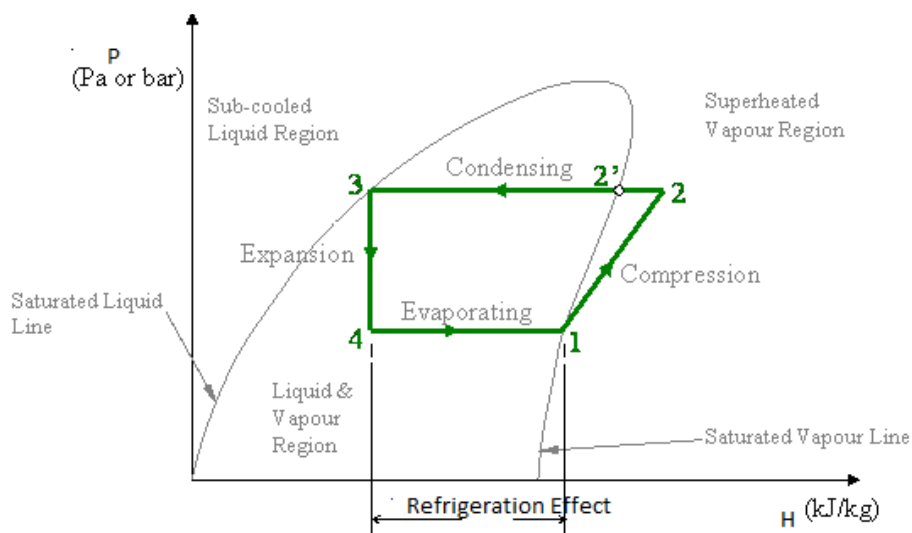


Figure 1: P-h curve for VCRS cycle

2.3 Specifications of setup

Table 1: Specifications of setup

Component	Description	Material
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Compressor	Single stage hermetic Reciprocating compressor: 230 volt, single phase, 50 Hz 235 watt	-
Condenser	Air-cooled fin type	Copper
Evaporator	Shell and coil type, Length 41.6 cm, 24.5 outer diameter, 17.8 cm inner diameter, 1.4 cm thickness	Inner coil (copper) Shell (stainless steel)
Capillary tube	0.36 mm diameter,	Copper
Storage tank	6 litres	Polystyrene
Scraper blade	Blade mounted on shaft	Stainless steel
Scraper motor	1426 rpm, reduced to 20 rpm 0.26 horse power	Copper
Gear reduction	Gear reduction ratio 17:23	Mild steel
Thermocouple	16 thermocouples {(temperature Sensor: 11), (mass flow rate sensor: 1), (pressure sensor: 4)}	Alloy

3. Observations and Calculations

The following section presents the observations and analysis obtained from the experimental study aimed at calculating the Coefficient of Performance (COP), refrigeration effect, heat rejected by condenser, and compressor work of an ice slurry system utilizing two different depressants, namely Ethylene Glycol and Propylene Glycol, at varying concentrations (10%, 18%, and 25%).

3.1 Ethylene glycol as a depressant

Ethylene Glycol is commonly used as an antifreeze agent in various applications due to its unique properties. In the context of the freezing process, an aqueous solution of Ethylene Glycol with water at different percentages of antifreeze concentration was utilized. By introducing Ethylene Glycol into the water, the freezing point of the solution is depressed compared to pure water. This depression of the freezing point enables the generation of an ice slurry at lower temperatures, allowing for enhanced cooling capabilities. Through the experimental study, different concentrations of Ethylene Glycol were tested to evaluate their impact on the freezing process and the resulting performance of the ice slurry system. By altering the concentration of the antifreeze in the solution, varying results were observed. These results encompass parameters such as the Coefficient of Performance (COP), refrigeration effect, cooling capacity, and compressor work, providing insights into how the concentration of Ethylene Glycol influences the overall efficiency and effectiveness of the ice slurry system.

3.1.1 10% v/v mixture

In test 1 a 10% v/v aqueous solution of ethylene glycol is used for ice slurry formation 0.5 litres of ethylene glycol is mixed with 4.5 litres of freshwater the system is started and the readings were the observed at an atmospheric temperature of 40 °C and after running the system for 120 minutes refrigeration effect is calculated to be 12.68 kw 1.98 kw is done by compressor heat rejected by compressor was 14.49 kw and cop of the system is found to be 6.39 additionally

the lowest temperature of ice slurry achieved of the mixture is -6°C .

Table 2: For 10% ethylene glycol

State points	m	T	P	H
	Mass flow rate (kg/s)	Temperature ($^{\circ}\text{C}$)	Pressure bar	Enthalpy KJ/kg
1	0.014	-19.0	3.34	26.85
2	0.014	-13.0	3.34	34.65
3	0.014	3.1	3.50	56.04
4	0.014	13.6	3.50	261.20
5	0.014	56.0	11.49	286.20
6	0.014	43.3	11.49	113.20
7	0.014	31.5	11.04	95.74
8	0.014	29.8	11.04	93.28
9	0.371-	31.2		
10	0.371	34.1		

ethylene 10%

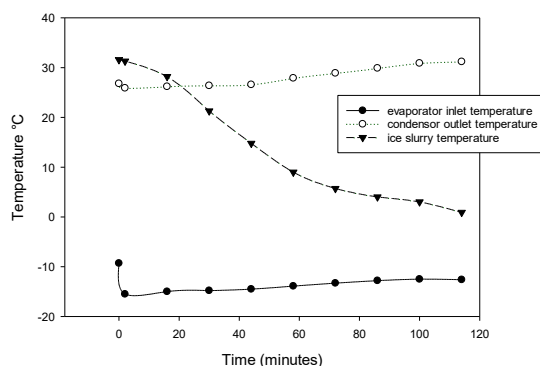


Figure 2: Temperature vs. Time graph for 10% aqueous ethylene solution

3.1.2 18% v/v mixture

In test 2, 18% v/v aqueous solution of ethylene glycol is used for ice slurry formation 1 litre of ethylene glycol is mixed with 4.5 litres of freshwater the system is started and the readings were the observed at an atmospheric temperature of 40°C and after running the system for 120 minutes refrigeration effect is calculated to be 12.98 kw 2.08 kw is done by compressor heat rejected by compressor was 14.67 kw and cop of the system is found to be 6.18 additionally the lowest temperature of ice slurry achieved of the mixture is -11.5°C .

Table 3: For 18% ethylene glycol

State points	m	T	P	h
	Mass flow rate (kg/s)	Temperature ($^{\circ}\text{C}$)	Pressure bar	Enthalpy KJ/kg
1	0.014	-19.0	3.34	26.85
2	0.014	-13.0	3.34	34.65

3	0.014	3.1	3.50	56.04
4	0.014	13.6	3.50	261.20
5	0.014	56.0	11.49	286.20
6	0.014	43.3	11.49	113.20
7	0.014	31.5	11.04	95.74
8	0.014	29.8	11.04	93.28
9	0.371-	31.2		
10	0.371	34.1		

ethylene 18%

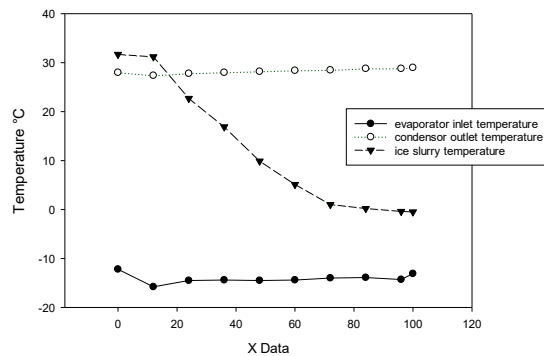


Figure 3: Temperature vs. Time graph for 18% aqueous ethylene solution.

3.1.3 25% v/v mixture

In test 3, a 25% v/v aqueous solution of ethylene glycol is used for ice slurry formation 1.5 litres of ethylene glycol is mixed with 4.5 litres of freshwater the system is started and the readings were the observed at an atmospheric temperature of 40 °C and after running the system for 120 minutes refrigeration effect is calculated to be 11.93 kw 3.38 kw is done by compressor heat rejected by compressor was 14.29 kw and cop of the system is found to be 3.52 additionally the lowest temperature of ice slurry achieved of the mixture is -14.8 °C.

Table 4: For 25% ethylene glycol.

State points	$\dot{m}$	T	P	h
	Mass flow rate(kg/s)	Temperature (°C)	Pressurebar	Enthalpy KJ/kg
1	0.014	-20.2	3.27	25.29
2	0.014	-14.0	3.27	33.35
3	0.014	-13.9	3.44	33.48
4	0.014	-8.2	3.44	40.96
5	0.014	54.7	11.39	285.00
6	0.014	41.8	11.39	110.90
7	0.014	31.4	10.84	95.59
8	0.014	29.9	10.84	93.43
9	0.371	31.6		

10	0.371	34.4		
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ethylene 25%

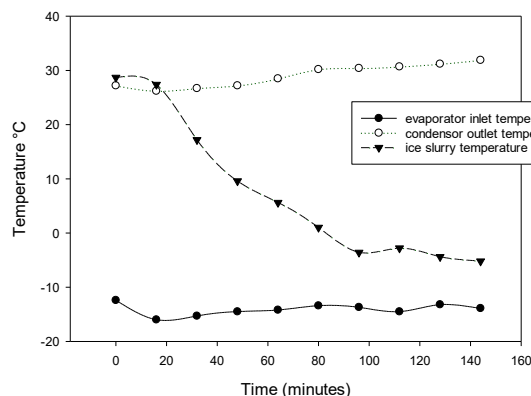


Figure 4: Temperature vs. Time graph for 25% aqueous ethylene solution.

3.2 Propylene glycol as a depressant

Propylene Glycol is another commonly used antifreeze agent that exhibits unique properties beneficial for various applications. In the context of the freezing process, an aqueous solution of Propylene Glycol with water at different percentages of antifreeze concentration was employed. By incorporating Propylene Glycol into the water, the freezing point of the solution is depressed compared to pure water. This depression of the freezing point enables the generation of an ice slurry at lower temperatures, allowing for improved cooling capabilities. Through the experimental study, different concentrations of Propylene Glycol were tested to assess their impact on the freezing process and the resulting performance of the ice slurry system. By adjusting the concentration of the antifreeze in the solution, varying results were observed. These results encompass parameters such as the Coefficient of Performance (COP), refrigeration effect, cooling capacity, and compressor work, providing insights into how the concentration of Propylene Glycol influences the overall efficiency and effectiveness of the ice slurry system.

3.2.1 10% v/v mixture

In test 4, a 10% v/v aqueous solution of ethylene glycol is used for ice slurry formation 0.5 litres of ethylene glycol is mixed with 4.5 litres of freshwater the system is started and the readings were the observed at an atmospheric temperature of 40 °C and after running the system for 120 minutes refrigeration effect is calculated to be 12.56 kw 2.15 kw is done by compressor heat rejected by compressor was 14.24 kw and cop of the system is found to be 5.82 additionally the lowest temperature of ice slurry achieved of the mixture is -3.7°C.

Table 5: For 10% propylene glycol.

State points	$\dot{m}$	T	P	h
	Mass flow rate (kg/s)	Temperature (°C)	Pressure bar	Enthalpy KJ/kg
1	0.014	-18.2	3.38	27.89
2	0.014	-11.9	3.38	36.10
3	0.014	5.0	3.54	58.61
4	0.014	15.9	3.54	263.20

5	0.014	61.6	12.33	290.80
6	0.014	49.4	12.33	276.70
7	0.014	36.5	12.32	103.00
8	0.014	34.7	12.32	100.40
9	0.371	35.9		
10	0.371	35.8		

Propylene 10%

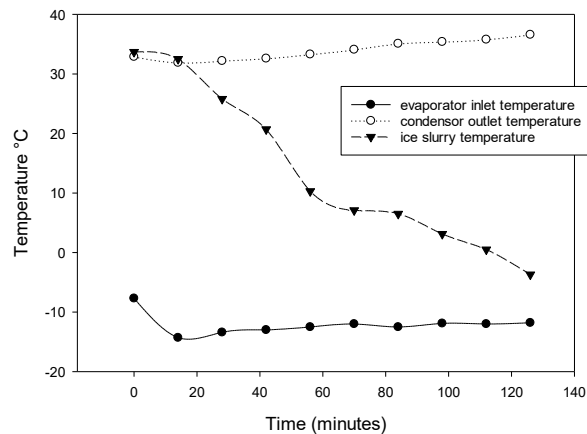


Figure 5: Temperature vs. Time graph for 10% aqueous propylene solution.

3.2.2 18% v/v mixture

In test 5 a 18% v/v aqueous solution of ethylene glycol is used for ice slurry formation 1 litre of ethylene glycol is mixed with 4.5 litres of freshwater the system is started and the readings were the observed at an atmospheric temperature of 40 °C and after running the system for 120 minutes refrigeration effect is calculated to be 12.37 kw, 2.17 kw is done by compressor heat rejected by compressor was 14.06 kw and cop of the system is found to be 5.68 additionally the lowest temperature of ice slurry achieved of the mixture is -6.8 °C.

Table 6: For 18% propylene glycol.

State points	m	T	P	h
	Mass flow rate (kg/s)	Temperature (°C)	Pressure bar	Enthalpy KJ/kg
1	0.014	-18.2	3.38	27.89
2	0.014	-11.9	3.38	36.10
3	0.014	5.0	3.54	58.61
4	0.014	15.9	3.54	263.20
5	0.014	61.6	12.33	290.80
6	0.014	49.4	12.33	276.70
7	0.014	36.5	12.32	103.00
8	0.014	34.7	12.32	100.40
9	0.371	35.9		

10	0.371	35.8		
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Propylene glycol 18%

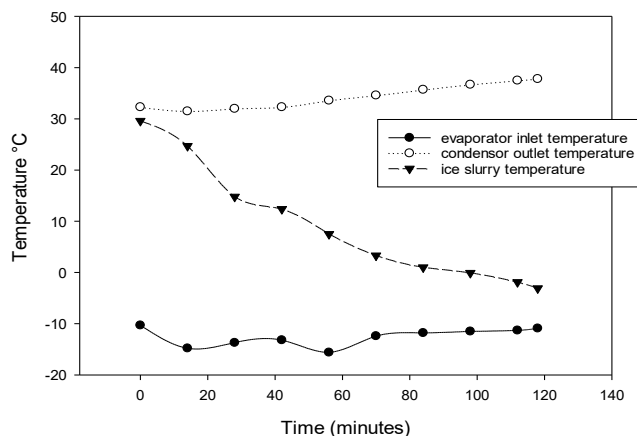


Figure 6: Temperature vs. Time graph for 18% aqueous propylene solution.

3.2.3 25 % v/v mixture

In test 6 a 25% v/v aqueous solution of ethylene glycol is used for ice slurry formation 1.5 litres of ethylene glycol is mixed with 4.5 litres of freshwater the system is started and the readings were the observed at an atmospheric temperature of 40 °C and after running the system for 120 minutes refrigeration effect is calculated to be 12.37 kw 2.47 kw is done by compressor heat rejected by compressor was 14.34 kw and cop of the system is found to be 5.00 additionally the lowest temperature of ice slurry achieved of the mixture is -10.5 °C.

Table 7: For 25% propylene glycol.

State points	m	T	P	h
	Mass flow rate (kg/s)	Temperature (°C)	Pressure bar	Enthalpy KJ/kg
1	0.014	-19.9	3.31	25.68
2	0.014	-13.2	3.31	34.39
3	0.014	0.2	3.41	52.13
4	0.014	11.4	3.41	259.40
5	0.014	59.6	11.62	289.90
6	0.014	45.0	11.62	115.80
7	0.014	33.9	11.39	99.23
8	0.014	33.7	11.39	98.93
9	0.371	33.5		
10	0.371	33.4		

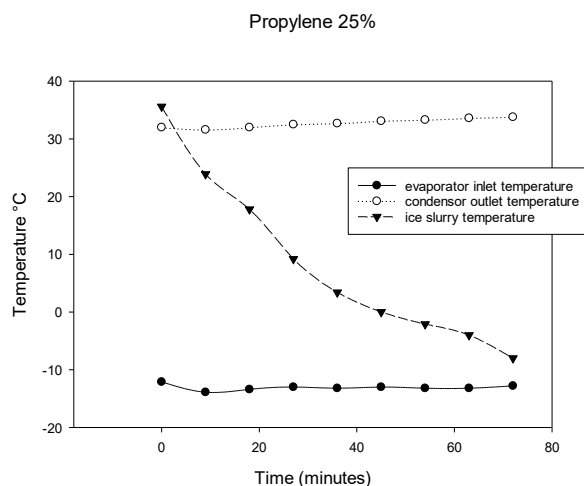


Figure 7: Temperature vs. Time graph for 25% aqueous propylene solution.

4. Results

The comparison of Ethylene Glycol and Propylene Glycol at different concentrations in the ice slurry system revealed important insights regarding their performance. Ethylene Glycol consistently demonstrated higher coefficients of performance (COP) and lower compressor work requirements compared to Propylene Glycol. This indicates that Ethylene Glycol is more efficient in converting work input into cooling output. However, both depressants exhibited similar refrigeration effects and cooling capacities. At the 10% concentration, Ethylene Glycol achieved a higher COP (6.39) compared to Propylene Glycol (5.82). Similarly, at the 18% concentration, Ethylene Glycol had a higher COP (6.18) compared to Propylene Glycol (5.68). At the 25% concentration, Ethylene Glycol still outperformed Propylene Glycol with a COP of 3.52 compared to 3. The refrigeration effects (Q_e) were similar for both depressants at each concentration, indicating that they have similar capabilities in providing cooling output. However, Ethylene Glycol consistently required lower compressor work (W_c) compared to Propylene Glycol, suggesting better energy utilization.

Table 8: Performance parameters

	Depressants					
	Propylene			Ethylene		
	10%	18%	25%	10%	18%	25%
Q_c	14.24	14.06	14.34	14.49	14.67	14.29
W_c	2.15	2.17	2.47	1.98	2.09	3.38
Q_e	12.56	12.37	12.37	12.68	12.98	11.93
COP	5.82	5.68	5.00	6.39	6.18	3.52

The following chart represents the comparison between different thermodynamic parameters obtained from ice slurry systems.

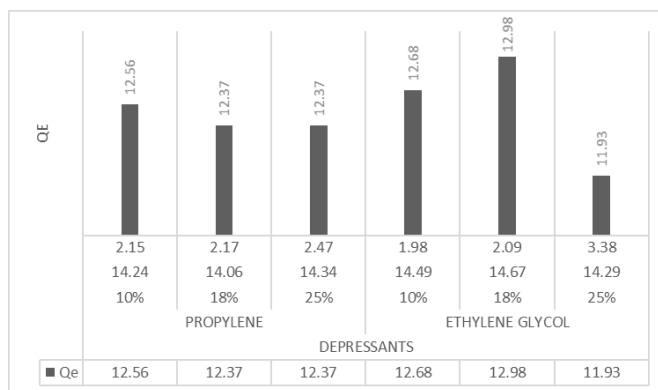


Figure 8: Comparison of Qc of Ethylene Glycol and Propylene Glycol at different concentrations (10%, 18%, and 25%).

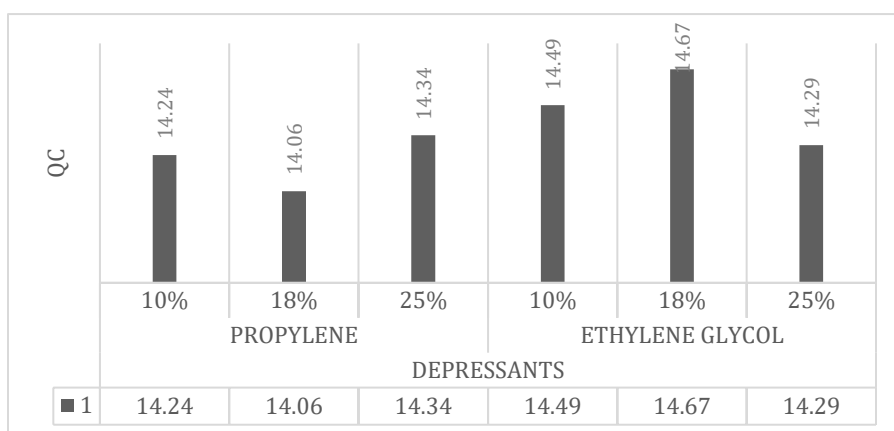


Figure 9: Comparison of Qc of Ethylene Glycol and Propylene Glycol at different concentrations (10%, 18%, and 25%).

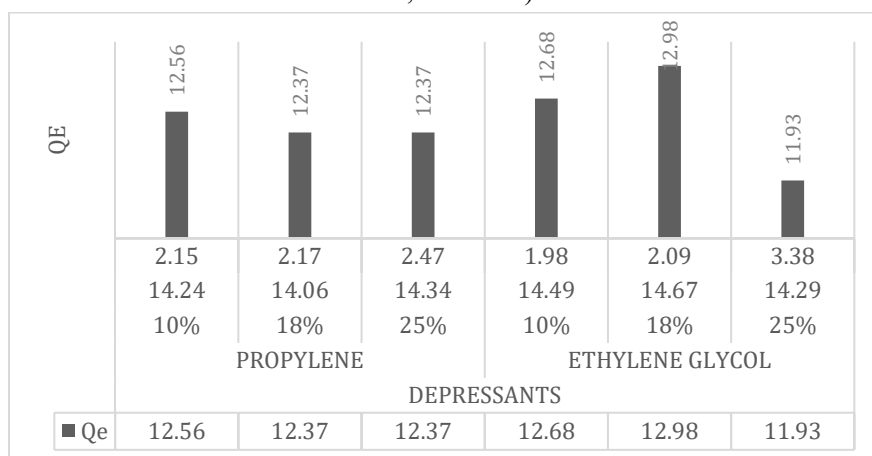


Figure 10: Comparison of Qe of Ethylene Glycol and Propylene Glycol at different concentrations (10%, 18%, and 25%).

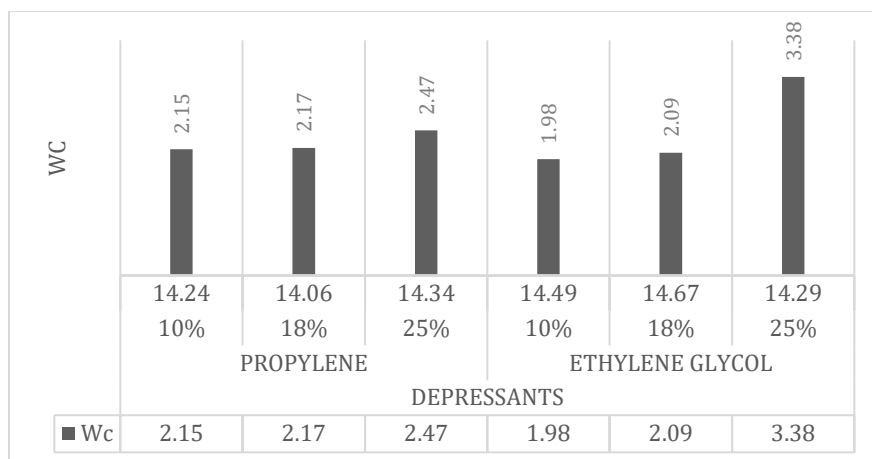


Figure 11: Comparison of Wc of Ethylene Glycol and Propylene Glycol at different concentrations (10%, 18%, and 25%)

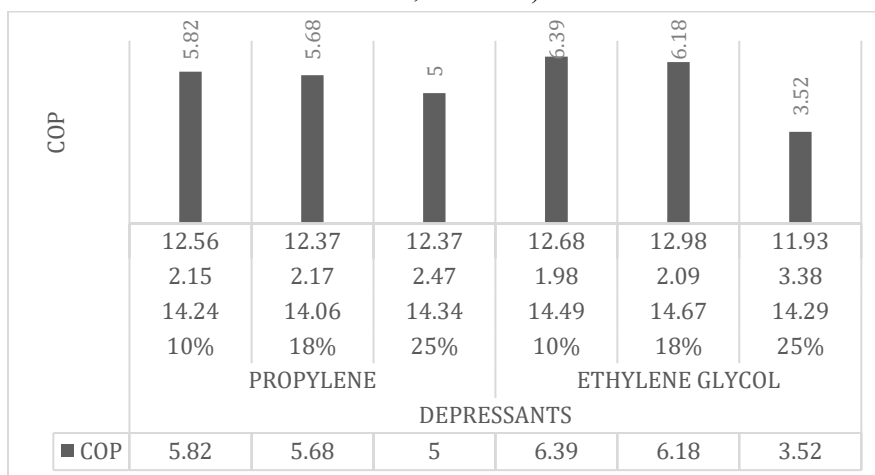


Figure 12: Comparison of COP of Ethylene Glycol and Propylene Glycol at different concentrations (10%, 18%, and 25%)

5. Conclusion

This study experimentally examines a mechanical scraper ice slurry generator using ethylene glycol and propylene glycol as depressants at 10%, 18%, and 25% to improve ice crystal formation, process, and system effectiveness. The study measures mass flow rate, pressure, temperature, and enthalpy at various state points, computes performance parameters, evaluates the relationship between slurry temperature and time, and compares the system's coefficient of performance (COP) at different concentrations. Our system's lowest temperature was -14.8°C for a 25% volume-by-volume ethylene glycol aqueous solution.

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