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Performance Analysis of Domestic Refrigerator with modified Evaporator using PCMC (Phase Change Material for Cooling) and Measure Cut-off Time of Compressor

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Abstract

This paper aims to investigate the performance of domestic refrigerator with the use of phase change material for cooling (PCMC). For experiment and analysis of system PCMC is compared with water and readings were taken. For the easement of performance normal refrigerator box is replace by a small size box. The results confirm that the use of PCMC is advantageous to system in manner of increases in performance of refrigerator and also economic point of view. To prove the concept, mainly cut-off time of compressor is focused and whole analysis based on that.

Keywords: *Cut-off time, Coefficient of performance, PCMC*

Nomenclature

Cpg - sensible heat of glycol (kJ/kg k)
Cpw – sensible heat of water (kJ/kg k)
λg – heat of fusion of glycol (kJ/kg)
λw- heat of fusion of water (kJ/kg)
ΔT – temperature Difference (k)
m_g – mass of glycol (kg)
m_w – mass of water (kg)
Q – Total sensible heat removed (kJ)
H – Total latent heat removed (kJ

INTRODUCTION

Now-a-days in a world, the biggest challenge for researchers is to store any kind of energy more and more anyhow. To meet the level of energy demands in today's world, it is compulsion for everyone to store the energy. To store the energy many technologies are available. But the Thermal Energy Storage (TES) is one of the most effective and appreciated technology all over the world. In the field of a latent heat thermal energy storage system, the choice of the phase change material (PCM) plays a vital and an important role in addition to heat transfer mechanisms in the PCM [1]. As per characteristics of PCM most of the phase change problems have been carried out for wide temperature ranges which are suitable for domestic applications [2].

TES can possible for both heating and cooling applications using different methodologies and technologies. But in this article, focus of study is cooling by use of TES. Now the world is very much focused on Phase change Material (PCM) since last two-three decades [1,2]. Because PCM is the new hope to improve quality and performance of many technologies. In the current article, domestic refrigerator which is having VCRS system is analysed using PCMC. The establishing the long-term stability of the storage materials is important factor [3]. PCM for domestic refrigerators to improve food quality is shown by author [4]. In article, a mathematical model had been prepared using algorithms for energy saving and finally COP is calculated for VCRS cycle. The improvement in COP is very well presented and shown [4].

Belen Zalba, Jose Ma Marin, Luisa F. Cabeza, Harald Mehling [5] reviewed many PCM which can be helpful. The article included almost 150 PCM with properties and also referenced over 230 articles for the review. Finally, they concluded review of TES using solid–liquid phase change using PCM. I.M. Rasta, I.N. Suamir [6] investigated development of water based PCM for thermal energy storage (TES). Mixtures of water with small amount vegetable oil addition were chosen as candidates of the PCM that were suitable for medium temperature refrigeration application with temperature range of products between 1^0C and 5^0C. It was found that addition of vegetable oils by 5% to 10% in water solution could `decrease the freezing temperature and could also minimize degree of super-cooling of the PCM candidates [6].

In the current article, domestic refrigerator which is having VCRS system is analysed using PCMC.

Selection Criteria of PCMC:[7-11]

In order to select the best quality PCMC for storing the thermal energy some criteria are mentioned:[7-11]

i) Thermodynamic properties:

a) Enthalpy transition with respect to the volume of the storage unit. b) High change of enthalpy near temperature of use. c) Phase change temperature according to application. d) To minimize the physical size of the heat storage, latent heat temperature should be as high as possible. e) A melting point in the required operating temperature range. f) Actual and clearly determined phase change temperature (freeze/melt point) g) Congruent melting point to avoid segregation h) Lower change of volume during phase change i) High density, so that a smaller container volume holds the material.

ii) Chemical properties:

a) No chemical decomposition, so that the latent TES system life is assured
b) Non-corrosiveness.
c) Long term chemical stability
d) Non-poisonous.
e) Non-toxic, Non-explosive, non-dangerous, Non-flammable.

iii) Physical properties:

a) Limited changes in density to avoid problems with the storage tank
b) High density with low density variation
c) Small unit size
d) Low vapour pressure
e) Favourable phase equilibrium.

iv) Economic properties:

a) Available in large quantities
b) Cheap in order to make the system economically feasible.

Why choose a Glycol as PCMC: [12-20]

The Glycol Chillers units are designed to be located externally (or an internal plant room) with a weather resistant casing – locations include rooftops; courtyards and basements.

The combination of the externally located chiller and the enhanced properties of glycol refrigeration mean this unique system offers a wide range of benefits including;

- Highly efficient temperature control
- Reliability
- Length of temperature holding time
- Ability to keep ambient temperatures to a minimum
- Increased efficiency and performance for reduced wastage and improved stock turnaround
- 100% fully flooded coils for almost instant pull down of temperature versus 65% in traditional refrigeration systems
- Up to 25% reduction in running costs

Environmental benefits

- Glycol is totally food safe, with no health risks to users and installers

- Little or no heat emissions into the kitchen – reducing ventilation and air conditioning requirements
- Reduced noise levels in the kitchen improving the working environment
- Reduced energy consumption meets Climate Levy demands
- Reduced refrigerant charge by up to 80%.

EXPERIMENTAL SET UP & METHODOLOGY

Major Components & specification

Hermetic or sealed compressor

A hermetic or sealed compressor is one in which both compressor and motor are confined in a single outer welded steel shell. The motor and compressor are directly coupled on the same shaft, with the motor inside the refrigeration circuit. The hermetic or sealed compressor used in our system consumes 0.250kW of electric power and it requires 240V/50Hz electricity supply.

Fig: 1. NX model of hermetically sealed compressor

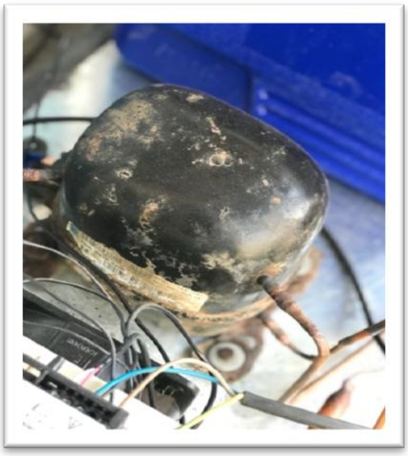

Fig: 2. Actual hermetically sealed compressor

Condenser

The high pressure and high temperature state of the vapor refrigerant is converted to liquid at the condenser. It is designed to condense effectively the compressed refrigerant vapor.

Fig: 3. Actual Air-cooled condenser

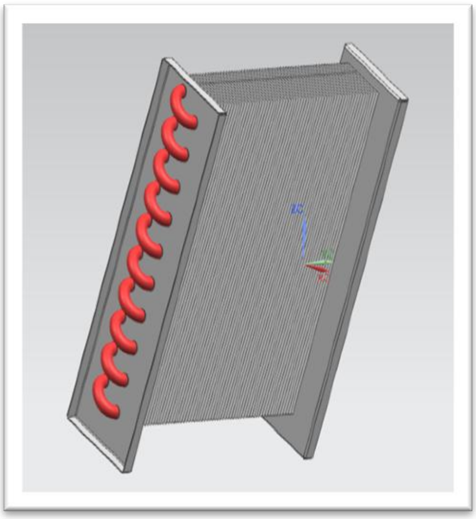

Fig: 4. NX model of Air cooled condenser

Evaporator

It is in the evaporator where the actual cooling effect takes place in the refrigeration systems. The evaporators are heat exchanger surfaces that transfer the heat from the substance to be cooled to the refrigerant, thus removing the heat from the substance. We modified the conventional type of evaporator as we needed space to pour PCM material with evaporator's tube. So for that we purchased an ice box and using other tin box we made arrangement in such a way that the evaporator have sufficient space for PCM material.

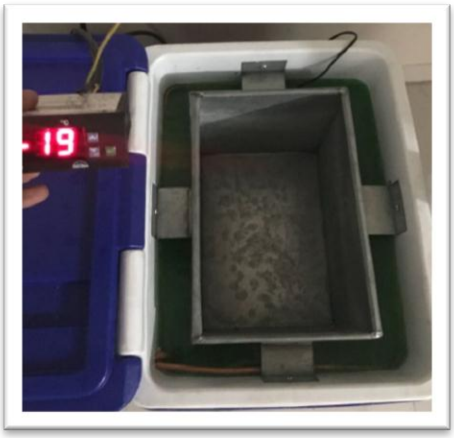

Fig: 5. *Actual Modified evaporator*

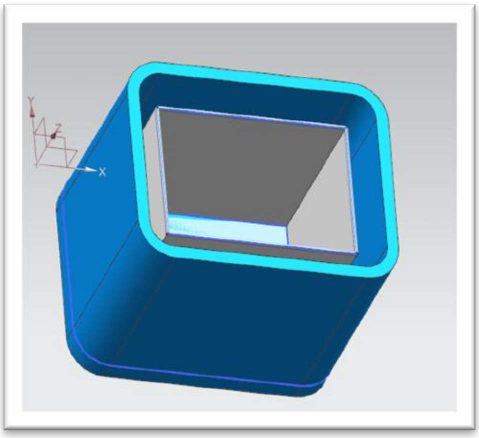

Fig: 6. *NX model of Modified evaporator*

Capillary tube

Capillary tube is one of the most commonly used throttling devices in the refrigeration and the air conditioning systems. The capillary tube is a copper tube of very small internal diameter. The internal diameter of the capillary tube used for the refrigeration and air conditioning applications varies from 0.5 to 2.28 mm (0.020 to 0.09 inches).

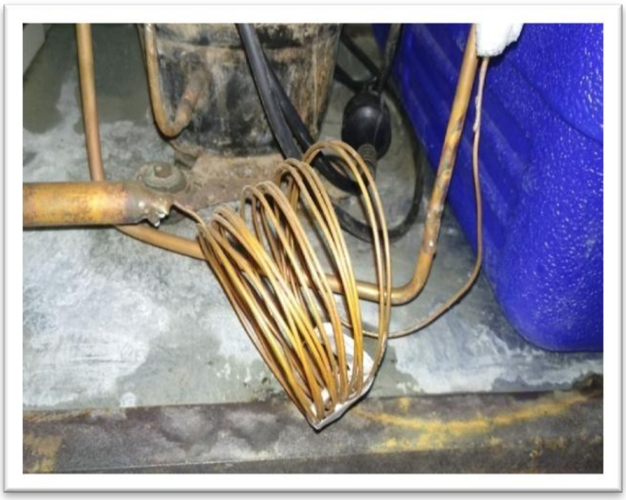

Fig: 7. *Actual Capillary tube*

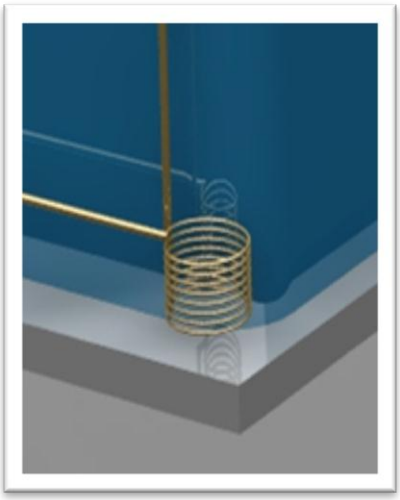

Fig: 8. *Capillary tube*

Subzero Controller

Subzero controller measures and controls the temperature inside of evaporator. We have used SZ7510E series digital controller for our system.

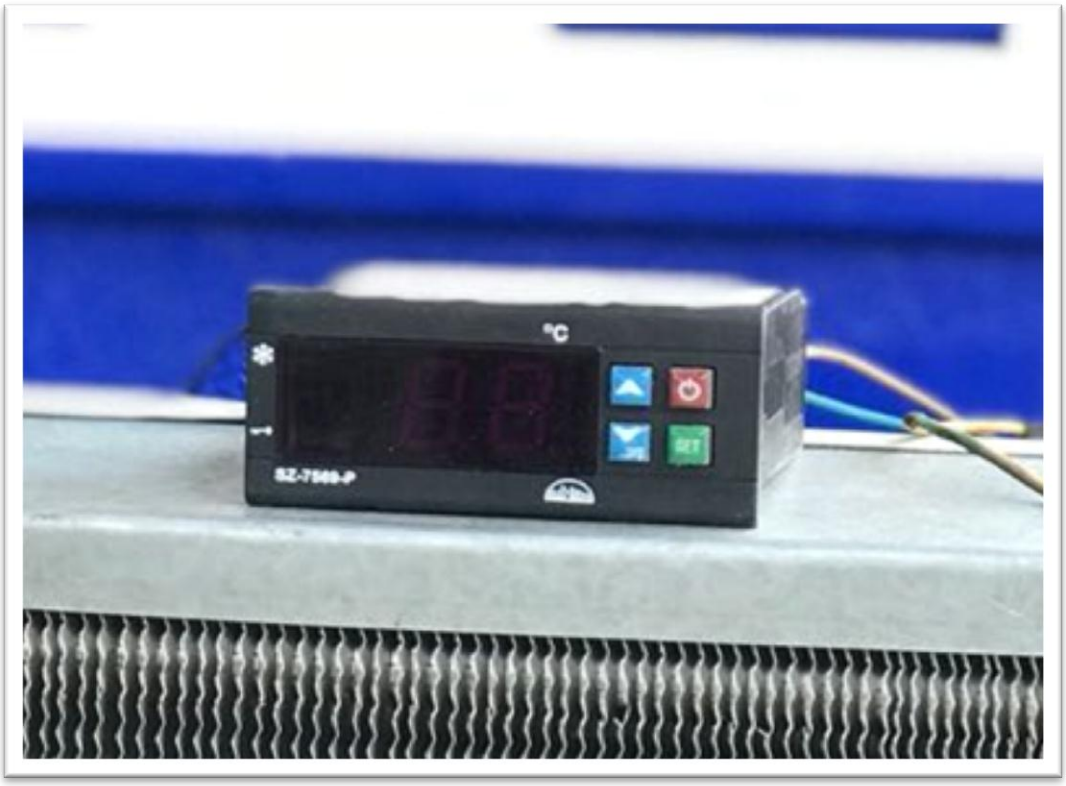

Fig: 9. *Subzero controller*

Experimental setup
In this study, a glycol based thermal storage system is experientially investigated for both charging and discharging periods. This system mainly consists of evaporator, compressor, condenser, capillary tube. Inside the evaporator has glycol around the copper tubes. This mixer works as a cold thermal energy storage system inside the evaporator.

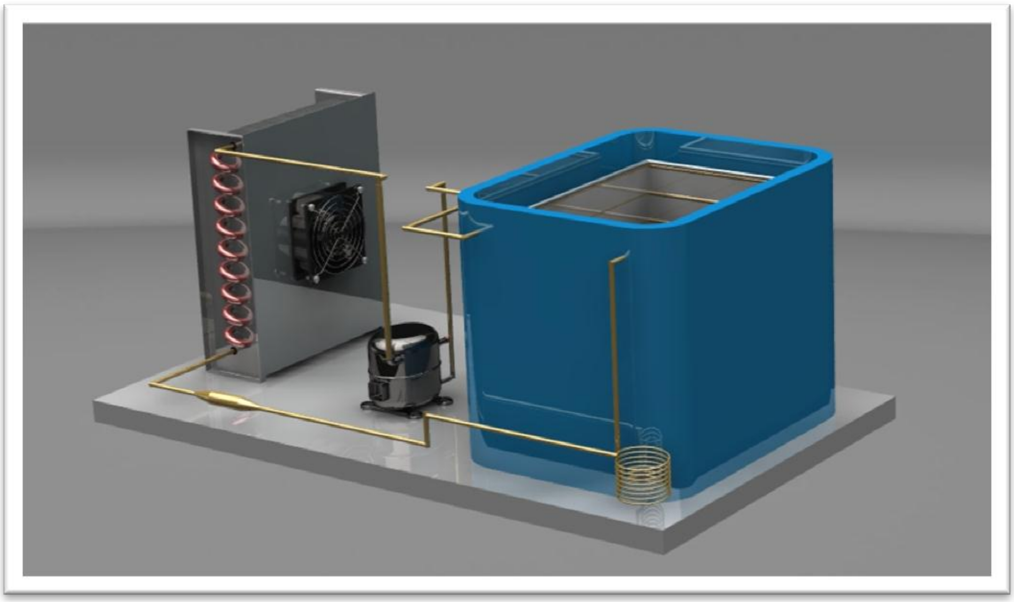

Fig: 10. *NX Modelling of Experimental setup*

***Fig: 11.** Actual Experimental setup*

RESULTS AND DISCUSSION

Total four experiments have been conducted on the set up. Firstly, two performances on domestic refrigerator with modified evaporator carried out with 100% water only and readings were noted. After that, two experiments had been carried out with 20% glycol and 80% water mixture on the same set up. For constant time period from 8.30 AM to 8.30 PM, all four performances have been conducted in continuous 4 days of period. Parallelly, the charging and discharging period noted on hourly basis.

Charging and Discharging process analysis:

Two performances on domestic refrigerator with modified evaporator conducted with 100% water only and the results are shown in graph below:

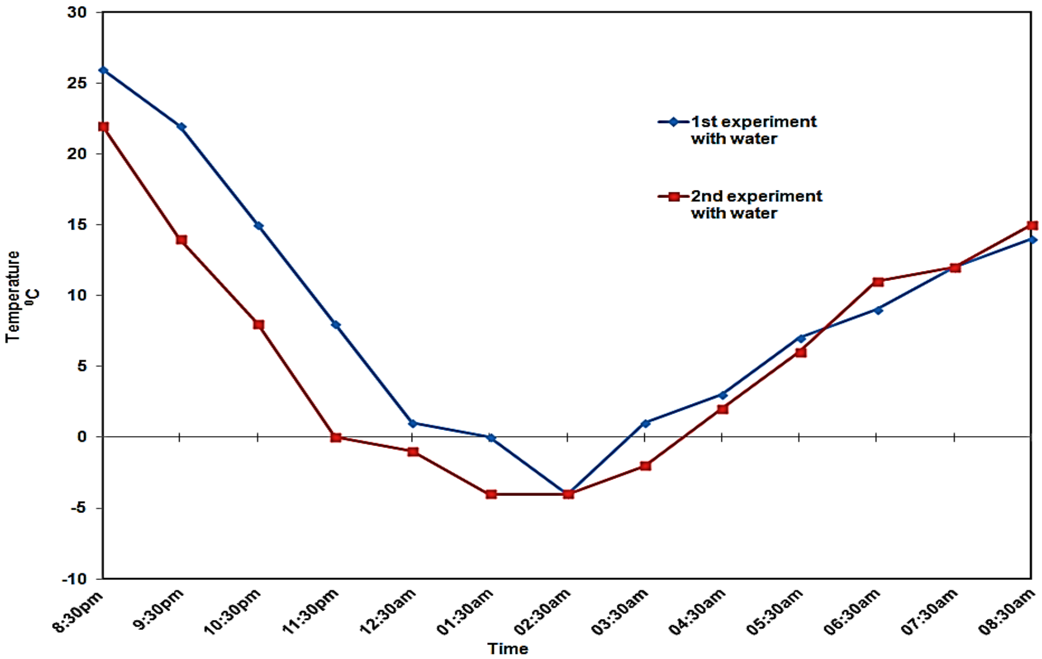

***Fig: 12.** Variation of temperatures w.r.t time for water*

During performance Modified evaporator consumes 6 litres of water in it. The experimental results show that starting temperatures for two cases having difference about 5^{0}C. For both the cases, lowest temperature achieved is about -5^{0}C.

Two performances on domestic refrigerator with modified evaporator conducted with 20% glycol and 80% water as PCMC and the results are shown in graph below:

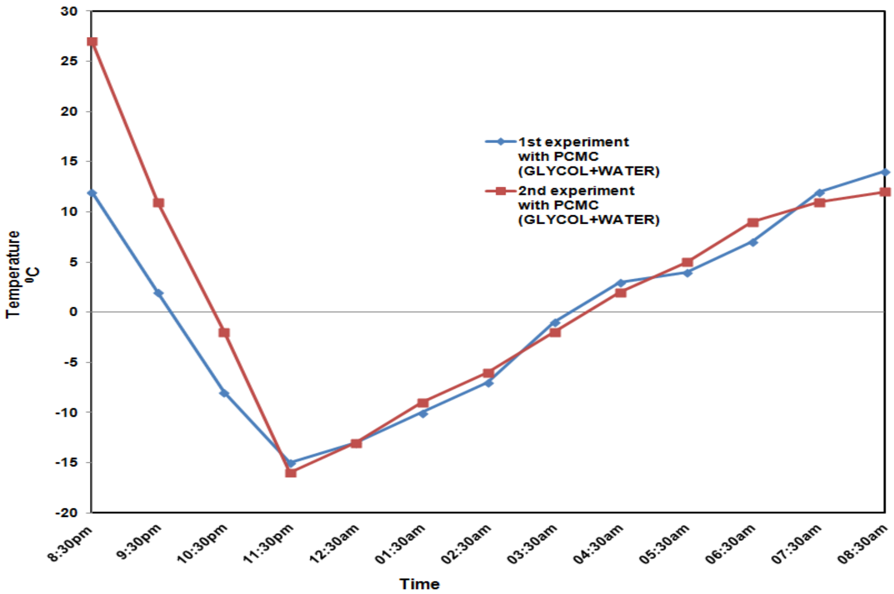

Fig: 13. *Variation of temperatures w.r.t time for PCMC*

During performance Modified evaporator consumes 4.8 litres of water and 1.2 litres of glycol in it. The experimental results show that starting temperatures for two cases having difference about 15^{0}C. With use of PCMC for both the cases, lowest temperature achieved is about -15^{0}C which is difficult to achieve with use of currently used refrigerant in domestic refrigerator. From the graph Fig2, it is clearly seen that the system takes almost the 3 hours to get freeze to achieve -15^{0}C in each case.

During charging process results shows that, due the property of PCMC, the lowest temperature achieved was -15^{0}C which is very low compare to -5^{0}C temperature achieved by only water. From the graph Fig12, it is clearly seen that the system takes almost the 6 hours to get freeze to achieve -5^{0}C in each case. From the graph Fig13, it is clearly seen that the system takes almost the 3 hours to get freeze to achieve -15^{0}C in each case. So, electricity consumption for the charging process with PCMC is less required compare to without PCMC by only water.

During discharging process results shows that, due the property of PCMC, from the graph Fig12, it is clearly seen that the system takes almost the 6 hours to get defreeze condition and also it achieved about 15^{0}C in each case. From the graph Fig13, it is clearly seen that the system takes almost the 9 hours to get defreeze condition and to achieve 13^{0}C in each case. So, these results shows that with use of PCMC, modified evaporator required more time duration compare to without PCMC by only water.

PCMC vs. Water – comparative study

By use of modified evaporator in domestic refrigerator including both water and PCMC as cooling medium, comparative study has been done based on performance.

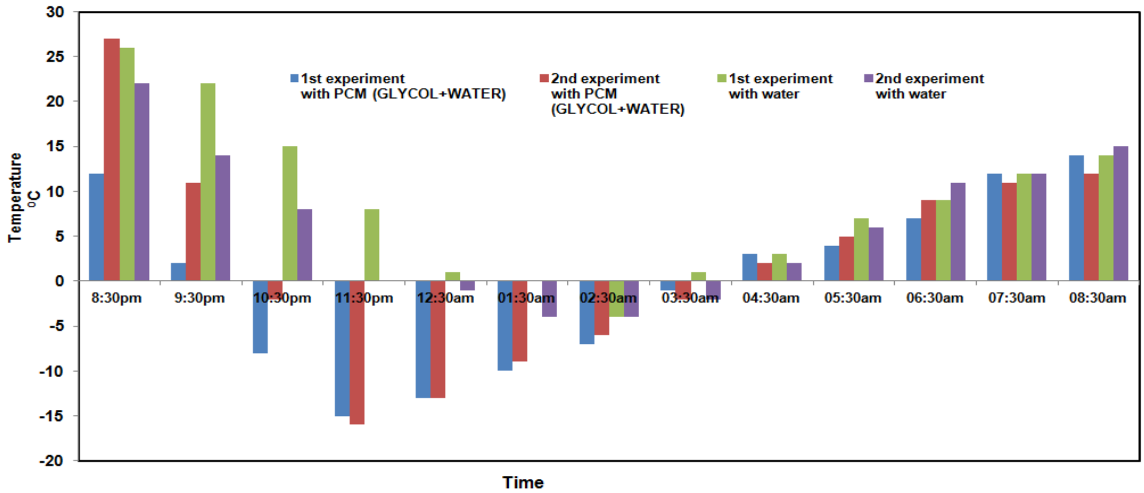

Fig: 14. *Comparisons between Water and PCMC on Modified Domestic Refrigerator*

Fig14 shows comparison of temperature changes according to time during performance with PCMC and without PCMC. The freezing point is very low for PCMC with compare to water as seen in graph. Due to low freezing point PCMC gives more amount of cooling effect or refrigeration effect to the evaporator box with less electricity consumption.

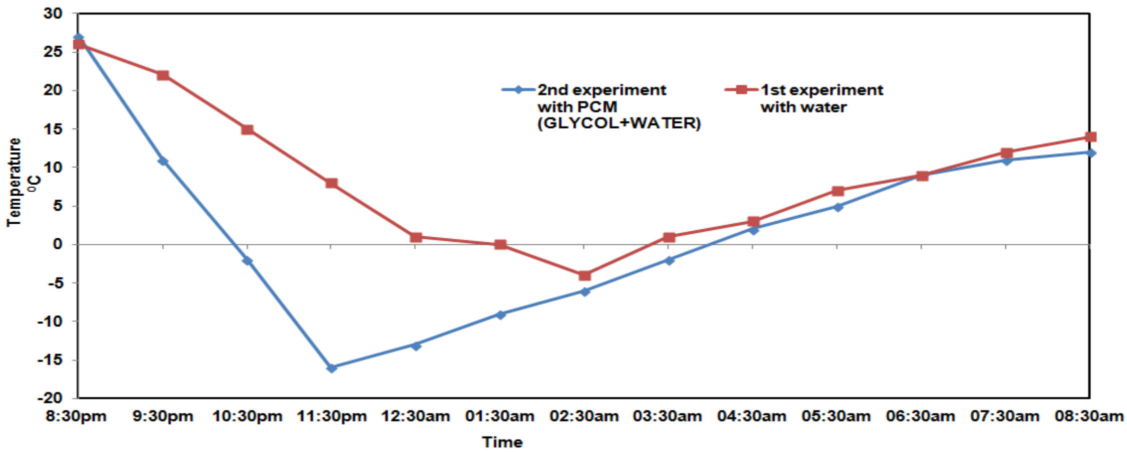

Fig: 15. *Variation of temperature w.r.t. time - between water and PCMC*

Fig15 shows a very accurate and clearly visible variation of temperature along with time duration for both with PCMC and without PCMC. The results shows the fact that without PCMC (with water) the refrigerator system achieved its minimum temperature in about 6 hours where with PCMC (glycol + water) it took only 3 hours to reach its minimum temperature.

It is also noted that Refrigeration effect would only last around 6 hours without use of PCMC. Where in comparison with use of PCMC, Refrigeration effect would last around 9 hours. It is a big advantageous to the system in terms of consumption of electricity and refrigeration effect.

Latent and Sensible Heat Calculations:
A typical latent heat removal and sensible heat removal calculations for all four experiments has been done and tried to explain some facts based on that. Properties of glycol and water are given in Table1 as under:

***Table: 1.** Properties of water and PCMC*

Property \ cooling medium	**GLYCOL**	**WATER**
Cpg	2.43 kJ /kg k	4.1818 kJ /kg k
λg	160.49 kJ/kg	334 kJ/kg

For glycol and water mixture:

Total sensible heat removed, Q =mg*Cpg*ΔT +mw*Cpw*ΔT

Total latent heat removed, H=mg*λg+mw*λw

For only water:

Total sensible heat removed, Q Q=mw*Cpw*ΔT

Total latent heat removed, H=mw*λw

***Table: 2.** Total sensible and latent heat removed from water and PCMC*

	PCMC (Glycol + water)		**Only water**	
Property	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**
Total sensible heat removed	620.69 kJ	988.51 kJ	752.72 kJ	652.36 kJ
Total latent heat removed	1805.41 kJ	1805.41 kJ	2004 kJ	2004 kJ

Table 2 explain that the latent heat removed from PCMC is about 200 kJ lesser than water. From calculations, the obtained results are very advantageous due to latent heat affect. Because the less amount of latent heat removed, the heat required for freezing is less. Also, from Table2 it is observed that sensible heat required is also less. During 2nd experiment with PCMC, the sensible heat removed was higher because of higher ambient temperature on the day of experiment.

Economic Analysis

Power consumption of compressor, P_c = 0.250 kW

Power consumption of fan, P_f = 0.020 kW

Also known that, 1 unit of electricity = 1 kWhr.

With use of PCMC

Total electricity consumption in 3 Hours = (0.250+0.020) * 3
= 0.81 kWhr
Therefore, 0.81kWhr 0.81 unit
At domestic rate of electricity 5 INR,
Running cost = 5*0.81
= 4.05 INR
At commercial rate of electricity 7 INR,
Running cost = 7*0.81
= 5.67 INR

Without use of PCMC (only water):

Total electricity consumption in 6 Hours = (0.250+0.020) * 6
= 1.62 kWhr
Therefore, 1.62 kWhr = 1.62 unit
At domestic rate of electricity 5 INR,
Running cost = 5*1.62
= 8.1 INR
At commercial rate of electricity 7 INR,
Running cost = 7*1.62
= 11.34 INR

The above calculations expressed simple economic calculations between the use of PCMC and without PCMC. The cost is almost half with use of PCMC. By viewing it is not too major difference but if increase no. of units per day, it will reflect in higher amount of cost savings.

CONCLUSIONS

This paper is to evidence the PCMC material can be used for Domestic purpose refrigeration and air conditioning field. PCMC is the very advantageous to save the energy and also economically. Few conclusions are under:

1. From charging and discharging processes, the results explained that we can cut-off compressor for 8 to 9 hours if PCMC used. So, also it is called prolong period of compressor with the

use of the PCMC is measured about 3 hours more than the use of water for the experiment.
2. From comparison and heat calculations of PCMC material and water. It was observed that refrigeration effect achieved more while using PCMC compare to water. It was also observed that the heat required in the form of electricity energy is less in the case of PCMC. Finally, result tends towards the increase the Co-efficient of performance (COP) of the system.
3. If large no. of units considered on very large scale, the economically use of PCMC is almost give half of cost than without PCMC.

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