PERFORMANCE ANALYSIS OF ELECTROLUX REFRIGERATION SYSTEM COUPLED WITH FLAT PLATE SOLAR COLLECTOR USING HYBRID HEAT EXCHANGER

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ABSTRACT

In the present study, domestic Electrolux refrigerator has been modified by coupling with hybrid pipe in pipe heater exchanger to supply heat to the generator. A modification in the practical cycle to achieve high temperature of generator by supplying heat from solar flat plate collector is proposed. In order to achieve the generator temperature to achieve the cooling effect in the evaporator of Electrolux refrigerator, the design of pipe in pipe heat exchanger was done. The flow rate of heat transfer fluid is optimized to enhance the heat transfer rate inside the proposed heat exchanger. In order to find the effect of proposed modification in system, the refrigeration system has been initially studied by using electric heater as a heat source to the generator and temperature variation has been studied and referred as case-1 in the study. Further the domestic Electrolux refrigerator is coupled with solar flat plate collector using heat exchanger to supply heat to generator and referred as case-2. It shows that the with the increase of collector surface temperature the outlet water temperature and the generator temperature increases, but produced no refrigeration effect. In this case no refrigeration effect produced at the high generator temperature of 64.6°C which was obtained at the high-water heater outlet temperature of 74.29°C after the 6 hours of the process. In order to get desired cooling effect in the cabin of refrigerator with solar collector, it further coupled with collector and electric heater simultaneously and referred as case-3. The COP of system was found to be 0.67, 0 and 0.88 for case 1, case-2 and case-3 respectively. Hence, the gain in coefficient of performance of domestic Electrolux refrigerator using solar collector and electric heater simultaneously was found to be 31%.

KEYWORDS: Solar Energy, Solar Collector, Heat Exchanger & Solar Refrigeration

Original Article

Received: Jun 09, 2020; **Accepted:** Jun 29, 2020; **Published:** Jul 30, 2020; **Paper Id.:** IJMPERDJUN2020543

1. INTRODUCTION

Nowadays, with the rapid growth of population the demand for energy also increases. Globally, the refrigerator sector consumes about 17% of the electricity[1]. Refrigeration play a very important role in the food preservation. Rather than developed countries refrigeration installation is still very insufficient in many developing countries. According to IIR worldwide one third of the production gone wasted[1]. In 2010, out of 6300 million tonnes food production only 400 million tonnes preserved while 2000 million tonnes required refrigeration process[2]. A striking example in India where less than 4% of the country fresh produced is transported under low temperature[1]. According to IIR 20% of the globally food gone wasted which cause a significant loss[1]. In developing countries its loss is almost 23% on an average and in developed countries it is about 9%[1]. The FAO estimate about 70% requirement of food production globally to feed an additionally 2.3 billion people by 2050[2]. So, here refrigeration plays an important role in this context. Development of bacteria on food which directly impact on the human health can be reduced by using the refrigeration. So far, the world's energy demand is completed with

the use of fossil fuels. The higher use of fossil fuels creates most of the problems in environment which directly increase the temperature and also affect the human comfort. To reduce this effect shifting toward the renewable energy is very important. Therefore, the new power generation plant establishment is important which run with the help of renewable energy. Solar energy is one of the most abundant sources of energy in earth and also a clean and noise free energy. Conventional refrigerator system consumes electricity, which is generally produced from conventional source of energy. The availability of conventional source of energy is decreasing at very alarming rate and required alternate source and solar energy is one of them. By supplying solar energy directly in the form of heat energy to the vapor absorption refrigeration system can play important role to reduce global warming effect. Further research is required in solar absorption refrigeration system so that it can be efficient and reliable Vapor absorption refrigeration system is one of the alternatives for this.

Many researchers have done a study on this context which can be useful to run the vapour absorption refrigeration system by providing the heat to the system by different sources. Kaushik et al.[3]done simulation work on the system to test the different type of fluid which has low viscosity and low vaporization temperature and for that alcohol-salt mixture found best pair which increased the cooling capacity of refrigerant in the range of 20 to 40%. Li and Sumathy[3]has done a study that by partitioning the heat storage system the COP of the system increased up to 0.54 approximately. Gomri[4] has done a simulation work by using single, double and triple effect generator and found efficiency between 1.8 to 1.9 at higher generator and evaporator temperature i.e, 210 & 10°C but its efficiency decrease with the increase of condenser temperature. Said et al.[5] done a study on the 24 hour operation of absorption refrigeration system it means a continuous supply of energy without interruption for that use of refrigerant storage used which connected with the other solar collector and it increase the temperature of that storage tank higher than the generator temperature and connected separately at night with the generator. It has been found that with this cycle COP of the system also increase then the other intermittent storage alternative used. Said et al.[6]has done a study on intermittent solar absorption refrigeration system connected with the economizer which is connected with the generator and these both were connected with the solar collector. This was the modification of the intermittent solar absorption refrigeration system to increase the coefficient of performance up to 20%. El-Shaarawi et al.[7]found that COP at the constant temperature process is lower that is approximately 12% as compared to the constant pressure process. Chen et al.[8]showed that the heat and mass transfer increase up to 33.4 and 55.4% with the M-W type of meshing of tubes. Sokhansefat et al.[9] has done a study on the TRNSYS software in which all components are modeled and vary their parameter for their performance and found that there must a chances of 28 percent enhancement if parameter changed for collector is 55 m², volume of storage tank 1m³, auxillary boiler setup at 77°C, mass flow rate varied up to 1000kg/h and for that collector slope set up at 33°. Mohammed and Yanlinget[10]found that the use of reflux increase the COP of the system up to 0.53 at 90°C of generator temperature. Fito et al.[11]has done an observation on the single stage absorption system coupled with the thermochemical substance by comparing the same components. It has been found that with the working pair of NH₃-LiNO₃ 0.58 COP obtained and with the NH₃-BaCl₂ 0.48 COP obtained.

Some experiment work and thermodynamic calculations also has been done on this context which increases the COP of the system. Busso et al.[12]has done a calculations on the basis of experimental and modeling data and compare their result and found that using solar concentrator and bubble pump the electric power consumption can be reduced up to 40%. Quintanar et al.[13]used a parabolic concentrator which obtained 120°C temperature to study the binary and tertiary mixture that is NH₃-LiNO₃ and NH₃-LiNO₃- H₂O provide the good efficiency and its COP became 24% more when added more water in the ternary mixture up to 25%. Ozgoren et al.[14]has found that the COP of cooling inversely proportional to

the atmospheric air temperature i.e., at morning time from 8 a.m. to 1 p.m. it provide maximum COP value i.e., 0.784 and minimum COP at noon time. This reading was taken on 29 June. Ouadha and El-Gotni[15] has done a thermodynamic study on the marine diesel engine where most of the energy gone wasted into the environment. So, that to increase the COP of the system the solution heat exchange effectiveness must be increased. Anand et al.[16] used the EES software and done a thermodynamic calculations to predict the performance of the evacuated solar tube collector and found that the COP of heating and cooling can be lies in the range of 0.012–0.498 & 1.012–1.498 at 0.9 kW/m^2 solar intensity which require the collector area of about 431.7 m^2 and hot water temperature range up to 90°C . Táboas et al.[17] has done a thermodynamic calculation on three different type of fluid mixture i.e., $\text{NH}_3/(\text{LiNO}_3 + \text{H}_2\text{O})$, $\text{NH}_3/\text{LiNO}_3$ and $\text{NH}_3/\text{H}_2\text{O}$ to provide the refrigeration effect for fish storage and as a result the evaporating temperature achieved for the three cycle is -18.8°C , -17.5°C and -13.7°C at a generating and condensing temperature of 85 and 25°C . Domínguez-Inzunza et al.[18] has done a mathematical calculation on the five different configuration of absorption system i.e, single, half, double, triple and inverse double effect and on an comparison it has been observed that the COP for the triple effect was double which is 1.12 then the other effects at a 30°C of condensing temperature. Saleh and Mosa [19] used a mathematically model to study the flat plate solar collector and has found that with the addition of auxiliary heater one can achieve the temperature of generator in the range of $80 - 90^\circ\text{C}$ and COP exceed at this range up to 0.8 which provide the desired cooling effect for the system. Dong et al.[20] has done a study on the comparison between the auxiliary heater and ultrasonic wave and found that with the use of ultrasonic wave the temperature of the generator can be increased than the auxiliary heater and the only disadvantage that its temperature increases up to a limited range. Yang[21] has done a study on the multistage heat storage system which require more than 91 m^2 collector area to satisfy the daily need for cooling system. COP analyzed using four different type of collector with the use of phase change material at different melting point temperature and found that the maximum COP is inversely proportional to melting point of phase change material which can be achieved at 0.8 KW/m^2 of solar intensity.

Further research has been done on this context when it has been found the heat storage capacity and COP of the system can also be increased with the use of phase change material. Siddiqui[22] observed better performance of the system with the increase of Reynold number of phase change material in the carrier fluid when absorber plate positioned at mid-height then the other position selections. Lin et al.[23] has done a review on the recent advancement of materials aspects of phase change material to increase the thermal energy storage capacity. PCM is a promising agent for refrigerator and can solve various issues regarding wastage of energy in environment. One can enhance the thermal conductivity of PCM by the addition of some additive with high thermal conductivity. For that carbon-based additive possess a best promising for application purpose. Nourakan et al.[24] analyzed the high speed centrifuge device to study the stability of binary and found that nano fluid significantly increase the light trapping efficiency and for that the rod-shaped iron oxide nanoparticles were found to be good option for absorption refrigeration system. Zeiny et al.[25] has done comparative study on two type of nano fluids one is gold and second one is carbon black and it was found that gold is not suitable in case of energy consumption and also cost wise as compare to cheap and cost-effective carbon black.

In the present study, the Electrolux refrigerator performance has been studied for three different cases. In case 1, refrigerator has been supplied heat from electric heater and then in case 2 it has been coupled with flat plate solar collector. While in case 3, a hybrid pipe in pipe heat exchanger is used to couple the refrigerator with electric heater and solar collector simultaneously. To the best knowledge of authors, there is no work reported on Electrolux refrigerator coupling with electric heater and solar flat plate collector simultaneously.

2. EXPERIMENTAL SETUP AND PROCEDURE

A domestic Electrolux refrigeration system was used as experimental setup by modifying it with hybrid pipe in pipe heat exchanger. The hybrid heat exchanger was fabricated to supply heat to generator through electric heater and solar flat plate collector. The components of vapor absorption system are shown in figure 1. The generator takes the heat either from the electricity or from sun and heat up the solution which is inside the generator and convert into the vapor phase. Then in condenser refrigerant changes its phase from the vapor to liquid by losing its latent heat. In expansion valve pressure drops occur along with the temperature. Further inside the evaporator refrigerant takes the heat from the space and maintain the inside temperature of the space. After taking the heat from the evaporator it enters into the absorber pipe where it again loses its latent heat and finally enters into the absorber tank. It again enters into the generator and repeats the process.

Figure 1: Vapour Absorption Refrigeration System.

Figure 2: Experimental Setup of Domestic Electrolux Refrigeration System with Flat Plate Solar Collector.

The experimental setup was fabricated at Chandigarh University, Mohali, Punjab India and shown in figure 2. The hybrid heat exchanger was attached with generator of Electrolux refrigerator to supply heat from solar flat plate collector. It was fabricated with a CPVC pipe of diameter 22 mm. Hot water from collector enters into the cpvc pipe from the upper side and transfer its heat to the generator pipe. The dimension of all these component given in the table 1.

Table 1: Dimensions of Solar Absorption Refrigeration System

Components		Dimensions				
		Volume, m ³	Diameter, m		Length, m	
CPVC pipe heat exchanger		9.42×10^{-7}	0.022, m(OD)	0.020, m(ID)	0.3, m	
Generator tube		7.24×10^{-5}	0.016		0.25	
Absorber unit	Absorber vessel	3.30×10^{-4}	0.06		0.125	
	Absorber tube	2.5×10^{-3}	0.03		3.6	
Evaporator		4.6×10^{-5}	0.014		0.3	
Condenser unit	Condenser tube	4.9×10^{-5}	0.014		0.32	
	Condenser fins	3.5×10^{-6}	Length, m	Width, m	Thickness, m	No. of fins
			0.07	0.05	0.001	35

The solar intensity was measured using solarimeter and temperature readings were taken using RTD sensors. The experimentation was carried in the following three phases:

- In first phase of experimentation, the electric heater was used as source of heat to generator of Electrolux refrigerator and COP of the system has been calculated.
- In second phase of study, the generator of domestic Electrolux refrigerator was coupled with flat plate solar collector using pipe in pipe heat exchanger.
- In third phase of experimentation, the generator was coupled with solar collector along with the electric heater simultaneously through hybrid pipe in pipe heat exchanger.

3. RESULTS AND DISCUSSIONS

3.1 Performance of Electrolux Refrigerator with Electric Heater

During first phase of study, the domestic Electrolux refrigeration was tested with electric heater as a heating source for generator. For the measurement of temperature of generator, ice tray and refrigerator cabin RTD sensors were used. The variation of generator, ice tray and refrigerator cabin temperature are shown in Figure 3. It shows that the electric energy plays a very important role for the production of refrigeration effect. The cause for this was the higher generator temperature of 128.155°C which meet after 7 hour of process and at this temperature the refrigerant cabin temperature reached up to 5.415°C and also the ice tray temperature reached 0°C.

Figure 3: Variation of Generator, Ice Tray and Refrigerator Cabin Temperature.

3.2 Performance of Electrolux Refrigerator with Solar Flat Plate Collector

The variation of average solar radiation intensity in the month of March from morning 10 a.m. to evening 4 p.m. is shown

in figure4. It shows the change of solar radiation intensity with time and observed that the maximum solar radiation intensity found at afternoon period around 1p.m. and it was 736.7814W/m^2 .

Figure 4: Variation in Monthly Average Solar Radiation.

The maximum intensity observed during noon when sun top position and it start decreasing its intensity when sun is at 45° . At afternoon the sun intensity has to travel shorter distance as compare to the morning and evening time. This is the cause that at afternoon time the solar radiation intensity found to be maximum. The variation of average ambient temperature and heater outlet temperature is shown in table 2.

Table 2: Change of Outlet Water Temperature from Solar Collector and Ambient Temperature with Time

Time(h)	Monthly Avg. Ambient Temperature($^\circ\text{C}$)	Monthly Avg. Water Heater Outlet Temperature($^\circ\text{C}$)
10:00am	27.65	39.24
11:00am	27.81	45.51
12:00am	28.23	54.44
1:00am	28.65	63.46
2:00am	28.81	70.87
3:00am	28.81	74.29
4:00am	28.65	73.95

The outlet temperature of the water varies with the variation of solar intensity. The outlet temperature of collector water increased with the increase of intensity level. It was found that the solar radiation intensity increases up to a certain limit and then soon it starts decreasing but outlet temperature of solar collector increases with time. It is because the storage tank of outlet water of the collector which is fully insulated and reduce the heat loss even at the low intensity level of the solar radiation intensity.

Figure 5 represent the evaluation of solar absorption refrigeration system using the hot water from the solar collector. It shows that the with the increase of collector surface temperature the outlet water temperature and the generator temperature increases, but produced no refrigeration effect. In this case no refrigeration effect produced at the high generator temperature of 64.6°C which was obtained at the high-water heater outlet temperature of 74.29°C after the 6 hours of the process.

Figure 5: Variation of Temperature of Solar Absorption Refrigeration System using Hot Water from Solar Collector.

For the operation of solar refrigerator, it was important to produce maximum generator input temperature so that better refrigeration effect can produced. When the generator input temperature is not according to requirement then the refrigeration production is nil. The bubble pump operation effects only if the generator temperature reach its minimum value. So that the bubble pump work when the heat input to generator increases. More heat input given to the generator more cooling effect occurs. From the result it was found that at the generator temperature of 64.6°C the refrigerant effect produce was nil. Even at the collector temperature of 80°C the chance of refrigeration effect production was found to be nil, because the ice tray temperature was not decreased as desired.

3.3 Performance of Electrolux Refrigerator with Solar Flat Plate Collector and Electric Heater

After performing experiment independently on electric heater and flat plate collector, the Electrolux refrigerator coupled with solar collector and electric heater simultaneously using hybrid pipe in pipe heat exchanger. The variation of temperature of Electrolux refrigerator with solar flat plate collector and electric heater is shown in Figure 6. It can be observed that temperature of generator achieved as desired to produce refrigeration effect after 4 hours of operation. Since the heat is supplied from solar flat plate collector, the required input energy from heater is controlled by using electric variac so that electric energy consumption can be reduced. Moreover, the desired cooling effect achieved in the cooling tray after 4 hours and reaches to 0°C after 7 hours of operation.

Figure 6: Variation of Generator, Ice Tray and Refrigerator Cabin Temperature for Case 3.

3.4 Coefficient of Performance of Solar Absorption Refrigeration System

In order to find the effect of using flat plate collector, electric heater and combined effect of both solar collector and electric heater on the performance of Electrolux refrigerator, COP of all three cases was calculated by using equation 1 and results are shown in figure 7.

$$\text{COP of solar absorption refrigeration system} = \frac{\text{refrigeration effect}}{\text{heat input given to the system}}$$

(1)

Figure 7: COPs of Solar Absorption Refrigeration System for all Three Cases.

It can be observed from figure 7 that COP of was found to be zero in case when only solar flat plate collector was attached with Electrolux refrigerator. It is because there is no refrigeration effect produced and unable to reach the desired temperature in the cabin of refrigerator. While when the electric heater was used as a source of heat to the generator then COP of system was found to be 0.67. Moreover, the COP of system increased further to 0.88 when it was coupled with solar collector and electric heater simultaneously using hybrid heat exchanger. It is due to supply of electric energy reduced because some part of energy is supplied from solar collector. So, in order to achieve similar effect in the cabin of refrigerator the less amount of electric energy is supplied and COP of system increased.

4. CONCLUSIONS

The following conclusions can be drawn from the present research work:

- It has been found that the refrigeration effect is proportion to temperature achieved in generator and it became zero in case of Electrolux refrigerator coupled with flat plate collector only.
- When the solar intensity was at its peak (736.7814 W/m^2) then the maximum temperature of outlet water was achieved to be 74.29°C in flat plate collector.
- The COP of system with solar collector and electric was to be 0.88 and it was found to be maximum among all three cases.
- The gain in coefficient of performance of domestic Electrolux refrigerator using solar collector and electric heater simultaneously was found to be 31%.
- It has been found that consumption of electric energy can be reduced by Electrolux refrigerator simultaneously

with electric heater and solar collector using hybrid heat exchanger.

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