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Research Article

PERFORMANCE EVALUATION OF SOLAR PHOTOVOLTAIC POWERED VAPOR COMPRESSION REFRIGERATION SYSTEM

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Abstract: In developing countries large number of people still lives in rural and remote area like in India where the grid electricity is unavailable or available for few hours. In these areas the vaccine preservation becomes an important issue and it is the basic need. The four components of the refrigerator, were designed separately (*i.e.* condenser, evaporator, compressor and the capillary tube) for 60 litre capacity. Eco-friendly refrigerant R-134a was selected. The nano-refrigerant (R-134a+Al_2O_3) was also used in this SPV operated refrigeration system to evaluate its performance and the results obtained are compared with the refrigerant R-134a. The per cent drop in the temperature among evaporator and condenser section of all various tests in two months (*i.e.* January and March) by using nano-refrigerant (R-134a+Al_2O_3) was observed to be 1.98 to 6.54 respectively. Average COP obtained varies from 1.95 to 2.26 and 2.13 to 2.46 by using refrigerant R-134a and nano-refrigerant (R-134a+Al_2O_3) respectively. The per cent increase in the value of COP and per cent saving in the power consumption of compressor varies from 8.85 to 10.19 and 14.03 to 18.36 respectively, during various test conditions using nano-refrigerant (R-134a+Al_2O_3) in place of refrigerant R-134a. The average monthly efficiency of solar photovoltaic system varies from 14.4 to 16.3 per cent for experimental duration.

Keywords: Refrigeration, vapor compression, photovoltaic, solar refrigeration and vaccine preservation

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Introduction

In the present context the energy demand is increasing with increasing the population and improvement in the living standard. It is the crucial input to the social, economic, industrial and technological development of any country. The rapid growth in world population and the economy, especially in developing countries, total world energy consumption has increased and is projected to increase by 71% during 2003-2030. The energy is harvested from conventional fossil fuel and due to its excess consumption, the greenhouse gases are releases to the lower atmosphere¬¬ which results in global warming and acid rain. This is the reason why legislative initiatives as well research activities aim at the utilization of systems, which lead to an increasing energy saving and use of renewable energy. The production of cold has applications in a considerable number of fields of human life for example the food processing field the air-conditioning sector and the conservation of pharmaceutical products. Refrigeration is available in the industrialized countries through the availability of electricity but is not readily available in the major part of the world. The greatest demand for cooling occurs when the solar radiation is most intense, thus making its use for cooling all the more attractive. In a tropical country, like India, the importance of refrigeration can hardly be over emphasized. Solar photovoltaic is best option to operate refrigeration in remote area, where electricity is not available. The refrigeration is required to preserve the lifesaving drugs and vaccines in the remote areas where the grid power is unavailable or limited to few hours [1]. To achieve refrigeration, a heat source is required to drive the refrigeration system. There are several sources of energy for production of refrigeration, the most important being gas, electricity and solar energy. Solar cooling is more attractive because the demand for cooling is generally the greatest at times of maximum availability of solar radiation and the cooling is far more need in hotter regions than in colder climate. Solar photovoltaic (PV) power system applications are increasing due to both technical and economic factors. Solar PV energy contributes to improved air quality and aids in the reduction of greenhouse gases that play a role in global warming. The heat transfer performance of various thermal devices may be augmented by active and passive techniques [2]. One of the passive techniques is the addition of ultrafine particles (called nano-particles) to the common heat transfer fluids so that the thermal transport properties of the prepared suspension (called nanofluid) will be enhanced as compared to the base fluid. Nano-refrigerants are a special type of nano-fluids which are mixtures of nano-particles and refrigerants and have a broad range of applications in diverse fields for instance refrigeration, air conditioning systems, and heat pumps. The effect of nano-refrigerant properties (such as nano-particle type, size and concentration) on heat transfer compared to pure refrigerant could improve the performance of the system.

Methodology

Refrigerant R-134a is commonly used as a working fluid in domestic vapour compression refrigeration system. Nano-materials are mixed with the different types of base fluids like water, oil, bio-fluids, polymer solutions and refrigerants. Here we used the alumina (Al_2O_3) nano-particles which were mixed with the refrigerant R-134a to prepare the required fluid [3] *i.e.*, nano-refrigerant (R-134a + 0.5% Al_2O_3 weight basis)[4]. The performance of the system was evaluated for 24 h of operation in controlled condition (at 25°C room temperature during January 2017) and in transient ambient conditions (during March 2017). A comparative study was carried out by using refrigerant R-134a (tetrafluoroethane) and nano-refrigerant (R-134a + 0.5% Al_2O_3) and following variables had been studied. The temperature of different points using temperature sensors connected to the data logger of the components of refrigerator like compressor inlet & outlet, condenser outlet, expansion device (capillary) inlet & outlet, evaporator outlet and cabinet temperature were taken during the test. The power to the refrigerator was supplied by the solar photovoltaic system (SPV) during day-time (sunshine hours) and battery back-up was provided during off sunshine hours which was charged by SPV system during sunshine hours.

Result & Discussion

Performance evaluation of SPV powered vapour compression refrigeration system using refrigerant R-134a and nano-refrigerant (R-134a + 0.5 % Al_2O_3)

The performance of the SPV powered refrigeration system was evaluated using the different treatments described in winter as well as in summer season. The type of refrigerant, load condition and thermostat set temperatures in evaporation chamber as independent variables were set for evaluating the performance of refrigerator in terms of COP_{actual}, and power consumption (kWh). The vaccines were loaded in the refrigerator during test of quantity 30 and 60 litre which was half load and full load condition respectively.

Table-1 Average performance parameters of SPV powered refrigerator during no load test

SN	Tetrafluroethane, (R-134a)			Nano-refrigerant, (R-134a+ 0.5% Al_2O_3)		
	COP	Power consumption, (kWh)	Cooling efficiency, (%)	COP	Power consumption, (kWh)	Cooling efficiency, (%)
1	2.14	1.38	61.11	2.4	1.25	67.23

From [Table-1] found that the COP, power consumption of compressor (kWh) and cooling efficiency of the SPV powered refrigerator was 2.14, 1.38 & 61.11 and 2.40, 1.25 & 67.23 using refrigerant R-134a and nano-refrigerant (R-134a + 0.5% Al_2O_3) respectively. There was increase in all performance parameters found by using the nano-refrigerant (R-134a + 0.5% Al_2O_3) with saving in the power consumption of compressor (kWh) [4].

Effect of three variables on COP of SPV powered refrigerator

Effect of refrigerant, load and temperature in evaporation chamber of refrigerator on COP in winter season

[Table-2] revealed that the COP of SPV powered refrigerator was found to be 2.06 using refrigerant R-134a at half load condition and at temperature in evaporation chamber of 2°C. The COP was observed decreasing at full load condition to 2.01 and at this same situation the COP of refrigerator increases from 2.06 to 2.26 and 2.01 to 2.20 when temperature in evaporation chamber of refrigerator increases from 2°C to 8°C at half load and full load condition respectively. The similar effect on the COP of refrigerator was observed using nano-refrigerant (R-134a+0.5% Al_2O_3) as it increases from 2.27 to 2.46 and 2.21 to 2.41 when temperature in evaporation chamber of refrigerator increases from 2°C to 8°C at half load and full load condition respectively. The COP also increases by using the nano-refrigerant (R-134a+0.5% Al_2O_3) in place of refrigerant R-134a from 2.06 to 2.27, 2.18 to 2.39, 2.26 to 2.46 and 2.01 to 2.21, 2.13 to 2.33, 2.20 to 2.41 at half load and full load condition during temperature in evaporation chamber of 2°C, 5°C and 8°C respectively.

Table-2 Combine effect of refrigerant, load and temperature in evaporation chamber of refrigerator on COP in winter season (Room temperature 25 ± 2°C) (Jan. 2017)

SN	Temperature, (°C)	COP			
		Type of refrigerant			
		R_1- (R-134a, tetrafluoroethane)		R_2-(R-134a + 0.5% Al_2O_3, nano-refrigerant)	
		Load, (Litre)			
		L_1= half load	L_2= full load	L_1=half load	L_2= full load
1	T_1= 2	2.06	2.01	2.27	2.21
2	T_2= 5	2.18	2.13	2.39	2.33
3	T_3= 8	2.26	2.2	2.46	2.41
	F test	Significant			
	SE(m)±	0.003			
	CD at 5 %	0.011			

The [Fig-1] shows that the per cent increase in the value of COP was 10.19, 9.63, 8.85 and 9.95, 9.39, 9.55 at half load and full load condition from temperature in evaporation chamber of 2°C to 8°C using refrigerant R-134a and nano-refrigerant (R-134a+0.5% Al_2O_3) respectively [5].

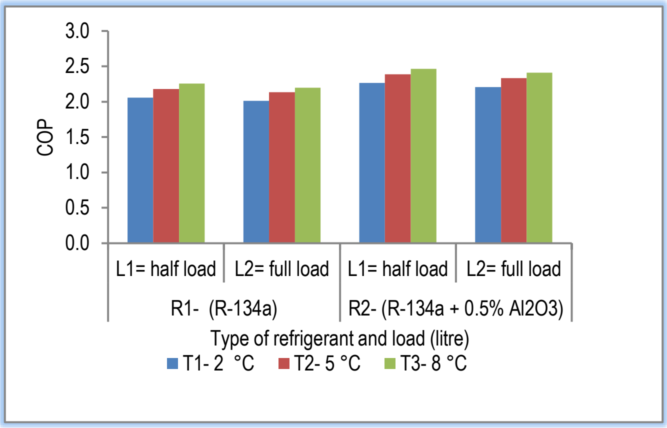

Fig-1 Effect of refrigerant, load and temperature in evaporation chamber of refrigerator on COP of SPV powered refrigerator

Effect of refrigerant, load and temperature in evaporation chamber of refrigerator on COP in summer season (March 2017)

[Table-3] revealed that the COP of SPV powered refrigerator was found to be 2.02 using refrigerant R-134a at half load condition and at temperature in evaporation chamber of 2°C. The COP was observed decreasing at full load condition to 1.97 and at the same condition the COP of refrigerator increases from 2.02 to 2.21 and 1.97 to 2.17 when temperature in evaporation chamber of refrigerator increases from 2°C to 8°C at half load and full load condition respectively. The similar effect on the COP of refrigerator was observed using nano-refrigerant (R-134a+0.5% Al_2O_3) as it increases from 2.23 to 2.43 and 2.18 to 2.35 when temperature in evaporation chamber of refrigerator increases from 2°C to 8°C at half load and full load condition respectively.

Table-3 Combine effect of refrigerant, load and temperature in evaporation chamber of refrigerator on COP in summer season (Average room temperature)

SN	Temperature (°C)	COP			
		Type of refrigerant			
		R_1- (R-134a, tetrafluoroethane)		R_2-(R-134a + 0.5% Al_2O_3, nano-refrigerant)	
		Load, (Litre)			
		L_1= half load	L_2= full load	L_1=half load	L_2= full load
1	T_1= 2	2.02	1.97	2.23	2.18
2	T_2= 5	2.11	2.07	2.35	2.27
3	T_3= 8	2.21	2.17	2.43	2.35
	F test	Sig.			
	SE(m)±	0.003			
	CD at 5 %	0.011			

The COP also increases by using the nano-refrigerant (R-134a+0.5% Al_2O_3) in place of refrigerant R-134a from 2.02 to 2.23, 2.11 to 2.35, 2.21 to 2.43 and 1.97 to 2.18, 2.07 to 2.27, 2.17 to 2.35 at half load and full load condition during thermostat set temperature in evaporation chamber of 2°C, 5°C and 8°C respectively.

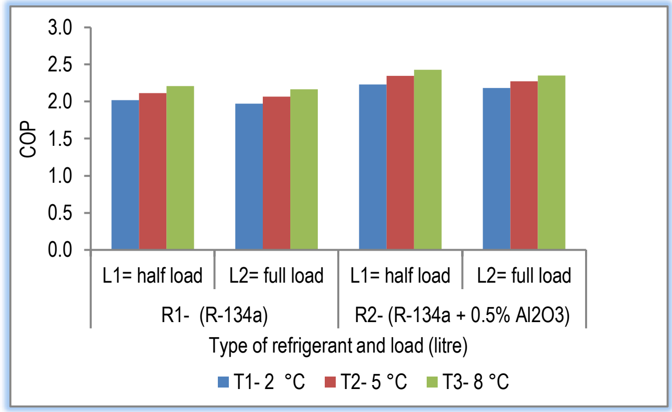

Fig-2 Effect of refrigerant, load and temperature on COP of SPV powered refrigerator

The [Fig-2] shows that the per cent increase in the value of COP was 10.39, 11.37, 9.95 and 10.66, 9.66, 8.29 at half load and full load condition from temperature in evaporation chamber from 2°C to 8°C using refrigerant R-134a and nano-refrigerant (R-134a+0.5% Al_2O_3) respectively [6]. The increasing trend of COP was found by using the nano-refrigerant [7,8].

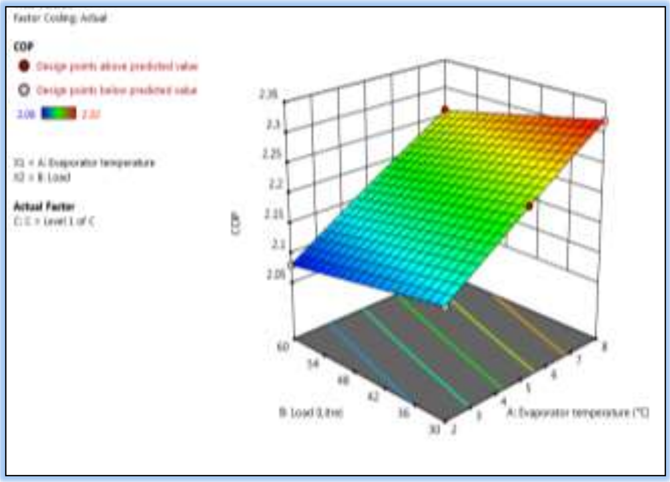

Fig-3 Effect of load and temperature on COP of SPV powered refrigerator

Conclusion

The energy supplied from the solar photovoltaic panels operated the refrigerator and charged the batteries. The installed system of solar photovoltaic refrigerator system is capable for cooling the vaccine for 24 hours of a day. The SPV powered refrigerator under test was able to maintain the temperature as specified by the WHO for the vaccine preservation (2°C to 8°C). The SPV powered vapor compression refrigeration system normally works under the designed environmental conditions. The SPV powered refrigerator normally works with the use of nano-refrigerant and increases it's COP as well as saves the power consumption of system. The average performance indicator of SPV powered refrigerator *i.e*., COP varies from 2.02 to 2.41 and maximum value was obtained by the use of nano-refrigerant. The test carried out indicates that 900Wp photovoltaic capacity and 150 Ah battery bank is the least possible configuration required for this vapor compression refrigeration system. The average monthly efficiency of solar photovoltaic system varies from 14.4 to 16.3 per cent for experimental duration it also supply the continuous power to the refrigerator for 24 hours of a day.

Application of research: Solar photovoltaic powered refrigeration system is useful in the areas of remote location for preserving the lifesaving drugs and vaccines where the electricity is unavailable.

Research Category: Renewable Energy Sources

Abbreviations:
COP: Coefficient of performance
SPV: Solar photovoltaic

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