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Experimental Studies on a Solar Assisted Heat Pump Working with R22: An Exergy Point of View

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ABSTRACT

This paper presents the exergy assessment of a simple direct expansion solar assisted heat pump (DX-SAHP) system under hot and humid environment conditions. Experiments are performed at Solar Energy Center in National Institute of Technology Calicut, India, located in the southern peninsula of the Indian continent. Experimental set up mainly incudes the hermetically sealed compressor, and an air cooled condenser, a solar collector/evaporator and a thermostatic expansion valve with R22 as the working fluid. The exergy relations for each component of the system and for total system are derived for performance assessment purposes. The results showed that the maximum average exergy destruction observed in the condenser and followed by the solar collector/evaporator, compressor and expansion valve of the system. The obtained result helps for the designer for the optimization of the system components and for the total system.

Keywords - DX-SAHP, Exergy and R22.

1. INTRODUCTION

Vapor compression based refrigeration system mainly used for different applications such as air-conditioning, domestic refrigeration, water chillers, and automobile air-conditioning and heat pump systems. Because of good thermodynamic and thermos-physical properties of R22, it is widely used as working fluid in the all systems. Heat pumps are the systems used for the space/room and process heating applications. To enhance the heat pump system performance these were connected with renewable energy system such as solar, geothermal and combination of the solar and geothermal energy sources.

Direct expansion solar assisted heat pump systems are more popular than the conventional solar assisted heat pump systems, because the DX-SAHP system has limited numbers of components, hence lesser the running and initial cost of the system. Several studies had been performed in terms of exergetic prospective, in order to optimize the system components and total system of DX-SAHP systems. Kara *et al.* [1] presented the review studies and exergetic modeling of DX-SAHP systems. The proposed exergetic modeling gives the satisfactory results with second law efficiency of the system components found in the range of 10.74 to 88.87%. Li *et al.* [2] performed the experimental investigation on DX-SAHP system considering the energy and exergetic prospective. A methodology was applied to optimization of the solar collector/evaporator of the system based on the exergetic assessment of the system. Mohanraj *et al.* [3] assessed exergetic performance of DX-SAHP using R407C/LPG mixture. Their results indicated that the overall exergy assessment of the system was found to be better with the new mixture (R407C/LPG) as compared to that of R22. Mohanraj *et al.* [4] also proposed an Artificial Neural Network (ANN) based methodology to predict the exergy assessment of the DX-SAHP systems.

Technological improvement in every field of science and engineering leads to need more energy demands in the sustainable way. So, it is necessary to supply the adequate amount of energy with existing energy systems. The present existing energy system should be optimized and these should capable to meet the present energy demands. From the above brief literature it was found that no sufficient work has been done exergy assessment of DX-SAHP system at hot and humid environment conditions. This paper gives the insight of the exergy assessment of DX-SAHP system at various ambient conditions.

2. METHODOLOGY

2.1 Experiments

Experimental investigations are carried out under the metrological conditions of National Institute of Technology Calicut (Latitude of 11.15 ^{0}N, Longitude of 75.49 ^{0}E). All the experiments are conducted in the winter season of 2015 with available average 10 h sunshine.

2.2 System description

The schematic representation of the experimental set up of DX-SAHP system (suitable for space/room heating applications) is shown in Fig. 1. Experimental set up mainly consists of a solar collector (glazed type) with a total area of 2.0 m^2 (2 x 1 m). It serves as the evaporator of the system. Copper tubes which act as the fins having 0.8 mm thick and 10 mm length are attached to the solar collector. In order to improve the solar collector absorptivity of the incident solar insolation its surface has selective material (Black chrome). R22 hermetic sealed (reciprocating type) compressor with a rated power of 1020 W is used. Air cooled condenser (forced type) with copper tube coils (9.52 mm diameter) with a maximum face velocity of 4.75 m/s. The sight glass and liquid receiver are mounted downstream of the condenser. To measure the refrigerant flow and moisture content a turbine type flow meter and dryer are installed in the circuit. The refrigerant flow in the solar collector/evaporator is controlled by using the thermostatic expansion valve. The system is adapted to face south in order to maximize the available solar insolation on the solar collector/evaporator. The solar collector is placed to an angle of 20^0 with respect to horizontal.

2.3 Data acquisition system

The temperatures, pressures, flow rate of working fluid (refrigerant) and velocity of the air are measured at specified locations/points in the experimental set up as shown in Fig. 1. Also, the other atmospheric parameters such as relative humidity, ambient temperature, solar insolation and wind velocity were measured. Compressor inlet and outlet pressure were measured with the help of bourdon type pressure gauges and pressure transmitters. In similar way the expansion valve inlet and out let pressure were measured

Resistance thermometers (RTDs) are used to measure the refrigerant temperature at compressor inlet and outlet, exit of the condenser and inlet of the expansion in the expansion valve. The condenser inlet and outlet air temperature are measured using the similar set of Resistance thermometers. The ambient temperature is measured with the help of a thermometer. Vantage-Pro weather station was installed in the Solar Energy Center at National Institute of Technology Calicut, India, is used to measure the wind velocity, relative humidity solar insolation etc.. Duct air velocity at the exit of the condenser is measured with the help of velocity sensor and vane type anemometer. A pyranometer is placed on the glazed type evaporator to record solar insolation. Refrigerant flow rate in the circuit is measured using the turbine type flow meter. Compressor power consumption was continuously recorded in the digital type, multi-function single phase energy meter. All parameters (pressure, temperature, velocity, solar insolation and compressor power consumption) are checked and recorded using a personal computer-based data-acquisition system. In data-acquisition system the data is recorded at every 2 minutes of time further used for the detailed analysis.

3. MODELLING

The general exergy balance equation of the thermodynamic system is given by;

$$\dot{E}_{in} = \dot{E}_{out} + \dot{I}_{rr} + \Delta\dot{E} \tag{1}$$

Where $\dot{E}_{in}$ and $\dot{E}_{out}$ are the input and output exergy rates respectively, $\dot{I}_{rr}$ total irreversibility’s in the system and $\Delta\dot{E}$ is the exergy change rate. Similarly exergy balance equation for the DX-SAHP system is given by following eq [2]

$$\dot{E}x_{rad} + \dot{W}_{comp} = \dot{E}x_{con} + \sum_i \dot{I}_{rr,i} \tag{2}$$

Where $\dot{E}x_{rad}$ is the exergy rate for solar radiation, $\dot{W}_{comp}$ in the total work input of the compressor, $\dot{E}x_{con}$ represents the exergy rate of the condenser (heat transfer rate) to air and $\sum_i \dot{I}_{rr,i}$ is the total exergy loss rate of the components of the DX-SAHP system. The subscript “i” represents the ith component of the DX-SAHP system.

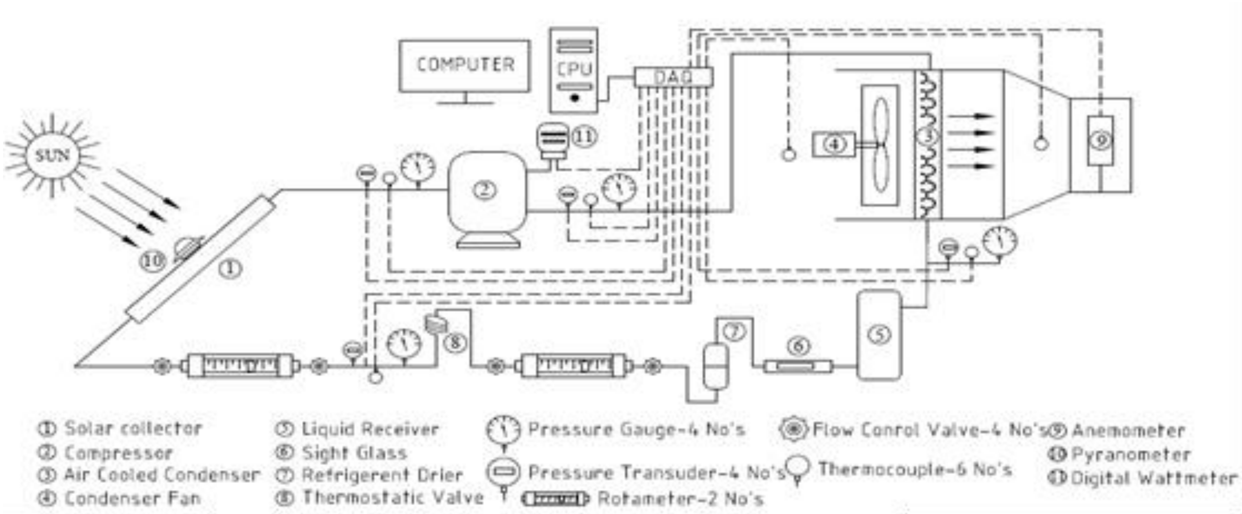

Fig. 1 Schematic diagram of experimental set up

The specific exergy (ex) rate at the inlet and outlet of the compressor (at points 1 and 2) and inlet and outlet of the expansion valve (knowns as points 3 and 4) and total exergy rate of the DX-SAHP system are calculated using the following equation as suggested by [1].

$$ex = (h - h_o) - T_o(s - s_o) \tag{3}$$

$$\dot{E}x = \dot{m}ex \tag{4}$$

3.1 Compressor

The exergy destruction due to compressor and exergy efficiency of the compressor are determined by using the following relations;

$$\dot{E}x_{dest,comp} = \dot{E}x_1 - \dot{E}x_2 + \dot{W}_{comp} \tag{5}$$

Where $\dot{W}_{comp}$ is compressor power and determined by means of the succeeding equation;

$$\dot{W}_{comp} = \frac{\dot{m}_r(h_2 - h_1)}{\eta_{mech} \times \eta_{ele}} \tag{6}$$

Where, $\dot{m}_r$ is the mass flow rate of the refrigerant The mass flow rate of the refrigerant is 0.03 kg/s, it assumed to be constant.

3.2 Condenser

Exergy destruction and exergy efficiency due to the condenser are calculated by using the following relations;

$$\dot{E}x_{dest,cond} = (\dot{E}x_2 - \dot{E}x_3) + (\dot{E}x_6 - \dot{E}x_5) \tag{7}$$

Where; $\dot{m}_a$ is the mass flow of air and it is found to be experimentally, 0.0228 kg/s in the system.

3.3 Expansion Valve

Modelling of the thermostatic valve for calculation of exergy destruction and efficiency are given as follows;

$$\dot{E}x_{dest,(exp.valve)} = \dot{E}x_3 - \dot{E}x_4 \tag{8}$$

3.4 Evaporator/Solar collector

Exergy destruction of evaporator/solar collector of in DX-SAHP is the difference between amount of exergy collected in the system to the amount of exergy used in the system. The exergy destruction and exergy efficiency of the solar collector are determined by means of the succeeding equation [1]

$$\dot{E}x_{dest,(solar.coll)} = (\dot{E}x_{collected} - \dot{E}x_{ued}) \tag{9}$$

The exergy utilized in the solar collector/evaporator of a DX-SAHP system are calculated using the following equations 10 and 11 respectively.

$$\dot{E}x_{ued} = \left[\dot{m}_r (h_{r-outlet} - h_{r-inlet}) \frac{T_o - T_e}{T_e} \right] \tag{10}$$

$$\dot{E}x_{collected} = AI_t\left[1+\frac{1}{3}\left(\frac{T_o}{T_s}\right)^4-\frac{4}{3}\left(\frac{T_o}{T_s}\right)\right] \qquad (11)$$

Where A is the area of the collector; I_t solar insolation; Ts is the solar radiation temperature and taken as 6000 K. T_e and T_o are evaporator and ambient temperatures, respectively.

3.5 Total System

The total system exergy destruction is the sum of all system component exergy destruction. The DX-SAHP system, total exergy destruction is given by following relations;

$$\dot{E}x_{dest,(system)} = \dot{E}x_{dest(comp)} + \dot{E}x_{dest(cond)} + \dot{E}x_{dest(exp.valve)} + \dot{E}x_{dest(solar.coll)} \qquad (12)$$

4. RESULTS AND DISCUSSION

Exergy destruction values obtained at various ambient conditions (such as ambient temperature and solar insolation) of the evaporator/solar collector, compressor, thermostatic valve, condenser, and total system are plotted in Figs. 2 to 6.

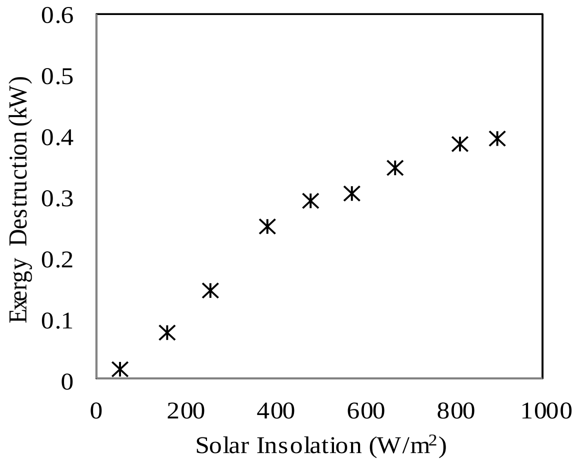

Fig. 2 Exergy destruction of compressor w.r.to solar insolation

The exergy destruction in compressor against solar insolation is show in Fig. 2. The exergy destruction of the compressor is changing from 0.09 to 0.39 kW. Fig. 3, shows the destruction of exergy in the condenser with respect to solar insolation. The exergy destruction of condenser is changing from 0.25 to 0.52 kW. It has been observed that maximum destruction of exergy occurred in the condenser. It is due to the temperature difference of the hot and cold fluid of air.

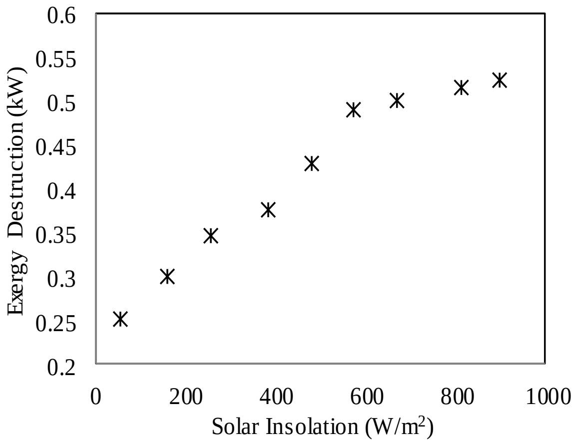

Fig. 3 Exergy destruction of condenser w.r.to solar insolation

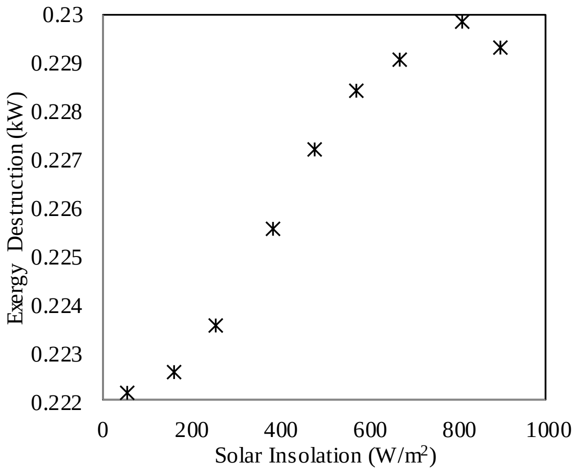

Fig. 4 Exergy destruction of thermostatic expansion valve w.r.to solar insolation

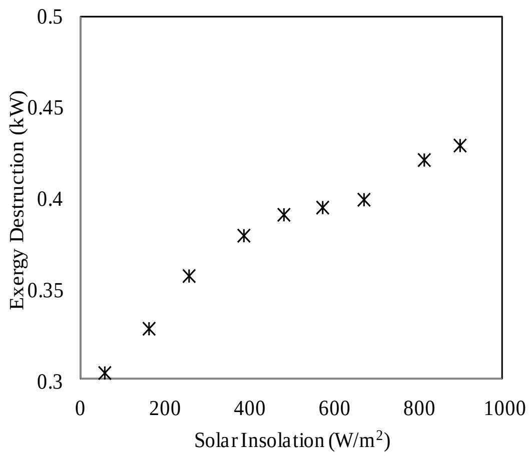

Fig. 5 Exergy destruction of evaporator/solar collector w.r.to solar insolation

Similarly it is observed that variation in the destruction of exergy in the expansion device is very low. The average exergy destruction value of the expansion valve is found to be 0.226 kW. The exergy destruction of expansion valve against the solar insolation is shown in Fig. 4. Similarly Fig. 5 shows the variation of exergy destruction in the evaporator/solar collector of the DX-SAHP system. It is found that exergy destruction value differs from 0.30 to 0.42 kW for the given solar insolation range from 55 to 935 W/m^2. The total system average exergy destruction is observed to be 1.2 kW. The total exergy destruction values obtained at different ambient conditions are plotted with respect solar insolation as shown in Fig. 6.

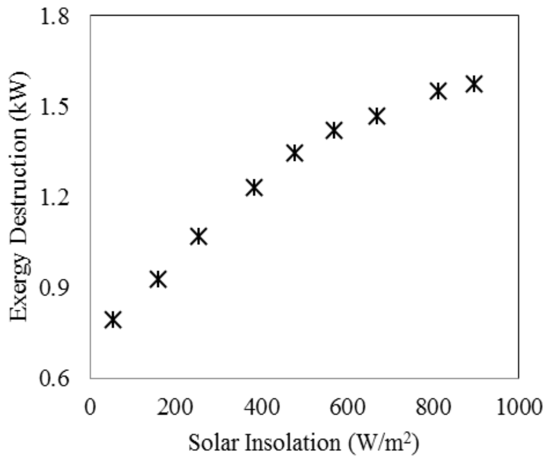

Fig. 6 Exergy destruction of the total system w.r.to solar insolation

5. CONCLUSION

The exergy assessment of the DX-SAHP system is performed at Solar Energy Center in National Institute of Technology Calicut, India. The average destruction of exergy values of the compressor, thermostatic expansion valve, condenser, solar collector and total system are observed to be 0.25, 0.22, 0.41, 0.37, 1.26kW, respectively. Exergy assessment of DX-SAHP system conducted at different ambient conditions is helpful for designer to identify the inefficient components of the system. In addition to that obtained results are helpful for the optimization of the entire system.

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