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Experimental Study on Direct Expansion Solar Assisted Heat Pump System

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ABSTRACT
In this paper, an experimental study for heating of domestic water using direct expansion solar assisted heat pump (DX-SAHP) was carried out. The refrigerant R-134a was expanded in the glazed solar collector which also plays the role of the evaporator in a conventional vapor compression heat pump device. The experiment on the above mentioned system was performed for four different days which were chosen depending upon the clear day. The average coefficient of performance (COP) of heating for this system under winter climatic conditions was found to be about 2.91. The parameters like refrigerant mass flow rate, temperature and pressure have been measured at different point in the system. It was concluded that the time taken for heating 30 liters of water from 15°C to 50°C is about 75 minutes for this system. At that time solar intensity varies from 523-710 W/m^2.
Keywords – solar energy, direct expansion solar assisted heat pump, coefficient of performance, heat transfer fluid.

I. INTRODUCTION

Among the alternative energy sources in nature, solar energy is free, easily available and non-polluting which could be used in domestic or industrial low temperature applications. The idea of the combination of heat pump and solar energy known as SAHP has been proposed and developed by many researchers [1] [2] [5]. The SAHP that were proposed could be differentiated as direct expansion solar assisted heat pump and indirect solar assisted heat pump. This paper is focused on estimating the performance of DE-SAHPWH system where DX-SAHPs integrate directly Reverse-Rankine refrigeration device with solar collector that also serves as evaporator. In the direct-expansion solar-assisted heat pump water heater (DX-SAHPWH) system, the refrigerant in solar collector absorbs the incident solar energy and ambient energy and in condenser, it contributes to water heating by heat rejection. In this regard, many theoretical and experimental studies have been reported [3] [4] [11] [12]. A review on such a field of work has indicated that the COP values of the DX-SAHP systems range from 2 to 9, where the experiment was carried out under different climate conditions. Since the overall performance of a solar system is influenced significantly by the changes in climatic conditions and load, it describes the variation in COP.

II. NOMENCLATURE

C_p --heat capacity of refrigerant, [kJ/kg-K]
C_{pw} –heat capacity of water, [kJ/kg-K]
COP -- coefficient of performance of DX-SAHP
h_1-- the enthalpy of the refrigerant exiting evaporator, [kJ/kg]
h_2-- the enthalpy of the refrigerant exiting compressor, [kJ/kg]
h_3 --the enthalpy of the refrigerant exiting condenser, [kJ/kg]
h_4-- the enthalpy of the refrigerant exiting capillary tube, [kJ/kg]
$\dot{m}_r$ -- the mass flow rate of the refrigerant (R-134a), [kg/s]
Q_e--the heat transfer rate through the evaporator, [kW]
Q_c--the heat transfer rate through the condenser, [kW]
T_1 --the temperature of the refrigerant exiting evaporator / entering compressor, [^{o}C]
T_2 --the temperature of the refrigerant exiting compressor / entering condenser, [^{o}C]
$T3$ --the temperature of the refrigerant exiting condenser / entering capillary tube, [^{o}C]
$T4$ --the temperature of the refrigerant exiting capillary tube / entering evaporator, [^{o}C]
Tw-- the temperature of water in condensor, [^{o}C]

U_L --the overall heat transfer coefficient, [kW/^{o}C]
W_{comp}-- the electrical power consumption of the compressor, [kW]

III. Literature Review

An analytical and experimental studies on direct-expansion solar-assisted heat pump (DX-SAHP) in Shanghai where the effects of various parameters under the constant compressor speed were performed [1]. In [2], authors carried out preliminary theoretical performance studies concerning a direct expansion solar-assisted heat pump that uses a bare collector as an evaporator for the heat pump. In [3], authors further developed a multi-functional domestic DX-SAHP system, which was able to offer multi-fold functions to residences at low costs, including space heating in winter, space cooling in summer, and hot water supply for the whole year.

A system that uses two-phase solar energy collector in conjunction with a heat pump is developed [4] [5]. Their results indicate that the system merits further investigation. Theoretical and experimental studies were made [6] on the thermal performance of a heat pump that used a bare flat plate collector as the evaporator. Experimental investigations were conducted on the direct expansion solar assisted heat pump (DX-SAHP) [7].

IV. Direct Expansion Solar Assisted Heat Pump

In a direct-expansion solar assisted heat pump system, heat pump refrigerant is directly circulated through a solar collector that acts as the system's evaporator. This collector evaporator absorbs the heat transferred by convection and solar radiation. Solar energy absorbed in the collector/evaporator is transferred to the load via the heat pump's condenser. The condenser can be arranged as an external heat exchanger supplying a hot water tank or arranged as an immersed coil in the hot water storage tank. The concept of the Direct Expansion SAHP as shown in Fig 1 was firstly considered in 1955 [8] and several authors has followed this study [9] [10] [11]. In [12], authors published an experimental validation of the work [13], with the COP ranging from 2 to 3.

V. Experimental Setup

5.1 Flat plate collector

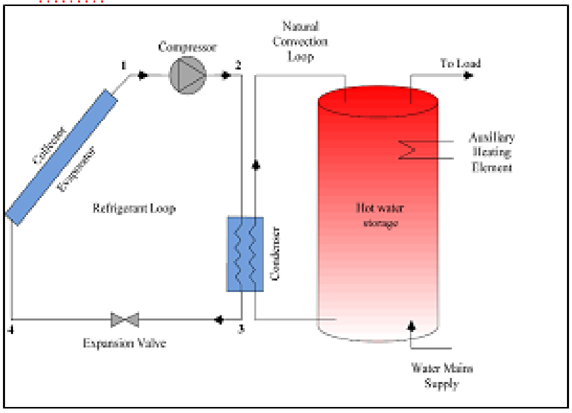


Fig.1. Schematic of a direct expansion SAHPWH

In the present study, a glazed solar collector of an area of 2.23m^2 was used. The solar collector has 0.3-mm thick copper fins attached with copper tube. The fins are coated with matt black paint to absorb the maximum incident solar radiation falling on the surface. The tubes along with fins are placed directly behind the glazing surface of 4 mm thickness with an air gap of 3 cm from the cover. Bottom side of the collector was insulated with a glass wool of 25 mm thickness, to avoid the back losses. The temperature of the air in the gap between the absorber and the glazing surface increases because of the greenhouse effect .The solar collector (evaporator) was tilted to an angle of about 45 degrees with respect to a horizontal surface. The solar collector was oriented to face south to maximize the solar radiation incident on the solar collector.

5.2 Reciprocating compressor

R-134a hermetically sealed reciprocating compressor with rated input power 245 W is used. To avoid the overload, high pressure cut-off switch was connected to the compressor. Compressor work is found by energy meter reading. A small R134a reciprocating-type hermetic compressor with piston swept volume 5.79 cc, and rated input power 245 W is adopted. R134a or 1, 1, 1, 2-tetrafluoroethane is the working fluid in this system. The refrigerant mass flow rate can be evaluated from the volumetric efficiency of the compressor given by Huang B. J. and Chyng J. P. (1999).

$$\dot{m}_r = \frac{\eta_v \times V_D}{v}$$

Where:

$$\eta_v = -0.0163 \times \left(\frac{P_2}{P_1}\right) + 0.6563$$

5.3 Storage tank

Hot storage water tank is assumed to be non-stratified i.e. neglect losses for finding out the coefficient of performance. The condenser is made up of copper tubes of outer diameter 9.5mm with length 9.7m which is immersed in the domestic hot water tank.

$$Q_w = m_w C_{pw} \left(dT_w / dt \right)$$

5.4 Capillary tube

Capillary tube is the throttling devices in the refrigeration and the air conditioning systems. The capillary tube is a copper tube of very small internal diameter. It is of very long length and it is coiled to several turns so that it would occupy less space. The internal diameter of the capillary tube used for the refrigeration and air conditioning applications varies from 0.5 to 2.28 mm. Capillary tube used as the throttling device in the heat pump is of 3 meter in length. When the refrigerant leaves the condenser and enters the capillary tube its pressure drops down due to very small diameter of the capillary.

The Coefficient of performance is defined as the ratio of heat gain Q_w in the condenser to the compressor work

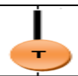
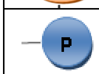
$$COP = \frac{Q_w}{W_{cm}}$$

VI. INSTRUMENTATION AND OTHER MEASURING DEVICES

In order to determine the performance of the prototype under various conditions of the DX-SAHP, The apparatus is equipped with necessary instrumentation.

Properties measured mainly includes temperature, pressure and radiation and these parameters were measured by respective devices as mentioned in table.1

Table 1: Conventions

Label	Instrument
	Thermocouple [Range: -50 to +99°C in 1 deg. Resolution]
	Pressure gauge [bourdon type]
	Wattmeter / Energy meter

A schematic diagram with measuring devices is shown in fig.2

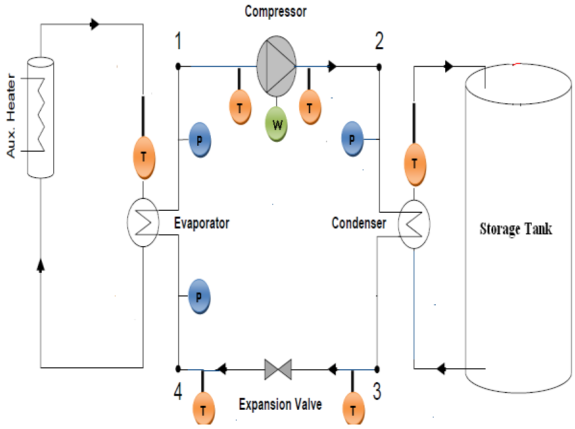


Fig.2. Schematic Diagram of the Apparatus Highlighting Instrumentation

VII. RESULTS

The experimental tests of DX-SAHPWH with glazed evaporator/Flat-plate collector have been conducted on different time of different days. Data was recorded for all tests. Out of that recorded data a single test data has been taken in which heat pump is giving best performance using a glazed evaporator. As Shown in Fig.3. Heat pump gave the best performance between 15:20 pm to 16:45 pm. At that time the coefficient of performance was 3.

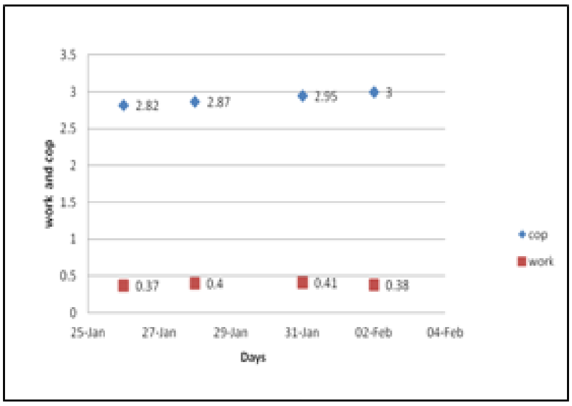


Fig 3: COP verses Work

VIII. CONCLUSION

The Coefficient of Performance of DX-SAHPWH is strongly influenced by the solar intensity and compressor work. The experiment on the above mentioned system was performed for four different days which were chosen depending upon the clarity of sky. The average coefficient of performance (COP) of heating for this system under winter climatic conditions was found to be 2.91. The parameters like. refrigerant mass flow rate, compressor work, temperature and pressure have been measured at different point in the system.

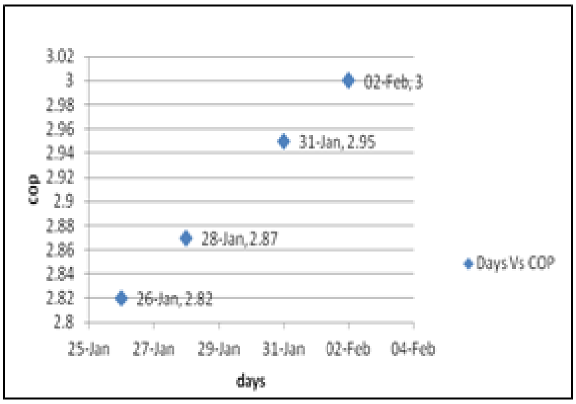


Fig 4: COP measured for different days

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