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INTEGRAL-TYPE SOLAR-ASSISTED HEAT PUMP WATER HEATER

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ABSTRACT

An integral-type solar-assisted heat pump water heater (ISAHP) is designed and tested in the present study. The storage tank and the Rankine cycle unit are integrated together to make a more compact size. A thermosyphon loop is used to transfer the heat from the condenser to the water storage tank. The highest COP obtained in the tests is 3.83. © 1998 Published by Elsevier Science Ltd. All rights reserved.

KEYWORDS

Solar Energy; solar thermal; heat pump

INTRODUCTION

During 1987-1992, Taiwan government launched a subsidy program for solar hot water heater utilization. This subsidy program is quite successful. The annual sale volume of solar water heater is about 0.5 billion US Dollars. The accumulated installation area of solar collector is around 0.8 million square meters in 1997. The annual installation collector area is among 69,000 to 93,000 m^2 in recent 6 years. Approximate 20,000 families install a solar hot water heater every year. Most of the solar water heaters use an electrical heater installed inside the storage tank as the backup for cloudy days. Expensive running cost as well as additional installation cost of a high power line (4kW to 6kW) causes a problem.

An integral-type solar-assisted heat pump water heater (ISAHP) is thus developed in the present study. It differs from the conventional design (Ito *et al*, 1997; Chaturvedi *et al*, 1984; Chaturvedi *et al*, 1998; O'Dell *et al*, 1984; Hino, 1995) in that the storage tank and the Rankine cycle unit are integrated together to make a more compact size. A thermosyphon loop is used to transfer the heat from the condenser to the water storage tank. ISAHP can be simply used as a backup system for solar water heaters or used independently as a solely hot water supply system.

DESIGN OF ISAHP

The ISAHP consists of a Rankine cycle unit, a collector/evaporator unit which combines the evaporator of the Rankine cycle and the solar collector, and a heat exchanger/condenser unit which combines the condenser of the Rankine cycle and the heater of a thermosyphon loop. Figure 1 shows the schematic of the ISAHP.

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The ISAHP absorbs energy from solar radiation and ambient air simultaneously and then pumps the heat to the storage tank through a Rankine cycle unit. For better reliability and reducing the cost, a heat exchanger/condenser unit is designed with a thermosyphon loop to transfer the heat from the condenser to the water storage tank. The condenser releases condensing heat from the Rankine cycle to the water side of the heat exchanger for producing a natural- circulation flow in the thermosyphon loop.

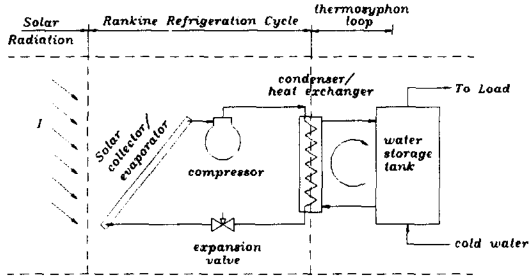

Figure 1 Schematic diagram of a ISAHP

The performance of an ISAHP is not steady due to the variation of ambient conditions including solar irradiation, wind speed, air temperature and humidity, and raining etc. The design of a Rankine cycle unit for running at unsteady-state conditions is a big challenge. Basically, the evaporation temperature of the Rankine cycle should be controlled at a temperature below the ambient temperature in order to absorb heat from air during cloudy periods. However, it would be close to the ambient temperature during shinny periods. Another design problem is the unbalance between the refrigeration capacity of the compressor and the heat-absorption capacity of the evaporator. This may result in the overheat or shut-down of the compressor.

The solar collector of the ISAHP used in the present study is of tube-in-sheet, unglazed type. The incident solar radiation is absorbed by the collector plate (copper) and transferred to the refrigerant inside the copper tubes (the evaporator of the Rankine cycle). In order to absorb energy from ambient air, no transparent cover is used for the solar collector. The collector plate is divided into 4 parts: top(50cm×

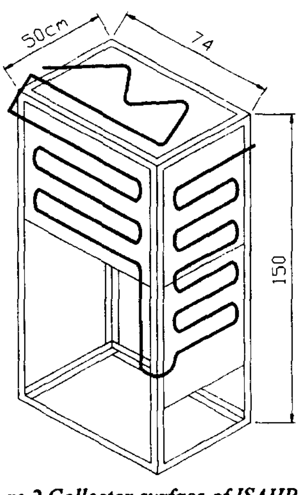

Figure 2 Collector surface of ISAHP

Figure 3 Prototype of ISAHP

Table 1 Test results of the ISAHP.

water temp. °C		ambient temp.	solar radiation	condensing pressure MPa		evaporating pressure MPa	condensing temp. °C		evaporating temp. °C	COP
initial T_{wi}	final T_{wf}	T_a °C	H_t kJ/m^2	initial P_{Hi}	final P_{Hf}	P_L	initial T_{ci}	final T_{cf}	T_e	COP
24.6	41.9	31.8	3950.0	1.13	1.46	0.56	44.0	54.1	19.3	3.53
24.8	36.3	31.1	3504.0	1.08	1.20	0.49	42.3	46.3	15.1	3.48
24.0	33.0	24.8	2636.1	1.05	1.16	0.49	41.2	45.0	15.1	3.56
24.6	35.1	31.3	1282.5	1.07	1.18	0.49	41.9	45.6	15.1	3.83
24.5	32.6	18.3	847.4	0.90	1.02	0.36	35.5	40.4	6.0	2.61
23.6	30.5	18.3	383.0	0.92	1.00	0.38	36.3	39.8	7.4	2.84
38.6	52.0	30.7	5581.9	1.36	1.78	0.57	51.3	62.4	19.9	2.54
36.1	48.5	31.7	3255.9	1.45	1.61	0.63	53.9	58.2	23.2	2.81
36.0	46.0	30.6	1329.4	1.40	1.55	0.58	52.4	56.6	20.4	2.55
36.0	44.4	18.3	602.6	1.06	1.30	0.37	41.6	49.5	6.6	1.47
36.4	39.9	17.3	223.6	1.15	1.26	0.37	44.7	48.5	6.6	1.34

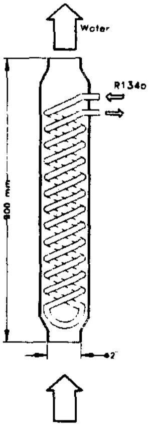

Figure 4 Heat exchanger/condenser unit.

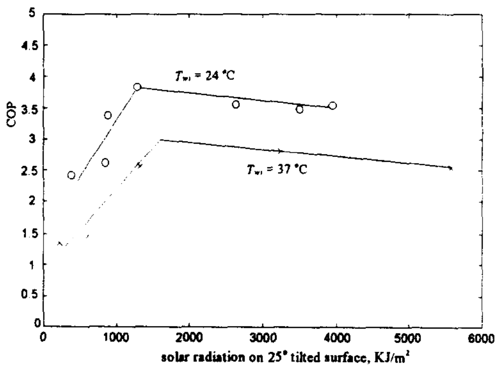

Figure 5 Test result.

74cm), front(50cm X 120cm) and two sides(50 X 60cm) as shown in Figure 2 and Figure 3. The prototype adopts a 120-liter water storage tank and a 110V/60Hz, 150W compressor used in household refrigerator. R134a is used as the working fluid. A double-wall heat exchanger is used as the heat exchanger/condenser unit as shown in Figure 4.

TEST OF ISAHP

The ISAHP is tested under various ambient temperatures and solar irradiation. The temperature variations in water, condenser and evaporator are recorded. The pressure variations of the Rankine cycle unit and the ambient temperature and COP are also measured. The COP is defined as the ratio of the actual heat input to the water storage tank Q_H to the electrical energy input to the compressor W_{comp}: i.e., $COP = Q_H / W_{comp}$. The accumulated solar radiation energy incident upon a 25 degree tilted surface is recorded during each test.

Tests were conducted at two initial water temperatures (24 and 37°C, in average). Shown in Table 1 and Figure 5 are the test results. We found that the COP first increases with increasing solar radiation and then reaches a maximum value. After that, COP starts to decrease or saturate. The ambient temperature has very little influence on the performance of the ISAHP. It is shown from experiments that the evaporation temperature of the Rankine cycle unit is about 10 to 16°C below the ambient temperature. This is different from the conclusion of Chaturvedi *et al* (1998) that the evaporating temperature of the Rankine cycle unit needs to be higher than the ambient temperature.

The highest condensing pressure is 1.78 MPa (62.4°C) when the solar irradiation has the highest value (5581kJ/m^2) and the final water temperature reaches 52°C with COP=2.54. The highest COP obtained in the present test is 3.83 which occurs at moderate solar irradiation (1282 kJ/m^2) and final condensing temperature 45.6°C. The ISAHP runs very well during shinny days. However, the performance is poor at cloudy days (at low solar radiation) when ISAHP absorbs heat mainly from the ambient. This may be improved by using an automatic throttling device or adding a backup evaporator. It is desired to design an ISAHP with a constant COP irrespective of the variation of solar radiation. Further study is still underway.

CONCLUSION

In the present study, we have shown the feasibility of an integral-type solar-assisted heat pump water heater (ISAHP). ISAHP integrates the storage tank and the Rankine cycle unit together to make a more compact size. A thermosyphon loop is used to transfer heat from the condenser to the water storage tank. Hence, no circulation pump is required. The performance test of a prototype shows that a high COP can be obtained.

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