ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Research and developments on solar assisted compression heat pump systems – A comprehensive review (Part-B: Applications)

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ARTICLE INFO

Keywords:
Solar assisted compression heat pumps
Drying
Space heating
Water heating
Desalination

ABSTRACT

The second part of this review presents a comprehensive review on applications of solar assisted compression heat pump systems and its associated research potentials. The reported investigations on solar assisted heat pumps are categorized into five major groups as follows: (a) drying, (b) room space heating; (c) agricultural green house space heating, (d) water heating and (e) desalination applications. Most of the reported investigations in open literature are reviewed. The study will then presents the major limitations of solar assisted compression heat pumps and further research tasks in various applications. This paper concludes that solar assisted compression heat pump system is the promising equipment used for heating applications. The information presented in the second part of the review is beneficial to the researchers, energy experts and decision makers in the field.

1. Introduction

The fast depletion of fossil fuel resources and its significant impacts on environment have created research interest on applications of solar assisted compression heat pump (SACHP) systems. Among the renewable energy options, solar energy is an economical, non-polluting and readily available energy source, which can be easily integrated with heat pumps. Hence, the fast research and developments were observed with SACHP systems when compared to the geothermal heat pumps. During, last two decades, many research and developments have been reported with the applications of SACHP systems. The SACHP systems have been widely used for drying, space heating, water heating and desalination applications. Earlier reviews in the field of heat pump technology highlighted the scope of applications for drying [1,2], space heating [3,4], water heating [5,6], desalination [7] and for industrial applications [8]. All these reported reviews are consolidated in Table 1. Following the cited reviews, it is understood that there was no explicit comprehensive review reported on applications of SACHP systems. Hence, the main objectives of this review are formulated as follows:

(i) to summarize the applications of SACHP systems for drying applications,
(ii) to review the applications of SACHP systems for room space heating applications,
(iii) to describe the applications of SACHP systems for agricultural space heating,
(iv) to consolidate the applications of SACHP systems for water heating,
(v) to review the applications of SACHP systems for desalination,
(vi) to identify the major limitations of SACHP systems and
(vii) to identify the further research needs associated with applications of SACHP systems.

The remaining part of this paper contains seven sections as follows: Section 2 describes the applications of SACHP systems for drying, Section 3 presents the applications of SACHP systems for room space heating applications, Section 4 reported the applications of SACHP systems for agricultural space heating. The studies reported on SACHP systems for water heating applications are reviewed in Section 5. In Section 6, an overview of the studies reported on applications of SACHP systems for desalination are presented. Further research challenges on SACHP are reviewed in Section 7. Finally, Section 8 provides the conclusions of this paper.

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http://dx.doi.org/10.1016/j.rser.2017.08.086

Table 1
Earlier review studies on heat pumps during last decade.

Authors [Ref.]	Year	Country	Topic of review
Daghigh et al. [1]	2007	Turkey	Heat pumps for drying applications
Fadhel et al. [2]	2009	Turkey	Heat pumps for drying applications
Ni et al. [3]	2015	China	Heat pumps for space heating applications
Chu and Cruickshank [4]	2014	Canada	SACHP systems for space heating in Canada
Hepbasli and Kalinci [5]	2011	Turkey	Heat pump water heaters
Buker and Riffat [6]	2016	UK	Water heating applications
Kalogirou [7]	2005	Cyprus	Sea water desalination
Zhang et al. [8]	2016	China	Industrial applications of heat pumps

2. Drying applications

Drying of agricultural materials is the most energy-intensive processes in food processing industries. The heat pump driers are reported to be an energy efficient device, which produce high quality dried products [9]. The integration of solar energy with heat pump is an energy efficiency option, which eliminates the drawbacks with conventional drying systems or exclusively using an ambient source heat pump. In this subsection, the studies reported with SACHP driers are reviewed and also consolidated in Table 2.

2.1. Solar assisted compression heat pumps

Best et al. [10,11] investigated the performance of a R22 based DXSAHP drier for drying of rice. In their work, about 44.8 kg of rice was dried from initial moisture content (dry basis) of about 25.5% to final moisture content (dry basis) of about 11.5% in 4.9 h. The COP and specific moisture extraction rate (SMER) of the drier were calculated as 5.3 and 3.5 kg/kW h. Similar experimental and theoretical investigations were carried out in a DXSAHP drier using R134a as refrigerant for drying of green beans [12,13]. The schematic view of the experimental setup is depicted in Fig. 1. They predicted the performance of the DXSAHP for the meteorological conditions of Singapore. The results showed that COP of the system was varied between 4.0 and 9.0, while the solar collector efficiency was varied between 40% and 75%. The SMER of the drier was reported as 0.65 kg/kW h for a load of 20 kg of green beans. They suggested that the performance can be improved by variable speed compressor. Further, the performance of an evaporator collector and air collector used in a DXSAHP drier was investigated under the meteorological conditions of Singapore [14]. It was reported that the energy efficiencies of the evaporator collector was varied in the range between 0.8 and 0.86 and the energy efficiency of the air collector was varied in the range between 0.7 and 0.75 with an additional humidifier. In a recent work, Rahman et al. [15] made an economic optimization of an evaporator and air collector of a DXSAHP drier. Their economic analysis reveals that the DXSAHP drier has significant cost savings with a payback period of 4.4 years using air collector area and evaporator collector area of 1.25 m^2 and 2 m^2, respectively. The air temperature and mass flow rate are 50 °C and 0.036 kg/s, respectively, which provides 89% of the total load.

Similarly, the performance of a DXSAHP drier using R22 as refrigerant was investigated for processing the copra under the meteorological conditions of Pollachi in India [16]. The line diagram of DXSAHP drier used in his work is depicted in Fig. 2. The standard energy performance parameters such as COP, condenser heat capacity and SMER were evaluated. It was reported that COP of a DXSAHP drier was varied between 2.31 and 2.77 with an average value of 2.54. The SMER was calculated as 0.79 kg/kW h. The moisture content (wet basis) was reduced from about 52% to about 9% in 40 h, which was found to be better when compared to the ambient source heat pump drier for copra processing [17]. Similarly, Li et al. [18] studied the performance of SACHP in-store drying system by both experimentally and theoretically. Their results reported that solar fraction of the unit is more than 20% under normal climates. During sunny days, the solar fraction was reached 28%. The maximum and average COP of the SACHP drier was calculated as 6.25 and 5.19, respectively with SMER of 3.0 kg/kW h. Further investigation confirmed that the quality of products obtained from the SACHP drier was significantly higher with reduced compressor power consumption when compared to the conventional drying systems [19]. Qiu et al. [20] investigated the performance of a SACHP system (with heat recovery and thermal storage) for drying of 10 kg of radish in China. In their heat pump configuration, the condenser and evaporator were integrated with drying chamber. It was reported that the COP of the heat pump drier was varied from 3.21 to 3.49 with about 40.5% energy savings in terms of heat recovery and energy storage. The payback assessment results reported that drying of radish, pepper and mushroom were 6, 4 and 2 years, respectively.

The performance of a SACHP drier was investigated by Sevik et al. [21] for mushroom drying. It was reported that experimental COP of the system was varied from 2.1 to 3.1 with their SMER value was varied between 0.26 and 0.92 kg/kW h. The moisture content (on dry basis) of mushroom was reduced from 13.24 g of water/g of dry matter to final moisture content of 0.07 g of water/g of dry matter in 230 min at 45 °C air temperature with good quality. In another work, Suleman et al. [22] investigated the performance of a SACHP for industrial heating applications. Their results reported that the energy and exergy efficiency of the process are 58% and 75%, respectively. The energetic COP and exergy efficiency of the heat pump are 3.54% and 42.5%, respectively. The energetic COP and exergy efficiency for the whole system was reported as 2.97% and 35.7%, respectively. In a recent work, Ceylan and

Table 2
Applications of SACHP systems for drying applications.

Authors [Ref.]	Location	Heat pump configuration	Conclusions
Best et al. [10,11]		DXSAHP drier used for rice drying	COP of the heat pump was reported as 5.3 with SMER of 3.5 kg/kW h.
Hawlader et al. [12–15]	Singapore	DXSAHP drier used for green beans drying	COP was varied between 4.0 and 9.0 with SMER of 0.65 kg/kW h.
Mohanraj [16,17]	India	Solar-ambient source heat pump direr	COP variations were in the range between 2.31 and 2.77 with SMER value of 0.79 kg/kW h.
Li et al. [18,19]	China	SACHP	The maximum COP of the drier was calculated as 6.25 with SMER of 3.0 kg/kW h.
Qiu et al. [20]	China	SACHP	About 40.5% improved energy savings were reported by integrating the system with heat storage and recovery unit.
Sevik et al. [21]	Turkey	DXSAHP for Mushroom drying	The COP was varied between 2.1 and 3.1 with SMER variations between 0.26 and 0.92 kJ/kW h.
Suleman et al. [22]	Canada	SACHP for industrial heating	COP of the heat pump was reported as 3.54 with exergy efficiency of 35.7%.
Ceylan and Gurel [23]	Turkey	Fluidized bed heat pump drier assisted by solar energy	The COP of the heat pump was reported to be about 5.0 with exergy efficiency of 0.26.
Mottezapour et al. [24]	Iran	Photovoltaic air heater assisted heat pump	About 33% of energy consumption was reduced with SMER of 1.16 kg/kW h.
Sevik [25]	Turkey	PV-TE assisted heat pump drier	COP of the system was varied in the range between 1.96 and 2.28 for processing different products such as tomato, strawberry, mint and parsley.