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Research and developments on solar assisted compression heat pump systems – A comprehensive review (Part A: Modeling and modifications)

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ABSTRACT

This paper presents a comprehensive review on research and developments on solar assisted compression heat pump systems, mostly reported during the last two decades. The first part of this paper provides a detailed description of the past efforts on various system configurations, system modeling, enhancement of system performance, modifications in compression heat pump cycles and environment friendly refrigerant options for solar assisted compression heat pump systems. The economical and environmental impacts of solar assisted compression heat pump systems are also described. Further research needs in this important field of solar assisted compression heat pump are listed. The outcomes of this review confirm that, there is a lot of research scope for improving the performance of the system and reducing its initial cost to make it competitive in the global market. The information presented in this paper is shall be highly beneficial for the active researchers working presently on solar assisted compression heat pumps.

1. Introduction

Heat pumps are identified as energy efficient devices due to its ability to deliver more amount of heat energy than the work input it takes. The performance of a heat pump can be improved by integrating it with renewable energy sources (RES) using solar thermal collector-evaporators [1], solar photovoltaic-thermal hybrid collector-evaporators [2], geothermal heat exchangers [3], and solar-geothermal hybrid heat exchanger configurations [4]. The geothermal energy integration with heat pump system is more expensive due to the excavation of geothermal heat exchangers. Hence, the fast research and developments were observed with solar assisted compression heat pump (SACHP) systems when compared to the geothermal heat pumps. During last decade, many research and developments have been reported on SACHP technology. Some of the earlier review reports in the field of heat pump technology highlighted areas like the thermodynamic analysis of SACHP systems [5], gas engine drive heat pumps [6], advancements on heat pumps [7], CO_2 based heat pump systems [8], direct expansion solar assisted heat pump (DXSAHP) systems [9], solar assisted heat pumps in Singapore [10], geothermal heat pump systems (GSHP) [11], waste water source heat pumps [12], solar systems and its integration and heat pumps in smart grids [13], etc. All these earlier reported reviews on heat pumps during last decade are consolidated and presented in Table 1. The time distribution of the number of studies reviewed in this paper during last two decades is depicted in Fig. 1. From Fig. 1, it can be understood that, the number of studies on SACHP systems has increased gradually during the last decade.

Following the cited reviews, there was no explicit comprehensive review reported on SACHP systems. The major objectives of the present review (Part-A) are formulated as follows:

(i) to describe the various possible heat pump configurations,
(ii) to describe the different modeling methodologies,
(iii) to summarize the studies reported on performance improvements,

Abbreviations: ANN, Artificial Neural Network; *CFC*, Chloro-fluro-carbon; *COP*, Coefficient of Performance; CSACHP, Conventional solar assisted compression heat pump; *DXSAHP*, Direct Expansion Solar Assisted Heat Pump; *GWP*, Global Warming Potential; *HCFC*, Hydro-chloro-fluro-carbon; *HC*, Hydrocarbon; *HFC*, Hydro-fluro-carbon; *MLFFN*, Multi Layer Feed Forward Network; *ODP*, Ozone Depletion Potential; PV-TE, Photovoltaic-Thermal Evaporator; RES, Renewable Energy Systems; SACHP, Solar Assisted Compression Heat Pump; SGHSHP, Solar Geothermal Hybrid Source Heat Pump; *SEIR*, Solar Energy Input Ratio; SPV-THP, Solar Photovoltaic-Thermal Heat Pump; *TEWI*, Total Equivalent Warming Impact

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Nomenclature

A_c	Area of the collector (m^2)
c_p	Specific heat ($J/kg\ K$)
E	Energy consumption per day ($kW\ h$)
ex	Specific exergy (kJ/kg)
$\dot{Ex}$	Exergy rate (kW)
h	Enthalpy (kJ/kg)
L	Life of the system (10 years)
I	Solar intensity (W/m^2)
$\dot{I}_{rr}$	Irreversibility (kW)
$\dot{m}$	Mass flow rate (kg/s)
n	Working hours of the system (8 h per day)
N	Speed of the compressor
p	Pressure (MPa)
Q	Heat transfer rate (W)
Q_c	Heating capacity (W)
s	Entropy ($kJ/kg\ K$)
T	Temperature (K)
U	Over all heat transfer coefficient ($W/m^2\ K$)
V	Velocity of air (m/s)
v	Specific volume of the refrigerant (m^3/kg)
V_{dis}	Volumetric displacement (cm^3/rev)
$\dot{W}_{comp}$	Power consumption (W)

Greek symbols

α	absorptance (0.97)
β	carbon dioxide emission factor
ε	exergy efficiency (%)
χ_i	relative exergy destruction (kW)
η_{elec}	electrical efficiency
η_{mech}	compressor mechanical efficiency
η_{vol}	volumetric efficiency

Subscripts

0	ambient condition (dead state)
1–6	typical locations in pressure enthalpy chart of vapor compression cycle
a	air
co	condenser outlet
comp	compressor
cond	condenser
ci	condenser inlet
CH	chemical
dest	destruction
dis	displacement
EV	expansion valve
e	evaporator
elec	electrical
$f(T_c)$	liquid state after condensation
F	liquid phase
$g(T_s)$	gaseous state at suction
G	vapor phase
in	inlet
KN	kinetic
mech	mechanical
out	outlet
p	pressure
pl	plate
PH	physical
PT	potential
r	refrigerant
rad	radiation
SC	solar collector
sys	system
T	total

(iv) to consolidate the workable modifications in solar assisted compression cycles,
(v) to identify the various environment-friendly refrigerant options for SACHP systems,
(vi) to assess the economical and environmental impacts and
(vii) to identify the further research needs in this field.

The remaining part of this paper is categorized into ten sections. Section 2 describes the various configurations of SACHP systems. In Section 3, the equations used for modeling of solar assisted compression heat pumps are presented. In Section 4, the performance improvements of SACHP systems using heat storage materials, modifications in collector-evaporators, heat pipe enhanced collectors and using variable frequency compressors are discussed. The studies reported on compression heat pump cycle modifications are discussed in Section 5. Section 6 consolidates the reported investigations on environment-friendly refrigerants. The performance of heat pumps using different energy sources are compared in Section 7. The economical and environmental impact assessments of the SACHP systems are discussed in Section 8. Further research extensions in the field of SACHP systems are listed in Section 9. Finally, Section 10 elaborates the conclusions.

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

Authors [Ref.]	Year	Country	Topic of review
Ozgener and Hepbasli [5]	2007	Turkey	Solar assisted heat pumps
Hepbasli *et al.* [6]	2009	Turkey	Gas engine drive heat pumps
Chua *et al.* [7]	2010	China	Advances in heat pump systems
Austin and Sumathy [8]	2011	Canada	Carbon-dioxide heat pumps
Omojaro and Breitkopf [9]	2013	Germany	Direct expansion solar assisted heat pumps
Amin and Hawlader [10]	2013	Singapore	Solar assisted heat pumps in Singapore
Sarbu and Sebarchievici [11]	2014	Romania	Ground source heat pumps
Hepbasli *et al.* [12]	2014	Turkey	Waste water heat pumps
Kamel *et al.* [13]	2015	Canada	Solar energy integration with heat pumps
Fischera and Madani [14]	2017	Germany	Heat pumps in smart grids

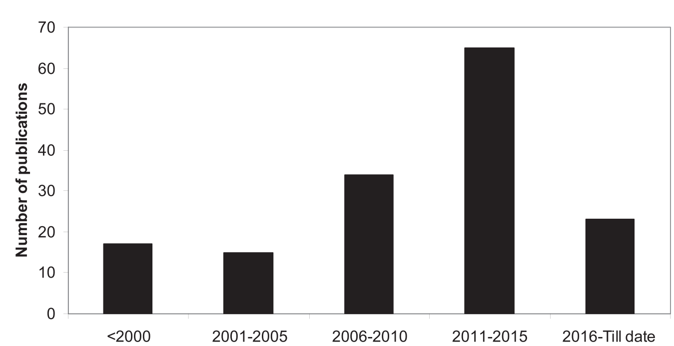

Fig. 1. Number of studies reviewed on SACHP systems during last two decades.