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Research Paper

Simulation studies on simultaneous power, cooling and purified water production using vapour absorption refrigeration system

G. Praveen Kumar, R. Saravanan *, Alberto Coronas

Department of Mechanical Engineering, Anna University, Chennai 25, India
Universitat Rovira I Virgili, Group of Applied Thermal Engineering, Tarragona 43007, Spain

HIGHLIGHTS

- A novel absorption system based combined cooling, power, desalination is proposed.
- The system can able to provide simultaneous power, cooling and purified water.
- Energetic and exergetic performance of combined cycles is analysed.
- Highest energy and exergy efficiencies are obtained at 95 °C heat source temperature.

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1. Introduction

Converting low-grade heat to high form of usable energy is an enduring area of interest in engineering applications, in which considerable research continues to be undertaken. Fresh water and usable energy are essential for sustaining human life on earth; they can also be produced by utilizing low temperature heat resources such as solar, biomass, geothermal and waste heat from industries. The demand for the generation of these two indispensable resources. i.e. safe water and electricity, grows proportional to population and industrial growth. Closed buildings are found responsible for at least 40% of electrical energy use in most countries. In a much-focused way, the primary energy of buildings with grid tied transmitted electric power that is generated through non-renewable energy sources leads to enormous danger to world sustainability by faster depletion of natural resources. Inefficiencies and energy transmission losses in traditional power plants would certainly be eliminated by on-site and near-site power generation from waste sources of bottoming cycles. Usage of renewable sources and reduction of primary energy consumption would decrease the dependency on fossil fuels. In buildings, the electric operated air-conditioning systems consume significant part of total energy consumption. Majority of air-conditioning systems in buildings are motor driven compression chillers. These primary energy consumptions can be reduced by maximised usage of renewable sources.

In this context, polygeneration is an energy efficient concept with simultaneous production of multiple outputs from one or more sustainable primary low form energy sources such as solar thermal, biomass, and biogas. The concept is highly flexible and can adapt to multiple input sources and can also be characterized with particular demand profiles of output to the end user. The polygeneration framework can develop by either through unitary or integrate the multiple system. In that sense to meet all capacity

* Corresponding author at: Department of Mechanical Engineering, Anna University, Chennai 25, India.
E-mail address: rsaravanan@annauniv.edu (R. Saravanan).

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Nomenclature

h	specific enthalpy (kJ/kg)
Q	heat load (kW)
T	temperature (°C)
Sp	solution pump
1–28	state points in the system corresponding to Fig. 1
$\eta_{I,eff}$	effective first law efficiency
η_{ref}	second law efficiency for vapour compression refrigeration cycles (assumed as 40%)
S	specific entropy (kJ/kg K)
ST	splitter
D_1–D_{11}	state points in desalination sub-system corresponding to Fig. 1
m	mass flow rate (kg/s)
X	concentration
P	pressure (bar)
R	refrigerant
T_0	reference temperature
P_0	reference pressure

Abbreviations

CPCD	combined power cooling and desalination
RR	recovery ratio
CR	circulation ratio
SR	split ratio
SHX	solution heat exchanger
SCR	solution cooled rectifier
VARS	vapour absorption refrigeration system
FD	freeze desalination
MSF	multi stage flash desalination
MED	multi effect distillation
SM	solidification-melting
AAR	ammonia absorption refrigeration system
LNG	liquefied natural gas
TDS	total dissolved solids

Subscripts

Exp	expander
EV	evaporator
G	generator
A	absorber
hw	hot water
cw	cooling water
B	brine solution

variations ammonia based Vapour Absorption Refrigeration System (VARS) is adapted to unitary polygeneration concept with potential output applications of power, cooling, heating and drying [1–3]. Moreover, VARS utilizes low-grade energy sources to adapt and meet flexible output demand.

The simultaneous differences in the output ratios of the system can be altered ensuring the system with offers with consistently good performance throughout the year. The working fluid of VARS system is ammonia-water varied composition binary working pair, non-azeotropic in nature that has good thermal glide with heat source, as an intrinsic property that can be effectively utilize the available heat source [4].

When compared to individual production individual production the combined cycles can improve the source utilization efficiency by possible arrangement of components in the system leadings to energy and exergy flows with its available driving forces within the system. In such ways, ammonia absorption cycle has been possibly integrated with Kalina or Rankine cycle for simultaneous power and cooling outputs [5]. In the past decades, several absorption based combined cycles have been proposed and discussed from optimization, efficiency point of view. Goswami [6] introduced the combined absorption cycle, in which low temperature cycle such as Rankine and absorption cycles are coupled to provide cooling and mechanical power as useful outputs. The cycle mainly emphasize on power output rather than cooling, in which the turbine exhaust provides cooling by sensible heat to chilled water. The author claimed a system operating with working fluid temperature of 193 °C could provide electrical power of 2 MW and cooling output of 175 kW at specified operating conditions. Further researchers have also analysed the system, in many aspects of parametric analysis, cooling output at very low temperatures, focussing on optimization of the cycle, modification of cycle for improving resource utilization ratios. Thermodynamic performance of the system was optimized for maximum second law efficiency; a maximum second law efficiency of 65.8% was obtained at 420 K [7,8]. Zhang et al. [9] proposed a parallel combined cycle by integrating ammonia water Rankine cycle and ammonia refrigeration cycle. Both the cycles are interconnected by absorption, separation and heat transfer process. The combined system performance was evaluated through energy and exergy efficiencies of 28% and 55–60% for base case condition of heat source at 450 °C. Zheng et al. [10] proposed a new ammonia absorption power and cooling system. The proposed system is a combination of Kalina and absorption cycles, for dual outputs in which Kalina cycle is slightly modified by replacing a flash tank with the rectifier to enhance the purity of refrigerant meant for low temperature refrigeration. Wang et al. [11] thermodynamically analysed the proposed combined Kalina and ARC cycle, the system has two separators operating with three pressure levels. Exergy destruction distribution in the system was analysed, the major exergy destruction existed in the exhausted heat source. Cao et al. [12] investigated a Kalina based CCP cycle; absorption refrigeration is a bottoming cycle and the optimized system was compared with a separate production system which was also optimized, the results showed that net power output and exergy efficiency was higher in the combined system. Researchers also analysed different combined cycle configurations from series to parallel outputs. Moreover, parametric analysis was performed to study the effect of heat source, sink and chilled water temperatures along with system potential that was optimized for dual outputs, first and second law efficiencies. Exergy analysis was performed in the combined cycle for both reversible and irreversible process in order to clearly show the effects of irreversibilities in components of the cycle [13,14]. Vapour generation and absorption condensation process exhibited a close agreement with theoretical results. Subsequently, rectifier and turbine were included in the experimental setup to get required quality of ammonia vapour and work output respectively. With few modifications in size of rectification column, falling film absorber and scroll expander for power generation, the performance and cycle of useful outputs increased.

Experimental systems have been established to study the feasibility and operating difficulties of the proposed theoretical combined power and cooling cycles. Demonstration of the combined cycles provides greater insight into the fundamentals of the systems with practical experience to incorporate further improvements further for commercialization. Han et al. [15] developed