



Exergy analysis of a H₂O–LiCl absorption refrigeration system with operating temperatures estimated through inverse analysis



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ABSTRACT

In this study, operating temperatures of a H₂O–LiCl vapor absorption refrigeration system (VARS) are first estimated using an inverse technique with weak solution concentration as objective function and a differential evolution (DE) optimization algorithm for objective function minimization. Total 34 combinational temperatures are obtained and for each of these combinations the VARS energetic and exergetic performance results are presented. Parametric analysis is performed to show performance variation with component temperatures. A performance comparison between H₂O–LiCl and H₂O–LiBr systems is also provided under identical conditions. Results show that coefficient of performance (COP) increases with evaporator temperature while the exergy efficiency decreases and the total system irreversibility increases. COP is also more at lower condenser and absorber temperature, however the exergy efficiency becomes less and total system irreversibility increases. This contradiction arises due to the water temperatures at entry and exit of the condenser, evaporator and absorber which are considered to vary with component temperatures in this analysis. However magnitude wise the exergy efficiency is more and total system irreversibility is less when variable water temperatures are considered instead of fixed. It was found that VARS performance variation with generator temperature solely depends upon selection of condenser and absorber temperatures. H₂O–LiCl system is found superior to the H₂O–LiBr system.

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1. Introduction

Vapor absorption refrigeration system (VARS) driven by waste heat stream, solar and geothermal energy are receiving significant research interest in the recent years. In a VARS, property of the refrigerant/absorbent pairs plays a major role and greatly affects the performance [1]. Water is considered to be a good refrigerant and eventually most of the VARSs uses water as refrigerant [2]. Marcriss et al. [3] mentioned about 40 various refrigerants and 200 absorbent compounds in his article. Among them, aqua ammonia (NH₃–H₂O) and water–lithium bromide (H₂O–LiBr) refrigerant/absorbent pairs are very common in VARS [4]. However the search for newer and better alternative refrigerant–absorbent pairs is on to realize improved system performance. H₂O–LiCl solution pair is another potential candidate with advantage of triple state point (solid, liquid and vapor form), long-term stability in the regeneration process under atmospheric conditions, comparatively less cost and better cycle performance [5,6]. Many experimental studies have been carried out to determine properties of H₂O–LiCl solution pair and mathematical correlations are developed through curve

fitting of experimental results [7–9]. In fact when some reasonably accurate empirical correlations are developed by researchers for calculation of thermodynamic properties of such binary mixtures, this is done with the purpose that these might benefit others in carrying out theoretical performance studies of VARS using these binary mixtures as working fluids. Grover et al. [10] made theoretical study of a single stage H₂O–LiCl VARS where they used a set of temperature dependent equations for calculating solution concentration and enthalpy to determine coefficient of performance (COP) and flow ratio (FR) at various combinations of component temperatures. FR is a performance parameter defined as the ratio of the mass flow rate of the salt solution entering the generator to the mass flow rate of refrigerant. Further, the COP and FR results of H₂O–LiCl system were compared with published results of H₂O–LiBr system. It was shown that FR is low and COP is more in the H₂O–LiCl system than those of the H₂O–LiBr system under identical operating conditions. Won and Lee [11] investigated the energetic performance (COP and FR) of a double-effect H₂O–LiCl VARS through computer simulation at various operating temperatures. A performance comparison between H₂O–LiCl and H₂O–LiBr systems was also provided in terms of energetic performance parameters where they observed higher COP and lower FR in respect of the H₂O–LiCl VARS. Saravanan and Maiya [12] also provided

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Nomenclature

COP	coefficient of performance
C_p	specific heat (kJ/kg K)
\dot{E}_x	exergy (kW)
h	enthalpy (kJ/kg)
i	exergy destruction (kW)
\dot{m}	mass flow rate (kg/s)
\dot{Q}	heat load (kW)
s	specific entropy (kJ/kg K)
T	temperature (°C)
T_0	reference temperature (°C)
\dot{W}	work transfer rate (kW)
X	solution concentration (%)

Greek letters

ψ	specific exergy (kJ/kg)
η	exergy efficiency (%)

Subscripts

A	absorber
C	condenser
c	Carnot
E	evaporator
ExV	expansion valve
G	generator
i	inlet
o	outlet
p	solution pump
r	refrigerant
ss	strong solution
s	steam
SHE	solution heat exchanger
tot	total
w	water
ws	weak solution

thermodynamic analysis of a water based VARS with four binary mixtures including that of H₂O–LiCl. The equations proposed by Grover et al. [10] were used for calculating thermodynamic properties of H₂O–LiCl solution and H₂O–LiCl was found superior in terms of cut-off temperature (minimum generator temperature at which the system can operate) and FR. She et al. [13] has recently proposed a novel low grade heat-driven VARS using H₂O–LiCl in the high-pressure cycle and H₂O–LiBr in the low-pressure cycle. In this work, three different heat source utilization modes viz. two parallel modes (PM-1 and PM-2) and one serial mode (SM) are considered to provide performance comparison among them and also with a traditional double-stage H₂O–LiBr VARS. The effect of heat source temperature, intermediate pressure and the component temperatures on system performance has also been analyzed in this paper. The research works [10–13] are however totally based on energy analysis which alone is not sufficient to evaluate features of energy resource utilization as it provides only the quantitative measurement and completely ignores the qualitative aspect of it. Energy analysis does not provide the designer the best insight into the system's operation. Exergy analysis based on second law is must if someone desires to evaluate the source of inefficiency and irreversible losses occurring in various system components. Any attempt to reduce system irreversibility would result in better performance through efficient utilization of energy resources. Therefore, to reduce irreversibility, it is necessary to quantify them through exergy analysis as it offers the system designers a plenty of scope for improvement of system operations [14]. Exergy analysis of H₂O–LiBr VARS has been performed in various studies [15–20]. Articles on exergy analysis of NH₃–H₂O systems are also available in the literature [21–23]. In article [23], NH₃–H₂O based GAX and GAX hybrid absorption refrigeration cycles are analyzed to calculate the total exergy destruction rate within the cycles and also to determine the contribution of different components to the total exergy destruction. In the GAX cycle, the waste energy from the absorber is used to supplement the generator heat. The difference between the two cycles is that the absorber operates at comparatively higher pressure in the hybrid cycle due to a compressor between the evaporator and the absorber. Exergy analysis of air-cooled non-adiabatic absorption refrigeration cycle using NH₃–NaSCN and NH₃–LiNO₃ refrigerant solutions has also been done [24]. In so far as H₂O–LiCl system is concerned, exergy analysis of H₂O–LiCl VARS is neither available nor it was attempted before to evaluate its exergetic performance analyzing the effect of operating temperatures on exergy

destruction of individual components or the overall H₂O–LiCl VARS as a whole. In this work, detail energy and exergy based parametric analysis of a H₂O–LiCl VARS is provided. Exergetic efficiency and component irreversibility of the H₂O–LiCl VARS are evaluated with the help of a MATLAB code and presented along with the energy based performance.

Crystallization characteristics of a particular aqueous salt solution in a VARS are governed by its component operating temperatures. Therefore, a VARS designer cannot arbitrarily choose operating temperatures for the generator, condenser, evaporator and absorber of the VARS. In articles [7–9], the formulations for thermodynamic properties of H₂O–LiCl solutions were provided for the composition range from pure water to 50 wt.% Grover et al. [10] also took the upper limit of solution concentration as 51% and accordingly the operating temperatures were selected. All combinations of operating temperatures don't fulfil this criterion of solution concentration $\leq 51\%$. Therefore to avoid this problem, a differential evolution (DE) based inverse method is used to estimate the generator, condenser, evaporator and absorber temperatures in the present work considering the weak solution concentration (X_{ws}) below 50% as objective function. Initialization, mutation, recombination (crossover) and selection are the various operations associated with DE based optimization algorithm. For the details, one can refer to the articles [25–28].

2. Single effect H₂O–LiCl VARS

The single effect H₂O–LiCl based VARS schematic is shown in Fig. 1. It consists of the basic components viz. the generator, condenser, evaporator, absorber, solution pump (SP) and two expansion valves (ExV1 and ExV2). A solution heat exchanger (SHE) is considered between the generator and absorber to preheat the absorber leaving strong H₂O–LiCl solution with the heat of high temperature weak solution that flows back from the generator to the absorber.

3. Assumptions

It is assumed that the system operates under steady state. The refrigerant (water) at condenser exit is saturated liquid and it is saturated vapor at the evaporator exit. Pressure losses in the pipelines and heat exchangers are neglected. Heat loss between the system and surroundings is negligible. The generator heat source is saturated steam with its saturation temperature 10 °C higher than

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