Applied Energy 133 (2014) 335–346

Contents lists available at ScienceDirect

Applied Energy

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

Thermodynamic analysis and comparison of combined ejector–absorption and single effect absorption refrigeration systems

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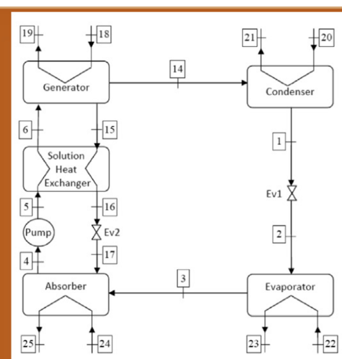
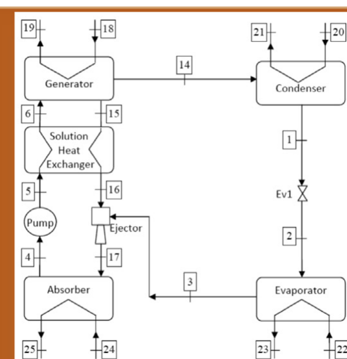
HIGHLIGHTS

- Ammonia/$LiNO_3$ and ammonia/NaSCN combined ejector–absorption refrigeration cycles are analyzed.
- The performance of combined cycles is compared to that of single effect cycles.
- Ejector is used to facilitate pressure recovery of the absorber and improve mixing.
- For low generator temperatures combined cycles have better performance.
- Influence of various operating parameters on performance of cycles is investigated.

GRAPHICAL ABSTRACT



Single effect Ammonia/$LiNO_3$ and Ammonia/NaSCN absorption refrigeration system



Combined ejector-absorption Ammonia/$LiNO_3$ and Ammonia/NaSCN refrigeration system

ARTICLE INFO

Article history:
Received 14 December 2013
Received in revised form 18 July 2014
Accepted 30 July 2014
Available online 20 August 2014

Keywords:
Ammonia/$LiNO_3$
Ammonia/NaSCN
Absorption refrigeration
Ejector
Thermodynamic analysis

ABSTRACT

Alternatives to ammonia/water absorption refrigeration cycles that have no need for purification include ammonia/$LiNO_3$ and ammonia/NaSCN cycles. Similar to the other absorption refrigeration cycles they have low coefficients of performance and exergy efficiencies at low generator temperatures. Combined single effect cycles can reduce this problem. In these cycles the solution expansion valve is replaced with an ejector to allow for pressure recovery from the absorber and to enhance mixing of the weak solution and refrigerant vapor from the evaporator. Simulations are used to examine the influence of various operating parameters on performance and the possibility of crystallization in these cycles, and to compare their performances with single effect cycles. It is shown that the combined cycles have better performance than single effect ones at low generator temperatures.

1. Introduction

In recent years, researchers have increasingly focused on the development of absorption chillers. The advantages of these cycles have been presented previously by the authors [1–5].

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http://dx.doi.org/10.1016/j.apenergy.2014.07.102
0306-2619/

Nomenclature

A	area, m^2
COP	coefficient of performance
D	diameter, m
DPL	double pressure level
h	specific enthalpy, kJ kg^{-1}
$\dot{I}$	exergy destruction rate, kW
$\dot{m}$	mass flow rate, kg s^{-1}
P	pressure, kPa
$\dot{Q}$	heat transfer rate, kW
T	temperature, K
TPL	triple pressure level
s	specific entropy, kJ kg^{-1} K^{-1}
T_{cold}	mean temperature of stream to be cooled, K
T_{hot}	mean temperature of heat source, K
V	velocity, m s^{-1}
$\dot{W}$	work rate, kW
X	mass concentration of ammonia in solution

Greek symbols

δ	relative exergy loss
η	efficiency or effectiveness
ψ	specific exergy of flow, kJ kg^{-1}
ρ	density, kg m^{-3}

Subscripts

0	surroundings
II	second law
abs	absorber
con	condenser
D	diffuser
e	exit
eva	evaporator
gen	generator
hx	heat exchanger
i	inlet or component
N	nozzle
M	mixing section
P	pump
r	refrigerant
s	solution
strong	flow with a high refrigerant concentration
weak	flow with a low refrigerant concentration

One of the most common absorption systems that can be used for low temperature (below 0 °C) applications is the ammonia/water cycle. This cycle requires removal of the portion of the water that evaporates with ammonia to purify the refrigerant vapor or the water can collect in the evaporator, causing a reduction in system performance. Also, this cycle has a relatively low coefficient of performance (COP). To overcome these problems, ammonia/$LiNO_3$ and ammonia/NaSCN cycles are proposed by many researchers [6–14] as alternatives to the ammonia/water cycle. An examination of these previous studies and a detailed analysis of single effect absorption refrigeration cycles using these solutions as working fluids are provided elsewhere by the authors [15].

Advantage of these cycles over the widely used ammonia/water units are higher coefficients of performance and no need to purify the vapor, because the vapor phase consists of only ammonia. Also, these solutions are not corrosive to steel [16–18].

The main disadvantage of the ammonia/$LiNO_3$ mixture is its high viscosity that can limit heat and mass transfer in the absorber of the system. Cerezo et al. [19] compared the absorber performance in bubble mode between ammonia/water, ammonia/$LiNO_3$ and ammonia/NaSCN working fluids using a plate heat exchanger at commercial refrigeration conditions. They found that, for the three cases studied, the ammonia/LiNO3 working fluid exhibited the lowest absorption mass transfer and absorber thermal load values in comparison with ammonia/water and ammonia/NaSCN mainly due to its higher viscosity; despite that, it showed the highest COP in the absorption refrigeration system simulation. Also, Ventas et al. [20] performed an experimental study of a thermochemical compressor with plate heat exchangers for single-effect absorption chiller cycles using ammonia/$LiNO_3$ as the working fluid. The solution was atomized to obtain small droplets inside the absorber plenum, so that viscosity related problems and tube wetting difficulties were mitigated. The droplets were formed using seven pressure swirl injectors of the solid cone type. The absorber was equipped with sight glasses in the lateral ends to allow visualizing the atomization process.

These studies show that the effect of high viscosity of ammonia/$LiNO_3$ on the absorption cycles performance can be reduced by some methods and that the COP of this system is the highest compared to ammonia/water and ammonia/NaSCN cycles.

Various approaches are reported in the literature for using ejectors in single effect absorption refrigeration systems to improve their performances. In this condition, a double pressure level (DPL) of the single effect cycle is converted to a triple pressure level (TPL) ejector–absorption cycle. A TPL ejector–absorption cycle is usually obtained by introducing:

- A vapor–vapor ejector at the entrance of the condenser [21–24].
- A liquid vapor ejector at the entrance of the absorber [25–31].

The second configuration of a combined ejector absorption cycle is considered in the present study. Chen [25] examined a combined cycle working with R22/ DME-TEG and found an improvement in COP compared to the conventional absorption cycle, especially at lower generator temperatures. Sözen and Özalp [26] performed energy and exergy analyses of an ejector–absorption refrigeration cycle working with water–ammonia. It was shown that the COP and exergy efficiency of the cycle improved compared to the conventional absorption refrigeration cycle, especially at lower generator temperatures. Also, the combined cycle can perform at a lower generator temperature compared to the conventional cycle. Jelinek et al. [27–30] performed similar studies for ejector–absorption refrigeration cycles working with organic absorbents and many refrigerants.

The objective of this work is to study the ammonia/$LiNO_3$ and ammonia/NaSCN absorption refrigeration cycles that use an ejector at the absorber inlet, and to compare the results with those of single effect cycles for a wide range of operating conditions. The ejector serves two major functions in the proposed cycles: it facilitates pressure recovery from the absorber and it improves mixing between the weak solution (the flow with a low refrigerant concentration) and the ammonia vapor coming from the evaporator.

The only reported work to the best of the authors' knowledge that deals with this objective is Ref. [31], but it is limited to an energy analysis of an ammonia/$LiNO_3$ refrigeration cycle. In the present work, an analysis of an ammonia/NaSCN cycle is added. Since, it is increasingly recognized that exergy analysis provides more meaningful information when assessing the performance of energy conversion systems, both cycles are analyzed from the viewpoints of the first and second laws of thermodynamics. In