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First and second law analysis of ammonia/salt absorption refrigeration systems

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ABSTRACT

Ammonia/$LiNO_3$ and ammonia/NaSCN absorption refrigeration cycles are alternatives to ammonia/water cycles for refrigeration applications at temperatures below 0 °C. They exhibit higher coefficient of performance (COP) values and do not require purification of the refrigerant vapor. Entropy data for such solutions calculated using their most recently published thermophysical property data; we study and compare the cycles thermodynamically. The simulation results are used to examine the influence of various operating parameters on performance and the possibility of crystallization in these cycles. It is shown that, for low generator temperatures, ammonia/$LiNO_3$ cycles have better performance. For high generator temperatures, ammonia/NaSCN cycles have better performance, but the range of allowable generator temperatures is quite limited for this mixture.

Analyse selon les premier et second principes de systèmes frigorifiques à absorption d'ammoniac/sel

Mots clés : Enthalpie ; Entropie ; Exergie ; Ammoniac/$LiNO_3$; Ammoniac/ NaSCN ; Froid à absorption

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Nomenclature

COP	coefficient of performance
c_p	specific heat at constant pressure, kJ kg^{-1} K^{-1}
g	free energy per unit mass, kJ kg^{-1}
G	molar free energy, kJ $kmol^{-1}$
f	fugacity in liquid solution, kPa
h	specific enthalpy, kJ kg^{-1}
$\dot{I}$	exergy destruction rate, kW
$LiNO_3$	lithium nitrate
M	molar weight, kg $kmol^{-1}$
$\dot{m}$	mass flow rate, kg s^{-1}
NaSCN	sodium thiocyanate
P	pressure, kPa
$\dot{Q}$	heat transfer rate, kW
$\bar{R}$	universal gas constant, kJ $kmol^{-1}$ K^{-1}
s	specific entropy, kJ kg^{-1} K^{-1}
T	temperature, °C or K
T_{cold}	mean temperature of stream to be cooled, °C
T_{hot}	mean temperature of heat source, °C
$\dot{W}$	work rate, kW
X	mass concentration
$\bar{X}$	molar concentration

Greek symbols

δ	relative exergy loss
η	efficiency or effectiveness
ψ	specific exergy of flow, kJ kg^{-1}
μ	chemical potential, kJ $kmol^{-1}$
γ	activity coefficient in liquid solution

Subscript

0	surroundings
II	second law
abs	absorber
con	condenser
e	exit
eva	evaporator
gen	generator
hx	heat exchanger
i	inlet or component
l	liquid solution
P	pump
s	solid
sat	saturated liquid solution
v	vapor phase

1. Introduction

In recent years, absorption refrigeration systems have attracted increasing interest. These systems can be superior to mechanical vapor compression refrigeration cycles powered by electricity in that absorption refrigeration systems can utilize waste heater thermal energy from solar, biomass, and geothermal energy sources. In many cases, the cost of supply is small, making thermally driven refrigeration a viable and economic option.

The most common absorption systems are based on water/LiBr and ammonia/water cycles. The advantage of ammonia as a refrigerant compared to water is that it can evaporate at temperatures below 0 °C (the "normal" freezing point of ammonia is −77 °C). Hence, ammonia can be used for low temperature applications. Ammonia/$LiNO_3$ and ammonia/NaSCN solutions are other alternatives to ammonia/water (Infante Ferreira, 1984; Rogdakis and Antonopoulos, 1995). In ammonia/water cycles, since both ammonia and water are volatile, the cycle requires purification of the vapor flow to strip away water that normally evaporates with ammonia. Without purification, the water accumulates in the evaporator and reduces the system performance. Furthermore, the ammonia/water cycle exhibits a relatively low COP.

However, the lack of crystallization phenomena in ammonia/water systems can be treated as an advantage. The drawback of ammonia/$LiNO_3$ compared to ammonia/NaSCN and ammonia/water is its high viscosity, however, for the ammonia/$LiNO_3$ cycle a lower generator temperature can be used (Abdulateef et al., 2008). This is an important factor for utilizing solar, geothermal and waste energies.

The superiority of ammonia/$LiNO_3$ and ammonia/NaSCN systems over the widely used ammonia/water units are due to their higher coefficient of performance values and cycle simplicity. For instance, there is no need for vapor purification, because the vapor phase in these ammonia/salt cycles consists of pure ammonia vapor.

According to NFPA 704 (2012), the rating of $LiNO_3$ is: Health:1, Flammability: 0, Reactivity: 0 and special information key: oxy. These ratings mean: It is a slightly hazardous (toxic) material which requires only minimal protection (for example, safety glasses and gloves) in addition to normal work clothing to work with safety. LiNO3 is a noncombustible material, and is stable, although it is a strong oxidizer.

The rating of NaSCN is: Health: 2, Flammability: 0, Reactivity: 0. These ratings mean it is a moderately toxic or hazardous material which requires additional equipment (for example lab/work smock and local ventilation). Similar to $LiNO_3$, NaSCN is noncombustible and stable.

Many assessments of ammonia/$LiNO_3$ and ammonia/NaSCN absorption refrigeration cycles have been carried out using energy analysis (Abdulateef et al., 2008; Best et al., 1991, 1993; Sun, 1998). However, it is increasingly accepted that exergy analysis provides more meaningful information when assessing the performance of energy conversion systems, as it provides meaningful efficiencies and identifies the locations, magnitudes and sources of thermodynamic inefficiencies in these systems. This information is also useful for comparing various systems and is required in exergoeconomic, thermoeconomic and environomic analyses.

Few analyses from the viewpoint of the second law of thermodynamics have been reported to date of the types of