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Estimation of differential heat of dilution for aqueous lithium (bromide, iodide, nitrate, chloride) solution and aqueous (lithium, potassium, sodium) nitrate solution used in absorption cooling systems

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ABSTRACT

The differential heat of dilution data are estimated theoretically using Duhring's diagrams for water/LiBr, water/(LiBr + LiI + $LiNO_3$ + LiCl) with mass compositions in salts of 60.16%, 9.55%, 18.54% and 11.75%, respectively, and water/($LiNO_3$ + KNO_3 + $NaNO_3$) with mass compositions in salts of 53%, 28% and 19%, respectively, as these can be potentially utilized as working fluids in absorption cooling systems. The differential heat of dilution data obtained were correlated with simple polynomial equations for the three working fluids as a function of the solution concentration and temperature. The results showed that the differential heat of dilution of the non-conventional working fluid mixtures is lower than that of water/LiBr at typical operating temperature and concentration of interest in absorption cooling cycles employing these working fluid mixtures. The correlations developed could be useful in predicting the differential heat of dilution value while performing heat and mass transfer analyses of these potential non-conventional working fluid mixtures in absorption cooling systems.

Estimation de la chaleur différentielle de dilution pour une solution aqueuse de (bromure, iodure, nitrate, chlorure) de lithium et une solution aqueuse de nitrate de (lithium, potassium, sodium) utilisées dans les systèmes de refroidissement à absorption

Mots-clés : Chaleur différentielle de dilution ; Diagramme de Duhring ; Eau/LiBr ; Eau/(LiBr + LiI + LiNO3 + LiCl) ; Eau/(LiNO3 + KNO3 + NaNO3) ; Refroidissement par absorption

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Nomenclature

a, b, c	constants
H	enthalpy [kJ kg^{-1}]
i	ith term
m	slope
P	pressure [Pa]
T	temperature [K]
V	volume [m^3 kg^{-1}]
w	mass fraction
y	y-coordinate intercept

Superscripts

s	solution
sup	superheated
sat	saturated
w	water

Subscripts

d	dilution
f	liquid state
v	vapour state

Chemical formula

H_2O	water
KNO_3	potassium nitrate
LiBr	lithium bromide
LiCl	lithium chloride
LiI	lithium iodide
$LiNO_3$	lithium nitrate
$NaNO_3$	sodium nitrate

1. Introduction

Absorption air-conditioning systems driven by solar thermal energy are gaining global acceptance for space cooling in summer due to their potential to utilize the free solar thermal energy efficiently. Working fluid mixtures employed in the absorption air-conditioning systems are environmental friendly and do not contribute to greenhouse gas emissions unlike vapour compression systems which also use costly mechanical energy input. Intensive research has been carried out to improve the performance and thermal efficiency of absorption air-conditioning systems by adopting suitable operating conditions and improved design and configuration of the components. In commercial absorption air-conditioning systems, water/LiBr is mainly employed as a working fluid mixture and offers outstanding features such as the non-volatility of LiBr absorbent and high heat of vaporization of water. However, water/LiBr based absorption air-conditioning systems suffer from corrosion problems and exhibit a high risk of crystallization when operated at air-cooled thermal conditions. At high cooling-water temperatures and high concentrations, the solution is prone to crystallization. In addition, because of the risk of crystallization, corrosion problems and thermal instability at higher temperatures, water/LiBr working fluid mixture limits the use of high temperature heat sources in triple-effect cycles which are intended to improve the thermal utilization and increase the coefficient of performance of absorption air-conditioning systems. In view of the above mentioned problems associated with water/LiBr working fluid mixture, new working fluid mixtures have been investigated to overcome problems associated with the conventional working fluid mixture.

The addition of other salts to water/LiBr can improve the solubility of the solution. Bourouis et al (2005a, 2005b) and Medrano et al (2002) investigated and recommended the use of an aqueous multi-component salt solution ($LiBr + LiI + LiNO_3 + LiCl$) with mass compositions in salts of 60.16%, 9.55%, 18.54% and 11.75%, respectively, as a potential absorbent with water as a refrigerant. The multi component salt solution exhibits higher solubility and also reduces the risk of crystallization. Bourouis et al (2005a) reported that the presence of lithium chloride decreases the vapour pressure, both lithium iodide and lithium nitrate improve the solubility, and lithium nitrate reduces corrosion in the system. The safety margin for crystallization is much higher as its crystallization temperature is about 30 K lower than that of water/LiBr. Thus, the use of the multi-salt working fluid mixture cannot only mitigate the problems associated with the conventional water/LiBr working fluid mixture but can also enhance the performance of an absorber operating at air-cooled thermal conditions.

Similarly, as water/LiBr cannot be used in triple-effect cycles driven by high temperature heat sources (above 180 °C) due to corrosion problems and thermal instability, investigations are being performed on the development of potential absorbents that are non-corrosive and thermally stable at higher temperatures so as to efficiently utilize the thermal potential of high temperature heat sources. Aqueous (lithium, potassium, sodium) nitrate solution (Alkitrate) has been suggested as a working fluid in the high temperature stage of a triple-effect cycle (Álvarez et al., 2015; Davidson and Erickson, 1986; Erickson et al., 1996; Howe and Erickson, 1990). The working fluid mixture is composed of water as a refrigerant, and a ternary salt mixture of lithium nitrate, potassium nitrate and sodium nitrate as an absorbent with a mass composition in salts of 53%, 28% and 19%, respectively. The use of an Alkitrate solution can be potentially useful in applications in which the available heat source temperature is very high because it is non-corrosive and has high thermal stability up to a temperature of about 260°C.

The aqueous multi-component salt solution ($LiBr + LiI + LiNO_3 + LiCl$) and aqueous (lithium, potassium, sodium) nitrate solution can be considered as promising alternatives to the conventional water/LiBr working fluid mixture to enhance the performance of absorption air-conditioning systems operating at air-cooled thermal conditions and high temperature heat source conditions, respectively.

Many researchers have investigated the thermophysical properties of these non-conventional working fluids such as vapour pressure, density, viscosity, specific heat, thermal conductivity, etc. Although thermodynamic simulations have been performed with these non-conventional working fluid mixtures to investigate the cycle performance, there is very scarce information in the literature about the absorption and desorption processes. Heat and mass transfer phenomena which simultaneously occur in the absorber and desorber of an