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Thermodynamic evaluation of new absorbent mixtures of lithium bromide and organic salts for absorption refrigeration machines

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Abstract

Mixtures of lithium bromide and organic salts of sodium and potassium (formate, acetate and lactate) have been evaluated as alternative absorbents for absorption refrigeration machines. The main objective is to overpass the limitations of lithium bromide and improve the characteristics and the efficiency of the refrigeration cycle. In order to select the mixture that presents better properties for its employment in absorption refrigeration cycles, a thermodynamic analysis have been done. Density, viscosity, enthalpies of dilution, solubility and vapour pressure data of the proposed mixtures have been measured. A simulation program has been developed to evaluate temperatures, heats exchanged in the different sections and the efficiency of the cycle.

Keywords: Absorption system; Survey; Mixture; Absorbent; Lithium bromide; Sodium; Potassium; Thermodynamic property; Physical property; Modelling

Evaluation themodynamique de nouveaux mélanges absorbants de bromure de lithium et de sels organiques utilises dans les systèmes frigorifiques à absorption

Mots clés : Système à absorption ; Enquête ; Mélange ; Absorbant ; Bromure de lithium ; Sodium ; Potassium ; Propriété thermodynamique ; Propriété physique ; Modélisation

1. Introduction

Absorption refrigeration technology has been used for cooling purposes for over a hundred years. Today the technology developments have made of the absorption refrigeration an economic and effective alternative to the vapour compression cooling cycle. The increase of electricity cost and environmental problems has made this heat-operated cycle more attractive for both residential and industrial applications. Absorption chillers are widely used in the air-conditioning industry, in part because they can be activated by hot water, steam and direct-fired natural gas, among others, instead of electricity.

A conventional absorption chiller consisting of a generator, absorber, condenser, and evaporator requires an additional water cooling tower in order to remove heats and maintain desirable temperatures in absorber and condenser units [1].

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Nomenclature

COP	ratio of cooling capacity to valuable thermal power input to the generator (Q_{ca}/Q_{ag})
h	specific enthalpy (kJ kg^{-1})
C_p	specific heat capacity (kJ kg^{-1} K^{-1})
m	mass flow (kg s^{-1})
T	temperature
Q	heat rate (kW)
Q_a	rate of heat flow across evapourator (kW)
Q_{ca}	rate of heat flow across absorber (kW)
Q_{abs}	rate of heat flow into absorber (kW)
Q_{ag}	rate of heat flow across generator (kW)
Q_{ac}	rate of heat flow across condenser (kW)

Subscripts

ref	refrigerant
vref	vapour refrigerant
LiBr	lithium bromide in solution

One of the traditional refrigerant–absorbent combination is water–lithium bromide. Water is one of the most acceptable natural refrigerants, because of its safety and cost. Lithium bromide was chosen as absorbent because meet the following desired solution characteristics for the absorption refrigeration systems: stability in aqueous solution and low vapour pressure at absorber conditions. The drawbacks of lithium bromide are the crystallization at high concentrations, the high temperature necessary in the generator to reach the boiling point of the lithium bromide solution, more than 90 °C, due to the high ebulloscopic increase that the elevated concentration of lithium bromide produces, and is very expensive and corrosive to metals.

Over the past 40 years a series of elaborate proprietary formulations have been built around the lithium bromide–water system with the objective of enhancing the performance of the working fluid by lowering its crystallisation temperature and reducing its corrosivity to metals.

Various new working fluids have been developed to improve the performance characteristics of the conventional lithium bromide + water system [2–4]. Potassium formate is cited in literature because of its physical properties and absorption–desorption rates, which make it suitable for its use in an absorption cycle. Potassium formate shows lower crystallization temperature, density and viscosity lower than lithium bromide, smaller vapour pressures, alkaline pH, less toxicity and it is biodegradable.

Potassium formate has a good compatibility with conventional absorption fluid additives and may be used in conjunction with other known absorbents such as lithium bromide to provide mixed salt brine formulations to enhance their performance by reducing their crystallisation temperature and to protect labile components from oxidative degradation [3].

This study proposes mixed salts brine formulations of potassium formate and other salts of similar chemical and physical properties (sodium formate, potassium acetate and sodium lactate), in combination with lithium bromide, the traditional absorbent employed in the industry. As a result, it was expected that lithium bromide–organic salt mixtures could show optimal properties: low vapour pressures due to lithium bromide, and less crystallization temperature and latent heat of absorption due to organic salt, that could provide better operation coefficients and economic advantages. Among them stand out the lower temperature required in the generator, and therefore the possible use of waste streams with less calorific power.

The thermodynamic properties of new working fluids have been determined in order to select the mixture that presents better properties for its employment in absorption refrigeration cycles.

In a previous paper the absorption cycle is illustrated [5]. The cycle performance is measured by the coefficient of performance (COP), which is defined as the refrigeration rate over the rate of heat addition at the generator, that is [6]

$$\mathrm{COP} = \frac{Q_e}{Q_g} \tag{1}$$

In order to provide the thermodynamic design data for absorption refrigeration machines a computer software is used to simulate the performance of absorption systems. The computer program analyses the thermodynamic reference cycle and evaluates the heat exchanges, temperatures around the cycle, and efficiency [7–9]. By means of the program, the efficiency of absorption cycle can be evaluated, that enables to compare different refrigeration cycles, and also evaluate the influence of the input variables in the cycle [10]. The program structure and the mass and energy balances at each part of the absorption cycle are described in a previous paper [5].

2. Experimental section

In order to compare the performance of the new absorbent solutions with that of lithium bromide, the pressure–temperature–concentration equilibrium data of the new absorbent solutions are needed. The equilibrium data for the new absorbents are not available in literature and an experimental device was designed out to obtain equilibrium data with accuracy. In a previous paper the experimental device is described and the vapour pressure, density and viscosity values of the mixture reported [11,12].