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Performance analysis of absorption heat transformer cycles using ionic liquids based on imidazolium cation as absorbents with 2,2,2-trifluoroethanol as refrigerant

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ABSTRACT

A detailed thermodynamic performance analysis of a single-stage absorption heat transformer and double absorption heat transformer cycles using new working pairs composed of ionic liquids (1-ethyl-3-methylimidazolium tetrafluoroborate ([emim][BF_4]) and 1-butyl-3-methylimidazolium tetrafluoroborate ([bmim][BF_4])) as absorbent and 2,2,2-trifluoroethanol (TFE) as refrigerant has been studied. Several performance indicators were used to evaluate and compare the performance of the cycles using the TFE + [emim][BF_4] and TFE + [bmim][BF_4] working pairs with the conventional H_2O + LiBr and organic TFE + TEGDME working pairs. The obtained results show that the ionic liquid based working pairs are suitable candidates to replace the conventional H_2O + LiBr working pairs in order to avoid the disadvantages associated with it mainly crystallization and corrosion and also they perform better (higher gross temperature lift) than TFE + TEGDME working pair at several operating conditions considered in this work.

1. Introduction

Enormous energy is dissipated as low temperature waste heat in the industry. Absorption heat pumps can recover low temperature waste heat from various industrial processes and upgrade it to deliver useful heat for heating and hot water supplies. The relative freedom from noise and vibrations and, above all, the possibility to use waste heat and renewable energy heat sources such as solar energy to energize the systems are prevailing arguments in favour of sorption systems. The drawbacks which are most often quoted are heavy weight and large footprint, lack of understanding of the process, and, above all, the relatively high first cost.

Unlike electrical driven heat pumps, absorption heat pumps can also work as heat transformers. The purpose of an Absorption Heat Transformer (AHT) cycle, also known as Absorption Heat Pump Type II, is to recover heat at an intermediate temperature level (T_m), for example, 60–80 °C and upgrade a portion of it to high temperature heat (T_h), for example, at 110 °C or higher and transfer this heat out of the cycle. A heat flow diagram of a simplified AHT that exchange heat at three temperature levels is illustrated in Fig. 1. It is important to note that a heat transformer is driven by recovery waste heat only, i.e. no primary energy is needed in the form of high temperature heat (absorption heat pumps) or electrical energy (compression heat pumps) apart from a small amount of electricity for the circulation and auxiliary pumps. The most used working fluid for absorption heat transformers (and chillers) has been water + lithium bromide (H_2O + LiBr) due to the excellent properties (no toxicity or flammability, high latent heat of water as a refrigerant, no need for rectification to separate the mixture, etc.) [1]. But the use of corrosion inhibitors is necessary and also the crystallisation problems have prevented a greater use of absorption heat transformers and their application has been restricted mainly to absorption chillers for cooling and air-conditioning applications. Other classical working fluid used in refrigeration by absorption has been ammonia + water (NH_3 + H_2O) but important practical disadvantages are the high vapour pressure of water as an absorbent that requires a costly rectifier unit or the toxicity and flammability of NH_3. Organic working pairs (such as 2,2,2-trifluoroethanol (TFE) + tetraethylene glycol dimethyl ether (TEGDME)) have been investigated as suitable working fluids but still have some drawbacks (e.g. low system performance) [2–4]. Therefore, the search for new working pairs continues till today.

Ionic Liquids (ILs) have been introduced as new absorbents [5] to overcome the problems of thermal instability, high volatility and low system performance that the organic working fluids show

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Nomenclature

1, 2, ..., 17	thermodynamic state points
ABS	absorber
ABS/EVA	absorber/evaporator
AHT	absorption heat transformer
[bmim][BF_4]	1-butyl-3-methylimidazolium tetrafluoroborate
CON	condenser
COP	coefficient of performance
DAHT	double absorption heat transformer
ECOP	exergetic efficiency
[emim][dmp]	1-ethyl-3-methylimidazolium dimethyl phosphate
[emim][BF_4]	1-ethyl-3-methylimidazolium tetrafluoroborate
EV	expansion device
EVA	evaporator
f	solution circulation ratio
IL	ionic liquid
g	thermodynamic quality
GEN	generator
GTL	internal gross temperature lift
h	specific enthalpy (kJ/kg)
LiBr	Lithium bromide
$\dot{m}$	mass flow rate (kg/s)
NH_3	ammonia
p	pressure (kPa)
PC-SAFT	Perturbed-Chain Statistical Associating Fluid Theory
$\dot{Q}$	thermal capacity (kW)
R	solution circulation ratio per unit of useful heat output
RP	refrigerant pump
SP	solution pump
SSAHT	single-stage absorption heat transformer
t	temperature (°C)
T	temperature (K)
T_0	environmental reference temperature
TFE	2, 2, 2-trifluoroethanol
TEGDME	tetraethylene glycol dimethyl ether
$\dot{W}$	mechanical power (kW)
X	absorbent mass fraction (kg/kg)

Subscripts

abs	absorber
abs/eva	absorber/evaporator
con	condenser
eva	evaporator
gen	generator
h	high
in/out	inlet/outlet
m	medium
r	refrigerant
s	strong solution (in absorbent)
shx	solution heat exchanger
w	weak solution (in absorbent)

Greek symbols

Δ	difference
ρ	density
$\sum$	summation

in absorption cooling systems. The special properties of ILs, as powerful solvent and non-volatility due to its low vapour pressure make them very interesting absorbents in absorption heat pumps and refrigeration systems [6,7]. Zhang et al. [8] investigated the performance of an AHT cycle using new working pair composed of water and IL: water and 1-ethyl-3-methylimidazolium dimethyl phosphate (H_2O + [emim][dmp]). They claimed that a similar cycle performance could be achieved using the H_2O + [emim][dmp] working pair in comparison with H_2O + LiBr working pair. In absorption cooling/heating and heat transformer cycles several physical processes occur, such as the absorption of refrigerant vapour by the solution rich in absorbent in the absorber and the regeneration of the refrigerant from the rich solution in the

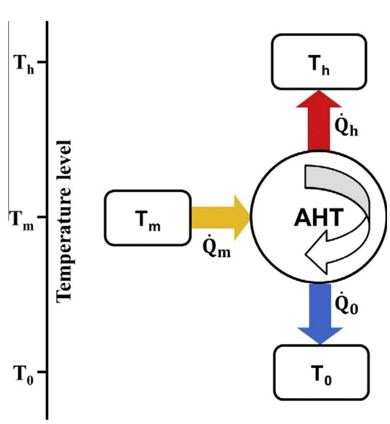

Fig. 1. Heat flows and temperature levels in a simplified AHT.

generator by using thermal energy. The performance and operating range of an absorption cycle depends basically on the thermodynamic properties of the working fluid mixture used in the cycle and its configuration. For this reason, accurate thermodynamic properties of pure and mixture fluids are necessary for the suitable design and optimisation of the absorption cooling and/or heating systems.

The objective of this work is to simulate the performance of a Single-Stage Absorption Heat Transformer (SSAHT) and a Double Absorption Heat Transformer (DAHT, type-3) which are suitable cycle configurations to achieve high Coefficient of Performance (*COP*) or high Gross Temperature Lift (internal, *GTL*) respectively using TFE as refrigerant and 1-ethyl-3-methylimidazolium tetrafluoroborate [emim][BF_4] or 1-butyl-3-methylimidazolium tetrafluoroborate [bmim][BF_4] as absorbents. The results of the simulation have been compared with the conventional working pair (H_2O + LiBr) and organic working pair (TFE + TEGDME). In addition, the influence of the alkyl length of the cation of IL on the thermodynamic performance of the cycle was analysed. Up to our knowledge only Kim et al. [9] have simulated the performance of an absorption refrigeration system using several ILs with hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) or water as refrigerant. Nevertheless, we should take into account the ozone depletion potentials (ODP) or the global warming potentials (GWP) are not negligible for CFCs and HFCs, respectively. Thus, we have selected as refrigerant TFE because it is a replacement with non-available ozone depletion potential (ODP) [10] and very low global warming potential (GWP) value, as a result of their short lifetime (117 days) [11].

Previously, several thermodynamic and transport properties of the ILs ([emim][BF_4] and [bmim][BF_4]) and their mixtures with