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Research Paper

Operation of an absorption heat transformer using water/ionic liquid as working fluid

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HIGHLIGHTS

- The first experimental results of an AHT, operated with water/IL are presented.
- The experiments at low temperature lifts match with the idealized simulation.
- The highest COP was 0.43 at a heat flow of 5.5 kW and a temperature lift of 18.5 K.
- The highest temperature lift was 47 K, the corresponding COP was 0.27.

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ABSTRACT

This work presents the first experimental results obtained with a single stage absorption heat transformer (AHT), which was operated with the working fluid water/ionic liquid. The ionic liquid (IL) used in this work was 1-ethyl-3-methyl-imidazolium methanesulfonate (EMIM OMs). Several sets of experiments were conducted by varying the inlet temperatures of the external circuits and the internal flow rates. The coefficient of performance (COP) decreases with increasing high temperature and decreasing medium temperature. At higher internal flow rates, the COP increases due to the improved efficiency of the solution heat exchanger and higher heat flows in the apparatuses. The comparison of the experimental results with simulation results shows a good agreement at low temperature lifts. At higher temperature lifts and lower heat flows in the apparatuses, the influences of heat losses, pump duties and uncertainties let the experimental results diverge from the simulated ones. The highest experimental COP was 0.43 at a heat flow of 5.5 kW in the absorber and a temperature lift of 18.5 K. The highest temperature lift was 47 K. The corresponding COP was 0.27 and the heat flow in the absorber 1.7 kW.

1. Introduction

In industrial processes, huge amounts of waste heat are released on a temperature level between 80 and 120 °C. An absorption heat transformer (AHT) offers the possibility to upgrade part of this still unused heat to e.g. provide process steam, by only consuming a low amount of electrical energy. The process is investigated since the beginning of the 20th century [1]. In the 1980s, several industrial pilot plants were built and analyzed [2–4], but the AHT never had a breakthrough in industrial applications, mainly because of the lack of suitable working fluids.

Working fluids for an absorption heat transformer should provide the following properties [3]:

- High enthalpy of evaporation of the refrigerant.
- Large difference of the boiling points of refrigerant and absorbent.
- Thermal and chemical stability of the fluids.
- High reduction of the vapor pressure of the refrigerant by the absorbent.
- Non-corrosive, non-toxic and inflammable fluids.
- Full miscibility of the fluids.
- Cheap and easily available fluids.

In literature, several working fluids for the AHT were analyzed. The working fluid water/lithium bromide (H_2O/LiBr) has the benefit of water as refrigerant with its high enthalpy of evaporation, good availability, low cost and low toxicity H_2O/LiBr is still mainly used in absorption refrigerators and was also used in an industrial AHT by Ma et al. [5]. Nevertheless, crystallization due to mixing gaps limits the process temperatures [6]. The corrosivity, which

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Nomenclature

A	area (m^2)
AHT	absorption heat transformer
B1, B2, ...	vessel number 1, 2, ...
BF_4	tetrafluoroborate
BMIM	1-buthyl-3-methylimidazolium
COP	coefficient of performance (-)
CH_3OH	methanol
DIR	density measurement (indication, record)
DMP	dimethylphosphate
E181	tetraethylen glycol dimethyl ether
EMIM	1-ethyl-3-methylimidazolium
f	circulation ratio (-)
FIR	flow meter (indication, record)
GTL	gross temperature lift (K)
h	specific enthalpy (kJ/kg)
H_2O	water
IL	ionic liquid
k	thermal transmittance (W/m^2K)
LiBr	lithium bromide
$\dot{M}$	mass flow rate (kg/s)
$\bar{M}$	molar mass (kg/kmol)
MMIM	1-methyl-3-methylimidazolium
NaOH	caustic soda
NH_3	ammonia
OMs	methanesulfonate
p	pressure (Pa)
P1, P2, ...	pump number 1, 2, ...
PIR	pressure gauge (indication, record)
$\dot{Q}$	heat flow (kW)
SHE	solution heat exchanger
T	temperature (°C)
τ	time (min)
TFE	trifluoroethanol
TIR	temperature sensor (indication, record)
U	Standard deviation
$\dot{V}$	volume flow rate (l/min)
w	mass fraction of water in solution (-)
ΔT	driving temperature difference (K)

Subscripts

A	absorber
C	condenser
cor	corrected
E	evaporator
ext	external
G	generator
H	high (pressure, temperature)
in	inlet
int	internal
L	low (pressure, temperature)
M	medium (temperature)
out	outlet
ss	strong solution
ws	weak solution
re	refrigerant

requires the addition of toxic inhibitors in absorption refrigerators [7], is an even severe disadvantage in the AHT, due to higher process temperatures. The disadvantage of crystallization can be diminished by increasing the solubility using ternary mixtures [8–10], though the disadvantage of corrosivity remains.

Water/caustic soda (H_2O/NaOH) has almost the same advantages and disadvantages as H_2O/LiBr, though NaOH is cheaper and shows lower potential of pitting corrosion than LiBr. Simulation results from Stephan et al. [11] show also thermodynamic advantages of this working fluid in comparison with H_2O/LiBr. Due to the mixing gap of H_2O and NaOH, certain temperature and concentration combinations have to be avoided during start-up and shutdown of the system [12].

In the case of the working fluid ammonia/water (NH_3/H_2O), which is used in absorption refrigerators when temperatures below 0 °C are required, the enthalpy of evaporation of NH_3 is slightly lower than the one of H_2O. Disadvantages of this working fluid are the toxicity of NH_3 and a relatively small difference in boiling points which requires a rectification step. Due to the steep vapor pressure curve, the process pressure exceeds 50 bar [6], which increases the energy consumption of the pumps and construction costs for piping and instrumentation.

Hernández-Magallanes et al. [13] studied the performances of single and double stage absorption and resorption heat transformers operating with ammonia-lithium nitrate (NH_3/$LiNO_3$). Though the performance of NH_3/$LiNO_3$ is lower than the one of NH_3/H_2O, it possesses the benefit that no rectification process is required. The resorption circuit offers an alternative to reduce the problem of high pressure with working mixtures using NH_3 as refrigerant.

Trifluoroethanol/tetraethylen glycol dimethyl ether (TFE/E181) has the advantage of low corrosivity, high difference of the boiling points, full miscibility and moderate process pressures [14]. Though the toxicity of TFE is comparable to NH_3 and its enthalpy of evaporation is much lower than the ones of H_2O and NH_3. Therefore the amount of vapor, which is needed to reach the same heat released in the absorber, is seven times higher than in the case of H_2O [15]. This leads to an increase in the dimensions of the apparatuses and piping.

The new group of working fluids water/ionic liquid (H_2O/IL) was firstly introduced by Kim et al. (2001). ILs are organic salts with a melting point below 100 °C and in many cases even below room temperature. They consist of an organic cation and an inorganic or organic anion. The low melting point can be explained by the low lattice energy which is mainly caused by the asymmetry of the cation [16]. Many research groups analyzed the potential of using them as refrigerants in absorption refrigerators [17–20]. First simulation results for the use of H_2O/IL in AHTs were published by Zhang and Hu in 2012 [15]. They identified a comparable performance for water/1-ethyl-3-methylimidazolium dimethylpshosphate (H_2O/EMIM DMP) like for H_2O/LiBr and TFE/E181. Ayou et al. [21] analyzed a single-stage absorption heat transformer and double absorption heat transformer cycles with the new working fluids trifluoroethanol/1-ethyl-3-methylimidazolium tetrafluoroborate (TFE/EMIM BF_4) and trifluoroethanol/1-butyl-3-methylimidazolium tetrafluoroborate (TFE/BMIM BF_4). Their simulation results showed that the new working fluids perform not as well as H_2O/LiBr but lead to a higher gross temperature lift and could still be used as substitutes to avoid corrosion and crystallization. Chen and Liang [22] studied the performance of a single stage AHT with the working fluids water/1-methyl-3-methylimidazolium dimethylpshosphate (H_2O/MMIM DMP) and methanol/1-methyl-3-methylimidazolium dimethylpshosphate (CH_3OH/MMIM DMP). Their performance was also slightly lower than the one of H_2O/LiBr and the gross temperature lift higher.