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On the development of high temperature ammonia–water hybrid absorption–compression heat pumps

Jonas K. Jensen [a,*], *Wiebke B. Markussen* [a], *Lars Reinholdt* [b], *Brian Elmegaard* [a]

[a] *Technical University of Denmark, Department of Mechanical Engineering, Nils Koppels Alle, Building 403, DK-2800, Kgs. Lyngby, Denmark*

[b] *Danish Technological Institute, Kongsvang Alle 29, DK-8000 Aarhus, Denmark*

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ABSTRACT

Ammonia–water hybrid absorption–compression heat pumps (HACHP) are a promising technology for development of efficient high temperature industrial heat pumps. Using 28 bar components HACHPs up to 100 °C are commercially available. Components developed for 50 bar and 140 bar show that these pressure limits may be possible to exceed if needed for actual applications. Feasible heat supply temperatures using these component limits are investigated. A feasible solution is defined as one that satisfies constraints on the COP, low and high pressure, compressor discharge temperature, vapour water content and volumetric heat capacity. The ammonia mass fraction and the liquid circulation ratio both influence these constraining parameters. The paper investigates feasible combinations of these parameters through the use of a numerical model. 28 bar components allow temperatures up to 111 °C, 50 bar up to 129 °C, and 140 bar up to 147 °C. If the compressor discharge temperature limit is increased to 250 °C and the vapour water content constraint is removed, this becomes: 182 °C, 193 °C and 223 °C.

Développement de pompes à chaleur à haute température ammoniac-eau hybrides à absorption-compression

Mots-clés : Pompe à chaleur à haute température ; Pompe à chaleur industrielle ; Absorption-compression ; Ammoniac-eau

* *Corresponding author.*
E-mail addresses: jkjje@mek.dtu.dk (J.K. Jensen), wb@mek.dtu.dk (W.B. Markussen), lre@teknologisk.dk (L. Reinholdt), be@mek.dtu.dk (B. Elmegaard).

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Nomenclature

COP	Coefficient of Performance (–)
f	Circulation ratio (–)
$\dot{m}$	Mass flow rate (kg s^{-1})
p	Pressure (bar)
PR	Pressure ratio p_H/p_L (–)
q	Vapour mass fraction (–)
$\dot{Q}$	Heat rate (kW)
T	Temperature (°C)
ΔT	Temperature difference (K)
v	Specific volume (m^3 kg^{-1})
$\dot{V}$	Volume flow rate (m^3 s^{-1})
VHC	Volumetric heat capacity (MJ m^{-3})
$\dot{W}$	Power (kW)
x	Ammonia mass fraction (–)

Abbreviations

EES	Engineering Equation Solver
HACHP	Hybrid absorption compression heat pump
IHEX	Internal Heat Exchanger
VCHP	Vapour compression heat pump

Greek letters

ε	Heat exchanger effectiveness
η	Efficiency

Subscripts

AB	Absorber
CM	Compressor
DS	Desorber
dis	Displacement
e	Electrical
GC	Gas cooler
H	High
IH	Internal heat exchanger
is	Isentropic
l	Lean
L	Low
pp	Pinch point
r	Rich
suc	Suction
v	Vapour
vol	Volumetric

1. Introduction

The hybrid absorption–compression heap pump (HACHP), or vapour compression heat pump with solution circuit is based on the Osenbrück cycle (Osenbrück, 1895). In the Osenbrück cycle the processes of condensation and evaporation are exchanged with absorption and desorption processes. It thus uses zeotropic mixtures as the working fluid, typically ammonia–water.

The first theoretical study of the HACHP was performed by Altenkirch (1950) and describes the advantage of the HACHP with the non-isothermal process of absorption–desorption compared to the isothermal process of condensation–evaporation in a conventional vapour compression heat pump (VCHP). Thereby the HACHP cycle approaches the Lorenz cycle (Lorenz, 1894), which can result in an increased COP due to the reduction of entropy generation driven by heat transfer over a finite temperature difference. The efficiency advantage of the HACHP over the VCHP requires the temperature change (glide) in the heat sink and heat source to be greater than 10 K (Berntsson and Hultén, 2002). The advantage remains even if economic considerations are included in the comparison (Berntsson and Hultén, 1999). This makes the HACHP a relevant technology for industrial heat supply and waste heat recovery as these processes often require large sink-source temperature glides.

A further advantage of using a zeotropic mixture as working fluid is the reduction of vapour pressure compared to the vapour pressure of the pure volatile component. This implies that the HACHP can achieve higher supply temperatures than a VCHP at the same working pressure. The HACHP is thus, of specific interest for high temperature applications. Brunin et al. (1997) showed that it is technically and economically feasible to use the HACHP up to a heat supply temperature of 140 °C, this however is based on a high pressure constraint of 20 bar corresponding to the limitations of standard refrigeration components at the time of the study. In the meantime new compressor types such as high pressure NH_3 (50 bar) and transcritical CO_2 (140 bar) have become commercially available and further standard refrigeration components now operate at 28 bar. It is therefore of interest to evaluate how the application of these components changes the working domain of the HACHP.

One design constraint that is not discussed in the study by Brunin et al. (1997) is the compressor discharge temperature. However, most compressor manufacturers require this to be lower than 180 °C (Nekså et al., 1998). This is mainly due the thermal stability of the lubricating oil and the thermal stress of the materials surrounding the compressor discharge line. This is mainly an issue for reciprocating compressors. Changing the lubricant from a mineral oil to synthetic oil could relax the constraint due to thermal stability. This however requires that a synthetic oil that meets the requirements of miscibility etc. is identified. Adjustments to the gasket materials and alike could also make the compressor durable at higher discharge temperatures. It is assumed to be a realistic estimate that compressor discharge temperatures up to 250 °C can be sustained with minor adjustments.

To evaluate the working domain of the HACHP using the recently developed high pressure equipment a set of design constraints are defined. A solution that satisfies this set of constraints will constitute an economically and technically feasible solution. The technical limitations are: the high pressure, governed by the choice of compressor technology, the low pressure, set to eliminate entrainment of air, and the compressor discharge temperature, as discussed above. Further, for the ammonia compressors a constraint is set on the vapour ammonia mass fraction. The economic constraints are: the Coefficient of Performance (COP) and the volumetric