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Hybrid absorption heat pump with ammonia/water mixture – Some design guidelines and district heating application

V. Minea[a,*], F. Chiriac[b]

[a]*Laboratoire des Technologies de l'energie (LTE), Hydro-Quebec Research Institute, 600 avenue de la Montagne, Shawinigan, G9N 7N5, Canada*
[b]*University of Civil Engineering, 66, Protopopescu, Bucharest, Romania*

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Abstract

An ammonia/water mixture can be used as an efficient working fluid in industrial-type heat recovery heat pumps and heat transformers. Several configurations of such systems are possible depending on the availability of the waste (thermal) and primary (thermal or electrical) energy sources. This article presents the configurations, the main thermodynamic and hydraulic parameters, and some design guidelines and operating experiences of a medium-temperature, ammonia/water-based compression/re-sorption heat recovery system for district domestic hot water production. In-field experiments have proven the advantages of the concept and its applicability limits in a particular economical environment, while hot water was produced at 55 °C with industrial cooling water at 36 °C as a waste heat source.

Keywords: Heat pump; Heat transformer; Refrigerant; Binary mixture; Ammonia/water; Design; Thermodynamic cycle; Sorption; Resorption; Heat recovery; Experiment; Performance

Pompe à chaleur hybride à absorption avec mélange ammoniac/eau – quelques règles de dimensionnement et application au chauffage urbain

Mots clefs : Pompe à chaleur ; Transformateur de chaleur ; Frigorigène ; Mélange binaire ; Ammoniac/eau ; Conception ; Cycle thermodynamique ; Sorption ; Résorption ; Récupération de chaleur ; Expérimentation ; Performance

1. Introduction

During the energy conjunctures in the 1970s and 1980s, large heat pumps were developed in several countries especially in regard to the utilization of low and medium potential heat sources, i.e. industrial waste water at 20–60 °C [3].

* Corresponding author. Tel.: +1 819 539 1400; fax: +1 819 539 1409.
E-mail address: minea.vasile@lte.ireq.ca (V. Minea).

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Nomenclature

B	height of the vertical film (m)
c	specific heat ($kJ\,kg^{-1}\,K^{-1}$)
C	molar concentration ($mol\,mol^{-1}$)
d	tube diameter (m)
DHW	domestic hot water
D_V	molecular diffusivity of ammonia in water
EWT	entering water temperature (°C)
g	gravitational acceleration ($9.8\,m\,s^{-2}$)
h	specific enthalpy ($kJ\,kg^{-1}$)
H	total enthalpy (kJ)
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
K	falling film mass transfer coefficient ($kg\,mol\,m^{-2}\,s^{-1}$)
L	tube length (m)
LWT	leaving water temperature (°C)
m	mass (kg)
$\dot{m}$	ammonia or solution flow rate ($kg\,s^{-1}$)
$\dot{M}$	water flow rate ($kg\,s^{-1}$)
Nu	Nusselt number
Pr	Prandtl number
P	pressure (kPa)
Pa	Pascal
q	heat transfer density ($kJ\,kg^{-1}$)
$\dot{Q}$	thermal power (kW)
Re	Reynolds number
S	heat transfer surface (m^2)
T	temperature (°C)
U	overall heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
V	flow velocity ($m\,s^{-1}$)
W	electrical power (kW)

Constants

$g = 9.8\,m\,s^{-2}$ gravitational acceleration

Subscripts

A	ammonia
C	compressor
D	desorber
E	economizer
eq	equivalent
i	internal
mix	mixture
p	poor solution
r	rich solution
R	resorber
s	solution
t	distance between two adjacent tubes (m)
w	water

Greek symbols

α	wetting density ($kg\,m^{-1}\,s^{-1}$)
ξ	concentration (%)
Δ	increment
δ	wall thickness (m)
ε	tube radius (m)
Ψ	thermal resistance ($m^2\,K\,W^{-1}$)
φ	circulation factor ($kg_{rich\ solution}\,kg^{-1}_{ammonia}$)
λ	specific work ($kJ\,kg^{-1}$)
μ	dynamic viscosity (Pa s)
ν	cinematic viscosity ($m^2\,s^{-1}$)
ω	security design factor (%)
ρ	mass density ($kg\,m^{-3}$)
θ	heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)

However, the use of ammonia/water heat pumps was very marginal at this time. The most widespread uses of such heat pumps were in air conditioning and industrial processess in Japan, and district heating in Romania [8]. One of the objectives was to supply heat at higher thermal potentials for process or space and domestic hot water heating. Depending on the ratio of the local costs of fossil fuels and electricity and on the availability of waste heat sources, the use of absorption, re-sorption or combined cycles was considered appropriate and even advantageous for large district heating systems. These cycles effectively proved to be potentially valuable alternatives to cycles using artificial refrigerants because of negligible levels of energy consumption, higher working temperatures since ammonia molecules are more stable, and because the critical point of an ammonia/water mixture is higher than that of the conventional refrigerants. Moreover, ammonia has no ozone depletion potential. This article deals with the configurations, general principles of the thermal design, and a number of operating experiences and performances of a single-stage, 4.5-MW, compression/re-sorption, industrial-scale ammonia/water heat pump aiming at supplying hot water to a large residential district. The objective is to provide a review of an industrial experiment aiming at initiating future research projects, especially in the Canadian industrial waste heat recovery field. The theory of this thermodynamic cycle is well known and was theoretically studied for refrigeration [1], but few applications in industrial plants were implemented before 1980. Even today, some work remains to be done before such systems can be widely accepted and applied.

During the early 1980s, about half of the space and domestic hot water (DHW) heating demand in Bucharest (Romania) was provided by cogeneration units using natural gas or oil as primary energy sources [5]. Many district heating transport network ensured the energy distribution to consumers located in several districts of the city. At that time, a strong increase in the energy demand for space and DHW heating was observed, but the option of the construction of