Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

Experimental investigation of the auxiliary gas circuit of a diffusion absorption chiller with natural and forced circulation

Fabian Schmid *, *Klaus Spindler*

Institute of Thermodynamics and Thermal Engineering (ITW), University of Stuttgart, Pfaffenwaldring 6, 70569 Stuttgart, Germany

ARTICLE INFO

Article history:
Received 7 March 2016
Received in revised form 14 July 2016
Accepted 16 July 2016
Available online 20 July 2016

Keywords:
Diffusion absorption chiller
Auxiliary gas circuit
Clamp-on ultrasonic flowmeter
Forced circulation

ABSTRACT

The auxiliary gas circuit has a significant influence on the cooling capacity and the efficiency of a diffusion absorption chiller. Nevertheless, there are only a few theoretical studies and experimental investigations concerning this topic. The reason is the difficulty to gain measurement data of the volume flow rate and the partial pressures without affecting the natural circulation of the auxiliary gas circuit negatively.

This paper presents a detailed experimental investigation of the auxiliary gas circuit. The gas mixture in the circuit mainly consists of the vapour of the refrigerant (ammonia) and the inert gas (helium). A clamp-on ultrasonic flowmeter measures the volume flow rate of the gas mixture and the mole fraction of helium and ammonia continuously. The influence of an increasing volume flow on the mass transfer in the auxiliary gas circuit is shown by using a propeller to force the circulation of the gas mixture.

Étude expérimentale du circuit auxiliaire au gaz d'un refroidisseur à diffusion-absorption avec une circulation naturelle et forcée

Mots clés : Refroidisseur à diffusion-absorption ; Circuit auxiliaire au gaz ; Débitmètre à ultrasons de type clamp-on ; Circulation forcée

1. Introduction

Nowadays, the diffusion absorption refrigeration process is mainly used in minibars and refrigerators in hotels and caravans. The absence of moving parts in the process causes a low-noise and wear-free operation. The process is based on the principle invented in 1922 by von Platen and Munters (Munters et al., 1923). A schematic of the principle is shown in Fig. 1 in Section 2. Ammonia as the refrigerant and water as the

* *Corresponding author.* Institute of Thermodynamics and Thermal Engineering (ITW), University of Stuttgart, Pfaffenwaldring 6, 70569 Stuttgart, Germany. Fax: +49 711 685 63503.

E-mail address: schmid@itw.uni-stuttgart.de (F. Schmid).

http://dx.doi.org/10.1016/j.ijrefrig.2016.07.012

Nomenclature

A	phase boundary [m^2]
c	sonic speed [$m\ s^{-1}$]
c_p	specific heat capacity [$kJ\ kg^{-1}\ K^{-1}$]
Δh	specific enthalpy of evaporation [$kJ\ kg^{-1}$]
$\dot{M}$	mass flow rate [$kg\ s^{-1}$]
p	pressure [bar]
$\dot{Q}$	heat flow rate [W]
T	temperature [K]
Δt	duration [s]
$\dot{V}$	volume flow rate [$m^3\ s^{-1}$]
y	mole fraction [$mol\ mol^{-1}$]
ϑ	temperature [°C]
ξ	mass fraction [$kg\ kg^{-1}$]
ρ	density [$kg\ m^{-3}$]

Subscripts

abs	absorber
amb	ambient
evap	evaporator
ext	external
gas	gas
gen	generator
He	helium
in	inlet
liq	liquid
max	maximal
NH_3	ammonia
out	outlet
ref	refrigerant
sol	solution
sys	system
weak	weak

absorbent is the common working pair in diffusion absorption refrigerators. In contrast to absorption chillers, a thermally driven bubble pump replaces the solution pump. The circulation of the solution cycle is maintained by the hydrostatic principle and the difference in density between two columns: One column of strong solution with a high density in the reservoir and another column of weak solution and ammonia vapour with a low density in the bubble pump. A mixture consisting of a high mass fraction of ammonia with a low mass fraction of water is named as strong solution. In contrast, a mixture with a low mass fraction of ammonia and a high mass fraction of water is named as weak solution. The ammonia vapour is desorbed from the strong solution by heat input with an electrical heating tape or a gas burner.

Another characteristic of a diffusion absorption refrigerator is the auxiliary gas circuit. The auxiliary gas circuit comprises the absorber, the evaporator, the gas heat exchanger and the refrigerant heat exchanger. The working principle is as follows: On the one hand, the auxiliary gas reduces the partial pressure of the refrigerant within the auxiliary gas circuit at a uniform system pressure. This enables the refrigerant to evaporate into the auxiliary gas atmosphere at a varying evaporation temperature due to the varying ammonia partial pressure. Usually hydrogen is used as inert gas. On the other hand, the difference of the refrigerant mole fraction as well as the temperature difference results in a difference in density, which causes the circulation of the auxiliary gas. The auxiliary gas circuit is of particular importance for the cooling capacity and the efficiency of the diffusion absorption refrigeration process. The mass transfer of the refrigerant through the gas–liquid interface is the limiting factor. The understanding of the principles of the mass transfer in the evaporator and the absorber is important for further improvements of the process.

There are several theoretical investigations and simulations containing the whole diffusion absorption refrigeration process; others are focusing only parts of it. The simulations are based on the state of equilibrium of the fluids as well as on mass and energy conservation equations in every component of the refrigerator. One study shows the influence of the generator temperature, the evaporator temperature and the system pressure on the cooling capacity and on the efficiency of the diffusion absorption refrigerator (Chaouachi and Gabsi, 2007). Another study analyses the effect of different inert gases (helium, hydrogen, neon and argon) on the efficiency of the refrigerator. Thermodynamically, helium is a better choice than hydrogen due to its heat capacity, which is only one third of the heat capacity of hydrogen. Hence, the heat losses because of the uncompleted heat recovery in the gas heat exchanger are smaller with helium as inert gas. However, the natural circulation of the auxiliary gas circuit is better with hydrogen as inert gas due to the lower viscosity and density than helium. The cooling performance of neon and argon as inert gas is equal to helium (Zohar et al., 2005). A simulation based on the finite-difference method analyses the three-dimensional evaporation of liquid ammonia into the parallel flowing inert gas. As the result, helium can replace hydrogen with less danger of explosion in bigger units (Kouremenos et al., 1994). The substitutability of hydrogen by helium is shown in the paper by Maiya (2003) by modelling the whole auxiliary gas circuit. Additionally, the influence of the system pressure on the mass transfer in the evaporator and the absorber respectively on the cooling capacity of the refrigerator is analysed. A simulation model for all components of a diffusion absorption refrigerator using sodium thiocyanate as solvent is shown in Rattner and Garimella (2016). The model is used to predict the cooling capacity and the coefficient of performance of the refrigerator as well as the flow rate of the auxiliary gas.

Gaining measurement data from the auxiliary gas circuit of a diffusion absorption refrigerator, for example the volume or mass flow as well as the mole fraction of the inert gas and the refrigerant, is very challenging. The main problem is that the utilized measurement device may not cause a significant pressure drop, which would affect the natural circulation of the auxiliary gas circuit negatively. Furthermore, the measurement device has to be helium pressure-tight up to a system pressure of 20 bar and resistant to an ammonia–water solution. Measurement data found in the literature concerning the auxiliary gas circuit are mainly temperatures and the system pressure (Jakob et al., 2007; Mazouz et al., 2014; Sözen et al., 2012; Vicatos, 2000; Yildiz et al., 2014).

One of the few efforts to analyse the auxiliary gas circuit based on a combination of theoretical and experimental investigations is shown in Kouremenos and Stegou-Sagia (1988).