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Horizontal tube bundle falling film distiller for ammonia–water mixtures

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ABSTRACT

This work presents an experimental study of an important component of an ammonia–water absorption refrigeration cycle based on the falling film technology – the distiller, which is formed by two parts: the generator and the rectifier. It was carried out a parametrical study on the operation of the distiller by testing several parameters. The experimental results showed that the distilled ammonia vapor concentration always degraded as rectifier, generator, and concentrated solution temperatures increased and improved as concentrated solution mass flow rates and concentrated solution concentrations increased. The highest distilled ammonia vapor concentration obtained was of 0.9974. Photographic documentation of flow pattern over the generator tube bundle was also obtained resulting in both jet column and sheet patterns. Finally, a Nusselt number correlation for the ammonia–water falling film over the generator tube bundle was proposed based on the experimental results and compared with other authors' correlations.

Distillateur à faisceau de tubes horizontaux à film tombant pour des mélanges ammoniac-eau

Mots clés : Ammoniac-eau ; Film tombant ; Distillation ; Absorption

1. Introduction

Absorption refrigeration cycles (ARC) are promising candidates for diminishing the dominating dependence on regular mechanical vapor compression refrigeration cycles (CRC) in the air conditioning and refrigeration industries. Their distinct advantage over CRC relies on the fact that they can be powered by either waste and recovered heat sources or be directly powered by solar energy at none or low electrical energy consumption. They can also operate in a combined heat and power (CHP) or cogeneration configuration increasing the final usage of the fuel chemical energy content used to power a thermal machine, i.e., increasing the energy utilization factor (EUF). On the other hand, absorption refrigeration cycles are usually heavier, larger, and have a higher capital expenditure than standard compression refrigeration cycles at the same nominal capacity. They are larger and heavier due to the high number

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Nomenclature

a	constant [–]
A	area [m^2]
b	constant [–]
COP	coefficient of performance [–]
c_p	specific heat at constant pressure [$J\ kg^{-1}\ °C^{-1}$]
d	diameter [m]
g	acceleration of gravity [$m\ s^{-2}$]
Ga	modified Galileo number, $Ga = \rho\gamma^3/\mu^4 g$ [–]
F	correction factor [–]
k	thermal conductivity [$W\ m^{-1}\ °C^{-1}$]
$LMTD$	logarithmic mean temperature difference [°C]
m	mass flow rate [$kg\ s^{-1}$]
n	constant [–]
Nu	Nusselt number, $Nu = \alpha(\upsilon^2/k^3 g)^{1/3}$ [–]
Pr	Prandtl number, $Pr = c_p\mu/k$ [–]
q	heat transfer rate [W]
Re	Reynolds number, $Re = 4\Gamma/\mu$ [–]
SF	shape factor [–]
T	temperature [°C]
TR	tons of refrigeration [3517 W]
U	overall heat transfer coefficient [$W\ m^{-2}\ °C^{-1}$]
x	ammonia–water concentration – liquid [$kg_{ammonia}\ kg_{solution}{}^{-1}$]
y	ammonia–water concentration – vapor [$kg_{ammonia}\ kg_{solution}{}^{-1}$]

Greek symbols

α	heat transfer coefficient [$W\ m^{-2}\ °C^{-1}$]
γ	surface tension [$N\ m^{-1}$]
Γ	mass flow rate per axial unit length of tube (each side) [$kg\ m^{-1}\ s^{-1}$]
Δ	difference [–]
ε	emissivity [–]
μ	dynamic viscosity [$kg\ m^{-1}\ s^{-1}$]
υ	kinematic viscosity [$m^2\ s^{-1}$]
ρ	density [$kg\ m^{-3}$]
σ	Stefan–Boltzmann constant [$W\ m^{-2}\ K^{-4}$]

Subscripts

c	correlation
$conv$	convection
cs	concentrated solution
d	distilled
ds	diluted solution
f	falling film
g	generator
in	inside
m	average
o	oil
out	outside
r	rectifier
rad	radiation
s	saturation
v	vapor
$vess$	vessel
w	wall

of heat and mass exchangers employed to increase its efficiency. ARC are commercially available in two technologies. The first one is based on lithium bromide–water mixtures, and the second one on ammonia–water mixtures. The former can be applied only to air conditioning systems, as the fluid refrigerant is plain water. However, that cycle has a higher coefficient of performance (*COP*). Simple effect ARC have typical *COP* of 0.6–0.7 for lithium bromide cycles and 0.5 for ammonia–water cycles (ASHRAE, 1994), higher *COP* can be obtained in multi-effects cycles (Srikhirin et al., 2001). The second one can be used to either subzero or above zero degree Celsius applications, as the fluid refrigerant is ammonia. Furthermore, the ammonia–water cycle demands smaller heat exchangers, it operates at above atmospheric pressure and there is no any crystallization concern (Herold et al., 1996).

In the evaporation process of the ammonia–water mixture, a small fraction of water is always present in the vapor phase dominated by ammonia. Thus, the wet vapor ammonia produced in the generator section must be purified to get rid of its water content, since liquid water can accumulate and increase the evaporator temperature, a phenomenon known as temperature glide. In accordance with such an operational problem, Fernádez-Seara and Sieres (2006) studied theoretically the consequences of exiting high amounts of water from the distiller in ammonia–water absorption refrigeration cycles and concluded that water content in wet ammonia is accountable for the low *COP* in experimental and industrial AARC.

The two key components of ammonia–water absorption refrigeration cycles (AARC) design and operation are the absorber and the distiller, wherein the former one has been the most studied (Determan and Garimella, 2011). The distiller must provide pure or at a very high purity degree of ammonia vapor to operate the cycle.

Small commercial ammonia–water absorption refrigeration cycles (5 *TR*) have flooded generators (also known as desorbers), in which wet ammonia vapor is produced from a liquid solution heated by hot flue gases. The wet ammonia vapor is driven to a tray filling type analyzer, also known as rectification column or fractionation column (Herold et al., 1996; Merrick, 1972). After that, the ammonia vapor is directed to the rectifier to, finally, reach the condenser where a high degree of purity has been reached. According to Merrick (1972), the tray type distiller is generally the largest component in an AARC. This is due to the use of the analyzer and a gas burner placed below the generator, in his work the gas burner was placed at side of the vertical generator to decrease its size.

Previous works on the distiller are Anand and Erickson (1999), who analyzed theoretically a distillation column for an 8*TR* AARC. Zavaleta-Aguilar and Simões-Moreira (2012) carried out a thermal modeling analysis and design of a holed tray distillation column for a 5 *TR* AARC. Those authors carried out a parametric analysis of the liquid and vapor ammonia–water mass flow rates, concentration, and temperature along with a study over geometrical parameters influence such as plate hole and column