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Investigations on R134a–DMAC vapour absorption refrigeration system with add-on components

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ABSTRACT

R134a (1, 1, 1, 2 tetrafluro ethane)–DMAC (N, N Dimethyl Acetamide) vapour absorption refrigeration system (VARS) can be used for sub–zero temperature applications and in industries where ammonia is forbidden. Because of the low boiling temperature difference between R134a and DMAC, a little amount of the latter also boils along with the former in the generator. Hence, this system needs a rectifier. Owing to incomplete rectification, a little amount of DMAC escapes to the condenser which ultimately results in residual liquid in the evaporator and cooling loss. This paper evaluates the performance of R134a–DMAC VARS with rectifier and liquid vapour heat exchanger (LVHX) at different operating conditions by simulation studies. The system performance becomes maximum at some optimum generator temperature which increases with sink temperature and decrease in cooling temperature. Owing to a large heat duty of solution heat exchanger (SHX), its efficiency is vital in increasing the system COP. Due to the presence of the residual liquid and low ratio of latent heat to specific heat of R134a vapour, LVHX plays an important role. Rectifier loses its importance when efficiency of LVHX is high. Significance of all the three components increases at low cooling and high sink temperatures.

1. Introduction

The vapour compression refrigeration systems (VCRS) are popular but are being replaced by vapour absorption refrigeration system (VARS) in many places owing to an increased cost and scarcity of electricity. For VARS the input is predominantly heat energy which may be available abundantly in the form of waste heat from industry or solar heat. Water–lithium bromide and ammonia water are widely used refrigerant–absorbent pairs in VARS. But, the former has the limitation of producing cooling only at above 0 °C and the latter cannot be used in certain industries. Consequently, attention was drawn to the new refrigerants. During selection of appropriate new refrigerant–absorbent pairs, very high solubility of refrigerant in the absorbent and their chemical and thermal stability were suggested as the most important criteria [1]. For developing new refrigerants apart from chloro-fluoro–carbon compounds, eight elements were considered, namely, carbon, nitrogen, oxygen, sulphur, hydrogen, fluorine, chlorine and bromine [2]. Due to high ozone depletion potential the possibility of making refrigerants with chlorine and bromine was discarded. R134a is a refrigerant which is capable of producing cold at sub–zero temperatures and can be used even where ammonia cannot be used [3]. DMAC is a good absorbent of R134a.

Two–stage half-effect R134a–DMAC VARS was theoretically studied [4]. The additional absorber and generator were operated at an intermediate pressure. Both the generators were supplied heat with the same source temperature. The claimed COP was in the range of 0.35–0.46 with a heat source at 70 °C, sink at 25 °C and cooling at −5 to 5 °C. Using a condensate pre–cooler COP can be increased up to 13%.

Experiments on R134a–DMAC VARS revealed that sink temperature plays an important role in the system performance and heat transfer in every component increases with an increase in generator temperature [5]. Efficiencies of the solution heat exchanger, generator and absorber increase with increase in source temperature.

The viscosity, density and equilibrium pressure of the mixtures of R134a with the absorbents DMETEG, DMEU and MCL were measured experimentally and the specific excess enthalpy was found out by using UNIFAC model [6]. These properties were expressed as the functions of temperature and the mass fraction of the refrigerant in the mixture.

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Nomenclature

A	Area (m^2)
c	Specific heat ($kJ\ kg^{-1}\ K^{-1}$)
COP	Coefficient of performance
d	Diameter (m)
D	Diffusivity ($m^2\ s^{-1}$)
g	Acceleration due to gravity ($m\ s^{-2}$)
G	Mass flux ($kg\ m^{-2}\ s^{-1}$)
h	Enthalpy ($kJ\ kg^{-1}$)
h_{air}	Air side heat transfer coefficient ($kW\ m^{-2}\ K^{-1}$)
h_c	Condensing heat transfer coefficient ($kW\ m^{-2}\ K^{-1}$)
h_{fg}	Latent heat ($kJ\ kg^{-1}$)
h_l	Liquid phase heat transfer coefficient ($kW\ m^{-2}\ K^{-1}$)
h_m	Mass transfer coefficient ($m\ s^{-1}$)
h_{ref}	Refrigerant side heat transfer coefficient ($kW\ m^{-2}\ K^{-1}$)
k	Thermal conductivity ($kW\ m^{-1}\ K^{-1}$)
LVHX	Liquid vapour heat exchanger
l	Length (m)
m	Mass flow rate ($kg\ s^{-1}$)
Nu	Nausselt number
Pr	Prandtl number
Q	Rate of heat transfer (kW)
R	Radius (m)
Re	Reynolds number
SHX	Solution heat exchanger
St	Stanton number
t, T	Temperature (°C, K)
t_e	Cooling temperature (°C)
t_{air}	Ambient air temperature (°C)
thick	Thickness of liquid layer in rectifier plate
TR	Ton of refrigeration
U	Overall heat transfer coefficient ($kW\ m^{-2}\ K^{-1}$)
U_m	Overall mass transfer coefficient ($m\ s^{-1}$)
V	Velocity ($m\ s^{-1}$)
x	Mole fraction
x'	Quality
X_{tt}	Lockhart–Martinelli parameter
w	Work input (kW)

Subscripts

a	Absorber
b	Bubble
c	Condenser
e	Evaporator
ev	Vapour at evaporator outlet
g	Generator
i	Incremental numbers, 1,2,3,….
in	Inlet
l	Liquid
M	Molar
mur	Murphree
o	Orifice
out	Outlet
p	Pump
r	Rectifier
ref	Refrigerant
rl	Residual liquid at evaporator outlet
s	Strong solution
tp	Two phase
v	Vapour
v′	Vapour at outlet of the rectifier
v"	Vapour at bottom of generator
w	Weak solution
1…9	State points as shown in Fig. 1

Greek letters

ε	Void fraction
μ	Dynamic viscosity ($kg\ m^{-1}\ s^{-1}$)
ξ	Mass fraction of R134a
ρ	Density ($kg\ m^{-3}$)
σ	Surface tension ($N\ m^{-1}$)
η	Efficiency
λ	Circulation ratio
τ	Contact time between bubble and liquid (s)

The possibility of using new refrigerant R124 (Chloro1 tetrafloro 1,1,2,2 ethane) with different organic absorbents like DMAC (N,N Dimethylacitamide), NMP (N–methyl–2–pyrrolidone), MCL (N–methyl–ε–caprolactam), DMEU (dimethylethylene urea) and DMETEG (dimethylether tetraethyleneglysol) was investigated [7]. Considering the stability and efficiency of the system, the pair R124–DMAC was found to be the best followed by R124–NMP, R124–DMEU and R124–DMETEG.

Theoretically the performance of R125–DMEU single stage triple pressure level absorption cycle was improved by using a specially designed jet injector which increases the absorption rate of refrigerant by weak solution [8]. Its purpose was to reduce the circulation ratio, achieve a low cooling temperature and operate the system with low generator and high sink temperatures.

Heat and mass transfer coefficients for R134a–DMAC mixture were found experimentally at different positions of horizontal absorber [9]. The values of heat transfer coefficients were much less than those for water-lithium bromide solution. Mass transfer coefficient at upper part of the absorber is higher than that at lower part.

Experimental analysis revealed that the overall heat transfer coefficient in the coiled tube absorber of R134a–DMAC VARS increases almost linearly with film Reynolds number which is non dimensional form of the solution flow rate at the inlet of absorber [10]. The cooling water temperature plays a vital role during the design of an absorber. At a constant absorber pressure and cooling water inlet temperature, refrigeration capacity increases with film Reynolds number.

Because of low difference between the boiling temperatures of ammonia and water, significances of the stripping and rectifying sections were theoretically investigated [11]. The rectifying section loses its importance when efficiency of the stripping section is high, sink temperature (for condenser and absorber) is low and cooling temperature is high. But both sections are needed for getting pure ammonia in the condenser. Heat and mass transfer analysis of the helical coil rectifier showed that its length depends mostly on the vapour phase heat and mass transfer coefficient [12]. The effects of the coolant and liquid phase heat transfer coefficients are negligible.

Hitherto use of rectifier is limited only to NH_3–H_2O system. All the vapour absorption systems with new refrigerants have been analysed without rectifier as it was assumed that only refrigerant boils out in the generator. Consequently residual liquid has not been considered in the liquid vapour heat exchanger (LVHX). As the difference in boiling temperatures of R134a and DMAC is not as high as water and lithium bromide (about 191 °C), in generator the latter also boils along with the former, particularly at high generator temperature which is required for low cooling and/or high sink temperatures. Depending on the rectifier efficiency some amount of DMAC escapes to the condenser and results in residual liquid in