Energy and Buildings 58 (2013) 86–92

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

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

Performance analysis of a diffusion absorption refrigeration cycle working with TFE–TEGDME mixture

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ARTICLE INFO

Article history:
Received 9 October 2012
Received in revised form 2 December 2012
Accepted 8 December 2012

Keywords:
Diffusion absorption refrigeration
Organic working fluid
TFE–TEGDME
Cycle performance

ABSTRACT

The binary mixture of TFE–TEGDME has good thermo-physical properties and been investigated by many absorption chiller and heat pump researchers. However, few studies have been reported on the diffusion absorption refrigeration (DAR) system using TFE–TEGDME as the working fluid. The present article numerically investigates the potential of TFE–TEGDME used in the DAR system with two cooling mediums, viz. water (32 °C) and air (35 °C). It is found that with the absorber effectiveness of 0.8, the optimum generation temperature for the air-cooled TFE–TEGDME DAR system is around 170 °C, and the corresponding coefficient of performance (COP) is up to 0.45. In comparison, the performance of the water-cooled system is better with a lower optimum generation temperature around 130 °C and a higher COP reaching 0.56. Parametric studies are also conducted to analyze the effects of the cooling medium, generation temperature, evaporation temperature and absorber effectiveness on the system performance. Finally, the performance of the TFE–TEGDME and NH_3–H_2O DAR cycles is compared in terms of the COP and circulation ratio. Overall, it can be concluded that the TFE–TEGDME mixture is a good working fluid for the DAR cycle.

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1. Introduction

In recent years, energy consumption in buildings has become a priority issue. The building sector currently accounts for approximately one third of the total primary energy consumption worldwide [1], and this value will be higher in the future as the development of the economy together with the improvement of people's living standard [2]. Meanwhile, the building sector produces large carbon dioxide emissions associated with the use of fossil fuels. For instance, buildings contribute to around 18% of global carbon dioxide emissions in China [3]. With respect to energy savings and emission reduction, the interest in the refrigeration systems driven by low-temperature heat sources, such as solar energy and waste heat, for building cooling is growing [4].

The thermally activated diffusion absorption refrigeration (DAR) cycle introduced by Platen and Munters [5] in the 1920s has been recognized as one of the most promising sustainable technologies for cooling production. The cycle operates at a constant total pressure level and utilizes a refrigerant–absorbent mixture as the working fluid and an inert gas for pressure equalization. Comparing with the conventional absorption refrigeration cycle, the DAR has no solution pump, which is instead of a bubble pump and leads to silent operation [6]. As the growing demand on high quality living condition in residential and commercial buildings in recent years, the advantages make the DAR attract gained attention.

The most common DAR system uses NH_3–H_2O as the working fluid and hydrogen or helium as the auxiliary inert gas, which has been extensively investigated. For example, Zohar et al. [7] and Starace and De Pascalis [8] developed thermodynamic models for the NH_3–H_2O DAR cycle with hydrogen as the auxiliary inert gas; Chen et al. [9] developed a new generator configuration that increases the COP of the cycle by 50%; Srikhirin et al. [10] carried out an experimental study on an NH_3–H_2O DAR cycle using helium as the auxiliary gas. Zohar et al. also compared the COP of two cycle configurations with and without condensate sub-cooling prior to the evaporator entrance [11], and investigated the influence of the generator and bubble pump configuration on the cycle performance [12]. Jakob et al. experimentally and theoretically studied a 2.5 kW solar heated NH_3–H_2O DAR machine with helium as pressure compensating inert gas [13–15], which demonstrates that the DAR system can be used for domestic air conditioning.

However, the NH_3–H_2O DAR system has some limitations resulting from the working fluid. It requires a generation temperature above 150 °C; it is a high-pressure system that needs a rectifier; in addition, ammonia is toxic, explosive and corrosive to copper [16]. To overcome the limitations, organic fluids are suggested.

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http://dx.doi.org/10.1016/j.enbuild.2012.12.003

Nomenclature

COP	coefficient of performance
DAR	diffusion absorption refrigeration
f	circulation ratio
m	mass flow rate (kg/s)
Q	heating capacity (W)
P	pressure (kPa)
SRC	condenser sub-cooling
T	temperature (K)
ΔT	temperature difference in the heat exchanger (°C)
ξ	mass concentration of TFE in solution (kg/kg)
C_4H_{10}	*n*-butane
C_9H_{20}	*n*-nonane
DMAC	N,N-dimethylacetamide
DMF	N,N-dimethylformamide
H_2O	water
LiBr	lithium bromide
NH_3	ammonia
R124	2-chloro-1,1,1,2-tetrafluoroethane
R125	pentafluoroethane
R134a	1,1,1,2-tetrafluoroethane
R22	chlorodifluoromethane
R23	trifluoromethane
R32	difluoromethane
TEGDME	tetraethylene glycol dimethyl ether
TFE	2,2,2-trifluoroethanol

Subscripts

1, 2, . . ., 10	system's state point
abs	absorber
C	ambient temperature
cond	condenser
evap	evaporator
E	evaporation temperature
gen	generator
G	generation temperature
GHX	gas heat exchanger
K	condensing temperature
r	rich solution
SHX	solution heat exchanger
syst	system
Vr	rich gas mixture
w	weak solution

Koyfman et al. [17] conducted an experimental investigation on the performance of the bubble pump for the DAR cycle with R22–DMAC as the working fluid, and they indicated that the cycle can be operated at the maximum average generator temperature below 90 °C. Zohar et al. [18] compared the performance of the DAR cycle using five refrigerants (R22, R32, R124, R125 and R134a) in combination with the organic absorbent DMAC with the NH_3–H_2O system. Ben Ezzine et al. [16] reported that the R124–DMAC DAR system gives a higher COP at lower driving temperatures comparing with the NH_3–H_2O system; they also experimentally investigated a DAR system using C_4H_{10}–C_9H_{20} as the working fluid and helium as the auxiliary gas [19]. Wang et al. [20] investigated a DAR with the binary refrigerants R23/R134a, the absorbent DMF and auxiliary inert gas helium for lower temperature applications with the generating temperature between 110 and 160 °C. These studies concluded the promising prospect of the organic working fluids for the DAR cycle.

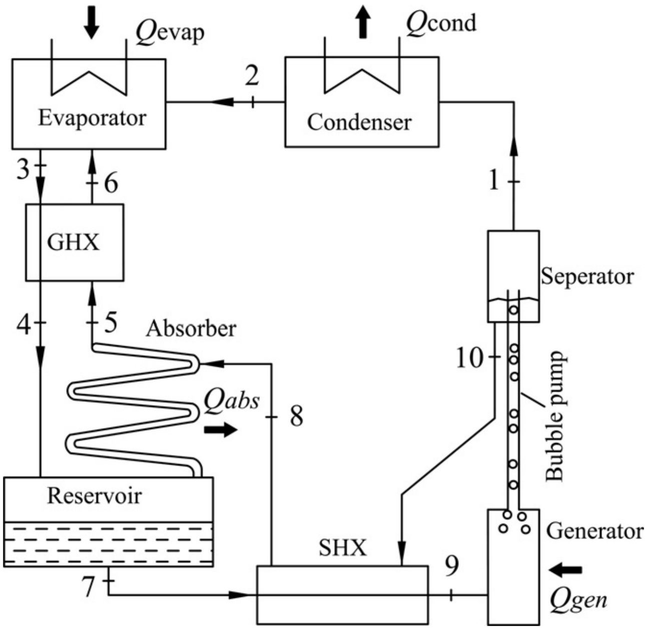

Fig. 1. Scheme of a diffusion absorption refrigeration cycle.

Among the organic working fluids, the binary organic mixture of 2,2,2-trifluoroethanol (TFE)-tetraethylene glycol dimethyl ether (TEGDME) has many advantages such as complete miscibility, wide working temperature range, low working pressure, no corrosion and good safety level. Also, owing to the great difference of the normal boiling temperature (about 200 °C) between TFE and TEGDME, the system does not need a rectifier, which makes the system simpler and cheaper [21]. The overall performances of TFE–TEGDME as the working pair utilized in the absorption systems (absorption chiller, absorption heat pump and absorption heat transformer) has been widely investigated [21–25]. However, to our knowledge, the investigation on the TFE–TEGDME DAR system has not been performed. With regard to the excellent thermo-physical properties, it is believed that a DAR system using TFE–TEGDME as working fluids will have a good performance. Hence, the present study aims to investigate the TFE–TEGDME DAR cycle with helium as the auxiliary gas. The effects of different operating parameters on the system performance are analyzed.

2. TFE–TEGDME DAR cycle

The flow chart of the DAR cycle is shown in Fig. 1. At the bottom of the generator, the rich TFE–TEGDME solution (9) is heated and releases some TFE vapor. The formed TFE vapor bubbles rise up and lift the solution to the top of the bubble pump by thermosyphon action. The resulting weak solution (10) flows back to the absorber through the solution heat exchanger (SHX) by the gravity effect, whereas the hot TFE vapor (1) enters the condenser where it condenses by releasing heat to the cooling medium, i.e. the air or cooling water. Then, the liquid TFE (2) at the system pressure reaches the inlet of the evaporator and meets the cold TFE-poor gas mixture (6) returning from the absorber through the gas heat exchanger (GHX). Due to the partial pressure effect of the auxiliary gas helium according to Dalton's law, the liquid TFE evaporates and produces cooling capacity. The TFE content in the gas mixture increases and the evaporation temperature also rises. The TFE-rich gas mixture (3) leaves the evaporator and flows to the GHX where is heated by the TFE-poor gas mixture (5) from the absorber. The hot TFE-rich gas mixture (4) enters the absorber bottom via the reservoir. In the absorber, the TFE is gradually absorbed from the rising TFE-rich gas mixture by the falling weak TFE–TEGDME solution (8) from the SHX. The auxiliary gas helium is insoluble in the solution,

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