Renewable and Sustainable Energy Reviews 31 (2014) 681–707

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

An overview of ammonia-based absorption chillers and heat pumps

Wei Wu, Baolong Wang, Wenxing Shi, Xianting Li *

Department of Building Science, School of Architecture, Tsinghua University, Beijing 100084, PR China

A R T I C L E I N F O

Article history:
Received 27 January 2013
Received in revised form
24 September 2013
Accepted 19 December 2013
Available online 22 January 2014

Keywords:
Absorption heat pump
Fluid properties
Subfreezing refrigeration
Heating
Renewable energy
Energy storage

A B S T R A C T

The use of ammonia-based working fluids for absorption prevails in a wide range of applications due to the low freezing temperature of the refrigerant and the absence of crystallization as well as the lack of problems under vacuum conditions. This paper presents a comprehensive overview on the use of ammonia-based absorption chillers and heat pumps. The thermodynamic and physical properties of pure ammonia and binary and ternary ammonia mixtures are presented in correlation formulas. Developments and applications in subfreezing refrigeration, heating/domestic hot water, renewable energy utilization, waste heat recovery, thermal energy storage and miniaturization of absorption systems are presented and summarized. In subfreezing refrigeration, the evaporation temperatures for single-stage absorption lie mainly between -30 °C and -5 °C, and they can reach as low as -70 °C in advanced absorption systems. Air-source and ground-source absorption heat pumps are suggested for heating/domestic hot water applications in cold regions. For renewable energy uses, ammonia-based solar absorption applications with various working fluids are quite popular, whereas geothermal and biomass energy systems are less studied. In thermal energy storage, ammonia-based working fluids are not advantageous for storage capacity or cycle efficiency, but they prevail for subfreezing energy storage. Additionally, ammonia-based fluids are also attractive options for the miniaturization of absorption systems due to the absence of crystallization.

Contents

* Corresponding author. Tel.: +86 10 62785860; fax: +86 10 62773461.
E-mail address: xtingli@tsinghua.edu.cn (X. Li).

1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.12.021

1. Introduction

Originally used for refrigeration, the absorption cycle was invented in the mid-1800s [1] but faded quickly after higher-performance vapor compression refrigeration was introduced. Since the 1960s, absorption technology, especially the absorption refrigeration cycle for air conditioning, has been gradually developed because it primarily consumes low-level heat energy [2] and can play an irreplaceable role in renewable energy use [3,4] and waste heat recovery [5,6]. Finally, the absorption heat pump (AHP) has also drawn attention due to its potential for use in sustainable energy systems providing a high primary energy efficiency and low environmental impact [7,8].

H_2O–LiBr and NH_3–H_2O are the most widely used absorption working fluids [9,10], with the former being more popular due to its higher performance [11]. However, several critical limitations exist for H_2O–LiBr:

- The freezing point of water is 0 °C, and therefore, an H_2O–LiBr AHP that uses water as a refrigerant cannot operate at an evaporation temperature below 0 °C, making it unusable for subfreezing refrigeration [12,13] or heating/domestic hot water (DHW) supplementation in cold regions.
- Crystallization of the H_2O–LiBr solution is quite common, especially when the absorption temperature is high or the evaporation temperature is relatively low, which presents a barrier for air-cooled absorption [14,15].
- High vacuum conditions should be maintained in the system for efficient operation of the H_2O–LiBr system; otherwise, the performance of the absorption cycle would be greatly degraded [16].

These factors render ammonia-based solutions more suitable for adoption as AHP working fluids in certain situations, especially for applications involving subfreezing refrigeration, air-cooled AHPs, AHP heating and DHW, among others. In other applications (i.e., renewable energy utilization, waste heat recovery and thermal energy storage), ammonia-based working pairs have also attracted great attention due to the absence of crystallization and vacuum issues.

Several critical reviews have been published in the literature on the subject of absorption technologies. In 2000, Kang et al. [17] reviewed the performance improvement and temperature lift enhancement of advanced absorption cycles. Srikhirin et al. [18] reviewed different working fluids and cycles for absorption refrigeration in 2001. In 2002, Ziegler [19] defined the state of the art in sorption heat pumping and cooling technologies, including the working fluids and cycles for both absorption and adsorption systems, and Sun et al. [20] presented a review of working fluids for absorption cycles in 2012. However, the previous literature has mainly focused on the development of working fluids and absorption cycles, with most attention centered on air conditioning and refrigeration. No previous review has comprehensively summarized the studies and applications of AHPs using ammonia-based solutions as working fluids, which have special advantages over other fluids. The main objective of this paper is to provide a complete review of ammonia-based AHPs, including both absorption chillers and heat pumps. The thermodynamics and physical properties of different ammonia-based working fluids are covered, which are

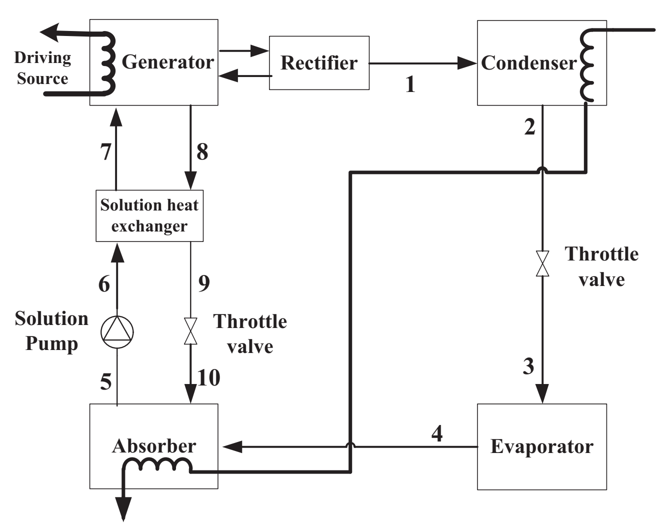

Fig. 1. Schematic of the basic NH_3–H_2O AHP cycle.