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A review of imidazolium ionic liquids research and development towards working pair of absorption cycle

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ABSTRACT

The concerns of energy consumption and environment pollution urge researchers to work on the development of clean energy and the utilization of waste energy. As one important topic, absorption cycle technology has attracted considerable attention because it can be powered by low-grade heat, e.g., solar energy and waste heat. In recent years, researchers proposed that ionic liquids (ILs) as novel alternative absorbent combined with refrigerant such as water, ammonia, alcohols, and hydrofluorocarbons can be used as working pairs for absorption refrigeration cycle, heat pump, and absorption power cycle. In this paper, researches done in imidazolium IL working pairs regarding to status of evaluation and selection methods, thermophysical property measurement and modeling, as well as their future prospect assessments, i.e., developing potential studies about the absorption cycle performance adopting new working pairs, have been reviewed.

Contents

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1. Introduction

1.1. Significance of R&D of absorption cycle and ionic liquid working pair

To deal with the changes in global climate, rapid growth of energy demand and rapid development of renewable energy and energy utilization, much attention has been focused on the research and development (R&D) of absorption cycles, such as absorption heat pump and absorption refrigeration cycle, because they can make effective use of low-grade heat [1–4]. However, the R&D of absorption technology faces a series of problems. For example, the temperature range of the heat source is wider, with a range of 80 – 90 °C collected by economic and efficient flat solar collectors to 500 – 600 °C exhausted from gas turbines or internal combustion engines. The functions and configurations of new absorption cycles are more diverse and complex, such as cogeneration systems that combine power and refrigeration cycles [5–7], compression and absorption hybrid cycles driven by low-grade heat and electrical energy [8,9], and distributed energy systems that combine cooling, heating, and power cycles [10] involving energy storage [11–15] and absorption technologies [16–18]. The above developments present new demands for the R&D of working pairs of absorption cycles as a key and essential work.

Generally, the working pair of absorption cycle is a multi-species solution, which is usually a binary solution consisting of two species with a large boiling point difference. The species with relatively low boiling point, i.e., the volatile species, acts as refrigerant, whereas the species with high boiling point, i.e., the non-volatile species, acts as absorbent. The main types, existing problems, and requests for future development of the absorption cycle working pairs are briefly summarized and listed in Table 1. Based on the species of refrigerant, the working pairs are divided into the following five categories: water, ammonia, alcohol, halohydrocarbon and hydrocarbon (HC). The combinations of five kinds of refrigerants and different absorbents can basically meet the needs of different applications. For example, the H_2O/LiBr working pair is mainly applied in room air conditioning. The NH_3/H_2O working pair can meet cooling requirements below 0 °C. The two working pairs described above are the most widely used systems with environmentally friendly features.

However, the H_2O/LiBr system presents certain disadvantages, such as crystallization, corrosion, and negative pressure operation. Some researchers have attempted to improve the H_2O/LiBr working pair by adding auxiliary species [19,20]. The NH_3/H_2O system also has some drawbacks, such as difficulty in separation and toxicity. Some researchers have added non-volatile species to reduce the separation difficulty [21–23].

Alcohol working pairs are mainly composed of low carbon alcohols, such as methanol and ethanol, or fluoroalcohols, such as 2,2,2-trifluoroethanol (TFE) and hexafluoroisopropanol (HFIP), as refrigerant and salts or high-boiling point organics as absorbent. Alcohols are inflammable and methanol is toxic, so greater interest has been given to fluoroalcohols. Fluoroalcohols are non-corrosive, non-combustible, and have good thermal characteristics. TFE composed of working pairs with some high-boiling point organics have been used, such as tetraethylene glycol dimethyl ether (E181) [24,25], N-methyl-2-pyrrolidone (NMP) [26], N,N′-dimethylpropyleneura (DMPU) [27], N,N′-dimethylethyleneurea (DMEU) [27], and quinoline [28,29]. These working pairs generally have no crystal restrictions, and therefore, have relatively wide operating ranges.

Hydrofluorocarbons (HFCs) are refrigerants with benign technical properties, which are extensively used in the vapor compression refrigeration cycle. It is worth mentioning that HFCs used in the absorption refrigeration cycle are almost harmless to the atmospheric ozone, whereas chlorofluorocarbons (CFCs) are harmful to the atmospheric ozone commonly cannot be used for the absorption refrigeration cycle [30]. HC working pairs have also attracted widespread attentions because of their naturally eco-friendly feature [8,31]. However, due to the flammability and explosibility, researches and applications of HC working pairs are impeded by numerous restrictions.

Both H_2O/LiBr and NH_3/H_2O systems can be developed for future applications, but existing problems need to be solved urgently. Unlike H_2O and NH_3, absorbents suitable for alcohols, HFCs, and HCs are still quite few. Considering that HFCs and HCs can meet the refrigeration technology demands of H_2O and NH_3, absorption cycle working pairs containing HFC or HC have great potential for exploration and are expected to fill the gaps of H_2O/LiBr or NH_3/H_2O systems. Around exploring advanced absorbents with HFC and HC, researchers are exerting efforts to develop novel absorption cycle working pairs [27,32].

Table 1
R&D of absorption cycle working pairs.

Refrigerant species	Absorbent species	Existing problems	Main of the past R&D	Requests of future development
H_2O	LiBr	Corrosion, crystallization	Adding other auxiliary species, e.g., octanol and other species	Abate or avoid the problems of corrosion and crystallization
NH_3	H_2O	Toxicity, difficulty in separating NH_3 from H_2O	Other organic ammoniates	Reduce the separating energy consumption
HFC & HC	Organic solvents	1) Absences of techno-economic significance 2) Values of ODP[a] and GWP[b] cannot meet the needs of developing	New refrigerants with higher ODP and GWP values	1) Meet needs of the R&D of new refrigerants, e.g., R152a, R32 2) Suitable for novel hybrid cycles and co-generation cycles
Alcohol (CH_3OH, C_2H_5OH, TFE)	Organic solvents	To be devoid of techno-economic significance as like as the system H_2O/LiBr	Few	Better techno-economic significance, and environmentally friendly characteristics

[a] Ozone depletion potential.
[b] Global warming potential.