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# Exergy analysis of an ionic-liquid absorption refrigeration system utilizing waste-heat from datacenters

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## ABSTRACT

Ionic-liquid (IL) was introduced as an absorbent of an absorption refrigeration system designed for high power electronics cooling. IL is a salt in liquid-state, which is nonvolatile, thermally-stable, nonflammable, and environmentally-benign. It provides an alternative to the normally toxic working fluids, such as ammonia, also eliminates crystallization and metal-compatibility issues of the water/LiBr system. The performance of IL absorption refrigeration system was theoretically examined using exergy analysis. Various combinations of refrigerant and imidazolium-based ILs were chosen as working fluid pairs. The thermodynamic properties of ILs were evaluated using the correlations based on group contribution methods. A non-random two-liquid (NRTL) model was built and used to predict the solubility of the mixtures. Both the coefficient of performance (COP) and the exergetic coefficient of performance (ECOP) were evaluated. The effects of operating conditions on ECOP were explored. Also, the exergy destruction of each component was evaluated and discussed as a means to identify the critical component(s) of the system that would require optimization.

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# Analyse exergétique d'un système frigorifique à absorption de liquide ionique utilisant de la chaleur récupérée provenant de centres de données

*Mots clés* : Liquide ionique ; Absorption ; Gestion thermique ; Centre de données ; Exergie

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**Nomenclature**

| | |
|---|---|
| $A$ | area, m$^2$ |
| COP | coefficient of performance |
| $c_p$ | specific heat, J kg$^{-1}$ K$^{-1}$ |
| $Ex$ | exergy, W |
| ECOP | exergetic coefficient of performance |
| G | Gibbs energy, J |
| $H$ | enthalpy, J |
| $h$ | specific enthalpy, J kg$^{-1}$ |
| $I$ | irreversibility, W |
| M | molecular weight, kg mol$^{-1}$ |
| $\dot{m}$ | mass flow rate, kg s$^{-1}$ |
| N | number of data in Table 2 |
| P | pressure, Pa |
| Q | heat transfer, W |
| R | gas constant, 8.314 J mol$^{-1}$ K |
| IL | ionic-liquid |
| S | entropy, J K$^{-1}$ |
| s | specific entropy, J kg$^{-1}$ K |
| T | temperature, K |
| $\Delta T_{LMTD}$ | log mean temperature difference |
| $U$ | overall heat transfer coefficient, W m$^{-2}$K$^{-1}$ |
| $\upsilon$ | specific volume, m$^3$ kg$^{-1}$ |
| x | liquid phase refrigerant mole fraction |
| $\overline{\Delta x}$ | average liquid phase refrigerant mole fraction difference between measurement and prediction using NRTL model in Table 2 |
| $x_m$ | liquid phase refrigerant mole fraction |
| $x^m$ | liquid phase refrigerant mass fraction |
| $x_n$ | liquid phase ionic-liquid mole fraction |

*Greek symbols*

| | |
|---|---|
| $\gamma$ | activity coefficient |
| $\theta$ | entropy generation, J kg$^{-1}$ K$^{-1}$ |
| $\rho$ | density, kg m$^{-3}$ |
| $\sigma$ | standard deviation of liquid phase refrigerant mole fraction difference between measurement and prediction using NRTL model in Table 2 |

*Subscripts*

| | |
|---|---|
| 0 | reference state |
| 1, …, 16 | state numbers indicated in Fig. 1 |
| 2nd | secondary fluid |
| a | absorber |
| c | condenser |
| chip | chip |
| d | desorber |
| e | evaporator |
| evr | refrigerant expansion valve |
| evs | solution expansion valve |
| in | inlet |
| irr | irreversible |
| l | liquid |
| out | outlet |
| p | pump |
| r | refrigerant |
| ref | reference state |
| rev | reversible |
| s | strong-refrigerant solution |
| sat | saturation |
| shx | solution heat exchanger |
| v | vapor |
| w | weak-refrigerant solution |

*Superscripts*

| | |
|---|---|
| E | excess property |
| id | ideal solution |

## 1. Introduction

According to the International Technology Roadmap for Semiconductors (ITRS) (International Technology Roadmap for Semiconductors, 2005), high performance chips are expected to dissipate an average heat flux as high as 75 W cm$^{-2}$, with the maximum junction temperature not exceeding 85 °C, in 2012, while in 2024 the numbers are more challenging, 120 W cm$^{-2}$ and 70 °C, respectively (International Technology Roadmap for Semiconductors, 2005). Conventional chip packaging solutions, which use air-cooling, face difficulties in dissipating such high heat fluxes in the limited space allocated to thermal management. While a variety of novel alternative thermal solutions for electronics cooling have been reported (Kim et al., 2012a), refrigeration system offers further increase in power by the insertion of "compressor work" which creates greater temperature difference between condenser and evaporator.

Datacenter thermal management challenges have been steadily increasing over the past decade due to rack level power density increases (Bash et al., 2006). Computer room air conditioner, known as CRAC unit, has been used for cooling datacenters. Since the chip temperature is maintained at 85 °C, the coolant leaving datacenter is wasted at relatively high temperatures. Besides, up to 50% of the consumed energy in date center is spent to power the cooling infrastructure (Meijer, 2010), significant amount of low-grade waste-heat is available from datacenter thermal management systems. Absorption refrigeration systems offer the advantages of utilizing a large fraction of the source energy stream down to very low grade energy such as waste-heat (Ma et al., 2003; Saha et al., 2003; Grossman and Perez-Blanco, 1982), solar thermal energy (Ghaddar et al., 1997; Assilzadeh et al., 2005; Atmaca and Yigit, 2003) and geothermal energy (Kaynakli and Kilic, 2007; Keçeciler et al., 2000), leading to sustainable use of energy (Ryan, 2004). Fig. 1 shows the schematic diagram of a thermally-driven absorption refrigeration system using a refrigerant/IL mixture as a working fluid pair. The absorption refrigeration system can be adopted as "auxiliary" thermal management system for datacenter (Haywood et al., 2010; Haywood et al., 2012). Most of the CPUs on each server blade will be cooled by a "liquid-cooled" primary cooling system (Srikhirin et al., 2001), which is beneficial to collect the waste-heat directly from the CPUs. Then, the fluid temperature

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