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# Exergy and energy analysis of a double evaporating temperature chiller

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ABSTRACT

Temperature and humidity independent control (THIC) has been demonstrated as an effective way to improve the performance for air-conditioning systems. As an alternative option of THIC method, a double evaporating temperature (DET) chiller using zeotropic mixture refrigerants of R32 and R236fa has been proposed to substitute the traditional water-cooled chiller. The low temperature chilled water of 7 °C and high temperature chilled water of 17 °C will be produced simultaneously by this DET chiller, and the latent and sensible cooling loads of buildings can be afforded by the produced low temperature chilled water and high temperature chilled water respectively. In this paper, the experiments with different concentration ratios of R32 to R236fa are carried out on a 4.0-kW DET chiller. To further improve the energy performance of the DET chiller, the exergy analysis is used to investigate the effects of chilled water temperature and mass concentration of zeotropic mixture on the DET chiller. The exergy loss for each component is discussed in detail to identify the inefficient components, and then indicate the ways to improve the performance of DET chiller. The results show that the DET chiller achieves the lowest exergy loss and highest exergy efficiency when the mass concentration ratio of R32 to R236fa is 40%: 60%. Furthermore, the design temperature of high temperature chilled water should be at 16 °C to improve the energy utilization of DET chiller. This study will help to understand the design and operation for the DET chiller based air-conditioning systems.



## 1. Introduction

Temperature and humidity independent control (THIC) has been demonstrated as an effective way to improve the performance for air-conditioning systems by reducing the irreversible loss in processing the air humidity [1–5]. Recent research indicated that the THIC based air-conditioner had 47.8% energy saving potential comparing against traditional room air-conditioners with simultaneous temperature and humidity control [6]. As an alternative option of THIC methods, a double evaporating temperature (DET) chiller using zeotropic mixture refrigerants of R32 and R236fa has been proposed [7]. Since the preliminary studies, the DET chiller has shown significant benefits on improving the performance of THIC systems and is environment friendly, which is considered as a preferable substitute of the traditional water-cooled chiller [8,9].

Most current studies reveal that the commonly used means to realize THIC are to remove the humidity using liquid or solid desiccant [10,11]. The liquid desiccant dehumidification technology is proposed as a high efficient approach for dehumidification and low-grade heat utilizing [12–14]. However, this technology is still at the laboratory prototype and experimental stage accounting for the corrosion of liquid desiccant [15]. The efficiency of solid desiccant is higher than the liquid desiccant dehumidification, and the air across the solid desiccant can be cleaned easily [16]. But a relatively higher regeneration temperature is required by solid desiccant, and a larger space should be reserved to accommodate the adsorbent [17]. All of above studies will increase the cost of the solid desiccant systems. Another type of THIC system, named as heat and humidity segment handling systems, was proposed by Liang et al. [18]. Although the performance of air-conditioning systems can be improved by the heat humidity segment handling, the latent heat and sensible heat will be removed by two separate air handling segments.

According to the Montreal protocol, traditional refrigerants like HCFCs and CFCs will be banned from utilizing in vapor compression system due to their effect to the depletion of ozone layer [19]. As an alternative substituted refrigerant, zeotropic mixture refrigerant was noticed by researchers for its obvious glide temperatures during phase change processes [20,21]. Compared to the traditional refrigerant, zeotropic refrigerant was generally mixed with a special concentration ratio of the high boiling point refrigerant

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**Nomenclature**

| | |
|---|---|
| $d_{ex}$ | exergy loss rate |
| $ex$ | specific exergy (kJ/kg) |
| $h$ | specific enthalpy (kJ/kg) |
| $m$ | mass flow rate (kg/s) |
| $P_0$ | atmospheric pressure (Pa) |
| $Q$ | volume flow rate (m³/h) |
| $s$ | specific entropy (kJ/kg•K) |
| $T_0$ | ambient temperature (K) |
| $W_{com}$ | compressor power input (kW) |

*Greek symbols*

| | |
|---|---|
| $\eta$ | exergy efficiency |
| $\rho$ | density (kg/m³) |

*Subscripts*

| | |
|---|---|
| c | cooling water |
| com | compressor |
| con | condenser |
| dest | destruction |
| eva,h | high temperature evaporator |
| eva,l | low temperature evaporator |
| h,c | high temperature chilled water |
| i | inlet |
| l,c | low temperature chilled water |
| o | outlet |
| r | refrigerants |
| sys | system |
| tvx | expansion valve |

and low boiling point refrigerant [20]. The zeotropic mixture refrigerant was characterized as a non-isothermal cooling process, in which the cooling efficiency of refrigeration system can be improved obviously [22]. Jin et al. [22] proposed a method to evaluate heat transfer efficiency between zeotropic mixture refrigerant and heat transfer fluid. The results indicated that the structure of heat exchanger and the characteristic of zeotropic mixture refrigerant would affect the performance of heat transfer. Yilmaz [23] compared the second law efficiency for the air-cooled heat pump using traditional refrigerant and zeotropic mixture refrigerant. His study showed that the coefficient of performance (COP) and second law efficiency were significantly improved by replacing the pure refrigerant with an appropriate zeotropic mixture refrigerant. Chen et al. [24] compared the performance of a room air-conditioner using zeotropic mixture refrigerant of R32 and R134a with a traditional refrigerating cycle and a proposed refrigerating cycle. From their calculating results, the COP only could be improved in their proposed refrigerating cycle, which indicated that the system cycle or structure should be designed carefully to achieve the benefit from zeotropic mixture refrigerant. Liu et al. [8,9] proposed a double evaporating temperature (DET) chiller using zeotropic mixture of R32 and R236fa based on the THIC method. The DET chiller could produce the chilled water with two different temperatures of 7 °C and 17 °C with a maximum experimental COP of 3.97, which was preferably applicable to substitute the traditional water-cooled chiller. However, the studies on the DET chiller were conducted based on the energy analysis of the whole system, which can only be used to evaluate the system performance rather than to be used for optimal design and economic operation of DET chillers. Thus, the further study should be done to provide a more realistic view of the DET chiller.

Exergy analysis is widely used to analyze the performance of vapor compression refrigeration system for identifying the inefficient components, and then indicating the ways to improve the performance of refrigeration systems [25]. Yumrutaş et al. [26] investigated the effects of the evaporating and condensing temperatures on the exergy losses. Their study showed that exergy losses in the evaporator and condenser were significantly affected by the evaporating and condensing temperatures. Ahamed et al. [27] found that the exergy losses were reduced with an increased evaporating temperature, and 60% of total exergy loss was destructed in compressor. The exergy analysis was adopted by Sivakumar et al. [28] to evaluate the performance of three-stage auto refrigerating cascade systems using zeotropic mixture. Their results showed that the zeotropic mixture of R290/R23/R14 could achieve 58.5% exergy efficiency at a very lower evaporating temperature of 176 K. Bayrakçi et al. [29] analyzed the effects of refrigerants on the exergy loss by comparing four different pure refrigerants, in which the exergy efficiency obtained with R1270 and R600 was higher than that with R600a and R290. Thus, the exergy analysis not only can be used to identify the component efficiency, but also used as an indicator to evaluate the coupling property for the refrigeration system and refrigerant.

In this paper, a series of experiments with different mass concentration ratios of R32 to R236fa are carried out on a 4.0-kW DET chiller. The exergy efficiency is adopted to analyze the characteristics of the DET chiller, and the exergy loss for each component is discussed in detail. Since the primary objective of this study is to reveal the efficiency of energy utilizing for each component, the suggestions on improving the energy performance are also proposed for the economic operation of DET chiller.

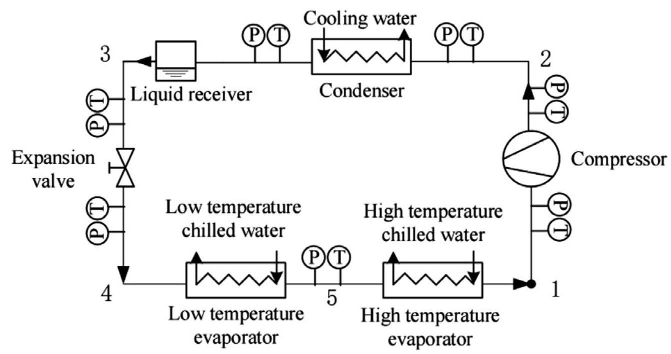


**Fig. 1.** Sketch of the DET chiller experimental platform.

## 2. Experimental setup and procedure

As shown in Fig. 1, a comprehensive DET chiller experimental platform, including a DET chiller and associated measurement sensors and devices, was constructed. The DET chiller consisted of a low temperature evaporator, a high temperature evaporator, a compressor, a condenser, a liquid receiver, and an expansion valve. The designed low temperature chilled water of 7 °C was provided by low temperature evaporator, and the high temperature evaporator was used to generate the designed high temperature chilled water of 17 °C. The return chilled water temperatures for the low temperature evaporator and high temperature evaporator could be adjusted by two electro-thermostatic water cabinets, separately. Furthermore, another electro-thermostatic water cabinet was adopted to simulate the cooling water to cool the condenser. The zeotropic mixture of R32 and R236fa was employed as the refrigerant of the DET chiller, and the theoretical cycle was shown in Fig. 2.

According to Fig. 2, the zeotropic mixture refrigerant was sucked in by the compressor (point 1) and compressed into the superheated gas with high temperature and pressure (point 2), and then condensed by the condenser to the supercooled liquid with high pressure (point 3'). The refrigerant was throttled as it passed