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Experimental investigation on binary ammonia–water and ternary ammonia–water–lithium bromide mixture-based absorption refrigeration systems for fishing ships

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ABSTRACT

Heat recovery of marine engine exhaust gas is an effective way of improving the onboard fuel economy and environmental compliance of fishing ships. Among such heat recovery techniques, the absorption refrigeration cycle shows potential as it can convert the exhaust thermal energy into refrigeration output and meet the on-board refrigeration requirement. However, the severe operating conditions on the shipboard poses a great challenge for its application. This paper presents an experimental investigation of an absorption refrigeration system for the heat recovery of marine engine exhaust gas. To overcome the adverse effect of the severe onboard condition on the rectification process of the absorption refrigeration system, a ternary ammonia–water–lithium bromide mixture is selected as the working fluid. A prototype of the absorption system is designed and an experimental investigation is conducted. Then, the performances of both the ternary ammonia–water–lithium bromide-based system and binary ammonia–water-based system are compared. The results show that the rectifier heat exchange area can be reduced by approximately 16% under the experimental working condition. Furthermore, the ternary system operates at a relatively lower pressure, with a refrigeration temperature of less than −15.0 °C, which is higher compared to the temperature of less than −23.6 °C associated with the binary system. Nevertheless, the ternary system achieves a remarkably higher cooling capacity. Moreover, by using the ternary ammonia–water–lithium bromide mixture, the heat loss of the prototype is reduced while the coefficient of performance and electric coefficient of performance are increased, indicating that the ternary system has a higher energy conversion efficiency.

1. Introduction

According to the International Maritime Organisation [1], maritime transport is responsible for 3.1% of the total global emissions of CO_2 and shipping emissions are forecast to rise by 250% in 2050. In order to reduce the CO_2 emissions, great efforts have been made to improve the efficiency of marine diesel engines. The thermal efficiency of such engines is approximately 50% [2], and 25% of the fuel energy cannot be converted into shaft work but is carried away by the high temperature exhaust gas [3]. The heat recovery from exhaust gas is deemed as an effective way of improving the onboard fuel economy and environmental compliance of fishing ships. Different techniques have been developed. Sun et al. [4] discussed a Sequential Turbocharging system for diesel engine heat recovery and proposed an accurate combustion model for this system. Vale et al. [5] conducted a parametric study on the thermoelectric generator (TEG) technology and the exhaust gas heat recovery efficiency reaches to 2%. Aly et al. [6] experimentally investigated the diffusion absorption refrigeration technology, the coefficient of performance (COP) of the refrigerator is approximately 0.1 and the refrigeration temperature reaches 10–14.5 °C. Yang et al. [7] investigated the organic Rankine cycle (ORC) based exhaust gas heat recovery technology for marine diesel engine and discussed the working fluid selection and effect of pre-heater on system performance. Cao et al. [8] conducted a theoretical investigation on the absorption refrigeration cycle driven by diesel engine exhaust gas of cargo ship and the COP can reach to 0.6.

Among the above techniques, the absorption refrigeration cycle shows potential as it can convert the exhaust thermal energy into refrigeration output, which can meet the refrigeration requirement of fishing ships. The major advantage of the absorption refrigeration cycle from the compression refrigeration cycle is that the former can be driven by the marine diesel engine exhaust gas and thus requires less electricity. In addition, the fuel consumption and CO_2 emissions can be reduced. A case study of the B. Delta37 bulk carrier [9] shows that a

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Nomenclature

Symbols

Q	heat input, kJ
T	temperature, K
W	electricity consumption, kJ
X	ammonia concentration
c_w	cooling water specific heat, kJ kg^{-1} K^{-1}
c_{RM}	refrigerating medium specific heat, kJ kg^{-1} K^{-1}
f	circulation ratio
m	mass flow rate, kg s^{-1}
h	specific enthalpy, kJ kg^{-1}
h'	vapour-phase enthalpy, kJ kg^{-1}
h''	liquid-phase enthalpy, kJ kg^{-1}
u	uncertainty

Subscripts

I, II	apparatus number
i = 1, 2, 3…	state points
A	absorber
C	condenser
G	generator
R	rectifier
Ref	refrigeration
RM	refrigerating medium
gas	exhaust gas

Acronyms

COP	coefficient of performance
ECOP	electric coefficient of performance

70% theoretical potential of electricity consumption of the compressor can be reduced by utilizing the absorption refrigeration cycle in ISO conditions. Palomba et al. [10] experimentally investigated the performance of an onboard absorption system driven by a 195 kW marine engine. The results show that up to 3500 kg/y of fuel can be saved, and CO_2 emissions can be reduced by up to three tons a year.

The lithium bromide absorption system can be applied on ships for cooling. Great efforts have been made to improve its performance. Ochoa et al. [11] investigated the transient performance of a single-effect lithium bromide absorption chiller as the thermal load varies. Ibrahim et al. [12] introduced a solar-assisted lithium bromide absorption refrigeration system and the results show that integrating the absorption energy storage with the absorption chiller is feasible. Wang et al. [13] combined the thermal recovery from the jacket water into an exhaust gas-driven absorption chiller, which effectively improved the cycle efficiency. Yan et al. [14] developed an enhanced single-effect or double-lift configuration for the absorption refrigeration cycle. Compared with the ammonia–water based absorption system, the lithium bromide absorption system obtains a relatively higher coefficient of performance (COP) [15]. However, the refrigeration temperature of the lithium bromide absorption system is restricted at a relatively high level (> 0 °C); thus, it cannot meet the requirement for aquatic product preservation (< −18 °C). In order to reach a much lower refrigeration temperature, the ammonia–water working pair should be selected as the working fluid. Cao et al. [8] modelled the whole structure of a ship including a waste heat-powered absorption cooling system. The simulation results indicate that this recovery system could help reduce the total energy by 8.23%. Furthermore, Cao et al. [16] introduced a

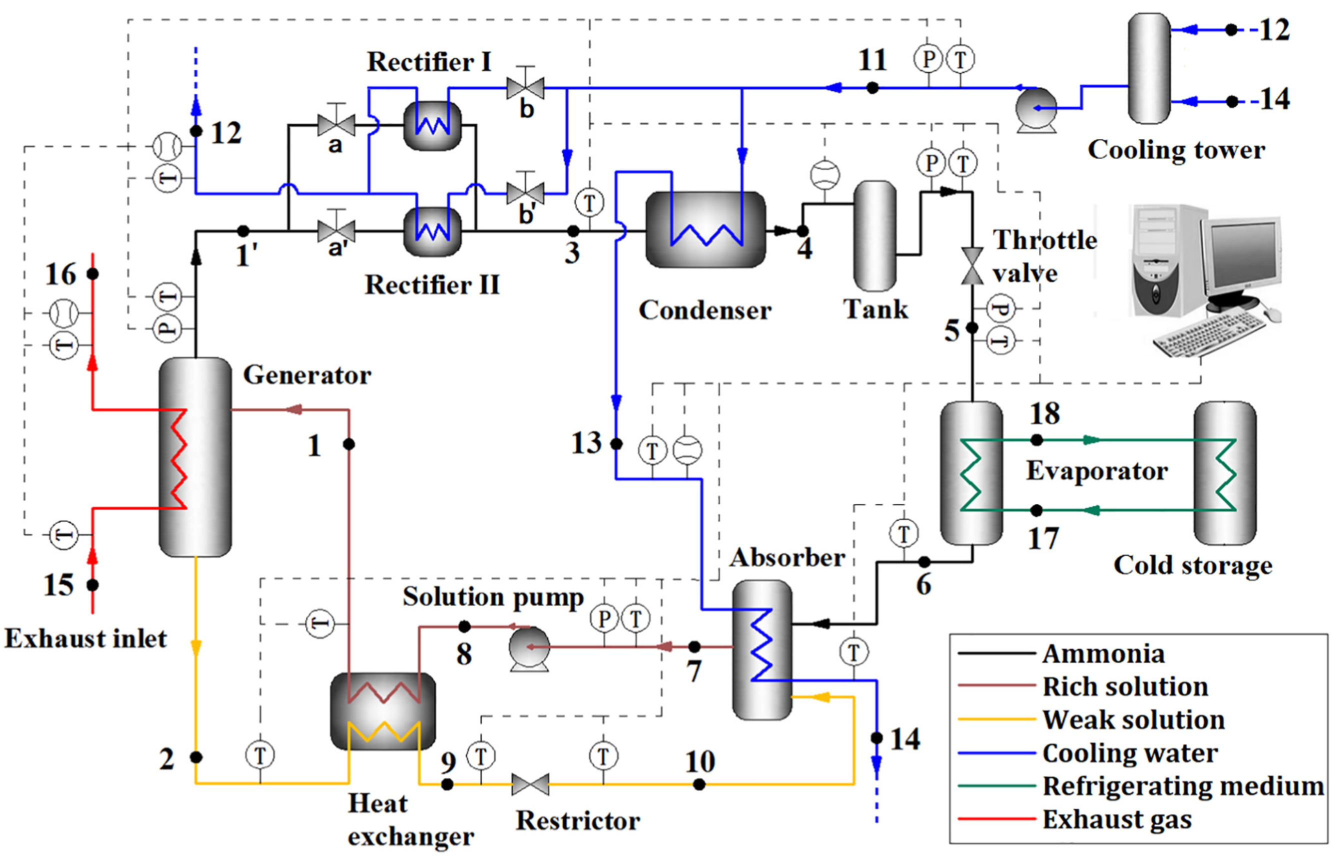

Fig. 1. Schematic of the absorption refrigeration cycle using binary ammonia–water and ternary ammonia–water–lithium bromide mixtures.