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Analysis of ammonia/water and ammonia/salt mixture absorption cycles for refrigeration purposes in fishing ships

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HIGHLIGHTS

- Ammonia absorption systems can provide refrigeration necessities for fishing ships.
- Absorption refrigeration systems reduce the energy consumption of fishing ships.
- The $NH_3/(LiNO_3 + H_2O)$ mixture is recommended for absorption refrigeration cycles.

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ABSTRACT

In this work, the use of waste heat energy of jacket water in diesel engines of fishing ships was analysed for use as a heat source for absorption refrigeration systems. The thermodynamic simulation of an absorption refrigeration cycle with three different working fluid mixtures that use ammonia as a refrigerant was carried out. This analysis was assessed in terms of the cooling demand and cycle performance as a function of the evaporator, condenser and generator temperatures. Moreover, the need for rectifying the vapour stream leaving the generator was analysed together with the drag of the fraction of non-evaporated liquid to the absorber.

The results show that the $NH_3/(LiNO_3 + H_2O)$ and $NH_3/LiNO_3$ fluid mixtures have higher values of COP as compared to NH_3/H_2O fluid mixture, the differences being more pronounced at low generation temperatures. If the activation temperature is set to 85 °C, the minimum evaporation temperatures that can be achieved are −18.8 °C for the cycle with $NH_3/LiNO_3$, −17.5 °C for the cycle with $NH_3/(LiNO_3 + H_2O)$ cycle and −13.7 °C for the NH_3/H_2O cycle at a condensing temperature of 25 °C. Also, for the $NH_3/(LiNO_3 + H_2O)$ fluid mixture, it has been demonstrated that the absorption refrigeration cycle can be operated without a distillation column and in this case the water content in the refrigerant stream entering the evaporator is less than 1.5% in weight at the operating conditions selected.

1. Introduction

The reduced profitability of the fishing activity due to the continuous rise in the price of fossil fuel is a problem for fishing ships the world over. According to the European Commission in 2000, the world's fishing fleets were responsible for around 1.2% of the total global fuel consumption, corresponding to 0.67 L of fuel per Kg of live fish and shellfish landed. In 2008, the EU fishing fleets consumed 3.7 billion litres of fuel, representing 25% of the value of landings.

Almost all types of fishing ships, from small boats to large fishing factories, use some type of refrigeration to preserve their catch. The methods range from the daily loading of ice to installations of sophisticated equipment for low-temperature freezing and cold storage. In large ships, cooling systems are used to produce onboard ice, cool tanks with sea water to store fish and cold stores to maintain the desired temperature to freeze the captures.

Refrigeration requirements in fishing ships vary widely depending on the application. Catches can be conserved on ice, in refrigerated sea water or ice can be produced on the ships. In most applications, the evaporator temperature varies from just below 0 °C to −25 °C. The condenser temperature depends on the sea water temperature and is in the range of 15–31 °C.

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Nomenclature

f	circulation ratio or flow ratio
h	enthalpy (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
P_{high}	condenser pressure (Pa)
P_{low}	evaporator pressure (kPa)
$\dot{Q}$	heat duty (kJ s^{-1})
reflux	reflux ratio
T	temperature (°C)
x	ammonia mass fraction
Greek symbols	
η	efficiency
ρ	density (kg m^{-3})
ξ	vapour mass fraction
Subscripts	
ABS	absorber
COND	condenser
EVAP	evaporator
COP	coefficient of performance
GEN	generator
LVHX	liquid–vapour heat exchanger
iso	isentropic efficiency
rect	rectification
sat	saturation state
SHX	solution heat exchanger
stripping	stripping section
rectifying	rectifying section

During the operation, the diesel engines of the fishing ships do not stop, and can deliver a large amount of waste heat energy available in the jackets of the engine and in the exhaust gases. Sorption machines are proposed in literature to utilise the large amount of waste heat energy in the diesel engines of fishing ships for air conditioning (Tse et al. [1]) or refrigeration (Wang et al. [2], Fernández-Seara et al. [3]).

Wang and Wang [4] analysed the developments reported in the literature related to the use of sorption technologies for refrigeration purposes in fishing ships. The authors concluded that sorption technologies were still not adapted for use on fishing ships and that solid sorption and NH_3/H_2O absorption systems have high potential for utilising the waste heat energy.

Fernandez-Seara et al. [3] demonstrated the ability of ammonia–water absorption refrigeration systems to provide onboard cooling using a gas-to-thermal fluid heat recovery system from engine exhausts on a fishing boat. Synthetic oil was used as a heat transfer fluid. The heat energy recovered from the engine exhaust gasses was 16.6 kW and the cooling capacity of the system was 8.33 kW. The authors reported that nowadays mechanical refrigeration is adopted for use in traditional fishing ships, which use crushed ice for caught fish preservation as it melts less quickly. However, these ships do not use any heat recovery system. They reported that in these fishing ships the hold capacity ranges from 80 to 150 m^3 and the refrigeration needs are from 5 to 10 kW while the hold and evaporation temperature are 0 °C and −10 °C, respectively. Ice production is not considered. Four-stroke diesel engines with a power in the range of 700–1200 kW are fitted in these fishing ships. Thus, a large amount of waste heat energy is available in the exhaust gasses which can be recovered using a gas-to-thermal fluid heat recovery system and can be utilized in the absorption refrigeration systems to provide the cooling needs of the fishing ships.

Peranić et al. [5] designed and compared the ammonia compression refrigeration system and the ammonia–water absorption refrigeration system powered by the heat recovered from the engine exhaust gasses of a medium size fishing boat for sea water refrigeration. They reported that the exhaust gasses from the engine have a temperature of 400 °C and carry 30% of the total heat power input of the fuel while the outgoing heat with cooling water is 28%. The available exhaust gas heat energy in the fishing boat investigated with a 700 kW diesel engine was 425 kW. Thus, the waste heat can be recovered and utilized in the absorption refrigeration system with an increase in energy efficiency compared to compression cycles.

There are technical problems to implement absorption technologies in ships, mainly in the handling of liquids in an accelerated motion system. The falling film configuration usually used in the thermal components of commercial absorption machines can be broken by the continuous movement, which negatively affects heat and mass transfer processes. Safarik et al. [6] reported about a water/LiBr absorption refrigeration machine that was adapted to the requirements of marine necessities and used to provide HVAC in cargo ships. The waste heat energy usually available from the main engine or the diesel generator was used to power the absorption refrigeration machine. Several internal adjustments were made in order to avoid the refrigerant mixing with the solution in certain conditions at sea and to enable the chiller to cope with static and dynamic heel. The absorption machine of a nominal capacity of 140 kW was tested at a German naval test facility under realistic marine conditions. A reduction of about 14% was observed in the COP of the system compared to normal operation when the chiller was continuously operated at ±20° dynamic heel. The authors reported that the installation cooling capacities in a common cargo ship vary from about 150 kW to 500 kW and consume 5%–15% of the onboard power supply during sea operation. They reported that absorption chillers for marine application must operate reliably even in heavy swell (±22.5° dynamic, 15° static) and must be mechanically strong to withstand (±0.8 g) accelerating force and vibrations.

The higher pressure of the NH_3/H_2O working pair allows for the use of bubble absorbers and generators of the plate heat exchanger type that are considered to be less affected by the inclination angle of the machine. Cerezo et al. [7] and Táboas et al. [8] studied the absorption and desorption processes with the NH_3/H_2O mixture using plate heat exchangers at operating conditions of interest for absorption refrigeration cycles. The experimental results showed the feasibility of absorption cycles employing plate heat exchangers. The drawback of using the NH_3/H_2O working fluid mixture in absorption cycles is that the vapours leaving the generator have to be rectified before entering the condenser. So, a distillation column is needed at the top of the generator. However, as Fernández-Seara et al. [3] pointed out, the distillation column operation can also be affected by the inclination of the ship and by deficiently purified ammonia with a significant water content which can reach the evaporator where the water tends to accumulate leading to reduce the efficiency of the cycle.

The $NH_3/LiNO_3$ working fluid mixture has been proposed in literature in order to avoid the use of distillation columns in ammonia based absorption refrigeration machines. The use of this