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Design and thermodynamic analysis of an H_2O–LiBr AHP system for naval surface ship application

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ABSTRACT

Absorption heat pump (AHP) systems are cleaner and more efficient energy solutions than vapour–compression heat pump systems for heating and cooling on board naval surface ships. Thermal management is a critical requirement for naval surface ships and submarines as well as commercial vessels and land-based industrial plants. Approximately 25% of a ship's thermal load is removed through the heating, ventilation and air conditioning (HVAC) system. In this study, design and thermodynamic analysis of a water-lithium bromide (H_2O–LiBr) AHP as an HVAC system for a naval surface ship application are presented and compared with those of a vapour–compression heat pump.

Conception et analyse thermodynamique d'un système au H_2O-LiBr AHP pour une application de navire maritime

Mots clés : Navire ; Moteur ; Eau de mer ; Bromure de lithium-eau ; Système à absorption ; Pompe à chaleur

1. Introduction

Thermal management is a critical requirement for naval surface ships and submarines as well as commercial vessels and land-based industrial plants. Approximately 25% of a ship's thermal load is removed through the heating, ventilation and air conditioning (HVAC) system.

Projected Next Navy's thermal loads are 2–5 times those of today's ships. It is expected that much of the increased load will be rejected via the HVAC system or directly to the chilled water system Frank and Helmick (2007). Despite the great technological development of modern marine diesel engines, only a small part of the energy contained in the fuel is converted to power output. The maximum efficiency remains

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Nomenclature

Variables

C	flow stream heat capacity,$\dot{m}c_p$, W K^{-1}
c_p	specific heat capacity, J(kg K)$^{-1}$
f	solution circulation ratio
h	specific enthalpy, J kg^{-1}
$\dot{m}$	mass flow rate, kgs^{-1}
mf	mass fraction,-
M	molecular weight, kg $kmol^{-1}$
P	pressure, Pa
ΔP	difference between inlet and exit pressures, Pa
$\dot{Q}$	heat transfer rate, W
T	temperature, °C
$\dot{W}$	power, W
$\dot{v}$	volume rate of flow, m^3 s^{-1}
X	mass fraction of lithium bromide in solution
x, y	molar amount

Greek letters

η	efficiency,-
ρ	density, kg m^{-3}
ε	effectiveness,-

Subscripts

A	absorber
C	condenser
cv	control volume
dm	driving motor
E	evaporator
e	exit
exh	exhaust gas
exht	exhaust
f	fluid
F	fan coil unit
g	gas
G	generator
h	hot
i	inlet, inner
m	mean value
p	pump
S	seawater
SHX	solution heat exchanger
LiBr	lithium bromide
ss	strong solution
w	water
ws	weak solution

Abbreviations

AHP	Absorption heat pump
AHU	Air handling unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
COP	Coefficient of performance
EEDI	Energy Efficiency Design Index
HVAC	Heating, ventilation and air conditioning
IMO	International Maritime Organization
SEEMP	Ship Energy Efficiency Management Plan

lower than 45%. The main losses are dissipated as heat in exhaust gases and coolants and then transferred to the environment Ouadha and El-Gotni (2013).

The International Maritime Organization has developed the first ever global CO_2 reduction index in the world known as the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. The new chapter added to MARPOL ANNEX VI Regulations for the prevention of air pollution from ships, which was implemented on January 1, 2013, aims to reduce the emission of greenhouse gases, specifically CO_2 emissions, as CO_2 is the most important greenhouse gas emitted by ships (IMO, 2010). Implementing CO_2 reduction measures will result in a significant reduction in fuel consumption, leading to a significant saving in fuel costs to the shipping industry. If EEDI and SEEMP are applied, the results obtained on naval ships can be evaluated.

Reduction and management of ship signatures should be taken as the major input during the whole design and operating phase. Moreover, many classified precautions should be taken to reduce hydrodynamic, acoustic, magnetic, infrared (IR) and radar signatures to achieve the specified level of stealth feature.

IR-guided missiles represent a major threat to naval ships such as in military applications. This threat will increase in the near future. Therefore, reducing or eliminating IR signature in naval ship susceptibility to IR-guided anti-ship missiles is vital. Also, acoustic signature on a naval ship should be reduced as well as IR.

Therefore, searching for new energy conservation methods that can be applied on board naval surface ships is necessary. One way to find a new solution to this problem is to apply an absorption heat pump (AHP) system to provide the required heating and cooling loads for the HVAC system instead of the traditional vapour–compression heat pump. Compared with automobile engine, marine engine on board ship has some advantages: more stable operation, larger spacing for installing, and larger quantity of exhaust gas and engine coolant, using seawater as cooling source directly Liang et al. (2013).

Unlike traditional heat pump units, which are powered by electricity, AHP works on surplus heat from a diesel engine. However, until now, the technique has been confined to land-based installations. AHP systems are particularly attractive in applications that have a cooling demand and at the same time a source of heat, which if not used will be ejected to the environment. For instance, Wärtsilä has produced 4977 kW chilled water (7/12 °C) using a direct exhaust gas-driven absorption chiller through a diesel engine generator, which has an electric power of 9730 kWe for district cooling. A number of research options, such as various types of absorption refrigeration systems, on working fluids and improvement of absorption processes, were discussed in Srikhirin et al. (2001). A single-stage H_2O–LiBr absorption chiller of 14 kW was experimentally characterised and modelled by Bakhtiari et al. (2011). It was reported that the heat pump cooling capacity was more sensitive to cooling stream and generator inlet