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**Design and Thermodynamic Analysis of a Steam Ejector Refrigeration/Heat Pump System for Naval Surface Ship Applications**

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**Abstract:** Naval surface ships should use thermally driven heating and cooling technologies to continue the Navy's leadership role in protecting the marine environment. Steam ejector refrigeration (SER) or steam ejector heat pump (SEHP) systems are thermally driven heating and cooling technologies and seem to be a promising technology to reduce emissions for heating and cooling on board naval surface ships. In this study, design and thermodynamic analysis of a seawater cooled SER and SEHP as an HVAC system for a naval surface ship application are presented and compared with those of a current typical naval ship system case, an $H_2O$-LiBr absorption heat pump and a vapour-compression heat pump. The off-design study estimated the coefficient of performances (COPs) were 0.29–0.11 for the cooling mode and 1.29–1.11 for the heating mode, depending on the pressure of the exhaust gas boiler at off-design conditions. In the system operating at the exhaust gas boiler pressure of 0.2 MPa, the optimum area ratio obtained was 23.30.

**Keywords:** ship; engine; sea water; ejector system; refrigeration; heat pump

1. Introduction

The International Maritime Organization's [1] Marine Environment Protection Committee published its final third IMO greenhouse gas (GHG) study report in 2014 providing updated estimates for GHG emissions from ships. In that report, for the year 2012, total shipping emissions were approximately 949 million tonnes $CO_2$ and 972 million tonnes $CO_2$e for GHGs combining $CO_2$, $CH_4$ and $N_2O$. International shipping emissions for 2012 were estimated to be 796 million tonnes $CO_2$ and 816 million tonnes $CO_2$e. International shipping thus accounted for approximately 2.2% and 2.1% of global $CO_2$ and GHG emissions on a $CO_2$ equivalent ($CO_2$e) basis, respectively. In addition, refrigerant and air conditioning gas released from shipping contributed an additional 15 million tons in $CO_2$ equivalent emissions. In the study, military forces were excluded from the total and international shipping calculations.

To reduce the emission of greenhouse gases, specifically $CO_2$ emissions, emitted by ships, the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships entered into force on 1 January 2013. New ships are ships that enter the fleet from 2013. 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.

The main and auxiliary engines are used to propel the ship, and to drive generators to produce electricity, respectively. Despite the great technological development of engines, the maximum efficiency is still less than 50%. The main and auxiliary engines onboard ships produce significant quantities of heat. The primary source of waste heat of main and auxiliary engines is the exhaust