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Waste heat driven absorption/vapor-compression cascade refrigeration system for megawatt scale, high-flux, low-temperature cooling

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ABSTRACT

A novel cascaded absorption/vapor-compression cycle with a high temperature lift for a naval ship application was conceptualized and analyzed. A single-effect LiBr–H_2O absorption cycle and a subcritical CO_2 vapor-compression cycle were coupled together to provide low-temperature refrigerant (−40 °C) for high heat flux electronics applications, medium-temperature refrigerant (5 °C) for space conditioning and other low heat flux applications, and as an auxiliary benefit, provide medium-temperature heat rejection (~48 °C) for water heating applications. A thermodynamic model was developed to analyze the performance of the cascaded system, and parametric analyses were conducted to estimate the performance of the system over a range of operating conditions. The performance of the cascaded system was also compared with an equivalent two-stage vapor-compression cycle. This cycle was found to exhibit very high COPs over a wide range of operating conditions and when compared to an equivalent vapor-compression system, was found to avoid up to 31% electricity demand.

Système frigorifique à absorption à compression de vapeur entraîné par la chaleur récupérée pour le refroidissement basse température à haut flux à l'échelle des mégawatts

Mots clés : Absorption ; Compression de vapeur mécanique ; Système en cascade ; Froid ; Water ; Bromure de lithium ; Dioxyde de carbone

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Nomenclature			
A	surface area	R''	thermal resistance
CAT	closest approach temperature	SHX	solution heat exchanger
COP	coefficient of performance	UA	overall heat transfer conductance
HX	heat exchanger	*Superscripts/subscripts*	
RHX	recuperative heat exchanger	All,Energy	total-energy-input
		All,Electric	total-electric-input

1. Introduction

Advanced naval electronics require cooling at large heat fluxes over large surface areas, while maintaining low junction temperatures. Heat removal rates approach tens of Megawatts due to heat fluxes of ~1 kW cm^{-2} acting over large surface areas. For the cooling of shipboard electronics, although fundamental advances in chip, interface, and convective cooling could reduce the thermal resistances significantly, these alone will be inadequate for meeting targets of removing fluxes as high as 1 kW cm^{-2} over areas of the order of m^2. Even the most optimistic projections of decreases in thermal resistance R'' through advances in heat removal techniques, and increases in surface area A from the chip-to-ship progression do not enable dissipation of 1 kW cm^{-2} over large areas while operating within the 35–50 °C range. Therefore, a third dimension, i.e., reduced heat sink temperature, is essential to address the heat rejection problem under consideration. If, for example, coolant can be made available at −40 °C, the chip operating temperature can be brought down to the desired 50 °C with plausible technical advances in R'' and A at each level. Additionally, most naval ships also have a need for medium-temperature cooling (for space conditioning and low heat flux electronics) and water heating. Use of a two-stage vapor compression system to address these needs results in a significant load on the power plants of the naval vessel which already use ~100 MW of electrical energy for propulsion alone. To address these needs a novel absorption/vapor-compression cascade cooling system with a high temperature lift is conceptualized and analyzed in this article (Fig. 1).

Prior work on absorption–compression systems has primarily been on using compression to boost the pressure of

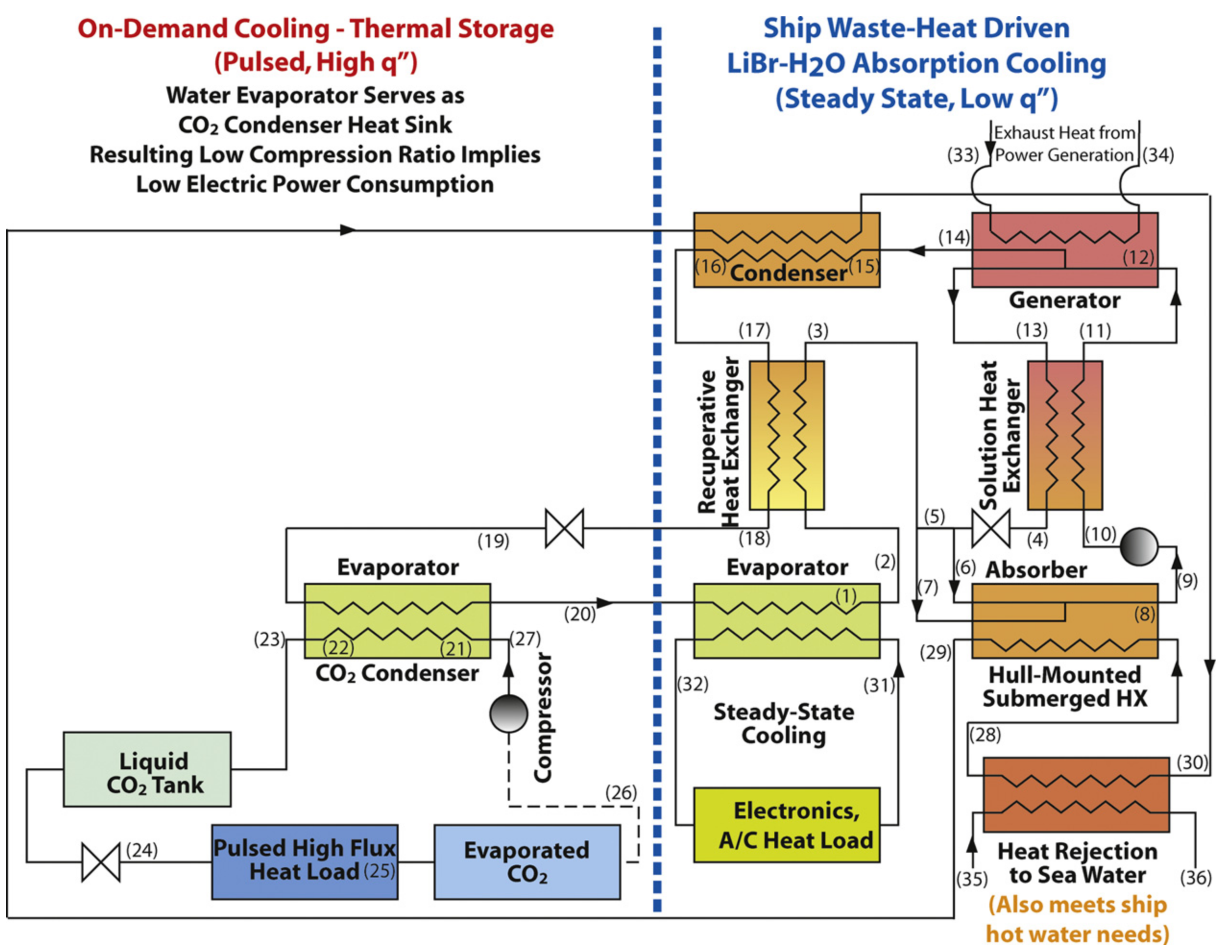

Fig. 1 – Cascade absorption/vapor-compression cycle schematic.