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Performance improvement of combined organic Rankine-vapor compression cycle using serial cascade evaporation in the organic cycle

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Abstract

This paper describes an improvement solution for ORC-VCC systems. The solution consists in using cascade evaporation in the ORC subsystem in order to increase its power on the expander shaft. The heat source is divided into high temperature and low temperature ranges, a solution allowing the utilization of all kinds of heat sources which are at different temperature levels. The paper also discusses performance of hydrocarbon refrigerants in such systems. The performance of the system using a cascade evaporation in the ORC subsystem are compared to those using a basic ORC subsystem

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Keywords: Organic Rankine cycle; vapor compression cycle; serial cascde; hydrocarbons

1. Introduction

Recently, heat recovery concepts have attracted much interest from ship owners interested in emissions and ship operating costs reduction. Traditionally, high-temperature waste heat from main Diesel propulsion engines is utilized in an exhaust gas economizer and a steam turbine generation system. However, low-temperature heat such

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as engine jacket water has been rarely used. A path of increase of the overall efficiency of a ship can be the heat recovery using technical solutions able to exploit low-temperature waste heat from Diesel engines. Among these solutions, the organic Rankine cycle (ORC) is probably the most reliable and mature technology.

Many recent studies have focused on the subject of applying of ORC technology to exploit low-grade waste heat from marine Diesel engines [1-8]. All these studies have applied ORC systems to produce additional mechanical energy or to drive electric generator. Alternatively the waste heat from the Diesel engine can be used to operate an organic Rankine cycle (ORC), which in turn produces the energy necessary to drive the compressor of a vapor compression cycle (VCC). The VCC unit can produce refrigeration effect at different temperatures. The advantage of a combined ORC-VCC system compared to absorption refrigeration systems is that when refrigeration is not needed, all the thermal energy can be converted to power and used for others applications. Although that thermally driven refrigeration cycles that combine organic Rankine cycle and vapor compression refrigeration cycle have been studied for several applications [9-19], their use in marine applications has received less attention [20].

This paper aims to verify thermodynamically the improvement of the performance of a combined ORC-VCC system in order to explore the feasibility of such system in marine applications. It is the first step to start a preliminary design of the proposed system. It serves also as an initial screening of some promising hydrocarbon refrigerants, namely propane (R290), butane (R600), isobutane (R600a) and propylene (R1270) in ORC-VCC systems in order to investigate the thermodynamic performance that can be attained using these substances.

2. Thermodynamic analysis

Figure 1 shows combined ORC-VCC systems mounted on a marine Diesel engine. The system is linked to the engine heat source using the boiler of the ORC sub system. Vapors formed are expanded in the expander producing mechanical work on its shaft to drive the compressor of the vapor compression sub system. A condenser is used to condense the working fluid after expansion. The liquid obtained is pumped to the boiler to absorb heat from the engine jacket water and repeat a new cycle. The two subsystems are linked by coupling the expander of the ORC subsystem to the compressor of the VCC subsystem. The first system is referred to as ORC-VCC (basic system) while the second one is referred to as SCORC-VCC (serial cascade system).

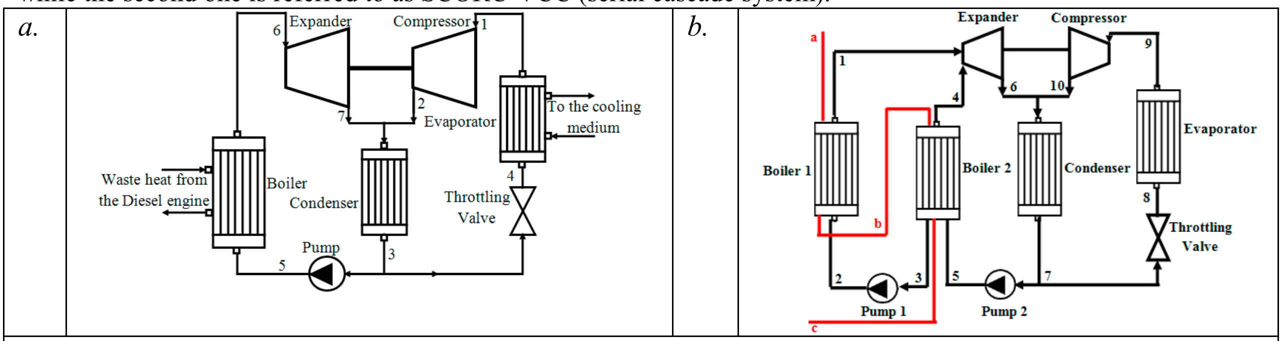

Fig. 1. Schematic of the combined organic Rankine cycle - vapor compression cycle: *a.* ORC-VCC; *b.* SCORC-VCC.

Habitually, thermodynamic cycles are analyzed using the energy analysis method which is based on the first law of thermodynamics, i.e. the energy conservation concept. Unfortunately, this method cannot locate the degradation of the quality of energy. Instead, exergy analysis which is based on both the first and second laws of thermodynamics can overcome easily the limitations of the energy analysis. It permits to quantify the magnitude and the location of exergy losses within the system. Furthermore, the total exergy losses can be considered as an optimization criteria which, by minimization, provide optimum processes configuration. The concept and the methodology of exergy analysis are well-documented in the literature [21-23]. Bosnjakovic [24] has defined exergy as the theoretically gainful amount of work obtained by bringing materials into equilibrium with the surroundings in a reversible process. The surroundings can be defined in terms of temperature, pressure and chemical composition.

Mass, energy and exergy balances for any control volume at steady state with negligible kinetic, potential and chemical energy changes can be expressed, respectively, by

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$