Fabrication and Study on the Performance Characteristics of Plate Heat Exchanger Condenser for marine ORC systems

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Abstract

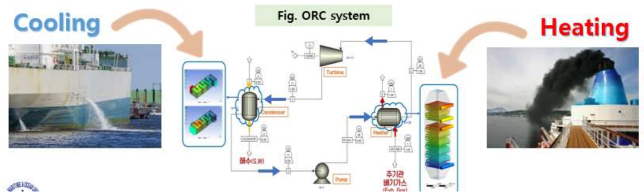
Research to improve the energy efficiency of ships is being conducted in various fields. Accordingly, the application of an Organic Rankine Cycle (ORC) power generation system for ships using exhaust gas waste heat generated from the main engine is being considered. The heat exchanger constituting the ORC system should be designed and manufactured to be suitable for stable operation and suitable for the system. In this study, in order to fabricate a plate type condenser that can be used in a marine ORC system, Computational Fluid Dynamics (CFD) modeling and Aspen Exchanger Design and Rating (EDR) modeling of a condenser made based on a given single heat transfer plate shape were compared and reviewed. As a result, similar heat transfer performance of CFD modeling and EDR modeling was confirmed. EDR condenser modeling was applied and a basic marine ORC system was constructed and simulated using R245FA refrigerant as the working fluid. As a result of the simulation, it was confirmed that the ORC system efficiency improved as the cooling water temperature increased, but the heat transfer rate of the condenser decreased. It was confirmed that the turbine output and ORC system efficiency were improved as the turbine inlet pressure increased. In particular, it was confirmed that the ORC system efficiency improved significantly in the range of 10 bar to 20 bar, which is a relatively low-pressure region than in the high-pressure region. In addition, the ORC system efficiency and heat transfer rate of the condenser increased as the flow rate of the working fluid of the ORC system increased. In particular, it was confirmed that the liquid fraction in the condenser decreased from a specific flow rate of working fluid through the change in the heat transfer rate distribution occupied by sensible and latent heat load inside the condenser.

Keywords : Organic Rankine Cycle, Condenser, Plate Heat Exchanger, Efficiency, Heat Transfer Rate

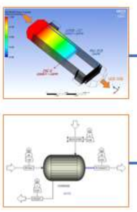
1. Introduction

The International Maritime Organization (IMO) is enacting and revising various international conventions such as MARPOL Convention to reduce greenhouse gas emissions from international shipping. As the main contents of such regulations, energy efficiency management and increase of ships, such as the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP), occupies a large part. In order to improve the energy efficiency of a ship, research related to the development of an ORC system for ships using waste heat from exhaust gas generated from the ship's main engine is being conducted. As a representative study, Moon et al. (2021) examined the appropriate operating pressure representing the maximum net power by simulating ORC performance using waste heat generated from ships and seawater used as cooling water. Song et al. (2012) confirmed the power generation output of 2,400 kW through a simulation using various eco-friendly organic refrigerants to optimize the marine ORC power generation system using the seawater temperature difference. Ibrahim et al. (2017) simulated a combine ORC system using waste heat generated from the 1,000kW power generation engine of a Naval ship and confirmed the effect of saving 67.2 tons of carbon dioxide and the economic effect of fuel saving. The above study is focused on identifying the optimal operating conditions applicable to ships in terms of overall efficiency of the system rather than the characteristics of individual elements constituting the ORC system. Therefore, for the stable operation of the power generation system, it is necessary to study the performance analysis of individual components such as the heat exchanger reflecting the characteristics of the marine ORC system. Sotirios et al. (2011) reviewed the changes in heat transfer coefficient and heat exchanger efficiency by analyzing the effect of major variables of ORC systems operating in the supercritical region, not for ships, on the heat exchanger performance. The final purpose of this study is to manufacture a 110kW brazed plate heat exchanger type condenser that can be applied to an ORC power system for ships. For this purpose, research and development was carried out in the following orders. First, CFD modeling is produced using ANSYS CFX (v.18.1), a commercial numerical analysis program, based on a single heat transfer plate to be used for manufacturing plate heat exchangers. Through simulation through the CFD modeling, the condenser design requirement conditions for stable operation are confirmed. Based on these design requirements, the ORC power generation system including the condenser to which this requirement has been applied was simulated by using Aspen Exchanger Design and Rating (EDR, v.12.1), a program dedicated to heat exchanger design, and Aspen Plus (v.12.1), a process simulation program. Through the simulation results, the performance characteristics of condenser analysis according to the major factors of ORC power generation system was reviewed. In this paper, the heat transfer performance of the CFD modeling and the EDR modeling of the condenser was compared and reviewed, and the heat transfer performance characteristics of the condenser according to the turbine inlet pressure, cooling water temperature, and flow rate of working fluid in the ORC system were reviewed.

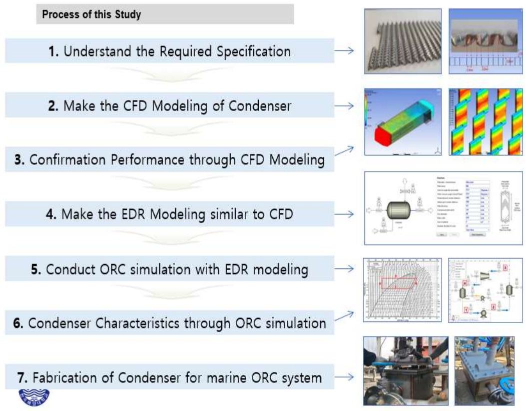
2. Figure and Table



Comparative review of CFD and EDR modeling



Modeling	Material	Content	Inlet	Outlet
CFD	R134a	Flow rate	0.642 kg/s	
		Pressure Drop	0.02 bar	
		Temperature	80.1℃	43.6℃
		Steam Quality	1	0
		Heat Transfer	106.1 kW	
	Water	Flow rate	4.8 kg/s	
		Temperature	30.0℃	33.1℃
EDR	R134a	Flow rate	0.642 kg/s	
		Pressure Drop	0.084 bar	
		Temperature	80.0℃	44.2℃
		Steam Quality	1	0
		Heat Transfer	112.3 kW	
	Water	Flow rate	4.8 kg/s	
		Temperature	30.0℃	34.8℃



3. Conclusion

In this study, CFD modeling and EDR modeling of the condenser constituting the marine ORC system were made and the heat transfer performance was compared. A marine ORC system using R245FA as the working fluid was designed, and the condenser performance characteristics were mainly reviewed through process simulation Aspen Plus (v.12.1). As a result, the following conclusions were drawn within the scope of this analysis and calculation conditions.

(1) When the superheat condition of 5 ℃ of the heater was applied, the ORC thermal efficiency increased as the cooling water temperature of the condenser increased.

(2) As the inlet pressure of the turbine increases, the turbine output and system efficiency are improved. In particular, the system efficiency improved significantly in the pressure range of 10 bar to 20 bar, which is a relatively low-pressure region than in the high-pressure range.

(3) As the flow rate of the working fluid increased, the ORC system efficiency and heat exchanger heat transfer rate increased. In particular, a decrease in the liquid fraction in the condenser was confirmed under a specific flow rate 1.1kg/s condition through the analysis of the heat transfer rate distribution occupied by sensible and latent heat inside the condenser. Therefore, appropriate working fluid flow rate should be selected for a stable condenser operation.

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