Economic Evaluation of Seawater Cooling System Applying Flooded Type Evaporator

Jung-In Yoon¹,*, Chang-Hyo Son¹, Choon-Geun Moon¹, Joon-Hyuk Lee¹, Kwang-Seok Lee¹, Suk-Ho Jung¹ and Doo-Yeong Kwak¹

¹ Pukyong National University, South Korea

*yoonji@pknu.ac.kr; Tel: +82-51-629-6180

Abstract. The ministry of oceans and fisheries of South Korea promoted the modernization of the purse seine vessels, and the seawater cooling system was proposed as part of the modernization. In the previous study, heat transfer characteristics were analysed with respect to material of tubes to offer fundamental design data of seawater cooling system applying flooded type evaporator by Yoon et al. In this paper, the economic evaluation of the seawater cooling system for comparison with the cooling method using crushed freshwater ice was performed. The initial investment cost of the seawater cooling system was calculated by 181 thousand dollars as the total cost of equipment and facility. The annual benefit was calculated by 47 thousand dollars which subtracts the maintenance cost of the seawater cooling system from the cost of ice and salt. Consequently, the net present value of the seawater cooling system presented positive when the discount rate is lower than 21.4%, which means the seawater cooling system can be considered economical. Moreover, the discount rate has 4.5% as the social discount rate in South Korea, so the net present value of the seawater cooling system has 154 thousand dollars approximately.

1. Introduction

The purse seine fishery supplies 90% of catch of mackerel in South Korea. The purse seine fishery is a method of catching fishes by lighting up at night and spreading the net, and the purse seine fishery consists of six vessels, which are one main vessel, two lighting vessels and three fish carriers. The ministry of oceans and fisheries in South Korea promoted the modernization of the purse seine vessels. Because of the modernization, the developed fishing vessels will be reduced from six to four vessels, which are one main vessel, one lighting vessel and two fish carriers, and it improved crew’s welfare of the fishing vessel as well. Moreover, seawater cooling system is proposed as a part of the modernization. Cooling method using freshwater ice damages on the catch due to the sharp crystal of the ice and change of salinity in the fish tank. But the seawater cooling system make seawater supplied into the fish tank be cooled directly, so it can solve the decline of the catch’s quality.

Gorgy. E et al. [1] focused on the pool boiling performance of both R123 and R134a on smooth and enhanced tubes. As results of this research, for smooth tube testing the heat flux ranger were 7.3~130.7kW/m² and 7.5 ~ 60.7kW/m² for R134a and R123, respectively; with resulting heat transfer coefficient ranges of 1,798.9 ~ 11,379W/m²oC and 535.4~3,181.8W/m²oC.

Kang et al. [2] analysed heat transfer characteristic of aluminium-brass tube using R-134a. As a result of this research, increase rate of heat transfer factor was decreased rapidly when flow velocity of
seawater was faster than 1.8m/s. Furthermore, overall heat transfer coefficient was decreased 60% approximately at low temperature comparing with high temperature.

Yoon et al. [3] analysed heat transfer characteristics of flooded type evaporator using R22 and R134a. The variables were flow velocity of seawater is changed from 0.6m/s ~ 2.1m/s, and inlet temperature of seawater is changed from 5°C to 15°C, respectively. As results of the experiment, the heat transfer coefficient of R22 had higher than R134a and the low-fin tube had a higher heat transfer coefficient than the plane tube in above conditions.

Yoon et al. [4] analysed heat transfer characteristics with respect to material of tubes applying flooded type evaporator in seawater cooling system. The material used aluminium-brass and copper-nickel to enhance heat transfer performance, and the results of the analysis presented that the aluminium-brass low-fin tube had higher heat transfer coefficient than copper-nickel low-fin tube.

Economic evaluation is as important as evaluation of the technological validity of the seawater cooling system. Economic evaluation is as important as evaluation of the technological validity of the seawater cooling system.

Hong et al. [5] used net present value, internal rate of return and cost-benefit ratio method to evaluate economical validity of the development of automatic operation system for hair tail trolling line in Jeju region, South Korea. Also, the net present value was calculated using social discount rate, 4.5%.

Bae et al. [6] used net present value method, internal rate of return and cost-benefit ratio to evaluate economic feasibility and impact analysis on energy transformation project of macro-algae biomass. Also, this was considered economical when the discount rate is lower than 15.7%.

In this paper, the economic evaluation of the seawater cooling system for comparison with the cooling method using crushed freshwater ice was performed with the net present value method. When economic evaluation was conducted, experimental results in the previous study of the seawater cooling system was used [4].

2. Seawater cooling system

2.1. Heat transfer characteristics of flooded type evaporator

Prior to designing the seawater cooling system for fishing vessel with 163kW or 238kW cooling capacity, seawater cooling system with 15kW was developed to provide system performance analysis and fundamental design data. The effect of material and the refrigerant R-22, R-134a on the heat transfer promoting tube in the flooded type evaporator used for the seawater cooling system was analysed to acquire fundamental data of design and heat transfer enhancement. When analysing of heat transfer characteristics, inlet temperature of the cooling seawater was set to 10°C, evaporating temperature was set to 0°C, and flow velocity was set to 1.8m/s.

2.1.1. Experimental apparatus

Figure 1 presents experimental apparatus of the flooded type evaporator and schematic diagram. The apparatus is composed of the flooded type evaporator, open type reciprocating compressor, condenser, receiver, expansion valve, oil recovery heat exchanger, surge drum, separator and oil return collector. Working principle is as follows. Gaseous refrigerant from the compressor outlet flows into the condenser, and the working fluid is condensed by exchanging the heat with cooling water. Liquid refrigerant at the outlet of the condenser is expanded through expansion valve, and evaporates at the evaporator by acquiring heat from the seawater. Evaporated refrigerant flows into the compressor, and it circulates.
2.1.2. Experimental results  As shown in figure 2, heat transfer coefficient tended to increase when evaporating temperature decreased. In addition, the heat transfer coefficient increased 76.6% as the evaporating temperature decreased from 5°C to -5°C. It was considered that increment of the evaporating capacity was larger than that of the mean temperature difference. Besides, heat transfer coefficient of R22 is 0.35kW/m²K higher than R134a with same material of the tube. While, aluminium-brass had 0.25kW/m²K higher coefficient than the copper-nickel tube with same refrigerant used.

The above discussion about the experimental result on heat transfer characteristics was referred in prior research [4].

2.2. Performance analysis of flooded type evaporator

2.2.1 Experimental apparatus  In order to analyse the efficiency of seawater cooling system, experimental apparatus was installed on land. Figure 3 shows schematic diagram and experimental apparatus of the seawater cooling system. It was composed of the steam boiler, fish tank, control panel, cooling tower, heat exchanger, inverctor, data acquisition equipment and the seawater cooling system. The inverter controlled the flow rate of the seawater, and cooling tower and steam boiler controlled temperature of that for making similar condition with vessel. Working principle is as follows. In the seawater cooling system, gaseous refrigerant from the compressor outlet into the condenser, and the working fluid is condensed by exchanging the heat with cooling water. Liquid refrigerant is collected in receiver and it is exchanged heat with refrigerant from the evaporator outlet in super heater. The refrigerant at the outlet of the super heater is expanded by expansion valve, and evaporates at the evaporator by acquiring heat from seawater. Evaporated refrigerant flows into the super heater, and it
circulates. In blue line, divaricated water from the evaporator outlet into fish hold heater, and the water is heated by exchanging with boiling water to maintain temperature steady. In addition, the water is mixed with else water from evaporator, and then flows into the fish hold tank. In the sky-blue line, water is cooled in cooling tower and divaricated water is heated in seawater heater to maintain temperature steady. Also, in the red line water which flows into the seawater heater or fish hold heater was heated with boiler.

Figure 3. The schematic diagram and experimental apparatus of the seawater cooling system

2.2.2. Experimental results

Table 1 shows the performance results of the 238kW seawater cooling system. The performance experiment of the system was conducted with the condition of flow rate of the seawater, 90m³/h. Steady state was considered when the seawater temperature maintains 3°C, which is the storage temperature for the mackerel.

Table 1. Experimental results of the performance analysis

| Parameter                   | Unit | Value |
|-----------------------------|------|-------|
| Evaporator duty             | kW   | 240.3 |
| Pump power consumption      | kW   | 50    |
| Compressor power consumption| kW   | 72    |
| Total power consumption     | kW   | 122   |
| Coefficient of performance  | -    | 3.34  |

3. Economic evaluation

As a method of economic evaluation, the net present value method was applied. Durable years of the system was set to 10 years, and the discount rate had 4.5% as the social discount rate. The discount rate means rate to evaluate present value having same value with future value.

3.1. Net present value method

Net present value means sum between the net benefit calculated as the present value for set period and the present value. For instance, if the net present value has positive value, it can be considered economical. The net present value is calculated using equation (1).

\[ NPV = -I + \sum_{r=1}^{n} \frac{C}{(1 + i)^r} \]  

In the equation (1), NPV means net present value, I is the initial investment cost, C is the benefit, i is the discount rate and r is durable years.
3.2. Conditions of economic evaluation

Target vessel of economic evaluation has used 70,000 kg of ice, 367 kg of salt per a fishing, and annual cost of the ice and the salt was calculated by 4 cents per kg, and 54.5 cents per kg investigated in South Korea. In addition, machine price and facilities are estimated by 130 thousand dollars and 51 thousand dollars respectively. The annual maintenance cost was calculated by 2% of the initial investment cost, 3,620 dollars, and operation cost is calculated by 12,357 dollars. These costs were calculated as follows.

Heat of fusion of the ice was divided into the evaporating capacity of the system, 201kW, then operation time was calculated by 81 hours. Vessels operate mainly in the 50-70% load range of the electric generator. The total power consumption was 125kW referred to Table 1, so the required power was calculated 137.5kW including the safety factor of 10%. The fuel consumption was investigated to be 36.2 litre per hour at 50% output of a diesel generator model having a rated output of 275kW [7]. Therefore, it was calculated as 31,280 dollars considering annual fuel consumption of 61,576.2L per year, considering the average value of 50.8 cents per litre of monthly diesel for 2017 provided by Korea National Oil Corporation. Table 2 shows the purchase cost of crushed freshwater ice and salt and the initial investment cost and maintenance and operation cost of the seawater cooling system. In addition, benefit is 47,023 dollars which subtracts the maintenance cost of the seawater cooling system from the cost of ice and salt.

| Table 2. Conditions of economic evaluation |
|-----------------|-----------------|
| Parameter       | Cost (dollars)  |
| Initial investment cost | 181,000         |
| Annual cost of crushed freshwater ice and salt | 63,000          |
| Annual maintenance and operation cost | 15,977          |
| Benefit         | 47,023          |

3.3. Results of economic evaluation

The net present value was calculated according to the discount rate, and the result is shown in figure 4. Consequently, the net present value of the seawater cooling system presents positive value when the discount rate is lower than 21.4%. It means the seawater cooling system is considered economical. Moreover, the discount rate has 4.5% as the social discount rate in South Korea, so the net present value of the seawater cooling system has 154 thousand dollars approximately.

![Figure 4. Net present value of the discount rate](image-url)
4. Conclusions

Prior to evaluate economic feasibility of seawater cooling system, heat transfer characteristics analysis and efficiency analysis gone along. In this paper, seawater cooling system was analysed heat transfer coefficients and evaluated economics based on that experimental results using the net present value. The summary of the results is as follows.

Heat transfer coefficient of R22 is 0.35kW/m$^2$K higher than R134a with same material of the tube, and aluminium-brass had 0.25kW/m$^2$K higher coefficient than the copper-nickel tube with same refrigerant used.

The net present value presented negative when the discount rate is larger than 21.4%. The net present value was 154 thousand dollars approximately when the discount rate has 4.5% as the social discount rate in South Korea.

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References

[1] Gorgy E and Eckels S 2012 Local Heat Transfer Coefficient for Pool Boiling of R-134a and R-123 on Smooth and Enhanced Tubes International Journal of Heat and Mass Transfer 55 pp. 3021-3028

[2] Kang I H, Seol S H, Yoon J I and Son C H. 2017 Evaporating heat transfer characteristics of Aluminum-brass tube for seawater cooling system using R-134a Journal of the Korean Society of Marine Engineering 41 pp 197-201

[3] Yoon J I, Son C H, Choi K H, Jung S H, Han H M and Seol S H 2018 Heat Transfer Characteristics of Flood-type Evaporator Using R22 and R 134a for Fishing Vessels Heat Transfer Engineering (Online)

[4] Yoon J I, Son C H, Han H M, Lee K S, Lee J M, I and You I D 2018 Heat Transfer Characteristics of Flooded Type Evaporator for Seawater Cooling System MATEC Web of Conferences 167 02014

[5] Hong S W, Yang U G, Kim M K, Park Y S, Park K I and Kim D H 2018 An economic feasibility analysis of the automatic operation system development for hairtail trolling line in Jeju region, Korea Journal of the Korean Society of Fisheries and Ocean Technology 54 pp 164-172

[6] Bae J H, Jung H Y and Kim M J 2015 Economic Feasibility and Impact Analysis on Energy Transformation Project of Macro-Algae Biomass The Korean Society for New And Renewable Energy 11 pp 29-38

[7] B. H. Lee 2016 A Study on Methodology of Optimal Operation of BESS and Diesel Generators in a Microgrid Considering Efficiency Characteristics According to the Power Ratios of diesel Generators The Transactions of the Korean Institute of Electrical Engineers 65 pp 539-546