DESIGN OPTIMIZATION OF A MARINE REFRIGERATION SYSTEM WITH WASTE HEAT RECOVERY CHANNEL

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ABTRACT

This paper presents the design of an optimized marine refrigeration system to be used as a preservation facility for fishermen on boats. This aims to help preserve and maintain the high quality of the catch during fishing operations. This is to replace the manual ice box method. The system is tested in an actual environment offshore. The lowest temperature reached inside the refrigeration when full load is -1.7°C with a maximum time of 6 hours, while the temperature of the fish inside the refrigeration is 2.5°C. These results show the capability of the enhanced marine refrigeration system to achieve the desired temperature for the catch to maintain its good quality. In addition, the usability and user experience survey results indicated that the target beneficiaries agreed that the following aspects of the marine refrigeration system include usefulness and functionality, ease of use, design capacity, dimension, aesthetics, and kerosene as the resources used are excellent.

***Keywords**: Absorption, Kerosene, Marine Refrigeration*

I. INTRODUCTION

The Philippines is an archipelago consisting of 7,107 islands, and has an extensive coastline of 17,460 km in length and about 26.6 million ha of coastal waters and 193.4 million ha of oceanic water. The country exercises authority over 2.2 million square kilometers of territorial ocean waters including its Exclusive Economic Zone (EEZ) [1]. One of the major fishing grounds of the Philippines is the West Philippines Sea where the exportation of fisheries, livelihood of the fishermen, and other economic benefits depend. There are several studies included in the Southeast Asian Fisheries Development Center (SEAFDEC) Collaborative Research Program which aimed for fishing gear technology, fishing ground survey, post-harvest technology and aquaculture in the said location to help improve the livelihood of the fisherfolk. And, to improve the preservation facility used by the fishermen on small boats during fishing operations, this technology was introduced.

According to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 2006, the cold storage facilities for fresh fish should be maintained from 0°C to 2°C. Air velocity should be limited to control ice loss. Temperatures less than 0°C retard ice melting and can result in excessive fish temperature. This is particularly important when storing round fish which generate heat from the autolytic process. Generally, when freshwater fish is properly stored in a refrigerated room, it may be held for 7 days preserving its quality [2].

There are several studies relative to marine refrigeration used in large fishing vessels to preserve the catch. Mostly are heat-driven refrigeration systems instead of power-driven, since there is a limited power source for fishing vessels.

According to Xiangguo et al., the systems that can harness waste heat can be adsorption, absorption, and ejection refrigeration systems. The adsorption refrigeration uses couples, one as the adsorbate and the other as adsorbent. The working media is the refrigerant. The absorption refrigeration consists of a generator, absorber, throttle valve, and pump, which acts as a compressor. Steam ejector refrigeration cycle is composed of a generator, ejector, a throttle valve, condenser, circulation pump, and evaporator [3].

Additionally, based on the study of Yuan et al., an absorption refrigeration system has undergone an experimental investigation relative to the recovery of heat of a marine engine exhaust gas.The fluid is an ammonia water lithium bromide mixture to overcome the effect of the critical onboard condition of the absorption refrigeration system. Both performances indicate that the mixture has greater energy efficiency, and the heat loss is reduced. Therefore, the electric COP and the COP is increased [4].

However, these types of refrigeration systems are applied to large vessels that can accommodate much equipment. Commonly, waste heat from engines of the fishing vessels became the target of many studies as the heat source to drive the refrigeration system. But in this case, for the typical boat of the fishermen used for fishing operations, and based on their operation, there will be no other heat source than the direct sunlight. Thus, there remains the need to develop an enhanced design of a heat-driven marine refrigeration system.

Marine refrigeration system (MaReSys), is a kerosene-driven absorption refrigeration system designed with a waste heat recovery channel (WHRC) for the enhancement of the coefficient of performance and for the sustainability of operation of the system (see Fig. 1). It is built to serve as a preservation facility on typical boats of fishermen in the Philippines, replacing the conventional ice box method applied by the fishermen during fishing operations.

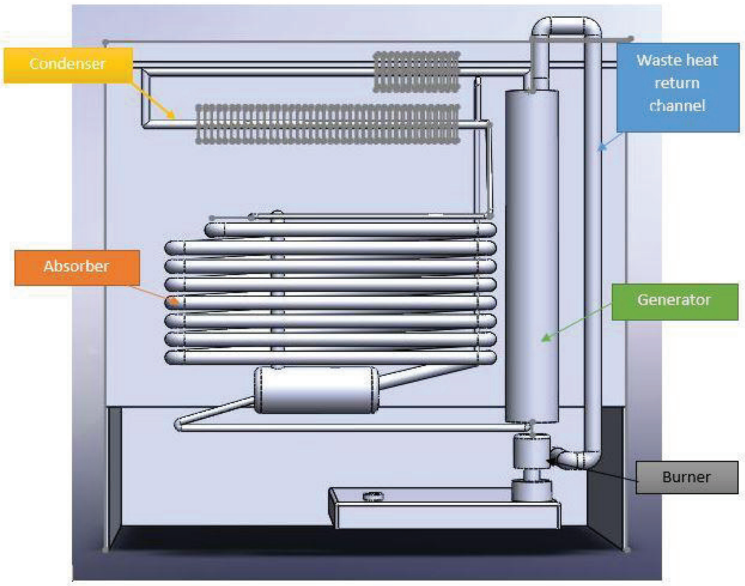

Fig. 1. Design of MaReSys with WHRC.

II. MATERIAL AND METHODS

The initial design of MaReSys without WHRC is tested, as well as the design of MaResys with WHRC. Their coefficient of performance (COP) is obtained for each trial and is compared.

For the next step, MaReSys is tested offshore. The following parameters are obtained during the test: temperature of the freezer, temperature of the fish inside the freezer, temperature of the burner, ice box temperature, temperature of the fish inside the ice box, ambient temperature, and weather condition.

Fig. 2. Usability and user experience survey is deployed.

After the test, the operation of equipment is demonstrated to the fishing community and the deployment of usability and user experience surveys is done (see Fig. 2).

III. RESULTS AND DISCUSSION

1. Coefficent of Performance

The coefficient of performance (COP) of MaReSys at evaporating temperatures ranging from 0°C down to -10°C for both designs with WHRC and without WHRC are shown (see Fig. 3).

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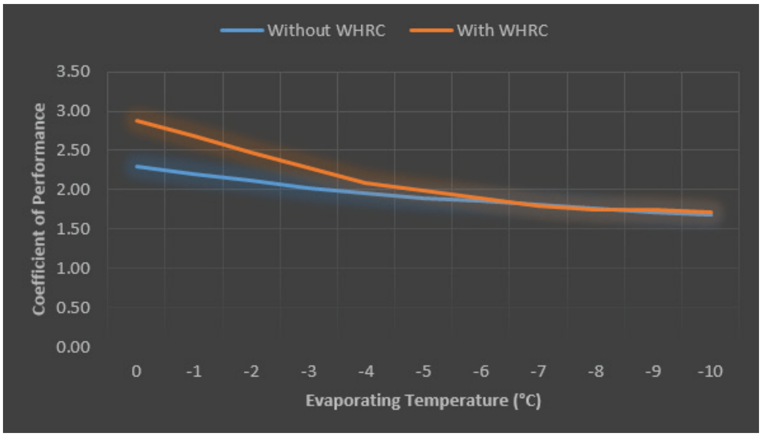

Fig. 3. COP of MaReSys with WHRC and without WHRC.

At 0°C, the COPs are 2.29 and 2.88 for the design without WHRC and with WHRC, respectively. At -5°C, the COP for that without WHRC is 1.90 and for that with WHRC is 1.99. At -10°C, 1.68 is the COP for that without WHRC and 1.72 for that with WHRC. As the evaporating temperature goes down from 0°C to -5°C, the values of COP are also declining. But from -6°C down to -10°C, the values of COP are still decreasing but with a little value. It is mostly maintained from 1.68 to 1.86 for that without WHRC and from 1.72 to 1.89 for that with WHRC. By observation, the COP of the MaReSys with WHRC is higher than that without WHRC.

2. Pilot Testing

The temperature of the freezer started from 22.1°C to -1.7°C in 6 hours, and at this point, the temperature of the fish inside MaReSys is 2.5°C. In comparison with the ice box, the temperature of the ice box ranges from 0.1°C to 0.5°C, and the temperature of the fish inside the ice box ranges from 3.7°C to 5.6°C. According to the Philippine National Standard, the chilling temperature for fish is at 0°C to 4°C [5]. Thus, the desired temperature of the fish is met by both methods.

3. Usability and User Experience Survey

Based on the survey, 92.3% of the respondents showed interest in acquiring the technology. The respondents mentioned that the technology would help them minimize their expenses in buying ice for their cooling storage. Since 59.1% of them used a styrofoam ice box, 27.3% used a plastic ice box, 9.1% said that they used a pail or "timba", and 4.5% said that they used a freezer (see Fig. 4), indicating that most of them used ice in their fishing operation. In terms of aspects of the technology such as usefulness and functionality, ease of use, design capacity, weight, dimension, aesthetics, and kerosene as the resources used to run the technology, the respondents rated all the aspects excellent except for the weight considering that most of the respondents have small and medium boats. Overall, the results indicated that the technology is excellent in terms of the stated specifications.

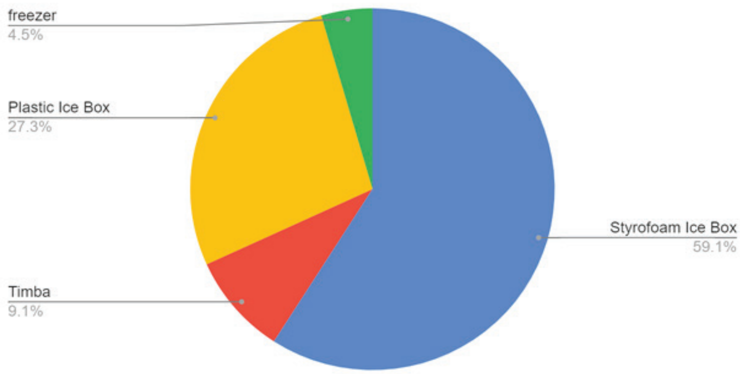

Fig. 4. Types of Cooling Storage used by the Respondents

IV. CONCLUSION

The performance of the MaReSys with and without WHRC were presented in this paper. It is evident that the COPs of MaReSys with WHRC are higher than that of without WHRC. Therefore, MaReSys with WHRC develops a better system performance. The time to achieve the target evaporating temperatures are comparable for both designs.

Based on the summarized findings of the pilot testing, the MaReSys with WHRC can be used as a replacement to the manual ice box method in preserving the quality of the newly caught fish.

The usability and user experience survey results indicated that the target beneficiaries agreed that the following aspects of the MaReSys that include usefulness and functionality, ease of use, design capacity, dimension, aesthetics, and kerosene as the resources used are excellent.

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REFERENCES

1. BFAR 2014, http://bfar.da.gov.ph./publication.jsp?id=2338#post , last accessed 2023/03/06.
2. American Society of Heating, Refrigerating, and Air-Conditioning Engineers. ASHRAE Standard: Standards for Natural and Mechanical Ventilation. New York: The Society,1973. (2006).
3. Xiangguo, X., Yishu, L., ShenYin, Y., Guangming, C.: A review of fishing vessel refrigeration systems driven by exhaust heat from engines, Applied Energy. Elsevier Ltd. (2017).
4. Yuan, H., Zhang, J., Huang, X., Mei, N.: Experimental investigation on binary ammonia water and ternary ammonia-water-lithium bromide mixture-based absorption refrigeration system for fishing ships. Elsevier Ltd. (2018).
5. Philippine National Standard. Code of Hygienic Practice (COHP) for the Sale of Fresh Agriculture and Fishery Products in Markets and Authorized Outlets,
6. https://bafs.da.gov.ph/bafs_admin/admin_page/pns_file/PNS.BAFS%2046%202020%20COHP%20Sale.pdf , last accessed 2023/03/07