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A review of fishing vessel refrigeration systems driven by exhaust heat from engines

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HIGHLIGHTS

- Application of heat driven refrigeration systems to fishing vessel is reviewed.
- Techniques for improving efficiency and stability for onboard application are detailed.
- In addition to three basic types of systems, hybrid system is also introduced.
- An overall table to summarize and compare the features of various systems is provided.

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ABSTRACT

For a fishing vessel, its diesel engine's energy efficiency is only at 35–40%, with more than half of the energy being wasted as exhaust heat taken away by jacket water, cooling air and exhaust gas. Fishing vessel refrigeration systems driven by the exhaust heat from engines can therefore help achieve energy saving. However, to improve the COP/EER of these heat driven refrigeration systems and to ensure their operational stability under severe conditions on ocean are of challenges. In this paper, the progress and prospect of utilizing three different kinds of heat driven fishing vessel refrigeration systems, i.e., adsorption refrigeration system, absorption refrigeration system and ejection refrigeration system, are reviewed with a special focus on the techniques for improving system efficiency and stability. A hybrid heat driven refrigeration system, which combines merits of different types of systems, is then introduced. A summary table is provided to summarize and compare the features of adsorption refrigeration systems, absorption refrigeration systems and ejection refrigeration systems used in fishing vessels, followed by conclusions and suggestions for future works.

Contents

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1. Introduction

According to the data from 2011 Statistical Yearbook of Ocean and Fishery of China [1], the number of fishing vessels in China was 1.06 million, and a total of 7.9 million tons of diesel oil per year was consumed, taking 70% of the total fishery cost [2]. In addition to powering vessel engines, much energy was also used to drive vapor compression refrigeration systems for ice making and air conditioning. Ice is extensively used for preserving fishery harvested [3–6] because an ambient temperature from −1 °C to 0 °C is the best for preventing both bacteria growth and low temperature damage to the freshness of fishery harvested. Generally one ton of fish would require 1.5–2.0 tons of ice, leading to a huge demand for ice during a fishing trip.

In a traditional way, ice was made in ice-making factories beforehand and loaded into the vessels. It was then chipped using a machine when there was a requirement for preserving. A large space would be required by ice storage and the preserving of ice itself was also a problem. Therefore, on-board ice making machines driven by electricity produced by vessel engine were invented and became a standard piece of equipment for large-scale fishing vessels [6,7]. Equipping an ice making machine could save some vessel space, reduce the cost for buying ice and, more importantly, extend cruising period which was dependent on the preservation time of ice. However, the use of an ice-making machine also increased energy consumption and the load for a fishing vessel engine.

On the other hand, also illustrated by the data from 2011 Statistical Yearbook of Ocean and Fishery of China [1], among all the fishing vessels, 0.297 million of them were motor fishing vessels and more than 85% of all were small scale wooden fishing boats. 90% of fishing vessels were more than 5 years old and 40% of all than 10 years old. The aging of a fishing vessel certainly led to a low energy efficiency of its engine and thus a high fuel consumption, which is becoming the biggest obstacle in the modernization of fishery industry [8–10]. Researches suggested that a diesel engine's energy efficiency was normally at 35–40% [11–15], with more than half of the energy being wasted as exhaust heat taken away by jacket water, cooling air and exhaust gas. Therefore, recovering the energy from the exhaust heat can be effective for reducing energy use in fishing vessels.

It has been proposed to use the exhaust heat from a fishing vessel engine for direct heating [16–18], producing electricity [19,20], desalinating sea water [21,22], charging turbos [23–25] and operating refrigeration systems [26–28]. As pointed out by Shu et al. [29], due to their unique characteristics and application temperature ranges, different waste heat recovery techniques may be selected based on both the requirements of normal daily routines and the availability of heat sources aboard a fishing ship. A heat driven refrigeration system normally require a medium temperature heat source at as low as 70 °C, thus having a high potential to be combined with other techniques for the maximization of energy recovery efficiency. For example, after being applied to a turbocharger, the temperature of exhaust gas is still high enough to operate a refrigerating system, then the exhaust heat from the refrigeration system can be used for heating water for daily use [16,18].

Due to the facts mentioned earlier, the use of refrigeration systems driven by exhaust heat from engines for ice making, refrigerating and air conditioning in fishing vessels can help achieve energy saving. Currently available heat driven refrigeration systems could be classified into three types, i.e., an adsorption refrigeration system, an absorption refrigeration system and an ejection refrigeration system. All of them could utilize low-grade heat energy. The consumption of electricity, which is normally regarded as a type of high-grade energy for operating vapor compression refrigeration systems, can be reduced. Furthermore, the working fluid used in a heat driven refrigeration system is more environmentally friendly than that used in a vapor compression refrigeration system, such as CFCs and HCFCs. In order to promote the use of heat driven refrigeration systems, lots of studies related to applying heat driven refrigeration systems have been carried out. However, due to the severe operating conditions that various heat driven refrigeration systems have to face on ocean and their different operational principles and system characteristics, applications of these heat driven refrigeration systems to fishing vessels would result in different challenges.

In this paper, for each of the three types of heat driven refrigeration systems, its fundamentals are firstly presented. Related researches, where heat sources other than exhaust heat from fishing vessel engines were used to operate refrigeration systems, are then reviewed to provide references for the research trends and possible further improvements of heat driven refrigeration systems applied to fishing vessels. Thirdly, applications of heat driven refrigeration systems to fishing vessels are extensively reviewed, focusing on the techniques for improving the operational efficiency and ensuring their operational stability under severe conditions on ocean. Finally, hybrid heat driven refrigeration systems which combine merits of different types refrigeration systems are introduced, followed by conclusions and suggestions for future works.

2. Adsorption refrigeration systems

2.1. Principles and related research works

An adsorption refrigeration cycle is a power conversion system driven by heat. It uses adsorption couples, one acting as adsorbent and the other as adsorbate and also refrigerant, as its working media. A basic adsorption cooling system mainly consists of a sorption chamber (ad- and desorber) as a thermal compressor, a condenser, an evaporator and a throttle value, as shown in Fig. 1 [30]. Initially, the refrigerant is adsorbed by the adsorbent inside the sorption chamber, which is alternately heated and cooled during the operation of an adsorption refrigeration system. When the sorption chamber is heated, the desorption procedure occurs. The input heat separates refrigerant from adsorbent and refrigerant vapor flows into the condenser. The refrigerant vapor aggregation in the condenser leads to a high pressure and the refrigerant is condensed after releasing its heat to the coolant in the condenser. Then the high pressure liquid expands to low temperature and low pressure two-phase flow through the throttle valve and provides cooling in the evaporator through evaporation. When the sorption chamber is cooled, the pressure drops down and refrigerant vapor at a low temperature and low pressure coming from the evaporator flows into the sorption chamber and would be adsorbed by the adsorbent. Cooling water removes the heat of adsorption through a heat exchanger in the sorption chamber. By