Commissioning and Initial Shipboard Operation of Hydrocurrent® 125 KW Marine Heat Recovery System

Abstract

The shipping industry is searching for ways to reduce vessel operating costs and comply with increasingly rigorous international emission regulations. Industrial heat recovery technology has the potential for reducing fuel consumption and emissions by converting waste heat from the jacket water in the ship's main engines into usable electric power for the ship's electrical demand, reducing the load on the ship's diesel generators.

Currently, jacket water heat from the main engine is discharged into the ocean as waste. At the same time, diesel generators are used to provide electricity for use on board. A new system developed by Calnetix Technologies in collaboration with Mitsubishi Heavy Industries Marine Machinery and Engine Company (MHI-MME) uses an Organic Rankine Cycle (ORC) process with proprietary turbo-generator power conversion technology to convert thermal energy from the engine's jacket water heat into mechanical power to generate electricity. The Hydrocurrent® system was first introduced in 2014 and underwent successful classification society tests with Lloyd's Register and Class NK in March 2015. The first ship installation took place in April 2016 on the A.P. Møller containership *MV Arnold Maersk*. In this paper, we describe the installation, commissioning and initial operational results achieved on the ship.

System Description

The Hydrocurrent system is designed to extract up to 125 kW of gross grid-quality electrical power with outputs meeting marine classification society requirements from ship engines ranging in size from 10 to 30MW output with a range of engine jacket water temperatures as low as 80^{o}C and with sea water cooling temperatures of 10-32^{o}C.

The system is shown in Figure 1. It comprises of three major subsystems:

- Closed-loop ORC module
- Calnetix proprietary Carefree Integrated Power Module (IPM)
- Electrical cabinet

Fig. 1. Hydrocurrent system

The ORC uses a working fluid with a low boiling point flowing through a closed-loop evaporation-condensation cycle. The liquid fluid flows from a receiver tank at a pressure slightly above atmospheric and a temperature a few degrees above seawater. The liquid is pressurized and pumped through an evaporator, where it vaporizes and absorbs heat from the engine coolant. The pressurized vapor is expanded through the IPM's turbine, which generates electrical power. The working fluid is cooled to a liquid state in the condenser and returns to the receiver tank to repeat the cycle.

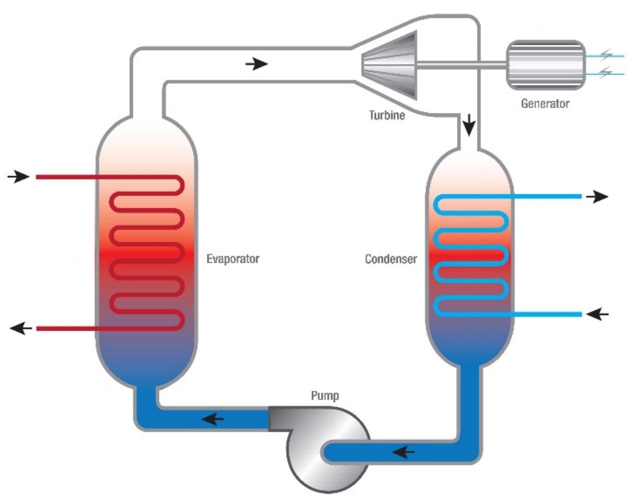

Fig. 2. ORC cycle

The IPM is a high-efficiency maintenance-free, fully-sealed module that consists of a radial turbine and a permanent-magnet generator. The magnetic bearings enable frictionless operation, eliminating energy loss, wear and maintenance associated with lubricated bearings. Electrical power produced in the IPM is converted to meet the power quality and specification requirements of the ship. This is accomplished in an active converter, which automatically synchronizes output power with the ship's grid voltage and frequency and maintains synchronization irrespective of ship grid fluctuations.

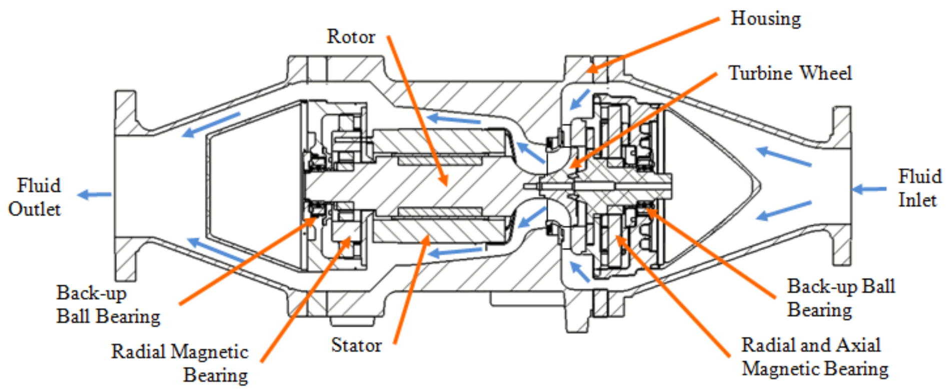

Fig. 3. Carefree IPM

Pilot System Installation and Commissioning

MV Arnold Maersk is a 336m containership of 93,496 gross tonnage built in 2003. The ship is classified by American Bureau of Shipping and sails worldwide under the Danish flag. The ship's main engine is a Wartsila 12RTA96C 63 MW diesel. A Hydrocurrent 125EWJ system was installed and commissioned on the ship in Singapore in April 2016.

Installation involved building a frame for the condenser, connecting piping to the condenser, moving the ORC components into the engine room and assembling the ORC, evaporator and condenser, and making all the piping connections. The Hydrocurrent's dimensions are 2.5m (l), 1.4m (w) and 2.3m (h).

Fig 4-5. Hydrocurrent installation on M/V Arnold Maersk.

The system was commissioned and tested on April 10. The test results from the commissioning are summarized below. Temperature, pressure and flow readings were recorded manually by an engineer.

Gross power output readings were collected from the ORC's sensors, which have an error of about +/- 1 kW.

Commissioning Test Results

Jacket water flow rate	264 ACMH
Jacket water inlet temp	83.8ºC
Jacket water outlet temp	78.2ºC
Heat extracted	1689.2 kW
ORC gross power	125kW
ORC gross efficiency	7.4%

During the commissioning tests, the ship supplied -213 ACMH cooling water at 29ºC. This allowed the ORC to operate with a receiving tank temperature of approximately 36ºC. The lower receiving tank temperature allowed the ORC to operate at a higher power output.

Once the commissioning tests were completed, the ship's engineers adjusted the cooling water flow to reduce their pumping power requirements. This resulted in a slightly reduced power output of 100-110kW.

Note:

In a closed-loop ORC, the amount of energy extracted is proportional to the mass flow through the turbine wheel and the pressure ratio (in/out) across the wheel. As the mass flow or pressure increases, the power output increases. A higher heat source temperature or mass flow will allow the cycle to operate with a higher inlet pressure, and a lower temperature cooling source decreases turbine outlet pressure. The heat-source temperature and mass flow in a ship ORC are more-or-less fixed. Power output can be increased by reducing the cooling temperature or increasing the cooling water flow to decrease turbine outlet pressure.

Operational Results

The ship sailed April 13 for a 12-day journey to Suez. The Hydrocurrent system was started by the crew at 12:42am April 13. Table 1 shows average gross power to the grid from April 13 to April 20, when the system was shut down. The graph shows a gradual increase in output from 105 kW to 113 kW over the 12 days, presumably related to the lower seawater temperatures as the ship sailed into cooler waters. Table 2 gives the cumulative kWh to the grid during the same period. Table 3 shows the hourly average supply temperature. It can be seen that the source temperatures ranged from 83.6 to 84 C. The dip on April 17 was when the ORC was briefly shut down and restarted by the crew. Table 4 shows the hourly average receiver tank temperature. The actual seawater temperatures used in the ORC condenser are not available. The receiver tank temperature is that of the refrigerant exiting the condenser and provides a good indicator of the seawater temperature and flow rate. When seawater temperature is high or the flow rate is low the receiver tank temperature rises. When seawater temperature is cooler or flow is higher, receiver tank temperature drops.

Examination of the data reveals that the power output increases as the receiver tank temperature decreases, causing the overall pressure ratio of the turbine to rise, thereby allowing the ORC to generate more power.

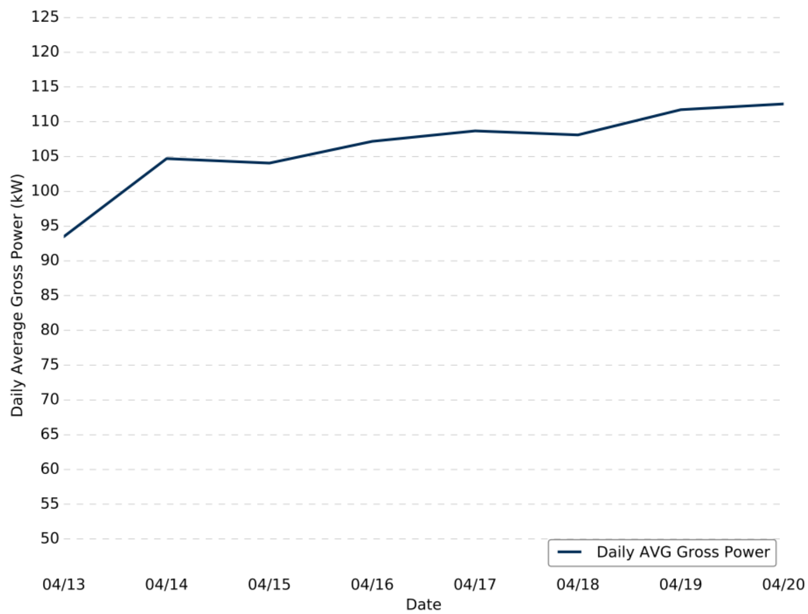

Table 1. Average Gross Power to Grid

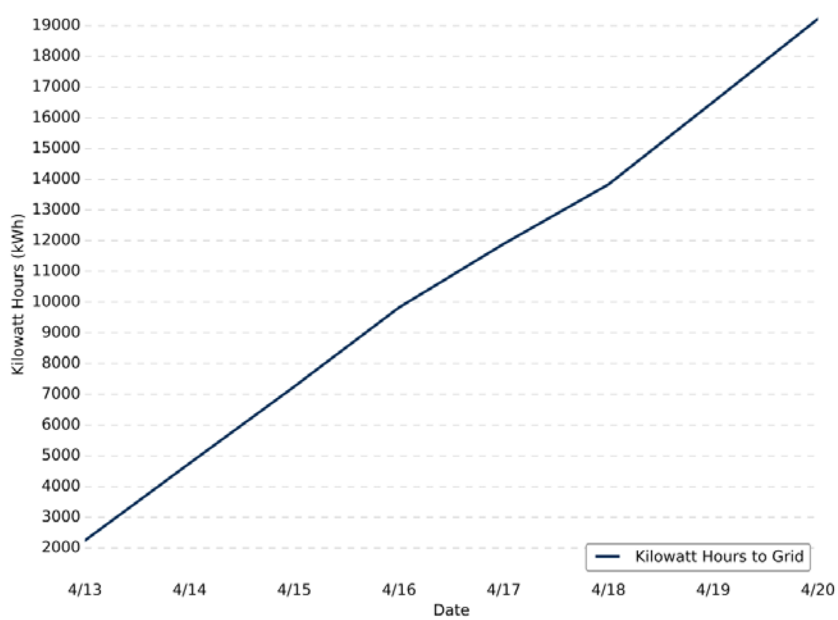

Table 2. Cumulative kWh to Grid

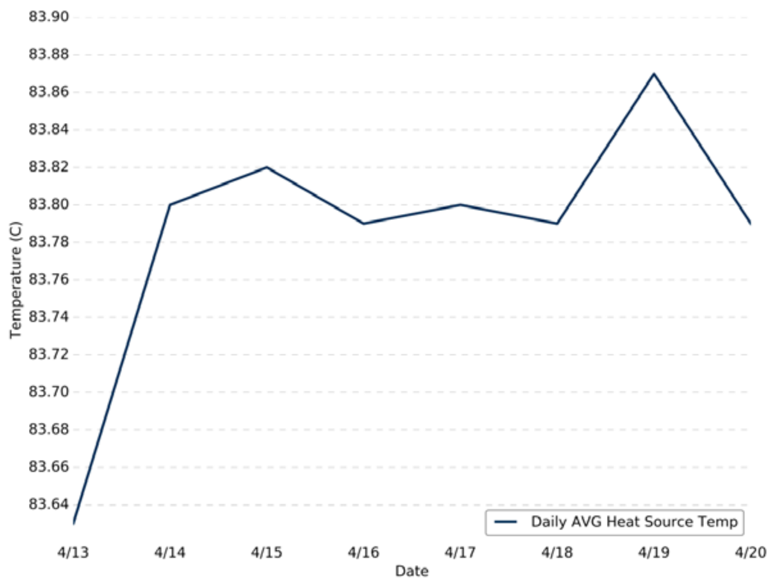

Table 3. Average Supply Temperatures

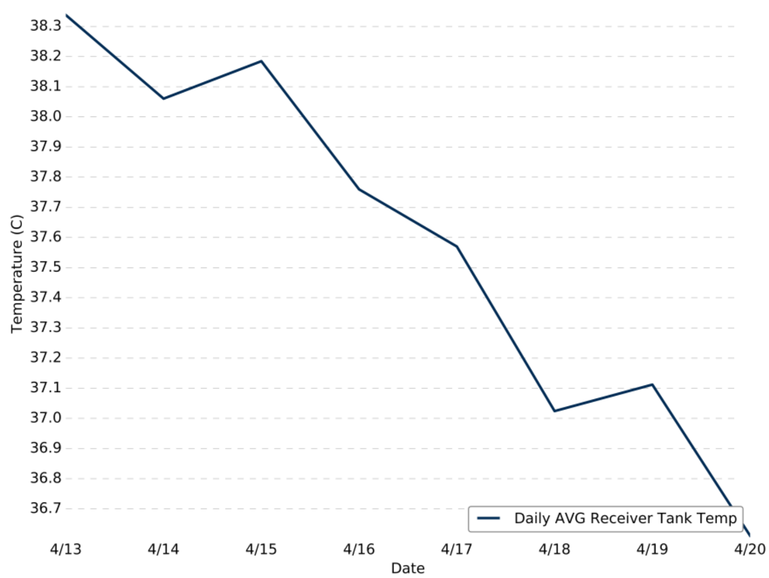

Table 4. Hourly Average Receiver Tank Temperatures

Conclusions

Commissioning tests and operational data reveal the Hydrocurrent installation on MV Arnold Maersk met or exceeded expectations. It consistently produced 110-115 kW during the voyage, slightly lower than the design specifications. This is because the crew adjusted the cooling water flow downward by reducing power to the water pump. When operated at full cooling water flow, the system put out 125 kW.

The installation process resulted in lessons learned that will be applied in future installations. A modular containerized approach should be considered for easier retrofit on existing ships.

Feedback from the ship’s engineers showed high levels of satisfaction with the system’s performance.