WASTE HEAT RECOEVRY SYSTEM FOR SHIPS

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Abstract - Globalization in the modern era is dependent on the international logistics, the economical and reliable means is provided by the ocean going merchant vessel. Most reliable method of propulsion applied by most of the vessels is marine diesel engine. Due to increase in the oil prices the ship operators explore for reduction cost of the operation of the ship. The newly adopted IMO's EEDI & SEEMP regulation calls for the most effective measures to be taken in this regard.
The main engine of the ship suffers a lot of thermal losses, they mainly occur due to exhaust gas waste heat, radiation and cooling. So to increase the overall efficiency of the system, we use the waste heat energy of main engine to increase the fuel economy. In our paper we deal with the problem of using this waste heat. The exhaust gas of the engine coming out of the turbocharger still holds considerable amount of heat. This heat of the exhaust gas can be used to heat the liquid of fewer boiling points, which can be used to drive turbine and produce electricity.

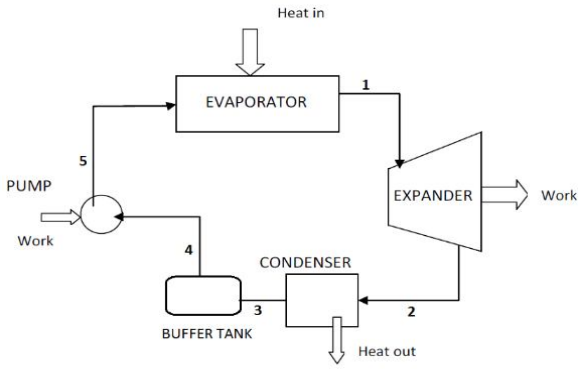
Keywords - Waste Heat Recovery System, Engine Exhaust, ORC, R245fa, Power Generation.

I. INTRODUCTION

The marine diesel engine is the most commonly used propulsion system for the merchant navy vessels due to its cost effectiveness. MDE engine have high combustion temperature and pressure, which provides the best energy conversion technology. The engine looses the part of the energy to the surroundings, mostly in the form of exhaust gas and radiation, which contain about 40% of the fuel energy. For large ships the fuel expenses are about 50-80% of the total operational costs, depending upon the type of the vessel.
Waste heat from the engines on board ship is an abundant source of energy. The recovery of even the fraction of this waste heat and turning them into electricity will have positive impact on the operational cost of the ship.
The electric needs of the ship is fulfilled by the auxiliary diesel engine which consumes the significant amount of the diesel oil and leaves behind carbon footprints and also emits the green house gases.
One of the global changes which we are facing today over the whole energy field is to further reduce the green house gas emissions, to combat the climate changes. This can be improved by increasing the energy efficiency of existing systems. With the rising fuel prices there are significant economic advantages associated with investing in the system. When considering very large ships, it's feasible to consider them as complex system.

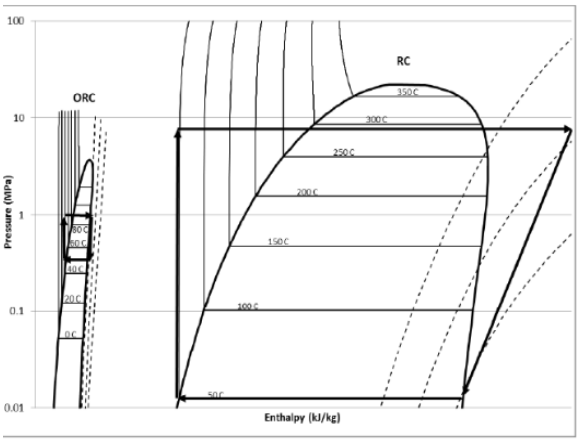
II. ORGANIC RANKINE CYCLE

This cycle is used to recover waste which is generally too low in temperature to be cost effectively extracted from other conventional steam systems. It is similar to rankine system but here we use organic working fluids. Basically it converts thermal energy into mechanical shaft powers, which can then be used to drive an electrical generator. This system is particularly useful for waste heat recovery system which usually works at low temperature range at 200 to 90 degree centigrade. The efficiency of the steam cycle is not feasible at these low temperatures, so we need a working fluid using this potentially low temperature source. The low grade heat input can be supplied through solar energy, biomass, geothermal, heat from internal combustion engines or waste heat from other industrial processes. This makes ORC'S widely suitable for many heat recovery and combined heat and power (CHP) systems.



III. BASIC LAYOUT OF ORC HEAT SOURCE

In our paper we are concentrating on the recovery of waste heat from the exhaust gas of the engine. This exhaust gas coming from the engine will be around 450 degree centigrade before the turbocharger. This exhaust is passed through the turbocharger and exhaust gas economizer boiler, after passing through this there is still energy left in the exhaust gas. The temperature of the exhaust gas at the end of the economizer is 200 degree centigrade. This temperature suits for the temperature of ORC.
A comparative p-h diagram of a conventional rankine cycle and an ORC is shown in the figure the main advantage of the ORC is it allows the use of lower temperature heat sources to drive the power cycles.



IV. P-H DIAGRAM OF RC AND ORC WORKING FLUID

The ship is compact consisting of various machineries, cargo space and accommodation for crew. In this type of environment it is necessary for the working fluid to have low toxicity, non flammability, and other criteria fulfilling the legislation requirements. Such as zero ozone depletion potential (due to absence of the chlorine molecule), low green house potential, since CFC's are banned in monetary protocol.

R245fa fulfills the criteria of the above needs. It has started to replace the earlier refrigerants in many relevant industrial applications. The ORC system being used in the study also consider R245fa which has the chemical nomenclature"HFC 1, 1, 1, 3, 3-pentaflouropropane".

The benefit of this system is that it will recover the useful energy, from low energy sources such as low pressure steam associated with steam driven turbines for electricity generation. Essentially, the waste heat source can be converted to a useful energy source such as electricity by utilizing R245fa working fluid.

V. PHYSICAL PROPERTIES OF R245fa

Molecular formula	$CF_3CH_2CHF_2$
Molecular weight	134
Ozone depletion potential	0
Global warming potential(100years)	950
Boiling point at 1.01 bar	14.9 degrees
Freezing point at 1.01 bar	<-107 degrees
Critical temperature	54.05 degrees
Critical pressure	36.4 bar

ORC WITH R245fa

The cycle consists of four major components turbine, condenser, pump and evaporator.
High pressure vapour enters the turbine. The controlled expansion of R245fa vapour produces mechanical power. Then it is supplied to electrical generator to produce electric power. The low pressure vapour from the turbine is passed through the condenser where heat is rejected and liquid condenses. Then it is stored in the buffer tank. A reciprocating pump that takes suction from the buffer tank raises the pressure of the working fluid to the working pressure and feeds it to the evaporator. From the evaporator the refrigerant is converted into superheated vapour. This then passed through the turbine where heat is extracted.
The cycle calculations have been calculated by the theoretical ideal states where the losses are not taken into the consideration. It is assumed that the turbine and the pump works with 100% efficiency, with no pressure drop in superheater and piping.

5.1 EVAPORATOR

In ORC the evaporator is used to add extra heat to the working fluid to generate into useful work. As discussed above the heat source for our
working fluid is the exhaust of the main marine engine funnel. Therefore it is necessary to place the evaporator inside the funnel.
R245fa enters the evaporator in the liquid from at the pressure at the 21 bars at 45 degree centigrade from the pump and exits the evaporator coils at the temperature of 130 degree centigrade. During evaporation there is a isobaric heat addition of 250KJ/KG to the refrigerant. Evaporator used may be of shell type and tube type.
The heat supplied to the working fluid may be found using the formula

Heat= MCPdT
WHERE
M mass flow kg/s
CP Heat capacity at constant pressure(kj/kgk)
dT temperature difference in centigrade

TURBINE
The turbine is used to convert the thermal energy into the mechanical energy. The working fluid enters the turbine at a pressure of 21bar and the temperature at 130 degree centigrade this fluid then exits the turbine at the pressure at 2 bars. This reduction in the pressure is used to generate the power.
Both radial and axial flow turbines can be used for this purpose. This turbine is coupled with an electric generator to produce electricity.
The work output of the turbine can be calculated by the difference of the inlet and outlet enthalpies of the turbine.
Work(output) = h1-h2
H enthalpy (kj/kg)

CONDENSER
The condenser is the heat exchanger where the heat is rejected from the working fluid and to condense it. It is of shell type and the tube type. The condenser can be dry cooled or wet cooled. Wet cooled condensers

can be required higher power to circulate the cooling medium and air cooled condensers, but the rate of cooling is higher. Since sea water is available in plenty we opt for water cooled condensers.

PUMP

The pump should be of positive displacement type of that takes the suction from the buffer tank where the fluid is in liquid state which has been condensed by the condenser. The buffer tank is used to give continuous supply to the pump and also provide the storage. The inlet pressure is 2 bar and temperature is 35 degree centigrade and at the outlet output pressure is 21 bars.

Work input to the pump is calculate by the following formula

Wi=vf3(p5-p3), Where

Vf3 specific volume of refrigerant at point 3

P pressure in bar

RESULTS

LOCATION(OUTLET)	TEMPERATURE (centigrade)	PRESSURE (bar)
evaporator	130	21
Turbine	51	2
Condenser	40	2
pump	40	
Mass flow	10kg/s	
Work done by turbine	48.55kj/kg	
Work done by pump	2.53kj/kg	
Heat supplied in evaporator	219.92kj/kg	
Thermal efficiency	20.92%	

CONCLUSION

Increasing the use of waste heat energy to produce electricity can help us to curb the use of fossil fuel and reduce the emission. In the ship electricity demand is fulfilled by the auxiliary diesel engine which also consumes significant amount of fuel, adding cost to engine and emissions. So our system seeks to produce electricity without consuming diesel for an auxiliary engine. The available power with this ORC system is approximately 350kw. This equals 275 tonnes of diesel oil for sufficient for six month voyage of the diesel generator were to be used. This power can be further increased by the increasing the number turbine and generator units. The weight of the turbine units is 50 tons which can be assembled in the compact area suitable for marine use. The efficiency of the ORC is around 20% and this system when integrated with the main engine can increase the overall efficiency of the engine by 5%.

NOMENCLATURE

ORC Organic rankine cycle
MDE marine diesel engine
IMO international maritime organization
SEEMP ship energy efficiency management plan
EEDI energy efficiency design index

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