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A Review on Energy Analysis and Performance of SRC and ORC Power Generation Systems Using Waste Heat Source

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Abstract- The development of the world today has largely been achieved through the increasingly efficient and extensive use of various forms of energy As the energy consumption is increasing day by day across the world non renewable sources of energy will not be able to meet the future demands alone .With the increase in demand the fossil fuel consumptions is also increasing day by day, Industrial activities will produce increasing amount of waste heat. A lot of energy is generated as a result of industrial activities which can't be practically fully utilized and goes on wasted which are further referred as industrial wastes. Conventional Rankine cycles is widely used to produce electricity but for extracting high grade energy using waste heat sources conventional Rankine cycle is not good option . Separate cycle is being developed so that energy from low grade heat source can be utilized to the greater extent. The price of the ORC components are less as compared to that of Conventional Rankine cycle also ORC are preferable for low temperature waste heat recovery. Several studies have shown that the specific amount of industrial waste heat is poorly measured, it has been studied that approximately 25 to 55% of the input energy can be converted into high grade energy in industries rest are not able to utilized.

Keywords: - SRC, ORC, Waste Heat Source, Organic Fluids, Rankine cycles, energy demands, working fluids.

I. INTRODUCTION

Recovery of maximum amount of low grade heat is the most challenging in the past few decade .The ORC is considered to be the most suitable for utilizing waste heat gases in order to produce electricity due to its simple design and availability of components.

The Organic working used in ORCs in the context of using heat source with low temperatures is more suitable than that of water. The ORC cycle is one of the effective methods to local and small scale power generation.

Frank W. Ofledt patented the naphtha engine in 1883.The ORC and naptha were considered to have same application. The naphtha was used as the working fluid and hence proved to be the supplement of water and hence able to replace the steam engine on boat.

The heat of vaporization for naphtha is lower than that of water, hence it produces more vapour if certain amount of heat added to it and therefore, more work output. There was a high risk of explosion when steam boats started using naphtha engine, for this reason the coast guides made it mandatory for operators to have licenses which later resulted in the population growth of the naphtha engine. The

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discovery by Frank W Ofledt was a substitute for using steam engines. Figure 1 shows an article about naphtha engine (1890) while figure 2 shows a simple design of naphtha engine.

Fig 1. An article on naphtha engine (Obafunmi, 2014).

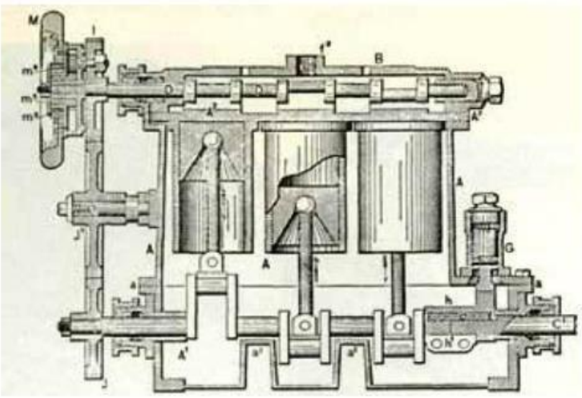

Fig 2. Sample design of naphtha engine (Obafunmi, 2014).

Harry Zvi develop first prototype of ORC's in the early 1960s. This was mainly used to produce electrical power from low grade heat. Harry Zvi also develops the turbine working and operating at low temperature. This invention was later privatized by an Israeli company in 1965.

II. WORLDWIDE ORC INSTALLATION

ORCs have been successful installed in many countries. Waste heat utilization is one of the major concerns around the world. Maximum utilization of ORC's are being seen in Germany, Italy, Canada and the USA while countries like Belgium, Austria, Romania, Russia, Finland, Swaziland, Morocco and India have also initiated using this to utilize waste heat to the greater extend.

The major companies that supplies ORC equipment are Tas Energy, Ormat and Turboden .ORC system is widely used now a days to recover waste heat. Recovery from the gas, glass and cement industries in different countries is more seen in picture.

III. LOW GRADE TEMPERATURE HEAT RECOVERY CYCLES

Use of conventional Rankine cycles with water as a working fluid to produce electricity especially when the temperature is extremely low is not a good option. To utilize low grade heat source effectively various cycle has been developed like Goswami cycle, Kalina cycle, trilateral flash and Organic Rankine cycle. ORC uses organic working fluids instead of water and provide higher benefits with low price of components.

IV. THE ORC AND THE CONVENTIONAL RANKINE CYCLE

The major differences between the ORC and Conventional Rankine cycle are as follows:

1. Working Fluids:
Apart from the operating parameters such as temperature and pressure; the major difference between the ORC and the conventional steam Rankine cycle is the working fluid used in each cycle. In the conventional Rankine cycle the only working fluid is water which is used in steam form while in an ORC over a wide range of working fluid can be used.

Discovering new working fluids having favourable environmental conditions for the ORC system is a continuous process. The components sizes of an ORC system can vary according to the thermodynamic property of the working fluid. The thermodynamic, environmental and safety properties of each working fluid are different. Safety and environmental data for most working fluids are not readily available. Selecting an appropriate working fluid for the ORC system is vital for better cycle efficiencies and higher network outputs.

2. Environmental and Safety Properties:
Working fluid like water is one of the best working fluid due to its various best properties like non-flammable, non toxic, no ozone depletion potential

and no global warming potential. Many organic working fluids are not environmentally friendly because they have ozone depletion potential and also some are causing greenhouse effect which is harmful to the environment.

High toxicity and High flammability can be proving as the limitations of using organic working fluids.

V. LITERATURE REVIEW

Eryanto et al. (2020) [1] presented a comparative analysis using ORC, Regenerative ORC (RORC), and RORC with Internal Heat Exchanger (IHE). The results shows that RORC with IHE has the higher value for energy efficiency (21.74%) and exergy efficiency (25.26%) both while net power produced 5479 kW.

This shows the addition of OFOH and IHE can improve performance and reduce energy degradation from the cycle.

Köse, Özkan et al. (2020)[2] evaluated performance improvement of SRC and ORC systems with bottoming system in a GT based triple combined system for varying turbine inlet temperature and pressure. Firstly SRC was parametrically optimized for a varying pressure (from 10 bars to 100 bars) and temperature (from saturated steam temperature to 480°C).

Then, a parametric optimization is performed to comprehensively evaluate the effects of acetone, R113, R141b, R152a, R245fa and R365mfc on thermodynamic performances of ORC (Organic Rankine Cycle) with the increase in turbine inlet pressure and temperature.

Along with the optimization, the ORC turbine inlet pressure was increased from 7.5 bars to the critical pressures of the working fluids with the increments of 2.5 bars.

Thanganadar and colleagues (2019) [3] aimed to explore the full potential of a CO2 cycle in commercial gas turbine plant and analyzed the maximum performance and cost of electricity for five CO2 cascaded cycles.
Sun and colleagues (2018) [4] developed a novel connected-top–bottom-cycle to cascade utilize flue gas heat, in which energies in high temperature levels were extracted by CO2 power cycle as the top cycle.

Mecheri and Moullec (2016) [5] concluded that CO2 coal-fired power plant theoretically offered around 6% LHV relative efficiency improvement performances (from about 45% to 48%) with existing materials at current operating condition [10].

Liu and colleagues (2018) [6] proposed a new conceptual system integrated with a CO2 cycle for waste heat recovery from boiler exhaust flue-gas at 350 °C.

Saleh (2018) [7] presented optimized ORC-VCR system with an energy efficiency of 53.8% .R602 was used as the working fluid. Compared with the Kalina cycle, the organic Rankine cycle and trilateral power cycle could yield better exergoeconomic performance.

Colorado (2017) [8] performed an advanced exergy analysis on a single stage absorption heat transformer operating with a lithium bromide water solution. The total irreversibility of the cycle was approximately 1.046 kW of which avoidable part sharing 14.78% could be reduced by improving its design and configuration.

Mohammadi and colleagues (2019) [9] evaluated the real potential of enhancement for the recompression CO2 cycle performance by means of calculating the first and second splitting levels of exergy destruction. They revealed that for improvement priority of components obtained by the conventional exergy analysis was different from that achieved by the advanced exergy analysis.

Galindo and colleagues (2016) [10] performed advanced exergy analysis on a bottoming ORC system coupled to IC engine and suggested that the first priority of improvement was the expander.

Nami and colleagues (2017) [11] applied the advanced exergy analysis to the dual fluid ORC power plant with geothermal heat source.

Liu, Xiangyang et al. (2020) [12] presented a system to efficiently convert the waste heat of the exhaust gas (EG) and jacket cooling water (JCW) of ME into electrical and cooling energies largely required on the ship. There are three proposed sub-cycles, namely, the steam Rankine cycle (RC), organic Rankine cycle (ORC) and absorption refrigeration cycle (ARC), which perform effectively in the utilization of high-medium-and low temperature heat sources respectively.

Liu, Xiangyang et al. (2020) [13] presented steam cycle and organic Rankine cycles. These both cycles were combined to convert the waste heat of the exhaust gas and jacket cooling water of marine engine into mechanical energy. A portion of the jacket cooling water is used as the working fluid for the steam Rankine cycle sub system to efficiently utilize the heat of jacket cooling water and to avoid using extre water which will in return increase the overall weight. The performance of the proposed system for recovering the waste heat of a 14-cylinder two-stroke marine engine was simulated and compared to performance of the WHRSs based on a single steam Rankine cycle (SSRC) and a dual pressure organic Rankine cycle (DPORC).

Kim, Jun-Seong et al. (2019) [14] presented the thermodynamic performance of waste heat recovery systems of a marine gas turbine was analyzed. These systems combine the steam Rankine cycle and the organic Rankine cycle to form a dual-loop cycle. Working fluids R32, R152a and R1234yf, that are low-global warming potential, were selected for the organic Rankine cycle.

Bălănescu et al. (2019) [19] presented the fuel savings and their cost are assessed. Two organic working fluid were considered, namely R134a and R123. The study shows that efficiency of the power plant increases by roughly 1.1 % when the ORC unit is added. Taking into account the current concerns regarding the fossil fuel depletion, the estimated fuel savings could be considered significant.

Energy sectors use conventional fuels and wasting enormous energy. In this regard, researchers have been trying to use waste heat as alternative energy source to produce useful commodities (Javan et al., 2016). Hybrid systems enable the recovery of the waste heat in the thermal systems and improve the efficiency as well as make systems cost effective. Hybrid systems that produce heating, cooling and/or power simultaneously have become potential alternative to overcome environment problem. Many researchers have used waste heat as energy source and analyzed ORC integrated VARS based hybrid system.

Ahmadi et al. (2012) [17]used waste heat energy of gas turbine to run the ORC integrated VARS and reported 89% and 55% energy and exergy efficiency, respectively. Chaiyat and Kiatsiriroat (2015) focused on feasibilities of energy, economic and environment aspects of diesel burner based waste heat powered ORC with absorption cooling system and reported 10 years of payback period. Fang et al. (2012) recovered waste heat based combine ORC, VARS, and coil based heating system for dynamically adjustable electricity to thermal energy ratio. Few researchers have also analyzed waste heat ORC system with VCRS.

Wang et al. (2011a) [18] integrated micro scale ORC with VCRS and reported overall COP about 0.48. Wang et al. (2011b) analyzed hybrid ORC-VCRS with sub cooling as well as with sub cooling and recuperation. The reported overall COP is 0.54 with basic VCRS, 0.63 with sub cooling and 0.66 with sub cooling and recuperation (Wang et al., 2011b). Moles et al. (2015) analyzed low temperature ORC powered VCRS based hybrid system for different low GWP working fluids and reported payback period of 3.3 years.

Dai et al. (2009) analyzed waste heat (composed of 96.16% N_2, 3.59% O_2, 0.23% H_2O, and 0.02% $NO+NO_2$ by volume) energy powered ORC integrated ejector refrigeration cycle and reported thermal and exergy efficiency about 13% and 22%, respectively. Javan et al. (2016) utilized waste heat of diesel engine to run the ORC based ejector refrigeration cycle and carried out fluid selection optimization for residential applications. Yang et al. (2016) analyzed ORC integrated ejector cycle using zeotropic mixture isobutene/pentane with 0.4%, 0.7% and 0.8% mass fraction.

Wang et al. (2012)[18] analyzed flat-plate collector powered ORC integrated ejector refrigeration cycle for different modes, like combine power and cooling, combine power and heating and power mode.

Rostamzadeh et al. (2017) investigated performance of solar energy powered ORC integrated ejector refrigeration cycle and reported R123/isobutene as most appropriated fluid pair among R123, R245fa, and isobutene ORC working fluids.

Based on the source temperature, geothermal energy has potential to generate power, heating and cooling and used in various applications, like, industrial drying, distillation and desalination. Usage of low temperature geothermal source with organic Rankine cycle has great potential for power generation. Few researchers have integrated geothermal powered ORC with different cooling technologies.

Suleman et al. (2014) [19] developed hybrid cycle based on two ORC units powered by solar energy (for power generation, drying process and VARS based cooling) and another ORC runs on geothermal energy for power generation.

Zare (2016) performed thermodynamic optimization of ORC integrated absorption cycle for trigeneration application and reported isobutene as a promising working fluid compared to n-pentane, R245fa, and R152a.

Akrami et al. (2017) carried out energetic and exergo-economic assessment of geothermal ORC integrated absorption cycle and reported 35% energy efficiency and 49% exergy efficiency.

Recent interest in small and micro scale organic Rankine cycle has coincided with increasing energy demand and carbon emission. Renewable thermal energy based ORC is also gaining importance due to generation of decentralized power. Therefore, there is no penetration of ORC systems in Indian market.

The development of indigenous ORC would serve as an economic solution as it reduces the levelized cost of energy and specific investment cost.

VI. CONCLUSION

Growing interest in low-grade heat recovery for power generation or cogeneration has given more attention to ORC due to its lower evaporation temperature and simplicity. At present, domestic and abroad had a great deal of research on the selection of working medium, improvement of system efficiency, experimental research of key components and optimization of operation parameters and so on and had achieved great results. The selection of working fluid plays a key role in the performance and economic efficiency of ORC system. There are very few studies on ORC-based combined system with waste heat source using R-123 as refrigerant.

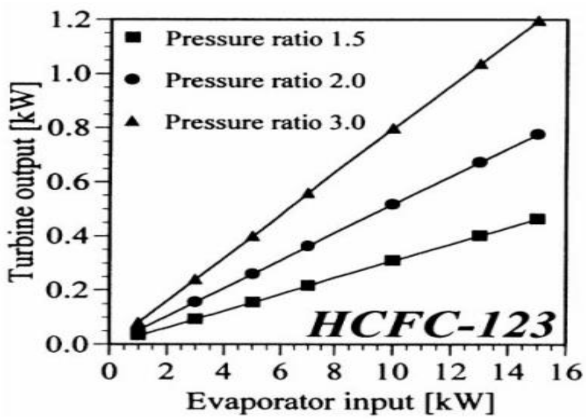

Fig 3. on ORC-based combined system with waste heat source using R-123 as refrigerant.

1. Effects of the evaporator input on turbine output for HCFC-123

The evaporator outlet condition of the working fluid is given by:

$$h_{in} = h_2 + (Q_{in}/\dot{m})$$

Where, Q_{in}, h_{in} and h_2 are the evaporator input, the specific enthalpy at the evaporator inlet and at the outlet, respectively.

The graph between evaporator input [KW] and Turbine Output [KW] is plotted

- As the evaporator input [KW] in increasing a subsequent increase in Turbine Output will be able to seen.
- The major factor which influences the turbine output factor other than evaporator inlet temperature is the pressure ratio.
- As the result obtained by the graph we can see that as the pressure ratio for the given evaporator input increase their will be more subsequent increase in turbine output.
- The higher the pressure ratio the higher is the turbine output.

2. Effects of TIT on the mass flow rate at the turbine inlet and output for HCFC-123

$$W_t = \dot{m} C_p \eta_t T_{in} \left[1 - \Pi^{(1-\gamma)/\gamma}\right] = \dot{m} \eta_t (h_{in} - h_{out})$$

Where, C_p and T_{in} denote the isobaric specific heat capacity and the turbine inlet temperature, respectively.

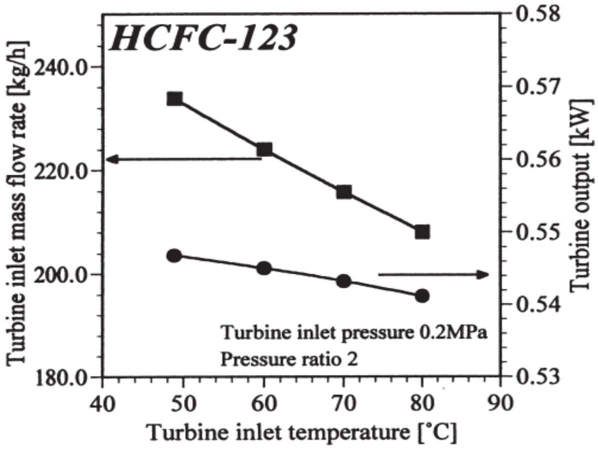

Fig 4. The Turbine Inlet Temperature, Respectively.

For the given evaporator input effect of TIT on the turbine inlet mass flow rate and the turbine output is studied.

- There is slight decrease in turbine output as the mass flow rate decrease.
- Turbine Inlet Temperature and the turbine inlet mass flow rate should be increased to raise the turbine output.

Therefore, the objective of the present research is to numerically investigate the alternative ORC-based combined systems. Then, the energy and energy performances of different systems are investigated to obtain the optimized system for different refrigerant. We will calculate and compare thermal efficiency, generating capacity, etc. for different working fluids.

VII. ACKNOWLEDGEMENT

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