International Journal of Scientific Research & Engineering Trends
Volume 5, Issue6, Nov-Dec-2019, ISSN (Online): 2395-566X

A Review on Organic Rankine Cycle (Orc) for Waste Heat Recovery with Different Refrigerant

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Abstract - **Rising energy demand due to industrial development, population growth, is pushing the mankind for utilizing more and more conventional energy sources such as coal, oil and gas. There is a need to minimize the use of such types of resources because; it contributes to the global warming, pollution and climate change. Use of alternative sources of energy such as solar, hydro, wind, tidal, geothermal, biofuel, and nuclear are preferable and are promising for the modern world.**

Keywords - **ORC, Heat Source Temperature, thermo-economic analysis.**

I. INTRODUCTION

Organic Rankine cycles have received much attention during last decade. This cycle obeys the fundamental rules of conventional Rankine cycles working with water in common plants but has some advantages over water Rankine cycle which made it popular. First this cycle can work under low temperatures and pressures in comparison to conventional Rankine cycle and shows a better performance than water especially from low grade heat sources because its working fluids include a variety of hydrocarbons and refrigerants and according to the range of accessible heat source temperatures and pressures, different outputs can be derived by using suitable working fluids, second, it can work without feed-water heaters and multi-stage turbines which makes it simple to use.

Among these, solar parabolic trough collectors are a huge source of thermal energy but with a low grade heat which makes it only suitable for some kilowatts to few megawatts electricity generation, also it shows a reliable means for electricity generation especially in rural areas or near factories to generate their electricity consumption without the need for connection to grid which may be expensive. Disadvantages of solar ORCs are relatively high costs [1] and low thermal efficiency (10 to 25 percent according to working fluids and working condition) mainly because of low HTF (Heat transfer fluid) temperature in solar collectors. As mentioned before, the organic fluids used in ORC cycles are divided into hydrocarbons and refrigerants, some of them are dry fluids which mean they have a positive slope T-S diagram in the saturation vapor region. This makes it possible for some organic fluids to work properly without superheating to a great extent and cause no damage to turbine. As shown in this study, a comparison of different dry organic fluids with and without superheating and recuperation has been done to show the variance in cycle efficiency and performance of the system which helps us to make a decision to choose the system conditions according to our needs. ORC cycle has been put under investigation by many authors, Wang and et al. presented a detailed analysis of organic Rankine cycle coupled with solar collector with a thermal storage system during a whole day [2]. MCMAHAN designed and optimized a solar-thermal ORC [3]. Quoilin and et al. presented an optimization and sizing procedure of heat exchangers in a small scale solar driven ORC by pinch and pressure drop and optimized it by turbine input pressure and evaporator temperature [4].

Ferrara F and et al. compared different organic fluids and in a 20 KWe solar plant [1] and chose Acetone as the best organic fluid choice with supercritical pressure. The extensive usage of fossil fuels in power generation worldwide has further escalated the global warming effects and concerns on imminent energy crisis. One of the challenges of the 21st century is to tackle the risks arising from excessive CO_2 emissions by replacing fossil fuels with recovered waste heat and renewable energy. Waste heat sources can be divided into three main categories according to their temperature range: high temperature (>650°C), medium temperature (230 °C~650 °C) and low temperature.

II. LITERATURE SURVEY

Kong et al. (2019)studied the first and the second law analyses of a 20 kWeR245fa organic Rankine cycle (ORC) with low-grade temperature heat sources. There were three different heat sources such as hot water, saturated steam, and combined hot water/saturated steam used to supply heat at the ORC evaporator. The heat source temperature was varied in a range of80–110 °C and the pinch temperature difference between the heat source temperature and theevaporating temperature was in a range of 1–10 °C. The ORC condensing temperature was kept constant at 40 °C. The results revealed that the combined hot water/saturated steam heat source provided a highest second law or exergy efficiency due to less irreversibility generated at the evaporator followed by the saturated steam and the hot water heat sources, respectively. The increase of heat source temperature at a specific pinch could increase the second law efficiency of the cycle. However, the increase of pinch value resulted in lower second law efficiency. In addition, for the below pinch zone, with the hot water/saturated steam heat source, the reduction of the hot water flow rate slightly enhanced the ORC second law efficiency as the exergy destruction below pinch was reduced. However, there was a limit that the flow rate should not be reduced below a specific value otherwise a very high heat exchanger area was needed.

Pathak et al. (2018) reviewed the performance of organic Rankine cycle with different heat sources. Plenty of waste heat is widely available in low to medium temperature range from various sources such as engines, machines and processes. The conversion of this low-grade waste heat into electricity is a feasible solution to provide clean energy. The Organic Rankine Cycle (ORC) is a suitable thermal cycle for the waste heat recovery application. The thermodynamic performance of ORC with different operational parameters and several working fluids is discussed. Further, the feasibility of integration of various absorption chillers in ORC, which is run by low-grade waste heat available at the outlet of the evaporator of ORC is evaluated.

Cheng Zhang et al. (2018)investigates the comprehensive effects of superheat and internal heat exchanger (IHX) on the thermo-economic performance of organic Rankine cycle (ORC). Exergy efficiency, net power output, and electricity production cost (EPC) are compared based on the working fluid properties and heat sources. The results indicate that under a lower heat source temperature and load, exergy efficiency of IHX-ORC does not always exceed that of simple ORC (S-ORC) when EPC is selected as an objective function, and IHX-ORC exhibits a worse economic performance than S-ORC for all fluids (R161, R1234ze, R152a, cyclopropane, butane, R123, cyclopentane, heptane, and cyclohexane). However, IHX-ORC with dry fluid achieves a better thermo-economic performance than that with wet fluid when the heat source temperature and load increase to a high level. The EPC of IHX-ORC is close to that of S-ORC with the increase in heat source temperature and load, and thus, IHX-ORC exhibits approximately 10–17% higher thermal efficiency and 5–10% higher exergy efficiency than those of S-ORC. With respect to butane and R123, the net power output exhibits approximately 22.5% and 23.5% growth, respectively. In order to evaluate the feasibility of IHX-ORC, a judgement indicator [$\alpha > 1.90625 + 0.4258\xi$] with respect to six factors is proposed.

Abam et al. (2018)presents a comparative analysis of thermo-sustainability indicators (TSIs) and performance of organic Rankine cycles (ORCs) with different working fluids. The objective of the study is to determine the sustainability of the ORCs using R245fa, R1234yf, and R1234ze refrigerants. The ORC configurations include the ORC-basic (ORCB), ORC-internal heat exchanger (ORCIHE), ORC-turbine bleeding (ORCTB), and ORC-turbine bleeding/regeneration (ORCTBR). The TSI evaluated comprise overall exergy efficiency (OEF), exergy waste ratio (EWR), and environmental effect factor (EEF) in addition to exergetic sustainability index (ESI). The results indicate that the OEF obtained using R245fa fluctuated between with 8.56% efficiency difference between ORCB and ORCTBR at evaporator pressure (EVP) of 2 and 3 MPa. The ESI values were maximum with R245fa while EEF values of 1.5 and 1.58 were obtained at same EVP range. Additionally, the ORCTBR and ORCTB had the least environmental impact and were ecologically stable with R245fa than R1234yf, and R1234ze. In conclusion, the performance of the ORCs is dependent on the following: working fluid, system configuration and operating conditions. Thus optimum conditions for each working fluid for a particular system configuration are central to achieving environmental stability.

According to **WenSu et al. (2018)** zeotropic mixtures have been widely investigated for the development of Organic Rankine Cycle (ORC) as an alternative option for pure fluids. However, few zeotropic mixtures have been applied to the ORC in practical engineering. Therefore, a nature question is that whether zeotropic mixture has better thermodynamic performance of ORC than pure fluid. In this contribution, a comprehensive performance comparison between zeotropic mixtures and pure fluids is conducted via cycle simulation for the basic ORC and recuperative ORC driven by open heat source. In the simulation, a certain range of mass flow rate of cooling water is considered as the condition of heat sink, and mixtures R600a/R601a, R600a/R227ea are employed. Performances of these mixtures are optimized and compared with those of their constituents from the points of first and second laws. It can be concluded that zeotropic mixture may have lower cycle performance than pure fluid. For the optimal mixture R600a/R601a (0.1/0.9, mass fraction) with the highest net power of basic ORC, the cycle efficiency 8.18% is lower than that of R601a 8.24%. Although zeotropic mixture generally has lower temperature differences in the evaporator and condenser, the exergy losses of these heat exchangers are not certain to be reduced. In the basic ORC, the exergy efficiency 34.61% of optimal R600a/R227ea (0.2/0.8, mass fraction) is lower than that of R227ea 35.68%. Furthermore, the introduction of internal heat exchanger (IHE) can enhance the output work and cycle efficiency. The exergy loss in the evaporator and condenser can be reduced by IHE. The mixture with a larger temperature glide can generally recover more heat in the IHE.

Pang et al. (2017) had done experimentally comparing of organic Rankine cycle (ORC) system, by using R245fa, R123 and their mixtures to generate maximum net power on simulated low-temperature industrial waste heat. Four mass fractions of R245fa:R123 have been injected into the system with the ratios of 1:0, 2:1, 1:2 and 0:1 to test the system performance separately. To imitate industrial low-temperature waste heat, the heat source temperature is fixed at 110 °C and 120 °C with specified mass flow rate of heat source. Focusing on the change of mass flow rate of working fluid and expander inlet superheating, experiment results show that the system heat input increases when mass flow rate of working fluid increases. All four mass fractions of working fluids generate maximum net power when the system mass flow rate is around 0.15 kg/s. The case of pure R245fa generates a maximum net power 1.56 kW with an electrical efficiency of about 3.9% when heat source temperature is fixed at 110 °C. While, the case of mixture R245fa:R123 = 2:1 generates a maximum net power 1.66 kW with an electrical efficiency of about 4.4% when heat source temperature input is fixed at 120 °C.

Feng et al. (2017) investigated the operation characteristic and performance comparison of low-grade organic Rankine cycle (ORC) using R245fa, R123 and their mixtures. Heat source temperature is set to be 120 °C, while the mass flow rate is controlled by adjusting the pump frequency. The basic operation parameters are first examined, while the detailed operation characteristics of pure and mixture working fluids are addressed. The system overall performance, including thermal efficiency and system generating efficiency, for pure and mixture working fluids are explored. The experimental results show that the mixtures own a relatively higher pump power consumption and enhancing the pump performance is also significant for ORC application. Whether the mixtures exhibit better thermodynamic performance than the pure working fluids depend on the operation parameters and mass fraction of mixtures. 0.67R245fa/0.33R123 owns the highest maximum net electricity output of 1.67 kW, 4.38% higher than that of R245fa and 63.73% higher than that of R123. Compared to the pure working fluids, the mixture working fluids own a better thermodynamic performance and a moderate economic performance.

JianLi et al. (2017) focused on subcritical and transcritical ORCs using R1234ze(E) driven by the 100–200 °C hot water without the outlet temperature limit. For various heat source temperatures, the optimal cycle type (subcritical or transcritical), optimized cycle parameters (turbine inlet temperature and turbine inlet pressure), and system performance were studied in the view of the maximum system net power output for the per mass flow rate heat source fluid. Results show that the transcritical ORC has a higher system efficiency, whereas its system heat absorption capacity is lower than that of the subcritical ORC for R1234ze(E). The subcritical ORC is more suitable for heat source temperatures below 160 °C with the transcritical ORC for higher temperatures. For subcritical and transcritical ORCs using R1234ze(E), the optimized turbine inlet temperature and turbine inlet pressure for various heat source temperatures among 100–200 °C were also provided. Compared to R245fa and R600a, the maximized system net power output of R1234ze(E) is the largest for the approximately 100–167 °C heat sources without the outlet temperature limit, and it is 31.4% larger than that of R245fa at most and 25.8% larger than that of R600a at most.

Javanshir et al. (2017)analyzed over a range of operating conditions for a number of working fluids to determine the effect of operating parameters on cycle performance and select the best working fluid. The results show that for an ORC operating with a dry working fluid, thermal efficiency decreases with an increase in the turbine inlet temperature (TIT) due to the convergence of the isobaric lines with temperature. The results also show that efficiency of an ORC operating with isentropic working fluids is higher compared to the dry and wet fluids, and working fluids with higher specific heat capacity provide higher cycle net power output. New expressions for thermal efficiency of a subcritical and supercritical simple ORC are proposed. For a subcritical ORC without the superheat, thermal efficiency is expressed as a function of the Figure of Merit (FOM), while for the superheated subcritical ORC thermal efficiency is given in terms of the modified Jacob number. For the supercritical ORC, thermal efficiency is expressed as a function of dimensionless temperature.

According to **Wenqiang Sun et al. (2017)** there is large amount of waste heat resources in industrial processes. However, most low-temperature waste heat is directly discharged into the environment. With the advantages of being energy-efficient, enabling investment-savings and being environmentally friendly, the Organic Rankine Cycle (ORC) plays an important role in recycling energy from low-temperature waste heat. In this study, the ORC system driven by industrial low-temperature waste heat was analyzed and optimized. The impacts of the operational parameters, including evaporation temperature, condensation temperature, and degree of superheat, on the thermodynamic performances of ORC system were conducted, with R113 used as the working fluid. In addition, the ORC-based cycles, combined with the Absorption Refrigeration Cycle (ARC) and the Ejector Refrigeration Cycle (ERC), were investigated to recover waste heat from low-temperature flue gas. The uncoupled ORC-ARC and ORC-ERC systems can generate both power and cooling for external uses. The exergy efficiency of both systems decreases with the increase of the evaporation temperature of the ORC. The net power output, the refrigerating capacity and the resultant exergy efficiency of the uncoupled ORC-ARC are all higher than those of the ORC-ERC for the evaporation temperature of the basic ORC >153 °C, in the investigated application.

III. CONCLUSION

Recently, distributed power generation systems especially with renewable sources have shown a promising result all over the world and have been a technical solution to demand growth for electricity. Among these, solar thermal power plants show a trustworthy source for electricity generation especially for rural areas where small scale solar plants are used. Organic Rankine Cycle (ORC) is a suitable means for electricity generation from low grade heat and has shown a good compatibility with parabolic trough solar collectors. The current global power generation is predominantly from the combustion of fossil fuels, which is responsible for a number of environmental impacts such as air pollution, excess CO2 emissions, and energy resource depletion. This has led the industry to explore several new alternatives of power sources. Among the alternatives, power generation using low-grade heat sources such as solar thermal.

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