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A Review on Thermal Analysis of Organic Rankine Cycle Based on Different Fluids

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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. Over the past decades, the growth in energy consumption around the world has shown that fossil fuel energy source alone will not be capable of meeting future energy demands. The increase in the energy consumption by burning of fossil fuel has led to several conflicts around the world, global warming and environmental pollution such as soil, water, air and acid rain pollution. Besides the adverse environmental effects, the prices of fossil fuels are not consistent but usually going up most of the time.

Keywords- ORC, EES, simulation model, Rankine cycle, First law efficiency, Second law efficiency, turbine size factor.

I. INTRODUCTION

Over the past years, the interest in recovering low grade heat has grown rapidly. Many researchers have come up with several ways of generating electrical power from low temperature heat sources available in solar energy, domestic boilers, biomass and industrial waste heat. Among all these the ORC is considered to be the most suitable due to its simple design and availability of components.

The ORCs use organic working fluids which are more suitable than water in the context of using heat source with low temperatures. The ORC cycle unlike conventional steam cycles is an attractive yardstick for local and small scale power generation.

Frank W. Of ledt patented the naphtha engine in 1883 which has the same application as the ORC. The naphtha was used in place of water as working fluid so as to replace the steam engine on boat [5]. During fractional distillation of crude petroleum oil, distinct liquid hydrocarbon naphtha is produced. Since the heat of vaporization for naphtha is lower compared to water, it was seen that if a certain amount of heat is added to the naphtha it produces more vapor and therefore, more work output could be realized from the engine if water is used. 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 [6]. The discovery by Frank W Ofledt was a substitute for using steam engines. Figure 2.1 shows an article about naphtha engine (1890) while figure 2.2 shows a simple design of naphtha engine.

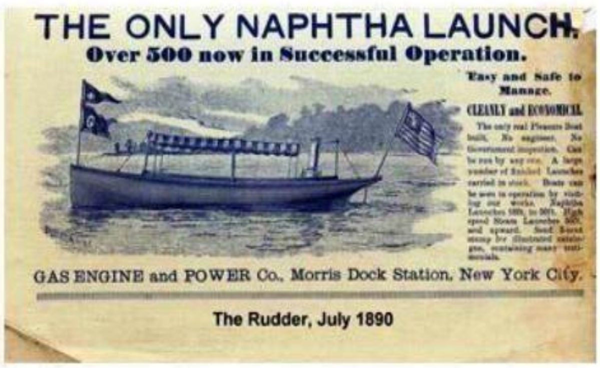

Figure 1: An article on naphtha engine.

The first prototype of the ORC system was first developed by Harry Zvi in the early 1960s [9]. This prototype was mainly used to recover low grade heat which is similar to the solar energy used to convert low temperature sources to electrical power. A turbine capable of working and operating at a comparatively low temperature was also developed by Harry Zvi. This invention was later privatized in 1965 by an Israeli company [10].

II. LITERATURE REVIEW

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 (Lee et al., 2014; Yu et al., 2016). An Organic Rankine cycle performs better than steam turbine in the typical range of 150-200°C source temperature and small scale systems (Tsoukpoe et al., 2016). The combined generation of heat and power using an ORC enhances the utilization of energy and reduces the carbon emission (Peris et al., 2015). Moreover, ORCs (using dry working fluids) are better suited for the micro-scale applications due to lower operating pressures, intake of saturated vapor at the expander inlet, dry expansion, positive gauge pressure in the cycle, improves expander life, reduces mechanical stress, and reduces operation and maintenance cost, etc. (Hung, 2001; Algieri and Morrone, 2012). Organic Rankine cycle, which uses organic working fluid instead of water in the conventional Rankine cycle, efficiently utilizes low-medium temperature energy sources (Uusitalo et al., 2016), like waste heat (Liu et al., 2016), solar thermal (Desai and Bandyopadhyay, 2016), geothermal (Coskun et al., 2012), biomass combustion (Al-Sulaiman et al., 2012), ocean thermal energy (Yang and Yeh, 2014), etc. For <1 MWe scale low-temperature operations ORC is a promising option compared to steam Rankine cycle (Desai and Bandyopadhyay, 2016).

Integration of an ORC in small-scale hybrid system (electric output 1–200 kWe) is a promising option due to superior thermodynamic and economic performance (Maraver et al., 2013a). Extensive investigations on organic Rankine cycle based hybrid systems powered by waste heat (Wang et al., 2011), solar thermal energy using parabolic trough collector (PTC) (Al-Sulaiman et al., 2011) and flat plate collector (Wang et al., 2012), solid oxide fuel cell (SOFC) (AlSulaiman et al., 2011), biomass (Al-Sulaiman et al., 2012), gas turbine exhaust (Ahmadi et al., 2012), combined biomass and solar thermal energy (Karellas and Braimakis, 2016), combined geothermal and solar thermal energy (Buonomano et al., 2015) have been reported in literature. Many researchers have analyzed ORC based hybrid system using VARS (Al-Sulaiman et al., 2011), VCRS (Wang et al., 2011) and other cooling system, like, liquid desiccant cooling system (Jradi and Riffat, 2014) and ejector cooling system (Wang et al., 2012), as cooling unit.

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. Ahmadi et al. (2012) 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) integrated micro scale ORC with VCRS and reported overall COP about 0.48. Wang et al. (2011) 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 isobutane/pentane with 0.4%, 0.7% and 0.8% mass fraction.

In past years, researchers are involved in improving existing solar thermodynamic cycles and finding newer one to reduce environment problems. Various solar technologies, like parabolic trough collector (PTC), linear Fresnel collector (LFR), paraboloid dish, evacuated tube collector, flat plate collector, and central tower technology etc. are used in different thermodynamic cycles. Many researchers have integrated low temperature solar technologies with the ORC as it has lower evaporation temperature. Solar-ORC based hybrid systems uses various cooling systems e.g. VCRS, VARS and ejector cooling system etc. For example, Al-Sulaiman et al. (2011a) integrated PTC, ORC and VARS to generate combine cooling, heating and power. Al-Sulaiman et al. (2011) reported overall efficiency for organic Rankine cycle based hybrid systems powered by solar thermal energy (90%), solid oxide fuel cell (76%), and biomass (90%). Suleman et al. (2014) analyzed integrated solar geothermal cycle where solar powered ORC integrated with VARS for cooling along with the drying process and geothermal powered ORC for power generation. The overall energy and exergy efficiencies of the system/cycle are found to be 54.7% and 76.4%, respectively. Buonomano et al. (2015) performed thermodynamic and economic analysis of micro scale ORC powered VARS using combine source of solar-thermal and geothermal.

III. CONCLUSION

The ORCs using R143a, R600a, R134a and RC318 as working fluids will be parametrically analysed and compared on the basis of the thermodynamic efficiencies and turbine size factor. Under constant external conditions, a computer program in EES will be developed to calculate the thermodynamic performance of the four working fluids under various turbine entry temperatures, pinch point temperature difference, heat source and turbine efficiency.

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