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A Review on the Thermal Analysis of Organic Rankine Cycle Based on Different Fluid Type

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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

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.

With the increase in fossil fuel consumptions, more and more industrial activities produce increasing amount of waste heat. Energy generated as a result of industrial activities that are not practically utilized is referred to as industrial waste heat. Several studies have shown that the specific amount of industrial waste heat is poorly measured, it is estimated that 25 to 55% of the input energy in industries are actually used while the remaining are discharged as waste heat [1]. While it is almost impossible to avoid waste heat losses from industrial activities, some facilities and heat recovery technologies can be put in place to reduce these waste heats by improving equipment efficiency and energy utilization. The extraction of energy from waste heat, turbine exhaust, solar energy and biomass energy is becoming a popular means of generating alternative energy for most industries. Low grade heat sources can be converted into electrical power and these can be achieved using an ORC system. The basic principles of the ORCs are very much like those of the conventional Rankine cycle. However, the main difference is that the ORC usesan organic working fluid which has a higher vapor pressure and lower boiling point compared to water. These properties of organic fluids boost the cycle efficiency of the ORCs considerably compared to the conventional Rankine cycle. There have been several successful installations of the ORCs around the world and more research is still being carried out to improve the ORC system.

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.Petroleum and natural gas and coal are fossil fuels and are non- renewable. Several countries today have been investing money to get new and efficient energy technologies that are alternative for fossil fuels to generate power. Low grade heat is largely available in renewable energy sources and in industrial waste. Utilizing this type of sustainable energy could help reduce the use of non-renewable energy, thus reducing the environmental impacts of non-renewable energy sources. Development of efficient and effective technologies is required to generate useful work by using these low grade heat sources. An ORC is a suitable means of carrying out this purpose. The ORC works with a high molecular mass organic working fluid with the characteristic of having a phase change of liquid to vapour occurring at a temperature which is lower than the phase change of water to steam for a given pressure. The recovery of low grade heat can be achieved using organic fluids. These low grade heat sources can be from biomass energy, solar energy, geothermal energy and industrial waste. The ORC converts the low grade heat into work and finally into electricity.

2. LITERATURE SURVEY

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 solargeothermal 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.

II. ORGANIC RANKINE CYCLE

As mentioned earlier the ORC and conventional Rankine cycle have the same working principles. They also have similar components like the condenser, pump, evaporator (boiler), and expander (turbine). However, there is a difference related to the kind of working fluid that is used in the cycles. The ORC extract and generate electrical power from low grade heat compared to the conventional Rankine cycle.

III. APPLICATIONS OF ORCS

The applications of the ORC to generate mechanical and electrical power are as follows:

1. Waste Heat Recovery

The extraction process of energy from waste heat as a result of numerous industrial activities is called waste heat recovery process. In some applications, regenerators and waste heat boilers are used to redirect and recover heat into their own system. The economics of waste heat recovery in steam cycle do not support when the waste heat temperature is low. The production of electrical power using low grade heat source can be done easily using an ORC cycle. Figure 1 shows the application of ORC in waste heat recovery.

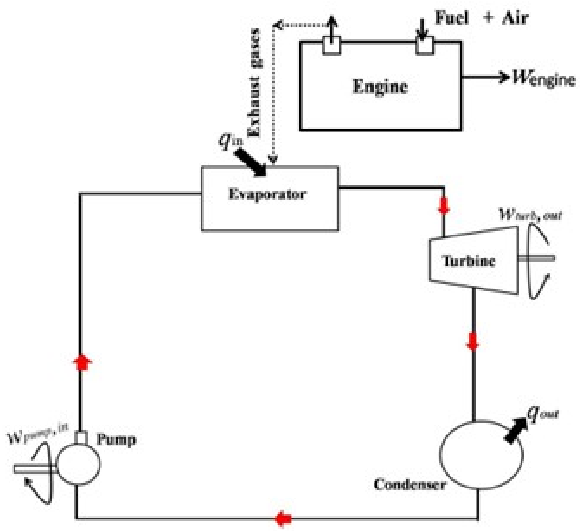

Figure 1: ORC in waste heat recovery.

2. Solar Thermal Power

Solar thermal power generation is a well-established technology. The extraction of solar thermal energy can be achieved using different components such as the parabolic dish, the parabolic trough and the solar tower. The working temperature of the parabolic dish ranges from 300ºC-400ºC. Several years ago the generation of electrical power from steam was connected to this technology. However, in order for the conventional Rankine cycle to be economically attractive, it requires a high source temperature and a high installation power capacity. The ORC works at a much lower temperature limits and is less capital intensive. The ORC requires and accepts smaller component size compared to the conventional Rankine cycle. Figure 2 shows a typical solar thermal power plant.

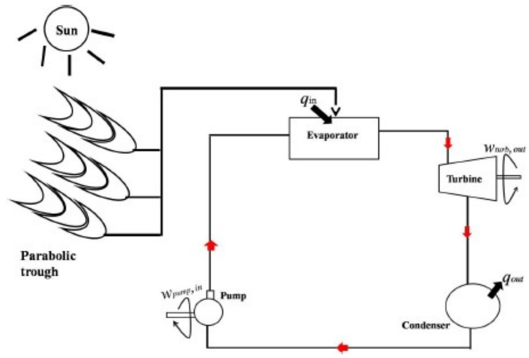

Figure 2: Solar thermal power plant.

3. Geothermal Power Plants

Geothermal power plant has the capability to supply a lot of communities with renewable electrical power. In 2008 the geothermal sources supplied 1% of world´s electrical power. Geothermal power plant energy source is renewable and also clean. The power generation in a geothermal power plant can be achieved by using three different technologies; these are the flash steam power plants, the binary cycle power plants and the dry steam power plants. Figure 3 shows the geothermal electric generation for the dry steam and flash steam system.

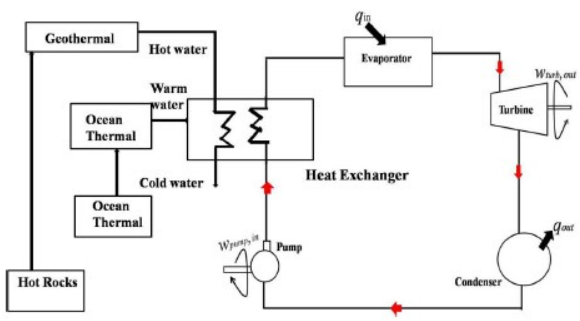

Figure 3: Geothermal electric generation system.

4. Biomass Power Plant

The price and use of conventional fossil fuel is continuously increasing. Fossil fuel consumption largely affects the environment; causing a change in the climate conditions and pollution as a result of exhaust gases. Presently, biomass energy resources are experiencing an increase in market growth due to the fact that it is cheaper and environmentally more friendly compared to fossil fuels. There are many forms in which biomass fuels exist, examples are the biogas from wood wastes and combustible agriculture wastes. Using biomass fuels has a lot of advantage when it comes to the reduction in prices of fuel and global warming potential. Figure 4 shows the application of the ORC using biomass.

IV. CONCLUSION

The ORCs using R143a, R600a, R134a and RC318 as working fluids will be parametrically analyses 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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