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Solar Thermal Collector Integrated Organic Rankine Cycle Technology

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Abstract—Nowadays, organic Rankine cycle (ORC) has emerged as an option for power production and waste heat recovery. This review paper deals with the working and layouts of ORC, and latest potential research work present in the field of ORC. Different configurations types of ORC and application of solar energy as a heat source has been discussed. Further applications of ORC in the combined cycle has been reviewed in this paper.

1. INTRODUCTION

In recent years, renewable energy sources have attracted more attention by converting renewable energy into useful forms of energy. In this way, there are several advantages of solar energy have been noticed such as it is accessible in numerous regions round the world and it does not cause environmental pollution, therefore, it is known as clean energy [1]. Nowadays as well as in future, in terms of power generation, solar energy can be considered as most promising and viable option [2]. Solar photovoltaic systems and solar thermal systems are two commercial methods used to convert solar energy into power, and in solar thermal device, solar energy either directly utilized in heating application or mechanical work could be generate from heat with the help of a power cycle [3]. The Rankine cycle, Brayton cycle or the Stirling engine can be used to convert solar thermal energy into mechanical power. To generate electricity from solar thermal energy, the rankine cycle is assumed as the most usual and competitive power generation cycle [4,5]. The efficient conversion of low grade thermal energy to generate electricity could be possible by thermodynamic cycles such as ORC, supercritical Rankine Cycle, Kalina cycle, and Trilateral Flash Cycle [6].

In order to recover waste heat, the well-known ORC is a promising solution because of its flexibility, high safety, low maintenance requirements and good thermal performance like advantages [7-9]. The ORC uses refrigerants or volatile organic fluids instead of water as in conventional Rankine cycle [10-12]. Because as compared to water, organic working fluids due to their lower boiling points can possibly recover energy from the waste heat sources with low temperature [13].

In a solar operated ORC, working fluid at high pressure is heated and evaporated by the solar radiations, after which mechanical shaft work is generated by the expansion of vapours. This shaft work is used to drive a pump or used to produce electricity with the help of a generator [14]. In this paper, detailed literature survey on the solar integrated ORC and its different layouts along with their various aspects has been presented.

2. WORKING OF ORC AND ITS LAYOUTS

The condenser, expander, pump, working fluid and heat source are the major components of an ORC [16]. The organic working fluid pressurized by using a pump and sent to the evaporator (process 1-2). The organic working fluid at high pressure after heated by a heat source, convert into high pressure and high temperature vapours enters in the turbine (process 2-3). The kinetic energy of the fluid used to rotate the turbine blades, then converted to mechanical energy which is further used to operate the generator in order to produce power (process 3-4). An external source is used to cooled down the exhaust from the turbine outlet to bring organic fluid to initial condition, as a result, cycle completes (process 4-1) [6]. The different layouts of ORC such as subcritical and transcritical cycles are shown in Fig. 1 and SORC is shown in Fig. 2.

Other types of ORC are Single stage regenerative ORC (SSRORC), Double stage regenerative ORC (DSRORC), Reheat ORC (RORC), and dual loop ORC (DLORC) [17].

In SSRORC system, some vapours are taken out between two stages of the turbine and added into the feed water heater [17-20] as shown in Fig. 3. The cycle efficiency can be enhanced by reducing the heat addition from the evaporator heat source with the help of a regenerator [17,21]. The DSRORC system is same as SSRORC system, only difference is that extraction will be happened between two stages as illustrated in Fig. 4. This configuration can enhance the efficiency of cycle by decreasing the evaporator load [17,19-21].

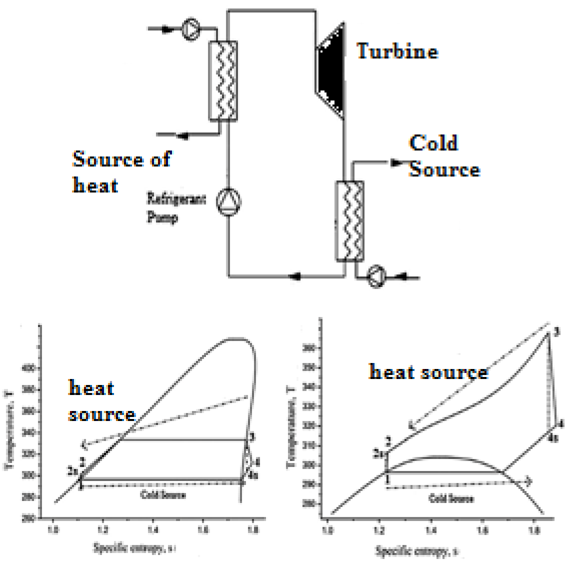

Figure 1: Layout of ORC and temperature-entropy diagrams (a) subcritical cycle (b) transcritical cycle [6,15]

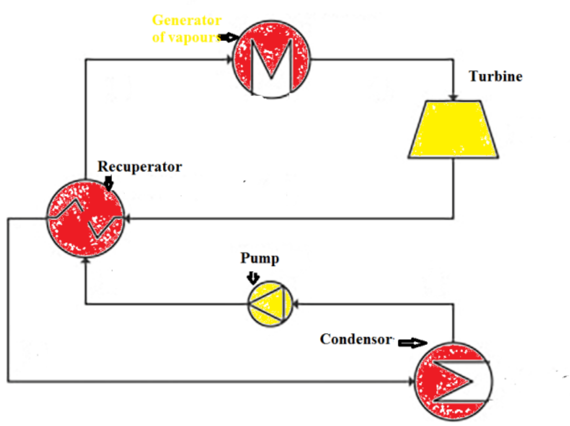

Figure 2: Diagram of SORC system [6]

In RORC, vapours at high pressure from the evaporator enters into the first turbine. After this, the outlet vapours again enter into the evaporator and where these vapours undergo reheated process by using the heat source before arriving to the second turbine with lower pressure as shown in Fig. 5. The RORC system has a purpose to eliminate the steam's moisture at the expansion process' final stages [17,21]. The high temperature loop in DLORC has been utilized to recover the waste heat source as illustrated in Fig. 6. To recover the cooling water of jacket and the HT loop's excess heat, the LT loop can be utilized. This system enhances the cycle's overall efficiency by reducing the heat load that dissipated to the environment [17,22-24].

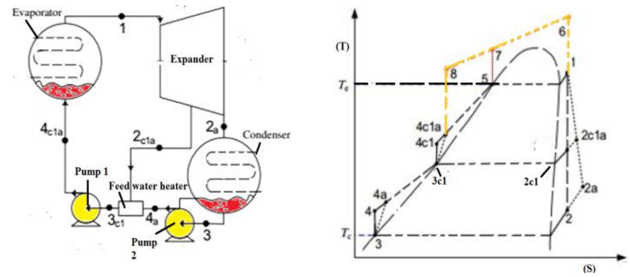

Figure 3: (a) Diagram of SSRORC (b) temperature-entropy diagram for SSRORC [17,19]

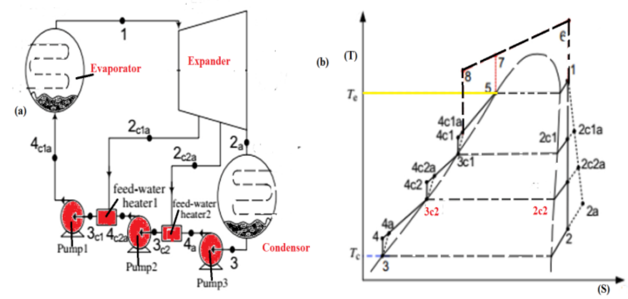

Figure 4: (a) Diagram of DSRORC (b) temperature-entropy diagram for DSRORC [17,19]

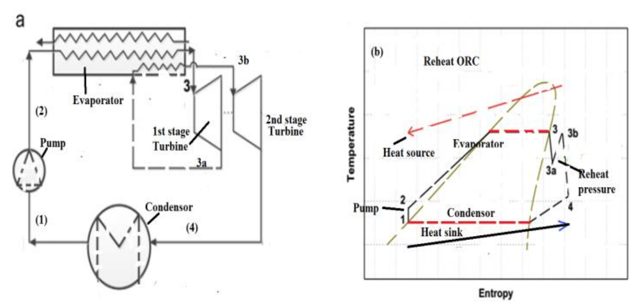

Figure 5: (a) Diagram of RORC (b) temperature-entropy diagram for RORC [17,21]

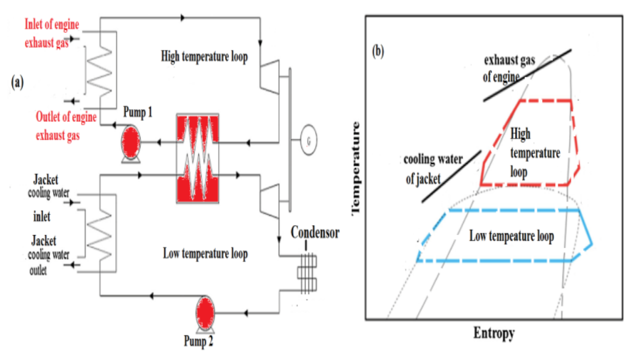

Figure 6: (a) Diagram of DLORC (b) temperature-entropy diagram for DLORC [17,24]

3. SOLAR ENERGY BASED ORC SYSTEM

Singh and Mishra [25] conducted an exergy and energy based analysis of parabolic trough collector integrated supercritical ORC. They found that R600a based supercritical ORC has the maximum exergy efficiency around 96.09% at solar direct normal irradiance of 0.95 kW/m^2. Ramos et al. [26] investigated the solar combined heat and power system based on ORC engine and found that by combining an evacuated-tube collector array and an ORC engine can deliver an electrical output of 3,605 kWh/year from collector array of 60 m^2. He et al. [27] proposed a cogeneration system with a single-extraction ORC as the top cycle and found that the cogeneration system's net power, production of water, and total efficiency found to be as 15.74 kW, 76.88 kg/h and 40.81%, respectively. Morrone et al. [28] analysed the performance of a micro-hybrid energy system for combined heat and power generation, and apparatus is based on a transcritical ORC which is fuelled by a conventional biomass boiler and parabolic trough collectors. They found that hybridisation of biomass and solar allows reducing the consumption of biomass, increasing the maximum operating hours, and improving the efficiency of global system. Freeman et al. [29] examined the domestic-scale solar combined heat and power system based on an ORC engine. They found that with the implication of evacuated flat-plate collectors, the overall solar-to-electrical conversion efficiencies found to be in the range 4.4–6.4% for UK and 6.3–7.3% for Cyprus. Bryszewska-Mazurek et al. [30] performed an analysis of a power plant with the ORC and found that ORC with a heat regenerator has the maximum thermodynamic efficiency of ~ 9%.

4. ORC APPLICATION IN COMBINED CYCLE

Singh and Mishra [31] performed an energy and exergy analysis of solar parabolic trough collectors driven combined supercritical CO_2 cycle and ORC as a bottoming system. They found that R407c based combined system has the highest exergy and thermal efficiency which is 78.07% and 43.49% at solar direct normal irradiance of 0.95 kW/m^2, respectively. In a different study, Singh and Mishra [32] replaced the simple configuration by recompression cycle in the combined system and found that R123 based combined recompression SCO_2 cycle and ORC system demonstrates the highest thermal and exergy efficiency which is around 73.4% and 40.89% at direct normal irradiance of 0.5 kW/m^2. Njoku et al. [33] performed an analysis of a combined gas- and steam- turbine cycle power plant integrated with ORC and absorption refrigeration cycle. They found by utilizing exhaust heat of the combined gas- and steam- turbine cycle power plant to power an R113 fluid based ORC, extra electricity of 7.5 MW was generated. Liu et al. [34] investigated the thermodynamic performance of ORC power generation system which has been used to recover and utilize the waste heat of the intercooled system and found that maximum enhancements of output power and thermal efficiency were 6.08% and 2.14%, respectively. Al-Sulaiman [35] conducted an exergy analysis of parabolic trough collectors integrated combined steam Rankine cycle and ORC. They found that the best exergy performance was possessed by the R134a based combined cycle with maximum value of exergy efficiency, i.e. 26% followed by the combined cycle based on R152a fluid with 25%, and R600a based combined cycle has the lowest exergy efficiency, i.e. 20-21%. In a different study, Al-Sulaiman [36] conducted an energy and solar field sizing analysis and found that due to best performance of R134a combined cycle, it requires the smallest size of solar field.

5. CONCLUSION

In this paper, working of ORC and its various layouts have been discussed. Furthermore, different studies related to ORC powered solar energy has been reviewed from Ref. [25-30]. Moreover, applications of ORC in combined cycle for power generation and waste heat recovery has been reviewed in Ref. [31-36].

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