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Photovoltaic Organic Rankine Cycle (ORC): Review for Indian conditions

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Abstract

India is located in the tropics and is a country blessed with sunlight. Given recent technological advances, the country requires a significant amount of energy to grow. One potential energy-harvesting technology is the photovoltaic Organic Rankine Cycle (ORC), which efficiently converts low-quality energy into high-quality energy. Organic Rankine Cycle (ORC) technology has a bright future as it helps meet energy demands with minimal impact on the environment. The system uses solar energy and can collect solar energy through a concentrating parabolic reflector. This system is similar to the Rankine cycle and uses water as the working medium to generate steam. The organic Rankine cycle uses an organic liquid (refrigerant) to generate vapor. The boiling point of refrigerants is much lower than that of water, and they tend to retain heat and generate steam. Considering the possibility of using renewable energy, this paper presents an overview of solar thermal technology and applications on the organic Rankine cycle. Validation is done with respect to ORC system capacity, fluid type, and solar panel type. The scope of application of solar ORC technology will be discussed for the Indian scenario, and finally the future prospects of solar technology for ORC will be discussed and presented.

Keywords: Organic Rankine Cycle, Solar Technology, Renewable Energy, Organic, fluids, Parabolic Reflector, Refrigerant, Specific net power, Thermal Efficiency, , Specific net power

1. Introduction

India is developing into a developing country in every field. technology, education, business and more. Today India is competing with all developed countries in the world. With development, the need for energy is increasing day by day. India ranks her fifth in global energy consumption, consuming her 3.9% of the world's commercial energy[1]. Industry, power plants and combustion engines also emit a large number of exhaust gases in the form of waste heat. Organic Rankine cycle (ORC) is a suitable technology for the task of power generation because waste heat is regarded as low-quality energy that can be converted to high-quality electrical energy [2].

The organic Rankine cycle is a thermodynamic process that uses a working fluid in a closed loop to convert thermal energy into mechanical energy using an evaporator and an expander, as shown in Figure 1. The mechanical energy obtained is converted into electrical power when combined with a generator. The working fluids used herein are generally carbonaceous elements with low boiling points and high molecular weights. The operating temperature of ORC is more suitable for low temperature operation as it operates at lower temperature compared to traditional steam Rankine cycle which requires higher heat input.

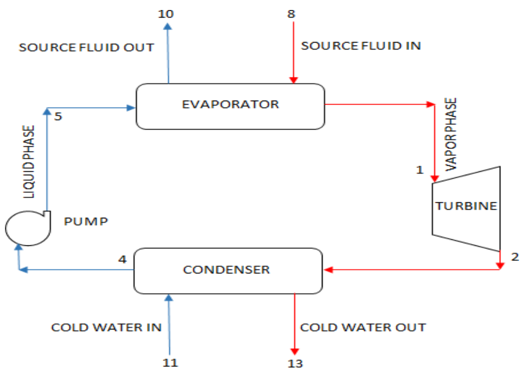

Figure 1 Conventional organic Rankine cycle

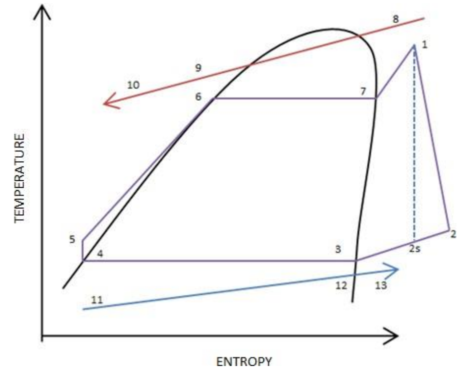

Figure 2 T s diagram

The thermal energy required for ORC operation can come from a variety of sources including biomass, solar ponds, geothermal heat, solar thermal technology, diesel engines, waste heat from industry and more. Among the many possible heat sources, renewable sources are sustainable sources that use fossil fuels to generate electrical energy. Common forms of renewable energy include tidal, geothermal, wind and solar power. The sun is thought to be an eternal source of energy, and technological advances in solar energy can power the organic Rankine cycle. Solar energy is abundant in India from a geographical point of view as most of the country is located in tropical and subtropical regions. In a photovoltaic ORC, the thermal fluid is heated using a solar panel and fed to a heat exchanger where the working fluid extracts the energy and transforms it into superheated steam. Steam is sent to an expander to produce output in the form of electrical energy. The steam is condensed in the condenser and returned to the heat exchanger and the cycle repeats.

The magnitude of solar energy is quantified by solar irradiance. Solar radiation is the amount of solar energy received per unit area per day. Table 1 shows the annual solar radiation of various states in India, with Gujarat receiving the highest amount of solar radiation, followed by Rajasthan making these locations suitable for solar ORC.

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Table 1 Solar irradiance in India [3]

State	Average Direct Normal irradiance (kWh/m^2/day)	Average Global Horizontal Irradiance (kWh/m^2/day)
Gujarat	5.95	5.83
Rajasthan	5.68	5.79
Himachal Pradesh	5.64	5.15
Madhya Pradesh	5.57	5.62
Karnataka	5.52	5.92
Uttar Pradesh	5.49	5.49

Further studies show that during January to May, states considered in the Table 1 receive maximum radiation and lowest during June to September. On the other hand, during winter season duration of the day is shorter as compared to summer season. Furthermore it was observed that according to Indian geography, some places receive good amount of sunlight throughout the year but has no sufficient irradiance.

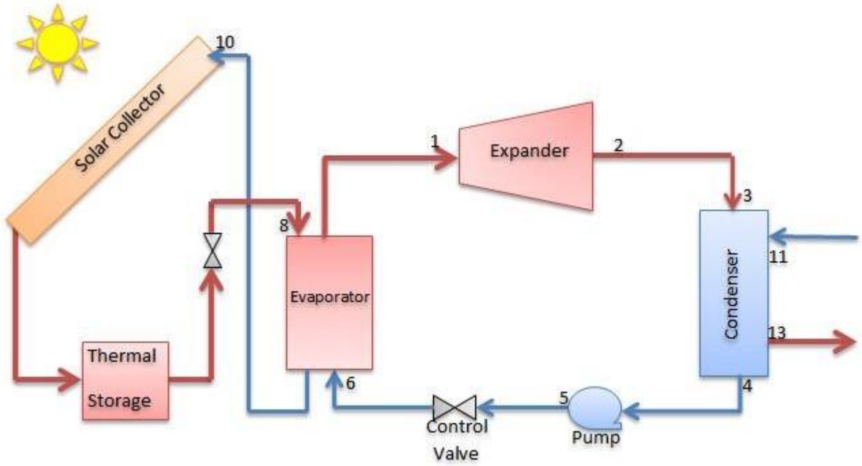

Figure 1 Solar powered ORC

2. Solar Thermal Technologies

Solar thermal technology is used to capture the sun's radiation to heat a working fluid, increasing the thermal energy of the fluid and turning it into superheated steam. The superheated fluid drives a turbine to convert thermal energy into mechanical energy and finally to electrical energy using a generator. Solar radiation is collected in various solar collectors. The following section describes different types of solar panels used in conventional technology.

Flat Plate Collector

A flat plate collector is a solar heat collector, and most of them are box-shaped as shown in the figure. 2. Solar radiation is directed through the transparent surface of a box, usually made of glass. Light rays incident on the FPC are absorbed by the highly absorbent tube, raising the temperature of the liquid inside the FPC and transporting this liquid to storage. Liquids in the FTC can reach temperatures between 10 °C and 80 °C. Wang et al. [4] found that the use of R24fa and R123 flat plate collectors are the best working fluids for the system due to their low working pressure and high system performance. A total of 300 of his 1.76* solar panels are used in this system. It was 1.6×1.1m3.

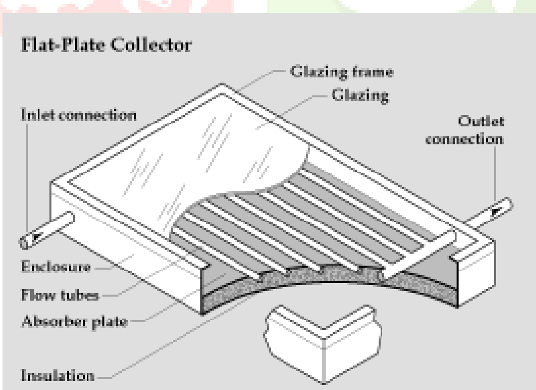

Figure 2 Flat plate collector [5]

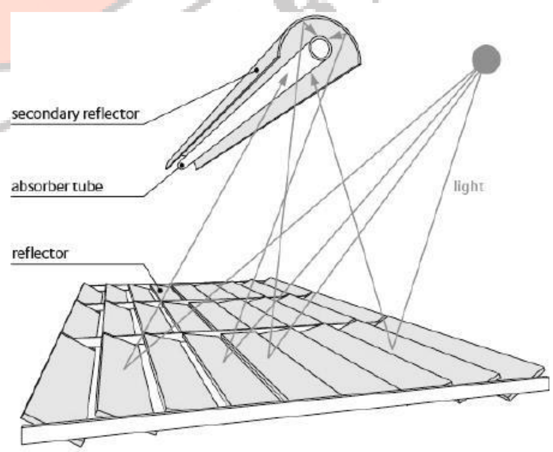

Figure 3 Linear Fresnel reflector [6]

Linear Fresnel-reflector (LFR)

Linear Fresnel reflector is one of the aspect of solar technology which helps in reflecting solar energy to a pre- defined position of tube through which thermal fluid flows. In this system the solar rays are concentrated to a specific point mostly a tube by reflecting type mirror which are adjustable in nature. Temperature range of 60ºC to 250ºC can be attained with LFR depending on the solar radiation and the type of material used. The energy conversion of solar to electrical energy varies from 10 to 200MW with an average efficiency of 8-10%. The largest operational LFR concentrating solar power plant was installed in 2014 in India, with capacity of 125MW which can produce electricity of 280,000 MWh/year [7]. Similarly, solar thermal power plant in Kimberlina US, Italy, Australia - The Liddell and the Puerto Errado 2 were installed with capacity of 5MW, 1MW, 9MW and 30MW respectively for commercial uses [8].

Parabolic trough collector

A parabolic trough collector is a type of solar thermal technology that uses a parabolic primary reflector to focus the sun onto a linear tubular receiver at the focal length of the primary reflector. Working medium temperature can be obtained using PTC with different materials and thermal energy from 60℃ to 300℃

Density of a parabolic reflector. Concentration can be analyzed by the ratio of the area of the parabolic reflector to the area of the receiver. Depending on the direction of the sun, with a north-south axis in the summer and an east-west axis in the winter he places the PTC so it can follow the sun in a north-south direction for maximum performance [9]. Zhy, ShiJ et al. [10] Using truncal oil as the working fluid was found to yield efficiencies of up to 66% under moving receivers. Wang, Liu Q et al. [11] We found that methanol increased the efficiency of the methanol reforming process by 16-fold, varying the concentration ratio along the length of the PTC, allowing an initial concentration of 37. PTC has 16.12% higher potential than LFR which is 10.92% [12]. In India, an annual potential of 1584 kWh/m2 is available with a potential of 23.16% for PTC and 12.17% for LFR [13]. The difference between LFR and PTC is that the reflector mirror used in LFR is of rectangular type whereas in PTC it is of parabolic type. Sagar et al. [14] He developed his 200 kWt solar-based ORC, which can operate at night with the help of a thermal storage system "TES". The concept will be useful in remote areas of India where sufficient energy sources are not available, allowing solar energy to be stored and used after sunset. Bellos et al. [15] he used PTC to operate a solar-powered cogeneration system. The collected solar energy is used to power the ORC and the heat released from the condenser is used to power the absorption heat pump. The developed system is capable of producing an optimum output of 177.6 kWel and heating and cooling capacities of 972 kW and 398.8 kW respectively. kings. [16] used dimethyl ether as the fuel for the PTC, with an efficiency of 9.87%, higher than the ORC system. Antonio et al. [17] His modeled ORC system powered by the exhaust from a gas turbine. PTCs using molten salt as heat transfer fluid are used as solar heat collectors .

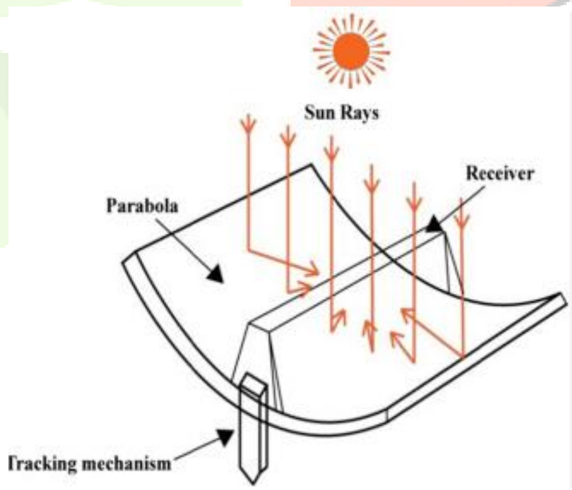

Figure 4 Parabolic trough collector [18]

3. Working Fluids

The liquids used in ORC are high molecular weight organic liquids containing carbon or its derivatives. These fluids are selected based on factors such as critical temperature, environmental safety factors, toxicity, flammability, and fluid condition (dry, wet, or isentropic). Most of these liquids have a lower boiling point than water, making them the preferred working fluids for ORCs. Organic liquids are usually classified as wet, dry, and isentropic liquids and describe the magnitude of dT/dS on the T-s curve. dT/dS corresponds to the state of the organic fluid at the end of the expansion process. It is recommended to leave the organic fluid in a superheated state to prevent partial condensation of the fluid. This can affect the turbine blades and ultimately shorten their life. of the turbine. For the same reason, systems with dT/dS > 1 should always prefer dry liquids.

Table 2 Cycle efficiency for different fluids

Fluids	Critical Temperature (^{O}C)	Boiling point (^{o}C)	Critical pressure (MPa)	ODP	GWP (100 years)	Efficiency for 1kW (%)
R113[19]	214.1	47.6	3.439	0.8	5820	6.8
R245fa [20]	154.2	15.14	3.65	0	820	8.13
Methanol[20]	240.2	64.7	8.1	-	-	8.50
R141b[20]	204.2	32	4.25	0.12	725	8.20
R600a[20]	134.7	-11.7	3.64	0	-	5.21

Table 2 shows the working fluid with different efficiency for an ORC plant of 1kW in which the highest efficiency was found 8.55% for methanol which was attained by the high thermal efficiency of 12.22% with the volume flow rate at 0.95 L/s .There are many other fluids like R11, CFC, HCFC, R12, etc. which gives better output but due to their toxicity and poor environmental performance, they were not considered.

4. System capacity and economic consideration

The capacity of the ORC can be determined based on the geography, solar irradiance, fluid type and requirement of the output power. So with respect to requirement of the output power the capacity of the orc is divided into three scales.

- Small scale (1-20 kW)
- Medium scale (20-80 kW)
- Large scale (80 kW above)

ORC power plants producing 1 to 20 kW of power are among the most viable on the market today due to their relatively low cost, low maintenance and efficient performance. A thermodynamic model was examined, working fluid data was simulated, and a mass flow rate of 1 kg/s was maintained, resulting in outputs of 17.5 kW and 22.5 kW by R134a and R245fa at 70°C. As the temperature increased further to 99 °C, output powers of 25 kW or 30 kW were measured with R134a or R245fa. In both cases an efficiency of 10% was measured [21]. R134a and R245fa cost $0.17/KWh and $0.14/KWh with payback periods of 10.5 and 7.5 years, respectively. India's ORC potential is 4.4 GW [22]. Although very small, this system can be installed in a vehicle to generate energy from the exhaust gases emitted by the vehicle and used to heat the working fluid. The generated electricity can be used in storage batteries.

Table 3 Consideration of organic fluid for different solar collectors

Fluid	Critical temperature (ºC)	Boiling temperature (ºC)	Linear	Flat	Parabolic
R134a	101	-26.3	✗	✓	✗
R11	198	23.77	✗	✓	✗
R141b	204.2	32	✓	✓	✗
Benzene	289	80.1	✗	✗	✓
Toluene	320	111	✗	✗	✓

Table 3, shows the working fluids that can give better performance with particular solar collector, based on the critical temperature and boiling point as of fluid with low critical temperature cannot be used as the working fluid for eg.R34a if used in PTC then it would reach temperature above critical temperature and hence cannot be used.

5. Conclusion

In the current work, a range of photovoltaic organic Rankine cycles is reported. Different types of solar panels can be installed as needed, depending on how sunny your location is. The highest solar irradiance was observed in Gujarat and Rajasthan, finally opening the realm of technological progress in the field of power generation using photovoltaic ORC. For small scale production, flat plate collectors with R134a can be used due to the lower temperature range of the FPC. Alternatively, for large-scale production, a parabolic trough collector with toluene as the working fluid can be used. R134a and R245fa are well suited for small batch production due to their performance and cost effectiveness. Most solar-based ORC systems are powered by parabolic trough collectors due to operational versatility and increased energy conversion efficiency. As India is developing day by day and traditional energy sources alone cannot meet the demand, his ORC of solar power is suitable as an alternative source for current and future scenarios.

References

[1] Yogesh Popat, Sourabh Shrivastava, Harshit Saxena : "Current Scenario and Future Scope of Solar Energy in India." SAR Journal. Volume 1, Issue 2, Pages 57-66, ISSN2619-9955, DOI: 10.18421/SAR12-05, June 2018.

[2] Parth P. Prajapati, Vivek K Patel, "Thermo-economic optimization of a nanofluid based organic Rankine cycle: a multi-objective study and analysis", Thermal Science and Engineering Progress, July 2019.https://doi.org/10.1016/j.tsep.2019.100381

[3] http://www.synergyenviron.com/tools/solar-irradiance [Last accessed on 15 September 2019]

[4] Wang, M., Wang, J., Zhao, Y., Zhao, P., & Dai, Y : "Thermodynamic analysis and optimization of a solar-driven regenerative organic Rankine cycle (ORC) based on flat-plate solar collectors". Applied Thermal Engineering, 50(1), 816–825. doi:10.1016/j.applthermaleng.2012.08.013.

[5] https://www.daviddarling.info/encyclopedia/F/AE_flat_plate_solar_thermal_collector.html[Last accessed on 15 September 2019]

[6] Andreas Poullikkas, Ioannis Hadjipaschalis, George Kourtis. A comparative overview of wet and dry cooling system for Rankine cycle based CSP plant. Trends in Heat and Mass Transfer, vol. 13, 2013.

[7] Müller-Steinhagen H, Trieb F, Trieb F. "Concentrating solar power: a review of the technology." Available from ⟨http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/publications/Concentrating_Solar_Power_ Part_1.pdf⟩;2004 . [Last accessed on 15 September 2019]

[8] SolarPACES. CSP projects around the world. Available from ⟨http://www.solarpaces.org/csp-technology/csp- projects-around-the-world⟩; 2016 [Last accessed on 15 September 2019]

[9] Duffie JA , Beckman WA . "Solar engineering of thermal processe ". third ed. NJ, USA: Wiley, Hoboken; 2006

[10] Zhu Y , Shi J , Li Y , Wang L , Huang Q , Xu G . "Design and experimental investiga- tion of a stretched parabolic linear Fresnel reflector collecting system". Energy Convers Manag 2016; 126 :89–98

[11] Wang Y , Liu Q , Sun J , Lei J , Ju Y , Jin H . "A new solar receiver/reactor structure for hydrogen production." Energy Convers Management 2017; 133 :118–26 .

[12] E. Bellos, C. Tzivanidis, "Assessment of linear solar concentrating technologies for Greek climate". Energy Conversion and Management 2018;171:1502-1513

[13] K.R. Kumar, K.S. Reddy, 4-E (energy–exergy–environmental–economic) "57 analyses of line-focusing stand- alone concentrating solar power plants", International Journal of Low-Carbon Technologies 2012;7(1):82-96

[14] Lakhani, S., Raul, A., & Saha, S. K. (2017). Dynamic modelling of ORC-based solar thermal power plant integrated with multitube shell and tube latent heat thermal storage system. Applied Thermal Engineering, 123, 458– 470. doi:10.1016/j.applthermaleng.2017.05.115

[15] Bellos, E., & Tzivanidis, C. (2017). Parametric analysis and optimization of a solar driven trigeneration system based on ORC and absorption heat pump. Journal of Cleaner Production, 161, 493– 509. doi:10.1016/j.jclepro.2017.05.159

[16] Wang, S., & Fu, Z. (2019). Thermodynamic and economic analysis of solar assisted CCHP-ORC system with DME as fuel. Energy Conversion and Management, 186, 535–545. doi:10.1016/j.enconman.2019.02.076

[17] Pantaleo, A. M., Camporeale, S. M., Sorrentino, A., Miliozzi, A., Shah, N., & Markides, C. N. (2017). Solar/biomass hybrid cycles with thermal storage and bottoming ORC: System integration and economic analysis. Energy Procedia, 129, 724–731. doi:10.1016/j.egypro.2017.09.105

[18] Cabrera, F. J., Fernández-García, A., Silva, R. M. P., & Pérez-García, M. (2013). Use of parabolic trough solar collectors for solar refrigeration and air-conditioning applications. Renewable and Sustainable Energy Reviews, 20, 103–118. doi:10.1016/j.rser.2012.11.081

[19] Saitoh T, Yamada N, Wakashima SI. "Solar Rankine cycle system using scroll expander". Journal of Environment and Engineering 2007; 2:708-719.

[20] Suresh Baral & Kyung Chun Kim "Thermodynamic Modeling of the Solar Organic Rankine Cycle with Selected Organic Working Fluids for Cogeneration", Distributed Generation & Alternative Energy Journal, 29:3, 7- 34, DOI:10.1080/21563306.2014.10879015

[21] Suresh Baral. "Experimental and Techno-Economic Analysis of Solar-Geothermal Organic Rankine Cycle Technology for Power Generation in Nepal". International Journal of Photoenergy Article ID 5814265, (2019)

[22] Sarkar, J., & Bhattacharyya, S. (2015). Potential of organic Rankine cycle technology in India: Working fluid selection and feasibility study. Energy, 90, 1618–1625. doi:10.1016/j.energy.2015.07.001

[23] Patel, Trushil, Nishant Mandal, and Parth Prajapati. "Review of Solar Powered Organic Rankine Cycle for Indian Conditions." Advances in Systems Engineering: Select Proceedings of NSC 2019. Springer Singapore, 2021.