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REVIEW OF ENERGY AND EXERGY ANALYSES IN SOLAR-ASSISTED ORGANIC RANKINE CYCLE SYSTEMS FOR ELECTRICITY GENERATION

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Abstract:

Solar-assisted Organic Rankine Cycle (ORC) systems have gained significant attention as a viable technology for electricity generation using solar energy. To assess the performance and efficiency of these systems, energy and exergy analyses play a crucial role. This review focuses on summarizing and analyzing the existing literature on energy and exergy analyses conducted in solar-assisted ORC systems for electricity generation.The energy analysis evaluates the energy flows within the system, including the solar energy input, heat transfer to the working fluid, and power output. It provides insights into the overall energy efficiency and identifies the major energy losses within the system. Several studies have investigated the impact of various factors, such as solar collector design, working fluid selection, and operating parameters, on the energy performance of solar-assisted ORC systems. These analyses have helped identify strategies for improving component efficiencies, optimizing operating conditions, and enhancing power production. Exergy analysis goes beyond energy analysis by considering the quality of energy within the system. It quantifies the irreversibilities and losses occurring during energy conversion processes, providing a comprehensive understanding of system performance. Exergy analysis has been applied to solar-assisted ORC systems to identify the sources of exergy destruction and losses, highlighting areas for improvement. Studies have explored the effects of working fluid characteristics, component efficiencies, and system configurations on exergy performance. These analyses have contributed to the development of strategies for reducing exergy losses and increasing system efficiency.

Introduction:

As a consequence of the growing need for energy around the globe **(**Asif,2007**)** as well as the imperative to reduce emissions of greenhouse gases, greater focus is being placed on the research and development of renewable energy technology. Due to its abundance and cleanliness, solar energy has drawn a lot of interest for use in power production. The Solar Assisted Organic Rankine Cycle (ORC) has become one of the most promising solar energy systems for producing electricity that is both efficient and sustainable **(**Setuek Acar M, 2019**)**.

The ORC is a thermodynamic cycle that transforms heat energy into electricity by using an organic working fluid (Quoilin S, 2013**)**. With lower working temperatures and pressures ideal for low-temperature heat sources, it runs on the same principles as the traditional Rankine Cycle used in conventional power plants. Because solar thermal energy is often accessible at lower temperatures than conventional fossil fuel sources, the ORC is especially well-suited for using it. Solar thermal collectors are used in a solar-assisted ORC system to collect and concentrate solar radiation, which is then utilized as the heat locate for the ORC. The selection of solar collectors is contingent upon the specific application and available resources, with options including parabolic troughs, linear Fresnel reflectors, and solar towers. The aforementioned collectors facilitate the conversion of solar energy into thermal energy, which is subsequently transferred to the working fluid of the ORC system **(**Agarwal, 2015**)**.

The efficacy of the Solar Assisted ORC is significantly impacted by the selection of the working fluid **(**Yinling Wang, 2021**)**. To effectively convert the absorbed heat into mechanical work, it should have a low boiling point and strong thermal stability. Hydrocarbons like R134a, R245fa, and R123 as well as other organic fluids like pentane and isobutane are examples of working fluids that are often utilized. The required operating temperature range, thermal qualities, environmental effect, and safety concerns all play a role in the working fluid selection process.

An important method for assessing the effectiveness of a Solar Assisted ORC system is energy analysis. It entails calculating the energy flows via the turbine, condenser, heat exchangers, solar collector, and other cycle components **(**Setuek Acar M, 2019**)**. It is possible to assess the system's total energy efficiency by looking at its energy inputs and outputs. Energy analysis allows the system components and operating parameters to be optimized in order to maximize energy usage by identifying areas of energy loss. Energy analysis adds to energy analysis by taking into account the energy's quality and capacity for meaningful work. Energy study sheds light on the irreversibilities and Energy losses inside the Solar Assisted ORC system.

Energy is a measure of a system's available work capacity. The system's efficiency may be increased, leading to a more sustainable use of energy resources, by recognizing and reducing energy destruction **(**Agarwal, 2015**)**.

Energy:

The capacity to do tasks or affect change might be characterized as energy. It may be found in a variety of forms, including electrical, chemical, thermal, and mechanical energy. Quantifying energy flows within a system and evaluating energy efficiency are the main goals of energy analysis. Energy analysis just takes into account the overall amount of energy transmitted or altered within a system, not the kind of energy. Exergy, on the other hand, is a measurement of the calibre or potential work of energy. It is described as the most productive amount of labour that may be produced when a system achieves equilibrium with its environment. Exergy analysis determines how well the available energy is used by taking into consideration the irreversibilities and losses inside a system. By taking into account the thermodynamic constraints and the possibilities for enhancing energy conversion, it offers a more thorough insight of the system performance **(**Saleh B, 2018**)**.

Exergy:

In contrast, energy analysis considers the quality of energy and measures the losses and degradation of energy within a given system. It entails figuring out the causes of irreversibilities by evaluating the energy fluxes at various phases of a process. Energy analysis assists in identifying areas for improvement and in fine-tuning system elements and operational parameters to enhance Energy efficiency. It allows for the discovery of possibilities for lowering energy waste and raising overall efficiency by providing a more thorough and accurate evaluation of the working of energy systems **(**Fan G, 2021**)**.

Literature Review:

O. Badar (1990) in his study used a computer program that was developed to predict the properties of halocarbon compounds such as R-11, R-12, R-22, R-113, R-114, and R-502. The program accurately estimated the properties of R-11 and had a maximum deviation of only 3% in predicting the specific enthalpy of the saturated liquid within a temperature range of 20°C to 180°C. Another program was created to evaluate the performance of Rankine-cycle systems that use R-11, R-113, or R-114 as working fluids.

Yamamoti (2001) experimented on how a closed-type Organic Rankine Cycle (ORC) performs using different working fluids: HCFC-123 and water. They used both simulations and experiments to understand how the system works. The simulations showed that, for water, higher turbine power is achieved by increasing the temperature at the turbine inlet. On the other hand, for HCFC-123, the best performance is obtained when the turbine inlet temperature is just above the boiling point of the fluid.

Kalyan Srinivasan (2008) analyzed an Organic Rankine Cycle (ORC) using four organic dry fluids. Thermal efficiency improved with higher turbine inlet pressure for all fluids. R113 performed best, while isobutane showed the worst performance. Regenerative ORC had higher thermal and second law efficiencies than basic ORC. Specific irreversibility increased with turbine inlet pressure, but regenerative ORC had 42% less irreversibility. Second law efficiency decreased with higher inlet pressure, but regenerative ORC consistently outperformed basic ORC. Combined analysis revealed regenerative ORC's advantages: 15% higher thermal efficiency, 42% reduced irreversibility, and 14.5% improved second law efficiency. Both law analyses are crucial for evaluating and optimizing ORC systems.

Nafey (2010) conducted a study on the PWT configuration in a desalination plant using a solar thermal power system. Key findings include an 80% efficiency for both the PWT unit and HPP unit. The PWT configuration required a 43.5% smaller solar collector field area (3038 m2) compared to the basic configuration, with a 43.5% reduction in power consumption, resulting in specific power consumption (SPC) of approximately 4.35 kWh/m3. To maintain operating conditions, the PWT configuration had an increased number of pressure vessels (44) in the RO section compared to the basic configuration (42). It exhibited a 37.2% decrease in total irreversibility (3.763 MW), with the highest exergy destruction in the RO section (50.7%), followed by the solar collector field (43.45%). The PWT configuration demonstrated a larger exergy efficiency of 11% compared to 9.3% in the basic configuration, indicating a 15% increase. Specific annual total costs for the PWT configuration were around 0.683 $/m3, with a total investment and operation & maintenance cost of 99.58 $/h, representing a 24% reduction compared to the basic configuration, with RO sector costs accounting for about 91.2% of the total costs. The PEX configuration, compared to other configurations, consumed significantly less power (2.7kWh/m3) with a developed power decrease of 65% (0.394 MW). The PEX configuration demonstrated an overall exergy efficiency increase to 11.6% and a 57.7% reduction in total irreversibility compared to the basic configuration, with specific annual total costs of 0.68 $/m3, and a total investment and operation & maintenance cost of 99.26 $/h. Thermo-economic analysis showed that the PEX configuration outperformed other configurations in several aspects.

Filiz Tumen Ozdil (2015) conducted his research on thermodynamic study on a small power station located in southern Turkey, which utilizes an Organic Rankine Cycle (ORC). The study analyzed various components of the system, including an evaporator, turbine, condenser, pump, and generator. By employing real plant data and a performance cycle, each system component was individually evaluated. One significant finding was the relationship between the pinch point and energy efficiency. It was observed that as the pinch point temperature decreases, the exergy efficiency increases, primarily due to the reduced exergy destruction rate. The energy and exergy efficiencies of the ORC, considering its saturated liquid state, were determined to be 9.96% and 47.22% respectively.

Surendra Kumar (2015) conducted the study which found that at a typical turbine back pressure of 0.4 MPa, R141b exhibited the highest energy efficiency (18.37%), while R600 demonstrated the highest exergy efficiency (7.65%). When compared to other refrigerants, R141b achieved the highest energy efficiency (17.98%), whereas R600 achieved the highest exergy efficiency (6.69%) at a conventional evaporator temperature of 270K. Moreover, increasing the turbine intake pressure of R141b from 0.5 MPa to 1.75 MPa resulted in an improvement in energy efficiency from 13.8% to 18.69% and an increase in exergy efficiency from 3.45% to 8.62%. These findings highlight the significant impact of operational parameters on the energy and exergy performance of the cycle.

Zhang, H., Liu, Y., Liu, X., & Duan, C. (2020) in his study presents an analysis of energy and Energy pertaining to a novel cogeneration system that utilises an ORC, along with an absorption heat pump that is integrated into a coal-fired power plant. The ORC involves the expansion of an organic working fluid through a turbine, which results in the generation of electrical power. Subsequently, the waste heat generated from the ORC is harnessed by means of an absorption heat pump, thereby facilitating the extraction of supplementary thermal energy and furnishing temperature regulation for diverse applications encompassing both heating and cooling. Energy analyses are performed to assess the efficiency of a system and pinpoint locations where energy losses occur.

Description and Working of Organic Rankine Cycle (ORC):

The solar operated Organic Rankine Cycle (ORC) system consists of various components such as solar energy collecting sub-system with Organic Rankine Cycle (ORC) sub-system. Figure 1 the schematic diagram of the ORC system. The Organic Rankine Cycle (ORC) sub-system consists of four main components, namely: an heat recovery vapour generator (HRVG), a turbine, a condenser and a pump. Solar waves falls on the heliostat ground and being reflected on the central receiver's aperture area which has been located at the peak of the tower. The concentrated waves which falls on the central receiver (CR) makes the central receiver temperature high, which is result heat the Duratherm oil. This heated duratherm fluid (oil) flows through the pipes which transfer its thermal energy from central receiver (CR) to the HRVG. The superheated refrigerant vapour is expanded in the turbine for power generation. The turbine exhaust is condensed in the condenser. Now the saturated liquid has been pumped to HRVG of Rankine Cycle. The main part of solar operated ORC collecting system is an arrangement of heliostat field and central receiver (CR). The central receiver is the pipe carrying heat transfer fluid. Outside this receiver is vacuum annulus to decrease heat losses. The heat transfer fluid preferred for the solar loop is duratherm 600. This oil has been preferred based on the fact that has better heat transfer properties and temperature control.

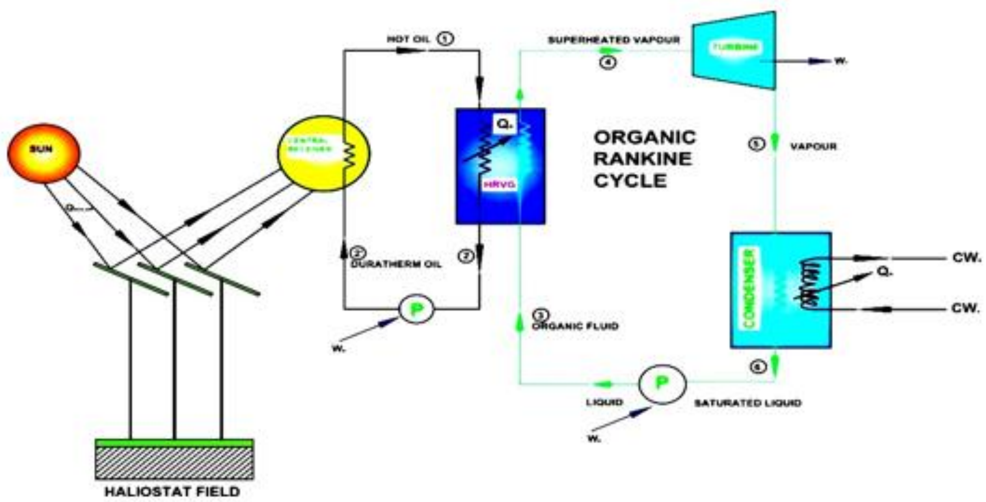

Figure 1: Schematic of Solar Operated ORC system

Need of the Study:

The study on energy and exergy analyses in solar-assisted Organic Rankine Cycle (ORC) systems for electricity generation is of utmost importance due to several reasons. With the increasing demand for sustainable energy sources and the growing concerns about climate change, there is a pressing need to explore and develop efficient and environmentally friendly power generation technologies. Solar energy is a clean and abundant source that has the potential to meet a significant portion of our energy needs. By integrating solar energy with ORC systems, we can harness the sun's energy and convert it into electricity, reducing our reliance on fossil fuels and minimizing greenhouse gas emissions.Understanding the energy and exergy performance of solar-assisted ORC systems is crucial for optimizing their efficiency and overall performance. Energy analysis provides insights into the energy utilization and losses within the system, enabling us to identify areas for improvement and maximize the energy conversion efficiency. Exergy analysis, on the other hand, assesses the quality of energy and quantifies the irreversibilities and inefficiencies in the system. It helps in identifying the sources of exergy destruction and potential areas for system optimization. Moreover, the study can contribute to the development of design guidelines and operational strategies for solar-assisted ORC systems. By analyzing the energy and exergy flows, researchers and engineers can determine the optimal operating conditions, system configurations, and component sizing for achieving the highest possible energy and exergy efficiency.

Problem Statement:

- Solar-assisted Organic Rankine Cycle (ORC) systems have emerged as a promising technology for efficient power generation using solar energy. However, several challenges and areas for improvement need to be addressed to maximize the potential of these systems.
- Energy Efficiency: Enhancing the overall energy efficiency of solar-assisted ORC systems is crucial. Factors such as solar collector design, working fluid selection, and system configuration significantly impact energy conversion and utilization. Addressing these factors can lead to improved energy efficiency and increased power output.
- Exergy Losses: Exergy losses during energy conversion processes within the system contribute to inefficiencies. Identifying and quantifying these losses is essential for optimizing system performance. Minimizing exergy losses through component design optimization, heat transfer improvements, and system control strategies can enhance power generation efficiency.
- Working Fluid Selection: The choice of working fluid plays a vital role in the performance of solar-assisted ORC systems. The working fluid should exhibit favorable thermodynamic properties, high thermal stability, and low environmental impact. Exploring and evaluating alternative working fluids can optimize system efficiency and reliability.
- Optimal System Design: The design and configuration of system components, including solar collectors, heat exchangers, and turbines, require optimization. Developing optimal designs that maximize solar energy utilization, improve heat transfer, and minimize pressure losses is crucial for efficient power production.
- Dynamic Operation: Solar radiation varies over time, necessitating dynamic operation strategies for solar-assisted ORC systems. Developing intelligent control algorithms that adapt to changing solar conditions and optimize system operation can improve power generation performance.
- Economic Viability: The economic viability of solar-assisted ORC systems is a key consideration for their widespread adoption. Cost-effective component selection, system installation, and maintenance strategies, as well as an analysis of the levelized cost of electricity (LCOE), are necessary to ensure the economic feasibility of these systems.

Addressing these challenges will contribute to maximizing the energy and exergy efficiencies of solar-assisted ORC systems, leading to increased power production from solar energy and promoting sustainable and clean power generation.

Conclusion:

In conclusion, the energy and exergy analyses in solar-assisted Organic Rankine Cycle (ORC) systems for power generation provide valuable insights and guidance for the development and optimization of these systems. The integration of solar energy with ORC technology offers a promising solution for clean and sustainable power generation. By conducting energy analysis, the study allows us to identify energy losses and inefficiencies within the system, enabling us to improve the overall energy conversion efficiency. This analysis helps in determining the optimal operating conditions, component sizing, and system configurations to maximize energy utilization. Exergy analysis, on the other hand, assesses the quality of energy and identifies the sources of irreversibilities and inefficiencies. By quantifying exergy destruction, researchers and engineers can identify areas for improvement and develop strategies to minimize energy wastage and maximize the exergy efficiency of the system. The findings from these analyses contribute to the design guidelines and operational strategies for solar-assisted ORC systems, enabling the development of more efficient and reliable power generation systems. Furthermore, the insights gained from this study can aid in the decision-making process for policymakers and investors, facilitating the wider adoption of solar energy and reducing our dependence on fossil fuels.

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