NUST COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

MODELING AND FABRICATION OF A SOLAR BASED ORC SYSTEM FOR STANDALONE APPLICATION

A PROJECT REPORT

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ABSTRACT

The purpose of this thesis was to examine the feasibility and performance of a solar-based Organic Rankine Cycle (ORC) for power generation. The study focused on employing solar irradiation as the heat source for driving the ORC, taking advantage of the compatibility between solar thermal collector technologies and the temperature needs of the cycle. Through a combination of experimental measurements and simulation modeling, the operation principles of solar-ORC technology were explored, and a detailed analysis of several solar-ORC systems was undertaken, including parameters such as pressure, temperature, heat input, and heat output. The data acquired from the experiments and simulations provided vital insights into the system's performance, including the efficiency levels achieved and the heat transfer characteristics. The limitations and constraints connected with solar-ORC technology were recognized and discussed, opening the way for future study in this sector. The findings of this study contribute to the understanding and development of renewable energy-based technologies, underlining the potential of solar-ORC systems for sustainable power generation.

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CHAPTER 1: INTRODUCTION

1.1 Motivation of work:

Fuels derived from fossil fuels are the major source of energy in today's world, but their availability is limited as they are being depleted at an alarming rate. As energy prices rise and environmental problems worsen, renewable energy sources are gaining attention.

There are many techniques to generate electricity from renewable sources but to extract energy from low energy sources like sunlight the Organic Rankine Cycle is one of the best methods used worldwide. Pakistan has been facing a serious energy crisis for the last two decades. Our region, however, shows sufficient solar radiation but lacks solar based ORC on a small scale completely. This opens the way for research and development that determines the potential of solar energy to fulfill energy demand in Pakistan.

Rankine cycle is traditionally used to produce electricity by using steam to drive the turbine and produces an efficiency of about 33-38 % but to generate energy in Rankine cycle temperature should be greater than the boiling point of water and that is not readily available. So, to utilize the low temperature of the sunlight, the Organic Rankine Cycle uses organic fluids such as (R245fa), (R134a), isopentane etc. as working fluids instead of steam because they have very small boiling point.

1.2 Problem Statement:

The problem statement ‘Design and fabrication of Solar based ORC for standalone application” constitutes of two parts i.e., Design and Modeling of the various parts of ORC and fabrication of a Simple ORC for the Proof of Concept.

The design of the ORC should be such that it produces maximum flow rate and the temperature difference to get the maximum efficiency of the Cycle.

The design of the components of the ORC can be done by using TRNSYS and ASPEN and for CFD ANSYS will be used to efficiently get the temperature profiles and a clear view of the model.

CHAPTER 2: Methodology

2.1 Flow Chart of Methodology

Methodology for carrying out project is represented below:

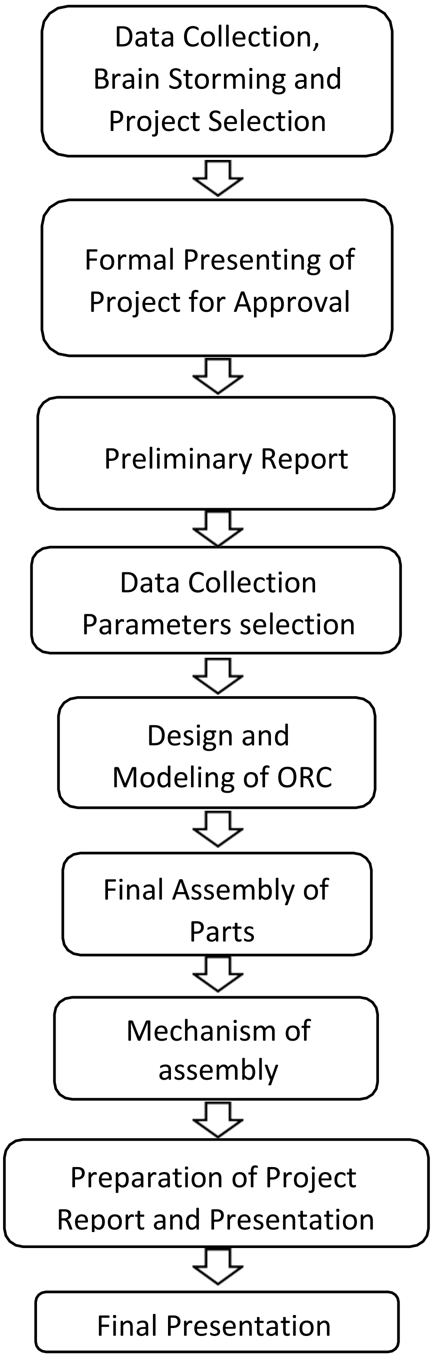


Figure 1: Flowchart for Methodology

An essential first step in ORC projects is the creation of a computer model utilizing process simulators like TRNSYS or Aspen HYSYS. These computer programmes offer a framework for building a thorough model of the ORC power plant and simulating its operation. For instance, Aspen HYSYS provides a user-friendly interface that enables input circumstances to be changed for each component, simulating real-world settings. Researchers may learn important things about the thermodynamic conditions at each stage of the ORC cycle by using process simulation. Calculations can be made for mass flow rates, work, power, and other performance factors. The benefit of modelling and simulation is that it allows for performance evaluation and analysis of the ORC system without the requirement for costly and time-consuming experimental experiments.

To represent the thermodynamic processes involved in the ORC, mathematical models are created. Researchers may simulate the system's behaviour using these models and predict the system's efficiency, power production, and overall performance. To find the best configuration for a given application, simulations can be used to examine various design configurations, operating parameters, and working fluids. An ORC system's modelling method requires taking a number of important factors and parameters into account. The heat source is one of them; it may be a solar thermal collector, waste heat from industrial activities, or geothermal energy. The working fluid selection—such as R134a or R245fa—is also crucial. The model incorporates the turbine, pump, condenser, boiler (evaporator), and heat exchangers, correctly simulating the behaviour of the system by taking into consideration variables such as pressure, temperature, mass flow rate, and heat transfer coefficients.

Modelling and simulating ORC systems can be done in a variety of ways, from straightforward steady-state models to more intricate dynamic models. While dynamic models take into account transient behaviour and offer a more realistic description of the system, steady-state models simplify the representation by assuming constant operating conditions. An ORC system's modelling method requires taking a number of important factors and parameters into account. The heat source is one of them; it may be a solar thermal collector, waste heat from industrial activities, or geothermal energy. The working fluid selection—such as R134a or R245fa—is also crucial. The model incorporates the turbine, pump, condenser, boiler (evaporator), and heat exchangers, correctly simulating the behaviour of the system by taking into consideration variables such as pressure, temperature, mass flow rate, and heat transfer coefficients.

In conclusion, ORC projects heavily rely on computer modelling and simulation employing process simulators like Aspen HYSYS or TRNSYS. They make it possible for researchers to examine different design configurations and operational parameters, analyses and rate the performance of ORC systems, and anticipate efficiency and power output. Key factors and parameters are taken into account during the modelling process, and validation processes guarantee the models' accuracy and dependability. In the end, modelling and simulation aid in the improvement and development of ORC technology.

CHAPTER 3: LITERATURE REVIEW

3.1 Working

The heat recovery system (HRS), the turbine, the condenser, and the pump are the main parts of the organic Rankine cycle (ORC). Together, these elements effectively transform heat energy into meaningful work. By absorbing heat from an energy source and raising the enthalpy of the working fluid, the HRS plays a critical part in the ORC system. The working fluid enters the HRS at State 2 as a subcooled liquid and transitions through three stages in the economizer, evaporator, and superheater. As a result of absorbing heat from the energy source in the economizer section, the subcooled liquid undergoes a phase transition and becomes a saturated liquid at State 2-1. The economizer's heat transfer aids in maximizing the use of thermal energy that is already present. The latent heat exchange that causes the saturated liquid from the economizer to transform into a saturated vapor at State 2-2 occurs in the evaporator portion. The working fluid undergoes this phase shift as it takes in more heat energy from the energy source, which causes the liquid to vaporize. If present in the ORC system, the superheater section raises the temperature of the vaporized working fluid even more, creating a superheated vapor at State 3. It's important to remember that ORC systems normally have a tiny superheating component, and occasionally there is no superheating at all. Superheating may or may not be included depending on the particular needs and characteristics of the application.

The working fluid exits the HRS and enters the turbine as a superheated vapor or saturated vapor. A connected generator converts the rotational mechanical energy produced by the turbine's vapor expansion into electrical power. The expanded vapour enters the condenser after the turbine, where it distributes heat to a cooling medium, usually air or water. The working fluid is ready for the next cycle by returning to a liquid form as a result of this heat transfer. The pump then pumps the condensed liquid back to the HRS, increasing its pressure to finish the cycle. Although the effort required by the pump is minimal in comparison to the system's overall energy output, it is not insignificant and must be considered when calculating system efficiency.

In conclusion, the ORC system is a thermodynamic cycle that transforms heat energy into useful work through the employment of a heat recovery system, a turbine, a condenser, and a pump. Within the HRS, the working fluid experiences phase transitions and heat exchanges that cause it to go from a subcooled liquid to a vaporized state. The expanding vapor's mechanical energy is extracted by the turbine and transformed into electrical energy. The cycle then restarts in the HRS once the working fluid is condensed and pumped back there.

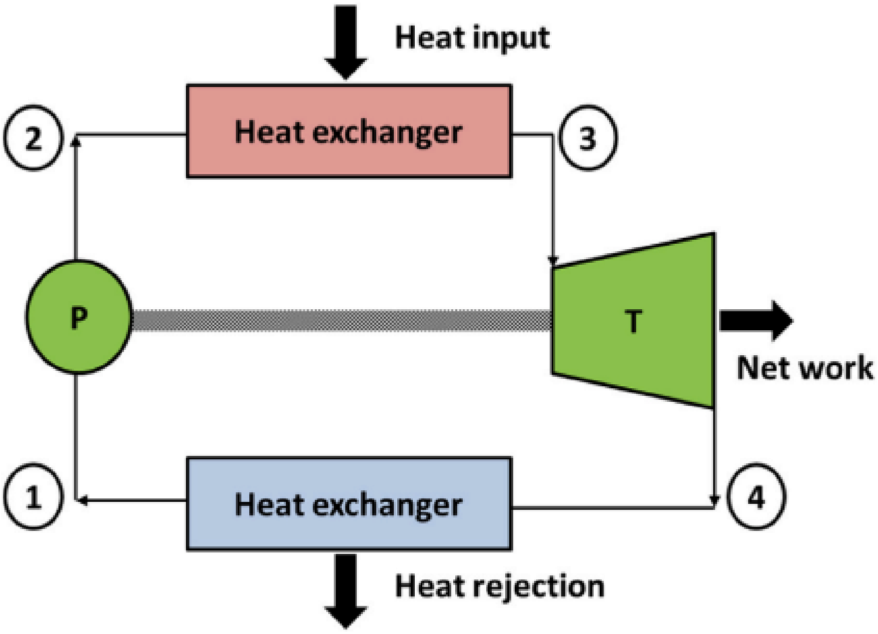


Figure 2: Rankine Cycle Schematic

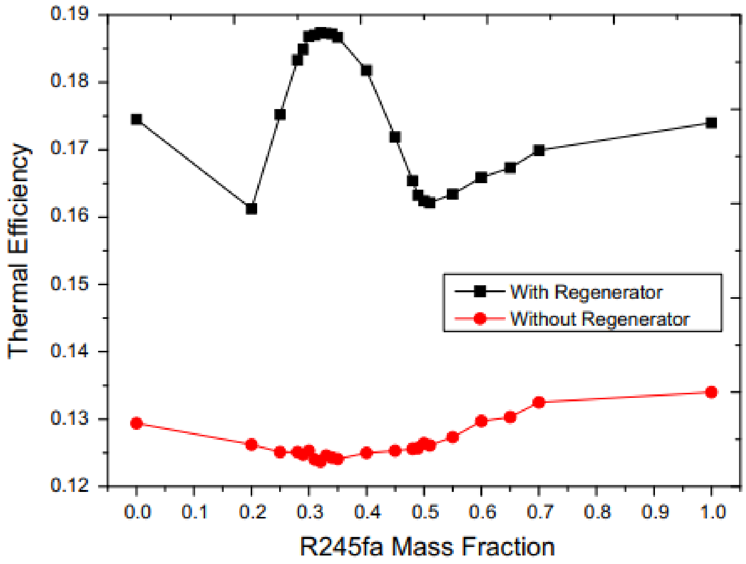


Figure 3: (Lu & Goswami, 2003) All effects are mentioned in this PAPER.

3.2 Working Fluid

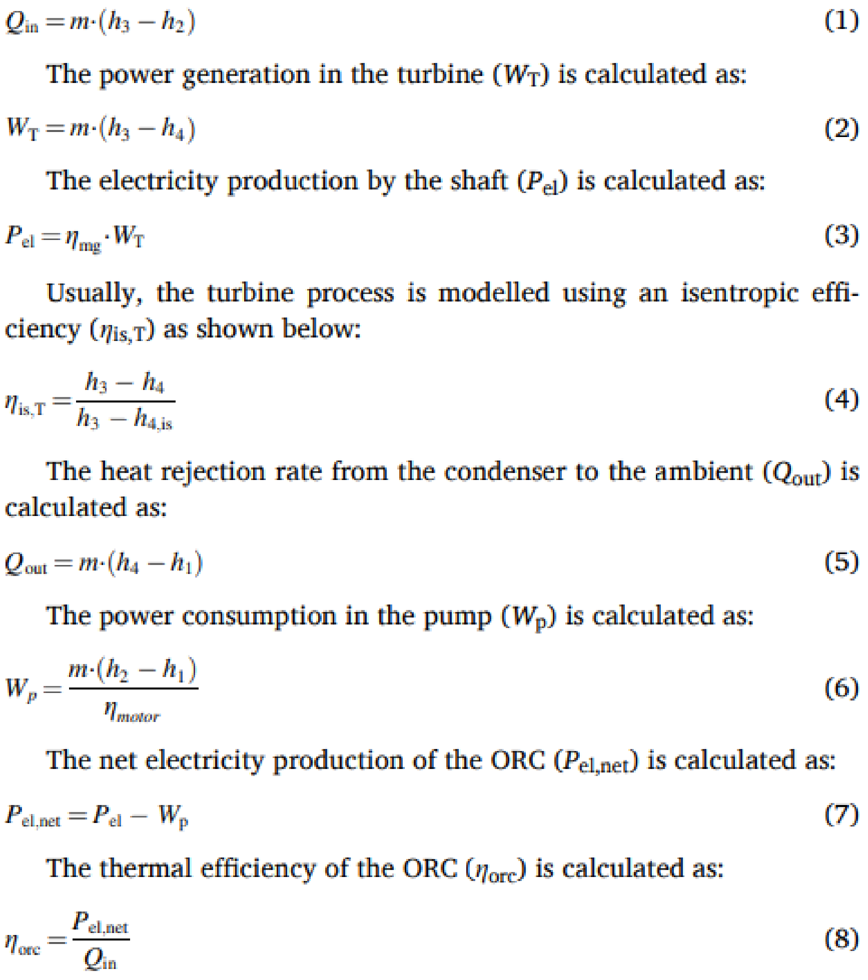
The use of organic working fluids, which have lower critical temperatures than water, makes the organic Rankine cycle (ORC) unique. Because of this feature, ORC systems are especially well suited for using solar systems and other low- and medium-temperature heat sources. One distinguishing feature of ORC systems over water/steam Rankine cycle (RC) systems is their applicability at smaller scales.(Rayegan & Tao, 2011) developed a procedure to compare ORC working fluids based on their molecular components and temperature–entropy (T–S) diagrams. In the study, about 117 organic fluids from the fluid database REFPROP 8.0 were compared; based on their study, R245fa, R245ca, Isobutene, and Isopentane were proposed as the most suitable candidates. ORC systems can be effectively combined with a variety of renewable and sustainable energy sources in addition to solar energy. Examples of such sources include geothermal energy, biomass, and industrial waste heat. The compatibility of organic fluids with various heat sources in terms of required temperature makes ORC the perfect option for next renewable energy systems. ORC technology aids in the creation of cleaner and more ecologically friendly energy solutions by effectively converting thermal energy from various sources into usable power.

Habka and Ajib (2016) conducted a comparison study to examine how well pure fluids and mixtures performed in ORC systems. They found that the R409A mixture performed better than pure fluids like R134a and R245fa, making it a more viable option for ORC applications. This study highlights the possibility for future fluid mixture optimization and investigation to improve the effectiveness and performance of ORC systems.

In conclusion, the ORC is well suited for applications like solar energy systems because it makes efficient use of low- and medium-temperature heat sources through the use of organic working fluids. Compared to water/steam RC systems, ORC systems can be scaled down to smaller proportions, allowing for deployment in a variety of settings. Additionally, geothermal, biomass, and industrial waste heat are just a few examples of renewable and sustainable energy sources that may be effortlessly integrated with ORC technology. The performance and viability of ORC systems for upcoming sustainable energy solutions are continually improved by ongoing research and development activities, including the investigation of fluid mixes.

3.3 Heat Sources

The use of ORC devices for capturing heat from low- or medium-temperature sources is highly recommended. An ORC system can be heated using a variety of energy sources, such as geothermal heat, solar energy, biomass, biodiesel, and biogas as well as waste heat from industrial processes. sun energy is particularly important among these and is effectively transformed into thermal energy by sun collectors. In solar-ORC systems, solar collectors are essential because they serve as heat exchangers, enabling the conversion of solar energy into thermal energy for the working fluid. Direct and indirect solar-ORC systems are the two main varieties.



$$Q_{\mathrm{in}} = m \cdot (h_3 - h_2) \tag{1}$$

The power generation in the turbine (W_{T}) is calculated as:

$$W_{\mathrm{T}} = m \cdot (h_3 - h_4) \tag{2}$$

The electricity production by the shaft (P_{el}) is calculated as:

$$P_{\mathrm{el}} = \eta_{\mathrm{mg}} \cdot W_{\mathrm{T}} \tag{3}$$

Usually, the turbine process is modelled using an isentropic efficiency ($\eta_{\mathrm{is,T}}$) as shown below:

$$\eta_{\mathrm{is,T}} = \frac{h_3 - h_4}{h_3 - h_{4,\mathrm{is}}} \tag{4}$$

The heat rejection rate from the condenser to the ambient (Q_{out}) is calculated as:

$$Q_{\mathrm{out}} = m \cdot (h_4 - h_1) \tag{5}$$

The power consumption in the pump (W_{p}) is calculated as:

$$W_p = \frac{m \cdot (h_2 - h_1)}{\eta_{motor}} \tag{6}$$

The net electricity production of the ORC ($P_{\mathrm{el,net}}$) is calculated as:

$$P_{\mathrm{el,net}} = P_{\mathrm{el}} - W_{\mathrm{p}} \tag{7}$$

The thermal efficiency of the ORC (η_{orc}) is calculated as:

$$\eta_{\mathrm{orc}} = \frac{P_{\mathrm{el,net}}}{Q_{\mathrm{in}}} \tag{8}$$

Figure 4: Power and Efficiency Calculation Formulas

Solar energy is absorbed by a special solar working fluid that circulates inside the solar collector in an indirect solar-ORC system. A heat exchanger is then utilised to transmit the heat from the absorbed energy to the organic fluid that is employed in the ORC system. In order to provide optimal energy conversion, this arrangement enables efficient heat transfer and separation between the organic fluid and the solar working fluid. A direct solar-ORC system, on the other hand, allows the organic fluid to move through the solar collector while also absorbing solar energy. The design of the entire system is made simpler by the direct absorption of solar energy by the organic fluid, which does not require a separate solar working fluid. The direct solar-ORC system has benefits including increased heat transfer effectiveness and decreased.

Depending on the particular requirements and conditions of the application, both direct and indirect solar-ORC systems can be used, and each offers distinct advantages. The decision between these configurations is influenced by elements like the available solar resource, operational temperatures, and desired system efficiency.

Finally, solar heat is a useful and adaptable heat source for ORC systems. The conversion of solar energy into thermal energy for the working fluid depends heavily on solar collectors. Based on the particular requirements of the application, one may choose between the direct and indirect solar-ORC systems, each of which has significant advantages. Solar energy can be used in conjunction with ORC technology to provide renewable and sustainable power, which will lead to cleaner and more effective energy production in the future.

3.4 Solar Thermal Collector Option

An ORC engine can be coupled with various solar collectors because the power cycle can operate in a large range of heat source temperatures from 80 ◦C to 500 ◦C.

A popular non-concentrating solar device created especially for low-temperature applications is the Flat Plate Collector (FPC). It is appropriate for a variety of heating and thermal energy applications since it functions efficiently at temperatures up to 100 °C. In environments with moderate temperature needs, such as residential, commercial, and industrial ones, the FPC is frequently used. Careful design considerations are required to guarantee the FPC's optimum functioning at temperatures close to 100°C. Due to their strong solar absorptivity and low thermal emissivity, selective absorbers must be used. Selective absorbers minimize heat loss from thermal radiation while effectively absorbing solar radiation. This property enables the FPC to capture the most sunlight and transform it into usable heat. Effective insulation is crucial for preserving high operating temperatures and reducing heat losses in the FPC in addition to selective absorbers. In order to keep the temperature gradient between the absorber plate and the surrounding air at a high level and prevent heat from dissipating, insulation materials are used on the collector's back and side surfaces. This insulation makes sure that the solar energy is maintained inside the FPC, increasing the total thermal performance and efficiency of the system. Because of its adaptability, the FPC can be used in many different low-temperature applications. For domestic use, swimming pools, and space heating, it can be included into solar water heating systems for homes and businesses. Additionally, the FPC is frequently employed in industrial processes like drying, sterilization, and fluid preheating that call for moderate temperature levels. The FPC is a practical option for these applications due to its simplicity and dependability.

An FPC consists of an absorber plate with water tubes (risers) located in an insulated box with a glass cover as the top surface. The FPC does not require tracking and usually, its inclination is chosen for optimal seasonal or annual operation. Flat plate collector, can be a best option because it,

a. Can utilize Beam and diffuse both radiations (Kalogirou, 2004) (Nixon et al., 2010)
b. Low cost and complexity (Eldighidy & Taha, 1983)

(Eldighidy & Taha, 1983) has performed a study on the optimization of the FPC by testing different tube diameters and working fluids such as R11, R21 and R113. They found that higher flow rates enhanced the system’s performance, and that the overall system efficiency was 6%.

(Marion et al., 2012) investigated single and double glazing FPC as well as different organic fluids (R134a, R227ea, and R365mfc) in the ORC. By optimizing their system, they found a maximum efficiency of 11%. Their results said that the overflow increases the thermal power Q_ b, reduces the collector temperature e hence heat losses, but at the expense of the collector exergy production and Rankine cycle efficiency. Underflow decreases the thermal power Q_ b, increases the collector temperature and hence heat losses, again at the expense of the collector exergy production, for R134a, using an optimized collector increases the optimum net power produced from 78% when G ¼ 600 W m2 to 52% for G ¼ 900 W m2.

(Marion et al., 2012) had also found impact of wind speed on an FPC-ORC. They found that a wind speed increase from 0 m/s to 10 m/s reduced the collector’s thermal efficiency from 48% to 34% and consequently reduced the system efficiency from 6.9% to 3.1%.

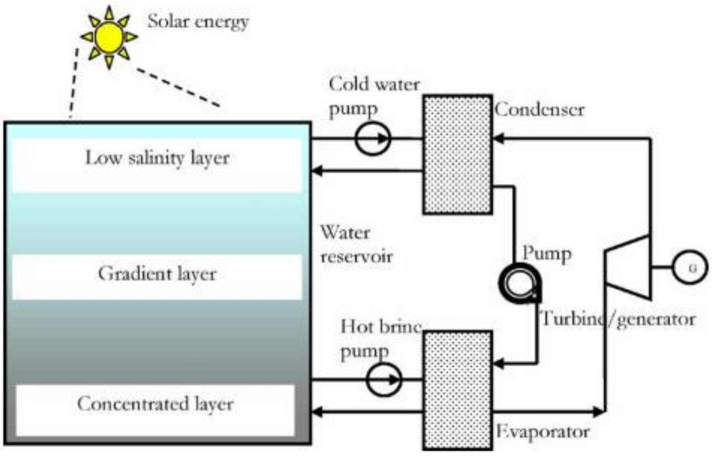


Figure 5: Solar Based ORC schematic (Tchanche et al., 2011)

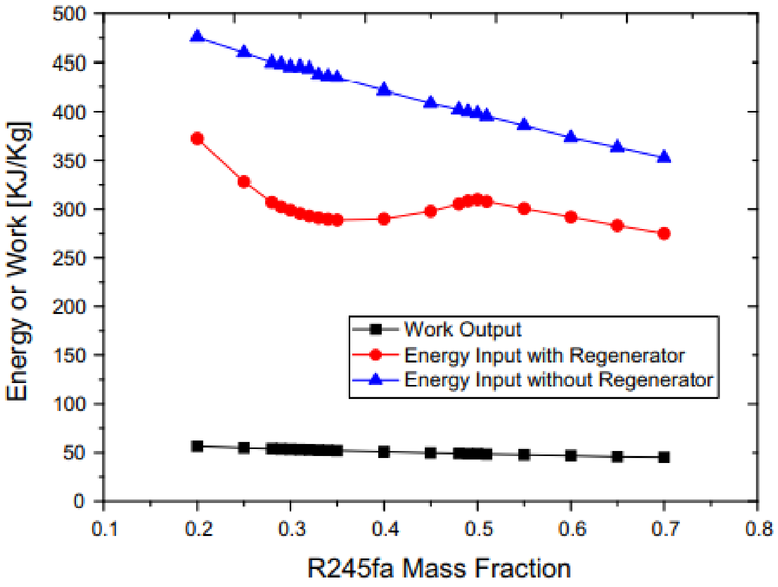
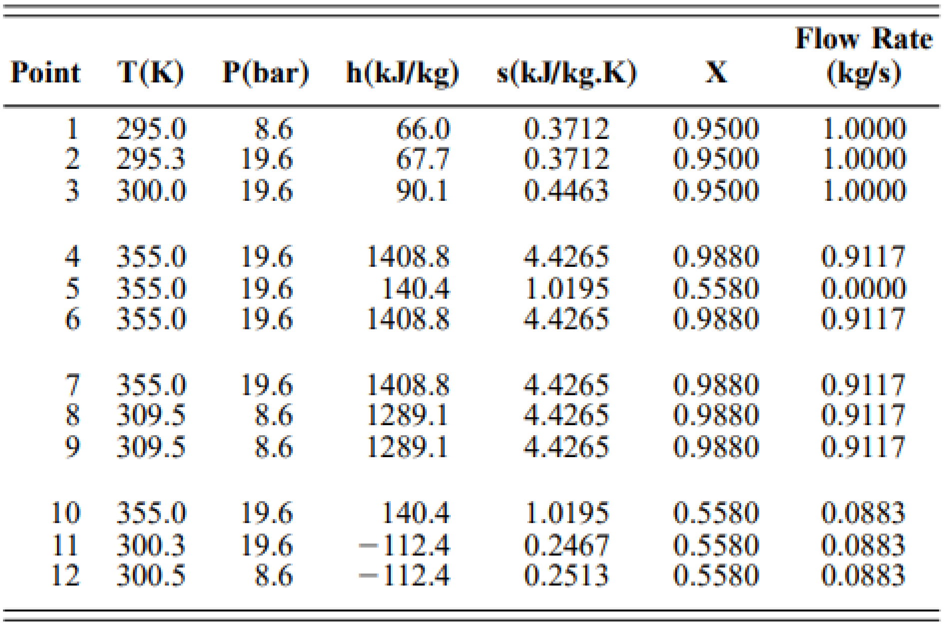


Figure 6: Solar Based ORC schematic (Lu & Goswami, 2003)

The optimization studies were conducted and minimum cooling temperatures and preferable operating conditions were determined by (Lu & Goswami, 2003).

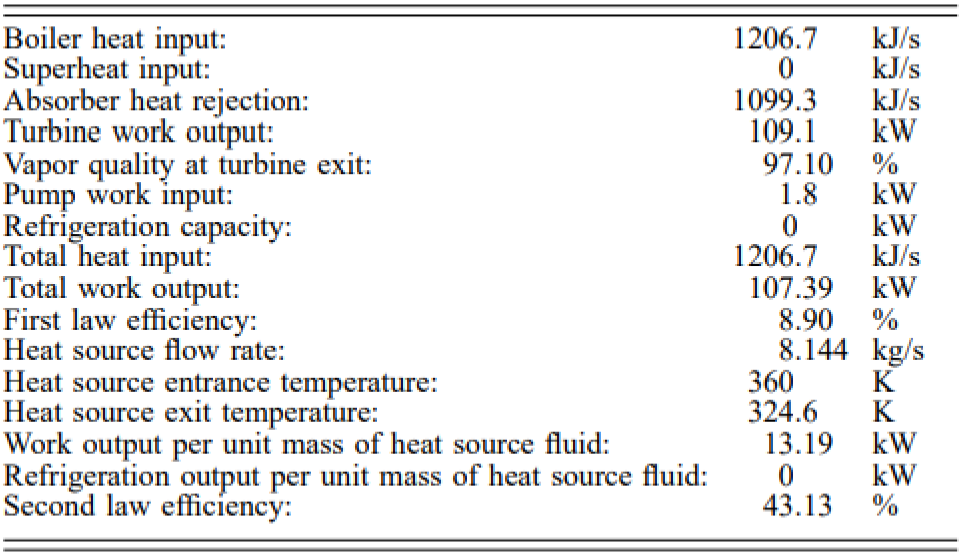
Table 1: Optimum working conditions based on maximum work output (360 K heat source temperature, 290 K ambient temperature)



Point	T(K)	P(bar)	h(kJ/kg)	s(kJ/kg.K)	X	Flow Rate (kg/s)
1	295.0	8.6	66.0	0.3712	0.9500	1.0000
2	295.3	19.6	67.7	0.3712	0.9500	1.0000
3	300.0	19.6	90.1	0.4463	0.9500	1.0000
4	355.0	19.6	1408.8	4.4265	0.9880	0.9117
5	355.0	19.6	140.4	1.0195	0.5580	0.0000
6	355.0	19.6	1408.8	4.4265	0.9880	0.9117
7	355.0	19.6	1408.8	4.4265	0.9880	0.9117
8	309.5	8.6	1289.1	4.4265	0.9880	0.9117
9	309.5	8.6	1289.1	4.4265	0.9880	0.9117
10	355.0	19.6	140.4	1.0195	0.5580	0.0883
11	300.3	19.6	−112.4	0.2467	0.5580	0.0883
12	300.5	8.6	−112.4	0.2513	0.5580	0.0883

Maximum temperature 360K, and utilization of flat plate collector.

Table 2: Cycle Performance parameters for conditions in Table 3 (Lu & Goswami, 2003)



Boiler heat input:	1206.7	kJ/s
Superheat input:	0	kJ/s
Absorber heat rejection:	1099.3	kJ/s
Turbine work output:	109.1	kW
Vapor quality at turbine exit:	97.10	%
Pump work input:	1.8	kW
Refrigeration capacity:	0	kW
Total heat input:	1206.7	kJ/s
Total work output:	107.39	kW
First law efficiency:	8.90	%
Heat source flow rate:	8.144	kg/s
Heat source entrance temperature:	360	K
Heat source exit temperature:	324.6	K
Work output per unit mass of heat source fluid:	13.19	kW
Refrigeration output per unit mass of heat source fluid:	0	kW
Second law efficiency:	43.13	%

3.5 Low temperature Rankine cycle applications:

3 main categories of applications are conceivable for the Organic Rankine Cycle (or more generally for the low temperature Rankine cycle):

Waste heat recovery

The Organic Rankine Cycle (ORC) is most useful when waste heat is recovered and used. Combined Heat and Power (CHP) plants, notably those using biomass as fuel, and general heat recovery applications from a variety of potential sources are the two main areas where ORCs are particularly helpful. ORCs can be extremely important for maximizing energy efficiency in CHP systems. These plants effectively utilize the available energy by producing both heat and power. A small-scale cogeneration facility combined with a home water heater is one illustration. There are two alternative configurations for the ORC system in this set up. The first choice is to give priority to the power generation cycle, in which the heat produced is promptly recovered from the boiler and the hot water is produced at a lower temperature in the ORC system's condenser. The second option is to priorities the generation of hot water, in which case the heat recovered from the combustion chamber's exhaust gases will be used as the ORC system's heat source. With this flexibility, waste heat may be used effectively in CHP plants, increasing total energy efficiency and lowering energy waste. ORCs can be used in a variety of heat recovery applications in addition to CHP facilities. There are several potentials for waste heat recovery in industrial and agricultural activities. Examples of potential heat sources for an ORC system include waste heat from the fermentation of organic products, hot exhausts from ovens or furnaces, exhaust gases from moving vehicles, intercooling of compressors, and condensers of power cycles. Industries and processes can increase their energy efficiency, lower their energy costs, and have a smaller environmental effect by capturing and using this waste heat. Because of its adaptability, ORCs can effectively recover waste heat from a variety of sources, allowing for the conversion of low-grade heat into usable electrical or thermal energy. By maximizing energy use and lowering reliance on additional fuel usage, this supports sustainability initiatives. The use of ORCs for waste heat recovery in a variety of applications has the potential to greatly improve overall energy sustainability as attention is being paid to energy efficiency and environmental responsibility.

In conclusion, waste heat recovery applications greatly benefit from the ORC technology. Its use in CHP facilities, especially those that burn biomass for fuel, enables effective energy generation. Additionally, ORCs have the ability to recover waste heat from agricultural and industrial activities, providing chances to increase energy efficiency and lessen environmental effects. We can efficiently use low-grade heat sources and contribute to a more sustainable and effective energy landscape by using waste heat through ORCs.

Solar thermal power

Compared to the conventional steam Rankine cycle, the use of Organic Rankine Cycles (ORCs) with solar parabolic trough technology offers a number of major benefits. The ORC makes it possible to operate the collector at lower temperatures, increasing collecting efficiency and lowering ambient losses. These advantages therefore create opportunities for decreasing the size of solar fields needed for power production.

In numerous research that have been published in the literature, the integration of ORCs in parabolic trough solar power plants has been investigated. n-Pentane was used as the working fluid with an intake temperature of 204°C in the parabolic trough ORC Solar Power Plant provided by S. Canada as one example [Canada, 2005]. This application shows that ORCs can successfully use parabolic trough technology to capture solar energy. Malick, E.H. For his doctoral thesis [Kane, 2002], Kane investigated the integration of two superposed ORCs on a parabolic trough solar collector. This study looked at a topping cycle with R-123 as the working fluid and a bottoming cycle with R-134a. This study demonstrated the possibility for increasing the overall performance and efficiency of solar power plants by combining several ORCs with parabolic troughs.

There are several significant advantages of using ORCs in solar parabolic trough technology. The ORC system can run more effectively and capture more of the solar energy available by allowing lower collector temperatures. This results in increased electricity production and overall system performance. The increased thermal efficiency caused by ORCs' lower ambient losses also helps to maximize the conversion of solar heat into electricity. The use of ORCs in parabolic trough systems also provides versatility in terms of choosing the working fluid. Based on their properties at different temperatures and pressures, different organic fluids can be used, allowing for customization in accordance with the particular operating circumstances and goals of the solar power plant. Overall, the use of ORCs in solar parabolic trough technology shows the potential to improve the effectiveness, performance, and affordability of solar energy generation. Solar fields can be optimised for more effective and sustainable solar energy use by utilising ORC advantages, such as lower collector temperatures and fewer ambient losses. To expand the use of solar energy as a practical renewable energy source and further improve the integration of ORCs in solar parabolic trough systems, continued research and development in this field are essential.

Geothermal plants

A valuable and renewable energy source that provides a wide variety of temperature fluctuations is geothermal heat sources. However, the efficiency of power plants using low-temperature geothermal sources—typically below 100°C—depends significantly on the surrounding temperature, which directly influences the heat sink temperature.

The heat from the geothermal fluid is transferred to a working fluid in a binary cycle system in low-temperature geothermal power facilities. The working fluid can vaporise and power a turbine to produce electricity because it has a lower boiling point than water. The temperature difference between the geothermal fluid and the heat sink, which is commonly ambient air or water, affects how effective this process is. There is a greater temperature difference between the geothermal fluid and the heat sink in areas with lower ambient temperatures because the heat sink temperature is lower. Because more heat can be transmitted to the working fluid due to the greater temperature difference, efficiency is increased. The temperature of the heat sink is higher in places with higher ambient temperatures, which reduces the temperature differential and the power plant's overall efficiency.

Various tactics can be used to lessen the impact of ambient temperature on low-temperature geothermal power plant efficiency. Utilizing cutting-edge heat exchanger technologies and enhancing the working fluid properties are two ways to improve the heat transfer process. This could increase the amount of heat exchange between the working fluid and the geothermal fluid, enhancing the system as a whole. Hybrid systems, which combine low-temperature geothermal power generation with other renewable energy technologies, provide an alternative answer. For instance, combining solar thermal or biomass systems with a low-temperature geothermal plant might add more heat input when the outside temperature is lower. Regardless of changes in the outside temperature, this hybridization strategy offers more reliable and effective electricity generation all year long. The effectiveness of low-temperature geothermal power plants has also been significantly increased because to developments in Organic Rankine Cycle (ORC) technology. Because ORC systems can function at lower temperature differentials, they are excellent for capturing energy from geothermal sources that produce heat at low temperatures. Even in areas with relatively high ambient temperatures, the use of ORC technology enables the efficient conversion of geothermal heat into power.

In conclusion, the ambient temperature, which influences the heat sink temperature, has a significant impact on the efficiency of low-temperature geothermal power plants. Higher ambient temperatures can cause a system's overall efficiency to decrease, while lower ambient temperatures typically lead to increased efficiency. However, the efficiency of low-temperature geothermal power plants can be optimised, ensuring a more dependable and sustainable energy generation from this valuable resource, through the implementation of advanced heat transfer technologies, hybridization with other renewable energy sources, and the use of ORC technology.

3.6 Applications of ORCs

Waste heat recovery offers a substantial opportunity for sustainability and energy efficiency in a variety of industries. Waste heat is frequently produced in large quantities during industrial processes including the production of chemicals, steel, and refinery. Industries can increase their energy efficiency and lessen their total environmental impact by successfully capturing and using this heat.

Waste heat recovery has a plethora of different uses. For instance, waste heat from exhaust gases, flue gases, or process streams can be used in industrial settings to pre-heat combustion air, water, or other fluids. This strategy decreases the need for additional fuel use, lowers greenhouse gas emissions, and conserves energy. Waste heat recovery systems can be combined with gas turbines, internal combustion engines or steam boilers in the context of power generation to increase energy output. These systems combine a heat exchanger and a power production device like an ORC to generate useable energy by extracting heat from the exhaust fumes or cooling water. Waste heat recovery has advantages for the economy as well as the environment. Industries can lower their energy expenses by relying less on conventional energy sources by capturing and using waste heat. The facility can use the recovered heat for a variety of things, like space heating, industrial process powering, or preheating feedwater. By lowering the requirement for extra energy inputs, this eventually saves a lot of money. Further offsetting energy costs and maybe generating a new source of income for the facility, waste heat recovery systems can make money by selling excess electricity to the local grid. A more dependable and robust energy infrastructure is also facilitated by the use of waste heat recovery devices. Industries can increase their energy independence and decrease their susceptibility to supply disruptions and price variations in the energy market by making the most use of the thermal energy that is currently available. Waste heat recovery is a decentralized energy option that enables companies to produce electricity locally and reduce their reliance on the grid. By assuring continuous operations and reducing downtime, this localized power generation can help reduce the hazards related to power outages and system instability.

Organic Rankine Cycles (ORCs) have become a well-liked technology for the conversion and recovery of waste heat. Because they use organic working fluids with lower boiling temperatures than water, ORCs can harness low-grade heat sources to produce electricity. The working fluid is vaporized by the waste heat, which subsequently powers a turbine or an expanded to create energy. ORCs are useful for a variety of waste heat recovery applications because of their flexibility in the heat source temperature range they can handle. Waste heat recovery can be used outside of industrial operations in various fields. For instance, waste heat from internal combustion engines in the automobile sector can be captured and turned into energy to power auxiliary systems, lowering the load on the engine and increasing fuel economy. Waste heat from cooling processes can be used to heat water or interior spaces, and waste heat recovery systems linked with HVAC systems can be beneficial for both residential and commercial buildings. In addition, waste heat recovery goes beyond uses in the industrial sector. With the use of ORC technology, electricity may be produced from specialized low-temperature heat sources like solar concentrators, geothermal energy, ocean thermal energy conversion, and biomass. These renewable energy sources frequently generate heat at temperatures that are unsuitable for using them to produce electricity. An effective way to turn this low-grade heat into useful electricity is through waste heat recovery utilizing ORCs, which helps to diversify the energy mix and lessen dependency on fossil fuels. By converting waste into a useful resource, waste heat recovery also adheres to the ideals of a circular economy. Heat is caught and put to use instead of being released into the environment unutilized, which minimizes waste and increases resource efficiency. Waste heat is seen as a valuable asset rather than a byproduct to be wasted, which encourages a more sustainable and responsible use of resources. We may transition to a more circular and regenerative model where waste is reduced, and energy resources are utilised as efficiently as possible by integrating waste heat recovery systems into industrial processes and energy production.

In conclusion, waste heat recovery is a flexible and environmentally friendly strategy with a lot of potential for raising the usage of renewable energy sources, lowering greenhouse gas emissions, and improving energy efficiency. Industries, residential structures, and the larger energy sector can take substantial steps towards a greener and more efficient future by introducing technology like ORCs and investigating other waste heat sources. Waste heat recovery has several advantages from the perspectives of the environment, the economy, and resilience. Industries may increase their energy efficiency, lower expenses, and reduce greenhouse gas emissions by using waste heat through technology like ORCs. More resilient energy infrastructure is made possible through waste heat recovery, which increases energy independence and decreases sensitivity to supply disruptions. It also adheres to the circular economy's guiding principles by maximizing resource efficiency and reducing waste. Businesses and industries have the chance to improve sustainability, encourage innovation, and contribute to a more sustainable future by using waste heat recovery technologies.

3.7 Other solutions for heat recovery

The ORC is not the only conceivable possibility to recover low grade heat. Some technologies are available and show good efficiencies, some other technologies are still under development but seem promising. Among those technologies, the most interesting ones are the following:

The water-ammonia cycle: When compared to the organic Rankine cycle (ORC), the cycle that uses a mixture of water and ammonia as the working fluid has a number of advantages. The heat exchangers' non-azeotropic temperature profile, which results in better heat transmission, is a major benefit. This temperature profile enables better temperature matching between the heat source and the working fluid at different stages of the cycle, increasing efficiency. This mixture-based cycle may be more efficient than the ORC under certain circumstances. Its higher performance is a result of the mixture's improved heat transfer properties. It's crucial to remember that this cycle's design is more intricate than the ORC. To address the unique properties and needs of the water-ammonia mixture, it often entails adding two pumps and extra heat exchangers. Two pumps are present in the cycle to maintain the required pressure levels across the entire system. After the combination goes through the condenser, Pump 1 is in charge of boosting the pressure, and Pump 2 raises the pressure even further before the mixture enters the evaporator. These pumps make sure that the working fluid is circulated and flows properly, which enables the cycle to function properly. In addition, compared to the ORC, the cycle uses more heat exchangers. These heat exchangers are essential in making it easier for heat to be transferred between the working fluid and the heat source as well as between various cycles' stages. The improved performance is a result of the more effective heat transfer made possible by the increased number of heat exchangers. While the mixture-based cycle does, in some circumstances, offer higher efficiency, it is crucial to take into account the trade-off between efficiency benefits and the resulting rise in system complexity. This cycle's conception and execution call for meticulous thought and engineering know-how. To guarantee optimal performance, considerations including the choice of suitable pumps, heat exchangers, and control systems must be made. In conclusion, the water-ammonia combination cycle offers an improvement over the ORC in terms of improved heat transmission and maybe higher efficiency. However, it is important to carefully control the cycle's design complexity, which includes two pumps and additional heat exchangers. To maximize the advantages of this system, system component selection and optimization are essential.

The supercritical CO2 cycle: Carbon dioxide (CO2) is used as the working fluid in this particular cycle. The fact that the heat source temperature is above the CO2 critical temperature is a noteworthy benefit of employing CO2. This feature gets rid of the pinch point restriction that is generally present in the evaporator of other cycles. The evaporator portion of the cycle performs better due to efficient heat transfer and the lack of a pinch point. Because there is no pinch point and CO2 has favorable thermodynamic characteristics, the cycle using it as the working fluid exhibits good efficiency. When used in applications where the heat source temperature is higher than the CO2 critical temperature, its performance can be especially beneficial. However, this cycle does have certain disadvantages. The necessity for extremely high pressures within the system is a significant problem. When compared to other working fluids, carbon dioxide operates at substantially greater pressures, which might increase installation complexity and cost. To meet the unique needs of CO2 as the working fluid, high-pressure parts and apparatus are required. When adopting this cycle, another factor to take into account is the increased installation cost. Higher initial expenses may result from the specialized equipment required to manage high pressures and related safety precautions. The economic viability and long-term advantages of using CO2 as the working fluid in connection to the particular application and its particular requirements must be carefully considered. In some circumstances, the CO2 cycle might nevertheless provide appealing efficiency and performance benefits despite the difficulties associated with high pressure and installation costs. It's crucial to perform a complete cost-benefit analysis, taking into account elements like the heat source's availability and properties, the desired output of power, and the overall system needs. The advantages of the CO2 cycle can be maximized, and the risks reduced with proper engineering design, which includes the choice of suitable components and system optimization. In conclusion, the cycle's use of carbon dioxide as the working fluid has benefits including good overall efficiency and the absence of a pinch point limitation in the evaporator. However, it is important to carefully evaluate the high-pressure needs and elevated installation costs related to CO2. To ascertain the feasibility and financial sustainability of this cycle, a thorough evaluation of the particular application and an adequate engineering design are required.

The Stirling and the Ericsson cycles: High theoretical efficiency is a characteristic of both the Stirling and Ericsson cycles. However, due to special requirements for effective heat transfer at the regenerator and at the heat source/sink level, their practical applications are somewhat constrained. A set volume of gas, usually helium or hydrogen, is compressed and expanded again within a closed system to power the Stirling cycle. The cycle depends on a regenerator's ability to efficiently transmit heat between the hot and cold ends of the system. Heat can be transferred between the working fluid and the surroundings thanks to the regenerator's dual function as a heat exchanger and thermal energy storage device. High heat transfer efficiency in the regenerator, however, is difficult to achieve because it necessitates a carefully designed. The Ericsson cycle, which also relies on external heat and work exchanges, is based on a closed-loop thermodynamic process. To perform at its best, it also needs effective heat transfer between the heat source and the heat sink. In order for the Ericsson cycle to function normally, effective heat exchange between the working fluid and the external heat sources or sinks is required for both the constant pressure heat addition process and the constant pressure heat rejection phase. Their practical uses have been rather constrained in comparison to other thermodynamic cycles like the Rankine or Brayton cycles because of the particular heat transfer needs in both cycles. The Stirling and Ericsson cycle has not been widely adopted due to difficulties in establishing effective heat transfer in the regenerator and at the heat source/sink levels. However, these cycles have been effectively used in a few specialized applications. Stirling engines, for instance, have been used in some solar power systems when it is possible to take advantage of the high temperature differences between the ambient temperature and the concentrated solar heat source. In some refrigeration and heat pump applications, Ericsson cycles have been used because the use of unusual working fluids and careful design can optimize their performance. To get over the heat transfer restrictions and expand the Stirling and Ericsson cycles' useful practical applications, more study and technological development are required. Improved heat transfer efficiency and a wider application of these cycles in different energy conversion systems could result from innovations in regenerator design, materials, and manufacturing techniques.

The thermoelectric generator: The thermoelectric generator (TEG), which functions using the Seebeck effect, is another innovation worth highlighting. TEG systems immediately convert heat into electricity by connecting modules in series. TEGs typically perform less efficiently than the Stirling and Ericsson cycles, but with improvements in materials and design, they offer a great deal of potential for growth and might one day be commercially feasible. The simplicity of TEG systems is one of their significant benefits. They are more dependable and durable because they don't have any moving parts. The absence of moving parts lowers the possibility of mechanical breakdowns and minimizes the need for maintenance, potentially extending operational lifetimes. In applications where simplicity, compactness, and longevity are sought, TEG technology can be especially helpful. For instance, they have been utilised in portable electronic gadgets, waste heat recovery from industrial operations, and remote and off-grid power generation systems. TEG systems' total efficiency, however, is currently less than that of other power generation technologies. The thermoelectric materials' characteristics, such as their thermoelectric figure of merit (ZT), have an impact on how much heat can be converted to electricity in TEGs. To increase the effectiveness and performance of TEG systems, research is aimed at creating new materials with improved thermoelectric properties. For some applications, the Organic Rankine Cycle (ORC) is frequently chosen over TEG technology in this context. The ORC has benefits in terms of simplicity and accessibility to affordable, widely used components. It is a desirable option for numerous energy conversion applications due to its established and mature nature, as well as the vast variety of working fluids and system components that are readily available on the open market. Although TEG technology has great potential and there are continuous research efforts to improve it, the ORC is now preferred due to its well-established track record, widespread acceptance, and strong industry support. Future breakthroughs may result in greater efficiency, cost effectiveness, and more application prospects for both systems as TEG and ORC technologies continue to advance.

CHAPTER 4: SUSTAINABLE DEVELOPMENT GOALS

4.1 SDGs related to ORC

Our programmed supports Sustainable Development Goal (SDG) 7, which aims to guarantee that everyone has access to reasonably priced, dependable, sustainable, and contemporary energy. We contribute to the creation of contemporary, dependable, and sustainable energy by utilizing the plentiful solar power of the sun in our power plants by utilizing the Organic Rankine Cycle (ORC) technology. Cost-effectiveness is a key benefit of ORC power plants, particularly on a larger scale. The cost of building ORC systems falls as technology advances and is more frequently used, making them more accessible and cheaper for a wider range of consumers. A major factor in attaining SDG 7 is cost because it directly affects fair access to power. Additionally, SDGs 12 and 13 are directly addressed by our project. SDG 12 is concerned with encouraging sustainable production and consumption practices. ORC power plants assist in attaining this aim by encouraging the use of environmentally friendly techniques for energy generation and use. We can use less limited resources and have a smaller negative impact on the environment by switching to sustainable energy sources like solar electricity. The urgency of taking immediate action to prevent climate change and its effects is emphasized in SDG 13. By producing clean and environmentally friendly energy, ORC power plants are essential in this regard. Because ORC systems emit fewer greenhouse gases than conventional power generation systems, which rely on fossil fuels, they contribute to the reduction of carbon dioxide and other dangerous pollutants in the atmosphere. This supports the transition to a more sustainable and low-carbon future and is in line with global efforts to combat climate change.

In conclusion, our project's use of ORC technology promotes sustainable production and consumption patterns (SDG 12) and helps to mitigate climate change (SDG 13), in addition to enabling inexpensive, dependable, sustainable, and contemporary energy access (SDG 7). We work to build a more resilient and sustainable future for everyone by advancing these sustainable development goals while also tackling the world's energy crisis.

CHAPTER 5: WORKING FLUID

5.1 Working Fluid Selection

The selection of the working fluid is of key importance in low temperature Rankine Cycles. Because of the low temperature, heat transfer inefficiencies are highly prejudicial to the efficiency. These inefficiencies depend very strongly on the thermodynamic characteristics of the fluid and on the operating conditions.

Optimal characteristics of the working fluid:

Isentropic saturation vapor curve

The Organic Rankine Cycle (ORC), which differs from the conventional Rankine cycle, focuses on the recovery of low-grade thermal power. The working fluid does not need to be extensively superheated in the ORC like it does in the conventional cycle. It is preferable to have a modest degree of superheating at the evaporator's exhaust instead. The best thermodynamic qualities of the working fluid can be determined by taking this design factor into account. Effective heat recovery in an ORC system depends on the working fluid selection. The low-grade heat source and the cycle's operating parameters must be consistent with the fluid's thermodynamic characteristics. The working fluid must possess the necessary qualities to effectively absorb heat from the heat source and undergo phase transitions during the cycle because the ORC operates at lower temperatures than the conventional Rankine cycle. The critical temperature, latent heat of vaporization, thermal stability, and environmental impact of the working fluid must all be carefully considered. To avoid the development of a pinch point and guarantee effective heat transmission in the evaporator, the working fluid should have a critical temperature that is higher than the heat source's maximum temperature. In order to enable efficient heat absorption and conversion inside the cycle, it should also have a suitable latent heat of vaporization.

Low freezing point, high stability temperature

Chemical stability at high temperatures is a key factor in the choice of working fluids for Organic Rankine Cycle (ORC) systems. Organic fluids, as opposed to water, which is frequently utilised in conventional Rankine cycles, are more prone to chemical deteriorations and decomposition when subjected to high temperatures. The greatest temperature that can be used as the hot source in an ORC system depends critically on the chemical stability of the working fluid. The system may operate worse overall and experience fluid degradation, an increase in corrosion rates, and other negative impacts if the temperature limit is exceeded. Selecting organic fluids that can keep their chemical stability and integrity within the appropriate temperature range is therefore necessary. The working fluid's freezing point should also be taken into account in addition to the chemical stability of the substance. To avoid any solidification or phase change problems that could impair fluid flow and hinder the system's functionality, the freezing point should be lower than the lowest temperature experienced throughout the ORC cycle. Researchers and engineers have created a variety of organic fluids specifically suited for high-temperature use in ORC systems to overcome these issues. The greater chemical stability, higher boiling points, and lower freezing points of these fluids allow them to function well at high temperatures without impairing the system's performance. The thermodynamic characteristics, chemical stability, environmental impact, and compatibility with the particular application and operating circumstances of the ORC system must all be considered when choosing the working fluid. To maintain the long-term dependability and efficiency of ORC systems, intensive research and development efforts are continuously made to identify and optimize working fluids that give the right thermodynamic properties and enough chemical stability. In conclusion, the chemical stability at high temperatures and the freezing points of organic working fluids must be taken into account when choosing them for ORC systems. Engineers can design ORC systems that efficiently harness low-grade heat sources and provide reliable and sustainable power while minimizing the hazards associated with fluid deterioration by selecting fluids that display suitable stability and compatibility with the operating circumstances.

High heat of vaporization and density

In an Organic Rankine Cycle (ORC) system, choosing a working fluid with a high latent heat and density can really offer a number of advantages, especially in the evaporator stage. By vaporizing the working fluid and absorbing heat from the hot source, the evaporator transforms thermal energy into mechanical or electrical energy. A working fluid with a high latent heat can vaporize with more energy absorbed from the heat source. Accordingly, a higher amount of energy can be delivered to the working fluid for a given heat input, increasing system efficiency. The required flow rate of the working fluid can be lowered while still attaining the acceptable power output by maximizing the energy absorption in the evaporator. The benefits of this flow rate reduction are numerous. First off, a reduced flow rate allows for the use of smaller pipes, valves, and heat exchangers in the system. This may lead to cost savings and a decrease in the amount of materials needed to build the facility. Second, a decreased flow rate may result in less pumping energy use. The pump's energy consumption is closely correlated with the flow rate, which is in charge of circulating the working fluid throughout the cycle. The pumping power requirements can be decreased by minimizing the flow rate, which lowers operating costs and boosts system effectiveness overall. A working fluid with a high density also enables a higher concentration of energy in a given volume. In applications where space is at a premium, this implies that the working fluid can store more thermal energy. Additionally, it helps make systems more compact, which is advantageous in mobile or portable ORC systems. It is crucial to remember that choosing a working fluid necessitates making a trade-off between its thermodynamic characteristics and other factors including its cost, availability, and impact on the environment. To guarantee optimum system performance and long-term reliability, a variety of criteria should be considered while selecting the working fluid. In conclusion, choosing a working fluid with a high latent heat and density can improve an ORC system's capacity to absorb energy, lower the needed flow rate, reduce the size of the facility, and use fewer pumps. The efficiency, cost-effectiveness, and general performance of the ORC system are all enhanced by these advantages.

Low environmental impact

The Ozone Depleting Potential (ODP) gauges a substance's capacity to contribute to the ozone layer's deterioration on Earth. When discharged into the atmosphere, substances with high ODP levels have a larger potential to thin the ozone layer. To minimize environmental harm and adhere to international accords like the Montreal Protocol, which aims to protect the ozone layer, it is essential to use a working fluid with a low or zero ODP.

In comparison to carbon dioxide (CO2), the Greenhouse Warming capacity (GWP) measures a substance's capacity to contribute to global warming over a given time period, typically 100 years. It displays a substance's capacity to trap heat in the atmosphere and support the greenhouse effect. The ODP and GWP values of prospective working fluids for an ORC system, as well as other elements like thermodynamic characteristics, chemical stability, toxicity, flammability, and availability, should all be taken into account. As substitutes for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which have high ODP and GWP values, several organic fluids, including hydrofluoroolefins (HFOs) and hydrofluorocarbons (HFCs), have been created. Additionally, on-going research and development initiatives concentrate on the identification and application of environmentally friendly working fluids with low ODP and GWP as well as enhanced thermodynamic performance. When choosing a working fluid for an ORC system or any other energy application, the goal is to achieve a balance between system effectiveness, environmental impact, and legal requirements. In conclusion, taking a working fluid's ODP and GWP into account is essential for reducing the environmental impact of an ORC system. We may support the preservation of the ozone layer and reduce the effects of climate change by selecting a fluid with low ODP and GWP values, in line with the Sustainable Development Goals and global environmental accords.

Safety

When choosing a fluid for an Organic Rankine Cycle (ORC) system, safety elements of the working fluid are just as important as the environmental factors already discussed. To ensure the safety of the system, the operators, and the environment, the fluid must have specific qualities. Because corrosive fluids can harm the ORC system's components, causing operational problems and potential leaks, non-corrosiveness is a crucial quality. The system's integrity may be jeopardized by corrosion, which can also decrease system performance and raise maintenance costs. Therefore, to reduce the possibility of corrosion-related issues, it is advisable to use a working fluid that is non-corrosive. Another important factor to take into account is flammability, particularly when the ORC system is situated in an area where fire threats are a concern. The overall safety of the facility is increased and the likelihood of fire incidents is decreased by using a non-flammable working fluid. Non-flammable fluids reduce the possibility of fires and explosions in the event of a leak or malfunction since they are less likely to catch fire or spread flames. Another crucial consideration when choosing a working fluid for an ORC system is toxicity. In order to protect the operators' safety and the environment, the fluid should not be poisonous. A non-toxic fluid reduces the health hazards associated with exposure to dangerous compounds in the event of a leak or unintentional release. A useful tool for determining a fluid's level of hazard is the ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) safety classification system. Refrigerants and working fluids are categorized according to their toxicity and flammability traits. The ASHRAE safety categorization can aid in the decision-making process by highlighting fluids that adhere to certain safety standards and are appropriate for the intended use and location of the ORC system. Overall, a working fluid's safety characteristics, such as non-corrosiveness, non-flammability, non-toxicity, and conformity to safety classifications, are crucial to maintaining the safe and dependable functioning of an ORC system. Potential dangers can be reduced, and the system's general safety can be improved by choosing a fluid that complies with certain safety standards, safeguarding.

Good availability and low cost

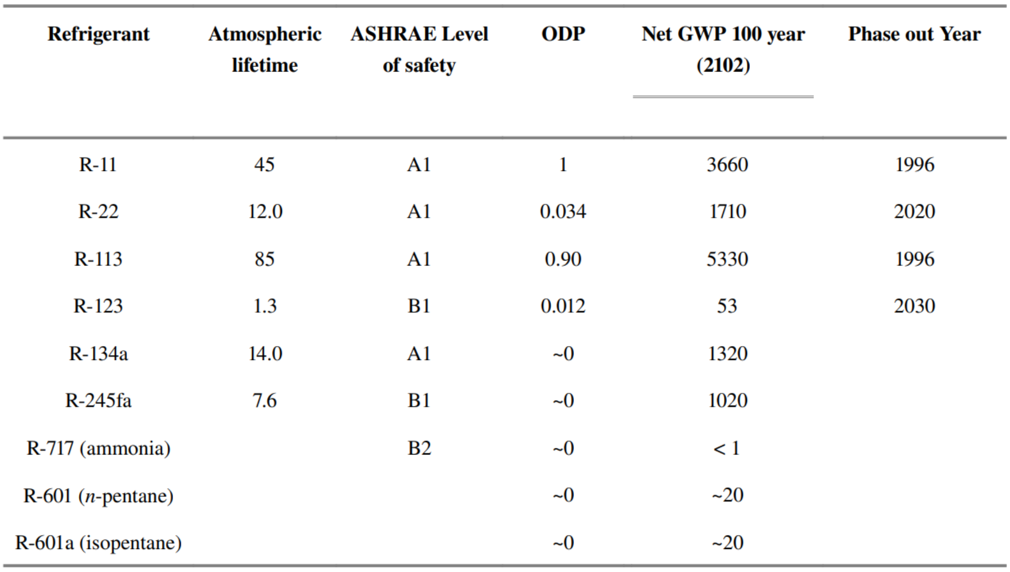
It's possible that the price of the conventional refrigerants used in Organic Rankine Cycle (ORC) systems will prevent them from being widely used. However, there may be ways to address this problem and reduce the cost of ORC technology. Increasing the production of conventional refrigerants is one approach. Faster demand and faster production rates can result in economies of scale, which lowers manufacturing costs. This might lead to classic refrigerants being priced more reasonably, making them more available for ORC applications. Investigating the use of affordable hydrocarbons as substitute working fluids is an additional strategy. Propane (R290) and isobutane (R600a), two hydrocarbons, are inexpensive and widely accessible materials. They are capable of providing effective energy conversion and have favourable thermodynamic characteristics for ORC applications. These hydrocarbons are considered environmentally beneficial since they have low global warming potential (GWP) and low ozone depletion potential (ODP). Low-cost hydrocarbons can be used as working fluids, which lowers the overall system cost of an ORC. Since hydrocarbons are often less expensive than conventional refrigerants, ORC systems can be made and run at significant cost savings. The usage of inexpensive hydrocarbons also supports the pursuit of more cost-effective and sustainable energy sources. The use of hydrocarbons as working fluids, it should be noted, necessitates careful consideration of safety issues. Since hydrocarbons might catch fire, using them calls for the right safety precautions, such as leak detection systems, adequate ventilation, and adherence to safety rules and guidelines. It's essential to follow proper installation, handling, and maintenance procedures to reduce any dangers that may be present. In conclusion, methods like boosting production can be used to lower the price of conventional refrigerants for ORC systems. Additionally, investigating the use of inexpensive hydrocarbons as working fluids is a possible route to increase the economic viability of ORC technology. The objective of establishing economical and sustainable energy generation through ORC can be further realized by integrating cost-effective solutions with environmentally favorable alternatives.

Acceptable pressures

Very high pressures have a negative impact on the reliability of the cycle. They lead to the need for more resistant and more expensive facilities.

A quick review of the literature about low temperature Rankine cycles gives an idea of the usual working fluids used in ORC systems. Table 1 and 2 give the main characteristics of those fluids, from an environmental and thermodynamic point of view.

Table 3: Environmental data for historical, current and candidate chiller refrigerants



Refrigerant	Atmospheric lifetime	ASHRAE Level of safety	ODP	Net GWP 100 year (2102)	Phase out Year
R-11	45	A1	1	3660	1996
R-22	12.0	A1	0.034	1710	2020
R-113	85	A1	0.90	5330	1996
R-123	1.3	B1	0.012	53	2030
R-134a	14.0	A1	~0	1320	
R-245fa	7.6	B1	~0	1020	
R-717 (ammonia)		B2	~0	< 1	
R-601 (*n*-pentane)			~0	~20	
R-601a (isopentane)			~0	~20	

R134a is considered efficient for the application in this work due to several reasons. Firstly, it falls within the working temperature range required for the heat source and heat sink in the envisaged system, which ranges from 100 to 200 °C for the heat source and 10 to 50 °C for the heat sink. This makes R134a a suitable candidate among the listed fluids since it can operate within this specific temperature range.

Moreover, R134a is known for its favorable thermodynamic properties, including its relatively high critical temperature and low boiling point. These properties enable efficient heat transfer and facilitate the conversion of thermal energy from the heat source to mechanical work in the organic Rankine cycle (ORC) process.

Additionally, R134a is an environmentally friendly choice compared to fluids like R-11 and R-113, which have a high ozone-depleting potential (ODP) and were phased out due to their detrimental impact on the ozone layer. In contrast, R134a has a significantly lower ODP and has become widely used as a replacement for ozone-depleting substances in various applications.

Considering these factors, including its compatibility with the required temperature range, favorable thermodynamic properties, environmental friendliness, and safety, R134a emerges as an efficient and suitable choice for the specific application described in this work.

The main parameter to take into account is the efficiency of the cycle with each one of those fluids. Several simulations performed with different working fluids are proposed in the literature and give an idea of their potential efficiencies:

CHAPTER 6: COMPONENTS OF ORC

6.1 Scroll Expander

The scroll expander is a positive displacement mechanism. It is initially a scroll compressor, converted to run in expander mode. The original scroll compressor is an oil free air compressor, with a swept volume of 148 cm^3 and an internal built-in volume ratio of 4.1.

6.1.1 Operating principle of a scroll compressor

A scroll compressor is constructed of two spirals, a stationary one and a mobile one. The movable scroll circles eccentrically without rotating, effectively trapping and compressing pockets of fluid between the scrolls. As seen in Figure 5, in compressor mode, the fluid is confined in two pockets at the edge of the two spirals. As the outer spiral orbits, the volume of the two confined pockets reduces, and the fluid is transported towards the center. Simultaneously, the pressure of the fluid increases. The pressurized fluid is finally expelled through the discharge port placed in the center of the two spirals. In expander mode, the fluid flows from the center to the periphery.

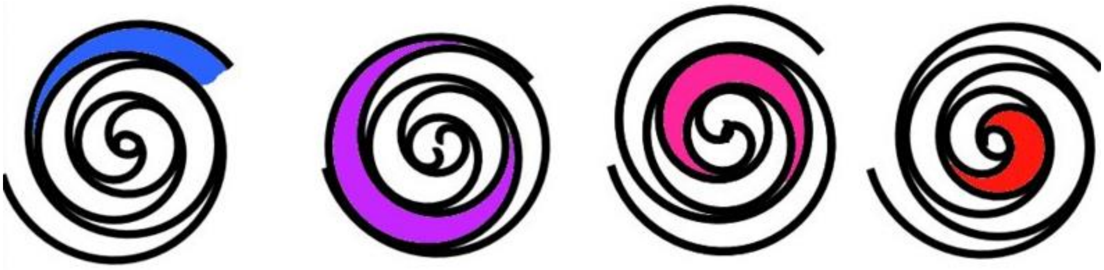


Figure 7: Working principle of the scroll compressor.

The scroll compressor is highly prevalent in refrigeration applications. It has fewer moving parts than reciprocating compressors, which enhances its reliability and decreases the sound pollution. Scroll compressors are renowned to be highly compact and to function very smoothly, as their vibration.

6.1.2 Leakages

There are two forms of leakage in a scroll compressor: the flank leakage is due to the clearance between the flanks of the two scrolls, and the radial leakage is due the clearance between the tip of one scroll and the plate of the other one [Chen et al, 2002].

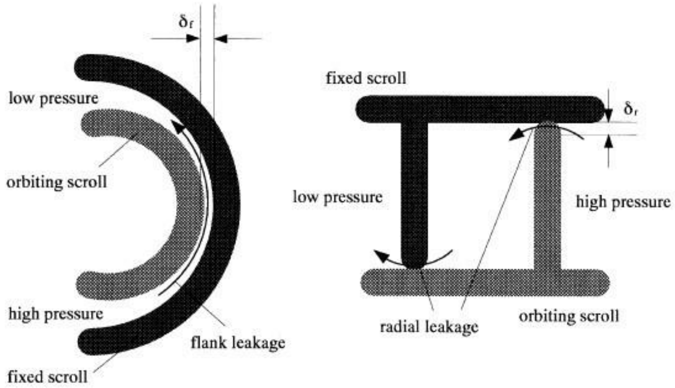


Figure 8: Leakages in a scroll machine

In compression mode, the leakage diminishes the volumetric efficiency and increases the specific compression effort, as the fluid, going from a high-pressure zone to a low-pressure region, needs to be re-compressed. In the same way, the leakage diminishes the output power of a scroll machine operating as expander, as the fluid flows directly from the high-pressure zone to the low-pressure region without producing any meaningful work.

6.1.3 Conversion of the scroll compressor into an expander

Scroll compressors may be greased or not. Lubrication lowers the friction between the two scrolls and reduces the leaking area. However, turning a lubricated scroll compressor into an expander creates many problems:

The rotation taking place in the opposite direction, the oil pump might not work anymore if it is directly attached to the shaft of the compressor. In this situation, a separate oil circuit has to be added. · The compatibility of the working fluid with the lubricating oil is not guaranteed if the compressor has not been designed for ORC fluids.

In order to cope with these challenges, the scroll machine adopted for this test bench is an oil free compressor.

Another criterion taken into account for the choosing of the compressor is the internal built-in ratio: it has to be fitted to the range of pressure ratios imposed to the

expander. With respect to the application researched here, a machine with a high internal built-in volume ratio is selected.
A schematic view of the scroll compressor is given in figure 9.

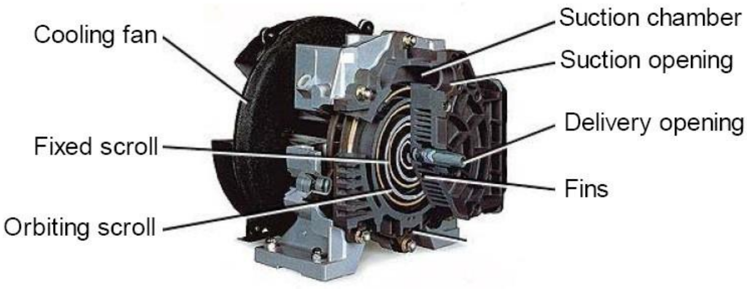


Figure 9: Oil free scroll compressor

Another unique aspect of this gadget is presented. Two different kinds of seals are incorporated into the compressor to lessen leaks:

- A nettled internal seal that is located at the very tip of each scroll (see figure 10). Its function is to lessen radial leakage.
- A circular peripheral seal, located on the fixed scroll, whose role is to isolate the inside of the scroll from the outside and to avoid either external infiltrations or leakages to the outside (depending on the pressure in the peripheral pockets).

Figure 10: Fix and orbiting scrolls

Figure 10 shows a view of the spirals of the two scrolls. The orbiting scroll is situated on the right and the fix scroll on the left. The seals are visible at the tip of each scroll.

The air tightness between the inside and exterior of the compressor is not as important when operating in compressor mode, when air is the working fluid. To stop the entrance of dust and toxins from the outside environment, it is nevertheless crucial to maintain a certain level of sealing. The peripheral seal is essential in preventing the introduction of outside particles, maintaining the compressor's lifetime and effective operation. However, in expander mode, where a higher-pressure fluid replaces air as the working fluid, stopping any leaks becomes crucial. Any working fluid leakage outside the scroll machine results in a cycle loss and must be prevented. Leakage can be decreased by adding an additional layer of material, like Reinzit 200, beneath the outer synthetic tube. By acting as an additional barrier against any potential leaks, this additional layer contributes to an improvement in the sealing's effectiveness. Additionally, by changing the Allen screws, the contact effort between the fixed and orbiting scroll bodies is enhanced, which improves sealing performance. Between the fixed scroll body and the mobile scroll, a sealant glue is used to further improve the sealing qualities. This adhesive aids in forming a tight seal between the two components, reducing the likelihood of any leaks. It's crucial to remember that these changes could cause the friction torque between the fixed and movable scroll bodies to rise. The design and operation of the scroll machine should account for this higher friction because it may have an impact on the system's overall effectiveness and performance. The blocking of the compressor's air-cooling circuit is another intriguing change. In contrast to compression mode, when cooling the gas is desirable, expansion mode does not require cooling the gas and it may even be detrimental. The air-cooling circuit is blocked, which prevents needless cooling and permits the expansion phase to proceed without any cooling effects that can potentially affect the cycle's efficiency.

6.1.4 Justification of the choice of the scroll expander.

The two primary types of expanders must first be distinguished: turbomachines and displacement type machines.

In conventional power plants, the first kind is most prevalent. However, when employed in low temperature heat recovery applications, turbomachines have a number of drawbacks:

- Rather of being directly correlated with shaft speed, the performance of the majority of rotary machines is determined by their peripheral speed (or tip speed), U [m/s]. They feature a perfect tip speed that is typically unaffected by machine size. This value normally ranges between 1 and 10 m/s for scroll compressors, whereas it is close to 300 m/s for turbomachines.
- The tip speed is given by:

  $$U = \frac{2\pi NR}{60}$$

  R being the radius of the rotary machine.
- The turbomachines have a lower radius R when utilized in smaller units, increasing their ideal rotational speed as a result. This extremely high shaft speed results in severe mechanical loads, bearing friction losses, a reduction in bearing life, the need for a larger reduction gear, etc. A excellent illustration is the conventional turbocharger found in cars, which often operates at 100 000 rpm or greater. The high speed in this instance is not an issue because the turbocharger is not mechanically connected to the engine or any other mechanical unit. The disadvantages listed above vanish, however, because a displacement type machine's tip speed is intrinsically lower. Pellell (1993)The pressure ratio of a single stage turbomachine has a low value (typically 1.5), while the displacement machine can have as high-pressure ratios as desired. This latter solution is hence preferred for the single stage expansion usually used in the low temperature Rankine cycle.
- Compared to turbines, volumetric machines are far more resistant to the eventual formation of a liquid phase in the fluid because of their robust construction and slow rotational speeds.

Among all displacement type machines, the scroll machine has been chosen due to its few moving parts, dependability, wide output power range, and high availability [Zanelli, 1994]. The scroll compressor also has the benefit of not requiring admission valves, which are great for use as check valves in compressor mode but require synchronization in expander mode, much like in an internal combustion engine. The scroll expander is not the only option that works with the ORC, though. Additionally, the Wankel engine and screw expander are presented in a few articles as suitable technologies for organic Rankine cycles [Badr, 1991; Persson, 1994].

6.2 Heat Exchangers

The completion of our Organic Rankine Cycle involved overcoming several challenges, with the Heat Exchanger being a particularly crucial component. To design the Boiler, we obtained the outlet temperature of water from the USPCASE NUST Solar thermal Collector through simulations. This water serves as the heat source for our system. The heat exchangers were designed to operate at the low temperature range provided by the collector.

Initially, we determined the number of turns based on specific parameters obtained from the Cycle design. After careful consideration, we concluded that the Boiler should consist of 19 coils made of copper pipe. Each coil has a diameter of 29 cm, with the coil tube having a diameter of 0.5 inches. The length of the boiler shell is 70 cm, and the diameter of the Boiler shell is 39 cm. The temperature difference within the boiler is approximately 48 degrees Celsius.

For the Condenser, we arrived at a similar conclusion. The Condenser consists of 17 coils made of copper pipe, with a coil diameter of 23.7 cm and a coil tube diameter of 0.5 inches. The length of the Condenser shell is 54 cm, while the diameter of the Boiler shell is 27 cm. The temperature difference within the Condenser is approximately 30 degrees Celsius.

Additionally, we have included pictures of the manufacturing process to demonstrate our dedication and hard work on this project.

Figure 11: Manufacturing of our heat exchangers

In our application, the cost of a single plate-type heat exchanger amounted to 1.5 lakh PKR per exchanger. However, through the implementation of coil-type heat exchangers, we were able to significantly reduce the cost to 15 thousand PKR per exchanger. This cost reduction proved to be a valuable advantage for our project.

6.3 Pump

In the process of selecting a suitable pump for the organic Rankine cycle (ORC) utilizing R134a as the working fluid, the GWE Pumpenboese VMC 2-50 model was chosen. This pump, a multistage centrifugal pump, was specifically selected based on several key factors. Firstly, its power consumption of 550 W was within the desired range for the application, ensuring efficient energy usage. Additionally, the multistage design of the pump allows for higher pressure ratios to be achieved, which is essential for the ORC system to operate optimally. The VMC 2-50 model offers reliable performance, durability, and is capable of handling the characteristics of R134a, making it well-suited for this particular application. Overall, the selection of the GWE Pumpenboese VMC 2-50 pump was based on its energy efficiency, suitable pressure capabilities, and compatibility with R134a, all of which are crucial considerations in the successful operation of the organic Rankine cycle.

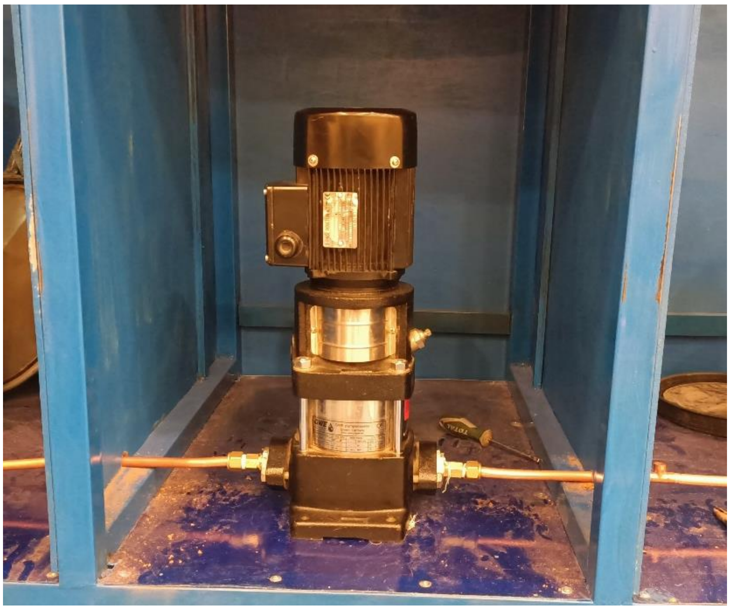


Figure 12: 3-phase Multistage Centrifugal Pump

Table 4: Pump Specifications

Identification Code	22-250-0.55	Motor Rating 0.55 kW			
Pump Model	VMC 2-50	V	400±5%	Pole	2
Discharge-M^3/Hr	1-3.5	Hz	50	R_p	32
Head-M	45-20	IP/Ins C	55/F	W_t	22kg

6.5 Pressure Regulator Valve

The piston-actuated pressure reducing valve, equipped with pressure gauge connections of 1/4" on both sides, and a brass body with female ends, has been selected for the Organic Rankine Cycle (ORC) application. This pressure regulator offers several key features that make it an ideal choice for the system.

Firstly, a pressure regulator is necessary in the ORC to control and maintain a specific pressure level within the system. As the ORC operates within a range of pressures, it is crucial to ensure that the pressure is regulated within safe and desired limits. By utilizing a pressure reducing valve, the inlet pressure can be effectively controlled, thereby allowing for optimized system performance and preventing any potential damage or safety hazards.

The selected pressure reducing valve incorporates an inlet pressure balancing system, which further enhances its functionality. This balancing system ensures that the inlet pressure is maintained evenly across the valve, promoting stability and accurate pressure regulation. With a maximum inlet pressure of 25 bar (362.50 psi), the valve can handle high-pressure applications typically found in ORC systems.

Additionally, the outlet pressure of this regulator is adjustable between 0.5 and 6 bar (7.25 and 87 psi), with a factory pre-set value of 3 bar (43.50 psi). This adjustability allows for flexibility in fine-tuning the pressure output according to specific system requirements, ensuring precise control over the working conditions of the ORC.

The temperature rating of the pressure regulator is another critical consideration, and this particular model can handle a maximum temperature of 80°C (176°F) for water. Given that the ORC operates within high-temperature environments, it is essential to have a pressure regulator capable of withstanding such conditions without compromising its performance or durability.

In terms of functionality, the piston-actuated mechanism inside the pressure reducing valve plays a crucial role. As the pressure in the system fluctuates, the piston responds by modulating the flow of fluid through the valve, effectively reducing the pressure to the desired outlet level. This ensures that the ORC operates within the specified pressure range, maintaining stability and optimal performance.

Due to the unequal pressure ratio between the pump and the Scroll Expander, it was necessary to employ a piston actuated pressure reducing valve. This valve proved instrumental in reducing the pressure within the system. The pump's pressure ratio greatly surpasses that of the Scroll Expander, prompting the utilization of this device to restore the cycle to its initial state. The pressure reducing valve operates within a range of **0.5** to **6** bars. The pump exhibits a pressure ratio of **2.1517**, while the Expander has a ratio of **1.6029**. Consequently, the regulator achieves a pressure reduction of **2.2102** bars.

Figure 13: Piston Actuated Pressure Reducing Valve

Specifications:

Piston Actuated Pressure Reducing Valve with Pressure Gauge Connections 1/4” on both sides With Inlet Pressure Balancing System
Inlet Pressure max. 25 bar (362,50 psi)
Outlet Pressure adjustable between 0,5 and 6 bar (7,25 and 87 psi), factory pre-set at 3 bar (43,50 psi)
Temperature Rating max. 80°C (176°F) water
Brass Body
Female Ends

6.6 Gauges

Bimetallic Temperature thermometer Gauge

A device used to detect temperature based on the concept of thermal expansion of two distinct metals is known as a bimetallic temperature thermometer spiral. In order to create the spiral shape, two metal strips with different coefficients of thermal expansion—typically brass and steel—are linked together. When exposed to temperature fluctuations, this spiral strip bends, making it possible to monitor temperature.

A bimetallic thermometer spiral operates on the following principles: The two metals in the spiral strip expand at different rates as the temperature rises. This differential in expansion leads the strip to bend in a certain direction because they are connected together. Temperature may be measured since the degree of bending is inversely related to the temperature change. Similar to how the spiral strip returns to its former place when the temperature drops is due to the differential contraction of the two metals.

A bimetallic temperature thermometer spiral can be used to track the temperature throughout an Organic Rankine Cycle (ORC) on a modest scale. Temperature variations can be precisely detected by bringing the spiral into touch with the necessary parts or fluid streams. The ORC process must be monitored and controlled in order to maintain the system's operation within the required temperature range.

There are various benefits to using a bimetallic temperature thermometer spiral in a small-scale ORC. It is suited for small-scale applications where elaborate and expensive instrumentation may not be required because it is a straightforward and cost-effective temperature measurement option. The bimetallic spiral can endure the working conditions of an ORC system since it is strong and resilient and has a wide temperature range capability.

The bimetallic thermometer spiral may also display temperature data in real time without requiring external power or laborious calibration procedures. Its operation is based on the characteristics of the metals utilized, which guarantees consistent, precise temperature readings.

For monitoring temperature in small-scale ORC systems, a bimetallic temperature thermometer spiral is a useful and dependable tool. It offers a reliable, affordable, and real-time temperature measurement solution and operates on the theory of differential thermal expansion of two metals. Operators may efficiently monitor and manage the temperature levels within the ORC system with this device, ensuring effective and secure operation.

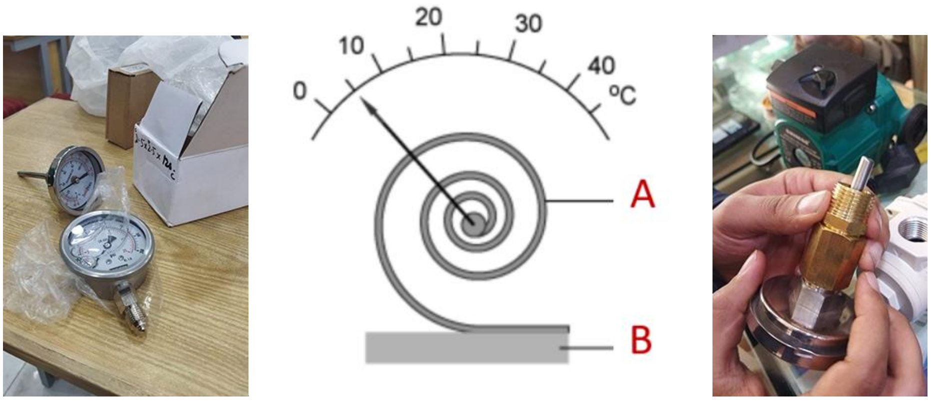


Figure 14: Temperature gauges and their working principle

Flange type Pressure Gauge:

A tool used to gauge the fluid pressure inside a system is a flange type pressure gauge. It normally comprises of a gauge body connected to a flange so that it may be placed onto a pipeline or vessel with ease. A pressure-sensitive element, frequently a bourdon tube, is used in the operation of a flange type pressure gauge to translate applied pressure into mechanical motion.

The following is how a flange type pressure gauge operates: The pressure-sensitive element (such as a bourdon tube) inside the gauge body is affected when fluid pressure enters the gauge. The element deforms as a result of the pressure, usually in a curved shape that is directly proportionate to the pressure exerted. A mechanical linkage receives this deformation and transfers it to it, moving the pointer on a calibrated dial to show the pressure value.

A flange type pressure gauge can be used to gauge pressure at various places throughout a small-scale Organic Rankine Cycle (ORC). Real-time pressure readings can be obtained by mounting the gauge to the flange connections of important parts or pipelines.

The ORC process must be monitored and controlled in order to maintain the system's operation within the required pressure range.

There are various benefits to using a flange type pressure gauge in a small-scale ORC. First off, it offers a straightforward and affordable option for measuring pressure, making it appropriate for small-scale applications where complicated apparatus might not be required. The flange connection makes maintenance and inspection tasks easier by enabling simple installation and removal.

In addition, flange type pressure gauges come in a range of pressures, making it possible to choose one based on the particular needs of the ORC system. They can endure the extreme pressures and temperature swings that are frequently experienced during ORC operations.

Flange style pressure gauges also deliver real-time pressure measurements without requiring external power or difficult calibration procedures. The pointer-equipped calibrated dial makes it simple to comprehend the pressure measurements.

Figure 15: Pressure gauges and their working principle

6.6 Piping:

In our organic Rankine cycle powered by solar energy, we employed 1/2 inch copper tubing.

Particularly in heat transfer applications, a 1/2 inch copper pipe can be extremely important to the operation of a small-scale Organic Rankine Cycle (ORC) system. Due to its great thermal conductivity, resistance to corrosion, and longevity, copper pipes are frequently employed in a variety of industries.

A 1/2 inch copper pipe can be used in an ORC system as a heat exchanger or a conduit to move heat between various components. The pipe's ability to transport the working fluid, such R134a, from one area of the system to another helps with heat transmission. The efficient extraction of thermal energy from the heat source and subsequent conversion of that energy into mechanical effort are made possible by copper's high thermal conductivity, which guarantees effective heat transfer.

In an ORC system, copper pipes have a number of advantages. First off, copper is an effective heat transmission medium since it has one of the highest thermal conductivities among frequently used metals. This maximizes the efficiency of the system by enabling improved heat exchange between the working fluid and the heat source or heat sink.

Additionally, copper pipes have a reputation for being resistant to corrosion, which is important for the ORC system. Particularly at high temperatures and pressures, the working fluid, like R134a, can be corrosive. The corrosion resistance of copper maintains the pipes' durability and dependability, reducing the possibility of leaks and sustaining the system's effectiveness over time.

Additionally, copper pipes are resilient and can survive the harsh ORC system operating conditions, such as high temperatures and pressures. They are able to withstand the mechanical and thermal pressures that are applied throughout the heat transfer process.

Copper is a suitable material for small-scale ORC applications since it is widely accessible and affordable. Copper pipes are a practical alternative for building the piping network within the system due to their simplicity of installation and compatibility with a variety of connectors and fittings.

Figure 16: Copper pipe used

6.7 Connectors and fittings:

Connectors and fittings are essential for joining pipes in an Organic Rankine Cycle (ORC) system, which results in a reliable and effective piping network. In piping systems for ORC applications, a variety of connections and fittings, including necks, collars, T-joints, L-joints, and flares, are frequently employed.

1. Necks and collars: Necks and collars are used to join pipes of various sizes together. They are frequently used to switch from bigger to smaller or vice versa sized pipes. Necks and collars make connections easy and reliable, preserving fluid flow while reducing pressure losses and potential leakage spots.

2. T-joints: T-joints allow fluid to flow in a variety of directions by forming branches in a pipe system. T-joints are frequently employed in ORC systems when branching off a main pipe to connect extra parts like heat exchangers, valves, or expansion tanks. They guarantee a dependable connection while guaranteeing that the system's fluid is distributed properly.

3. L-joints: Also known as elbow fittings, L-joints are utilised to adjust the pipe's direction. They are frequently utilised when a change in direction is necessary to optimise the construction of the ORC system or when pipes must traverse around obstructions. L-joints offer a seamless direction change, reducing flow disruptions and pressure losses.

4. Flares: A flared connection is a form of fitting that is used to link pipes. For sealing and connecting refrigerant lines, this kind of connection is frequently used in refrigeration and air conditioning systems, including ORC systems. In order to ensure the effective transmission of the working fluid without the use of additional sealing materials, flares offer a dependable and leak-free connection.

All of the aforementioned connectors and fittings are intended to provide the ORC piping system with optimal alignment, sealing, and longevity. They make it simple to assemble, disassemble, and perform maintenance. The performance and integrity of the piping network of a small-scale ORC system depend on the proper selection and installation of these connectors and fittings.

In conclusion, the pipe system of a small-scale ORC requires connectors and fittings such necks, collars, T-joints, L-joints, and flares. They allow for appropriate fluid flow, make direction changes easier, and offer sturdy connections between pipes and different parts. The ORC system can function well by making good use of certain connectors and fittings, ensuring ideal heat transmission and overall system performance

.

Figure 17: Copper Pipe Connectors

CHAPTER 7: INSTRUMENTATION AND ASSEMBLY

7.1 PID Diagram

The solar-based ORC system is completely shown visually in the PID diagram. It is made up of a number of parts, including pipelines and conduits that connect solar collectors, pumps, heat exchangers, turbines, condensers, and expansion valves. The diagram also shows instrumentation and control elements like flow meters, valves, temperature and pressure sensors, and controllers.

The PID diagram's significance comes from its capacity to communicate essential system information. Let's examine its main features:

1. System Understanding: By providing a thorough overview of the solar-based ORC system, the PID diagram enables engineers, operators, and stakeholders to comprehend the overall procedure and the function of individual components. Understanding the underlying ideas and connections within the ORC is made easier by the way it depicts the movement of energy and the working fluid across the system.

2. Process Optimization: The PID diagram makes it easier to identify possible areas for process optimization by graphically displaying the system's components and their linkages. In order to improve the system's effectiveness and efficiency, engineers might examine the flow channels, spot bottlenecks, and make improvements. They can spot chances to maximize heat transfer, enhance fluid flow distribution, or reduce pressure drops, for instance.

3. Safety and Risk Assessment: The PID diagram is essential to risk reduction and safety evaluations. It enables engineers to locate possible dangers, including high-pressure regions or leakage locations, and create the necessary safety precautions. In order to ensure the system runs properly, it also helps to comprehend emergency shutdown protocols and the deployment of safety devices.

4. Design of the Control System: The design and implementation of the control system for the solar-powered ORC rely heavily on the PID diagram. It emphasizes the tools, sensors, and controls required to monitor and manage different factors like temperature, pressure,

and flow rates. This knowledge is essential for creating a thorough control plan and choosing the right automation components.

The PID diagram plays a crucial role in providing instructions for building a working model of a solar-powered ORC. Engineers and technicians can use it as a comprehensive reference to make sure all required parts are present and correctly linked. By following the PID diagram, they can put the physical parts together, place the sensors and control equipment where they need to be, and create the necessary flow channels for the working fluid.

The PID diagram acts as a template for building the ORC system, ensuring that the actual system conforms to the anticipated functionality and design. It helps to ensure correct heat transfer, fluid circulation, and system performance by assisting in the verification that the assembled components fit the system's anticipated flow patterns.

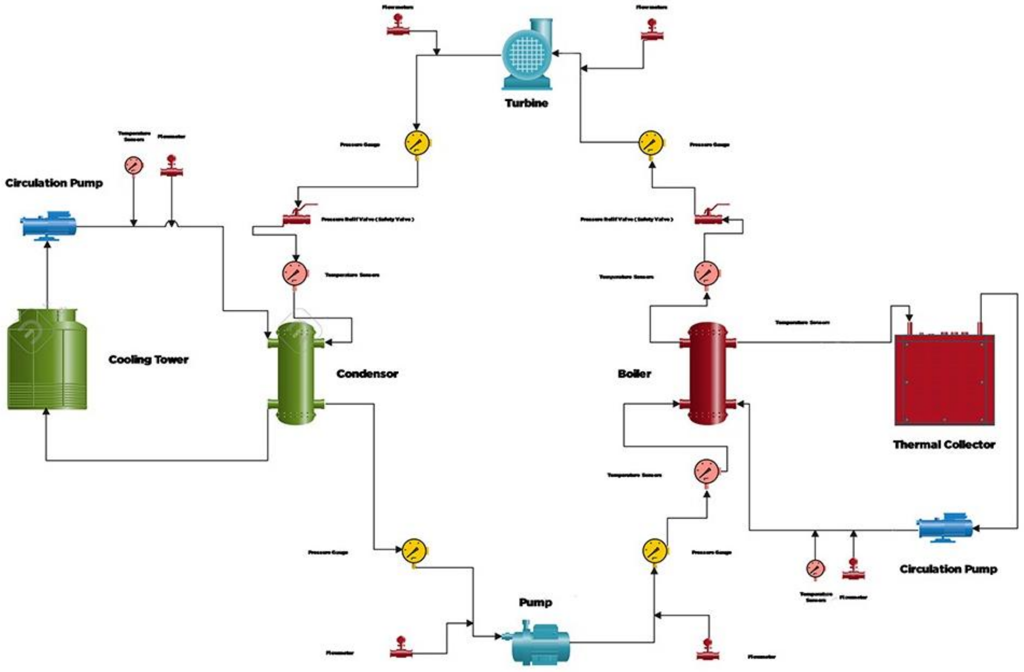


Figure 18: PID Diagram

7.2 Assembly

The Evacuated Thermal Collectors, which are the main heat source for the ORC system, are carefully chosen and installed as the first step in the production process. In these collectors, solar energy is absorbed and transformed into heat in a network of evacuated glass tubes. The working fluid within the system receives the heat that was initially captured.

Figure 19: Solar Collectors

Due to its advantageous thermodynamic characteristics, R134a is frequently utilized as the working fluid in solar-powered ORC systems. It is an ideal refrigerant for ORC applications since it is non-toxic, non-flammable, has strong heat transfer properties, and operates at relatively low pressures.

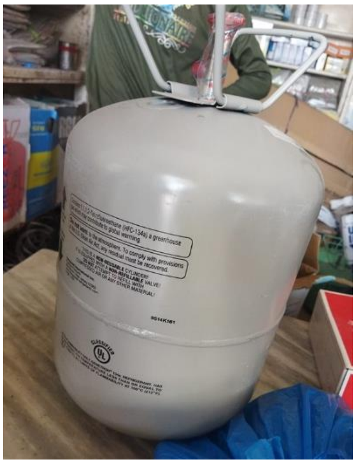


Figure 20: R134a Refrigerant Container

In the ORC system, the Scroll Compressor, which generally performs as a compressor in conventional systems, serves as an expander. The working fluid can expand and release energy as it moves through the scroll chambers when the check valve is removed, which causes the compressor to run in reverse. The mechanical work created by this energy can be used to power a generator and generate electricity.

Figure 21: Scroll Expander

The 3-Phase Multistage pump, which circulates the working fluid throughout the system, is an essential part of the ORC system. By maintaining the required pressure and flow rate for effective operation, this pump assures a constant flow of the working fluid.

Figure 22: The 3-Phase Multistage pump

The coil-type heat exchangers are made to make it easier to transfer heat from the working fluid to the environment. The heat exchanger in the boiler is in charge of transferring heat from the working fluid to water, creating steam. Contrarily, the Condenser heat exchanger's job is to transmit heat from the working fluid to a cooling medium, like outside air or water, in order to condense the working fluid back into a liquid state.

Due to its superior heat conductivity and resistance to corrosion, copper pipes are frequently utilized in ORC systems. These pipes provide effective heat transfer and sustain the system's integrity throughout time.

Figure 23: Heat exchangers

In order to track and measure the pressure and temperature values at each state, pressure gauges and temperature gauges are strategically positioned at various points throughout the ORC system. These measurements are essential for determining how well the system is working, finding any irregularities, and guaranteeing its security.

Figure 24: Gauges

To keep the system's pressure levels where they should be, a pressure regulator is used. This part makes sure that the working fluid is delivered to the right parts at the right pressure, maximizing the stability and efficiency of the system.

Figure 25: Components of ORC

To ensure appropriate assembly and connection of the numerous components during the production process, care must be taken to the smallest of details. To ensure a flawless system integration, care must be given to adhere to the manufacturer's instructions and requirements for each component.

A crucial part of the manufacturing process is quality control. Each component undergoes a careful inspection to make sure it complies with all norms and requirements. The system's performance is tested for pressure and temperature to make sure it functions safely and complies with design specifications.

Figure 26: Careful Installation of Components

The piping and components are insulated to reduce heat losses and increase the overall effectiveness of the ORC system. To stop unwelcome heat transfer and maximize the system's usage of thermal energy, insulating materials with high thermal resistance are utilized.

The manufacturing process includes safety precautions as a standard practice. In order to safeguard the system from potential overpressure scenarios, pressure relief valves are fitted. Additionally, emergency shutdown mechanisms may be included to swiftly and safely shut down the system in the event of crises or unusual operating circumstances.

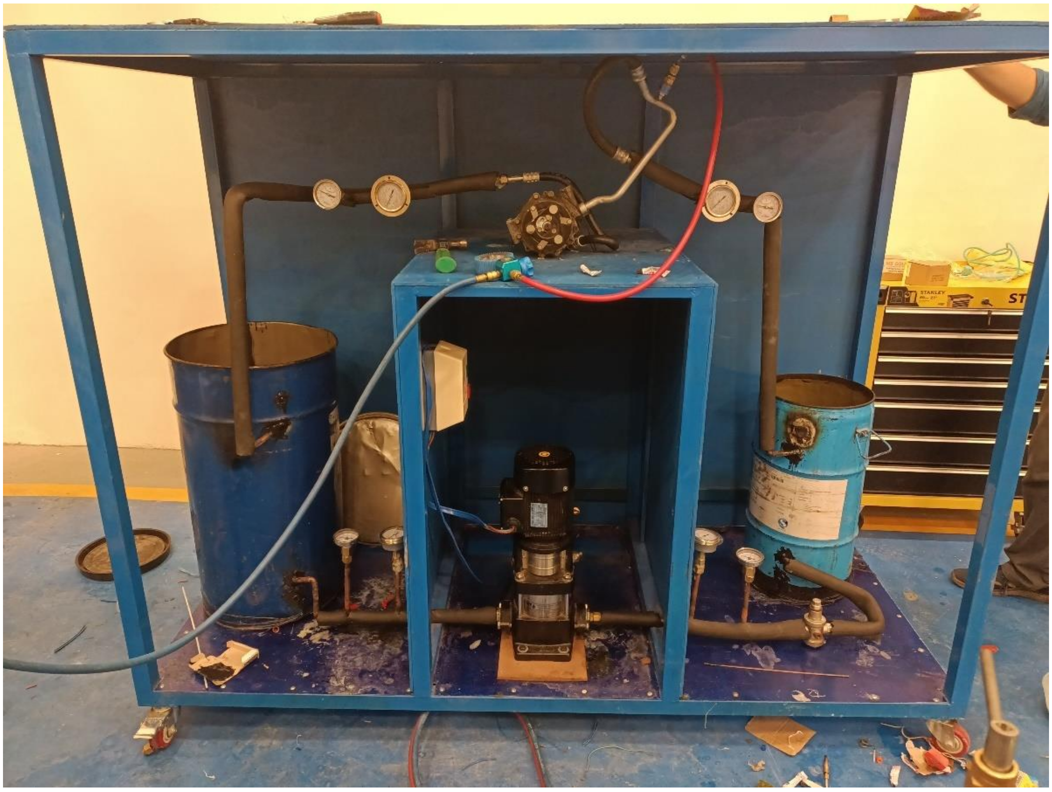


Figure 27: Assembled ORC

The solar-based ORC system's commissioning and testing are essential milestones in the production process. Assessing the system's performance in-depth under various operating conditions.

7.3 Preventing leaks during assembly

An Organic Rankine Cycle (ORC) system based on solar energy must be manufactured with leakage prevention as a top priority to ensure long-term performance and efficiency. Here, I'll go over some typical tactics used to stop leakage in an ORC system.

1. Choosing a component Leak prevention starts with selecting premium components from reliable suppliers. The working fluid and operating conditions of the ORC system should be taken into account while designing components including valves, fittings, seals, and gaskets.

2. Correct installation: To avoid leaks, careful installation is necessary. Installing components in accordance with the manufacturer's instructions and specifications will guarantee accurate alignment and effective sealing. In order to avoid potential leaks at these locations, flange connections should be tightened to the recommended torque.

3. Sealing materials: It's important to choose the right sealing materials. Use gaskets that can resist the operating temperature and pressure conditions and are compatible with the working fluid. To further guarantee a solid seal, sealing pastes or tapes can be used on threaded connections.

Figure 28: Gas Welding

4. Consistent inspections: Consistent inspections are necessary to spot possible leaks early and fix them. Visual inspections, searching for corrosion or fluid leaks, and performing pressure tests to gauge the system's integrity may all be part of this process.

5. Pressure testing: Pressure testing the system can assist find leaks or weak spots before and after installation. In order to do this, the system must be pressurized with an inert gas or the working fluid to a specific pressure, then the pressure must be watched for decreases that could be signs of leaks. When doing pressure tests, appropriate safety precautions should be taken.

6. Brazing and welding: If brazing or welding is required during the manufacturing process, it should be done by qualified experts using the right methods. Welded joints should undergo a thorough inspection to make sure there are no flaws that could cause leaks.

7. Vibration and movement considerations: In order to reduce stress on connections and potential leaks, components that may vibrate or move while in use should be adequately secured. Expandable joints or flexible connectors can be employed to minimize system stress and accommodate any movement.

8. Ongoing maintenance: To stop leaks, regular maintenance and inspections are crucial. This entails inspecting for corrosion, changing damaged gaskets or seals, and making sure that all connections are well fastened. Any leaks discovered during maintenance should be fixed right away.

9. Monitoring systems: Setting up a thorough monitoring system can assist in real-time leak detection. At crucial system points, sensors or leak detection systems may need to be installed. When a leak is discovered, these sensors can detect pressure dips or changes in fluid levels, resulting in warnings or automatic shutdowns.

10. Training and knowledge: The ORC system's production, installation, and maintenance teams must be properly trained. Leak risk can be considerably decreased by ensuring that they are aware about leak prevention techniques and adhere to recommended practices.

11. System integration: Creating a solar-based ORC system requires the fusion of numerous parts into a cohesive whole. This includes creating the mounting structure or framework to hold up the evacuated thermal collectors and other system parts. The collectors must be positioned and aligned correctly to maximize solar energy capture and improve system performance.

12. Electrical and control systems: The installation of electrical and control systems is also a part of the production process. This entails wiring the control panel with electrical components such sensors, actuators, pumps, and valves. Careful wiring and connection must be made in order to guarantee the ORC system's safe and dependable operation.

13. System optimization: Optimization factors are taken into account during the manufacturing process. To optimize fluid flow, enhance heat transfer efficiency, and fine-tune the design of the heat exchangers, computational fluid dynamics (CFD) simulations and modelling may be used. To maximize energy conversion and improve system performance, iterative testing and adjustment may be used.

14. Quality assurance and compliance: Strict quality assurance procedures should be put in place throughout the manufacturing process. To guarantee that the ORC system satisfies requirements for safety, effectiveness, and environmental sustainability, compliance with pertinent industry standards and regulations is essential. At several phases of the manufacturing process, quality control tests should be performed to ensure the system's reliability, performance, and integrity.

15. Comprehensive documentation and user manuals should be developed as part of the production process. These publications offer instructions for setting up, running, and maintaining the solar-powered ORC system. Users and technicians may efficiently administer and maintain the system thanks to clear instructions, diagrams, and troubleshooting techniques.

16. Thorough testing and validation procedures are carried out when the production process is finished. The system's effectiveness, output of energy, and general dependability are verified by performance testing under varied operating situations. In these tests, measurements of variables like temperature differences, pressure drops, fluid flow rates, and power output may be made.

17. Field installation: The solar-based ORC system is prepared for field installation following successful testing and validation. Transporting the parts to the installation site and assembling them there in accordance with the agreed design and layout make up this operation. To achieve a seamless and efficient installation procedure, proper coordination with construction teams, electrical contractors, and other stakeholders is essential.

18. Commissioning and startup: The commissioning and startup phase is started after installation. This is a thorough examination of the complete system to confirm that all parts and subsystems are operating correctly. In order to make sure the system works as planned, startup procedures are performed, including system purging, filling with the working fluid, and running preliminary testing.

19. Performance monitoring and optimization: After the solar-powered ORC system is put into use, continuous performance monitoring and improvement work is crucial. In doing so, data on energy output, efficiency, and system performance must be gathered and analyzed. Real-time data from monitoring software and remote monitoring systems can help operators spot possible problems, boost performance, and decide on system maintenance and enhancements.

20. End-users, operators, and maintenance staff may receive training and assistance from manufacturers. This entails leading training sessions on system usage, upkeep practices, and troubleshooting methods. To guarantee the long-term effectiveness and dependability of the solar-powered ORC system, regular maintenance schedules and support services can be made available.

Figure 29: Checking Leakages

CHAPTER 8: RESULTS

The findings and conclusions of the investigation into the Organic Rankine Cycle (ORC) system, which is powered by solar energy, are presented in this thesis' result chapter. Five distinct software tools, each with a specialized function, were used to design and choose the parts for our system. Python, TRNSYS, Aspen, Creo, ANSYS, and ANSYS were the software programs used.

8.1 TRNSYS

Throughout the year, the thermal collector's temperature data were obtained using the TRNSYS software. As a result, we were able to evaluate the collector's effectiveness and performance under various working circumstances. The temperature data from TRNSYS helped to identify the ideal design parameters and gave useful insights into the thermal behavior of the system.

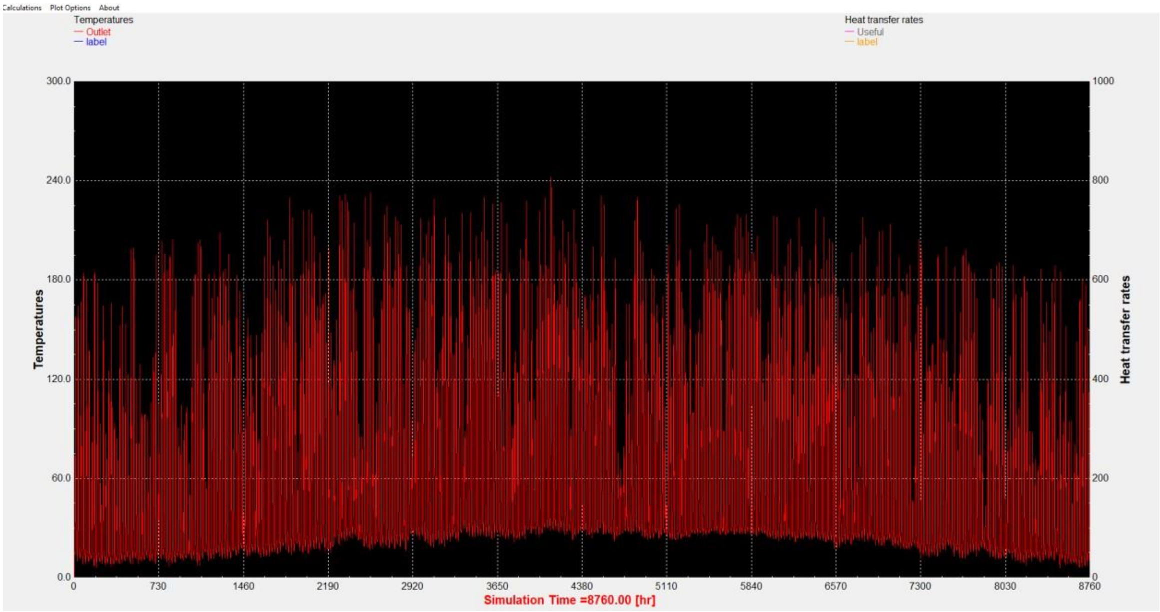
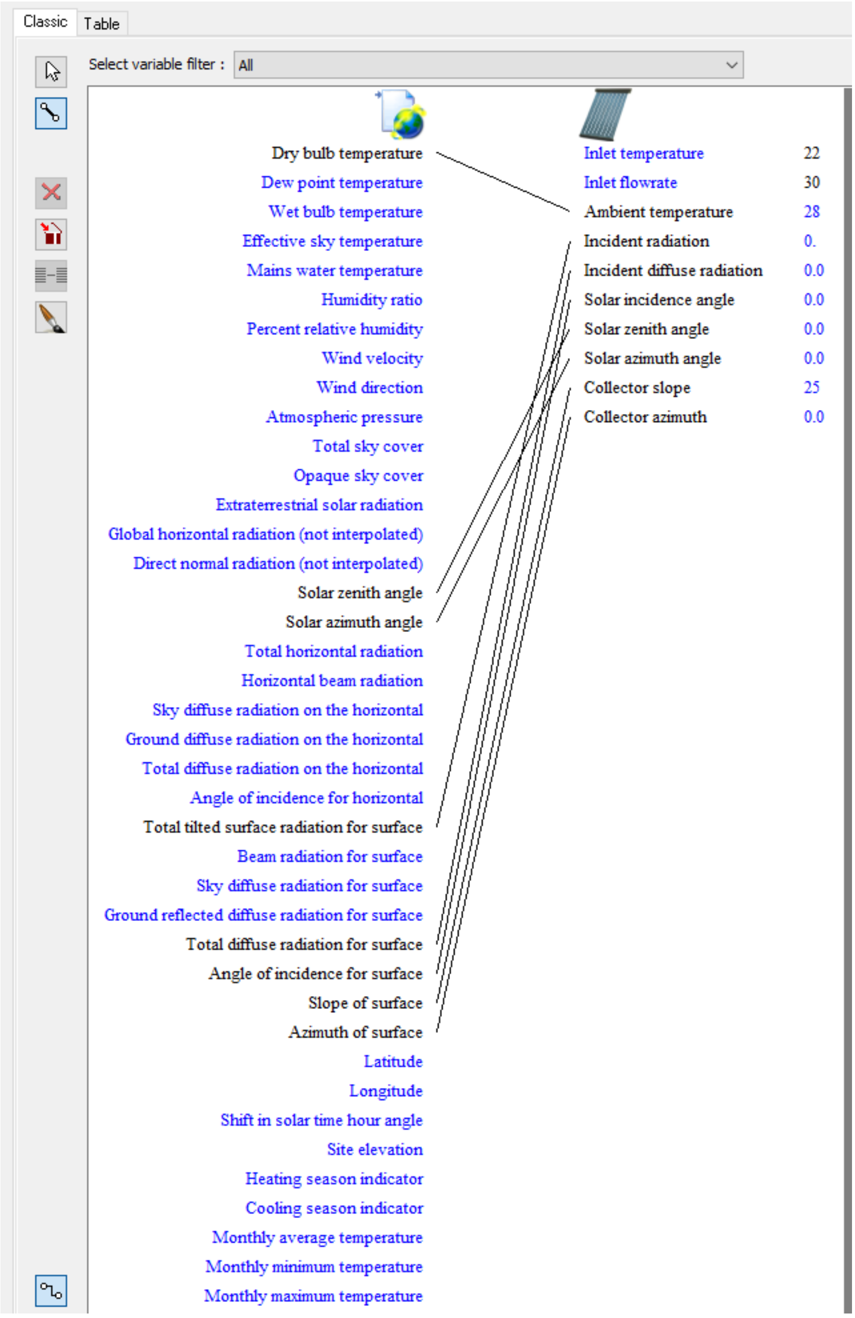


Figure 30: Temperature and heat transfer rates



Select variable filter : All

Inlet temperature	22
Inlet flowrate	30
Ambient temperature	28
Incident radiation	0.
Incident diffuse radiation	0.0
Solar incidence angle	0.0
Solar zenith angle	0.0
Solar azimuth angle	0.0
Collector slope	25
Collector azimuth	0.0

Figure 31: Analysis of solar collectors

8.2 Aspen

By modifying a few system variables, the Aspen software was used to calculate the cycle parameters. We were able to evaluate many scenarios and identify the best work output for our expander by using Aspen. The software allowed for a thorough analysis of the system's performance while taking various operating variables into account. Diagrams representing the Aspen results allowed for a clear visualization of the system's performance characteristics.

We ran simulations with the Aspen program to determine the Organic Rankine Cycle (ORC) system's power output utilizing R245fa as the working fluid. The graphics and outcomes were initially based on the R245fa refrigerant. We had to choose an alternative working fluid due to the unavailability of R245fa for our system, which caused us to choose R134a for the ORC system.

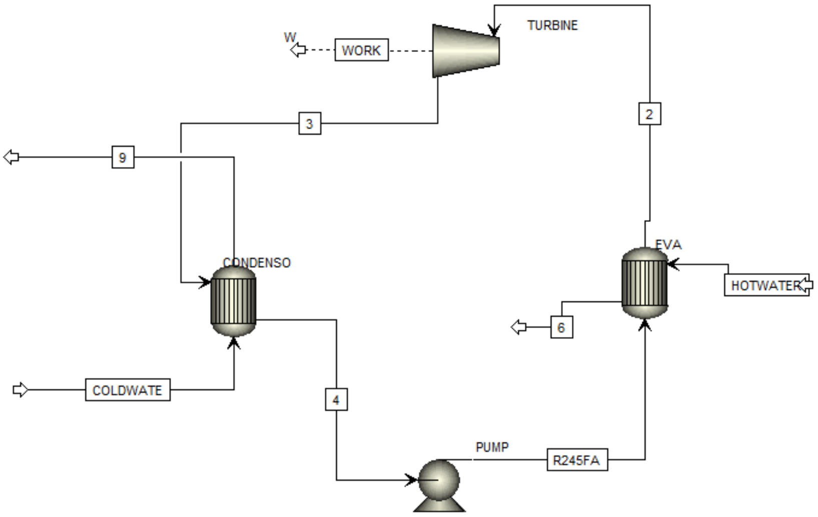


Figure 32: Initial ASPEN Model ORC

R134a was used as the working fluid during the cycle, and the ORC system's performance was judged to be good. The simulations revealed that the expander's calculated power output was 1026.6 W, demonstrating the potential for effective power generation.

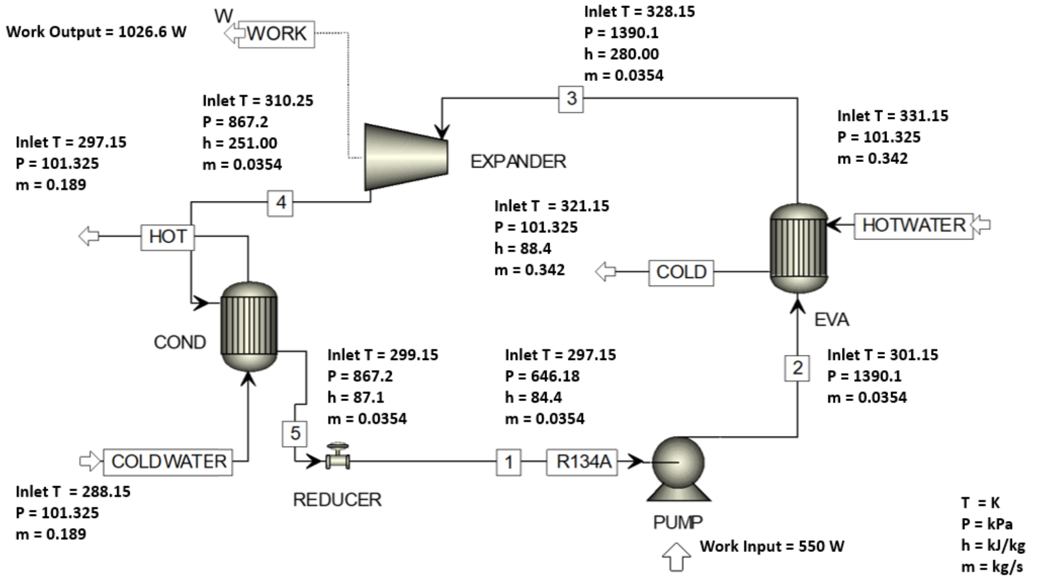


Figure 33: Final ASPEN Model ORC

It is significant to note that there were some differences between the simulated results and the experimental data. This can be explained by elements like experimental uncertainty, measurement error, and minor variations in the system configuration. A temperature-entropy (TS) map was displayed to graphically contrast the experimental and simulation data, showcasing the discrepancies between the two datasets.

The overall performance of the ORC system employing R134a as the working fluid remained encouraging despite the modest differences between the simulation and experimental results. The simulations performed with Aspen software gave important insights into the system's behavior and potential for electricity generation. These results provided the foundation for more investigation and ORC system improvement.

8.3 PTC Creo

The heat exchangers were modelled using the Creo software. We were able to develop thorough and precise simulations of the heat exchangers utilized in the ORC system because to this robust software. We were able to ensure exact measurements and specifications for the heat exchangers using Creo, which improved both their capacity for heat transmission and overall performance.

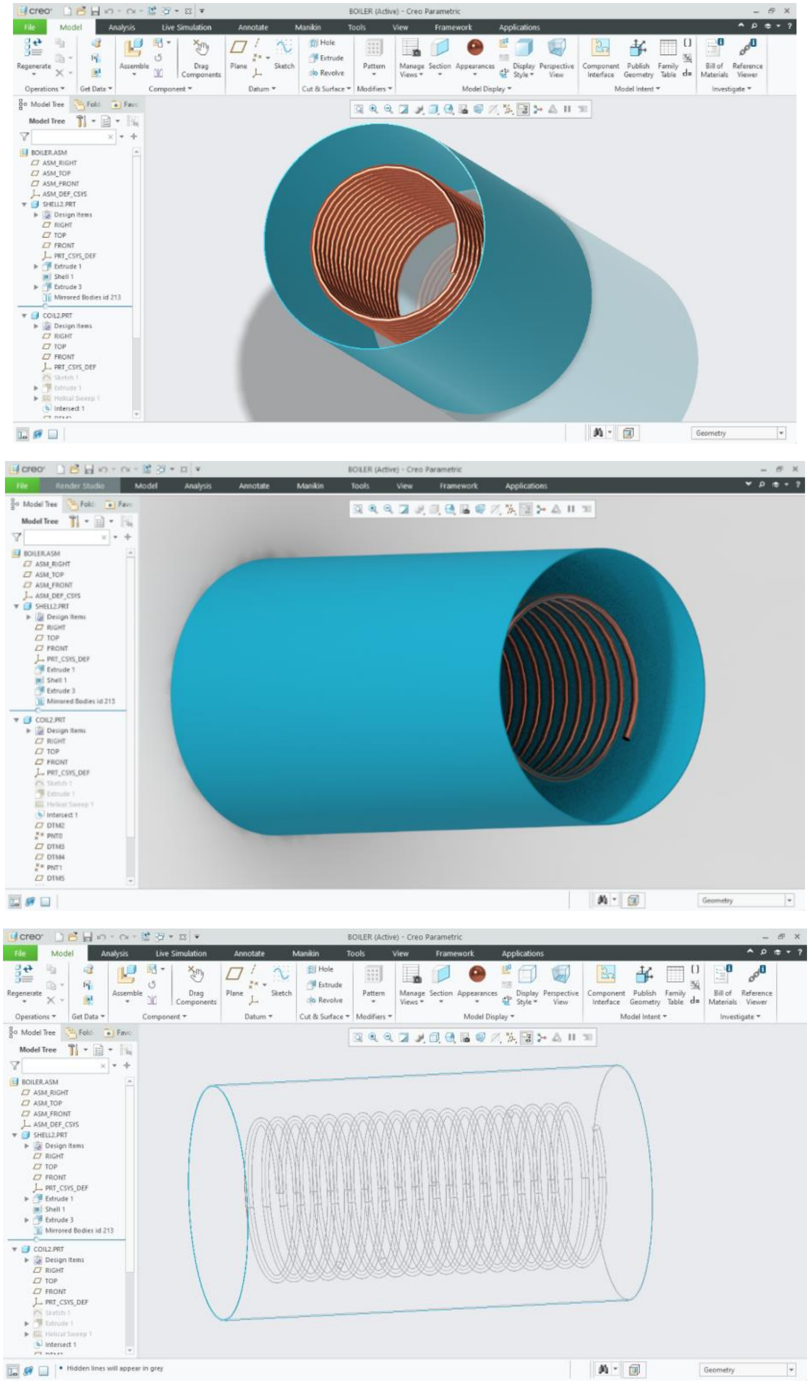
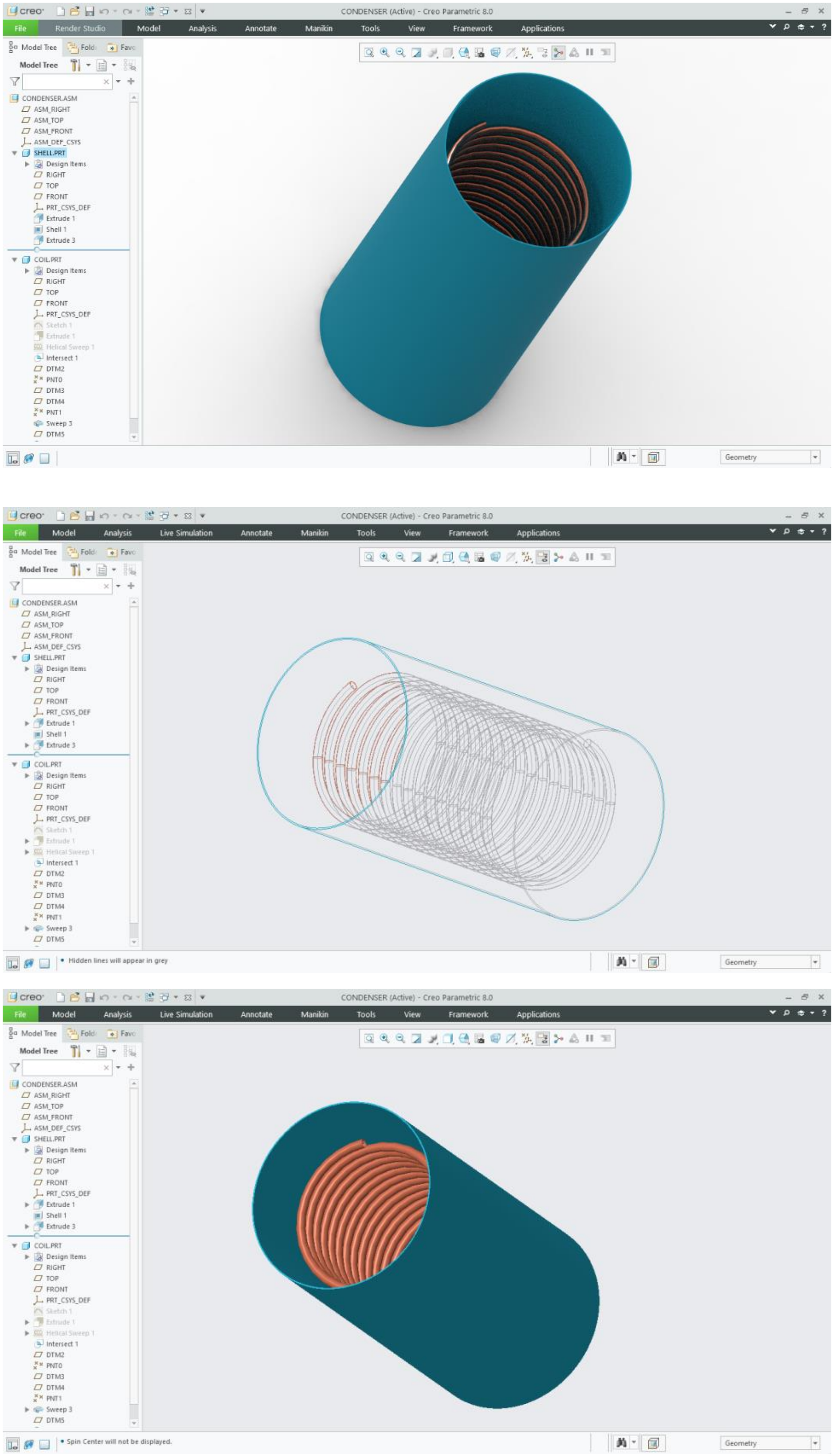


Figure 34: Boiler CAD Diagram



• Hidden lines will appear in grey

• Spin Center will not be displayed.

Figure 35: Condenser CAD Diagram

8.4 ANSYS

The heat transport in the heat exchangers was calculated using the ANSYS software. We were able to examine the heat transfer properties in the heat exchangers using the computational fluid dynamics (CFD) module of ANSYS. In order to ensure effective heat transfer from the working fluid to the heat exchangers, we used ANSYS to simulate and assess the temperature contours. The ANSYS results produced insightful information about the system's thermal performance.

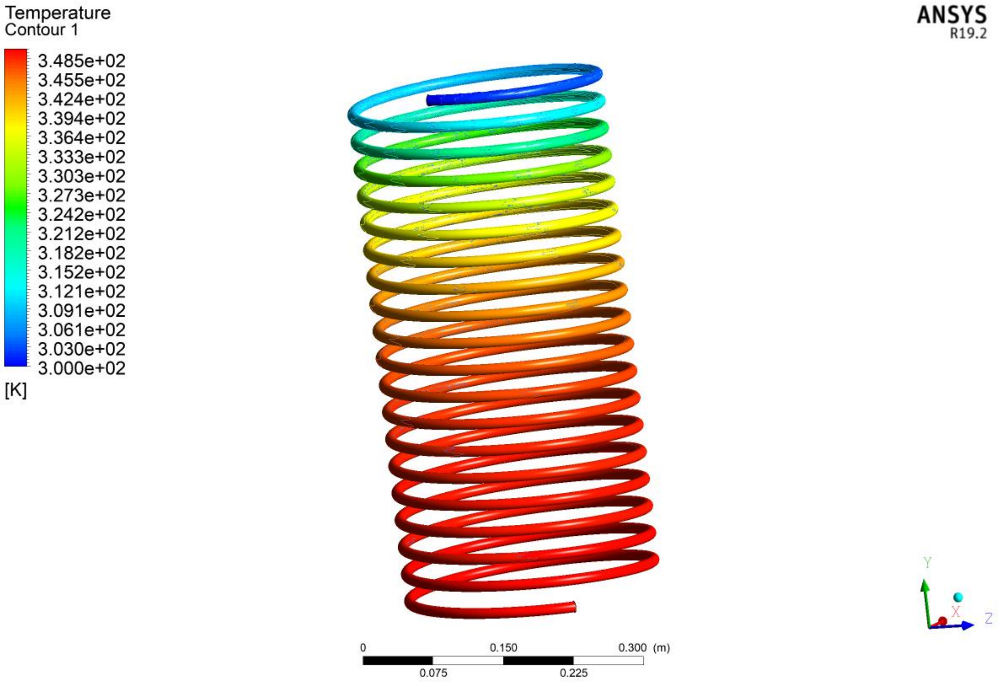


Figure 36: Computational fluid Dynamic Simulations (Boiler)

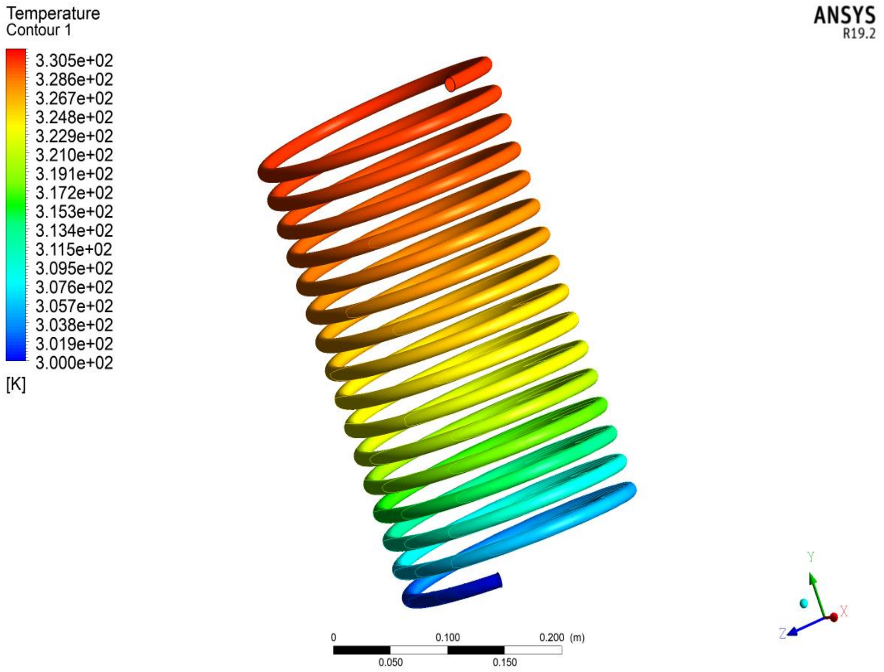


Figure 37: Computational fluid Dynamic Simulations (Condenser)

8.5 Python

The temperature-entropy (TS) and pressure-volume (PV) graphs of the simulations and experimental data were plotted using Python and the CoolProp module. The thermodynamic capabilities of the CoolProp module combined with Python's adaptability made it simple to visualize the system's performance characteristics. These diagrams made it possible to compare the simulated and experimental data visually, supporting the model's validation and giving a thorough grasp of the system's behavior.

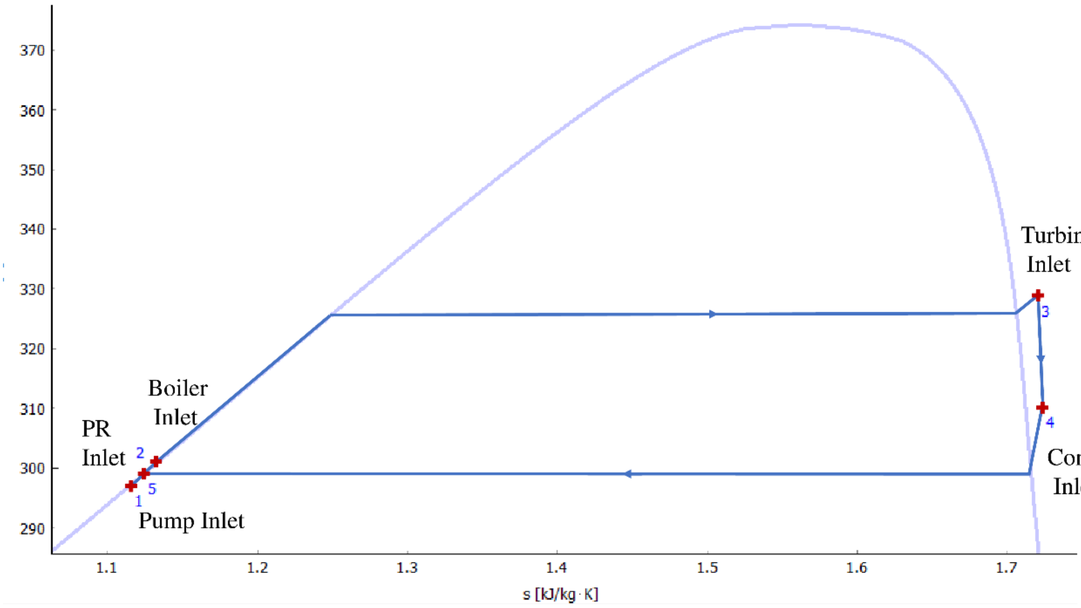


Figure 38: T-s Diagram

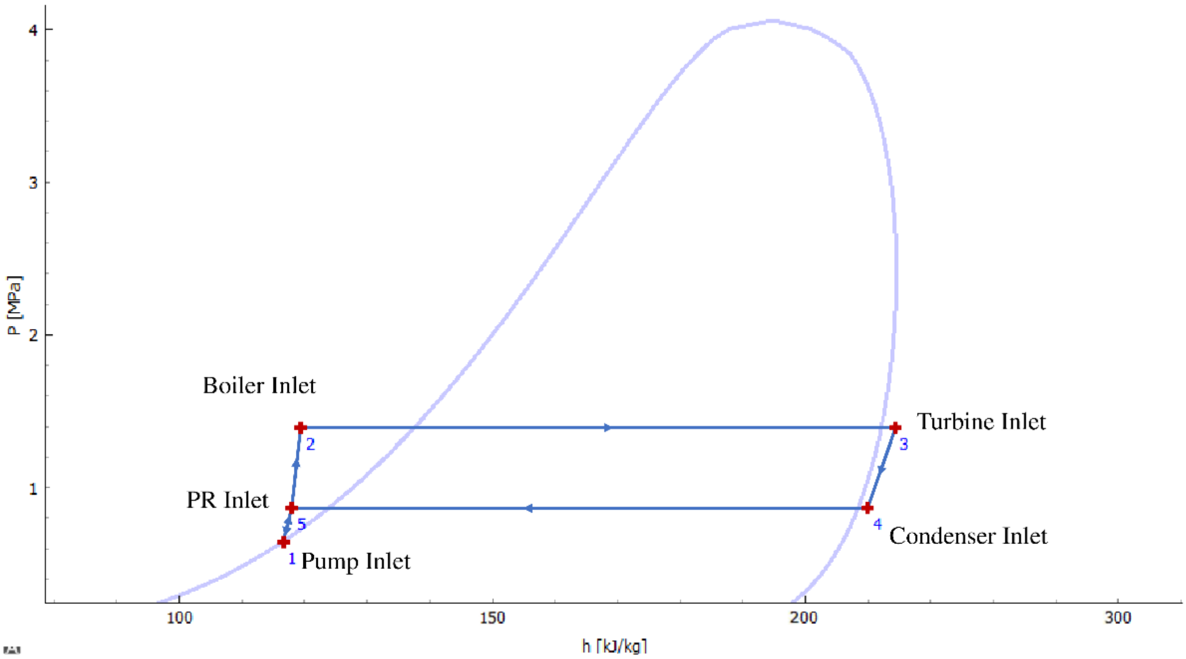


Figure 39: P-h Diagram

8.6 Results comparison

The information given reflects the outcomes of simulations and experiments conducted on an Organic Rankine Cycle (ORC) with R134a as the working fluid. The results are based on the pressure (P), temperature (T), heat input (Qin), and heat output (Qout) values at various stages of the cycle. The ORC system's electrical efficiency and thermal efficiency are also presented.

Let's examine the importance of each ORC parameter and stage in order to comprehend these results:

Pump In (step 1): At this step, the pressure and temperature data describe the pump's inlet conditions. The inlet pressure (P1) and temperature (T1) in the simulation are 6.4618 bar and 297.15 K, respectively. P1 is slightly greater in the experiment at 6.5 bar, whereas T1 is slightly lower at 296 K. These numbers represent the working fluid's initial condition when it enters the pump.

Figure 40: Pump In

Pump Out (Stage 2): At this point, the pressure and temperature readings represent the pump's outlet conditions. In the simulation, the output pressure (P2) and temperature (T2) are 301.15 K and 13.901 bar, respectively. In the experiment, P2 and T2 are both somewhat lower at 12 bar and 300 K, respectively. These numbers show the rise in temperature and pressure of the working fluid following its passage through the pump.

Figure 41: Pump Out

The pressure and temperature readings at this step describe the turbine's inlet conditions.

Turbine In (step 3). In the simulation, the inlet pressure (P3) and temperature (T3) are both 13.901 bar and 331.15 K, respectively. In the experiment, T3 is somewhat lower at 330 K and P3 is lower at 11 bars. These numbers represent the working fluid's condition when it enters the turbine for expansion.

Figure 42: Turbine In

Turbine Out (Stage 4): These numbers for pressure and temperature describe the turbine's exit conditions. The outlet pressure (P4) and temperature (T4) in the simulation are 8.672 bar and 310.25 K, respectively. In the experiment, P4 and T4 are both somewhat lower at 8 bar and 308 K, respectively. These numbers represent the working fluid's pressure and temperature after expanding in the turbine, respectively.

Figure 43: Turbine Out

The heat input value, or Qin, denotes how much heat is given to the system. The heat input in the simulation is 7 kW, whereas it is 6.6 kW in the experiment. The working fluid is vaporized using this heat input, which also supplies the cycle with the energy it needs to run.

The heat output value, or Qout (Heat Output), denotes the volume of heat drawn from the system. The heat output in the simulation is 5.8 kW, whereas it is 5.5 kW in the experiment. The energy taken from the working fluid during condensation is represented by this heat output.

Electrical Efficiency: The ORC system's electrical efficiency measures how well heat input is converted to electrical power. The electrical efficiency in this instance is determined to be 52.1%. This translates to a successful conversion of 52.1% of the heat energy into electrical energy.

Thermal Efficiency: The ORC system's overall effectiveness in utilizing heat energy is indicated by its thermal efficiency. It is computed by subtracting the heat input from the net work output. The thermal efficiency in this instance is found to be 29.4%.

These findings shed light on how well the ORC system performs when R134a is used as the working fluid. Measurement errors, simulation model assumptions, and tiny differences in operating circumstances are just a few of the causes of the discrepancy between simulation and experimental values. Overall, nevertheless, the results show that the ORC system can convert heat energy into electrical power, with the thermal efficiency demonstrating how well the system utilizes the heat input that is available.

Table 5: Experimental Vs. Simulation Data

Simulation		Experiment	
P1 = 6.4618 bar	T1 = 297.15 K	P1 =6.5 bar	T1 = 296 K
P2 = 13.901 bar	T2 = 301.15 K	P2 = 12 bar	T2 = 300 K
P3 = 13.901 bar	T3 = 331.15 K	P3 = 11 bar	T3 = 330 K
P4 = 8.672 bar	T4 = 310.25	P4 = 8 bar	T4 = 308 K
Qin = 7 kW		Qin = 6.6 kW	
Qout = 5.8 kW		Qout = 5.5 kW	
Electrical Efficiency: 52.1 %			
Thermal Efficiency: 29.4 %			

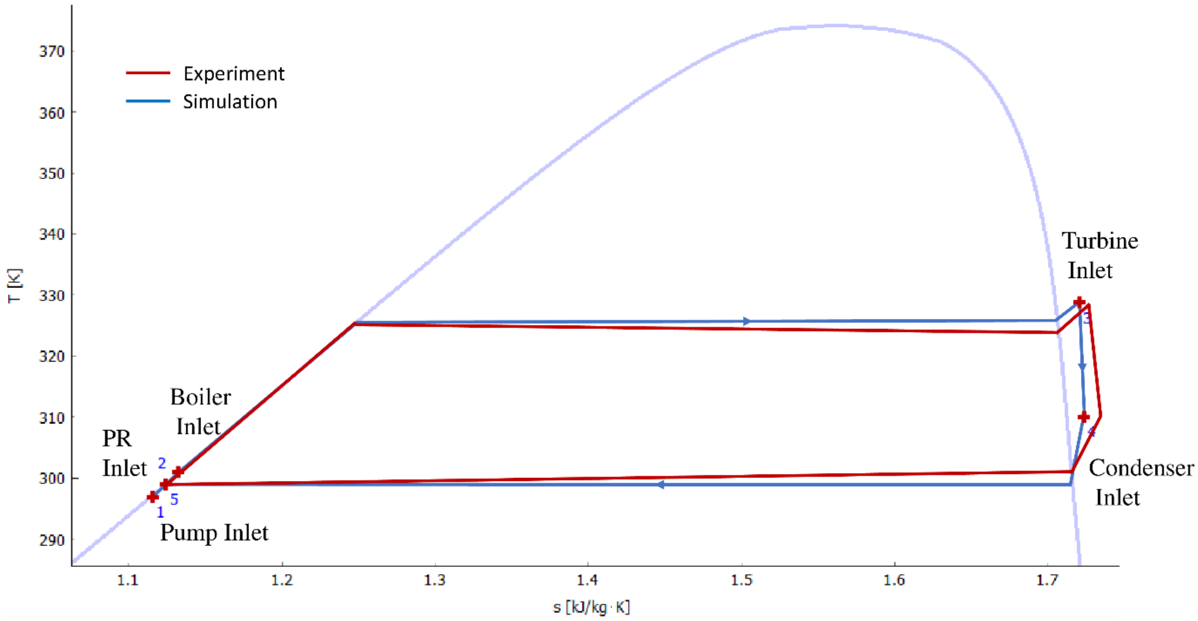


Figure 44: Comparison of Experimental and Simulation Results (T-s Diagram)

LIMITATIONS

Organic Rankine Cycle (ORC) solar energy systems have attracted a lot of interest as a viable renewable energy source. They do, however, have some limits that must be taken into account, just like any other technology. The following are some of the main drawbacks of solar-powered ORC systems:

1. The presence of sunlight: The production of solar energy depends on the presence of sunlight. Therefore, regions with poor sun irradiation, such as those with frequent cloud cover or short daylight hours, are vulnerable to constraints for solar-based ORC systems. The system's overall performance and energy output may be greatly impacted by this.

2. Variations in efficiency: A number of factors, including as temperature changes, the buildup of dust or debris on solar collectors, and shadowing, can have an impact on the efficiency of solar-based ORC systems. These elements may impair the system's overall effectiveness and lower energy output.

3. Capital and operating expenses: The installation of solar collectors, heat exchangers, and other components for solar-based ORC systems frequently requires a sizable initial expenditure. To maintain optimal operation, frequent maintenance is also required. Particularly for small-scale applications or in regions with limited financial resources, the upfront costs and continuing maintenance costs can be a barrier.

4. Energy storage restrictions: Solar energy is sporadic and not always available. For solar-based ORC systems, this presents a hurdle when reliable power supply is needed. Batteries and thermal storage systems are examples of energy storage technologies that can lessen this restriction, but they can also increase system costs and complexity.

5. The quantity of land and space needed: Solar collectors, which collect sunlight and turn it into heat, need a lot of room. Large-scale solar-based ORC systems may need a lot of land, which might be a problem in areas with limited land or dense populations.

6. Environmental factors: Solar-based ORC systems are regarded as being environmentally benign because they use renewable energy, but the manufacturing and disposal of system parts, such as solar panels, can have an influence on the environment. To determine these

systems' overall environmental impact, it is critical to take into account the life cycle analysis of such systems.

Additionally, a drawback is brought on by the pressure ratio difference between the pump and the Scroll Expander, which is unique to the operation of solar-based ORC systems. A pressure regulator is used in the system since the pressure ratios are not equal. By decreasing the pressure as needed, this regulator aids in pressure control and maintenance. The employment of a pressure regulator is necessary to ensure the system's correct operation and efficiency due to this mismatch in pressure ratios.

In fact, while constructing organic Rankine Cycle (ORC) systems fueled by solar energy, the availability of adequate working fluids is a critical factor to take into account. As previously indicated, it is difficult to get the best performance in solar-based ORC systems because to the lack of R245fa in Pakistan, which has a greater efficiency than R134a. In defining the effectiveness and efficiency of ORC systems, the choice of the working fluid is crucial. Because R245fa can operate at greater pressures and temperatures, the cycle efficiency may be increased. This is due to its favorable thermodynamic characteristics, which include a higher critical temperature and reduced viscosity. The lack of R245fa in Pakistan, however, may be attributable to elements including market demand, political restrictions, or constrained regional supply networks. As a result, alternate working fluids must be taken into account for solar-powered ORC systems throughout the nation. Despite being widely used and easily accessible, R134a could not be as efficient as R245fa. Under these conditions, thorough analysis and evaluation of the currently available working fluids must be made in order to maximize the effectiveness of solar-based ORC systems. The emphasis should be on locating substitute solutions that provide increased efficiency while still being readily available on the local market. The exploration and development of alternative working fluids that are accessible and provide more efficiency for solar-based ORC systems should be prioritized in order to alleviate this restriction. In places with few options, research and development in this field may result in the identification of new suitable working fluids or the modification of current fluids to improve the performance of solar-based ORC systems.

In spite of these difficulties, solar-based ORC systems still provide a number of benefits, such as the generation of clean energy, lower greenhouse gas emissions, and the potential for decentralized power generation. The efficiency and viability of solar-based

ORC systems can be significantly increased in the future by overcoming the limitations caused by working fluid availability and developing technology.

To overcome these issues, encourage the development of substitute working fluids, and hasten the implementation of solar-based ORC systems in places like Pakistan, it is crucial to stimulate collaboration between researchers, industry players, and policymakers. By doing this, we can fully utilize solar energy and help to create a future that is both sustainable and energy efficient.

SUMMARY

There are more factors to take into account in order to maximize the potential of solar-based Organic Rankine Cycle (ORC) systems in addition to the limits described above. When integrating solar-based ORC systems into the current power infrastructure, grid integration is a critical issue to take into consideration. Due to the intermittent nature of solar energy production, precise coordination with the grid is necessary to guarantee a steady and dependable supply of electricity. Effective grid integration techniques can assist in overcoming the difficulties of sporadic solar power generation and enable seamless integration into the larger electricity network. These tactics include smart grid technology, energy management systems, and grid-balancing mechanisms. The ability of solar-based ORC systems to scale is another factor to take into account. Smaller installations can generate localized power, but larger systems have the potential to make a considerable contribution to the world's energy mix. It takes careful planning and consideration of variables including land availability, grid capacity, and economic viability to scale up solar-based ORC systems. It is possible to hasten the adoption of larger-scale solar-based ORC systems and increase the impact they have on the production of renewable energy by creating laws and incentives that favor their deployment. Innovating and advancing technology are essential to overcoming the constraints of solar-based ORC systems. The effectiveness of solar collectors, heat transmission mechanisms, and thermal energy storage systems should be the main focus of research and development. The effectiveness of solar energy conversion and overall system performance can be improved by advances in materials science, such as the creation of high-performance solar absorbers and selective coatings. The limits of fluid supply and efficiency can also be addressed by continuous research into new working fluids with enhanced thermodynamic properties that are appropriate for solar-based ORC systems. Collaboration and knowledge exchange among researchers, policymakers, and industry stakeholders are essential for promoting the development and deployment of solar-based ORC systems. It is possible to hasten the transmission of cutting-edge technologies, lessons learnt, and best practices by establishing partnerships and venues for information exchange. Additionally, promoting global cooperation can aid in the flow of information and expertise between regions, helping the deployment of solar-based ORC systems in places where resources and knowledge may be scarce.

The development of solar-based ORC systems is strongly influenced by regulatory and policy frameworks. To encourage the creation of solar-based ORC installations, governments can enact feed-in tariffs, tax incentives, and renewable energy objectives. The required confidence to invest in these systems can be given to investors and developers through clear and transparent regulatory frameworks. Additionally, subsidies and financing for R&D can encourage creativity and technological growth in the industry, increasing the effectiveness and viability of solar-based ORC systems.

Finally, solar-based ORC systems have enormous promise for producing clean, sustainable energy. Stakeholders may fully realise the advantages of solar-based ORC systems by addressing the restrictions described previously, such as sunshine availability, efficiency variations, prices, energy storage, space needs, environmental considerations, pressure ratio mismatch, and grid integration. We can create the conditions for a future in which solar-based ORC systems that are effective and ecologically friendly take over as the primary source of power.

RECOMMENDATIONS FOR FUTURE WORK

Although Organic Rankine Cycle (ORC) systems based on solar energy have showed potential, there are a number of recommendations for the future to boost their effectiveness and get through current obstacles:

1. Research and development: To enhance the performance of solar-based ORC systems, ongoing research activities are required. This entails investigating cutting-edge solar collector materials, improving heat transfer processes, and creating novel system and component designs. Initiatives for collaborative research can hasten the growth of the discipline.

2. Efficiency improvements: It is essential to concentrate on raising the general efficiency of solar-based ORC systems. Investigating different working fluids with improved efficiency and thermodynamic characteristics can help with this. To maximize energy output, research should also focus on improving solar collector conversion efficiency and streamlining system controls.

3. Energy storage technology: Improvements in energy storage technologies can help with solar energy's sporadic nature. Even during times of poor solar irradiation, improvements in battery storage, thermal storage, or other creative storage techniques can help maximize the use of solar energy.

4. Integration with additional renewable technologies: Look into the possibility of hybrid systems that combine solar-based ORC with additional renewable energy sources like wind or geothermal energy. By utilizing the advantages of several renewable energy sources and lowering reliance on a single energy input, this can offer a more dependable and stable energy producing system.

5. Cost-cutting: For solar-based ORC systems to be more widely adopted, attention must be paid to lowering the initial investment and ongoing maintenance costs. This can be done by utilizing economies of scale, better manufacturing techniques, and component cost-reducing technology. Solar-based ORC systems can be made more accessible and inexpensive with the aid of financial support systems and policy incentives.

Environmental factors should be taken into account in the production and disposal of system components. To reduce the environmental impact of these systems, advocate for the use of eco-friendly materials in solar collectors and system components and set up suitable recycling and disposal procedures.

7. Market incentives and policy support: Governments should offer market incentives and supportive policies to promote the use of solar-based ORC systems. Feed-in tariffs, tax breaks, research funding, and expedited permitting procedures are a few examples of this. Such actions could encourage investment, promote innovation, and hasten the use of solar-based ORC systems.

8. Promote education and awareness among stakeholders, including decision-makers, investors, and the general public, about the advantages and potential of solar-based ORC systems. To promote greater adoption and acceptance, disseminate information on effective case studies, technological developments, and the environmental benefits of solar-based ORC systems.

Stakeholders can work to maximize the effectiveness, scalability, and cost-effectiveness of solar-based ORC systems by concentrating on these future recommendations. It is crucial for the area to grow and for solar-based ORC technology to reach its full potential in the renewable energy sector that academia, industry, and government continue to work together. Regeneration and turbine bleeding are two specific strategies that can be applied in solar-based Organic Rankine Cycle (ORC) systems to further increase efficiency.

1. Regeneration: The ORC system can be made substantially more efficient overall by implementing a regeneration mechanism. Regeneration includes heating the working fluid before it enters the evaporator using system waste heat. By lowering the temperature differential between the heat source and the working fluid, this preheating improves heat transmission and cycle efficiency. The overall thermal efficiency of the ORC system can be raised by efficiently using waste heat.

2. Turbine Bleeding: In order to perform turbine bleeding, a portion of the high-pressure working fluid from the turbine must be removed at an intermediate step and used elsewhere in the system. This extracted fluid can be used in additional heat exchange procedures or

to preheat the working fluid. By using the extracted fluid to maximize heat transmission and reduce heat losses inside the system, the overall system efficiency can be raised in this way.

In solar-based ORC systems, the application of combined regeneration and turbine bleeding techniques can result in large efficiency gains. These methods enhance system performance by lowering energy losses, increasing energy efficiency, and boosting the utilization of available heat energy.

It is crucial to remember that system optimization and careful design considerations are required for the implementation of the regeneration and turbine bleeding processes. To achieve successful implementation and maximize efficiency gains, factors such the heat source temperature, working fluid characteristics, and system structure must be taken into consideration.

Exploring cutting-edge regeneration methods including cascade and counter-flow regeneration, as well as streamlining the bleeding procedure to find the most effective configurations, should be the main goals of future research and development. The effectiveness and efficiency of these methods can also be increased by improvements in control systems, component design, and heat exchanger technologies.

Regeneration and turbine bleeding can maximize energy conversion and increase the overall efficiency of solar-based ORC systems, making them more economically and environmentally viable for the production of renewable energy.

CONCLUSION

The significance of ongoing research and development efforts in the area of solar-based Organic Rankine Cycle (ORC) technologies should also be emphasized. To overcome the highlighted constraints and further improve the performance of these systems, these initiatives are crucial.

The availability of sunshine is one issue that needs constant attention. To make the most of the available sunshine, methods for improving solar energy collecting, such as tracking systems and sophisticated solar concentrators, can be investigated. Furthermore, the use of predictive and energy forecasting models can aid in anticipating variations in solar irradiation and optimizing system functioning accordingly. As was previously said, there are several ways to reduce changes in efficiency. Advanced control algorithms and optimization methods can be used to make sure the system works as efficiently as possible under a variety of circumstances. Real-time data on system performance can be provided by intelligent sensors and monitoring systems, enabling proactive maintenance and modifications for successful operation. The widespread use of solar-based ORC systems is greatly influenced by economic factors. The cost-effectiveness of these systems can be increased by lowering up-front expenses and utilizing economies of scale, streamlining manufacturing processes, and reducing technological barriers to entry. The development and deployment of solar-based ORC facilities can also be influenced by financial incentives and enabling regulations like feed-in tariffs and tax incentives.

As energy storage technologies advance, they provide ways to get around solar energy's sporadic nature. The reliability and dispatchability of solar-based ORC systems can be improved by advancements in battery storage, thermal energy storage, and other new storage methods, enabling steady power generation even during times of poor solar irradiation. Integration with demand response programmes and smart grids can further optimise the use of stored energy and raise system efficiency as a whole. In the creation and use of renewable energy technology, environmental considerations are of the utmost importance. The manufacture, operation, and end-of-life stages should all be included in the life cycle analysis of solar-based ORC systems. This analysis can point up areas that need to be improved, such as lowering the environmental effect of component manufacture, using sustainable materials, and making sure that system components are disposed of or recycled properly.

By utilizing waste heat and maximizing the energy conversion process, regeneration operations and turbine bleeding, as previously indicated, can improve system performance. To maximize energy extraction and overall system efficiency, research and development efforts should concentrate on creating effective heat exchangers, cutting-edge heat recovery systems, and cutting-edge turbine designs.

To promote innovation and knowledge exchange in the field of solar-based ORC systems, collaboration between researchers, industry stakeholders, policymakers, and academic institutions is essential. International partnerships can speed up progress and enable the transfer of technology to areas with scarce resources by facilitating the sharing of knowledge and best practices.

In conclusion, a multifaceted strategy is needed for the improvement and further development of solar-based ORC systems. The key to overcoming the constraints, enhancing system performance, and realizing the full potential of solar-based ORC technology is ongoing research, technological developments, supportive legislation, and international cooperation. By overcoming these obstacles, solar-based ORC systems can significantly contribute to the transition to a clean and sustainable energy future, aiding in efforts to combat climate change and achieve energy security on a global scale.

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Liu et al [Liu, 2002] performed a simulation on an ORC with various working fluids for a hot temperature of 150°C and a cold temperature of 30°C. It turned out in this simulation that R123 had a slightly better efficiency than isopentane. R245fa and npentane were not taken into account in that study.

V. Lemort [2007] compared three working fluids on an ORC application (hot side temperature: 130°C; cold side temperature: 30°C). The 3 working fluids were R123, R245fa, R134a and pentane. The calculated efficiencies were respectively: 9.71, 9.3, 7.86 and 9.74 %.

H.D. Madhawa [Hettiarachchia, 2007], simulated a geothermal ORC with a hot source temperature of 70 to 90°C, a temperature difference ranging from 40 to 60 degrees and various working fluids. Among those working fluids, R123 and npentane outperformed the other fluids (ammonia and PF5050) with a higher efficiency of 9.8 and 9.9 % respectively