International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Special Issue, MAY 2022

Performance Improvement of an Organic Rankine Cycle with Low Grade Thermal Energy Input From A Compound Parabolic Collector

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ABSTRACT -Solar energy collectors have been the need of the hour for the past couple of decades as the world has been desperately trying to find new and innovative ways to shift the dependency on fossil fuel to clean and green energy sources for power generation. The aim of the present study is two folds modelling of "Compound Parabolic Collector" and studying its contribution in the performance improvement of "Organic Rankine Cycle" engine for different ambient and operating conditions. Compound Parabolic Collectors (CPC) are mostly used for low temperature applications such as process heating, waste heat recovery etc., but with integration of the same to a proper heat engine, considerable amount of work output can be obtained. A concentration ratio of 2 was employed for the CPC, to have a higher acceptance angle so that maximum amount of solar radiation can be focussed on to the absorber. This also eliminates the use of tracking for the collector. The CPC module used for this study is the tubular absorber module. The performance of the CPC has been modelled with the use of a CFD tool, namely "Ansys". The physical and the mathematical models are also discussed in details. The model generated has been validated with similar experimental work. The use of ORC for the generation of work from the CPC unit has been explored in the second part of this study. The overall heat loss coefficient and the heat losses from the collector have been expressed as a function of the outlet temperature of the CPC unit. The effect of the solar radiation intensity, mass flow rate of the working medium, inlet temperature of the working medium has been discussed in the results. Finally, the thermal efficiency and the optical efficiency of the collector have been expressed as a function of the outlet temperature of the working medium. The thermal efficiency has been found to be in the range of 60-80% at a maximum temperature of 100° C as attained from the computational study for varying solar radiation (700-1500) W/m2. The performance of the ORC has been studied with the help of "Engineering equation solver". The effects of parameters such as pressure ratio, condenser or the cold side temperature are discussed in the results. The effect of incident solar radiation of the CPC on the efficiency of the ORC has been studied. The efficiency of the ORC cycle with the CPC unit as the heat source has been found and compared with a conventional ORC cycle. The efficiency of the ORC with a suitable working medium for the study has been found to be 13.03%. The ORC with CPC as the heat input showed considerable improvement in thermal efficiency over the conventional ORC unit where the later had an efficiency of 9 %. The present study illustrates the significance of low-grade process heat in the improvement of the performance of ORC.

Key words: CPC, CFD, ORC, Modelling, Solar energy collector

I. INTRODUCTION

The sun is a massive celestial object with a diameter of 1.39 × 109 m. The solar energy hits earth for a mere 8 min and 20 seconds after leaving the giant star, which is 1.5 × 1011 m away from the green planet. The sun hasan effective blackbody temperature of 5762 K. The temperature in the central region is much higher and it is estimated at 8 × 106 to 40 × 106 K. The sun is a continuous fusion reactor in which hydrogen is turned into helium. The sun's total energy output is 3.8 × 1020 MW which is equal to 63 MW/m2 of the sun's surface. This energy radiates outwards in all directions. Only a tiny

DOI : 10.35291/2454-9150.2022.0234

fraction, 1.7 × 1014 kW, of the total radiation emitted is intercepted by the earth. However, even with this small fraction it is estimated that 30 min of solar radiation falling on earth is equal to the world energy demand for one year. All the forms of energy in the world as we know it are solar in origin. Oil, coal, natural gas and woods were originally produced by photosynthetic processes, followed by complex chemical reactions in which decaying vegetation was subjected to very high temperatures and pressures over a long period of time. Even the wind and tide energy have a solar origin since they are caused by differences in temperature in various regions of the earth. Advantages of solar energy as compared with other forms of energy are that, it is clean and can be supplied without any environmental pollution. The objective of this study a particular type of collector used to harness solar energy, its thermal analysis and performance, and review of its applications. Another objective of this study is to find a suitable heat engine for utilizing the heat obtained from the collector outlet as an input to the cycle and investigate its effects on the efficiency. The solar energy is very successfully utilized in the photovoltaic and solar thermal industry. Through different types of collectors and concentrating systems, solar energy can be collected.

Classification of solar collectors

Solar energy collectors are basically distinguished by their motion, i.e., stationary, single axis tracking and two axes tracking, and the operating temperature [4]. A typical flat-plate solar collector is designed in such a way that when solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short-wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate (greenhouse effect). FPC are usually permanently fixed in position and require no tracking of the sun. The collectors should be oriented directly towards the equator, facing south in the northern hemisphere and north in the southern. ETC has demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. The vacuum envelope reduces convection and conduction losses, so the collectors can operate at higher temperatures than FPC. Like FPC, they collect both direct and diffuse radiation. However, their efficiency is higher at low incidence angles. This effect tends to give ETC an advantage over FPC in day-long performance. ETC use liquid–vapor phase change materials to transfer heat at high efficiency. Because no evaporation or condensation above the phase-change temperature is possible, the heat pipe offers inherent protection from freezing and overheating. This self-limiting temperature control is a unique feature of the evacuated heat pipe collector. In order to deliver high temperatures with good efficiency a high-performance solar collector is required. Systems with light structures and low-cost technology for process heat applications up to 400°C could be obtained with parabolic through collectors (PTCs). PTCs can effectively produce heat at temperatures between 50°C and 400°C. When the parabola is pointed towards the sun, parallel rays' incident on the reflector are reflected onto the receiver tube. It is sufficient to use a single axis tracking of the sun and thus long collector modules are produced. The collector can be orientated in an east–west direction, tracking the sun from north to south, or orientated in a north–south direction and tracking the sun from east to west. The advantages of the former tracking mode are that very little collector adjustment is required during the day and the full aperture always faces the sun at noon time but the collector performance during the early and late hours of the day is greatly reduced due to large incidence angles. Linear Fresnel reflector technology relies on an array of linear mirror strips which concentrate light on to a fixed receiver mounted on a linear tower. The LFR field can be imagined as a broken-up parabolic trough reflector but unlike parabolic troughs, it does not have to be of parabolic shape, large absorbers can be constructed and the absorber does not have to move. The greatest advantage of this type of system is that it uses flat or elastically curved reflectors which are cheaper compared to parabolic glass reflectors. Additionally, these are mounted close to the ground, thus minimizing structural requirements. One difficulty with the LFR technology is that avoidance of shading and blocking between adjacent reflectors leads to increased spacing between reflectors. Blocking can be reduced by increasing the height of the absorber towers, but this increases cost. A parabolic dish reflector is a point-focus collector that tracks the sun in two axes, concentrating solar energy onto a receiver located at the focal point of the dish. The dish structure must track fully the sun to reflect the beam into the thermal receiver. For this purpose, tracking mechanisms similar to the ones described in previous section are employed in double so as the collector is tracked in two axes. The receiver absorbs the radiant solar energy, converting it into thermal energy in a circulating fluid. Because the receivers are distributed throughout a collector field, like parabolic troughs, parabolic dishes are often called distributed-receiver systems.

For extremely high inputs of radiant energy, a multiplicity of flat mirrors, or heliostats, using altazimuth mounts, can be used to reflect their incident direct solar radiation onto a common target. This is called the heliostat field or central receiver collector. By using slightly concave mirror segments on the heliostats, large amounts of thermal energy can be directed into the cavity of a steam generator to produce steam at high temperature and pressure. The concentrated heat energy absorbed by the receiver is transferred to a circulating fluid that can be stored and later used to produce power.

Advantages of compound parabolic collectors

There are many practical applications where moderate temperature (not very high or low) is required. Such applications are water heating, steam generation, industrial process heating, pumping of ground water, power generation and many more. The temperature needed for such application is about 100°C. CPC is most suitable for this purpose. Even when it is non-evacuated and without any selective surface coating, it can attain the temperature up to 100°C and higher.

CPC can also attain higher temperatures up to 200°C to 300°C at higher concentration ratio or when it is evacuated between absorber and envelope and the selective coating is applied on absorber surface or by using some special modifications.

Focusing type simple parabolic concentrator needs a continuous tracking of the sun, so the costly arrangement for tracking device is required, whereas for CPC, no continuous tracking is needed. It requires only a few tilt adjustments per year.

No diffuse radiation is accepted by simple parabolic concentrator, while a significant fraction (= 1/C) of diffuse radiation is accepted by CPC.

Due to smaller size of absorber in CPC, loss coefficient and hence losses are less as compared to that in FPC.

Concentration Ratio

The most common definition of concentration ratio, and that used here, is an area concentration ratio,1 the ratio of the area of aperture to the area of the receiver. (A flux concentration ratio is defined as the ratio of the average energy flux on the receiver to that on the aperture, but generally there are substantial variations in energy flux over the surface of a receiver. A local flux concentration ratio can also be defined as the ratio of the flux at any point on the receiver to that on the aperture, which will vary across the receiver.) The area concentration ratio is:

The higher the temperature at which energy is to be delivered, the higher must be

the concentration ratio and the more precise must be the optics of both the concentrator and the orientation system. Figure 1.3 shows practical ranges of concentration ratios and types of optical systems needed to deliver energy at various temperatures.

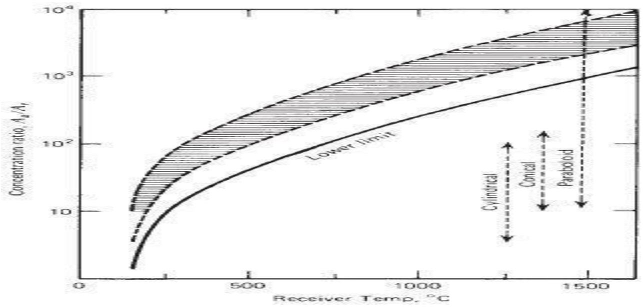


FIGURE 1.3 Relationship between concentration ratio and temperature of receiver operation

The abbreviation CPC stands for "Compound Parabolic Concentrator" and a CPC is a type of non- imaging concentrators. Imaging optics form an image of the source on the receiver, a non- imaging concentrator does not form an image of the source, but transfers the radiation from source to receiver over a larger distance. [1]. After extensive literature research, it can be said that the main use of CPC´s in solar applications is for use in thermal collectors. Some of the literature research has been discussed in brief in this section, based on which the objective for this study has been pinpointed. Study for the organic Rankine cycle has also been done to explore the feasibility of the ORC as a heat engine for low temperature applications. In thermal collectors, the use of CPC technology reduces the absorber area relative to the aperture area and this can reduce the overall heat loss coefficient since the absorber area is reduced. On the other hand, the use of CPC in thermal collectors reduce the optical efficiency due to increased reflector losses, and the optimal use of CPC reflectors in thermal collectors is the trade of between these two parameters. This chapter also elaborates the use of ORC as a potential heat engine to be used along with solar collectors based on the extensive literature review.

State of Research in thermal performance of CPC-Thermal collector

Bernardo et al. [2] evaluated the performance of the above mentioned low concentrating thermal CPC collector system and compared it with a traditional flat plate collector system. The compound parabolic collector which has a geometrical concentration of 1.5 was tested according to the quasi-dynamic method. This collector had no thermal insulation but still, due to the bifacial absorber and the low concentration, the heat loss factor 8 was low. A previous work by Haddi [3] in which the thermal performance of the Solarus CPCPV/ T collector and a new prototype of the Solarus CPC- Thermal collector was determined, showed significantly high values of the heat loss coefficient UL. The determined heat loss coefficients of the two different troughs of the new prototype CPC-Thermal colleced values of around 8.4W/m2K. Reichl et al [4] showed that 3D-transient calculations are necessary for a detailed reproduction of the velocity field. However,

DOI : 10.35291/2454-9150.2022.0234

overall temperatures and hence the involved heat fluxes can be extracted out of 2D-steady calculations, if small local deviations are accepted. Computationally cheap 2D-steady calculations can be sufficient if overall temperatures and heat fluxes are required and local effects can be ignored. The CFD mesh must resolve thin features (mirror and absorber tube) to allow physically correct temperature redistribution by thermal conduction along the walls. The CFD model allows simulating several scenarios, which provide insight into the heat transfer inside the collector and to the ambient. For example, efficiency curves can be calculated for various material parameters, heat transfer coefficient, inert gas fillings and reduced pressures. The CFD simulation model allows separating and quantifying the individual heat transfer mechanisms. The prediction of the heat losses and their origin is an important aid in the design of collectors with low thermal losses.

Omer and Infeld [5] studied a design procedure and thermal performance analysis of a two-stage solar energy concentrator. The concentrator is comprised of a primary one axis parabolic trough concentrator and a second stage compound parabolic concentrator mounted at the focus of the primary. Results indicate that in addition to improving the concentration efficiency, the second stage compound parabolic concentrator of the proposed design also inhibits convective air movement and, consequently, improves the overall performance of the solar concentrator.

II. PHYSICAL AND MATHEMATICAL MODELLING OF CPC

Modelling of the CPC

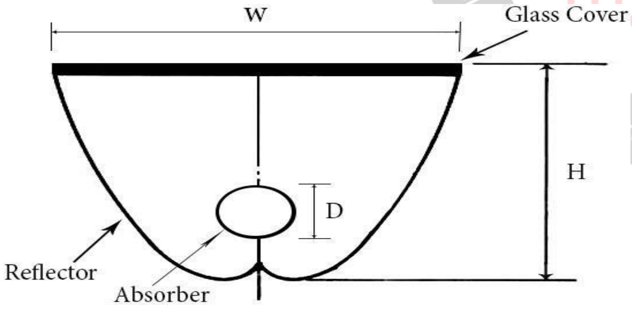


FIGURE 3.1 Schematic Diagram of the CPC

The CPC module undertaken for the current study consists of a complex cylindrical- parabolic reflection surface and a copper tube with ø15 mm diameter used as the absorber. The schematic diagram is shown in Fig 3.1. Conversion of solar energy into heat is conducted on the pipe collector. Pipe absorber is painted with selective color of high absorbing properties and low emissivity (εr). The area of the reflector has high reflection ratio (ρm). Between the pipe absorber and the reflector there is a gap (hole) which stops heat transfer from the collector pipe to the reflector. Water is the working fluid, with a laminar flow through the pipe of the collector. Apparatus of the collector is covered by transparent cover layer made of glass so the reflector area could be saved from wearing and to lower the value of heat loss from the assembly pipe absorber-surrounding pipe layer.

The reflector is modelled using aluminum. The physical properties of solid materials were considered constant with temperature. The air in the cavity was modelled as incompressible ideal gas. Thickness of the aluminum reflector is taken as 1 mm. The glass cover at the top has a thickness of 4 mm. The length of the reflector is taken as 1 m in the axial direction. A concentration ratio of 2 was adopted for this study. For the circular receiver the gap between receiver and bottom of enclosure was obtained joining two parabolas by a corner radius of 1 mm. Values of tilt angle, measured in relation to the ground is chosen as 45°. Copper is chosen as the absorber material. The thickness of the copper tube is taken as 1 mm.

Basic assumptions

The following assumptions were introduced for the definition of mathematical model:

Steady state performance is assumed.

The sky was treated as an absolute black object, which is the source of infrared radiation during an equivalent sky temperature.

Reflected radiation from surrounding objects was considered negligible and was not taken into account.

Diffusive insulation on the apparatus of the cover is isotropic.

CPC collector has permanent Sun tracking; thus, Sun rays are normal to the plane of transparent cover (aperture plane).

Radiation to the collector is unified.

The aperture, envelope, receiver and reflector have uniform temperature distributions and the CPC component properties are independent of temperature.

Heat transport in the transparent cover, surrounding cover layer, collector surrounding layer, pipe absorber and the fluid is transient.

Transparent cover, transparent cover layer, collector surrounding layer, and pipe absorber are homogenous and isotropic objects.

Heat transport by conduction in the transparent cover layer and the glass layer is negligible due to small heat conductivity of glass.

Thermo-physical properties of the CPC collector component material (ρ*, c, λ) as well as optic properties (ρ, τ, ε, α) of the components of CPC collector do not depend on coordinates, temperature or time;

Fluid flow is steady state and it is conducted only in the

DOI : 10.35291/2454-9150.2022.0234

axial direction, thus the velocity field is related just to the speed component.

Fluid flow shape is the same in every axial cross section, thus the tangential velocity component does not exist.

Radial velocity component is neglected as a value of smaller order and thus the convection in radial direction is also neglected.

Fluid flow may be considered incompressible.

Conduction in the axial direction has a negligibly small contribution to the resulting heat transport compared to the convection.

Geometric construction

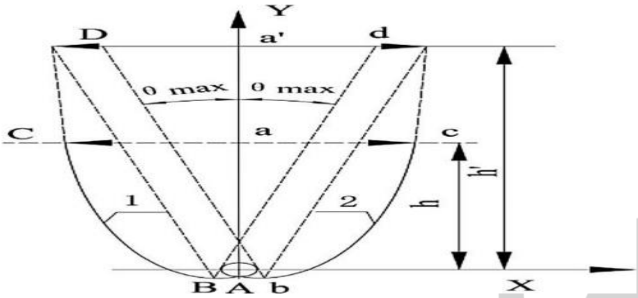


FIGURE 3.2 Geometric specifications of the CPC

When the CPC collector is reduced as half as its height, the concentration ratio decreases by 10% and the average number of reflections decreases by 17%, which shows that the truncated CPC has a high optical efficiency but a little effect on the concentration ratio. In the Fig 3.2 h′ and a′ are the theoretically values of the height and aperture width, h and a are the truncated values.

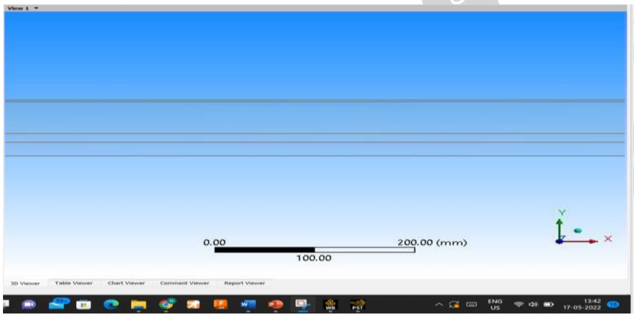


FIGURE 4.1 Geometry of the CPC from the front view showing the inlet and outlet of the tube.

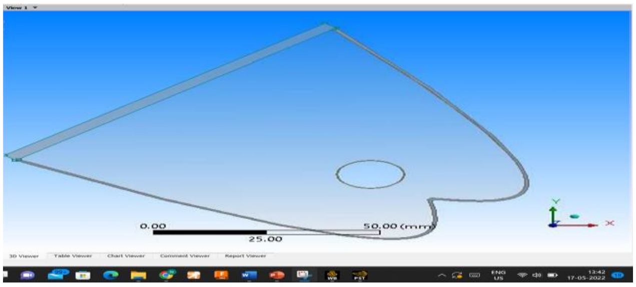


FIGURE 4.2 Geometry of the CPC from the side view showing the parabolic cavity

After the creation of the geometries, it has been exported to Ansys Mesh (v14.0) so that it can be meshed with a suitable grid. Figs 4.3, 4.4 show the mesh of the collector geometry from two different cross sections. The design of the cross-sectional view of the CPC is quite complex. Therefore, multi zone method is used to mesh the geometry shown in figure. All the domain including the inner fluid domain, the reflector domain, and the glass cover domain. Edge sizing is applied to refine the mesh along the glass cover. Since it is geometry of curvature in nature, hence curvature and proximity option were used in the mesh table. The upper glass cover with a minimum element size of 0.1 mm. The minimum and the maximum face size used for the meshing are 0.2 mm and 0.3 mm respectively. The quality of the mesh yielded an average value of 0.99. Various named selections have been created to define the incident radiation flux, absorber, reflector and the glass cover. The contact region is not automatically resolved here, hence interface zones have been created manually. Four interface zones have been created between the glass-inner fluid domain, glass-reflector, inner fluid-reflector and inner fluid domain-absorber by considering each face as being part of both the domain.

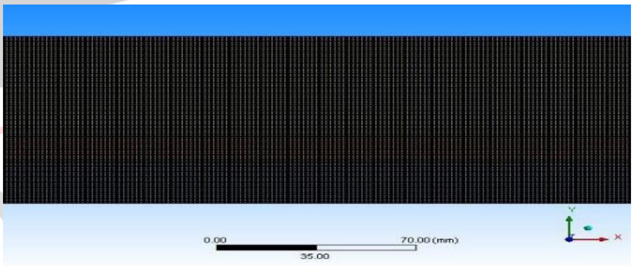


FIGURE 4.3 Mesh profile of the first geometry

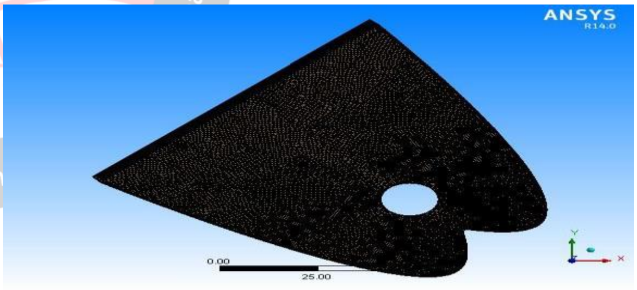


FIGURE 4.4 Mesh of the second geometry

The second mesh have been generated by refining all the edges using the edge sizing method with number of divisions of an edge depending on the length of the edge. Finally, the entire domain has been meshed with multi zone method. The quality of the mesh yielded an average of 1. Various named selection has been created to define the inlet fluid, outlet fluid, inlet radiation, the outer walls. Contact regions have been manually created by generating six interfaces.

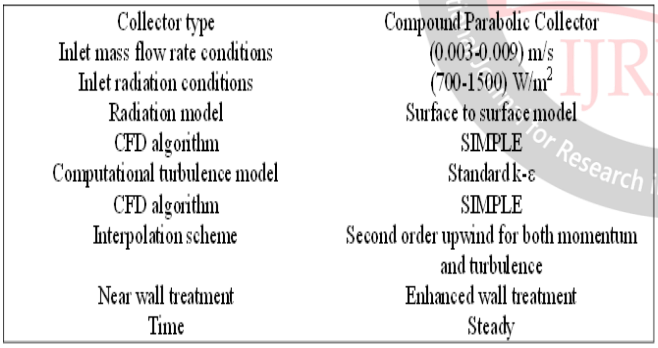
CFD formulation of the models

The engineering problems after being undergone through the pre-processing phenomenon with the creation of the geometry and grid, the process is continued with the solving of the considered problem. The generated mesh on the geometry has been exported to the computational solver Ansys Fluent (v14.0) wherein the case has been defined and solved with necessary conditions. The standard k-ε turbulence model has been adopted that solves two separate transport equations and allows the independent determination of the turbulent kinetic energy (k) and its dissipation rate (ε). The standard k-ε turbulence model has the significance over the other models for the fact that it is suitable to determine the problems involving fluid flow through the vicinity of the complex geometries.

interpolation scheme for both momentum and turbulence to obtain results with more accuracy.

Various boundary conditions have been assigned to the meshed geometry. This is required so as to define a problem. The inlet radiation has been assigned to the upper glass aperture which has been designated as a wall. The inlet and the outlet of the copper tube have been defined as a wall to define the mass flow inlet and mass flow outlet of the working fluid. The outlet wall has been designated as outflow in the boundary conditions to avoid the problem of reverse flow. In the Fig 4.3, the outlet temperature obtained has been assigned to the absorber so as to obtain the isotherms inside the cavity of the collector. Radiation model have been used to study the effect of radiation inside the collector. The various computational conditions adopted for the study has been tabulated below in Table 4.1.

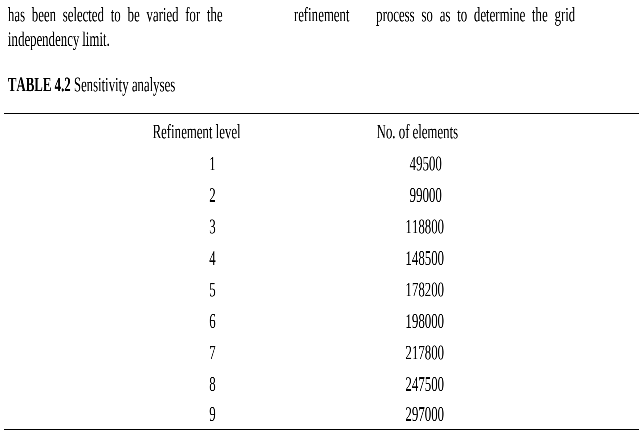
TABLE 4.1 Computational conditions



Collector type	Compound Parabolic Collector
Inlet mass flow rate conditions	(0.003-0.009) m/s
Inlet radiation conditions	(700-1500) W/m^2
Radiation model	Surface to surface model
CFD algorithm	SIMPLE
Computational turbulence model	Standard k-ε
CFD algorithm	SIMPLE
Interpolation scheme	Second order upwind for both momentum and turbulence
Near wall treatment	Enhanced wall treatment
Time	Steady

Sensitivity study

The process of simulation has been repeated with different refinement levels of the mesh. The refinement is carried on undertaking different mesh size and is extended up to a limit after which there is no significant quantitative change in the result. This limit of the refinement is called grid independency limit (GIL) and the mesh is said to have attained the limit of grid independence. The entire mesh size has been varied several times that is aimed towards the limit of grid independence. Various levels of refinements of the mesh that have been adopted are listed in Table 4.2. The outlet temperature of the absorber tube



has been selected to be varied for the refinement process so as to determine the grid independency limit.

TABLE 4.2 Sensitivity analyses

Refinement level	No. of elements
1	49500
2	99000
3	118800
4	148500
5	178200
6	198000
7	217800
8	247500
9	297000

The selected level 6 has 198000 numbers of cells with average orthogonal quality and aspect ratio of 0.9 and 1.95 respectively which lie in the acceptable and very good quality level. Level 6 has been used in all the simulations. Fig 4.5 shows the result of sensitivity analysis in the variation of the outlet temperature with number of elements of the selected mesh. The following readings have been taken at boundary conditions of 1000 W/m2 and 0.009 m/s inlet mass flow rate.

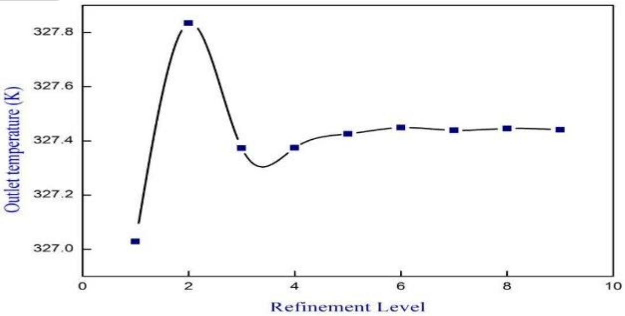


FIGURE 4.5 Variation of outlet temperature with different refinement levels

Post Processing of the models

The performance of the Compound Parabolic Collector has been evaluated with the help of CFD and has been studied in detail to explore the influence of incident radiation and the flow physics on the performance. The process of obtaining results is carried out in the post processing section. The post processing of the simulations process enables the placing of the planes, lines and points at the desired locations so as to acquire the information of the temperature at the outlet. Figure shows the placing of lines starting from the inlet of the flow to the outlet of the flow to evaluate the temperatures at various locations along the lines. Further results can be evaluated from the temperatures obtained from various boundary conditions.

Computational results of performance of compound parabolic collector

The post-processing of the models enables the researchers to accumulate the required parametric values so as to determine the performance of the compound parabolic

DOI : 10.35291/2454-9150.2022.0234

collectors. During the calculations, it was assumed that the solar rays fall normal to the aperture plane.

Various thermo physical properties for the compound parabolic collector module is given in the Tables 4.3 and 4.4.

TABLE 4.3 Thermophysical properties of the solid components

Mate rials	Density (kg/m^3)	Properties Specific Heat	Thermal conductivity (W/m-
		(J/kg-k)	k)
Glass	2500	840	1.05
Alum inum	2719	871	202.4
Copp er	8978	381	387.6

TABLE 4.4 Thermophysical properties of the fluid components

Materials	Density(kg/m^3)	Properties Specific Heat (J/kg-k)	Thermal conductivity (W/m-k)	Viscos y(kg/r s)
Air	1.225	1006.43	0.0242	0.000
Water	998.2	4182	0.6	0.0010

During the calculations, the ambient temperature, Tamb is fixed to 27° C. The values of incident solar radiation flux have been varied from 700W/m2 to 1500W/m2. The mass flow rate of the working fluid has been varied from 0.005 m/s to 0.009 m/s. The various results obtained for the above said condition has been thoroughly studied in the following section. Various iterations have been performed on Ansys to obtain a feasible value for the outlet temperature which has been used to obtain the efficiency of the collector.

CFD model validation with experimental results

The CPC model described in the previous chapter (sec 3.3) has been validated by the experimental results obtained by Patel and Patel [7]. The results have been obtained by taking the boundary conditions of 1500 W/m2 solar flux intensity and mass flow rate of

0.012 m/s. The comparison between the results obtained computationally and experimentally from the reference paper has been shown in the **Fig 4.6. The deviation between the two results have been found to be 0.6 %.**

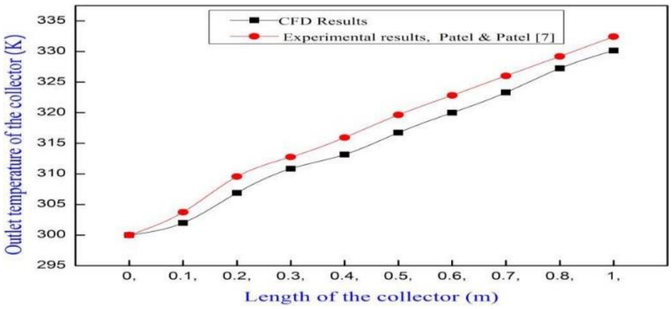


FIGURE 4.6 Model validation

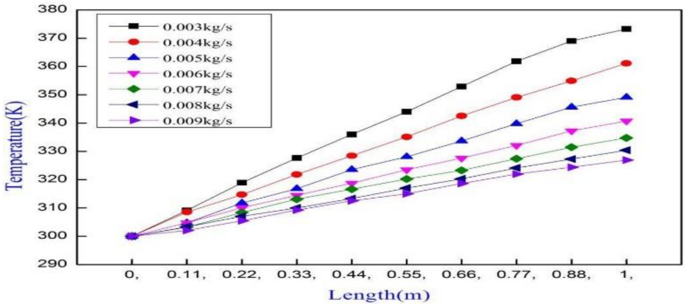


FIGURE4.7 Variation of mass flow rate on the outlet temperature

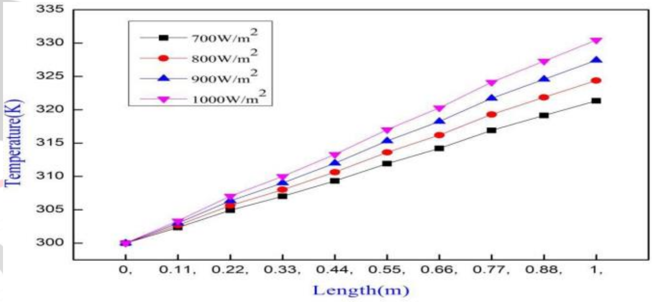


FIGURE 4.8 Variation of outlet temperature due to the variation of the radiation flux

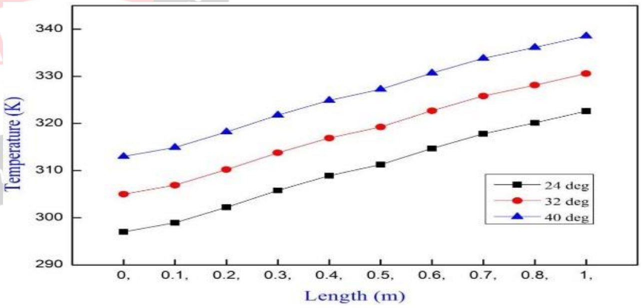


FIGURE 4.9 Variation of outlet temperature with the inlet temperat

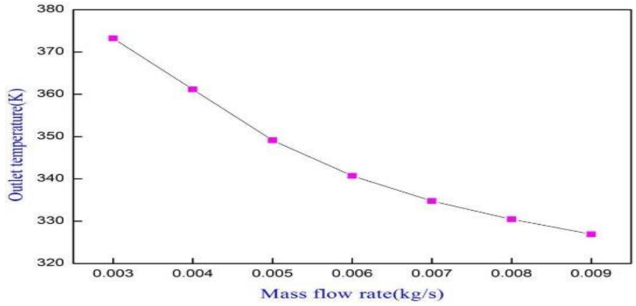


FIGURE 4.10 Variation of outlet temperature due to the change in mass flow rate

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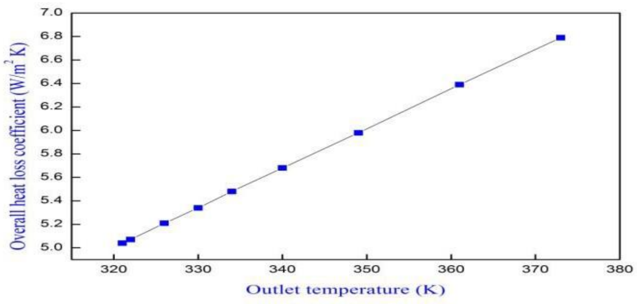

FIGURE4.11 Overall heat loss coefficient variations with the outlet temperatur

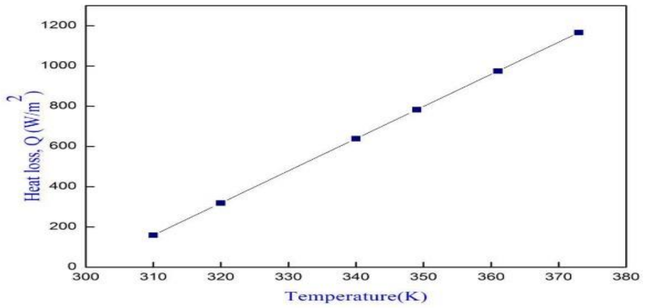

FIGURE 4.12 Thermal heat loss variation against the outlet temperature

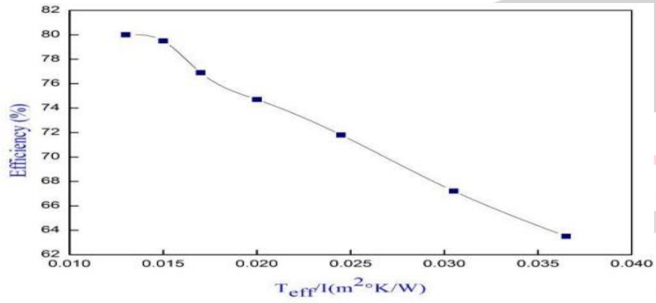

FIGURE 4.13 Variation of collector efficiency with the outlet temp at the same solar insolation

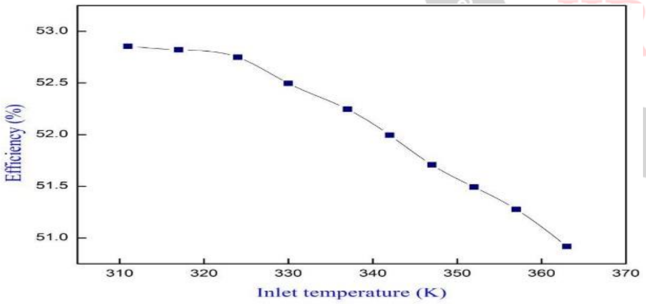

FIGURE 4.14 Variation of thermal efficiency with the inlet temperature of the working fluid

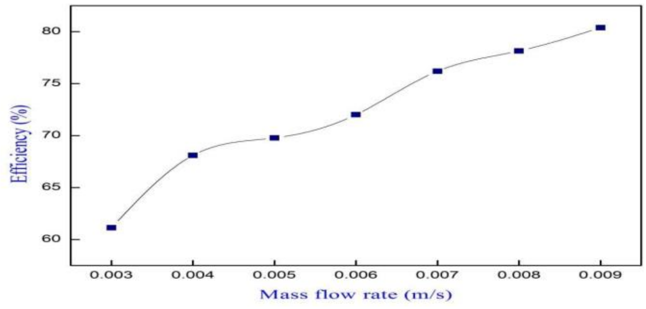

FIGURE 4.15 Variation of efficiency against the variation of mass flow rate

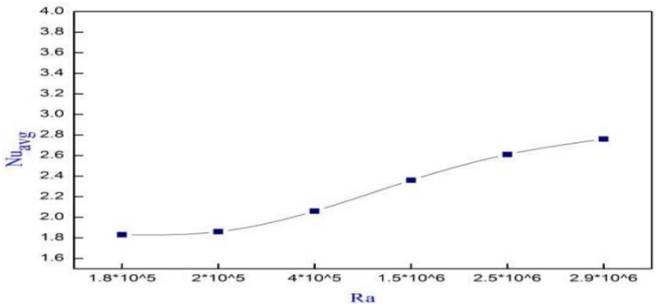

FIGURE 4.16 Variation of Nusselt number with Rayleigh Number

Temperature distributions inside the CPC

Using the contour option in Ansys 14.0, temperature contours at different boundary conditions are extracted which are shown in this section. These contours are helpful in understanding the temperature change over any profile. From the contours, the temperature change from the inlet condition to the outlet can be seen with the color coding. Fig 17 to 26 shows the temperature distribution inside the CPC at different operating conditions. It can be seen that as the heat flux increases, the temperature at the outlet of the absorber tube increases or decreases depending on whether the mass flow rate is decreasing or increasing respectively and as the inlet temperature of the absorber tube increases, the outlet temperature of the absorber tube decreases. The above temperature distributions corroborate the results obtained in sec 4.12. Fig 4.27 shows the streamlines inside the parabolic cavity of the CPC.

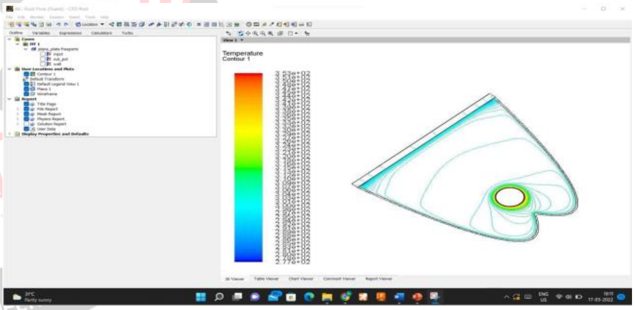

FIGURE 4.17 Isotherms at 45° angle and at receiver temperature of 80°C

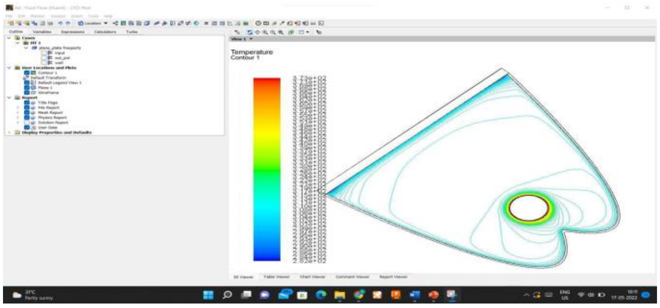

FIGURE 4.18 Isotherms at 45° angle and at receiver temperature of 100°C

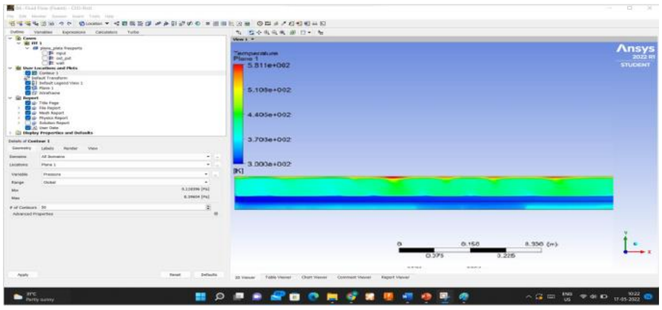

FIGURE 4.19 Temperature distributions at 900W/m2, mass flow rate of 0.008 kg/s and 27° C inlet temperature

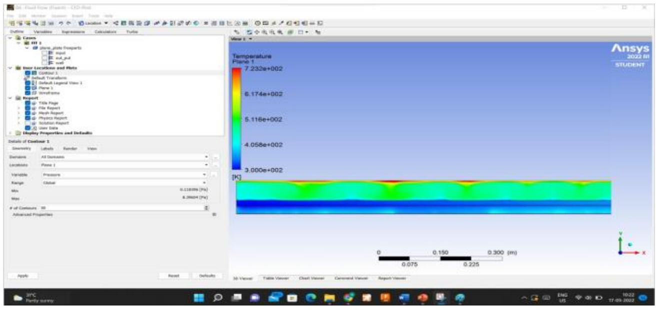

FIGURE 4.20 Temperature distributions at 1000W/m2, mass flow rate of 0.005 kg/s and 27° C inlet temperature

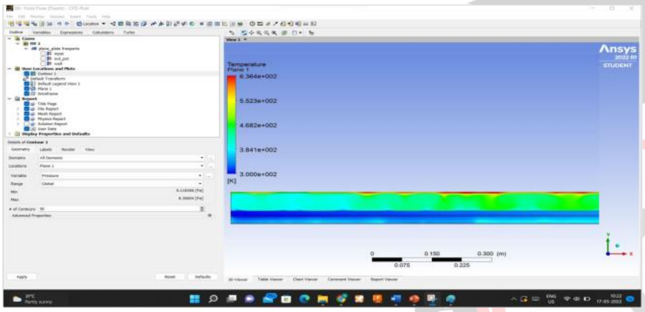

FIGURE 4.21 Temperature distributions at 1000W/m2, mass flow rate of 0.006 kg/sand 27° C inlet temperature

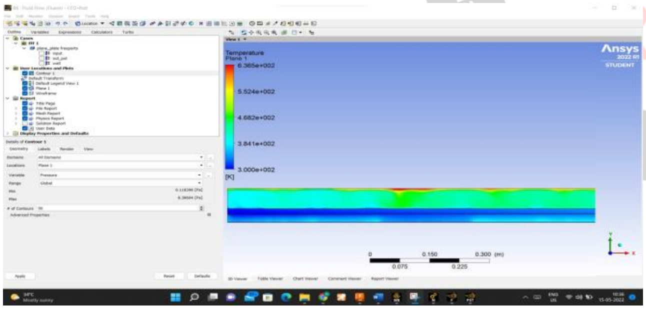

FIGURE 4.22 Temperature distributions at 1000W/m2, mass flow rate of 0.007 kg/s and 27° C inlet temperature

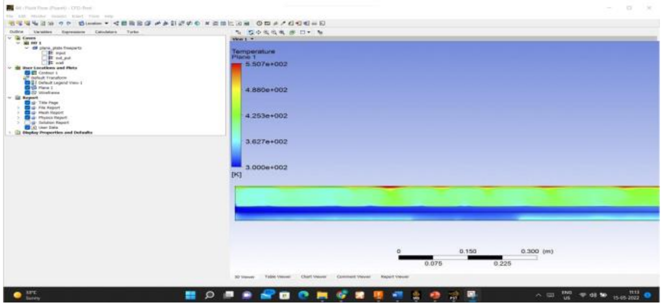

FIGURE 4.23 Temperature distributions at 800W/m2, mass flow rate of 0.008 kg/s and 27° C inlet temperature

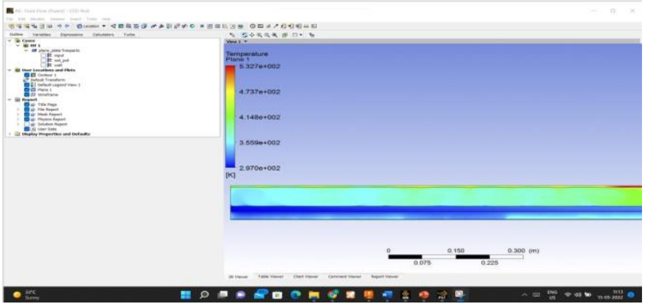

FIGURE 4.24 Temperature distributions at 950W/m2, mass flow rate of 0.009 kg/s and 24° C inlet temperature

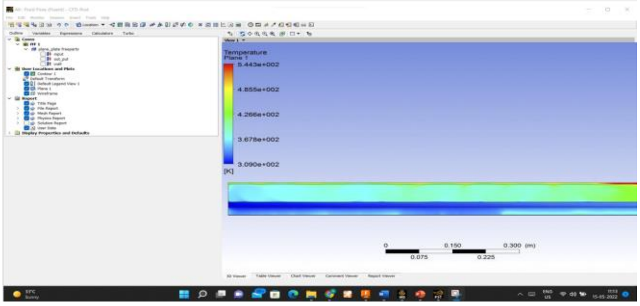

FIGURE 4.25 Temperature distributions at 950W/m2, mass flow rate of 0.009 kg/s and 36° C inlet temperature

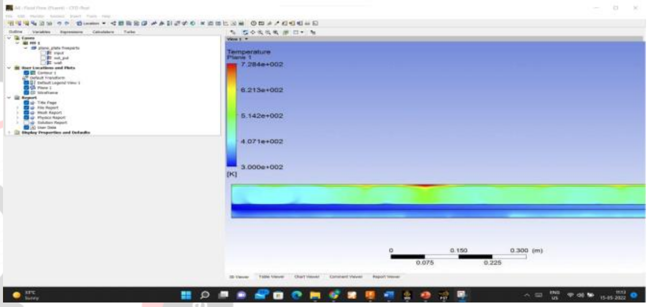

FIGURE 4.26 Temperature distributions at 1000W/m2, mass flow rate of 0.004 kg/s and 27° C inlet temperature

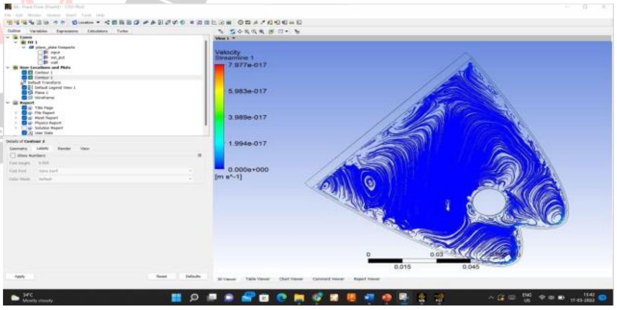

FIGURE 4.27 Streamlines at 45° angle and at receiver temperature of 100℃

III. CONCLUSIONS

Computational study of the ideal compound parabolic collector has been carried out in ANSYS 14.0 and the results are shown. A number of assumptions have been taken for simplifying the analysis. The CPC collector under study shows thermal efficiency in the range of 60-80% under the variation of mass flow rate of 0.003-0.009 kg/s. The temperature output can also be increased by using series of collectors. The efficiency shows an increasing trend with respect to the mass flow rate. The heat efficiency also shows a decreasing trend with respect

DOI : 10.35291/2454-9150.2022.0234

to the inlet temperature of the absorber tube. The instantaneous efficiency or the collector efficiency shows a decreasing trend with respect to the increasing temperature of the absorber outlet. Although the thermal efficiency is of utmost importance as compared to the collector efficiency, but the collector efficiency cannot be ignored. An optimum point has been showed in the results for both the efficiencies. All the results have been obtained with the highest quality mesh possible to get the most accurate results. The efficiency shows a decreasing trend with increase in the inlet temperature of the absorber fluid. This is due to the fact, given the insolation and the ambient conditions are fixed, the temperature difference decreases hence the decrease in the heat efficiency. The heat loss and the overall heat transfer coefficient show a linear rise with the rise in the outlet temperature. The Nusselt number curve also rises but non- linearly with the increasing Grassof number but within the range of the natural convection. Parametric study of the Organic Rankine Cycle is carried out in the Engineering equation solver and consequently the results are shown. The governing factor for the expander of the ORC has been designated to the outlet of the absorber of the compound parabolic collector. The study of the ORC has been carried out withR600a commonly known as iso- butane. Calculations have been carried out by considering the outlet temperature of the CPC as a heat input to the expander. Depending on the critical temperature of R600a, the highest efficiency obtained from the parametric study is 13.03%. ORC has been designed for low temperature applications, hence the low efficiency. The use of the ordinary steam Rankine cycle in this study would have yielded lower efficiency at temperatures obtained in the CPC. Hence the use of ORC is justified as ORC's are fundamentally designed to work at lower temperatures as compared to steam Rankine cycle. Because of the use of high-density organic fluid as working medium, the requirement of the working medium per unit energy produced is low and also because of this the volume flow also reduces such that the size of the components can be lower in ORC. The ORC efficiency has been plotted against the solar flux intensity to reflect the effect of solar radiation on ORC efficiency. The efficiency obtained from the current study of ORC with a CPC unit as the heat input has been compared with a conventional ORC (sec 5.6). The results showed an increase in the efficiency by 44.77 % due to the use of CPC as a heat source. A correlation can be found out between the solar flux and the ORC efficiency as the outlet temperature is a function of the heat flux and mass flow rate of the working fluid as well, whereas the efficiency of the ORC is a function of the outlet temperature of the CPC module. Hence, we can say that the ORC efficiency is a function of the solar heat flux.

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DOI : 10.35291/2454-9150.2022.0234