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Experimental Analysis on Power Generation Unit Using R134a Powered by Fresnel Lens

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Abstract - *This paper mainly gives a thermodynamic process on utilizing low-temperature sources of range (150℃-250℃) mainly from solar energy by using a Fresnel lens. Generally, the thermal power plant runs on the Rankine cycle with water as the working fluid. By using organic compounds having a lower boiling point as a working fluid Rankine cycle can utilize low-temperature sources effectively than water. So, the usage of fossil fuels for the Rankine cycle can be replaced with renewable solar energy. Fresnel lens is a technology that utilizes solar energy from the sun and concentrates on a smaller area. This paper gives an investigation of the operating temperature of working fluid to run a steam turbine and experimental analyzation of the Organic Rankine Cycle to run a generator using R134a refrigerant as a working fluid.*

Key Words: **Organic Rankine Cycle, Power, Fresnel Lens, R134a, Solar Energy, Thermal Power Plant.**

1. INTRODUCTION

Generally, the thermal power plant is a facility for industries for the generation of electric power. It is also called an energy centre because it describes mostly and exactly what a plant does, which is changing one form of energy like heat energy, chemical energy into electrical energy. Energy can also be present in different forms like mechanical, electrical, thermal, etc. The main theme is to change a form of energy into others by using the required arrangements. Electrical energy is preferred because it has the following advantages.

- Transportation of electrical energy is easy from place to place.
- Losses of energy are minimized during transportation.
- It can be subdivided easily.
- Its use is economical in nature.
- It can easily change one form of energy into another.

Power is mainly connected with electrical energy and mechanical work. So, power is generally characterized as the rate of flow of energy and power plant is the station for producing and delivering of mechanical and electrical energy. In like manner uses a machine or gathering of equipment that produces and conveys a stream of mechanical or electrical energy is control plant.

1.1 Importance of the Project

- Effectively use the energy from the sun as thermal energy and reduce the usage of fuels in thermal power plants.
- Utilization of low-temperature sources from the sun i.e. below 200°C thereby replacing water with a low boiling point fluid.

2. STATEMENT OF THE PROBLEM

The steam power plant is a standout amongst the most vital approaches to change on a substantial measure of thermal energy into power [1]. Precedents are coal-fired and nuclear power plants [1]. Fundamental parts of a Rankine cycle are a turbine, working liquid, pump, condenser, and vaporizer. In this cycle, water is utilized as working liquid has following thermodynamic attributes [1]:

Table -1: Thermodynamic Characteristics of Water [1]

Property	**Value**	**Units**
Specific Heat	4.18	kJ/kg K
Triple Point	273.16 at 0.611 kPa	K
Freezing Point	273.15 at 101.325 kPa	K
Latent Heat	2256.6 at 101.325 kPa	kJ/kg
Critical Point	647 at 22.06 MPa	K
Boiling Point	373.15 at 101.325 kPa	K
Molecular Weight	18	kg/kmol

Very low viscosity, Non-flammable, non-toxic and no harm to the environment, cheap and abundant, good energy carrier, good thermal/chemical stability.

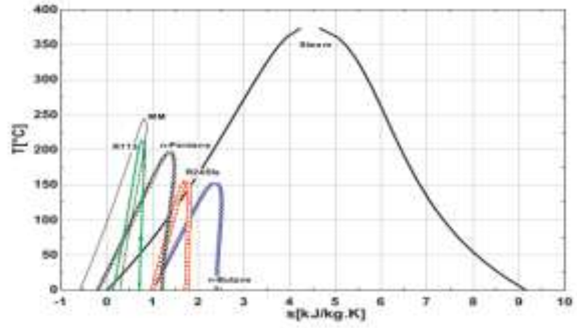


Fig -1: T-S Diagram

Anyhow, lots of problems occur by using water in the Rankine cycle.

- Superheating of fluid is required before condensation in the evaporator.
- There is a great chance of causing turbine blade erosion
- There will be more pressure inside the evaporator
- The turbine design is complicated and very costly

From the above reason, we can say that water is mainly used in high-temperature sources and in large centralized systems [1]. Looking for medium and small-scale power plants, the issues experienced with water can be mostly moderated by choosing a suitable fluid [1]. Organic compounds have high molecular weight and low ebullition also called 'Critical temperature' when compared to water. This cycle using organic compounds is known as "Organic Rankine Cycles". The traditional steam power plant has fewer advantages when compared to the ORC plant.

- Less amount of heat is required in the process of evaporation
- The process of evaporation happens at low temperature and pressure.
- The process of expansion finishes in the region under vapor and consequently, the superheating isn't necessary, and the danger of blade disintegration is prevented.
- The ratio of pressure drop is very small and so the single-stage turbine is used because the temperature difference between condensation and evaporation is smaller

Aldehydes, Hydrocarbons, Fluids mixtures, Amines, Hydrofluorocarbons

Hydrochlorofluorocarbons, Chlorofluorocarbons, Ethers Siloxanes, Perfluorocarbons, Alcohols, Hydrofluoroethers.

A working liquid in the ORC machine assumes a key job – It decides the financial aspects and the execution of the plant. This legitimizes the copious writing devoted to liquids choice for altogether different heat recuperation applications from which attributes of good liquids can be extricated.

Table -2: Thermodynamic Characteristics of ORC working fluid

Property	Status
Vapor saturation curve	Zero
Condensing and evaporating pressures	Acceptable
Latent heat of vaporization	High
Specific heat	High
Thermodynamic performance	High
Critical temperature, pressure	Moderate
Chemical and thermal stability	Good
Heat transfer properties	Good
Density	High
Material compatibility	Good
Environmental impacts	Low
Safety characteristics	Good
Cost and availability	Low

Although the Rankine cycle gives better output for low-temperature sources its implementation has been never done worldwide. It is 1st used by the USA, Canada, Germany. Organic Rankine Cycle should be implemented effectively as it has many advantages when compared to the conventional Rankine cycle. Research should be done in order to improve the efficiency of the ORC.

3. METHODOLOGY

The methodology is nothing but a set of rules to be followed in a series based on tasks, phases, and techniques used by using the required tools.

3.1 Problem Identified

- Leakages between copper tube joints
- Condensation the fluid
- Availability of sunlight
- Right placement of the copper tube
- Instant heating of the fluid

3.2 Need of the Work

- Should prevent leakages
- Change the suitable nozzle
- Adjust the heat exchanger according to sunlight

3.3 Solution for the Problem

For condensation of fluid pentane is the most efficient fluid to use because its boiling point is at normal room temperature. For condensing R134a a pressurized container at a very lower temperature is required.

3.4 Feasibility Study

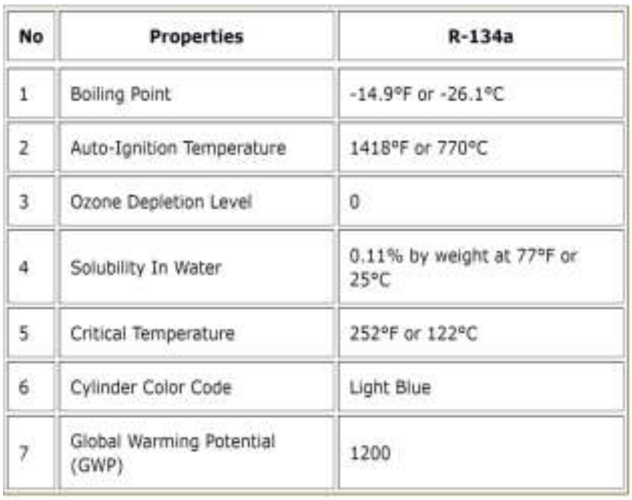
To see whether all the resources used for making the project are in availability or not.

3.5 Testing and Implementation

Fabrication of different components according to the required design and testing them out and changing the design if required

4. WORKING PRINCIPAL

- In this project, the following components are used such as Fresnel lens, copper tube, tank, pump, turbine, and frame.
- The Fresnel lens is fixed as per the required area. This lens will absorb solar heat energy, reflect the copper tube.
- The copper tube is used to passes the fluid from the tank and it converts this fluid into steam.
- Here, the R134a is work as a working fluid. Its boiling point temperature is less than low compared to the water.
- This steam is passed through the turbine to convert to the steam into electrical energy.



No	Properties	R-134a
1	Boiling Point	-14.9°F or -26.1°C
2	Auto-Ignition Temperature	1418°F or 770°C
3	Ozone Depletion Level	0
4	Solubility In Water	0.11% by weight at 77°F or 25°C
5	Critical Temperature	252°F or 122°C
6	Cylinder Color Code	Light Blue
7	Global Warming Potential (GWP)	1200

Fig -2: Properties of fluid selected

5. CALCULATION

Heat Transfer Fluid: R134a

5.1 Inner Area of the Copper Tube (A)

D Diameter of the Copper Tube (m) = 0.012 m

L Length of Copper Tube (m) = 4.2 m

$$A = \pi \text{ x } D \text{ x } L$$

$$A = \pi \text{ x } 0.012 \text{ x } 4.2$$

$$A = 0.158336 \text{ m}^2$$

5.2 Volume of the receiver (V)

$$V = (\pi \text{ x } D^2 \text{ x } L) / 4$$

$$V = (\pi \text{ x } 0.012 \text{ x } 4.2) / 4$$

$$V = 4.75 \text{ x } 10^{-4} \text{ m}^3$$

5.3 Mass Flow Rate (m·)

The mass flow rate is calculated by emptying the 500gms tin. Time is taken to empty it is noted.

t Time taken = 14min

m· Mass flow rate

$$m\cdot = 1/(2 \text{ x } 14 \text{ x } 60) \text{ kg/sec}$$

$$m\cdot = 5.952 \text{ x } 10^{-4} \text{ kg /sec}$$

5.4 Velocity of Heat Transfer Fluid

From the above mass flow rate ($m\cdot = 5.952 \text{ x } 10^{-4}$ kg/s), we can find velocity of inlet fluid inside the tube (heat exchanger) by using mass flow rate equation containing velocity.

$$m\cdot = \rho \text{ x } A \text{ x } V$$

$$V = m / (\rho \text{ x } A)$$

$$V = 5.952 \text{ x } 10^{-4} / (4.25 \text{x } 0.158336)$$

$$V = 8.845 \text{ x } 10^{-4} \text{ m/s}$$

The material used as the heat receiver is copper. We know that the temperature of the surface of the receiver (250°C = 523K). Per Stefan-Boltzmann's Law, the energy emitted by a body is [3]

Q_{rad} heat transfer radiation

T temperature of the body's surface

A area of the body

σ Stefan-Boltzmann constant = 5.669 x 10−8 W/m^2.K^4

ε the emissivity of copper = 0.88

$$Q_{rad} = \varepsilon \text{ x } \sigma \text{ x } A \text{ x } T^4$$

$$Q_{rad} = 0.88 \text{ x } 5.669 \text{ x } 10-8 \text{ x } 0.15833 \text{ x } 523^4$$

$$Q_{rad} = 590.96 \text{ W/m}^2\text{K}$$

5.5 Reynold's Number

The average velocity is half the maximum velocity in a fully developed laminar flow centerline. μ For R134a at pressure 5 bar and temperature 323K is 12.93 x 10^{-6} pa-sec

$$Re = (\rho \text{ x } V_{avg} \text{ x } D) / \mu$$

$$V_{max} = 8.845 \text{ x } 10^{-4} \text{ m/s}$$

$$V_{max} = 4.4225 \text{ x } 10^{-4} \text{ m/}s$$

The Reynold's Number Equation becomes:

$Re =$ 4.25 x 4.4225 x 10^{-4} x 0.012 / 12.93 x 10^{-6}

$Re =$ 1.74437

We know that when Re < 2300 which our case the flow is laminar

5.6 Convective Heat Transfer Coefficient Using Nusselt Number

In laminar flow with a constant surface heat flux and for a circular cross-sectional area the Nusselt number is

k Thermal conductivity of copper = 386 W/m.K

D_{in} Inner diameter of the tube = 0.012 m

The convective heat transfer coefficient

$Nu = (h \times D) / k = 4.36$

$h = k \times Nu / D$

$h = 386 \times 4.36 / 0.012$

$h = 140246.66\ W/m^2K$

5.7 Hydrodynamic Entry Length Calculation

$L_{h\ laminar} = 0.05\ Re$

$L_h = 0.05 \times 1.74437$

$L_h = 0.872185\ K$

5.8 Calculation of Pressure Drop

Generally, a pressure drop occurs mainly due to the viscosity of the fluid inside the copper tube. So, pressure drop due to viscosity is calculated.

$\Delta P = P_1 - P_2$

$\Delta P = 32 \times \mu \times L \times V_{avg} \times D^2$

$\Delta P = 32 \times 12.93 \times 10^{-6} \times 4.2 \times 4.4225 \times 10{-}4\ \ \times 0.012^2$

$\Delta P = 1.10669 \times 10^{-10}$ Pa

The pressure loss in the heat receiver is very small. Hence constant pressure heating is done per the Rankine cycle.

- **Turbine**

Number of Blades = 47; Diameter = 9 cm

- **Formula Used**

Swept Area = A= π x (radius of turbine) ^{2}

Turbine Velocity = (π x D x N)/60

D diameter of turbine (m)

N = number of revolutions per minute(rev/min)

- **Power Available at the Turbine** [2]

P = (1/2) x Density x (Velocity) ^{3} x C_p x Area [2]

6. MODEL CALCULATION

A Area Swept by the turbine (m/sec)

v Turbine Velocity (m/sec)

P Power from the Turbine (watts)

$A = \pi \times R^2$

$v = (\pi \times D \times N)/60$

$P = 1/2 \times \rho \times A \times V^3 \times C_p$

$A = 3.14 \times (0.045)^2 = 6.361725 \times 10^{-3}\ m^2$

$v = (3.14 \times 0.09 \times 2000)/60 = 9.42477$ m/s

$P = 1/2 \times 4.25 \times 6.361725 \times 10^{-3} \times (9.42477)^3 \times 0.4$

P = 4.52 watts

Table -3: Power available at the turbine

Revolutions Per Minute for the turbine (rpm)	Speed of turbine in (m/s)	Power Available at The Turbine (watts)
4000	18.84	36.156
3000	14.13	15.25
2000	9.424	4.52
1000	4.7123	0.56577

6.1 Efficiency Calculation by Graph

Mini REFPROP software is used to draw a graph by taking inputs of temperature, pressure, and quality of the fluid. Different working fluids can be selected in the software. For our calculations, R134a is selected as a working fluid in the software.

By assuming 3 different pressures and temperatures of the heated working fluid condensing pressure and temperature can be calculated.

In the below graphs they follow Organic Rankine Cycle

η_{th} Thermal efficiency

W_t Work done by the Turbine (kJ/kg)

W_p Work done by the Pump (kJ/kg)

Q_{in} Heat supplied (kJ/kg)

$h_{1,2,3,4,5,6,7,8}$ enthalpy at respective points (kJ/kg)

P pressure at that point

$$\eta_{th} = (W_t - W_p)/Q_{in}$$

$$W_t = h_1 - h_2$$

$$W_p = h_5 - h_4$$

$$Q_{in} = h_1 - h_5$$

Table -4: Process in Organic Rankine Cycle

No	Label	Process
1.	1-2	Isentropic expansion inside the turbine
2.	2-3	Isobaric heat rejection by the heat exchanger
3.	3-4	Isobaric heat rejection
4.	4-5	Isentropic compression in pump
5.	5-6	Constant pressure heat addition (Boiler)
6.	6-7	Constant pressure heat addition (Boiler)
7.	7-8	Constant pressure heat addition (Boiler)

CASE 1

Here $P_1 = 0.5$ MPa

$P_2 = 0.1$ MPa

Temperatures and enthalpy can be found in the respective table.

$W_t = h_1 - h_2 = 439.97 - 402.96 = 37.01$

$W_p = h_5 - h_4 = 165.73 - 165.44 = 0.9$

$Q_{in} = h_1 - h_5 = 439.97 - 165.73 = 274.24$

$\eta = W_t - W_p/Q_{in} = 37.01 - 0.9/274.24 = 0.131 = 13.1\%$

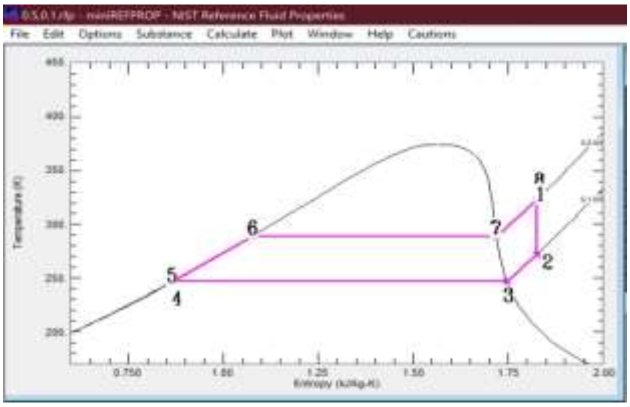


Fig -3: T-s Diagram case 1

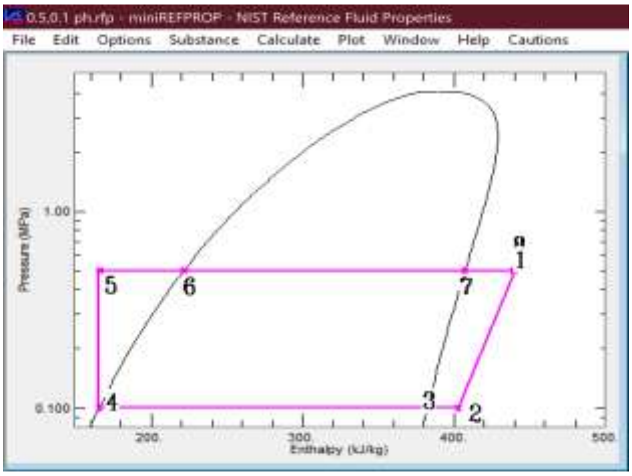
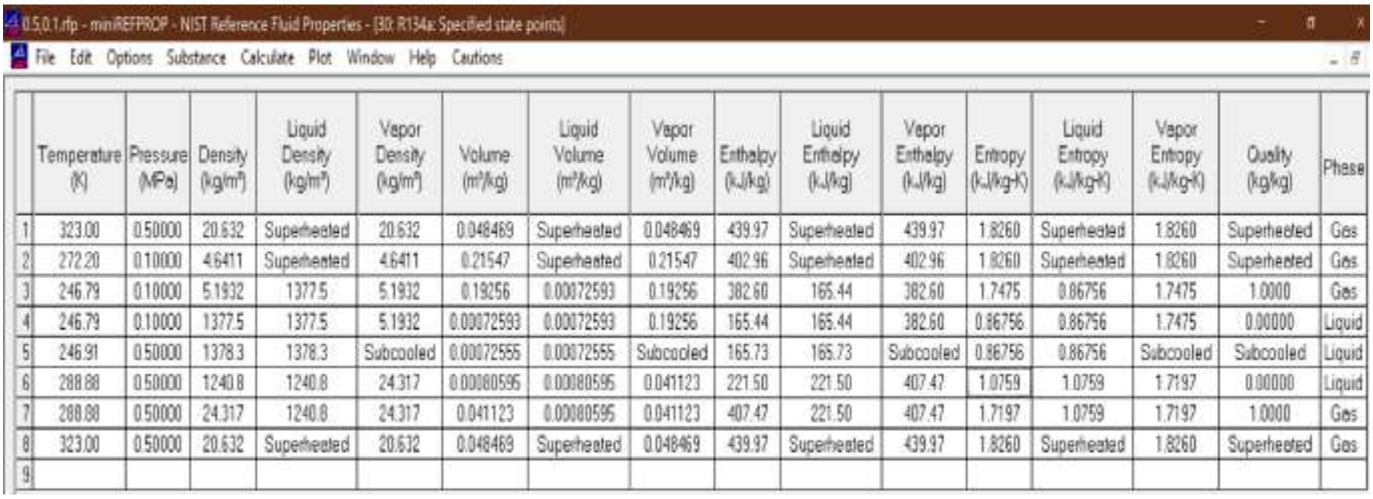


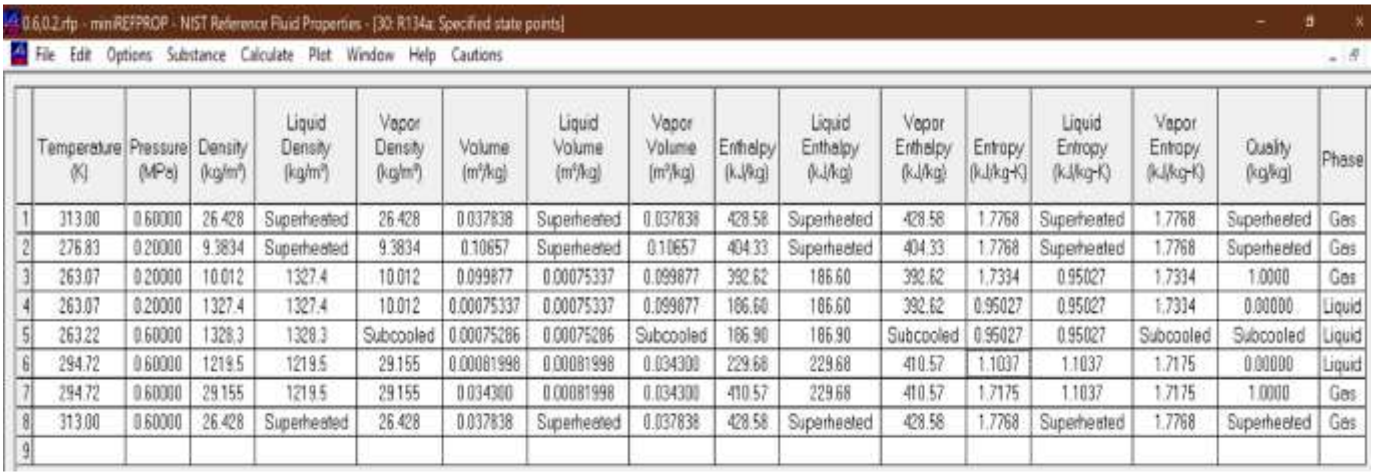
Fig -4: P-h Diagram case 1



0.5,0.1.rfp - miniREFPROP - NIST Reference Fluid Properties - [30: R134a: Specified state points]

	Temperature (K)	Pressure (MPa)	Density (kg/m^3)	Liquid Density (kg/m^3)	Vapor Density (kg/m^3)	Volume (m^3/kg)	Liquid Volume (m^3/kg)	Vapor Volume (m^3/kg)	Enthalpy (kJ/kg)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)	Quality (kg/kg)	Phase
1	323.00	0.50000	20.632	Superheated	20.632	0.048469	Superheated	0.048469	439.97	Superheated	439.97	1.8260	Superheated	1.8260	Superheated	Gas
2	272.20	0.10000	4.6411	Superheated	4.6411	0.21547	Superheated	0.21547	402.96	Superheated	402.96	1.8260	Superheated	1.8260	Superheated	Gas
3	246.79	0.10000	5.1932	1377.5	5.1932	0.19256	0.00072593	0.19256	382.60	165.44	382.60	1.7475	0.86756	1.7475	1.0000	Gas
4	246.79	0.10000	1377.5	1377.5	5.1932	0.00072593	0.00072593	0.19256	165.44	165.44	382.60	0.86756	0.86756	1.7475	0.00000	Liquid
5	246.91	0.50000	1378.3	1378.3	Subcooled	0.00072555	0.00072555	Subcooled	165.73	165.73	Subcooled	0.86756	0.86756	Subcooled	Subcooled	Liquid
6	288.88	0.50000	1240.8	1240.8	24.317	0.00080595	0.00080595	0.041123	221.50	221.50	407.47	1.0759	1.0759	1.7197	0.00000	Liquid
7	288.88	0.50000	24.317	1240.8	24.317	0.041123	0.00080595	0.041123	407.47	221.50	407.47	1.7197	1.0759	1.7197	1.0000	Gas
8	323.00	0.50000	20.632	Superheated	20.632	0.048469	Superheated	0.048469	439.97	Superheated	439.97	1.8260	Superheated	1.8260	Superheated	Gas
9																

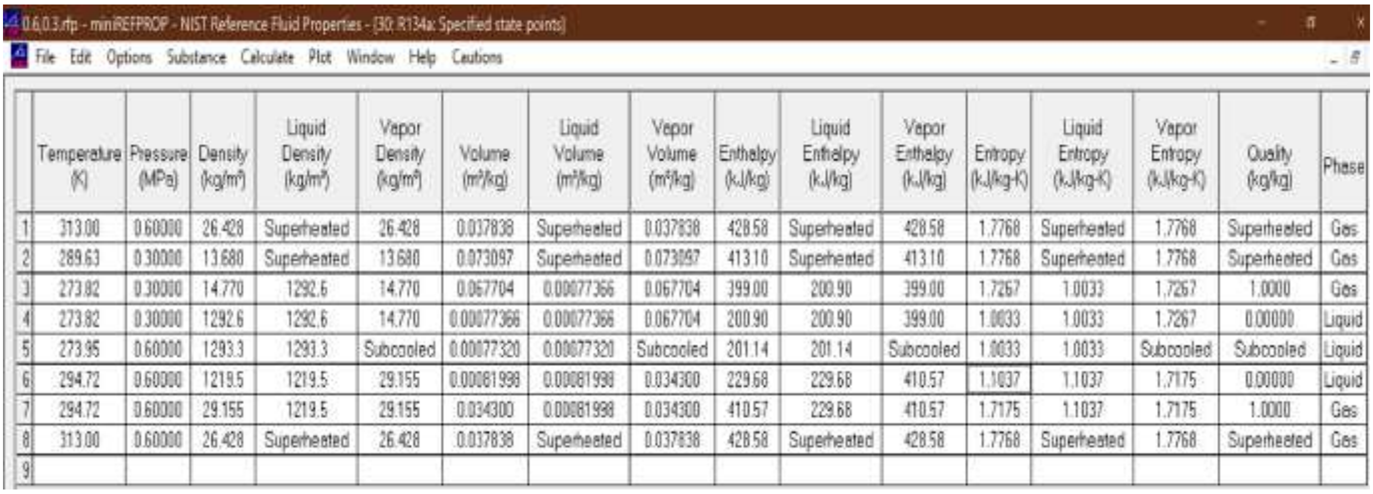
Fig-5: State points of case 1



0.6,0.2.rfp - miniREFPROP - NIST Reference Fluid Properties - [30: R134a: Specified state points]

	Temperature (K)	Pressure (MPa)	Density (kg/m^3)	Liquid Density (kg/m^3)	Vapor Density (kg/m^3)	Volume (m^3/kg)	Liquid Volume (m^3/kg)	Vapor Volume (m^3/kg)	Enthalpy (kJ/kg)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)	Quality (kg/kg)	Phase
1	313.00	0.60000	26.428	Superheated	26.428	0.037838	Superheated	0.037838	428.58	Superheated	428.58	1.7768	Superheated	1.7768	Superheated	Gas
2	276.83	0.20000	9.3834	Superheated	9.3834	0.10657	Superheated	0.10657	404.33	Superheated	404.33	1.7768	Superheated	1.7768	Superheated	Gas
3	263.07	0.20000	10.012	1327.4	10.012	0.099877	0.00075337	0.099877	392.62	186.60	392.62	1.7334	0.95027	1.7334	1.0000	Gas
4	263.07	0.20000	1327.4	1327.4	10.012	0.00075337	0.00075337	0.099877	186.60	186.60	392.62	0.95027	0.95027	1.7334	0.00000	Liquid
5	263.22	0.60000	1328.3	1328.3	Subcooled	0.00075286	0.00075286	Subcooled	186.90	186.90	Subcooled	0.95027	0.95027	Subcooled	Subcooled	Liquid
6	294.72	0.60000	1219.5	1219.5	29.155	0.00081998	0.00081998	0.034300	229.68	229.68	410.57	1.1037	1.1037	1.7175	0.00000	Liquid
7	294.72	0.60000	29.155	1219.5	29.155	0.034300	0.00081998	0.034300	410.57	229.68	410.57	1.7175	1.1037	1.7175	1.0000	Gas
8	313.00	0.60000	26.428	Superheated	26.428	0.037838	Superheated	0.037838	428.58	Superheated	428.58	1.7768	Superheated	1.7768	Superheated	Gas
9																

Fig-6: State points of case 2



0.6,0.3.rfp - miniREFPROP - NIST Reference Fluid Properties - [30: R134a: Specified state points]

	Temperature (K)	Pressure (MPa)	Density (kg/m^3)	Liquid Density (kg/m^3)	Vapor Density (kg/m^3)	Volume (m^3/kg)	Liquid Volume (m^3/kg)	Vapor Volume (m^3/kg)	Enthalpy (kJ/kg)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)	Quality (kg/kg)	Phase
1	313.00	0.60000	26.428	Superheated	26.428	0.037838	Superheated	0.037838	428.58	Superheated	428.58	1.7768	Superheated	1.7768	Superheated	Gas
2	289.63	0.30000	13.680	Superheated	13.680	0.073097	Superheated	0.073097	413.10	Superheated	413.10	1.7768	Superheated	1.7768	Superheated	Gas
3	273.82	0.30000	14.770	1292.6	14.770	0.067704	0.00077366	0.067704	399.00	200.90	399.00	1.7267	1.0033	1.7267	1.0000	Gas
4	273.82	0.30000	1292.6	1292.6	14.770	0.00077366	0.00077366	0.067704	200.90	200.90	399.00	1.0033	1.0033	1.7267	0.00000	Liquid
5	273.95	0.60000	1293.3	1293.3	Subcooled	0.00077320	0.00077320	Subcooled	201.14	201.14	Subcooled	1.0033	1.0033	Subcooled	Subcooled	Liquid
6	294.72	0.60000	1219.5	1219.5	29.155	0.00081998	0.00081998	0.034300	229.68	229.68	410.57	1.1037	1.1037	1.7175	0.00000	Liquid
7	294.72	0.60000	29.155	1219.5	29.155	0.034300	0.00081998	0.034300	410.57	229.68	410.57	1.7175	1.1037	1.7175	1.0000	Gas
8	313.00	0.60000	26.428	Superheated	26.428	0.037838	Superheated	0.037838	428.58	Superheated	428.58	1.7768	Superheated	1.7768	Superheated	Gas
9																

Fig-7: State points of case 3

CASE 2

Here P1 = 0.6 MPa

P2 = 0.2 MPa

Temperatures and enthalpy can be found in respective table.

$W_t = h_1 - h_2 = 428.58 - 404.33 = 24.25$

$W_p = h_5 - h_4 = 186.90 - 186.60 = 0.3$

$Q_{in} = h_1 - h_5 = 428.58 - 189.90 = 241.68$

$\eta = W_t - W_p/Q_{in} = 24.25 - 0.3/241.68 = 0.09 = 9.00\%$

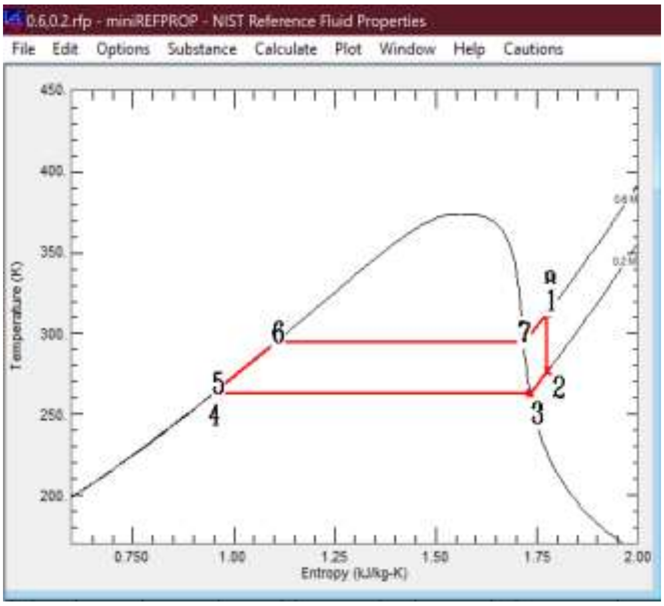


Fig -8: T-s Diagram case 2

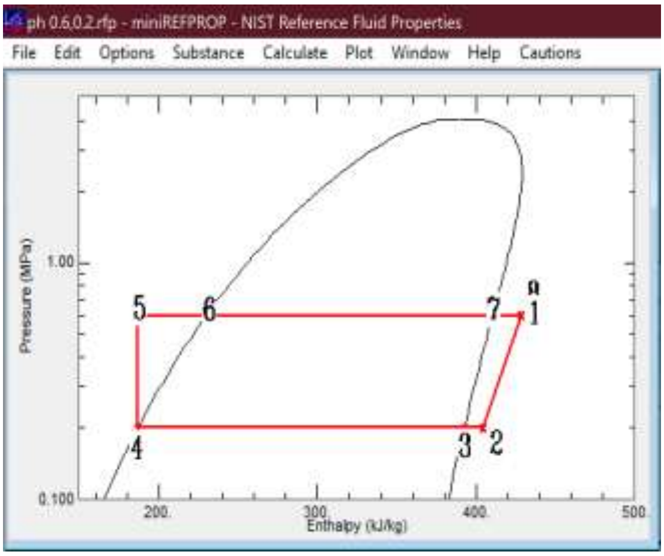


Fig -9: P-h Diagram case 2

CASE 3

Here $P_1 = 0.6$ MPa

$P_2 = 0.3$ MPa

Temperatures and enthalpy can be found in respective table

$W_t = h_1 - h_2 = 428.58 - 413.10 = 15.48$

$W_p = h_5 - h_4 = 201.14 - 200.90 = 0.24$

$Q_{in} = h_1 - h_5 = 428.58 - 201.14 = 224.44$

$\eta = W_t - W_p/Q_{in} = 15.48 - 0.24/224.44 = 0.06 = 6.00$

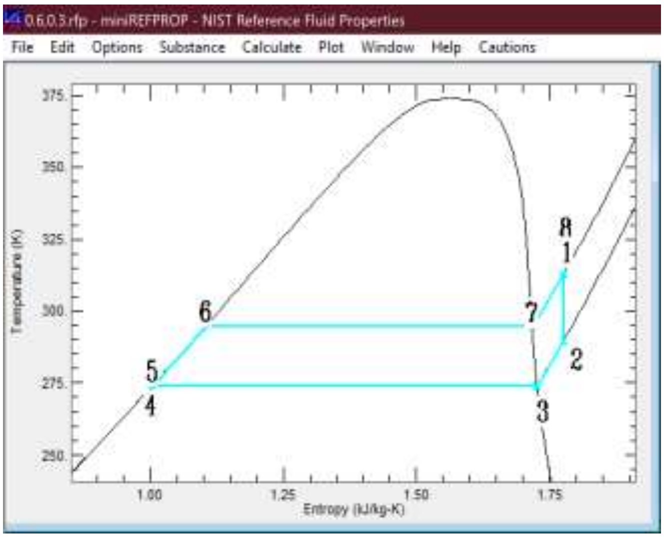


Fig -10: T-s Diagram case 3

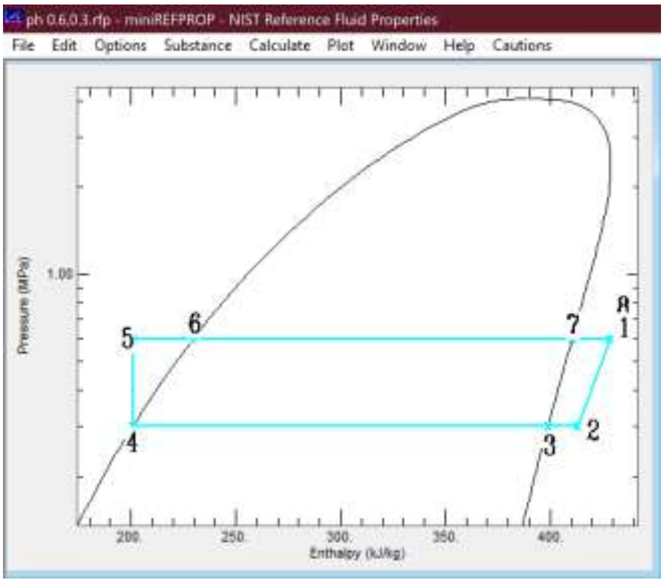


Fig -11: P-h Diagram case 3

RESULT

In this work, the Development of the power generation unit has been evaluated with the help of fabricated experimental setup using the Fresnel lens and by using mini REFPROP software different graphs are plotted by assuming different condensing pressures and heating temperatures. Efficiencies of the respective cycles are calculated. Experimental calculations are done, and output has been given in a table based on the rpm of the motor.

FUTURE SCOPE

So, this project can mainly utilize solar energy effectively by the Fresnel lens. It does not require fluid to be superheated therefore low-temperature sources are enough in order to run the cycle effectively. This can be applied in low-grade heat sources which can be used effectively. This project saves the earth from global warming caused because of burning coal, instead of renewable solar energy is directly utilized. The cost of manufacturing the plant is almost the same as the conventional type. By using R134a, pentane, R245a its thermal efficiency can be increased to a great extent. They are mainly useful for small scale applications. In the near future, coal may get extended in use and the usage of renewable energy will become much more important. So, this project is the best way to utilize solar radiation for the heat input in the Rankine Cycle.

7. CONCLUSION

We can conclude that Fresnel Lens can be effectively used in the case of low-grade temperature sources like solar energy. It overcomes the traditional PV type of solar technology in terms of advantages. And R134a can be preferably used as a working fluid because it is non-toxic in nature and does not damage the atmosphere.

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