Design and Analysis of 10KW ORC using Rooftop Linear Fresnel Solar Concentrator

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Abstract: The sun has always been viewed as a viable, inexhaustible form of energy for thousands of years. Though it has vast source for power generation the use of solar power is not completely utilized. The current study deals with the generation of power using solar. As Organic Rankine cycles have unique properties that are well suited to solar power generation. Now a day's using medium temperature heat source is employing much, this study is carried out using medium as the heat source, the thermodynamic potential of a variety organic Rankine cycle working fluids and configurations are analysed. New refrigerants such as R-600 and R-600a are used as working fluids, and roof top linear Fresnel solar concentrator as the heat source and analysis is done keeping pressure as constant and varying turbine inlet temperature, Dowtherm is taken as working fluid.

Keywords: ORC, SOLAR, ORGANIC FLUID

I. INTRODUCTION

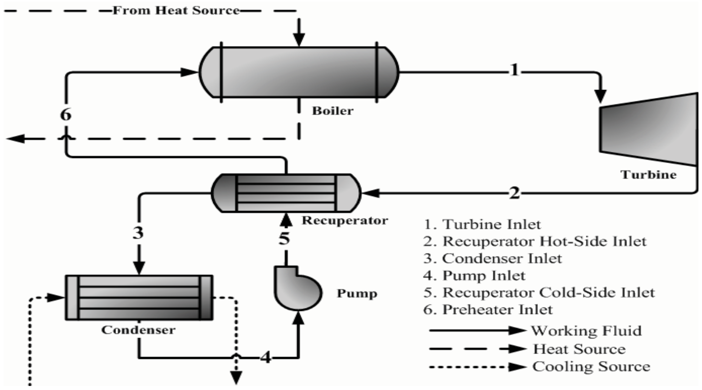
The global demand for energy continues to increase while traditional energy resources are becoming scarcer. Exacerbating the situation is the growing realization that the use of traditional fuels carries a significant environmental burden. Adoptions of environmentally benign and renewable energy conversion technologies are essential if our society is to retain its advanced lifestyle in the face of global development. Economic opportunity drives the energy market just as it drives every market. Maximizing the economic opportunity associated with safe and renewable energy technologies is an essential step towards increasing their use. The principle focus of this paper, however, is improving economic opportunity by providing tools for the evaluation of organic Rankine power cycles

Roof-top Linear Fresnel solar-thermal power generation is a proven technology, with several utility scale plants in operation. Current large-scale systems rely on traditional steam-based Rankine cycles for power production. Organic Rankine cycle power plants are more compact and less costly than traditional steam cycle power plants and are able to better exploit lower temperature thermal resources. Utilizing organic Rankine cycles allows solar-thermal power generation to become a more modular and versatile means of supplanting traditional fuels. While solar-thermal power generation has the potential to play an important role in future energy markets, it is fundamentally limited by its energy source, the sun. The ability to store large amounts of high-temperature thermal energy enables the delivery of solar thermal power independent of variation in insulation. Storage can be used to make output mimic grid demand, compensate for variation in radiation levels throughout the day, or provide 24-hour on-demand solar-thermal power. This flexibility, if achieved both efficiently and at low-cost, has the potential to increase the economic viability and overall market potential of solar power generation.

II. ORGANIC RANKINE CYCLE BACKGROUND:

Organic Rankine cycle (ORC) power plants are of interest for solar electricity generation due to their versatility and simplicity. They are most often used when exploiting low temperature thermal resources for power generation, or small-scale applications (typically<5 MW). The most common uses are for geothermal and solar power generation, waste heat recovery, and remote-power. This chapter provides general background on the history and variety of ORC systems with particular emphasis on solar energy applications

Organic Rankine Cycles are not new technology. They have been used in large numbers for various purposes since the first-half of the 20th century



Process flow for a typical solar driven ORC

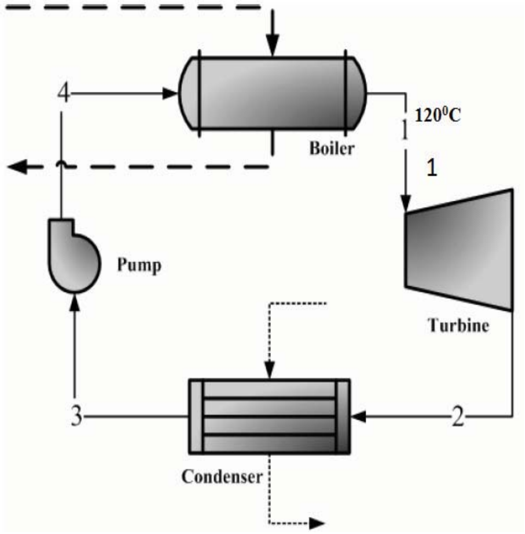
III. IMPACT OF SUPER HEAT ON ORC PERFORMANCE

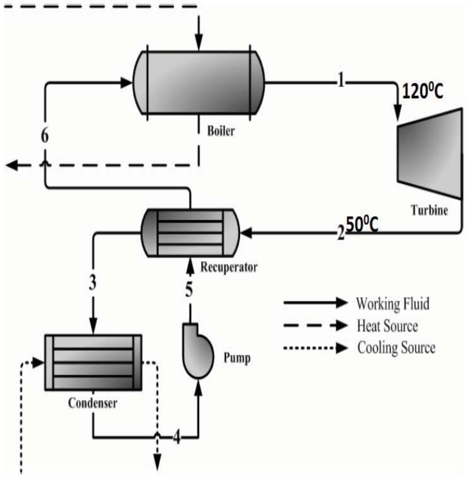
A large degree of superheat is employed in traditional steam Rankine plants for several reasons. The first is to prevent low-quality steam from being sent through the turbine as discussed in section. The second reason is thermodynamic. First-Law thermodynamic efficiency in a steam Rankine cycle increases as the degree of superheat increases at a fixed pressure (increasing temperature), where the degree of superheat is defined as

$$T_{sh} = \frac{T}{T_{sat}} \Big|_{P}$$

IV. ANALYSIS:

The analysis is carried out by considering two refrigerants as working fluids. Iso-butane (R-600) and N-Butane (R-600a) are selected as working fluids and these come under the family of Hydro-carbons.





V. CALCULATION:

W net= W turbine- Wpump--------------→ 1

As Pump Work is negligible we will not consider the pump work

Therefore W net= W turbine------------→ 2

W turbine = h $_{\text{turbine inlet}}$-h $_{\text{turbine outlet}}$ --------→ 3

Heat Supplied (without Recuperator) = h $_{\text{turbine inlet}}$- h $_{\text{boiler inlet}}$---------→4

Efficiency = $\eta = \frac{W_{net}}{Q_s}$---------→ 5

The net work done, heat supplied, Work done by turbine and efficiencies with recuperator and without recuperator are calculated using the equations 1, 2, 3, 4 and 5. The results are tabulated in tables 1, 2, 3 and 4.

Table 1 For Iso-butane(R-600a) without Recuperator with mass flow rate 1 Kg/s

Components	**Temperature (^{O}C)**	**Enthalpy kJ/kg**	**Work Done kJ/kg**	**Heat Supplied kJ/kg**	**Efficiency %**
Turbine Inlet	**120**	685	60	400	15.1
Turbine Outlet	35	625			
Boiler Inlet	30	285			
Turbine Inlet	**132**	725	83	445	18.65
Turbine Outlet	35	642			
Boiler Inlet	30	285			
Turbine Inlet	**144**	780	105	495	21.2
Turbine Outlet	35	675			
Boiler Inlet	30	285			
Turbine Inlet	**156**	802	97	517	18.76
Turbine Outlet	35	705			
Boiler Inlet	30	285			

Table 2 For N-butane(R-600) without Recuperator with mass flow rate 1 Kg/s

Components	**Temperature (^{O}C)**	**Enthalpy kJ/kg**	**Work Done kJ/kg**	**Heat Supplied kJ/kg**	**Efficiency %**
Turbine Inlet	**120**	745	85	463	18.35
Turbine Outlet	35	660			
Boiler Inlet	30	282			

Turbine Inlet	**132**	790	86	508	17.00
Turbine Outlet	35	704			
Boiler Inlet	30	282			
Turbine Inlet	**144**	844	94	562	16.70
Turbine Outlet	35	750			
Boiler Inlet	30	282			
Turbine Inlet	**156**	850	90	568	15.84
Turbine Outlet	35	760			
Boiler Inlet	30	282			

Table 3 For Iso-butane(R-600a) with Recuperator with mass flow rate 1 Kg/s

Components	**Temperature (^{O}C)**	**Enthalpy kJ/kg**	**Work Done kJ/kg**	**Heat Supplied kJ/kg**	**Efficiency %**
Turbine Inlet	**120**	685	60	385	16.00
Turbine Outlet/Recuperator Inlet	50	625			
Recuperator outlet/Condenser Inlet	35	630			
Condenser outlet / recuperator inlet	35	282			
Recuperator to boiler	45	310			
Turbine Inlet	**132**	730	80	405	19.75
Turbine Outlet/Recuperator Inlet	60	650			
Recuperator outlet/Condenser	35	630			

Inlet					
Condenser outlet to recuperator inlet	35	280			
Recuperator to boiler	50	325			
Turbine Inlet	**144**	772	87	397	21.91
Turbine Outlet/Recuperator Inlet	78	685			
Recuperator outlet/Condenser Inlet	35	630			
Condenser outlet to recuperator inlet	35	280			
Recuperator to boiler	68	375			
Turbine Inlet	**156**	802	84	384	21.81
Turbine Outlet/Recuperator Inlet	93	718			
Recuperator outlet/Condenser Inlet	35	630			
Condenser outlet to recuperator inlet	35	280			
Recuperator to boiler	83	418			

Table 4 For N-butane(R-600) with Recuperator with mass flow rate 1 Kg/s

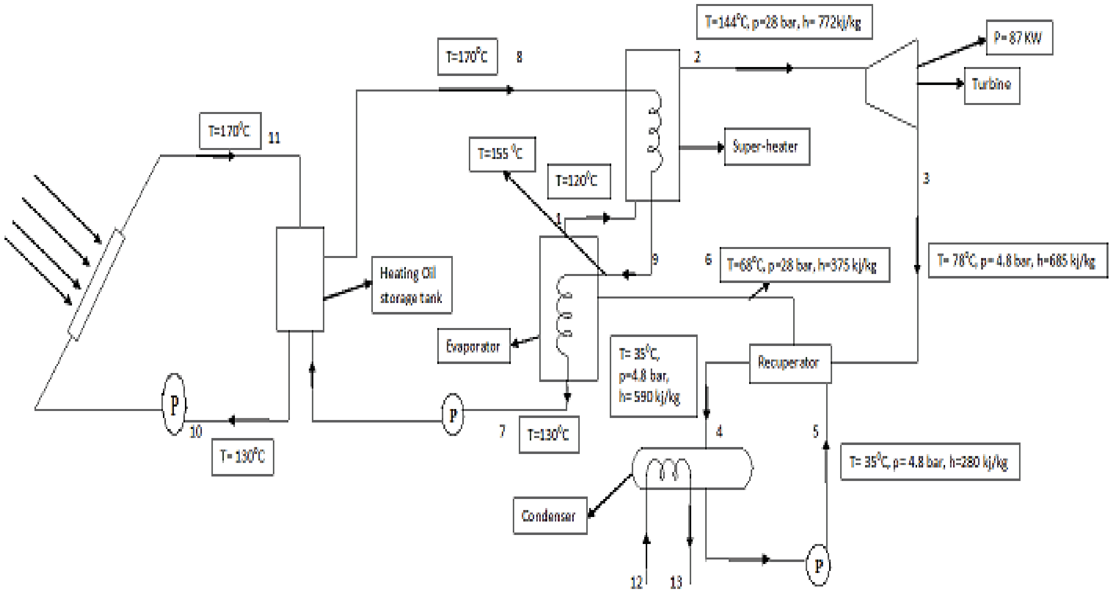
Components	**Temperature (^{O}C)**	**Enthalpy kJ/kg**	**Work Done kJ/kg**	**Heat Supplied kJ/kg**	**Efficiency %**
Turbine Inlet	120	750	85	430	19.76
Turbine Outlet/Recuperator Inlet	50	665			
Recuperator outlet/Condenser Inlet	35	630			
Condenser outlet / recuperator inlet	35	280			
Recuperator to boiler	45	320			
Turbine Inlet	132	787	84	447	18.80
Turbine Outlet/Recuperator Inlet	68	703			
Recuperator outlet/Condenser Inlet	35	635			
Condenser outlet to	35	280			

recuperator inlet					
Recuperator to boiler	58	340			
Turbine Inlet	144	846	121	476	25.42
Turbine Outlet/Recuperator Inlet	78	725			
Recuperator outlet/Condenser Inlet	35	630			
Condenser outlet to recuperator inlet	35	280			
Recuperator to boiler	68	370			
Turbine Inlet	156	845	95	445	21.44
Turbine Outlet/Recuperator Inlet	90	750			
Recuperator outlet/Condenser Inlet	35	630			
Condenser outlet to recuperator inlet	35	280			
Recuperator to boiler	80	402			

VI. DESIGN OF 10KW ORC

In the present study design and analysis of 10kw organic Rankine cycle using roof top linear Fresnel solar concentrator is performed.

Considering R-600a as refrigerant and turbine inlet temperature as 144^0C solar ORC is designed



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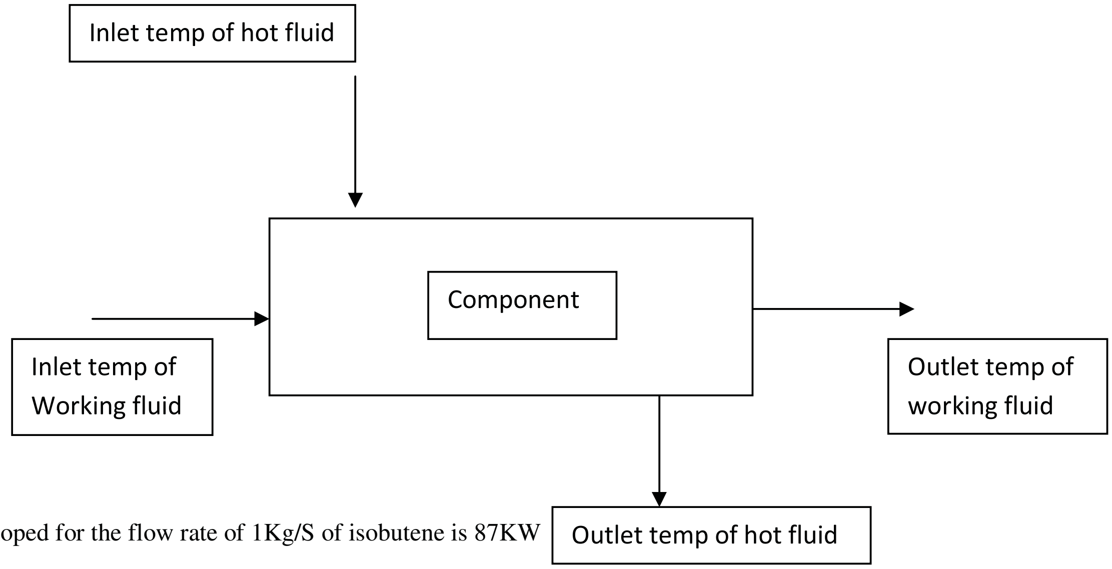
Calculation:



Power developed for the flow rate of 1Kg/S of isobutene is 87KW

For 10 KW the flow rate of isobutene is calculated

Now heat load of isobutene is = m*Δh-----------------→ 1

From p-h chart the enthalpy values working fluid are calculated

By substituting the values of mass flow rate and enthalpy's in equation 1 and also considering the effectiveness the heat load of Iso-butane is calculated

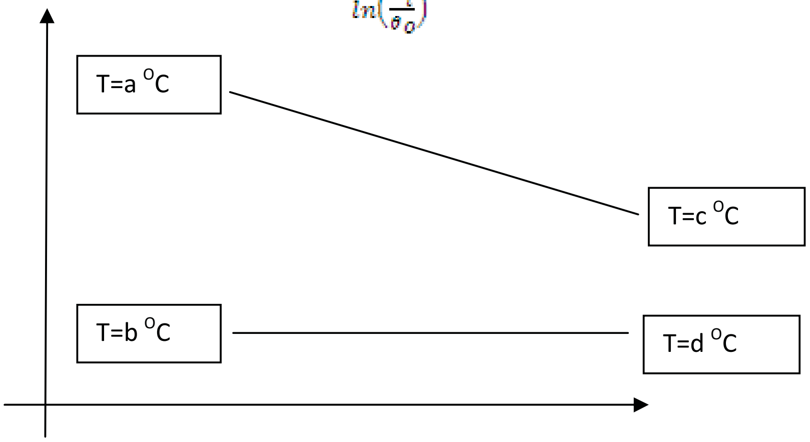
We know that $Q = U_o A_o (LMTD)$------------------→ 2

Where U_0= Over all heat transfer coefficient

A_o= Area of the tubes.

LMTD = Log mean temperature difference

Formula for LMTD is $LMTD = \frac{\theta_i - \theta_o}{ln\left(\frac{\theta_i}{\theta_o}\right)}$------------------→3



Where, $\theta_i = a - b$ and $\theta_o = c - d$

On substituting the values in equation 3 we will get the value of LMTD

From Heat transfer data book the value of overall heat transfer coefficient is taken

Therefore by substituting the values of Q, Uo, and LMTD in the equation 2, we get the area

To calculate the length of the tubes

We know that $A_o - \pi * D * l * n$--------------→ 4

Where D is the outer diameter

n= no.of tubes

l= length of the tubes.

From standard pipe dimensions data book considering the corresponding pipes sizes according to components

By substituting the values in equation 4 we get the length of the tubes

Table 5: Showing mass flow rate, overall heat load, LMTD, Area and length for various components

Components	**Mass flow rate of iso-butane $(\dot{m})$ kg/s**	**Over all heat load (Q) kj/s**	**LMTD**	**Area (A) m^2**	**Length(l) m**
Evaporator	0.115	41.94	19.95	4.36	1.75
Super-heater	0.115	12.44	26	2.17	1.07
Recuperator	0.115	12.85	38	1.12	1.12
Condenser	0.115	42	22	2.76	1.38

VII. RESULTS&DISCUSSION

In the present study design and analysis of 10kw organic Rankine cycle using roof top linear Fresnel solar concentrator is performed.

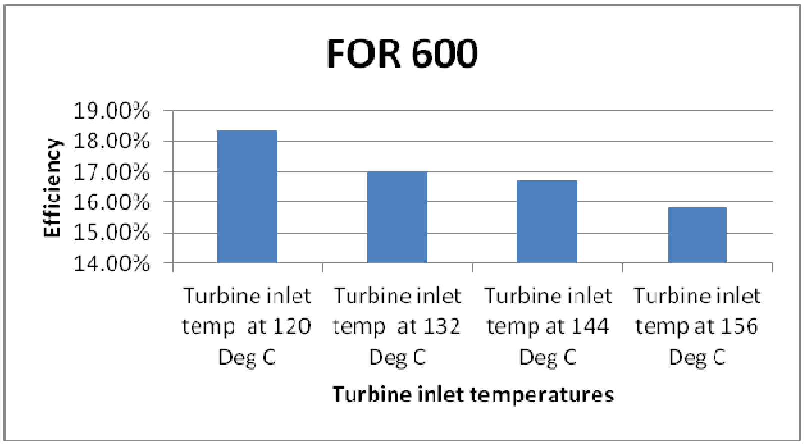


FIG: 01: EFFICIENCES OF ORC AT DIFFERENT TURBINE INLET TEMPERATURES WITHOUT RECUPERATOR FOR 600

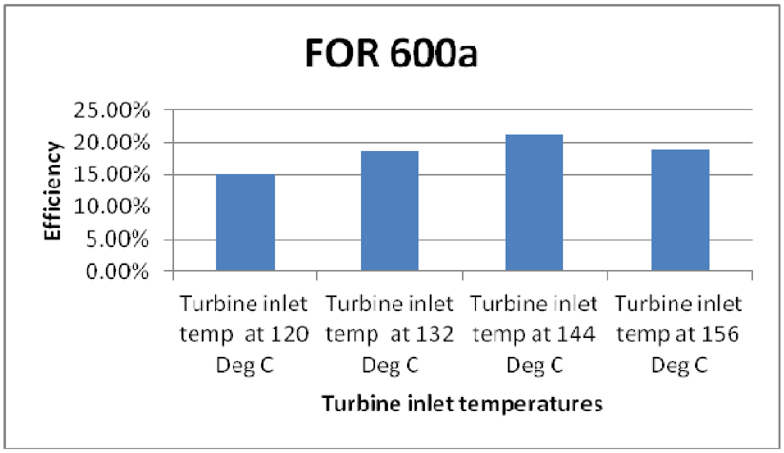


FIG: 02EFFICIENCES OF ORC AT DIFFERENT TURBINE INLET TEMPERATURES WITHOUT RECUPERATOR FOR 600a

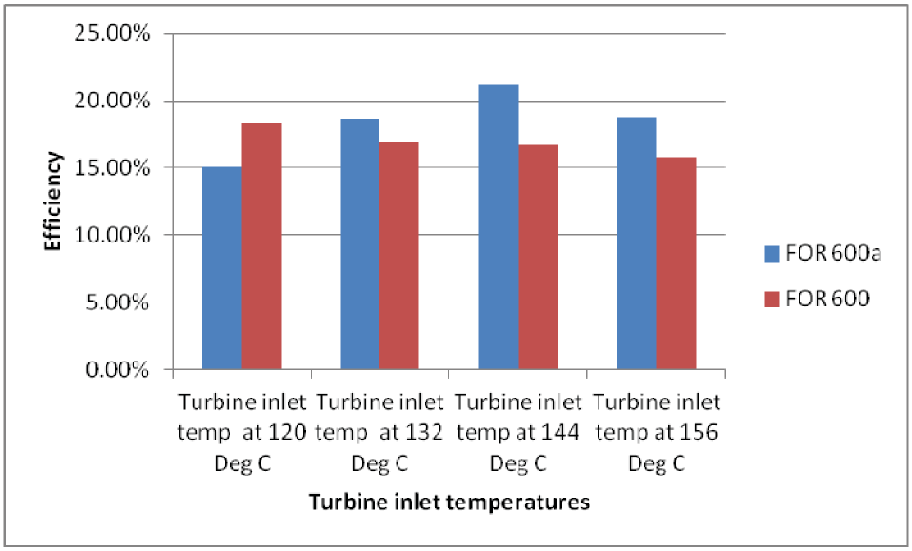


FIG: 03EFFICIENCES OF ORC AT DIFFERENT TURBINE INLET TEMPERATURES WITHOUT RECUPERATOR FOR 600 & 600a

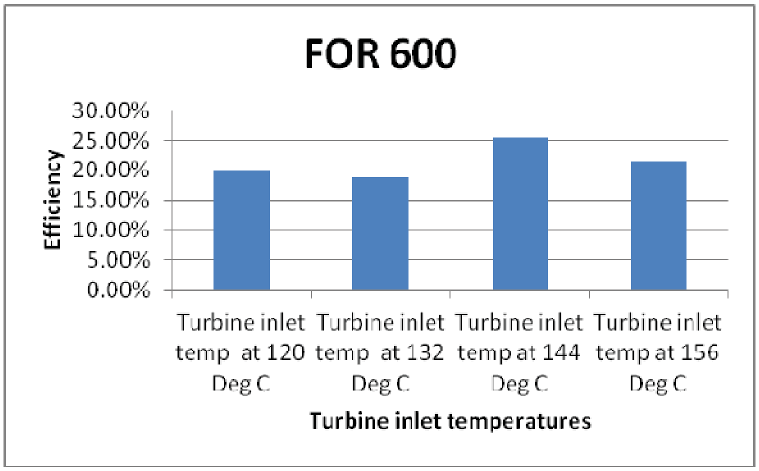


FIG: 04: EFFICIENCES OF ORC AT DIFFERENT TURBINE INLET TEMPERATURES WITH RECUPERATOR FOR 600

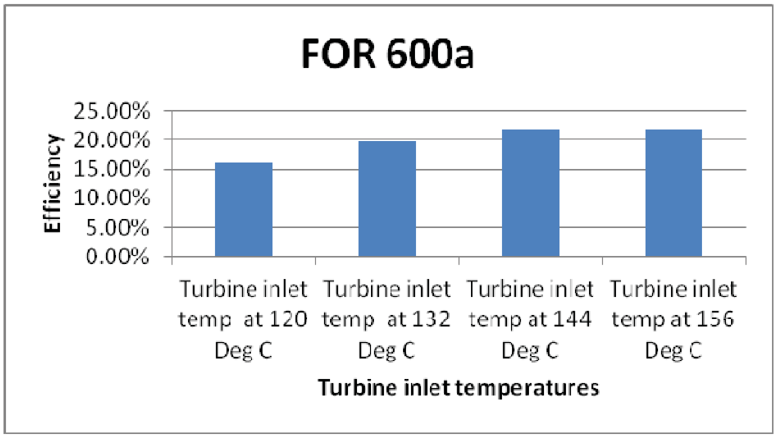


FIG: 05: EFFICIENCES OF ORC AT DIFFERENT TURBINE INLET TEMPERATURES WITH RECUPERATOR FOR 600a

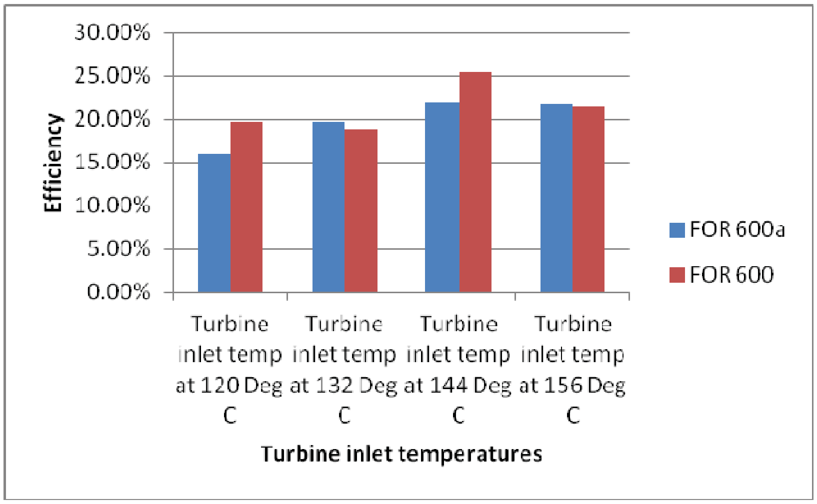


FIG: 06: EFFICIENCES OF ORC AT DIFFERENT TURBINE INLET TEMPERATURES WITH RECUPERATOR FOR 600 & 600a

Figures (1) (2) (3) (4) (5) (6) shows how efficiencies varies with the turbine inlet temperatures considering with and without recuperator for refrigerants R-600 & R600a
From the figures it is observed that the efficiency high for refrigerant R-600a with recuperator

VIII. CONCLUSION:

In this present study thermodynamic analysis and design of ORC is done using medium temperature heat source from roof top linear Fresnel solar concentrator. R-600&R-600a are used as refrigerants with dowtherm as the heat transferring fluid, comparing the ORC analysis the system having with recuperator is obtaining the higher thermal efficiency, In the design process system with temperature at 144^{O}C at the turbine inlet is taken into consideration because of its higher thermal efficiency

Nomenclature:

A=Area (m^2)

$\dot{m}$ =Mass flow rate (kg/s)

m=mass [kg]

W work [kJ]

P=Power output (kW)

h= enthalpy

U$_o$=over all heat transfer coefficient

Q= overall heat load

n= no.of tubes

l= length of the tubes

d= diameter of the tubes

LMTD= Log mean temperature difference

ORC= Organic Rankine Cycle

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