Thermodynamic Analysis of Solar Organic Rankine Cycle by using Working Fluid for Low Temperature Application

Lokanath M, Santhosh Kumar B, Kiran Avns, Saleemuddin S M

Abstract: ***The increasing energy need due to industrial expansion and population size led the human race for usage of major conventional energy sources like oil, coal, gas. But these resources trouble the environment leading to potential problems like pollution, global warming etc. Thus, in order to overcome the burning issues, many alternative energy sources are developed such as wind, hydro, solar, tidal, geothermal, biofuel, nuclear etc. are used for power generation. Among these the solar energy is plentifully available resource and can be employed to organic rankine cycle technology for power generation. The main aim of this research work is to develop a novel power generating system by using alternative energy resource i.e. solar energy. The work focussed on simulating the power generation of producing unit by employing solar organic rankine cycle and working fluids R-245fa, R-227ea & R-245fa/ R-227ea mixture. The Organic Rankine cycle efficiency mainly depend on the Selection of working liquid, working condition has extraordinary impact, and its vitality proficiency and effect on nature. The performance parameters like Solar Organic Efficiency, Solar Collector Area, second law efficiency, Turbine volume expansion ratio etc. are studied. It is noticed that organic efficiency of refrigerant mixture R245fa/R227ea is 4% more compared to pure fluid R227ea at turbine outlet temperature of 353K.The Volume expansion ratio of the turbine comparing to refrigerant mixture is reduced by 25.4% & 30% compared to pure refrigerant R227ea and R245fa.***

Keywords: Organic Rankine Cycle, Working fluids, Waste heat Recovery, Low Temperature Application, Solar collectors.

I. INTRODUCTION

Organic Rankine Cycle (ORC) can convert low medium grade heat into electrical or mechanical power and has been widely recognized as the most promising heat-driven technologies. The ORC generate power from low-temperature heat, they can be implemented as power generation units for waste heat recovery systems, geothermal applications, and solar applications.

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The Organic Rankine Cycle's work on Rankine cycle instead of water it utilise Organic Working Fluid which have higher molecular mass and lower Boiling point that can produce power from Low temperatures heat sources.

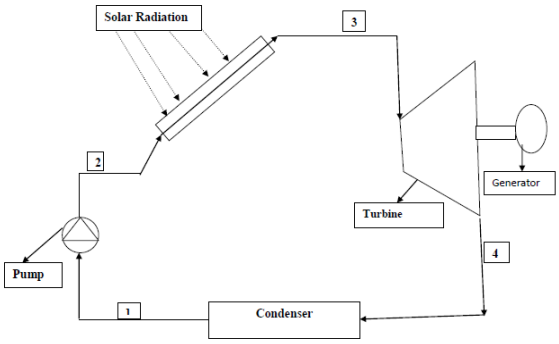
1.1. PROBLEMS IN TRADITIONAL RANKINE CYCLE

In spite of the fact that Rankine Cycle is chosen as the power cycle however there are various issues which exist in traditional Rankine Cycle.

- A Rankine cycle uses the water as working fluid and it doesn't allow productive recuperation of waste warmth beneath 370°C.
- One of the crucial issues of water is ought to be superheated in the Rankine Cycle. The superheating is imperative to ensure the idea of submerged water after the development in the turbine is dry.
- The nature of submerged water should not be underneath 0.88. Right when the quality is lower, dimension of vapor will be higher and deterioration in turbine front line will be at a higher rate.
- Due to low develop temperature, low weight, high unequivocal volume, tremendous turbine estimation required.
- High weight drops to transform into a high enthalpy drop thusly exorbitant multi sort out turbines required.

1.3. SOLAR ORGANIC RANKINE CYCLE

1.Organic Rankine cycle Uses Organic Working fluid instead of water. The Working fluid is pumped from low pressure to high pressure with help of a pump by isentropic compression process.



2.Thhigh-pressurere working fluid enters the Flat plate collector where it is changes it phase from liquid to vapor by absorption an external solar radiation at constant pressure process.

3.The super-heated vapor expand Isentropically through turbine which is coupled to generator to produce power output.
4. The vapor be admitted to condenser where it is change it phase to saturated liquid at constant pressure, this working liquid revert the pump and cycle replicates
figure 1.1 Schematic of low emperature Solar organic Rankine cycle

II. LITERATURE SURVEY

2.1 INTRODUCTION

The present literature survey has been done to have knowledge of available in different application of waste heat recovery on low temperature Organic Rankine cycle and also discussed the theoretical investigations, thermodynamic analysis, experimental analysis, renewable energy and comparison Organic Rankine cycle and Rankine cycle.

HUNG.T.C et al [1] Examine Parametrically and analyzed the productivity of ORCs utilizing cryogens, for example, benzene, ammonia, R11, R12, R134a and R113 as working liquid and contrasted and water as reference. These effects of working liquids rely on the slant of the are immersion vapor bends on T-S chart. Isentropic liquids are the most appropriate for recouping low-temperature squander heat. When liquid was chosen, variety of framework effectiveness with turbine bay temperature and weight, at Specified Operating condition Temperature of condenser Tc=293K and Condenser outlet weight P3=2.5Mpa among the fluid inspected, benzene was to give most raised most astounding productivity pursued successively by R113, R11, R12, R134a and ammonia.

Sanjayan Velautham et al[2] examine the practicality of an ORC driven by Solar thermal energy as a sustainable power source choice for little and medium measured business utilization, power generation under 10MW. The solar thermal cycle circulates heat move liquid in the cycle and bridle thermal energy from the sun and exchange it to the natural compound in the ORC by means of a heat exchanger R123 and iso-butane are chosen as working liquid ,among R123 gives a higher warm proficiency contrasted with iso-butane, R123 productivity ranges from 22 to 26% while iso-butane ranges from 17 to 19%.

LouayChamra.M et al[**3]** have examined the regenerative Rankine cycles "ORC" using dry normal fluids, to convert low grade heat sources into useful energy. The working liquids decided for this examination are R113, R245ca, R123, and iso-butane, with breaking points reaching out from −12 °C to 48 ° C. Regenerative ORC is broke down and contrasted and the fundamental ORC so as to decide the best thermal efficiency with least irreversibility

Rayegan .R et al[4] had built up a method to analyze the efficiency enhancement of collector efficiency of working liquids when they are utilized in SORC and compare the results at same working conditions.

Zaho .L et al[5].proposed an exploratory framework is structured, developed and tried for low-temperature solar Rankine framework using R245fa as the working liquid. Both the emptied sunlight-based authorities and the level plate sun powered gatherers are utilized in the trial framework, in the meantime, a moving cylinder R245fa expander is likewise mounted in the framework.

Bertrand F et al[6] have completed an audit on Low-grade heat transformation into power utilizing natural Rankine cycles for different applications. This paper presents existing applications and researches their improvement of geothermal and matched biomass CHP to Provide the enthusiasm to recuperate squander heat dismissed by warm gadgets and mechanical procedures proceed to develop, and positive administrative conditions are received, squander heat recuperation natural Rankine cycle frameworks soon will encounter a quick development.

Roy.J.P et al[7] have investigation of non-regenerative Organic Rankine Cycle (ORC) by utilizing R-12, R-123, R-134a and R-717 as working liquids. The determined outcomes uncover that R-123 produces the most extreme efficiencies and turbine work yield with least irreversibility for utilized consistent just as factor heat source temperature conditions.

By Studying through all the journals in the area of natural Rankine cycle to upgrade the conduct of Solar Organic Rankine Cycle utilizing distinctive refrigerant blends and effect on the ORC execution. Vitality and Exergy examinations were connected to even more likely comprehend the advantages of utilizing refrigerant blends between a similar temperature limit. I deduced that embracing Refrigerant blends in Solar natural Rankine cycle expands the waste heat recovery and produce control from low and medium temperature squander heat. Contrast with the unadulterated refrigerant as working liquid.

III. SELECTION OF WORKING FLUIDS

3.1. TYPES OF WORKING FLUIDS

Depending on inclination of Saturation vapor curve on a T–s diagram ds/dT. The sort of working liquid can be grouped by the estimation of ds/dT, i.e. ds/dT> 0 a dry fluid (e.g. pentane), ds/dT = 0 an isentropic fluid (e.g. R11), and ds/dT< 0 a wet fluid (example water) demonstrates the three kinds of liquids in a T–s diagram.

Isentropic or dry fluids may be proposed for an ORC to avoid liquid bead that strikes to the turbine blades amid the development and to prevent erosion of turbine blades

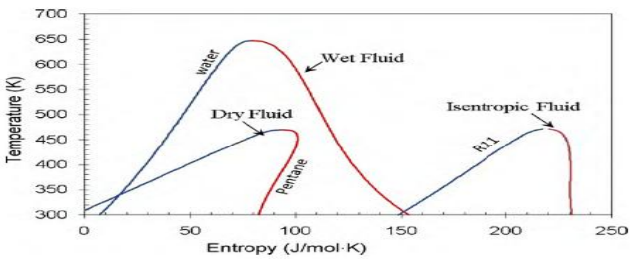


Figure 3.1 slope of Temperature –Entropy diagram for different working fluid

3.2. THERMODYNAMIC PROPERTIES OF WORKING FLUID

A Working liquid determination must not just have the necessary thermo-physical that coordinate the application but also possess adequate chemical stability in the covet temperature range. The liquid selection framework proficiency, working conditions, natural effect and economic viability. For Simulating the Solar Organic Rankine Cycle the thermo physical properties of the working liquid of are R245fa-R227ea are considered. The properties of these liquids are talked about as underneath.

R245fa is presently utilized and considered as option in contrast to the CFCs R-11 and R-114 in the chillers and ORC applications.
This is because of high warmth exchange proportion between the warm vitality and dynamic vitality at the turbine side just as weight proportion.
R245fa-R227ea Properties The properties of R245fa-R227ea are referred from models or from some software's like REFPROP and MAT LAB and so on.

REFRIGERENT	MW(g/mol)	BP(° C)	P_c (kpa)	T_c(° C)	ASHRAE 34 Safety group	ODP	GWP
R227ea	170.03	-16.42	2990	102.75	A1	0	3500
R245fa	134.02	15.14	3.65	154.01	B1	0	950

Table 3.1. Thermo physical properties of R245fa and R227ea

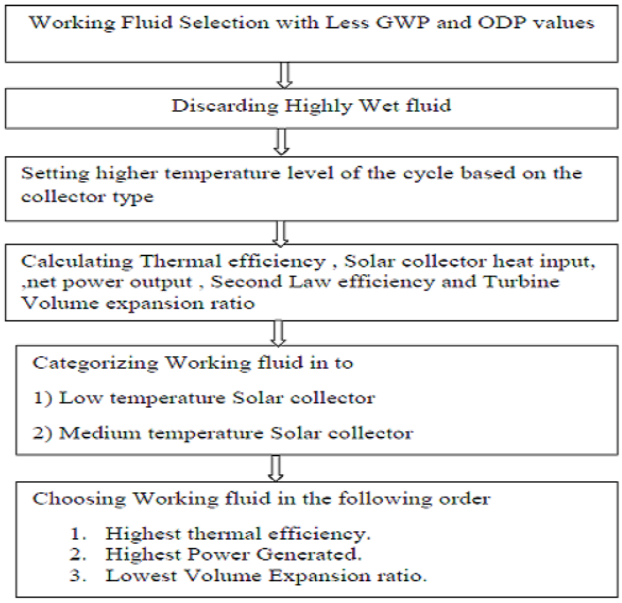
IV. SIMULATION

The engineering calculation and simulation of the Solar Organic Rankine Cycle system requires the availability of simple and efficient mathematical methods for the determination of thermo physical property values of the operating fluid (mixture).Values of the thermo -physical property are necessary both at the key points in the cycle and along the process taking in the various components.

4.1. Assumption of ORC

- The ORC depends on Unit mass working liquid.
- The composition of the refrigerant Mixture doesn't change in each process of the cycle
- Temperature skimming of the working liquid disperses directly along heat exchanger and solar collector.

4.2. PROPOSED METHOD OF WORKING FLUID IN A SOLAR ORC



4.3. OPERATING CONDITIONS

Refrigerant Mixture R227ea/R245fa [0.2 /0.8] by Mass Fraction
Condenser inlet temperature t_1 =25 ^{o}C
Condenser Pressure $p_1 = p_6 = p_{61} = p_7$
Evaporator Pressure $p_2 = p_3 = p_4 = p_5$
Saturated Turbine Inlet temperature $t_4 = 80\ ^{o}C$
Superheated Turbine Inlet temperature $t_5 = 85\ ^{o}C$
Turbine Efficiency = $(h_5 - h_6)/(h_5 - h_{61}) = 0.8$
Solar collector heat input $Q_E = h_5 - h_2$ kW
Expansion work output $W_S = h_5 - h_6$ kW
Condenser heat rejection $Q_C = h_6 - h_1$ kW
Pump work input $W_P = h_2 - h_1$kW
Net power output $W_N = W_S - W_P$ kW
Volume expansion ratio = v_6 / v_5
Solar Organic Rankine cycle efficiency $\eta_R = W_N / Q_E = W_S - W_P / Q_E$
Second Law Efficiency $\eta_{II} = (W_N) / (Q_{E*}(1-(T_1/T_4))$

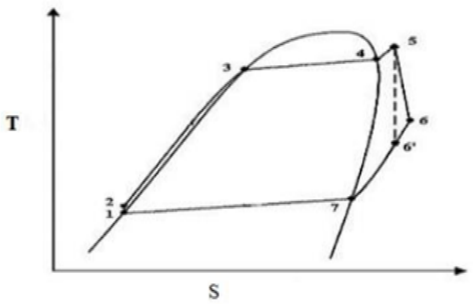


Figure 4.1.T –s diagram for Refrigerant mixture as working fluid

V. RESULTS AND DISCUSSIONS

In a simulation of the ORC with the refrigerant blend R227ea/R245fa [0.2/0.8] by mass part as working liquid between Condenser outlet temperature 25oC and Turbine inlet temperature 80oC, isentropic efficiency of turbine is 0.8%, considering for unit mass stream rate of working liquid. A parametric examination of the cycle portrayed beneath demonstrates that the cycle conditions can be enhanced within the scope of low temperature solar collectors for maximum overall efficiency. The SORC can be improved to give greatest power produced and most extreme effectiveness for the refrigerant blend.

5.1. EFFECT OF WORKING FLUIDS ON ORC EFFICIENCY

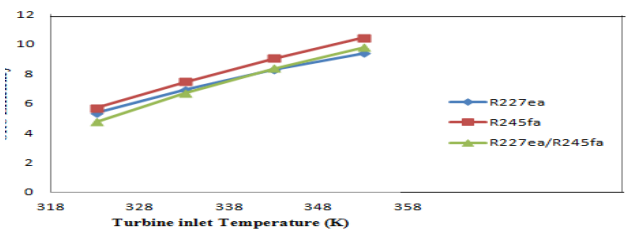


Figure 5.1 Effect of working fluids on the ORC efficiency by keeping constant Condenser temperature (298K)

From the figure 5.1 observed that by increasing Turbine inlet temperature SORC efficiency for refrigerant mixture R227ea/R245fa [0.2/0.8] by mass fraction is greater by 4% compare to pure working fluid R227ea at turbine inlet temperature of 358K.This is mainly due to the lower boiling temperature and higher latent heat of evaporation compared to refrigerants.

The SORC efficiency for Pure Refrigerant R245fa is greater compare to the Refrigerant mixture R227ea/R245fa and Pure R227ea as turbine inlet temperature increases.

5.2 EFFECT OF NET POWER OUTPUT

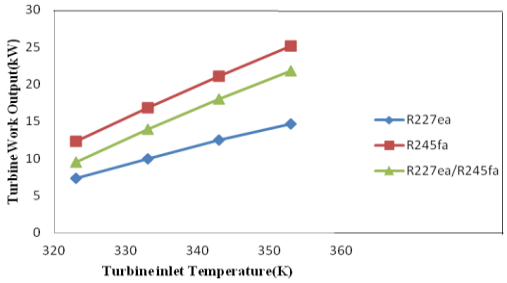


Figure 5.2 Effect of Net power output in kW by keeping constant Condenser temperature (298K)

From the figure 5.2 observed that by increasing Turbine inlet temperature the net power produce by the refrigerant mixture R245fa/R227ea is greater compare to pure refrigerant R227ea, this is because of increment in work produced by the refrigerant blend at same heat source.

5.3 EFFECT OF SOLAR COLLECTOR HEAT INPUT

From the figure 5.3 observed that by increasing Turbine inlet temperature The Solar collector heat input produce by the refrigerant mixture R245fa/R227ea is greater compare to pure refrigerant R227ea, by using Refrigerant mixture as working liquid in solar Organic Rankine cycle and it is better collector efficiency at same temperature ranges

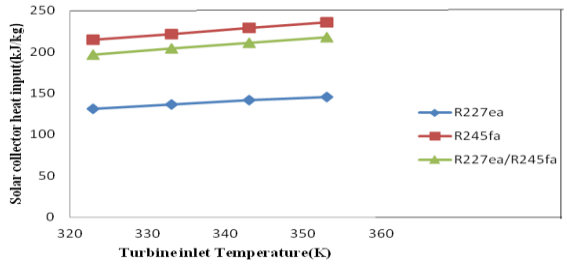


Figure 5.3 Effect of Solar Collector Heat Input by keeping constant Condenser temperature (298K)

5.4 EFFECT OF VOLUME EXPANSION RATIO

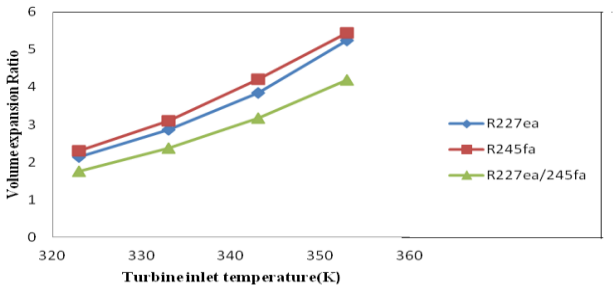


Figure 5.4 Effect of Volume Expansion ratio by keeping constant Condenser temperature (298K).

From the figure 5.4 observed that by increasing Turbine inlet temperature. Volume expansion ratio is defined as ratio flow rate of at turbine outlet to flow rate at turbine inlet. For refrigerant mixture R245fa/R227ea the Volume Expansion ratio is less compare to pure refrigerant R227ea & R245fa, by comparing refrigerant mixture volume expansion ratio is reduced by 25.4% & 30% compare to pure refrigerant R227ea and R245fa. This implies that by using refrigerant mixture reduce smaller dimension and less expensive of Turbine that reduce cost of the system.

5.5 EFFECT OF SECOND LAW EFFICIENCY

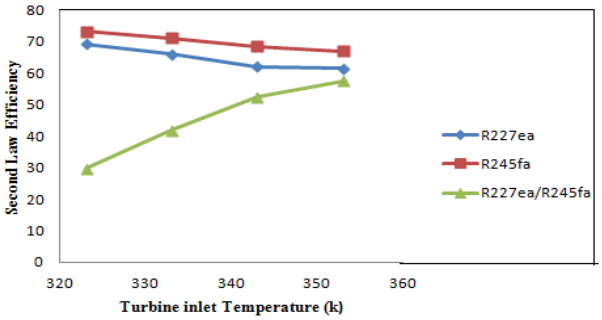


Figure 5.5 Effect of Second Law Efficiency by keeping constant Condenser temperature (298K)

From the figure 5.5 observed that by increasing Turbine inlet temperature The Second law efficiency can be decreased by utilizing refrigerant blend compare to pure refrigerants, these is due to minimizing the system irreversibility which could be utilized to mismatch of temperature profile between heat transfer fluid and evaporating or condensing working fluid blends.

5.6. EFFECT OF WORKING FLUIDS ON ORC EFFICIENCY Vs CONDENSER OUTLET TEMPERATURE

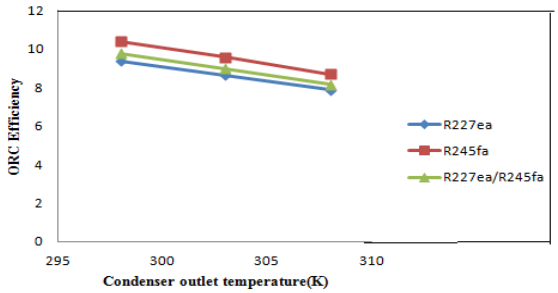


Figure 5.6 Effect of Working fluids working fluid on the ORC efficiency by keeping constant turbine inlet temperature at 353 K.

From the figure 5.6 observed that by increasing Condenser outlet temperature The Solar organic Rankine efficiency is decreasing linearly for both refrigerants' mixtures and for pure refrigerants.

5.7. EFFECT OF SECOND LAW EFFICIENCY Vs

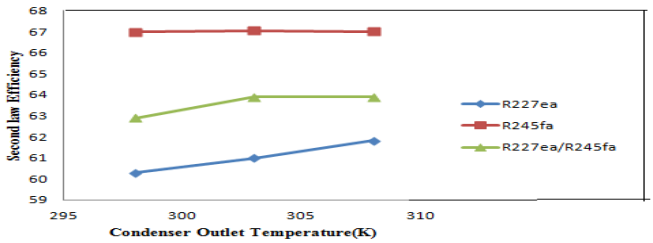


Figure 5.7 Effect of second law efficiency by increase condenser outlet temperature by keeping constant turbine inlet temperature at 353 K.

From the figure 5.7 observed that by increasing the Condenser outlet temperature Second law efficiency decreasing linearly for both refrigerants' mixtures and for pure refrigerants.

Table 5.1 Performance comparison between Refrigerant Mixture and Pure Refrigerant

Refrigerants	R227ea	R245fa	R227ea/R245fa[0.2/0.8]by mass Fraction
Evaporation bubble point temperature t_3 (^{0}C)	80	80	74.78
Evaporation dew point temperature t_4(^{0}C)	80	80	80
Evaporation temperature glide t_4- t_3 (^{0}C)	0	0	5.21
Evaporation Pressure p_3 (Kpa)	1860.2	788.1	899.3
Condensation bubble point temperature t_1 (^{0}C)	25	25	25
Condensation dew point temperature t_7(^{0}C)	25	25	32.28
Condensation temperature glide t_7- t_1 (^{0}C)	0	0	7.2
Condensation Pressure p_1(Kpa)	455.17	149.43	223.4
Pump work input $W_P = h_2 - h_1$(kJ/kg)	1.012	0.47	0.5
Expansion work output $W_t = h_5 - h_6$(kJ/kg)	14.69	25.12	21.78
Net power output $W_N = W_t - W_P$(kJ/kg)	13.68	24.64	21.28
Solar collector heat input $Q_E = h_5 - h_2$(kJ/kg)	145.6	236.15	217.9
SORC Efficiency	9.39	10.43	9.78
Second law Efficiency	60.2	66	57.5
Turbine Expansion ratio	5.24	5.44	4.18

VI. CONCLUSION

The simulation studies are carried for power generation by employing solar organic Rankine cycle and working fluids (R-245fa, R-227ea & R-245fa/ R-227ea mixture). From the studies it is inferred that

1.The Refrigerant mixture have variable temperature during the phase change process which could be used to reduce the mismatch of temperature profile between heat transfer fluid and the evaporating or condensing working fluid mixture.

2. The Organic efficiency of refrigerant mixture R245fa /R227ea is 4% more compared to pure fluid R227ea at turbine inlet temperature of 353K.

3.The Volume expansion ratio comparing refrigerant mixture is reduced by 25.4% & 30% compare to pure refrigerant R227ea and R245fa.This reduces more diminutive estimation and progressively moderate of turbine that lessen cost of the Power Plant.

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