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Exergy and energy analysis of modified organic rankine cycle for reduction of global warming and ozone depletion

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Abstract

There is great importance of using the Organic Rankine cycle plant in world. Low and medium grade energy from the low grade energy source is converted into the useful high grade energy. These low and medium grade energy sources are geothermal, solar energy, exhaust from the engine and other industrial waste energy. In this study the solar energy source is used. The main purpose of the solar integrated power plant is to mitigate the emission and risk associated with the already running plants and the other important purpose of integration of solar energy into already running power cycles is to minimize the cost keeping running already existing equipments. In this work exergy and energy analysis of Organic Rankine cycle with the solar heating source for organic fluid is done and bleeding regeneration is used for obtaining good performance. The performance of system is compared with different organic fluids like R134a, R407C, R404A, and R410A at different organic Rankine cycle maximum temperature and maximum pressure. R410A shows maximum in efficiency by regeneration around 64%. R410A shows maximum organic Rankine cycle efficiency of 16.51%. Exergetic efficiency of cycle with regeneration 61.78%, 64.75%, 60.14%and 48.51% for R407C, R410A, R404A and R134a respectively. Due to highest Exergy and energy efficiency and also it has low global warming potential and zero ozone depletion potential. R410A is useful for organic Rankine cycle for practical applications and there is no problem such as flammability and explosion risks.

Keywords: Modified organic Rankine Cycle, Energy Exergy Analysis, Thermodynamic analysis, Thermal Power Plant

1. Introduction

A regenerator is installed that heat the organic fluid (liquid) by the high temperature vapour that is coming from the organic turbine. In many organic fluid when expanded in orc turbine, at the exit give superheated vapor this vapor enthalpy is used in heating organic fluid that results heat addition required in the boiler is reduced. and condenser temperature is again set 35˚C.some steam at intermediate pressure the organic fluid vapor is extracted .this bled of vapor is goes to heater for heating the organic liquid coming out from the pump-1.after gating heat from heater liquid is heated and then go to the pump -2 .from pump -2 it is pumped to the evaporator pressure. Main purpose of the bleeding regeneration is that it is reduced the heat addition in evaporator. Several solar integrated combined cycles (ISCCs) are being used in all the world (USA Africa, North America ,Italy,) and there are many projects are processing (China, Mexico, USA). ISCCs have several advantages as compared to solar thermal power plants, because these give higher conversion solar efficiency and it have very low investment cost. Many entrepreneurs and owners are ready to invest the many due to it low risk associated with the smaller plants as compared to the solar thermal power plants. The procedure for changing over the vitality in a fuel into electric power incorporates the formation of mechanical work, which is then changed over into electric power by a generator. Contingent upon fuel sort and thermodynamic process, the in general productivity of this change can be as low as 31 %. This implies 66% of the inert vitality of the fuel goes up squandered. For instance, steam electric power plants which utilizes boilers to combust a petroleum derivative normal 33% efficiency. Basic cycle gas turbine (GTs) plants normal just shy of 30 percent productivity on gaseous petrol, and

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around 25 % on fuel oil. Quite a bit of this squandered vitality misfortunes as warm vitality in the hot fumes gasses from the ignition procedure.

To build the general proficiency of electric power plants, various procedures can be consolidated to recoup and use the leftover warmth vitality in hot fumes gasses. In joined cycle mode, control plants can accomplish electrical efficiencies up to 60 %. The expression alludes to the consolidating of numerous thermodynamic cycles to create control. Joined cycle operation utilizes a heat recovery boiler (HRB) that assimilates warm from high temperature deplete gasses to deliver natural vapor, which is then provided to a natural turbine to produce additional electric power. The procedure for making vapor to create work utilizing a natural turbine depends on the Rankine cycle.

2. Organic Rankine Cycle

Organic Rankine Cycles have gotten more consideration amid the most recent decade. This cycle takes after the crucial principles of regular Rankine cycles working with steam in like manner plants however has a few points of interest over steam Rankine cycle which made it prevalent. Firstly this cycle can work on low pressures and temperatures in comparison to the conventional Rankine cycle and reveals a better result than steam Rankine cycle especially from low grade heat sources because it has working fluids include such as variety of HCs and other refrigerants what's more, as per scope of open heat source pressure and temperatures, different outputs can be obtained by using useful working fluids, secondly, it can also work without multi-stage turbines and feed-water heaters and that thing makes it simple using.

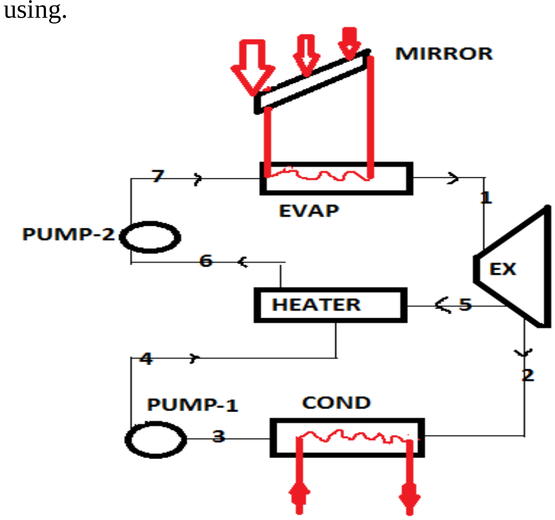

Figure: 1 Organic Rankine cycle without regeneration

Although this, solar parabolic collectors are a tremendous source of heat energy but these have low grade thermal energy. Because of this ,these solar collectors give only some KWs to some megawatts of power generation mainly near factories and rural areas to generate own electricity consumption without the necessity for connection to grid that may be costly. Disadvantages of solar ORCs are comparatively high costs and low thermal efficiency (10 to 25 % according to working fluids and working conditions) mainly because of low HTF (Heat transfer fluids) temperature in solar collector. As described before, the organic fluid works in ORC cycles are classified into HCs and refrigerants, some of those are dry liquids which mean they have a +ve slope T-S graph in the immersion vapor area. This makes it reasonable for some organic liquids to works legitimately without superheating to an extraordinary possibility and make no harm turbine. It has been appeared in this review, an examination of various dry organic liquids with or without superheating and recuperations has been done to reveal the difference in cycle effectiveness and execution of the system that encourages us to settle on a choice to pick the system condition as indicated by our requirements.

2.1 Principle of solar heating

The organic Rankine cycle works on the principle of a turbo generator which works as a simple steam turbine to convert thermal power into mechanical power and then into electrical power by an electrical generator. Besides of using steam of water, orc system evaporates organic fluid, classified by a molecular weight higher than the water that leads to slow rotation of the organic expander that also leads to the less erosion of metallic parts and the blades. Organic Rankine cycle is normally a Rankine cycle in which besides of using water other organic fluid is used like R134a, R407C, R404A, R410A etc. Evaporator is nothing but is the simple heat exchanger, or it can be used as a series of heat exchangers. It is also can be called a boiler, because it produces organic vapour for the ORC turbine by taking energy from the solar heat source. This heat source is nothing simple solar heat flate plate collector. From solar plate heat collector the heat is taken by the evaporator and the in evaporator working fluid is heated and converted in to the hot vapor this vapor goes to the expander and this heat energy converted in to the rotation of expander. Instead of the flat, plate heat collector there concentrated parabolic heat collector can be used.

The economizer works as a heat exchanger which preheats the organic fluid (liquid) to get the temperature to the saturation temperature (boiling point), that liquid to be supplied to a thick-walled boiler drum. That drum is installed where finned evaporator tubes is located that circulate heated organic fluid. The solar radiation incident on to the evaporator tubes, and the heat is being absorbed and then the vapor is being created of in the tubes. This vapor-liquid mixture goes to the boiler drum where the vapour is separated from the hot liquid by using moisture cyclones and separators. And that separated liquid is again recirculated to the evaporator tube. The

function of the some boiler drums is also to storage and water treatment functions. There are several other design of steam boiler in which another design is a once-through, where thin-walled components are used in place of boiler drum which are better for handling changes in exhaust gas temperature and vapour pressures during frequently stops and starts. In other designs, duct burners can be used for adding heat to the exhaust gas current and boost vapour manufacturing; it's have been used to generate vapour even if no not sufficient exhaust gas flow is there.
Saturated vapour from boiler drums or any once-through boiler system has been sent to super heater to produce dry vapour that is requirement for the organic turbine. And the organic fluids goes to the preheaters, that are placed where very low amount of heat is available and then this fluid takes energy from the and heated by the heat exchanger liquids such as the mixture of glycol water and from there very economic and useful amount of heat is extracted.
The superheated organic vapour produced from the evaporator is supply to organic turbine where it is expanded by the turbine blades, and gives rotation to turbine shaft. The mechanical energy delivered to the generator driving shaft is transformed into high grade energy (electricity). After exiting the organic turbine, the organic vapor goes to the condenser which paths the condensed organic liquid back to evaporator.
In this research the main purpose is the selection the working fluid which is given the maximum exergetic and the first law efficiency and low global warming potential and the zero ozone depletion potential.
And give lower exergy destruction in the each component. Some important properties of working fluids. Are given in Table-1.

Table: 1 properties of the working fluids

Working fluids	Constituents	Toxicity	Flammability	ODP	GWP
R407C	R32(23%),R 125(25%), R134(52%)	None toxic	None flammability	0	1526
R410A	R125(50%), R32(50%)	None toxic	None flammability	0	1725
R134a	Tetra floro ethane	None toxic	None flammability	0	1300
R404A	R125(44%), R143a(52%) R134a(4%)	None toxic	None flammability	0	3260

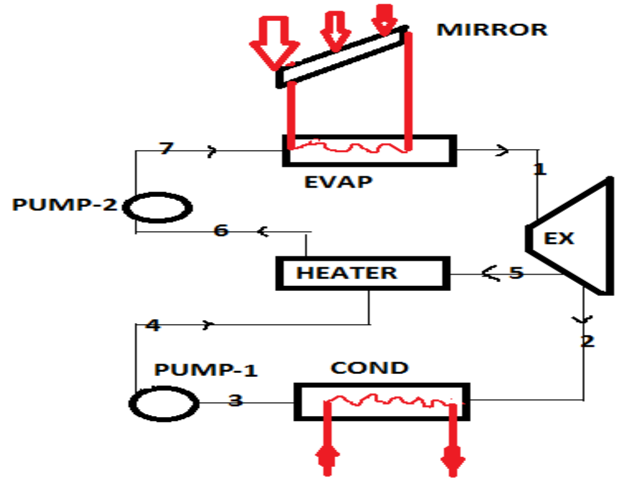

Figure: 2 Organic Rankine cycle with regeneration

This is the organic Rankine cycle without regeneration, working fluid flows from 1 point to 2-3-4-1.in evaporator working fluids gets heated from the solar radiation .and then is heated from saturated liquid to super heated vapor .after that this vapor goes to the turbine and there it is expanded, and heat energy is converted in the mechanical energy and after the expansion the mechanical energy further it is transformed in to the electrical energy in generator. After the expansion the remaining vapor which has some heat energy goes to the condenser where heat from the vapor rejected from the condenser .in condenser cooling water is enter for cooling purpose after then it is pumped to the boiler pressure by liquid pump. Then again the heating process is done and the cycle is repeated
A regenerator is installed that heat the organic fluid (liquid) by the high temperature vapour that is coming from the organic turbine. In many organic fluid when expanded in orc turbine, at the exit give superheated vapor this vapor enthalpy is used in heating organic fluid that results heat addition required in the boiler is reduced. and condenser temperature is again set 35˚C.some steam at intermediate pressure the organic fluid vapor is extracted .this bled of vapor is goes to heater for heating the organic liquid coming out from the pump-1.after gating heat from heater liquid is heated and then go to the pump -2 .from pump -2 it is pumped to the evaporator pressure. Main purpose of the bleeding regeneration is that it is reduced the heat addition in evaporator.
Kelly et al [1] demonstrated that the most efficient way for converting solar thermal energy into electricity is to withdraw feed water from the heat recovery steam generator (HRSG) downstream of the last economizer, to produce high pressure saturated steam and to return the steam to the HRSG for superheating and reheating. The integrated solar plant concept offers an effective means for the continued development of parabolic trough technology. In a careful plant design, solar thermal to electric conversion efficiencies will exceed, often by a significant amount, those of a solar-only parabolic trough project. An integrated plant bears only the incremental

capital cost of a larger Rankine cycle, which provides further reductions in the levelized cost of solar energy.

He Ya Ling et al [2] proposed a model for a typical parabolic trough solar thermal power generation system with Organic Rankine Cycle (PT-SEGS–ORC) was built within the transient energy simulation package TRNSYS. They found that the heat loss of the solar collector (qloss) increases sharply with the increase in pinter at beginning and then reaches to an approximately constant value. The variation of heat collecting efficiency (η_{hc}) with v is quite similar to the variation of gloss with pinter. However, Idn and θ exhibit opposite effect on η_{hc}. In addition, it is found that the optimal volume of the thermal storage system is sensitively dependent on the solar radiation intensity. The optimal volumes are 100, 150, 50, and 0 m^3 for spring equinox, summer solstice, autumnal equinox and winter solstice, respectively.

Gang et al. [3] proposed the innovative configuration of low temperature solar thermal electricity generation with regenerative Organic Rankine Cycle (ORC), mainly consisting of small concentration ratio compound parabolic concentrators (CPC) and the regenerative ORC. The effects of regenerative cycle on the collector, ORC, and overall electricity efficiency are then analyzed. The results indicate that the regenerative cycle has positive effects on the ORC efficiency but negative ones on the collector efficiency due to increment of the average working temperature of the first-stage collectors. And found that the regenerative cycle optimization of the solar thermal electric generation differs from that of a solo ORC. The system electricity efficiency with regenerative ORC is about 8.6% for irradiance 750 W/m2 and is relatively higher than that without the regenerative cycle by 4.9%.

Manolakos D et al [4] proposed co-generation system producing electricity and freshwater by a solar field driven supercritical organic Rankine cycle (SORC) coupled with desalination. The proposed system can use parabolic trough solar collectors (among other options) to produce 700 kW thermal energy with temperatures up to 400°C at peak conditions. Thermal energy is delivered to the SORC which uses hexamethyldisiloxane (MM) as the working organic fluid and could achieve cycle efficiency close to 21%. The SORC condensation process is undertaken by the feed seawater to reduce thermal pollution. Due to the elevated temperature of the preheated seawater, the RO unit specific energy consumption decreases.

Nafey and Sharaf [5] carried out design and performance analysis using MatLab/SimuLink computational environment. The cycle consists of thermal solar collectors (Flat Plate Solar Collector (FPC), or Parabolic Trough Collector (PTC), or Compound Parabolic Concentrator (CPC)) for heat input, expansion turbine for work output, condenser unit for heat rejection, pump unit, and Reverse Osmosis (RO) unit. Reverse osmosis unit specifications used in this work is based on Sharm El-Shiekh RO desalination plant. Different working fluids such as: butane, iso butane, propane, R134a, R152a, R245ca, and R245fa are examined for FPC. R113, R123, hexane, and pentane are investigated for CPC. Dodecane, nonane, octane, and toluene are allocated for PTC. Exergy and cost analysis are performed for saturation and superheated operating conditions. Toluene and Water achieved minimum results for total solar collector area, specific total cost and the rate of exergy destruction.

Sharaf et al [6] carried out thermo-economic analysis of PTSC integrated with an ORC and a multi-effect distillation. Two scenarios of generation were considered in their study: the first one was with only water production and the second one was with both power and water production. The comparison is implemented according to the operation of Parabolic Trough Collector (PTC) with toluene organic oil and water working fluids. Therminol-VP1 Heat Transfer Oil (HTO) is considered for indirect vapor generation operation across the solar field and evaporator heat exchanger. The comparisons are manipulated according to 100 m^3/day of distillate product as a case study. As a result, only desalination technique is considered more attractive than desalination and power technique due to higher gain ratio and lower solar field area needed.

Delgado-Torres and Garcia Rodriguez et al [7] & [8] conducted thermodynamic analysis of a thermal system which consists of an ORC, a PTSC, and an RO (Reverse Osmosis). Initially they analyzed the system assuming only water production through RO then they extended their study to include both electrical and water production the main objective of their study was to examine the effect of different organic fluids on the aperture area of the PTSC.

Al-Sulaiman et al. [9] & [10] proposed the energetic performance analysis of PTSC integrated with an ORC in which the waste heat from the ORC is used for cogeneration was conducted. It was found that there was an energy efficiency improvement, when tri generation was used, from 15% to 94% (utilization efficiency). On the other hand using exergy analysis, found that there was an exergetic efficiency improvement from 8% to 20% when tri generation is used as compared to only power generation.

Al-Sulaiman [11] carried out solar field sizing and overall performance analysis of different vapor cycles. The systems considered are parabolic trough solar collectors integrated with either a binary vapor cycle or a steam Rankine cycle (SRC). The binary vapor cycle consists of an SRC as a topping cycle and an organic Rankine cycle as a bottoming cycle. Seven refrigerants are examined for the bottoming cycle: R600, R600a, R134a, R152a, R290, R407c, and ammonia. Founds that significant reduction in the solar field size is gained due to the performance improvement when the binary vapor cycle is considered as compared to a steam Rankine cycle with atmospheric condensing pressure; however, SRC with vacuum pressure has the best performance and smallest solar field size. It further reveals that the R134a binary vapor cycle has the best performance among the binary vapor cycles considered and, thus, requires the smallest solar field size while the R600a binary vapor cycle has the lowest performance.

Fahad A. Al-Sulaiman [12] carried out detailed exergy analysis of thermal power system driven by parabolic trough solar collectors (PTSCs). The power is produced using either a steam Rankine cycle (SRC) or a combined cycle, in which the SRC is the topping cycle and an organic Rankine cycle (ORC) is the bottoming cycle. Seven refrigerants for the ORC were examined: R134a, R152a, R290, R407c, R600, R600a, and ammonia. The R134a combined cycle demonstrates the best exergetic performance with a maximum exergetic efficiency of 26% followed by the R152a combined cycle with an exergetic efficiency of 25%. Alternatively, the R600a combined cycle has the lowest exergetic efficiency, 20–21%.

Milad Ashouri et al [13] carried out analysis of a photovoltaic through collector (PTC) integrated with an organic Rankine cycle (ORC) for small scale electricity generation near Tehran. The system includes a solar field, a storage tank, and a small scale ORC engine. Performance evaluation has been done by means of commercial software Thermoflex19. A comparison of different working fluids is presented and results shows that Benzene has the best performance among fluids butane, n-pentane, isopentane, R123 and R245fa for the system conditions described.

Dimityr Popov [14] proposed a concept for innovative hybridization of gas turbine combined cycle plant and solar power system. This conceptual plant is named as Solar Assisted Combined Cycle, as the solar energy is indirectly involved in power generation. The proposed solar hybridization can be accomplished in two ways. The first solar assisted option introduces mechanical chillers for a complete cooling of gas turbine inlet air. The next solar assisted option does the same but with an absorption chiller. They find that the configuration with absorption chillers has lower specific incremental plant capital costs and requires smaller land area than the others.

Wang et al [15] analyzed a 1.6 kWe solar ORC using a rolling piston expander. An overall efficiency of 4.2% was obtained with evacuated tube collectors and 3.2% with flat-plate collectors. The difference in terms of efficiency was explained by lower collector efficiency (71% for the evacuated tube vs. 55% for the plate technology) and lower collection temperature.

S. Quoilin et al [16] carried out thermodynamic modeling of a proposed small scale PTSC integrated with an ORC for power production, considering different design options to be located in a rural location in South Africa and presented an optimization and sizing procedure of heat exchangers in a small scale solar driven ORC by pinch and pressure drop and optimized it by turbine input pressure and evaporator temperature. Then they further focused on the evaluation of the thermodynamic performance of the system. With conservative hypotheses, and real expander efficiency curves, it was found that an overall electrical efficiency between 7% and 8% reached. This efficiency is steady-state efficiency at a nominal working point. The comparison between working fluids showed that the most efficient fluid is Solkatherm. R245fa also shows a good efficiency and has the advantage of requiring much smaller equipment.

Maria E Madejar et al.[17] presents the quasi-steady state simulation of a regenerative organic Rankine cycle (ORC) integrated in a passenger vessel, over a standard round triple used experimental data like exhaust gas temperature, engine speed, electricity demand on board for simulation purpose and to estimate the average net power production of the ship over a round trip.

Finally he conclude that the maximum net power production of the ORC during the round trip was estimated to supply approximately 22% of the total power demand on board. The results showed potential for ORC as a solution for the maritime transport sector to accomplish the new and more restrictive regulations on emissions, and to reduce the total fuel consumption.

Harrison Warren et al.[18] proposes enhancement of power generation unit-organic Rankine cycle (ORC) system through the electric energy storage and proposes the use of an electric energy storage (EES) device in conjunction with a PGU-ORC. The idea is to use the energy stored by EES at different times of the day so that continuous operation of the PGU is not required. The potential of the proposed PGU-ORC-EES system is assessed by evaluating the performance in terms of operational cost, primary energy consumption (PEC)

He concluded that the potential of a PGU-ORC-EES system to reduce the operational cost, CDE, and PEC compared with a conventional system. Performance of simulations of a restaurant facility at 12 different geographical locations reflecting a variety of climate conditions. Results indicated that the addition of EES is beneficial to the PGU-ORC system for most locations in terms of the three evaluated parameters.

Ayad M. Al Jubori et al [19] proposed Modelling and parametric analysis of small-scale axial and radial outflow turbines for Organic Rankine Cycle applications using a range of organic working fluids (R141b, R245fa, R365mfc, iso butane and n–pentane).

And he conclude that the efficiency of axial small scale turbine is better than radial out flow turbine .axial turbine have efficiency 82.5% and power output 15.15kw.and on other hand the efficiency of radial outflow efficiency is 79.05% and power output is 13.625kw with n-pentane as the working fluid in both cases. The maximum cycle thermal efficiency was 11.74% and 10.25% for axial and radial-outflow turbine respectively with n-pentane as the working fluid and a heat source temperature of 87 _c

Jui-Ching Hsieh et la [20] Design and preliminary results of a 20-kW trans critical organic Rankine cycle with a screw expander for low-grade waste heat recovery and they examine a trans critical Rankine cycle with screw expander with R218 as the working fluid in both sub critical and super critical state of working fluid they used the low grade heat at 90 -100_C.and they used two centrifugal pumps in series .for control controlling the pressure used variable frequency drive (VFD).

Finally they concluded the efficiency of the expander and the working fluid pump is peak at peak pressure. the output power was not significantly effected by heat source temperature but thermal efficiency slightly decreased by increasing heat source temperature The present TRC system successfully converted the low-grade heat into approximately 20 kW of power. The thermal efficiency of the TRC system was 5.7%, 5.38%, and 5.28% for the heat source temperatures 90, 95, and 100 _C, respectively, with the VFD at 50 Hz.

Dong junqi et al [21] proposed Experimental investigation on heat transfer characteristics of plat heat exchanger applied in organic Rankine cycle (ORC) .and experimentally study the single phase and boiling heat transfer characteristics of three types of working fluids on plate types of heat exchangers surface. These three working fluid are water and 50%coolant and R 245fa.and heat transfer dimensionless empirical equation for three types of working fluids are provided.

Finally he obtained evaporation heat transfer empirical equation for the organic fluid R245fa is given with the mean absolute error9.97%which prevents 90% data with error less than ±20%.

Ayad Al Jubori et la [22] proposed Three dimensional optimization of small-scale axial turbine for low temperature heat source driven organic Rankine cycle Advances in optimization techniques can be used to enhance the performance of turbines in various applications. However, limited work has been reported on using such optimization techniques to develop small-scale turbines for organic Rankine cycles. This paper investigates the use of multi-objective genetic algorithm to optimize the stage geometry of a small-axial subsonic turbine.

And he concluded that using working fluid R123 for a turbine with mean diameter of 70 mm, the maximum isentropic efficiency was about 88% and power output of 6.3 kW leading to cycle thermal efficiency of 10.5% showing an enhancement of 14.08% compared to the baseline design. Such results highlight the potential of the 3D optimization technique to improve the organic Rankine cycle performance.

Constantine N. Michos et al.[23] proposed the backpressure effect of an Organic Rankine Cycle (ORC) evaporator on the exhaust line of a turbocharged, V12 heavy duty diesel engine, for typical marine and power generation applications has been investigated using the commercial software Ricardo WAVE. Three different state-of-the art turbocharging strategies are assessed in order to counterbalance the increased pumping losses of the engine due to the boiler installation: fixed turbine, Waste-Gate (WG) and Variable Geometry Turbine (VGT). At the same time, the And he concluded that engine side point of view, a VGT turbocharger is the most favorable solution to withstand increased backpressure, while, regarding the ORC side, between the considered fluids and layouts, acetone and a recuperated cycle show the most promising performance.

3. Outcomes from Literature review and Research gap identified

By incorporation of solar energy in organic Rankine cycle plant the output of plant can be increased. From literature survey of solar integrated ORC plant, it is found that detailed energy and exergy analysis of Organic Rankine cycle plant and combined cycle power plant are done earlier. From literature survey it is found that energy and exergy analysis of solar operated organic Rankine cycle with regeneration and selection of working fluid are not done yet. Solar energy is used for reheating source for the heating of working fluid in the evaporator.

In the present study thermodynamic analysis of Organic Rankine cycle plant with solar reheating source is investigated and comparison of various organic fluids is carried out to find best organic fluid which will give maximum efficiency. The effect of regeneration on organic Rankine cycle plant. It is proposed to examine the effect of following parameters on the efficiency of organic Rankine cycle and Organic Rankine cycle plant of solar heated cycle plant and evaluation of better organic fluid for global warming and ozone depletion.

- Effect of using regeneration in system on efficiency and exergy destruction.
- Effect of Organic turbine inlet temperature.
- Effect of Organic turbine inlet pressure.
- Effect of various organic fluids.
- And find maximum exergy destruction component.
- Effect of varying solar plate area.

4. Thermodynamic Analysis

For thermodynamics (energy and exergy) analysis of organic Rankine cycle with the regeneration and solar heating source is considered .which is given in figure .In this figure there are four component which are given as

- An organic expander
- A condenser
- Two pumps
- An evaporator

All stages are defined by the numbers at stage 1 the organic fluid which in vapor forms goes to the organic expander where it is expanded and gives the work W_{ex}

After expansion the organic fluids goes to condenser for rejection of the heat from the remaining organic vapor at stage 2 and heat Q_r heat is rejected. After rejection of heat it goes to pump 1 giving work of Wc_1 where it is brought to the heater pressure or intermediate pressure where some part of vapor is extracted for heating purpose for the organic liquid. The organic vapor is extracted from the turbine at the stage 5.and it is mixes at the heater .after mixing and getting heat the it goes to the pump 2 at the stage of 6 and pump-2 increases the pressure to the evaporator pressure at the stage of 7 and Wc2 work is done the stage of 7 saturated fluid goes to the evaporate where heat is taken by the liquid working fluid is heated by solar heating constant temperature heat source .Qs heat is supplied to the working fluid and then cycle is repeated.

4.1 Thermodynamic Model

In this present work, a parametric study with various temperature and pressure at organic turbine inlet has been considered to determine efficiency and performance of organic fluid in system. The following assumptions are there to simplify the analysis, also taking energy analysis

1. Assumed all the components are steady-state process and steady flow.
2. The changes in the kinetic energy and the potential energy are assumed to be negligible.
3. There are negligible heat and pressure loss in pipes that are connecting all the components to each other.
4. Expander and pumps work adiabatically.
5. Pressure drops in feed heater and condenser are neglected.
6. It is assumed the vapor after expansion is saturated.
7. Liquid after pump 1 is saturated.
8. No pressure loss in evaporator.
9. Constant heat source and 100 % is solar collector efficiency.

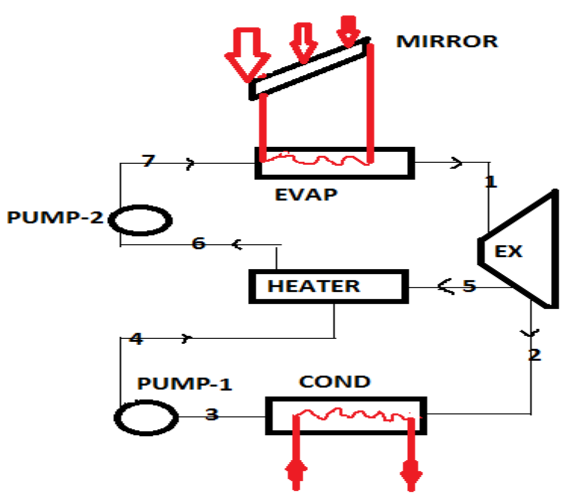

Figure: 3 Model for organic Rankine cycle with regeneration

4.2 Energy Analysis

Based on assumptions, the equations for mass balance and energy are written for each component. Each component in a solar heated source organic Rankine cycle plant is shown in Fig.3 considered as control volume.

Mass Balance

$\sum m_{in} = \sum m_{out}$

Energy balance

Q-W+ $\sum m_{in}$- $\sum m_{out}$=0

4.3 Energy changes in the each component of organic Rankine cycle with regeneration cycle plant

4.3.1 Organic Rankine expander

Organic expander is a work obtaining device in which organic fluid is expanded from evaporator pressure to condenser pressure adiabatically. The isentropic work output of expander.

$W_{EX} = m_f * (h_1 - h_{2s})$

Organic expander efficiency given as,

$\eta_{EX} = (h_1 - h_2)/(h_1 - h_{2s})$

Actual organic turbine work is

$W_{EX} = (h_1 - h_2)$

4.3.2 Condenser

Condenser is a heat exchanger in which heat is rejected to environment is given by

$Q_{cond} = (m_f - m_x) * (h_2 - h_3)$

4.3.3 Organic pump 1

Organic pump is used for increasing pressure of organic fluid from condenser pressure to boiler pressure. Ideal work of organic pump

$W_{OPi} = (m_f - m_x) * v_3 * (P_5 - P_2)$

Organic pump efficiency as,

$\eta_{OP} = W_{OPi} / W_{OP}$

Actual organic pump work is given by

$W_{OP1} = m_f * v_3 * (P_5 - P_2) / \eta_{OP}$

4.3.4 Organic pump 2

Organic pump is used for increasing pressure of organic fluid from condenser pressure to boiler pressure. Ideal work of organic pump.

$W_{OPi} = m_f * v_6 * (P_1 - P_5)$

Organic pump efficiency as,

$\eta_{OP} = W_{OPi} / W_{OP}$

Actual organic pump work is given by

$W_{OP2} = m_f * v_6 * (P_1 - P_5) / \eta_{OP}$

4.3.5 Feed heater

Feed water heater is the device in which the vapor is extracted from the turbine and mixes with liquid and heat is transferred from vapor to the liquid. And feed liquid is heated.

Energy balance in feed heater is given as

$m_f * h_6 = (m_f - m_x) * h_4 + m_x * h_5$

4.3.6 Evaporator

Evaporator is a device in the organic fluid is heated by solar collectors heater and working fluid is converted in to the vapor this vapor goes to the expander.
Heat is given by evaporator per unit mass as

$q_s = h_7 - h_1$

Total heat supplied to the working fluid from solar energy collector

$Q_s = I_s * A_s$

Mass flow rate is calculated as

$m_f = Q_s / q_s$

4.3.7 Efficiency of Organic Rankine cycle

It is the ratio of the net work output of ORC and total heat supplied in ORC

$\eta_{ORC} = (W_{OT} - W_{OP1} - W_{OP2}) / Q_S$

4.4 Exergy Analysis

Exergy loss or destruction is given by

$$\dot{E}D_i = \Sigma(\dot{me})_{in} - \Sigma(\dot{me})_{out} + \left[\Sigma\left(\dot{Q}\left(1 - \frac{T_o}{T}\right)\right)_{in} + \Sigma\left(\dot{Q}\left(1 - \frac{T_o}{T}\right)\right)_{out}\right] \pm \Sigma\dot{W}$$

4.5 Exergy analysis of the each component of the organic Rankine cycle plant with regeneration

Exergy destruction in organic expander given as

$ED_{EX} = m_f*[(h_2 - h_1) - T_0*(s_2 - s_1)] + m_{x*}[(h_5 - h_2) - T_0*(s_5 - s_2)] - W_{EX}$

Exergy destruction in condenser given as

$ED_{cond} = (m_f - m_x)*[T_0*(s3-s2) + q_r*T_0/T_c]$

Exergy destruction in pump given as

$EDpump1 = (m_f - m_x)*T_0*(s_4 - s_3)$

Exergy destruction in pump 2 given as

$EDpump\ 2 = m_f*T_0*(s_7 - s_6)$

Exergy destruction in the feed heater given as

$ED_{HE} = m_x*Ex_5 + (m_f - m_x)*Ex_4 - m_f*Ex_6$

Exergy destruction in the evaporator given as

$ED_{EVAP} = m_f*[T_0*(s1-s7) - qs*T_0/T_H]$

Exergy transfer from evaporator given as

$ET_{EVAP} = Qs*(1 - T0/T_H)$

Second law efficiency of orc plant given as

$\dot{\eta}_{second} = (W_{EX} - W_{pump1} - W_{pump2}) / ET_{EVAP}$

Exergy destruction ratio given as

$EDR = (ED_{EX} + ED_{cond} + ED_{pump1} + ED_{pump2} + ED_{HE} + ED_{EVAP}) / ET_{EVAP}$

5. Results and Discussion

A computational model is developed by using Engineering equation Solver (Klein and Alvarado, 2005) for evaluating Exergy and the energy analysis of organic Rankine cycle plant with Solar reheating source and Regeneration from vapor bled of. The input data for evaluation are mentioned in chapter 4 except the parameter, whose effect is discussed in particular plot, has been varied. The following input parameters have been taken for computation of first law and second law efficiency and results are given below.

Organic expander inlet pressure
P_1= 4000 kPa
Organic expander inlet temperature
T_1= 100 ˚C
Isentropic efficiency of Organic expander
η_{EX}= 0.80
Condenser fixed temperature
Tc= 35^0 C
Isentropic efficiency of both pumps
η_{pump}= 0.60
Intermediate or bled off pressure
P_5 = 1000 kPa
Organic expander inlet pressure
P_1= 2500 to 4500 kPa
Organic expander outlet pressure
P_2=500 kPa
Solar irradiation on CSP collector
I_S= 700 W/m^2
Condenser Temperature
Tc = 35 ˚C
Constant heat source temperature
T_H=127^0C
Dead State Temperature
To= 25^0C
Organic fluid used
R404A, R410A, R407C and R134a

5.1 Comparisons of different working fluids with Regeneration and Solar reheating source

Figure 4 to 6 shows comparison of the efficiency against the organic turbine inlet pressure and temperature. It is obvious that the efficiency of organic Rankine cycle increases with regeneration. By using the regeneration heat supplied to the organic cycle plant decreases hence the rate of evaporation increase which results output increases and hence the organic Rankine cycle efficiency increases.

5.2 Comparison of the various organic fluids

Figure 4 to 6 shows variation of efficiencies of the system at organic turbine inlet pressure, temperature, mass of vapor extracted, and the comparison fluids also done to the maximum work done by the turbine, Among all organic fluid the shows maximum efficiency of the organic Rankine cycle which is about 16.51% and R134a, R407C, R410A and R404A have maximum organic Rankine cycle efficiency of 12.37%, 15.75%, 16.51.% and 15.34% respectively at 4000kPa maximum pressure and 200˚C maximum temperature of ORC fluid.

And mass of fluid extracted at intermediate pressure also plotted in figure with respect to the inlet temperature of organic expander.

5.3 Exergy efficiency

Variation of the Exergy efficiency of various organic fluids with maximum pressure and maximum temperature, of organic cycle is shown in figure 7 to 9. It is seen that the Exergy efficiency of the organic Rankine cycle increases with maximum pressure and maximum temperature.

5.4 Exergy destruction ratio

Exergy destruction ratio is plotted with respect to the inlet temperature and pressure of expander and what was the effect on cycle founded.it is shown in fig10 and 11.

5.5 Expander output

Expander output with respect to the temperature and pressure inlet of the expander is plotted in figures 12 and 13.

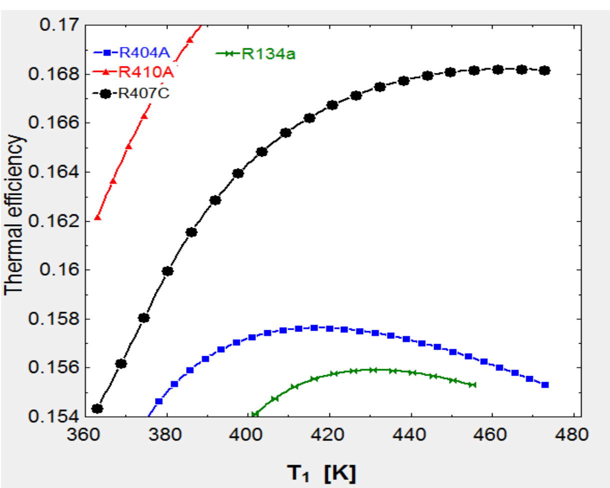

Figure 4: Variation of thermal efficiency of organic rankine cycle with expander inlet tempreture.

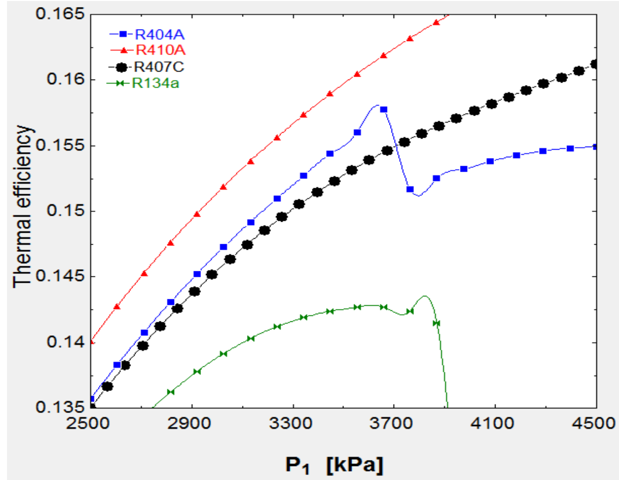

Figure 5: Variation thermal efficiency of organic rankine cycle with turbine inlet pressure

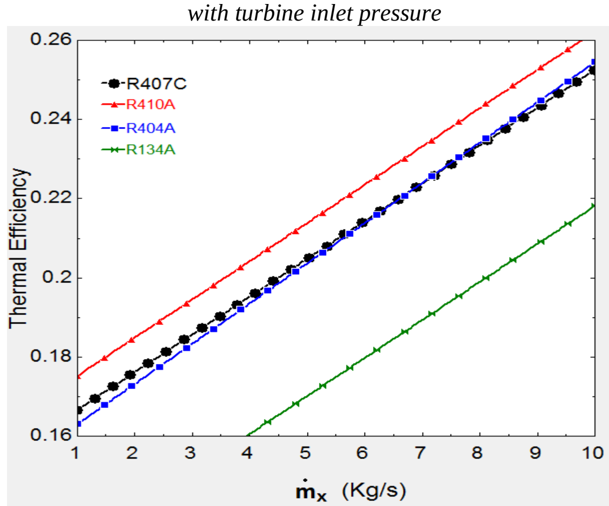

Figure 6: Variation of thermal efficiency with extraction mass from expander

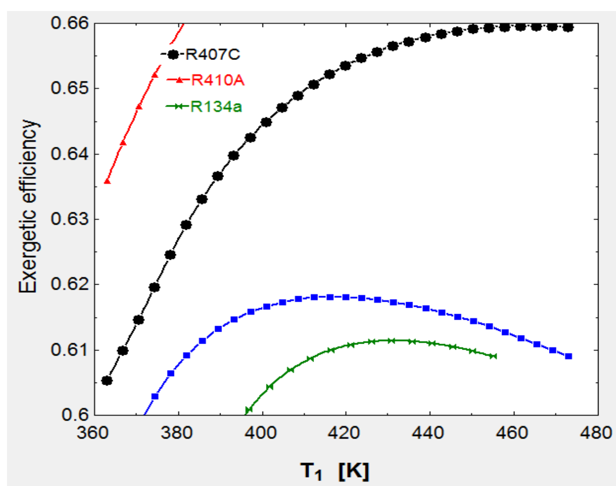

Figure 7: Variation of exergetic efficiency with inlet temperature of expander

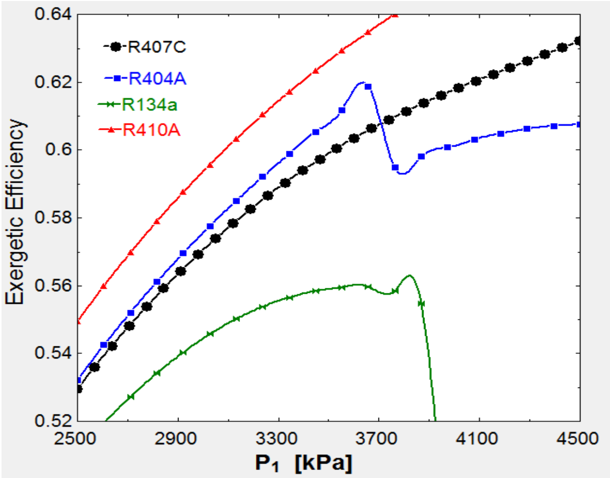

Figure 8: Variation of exergetic efficiency with the inlet pressure of expander

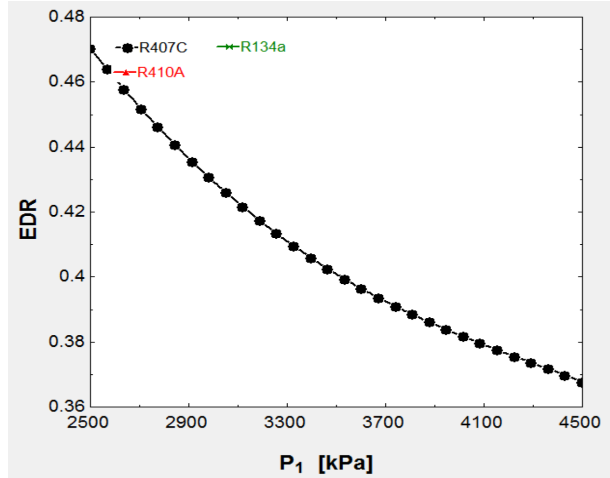

Figure 11: Variation of EDR with the inlet pressure of expander

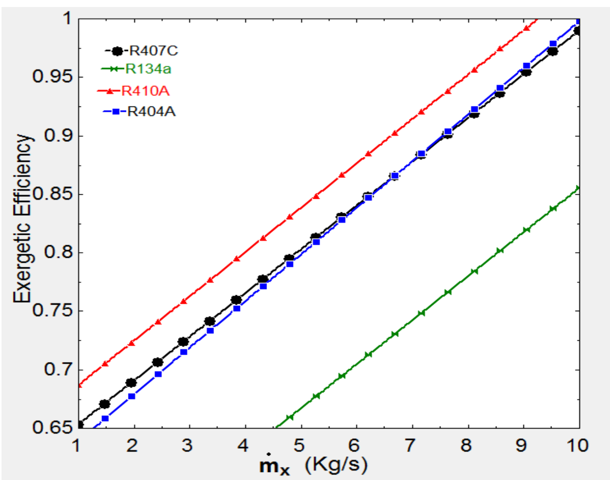

Figure 9: Variation of exergetic efficiency with mass extracted from expander

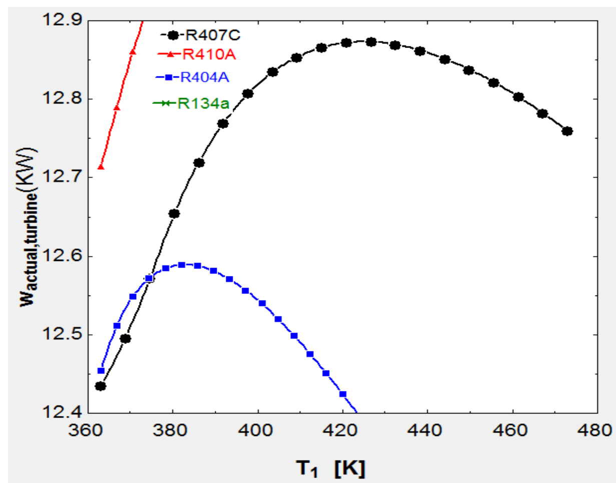

Figure 12: Variation of turbine work output with the inlet temperature of the expander

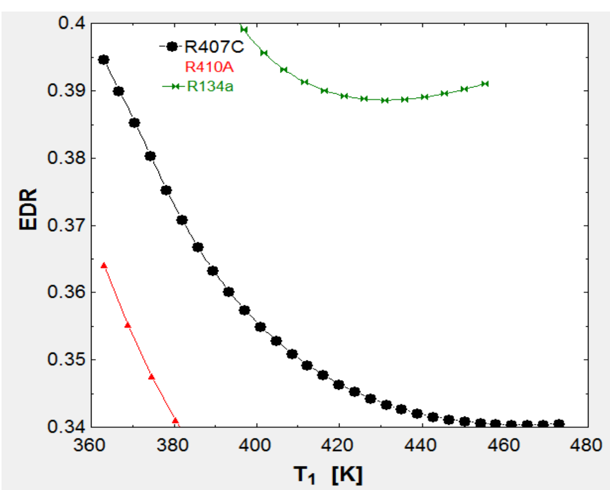

Figure 10: Variation of EDR with the inlet temperature of expander

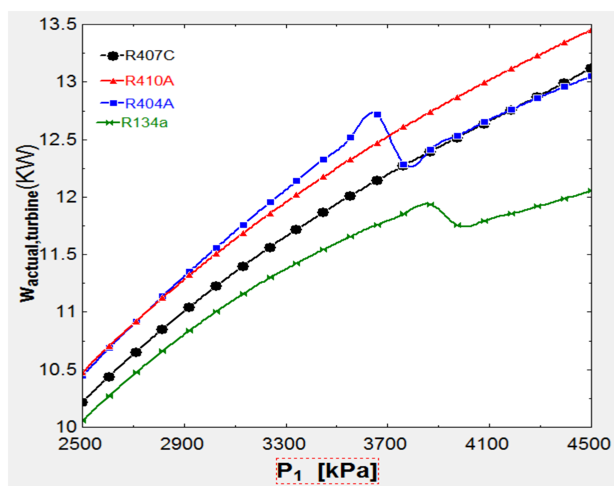

Figure 13: Variation work output of expander with the inlet pressure of expander

6. Conclusion

An extensive first law (energy) and second law (Energy) analysis of R134a, R407C, R410A, and R404A Organic fluids in cycle with regeneration and reheating is presented. Conclusions of this analysis are summarized as follows:

1. Exegetic efficiency (second law efficiency) and Energy efficiency (first law efficiency) of Organic Rankine cycle using R134a, R407C, R410A, and R404A organic fluids with regeneration is higher than without regeneration.
2. R410A have higher first law efficiency and Exergetic efficiency (second law efficiency) in Organic Rankine cycle but R407C have higher first law efficiency and Exergetic efficiency (second law efficiency) improvement from basic system.
3. From solar reheating source there is no effect of area of solar collectors on the first law and second law efficiency.
4. Exergetic efficiency of plant increases rapidly with respect to the inlet expander temperature. And maximum for R410A among all selected working fluids.
5. Exergetic efficiency for the R410A is maximum among the other selected working fluids and increases gradually with inlet pressure of expander.
6. Thermal efficiency for the plant is increases with respect to inlet temperature of expander.
7. Thermal efficiency for the R410A is maximum among the selected working fluids and increases gradually with respect to the inlet expander temperature.
8. Exergy Destruction Ratio is lowest for R410A and decreases with the inlet temperature of the expander.
9. Work output for R410A is maximum among the other selected working fluids .And increases with increase in inlet temperature.
10. Since work output is maximum for the R404A than R410A but decrease rapidly at 3700kPa pressure.
11. Thermal efficiency is increases with the extraction mass for regeneration from the expander
12. Exergetic efficiency is also increases with the increase in mass extraction. That's why R410A is selected for organic Rankine cycle power generation and this also suitable for low global warming and ozone depletion.

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