Thermodynamic analysis and comparison of various organic fluids for ORC in Gas turbine-Organic Rankine combined cycle plant with solar reheating and regeneration of ORC fluid

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Abstract - *In this work energy and exergy analysis of Gas turbine-Organic Rankine combined cycle with solar reheating of organic fluid is done and results are compared with simple combined cycle, combined cycle with regeneration, combined cycle with solar reheating of organic fluid. The performance of the system is compared with different organic fluids such as R134a, R245fa, Acetone, and R1234yf at different organic Rankine cycle maximum pressure and maximum temperature. R1234yf shows maximum increase in efficiency by regeneration about 70%. Acetone shows maximum organic Rankine cycle efficiency of 25.96%. Exergetic efficiency of combined cycle with regeneration and reheating 64%, 72%, 64%and 82% for R134a, R245fa, R1234yf and Acetone respectively. Acetone is recommended for practical applications due to its highest energy and exergetic efficiency among all selected organic fluids but some important problem related to flammability and explosion risk have to be considered while managing it. After Acetone, R245fa can be considered as better option in solar reheated combined cycle plant with regeneration.*

Key Words: **Combined cycle plant, Organic Rankine cycle, Organic fluids, Solar reheating, Regeneration, Energy and exergy analysis**

1. INTRODUCTION

Several integrated solar combined cycles (ISCCs) are in operation all around the world (North Africa, Iran, Italy, USA) and many projects are underway (Mexico, China, USA). ISCCs offer many advantages compared to solar thermal power plants, primarily associated with the higher solar energy conversion efficiency and the lower investment costs. Investors and owners are attracted by the mitigated risk associated with the construction of smaller solar fields compared to solar thermal power plants. The process for converting the energy in a fuel into electric power involves the creation of mechanical work, which is then transformed into electric power by a generator. Depending on the fuel type and thermodynamic process, the overall efficiency of this conversion can be as low as 30 percent. This means that two-thirds of the latent energy of the fuel ends up wasted. For example, steam electric power plants which utilize boilers to combust a fossil fuel average 33 percent efficiency. Simple cycle gas turbine (GTs) plants average just under 30 percent efficiency on natural gas, and around 25 percent on fuel oil. Much of this wasted energy ends up as thermal energy in the hot exhaust gases from the combustion process. To increase the overall efficiency of electric power plants, multiple processes can be combined to recover and utilize the residual heat energy in hot exhaust gases. In combined cycle mode, power plants can achieve electrical efficiencies up to 60 percent. The most common type of combined cycle power plant utilizes gas turbines and is called a combined cycle gas turbine (CCGT) plant. Because gas turbines have low efficiency in simple cycle operation, the output produced by the steam turbine accounts for about half of the CCGT plant output. There are many different configurations for CCGT power plants, but typically each GT has its own associated HRB, and multiple HRBs supply vapour to one or more organic turbines. In ORC instead of using steam as working fluid we use other organic fluid in Rankine cycle. Utilization of solar energy has become crucial and it is expected to increase significantly in the near future. Therefore, there is a need to improve the performance of thermal power plants integrated with solar thermal energy. Parabolic trough solar collector technology is considered the most established solar thermal technology for power production. It has been used in large power plants since the 1980s in California and has demonstrated a promising renewable energy technology for the future.

2. LITERATURE REVIEW

Kelly et al. [1] finds 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.

Quoilin et al.[2] carried out thermodynamic modeling of a proposed small scale PTSC(Photovoltaic through solar collector) integrated with an ORC for power production, considering different design options to be located in a rural location in Berea District of Lesotho, South Africa.

Bamgbopa and Uzgoren [3] developed a transient model for a simple ORC in which the working fluid was R245fa and found that the heat exchanger was the critical part of the model. The performance of a low temperature solar thermal electric system using an ORC was carried out.

Derscha et al. [4] carried out a study that compared the performance of integrated solar combined cycle systems (ISCCs) with a solar electric generating system (SEGS) and found that ISCCs provided a better option than SEGS.

Nafey and Sharaf [5] conducted thermodynamic analysis for both power and water desalination using RO. They selected four refrigerants for the PTSC case: dodecane, nonane, octane, and toluene and found that toluene was the best option.

Sharaf et al. [6] conducted 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. It was found that the first option is more attractive.

Delgado-Torres and Garcia Rodriguez [7]&[8]conducted thermodynamic analysis of a thermal system consists of an ORC, a PTSC, and an RO. 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] the energetic performance 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 trigeneration 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 trigeneration is used as compared to only power generation.

Al-Sulaiman [11] conducted energy analysis of PTSC integrated with a steam Rankine cycle as a topping cycle and an ORC as a bottoming cycle. His study considered the energetic performance of his system and the effect of selected parameters on the size of the solar collector field.

Fahad A. Al-Sulaiman [12] carried out detailed exergy analysis of selected thermal power systems driven by parabolic trough solar collectors (PTSCs) is presented. 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%.

Dimityr Popov[13] 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 chillers The configuration with an absorption chillers has lower specific incremental plant capital costs and requires smaller land area than the others.

Dersch et al., 2004 [14] have studied how parabolic troughs could provide the latent-heat part of the input for a Rankine cycle, with a topping Brayton cycle providing the other part.

Wang et al 15] studied 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.

By incorporation of solar energy in combined cycle plant the output of plant can be increased. From literature survey of solar integrated combined cycle plant, it is found that detailed energy and exergy analysis of Gas-turbine power plant, 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 reheated organic Rankine cycle combined with Gas-turbine cycle are not done yet. Solar energy is used for reheating the organic vapour leaving the high pressure organic turbine and after reheating supplied to low pressure organic turbine.

In the present study thermodynamic analysis of Gas turbine-Organic Rankine combined cycle plant with solar reheating is investigated and comparison of organic fluids R134a, R245fa, R1234a and Acetone are carried out to find best organic fluid which will give maximum efficiency and output. The effect of regeneration and reheating are also evaluated on performance of combined cycle plant. It is proposed to examine the effect of following parameters on the efficiency of combined cycle and Organic Rankine cycle of solar reheated combined cycle plant and comparison of organic fluids to find better one.

- Effect of using regenerator and solar reheater in system on efficiency and exergy destruction.
- Effect of Organic turbine inlet temperature.
- Effect of Organic turbine inlet pressure.
- Effect of various organic fluids.

3. SYSTEM DESCIPTION

Gas turbine-Organic Rankine combined cycle plant shown in below figure. Air from atmospheric pressure and temperature is compressed adiabatically in air compressor from1 to 2 and consumes Wc. this compressed air is heated at constant pressure in external heat exchanger from 2 to 3 where the temperature of air is increased and Q_{s1} heat supplied. Here composition of air remains same no combustion product mixed with compressed air, this heated air is expanded in Gas turbine from 3 to 4 and work is obtained W_{GT}. Some work is used in driving the compressor.

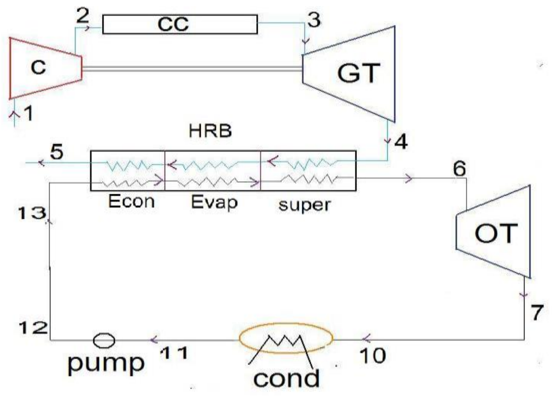


Fig 1: combined cycle plant without regeneration of ORC fluid

Exhaust gas from Gas turbine have considerably high temperature and energy. This energy is used in Organic Rankine cycle for boiling the organic fluid. This energy is utilised in HRB to heat Organic fluid to produce superheated vapour by absorbing Q_{s2} heat from 4 to 5. This superheated vapour is expanded in organic turbine from 6 to 7 and W_{OT} work is extracted. There is condenser at the exit of organic turbine where organic fluid is condensed from 10 to 11 to get saturated organic liquid. Than this liquid is pumped from condenser pressure to boiler pressure in pump from 11 to 12. There after organic fluid is heated in HRB by hot exhaust gas of Gas turbine plant and superheated vapour is produced from 13 to 6, and supplied to organic turbine.

In steam Rankine cycle steam at the exit of steam turbine is in wet region generally while in Rankine cycle organic fluid is used which is in superheated region at exit of organic turbine at state 10. This enthalpy of superheated vapour is utilized in heating the feed liquid in liquid vapour heat exchanger also called regenerator. In regenerator Organic liquid is heated from state 12 to state 13 and Organic vapour cools from state 7 (or 9) to state 10 at constant pressure. By using regenerator in combined cycle plant rate of organic fluid vapour production increases which results work output increased.

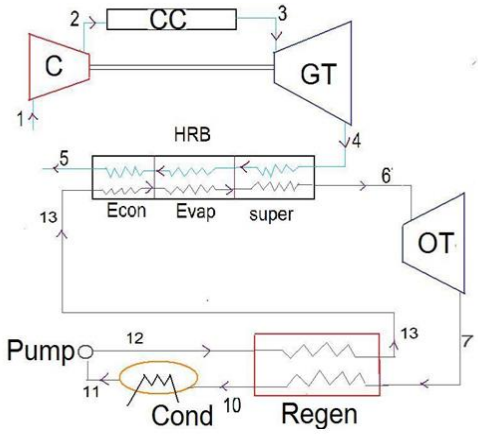


Fig 2: combined cycle plant with regeneration of ORC fluid

As we know that solar energy is most abundantly available, if this energy is utilized in combined cycle plant than output of the plant is increased. In this project dual pressure organic Rankine cycle is used. The superheated organic vapour from state 6 boiler pressure to state 7 intermediate pressure is expanded in OT_1 which produce work W_{OT1}. Solar energy is used to reheat organic vapour from state 7 to state 8 at constant pressure. Concentrated solar plate collector is used to capture solar energy. Than this reheated organic vapour is expanded in OT_2 from state 8 to state 9 which produce work $W_{OT2.}$ It is assumed that the total pressure drop in organic turbine is equally divided in both organic turbines. In each case the condenser temperature taken to be constant which is 40°C to ensure proper heat transfer.

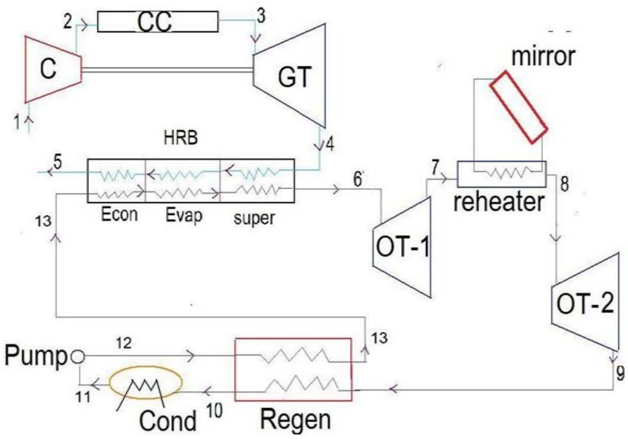


Fig 3: combined cycle plant with regeneration and solar reheating of ORC fluid

For thermodynamic analysis of combined cycle plant an existing 25MW Gas turbine power plant is selected. For this toping cycle an Organic Rankine cycle is combined with HRB and the effect of regeneration, solar reheating, and various organic fluids is evaluated. Efficiency of Organic Rankine cycle and combined cycle plant are analyses for different boiler pressure superheated cycles of with and without regeneration and solar reheating. The following organic fluid R134a, R1234yf, R245fa, Acetone is analyzed in this system.

4. THERMODYNAMIC ANALYSIS

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

1. All components are assumed to be a steady flow and steady-state process.
2. The changes in the kinetic energy and the potential energy of the components are negligible.
3. The pressure drops and heat loss in the piping connecting the components are negligible.
4. All turbines, compressor, and pump work adiabatically.
5. Pressure drops in HRB, regenerator, and condenser neglected.

Based on assumptions, the equations for energy and mass balance are written for each component. Each component in a solar reheated combined cycle plant is shown in Fig.6 considered as control volume.

Mass Balance

$$\Sigma_{in}\, m_{in} = \Sigma_{out}\, m_{out}$$

Energy Balance

$$\textbf{Q-W+}\ \Sigma_{in}\, m_{in} - \Sigma_{out}\, m_{out} = 0$$

Energy changes in each component of combined cycle plant with regeneration and solar reheating:-

Air Compressor: Compressor is a work absorbing device. Air compressor is used for compressing air from atmospheric condition to high pressure. Isentropic work input to the compressor is expressed as

$$W_c = \dot{m}_a * (h_{2s} - h_1)$$

We have compressor efficiency as

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1}$$

Actual compressor work is specified by

$$W_c = \dot{m}_a * (h_2 - h_1)$$

Combustion chamber: In combustion chamber fuel is burnt and heat released by combustion is supplied to compressed air in External heat exchanger at constant pressure. Heat supplied through combustion chamber is given by

$$Q_{s1} = \dot{m}_a * (h_3 - h_2)$$

Gas turbine: turbine is a work producing device. Air is expanded adiabatically in gas turbine. Isentropic work output of gas turbine is

$$W_{GTi} = \dot{m}_a * (h_3 - h_4)$$

We have gas turbine efficiency as,

$$\eta_{GT} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

Actual gas turbine work is

$$W_{GT} = \dot{m}_a * (h_3 - h_4)$$

Heat Recovery Boiler: In HRB energy of hot exhaust gas of gas turbine is utilised for producing superheated vapour of organic fluid. HRB is simply a heat exchanger in which heat transfer is taking place from hot exhaust gas to organic fluid. Energy balance for HRB is

$$\dot{m}_a h_4 + \dot{m}_f h_{13} = \dot{m}_a h_5 + \dot{m}_f h_6$$

Heat supplied to organic fluid,

$$Q_{HRB} = \dot{m}_f * (h_6 - h_{13})$$

Organic Rankine Turbine-1: turbine is a work producing device. Organic fluid is expanded from boiler pressure to intermediate pressure in organic turbin-1 adiabatically. The isentropic work output,

$$W_{OT1i} = \dot{m}_f * (h_6 - h_{7s})$$

We have organic turbine efficiency as,

$$\eta_{OT1} = \frac{h_6 - h_7}{h_6 - h_{7s}}$$

Actual organic turbine work is

$$W_{OT1} = \dot{m}_f * (h_6 - h_7)$$

Solar reheater: solar reheater is a concentrated solar plate collector in which solar energy is used for reheating the organic fluid. Heat supplied to solar collector is given by

$$Q_{S2} = A_s I_s \eta_m$$

Heat supplied to organic fluid

$$Q_{S2} = \dot{m}_f * (h_8 - h_7)$$

Organic Rankine Turbine-2: turbine is a work producing device. Organic fluid is expanded from boiler pressure to intermediate pressure in organic turbin-2 adiabatically. The isentropic work output,

$$W_{OT2i} = \dot{m}_f * (h_8 - h_{9s})$$

We have organic turbine efficiency as,

$$\eta_{OT1} = \frac{h_8 - h_9}{h_8 - h_{9s}}$$

Actual organic turbine work is

$$W_{OT2} = \dot{m}_f * (h_8 - h_9)$$

Regenerator: regenerator is a liquid-vapour heat exchanger in which feed organic liquid is heated by superheated vapour leaving from organic turbine.

$$\dot{m}_f h_9 + \dot{m}_f h_{12} = \dot{m}_f h_{10} + \dot{m}_f h_{13}$$

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

$$Q_{cond} = \dot{m}_f * (h_{10} - h_{11})$$

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

$$W_{OPi} = \dot{m}_f * v_{11} * (P_{12} - P_{11})$$

We have organic pump efficiency as,

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

Actual organic pump work is given by

$$W_{op} = \frac{\dot{m}_f * v_{11} * (P_{12} - P_{11})}{\eta_{OP}}$$

Efficiency of Gas Turbine cycle: efficiency of gas turbine plant is given by the ratio of net work output of gas turbine plant and heat supplied in combustion chamber,

$$\eta_{GTP} = \frac{W_{GT} - W_C}{Q_{S1}}$$

Efficiency of Organic Rankine cycle: it is the ratio of net work output of ORC and the total heat supplied in ORC

$$\eta_{ORC} = \frac{W_{OT1} + W_{OT2} - W_{OP}}{Q_{S2} + Q_{HRB}}$$

Efficiency of combined cycle plant: it is defined as the ratio of total work output of the combined cycle plant and total external heat supplied

$$\eta_{CCP} = \frac{(W_{GT} - W_C) + (W_{OT1} + W_{OT2} - W_{OP})}{Q_{S1} + Q_{S2}}$$

Exergy destruction-Exergy destruction is given by

$$ED = T_0 * \dot{m}_a * (\Delta s_{sys} + \Delta s_{surr})$$

Exergy analysis of each component of combined cycle plant with regeneration and solar reheating-

"Exergy destruction of compressor"

$$ED_C = \dot{m}_a * T_0 * (s_2 - s_1)$$

"Exergy destruction of gas turbine"

$$ED_{GT} = \dot{m}_a * T_0 * (s_4 - s_3)$$

"Exergy destruction in Heat Recovery Boiler"

$$ED_{HRB} = \dot{m}_a * T_0 * (s_5 - s_4) + \dot{m}_f * T_0 * (s_6 - s_{13})$$

"Exergy destruction in organic turbine-1"

$$ED_{OT1} = \dot{m}_f * T_0 * (s_7 - s_6)$$

"Exergy destruction in solar reheater"

$$ED_{reheater} = \dot{m}_f * T_0 * (s_8 - s_7) - Q_{S2} * (T_0 / T_s)$$

"Exergy destruction in organic turbine-2"

$$ED_{OT2} = \dot{m}_f * T_0 * (s_9 - s_8)$$

"Exergy Destruction in regenerator"

$$ED_{REG} = \dot{m}_f * T_0 * (s_{10} - s_9) + \dot{m}_f * T_0 * (s_{13} - s_{12})$$

"Exergy destruction in condenser"

$$ED_{cond} = \dot{m}_f * T_0 * (s_{10} - s_{11}) + \dot{m}_f * T_0 * (h_{10} - h_{11})$$

"Exergy destruction in organic Rankine cycle pump"

$$ED_{OP} = \dot{m}_f * T_0 * (s_{12} - s_{11})$$

"Exergy transfer in gas turbine cycle by combustion chamber"

$$ET_{CC} = Q_{S1} - \dot{m}_a * T_0 * (s_3 - s_2)$$

"Exergy transfer by HRB to organic fluid"

$$ET_{HRB} = Q_{HRB} - \dot{m}_f * T_0 * (s_6 - s_{13})$$

"Exergy transfer by solar heater to organic fluid"

$$ET_{reheater} = Q_{S2} - \dot{m}_f * T_0 * (s_8 - s_7)$$

"Second law efficiency of gas turbine power plant"

$$\eta_{II\ law\ GTP} = \frac{W_{GTP}}{ET_{CC}}$$

"Second law efficiency of organic Rankine cycle"

$$\eta_{II\ law\ ORC} = \frac{W_{ORC}}{ET_{HRB}}$$

"Second law efficiency of combined cycle plant"

$$\eta_{II\ law\ CCP} = \frac{W_{ORC} + W_{GTP}}{ET_{CC}}$$

5. RESULTS

A computational model is developed using Engineering Equation Solver (Klein and Alvarado, 2005) for evaluating Exergy and energy analysis of combine cycle plant with Regeneration and Solar reheating. The input data for evaluation are same as mentioned in chapter 3 except the parameter, whose effect is discussed in particular plot, has been varied.

5.1 Comparisons of without Regeneration, with Regeneration, and Regeneration with Solar reheat cycle:-

Figure 4 to 19 shows comparison of efficiency against the organic turbine inlet temperature and pressure. From the figures it is clear that the efficiency of organic Rankine cycle increases with regeneration while the efficiency of combined cycle plant remains almost constant. By using regeneration heat supplied to organic cycle plant decreases hence rate of evaporation increase which results output increases and hence organic Rankine cycle efficiency increases. With solar reheating organic Rankine cycle plant shows increase in efficiency while combined cycle plant shows decrease in efficiency because of decrease in mean temperature of heat addition in the system with superheating.

5.2 Comparison of various organic fluids:-

Figure 20 to 26 shows variation of efficiencies of the system at organic turbine inlet temperature, pressure, effectiveness of regenerator and solar collector mirror area. Among all organic fluid Acetone shows maximum efficiency of organic Rankine cycle which is about 25.96% and combined cycle has efficiency about 54.6%. R134a, R245fa, R1234yf and Acetone have maximum organic Rankine cycle efficiency of 13.31%, 21.44%, 13.65% and 25.96% respectively at 2500kPa maximum pressure and 200˚C maximum temperature of ORC fluid.

5.3 Exergy efficiency:-

Variation of Exergy efficiency of various organic fluids with maximum temperature, maximum pressure of organic cycle is shown in figure 27 to 32.It is seen that Exergy efficiency of organic Rankine cycle increase with maximum temperature and maximum pressure. It is seen that efficiency of combined cycle plants decreases with increase in organic Rankine cycle maximum temperature but increases with increase in maximum pressure.

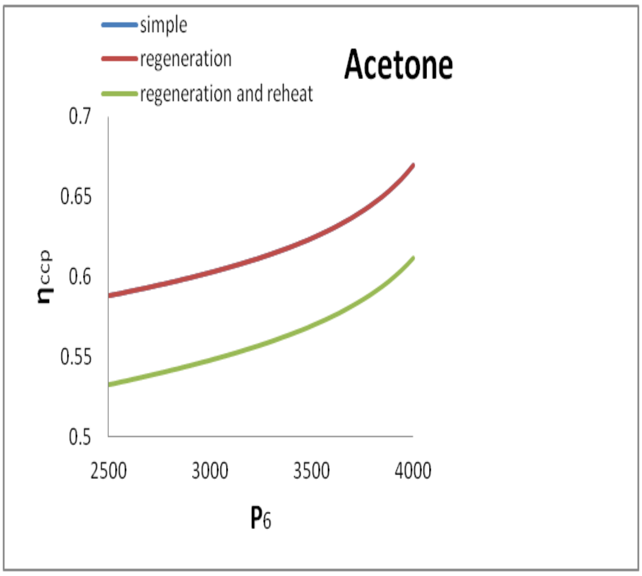


Fig 4: variation of efficiency of combined cycle plant with organic Rankine cycle maximum pressure of Acetone

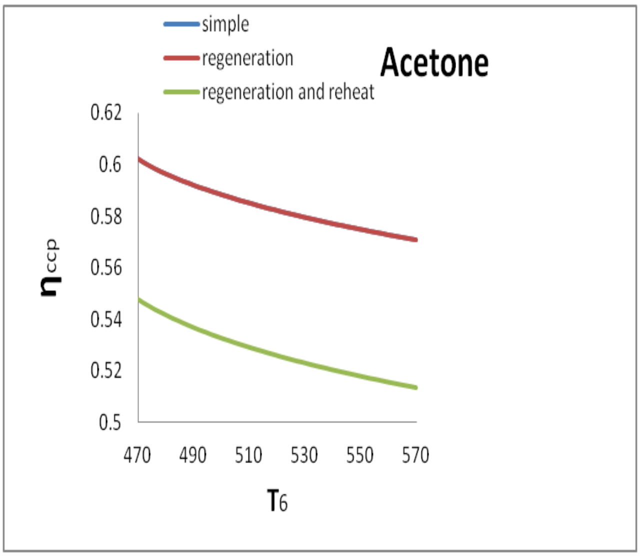


Fig 5: variation of efficiency of combined cycle plant with organic Rankine cycle maximum temperature of Acetone

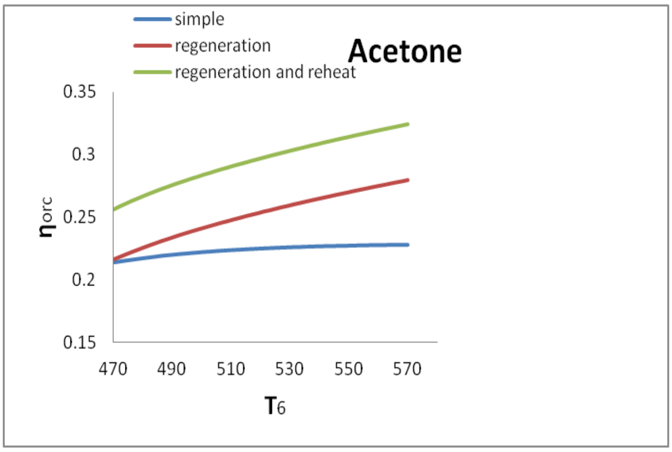


Fig 6 variation of efficiency organic Rankine cycle with organic Rankine cycle maximum temperature of Acetone

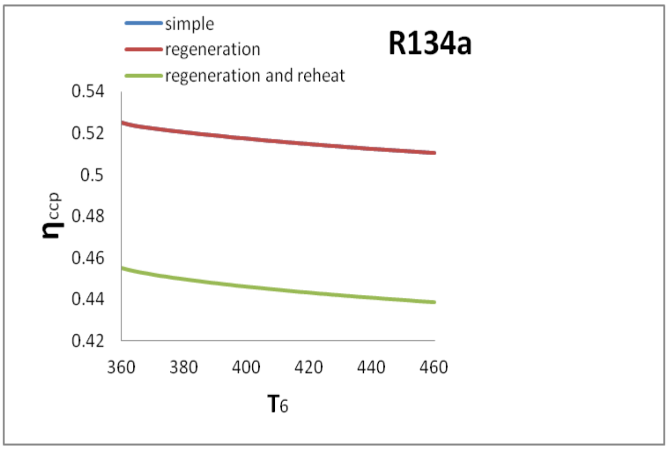


Fig 9: variation of efficiency of combined cycle plant with organic Rankine cycle maximum Temperature of R134a

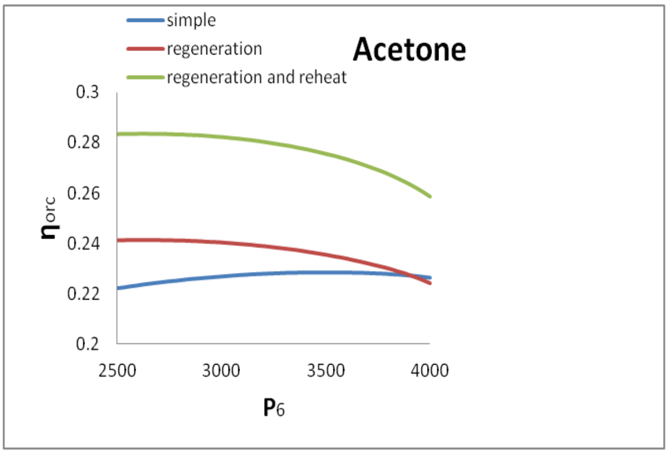


Fig 7: variation of efficiency organic Rankine cycle with organic Rankine cycle maximum pressure of Acetone

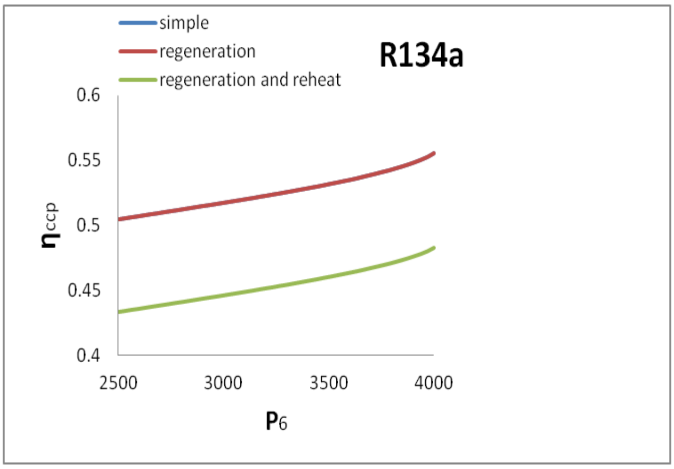


Fig 10: variation of efficiency of combined cycle plant with organic Rankine cycle maximum Pressure of R134

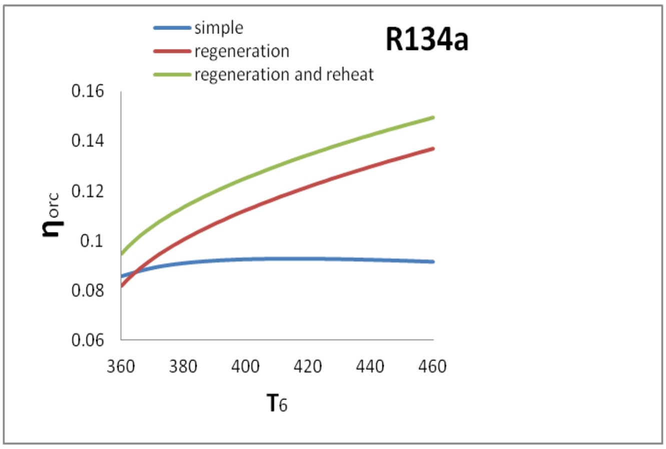


Fig 8: variation of efficiency of organic Rankine cycle plant with organic Rankine cycle maximum Temperatur of R134a

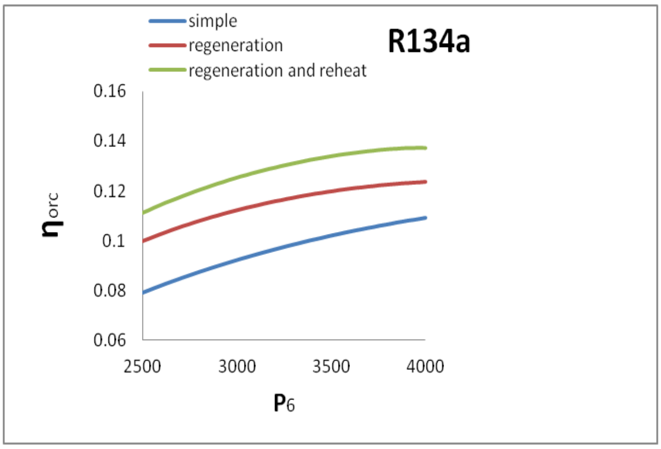


Fig 11: variation of efficiency of organik Rankine cycle with organic Rankine cycle maximum Pressure of R134a

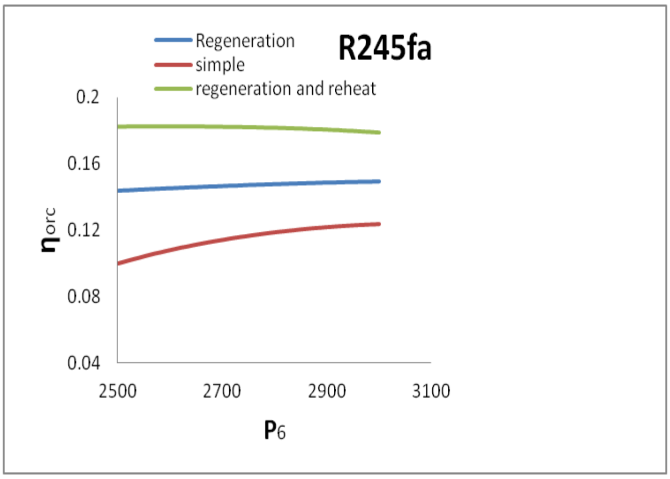


Fig12: variation of efficiency of organik Rankine cycle plant with organic Rankine cycle maximum Pressure of R245fa

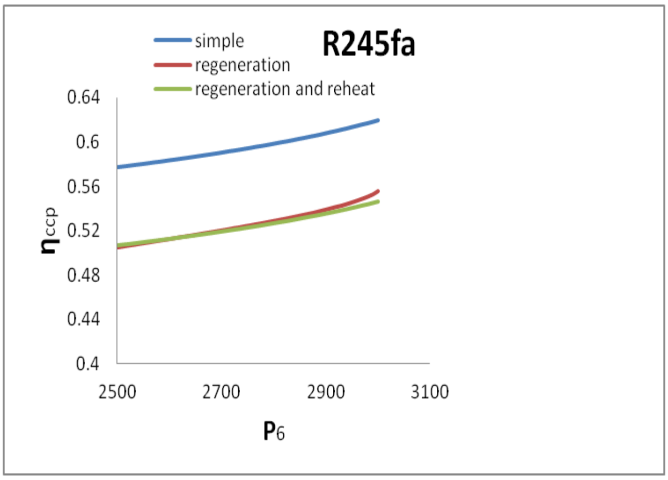


Fig 15: variation of efficiency of combined cycle plant with organic Rankine cycle maximum pressure of R245fa

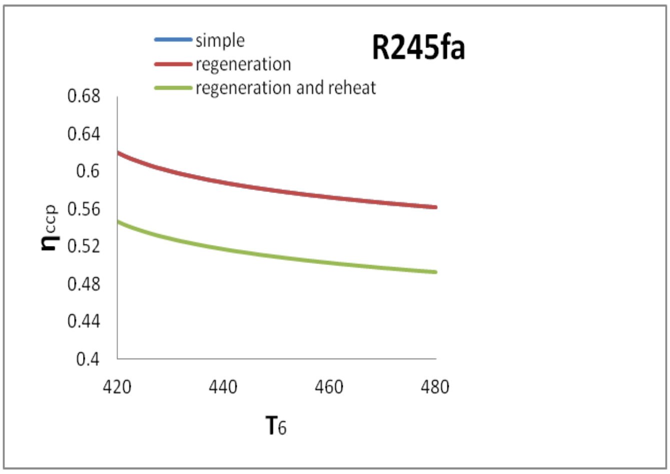


Fig 13: variation of efficiency of combined cycle plant with organic Rankine cycle maximum Temperature of R245fa

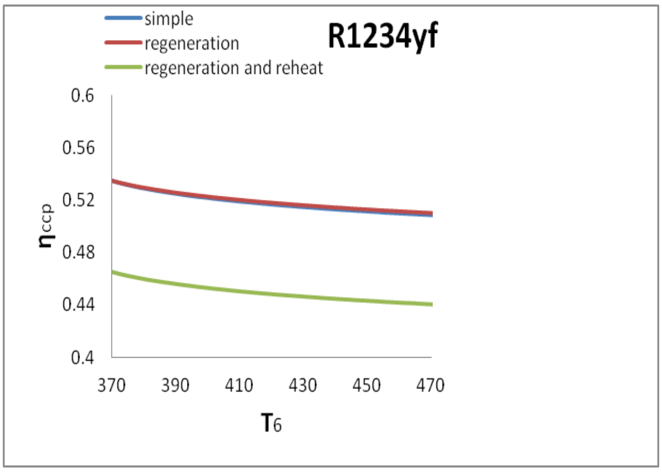


Fig 16: variation of efficiency of combined cycle plant with organic Rankine cyclemaximum Temperature of R1234yf

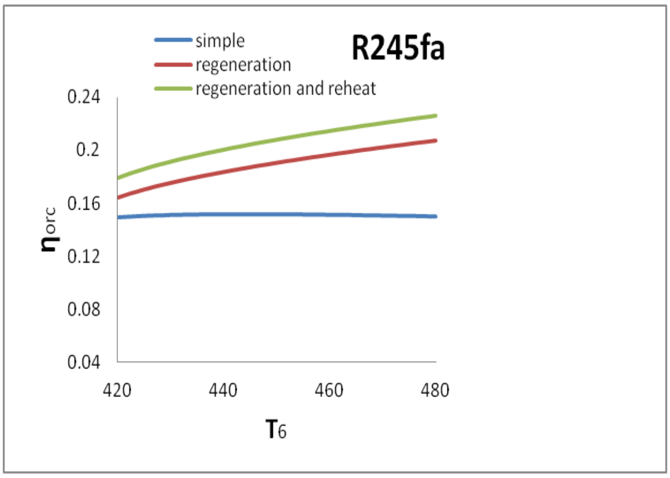


Fig 14: variation of efficiency of organik Rankine cycle plant with organic Rankine cycle maximum Temperature of R245fa

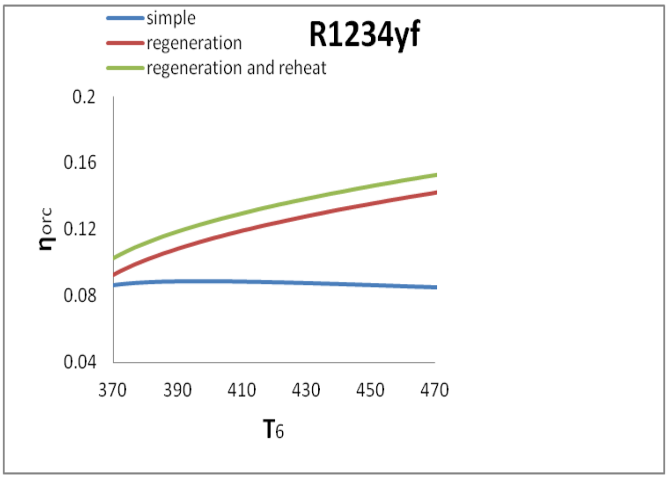


Fig 17: variation of efficiency of organic Rankine cycle with organic Rankine cycle maximum temperature of R1234yf

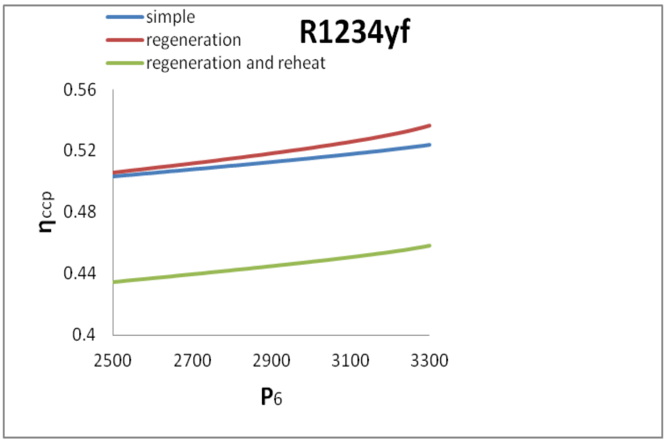


Fig 18: variation of efficiency of combined cycle plant with organic Rankine cycle maximum Pressure of R1234yf

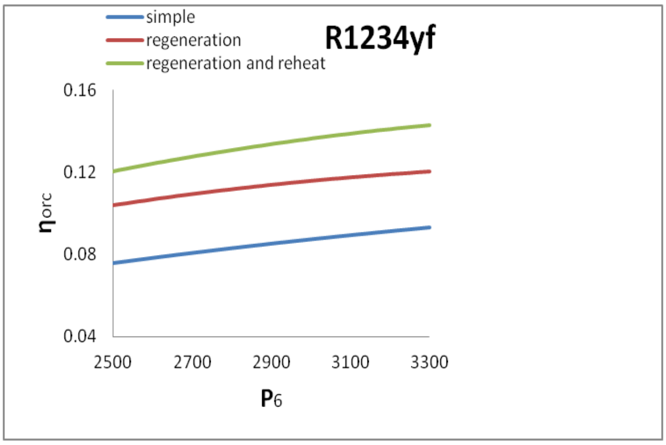


Fig 19: variation of efficiency of organik Rankine cycle plant with organic Rankine cycle maximum Pressure of R1234yf

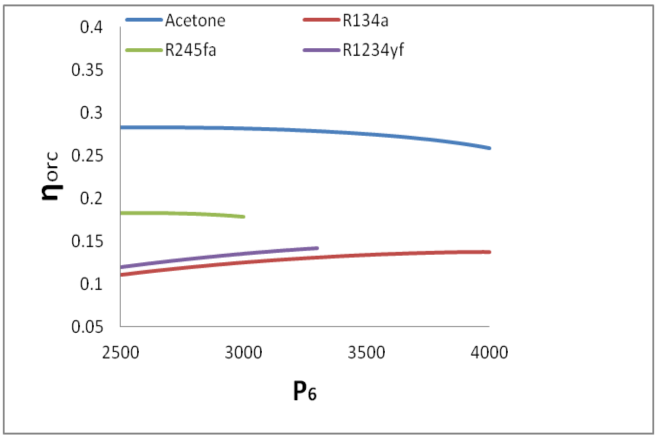


Fig 20: variation of efficiency of organik Rankine cycle plant with organic Rankinecycle maximum Pressure

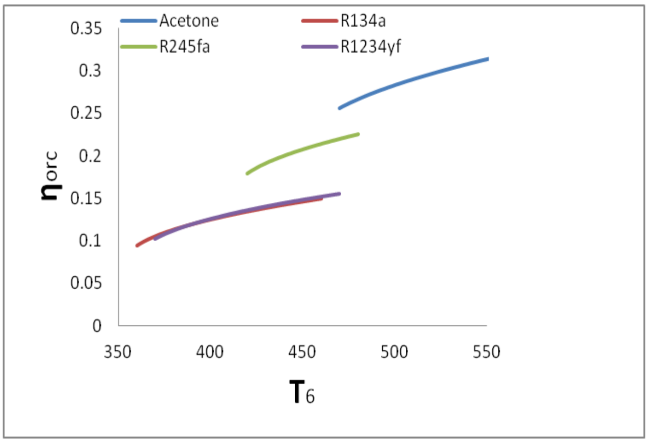
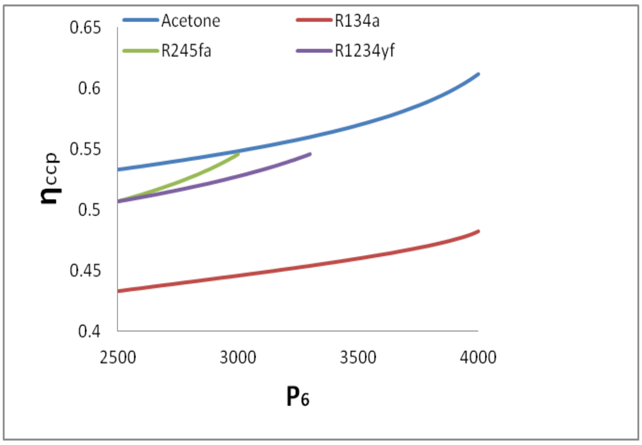


Fig 21: variation of efficiency of organic Rankine cycle with organic Rankine cycle maximum temperature

Fig 22: variation of efficiency of combined cycle plant with



organic Rankine cycle maximum pressure

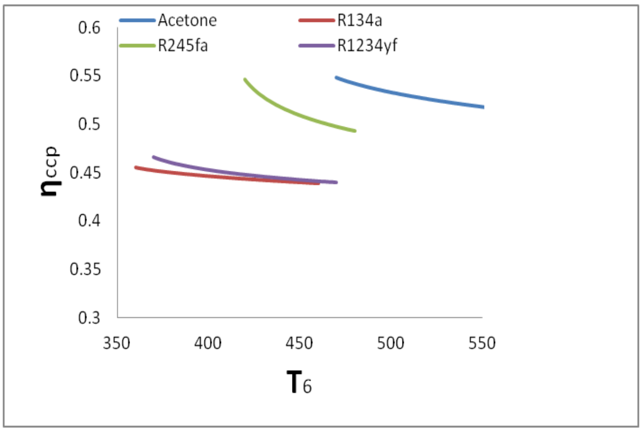


Fig 23: variation of efficiency of combined cycle plant with organic Rankine cycle maximum temperature

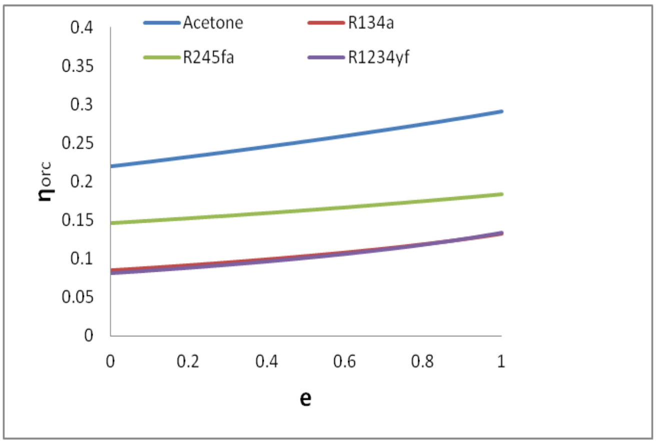


Fig 24: variation of efficiency of organik Rankine cycle plant with effectiveness of regenerator

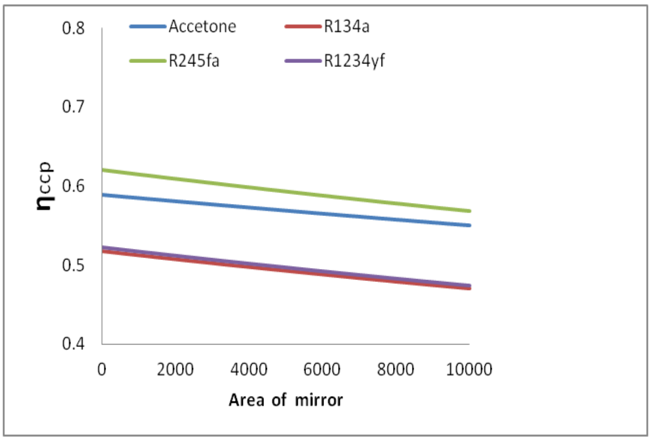


Fig 25: variation of efficiency of combined cycle plant with solar reheater mirror area

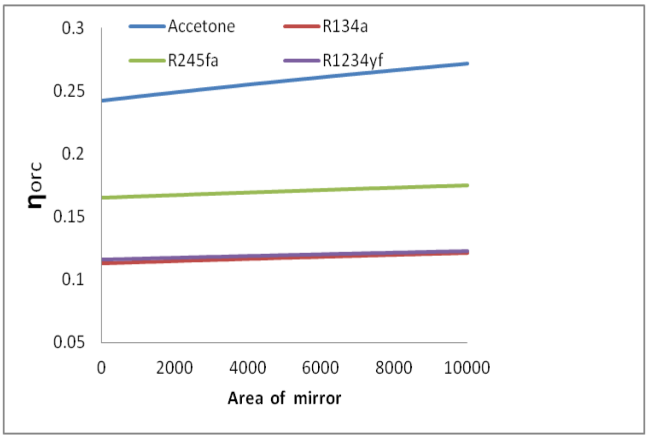


Fig 26: variation of efficiency of organic Rankine cycle plant with solar reheater mirror area

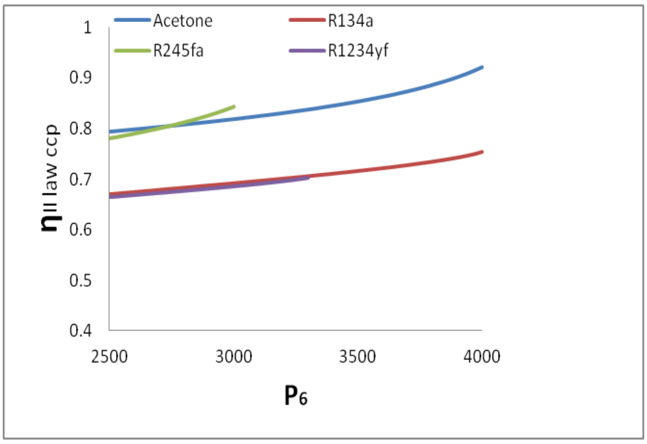


Fig 27: variation of second law efficiency of combined cycle plant with organic Rankine cycle maximum pressure

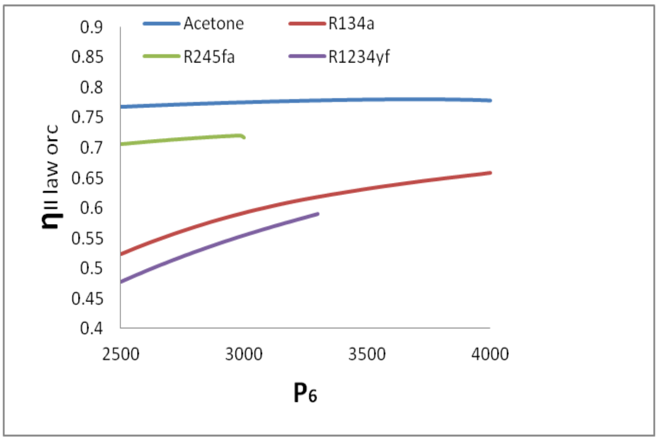


Fig 28 : variation of second law efficiency of Organic Rankine cycle with maximum pressure of organic Rankine cycle

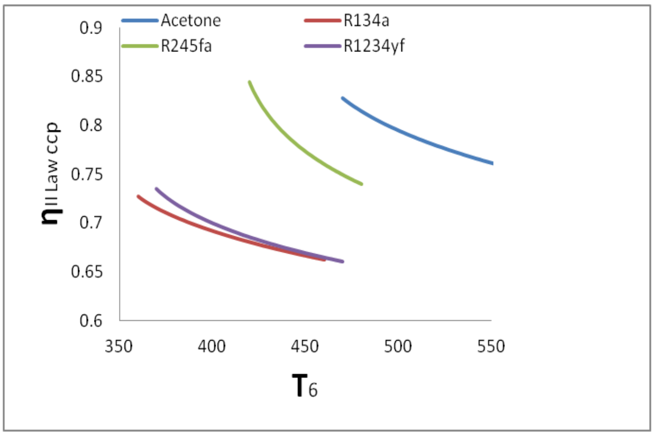


Fig 29: Variation of second law efficiency of combined cycle plant with organic Rankine cycle maximum temperature

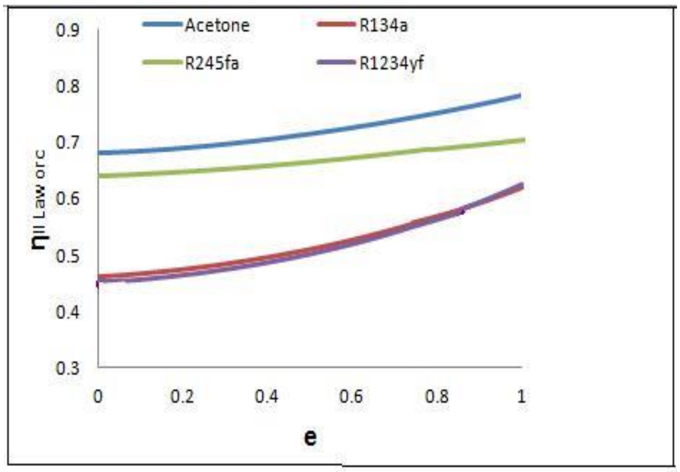


Fig 30: variation of second law efficiency of ORC with effectiveness of regenerator

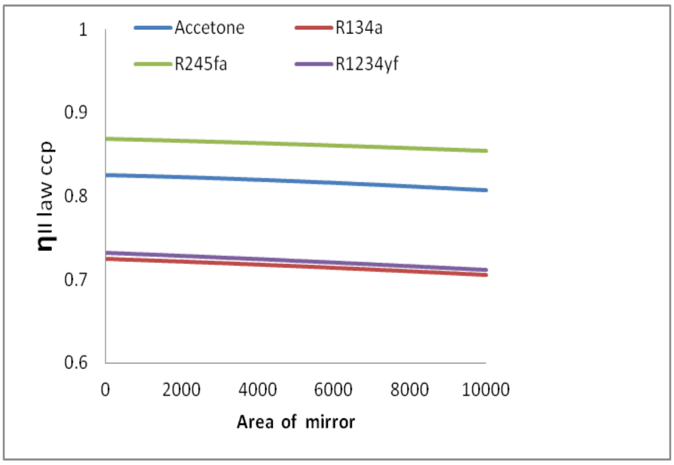


Fig 31: variation of second law efficiency of combined cycle plant with area of mirror

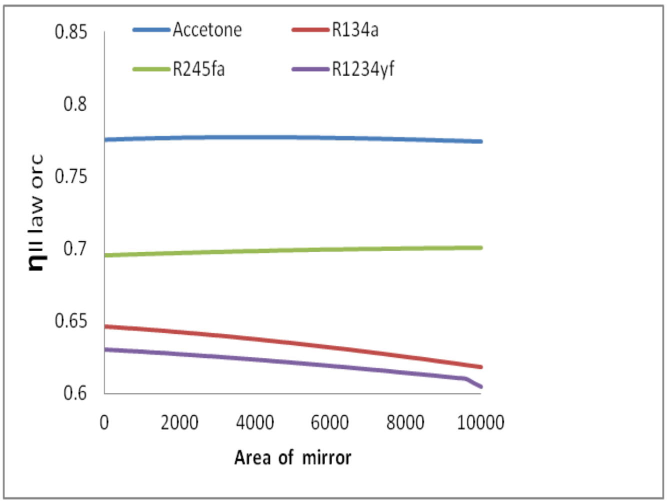


Fig 32: variation of second law efficiency of ORC with solar reheater mirror area

5.4 Efficiency of the plant at organic Rankine cycle maximum pressure 2500kPa and maximum temperature 200˚C

5.4.1 Efficiency of Combined cycle plant:

	R134a	R245fa	R1234yf	Acetone
Without Regeneration	49.97	55.02	49.18	60.03
With Regeneration	49.97	55.02	49.18	60.03
Regeneration and Solar Reheating	43.14	48.16	42.94	54.6

5.4.2Efficiency of Organic Rankine cycle:

	R134a	R245fa	R1234yf	Acetone
Without Regeneration	7.68	14.20	7.21	21.53
With Regeneration	12.30	19.63	12.79	21.90
Regeneration and Solar reheating	13.33	21.44	13.65	25.96

5.4.3 Second law efficiency:

	R134a	R245fa	R1234yf	Acetone
$\eta_{II\ law\ ccp}$	64.57	72.34	64.33	82.34
$\eta_{II\ law\ orc}$	38.65	66.05	38.32	77.27

6. CONCLUSIONS

In this paper, an extensive first law (energy) and second law (Exergy) analysis of R134a, R245fa, R1234yf, and Acetone Organic fluids in combined 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 with Regeneration is higher than without Regeneration for all selected organic fluids.

2. Acetone have higher first law efficiency and Exergetic efficiency (second law efficiency) in Organic Rankine cycle but R1234yf have higher first law efficiency and Exergetic efficiency (second law efficiency) improvement from basic system.

3. When reheating is done in Organic Rankine cycle than efficiency of Rankine cycle is improved but the efficiency of combined cycle is decreased.

4. Efficiency of combined cycle plant remains almost constant with Regeneration.

5. With increase in maximum pressure of Rankine cycle, efficiency of combined cycle shows increasing trend while with increase in maximum temperature of Rankine cycle, efficiency of combined cycle shows decreasing trend.

6. Acetone is recommended for practical applications due to its highest exergetic efficiency among selected organic fluid but some important problem related to flammability and explosion risk have to be considered while managing it.

7. R245fa has highest exergetic efficiency after Acetone, compared to remaining selected organic fluids and it is recommended for practical applications after Acetone.

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