REHEAT PERFORMANCE ANALYSIS OF ORGANIC RANKINE CYCLE USING R245fa AS WORKING FLUID FOR WASTE HEAT RECOVERY

[1]K. Venkateswara Rao, [2]K. Satyanarayana
[1]Assistant professor, [2]Research scholar
[1]Department of Mechanical Engineering,
[1]Godavari institute of engineering and technology(A), Rajahmundry, India

Abstract: Energy has played important role to create the world as we observe it today. Fossil fuels account for the most of the world's energy consumption, but they have been estimated to be finite sources because the rate of resource usage is much higher than the rate of discovery of new reservoirs. Due to rapid consumption of fossil fuel resources and their environmental impact, the world is being challenged to shift the energy dependence from fossil fuel. New energy conversion technologies are required to effectively utilize energy resources suitable for power generation without causing environmental pollution an organic Rankine cycle (ORC) used to recover waste heat to produce additional power. WHR using ORCs involves potential use, the utilization of the sensible enthalpy of the hot exhaust to heat an organic fluid, preferably to saturated or superheated vapour, and then the energy of the vapour is used to obtain additional useful power from a small turbine. Organic Rankine cycle (ORC) technology has been identified as one of the most promising technologies in recovering low-grade heat sources there is an essential demand for using sustainable and renewable energy systems for an energy production in the future. This paper mainly concentrates on the power production and increasing efficiency by recovering waste heat from steam power plant using Organic Rankine Cycle (ORC). This paper also had a discussion of using a reheating and preheating process in ORC to increase the output of cycle by using an Aspen HYSYS V9 package**.**

Key words: - Energy, Organic Rankine cycle, Waste heat recovery, Aspen HYSYS V9

1.INTRODUCTION

1.1. WASTEHEAT

Many processes, especially in industrial applications, production of large amounts of waste heat, i.e., heat beyond what can be efficiently used. Waste heat is heat generated in a process by way of fuel combustion or chemical reaction, which is usually thrown away into the environment and not used. Waste heat recovery (WHR) methods act to extract some of the energy that otherwise would be wasted. The mechanism to recover the not used heat depends on the temperature of the waste heat gases and the economics involved. Typical methods of recovering heat in industrial applications include direct heat recovery to the process itself, recuperates, regenerators, and waste heat boilers. If some of the waste heat could be recovered, then a considerable amount of primary fuel could be saved. An important issue to consider is that in many applications, especially those with low-temperature waste heat streams.

1.2. CLASSIFICATION OF WASTE HEAT

Waste heat can be classified as high, medium, and low-temperature

i. Waste heat at temperatures between 923 and 1,873 K is considered high-temperature waste heat and results from devices, such as solid waste incinerators and zinc, aluminium, and copper refining furnaces, among others

ii. Waste heat, which ranges from 503 and 923 K is considered medium-temperature waste heat. Some examples of medium-temperature waste heat sources are steam boiler exhaust (503–753 K), gas turbine exhaust (642–813 K), and reciprocating engine exhaust (588–873 K), among others

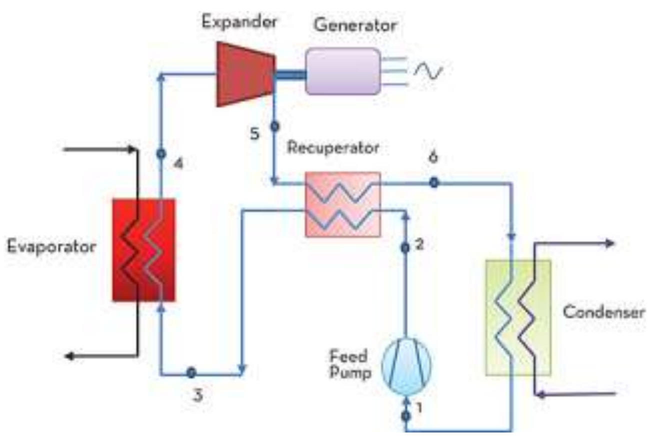
iii. Waste heat at temperatures between 328 and 503 K is considered low-temperature waste heat. Examples of low temperature waste heat include process steam condensate, cooling water from furnaces, etc

1.3. WASTE HEAT RECOVERY BY ORC

About 50 % of the fuel we use to produce power in conventional power plants is wasted due to the limitations of the power conversion processes. Waste heat recovery is an economic method to increase the overall efficiency of the plant and, thus, to lower fuel demand. Exhaust gas of various processes is carrying a huge amount of energy also referred to as waste heat. Often industrial processes produce enough waste heat to generate electricity. Waste Heat Recovery Units (WHRUs) or heat to power units could recover the waste heat and transform it into electricity by using, for example, an Organic Rankine Cycle (ORC). Often, waste heat is of low temperature quality. It can be difficult to efficiently utilize the heat contained. In these cases, the ORC-Technology can bring an additional benefit to raise the overall plant efficiency. The ORC-Unit utilizes this otherwise wasted energy and converts it into power

The temperatures of the waste heat from most industrial processes and power plants are less than 370 °C (643 K). If this kind of waste heat is let into the environment directly, it would not only waste heat but also make heat pollution to the environment. Using conventional methods to recover energy from this kind of exhaust is economically infeasible. The organic Rankine cycle (ORC) system exhibits great flexibility, high safety and low maintenance requirements in recovering this grade of waste heat. Integrating the ORC to the energy system, such as power plants, could achieve using low grade energy (waste heat) to generate high grade energy (power), easing the power burden and enhancing system efficiency. Since the ORC consumes virtually no additional fuel, for the same added power, the emission of environmental pollutants such as carbon dioxide (CO_2), sulphur dioxide (SO_2) and so on would be decreased. According to the local demand, the exhaust heat exiting from the ORC could be further utilized to drive chillers such as absorption chillers to supply cooling capacity.

1.4. PERFORMANCE OF ORC:



An ORC system using low-grade energy sources in the system is composed of an evaporator (waste heat boiler), a turbine expander, a condenser, and a pump. A working fluid flows into the evaporator in which the high-temperature heat source (which is in the form of steam) is utilized. The vapour of the boiling fluid enters the turbine expander and generates power.

The exit fluid from the turbine expander then enters the condenser in which the low-temperature cooling water (i.e., the cold water) is utilized to condense the fluid. Finally, a fluid pump raises fluid pressure and feeds the fluid into the evaporator to complete the cycle. So long as a temperature difference between the high and low-temperature ends is large enough, the cycle will continue to operate and generate power. The objective of this study is focused on thermodynamic analyses of the working fluid and the overall system efficiency rather than hard ware arrangements such as the system integration of thermal energy. Therefore, issues regarding material selections, component configurations, frictional losses, heat transfer performances of the evaporator and condenser, and cost analysis are not considered in this study.

2.LITERATURE SURVEY

Usman muhammad, et al., [1], presents an experimental investigation of a small scale (1 kW range) organic Rankine cycle system for net electrical power output ability, using low-grade waste heat from steam. The system was designed for waste steam in the range of 1–3 bar. After the organic Rankine cycle system was designed and thermodynamic simulation was performed, equipment selection and construction of test rig was carried out. R245fa was used as working fluid; a scroll type expansion directly coupled with electrical generator produced a maximum electrical power output of 1.016 kW with 0.838 kW of net electrical power output. The thermal efficiency of the system was 5.64%, Maximum thermal efficiency was 6.9% and maximum expander isentropic efficiency obtained was 77.74% during the experiment. Both expander and screw pump were losing power in electric and mechanical losses (generator/motor) presenting a need of further development of these components for better efficiency. Heat loss in piping is also a factor for improving efficiency along with the ability of heat exchangers and control system to maintain the least possible degree of superheat of working fluid at expander inlet.

Junjiang bao,et al.,[2] :This journal presents How to effectively utilize low and medium temperature energy is one of the solutions to alleviate the energy shortage and environmental pollution problems. In the past twenty years, because of its feasibility and reliability, organic Rankine cycle has received widespread attentions and researches. In this paper, it reviews the selections of working fluids and expanders for organic Rankine cycle, including an analysis of the influence of working fluids' category and their thermodynamic and physical properties on the organic Rankine cycle's performance, a summary of pure and mixed working fluids screening researches for organic Rankine cycle, a comparison of pure and mixture working fluids applications and a discussion of all types of expansion machines' operating characteristics, which would be beneficial to select the optimal working fluid and suitable expansion machine for an effective organic Rankine cycle system.

Donghong wei, et al., [3]: This paper refers the performance analysis and optimization of an organic Rankine cycle (ORC) system using HFC-245fa (1,1,1,3,3-penta- fluoropropane) as working fluid driven by exhaust heat is presented. The thermodynamic performances of an ORC system under disturbances have been analyzed. The results show: maximizing the usage of exhaust heat as much as possible is a good way to improve system output net power and efficiency; the degree of sub-cooling at the condenser outlet should be small (0.5–0.6 K); when the ambient temperature is too high, the system output net power and efficiency will deteriorate with the departure from nominal state possibly exceeding 30%. According to the running environment, choosing a proper nominal state is a good idea for improving the system output net power and efficiency.

P. J. Mago,et al.,[4]: This article presents an exergetic analysis for an organic Rankine cycle that converts waste energy to power from medium-grade heat sources (503 to 923 K). In addition, the effect of the waste heat temperature, the evapourator pressure, and the pinch point temperature difference on the thermal and exergetic performance of the system is studied. Several organic working fluids were selected to investigate the effect of the fluid's critical temperature on the performance of organic Rankine cycles. The working fluids under investigation are R245fa, R123, R142b, Isobutane, R113, and R141b with critical temperatures in the range of 407.7 to 524.9 K.

Takahisa Yamamoto, et al., [5]: This system combines a circulated thermosyphon with a turbine system. The working fluid used in this study is an organic substance which has a low boiling point and a low latent heat for using low-grade heat sources. A numerical simulation model of the ORC is made in order to estimate its optimum operating conditions. An experimental apparatus is also made in this study. From the numerical simulation, it is suggested that HCFC-123 gives higher turbine power than water which is a conventional working fluid, and operating conditions where saturated vapour at the turbine inlet would give the best performance. From the experimental results, HCFC-123 improves the cycle performance drastically. In addition, the turbine made for trial use in this study gives good performance.

T.C. Hung,et al.,[6] ; T.C.Hung discussed regard Rankine cycles using organic fluids (as categorized into three groups: wet, dry, and isentropic fluids) as working fluids in converting low-grade energy are investigated in this study. The main purpose is to identify suitable working fluids which may yield high system efficiencies in an organic Rankine cycle (ORC) system. Efficiencies of ORC systems are calculated based on an assumption that the inlet condition of the working fluid entering turbine is in saturated vapour phase. Parameters under investigation are turbine inlet temperature, turbine inlet pressure, condenser exit temperature, turbine exit quality, overall irreversibility, and system efficiency. The low-grade energy source can be obtained from a solar pond or/ and an ocean thermal energy conversion (OTEC) system. Results indicate that wet fluids with very steep saturated vapour curves in T-s diagram have a better overall performance in energy conversion efficiencies than that of dry fluids. It can also be shown that all the working fluids have a similar behaviour of the efficiency-condenser exit temperature relationship. Furthermore, an appropriate combination of solar energy and an ORC system with a higher turbine inlet temperature and a lower condenser temperature (as operated deeply under sea level) would provide an economically feasible and environment-friendly renewable energy conversion system.

F.J. Fernández, et al., [7]: this journal presents the siloxanes used as working fluids in high-temperature organic Rankine cycles, is applied in a mathematical model to solve cycles under several working conditions. The proposed scheme includes a thermo-oil intermediate heat circuit between the heat source and the organic Rankine cycle. Linear and cyclic siloxanes are assayed in saturated, superheated and supercritical cycles. The cycle includes an internal heat exchanger (regenerative cycle), although a non-regenerative scheme is also solved. In the first part of the study, a current of combustion gases cooled to close to their dew point temperature is taken as the reference heat source. In the second part, the outlet temperature of the heat source is varied over a wide range, determining appropriate fluids and schemes for each thermal level. Simple linear (MM, MDM) siloxanes in saturated regenerative schemes show good efficiencies and ensure thermal stability of the working fluid.

Teemu Turunen-Saaresti,et al.,[8] : In this paper, a design procedure of the ORC process is described and discussed. The analysis of the major components of the process, namely the evaporator, recuperator, and turbo generator is done. Also preliminary experimental results of an ORC process utilizing high temperature exhaust gas heat and using siloxane as a working fluid are presented and discussed. The turbine type utilized in the turbogenerator is a radial inflow turbine and the turbogenerator consists of the turbine, the electric motor and the feed pump. Based on the results, it was identified that the studied system is capable to generate electricity from the waste heat of exhaust gases and it is shown that high molecular weight and high critical temperature fluids as the working fluids can be utilized in high-temperature small-scale ORC applications. 5.1 kW of electric power was generated by the turbo generator.

Bertrand F,et al.,[9]:This paper Provided the interest to recover waste heat rejected by thermal devices and industrial processes continue to grow, and favourable legislative conditions are adopted, waste heat recovery organic Rankine cycle systems in the near future will experience a rapid growth. Solar modular power plants are being intensely investigated at smaller scale for cogeneration applications in buildings but larger plants are also expected in tropical or Sahel regions with constant and low solar radiation intensity. OTEC power plants operating mainly on offshore installations at very low temperature have been advertised as total resource systems and interest on this technology is growing in large isolated islands.

Ho-Myung Chang,et al.,[10]: A thermodynamic study is carried out to investigate the effect of multi-stream heat exchanger on the performance of natural gas (NG) liquefaction with mixed refrigerant (MR). A cold stream (low-pressure MR) is in thermal contact with opposite flow of two hot streams (high-pressure MR and NG feed) at the same time. In typical process simulation with commercial software (such as Aspen HYSYS®), the liquefaction performance is estimated with a method of minimum temperature approach, simply assuming that two hot streams have the same temperature.

Ulli Drescher,et al.,[11]; In small solid biomass power and heat plants, the ORC is used for cogeneration. This application shows constraints different from another ORC. These constraints are described and an adapted power plant design is presented. The new design influences the selection criteria of working fluids. Software has been developed to find thermodynamic suitable fluids for ORC in biomass power and heat plants. Highest efficiencies are found within the family of alkylbenzenes

L. WEI,et al.,[12]: low-grade energy conversion systems based on Organic Rankine Cycles, and several optimization methods have been proposed. In this study, correlative literatures are reviewed and the efficiency improving strategies are elucidated. Guidelines for the promotion of this low-temperature heat conversion system are also presented.

3.SELECTION OF WORKING FLUID:

R245fa (1,1,1,3,3 pentafluoro propane), which having zero Ozone Depletion Potential (ODP) and less Global Warming Potential (GWP), has been proposed as a substitute in waste heat recovery. R245fa is not a volatile organic compound (VOC), and it has low toxicity and is non-flammable. Many efforts had been devoted to the study on R245fa. using R245fa as working fluid for low grade waste heat recovery from steam, it is demonstrated from the results that the thermal efficiency of R245fa was better. R245fa was found to the best distribution, owing to the low steam density and high liquid density. R245fa had a good boiling heat transfer performance with an outstanding efficiency. R245fa had a significant lower volume flow ratio, especially at higher temperature and lower rotational speed of the turbine. R245fa has a great heat transfer performance in flow heat transfer, while the heat transfer performance when considering the gravity, shear force and viscosity in general tubes cycle.

4.DESIGN AND SIMULATION OF ASPEN HYSYS:

Aspen Hysys is a mechanical and Chemical process simulator Used to mathematically model mechanical chemical Processes from unit operations to full chemical plants, thermal plants and refineries. HYSYS can perform many of the core calculations of thermal engineering, including those concerned with mass balance, vapor-liquid equilibrium, energy balance, heat and mass transfer, chemical kinetics, fractionation, and pressure drop. HYSYS is used extensively used in industry for steady state and dynamic simulation, process design, performance modelling, and optimization.

Fig:4.1- selecting a component list type

Fig:4.2 - select a database for the fluid package

5.DESIGN AND SIMULATION OF REHEAT ORGANIC RANKINE CYCLE

First of all, Open the Aspen HYSYS V9 workbench and Select the fluid package then select the Aspen Properties. After that Select the basis 1, select property package and select Peng-Robinson. Add component list1 [Aspen Properties database], select component in R245fa(1,1,1,3,3-pentaflurópropane), Open the Simulation work bench. Now Open model palette containing all the components, Add the components from palette to flow sheet and Add heaters, turbines, condenser, pump to work bench and Rename the components. Give the connections of material streams, then Give the connections of energy streams. Give the input data for material stream at pump inlet, Give the output data for material stream at pump outlet 1and worksheet of pump is generated 1. Give output data for heater 1then Worksheet of heater 1 is generated. Give output data for turbine 1, So Worksheet of turbine 1 is generated, Next give input data for turbine 2, Then Worksheet of heater 2 is generated. Give output data for turbine 2, Worksheet of turbine 2 is generated.

Fig:5.1-Adding components in flow sheet

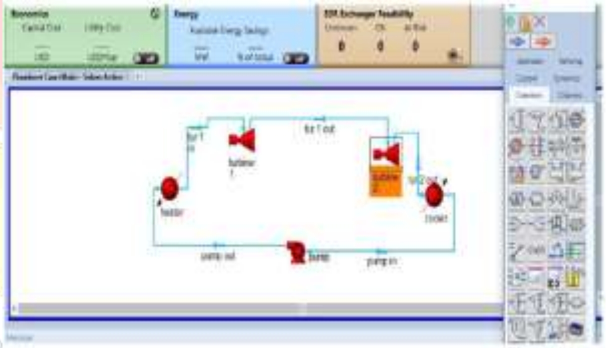


Fig:5.2-Giving material connection

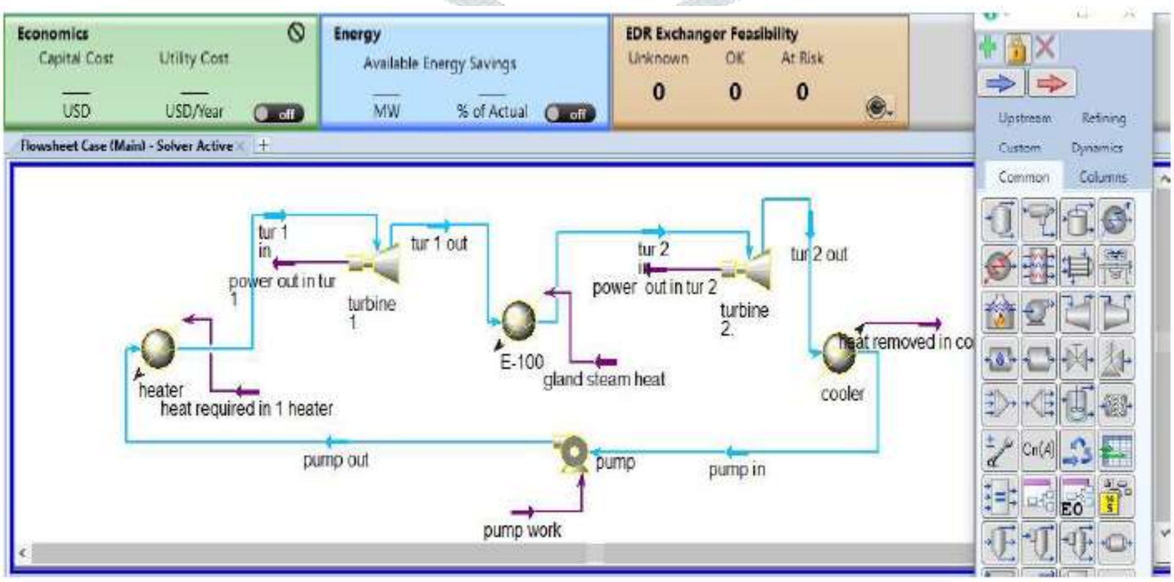


Fig:5.3- Energy connections

By using workbook table tool results are found:

Energy Streams							
		power req	heat supplied	work out 1	gland heat	work out 2	cond energy out
Heat Flow	kJ/h	217.3	4.831e+004	3150	3965	2227	4.711e+004

Material Streams							
		1st tur in	1st tur out	2nd tur in	cond in	pump out	pump in
Vapour Fraction		1.0000	1.0000	1.0000	1.0000	0.0000	0.0000
Temperature	C	110.0	82.00	102.0	88.00	30.65	30.00
Pressure	kPa	1290	422.6	412.6	203.0	1300	188.0
Molar Flow	kgmole/h	1.450	1.450	1.450	1.450	1.450	1.450
Mass Flow	kg/h	194.4	194.4	194.4	194.4	194.4	194.4
Liquid Volume Flow	m3/h	0.1425	0.1425	0.1425	0.1425	0.1425	0.1425
Heat Flow	kJ/h	-1.690e+006	-1.693e+006	-1.690e+006	-1.692e+006	-1.739e+006	-1.739e+006

Fig:5.4- workbook table of reheat orc

Overall view of the reheat is as follow:

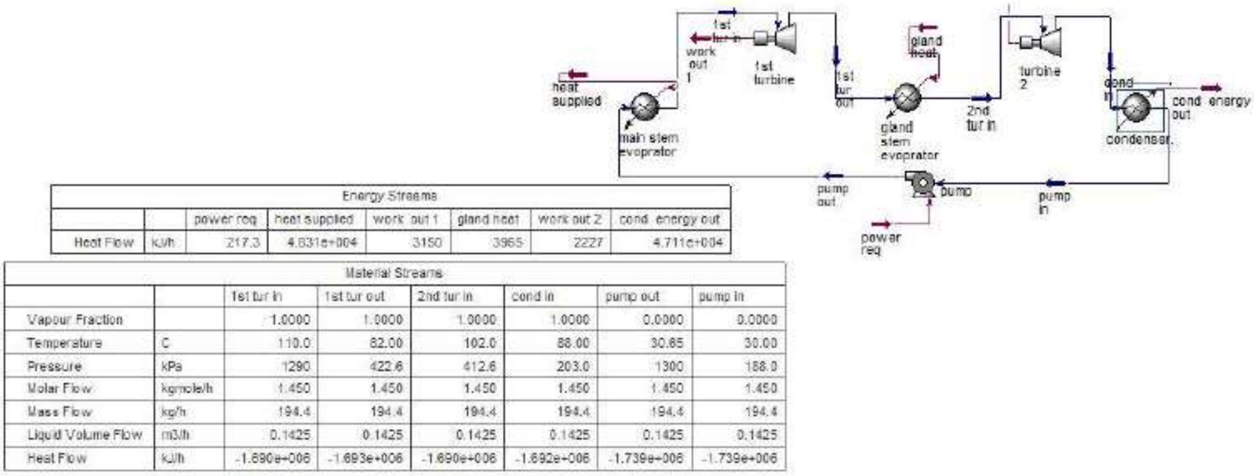
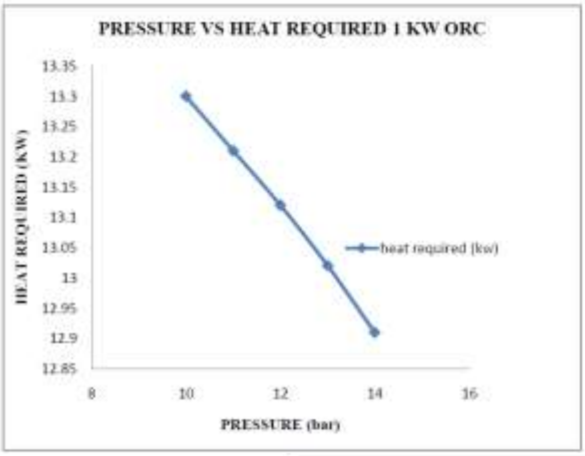
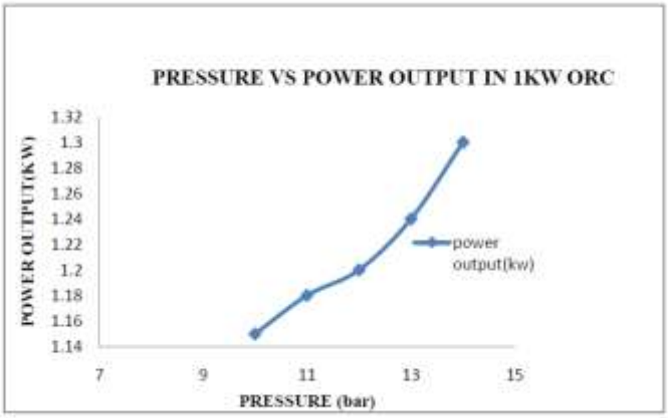


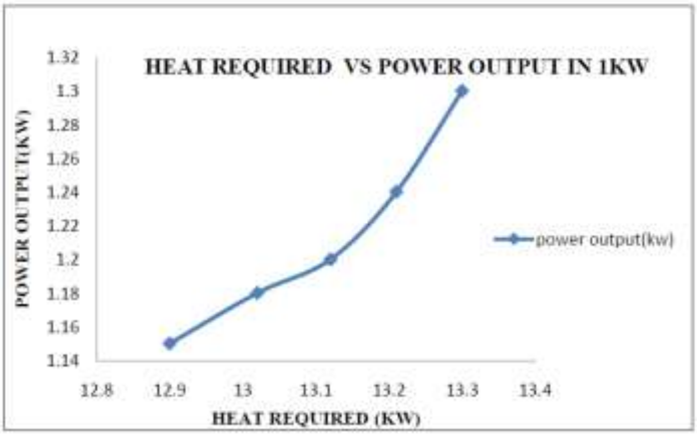
Fig:5.5-Overall view of reheat orc with output

6.RESULTS AND DISCUSSIONS

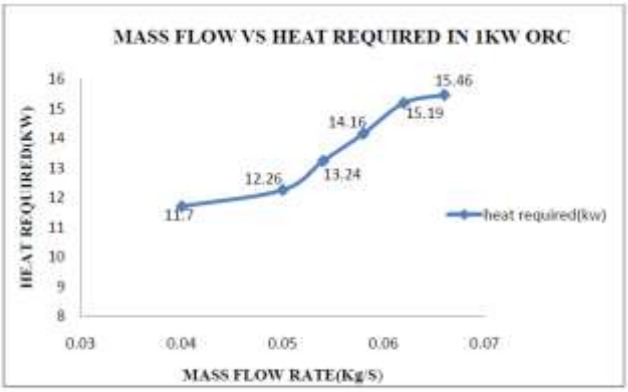
During the analysis of a simple organic rankine cycle with refrigerant R245fa in Aspen HYSYS if the pressure increases the amount of heat required in heater is decreasing. During the analysis of a simple organic rankine cycle with refrigerant R245fa in Aspen HYSYS as the pressure increases the power out is also increases. During the analysis of a simple organic rankine cycle with refrigerant R245fa in Aspen HYSYS as the heat input increases the power output also increases.

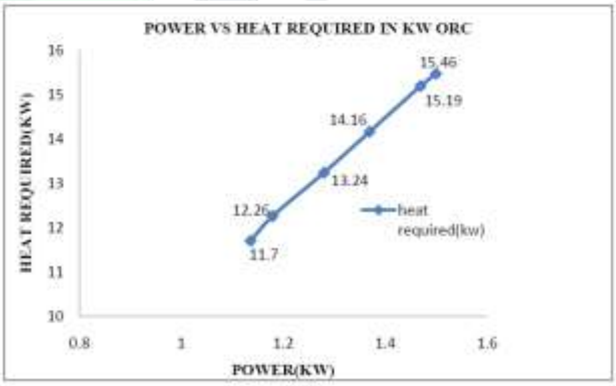


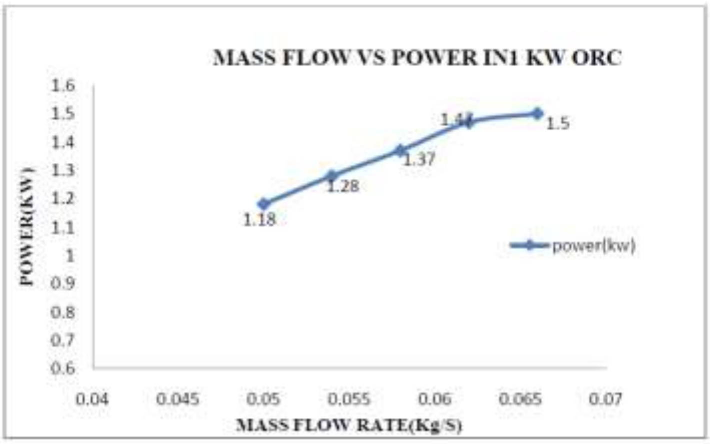




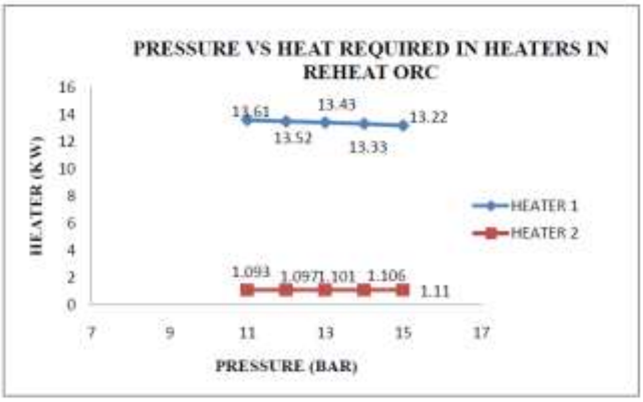
During the analysis of a simple organic rankine cycle with refrigerant R245fa in Aspen HYSYS as the mass flow of refrigerant increases the heat required also increases, During the analysis of a simple organic rankine cycle with refrigerant R245fa in Aspen HYSYS more heat is required to produce maximum power output through turbine. During the analysis of a simple organic rankine cycle with refrigerant R245fa in Aspen HYSYS as the mass flow of refrigerant increases the power output also increases.

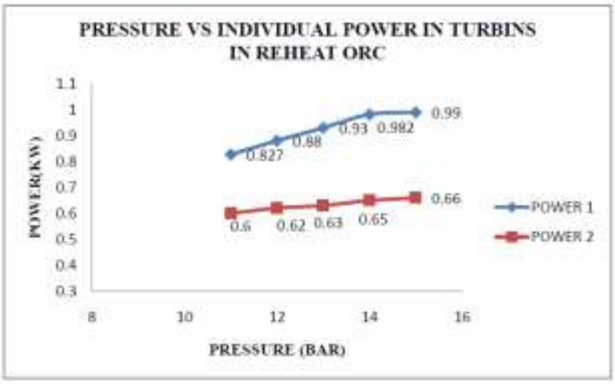


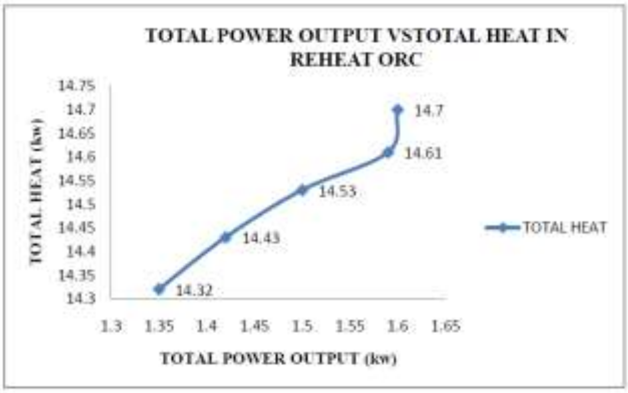


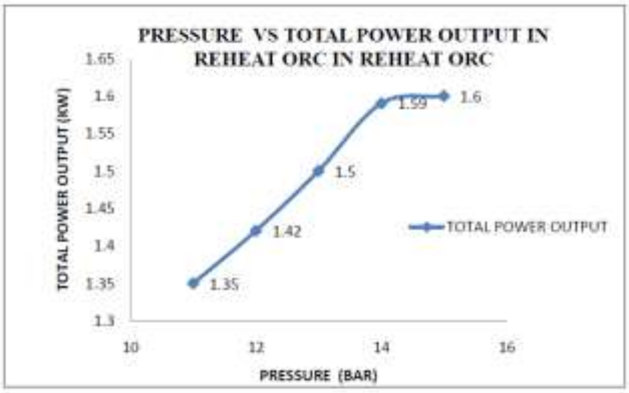


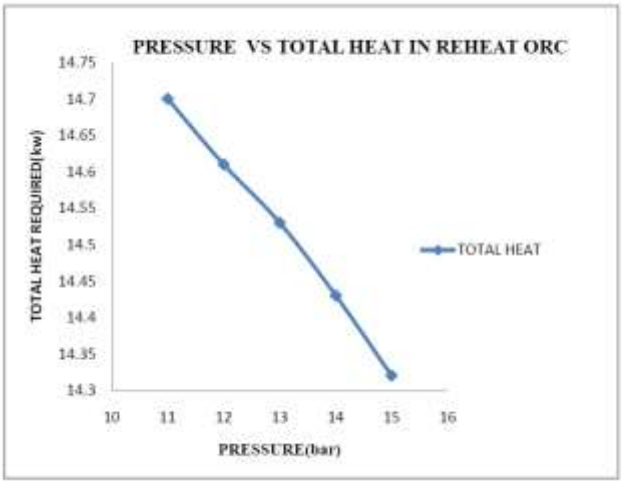
During reheat ORC as the pressure increases the heat required is high. During reheat ORC as the pressure increases the power output also increases. During reheat ORC as the pressure increases the heat required is high and the power output is also increasing. During reheat ORC as the pressure increases the total power output from unit is increases. During reheat ORC as the pressure increases the total heat required for the unit is decreases due to which the efficiency is increases



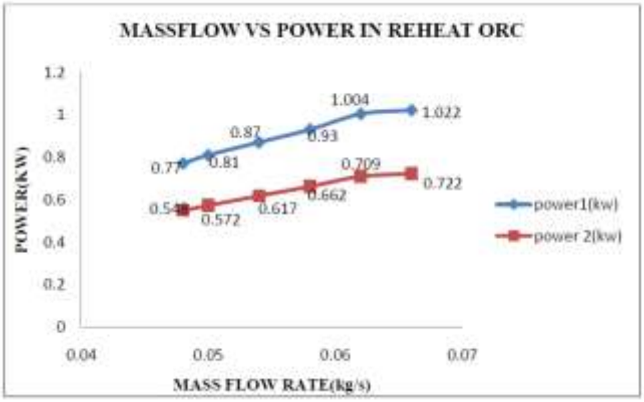


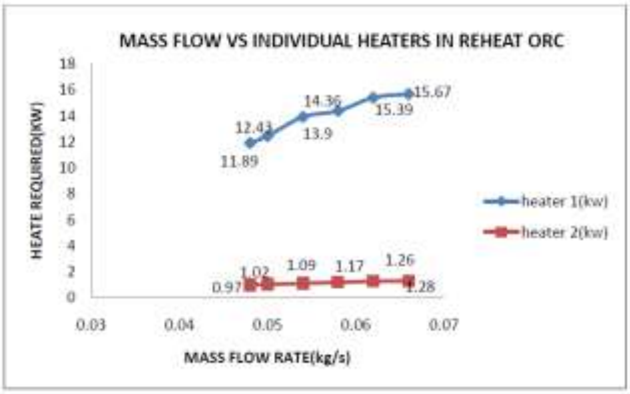




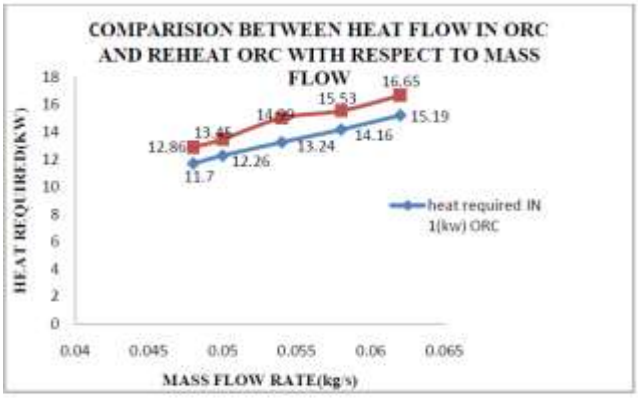


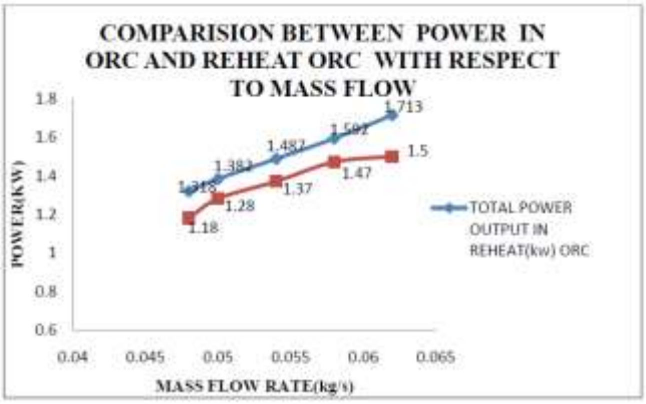
During reheat ORC as the mass flow rate increases the power output also increases. During reheat ORC as the mass flow rate increases the heat required in heater is also increases. During reheat ORC as the mass flow rate increases the total power output from the is increases. During reheat ORC as the mass flow rate increases the total heat required is increases.



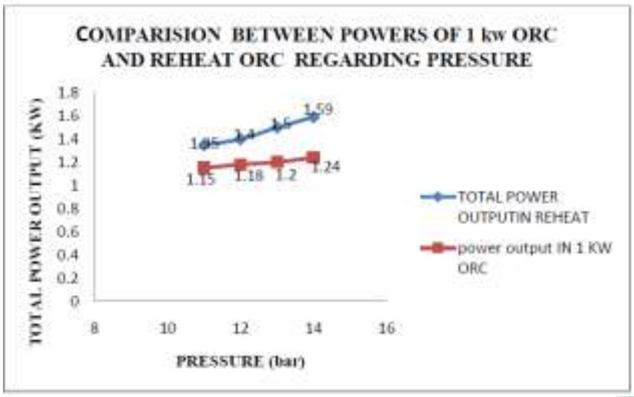


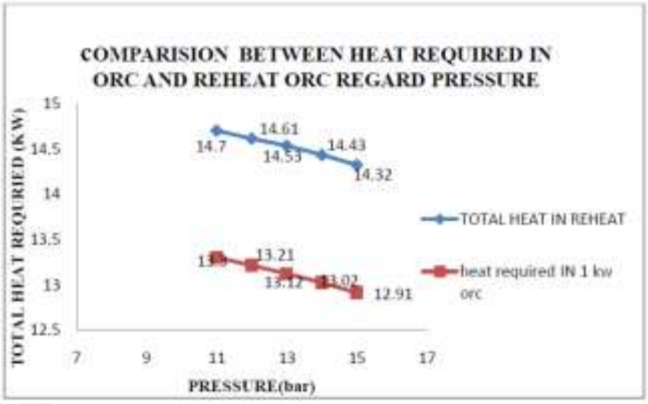
By comparing the simple ORC and Reheat ORC as the mass flow rate increases the heat required in reheat process is high. By comparing the simple ORC and Reheat ORC as the mass flow rate increases the total power output in reheat is high.





By comparing the simple ORC with Reheat ORC as the pressure increases the total power increases.
By comparing the simple ORC with Reheat ORC as the pressure increases the total heat required is increases





7.CONCLUSION AND FUTURESCOPE

Many power plants, industrial processes produced waste heat that is typically rejected to lower temperature. There are number of methods in which this waste heat can be recovered to produce useful energy. Recovery of waste heat helpful to increasing overall efficiency in case of power generation or provides auxiliary power in other waste heat application in steam power plants a medium–low grade waste heat can be recovered from steam condenser to produce power using organic rankine cycle. A reheat organic rankine cycle can be used instead of a simple organic rankine cycle to increase the overall efficiency of plant. By comparing the efficiencies of simple ORC and Reheat ORC the Reheat ORC will give the high efficiency under the same working conditions. From above it can be concluded that the efficiency of reheat organic rankine cycle is much better than simple organic rankine cycle to produce power form steam power plants.

The temperature of the exhaust forms the most industrial process and power plants are less than 370°C. If this type of waste heat is allowed in to environment directly, it would not only waste heat but also make pollution to environment. Using conventional methods to recover energy from this type of exhaust is economically not feasible. The organic Rankine Cycle (ORC) system shows great flexibility, high safety and low maintenance requirements in recovering this low grade of waste heat. ORC can be used in gas power plants as the exhaust gases exit from turbine is at higher temperatures organic rankine cycle can be used in chemical industries, cement industries as they liberate large amount of heat through exhaust.

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