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A REVIEW ON EXERGY ANALYSIS OF SUPER CRITICAL THERMAL POWER PLANT

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Abstract:

The art of energy conversion to provide convenience of doing work gave rise to various energy producing devices. Integral of these devices is thermal power plant which consumes heat energy at input end and produces mechanical work at its output end. Working according to Rankine cycle, thermal power plant has seen a paradigm shift from sub critical to critical and super critical of which super critical technology of power plant stand today on the arena of efficient power generation. The analysis of any system is done in context of finding loop ends so as to get higher efficiency system and this analysis in power plant is done conventionally by energy analysis. Exergy which provides an account of maximum amount of work stands apart from energy analysis to provide quality index to energy conversion. This quality index fetches results for each integral component of whole system and attempts to locate the major components where exergy destruction or work to be developed is lost. Super critical technology of power generation is also subjected to energy and exergy analysis which in form of various research work is presented in this paper. An attempt to define the parameters of further study on the platform of existing research is done in this present work.

Keywords: Super crtical, Exergy , Rankine cycle

INTRODUCTION

A thermodynamic cycle producing net amount of work as output is called power cycle. The vapor power cycle is a cycle with a working substance which alternatively vaporizes and condenses. Rankin cycle is the standard thermodynamic cycle in general use for electric power generation and this cycle is a heat engine with a vapor power cycle. The common working fluid is water. The Rankine cycle uses complete condensation of steam and only liquid water is pumped back to boiler. Actually, Rankine cycle requires very less pumping work (back work), therefore, it has practically higher efficiency than that of Carnot vapor power cycle. Thermal efficiency of Rankin cycle can be improved by increasing the mean temperature of heat addition and the mean temperature of heat addition can be increasing by using reheat, superheat and regeneration. The Rankine cycle has been using water to generate useful work since the mid 1800's. With the advent of modern super alloys, the Rankine steam cycle has progressed into the supercritical region of the coolant and is generating thermal efficiencies into the mid 40% range. These plants are operating at temperatures around 1000 oF and pressures around 3500 psia. One of the current engineering challenges are to adapt the supercritical Rankine cycle to coolants other than water. With the advent of modern materials, i.e. super alloys and ceramics, not only are the physical limits of the materials being pushed to extremes, but the systems are functioning much closer to their limits.

II. RANKINE CYCLE FOR SUB CRITICAL AND SUPER CRITICAL TECHNOLOGY.

In a simple Rankin cycle, steam is used as the working fluid, generated from saturated liquid water (feed water). This saturated steam flows through the turbine, where its internal energy is converted into mechanical work to run an electricity generating system. All the energy from steam cannot be utilized for running the generating system because of losses due to friction, viscosity, bend-on-blade etc. Most of the heat energy is rejected in the steam condenser. The feed-water brings the condensed water back to the boiler. The heat rejected during condensation of steam in the condenser is given away by a sink. As a result of the conversion of much of its thermal energy into mechanical energy or work, steam leaves the turbine at a pressure and temperature well below the turbine entrance valves. Basically the low pressure steam leaving the turbine at the state 2 is first condensed to a liquid at state 3 and then pressurized in a pump to state 4, and this high pressure liquid water is then ready for its next pass through the steam generator to state 1 and is reused around the Rankin cycle again. The Rankin cycle as a system converts thermal energy of the steam into mechanical energy by means of a turbine rotation, which runs the generator to produce electrical energy.

pre The four basic components of a vapor power plant are shown in Fig 1.Each component in the cycle is regarded as a control volume, operating at steady
state.

Turbine: The vapor leaving the boiler enters the turbine, where it expands isentropic ally to the condenser pressure at the state 2 (shown in Fig1&2).

Condenser: The condenser is attached at the exit of the turbine. The vapor leaving the turbine is wet vapor and it is condensed completely in the condenser to the state 3 (shown in Fig 1&2), by giving its latent heat to some other cooling fluid like water.

Pump: The liquid condensate leaving the condenser at the state 3 (shown in Fig1&2) is pumped to the operating pressure of the boiler.

Boiler: The heat is supplied to the working fluid (feed water) in the boiler and thus vapor is generated. The vapor leaving the boiler is either saturated at the state 1 or superheated at the state1' (shown in Fig1&2).

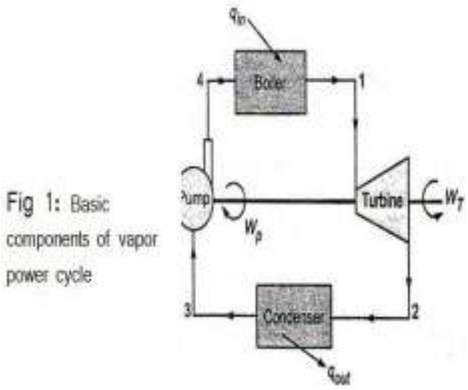

Fig.no.1. Rankine Cycle

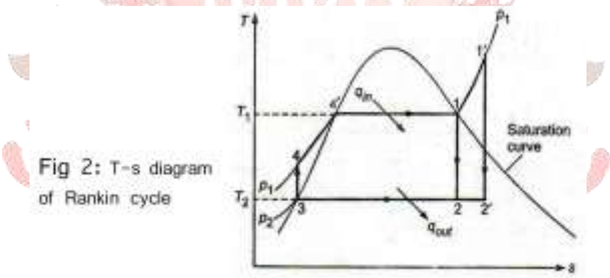

Fig.no.2. Rankine Cycle on T –S Diagram

The simple Rankine cycle is modified such that the steam is superheated prior to entering the turbine. This is indicated by line 3-4 in the T-S diagram shown in Figure 3. When properly designed, this modification increases W (the work capacity of the system) without significant increase to Qr (the unavailable heat of the system). Typically, point 4 represents temperatures up to approximately 900 oF (755 K). Theoretically, it should be possible to superheat the steam to the same temperature as the heat source; which in a boiler, is on the order of 3500 of (2200 K). However, the temperature that corresponds to point 4 is physically limited to a differential temperature of about 1000 Of (811 K), the metallurgical limit . In other words, so long as the heat transfer across the materials in the boiler and the turbines maintains a temperature differential less than the operational limits of the material, it should not experience catastrophic failure. Additionally, superheating allows the steam to still remain approximately 90% (or greater) dry as it exhausts from the turbine. This feature of the superheated cycle simplifies the turbine design and extends turbine life due to reduced wear from water impingement on the blades.

The supercritical Rankine cycle, in general, offers an additional 30% relative improvement in the thermal efficiency as compared to the same system operating in the subcritical region. The cycle has been successfully utilized in fossil fuel plants but the current available materials prohibit reliable application of the supercritical cycle to nuclear applications. There is much work to be done in order to advance materials to the point where they will be able to reliably withstand the stresses of a supercritical environment inside a nuclear reactor for a designed life span of approximately 60 years. While many of the material advances are due to the advent of specialized coatings, it is reasonable to suspect that new advances could also be made by improvements in the isotopic quality of the base metals. It has been known for decades that isotopically pure materials have considerably better thermal conductivity. Improvements in isotopic purity can affect heat transfer characteristics by up to a factor of three , possibly more. It should be noted however, the cost of obtaining sufficient quantities of such materials may be prohibitive and the benefit gained is temperature dependant.

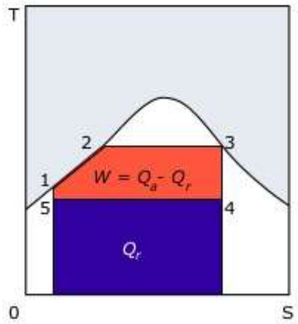

Fig.no.3. Basic Rankine cycle

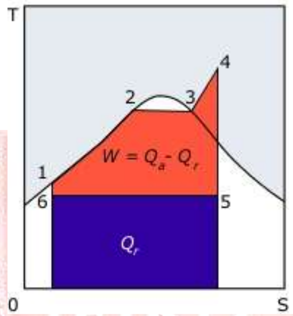

Fig.no.4. Rankine cycle with super heating

IV. Exergy Analysis

Exergy is the tool, which indicates how far the system departs from equilibrium state. The concept of exergy was put forward by Gibbs in 1878. It was further developed by Rant in 1957.

3.1 QUALITY OF ENERGY

Quantative evaluation of energy in a cycle or in a process can be done using the first law of thermodynamics. The direction of flow of heat or work is known from the second law of thermodynamics. However, it is equally important to assign the quality to the energy. As discussed in Chapter 1, energy can be broadly classified into (1) High grade and (2) Low grade energy. High grade form of energy are highly organised in nature and conversion of such energy to some other high grade form ()$WW\rightarrow$ is not dictated by the second law of thermodynamics. Conversion of high grade energy to low grade energy is not desirable. However, there may be some conversion to low grade energy as work is converted into other useful form. This is because of dissipation of heat due to friction (example: mechanical work Electricity, some losses are there due to the friction in bearing of machineries). Thus both the first and the second law of thermodynamics are to be considered for analysis. →
Low grade energy such as heat due to combustion, fission, fusion reactions as well as internal energies are highly random in nature. Conversion of such form of energy into high grade energy (is of interest. This is due to the high quality of organised form of energy obtained from low quality energy. Second law of thermodynamics dictates that conversion of 100% heat into work is never possible. That part of low grade energy which is available for conversion is termed as available energy, availability or exergy. The part, which according to the second law of thermodynamics, must be rejected is known as unavailable energy. Exergy analysis helps in finding the following: $QW\rightarrow$)

- It can be used to determine the type, location and magnitude of energy losses in a system
- It can be used to find means to reduce losses to make the energy system more efficient

In case of coal fired power plant, the first law indicates that the condenser greatly effects the power plant efficiency as large amount of heat is transferred to the cooling water without providing any clue on the real usefulness of this relatively low temperature fluid. Also, energy balances do not provide information about the internal losses such as throttling valve and heat exchanger. Second law or exergy balance, however indicates that there is hardly 1% exergy loss in the condenser with more than 60% in the boiler. The contribution in the boiler exergy loss accounts for irreversibilities associated with combustion and finite temperature differences. Hence, analysis of exergy plays a deterministic role in identification of processes and rectifying the components.

Unlike the traditional criteria of performance, the concept of irreversibility is firmly based on the two main laws of thermodynamics. The exergy balance for a control be derived by combing the steady flow energy equation {First law} with the expression for the entropy production rate {second law}. Although the second law is not used explicitly in the Exergy method, its application to process analysis demonstrates the practical implications of the second law. Thus studying different forms of irreversibility and their effect on plant performance, gives a better and more useful understanding of the second law than studying its statements and corollaries .
According to the first law of thermodynamics, energy is neither lost nor destroyed but it is converted from one form to another. During this conversion, however, the energy loses a certain quality which can be described as its ability to do
work. Since it is the ability of energy to do work which gives energy its value to society, it is important to conserve available work rather than energy. Performing a second law efficiency analysis, quality energy consumption could be reduced considerably in many areas of the economy. The world is changing rapidly due to the increasing wealth and size of the population. Therefore, there is a growing need for more efficient and sustainable production processes. The general form of exergy balance equation of a system is described as follows

Input Exergy - Exergy Consumption =Stored Exergy + Output Exergy

The difference between the input exergy and the exergy consumption becomes either stored exergy or output exergy shown in the right-hand side of the above equation.

Mass, energy, and exergy balances for any control volume at steady state with negligible potential and kinetic energy changes can be expressed, respectively
Specific exergy for boiler is given by

= (h-ho)-To(s-so)........(1)

Where ho, so, To represents the reference state point (standard environment)

Total Exergy is given by Xo =mo
= mo [(h-ho)-To(s-so)]..............(2)

the specific physical exergy of the stream was evaluated from the following equation

ei= (hi-ho) - To (si- so) = Δh-ToΔs.........(3)

Exergy Destruction (i) =Exin – Exout- W----------------- (4)
Percentage Exergy Destruction = (Exergy destruction/Total exergy destruction of the power cycle) * 100............ (5)

Second law efficiency or Exergy efficiency is defined as the = exergy output ÷exergy input................(6)

IV. LITERATURE SURVEY

With a an attempt to optimize various parameters of tenergy conversion operations involved in power generation by using thermal power plant we need to study various research involved to understand the role of exergy analysis in efficiency evaluation of power plant. The energy supply to demand narrowing down day by day around the world, the growing demand of the power made the power plant scientific interest, but the most of power plant designed by the energetic performance criteria based on the first law of thermodynamics. The real energy losses of the power plant cannot be justified by the first law of thermodynamics, because it does not differentiate between quality and quantity of energy. Based on the several activity and power plant experience some key observation has made and is presented in this work.

Ibrahim Bin Hussain, Mohd Zamri Bin, Mohd Hariffin Boosorh “Exergy analysis of a 120 MW Thermal Power Plant”

This paper prsents the result of an exergy analysis performed on 120 Mw steam power plant in malasiya. The result of the analysis indicates that the boiler produces the highest exergy destruction of 54 Mw. Compareing the three turbine stages the result of the analsyis indicates that the High pressure(HP) and intermediate pressure(IP) turbine produces higher exergy destruction than the Low pressure(LP) turbine. Comparing the results of analysis on the feed water heaters, the feed water heater 4 produces the highest exergy destruction. In the analysis of the plant, the cycle was assumed to be operate at steady state with no stray heat transfer from any component to its surroundings and negligible potential and kinetic energy effect. It has been seen that the large exergy losses occurs into combustion reaction and large temperature difference during heat transfer between the combustion gases and steam. The result of analysis for the main component of plant 80MW. This paper has presented the result of an exergy analysis performed on a 120 MW power plant. The analysis applied on the unit with running load 80 MW.

Power Plant with measured boiler and turbine Losses”

In this paper, a thermodynamic analysis of a sub-critical boiler turbine generator is performed for a 31 Mw coal-fired power plant. Both energy and exergy formulation are developed for the system. Finally, it will perform parametric study to determine how the system performance varies with different operating parameters. The performance of the system depends on the surroundings. It is evident that the efficiency rises with an increase in the superheated steam parameters. Increasing the cycle pressure and temperature will result in a higher Power output for the same mass flow rate of steam and fuel input into the boiler. The steam has a higher energy/exergy content resulting into higher work output of the Turbine. Combustion in the boiler is another major source of irreversibility Improvement in fuel consumption can greatly contribute to improving boiler and system performance.[1]

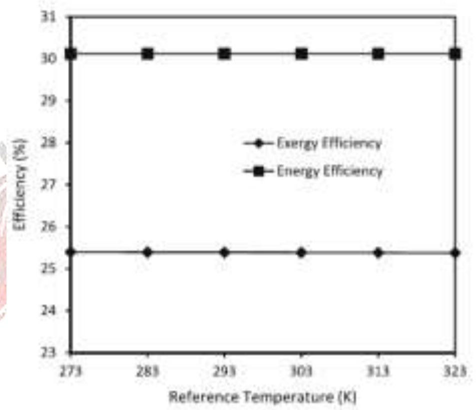

Fig.no.5. Efficiency vs temperature

Isam H. Aljundi “Energy and Exergy analysis of a steam power plant in Jordan”

In this study, the energy and exergy analysis of Al-Hussein power plant in Jordan is presented. The performance of the plant was estimated by a component wise modelling and a detailed break-up of energy and exergy losses for the considered plant has been presented. Energy losses mainly occurred in the condenser where 134MW is lost to the environment while only 13 MW was lost from the boiler system. The percentage ratio of the exergy destruction to the total exergy destruction was found to be maximum in the boiler system (77%) followed by the turbine (13%), and then the forced draft fan condenser (9%). In addition, the calculated thermal efficiency based on the lower heating value of fuel was 26% while the exergy efficiency of the power cycle was 25%. For a moderate change in the reference environment state temperature, no drastic change was noticed in the performance of major components and the main conclusion remained the same; the boiler is the major source of irreversibilities in the power plant. Exergy is a measure of the maximum capacity of a system to perform useful work as it proceeds to a specified final state in equilibrium with its surroundings. Exergy is generally not conserved as energy but destructed in the system. Exergy destruction is the measure of irreversibility that is the source of performance loss. Therefore, an exergy analysis assessing the magnitude of exergy destruction identifies the location, the magnitude and the source of thermodynamic inefficiencies in a thermal system.[2]

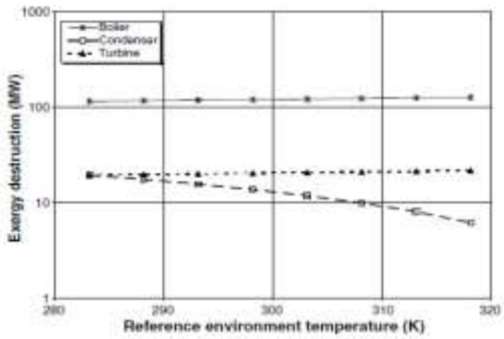

Fig.no.6. Dead State Temperature vs Exergy destruction

A. G. Tumanovskii Review of the Coal-Fired, Over-Supercritical and Ultra-Supercritical Steam Power Plants

The article presents a review of developments of modern high-capacity coal-fired over-supercritical (OSC) and ultra-supercritical (USC) steam power plants and their implementation. The basic engineering solutions are reported that ensure the reliability, economic performance, and low atmospheric pollution levels. The net efficiency of the power plants is increased by optimizing the heat balance, improving the primary and auxiliary equipment, and, which is the main thing, by increasing the throttle conditions. As a result of the enhanced efficiency, emissions of hazardous substances into the atmosphere, including carbon dioxide, the “greenhouse” gas, are reduced. To date, the exhaust steam conditions in the world power industry are $p0 \approx 30$ MPa and $t0$ = 610/620°C. The efficiency of such power plants reaches 47%. The OSC plants are being operated in Germany, Denmark, Japan, China, and Korea; pilot plants are being developed in Russia. Currently, a project of a power plant for the ultra-supercritical steam conditions $p0 \approx 35$ MPa and $t0$ = 700/720°C with efficiency of approximately 50% is being studied in the EU within the framework of the Thermie AD700 program, project AD 700PF. Investigations in this field have also been launched in the United States, Japan, and China. Engineering solutions are also being sought in Russia by the All-Russia Thermal Engineering Research Institute (VTI) and the Moscow Power Engineering Institute. The stated steam parameter level necessitates application of new materials, namely, nickel-base alloys.[3]

Marc A. Rosen and Cornelia Aida Bulucea Using Exergy to Understand and Improve the Efficiency of Electrical Power Technologies.

The benefits are demonstrated of using exergy to understand the efficiencies of electrical power technologies and to assist improvements. Although exergy applications in power systems and electrical technology are uncommon, exergy nevertheless identifies clearly potential reductions in thermodynamic losses and efficiency improvements. Various devices are considered, ranging from simple electrical devices to generation systems for electrical power and for multiple products including electricity, and on to electrically driven. The insights provided by exergy are shown to be more useful than those provided by energy, which are sometimes misleading. Exergy is concluded to have a significant role in assessing and improving the efficiencies of electrical power technologies and systems, and provides a useful tool for engineers and scientists as well as decision and policy makers.[4]

Sarang j gulhane Exergy Analysis of Boiler In cogeneration Thermal Power Plant
It is estimated in this work that boiler seem most exergy destruction part to which need to improve for 6 mw power plant analysis of exergy indicate that the boiler has exergy destruction at home load 1.1 mw is around 83.35% and as load increases for highest load 5.6 mw the exergy destruction found to be 76.33%thus efficiency of 1 st law and 2 law increases with load ,we have to work on the peak load for reduce the irreversibility The material capability study and exergy study on various component of boiler can b e the scop of the study, with the passage of time the technology getting matured and new material wi th higher capacity heat transfer rate like heat pipe and thermo sypon is used ,the data designer of the boiler can redesign the boiler with efficient auxiliary devices.[5]

Ibrahim Dincer and Yunus A. Cengel have discussed the concepts of energy, entropy and exergy concepts and their roles. The first law of thermodynamics refers to the energy analysis which only identifies losses of work and potential improvements or the effective use of resources, e.g., in an adiabatic throttling process. However, the second law of thermodynamics, i.e., exergy analysis takes the entropy portion into consideration by including irreversibilities. During the past decade exergy related studies have received considerable attention from various disciplines ranging from chemical engineering to mechanical engineering, from environmental engineering to ecology and so on. As a consequence of this, recently, international exergy community has expanded greatly. Exergy analysis is based on the second law of thermodynamics, and generally allows process inefficiencies to be better pinpointed. Exergy is often treated as a measure of economic value. Some researchers have portrayed costs of energy conversion devices as functions of their exergy efficiencies .[6]

Sengupta et al. have carried out exergy analysis of a coalbased210MW thermal power plant in subcritical range. They have split entire plant cycle three zones for the sake of their analysis such as only the turbo-generator with its inlets and outlets, turbo-generator, condenser, feed pumps and the regenerative heaters, the entire cycle with boiler, turbo-generator, condenser, feed pumps, regenerativeheaters and the plant auxiliaries. The exergy efficiency is calculated using the operating data from the plant at different conditions, viz. at different loads, different condenser pressures, with and without regenerative heaters and with different settings of the turbine governing. The load variation is studied with the data at 100, 75, 60 and 40% of full load. They concluded that, the boiler causes the maximum destruction of exergy amounting to almost 60% at all loads. The contribution of the turbine including its control valves comes next, while the contribution of the regenerative feed cycle with all the feed water heaters and pumps is the least in the above order. But when the boiler is included the exergy efficiency decreases on the heater withdrawal. Comparison of the exergy efficiencies shows that less throttling at the control valves with sliding pressure mode of operation helps to reduce exergy destruction in the plant.[7]

IV. OBJECTIVES

A thorough literature survey has revealed that a substantial amount of work has been carried out on thermodynamic analysis of Rankine cycle in subcritical ranges of temperatures and pressures and established that the energy and exergy efficiency of the cycle can be enhanced by operating the Rankine cycle at higher temperatures and pressures. Further, reheating the steam in between the stages of the turbine also enhances the performance of the Rankine cycle. But so far, not much of focus has been made on energy and exergy analysis of supercritical, ultra supercritical and advanced supercritical cycles. The important hurdle in implementing the supercritical Rankine cycle for the generation of power in steam based power plants is in developing the material that can sustain very high pressures and temperatures involved in supercritical/ultra supercritical/advanced ultra supercritical cycles. However, the hurdle in carrying out the analysis on supercritical Rankine cycle is in obtaining the values of steam properties at these operating conditions of high pressures and temperatures. Though the thermodynamic relations exist for the calculation of steam properties, they are very complicated and require several iterations. Even a small gain in efficiency of the power plant will lead to substantial savings in the expenditure. At this stage, it is pertinent to recall that the efficiency of the power plant can be enhanced by operating it under supercritical conditions. This magnitude of saving that can be derived byoperating the power plant with increased efficiency demands thorough concentrated efforts from research community in this area. As themetallurgical scientists are significantly progressing in the developmentof newer material that can withstand higher temperatures and pressures,the present investigation got motivated to carryout of thermodynamic analysis of Rankine cycle under supercritical/ultrasupercritical/advanced ultra supercritical conditions. Literature also revealed that the reheating of the steam in between the stages of the turbine also enhances the efficiency of the cycle under subcritical conditions. In view of this, the present investigation has set an objective of analyzing the Rankine cycle with single and multiple reheats also. Further, it is proposed to study and analyze the effect of operating parameters, mentioned in the next page, on the performance of supercritical, ultra supercritical and advanced ultra supercritical power cycle without reheat, with single reheat and with double reheat.

The various objectives of the proposed work can be enumerated as follows.

- The power plant technology which has shifted for sub critical to super critical will be subjected to exergy analysis of the whole system.
- The power plant selected for study will be thermal power plant employing super critical technology for power generation whose data for various components will be used to analyse the exergy of each system.
- The values of differences of exergy will be calculated for various components of the power plant to study the exergy destruction in each energy conversion or heat transfer process.

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