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EXERGY ANALYSIS OF THERMAL POWER PLANT

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ABSTRACT

The use of feed water heater reduces the amount of heat required to generate the superheated steam in the boiler. Thermodynamic analyses have been carried out for analyzing the effect of number of feed water heaters on overall performance of the rankine cycle. With the increase of number of feed water heaters, both energetic and exergetic efficiencies are found to be increasing. This is due to reduction in irreversibility in the boiler with the increase of feed water heater. The energy assessment must be made through the energy quantity as well as the quality. But the usual energy analysis evaluates the energy generally on its quantity only. However, the exergy analysis assesses the energy on quantity as well as the quality. The aim of the exergy analysis is to identify the magnitudes and the locations of real energy losses, in order to improve the existing systems, processes or components.

Keywords: Feed water heater, Exergy, Energy, Coal-based thermal power plant.

1. INTRODUCTION

The performance of the rankine cycle can be improved by increasing the mean temperature of heat addition i.e.increasing the degree of superheat, steam pressure by multistage expansion with reheating.The research so far was focused on increasing the mean temperature of heat addition by increasing steam pressure by multistage expansion of steam. The efficiency of the steam power cycle can be improved to a large extent by the incorporation of feed water heater or by the use of regenerative feed heating system [7].

Regenerative feed heating system is an important part of the thermal system of the power plant. Preheating the feed water reduces the irreversibility's involved in steam generation and therefore improves the thermodynamics efficiency of the system. This reduces plant operating costs and also helps to avoid thermal shock to the boiler metal when the feed water is introduced back into the steam cycle [16]. Heat is transferred from the steam to the feed water either by mixing up the fluids in an open heater or without mixing in closed heater. Open feed water heaters are simple and inexpensive and have good heat transfer characteristics. Closed feed water heaters are more complex due to their internal piping and have less effective heat transfer than open heater. Since, two streams do not come into direct contact [10]. In most steam power plants, closed heaters are favoured because closed heater requires only a single pump for the main feed water stream regardless of the number of heaters, but at least one open heater is used, primarily for the purpose of feed water deaeration. The open heater in such a system is called the deaerator [1].

At present there are two traditional way to analysis the performance of the feed heating system. One is by the energy balance across the system. The other is by calculating separately the rate of entropy generation in process. In our study, energy and exergy balance of feed heaters are provided based on the first law and second law. The energy assessment must be made through the energy quantity as well as the quality. But the usual energy analysis evaluates the energy generally on its quantity only. However, the exergy analysis assesses the energy on quantity as well as the quality [14].

1.1 The Ideal Rankine Cycle

The theoretical basic cycle for the simple steam turbine power plant is the Rankine cycle which is closed one. The modern power plant uses the rankine cycle, modified to including super-heating, regenerative feed water heating and re-heating. As shown schematically a simple Rankine cycle in Fig 1 and T-s diagram in Fig 2. This is the ideal cycle for vapour power plants. The ideal Rankine cycle does not involve any internal irreversibility and consist of the following four processes [5].

1-2 Isentropic compression in a pump.

2-3 Constant pressure heat addition in a boiler.

3-4 Isentropic expansion in a turbine.

4-1 Constant pressure heat rejection in a condenser.

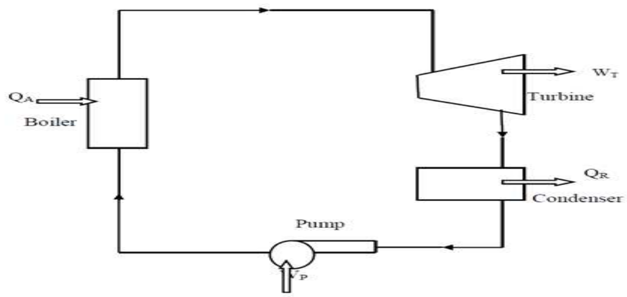

Fig 1: Simple Rankine Cycle

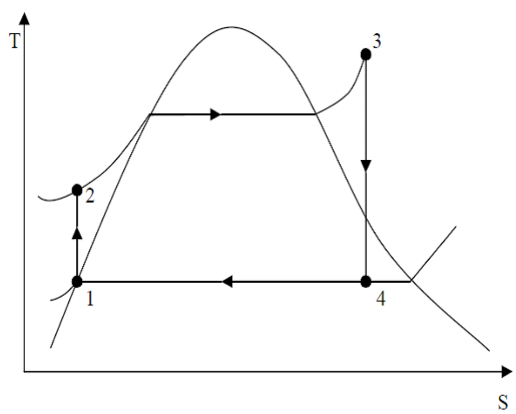

Fig 2: T-S Diagram for simple rankine cycle

Water enters the pump at state 1 as saturated liquid and is compressed isentropically to the operating pressure of the boiler. The water temperature increases somewhat during this isentropic compression process due to a slight decrease in the specific volume of water. The vertical distance between 1 and 2 on the T-s diagram is greatly exaggerated for clarity. Water enters the boiler as a compressed liquid at state 2 and leaves as a superheated vapor at state 3. The boiler is basically a large heat exchanger where the originating from combustion gases, nuclear reactors or other sources is transferred to the water essentially at constant pressure. The boiler, together with the section where the steam is superheated, is often called the steam generator. The superheated vapor at state 3 enters the turbine, where it expands at isentropically and produces work by rotating the shaft connected to an electric generator .The pressure and the temperature of steam drop during this process to the values at state 4, where steam enters the condenser. At this state, steam is usually a saturated liquid vapor mixture with a high quality. Steam is condensed at constant pressure in the condenser, which is basically a large heat exchanger, by rejecting heat to a cooling medium such as a cooling tower, lake, a river, or the atmosphere. Steam leaves the condenser as a saturated liquid and enters the pump, completing the cycle. Remembering that the area under the process curve on a T-s diagram represents the heat transfer for internally reversible processes, we see that the area under process curve 2-3 represents the heat transferred to the water in the boiler and the area under the process curve 4-1 represents the heat rejected in the condenser. The difference between these two is the net work produced during the cycle.

1.2 Deviation of Actual Vapor Power Cycles from Idealized Ones

The actual vapor power cycle differs from the ideal Rankine cycle, as illustrated in Fig 3, as a result of irreversibility's in various components. Fluid friction and heat loss to the surrounding are the two common sources of irreversibility's. Fluid friction causes pressure drops in the boiler, the condenser, and the piping between various components. As a result steam leaves the boiler at a somewhat lower pressure. Also the pressure at the turbine inlet is somewhat lower than that at the boiler exit due to the pressure drop in the connecting pipes. The pressure drop in the condenser is usually very small. To compensate for these pressure drops, the water must be pumped to a sufficiently higher pressure than the ideal cycle calls for. This requires a larger pump and larger work input to the pump. The other major source of irreversibility is the heat loss from the steam to the surroundings as the steam flows through various components. To maintain the same level of net work output, more heat needs to be transferred to the steam in the boiler to compensate for these undesired heat losses. As a result cycle efficiency decreases. Of particular importance is the irreversibility occurring within the pump and the turbine. A pump requires a greater work input, and a turbine produces a smaller work output as result of irreversibility's. Under ideal conditions, the flow through these devices is isentropic. The deviation of actual pumps and turbines from the isentropic ones can be accurately accounted for. however, by utilizing isentropic efficiencies, where state 2a and 4a are the actual exit states of the pump and the turbine, respectively, and 2s and 4s are the corresponding states for the

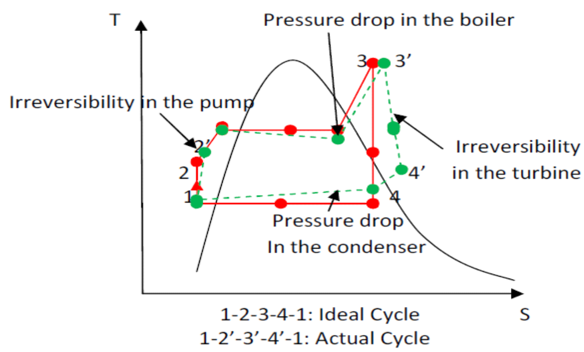

Fig 3: Deviation of Rankine cycle

isentropic case. Other factors also need to be considered in the analysis of actual vapor power cycles. In actual condensers, for example, the liquid is usually sub-cooled to prevent the onset of cavitations, the rapid vaporization and condensation of the fluid at the low-pressure side of the pump impeller, which may damage it. Additional losses occur at the bearings between the moving parts as a result of friction. Steam that leaks out during the cycle and air that leaks into the condenser represent two other sources of loss. Finally, the power consumed by the auxiliary equipment such as fans that supply air to the furnace should also be considered in evaluating the performance of actual power plants.

1.3 The Ideal Regenerative Rankine Cycle

A careful examination of the T-s diagram of the Rankine cycle redrawn in Fig 4 reveals that heat is transferred to the working fluid during process 2-2' at a relatively low temperature. This lowers the average heat-addition temperature and thus the cycle efficiency. To remedy this shortcoming, we look for ways to raise the temperature of the liquid leaving the pump (called the feed water) from the expanding One such possibility is to transfer heat to the feed water from the expanding steam in a counter flow heat exchanger built into the turbine, that is to use regeneration. This solution is also impractical because it is difficult to design such a heat exchanger and because it would increase the moisture content of the steam at the final stages of the turbine. A practical regeneration process in steam power plants is accomplished by extracting or "bleeding," steam from the turbine at various points. This steam which could have produced more work by expanding further in the turbine, is used to heat the feed water instead The device where the feed water is heated by regeneration is called a regenerator, or a feed water heater. Regeneration not only improves cycle efficiency, but also provides a convenient means of dearerating the feed water (removing the air that leaks in at the condenser) to prevent corrosion in the boiler.

It also helps control the large volume flow rate of the steam at final stages of the turbine (due to the large specific volumes at low pressures). Therefore regneration is used in all modern steam power plants. A feed water heater is basically a heat exchanger where heat is transferred from the steam to the feed water either by mixing the two fluid streams (open feed water heaters) or without mixing they (closed feed water heaters).

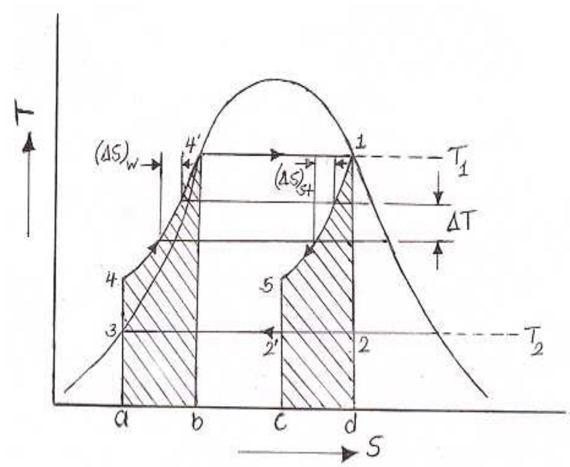

Fig 4: Ideal Regenerative Rankine Cycle

2. EXERGY

2.1 Introduction

The second law analysis of a power cycle enables us to identify the major source of loss and shows avenues for performance improvement. Practical devices involving energy conversion and transfer always observe energy conversion law, but the quality of energy degrades i.e. work potential is lost or energy is destroyed. Degradation of energy is equivalent to the irretrievable loss exergy or irreversibility provides a quantitative measure of process inefficiency. This method provides the information, which is useful for engineers or managers to known about the power plant performance. Exergy is the maximum possible work that can be produced by a system as it is brought into equilibrium with a specified reference environment. Thus exergy can be reckoned as a measure of the quality of energy. Energy 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 enegy conversion devices as functions of their exergy efficiencies. The exergy consumption during a process is proportional to entropy creation, which accounts for inefficiencies due to irreversibility's. The potential for improvement in a given component is determined by its irreversibility rate under a given set of conditions in relation to the intrinsic irreversibility's rate within the limits imposed by physical, technological, economic and other constraints. The exergy destruction is a form of environmental damage. By preserving exergy through increased efficiency (i.e. degrading as little exergy as necessary for a process), environmental damage is reduced. Therefore, exergy analysis is as important as energy analysis for design, operation and maintenance of different equipment, and systems of power plant. It is important that the performance monitoring of an operative power plant includes exergy analysis besides the conventional energy analysis.

The term availability was made popular in the United States by the M.I.T. School of Engineering in the 1940_s. Today, an equivalent term, exergy, introduced in Europe in the 1950s, has found global acceptance partly because it is shorter, it rhymes with energy and entropy, after that the term exergy was introduced by Rant in 1953. The concepts of first and second law were established by Von Mayer and Carnot, respectively, in the first half of the 19-th century. Important contributions to the thermodynamics were given by Gibbs in the second half of the 19-th century. The basic law of second law analysis was made by Goeuty in 1989 and Stool in 1898 by the law, which has been named after them (Szargut, 1980). A second law analysis has already been performed by Stodola in 1905(Baehr, 1965 and Motz, 1989) a by Jouguet in 1907 (Jouguet, 1907). In 1932 Keenan (1932) defined the concept of physical exergy, at the time called availability [5].

2.2 Definition of Exergy

It is the maximum possible useful work that could be obtained from the system at a given state in a specified environment. The work potential of the energy contained in a system at a specified state is simply the maximum useful work that can be obtained from the system. The work done during a process depends on the initial state, the final state, as well as the condition of the environment. In an exergy analysis, the initial state is specified, and thus it is not a variable. The work output is maximized when the process between two specified states is executed in a reversible manner, as therefore, all the irreversibility are disregarded dead state at the end of the process to maximize the work output. A system is said to be in the dead state when it is in thermodynamics equilibrium with the environment.

2.3 Exergy Analysis

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.

Irreversibility's such as mixing, chemical reactions, heat transfer through a finite temperature difference, unrestrained expansion, non quasiequilibrium compression or expansion always generate entropy, and anything that generates entropy always destroys exergy.

3. CONCLUSION

The aim of the exergy analysis is to identify the magnitudes and the locations of real energy losses, in order to improve the existing systems, processes or components.In this study, performance analyses of 50 MW coal fired regenerative power plant have been performed at design and working conditions by means of energetic and exergetic methods.The use of feed water heater reduces the amount of heat required to generate the superheated steam in the boiler. Thermodynamic analyses have been carried out for analyzing the effect of number of feed water heaters on overall performance of the rankine cycle.

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