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Second Law Based Thermodynamic Performance analysis of Steam Power Cycle

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ABSTRACT

The generation of mechanical power had been a challenge for mechanical engineers and a great deal of attention has been focused on designing system for power generation. Thermal power cycles are important devices used in practical engineering application for thermal power generation and control of environment. Several thermodynamic approaches are possible to analyze the performance of these cycles. The most traditional approach is the first law of thermodynamics or energy balance analysis; however, this concerned only with the conversion of energy, and therefore it can not be show how or where irreversibility in a system or process occur. Second law analysis is another well- known method used to analyze thermodynamic cycles, but to some, it may be still new. Unlike first law analysis,second law analysis determines the magnitude of irreversible processes in a system, and thereby provides an indicator that the points the direction in which the engineers should concentrate their efforts to improve the performance of thermodynamic systems. This thesis is an attempt to physically understand and evaluate the internal irreversibilities due to heat transfer and fluid flow in various thermal power cycle used for power generation. This thesis present investigations on thermodynamic modelling and effects of irreversibilities in thermal power cycles using the concept of exrgy analysis and entropy generation. Detail literature review on second law analysis of thermal power cycles is reported in Section I.0 First and second law analysis of stem power cycle , gas turbine cycle , combine Brayton/Rankine power cycle, indirect fired air turbine multi stage ..... have been carried out.Analytical expressions for the performance parameters involving the relevant variables for these systems under given conditions, corresponding to available power output and exergy destruction in the system, have been obtained. Detailed parametric study has been done and result are presented.This study include the effect of pressure ratio,cycle temperature ratio, number of reheat stages, pressutre drop in heat transfer devices, and the refrigeration temperature on the performance parameters of the thermal power cycles. Second law based performance assessment of regenerative-reheat steam power cycle has been carried out in terms of irreversibility analysis. The reduction in irreversible losses with the addition of backward, cascade type feed water heater and a reheat options are compared with a conventional first -law assessment. The second law indicate that the maximum exergy is destroyed in the boiler and that these thermodynamic losses are significantly reduced by incorporating feed water heater. The incorporation of feed water heating results in a reduction of total irreversility rate of the plant by 18%. The corresponding improvement in thermal efficiencies is 12%. These two values are enhanced to 24% and 14% respectively, by the incorporation of reheat in addition to regeneration.

Key words: Energy efficiency; Exergetic analysis; Energy loss; Thermal Power Plant; Power Enhancement; Incorporating Feed Water Heater; Cascade Type Feed Water Heater; Regenerative -Reheat Steam Power Cycle; Thermal Power Cycles.

1. INTRODUCTION

The energy crisis of 1970 and the continuing emphasis on efficiency (conservation of fuel resources) has led to a complete overhaul of the way in which thermal power cycle are analyzed and improved thermodynamically. In the present civilization the use of energy resources has increased tremendously. Fast depleting fossil fuel reserves have inevitably gathered the attention of one and all to think and devise for optimum energy utilization in order to optimally use energy, the efforts are required for identification and elimination of the sources of inefficiency during its use, which obviously requires in depth study and analysis.

A look into the laws of thermodynamics shows that the first law of thermodynamics bases upon the series of experiments done by James Joules demonstrating the bidirectional numerical equivalence of work and heat while second law of thermodynamics as a unidirectional equivalence between work and heat i.e. for a given amount of heat the equivalent amount of work cannot be obtained whereas vice-versa may be there. Thus the concept of quality of energy came into existence and work is considered as high grade energy, and also electrical energy wind energy, tidal energy etc and low grade energy may be heat from nuclear reactions, heat from combustion of fuel *etc.*

Engineers have been using the first law of thermodynamics stating the energy conservation, therefore it could be concluded that energy cannot be destroyed and exists with matters in all forms e everywhere. It is not quite convincing to understand that the scarcity of energy resources and energy crisis is a paradox. Still in real life we find scarcity of energy, as in practice, one is interested in the ability to feed, drive machines, and occurrence of energy processes etc. Such discussions gave birth to the concept of 'available energy' and unavailable energy' or a concept of maximum work.

This concept became very important in phenomenological thermodynamics as it is referred to the possibilities of performing work in real conditions. Gouy (1889) and Stodola (1905) pioneered in the studies pertaining to effect of ambient temperature upon the obtainable work and law of the loss of maximum work. The law of the loss of maximum work says that the work obtained is always less than the maximum obtainable work due to the irreversibility in thermal processes. Available energy concept came out of these prepositions.

Quality of energy, its convertibility into other forms and capability to perform work *etc.* And quantitatively defined using availability analysis. New term "Exergy" was introduced by Z. Rant in 1956, so as to differentiate it from 'Energy'. "Exergy" analysis or 'availability analysis' has capability to identify and quantify the causes of thermodynamic imperfections of thermodynamic processes and thus indicate about the possibilities of improving the processes. It is preferred over energy analysis as energy analysis cannot detect majority of thermodynamic imperfections, such as irreversible heat transfer, throttling, and adiabatic combustion *etc.* do not have any energy loss but make the quality of energy inferior.

Energy entering with fuel, electricity, flowing streams of matter and so on can be accounted for in products and by products. Energy cannot be destroyed. The idea that something can be destroyed is useful but should not be applied to 'energy'. However, it could be applied to another variable 'Exergy'. Moreover, it is exergy and not energy that properly gauges the quality (utility) of, say one kJ of electricity generated by a power plant versus one kJ in plant cooling water stream. Electricity obviously has grerater quality and the greater economic value.

2. EXERGY DESTRUCTION AND ENTROPY GENERATION ANALYSIS

Consider first the multiport system in the fig 1.1. At a certain point in time, the system can be in thermal contact with any number of heat reservoirs of temperature T_i (i = 0, 1, 2....n). We will soon see that a special role in the functioning of an engineering installation is played by the atmosphere, which in fig. 1.1 is represented by the temperature and pressure reservoir (T_0, P_0). The work transfer rate W represents any combination of possible modes of work transfer (p dV/dt, W_{shear}, $W_{electrical}$, $W_{magnetic}$). One possible work transfer interaction of the pdV/dt type is the work done against the atmosphere, while the atmosphere acts as a pressure reservoir P_0 dV/dt, this possible mode is illustrated in fig 1.1. because it is essential to the discussion that concludes this section.

With reference to the open system defined in fig. 1.1 the first law and the second law equations are written as :

$$\frac{dE}{dt} = \sum_{i=0}^{n} Qi - w + \sum_{in} mho - \sum_{out} mho \qquad (1.1)$$

$$Sgen = \frac{dS}{dt} = \sum_{i=0}^{n} Qi / Ti - \sum_{in} ms - \sum_{out} ms \geq 0 \qquad (1.2)$$

Where the methalpy symbol ho is short hand notation for the generalized enthalpy group

$$(h+v^2/2 + gz).$$

ext, we consider the possibility of changing the design (the internal functioning) of the system for the purpose of maximizing the work transfer rate W of long term engineering interest is the common characteristic of all the changes that consistently lead to increases in W. We must recognize, however, that since the first law of thermodynamics is an equation, the wish to see changes in W means to allow the variation of at least one other terms eq. (1.1). Let us assume that the heat transfer interaction with the atmosphere, Q, varies as W is maximized. In other works, let us assume that all the other interactions that are specified around the system (heat transfer rates Q_1......Q_n in flows

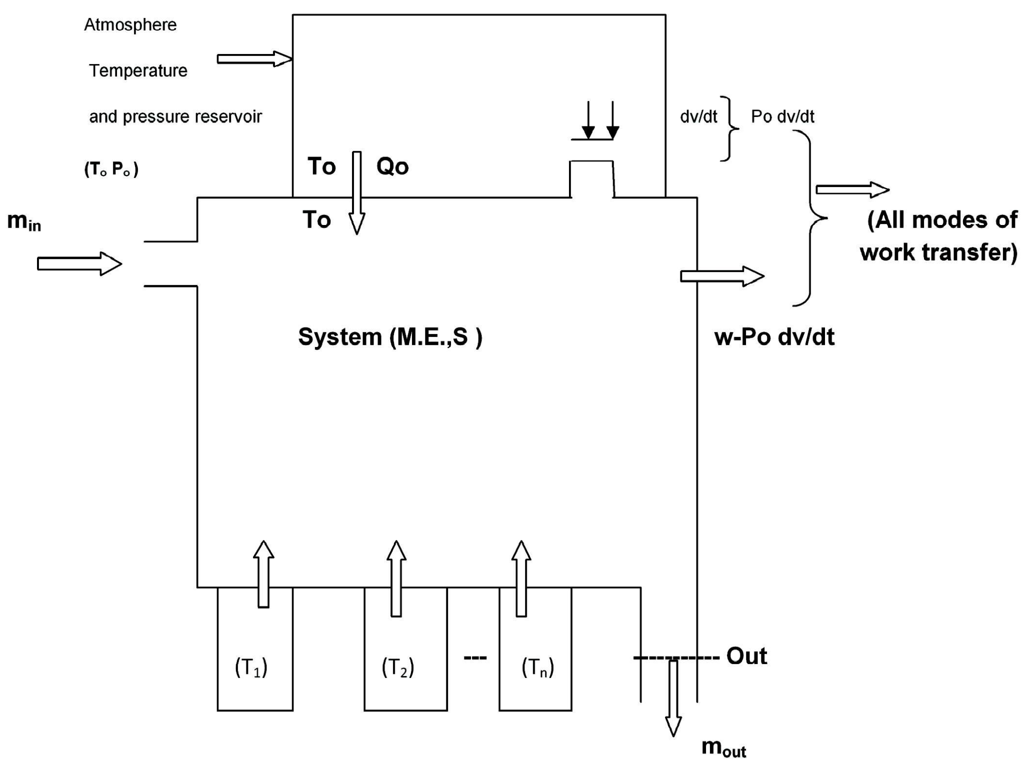

Fig. 1.1. Open system in communication with the atmosphere and additional heat reservoirs.

and outflows of methalpy and entropy) are fixed by design and that only Q_n " float" in order to balance the changes in W. The choice of Q_0 as the interaction that floats in the wake of design changes is consistent with the role that is assigned traditionally to the rate of heat rejection to the atmosphere in design of power and refrigeration systems. If we eliminate Q_0 between the first law Eq. (1.1) and the entropy generation rate definition Eq. (1.2), we find that the work transfer rate depends explicitly on the degree of thermodynamic irreversibility of the system sgen.

$$W = -\frac{d}{dt}(E - ToS) + \sum_{i=0}^{n}(1 - To/Ti)Qi + \sum_{in} m(ho - ToS) - \sum_{out} m(ho - ToS) - To\ To\ Sgen \quad (1.3)$$

3. FURTHER RECOMMENDATION

The persent energy cries and the continuing emphasis on efficiency (conservation of fuel resources) has led to complete overhaul of the way in which thermal power systems are to be analyzed and improve thermodynamically. The new methodology is based on exergy analysis and its optimization component is known as thermodynamic optimizarion or entropy generation minimization. The new approach is based on the simultaneous application of first - law and second law in analysis and design.

1. The second-law assessment of steam power plant identify and qualified the irreversible losses in each of power plant component at different condition of reheat and non - reheat option.
2. Second law analysis also indicate that incorporating combine reheating and regeneration can further improve the thermal efficiency of cycle and total irreversible losses. These improvement increase at a decreasing rate as the number of feed heater increases.
3. The second-law efficiency of steam cycle is larger than the first law efficiency so long a boiler exhaust temperature ratio is less than the gas turbine exhaust temperature ratio plus unity,a condition satisfied in any practical steam bottoming cycle.
4. Second-law based thermodynamics analysis of an intercooled,reaheat regenerative gas turbine based combined heat and power system can be carried out by using the concept of exergy analysis.

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