Exergy Analysis Of Thermal Power Plant; A Review

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Abstract

Power generation industry plays a key role in the economic growth of the country. The energy supply to demand narrowing down day by day around the world, the growing demand of power has made the power plants of scientific interest, but most of the power plants are designed by the energy performance criteria based on first law of thermodynamics only. The real useful energy loss cannot be justified by the fist law of thermodynamics, because it does not differentiate between the quality and quantity of energy. The present study deals with the exergy analyses of thermal power plants stimulated by coal and provide a detailed review of different studies on thermal power plants over the years. This review will identify major sources of losses and exergy destruction in the power plant. It will provide ways and means to improve the system performance and reduce environment impact.

Keywords: Thermal power plant, Exergy analysis, Rankine cycle, Efficiency, Exergy destruction.

1. Introduction

Energy consumption is one of the most important indicator showing the development stages of countries and living standards of communities. Population increment, urbanization, industrializing, and technologic development result directly in increasing energy consumption. This rapid growing trend brings about the crucial environmental problems such as contamination and greenhouse effect. Currently, 80% of electricity in the world is approximately produced from fossil fuels (coal, petroleum, fuel-oil, natural gas) fired thermal power plants. In recent decades, exergy analysis based on Second Law of Thermodynamics has found as useful method in the design, evaluation, optimization and improvement of thermal power plants. The exergy analysis of thermal power plant is based upon both the first and the second laws of thermodynamic together, while the energy analysis is based upon the first law only. For these reasons, the modern approach to process analysis uses the exergy analysis, which provides a more realistic view of the process and a useful tool for engineering evaluation [1].

In thermal power plant the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a Rankine cycle.

1.1. Exergy System

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.

$$\acute{\eta} = \text{Exergy output} / \text{Exergy input}$$

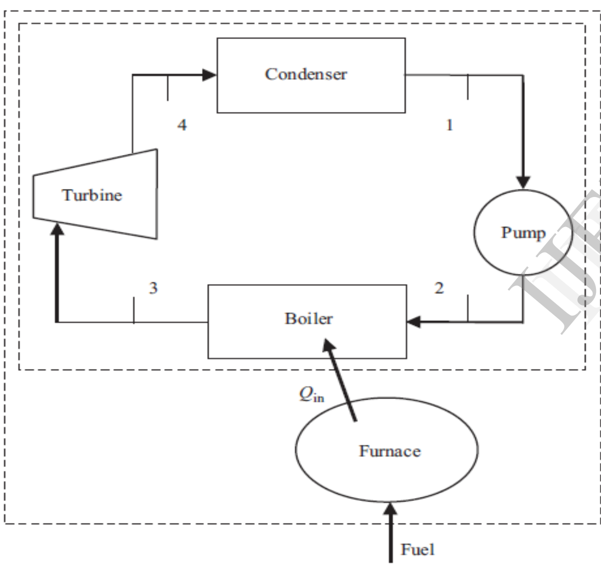

fig. 1 power cycle in thermal power plant

2. Equations

The exergy (Ψ_Q) of heat transfer Q from the control surface at temperature T is determined from maximum rate of conversion of thermal energy to work W_{max} is given by:

$$W_{max} = X_Q = \sum Q\left(1 - \frac{T_o}{T}\right) \quad (1)$$

And the specific exergy is given by

$$\Psi = (h - h_o) - T_o(s - s_o) \quad (2)$$

Then the total exergy rate associated with a fluid stream becomes

$$X = m\Psi \quad (3)$$

$$X = m[(h - h_o) - T_o(s - s_o)] \quad (4)$$

For a steady state operation, and choosing each component in control volume, the exergy destruction rate (I) and the exergy efficiency (ή) is given by:

For boiler:

$$I_B = X_{fuel} + X_{in} - X_{out} \quad (5)$$

$$\acute{\eta}_{II_B} = (X_{out} - X_{in}) / X_{fuel} \quad (6)$$

For turbine:

$$I_T = X_{in} - X_{out} - W_T \quad (7)$$

$$\acute{\eta}_{II_T} = 1 - I_T / X_{in} - X_{out} \quad (8)$$

For condenser:

$$I_C = X_{in} - X_{out} + W_F \quad (9)$$

$$\acute{\eta}_{II_C} = X_{out} / X_{in} + W_f \quad (10)$$

For pump:

$$I_P = X_{in} - X_{out} + W_P \quad (11)$$

$$\acute{\eta}_{II_P} = 1 - I_P / W_P \quad (12)$$

For cycle:

$$I_{Cycle} = \sum I_{all\ component} \quad (13)$$

$$\acute{\eta}_{II_{Cycle}} = W_{net\ out} / X_{fuel} \quad (14)$$

3. Literature Review

The following literature review describes important research results regarding the thermal power plant's analysis:

Isam H. Aljundi (2009) – is studied that the energy and exergy analysis of Al-Hussein power plant (396MW) in Jordan is presented. The performance of the plant was estimated by a component wise modeling and a detailed break-up of energy and exergy losses for the considered plant has been presented. It was found that the exergy destruction rate of the boiler is dominant over all other irreversibility in the cycle. It counts alone for 77% of losses in the plant, while the exergy destruction rate of the condenser is only 9%.The real loss is primarily back in the boiler where entropy was produced. Contrary to the first law analysis, this demonstrates that significant improvements exist in the boiler system rather than in the condenser. Exergy analysis provides the tool for a clear distinction between energy losses to the environment and internal irreversibility in the process. Exergy analysis is a methodology for the evaluation of the performance of devices and processes, and involves examining the exergy at different points in a series of energy-conversion steps. With this information, efficiencies can be evaluated, and the process steps having the largest losses (i.e., the greatest margin for improvement) can be identified [1].

Kiran Bala Sachdeva and Karun (2012) – are determined that the magnitude, location and source of thermodynamic inefficiencies of thermal power plant. The first law of thermodynamics introduces the concept of energy conservation, which states that energy entering a thermal system with fuel, electricity, flowing streams of matter, and so on is conserved and cannot be destroyed. In general, energy balances provide no information on the quality or grades of energy crossing the thermal system boundary and no information about internal losses. By contrast, the second law of thermodynamics introduces the useful concept of exergy in the analysis of thermal systems. Exergy is a measure of the quality or grade of energy and it can be destroyed in the thermal system. The second law states that part of the exergy entering a thermal system with fuel, electricity, flowing streams of matter, and so on is destroyed within the system due to irreversibility. The exergy losses in the turbines are due to the frictional effects and pressure drops across the turbine blades as well as the pressure and heat losses to the surroundings. Hence the First law analysis (energy analysis) cannot be used to pinpoint prospective areas for improving the efficiency of the electric power generation. However, the Second law analysis serves to identify the true power generation inefficiencies occurring throughout the power station. This paper has presented the results of energy and exergy analysis performed in a steam power plant. From the energy analysis, the overall plant energy losses are calculated as 68%.The results of the exergy indicate that the boiler produces the highest exergy destruction [2].

M.A. Ehyaei, A. Mozafari and M.H. Alibiglou (2011) – are presented that the exrgy, economic & environmental analysis of Shahid Rajaee gas turbine power plant in Iran. Also a new function is proposed for system optimization that includes the social cost of air pollution for power generating systems. The new function is based on the first law efficiency, energy cost and the external social cost of air pollution for an operational system. In the present paper, the following specific contributions could be considered from this study results obtained in Shahid Rajaee power plant:

- Entropy production, exergy and economic analysis of gas turbine power plant with inlet air cooling.
- Development of a computer program code in FORTRAN language which can be applied for simulation of any type of gas turbine with and without fogging system in the inlet air cooling.
- Calculating electricity production costs for two cases of with and without fogging system, with considering the cost of environmental impacts from economical view point.

Economic activity and environmental conditions are related. Production and consumption may pollute the environment, and at the same time the state of the environment may affect the production capacity. Thus, studying external cost of air pollution should be handled within an integrated model. So that, in economic analysis of these systems, external cost of air pollution is considered. The economic aspect of these effects is called internalized external cost of air pollution [3].

Mali Sanjay D and Dr. Mehta N S (2012) – are observed that the energy and exergy analysis method for thermal power plant and analysis carried out on 125 MW coal base thermal power plants is presented. Most of the power plants are designed by the energetic performance criteria based on first law of thermodynamics only. The real useful energy loss cannot be justified by the fist law of thermodynamics, because it does not differentiate between the quality and quantity of energy. Energy analysis presents only quantities results while exergy analysis presents qualitative results about actual energy consumption. In this analysis shows exergy efficiency is less at each and every point of unit equipments. Also presents major losses of available energy at combustor, super heater, economizer and air-pre heater section. In this article exergy efficiency, exergy destruction and energy losses comparison charts are also define. The definite value of thermal energy can only be obtained by a qualitative or exergy analysis of its conversion, transport and distribution.

- It has been observed that Exergy efficiency is lower than Energy efficiency it has been observed that APH, Super heater and economizer (heat exchanger) are main parts that contributed loss of exergy.
- It has been found that 47.43% exergy loss occur in combustor (furnace) which shows combustor is not fully adiabatic and combustion may not be complete. It is due to the irreversibility within the combustion process. This study pin points that the combustor requires necessary modification like refractory (insulation) modification to reduce exergy destructions thereby plant performance can be improved.

- The major energy destruction occurs in the heat recovery system which leads to inefficient heat transfer between hot stream (flue gas) and cold stream (water & air).It indicates heat exchanger system need to be carefully inspected [4].

Alvaro Restrepo, Raphael Miyake, Fabio Kleveston and Edson Bazzo (2012) – are determined that the results of exergetic and environmental analysis of a typical pulverized coal power plant located in Brazil. The goal was to quantify both the exergy destruction and the environmental impact associated with a thermal power plant. According to the results, it can be noted that the exergetic and environmental models showed a similar behavior. The greater the exergy destruction, the greater the environmental impact from the power plant. The study focused only on the operation period. The efficiency of the power plant is the main parameter to be considered, since is closely related to the consumption of coal and therefore with the CO2 release. The study considered an extended boundary following the entire coal route and the associated processes. The exergy analysis showed that the highest irreversibility was associated with the power plant. This result was expected due to the high level of entropy generation in the combustion process. A sensitivity analysis was also conducted, showing that an improvement of the power plant efficiency leads to a meaningful improvement of the exergy and environmental performance [5].

Naveen Shrivastava, Seema Sharma and Kavita Chauhan (2012) – are presented that the efficiency assessment and benchmarking of thermal power plants in India. Performance improvement of very small amount can lead to large contribution in financial terms, which can be utilized for capacity addition to reduce demand supply gap. With this view, relative technical efficiency of 60 coal fired thermal power plants (being main source of electricity in India) has been evaluated. In India, total energy shortage and peaking shortage were recorded as 11.2% and 11.85%, respectively in 2008–09 (Central Electricity Authority, 2009a,b,c,d), reflecting non-availability of sufficient supply of electricity. According to National Perspective Plan for R&M, Central Electricity Authority (Central Electricity Authority, 2009c), and some power plants have completed or about to complete their economic life. Replacement of over aged power plants with latest technology power plants is also recommended in order to improve overall efficiency [6].

Mohammad Ameri and Nooshin Enadi (2012) – are presented that complete thermodynamic modeling of one of the gas turbine power plants in Iran based on thermodynamic relations. The exergy analysis results revealed that the combustion chamber (CC) is the most exergy destructive component compared to other cycle components. Also, its exergy efficiency is less than other components, which is due to the high temperature difference between working fluid and burner temperature. Both thermodynamic modeling and exergy analysis of a gas turbine cycle were performed as part of this research study. The results from the exergy analysis show that the combustion chamber is the most significant exergy destructor in the power plant, which is due to the chemical reaction and the large temperature difference between the burners and working fluid [7].

P. Regulagadda, I. Dincer and G.F. Naterer (2010) – are performed that a thermodynamic analysis of a subcritical boiler–turbine generator for a 32 MW coal-fired power plant. Both energy and exergy formulations are developed for the system. A parametric study is conducted for the plant under various operating conditions, including different operating pressures, temperatures and flow rates, in order to determine the parameters that maximize plant performance. The maximum exergy destruction is found to occur in the boiler. As a result, efforts at improving the performance of the power plant should be directed at improving the boiler performance, since this will lead to the largest improvement to the plant's efficiency [8].

T. Ganapathy, N. Alagumurthi, R. P. Gakkhar and K. Murugesan (2009) – are studied that 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. The present paper deals with an exergy analysis performed on an operating 50MWe unit of lignite fired steam power plant at Thermal Power Station-I, Neyveli Lignite Corporation Limited, Neyveli, Tamil Nadu, India. The exergy losses occurred in the various subsystems of the plant and their components have been calculated using the mass, energy and exergy balance equations. The comparison between the energy losses and the exergy losses of the individual components of the plant shows that the maximum energy losses of 39% occur in the condenser, whereas the maximum exergy losses of 42.73% occur in the combustor. The real losses of energy which has a scope for the improvement are given as maximum exergy losses that occurred in the combustor [9].

Marc A. Rosen, Ibrahim Dincer and Mehmet Kanoglu (2008) – are studied that the use of exergy is described as a measure for identifying and explaining the benefits of sustainable energy and technologies, so the benefits can be clearly understood and appreciated by experts and non-experts alike, and the utilization of sustainable energy and technologies can be increased. Exergy can be used to assess and improve energy systems, and can help better understand the benefits of utilizing green energy by providing more useful and meaningful information than energy provides. Exergy clearly identifies efficiency improvements and reductions in thermodynamic losses attributable to more sustainable technologies. Exergy clearly identifies efficiency improvements and reductions in thermodynamic losses attributable to green technologies. Exergy can also identify better than energy the environmental benefits and economics of energy technologies. Thus, exergy has an important role to play in increasing utilization of green energy and technologies [10].

4. Conclusion

Following conclusions can be drawn from this study;

1. The first law analysis shows major energy loss has been found to occur in condenser. The second law (exergy) analysis shows that combustion chamber in both steam and gas turbine thermal power plants are main source of Irreversibility. An exergy method of optimization gives logical solution improving the power production opportunities in thermal power plants.
2. The first law analysis shows major energy loss has been found to occur in condenser. The second law (exergy) analysis shows that combustion chamber in both steam and gas turbine thermal power plants are main source of Irreversibility.
3. The major energy destruction occurs in the heat recovery system which leads to inefficient heat transfer between hot stream (flue gas) and cold stream (water & air). It indicates heat exchanger system need to be carefully inspected.
4. Preheating the reactants is the most common way of reducing the irreversibility of a combustion process. The preheating is usually carried out using product of combustion after they have performed their main heating duty and before they are discharged into atmosphere.
5. The exergy analysis showing that an improvement of the power plant efficiency leads to a meaningful improvement of the overall performance.
6. In every plant component such as a boiler, combustion chamber there is some intrinsic irreversibility which cannot, owing to the present state of technological development, be eliminated.
7. The maximum exergy destruction is found to occur in the boiler. As a result, efforts at improving the performance of the power plant should be directed at improving the boiler performance, since this will lead to the largest improvement to the plant's efficiency.

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