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Exergy Based Evaluation of Coal Based Thermal Power Plants: A Review

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Abstract

The electricity sector in India supplies the world's 6th largest energy consumer, accounting for 3.4% of global energy consumption by more than 17% of the global population. Due to the fast paced growth of Indian economy there has been an average increase of 3.6% in the energy demand per annum over the last 30 years. This paper presents a review of the methodology to evaluate the performance of coal based thermal power plant using the exergy as the main criterion instead of the conventional First Law of thermodynamics based approach which does not account for the inherent irreversibilities of the system and is hence inappropriate for evaluation of coal based thermal power plants.

I. Introduction

The electricity sector in India supplies the world's 6th largest energy consumer, accounting for 3.4% of global energy consumption by more than 17% of the global population. Due to the fast paced growth of Indian economy there has been an average increase of 3.6% in the energy demand per annum over the last 30 years. In December 2010, the installed power generation capacity of India stood at 165,000 MW and the per capita energy consumption was 612 KW. Hence it can be safely concluded that India is an energy deficient country and to meet the energy requirements of the fast developing economy.

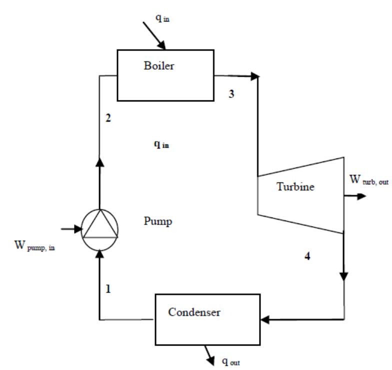
This paper presents a review of the methodology to evaluate the performance of coal based thermal power plant using the exergy as the main criterion instead of the conventional First Law of thermodynamics based approach which does not account for the inherent irreversibilities of the system and is hence inappropriate for evaluation of coal based thermal power plants. The paper illustrates the work done by some of the leading researchers in this field.

II. Cycle Analysis Of Coal Fired Power Plants

Coal based thermal power plant working base on Rankine power cycle. The ideal cycle for vapor power cycles many of the impracticalities associated with the Carnot cycle can be eliminated by superheating the steam in the boiler and condensing it completely in the condenser.

The cycle that results is the Rankine cycle, which is the ideal cycle for vapor power plants. The ideal Rankine cycle does not involve any internal irreversibility and consists of the following four processes:

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



(a)

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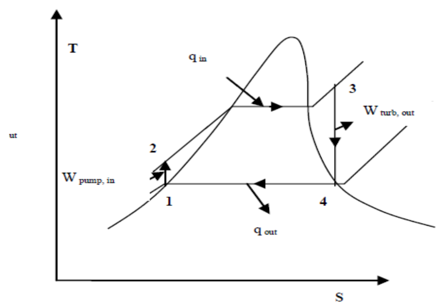

T-S diagram

(b)

Fig. 1 Schematic of the Rankine Cycle

The efficiency of Rankine cycle can be improved by considering following points [1]:

1. Lowering the Condenser Pressure
2. Superheating the Steam to High Temperatures
3. Increasing the Boiler Pressure

III. First And Second Law Analysis Of Coal Fired Power Plants

Second law is a generic term for a group of concepts that define the maximum work potential of a system, a stream of matter or a heat interaction; the state of the (conceptual) environment being used as the datum state. In an open flow system there are three types of energy transfer across the control surface namely working transfer, heat transfer, and energy associated with mass transfer or flow.

Exergy of steady flow stream of matter is sum of kinetic, potential and physical exergy. The kinetic and potential energy are again equivalent to exergy. The physical specific exergy depends on initial state of matter and environmental state.

Energy analysis is based on the first law of thermodynamics, which is related to the conservation of energy. Second law analysis is a method that uses the conservation of mass and conservation of energy principles together with the entropy for the analysis.

The exergy analysis is the combination of the First and Second laws of thermodynamics. This analysis provides a quantitative measure of the quality of the energy in terms of its ability to perform work and leads to a more rational use of energy.

In general, the specific exergy denoted by "ε" is calculated using the equation as given below.

$$\varepsilon = \varepsilon_{k.e} + \varepsilon_{p.e} + \varepsilon_{ch} + \varepsilon_{ph} \qquad (1)$$

Where $\varepsilon_{k.e}$ & $\varepsilon_{p.e}$ are the exergies due to kinetic & potential energies respectively, ε_{ph} is the physical exergy and ε_{ch} is the chemical exergy.

The exergy analysis [2] of a cogeneration system provides exergetic efficiency as a parameter for evaluating thermodynamic performance. The exergetic efficiency (second law efficiency) provides a true measure of performance of an energy system from the thermodynamic viewpoint.

The first law of thermodynamics or energy balance for steady flow process of an open system is given by:

$$\sum Q_K - \dot{W} + \dot{m}(E_1 - E_2) \qquad (2)$$

Where E_1 and E_2 are respectively the energy associated with mass entering and leaving the system, Q_K is heat transfer to system from source at T_k, and W is net work developed by the system.

The energy or first law efficiency of a system or system component is defined as the ratio of energy output to the energy input of system or system component:

$$\eta_a = \text{Output Work / Input Energy} \qquad (3)$$

The second law efficiency is defined as:

$$\eta_b = \text{Desired Output / Max. Possible Output} \qquad (4)$$

IV. Work Done On First And Second Law Analysis Of Coal Fired Power Plants

Bejan [3] outlines the fundamentals of the methods of exergy analysis and entropy generation minimization (or thermodynamic optimization-the minimization of exergy destruction).

George and Park [4] discusses how to estimate the avoidable and unavoidable exergy destruction and investment costs associated with compressors, turbines, heat exchangers and combustion chambers.

S. K. Som et. al. [5] pointed out that, in almost all situations, the major source of irreversibilities is the internal thermal energy exchange associated with high temperature gradients caused by heat release in combustion reactions and the primary way of keeping the exergy destruction in a combustion process within a reasonable limit is to reduce the irreversibility in heat conduction.

P. Regulagadda et. al. [6] carried out the thermodynamic analysis of a subcritical boiler–turbine generator for a 32 MW coal-fired power plant and concluded that the boiler and turbine irreversibilities yield the highest exergy losses in the power plant.

J. H. Horlock et al. [7] estimated the rational efficiencies of three modern fossil-fuel power plants using the exergy calculations. They analyzed the effect of water or steam injection on the rational efficiency of the plant. The correlation between the irreversibility in combustion and the loss of exergy due to mixing in the exhaust was also considered in their work.

Z. Oktay [8] analyzed a coal based thermal power plant with a total installed capacity of 2 *160 MW. Exergy efficiencies, irreversibilities, and improvement factors of turbine, steam generator and pumps have been calculated for selected plant. Comparison between conventional and fluidized bed power plant have been made and improving techniques have also been given for the conventional plants.

H. Jin et al. [9] analyzed two operating advanced power plants using a methodology of graphical exergy analysis. They located the inefficient segments in the combined cycle plant. They concluded that the inferior performance of the combined cycle plant is due to the higher exergy loss caused by mixing in the combustor.

T. Ganpathy et. al. [10] carried out the exergy analysis for each component in the subsystems, to evaluate the exergy losses in the individual component and then the analysis was performed on the overall individual subsystems, to find out the exergy losses in each subsystem. Finally the exergy analysis for the overall plant was done and the total plant exergy losses were computed. The energy and the exergy losses of the components of each system were determined using their mass, energy and exergy balance equations.

V. Conclusions & Discussion

This study illustrates the novel work done by the leading researchers in the field of thermal and power plant engineering and puts forward the exergy based analysis of a power plant as the way to approach the analysis of a power plant.

The study points out that the boiler, combustor and turbine are the critical components where maximum exergy losses occur. 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. The Irreversibility in condenser is insignificant, because in the condenser the low quality energy is lost. An Exergy method of optimization gives logical solution improving the power production opportunities in thermal power plants.

REFERENCES

[1] Vundela Siva Reddy et. al., "An Approach to Analyse Energy and Exergy Analysis of Thermal Power Plants: A Review", Smart Grid and Renewable Energy, 2010, 1, 143-152.

[2] Adrian Bejan, George Tsatsaronis, Michael Moran, "Thermal Design and Optimization", John Wiley & Sons Inc., 1996.

[3] A. Bejan, "Fundamentals of Exergy Analysis, Entropy Generation Minimization, and the Generation of Flow Architecture," International Journal of Energy Research, Vol. 26, No. 7, 2002, pp. 545-565.

[4] G. Tsatsaronis and M. Park, "On Avoidable and Unavoidable Exergy Destructions and Investment Costs in Thermal Systems," Energy Conversion & Management, Vol. 43, No. 9-12, 2002, pp. 1259-1270.

[5] S.K. Som, A. Datta, "Thermodynamic irreversibilities and exergy balance in combustion processes", Progress in Energy and Combustion Science 34, 351–376, 2008.

[6] P. Regulagadda, I. Dincer, G.F. Naterer, "Exergy analysis of a thermal power plant with measured boiler and turbine losses", Applied Thermal Engineering 30, 970–976, 2010.

[7] J.H. Horlock, J.B. Young, G. Manfrida, "Exergy Analysis of Modern Fossil– Fuel Power Plants", Journal of Engineering for Gas Turbines and Power, Vol. 122, 1 – 7, Jan. 2000.

[8] Zuhal Oktay, "Investigation of coal-fired power plants in Turkey and a case study", Applied Thermal Energy, Vol. 29, 550-557, 2009.

[9] H. Jin, M. Ishida, M. Kobayashi, M. Nunokawa, "Exergy Evaluation of Two Current Advanced Power Plants: Supercritical Steam Turbine and Combined Cycle", Trans. of ASME, Vol. 119, pp 250 – 256, Dec. 1997.

[10] T. Ganapathy, N. Alagumurthi, R. P. Gakkhar and K. Murugesan, "Exergy Analysis of Operating Lignite Fired Thermal Power Plant", Journal of Engineering Science and Technology Review 2 (1), 123-130, 2009.