International Journal of Engineering Studies.
ISSN 0975-6469 Volume 8, Number 1 (2016), pp. 11-19

http://www.ripublication.com

# Thermoexergetic analysis of Steam Power Plant

**Rajat Pardal[1], B. B. Arora[2] and Subhashish Maji[3]**

*[1*]Directorate of Training & Technical Education, Delhi (India)*
*[2]Deptt. of Mech. Engg., Delhi College of Engineering, Delhi (India)*
*[3]School of Engineering & Technology, IGNOU, Delhi (India)*
*[*]Corresponding Author E-mail: rp0160@yahoo.com*

**Abstract**

The present paper investigates the effectiveness of the power plant to offset the increasing demand of power. Energy and Exergy analysis has been carried out to determine the efficiency of each componet and the overall efficiency of the plant, Further evaluation of energy and exergy loss and destruction has been analysed. This has been done in order to identify the component where useful energy loss can be recoverd by making the necessary arrangements to the system components so that it improves the efficiency of the component and the plant thereoff. Boiler and turbine are the sources of maximum exergy loss which needs to be redesigned.

## Introduction

The use of various energy by humans in a range of activities has dominated the scene for several centuries. However, in last two centuries, the per capita consumption of energy has assumed great importance. Demand of energy is increasing day by day. To meet this demand there are two ways one is to generate more energy and the second one is to tap the otherwise waste energy. First one requires huge amount of money whereas the second one can be easily achieved by changing the strategy to generate universal energy namely Electrical energy. Most of the power/energy is generated by burning fossil fuel namely coal. To reduce the rate of consumption of fossil fuel for same amount of energy in a coal fired power plant is one of the important aspects, with rapid growth of civilization and increasing consumption of energy.

Researchers such as Evans, 1962; Tribus et al., 1960; Tribus and Evans, 1963,El-Sayed and Aplenc, 1970; El-Sayed and Evans, 1970, Darwish, Al-Najem and Al-Ahmad, 1993; El-Nashar,1993 Al-Sulaiman and Ismail, 1995; Hamed et al., 1999; have been striving for generating more power using all resources but the thermal plants based upon coal, gas and liquid fossil fuels are still in vogue rather in predominant use.Needless to say that energy in form of electricity, has become one of the most important aspect of human life. Most of the activities of time rely upon electrical emergy and its breakdown simply perturbs all of them. It would not be an exaggeration to say basic need for human beings next to food, clothing and shelters is electrical energy.

Generation of electrical power/energy seems to be simple however it a formidabale task. Its generation necessitates high investment and a sound technical know- how. Besides, it poses several hazards. Effiecient advanced, and a proven technical know-how is essential for economical generation of electrical power/energy.

The generation process of electrical power/energy being complex energy system can be analyzed in terms of its economics and efficiency as a function of resource consumption. Thermoexergetics, and its applications to energy systems, can help us to formulate improved and effcient designs.

Energy analysis is based on first law of thermodynamic where irreversibility of the systems is not distinguished which means degradation of energy quality is not considered. So the first law of thermodynamics does not differentiate between the quality and quantity of energy. Therfore the justification of real useful energy loss cannot be predicted by the first law of thermodynamics, though it is the starting point of any thermodunamic analysis.

So in order to achieve higher efficiency an analysis which could take into accout the irreversibilities of the system is necessary. Exergy analysis based on second law of thermodynamics is appropriate ome to take care of the possible irreversibilities in the system or system components.

Exergy (an energetic property) analysis locates and quantifies irreversibilities(losses) in a process and hence tells us about the quality of energy. Exergy based thermoeconomic methods are also referred to as “exergoeconomics” (Tsatsaronis and Winhold, 1985).

Destruction in exergy is proportional to entropy generation, which accounts for inefficiencies. The exergy analysis identifies the area where and how much the loss or destruction occurrs. It also analyses the components where there is a possibility to improve the efficiency of the power plant.

In the present work Energy and Exergy analysis has been carried out to determine the efficiency of each componet and the overall efficiency of the 122 MW Steam Power plant.

## Methodology

Major components of steam power plant were listed. Terminal points were selected in order to measure the thermodynamic parameters such as temperature, pressure, mass flow rate etc. Readings were recorded at each entryand exit of components of the system.

At full load condition parameter reading were recorded.

Enthalpy and entropy values at these terminal points were computed from the steam tables. Energy and exergy analysis was computed for each components of the system.

The Exergy destruction at each terminal point was computed and the loss was determined with location and magnitude. The energy and exergy efficiency was also computed and in order to identify the loss occurring in power plant components.

## Energy and Exergy equations of steam power plant

Figure 1 shows the schematic diagram of steam power plant and Figure 2, describes the Temperature Entropy diagram for the plant.

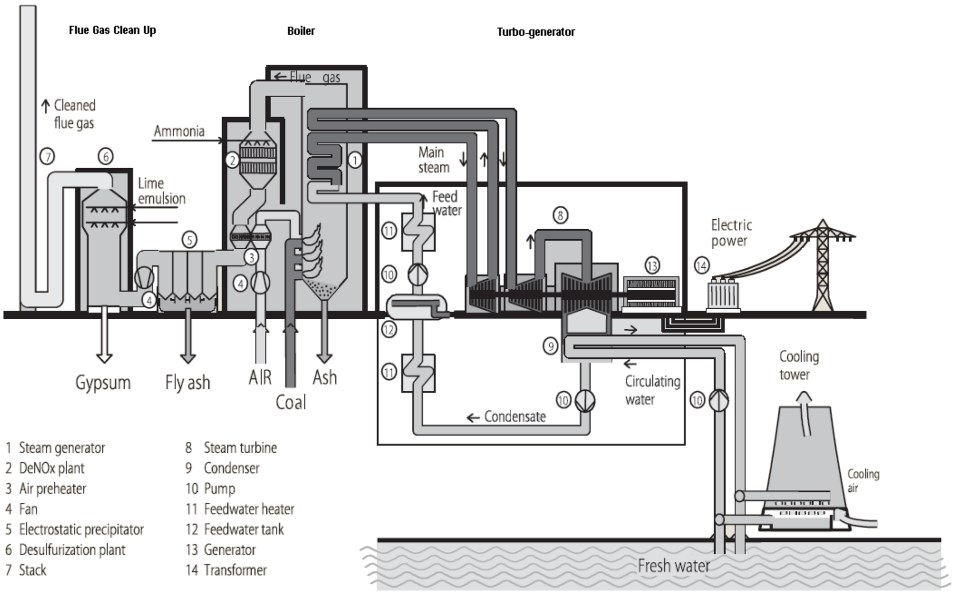


**Figure 1:** Steam power plant

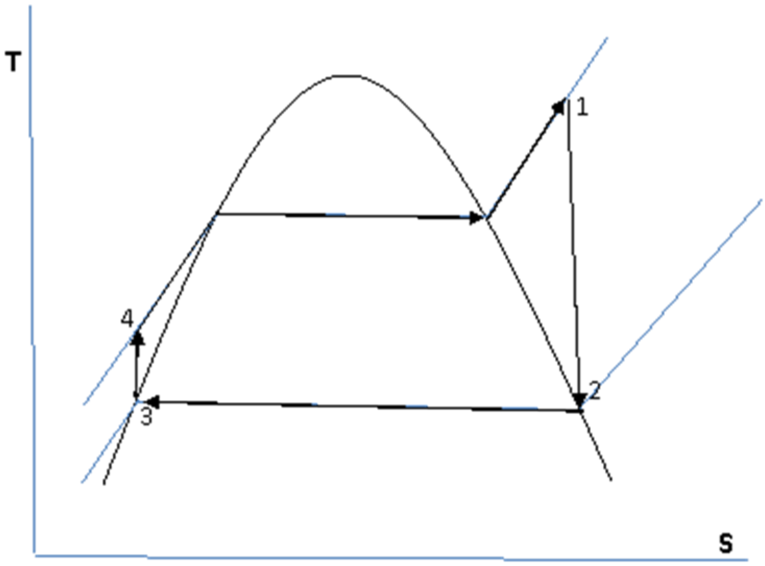


**Figure 2:** T-S diagram of steam cycle

## Operating conditions of the power plant

Feed water inlet temperature to boiler= 494.15 K
Steam Flow rate (100%: 311.5 ton/h) (75%: 225 ton/h) (50% 198 ton/h)
Steam temperature 811K
Steam pressure 166.4 bar
Power output 122 MW max

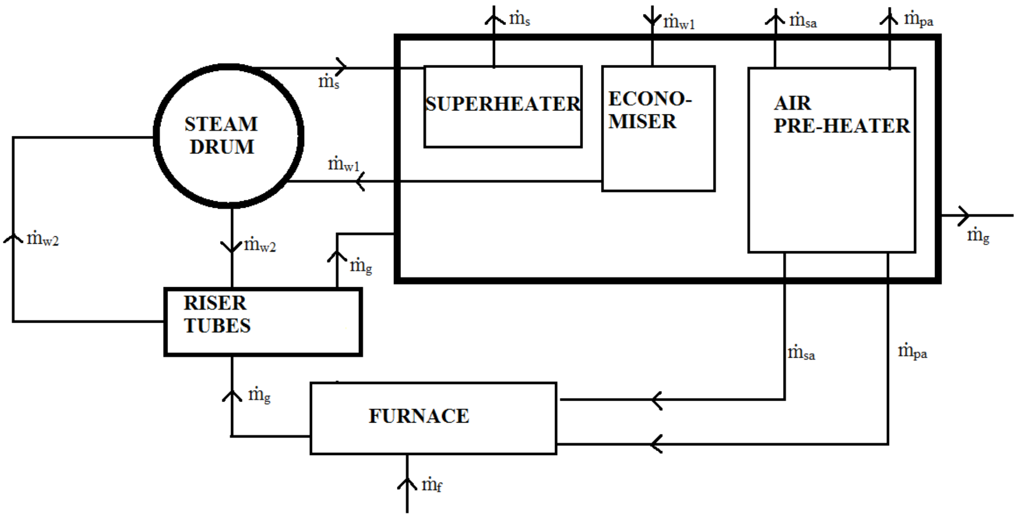


**Figure 3:** Boiler and its components

**(a) Furnace:**
**Energy analysis**:-

$E_i = \dot{m}_f h_f + \dot{m}_{pa} h_{pa} + \dot{m}_{sa} h_{sa}$
$E_o = \dot{m}_g h_g$
$E_{loss} = E_i - E_o$
$\eta_I = E_o/E_i$

**Exergy analysis:-**

$X_i = \varepsilon_f + \varepsilon_{pa} + \varepsilon_{sa}$
$X_o = \varepsilon_g$
$I = X_i - X_o$
$\eta_{II} = X_o/X_i$

Where-
$\varepsilon_{pa} = \dot{m}_{pa} (h_{pa} - T_o s_{pa})$
$\varepsilon_{sa} = \dot{m}_{sa} (h_{sa} - T_o s_{sa})$
$\varepsilon_g = \dot{m}_g (h_g - T_o s_g)$
Exergy of fuel is given by the equation proposed by Shieh and Fan for calculating the Exergy of fuel
$\varepsilon_f$ =34183.16(C) +21.95 (N) +11659.9 (H) +18242.90 (S) +13265.9 (O) KW

**(b). Heat Recovery System-**

**Energy analysis:-**

$E_i = \dot{m}_g (\Delta h_{i\text{-}o})_g$

$E_o = \dot{m}_{sup} (\Delta h_{i\text{-}o})_{sup} + \dot{m}_w (\Delta h_{i\text{-}o})_w + \dot{m}_{pa} (\Delta h_{i\text{-}o})_{pa} + \dot{m}_{sa} (\Delta h_{i\text{-}o})_{sa}$

$E_o = \dot{m}_{sup} (h_o - h_i)_{sup} + \dot{m}_w (h_o - h_i)_w + \dot{m}_{pa} (h_o - h_i)_{pa} + \dot{m}_{sa} (h_o - h_i)_{sa}$

$E_{loss} = E_i - E_o$

$\eta_I = E_o/E_i$

**Exergy Analysis**:-

$X_i = \varepsilon_{gi} - \varepsilon_{go} = \dot{m}_g (h_g - T_o s_g)_i - \dot{m}_g (h_g - T_o s_g)_o$

$X_o = (\varepsilon_{sup\,(o)} - \varepsilon_{sup\,(i)}) + (\varepsilon_{w\,(o)} - \varepsilon_{w\,(i)}) + (\varepsilon_{pa\,(o)} - \varepsilon_{pa\,(i)}) + (\varepsilon_{sa\,(o)} - \varepsilon_{sa\,(i)})$

$X_o = [\dot{m}_{sup} (h_{sup} - T_o s_{sup})_o - \dot{m}_{sup} (h_{sup} - T_o s_{sup})_i] + [\dot{m}_w (h_w - T_o s_w)_o - \dot{m}_w (h_w - T_o s_w)_i] + [\dot{m}_{pa} (h_{pa} - T_o s_{pa})_o - \dot{m}_{pa} (h_{pa} - T_o s_{pa})_i] + [\dot{m}_{sa} (h_{sa} - T_o s_{sa})_o - \dot{m}_{sa} (h_{sa} - T_o s_{sa})_i]$

$I = X_i - X_o$

$\eta_{II} = X_o/X_i$

**Analysis of Turbine:**

**(a) Energy analysis:**

For adiabatic turbine-

$E_i = \dot{m}_s h_1$

$E_o = \dot{m}_s h_2$

Energy balance

$E_i = E_o + W$

$\eta_I = 1 - E_o/E_i$

(b) Exergy analysis:

$X_i = \dot{m}_s (h_1 - T_o s_1)$

$X_0 = \dot{m}_s (h_2 - T_o s_2)$

Exergy balance

$X_i - I - W_o = X_0$

$\eta_{II} = 1 - I / (X_i - X_0)$

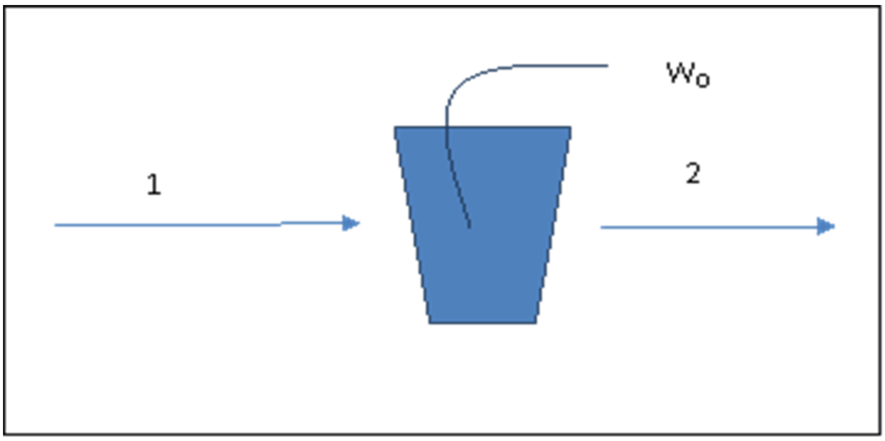


**Figure 4:** Steam Turbine TURBINE

**Table 1:** Exergy destruction rate and the exergy efficiency plant

| COMPONENTS | EXERGY DESTRUCTION | EXERGY EFFICIENCY |
|---|---|---|
| 1.PUMP | $I_P = X_3 + W_P - X_4$ | $\eta = \frac{X4 - X3}{W_P}$ |
| 2. CONDENSOR | $I_{con} = (X_2 - X_3) - (X_{3'} - X_{2'})$ | $\eta = 1 - \frac{Icon}{(X_2 - X_3)}$ |
| 3. TURBINE | $I_t = X_i - X_o - W_t$ | $\eta = \frac{W_t}{(X_i - X_o)}$ |

## Results and discussion

The energy losses at various components of power plant were analysed and the results computed for energy as well as exergy analysis were as under

**Table 2:** Comparision of Energy and Exergy analysis

| | I Law (Energy Efficiency(% )) | II Law (Energy Efficiency(% )) |
|---|---|---|
| Boiler | 76 | 42 |
| Turbine | 87 | 65 |
| Condenser | 18 | 13 |
| Condenser Pump | 90 | 84 |
| Low Pressure Heater | 91 | 86 |
| Deaerator | 68 | 66 |
| Boiler feed Pump | 98 | 96 |
| Economizer | 85 | 72 |
| Air Pre Heater | 75 | 71 |

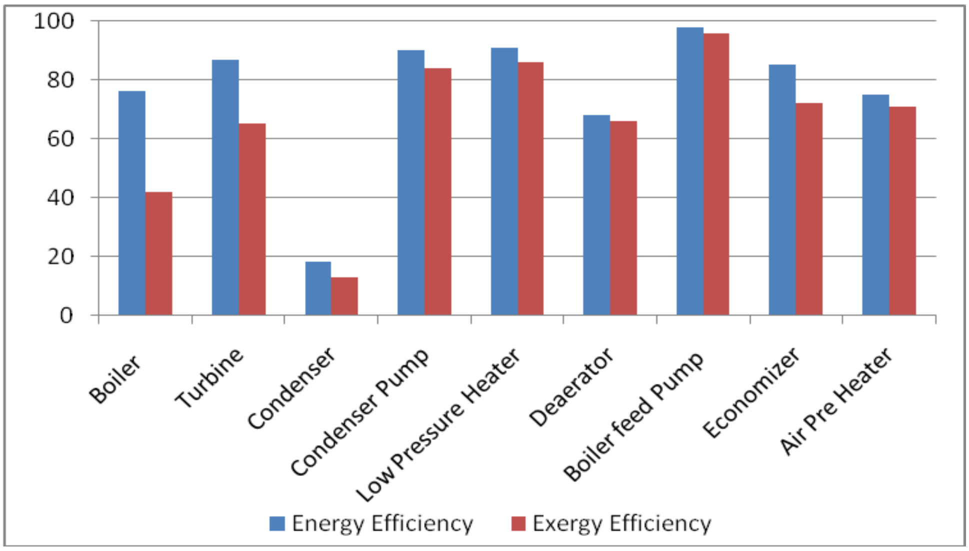


**Figure 5:** Comparision of Energy and Exergy analysis

The Exergy analysis of major components were carried out, where from the above graph we can identify the useful energy loss that is taking place in the plant are determined through various components as listed above. Boiler and turbine show major losses are in boiler and turbine both in energy and exergy estimatation.
So there is need to redesign the Boiler as well as turbine is in order to reduce the heat loss and better heat transfer in boiler and turbine.

## Conclusion

The following conclusions have been drawn from the drawn from the site study at thermal power plant,

- The exergy analysis of the power plant components identifies that useful energy is less in almost all the components of the power plant as computed from the energy analysis. This
- Boiler and turbine of a power plant are the major sources of useful energy loss.
- Only negligible amounts of useful waste energy can be recovered through implementing some heat recovery system.
- In order to achieve significant improvement of energy efficiency the boiler and turbine systems need to be redesigned.

## Nomenclature-

| | |
|---|---|
| $\dot{m}$ | mass flow rate (kg/sec) |
| h | specific enthalpy (kJ/kg) |
| $T_o$ | surrounding temperature (Kelvin) |
| s | specific entropy (kJ/kg K) |
| I | exergy destruction (kJ/sec) |
| X | exergy rate (kJ/sec) |
| W | power (KW) |
| e | specific exergy (KJ/Kg) |
| x | mole fraction of constituents |

**Suffix-**

| | |
|---|---|
| f | fuel |
| pa | primary air |
| sa | secondary air |
| g | hot gas stream |
| i | input |
| o | output |
| sup | superheated steam |
| t | Turbine |
| p | pump |
| con | condenser |
| cc | combustion chamber |

com compressor
t turbine
ph physical
ch chemical

**Greek symbols-**
$\eta_I$ first law efficiency
$\eta_{II}$ second law efficiency
$\varepsilon$ exergy associated with individual's component (kJ/sec)
X exergy rate (kJ/sec)

## References:

[1] Abdel-Jawad, M.,Al-Tabtabaei, M.(1999). *Impact on Current Power Generation and Water Desalination Activities on Kuwait Marine Enviornment*. Proceedings of the IDA word congress on desalination and water reuse. San Deiego.USA
[2] Ahrendts, J. (1980). *Reference States.*Energy 5, Vol. 8, pp. 667-677.
[3] Aljundi, I.H." Energy and exergy analysis of a steam power plant in Jordan" Applied Thermal Engineering, Volume 29, Issues 2-3, February 2009, Pages 324-328.
*[4]* American Society of Mechanical Engineers (ASME) (1967). *1967 ASME Steam Tables.*
[5] The American Society of Mechanical Engineers. New York, USA.
[6] Badr, O., Probert, S. D., O'Callaghan, P. (1990).*Rankyne Cycles for Steam Power-Plants.*Applied Energy 36, pp. 191-231.
[7] Barner, H. E., Scheuerman, R. V. (1978). *Handbook of Thermochemical Data for Compounds and Acqueous Species.* John Wiley and Sons Inc.
[8] Brown Boveri Co. (BBC) (1979). *Thermal Kit, Simplified Instructions for the Thermal Calculation of the Antikokan Units*. HTGD 12246 E.
[9] Bejan,A., Tsatsaronis,G.,Moran, M.(1997). *Thermal Design And Optimization*.John Wiley and Sons Inc., New York.
[10] Benelmir,R(1989). *Second Law Analysis of a Co-generation Cycle*. Ph.D thesis, Georgia Institute of Technology.
[11] Boehm,R.. F. (1987). *Design Analysis of Thermal Systems*. Ed John Wiley and Sons, New York.
[12] Cengel, Y.A., Boles, M.A.," Thermodynamics: An Engineering Approach", fifth ed. McGraw-Hill, New York. 2006.
[13] Cooke,D.H. (1985) *On Prediction of off design Multistage Turbine Pressures by Stodola's Ellipse. Journal of Engineering for Gas Turbines and Power*. Transactions of ASME. Vol.107,pp.596-606.
[14] Corripio,A. B.,Chrien, K. S., Evans, L,B. (1982). *Estimate Costs of Heat Exchangers and Storage Tanks Via Correlations*. Chemical Engineering, January 1982, pp125-127.

[15] El-Sayed,Y. M., Aplenc,A. J.(1970). *Application of the Thermoeconomic Approach in the Analysis and Optimization of Vapor-Compression Desalting System*. Transactions of the ASME. Journal of Engineering and Power,Vol. 92 no. 1, pp 17-26.

[16] El-Sayed,Y. M., Tribus, M. (1983). *Strategic Use of Thermoeconomics for Systems Improvement*. Acs Symposium series, no. 235, pp. 215-238. Washington D.C., U.S.A..

[17] Frangopoulus,C.A. (1988). *Optimal Design of a Gas Turbine Plant by a Thermoeconomic Approach*. ASME COGEN-TURBO, pp. 563-571. ASME, New York, USA.

[18] Gaggioli, R. A., El- Sayed, Y.M.(1987). *A Critical Review of Second Law Costing Methods. Proceedings of IV International Symposium on Secon Law Analysis of thermal Systems*.(ASME Book I00236). ASME, pp. 59-73. New York, USA.

[19] Kotas, T. (1985). *The Exergy Method of Thermal Plant Analysis*. Butteerworth eds., London UK.

[20] Lozano, M.A., Valero,A. (1993). *Theory of Exergetic Cost*. Energy, Vol. 18, no.3, pp. 939-960. Elsevier Science Ltd., UK.

[21] Sarang, J and Amit, k.,Exergy Analysis of Boiler In cogeneration Thermal Power Plant, 2013, Volume-02, Issue-10, pp-385-392.

[22] Sciubba, E.; Wall, G. “A brief Commented History of Exergy From the Beginnings to 2004” Int. J. of Thermodynamics ISSN 1301-9724 Vol. 10 (No. 1), pp. 1-26, March 2007.