

# Exergetic Analysis of Bagasse & Coal Based Thermal Power Plant for Efficiency Optimization & Performance Improvement

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## Abstract

The examination is based on the data's of an active co-generation plant, it is aimed to determine which component of the system revised first & decrease the loss of exergy. This study carried out exergy & exergy analysis of thermal power plant in order to evaluate the exergetic efficiencies. The objective of this paper is to analyze the system components separately and to identify and quantify the site having largest exergy losses at cycle. The study involves the application of first and second laws of thermodynamics to components of co-generation plant. The study was an exhaustive one and the results shows that there was a scope of improving the overall efficiency. Finally it's concluded that a total review of the plant in terms of Exergy would be of great commercial interest to the thermal power plant.

## Keywords

Exergy, Exergetic Efficiency, Rankine Cycle, Exergy Loss.

## 1. Introduction

The term Exergy was used for the first time by Zoran Rant in 1956, he was Yugoslavian chemical engineer, scientist & professor, associated member of SAZU (Slovenian Academy of sciences & arts). The word refers to the Greek Words *ex* (external) and *ergos* (work), but the concept was developed by J. Willard Gibbs in 1873. Another term describing the same is Available Energy or simply Availability.

In thermodynamics, the exergy (in order usage, available work or availability) of system is the maximum useful work possible during a process that brings the system in equilibrium with heat reservoir. When the surrounding are the reservoir, exergy is the potential of the system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surrounding reach equilibrium exergy is zero. Exergy analysis is a thermodynamic analysis technique based on the first and second laws of thermodynamics which provides an alternative and illuminating means of assessing and comparing processes and systems rationally and meaningfully.

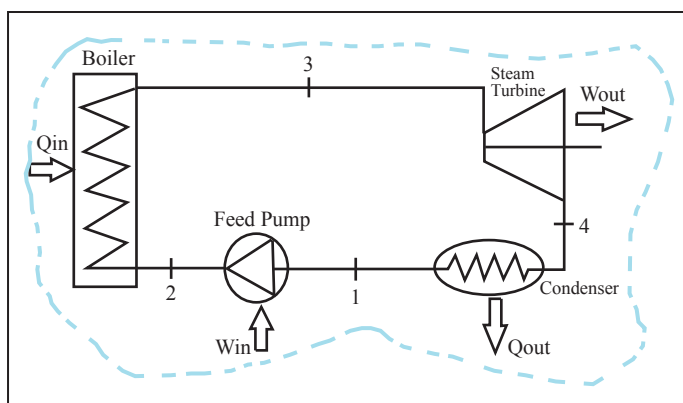


Fig. 1: Simple Rankine Cycle

A thermodynamic analysis of a Rankine cycle reheat steam power plant was carried out to study the energy and exergy efficiencies at different operating conditions of boiler temperature, boiler pressure and mass fraction ratio and work output from the cycle.

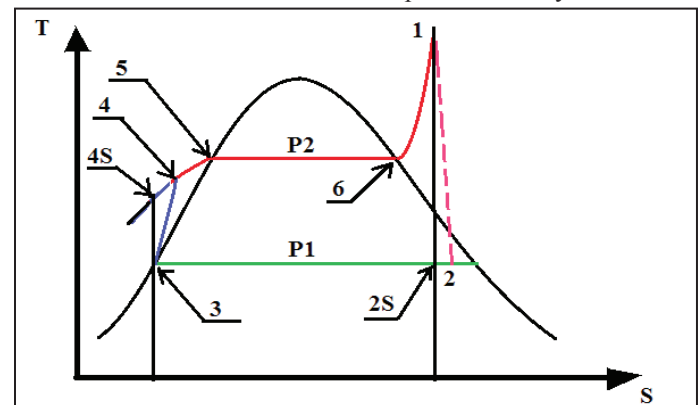


Fig. 2: T-S Diagram for Rankine Cycle

Basically the performance of system is assessed by exergy analysis as it is derived from the second law of thermodynamic which makes it rise from the limitation of an energy based analysis. Exergy is annihilated in the system rather than conserved. The chief source of inefficiency in a system is amount of irreversibility which is exergy destruction. Thus, in a thermal system the location, the amount and the cause of thermodynamic deficiencies are determined by exergy analysis evaluating the degree of exergy destruction. The exergy analyses are based on the Second law of thermodynamics. It is the function of irreversible production of entropy.

We can obtain results for planning and optimizing energy. For this purpose, we need data analysis instrument, which we may find in two laws of thermodynamics. Exergy of a thermodynamic process shows efficiency or inefficiency of that process.

The first law of thermodynamics states that "total energy of isolated system (closed system) is constant; energy can be transformed from one form to another, but can be neither created nor destroyed." The second law of thermodynamics states that "the total entropy can never decrease over time for an isolated system." In all spontaneous processes, the total entropy always increases and the process is irreversible.

Analysis of energy, exergy and exergoeconomics were performed on a natural gas based steam power plant. Exergy destruction is the summation of exergy destruction of each component of the power plant. So exergy destruction of a cycle can be determined by tracing the individual component of the plant. During the operation some amount of energy is rejected into the surrounding and this energy cannot be converted into work, this is called unavailable energy.

We can obtain results for planning and optimizing energy. For this purpose, we need data analysis instrument, which we may find in two laws of thermodynamics. Exergy of a thermodynamic process shows efficiency or inefficiency of that process. Exergy provides us with a better understanding of processes for qualifying energy. Therefore, it would better to use exergy to locate, qualify and quantify energy destruction. Exergy can play an important role in strategic development of power plants and provision of use instructions in existing power plant.

## II. Objective

In today's era the demand of energy is much more than the available energy hence it is required to minimize the energy losses and thereby increasing available energy.

The objectives of the study are:

1. To examine the losses of steam, fuel, improper combustion of fuel and waste heat recovery.
2. To audit the Steam and calculations of efficiencies of boiler, steam turbine.
3. To taken a necessary action for to increase the efficiency with the help of results, calculations of efficiency of power plant and topping cycle ratio.
4. To analyze the Design parameters and working conditions of power plant.

## III. Methodology

There are two methods for analysis of efficiency

1. Direct Method
2. Indirect method

### 1. The Direct Method

Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel. This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. This efficiency can be evaluated using the formula:

$$\text{Efficiency} = \frac{\text{Heat output}}{\text{Heat input}} \times 100$$

### 2. The Indirect Method

Where the efficiency is the difference between the losses and the energy input. In order to calculate the boiler efficiency by indirect method, all the losses that occur in the boiler must be established. These losses are conveniently related to the amount of fuel burnt. In this way it is easy to compare the performance of various boilers with different ratings.

## IV. Method

The monitoring of co-generation plant is fully automated. Plant uses ABB (ASEA Brown Boveri) software for control operations. ABB software is used to control the power plant operation, and for daily report of plant. The controller are installed with design parameters. All power plant drives, parameters are controlled by Distribution Controlled System.

SCADA System is used for analyzing electrical power system. To analyze voltage ampere, Import, export, Grid of power supply.

## V. Literature Survey

Amir Vosough et al in his paper titled "Improvement Power Plant Efficiency with Condenser Pressure" the energy and exergy analysis of an ideal Rankin cycle with re-heat is presented. The primary objectives of this paper are to analyze the system components separately and to identify and quantify the sites having largest energy and exergy losses at cycle. In the analysis, exergy methods in addition to the more conventional energy analyses are employed to evaluate overall and component efficiencies and to identify and assess the thermodynamic losses [1].

Naveen Hooda et al in his paper titled "Exergy Analysis of Thermal Power Plants" studied exergy analysis to analyze the system components separately and to identify and quantify the sites having the maximum energy and exergy losses. It is possible to analyse each element of the cycle separately and to obtain the share of each one in total loss of the cycle [2].

Dr. Mehta N.S. et al in his paper titled "Exergy Analysis of a Cogeneration Plant" determines which component of the system should be revised first to raise the efficiency and decrease the loss of exergy. For this purpose, second law analysis of thermodynamics is applied to each component due to consider the effects of environmental conditions and take the quality of energy into consideration as well as the quantity of it. The exergy balance equations are produced and exergy loss is calculated for each component [3].

Raviprakash kurkiya et al in his paper titled "Energy Analysis of Thermal Power Plant" find ways to improve the performance of a system in a many ways, Most of the conventional energy losses optimization method are iterative in nature and require the interpretation of the designer at each iteration [4].

Luiz Felipe Pellegrini et al in his paper titled "Exergy Analysis of Advanced Cogeneration Plants for Sugarcane Mills: Supercritical Steam Cycles and Biomass Integrated Gasification Combined Cycles" cogeneration plants in sugarcane mills were primarily designed to consume all bagasse, and produce steam and electricity to the process [5].

## VI. Theory

Detected losses in co-generation power plant are:

1. Incomplete combustion of the fuel: It is very difficult to burn the fuel 100 %.
2. Content in the fuel: The moisture present in the fuel will absorb the latent Moisture heat of vaporization and traces of sensible heat, which adds small portion of losses.
3. Excess air loss: Hoping to achieve complete combustion, excess air is admitted in the boiler, which absorbs heat of combustion but may not take part in the combustion fully, which again adds the losses in the boiler.
4. Blow Down loss: Boiler blowdown is water intentionally wasted from a boiler to avoid concentration of impurities during continuing evaporation of steam. The water is blown out of the boiler with some force by steam pressure within the boiler.
5. The efficiency of a boiler also depends upon the ambient air temperature surrounding the boiler. For every 40 degree shift in ambient temperature, the efficiency of a boiler can get affected by at least 1%.

## A. Suggestions

1. Baggase feed to boiler is preheated by flue gas wasted from boiler, Moisture in bagasse can be reduced by 8 to 10 %. The amount of moisture content was 49%.

2. If flue gas is employed in plant the moisture content can be reduced up to 40%.
3. The temperature of waste water from co-generation plant is relatively high. The heat of that water goes to waste to the atmosphere. The loss of heat can be recovered to heat the make-up water by employing heat exchanger. This reduces the required amount of fuel to boiler and helps to improve the efficiency of boiler which further leads to enhance efficiency of co-generation plant.
4. Make up water is already pre-heated by solar or condensate before water feed to the boiler.

## B. Analysis

Boiler efficiency by indirect method

### 1. Efficiency before Suggestions

$$\begin{aligned} \text{Bagasse GCV} &= 4600 \times (1 - \omega) - \\ &(1200 \times S) \\ &= 2319.36 \text{ KCal/Kg} \end{aligned}$$

#### (i). Computation of theoretical air required:

$$\begin{aligned} &= \frac{[11.6 \times C + (34.8 \times H_2 - O_2/8) + (4.35 \times S)]}{100} \\ &= 3.085 \text{ Kg / Kg of Bagasse} \end{aligned}$$

#### (ii). To find out the excess air supplied on the basis of % O<sub>2</sub> (EA):

$$\begin{aligned} \% \text{ Excess air} &= \frac{O_2}{(21 - O_2)} \times 100 \\ &= 31.25 \% \end{aligned}$$

#### (iii). To find out the actual air supplied (AAS):

$$\begin{aligned} \text{AAS} &= \left[1 + \frac{\text{EA}}{100}\right] \\ &\times \text{Theoretical Air} \\ &= 4.049 \text{ Kg/Kg of Bagasse} \end{aligned}$$

#### (iv). To find out the actual mass of dry flue gas :

$$\begin{aligned} &\text{Actual mass of dry flue gas} \\ &= \left(C \times \frac{44}{12}\right) \\ &+ \left[\frac{N_2}{100} + (\text{Actual mass of air})\right] \\ &\times \frac{77}{100} \\ &+ (\text{Actual mass of air} \\ &- \text{Theoretical mass of air}) \times \frac{23}{100} \\ &= 4.1764 \text{ Kg/Kg of Bagasse.} \end{aligned}$$

#### (v). Computation of sensible heat loss in dry flue gas : L1

Formula used:

$$\begin{aligned} &= (\text{Mass of flue gas} \times \\ &\text{Specific heat of flue gas} \times \\ &\text{Temperature difference}) \times \\ &\frac{100}{\text{GCV of bagasse}} \\ &= 4.6235 \% \end{aligned}$$

#### (vi). Heat loss due to moisture formed due to Hydrogen in the fuel : L2

$$\begin{aligned} &= 9 \times H_2 \times (584 + C_p \times (T_2 \\ &- T_1)) \times \frac{100}{\text{GCV of fuel}} \\ &= 9.71 \% \end{aligned}$$

#### (vii). Heat loss due to moisture in fuel: L3

Formula used:

$$\begin{aligned} &\% \text{ Heat loss due to moisture in fuel} \\ &= \text{Moisture in fuel} \\ &\times [584 + \text{Specific heat of steam}(T_2 \\ &- T_1)] \times \frac{100}{2319.36} \\ &= 13.355 \% \end{aligned}$$

#### (viii). Heat loss due to radiation: L4 : Assumed as 1%

#### (ix). Heat loss due to unburnt carbon in ash: L5

Formula used:

$$\begin{aligned} &\% \text{ Heat loss due to unburnt carbon in ash} \\ &= \frac{(\text{Quantity of ash in fuel} \times \text{GCV of ash} \times 100)}{\text{GCV of fuel}} \\ &= 0.54 \% \end{aligned}$$

#### (x). Total % Heat loss

$$\begin{aligned} &= L1+L2+L3+L4+L5 \\ &= 29.2296 \% \end{aligned}$$

#### (xi). Boiler efficiency:

$$\begin{aligned} &\text{Boiler efficiency} \\ &= 100 \\ &- \text{Total \% heat loss} \\ &= 70.77 \% \end{aligned}$$

#### (xii). Computation of steam to fuel ratio:

$$\begin{aligned} &\text{Steam to fuel ratio} \\ &= \frac{(\text{GCV of bagasse} \times \text{Boiler efficiency})}{(\text{H}_{\text{steam}} - \text{H}_{\text{feed water}})} \\ &= 2.5326 \text{ Kg of steam/Kg of bagasse} \end{aligned}$$

**2. Efficiency of boiler after employing moisture unit:**

$$\begin{aligned} \text{Bagasse GCV} &= 4600 \times (1 - \omega) \\ &\quad - (1200 \times S) \\ &= 2457.36 \text{ K Cal/Kg} \end{aligned}$$

**(i). Computation of theoretical air required:**

$$\begin{aligned} &= \frac{[11.6 \times C + (34.8 \times H_2 - O_2 / 8) + (4.35 \times S)]}{100} \\ &= 3.085 \text{ Kg / Kg of Bagasse} \end{aligned}$$

**(ii). To find out the excess air supplied on the basis of % O<sub>2</sub> (EA):**

$$\begin{aligned} &\% \text{ Excess air} \\ &= \frac{O_2}{(21 - O_2)} \times 100 \\ &= 31.25 \% \end{aligned}$$

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**(iv). To find out the actual mass of dry flue gas:**

$$\begin{aligned} &\text{Actual mass of dry flue gas} \\ &= \left(C \times \frac{44}{12}\right) \\ &\quad + \left[\frac{N_2}{100} + (\text{Actual mass of air})\right] \\ &\quad \times \frac{77}{100} \\ &\quad + (\text{Actual mass of air} \\ &\quad - \text{Theoretical mass of air}) \times \frac{23}{100} \\ &= 4.1764 \text{ Kg/Kg of Bagasse.} \end{aligned}$$

**(v). Computation of sensible heat loss in dry flue gas : L1**  
Formula used:

$$\begin{aligned} &= (\text{Mass of flue gas} \times \\ &\quad \text{Specific heat of flue gas} \times \\ &\quad \text{Temperature difference}) \times \\ &\quad \frac{100}{\text{GCV of bagasse}} \\ &= 4.364429\% \end{aligned}$$

**(vi). Heat loss due to moisture formed due to Hydrogen in the fuel: L2**

$$\begin{aligned} &= 9 \times H_2 \times [584 + C_p \times (T_2 \\ &\quad - T_1)] \\ &\quad \times \frac{100}{\text{GCV of fuel}} \\ &= 9.16828 \% \end{aligned}$$

**(vii). Heat loss due to moisture in fuel: L3**  
Formula used:

$$\begin{aligned} &\% \text{ Heat loss due to moisture in fuel} \\ &= \text{Moisture in fuel} \\ &\quad \times [584 + \text{Specific heat of steam}(T_2 \\ &\quad - T_1)] \times \frac{100}{2457.36} \\ &= 11.8333 \% \end{aligned}$$

**(viii). Heat loss due to radiation: L4 : Assumed as 1%**

**(ix). Heat loss due to unburnt carbon in ash: L5**  
Formula used:

$$\begin{aligned} &\% \text{ Heat loss due to unburnt carbon in ash} \\ &= \frac{(\text{Quantity of ash in fuel} \times \text{GCV of ash} \times 100)}{\text{GCV of fuel}} \\ &= 0.51437\% \end{aligned}$$

**(x). Total % Heat loss**  
= L1+L2+L3+L4+L5  
= 26.8802 %

**(xi). Boiler efficiency:**  
Boiler efficiency  
= 100 - Total % heat loss  
= 73.1197 %

**(xii). Computation of Steam to Fuel Ratio:**

$$\begin{aligned} &\text{Steam to fuel ratio} \\ &= \frac{(\text{GCV of bagasse} \times \text{Boiler efficiency})}{(\text{H}_{\text{steam}} - \text{H}_{\text{feed water}})} \\ &= 2.7723 \text{ Kg of steam/Kg of bagasse .} \end{aligned}$$

**VII. Result**

The graph represents efficiencies before and after suggesting solutions on respective losses in boiler of co-generation power plant. The efficiency of boiler before suggestions is 70.77 %

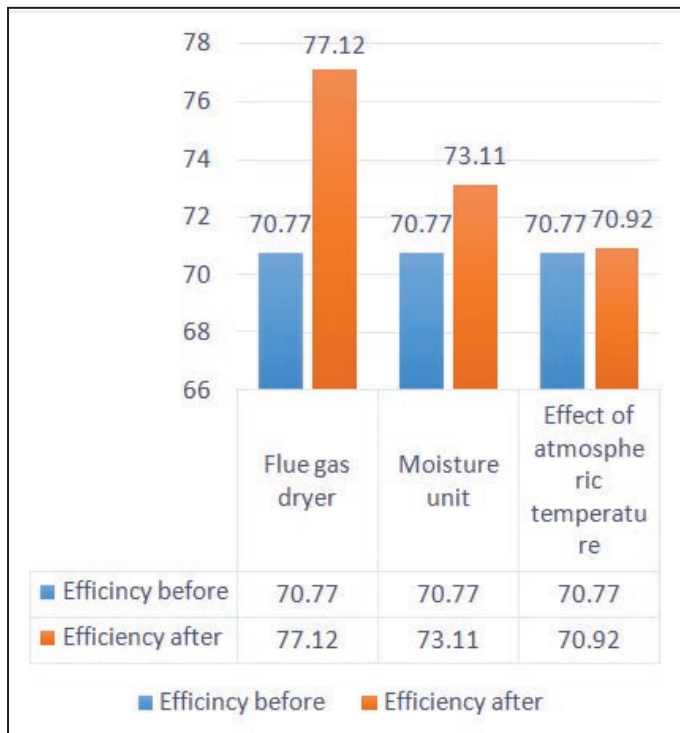


Fig. 1: Graph Represents Efficiencies before and After Suggesting Solutions on Respective Losses in Boiler of Co-Generation Power Plant

1. After suggesting to implement flue gas dryer the efficiency can be increased up to 77.12 %.
2. After suggesting to implement moisture removal unit the efficiency can be increased up to 73.11 %.
3. If the ambient temperature increased from normal temperature (27°C) to 34°C the efficiency increases up to 70.92 %.

### VIII. Conclusion

The present energy crisis and continuing stress on enhancing the efficiencies has led to the development of various analysis and overhauling techniques by which thermal power system can be improved.

This exergy analysis usually predicts the thermodynamic performance of energy system and efficiency of the system components by quantifying the exergy destruction within the components.

For efficiency improvement of thermal power plant, we got the information about the cogen plant.

We found the various losses in the plant, for reducing that losses we develop some plan and working on that plan. While working we done some changes in the plant according to need.

In co-gen plant we used a moisture unit to reduced moisture content in baggase for increased the efficiency of boiler. We concluded that by using moisture unit 2.34% efficiency increased.

### Reference

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