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EXPLORATION OF PERFORMANCE FROM THE EFFICIENCY ASSESSMENT OF SODA RECOVERY BOILER

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Abstract: In a paper industry all paper is produced from one raw material: pulp. One of the most common methods used to produce pulp is the Kraft process, which consists of two related processes. The first is a pulping process, in which wood is chemically converted to pulp. The second is a chemical recovery process, in which chemicals used in pulping are returned to the pulping process to boiler. It serves two main purposes. The first is to "recover" chemicals in the black liquor through the combustion process (reduction) to be recycled to the pulping process. Secondly, the boiler burns the organic materials in the black liquor and produces process steam. At the present time, one of the existent necessities of this part of industry is improvement the performance of such type of boilers which have special designing and different operation conditions because of its used fuel. An essential tool for performance improvement is to optimized boiler efficiency. In this paper recovery boiler efficiency is estimated by two method, direct method and indirect method. Both methods give a different result. Direct method did not include any losses for calculating boiler efficiency, while indirect method includes all the heat losses from a system to find boiler efficiency. Finally a comparison of efficiencies of the soda recovery boiler is made between the existing efficiency and the maximum efficiency achieved by the soda recovery boiler and also mentioning the factors impact on the efficiency.
Keywords: Boiler efficiency, heat balance, heat losses ,direct method, indirect method, black liquor composition.

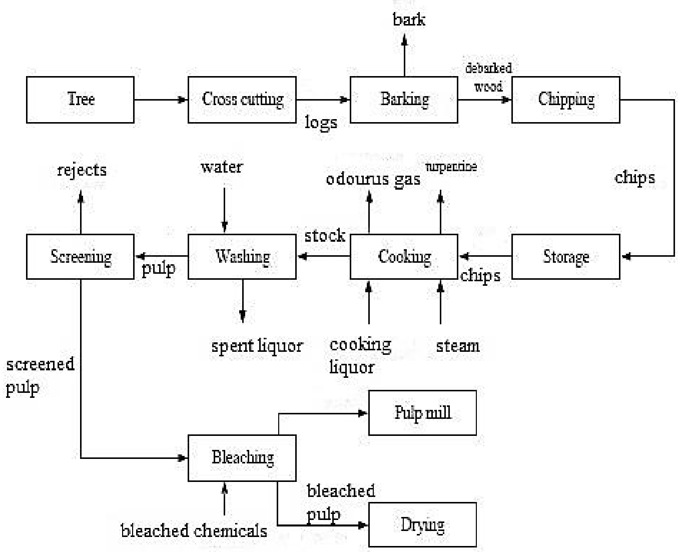
I. INTRODUCTION

For all industries associated with the processing of raw wood, the most important factor is the cost of raw wood material, including the cost of its transportation to consumers and the costs of fuel and energy. In the pulp's price structure, 50 % of costs belong to initial raw materials and approximately 40 % to energy. Consequently, in order to increase the efficiency of pulp mills, the priority is to reduce the consumption of raw wood material and energy. The works directed to the essential decrease of wood consumption during pulp production are unknown. In these circumstances, the only way to significantly improve the profitability of pulp manufacture is to reduce its energy costs. One of the opportunities for reducing costs associated with the consumption of energy at the pulp mills is the use of renewable energy sources such as black liquor, which are by-products of the pulp production. Indeed, modern pulp mills are energy self-sufficient due to using recovery systems in which black liquor combustion is carried out with the regeneration of chemicals and energy. Normally within the Kraft pulping industry efficiency based on the Gross Calorific Heating value GCV value is used. The efficiency of recovery boiler is quoted as the % of useful heat available, expressed as a percentage of the total energy potentially available by burning the fuel. This is expressed on the basis of gross calorific value (GCV) of fuel.

II. THE PROCESS

Functions of Chemical Recovery Boilers:

- To recover the inorganic chemicals from black liquor.
- To produce high pressure and high temperature steam for captive power generation and also provide steam for use in Pulp and Paper mill operations.



Pulp mill operations totally depend upon the chemical recovery boiler. Generally, each paper mill is linked up with one recovery boiler and hence its availability and efficient operation are of utmost importance. Unlike other types of boiler in chemical recovery boiler the combustion takes place in reducing atmosphere and with coarser particle sizes. The process starts when the pulpwood arrives to the pulp mill and the debarked and chipped. The bark is dried and then burned in the biomass boiler in order to utilize all available energy.

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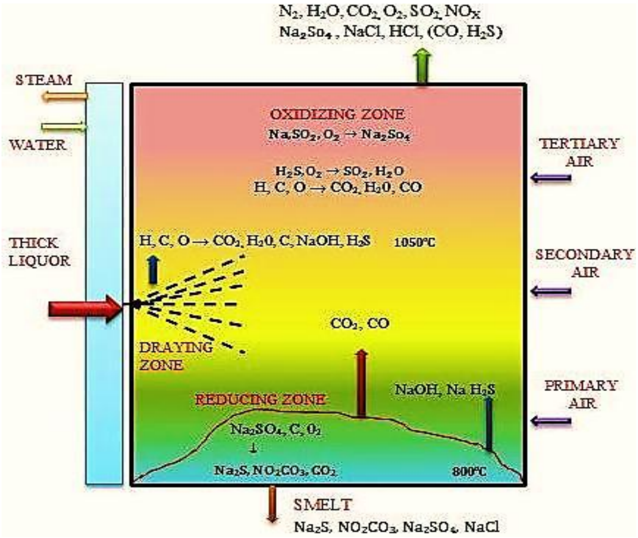
The woodchips are digested in white liquor in order to separate lignin and cellulose. The pulp is screened and washed. The wash liquor together with the spent cooking liquor is evaporated. Some of the pulp is then bleached and transferred on to the paper machines. After evaporation of the liquor the thick liquor is burnt in the recovery boiler. During the combustion process a smelt of inorganic cooking chemicals is obtained which is dissolve in weak liquor. Green liquor is formed and returned to white liquor preparation.



The energy released from the combustion processes is used to generate process steam, which is expanded through a backpressure turbine to generate electricity and process steam of suitable pressure. Rated capacity of boiler is 60 kg/cm2 at 60 TPH. The maximum efficiency achieved by the SODA Recovery boilers is 74 %. Black liquor flow to the boiler is difficult to determine, because of different moisture levels, different composition of fuels and latent heat losses in the unburned inorganic collection material at the bottom of the boiler.

III. RECOVERY BOILER EFFICIENCY ESTIMATION METHODS

Most standards for calculation of boiler efficiency, including IS 8753 and BS845 are designed for measurement of boiler efficiency. Unvaryingly, all these standards do not include blow down as a loss in the efficiency determination process. Because for a mill with a new modern and well-functioning feed water and condensate treatment the blow-down can be kept at a low level.

Basically Boiler efficiency can be tested by the following methods:

A. *Direct Method or Input Output Method.*
B. *Indirect Method or Heat Loss Method.*

A. Direct Method or Input Output Method:

Direct method associates the energy gain of the working fluid to the energy content of the black liquor. 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.

$$\boxed{boiler\ efficiency, \eta = \frac{heat\ output}{heat\ input} x100\%}$$

$$\boxed{\eta = \frac{SFR(SE - FWE)}{BLFR\ x\ GVC} x100\%}$$

Where,
η = boiler efficiency in %.
SFR= steam flow rate in Tons/day.
SE= steam enthalpy in kCal/kg.
FEW= feed water enthalpy in Tons/day.
BLFR= fuel firing rate in Tons/day.
GVC= gross calorific value of black liquor in kCal/kg.

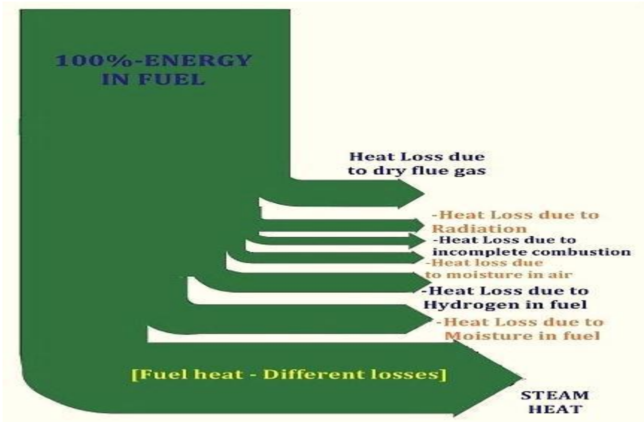
B. Indirect Method or Heat Loss Method:

In the heat loss method the efficiency is the difference between the losses and the energy input. In indirect method the efficiency can be measured easily by measuring all the losses occurring in the boilers using the principles to be described. The weaknesses of the direct method can be overwhelmed by this method, which calculates the various heat losses associated with recovery boiler. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. An important advantage of this method is that the errors in measurement do not make significant change in efficiency.

Heat loss method is better to use in practice. The main reasons for that are following.

- It is easier to calculate the losses as compared to measure the Black liquor flow.
- Easy to check the controllable & uncontrollable losses & can do try to reduce the controllable losses.
- Complementary ideas for efficient boiler operation can be generated.
- Efficiency can be improved by combined effect of these entire things.
- It is more accurate as compared to direct method.

Valid losses incorporate with the recovery boiler:



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1. Heat Loss due to dry flue gas (L_1).
2. Heat Loss due to Hydrogen in fuel (L_2).
3. Heat Loss due to Moisture in fuel (L_3).
4. Heat loss due to moisture in air (L_4).
5. Heat Loss due to incomplete combustion (L_5).
6. Loss due to radiation (L_6).

$$\text{Total loss in } \% = \sum_{i=1}^{6} L_i$$

7. Boiler efficiency by indirect method:

Boiler efficiency, Ƞ = 100- (Total loss in %)

B. Procedure for Indirect Method:
Collection and Analysis of different samples required for indirect method of testing:

- Flue gas temperature at air heater outlet.
- Dry & wet bulb temperature of ambient air.
- Flue gas analysis.
- Relative humidity from psychometric chart.
- Front ash temperature at furnace outlet.
- Fuel sampling is done with the collected sample. Ultimate analysis is carried out with standard formula.

THE VARIOUS HEAT LOSSES:

1. Heat loss due to dry flue gas:
This is the greatest boiler loss and can be calculated with the following formula:

$$L_1\% = \frac{[m\ x\ (Cp)_1\ x\ (FGT - AAT)]}{GCV} x100\%$$

Where,
m = weight of dry flue gas, kg/kg of fuel,
Cp_1 = specific heat of flue gas in kCal/kg °C, usually 0.24
FGT = the flue gas temperature, °C
AAT = the ambient air temperature, °C
GCV = gross calorific value of black liquor in kCal/kg.

The mass "m" will be different basing on the location of calculation. Here two locations are mentioned namely before ID fan and before ESP. Water vapour is produced from Hydrogen in fuel, moisture present in fuel and air during the combustion. The losses due to these components have not been included in the dry flue gas loss since they are separately calculated as a wet flue gas loss.

2. Heat Loss due to Hydrogen in fuel (%):

$$L_2\% = \frac{[9\ x\ H_2\ x\ \{584 + Cp_2\ x\ (FGT - AAT)\}]}{GCV} x100\%$$

H_2 = weight fraction of hydrogen in the ultimate analysis of the fuel = kg of hydrogen present in fuel on 1kg basis.
Cp_2 = specific heat of superheated steam in kCal/kg °C
FGT = the flue gas temperature, °C
CAT = the ambient air temperature, °C
GCV = gross calorific value of black liquor in kCal/kg.
584=latent heat for corresponding partial pressure of water vapour in kCal/kg.

3. Heat loss due to moisture present in fuel (%):
This moisture loss is made up of the sensible heat to bring the moisture to boiling point, the latent heat of evaporation of the moisture, and the superheat required bringing this steam to the temperature of the exhaust gas.

$$L_3\% = \frac{M\{584 + Cp_2\ x\ (FGT - AAT)\}}{GCV of\ coal} x100\%$$

M = kg of moisture present in fuel on 1kg basis.
Cp_2 = specific heat of superheated steam in kCal/kg °C.
FGT = the flue gas temperature, °C
AAT = the ambient air temperature, °C
GCV = the higher heating value of the black liquor, kCal/kg.
584=latent heat for corresponding partial pressure of water vapour in kCal/kg.

4. Heat loss due to moisture present in air (%):
Vapour in the form of humidity in the incoming air, is superheated as it passes through the boiler. Since this heat passes up the stack, it must be included as a boiler loss.

$$L_4\% = \frac{AMAxHF\ xCp_2\ x\ (FGT - AAT)\}}{GCV of\ coal} x100\%$$

AMA = Actual mass of air supplied per kg of fuel.
Cp_2 = specific heat of superheated steam in kCal/kg °C.
FGT = the flue gas temperature, °*C.*
GCV = gross calorific value of black liquor in kCal/kg.
HF=Humidity Factor = $\frac{\text{kg of water}}{\text{kg of dry air}}$
AAT = the ambient air temperature, °C (Dry Bulb)

5. Heat loss due to incomplete combustion (%):
The generated products by partial combustion could be mixed with O_2 and burned again with a further release of energy.

6. Heat loss due to radiation and convection (%):
The actual radiation and convection losses are difficult to assess because of particular emissivity of various surfaces, its inclination, air flow pattern etc. Normally surface loss and other unaccounted losses is assumed based on the type and size of the boiler as given below:

For industrial fire tube / packaged boiler = 1.5 to 2.5%
For industrial water tube boiler = 2 to 3%
For power station boiler = 0.4 to 1%

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Finding % of all the losses, a simple heat balance would give the efficiency of the boiler. The efficiency is the difference between the energy input to the boiler and the heat losses calculated as depicted in boiler efficiency, Ƞ formula.

IV. BOILER EFFICIENCY ESTIMATION

Here all the data and parameters are measured and depicted for 24 hours. A coal fired boiler is selected for the estimation. Rated capacity of boiler is 60 kg/cm^2 at 60 TPH.

Ultimate analysis of black liquor:

Carbon	34.3%
Hydrogen	3.8%
Oxygen	25.1%
Nitrogen	0.5%
Sulphur	2.5%

Table 2: Efficiency estimation by Direct Method

Particulars	Unit	Boiler
Operating Hours	Hrs.	24
Steam Pressure	kg/cm2	60
Steam Temp	°c	400
Steam outlet	Tons/day	1178
Black Liquor Consumption	Tons/day	433
Calorific Value (GCV)	kcal/kg	2890
Evaporation Ratio	Kg of steam/ kg of BL	2.72
Feed water Inlet Temperature	°c	80
Feed water Flow rate	m^3/hr	4.9
Ambient Temperature	^{0}C	34.3
Enthalpy of HP steam	kcal/kg	760
Enthalpy of Feed water	kCal/kg	80
Efficiency	**%**	**64.01**

Table 3: Efficiency estimation by Indirect Method

Particulars	Unit	Before ID	Before ESP
Flue Gas Temperature	$_0$C	148.3	307.4
O2	%	10.5	3.6
CO_2	%	9.5	15.7
Excess Air	%	101	21
CO	%	0.1404	0.0588
NO	ppm	19	25
SO_2	ppm	1	1
No_x	ppm	40	31
Moisture in fuel	%	60	60
Surface Temp. of Boiler	^{0}C	69	69
Wind velocity around the boiler	m/s	3.3	3.3
Total Surface area (Approximate)	m^2	300	300
Measured Excess Air	%	100.00	20.69
Actual Air Supplied	kg/kg of fuel	7.77	4.69
Moles of N2	Moles	0.12	0.12
Moles of C	Moles	0.03	0.03
Theoretical CO2	%	18.65	18.65
Mass of dry flue gas	kg/kg of fuel	8.136	5.056

Table 4: Boiler Heat Balance

Losses in boiler			
Particulars	**Unit**	**Before ID**	**Before ESP**
Heat Loss due to dry flue gas	%	8.29	13.13
Heat Loss due to Hydrogen in fuel	%	7.52	8.36
Heat Loss due to Moisture in fuel	%	11.90	11.83
Heat loss due to moisture in air	%	0.25	0.36
Heat Loss due to incomplete combustion	%	0.99	0.25
Loss due to radiation	%	2.00	3.00
Total loss		**30.95**	**36.93**
Boiler Efficiency (100- total loss)	%	**69.05**	**63.07**

Following are the Observations made:

1. The O_2 level before ID Fan (10.5%) is quite high compare to the Economizer outlet level (3.6%), which shows high excess air (80%) and incomplete combustion at the stack. Since the dry flue gas losses has been more in recovery boiler.
2. Air ingress due to more leakages in the duct leads to this problem and it also increases the load of the ID fan.
3. The radiation losses were on higher side comparing to standards. Due to insufficient insulation in many places of the boilers.
4. Sensible heat loss due to high moisture content (about 50%) in the fuel leads to 10% loss in the boiler.
5. The losses in unburned inorganic material & smelt heat losses were not considered by reason of insufficient data availability and instruments.
6. The efficiency evaluated shows 69% without

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considering the unaccounted losses.

V. PERFORMANCE OPTIMIZATION OF CHEMICAL RECOVERY BOILER

Optimized operation of the chemical recovery boiler means more steam and chemical recovery. Energy savings of major proportions can be realized in recovery boiler operation by focusing attention to the following:

- Develop and maintain a properly tuned process control system.
- Better control on input streams such as dry solids concentration, excess air, and salt cake makeup.
- Optimize the boiler cleaning system steam usage.
- Maximum concentration of black liquor reduces the moisture loss.
- The firing pressure and temperature are to be optimized to minimum.
- The next very important parameter to be optimized is the total air flow, meaning the air flow proportion between primary and secondary, and air temperature. Increasing primary air quantity will tend to increase char bed temperature, increase the burning rate, and lower the reduction efficiency.
- Combustion air temperature, higher combustion air temperature increases the efficiency but also increases the heat consumption outside the boilers battery limit.
- Black liquor dry solids, higher dry solids content to the boiler gives a higher efficiency but also a somewhat higher heat consumption in the evaporation plant.
- Black liquor sulfur content, ah higher sulfur content gives a lower efficiency at constant green liquor reduction degree.

VI. CONCLUSION

This paper is convergent on the diverse aspects of the operation of recovery boiler efficiently. The maximum efficiency achieved by the SODA Recovery boilers is 74 %.while direct and indirect method efficiency is 64.01 % and 69.05% (Before ID fan) and 63.07(Before ESP). Many variables in black liquor firing can affect boiler operation. Understanding and controlling these variables can help in greatly improving boiler efficiency and throughput. By using latest technology and management skills in all spheres of activities to per-form its effective role in profitability of the company.

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