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# Analysis for Efficiency Improvement and Fuel Savings Opportunities in Thermal Power Plant

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***Abstract:***
*The availability of electrical energy is regarded as an index of progress. In India, still the major portion of electrical energy produced from thermal power stations using fossil fuels. In present scenario the per capita energy consumption determines the level of development of the nation. The energy supplies to demand narrowing down every day around the world. The growing energy demand overcome by implementing new concept into the existing system. This present work deals the way of reducing the losses in power plant and improving the performance of existing lignite fired thermal power plant. Lignite is considered as a domestic and abundant energy source for several countries. However its high moisture content has a negative effect on power plant. The aim of present work is to analyse the new concept and technology for improving overall performance and fuel savings. This paper discusses the concept of utilising the heat of flue gas for pre-drying the lignite to achieve the fuel savings about 40%. The waste heat energy used for drying the lignite before entering into the boiler unit increased the efficiency of boiler and reduced the fuel consumption. Because reduction in the flue gas temperature will save the fuel. This also reviews the concept of reducing the environmental effect caused due to $CO_2$ emissions by installing $CO_2$ capturing unit using dry regenerable solvent as a absorber in existing power plant. By implementing the proposed concept, the improvement in efficiency and fuel savings can be achieved.*

***Keywords:*** *Energy loss, lignite Dying, Efficiency improvement, Fuel Savings, $CO_2$ Capturing,*

## 1. Introduction

Energy consumption is the most important problem in the today's era in the present scenario per capita energy consumption determines the development of the nation. A steam or thermal power plant continuously converts the energy stored in the coal into shaft work and ultimately into electricity by coupling the steam turbine to the generator. Currently, 80% of electricity in the world is approximately produced from fossil fuels (coal, petroleum, fuel-oil, natural gas) fired power plants. Nearly 45% of global electricity generation is derived from coal. Despite the rapid growth of cleaner sustainable energies, the heavy dependence of world energy on coal expected to continue for decades The increased awareness that the world's energy resources are limited has caused many countries to re-examine their energy policies and take drastic measures in eliminating the waste. Energy security and emission reduction are two important major concerns of today's world. It has also sparked the interest in the scientific community to take a closer look at the energy conversion devices and to develop new techniques to better utilize the existing limited resources.

Generally the performance of thermal power plants is evaluated through energetic performance criteria based on the First Law of Thermodynamics, including electrical power and thermal efficiency. The real useful energy loss cannot be justified by the First Law of Thermodynamics, because it does not differentiate between the quality aspects of energy. Therefore, it can be said that performing various analyses together can give a complete depiction of system characteristics. And also there are various adopting methods are available for improving the efficiency.

Such a comprehensive analysis will be more convenient approach for the performance evaluation and determination of the step towards improvement of performance of the thermal power plants.

## 2. Lignite Drying Using Hot Flue Gas

Lignite is a coal mined from the earth which contains high moisture content in nature. So if the moisture exists in the coal that will reduce the heating value in the power production. The pre-drying of the lignite is to be carried in the power plant. Pre-drying of raw coal is a process solution for efficiency improvement in brown coal-based power plants In the case of brown coal, particularly, it is estimated that the optimization of the drying process in future brown coal power plants may lead to an efficiency increase of 4-6 percentage points. There are various research and development going on to produce the efficient drying model for powerplant. Presently, numerous evaporating technologies for coal are purported as suitable for lignite drying: each of these technologies has their own merits. Hot air, combustion flue gas or superheated steam may be used as the heating medium during the convective and evaporative drying processes. Lignite is highly reactive and susceptible to fire and explosion hazards due to spontaneous combustion. Pre-drying of lignite is very essential in lignite based power plant, to improve the performance of the plants and cycle. By installing the waste heat model to the existing power plant will increase the efficiency and reduce the fuel consumption in direct and indirect ways Hence, in order to avoid fire and explosion hazards, the oxygen content and temperature of the drying medium should not too high.

Hot flue gas has been used in drying processes of lignite, there are two process systems used for drying. The rotary drum dryer and the flash mill pre-drying system. In a Flash mill pre-drying emerged in the first half of the 20$^{th}$ Century and has since become the standard equipment in conventional large-scale lignite-fired power plants. This involves the simultaneous milling and drying of raw coal immediately before combustion in a beater-type mill, aerated by the hot flue gas drawn off at 900 – 1000°C from the upper levels of the furnace chamber. Such pre-drying requires a boiler substantially larger to cope with the large quantity of evaporated water. This system used in 50 MW plant and achieved 40% fuel savings.

### 3. Waste Heat Recovery from Flue Gas

Waste heat is heat, which is generated in a process by way of fuel combustion and chemical reaction, and then “dumped” into the environment though it could still be reused for some useful and economic purpose. The recovery way dependent on the temperature of the waste heat gases and the economics involved [11]. If some of this heat could be recovered, a considerable amount of primary fuel can be saved. There are various direct and indirect benefits are associated with the waste heat recovery. Pre-drying of lignite is very essential in lignite based power plant, to improve the performance of the plants and cycle. By installing the waste heat model to the existing power plant will increase the efficiency and reduce the fuel consumption in direct and indirect ways. The main source for the waste heat recovery system is the hot flue gas, which carrying large amount of heat, if that heat is recovered by installing suitable recovery model more than 20 % of fuel saving can be achieved. This recovered heat can be used for useful purpose like primary combustion air heating, pre-heating of boiler feed water. In a heat recovery system it is essential to know the amount of heat recoverable and also how it can be used effectively and also it is researched that for every 22$^{o}$C in flue gas temperature there is 1% increase in efficiency.

### 4. Co$_2$ Capture from Flue Gas Using Dry Regenerable Sorbents

One of the most drawbacks in the brown coal based power plant is emission of the $CO_2$, because the lignite contains more than 70% of carbon in the fuel constituents. So the $CO_2$ should be captured from the power plant gases and to find the way to reduce the $CO_2$ emission. Currently available commercial processes to remove $CO_2$ from the flue gas streams are costly and energy intensive [16]. In this $CO_2$ removal process uses a sodium carbonate-based sorbent. Sodium carbonate is converted to sodium bicarbonate through reaction with $CO_2$ and water vapor. The sorbent is regenerated using a thermal swing and produces a gas stream containing only $CO_2$ and water. The water is removed by condensation to produce a pure $CO_2$ stream for subsequent use or sequestration.

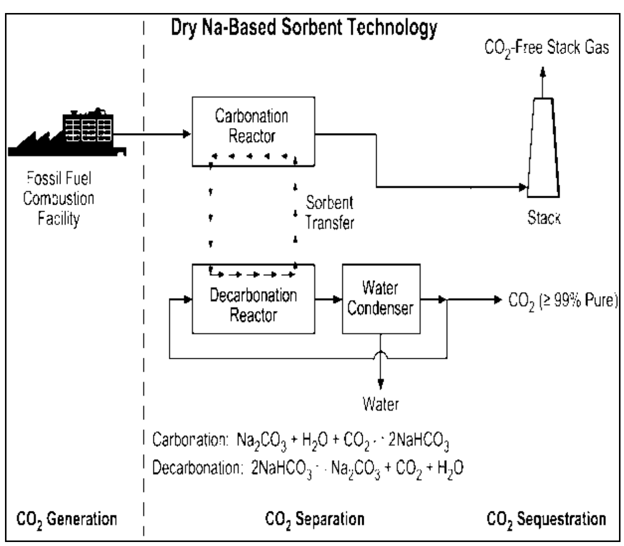


*Figure 1: Dry Na-Based Technology [16]*

By based on this, the flue gas is tested over the running periods of time say 100 hrs the capturing capacity of the system is 99%. This system is captured more than 85% of the $CO_2$ from the flue gas.

**5. Energy Loss Analysis**

The efficiency of the boiler is lowered by the losses and out of all boiler losses, the major one being the exit flue gas loss which turn, mainly depends upon the exit gas temperature and excess air levels. Energy analysis is carried out based on the First Law of Thermodynamics, which is concerned with the Law of Conservation of energy. The energy losses in the boiler of TPS-1 are calculated on the basis of First Law of Thermodynamics which mainly concentrates on the quantity of energy. It is usually observed that a certain portion of heat input is lost due to many reasons. The various energy loses occurring in a boiler are [10],

i. Loss due to Unburnt Carbon ($L_1$)
ii. Loss due to Dry Flue Gas ($L_2$)
iii. Loss due to Moisture in Fuel ($L_3$)
iv. Loss due to Hydrogen in Fuel ($L_4$)
v. Loss due to Moisture in Air ($L_5$)
vi. Loss due to Sensible Heat of BAH ($L_6$)
vii. Loss due to sensible Heat of Fly Ash ($L_7$)
viii. Radiation Loses ( $L_8$)
ix. Loss due to Mill Heat Rejects ($L_9$)

. The efficiency can be arrived by subtracting the heat loss fractions from 100.

| SI. no | Parameters | unit | 13/02/2015 |
|---|---|---|---|
| 1 | Total Moisture | % | 53.32 |
| 2 | Inherent Moisture | % | 10.12 |
| 3 | Ash Content | % | 6.12 |
| 4 | Volatile matter | % | 22.50 |
| 5 | Fixed carbon | % | 19.15 |
| 6 | Gross Calorific Value | Kcal/kg | 2790 |
| 7 | Combustibles in Bottom Ash | % | 4.15 |
| 8 | Combustibles in fly ash | % | 1.01 |
| 9 | $CO_2$ in flue gas | % | 14.5 |
| 10 | $O_2$ in flue gas | % | 5.5 |

*Table 1: data for Energy Analysis of the Boiler*

| Constituents | Unit | Lignite Sample |
|---|---|---|
| C | % | 27.34 |
| H | % | 2.5 |
| N | % | 0.35 |
| O | % | 10.8 |
| S | % | 0.801 |
| Ash | % | 6.12 |
| Moiture | % | 53.32 |

*Table 2: Ultimate Analysis of Lignite*

1. Unburnt Carbon Loss ($L_1$)

$$L_1 = \frac{U \times 8077.8}{GCV} \times 100 = 0.2845\ \%$$

2. Dry flue gas Loss ($L_2$)

$$L_2 = \frac{S_h \times 100}{GCV \times 4.186} = 9.15\ \%$$

3. Loss Due to Moisture in Fuel ($L_3$)

$$L_3 = \frac{S_w \times moisture}{GCV \times 4.186} = 3.34\ \%$$

4. Loss due to Hydrogen in Fuel ($L_4$)

$$L_4 = \frac{9H \times S_w}{GCV \times 4.186} = 5.17\ \%$$

5. Loss Due to Moisture in air ($L_5$)

$$L_5 = \frac{M_a \times 1.88 \times (T_g - T_a)}{GCV \times 4.186} \times 100 = 0.128\%$$

6. Loss due to Sensible heat of Bottom ($L_6$)

$$L_6 = \frac{\frac{A}{100} \times \frac{D_b}{100} \times C_{pb} \times (T_g - T_a)}{GCV \times 4.186} \times 100 = 0.075\ \%$$

7. Loss due to Sensible heat of fly ash ($L_7$)

$$L_7 = \frac{\frac{A}{100} \times D_f \times C_{pf} \times (T_g - T_a)}{GCV \times 4.186} \times 100 = 0.0602\ \%$$

8. Radiation Loss ($L_8$)
$L_8 = 0.5$ %

9. Unaccounted Losses ($L_9$)
$L_9 = 1.25$ %

Total Energy Losses = ($L_1$+ $L_2$+ $L_3$+ $L_4$+ $L_5$+ $L_6$+ $L_7$+ $L_8$+ $L_9$) = 19.95 %
Boiler Efficiency = 100- 19.95 = 80.05 %

**6. Fuel Savings Analysis**

For analyzing the fuel savings in power plant we should know the ways to achieve the fuel savings. Waste heat recovery system is one the efficient way to increase efficiency and fuel savings in boiler industries. From the furnace of the boiler the flue gas generated having the heat energy, that energy should be recovered and utilized for the performance improvement.

Heat Transferred by the flue gas through "GAS OFFTAKE DUCT"

$$\mathbf{Q = V \rho C_p \Delta T} \qquad (1)$$

V- Volume flow rate of flue gas ($m^3$/hr), ρ-density of flue gas (kg/$m^3$), $C_p$-Specfic heat of Flue gas (Kcal/kg), ΔT-Temperature Difference. [12]

The fuel savings can be attained by reducing the flue gas temperature that by means installing waste heat recovery model.

Heat gained by the Lignite $\mathbf{Q = m \times C_p \times \Delta T}$ (2)

Fuel saving can be calculated by basics of heat transfer principle.

**Heat Lost by flue gas = Heat gained by Lignite**

- Recovered heat = Heat Transferred– Heat Gained

Primary data's for calculations. In TPS-I 50MW Boiler,
Air Supply Through 2FD fans = 2 X 153000 $m^3$/hr
= 30,6000 $m^3$/hr
Fuel supply to the Furnace = 4 Mills each 15TPH
= 4 x 15 = 60TPH
Total Flue Gas Without losses = 306060 $m^3$/hr Practical Flue gas Generated = 287600 $m^3$/hr

| MILL | After Mill Temperature ($^oC$) | Before Mill Temperature ($^oC$) |
|---|---|---|
| A | 53 | 836 |
| B | 66 | 852 |
| C | 51 | 799 |
| D | 57 | 767 |

*Table 3: Observation on 13/02/15 in TPS-I, Unit-III*

| MILL | HEAT CONTENT (kJ/s) |
|---|---|
| A | 18699 |
| B | 18771 |
| C | 17863 |
| D | 16956 |
| Total Heat | 72289 |

*Table 4: Heat Transferred by flue gas through "GAS OFF TAKE DUCT" to Lignite in Mill*

| MILL | HEAT CONTENT (kJ/s) |
|---|---|
| A | 127 |
| B | 190 |
| C | 117 |
| D | 146 |

*Table 5: Heat Gained by Lignite*

| MILL | HEAT CONTENT (kJ/s) |
|---|---|
| A | 18572 |
| B | 18581 |
| C | 17746 |
| D | 16810 |
| Total Heat | 71709 |

*Table 6: The Recovered Heat from flue gas (Heat which is used to remove the 40% of total moisture from lignite)*

From the above tabulated values the energy savings and fuel savings can be calculated.

- Energy Saving Rate

Total heat Liberation rate = 1253x119000

= 173582 kJ/s

$$= \frac{\textit{TOtal recovered heat or saved heat}}{\textit{Total Liberated heat}} \times 100$$

= 41.33 %

- Fuel Saving Estimation

Amount of saved Lignite

$$= \frac{\textit{Amount of lignite fired}}{\textit{Total Liberated heat}} \times \textit{total heat saved}$$

= 6.60 kg/s

Percentage of Lignite fuel saved

$$= \frac{\textit{Amount of lignite saved}}{\textit{Total amount of lignite fired}} \times 100$$

= 41.25 % of fuel.

**7. Results and Discussion**

| Ideal Efficiency (%) | First Law Efficiency (%) |
|---|---|
| 88 | 80.05 |

*Table 7: The Efficiency from Direct and Indirect Method*

The percentage deviations are calculated from the ideal and actual efficiencies, This deviations is an important factors since it gives the measure of performance of the equipment. In TPS-I Unit III boiler gives deviation 7.95 %. This is due to the equipment inability and losses in flue gas. If this Loss is minimized the Efficiency of the System can be increased.

- Fuel savings

| Energy Savings (%) | Lignite Fuel Savings (%) |
|---|---|
| 41.33 | 41.25 |

*Table 8: Fuel and energy savings*

From the Table 3 to 6 it is measured from the utilizing the hot flue gas drying the lignite before the combustion, the fuel savings is achieved about 41.25 % per Hour. If that heat was not used for drying lignite there would be heat energy loss in boiler. The heat energy also saved about 41.33% by using Hot Flue Gas Drying. It is also noted that every 22$^{o}$C in flue gas temperature 1 % of fuel savings are achievable.

**8. Efficiency Improvement and Fuel Saving Opportunities**

- Proper water treatment [8] because various contaminations are present in bore well water that must be properly treated with chemicals before fed in the boiler. Otherwise they moves with water and concentrate in the boiler, as a result deposition and scales are form which may reduce the heat transfer, reduce the boiler efficiency
- Total dissolved Solids level should be controlled by blow down operation otherwise that water forms scale and rust in boiler will reduce the efficiency.
- Reducing the flue gas Temperature to reduce the flue gas loss because flue gas loss is the major loss in thermal power plant boilers. If the flue gas loss is minimized the efficiency of the system will be increased.
- Pre Heating the Combustion air [8] by using the waste heat of flue gas combustion air can be preheated. If $20^{o}C$ rise in air temperature there will be 1% increase in Thermal efficiency.
- Reduce the Unburnt bottom Ash gives the result increase in efficiency.
- Controlling the excess air and reduce the air ingress supply of excess air minimized the temperature of the flue gas get reduced results in increase the efficiency.
- Feed Water preheating using heat recovery device [10], if the waste heat from the flue gas has recovered will be used to pre heat the feed water. For every $5^{o}C$ rise in temperature of feed water gives 1% rise in thermal efficiency of the plant.

**9. Conclusion**

This paper represents the result of energy and fuel savings analysis performed on a 50MW Lignite Fired Thermal Power plant Boiler at Neyveli Thermal Power Station-1, Tamil Nadu. The analysis was performed on the unit with the running loads of 48.5MW. The result of Energy analysis is found that major loss area and efficiency of the system is about 80.05% and also found that 19.95 % of energy lost by various factors. Hot flue gas drying model was performed and results in 41.33 % energy savings and 41.25% of fuel savings achieved. The $CO_2$ capture was performed by using Dry Regenerable sorbents during the 100 running hours and produced more than 85% carbon dioxide free gas. There are various opportunities are discussed to increase the efficiency and fuel savings in power plant. This analysis can help the power plant industries to improve the performance of the existing power plants.

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**Annexure**

NOMENCLATURE

- → A  Ash
- → C  Carbon
- → $C_{pb}$  Specific heat of bottom ash (kCal/kg)
- → $C_{pf}$  Specific heat of fly ash (kCal/kg)
- → $D_b$  Distribution of ash in bottom ash (%)
- → $D_f$  Distribution of ash in fly ash (%)
- → GCV  Gross Calorific Value (kCal/kg)
- → H  Hydrogen
- → $M_a$  Moisture of air (kg/S)
- → $m_a$  Mass flow rate of air (kg/S)
- → $m_f$  Mass flow rate of fuel (kg/S)
- → $m_g$  Mass flow rate of flue gas (kg/S)
- → $m_s$  Mass flow rate of steam (kg/S)
- → $m_w$  Mass flow rate of water (kg/S)
- → N  Nitrogen
- → O  Oxygen
- → S  Sulphur
- → $S_A$  Stoichiometric Air
- → $S_h$  Sensible heat of Dry flue gas (kCal/kg)
- → $S_w$  Sensible Heat of Water (kCal/kg)
- → TPS-I  Thermal Power Station-I
- → $T_a$  Ambient Temperature ($^oK$)
- → $T_g$  Flue gas temperature ($^oK$)
- → $\eta_e$  Efficiency (%)
- → $\rho$  Density ($kg/m^3$)
- → $\upsilon$  Flow rate ($m^3/hr$)