Experimental Study of Oxygen Enrichment in a Circulating Fluidized Bed Combustion Boiler

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Abstract— The Proposed case study is to identify the Scope of energy conservation and Optimization of Oxygen enrichment in a CFBC Boiler. The study was undertaken at BMM Ispat Pv.Ltd, Danapur. The Scope of the study covers the better combustion and Complete Burning of coal in a 130TPH Boiler and The effect on efficiency of Boiler operation by Indirect Method is used to calculating the efficiency.

Key words: Thermal Power Plant, liquid oxygen, CFBC Boiler, Nozzle

I. Introduction

A. Profile of BMM Ispat Thermal Power Plant:

The BMM Ispat power plant has 4 units having a generation capacity of 3 units 70MW each and 1 unit is 25MW. The electricity produced is supplied to private and government parties, 42MW are used by the company itself and the rest is sold. The 25MW power plant consists of turbine backed by one atmosphere fluidized bed boiler and 2 Waste heat Recovery boiler. The company has installed one AFBC Boiler of 95TPH and 2 WHRB of 10TPH capacity.

The study specifically directed at identifying the oxygen enrichment in a CFBC Boiler. The CFBC Boiler at BMM has been manufactured Hanzhou china, a peak capacity of 130TPH. The operating temperature 545±5°C and the operating pressure is 115 Kg/cm2.

B. Development of Fluidized Bed Combustion (FBC) Technology:

With escalating prices of oil & gas during the last decade, the World power industry shifted its focus from oil to coal, as coal is more abundant than oil or gas. Now-a-days Indian power industry is struggling with coal also, but to know how the FBC technology comes into the picture, it is necessary to go through the following considerations. The pulverized fuel firing was developed earlier this century and universally used throughout the world for power generation but there are some limitations of the PF system. A pulverized fuel fired furnace designed for a particular type of coal cannot be used for any type of coal with same efficiency and safety. The size of the coal used is limited i.e. 70-100 micron therefore large investment is needed for coal preparing equipment & it's Maintenance. The ignition of the coal particles becomes easy & combustion becomes steady when the temp in the furnace is 1650 deg centigrade. The amount of NOx formed is large compared to any type of combustion system as the temperature maintained in the furnace is high. The removal of SO2 demands high capital cost equipment. New rules & regulations imposed by government for the air pollution the cost of power generation went high as extra equipment are needed to control the air pollution to the required level. At present the boiler are designed to suit the fuel characteristics. The configuration and size of the boiler furnaces and the burner differ considerably depending upon whether the coal is anthracite, bituminous or lignite. Compared with the PF boilers the FBC Boilers can accept any fuel including low grade coals, oil, gas or municipal waste and can also control SOx and NOx emissions effectively.

C. Principal of FBC System:

When a air is passed through a packed bed of finely divided solid particles it experiences the pressure drop across the bed. The mixture of solid particles and air is like a fluid. Burning of a fuel in such a state is known as fluidized bed combustion. The fuel & inert material (dolomite/limestone) are fed on a distributor plate and air is supplied from the bottom of the distributor plate. High velocity of air keeps the solid feed material in suspended condition. During combustion of the feed the generated heat is rapidly transferred to the water passing through the tube immersed in the bed & generated steam taken out. During the burning SO2 formed is absorbed by the dolomite /lime stone thereby preventing its escape with the exhaust gases. The molten slag is tapped from the surface of the bed in form of bed drain. The combustion efficiency remains very high (approx.99.5 %) as very high heat transfer rate are maintained over the surface of the tube. Even the poorest grade coal could be burnt without sacrificing combustion efficiency. The heat transfer rate to the surface is high as the system behaves like a violently boiling liquid & nearly 50% of heat transfer released in the bed is absorbed by the tubes. The bed operating temperature of 800-900°C is ideal for sulphur retention. Addition of limestone or dolomite to the bed brings down SOx emission level to 15% of that in conventional firing method. Low NOx emission is automatically achieved in FBC due to low bed temperature & low excess air compared with pulverized fuel furnace. The cost economics show that a saving of about 10% in operating cost & 15 % in capital cost could be achieved for unit rating 120mw.Size of the coal used is 6 to 13mm

D. Fundamentals of Fluidization:

Fluidization is the operation by which the solid are transformed into fluid like state through air when air is passed vertically upward through a bed of solid particles supported by a grid.

1) Fixed bed:

The air at low velocity will tends to follow the path of least resistance & pass upward through the bed with pressure drop. This is called fixed bed.

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2) Minimum Fluidization:
With increase in velocity of air a point is reached when the solid particles just suspended in the upward flowing air. The bed is considered to be just fluidized and referred to as a bed at minimum fluidization. (The weight of the air in any section of bed is equal to weight of air & solid particles in that section).

3) Bubbling Bed:
Any excess air above the minimum fluidization will cause bubble formation and the excess air will escape the bed as bubble. This state is called as bubbling bed.

4) Turbulent Bed:
As the velocity of air through bubbling bed is increased the bed expands & the bubbles constantly collapse and reform the bed surface is highly diffused & particles are thrown off into freeboard above. Such a bed is called as turbulent bed.

5) Circulating Fluidized Bed:
With further increase in air velocity the bed particles are entrained, separated from air and returned to the base of furnace. This is called circulating bed.

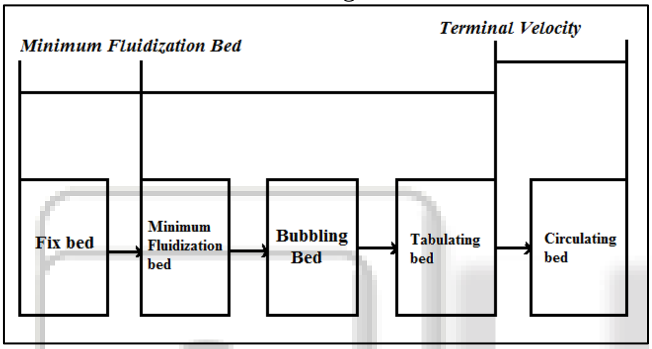

Fig. 1: Flow Diagram of Fluidization of Bed with Increase in Air Velocity

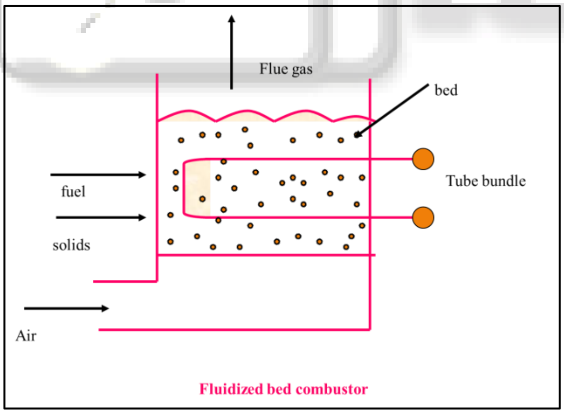

Fig. 2: Schematic of Fluidization Bed

E. Circulating Fluidized Bed Combustion (CFBC):

CFBC technology has evolved from conventional bubbling bed combustion as a means to overcome some of the drawbacks associated with conventional bubbling bed combustion. This CFBC technology utilizes the fluidized bed principle in which crushed (6±12 mm size) fuel and limestone is injected into the furnace or combustor. The particles are suspended in a stream of upwardly flowing air (60-70% of the total air), which enters the bottom of the furnace through air distribution nozzles. The fluidizing velocity in circulating beds ranges from 3.7 to 9 m/sec. The balance of combustion air is admitted above the bottom of the furnace as secondary air. The combustion takes place at 840-900 °C and the fine particles (<450 microns) are elutriated out of the furnace with flue gas velocity of 4±6 m/s. The particles are then collected by the solids separators and circulated back into the furnace. Solid recycle is about 50 to 100 kg per kg of fuel burnt. There are no steam generation tubes immersed in the bed. The circulating bed is designed to move a lot more solids out of the furnace area and to achieve most of the heat transfer outside the combustion zone ± convection section, water walls, and at the exit of the riser. Some circulating bed units even have external heat exchanges. The particles circulation provides efficient heat transfer to the furnace walls and longer residence time for carbon and limestone utilization. Similar to Pulverized Coal (PC) firing, the controlling parameters in the CFB combustion process are temperature, residence time and turbulence. For large units, the taller furnace characteristics of CFBC boiler offer better space utilization, greater fuel particle and sorbent residence time for efficient combustion and SO2 capture and easier application of staged combustion techniques for NOx control than AFBC generators. CFBC boilers are said to achieve better calcium to sulphur utilization ± 1.5 to 1 vs. 3.2 to 1 for the AFBC boilers although the furnace temperatures are almost the same. CFBC boilers are generally claimed to be more economical than AFBC boilers for industrial application requiring more than 75 - 100 T/hr. of steam. CFBC requires huge mechanical cyclones to capture and recycle the large amount of bed material, which requires a tall boiler.

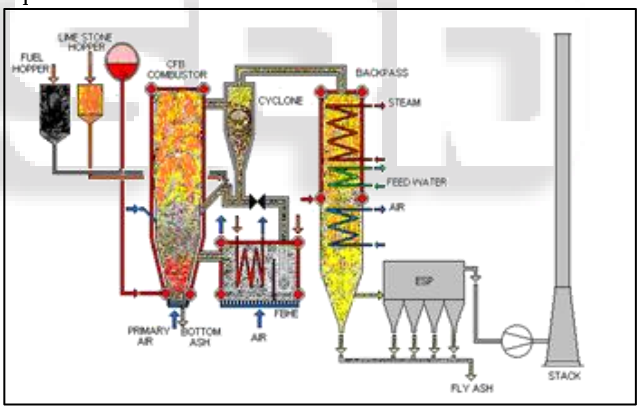

Fig. 3: Schematic of a Circulating Fluidized Bed Combustion Boiler

F. Oxygen Enriched Combustion:

When a fuel is burned, oxygen in the combustion air chemically combines with the hydrogen and carbon in the fuel to form water and carbon dioxide, releasing heat in the process. Air is made up of 21% oxygen, 78% nitrogen, and 1% other gases. During air–fuel combustion, the chemically inert nitrogen in the air dilutes the reactive oxygen and carries away some of the energy in the hot combustion exhaust gas. An increase in oxygen in the combustion air can reduce the energy loss in the exhaust gases and increase heating system efficiency.

Most industrial furnaces that use oxygen or oxygen-enriched air use either liquid oxygen to increase the oxygen concentration in the combustion air or vacuum pressure swing adsorption units to remove some of the nitrogen and increase the oxygen content. Some systems use almost 100% oxygen in the main combustion header; others

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blend in oxygen to increase the oxygen in the incoming combustion air. Some systems use auxiliary oxy-fuel burners in conjunction with standard burners. Other systems use staged combustion and vary the oxygen concentration during different stages of combustion. Still others "lance" oxygen by strategically injecting it beside, beneath, or through the air–fuel flame.

G. Potential Applications:

Oxygen-enhanced combustion is used primarily in the glass-melting industry, but other potential applications can be found in Table 1.

Industry	Applications
Steel	Reheat, soaking pits, ladles
Aluminum	Melting
Copper	Smelting and melting
Pulp and Paper	Lime kilns, black liquor boilers
Petroleum	Process heaters, crackers
Power Production	Coal-fired steam boilers
Chemical	Sulfur
Glass	Melting

Table 1: Potential Applications for Oxygen- Enhanced Combustion

– Liquid Oxygen Tank Specification:

1) Maximum Capacity : 20000 Ltr.
2) Gross Capacity : 19411 Ltr.
3) Net Capacity : 18441 Ltr.
4) Total weight in Empty : 8340 Kgs
5) Operating Fluid : LIN/LOX/LAR
6) MAWP : 17.6 Kg/cm2
7) Design Pressure : 18.663 Kg/cm2
8) Design Temperature : 196 to 40 °C
9) HyD.Test Pressure : 26.65 Kg/cm2

H. Bed Material Details:

– Maximum temperature : 1400°C
– Shape : Sub Angular
– Bulk Density : 1000-1050 Kgs/cm3

SiO_2	59.1
Al_2O_3	36.8
Fe_2O_3	1.7
TiO_2	1

Table 2: MnO_2, CaO, MgO, Na_2O are Traces

II. LITERATURE REVIEW

History of FBC during the 70s and also in 80s, it appeared that conventional pulverized coal-fired power plants had reached a plateau in terms of thermal efficiency. The efficiency levels achieved were of the order of 40 percent in the US and also in UK. An alternative technology, Fluidized Bed Combustion (FBC), was developed to raise the efficiency levels. In this technology, high pressure air is blown through finely ground coal. The particles become entrained in the air and form a floating or fluidized bed. This bed behaves like a fluid in which the constituent particles move to and fro and collide with one another.

Simultaneous developments in bubbling fluidized bed (BFB) boilers continued in the U.S.A. and China, but the lack of a recorded history of the development of the fluidized bed boiler in these two countries does not permit those developments to be included here. Steam generation from biomass-fired BFB boilers began perhaps in 1982 with the commissioning of a 10 t/h rice-husk fired BFB boiler in India, designed by the author. Since then, many types of bubbling fluidized bed boilers, burning a wide variety of fuels, have been developed and commercialized around the world. The BFB boiler has rightfully taken over from the old stoker-fired boilers of the past.

The circulating fluidized bed (CFB) had a curious beginning. Warren Lewis and Edwin Gilliland conceived a new gas–solid process at the Massachusetts Institute of Technology in 1938 when they were trying to find an appropriate gas–solid contacting process for fluid catalytic cracking. Interestingly, they invented the fast fluidized bed process while unaware of the invention of the other form of essentially the same fluidized bed process invented by Winkler for gasification at least 17 years earlier (Squires, 1986).

The first CFB boiler, designed exclusively for the supply of steam and heat, was built in the Vereingte Aluminum Werke at Luenen, Germany in 1982. This plant generated 84 MW total (9MW electricity, 31 MW process steam, 44 MW molten salt melt) by burning low-grade coal washery residues in the presence of limestone. Following a series of experiments in their Hans Ahlstrom Laboratory, they built the first commercial CFB boiler in Pihlava, Finland. It was a 15 MW (thermal output) boiler retrofit to an existing oil-fired boiler to replace expensive oil with peat. Initially the circulating fluidized bed boilers built by Ahlstrom were primarily for burning multifuel or low-grade fuels including bark, peat, and wood waste. Later boilers were designed exclusively for coal.

III. METHODOLOGY-INDIRECT METHOD

A. Thermal Calculation Table: Thermal Calculation (Fuel, anthracite, 130t/h):

Material Flow		
Fuel consumption	Kg/hr	25456
Calculated fuel consumption	Kg/hr	22797
Inert bed material	Kg/hr	0
Limestone Consumption	Kg/hr	678
Combustion air flow	Nm3/h	128441
Primary air flow	Nm3/h	57299
Secondary air flow	Nm3/h	60643
Fuel spreading air flow	Nm3/h	10000
Loop seal air flow	Nm3/h	1150
Boiler exit gas flow	Nm3/h	141213
Total ash and slag flow	Kg/h	11634
Fly ash flow	Kg/h	9424
Bottom slag flow	Kg/h	2211
Fly ash ratio	/	0.91
Fly ash carbon content	%	15.0
Bottom slag carbon content	%	1.0
Attemperation water flow	Kg/h	8447
SH-steam primary spray water flow	Kg/h	5631
SH-steam secondary spray water flow	Kg/h	2765

Table 3: Thermal Calculation Table

B. Boiler Design Data and Material Flow:

DESCRIPTION	UNIT	DATA

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Boiler parameters		
SH steam flow	t/h	130
SH steam temp.	˚C	545
SH Steam pressure	MPa.g	11
Feed water temp.	˚C	140
Air preheater inlet air temp.	˚C	30
Drum pressure	MPa.g	12.2
Bed temp.	˚C	893
Furnace outlet temp.	˚C	911
Furnace outlet excess air factor	/	1.2
Bottom ash temp.	˚C	250
Fuel circulating ratio	/	24.3
Fuel analysis		
Carbon	%	47
Hydrogen	%	2.43
Oxygen	%	3.99
Nitrogen	%	0.99
Sulfur	%	0.19
Moisture	%	5.24
Net heating value	kCal/kg	4217

Table 4: Design Data and Metrical Flow

C. Boiler Efficiency without Oxygen Enrichment:

Input/output Parameters	UNIT	DATA
Heat Input in fuel	%	100
Various Heat losses in boiler		
1.Dry flue gas loss	%	7.88
2.Loss due to hydrogen in fuel	%	3.44
3.Loss due to moisture in fuel	%	5.91
4.Loss due to moisture in air	%	0.29
5.Partial combustion of C to CO	%	2.58
6.surface heat losses	%	0.25
7.Loss due to Unburnt in fly ash	%	0.11
8.Loss due to Unburnt in bottom ash	%	1.76
Total Losses	%	22.22

Table 5: Boiler Efficiency without Oxygen Enrichment

Boiler Efficiency
=100-(7.88+3.44+5.91+0.29+2.58+0.25+0.11+1.76)
=100 – 22.22
= 77.78 %

D. Boiler Efficiency with Oxygen Enrichment:

DESCRIPTION	UNIT	DATA
Flue gas loss	%	5.08
Chemical incomplete combustion loss	%	0.10
Mechanical incomplete combustion loss	%	10.45
External heat loss	%	0.40
Slagging heat loss	%	0.11
Limestone heat absorption	%	0.00
SO2 sallification heat emission	%	0.00
Overall heat loss	%	16.13
Redundancy	%	0.87
Calculated thermal efficiency	%	83.87
Guaranteed thermal efficiency	%	83

Table 6: Boiler Efficiency with Oxygen Enrichment

E. Gas Profile Temperature:

- Furnace Outlet Temperature : 911°C
- Cyclone Outlet temperature : 841°C
- HRA wall Inlet Temperature : 842°C
- Final SH Inlet Temperature : 800°C
- Primary SH Inlet temperature I&II : 632°C
- Primary SH Outlet Temperature I&II : 632°C & 507°C
- Economizer Outlet Temperature I : 507°C
- Economizer Outlet Temperature II : 372°C
- Economizer Outlet Temperature III : 292°C

F. Nozzle Dimension:

- Diameter : 96mm
- Height : 100mm
- Pitch : 160mm
- Number of Nozzle
- Row wise : 15
- Column wise : 43

G. THERMAL Nox WITH 850˚C AS BASE VALUE:

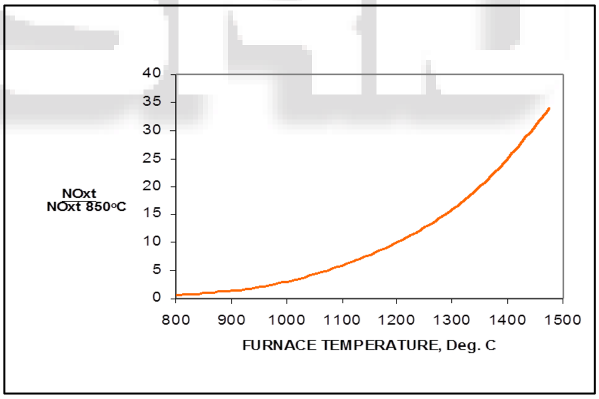

Fig. 4:

H. Pressure Drop versus Combustor Height:

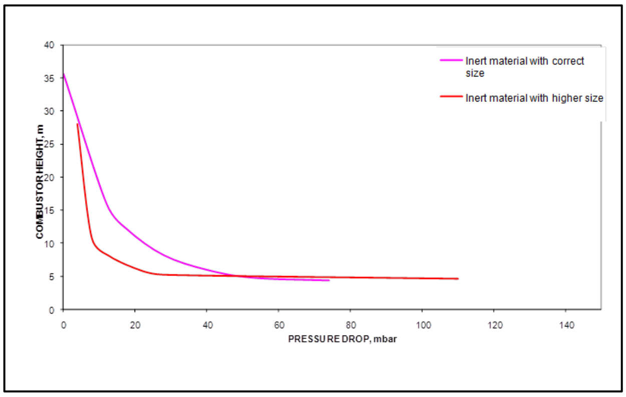

Fig. 5: PRESSURE DROP VERSUS COMBUSTOR HEIGHT

I. Turbo Generator Specifications:

– Rated Power	: 70MW
– Rated Output	: 87.5MVA
– Rated Voltage	: 11000V
– Rated Current	: 4592.6A
– Rated Speed	: 3000rpm
– Rated frequency	: 50Hz
– Power factor	: 0.8 lagging
– Exciting Current	: 1132.3A
– Phase Number	: 3

IV. Result and Discussion

The Performance of the Oxygen Enriched combustion in a Circulating Fluidized bed combustion Boiler is Varies the Air Supply and Fluidizing Velocity is shown in Graph:

A. Effect of Fluidising Velocity on Percent Load Reduction on Combustion Chamber:

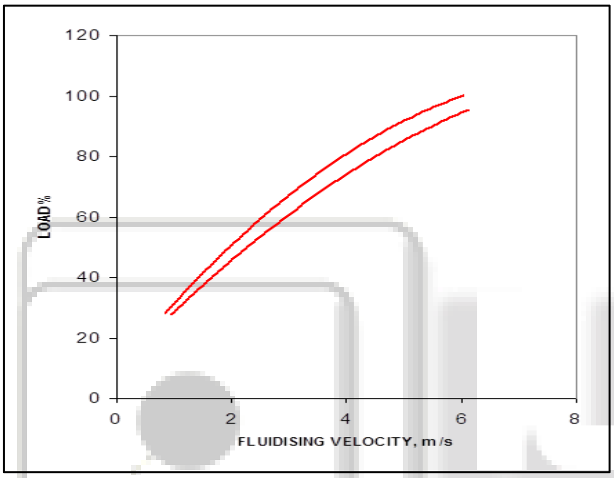

Fig. 6: Effect of Fluidising Velocity on Percent Load Reduction on Combustion Chamber

B. Effect of Load Reduction on Heat Transfer Components:

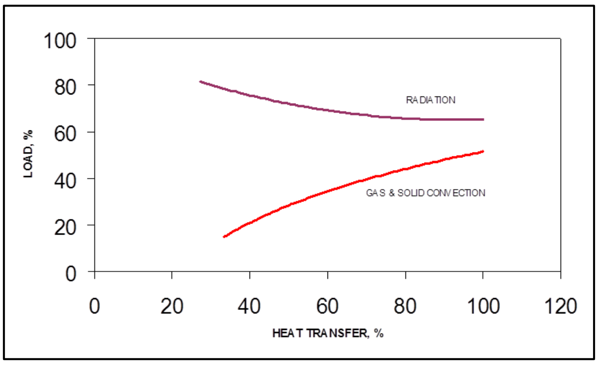

Fig. 7: Effect of Load Reduction on Heat Transfer Components

– Oxygen-enriched combustion can:

1) Increase efficiency. The flue gas heat losses are reduced because the flue gas mass decrease as it leaves the furnace. There is less nitrogen to carry heat from the furnace.
2) Lower emissions. Certain burners and oxy-fuel fired systems can achieve lower levels of nitrogen oxide, carbon monoxide, and hydrocarbons.
3) Improve temperature stability and heat transfer. Increasing the oxygen content allows more stable combustion and higher combustion temperatures that can lead to better heat transfer.
4) Increase productivity. When a furnace has been converted to be oxygen enriched, throughput can be increased for the same fuel input because of higher flame temperature, increased heat transfer to the load, and reduced flue gas.
5) Using oxygen-enriched combustion for specific applications may improve efficiency, depending on the exhaust gas temperature and percentage of oxygen in the combustion air.

V. Scope of Application

The proposed method can be effectively and efficiently used for all CFBC boilers regardless of the capacity of the boiler. Since, there is no drop in efficiency of boiler either during start-up or during normal operation. The proposed method allows safe and smooth operation of the boiler. This method is effective when lack of oxygen in the furnace and Increases the efficiency of the Boiler. Also, it is an energy conservation methodology.

VI. Conclusion

The Oxygen enrichment is recommended to be used as alternative of the circulating Fluidized bed combustion boiler. This method can be applied to CFBC Boiler & AFBC Boiler and there is no drop in efficiency of the boiler.

1) Improvement of Better Combustion with Oxygen enrichment and reduction in Emissions of SOx and NOx.
2) Study of Oxygen enrichment of CFB Boiler Combustion parameters
3) Comparison of Experimental Values with and Without Oxygen Enrichment
4) To validate the experimental results.

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