International Journal of Engineering Research
Volume No.4, Issue No.1, pp : 27 - 32
ISSN:2319-6890)(online),2347-5013(print)
01 Jan. 2015

Optimization of Bed Material Consumption in a CFBC Boiler

[1] Ashish M. Pullekunnel, [2] Manish R. Moroliya
[1]Engineer (Operations) - Abhijeet MADC Nagpur Energy Pvt. Ltd, Nagpur – India
[2]Department of Mechanical Engineering, Dr. Babasaheb Ambedkar College of Engineering & Research, Wanadongari, Nagpur
E-mail: ashish.pullenkunnel@gmail.com

Abstract: ***The proposed Case-Study is to identify the scope of energy conservation and cost saving through optimization of bed material in a CFBC Boiler during plant start up. The study was undertaken at Abhijeet MADC Nagpur Energy Pvt. Ltd (AMNEPL), a 4X61.5 MW power plant at MIHAN, Khairy Khurd, Hingna, Nagpur. The scope of the study covers the savings achieved during light up of 4X250 TPH boiler and the effect of the application of the proposed method on the energy conservation possibilities and efficiency of boiler operation. The proposed method is an alternative to the conventional boiler light up of a CFBC boiler.***

Keywords: *Thermal Power Plant, CFBC Boiler, Bed Material, Energy Conservation, Cost Effectiveness, Energy Audit.*

1. Introduction:

1.1 Profile of AMNEPL MIHAN Thermal Power Plant:

The AMNEPL MIHAN power plant has 4 units having a generation capacity of 61.5 MW each. The electricity produced is supplied to Multimodal International Hub and Airport at Nagpur (MIHAN) as well as to private and government parties.

The study is specifically directed at identifying the energy conservation and cost saving opportunities during the CFBC boiler light up. The CFBC boiler at AMNEPL has been manufactured by Wuxi Huaguang Boiler Co. Ltd. There are 4 units at AMNEPL and each boiler has a capacity 250 TPH and a peak capacity of 270 TPH. The operating temperature is 540 ^{0}C and the operating pressure is 117 Mpa.

1.2 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 & its 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 NO_x 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 SO_x and NO_x emissions effectively.

1.3 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 SO_2 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 ^{o} C is ideal for sulphur retention. Addition of limestone or dolomite to the bed brings down SO_2 emission level to 15% of that in conventional firing method. Low NO_x 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.

1.4 Fundamentals of Fluidization:

ISSN:2319-6890)(online),2347-5013(print)
01 Jan. 2015

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.

1.4.1 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.

1.4.2 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).

1.4.3 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.

1.4.4 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.

1.4.5 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.

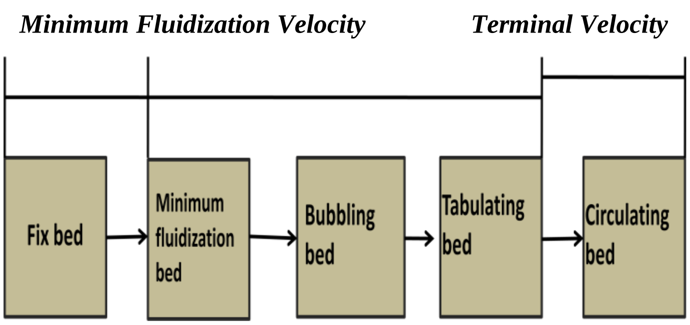


Fig.1. Flow Diagram of Fluidization of Bed with Increase in Air Velocity

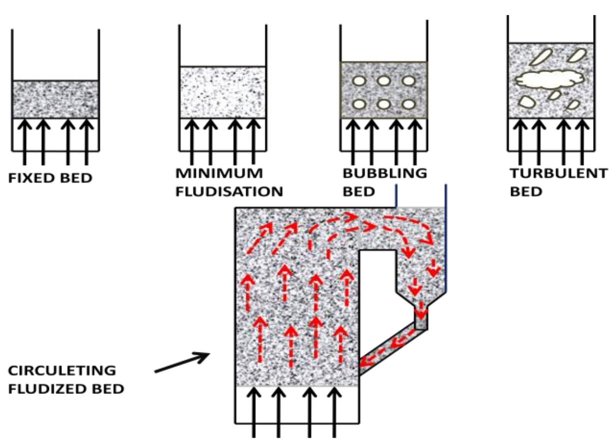


Fig.2. Schematic of Fluidization of Bed

1.5 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 utilises the fluidised bed principle in which crushed (6–12 mm size) fuel and limestone are 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 fluidising 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 utilisation. Similar to Pulverised 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 utilisation, greater fuel particle and sorbent residence time for efficient combustion and SO_2 capture and easier application of staged combustion techniques for NO_x control than AFBC generators.

CFBC boilers are said to achieve better calcium to sulphur utilisation – 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.

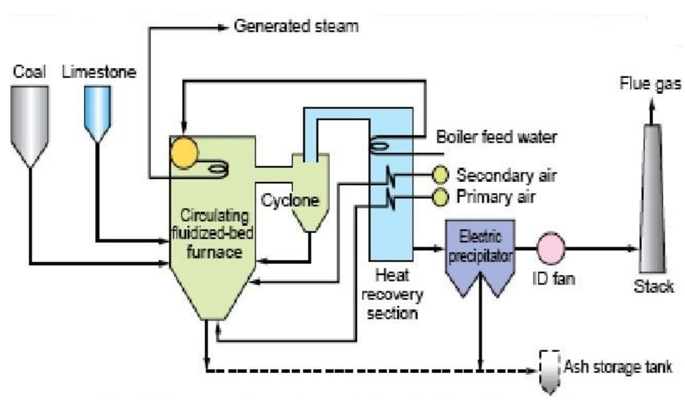


Fig.3. Schematic of a Circulating Fluidized Bed Combustion Boiler

International Journal of Engineering Research ISSN:2319-6890)(online),2347-5013(print)
Volume No.4, Issue No.1, pp : 27 - 32 01 Jan. 2015

1.6 Bed Material:

It can be understood from above theory that the CFBC system works on a continuous fluidized bed of the feed material. Initially, during the boiler light up, the bed is majorly made up of Silica (SiO_2) and Alumina (Al_2O_3). This bed material is fluidized by means of PA air. The initial light up is done by using Light Diesel Oil. After proper temperature is achieved coal feeding is started. The initial bed material is consumed in this process and the ash from the coal takes the place of the bed and acts as the new bed for fluidization.

The bed material used at AMNEPL has the following specifications:

Bed Material Size: 0.85mm to 2.36mm (not below 0.85mm)

Distribution: 0.85 mm to 1.0 mm: 10%

1.0 mm to 1.5 mm: 50%

1.5 to 2.36 mm: 40%

Bed Material Specifications:

Crushed Fire Bricks Cast-able IS8 grade Bricks or River Silica Sand

Fusion Temperature: 1300 Deg. C.

Shape: Spherical Angular

Bulk Density (gm/cc): 1.3

SiO_2: 68 %	Al_20_3: 28 %
Fe_20_3: 1.05%	PiO_2: 1.67%
CaO: 0.54%	MgO: 0.23%
P_2O_5: 0.08%	Na_2O: 0.22%
K_2O: 0.45%	MnO: Trace

Fig.4. Bed Material

2. Methodology – Test Theories and Diagnostic Journey

2.1 Conventional Method: As it can be seen, the bed material is mostly Silica and Alumina, with small traces of other compounds. In the conventional method, during boiler Cold light up, the furnace is filled with bed material to a height that is below the combustion zone. After coal is fed into the furnace and normal operation is achieved, some part of the bed material is lost in ash. This ash, known as Bed Ash, is drained from the boiler furnace regularly through bed ash conveying system. The loss of bed material is to be made up. In coal fired boilers the ash from coal makes up for the lost bed material. This is a continuous replacement process.

During operation of boiler, it was observed that the bed ash contained 1 – 1.5% of unburned coal. This coal along with the bed ash was conveyed through conveying system into an ash silo. The ash was then transferred from the silo to an ash dyke through a road transport system. In the ash dyke the ash was converted into slurry and used for other purpose. This movement of ash through transport system was costly. Also, for every light up, new bed material was required (25 Tonnes), which was also costly.

2.2 Proposed Method: A remedial measure was required to counter the high cost of purchasing new bed material for every light up and the cost of transportation of ash from ash silo to ash dyke. During the research and analysis, it was observed that the bed ash had almost comparable physical and chemical properties to that of the bed material used during light up of the boiler. Since, the bed material is automatically replaced with ash during operation; it was evident that the ash did not affect the efficiency of the boiler. Also, it was understood that the Presence of unburned coal in the bed ash can be utilized during the light up process. Hence, it was proposed to use Bed Ash in place of new bed material.

A comparative of Bed Material and Bed Ash properties is listed in the table below:

Properties	Unit	Bed Material	Bed Ash
Particle Size	mm	≥0.85 to ≤2.4	≥1.0 to ≤2.0
Alumina Contents (Al_2O_3)	%	25 - 35	24.11
SiO_2	%	60 - 75	61.41
Alkali (Na_2O+K_2O)	% Max	2.0	0.113+0.147 = 0.26
Fe_2O_3	% Max	3.0	2.29
Bulk Density	gm/cc	1.1 to 1.3	1.3
Moisture(H_2O)	%	<1.0	0.08
Initial Deformation Temperature	Deg C	>1300	>1000
Unburned coal	%	Nil	1-1.5

Table.1. Bed Material Vs Bed Ash Properties

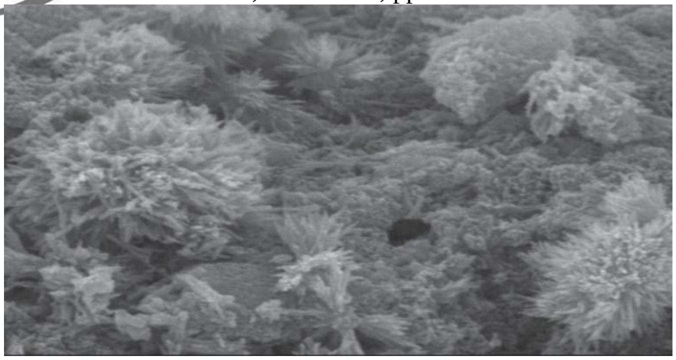


Fig. 4. Micrograph of Bed Material

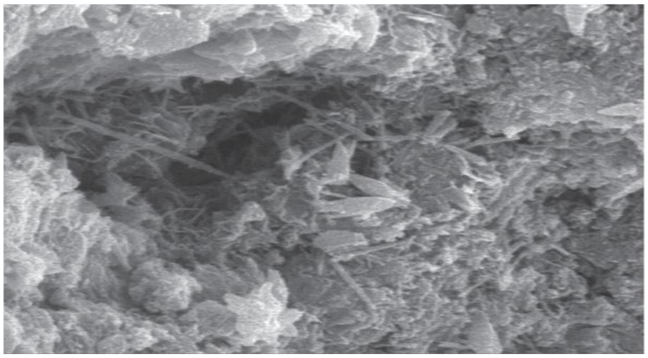


Fig. 5. Micrograph of Bed Ash

2.3 Disadvantages of the Conventional System:

- Purchase of new bed material with required specification is costly.
- In order to store new bed material extra space with appropriate shade is required.
- Laboratory analysis for quality check of new bed material adds extra cost on the already high cost of purchase of new bed material.
- Maintaining sufficient bed material for every light up increased the process of inter departmental transactions.
- Bed material cannot be stored for longer periods as it presents problems of deteriorating mechanical properties of the material.
- More time is required for boiler light up as bed material absorbs moisture quickly and this in turn increased dependence on Light Diesel Oil for a longer period.
- The transportation of bed material from storage facility to the site incurred additional transportation charges.
- The unburned coal in bed ash is lost.
- The transportation of bed ash from silo to ash dyke is costly.

2.4 Disadvantages of the Proposed System

- The system is valid only for CFBC boilers.
- The process is limited only during the Cold light up of CFBC boilers.

3. Executive Summary:

The details and calculations are presented below-

3.1 Key Performance Indicator:

S. No.	KPI	UOM	Level (Before Study)	Expected level	Actual Level (After Study)
1.	*Bed material consumption*	*MT*	*100% new bed material*	*100% bed Ash used in place of new bed material*	*Achieved 100% Successfully*

3.2 Details and Calculations:

Assessment Parameters (Conventional System)	UOM	Consumption	Per Unit Cost (INR)	Total Cost (INR)
Bed Material Consumption	*Tonnes*	*25*	*5865*	*1,46,625*
Coal Consumption for Start-Up	*Tonnes*	*47*	*4150*	*1,95,050*
LDO Consumption for Start-Up	*KL*	*8*	*61000*	*4,88,000*
Bed Ash Transportation Charges	*Tonnes*	*25*	*28*	*700*
DM Water Consumption	*Cu.mtr*	*305*	*41*	*12,505*
Auxiliary Power Consumption	*KWH*	*32000*	*4.25*	*1,36,000*
Heat Loss from system	*Kcal*	*102718*	*1.2*	*1,23,262*
Total Start-Up Cost (Approx.)	***INR***	***11,02,142***		

 ISSN:2319-6890)(online),2347-5013(print)
01 Jan. 2015

Assessment Parameters (Proposed System)	**UOM**	**Consumption**	**Per Unit Cost (INR)**	**Total Cost (INR)**
Bed Material Consumption	*Tonnes*	*0*	*5865*	*0*
Coal Consumption for Start-Up	*Tonnes*	*47*	*4150*	*1,95,050*
LDO Consumption for Start-Up	*KL*	*7.85*	*61000*	*4,78,850*
Bed Ash Transportation Charges	*Tonnes*	*0*	*28*	*0*
DM Water Consumption	*Cu.mtr*	*305*	*41*	*12,505*
Auxiliary Power Consumption	*KWH*	*32000*	*4.25*	*1,36,000*
Heat Loss from system	*Kcal*	*102718*	*1.2*	*1,23,262*
Total Start-Up Cost (Approx.)	***INR***	***9,45,667***		

Total Savings: 1102142 - 945667 = INR 1, 56, 475 per unit start-up

The lower consumption of Light Diesel Oil is an effect of the variations in the percentage of unburned carbon in the ash used as bed material. A general approximation on the effect of unburned carbon percentage on less LDO consumption can be generalized in the following manner.

Heat required in conventional system during light-up $(G.C.V_{oil} + G.C.V_{coal})$ = ***Heat required in conventional system during light-up*** $(G.C.V_{oil} + G.C.V_{coal} + G.C.V_{unburned\ carbon})$

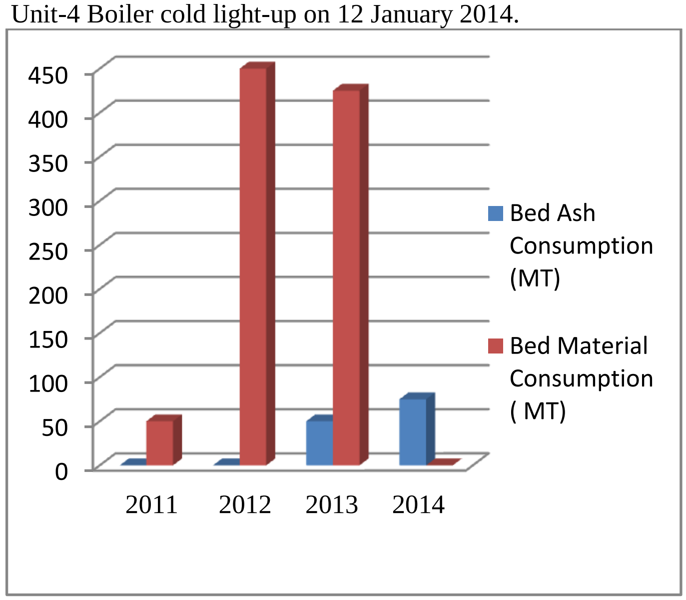
The effect of unburned carbon in the bed material results in the less consumption of LDO. This is so because, initially during light-up the LDO burners are started to increase the temperature of the system and the burners are cut-off from service only when the bed temperature reaches 600 ^{0}C – 650 ^{0}C. However, the coal feeding from the fuel feeding system is started when the bed temperature reaches 450 ^{0}C. This feeding of coal is intermittent and in the form of a coal spray until the bed temperature reaches 600 ^{0}C – 650 ^{0}C. As a result, the total coal fed through the fuel feeding system is almost constant under ideal conditions of start up. Thus, it can be understood that the unburned coal in the ash used as bed material releases it heat content while the burners are in line and its direct effect is on the consumption of LDO. The more the heat released in the initial phase the lesser is the LDO consumption. This is so because the boiler temperature has to be raised in a controlled fashion (150 ^{0}C per hour) and if more heat is released then the oil flow has to be reduced to maintain a constant trend of rise in bed temperature.

However, the above formula cannot be too definitive as it is difficult to measure exactly the quantity of carbon in bed ash. Though the sampling results show 1 – 1.5% of unburned carbon in bed ash, the bed ash used as bed material might contain varying carbon percentage. The limitation is caused by the relatively small sample size compared with the large quantity of bed ash generated in 24 hrs. After implementation of study analysis, the practical results show a 0.15 KL reduction in LDO consumption.

4. Performance Analysis:

Till date the proposed method has been successfully implemented 5 times during light-up of the boiler. The details of light-up are given below.

- Unit-2 boiler cold light-up on 3 October 2013. During light-up observe the parameters & found normal as per operating parameters. So we again light-up with bed ash for unit-1Unit-1 boiler cold light-up on 22 November 2013. In this light-up we again found normal parameters, so we confirmed that the used of bed ash in place of bed material is better solution for reducing the light-up cost.
- Unit-4 Boiler cold light-up on 01 January 2014.
- Unit-3 Boiler cold light-up on 08 January 2014.
- Unit-4 Boiler cold light-up on 12 January 2014.



As per operation monitoring & performance evaluation of boiler, it is observed that there is no bad effect on efficiency of boiler.

Total Savings per light-up	=	***Savings on New Bed Material Purchase + Savings on low LDO required + Savings on Transport of Bed Ash***
	=	***146625 + 9150 + 700***
Total Savings per light-up	=	***INR 1, 56, 475***

Therefore, the total savings realized till date since the application of recommended method amounts to

Total Savings till date = 1, 56, 475 X Total Number of Light-Up till date

= 5 X 1, 56, 475

Total Savings till date = INR 7, 82, 375

4.1 Major advantages of using bed ash in place of bed material in boiler cold light-up:

- 100% Cost saving of bed material for every cold light up.
- LDO consumption becomes less due to presence of unburned particle in bed ash (1-1.5%)
- Saving of bed ash transportation cost from silo-2 to ash dyke.
- Safe and smooth operation of boiler.
- Emissions from the boiler flue gas remain relatively unchanged.

5. 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 cost effectiveness and control over unnecessary wastage of resources is a priority. Also, it is a energy conservation methodology.

6. Conclusion:

The bed ash is recommended to be used as an alternative to bed material during boiler light-up. The method can be applied to CFBC boilers and there is no drop in efficiency of the boiler.

References

i. *Boiler Technologies. Energy Manager Training. Available at: <http://www.energymanagertraining.com/Journal/• Boiler%20Technologies.*

ii. *FBC Boilers. Bureau of Energy Efficiency. Available at: <http://www.bee-india.nic.in/energy_managers_auditors/• documents/guide books/2Ch6.*

iii. *Grace, J. R., Heat Transfer in Circulating Fluidized Beds, "In Circulating Fluidized Bed Technology I. P. Basu (Eds.), Pergamon Press, Oxford, 63 –72,1986.*

iv. *Kunii. D, Levenspiel. O," Fluidization engineering". Butterworth-Heinemann, Boston, USA, 1991.*

v. *Basu, P., Subbarao, D., An experimental investigation of burning rate and mass transfer in a turbulent fluidized bed, "Combust. Flame" 66, 261-269, 1986.*

vi. *Basu. P, & Fraser SA, Circulating fluidized bed boilers– design and operations. Butterworth- Heinemann, Boston, 1991.*

vii. *Waqar Ali Khan, Khurram Shahzad, and Niaz Ahmad Akhtar, Hydrodynamics Of Circulating Fluidized Bed Combustor: A Review, "Journal of Pakistan Institute of Chemical Engineers", Vol. XXXVII, 1999.*

viii. *Bo Leckner, Fluidized Bed Combustion Research And Development In Sweden – A Historical Survey, "Thermal Science:" Vol. 7, No. 2, Pp. 3-16, 2003*

ix. *Basu, P, and Nag P.K., Heat Transfer to the Walls of a Circulating Fluidized Bed Furnace A Review, "Chem. Eng. Science", 51 (1), 1 – 26, 1996.*

x. *Sung won kim, Won Namkung and Sang Done kim, Solids flow characteristics in loop seal of a circulating fluidized bed, "Korean journal of Chemical Engineering", 16(1),82-88, 1999.*

xi. *Basu, P., Cheng, L., An Analysis of Loop Seal Operations in a Circulating Fluidized Bed, "Transactions of Institution of Chemical Engineers", v. 78, Part A, pp 991– 998, , Oct 2000.*

xii. *Yue, G. X., Lu, J. F., Zhang, H, et al. Design Theory of Circulating Fluidized Bed Boilers, "18th International Fluidized Bed Combustion Conference", May 18-21, Toronto Canada, 2005.*

xiii. *Maryamchik. M., Wietzke. D.L., B&W PGG IR – CFB: Operating experience and new developments, "21st International; Fluid Bed Combustion Conference", Italy, 2012.*