Fluidised Bed Combustion Boilers With Co-Generation of Power the Appropriate Technology for the Indian Industry

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WHAT IS A FLUIDISED BED BOILER?

A fluidised bed boiler is a device for generating steam by burning various fuels both conventional and non-conventional such as coal, lignite, rice husk etc., under a special hydro-dynamic condition where fine solids are put up in temporary suspension which is called a Pseudo-Fluid State.

In India the application of this technology started activity in the early seventies. It is said that the during World War-II this technology was experimented by the Germans. Today this technology has been successfully commercialised all over the world.

TYPES OF FLUIDISED BED COMBUSTION BOILERS

Fluidised bed combustion technology is presently classified in two distinct spheres:

1. Atmospheric Fluidised Bed Combustion Boilers
2. Pressurised Fluidised Bed Combustion Boilers

In the atmospheric Fluidised Bed Combustion Boilers there are two concepts, namely the bubbling fluidised bed boilers and circulating fluidised bed boilers.

The pressurised fluidised bed combustion boilers were mainly designed so as to operate a gas turbine and research work for the same is being done all over the world.

In India the bubbling bed technology has been successfully developed and commercialised as it meets our present industrial requirements.

Fluidised Bed Combustion technology all over the world has been developed for various different reasons, individually, to cater to specific requirements. In the United Kingdom the technology was developed for high sulphur British coals which could be burnt successfully with low pollution due to addition of Limestone in the bed which absorbs the Sulphur during the very process of combustion itself. This avoided very extensive and costly filtering/ washing system of the flue gases.

In the Indian context, Fluidised Bed Combustion Technology was developed to burn low calorific value, high ash content, bituminous Indian Coal which contains less or practically no sulphur and hence lime stone addition is not required. Another important advantage of the Fluidised bed combustion system is that due to low temperature combustion in the region of 800 to 900 Deg C, NO-X formations are considerably low. NO-X, as we know depletes the ozone layer of our Earth which dangers the very existence of life.

PRINCIPLES OF FLUIDISED BED COMBUSTION (BUBBLING BED)

At flow rates higher than that for minimum fluidising velocity the particles are buoyed up. They exhibit great mobility and behave like a fluid. This is said to be in a fluidised bed state.

In a gas-solid system, different powders show strongly different fluidisation characteristics. For instance, a bed of fine particles (typically 50-200 microns) fluidised by a gas exhibits particulate

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fluidisation just above minimum fluidisation velocity. Bed expansion however is limited and as the velocity is raised further, at a second stage, the minimum bubbling velocity is reached. Beyond it, any additional gases transverse the bed only in the form of rising voids or bubbles which are virtually devoid of particles. This is termed fluidisation.

In beds of coarser particles, bubbling occurs right at the start of fluidisation. In the following, we will focus on these systems.

A fluidised bed resembles a liquid and exhibits several aspects of liquid-like behaviour. For example a light object can float upon the surface of the bed whereas a heavy object will sink. The upper surface remains horizontal even when the container is tilted. When two beds are connected their levels equalise. So also the pressure drop between any two points is essentially equal to the static load of the bed.

Solids will gush in a jet from a hole bored in the side of the vessel, and finer solids especially can be made to flow very much like a liquid through ducts and pipes from one vessel to another.

Bubbles rising through a fluidised bed sets it into a continuous vigorous agitation. Viewed through transparent walls, the bed appears similar to a boiling liquid. The upper surface of the bed is well defined, always, in motion. The bubbles burst at the surface, flinging particles into the space above. Hence some, especially the smaller ones, are elutriated.

Principally, in the fluidised bed, air is supplied uniformly throughout the distributor plate. The bed which mainly consist of refractory material, sand or ash gets into suspension. Then the fuel is injected into the bed and the combustion practically take place instantaneously.

OPERATING CONDITIONS

Bed temperatures	: 850 to 950 Deg C
Fluidisation velocity	: 2 to 3 m/s
Excess air	: 10 to 20%
Expanded bed height	: 200-400 mm
Bed particle size	: 0.8 mm - 3.0 mm
Compartmental operation	: multiple
Coal feed size	: 0-6 mm
Feeding System	: Peneumatic Underbed / Over bed

CO GENERATION OF POWER

Looking to the acute power shortage and the prevailing power cuts it has become imperative and thought be given for co generation of power.

The data has been taken for paper mill size up to 100 TPD as there are maximum number of units in this region in this sizes.

In higher capacity plants Co generation becomes more attractive and the pay backs are faster.

The following Table gives an approximate general idea of power consumption & steam consumption.

PAPER PLANT UTILITY REQUIREMENT 100% RECYCLED WASTE PAPER BASED MANUFACTURE OF KRAFT PAPER.

PLANT SIZE	STEAM CONSUM	BOILER CAPACITY	TOTAL POWER REQUIRED	POWER GENERATED
30 TPD	3.3 T/Hr	4 T/Hr	800 KW	230 KW
40 TPD	4.4 T/Hr	5 T/Hr	900 KW	325 KW
50 TPD	5.5 T/Hr	6 T/Hr	1100 KW	410 KW
60 TPD	6.6 T/Hr	8 T/Hr	1300 KW	500 KW
100 TPD	11 T/Hr	12 T/Hr	2100 KW	850 KW

Looking to the above data it can be seen that roughly 30 to 40% of the mills power requirements can be met from internal generation.

The following Table gives an approximate general idea of the additional fuel consumption in an High pressure boiler as compared to an conventional low pressure boiler.

Note: The above data is for utilising FBC boilers. Fuel Calorific Value take at 3800 Kcal/kg.

BOILER CAPACITY	10.54 KG/CM² PRESSURE	42 KG/CM² PRESSURE	ADDITIONAL FUEL CONSUMED
4 TPH	775 Kg/Hr.	866 Kg/Hr.	91 Kg/Hr.
5 TPH	970 Kg/Hr.	1080 Kg/Hr.	110 Kg/Hr.
6 TPH	1162 Kg/Hr.	1300 Kg/Hr.	138 Kg/Hr.
8 TPH	1550 Kg/Hr.	1733 Kg/Hr.	183 Kg/Hr.

It is also seen that there are frequent tripping in the grid power. In order to over come the above problem it can be suggested to connect the main paper machine & boiler on the Co generation as under the above data is for a typical 60 TPD plant.

Main Motor	200	HP.
Evener Roll	1	HP.
Shake Unit	3	HP.
Couch Pit Agitator	5	HP.
Couch Pit Pump	5	HP.
Vacuum Pump	150	HP.
Tray Water Pump	20	HP.
Mg. G. Blower	20	HP.
Chest Agitator	15	HP.
Pump	100	HP.
Pump	20	HP.
Boiler	110	HP.
Total	649	HP.
	484	KW.

Average running Load will be between 80 To 90% only.

The balance equipment such as the following will be connected to a grid power.

Re winder	30	HP.
Pumps	330	HP.
Conveyor	10	HP.
Pulper	200	HP.
Thickener	30	HP.
Chest Agitators	160	HP.
Torbos	130	HP.
DDR	300	HP.
Vibrating Screen	10	HP.
ETP	50	HP.
Total	1250	HP.
	932	KW.

Average running Load will be between 80 To 90% only.

Given below are the pay back calculations for the co generation system.

COST COMPARISON & PAYBACK CALCULATIONS CO-GENERATION SYSTEM Vs SATURATED STEAM GENERATOR Vs GRID POWER

	COGEN SYSTEM	SATURATED STEAM BOILER
A. TECHNICAL SPECIFICATIONS		
	6 TPH (ACTUAL)	6 TPH (ACTUAL)
	42 KG/CM² 400 DEG. C	10.54 KG/CM² SATURATED
	COAL FIRED BIDRUM FBC BOILER + TG SET BACK PRESSURE 3 KG/CM².	

B. CAPITAL COST

1. Main unit & Auxiliaries	Rs. 95 Lacs	Rs. 60 Lacs
2. Cost of TG set & access	Rs. 75 Lacs	----
3. Total cost	Rs. 170 Lacs	Rs. 60 Lacs
4. Diffenrece in capital cost	Rs. 110 Lacs	----
5. Interest @ 20% per year on (4)	Rs. 22 Lacs	----

C. RUNNING COST

a) FUEL

1. Fuel consumption Hr/Kg. on coal (CV of 3800 Kcal/kg)	1300	1150
2. Difference in fuel consumption Kg/Hr.	150	
3. Difference in fuel consumption per year (tones) - 7200 Hrs.	1080	
4. Cost of difference in fuel cost per year (Rs. 1800/- per ton).	Rs. 19.00 LACS	

D. POWER GENERATION

We select turbine condition as :-

INLET

Pressure	: 40 KG/CM²
Temperature	: 400 Deg.C.

OUTLET

pressure	: 3 KG/CM²
Temperature	: 150 Deg.C.

From Mollier diagram

On Mollier diagram, we select turbine inlet pressure as 40 Kg/cm² and steam temperature as 400 Deg. C.

Correspondingly, enthalpy of steam at 40 Kg/cm² pressure and 400 Deg.C. steam temperature.

$$h_1 = 3215 \text{ KJ/kg.}$$

On Mollier diagram, we select turnine outlet pressure as 3 Kg/cm² Correspondingly, enthalpy of steam at 3 Kg/cm² and 150 Deg. C. steam temperature.

h_2 = 2746 KJ/kg.

So utilisable enthalpy drop

$$DJ = h_1 - h_2 = 469 \text{ KJ/kg}$$

Since actual steam flow through turbine is 6 TPH and considering turbine efficiency as 65%.

$$\text{Power generated KW} = \frac{6000 \times 0.65 \times 469}{3600}$$

$$= 508 \text{ KW}$$

Considering mechanical losses in the reduction gear as 1% and efficiency of alternator as 98%.

Power generated = 508 x 0.99 x 0.98
= 493 KW.

1.	Power generated by the system (per hr)	493 kw
2.	Cost of power generated per hr (@ Rs. 2.50 per kwh)	Rs. 1232.00
3.	Cost of power generated per year 7200 hrs	Rs. 89.00 LACS

E. TECHNO ECONOMICS

Difference in operating cost due to additional fuel consumption

Rs. 19.00 LACS.

Difference in capital cost due to High pressure boiler and Interest.

Rs. 132.00 LACS.
= Rs. 151.00

F. PAYBACK

THE ADDITIONAL CAPITAL COST OF THE SYSTEM IS	=Rs. 151.00 LACS
SAVINGS IN THE FIRST YEAR	= Rs. 89.00 LACS
PAYBACK	= Less than 22 Months

NOTE : The above figures given are indicative and approximate.

The following are the techno economics for paper plant of 75 TPD & 100 TPD.

COST COMPARISON & PAYBACK CALCULATIONS Vs SATURATED STEAM GENERATOR Vs GRID POWER SUITABLE FOR 75 TPD PLANT

	COGEN SYSTEM	SATURATED STEAM BOILER

A. TECHNICAL SPECIFICATIONS

COGEN SYSTEM	SATURATED STEAM BOILER
8 TPH (ACTUAL) 42 KG/CM² 400 DEG.C COAL FIRED BIDRUM FBC BOILER + TG SET BACK PRESSURE 3 KG/CM².	8 TPH (ACTUAL) 10.54 KG/CM² SATURATED

B. CAPITAL COST

		COGEN SYSTEM	SATURATED STEAM BOILER
1.	Main unit & Auxiliaries	Rs. 105 Lacs	Rs. 60 Lacs
2.	Cost of TG set & access	Rs. 75 Lacs	----
3.	Total cost	Rs. 180 Lacs	Rs. 60 Lacs
4.	Difference in capital cost	Rs. 120 Lacs	----
5.	Interest @ 20% per year on (4)	Rs. 24 Lacs	----

C. RUNNING COST

a) FUEL

		COGEN SYSTEM	SATURATED STEAM BOILER
1.	Fuel consumption Hr/Kg. on coal (CV of 3800 Kcal/kg)	1750	1550
2.	Difference in fuel consumption Kg/Hr.	200	
3.	Difference in fuel consumption per year (tonnes) - 7200 Hrs	1440	
4.	Cost of difference in fuel cost per year (Rs. 1800/- per ton).	Rs. 26.00 LACS	

D. POWER GENERATION

We select turbine condition as :-

INLET

Pressure	: 40 KG/CM²
Temperature	: 400 Deg.C.

OUTLET

pressure	: 3 KG/CM²
Temperature	: 150 Deg.C.

From Mollier diagram

On Mollier diagram, we select turbine inlet pressure as 40 Kg/cm² and steam temperature as 400 Deg. C.

Correspondingly, enthalpy of steam at 40 Kg/cm² pressure and 400 Deg.C. steam temperature.

h_1 = 3215 KJ/kg.

On Mollier diagram, we select turnine outlet pressure as 3 Kg/cm² Correspondingly, enthalpy of steam at 3 Kg/cm² and 150 Deg. C. steam temperature.

h_2 = 2746 KJ/kg.

So utilisable enthalpy drop

$$DJ = h_1 - h_2 = 469 \text{ KJ/kg}$$

Since actual steam flow through turbine is 18 TPH and considering turbine efficiency as 65%.

$$\text{Power generated KW} = \frac{8000 \times 0.65 \times 469}{3600}$$

$$= 677 \text{ KW}$$

Considering mechanical losses in the reduction gear as 1% and efficiency of alternator as 98%.

Power generated = 677 x 0.99 x 0.98
= 655 KW.

1.	Power generated by the system (per hr)	655 KW
2.	Cost of power generated per hr (@ Rs. 2.50 per kwh)	Rs. 1635.00
3.	Cost of power generated per year 7200 hrs	Rs. 118.00 LACS

E. TECHNO ECONOMICS

Difference in operating cost due to additional fuel consumption

Rs. 26.00 LACS.

Difference in capital cost due to High pressure boiler and Interest.

Rs. 144.00 LACS.
= Rs. 170.00

F. PAYBACK

THE ADDITIONAL CAPITAL COST OF THE SYSTEM IS	=Rs. 170.00 LACS
SAVINGS IN THE FIRST YEAR	= Rs. 118.00 LACS
PAYBACK	= Less than 18 Months

NOTE : The above figures given are indicative and approximate.

COST COMPARISON & PAYBACK CALCULATIONS Vs SATURATED STEAM GENERATOR Vs GRID POWER SUITABLE FOR 100 TPD PLANT

COGEN SYSTEM	SATURATED STEAM BOILER

A. TECHNICAL SPECIFICATIONS

12 TPH (ACTUAL)	12 TPH (ACTUAL)
42 KG/CM² 400 DEG.C	10.54 KG/CM² SATURATED
COAL FIRED BIDRUM FBC BOILER + TG SET BACK PRESSURE 3 KG/CM².	

B. CAPITAL COST

1.	Main unit & Auxiliaries	Rs. 125 Lacs	Rs. 70 Lacs
2.	Cost of TG set & access	Rs. 75 Lacs	----
3.	Total cost	Rs. 200 Lacs	Rs. 70 Lacs
4.	Difference in capital cost	Rs. 130 Lacs	----
5.	Interest @ 20% per year on (4)	Rs. 26 Lacs	----

C. RUNNING COST

a) FUEL

1.	Fuel consumption Hr/Kg. on coal (CV of 3800 Kcal/kg)	2600	2325
2.	Difference in fuel consumption Kg/Hr.	275	
3.	Difference in fuel consumption per year (tones) - 7200 Hrs	1980	
4.	Cost of difference in fuel cost per year (Rs. 1800/- per ton).	Rs. 36.00 LACS	

D. POWER GENERATION

We select turbine condition as :-

INLET

Pressure	: 40 KG/CM²
Temperature	: 400 Deg.C.

OUTLET

pressure	: 3 KG/CM²
Temperature	: 150 Deg.C.

From Mollier diagram

On Mollier diagram, we select turbine inlet pressure as 40 Kg/cm² and steam temperature as 400 Deg. C.

Correspondingly, enthalpy of steam at 40 Kg/cm² pressure and 400 Deg.C. steam temperature.

$$h_1 = 3215 \text{ KJ/kg.}$$

On Mollier diagram, we select turbine outlet pressure as 3 Kg/cm² Correspondingly, enthalpy of steam at 3 Kg/cm² and 150 Deg. C. steam temperature.

$$h_2 = 2746 \text{ KJ/kg.}$$

So utilisable enthalpy drop

$$DJ = h_1 - h_2 = 469 \text{ KJ/kg}$$

Since actual steam flow through turbine is 12 TPH and considering turbine efficiency as 65%.

$$\text{Power generated KW} = \frac{12000 \times 0.65 \times 469}{3600}$$

$$= 1016 \text{ KW}$$

Considering mechanical losses in the reduction gear as 1% and efficiency of alternator as 98%.

Power generated = 1016 x 0.99 x 0.98
= 985 KW.

1.	Power generated by the system (per hr)	985 KW
2.	Cost of power generated per hr (@ Rs. 2.50 per kwh)	Rs. 2465.00
3.	Cost of power generated per year 7200 hrs	Rs. 117.00 LACS

E. TECHNO ECONOMICS

Difference in operating cost due to additional fuel consumption

Rs. 36.00 LACS.

Difference in capital cost due to High pressure boiler and its Interest.

Rs. 156.00 LACS.

3. Therefore capital plus running cost (from B & C)
= Rs. 156.00 + Rs. 36.00 LACS
= Rs. 192.00

F. PAYBACK

THE ADDITIONAL CAPITAL COST OF THE SYSTEM IS	=Rs. 192.00 LACS
SAVINGS IN THE FIRST YEAR	= Rs. 177.00 LACS
PAYBACK	= Less than 10 Months

NOTE : The above figures given are indicative and approximate.

- There is also a cheaper alternative for the paper industry and that is motive power generation. In this system you may connect the Vacuum pumps/ DDR etc. as per the motive power load available this system has a very low capital investment and quick pay back. Given below is the cost comparison.

COST COMPARISON & PAYBACK CALCULATIONS Vs SATURATED STEAM GENERATOR Vs GRID POWER

MOTIVE POWER SYSTEM	SATURATED STEAM BOILER

A. TECHNICAL SPECIFICATIONS

4.5 TPH (ACTUAL)	4.5 TPH (ACTUAL)
21 KG/CM² 300 D.C.S.HS.	10.54 KG/CM² SATURATED
FBC BOILER + TG SET	
BACK PRESSURE 3 KG/CM².	

B. CAPITAL COST

1.	Main unit & Auxiliaries	Rs. 40 Lacs	Rs. 30 Lacs
2.	Cost of TG set & access	Rs. 14 Lacs	----
3.	Total cost	Rs. 54 Lacs	Rs. 40 Lacs
4.	Difference in capital cost	Rs. 24 Lacs	----
5.	Interest @ 20% per year on (4)	Rs. 05 Lacs	----

C. ADDITIONAL OPERATING COST

FUEL

1.	Fuel consumption Kg/hr. on coal (CV of 3800 Kcal/kg)	1000	950
2.	Difference in fuel consumption Kg/hr.	50	----
3.	Difference in fuel consumption per year (tones) - 7200 Hrs	360	----
4.	Cost of difference in fuel cost per year (Rs. 1800/- per ton).	Rs. 07.00 lacs	

D. EQUIVALENT MOTIVE POWER GENERATION

We select turbine condition as :-

INLET PRESSURE

Pressure	: 19 bar (abs.)
Temperature	: Super heated steam 300 deg.C.

OUTLET PRESSURE

pressure	: 3 bar (abs.)

EQUIVALENT POWER GENERATED 200 KW

E. TECHNO ECONOMICS

1.	Cost of power generated per hr (@ Rs. 2.50 per kw/hr)	Rs. 500.00
	Cost of power generated per year 7200 Hrs./Year	Rs. 36.00 LACS

Difference in capital cost due to High pressure boiler and its Interest.

Rs. 29.00 LACS.

Difference in operating cost due to additional fuel consumption

Rs. 07.00 LACS.

3. Therefore capital plus running cost (from B & C)
= Rs. 29.00 + Rs. 07.00 LACS
= Rs. 36.00 LACS

F. PAYBACK

THE ADDITIONAL CAPITAL COST OF THE SYSTEM IS	= Rs. 39.00 LACS
SAVINGS IN THE FIRST YEAR	= Rs. 40.00 LACS
PAYBACK	= One year.

NOTE : The above figures given are indicative and approximate.

COST COMPARISON & PAYBACK CALCULATIONS Vs SATURATED STEAM GENERATOR Vs GRID POWER

MOTIVE POWER SYSTEM	SATURATED STEAM BOILER

A. TECHNICAL SPECIFICATIONS

6 TPH (ACTUAL)	6 TPH (ACTUAL)
21 KG/CM² 300 D.C.S.HS.	10.54 KG/CM² SATURATED
FBC BOILER + TG SET	
BACK PRESSURE 3 KG/CM².	

B. CAPITAL COST

1.	Main unit & Auxiliaries	Rs. 50 Lacs	Rs. 40 Lacs
2.	Cost of TG set & access	Rs. 14 Lacs	----
3.	Total cost	Rs. 64 Lacs	Rs. 40 Lacs
4.	Difference in capital cost	Rs. 24 Lacs	----
5.	Interest @ 20% per year on (4)	Rs. 05 Lacs	----

C. ADDITIONAL OPERATING COST

FUEL

1.	Fuel consumption Kg/hr. on coal (CV of 3800 Kcal/kg)	1075	1000
2.	Difference in fuel consumption Kg/hr.	75	----
3.	Difference in fuel consumption per year (tones) - 7200 Hrs	540	----
4.	Cost of difference in fuel cost per year (Rs. 1800/- per ton).	Rs. 10 lacs	

D. EQUIVALENT MOTIVE POWER GENERATION

We select turbine condition as :-

INLET PRESSURE

Pressure	: 19 bar (abs.)
Temperature	: Super heated steam 300 deg.C.

OUTLET PRESSURE

pressure	: 3 bar (abs.)

EQUIVALENT POWER GENERATED 225 KW

E. TECHNO ECONOMICS

1.	Cost of power generated per hr (@ Rs. 2.50 per kw/hr)	Rs. 560.00
	Cost of power generated per year 7200 Hrs./Year	Rs. 40.00 LACS

Difference in capital cost due to High pressure boiler and its Interest.

Rs. 29.00 LACS.

Difference in operating cost due to additional fuel consumption

Rs. 10.00 LACS.

3. Therefore capital plus running cost (from B & C)
= Rs. 29.00 + Rs. 10.00 LACS
= Rs. 39.00 LACS

F. PAYBACK

THE ADDITIONAL CAPITAL COST OF THE SYSTEM IS	= Rs. 39.00 LACS
SAVINGS IN THE FIRST YEAR	= Rs. 40.00 LACS
PAYBACK	= Less than one year.

NOTE : The above figures given are indicative and approximate.