DESIGN OF FLUIDISED BED COMBUSTION BOILERS FOR MULTIFUELS

By K.K.PARTHIBAN, Boiler Consultant
Venus Energy Audit System
Email ID:parthi2006@gmail.com / venus.energy@gmail.com

INTRODUCTION

To be competitive in the market, the cost of production of a product has to be less. For many products, steam / power cost is the major factor. Many Industries have realized this, and have gone ahead with Multi fuel fired boilers, Multi fuel fired co generation plants & captive generation plants. Today, no single buyer thinks about single fuel for the boiler. In this article, the factors and their effects, which affect the boiler design, have been brought out for the understanding of the Boiler users.

BASIS FOR SELECTION OF FUELS

The selection of fuels is to be based on the following factors. It is necessary to analyze the long range availability & economics of the fuels.

- Source
- Year long availability
- Transportation cost
- Handling cost at plant
- Fuel preparation cost
- Wastage / deterioration cost
- Initial cost of boiler
- Fuel handling system cost
- Pollution control equipment cost
- Ash handling system investment
- Ash disposal cost / difficulties
- Government regulations
- Fuel storage space requirement
- Cost of stocking
- Boiler maintenance cost
- Fuel price escalation

PARAMETERS WHICH AFFECT THE DESIGN OF BOILER

- *FUEL HEAT DUTY*

The boiler design is based on the design fuel for which the design will be optimum. It is usually the inferior fuel. The inferior fuel is the one that calls for more fuel consumption. The flue gas produced will be more for the inferior fuel.

Depending on the location the main fuel chosen is coal / lignite / rice husk / De oiled bran / Bagasse. At times furnace oil / Natural gas are also being specified for 100 % boiler duty. The fuels that are specified for co firing are usually Bagasse pith, Rice husk, Biogas, Sawdust, Wood chips, Coffee husk. Co firing has an advantage that the fuel quantity as received is fired directly with the support of main supporting fuel. Many times 60 % of heat input may be substituted by the auxiliary fuel. Twin furnaces that may be required for certain combinations can be avoided, thus bringing down the initial investment cost.

Table 1 gives the ultimate analysis of fuel & GCV of varieties of fossil & agro waste fuels. Table 2 summarizes the air requirement, flue gas produced, and flue gas composition on the basis of One million kcal/hr useful heat output.

TABLE 1: Gross calorific value & Ultimate analysis of fuels C-carbon, H-hydrogen, N-Nitrogen, S- Sulfur , M-Moisture, A- ash, O-Oxygen, in % by wt								
Fuel	GCV Kcal/kg	C	H	N	S	M	A	O
Coal (typical)	3800	39.9	2.48	0.67	0.38	8.0	42.0	6.76
Rice husk (dry & fresh)	3275	36.67	4.51	1.25	0.18	9.44	15.01	32.88
Rice straw	2660	36.0	5.0	0.5	-	15.75	4.75	38
Bagasse	2272	23.5	3.2	-	-	50.0	1.3	22.0
Neyveli Lignite	2800	32.0	2.8	-	0.7	52.0	2.5	10
Kutch lignite	3800	38	2.8	0.5	2	36	10	10.7
Groundnut shell	4130	47.68	42.9	0.51	0.42	10.12	2.4	34.58
Rap seed Bagda	3350	34.55	4.22	-	-	6.12	8.63	46.48
Deoiled bran	3258	34.35	4.89	0.38	-	8.98	21.42	29.98
Bamboo dust	4235	44.31	4.21	0.77	-	9.86	6.47	34.38
Tea spent	4010	41.55	3.69	-	-	11.8	2.7	40.19
Coffee spent	1172	14.01	1.9	0.15	0.17	74.8	0.4	8.46
Chicken droppings	2102	21.25	1.95	0.62	0.41	5.5	42.6	27.58
Coffee husk (parchment)	4199	44.11	2.89	0.11	-	7.8	0.8	44.29
Coffee husk (Cherry)	3726	39.18	2.71	0.13	-	11.1	5.0	41.88
Coconut fibre	3838	41.34	4.24	0.21	0.11	11.9	3.1	39.04
Leco	6900	72.5	2	0.2	0.9	6.07	12.0	6.5
Bagasse pith	4000	41.08	5.21	0.34	0.09	10.19	6.81	36.28
Castor seed cake	4250	46.35	5.18	5.1	0.11	9.7	5.5	28.01
Saw dust	3396	36.92	4.59	-	0.11	18.22	7.26	32.9
Wood shaving	4278	47.2	5.02	-	0.1	10.6	0.38	36.6
Mezda	3760	42.26	5.19	-	0.22	10.49	3.05	38.79
Coffee ground	5009	49.56	5.92	2.62	-	2.6	2.09	36.61
Char	4109	43.08	0.79	0.63	0.41	5.66	41.44	7.99
Dolo char	4753	49.13	0.88	0.71	0.47	3.77	35.99	9.05
Charcoal	6300	93	2.5	-	1.5	-	-	3.0

**The values in the tables are based on the analytical reports of samples actually tested. Discrepancies may be encountered, as these values are not based on average values of several samples.

Table 3 may be used for specifying the fuels to be fired. The fuel samples need to be analyzed for fuel chemical composition, ash chemical composition & ash fusion temperature.

Table 3. Fuel Specification & firing combinations											
Specification of Solid fuels / Liquid fuels											
Fuels		Ultimate analysis by weight							GCV kcal/kg	Fuel availability	
		C	H	S	N	O	Ash	Moist		All day yes/No	Kg/day
A											
B											
C											
D											
E											
F											

Specification of Gaseous fuels													
Fuels		Ultimate analysis by volume									GCV kcal/m3	Fuel availability	
		CH_4	C_nH_m	N_2	O_2	CO	CO_2	H_2O	H_2S			All day yes/No	Kg/day
G													
H													

Fuel firing combination in % heat duty wise								
	Fuel A	Fuel B	Fuel C	Fuel D	Fuel E	Fuel F	Fuel G	Fuel H
Combination 1								
Combination 2								
Combination 3								

- *FUEL TYPE FIBROUS / NON-FIBROUS / LIQUID / GASEOUS*

Fossil fuels such as coal, lignite are prepared, stored in bunkers and fired in the boiler. The materials that have good flow properties are stored & fired. Fibrous materials such as Bagasse, Bagasse pith, bamboo dust, coconut fiber, wood shavings are directly fired without any intermediate storage system. Though fibrous, groundnut shell can be fired indirectly with properly designed storage bunkers. Improper bunker design leads to severe flow problems with groundnut shell. Rice husk, deoiled bran, coffee husk are stored in bunker and fired in FBC boilers. The size of the fuel is so uniform that flow problems are not encountered.

The FBC boilers are designed with under bed feeding system / over bed feeding system or with both the systems depending upon the fuel combinations & flexibility desired. In the case of multi fuels, it is possible to have metering of all fuels. Or only the main fuel can be metered and the other fuels may be designed for direct firing. See figure 1 & 2 showing the fuel feed arrangements. The table 4 compares the merits and demerits of underbed & over bed feeding systems.

Table 4 : General comparison between underbed & over bed feeding system- fluidized bed combustion boilers

UNDERBED FEEDING SYSTEM	OVERBED FEEDING SYSTEM
Preferred for powdery fuels such as Coal, Lignite	Preferred For Agro fuels such as Rice husk, Groundnut shell, Bagasse, Wood chips, Saw dust.
Suited for fines. As the combustion will be stable even if the fines are more than 40 %.	Leads to Unstable combustion if the fines are more.
Start up with fines is not difficult.	Start up with fines is difficult, as the bed would not catch fire.
Needs minimum two months for operator training.	Needs less time as compared to underbed.
More compartmentalization is easier & practical to suit load turn down requirement.	Compartmentalization to more than two compartments complicates the layout of fuel handling system.
Power consumption is more due to PA fan.	Power consumption is less, as PA fan is not required.
Unburnt in the ash is less. Where less unburnt is demanded for other uses, Underbed is the only choice.	Unburnt is a function of fines in the fuel. The ash will have more unburnt.
Excess air required for underbed is less. Usually 20 – 25 % is sufficient to bring smoke free combustion.	Excess air required is about 60 %.For rice husk, The combustion efficiency is affected to 1.8 % due to excess air.
Oversize fuel / foreign material results in choking of fuel lines. This is due to failure in the screen system in the yard. Frequent oversize ingress affects interrupts the boiler operation.	Oversize fuels / foreign materials would go to the bed. More oversize materials lead to defluidization. Over size materials directly fall below the fuel feed point and form clinker.
Back fire in boiler does not allow flame to come to bunker.	Backfire in boiler needs to fire in bunker. Agro fuels promote bunker fires.
There is no settling chamber irrespective of the fuel. Hence the ash is collected at low temp zones down the flue path.	For rice husk / groundnut shell, ash settling chamber is provided to enable unburnt carbon within the furnace. The hot ash is to be removed directly from the furnace. The removal of hot ash by a feeder is difficult though not impossible. Water-cooled ash feeder is required. Hot ash discharge from furnace increases heat loss by 1 % compared to underbed feeding system.

Figure 3 shows the arrangement followed for biogas firing arrangement followed for distilleries. The gas is fed thro the air nozzles only. This has been found to be very efficient way of burning since the gas flow may be varying. The support fuel can be increased as required. It has been found that minimum 30% solid fuel support is required for biogas. The biogas composition & GCV details are given in table 5.

Table 5. Bio Gas chemical composition & calorific value			
GCV, Kcal /m3	CH 4 by vol %	H2S by vol %	CO2 by vol %
4697.0	54.0	2.0	44.0

Very rarely 100 % oil firing along with 100 % solid fuels has been requested by a user. 60 % furnace oil firing had been given. Pressure jet burners / steam atomized burners have been used.

- *FUEL BULK DENSITY*

  - *Fuel feeder sizing*

Higher the bulk density of the fuel, the greater the volume of the feeder. A fuel feeder sized for coal will be too small for rice husk. Metering coal with a feeder designed for rice husk would be difficult. The fuel feed regulation can not be smooth. Usually separate metering feeders are given for such applications. See figure 4. Some boilers are designed with a single bunker so that the either coal or rice husk can be fired from the same bunker. In such a case the feeders are provided with multiple sprockets so that wide rpm variation can be achieved.

Underbed fuel piping is selected based on the fuel bulk density of the fuel. Table 6 shows the design criteria for different fuels for underbed feeding. Again depending on the size & no off fuel feeding lines the PA fan sizing is done.

Table 6: Maximum fuel carrying capacity in kg/hr per line			
Fuel	Fuel line size, nb		
	100 nb	125 nb	150 nb
Rice husk / DOB	400	600	900
Ground nut shell	300	450	600
Coal / lignite	800	1200	1800

  - *Fuel storage bunker*

A bunker that is meant for 16 hrs storage will hold rice husk for 2 hrs only. Table 7 compares the bulk densities of certain fuels.

Table 7. Bulk densities of fuels, in kg/m3				
Coal	1000		Ground nut shell	100
Lignite	800		Bagasse	60
Rice husk	125		Wood shaving	175
DOB	400		Coir pith	60

- *Fuel storage & handling*

Depending upon the boiler size, fuel storage & reclaiming should be given sufficient thought. A single feed hopper for coal is usually sufficient. It will not be adequate for rice husk, when it comes to higher capacity boilers. Multiple hoppers will have to be planned for rice husk. This helps in matching the filling rate with emptying rate.

For Bagasse & fibrous materials, flight chain conveyor or belt conveyors are selected to convey the fuel from the yard to boiler. In this applications a horizontal run is planned to enable feeding the conveyor anywhere along the length. When it comes to regulating the fuel feed to the boiler, the return Bagasse conveyor is planned so that surplus fuel can be returned to yard.

- *Hours of operation of fuel handling system*

The fuel handling system will have to operate for all three shifts in the case of low bulk density / fibrous fuels.

➢ *FUEL SIZE*

The fuel size is the factor that decides the type of fuel handling system.

- Coal will have to be sized to minus 8 mm, whereas minus 10 mm is allowable for lignite in the case of underbed system. In the case of over bed system, minus 15 mm is recommended.
- The groundnut shell / rice husk handling system calls for pre screening as stones and other foreign materials are likely to get mixed up.
- Bagasse if received in bale form needs a debaler. Bagasse shall be in the form of loose fibers of length below 125 mm.
- Wooden logs need a shredder. Saw dust handling system needs to have a screen to limit the chip size to 25 mm & below.
- Bagasse pith can be directly fired using a flight chain conveyor system along with a pneumatic spreader at the furnace. Alternately the Bagasse pith can be mixed with the main fuel that may be coal or rice husk. The advantage is that the Bagasse pith can be fed and at uniform ratio, irrespective of the operational hours of depither. In case depither is not closer to boiler, mixing with the main fuels is the right option.

➢ *ASH MELTING POINT*

FBC furnaces are designed for bed temperatures of 800 to 900 deg C in the case of the underbed feeding system. In the case of the over bed feeding arrangement, the over bed temperature is likely to exceed 1000 deg C. For fuels which have low ash melting points, it is desirable that Combustion temperatures are kept lower. For fuels like coffee husk, 100 % firing has not been practical for its ash melting temperature is as low as 800 deg C. In the case of Co-firing with high ash fuels such as coal, rice husk, the slagging is greatly reduced. The higher the alkali contents of the ash, the lower the ash-melting temp. Hence, the percent co firing is limited by the tendency of fuels to slag.

For Kutch lignite recommended combustion temperature is 850 deg C. Only underbed feeding system has been found reliable since the bed temperature control is much better. Studded bed coils can not be used for Kutch lignite as the stud tip form as nucleus for slagging. More no of feed points is desirable for Kutch lignite, as this would reduce the risk of local high temperatures.

Ash Slagging calls for soot blowers wherever the high metal temperatures exist. In the case of convection superheater, the counter flow superheater will have more tendencies to slag deposition as compared to parallel flow Superheater. Retractable soot blowers have to be used for the superheater zone.

For Slagging fuels, the water wall furnaces are recommended. Depending upon the moisture content of the fuel a minimum portion of refractory would be required for drying the fuel.
The spacing of super heater coils / boiler bank tubes is given due consideration for slagging fuels.

In case of smaller capacity boiler shell type boilers are offered. In such cases, the water wall is adequately sized so that inlet temperature to I pass tube sheet is lower. When this is not done, ash deposition and choking have been encountered in the I pass tubes sheet.

- *ACID DEW POINT*

The acid dew point governs the design of cold end block of air preheater. The cold end preheater is made as a separate block since the tubes would fail due gas side corrosion.

In case of oil firing, air preheater is not recommended following a high combustion temperature and Nox formation. Economizer is provided for heat recovery in case of oil firing. The feed water inlet temperature should be 125 deg C to avoid cold end corrosion of economizer tubes.

- *SULFUR CONTENT IN FUEL*

Sulfur content in fuel is an important pollutant. As per the regulations the chimney height is to be maintained a minimum given as per the formula below.

$$H = 14 \text{ x } (Q)^{0.3}$$

Where,

H = height of chimney in meters
Q = Sulfur dioxide produced in kg / hr

The choice of material of construction of chimney is dependent on the acid dew point of flue gas. Concrete chimney with inner refractory lining is usually the choice when the fuel is Bagasse. Concrete chimney will be uneconomical for smaller diameter.

In the case of high sulfur fuels, limestone feeding has to be fed to the fluidized bed. This material absorbs the SO2 produced and the Sox emission comes down. The absorption reaction is as below.

$$CaCO_3 = CaO + CO_3 \text{ by dissociation}$$

$$CaO + SO_2 = CaSO_4$$

- *ASH CONTENT*

    - Ash discharge equipment

The ash feeders are selected for the worst fuel. The total ash produced is calculated and based on the percentage collection expected in the various collection zones, the ash discharge equipment are selected. Table 8 suggests the % ash collection rate and sizing philosophy for ash feeders for Bi drum type boiler. Bed ash removal is dependent on the size of the fuel particles and the fuel itself. For fuels like coal, bed ash cooling system shall be sized for 40 %.

Table 8. % Fly ash Collection at various zones

	Boiler Bank	Economizer	Airheater	ESP field 1	ESP field 2	ESP field 3
Actual	10	10	10	40	20	10
Design	20	20	20	60	60	60

- Fly ash collection equipment

Depending upon the local pollution control act, 1200 /500 / 350/ 150 / 115 mg/nm3 may be the permissible dust emission in chimney. The mechanical dust collector (multi cyclone type) is offered for smaller capacity boiler. When it comes to lower limits, bag filter / venturi scrubber / Electro static precipitator. Ash chemical composition, flue gas composition, particle size distribution, flue gas temperature, water availability, effluent disposal arrangement are critical factors in selection & sizing of type pollution control equipment.

- Ash handling system & ash silo

The bed ash discharged from the bed is in the range of 800 to 900 deg C. Fluidized bed ash coolers are available to extract heat from the bed ash. The bed ash is negligible in the case of the Rice husk and other agro wastes. Hence for fossil fuels such as coal / lignite only the bed ash cooling system & bed ash conveying systems are planned. For fly ash, lean phase system and dense phase system are preferred as the dust nuisance is less.

- Ash erosion

The % ash content in the fuel and erosive ness of ash decide the flue gas velocities to be adopted. The recommended gas velocities are given in table 9.

Table 9: Typical design gas velocities for Various fuels

Location	Coal	Lignite	Rice husk	Bagasse	Oil / Gas
At superheater	8	10	8	10	25
Shell flue tube entry	18	18	18	18	30 -45
Bank tubes	8	10	8	12	25
Economizer	8	10	8	12	20
Airheater	16	16	16	18	-
Mechanical dust collector	15	15	11	12	-

- *FURNACE HEAT RELEASE RATE*

In an FBC boiler the Fluidized bed area is selected based on a fluidization velocity of 2.5 to 2.8 m/s. The free board height is based on the manufacturers' practice for a complete combustion of unburnt particles before the flue gas enters the convection bank zone. Usually 4 m is found to be adequate for Underbed FBC system. In the case of over bed system the residence time needs to be improved. For this purpose, ash settling chamber is given in furnace.

Design of furnaces for Natural gas / Oil cum solid fuel fired boilers (all 100% firing) is more complicated. The free board furnace has to be sized for permissible heat release rate. Table 10 gives the recommended heat release rates. The combustion temperatures are much higher than the FBC furnace. Accordingly the furnace exit temperatures are higher and the superheater surfacing required is much less. Whereas, the boiler bank, economizer surfacing has to be more. Bed Superheater is required in order to obtain the required superheating when the solid fuel firing is done.

In Underbed FBC boilers, where only solid fuels are fired the Waterwall fin width can be 50 mm even for pressures up to 66 kg/cm2 g. The same fin width can not be adopted for oil firing as the heat flux & combustion temperatures are higher. The heat flux & combustion temperature govern the selection of fin width.

Table 10 : Recommended furnace volumetric heat loading					
		MW /m3	MW / m3	Kcal / hr / m3	Kcal/ hr / m3
		minimum	maximum	minimum	maximum
Furnace oil	Field assembled	0.6	0.8	258000	344000
Furnace oil	Shop assembled	0.3	0.4	516000	688000
Natural gas	Any	0.3	0.46	258000	395600

- *MOISTURE CONTENT IN FUEL*

  Wet fuels would need drying before feeding into the furnace or within the furnace. Mill Bagasse has as much as 50 % moisture. The furnace Volume should be adequate for drying & release of heat. The recommended furnace volume is given by the following formula.

$$\text{Furnace volume reqd, m3} = \frac{\text{Fuel firing rate in kg/h x NCV in kcal/kg x } 0.1124}{28000}$$

Where,

NCV = (4250 – (4850*moisture content by wt in a kg of fuel))

While designing the fluidized bed for furnace for Bagasse & rice husk, the fluidized bed sizing is based on rice husk. The furnace volume will be based on the above volume. In addition the convection bank will be located a height of 7 to 8 meters from fuel feed point. Refractory lining will be required to improve the Furnace outlet temperature in order to obtain desired convection superheater outlet steam temperature. Traveling grate furnace is not the right solution for coal / Bagasse or rice husk/ Bagasse firing. Because it is not possible to obtain the steam temperature as the combustion temperature is different for the different fuels and the furnace heat absorption pattern is different between high & low moisture fuels.

For e.g., the adiabatic combustion temperature for mill Bagasse is 1079 deg C where as for rice husk this is 1400 deg C.

- *BED COILS SURFACING & EXCESS AIR.*

In under bed FBC system the bed coil surfacing is done based on the fuel to be fired. The fuel chemical composition and the volatile matter are the deciding factors. Table 11 shows a heat balance of the bed for selected fuels. The heat balance is drawn assuming recommended bed temperatures.

Table 11: Percentage bed duty to the heat input by fuel			
	Coal	Rice husk	Kutch Lignite
Carbon loss	4.0	4.0	2.0
Loss due to air moisture	0.947	0.93	0.92
Loss due to fuel moisture	8.53	16.5	28.35
Heat loss due to sensible heat in ash	2.09	0.87	0.23
Dry flue gas loss	40.28	41.91	41.97
Radiation loss	5.25	4.83	4.4
Total losses	61.1	69.04	77.87
% heat duty of bed coil to the fuel heat input	38.9	30.96	22.13

As the figures indicate, a coal fired FBC boiler would need more bed coil surface in order to maintain the combustion temperature.

The recommended bed temperatures are given in table 12. The bed coil surfacing is based on the worst fuel, that is the one that need the least bed coil surface. For other fuels, the bed will be operated on slightly high excess air (25 % to 35 %).

Table 12 : Recommended bed temperatures for various fuels			
Fuel	Bed temperatures, deg C		
	Normal	Minimum	Maximum
Coal	900	800	950
Rice husk	850	750	900
Kutch lignite	850	750	850
Neyveli lignite	850	750	900
Char / Dolochar	900	800	950
Bagasse pith	900	750	900
Ground nut shell	850	750	850
De oiled bran	850	750	850
Coffee husk	750	650	750

- *VOLATILE MATTER IN FUEL*

The fuels, which contain more volatile matter, tend to burn above the bed. In such circumstances the coil surfacing is reduced accounting certain % heat release above the bed. This is to an extent of 15 % to 25 %.

- *BOILER DESIGN PARAMETERS*

  The boiler configurations can not be a standard one when it comes to multifuels. Further, the boiler design parameters such as Steam pressure, Steam temperature, steaming capacity, load down desired, fuel flexibility range.

CONCLUSION

The FBC boilers have been able to perform to the expectations of customer in terms of fuel flexibility, turn down, faster load response, best efficiency. Several boilers are in operation ranging from 6 TPH to 100 TPH with many fuels. A through understanding of fuel characteristics before design will help the designer to offer the best reliable & flexible Boiler.

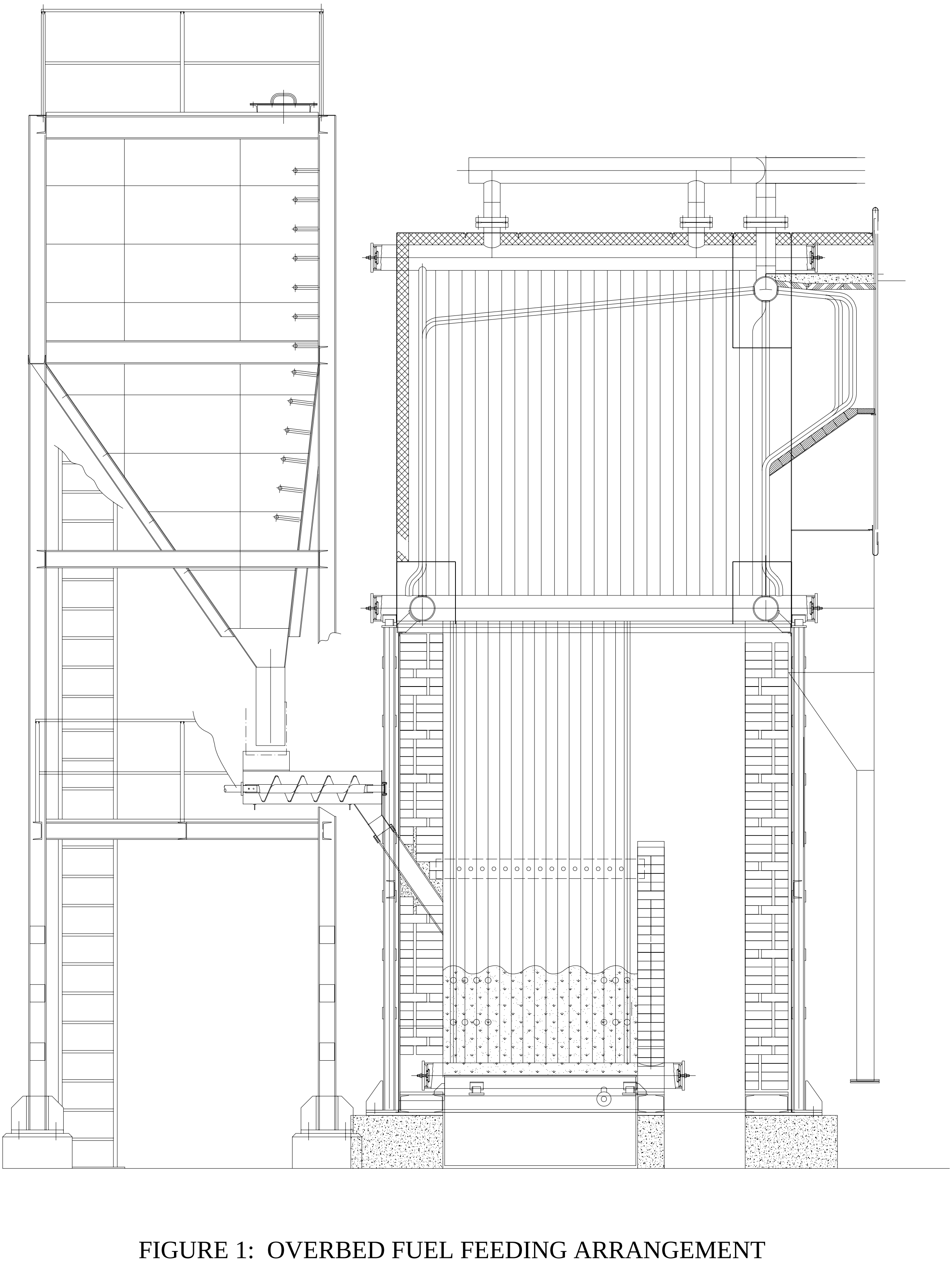

FIGURE 1: OVERBED FUEL FEEDING ARRANGEMENT

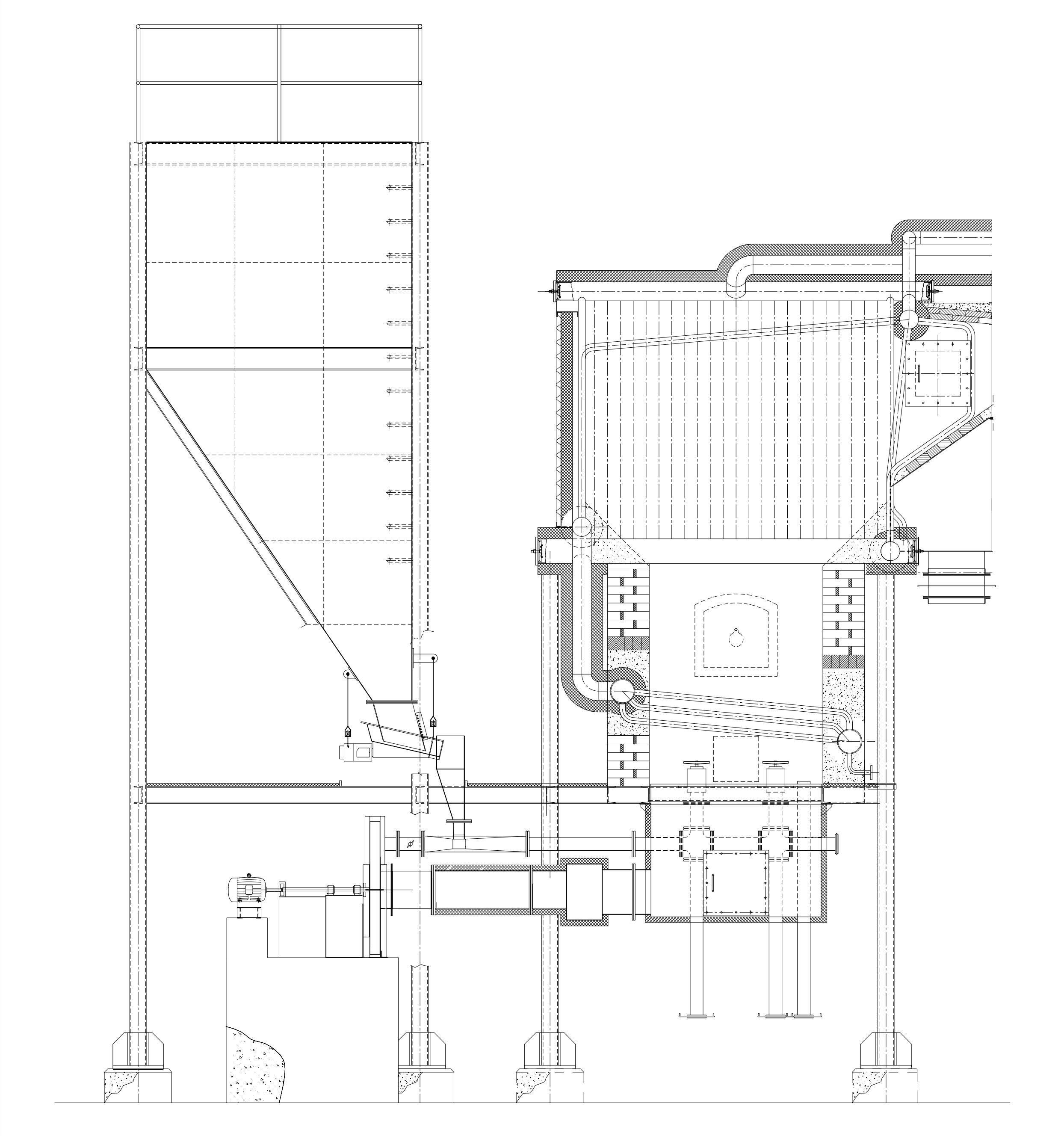

FIGURE 2. UNDERBED FEEDING ARRANGEMENT IN FBC BOILERS

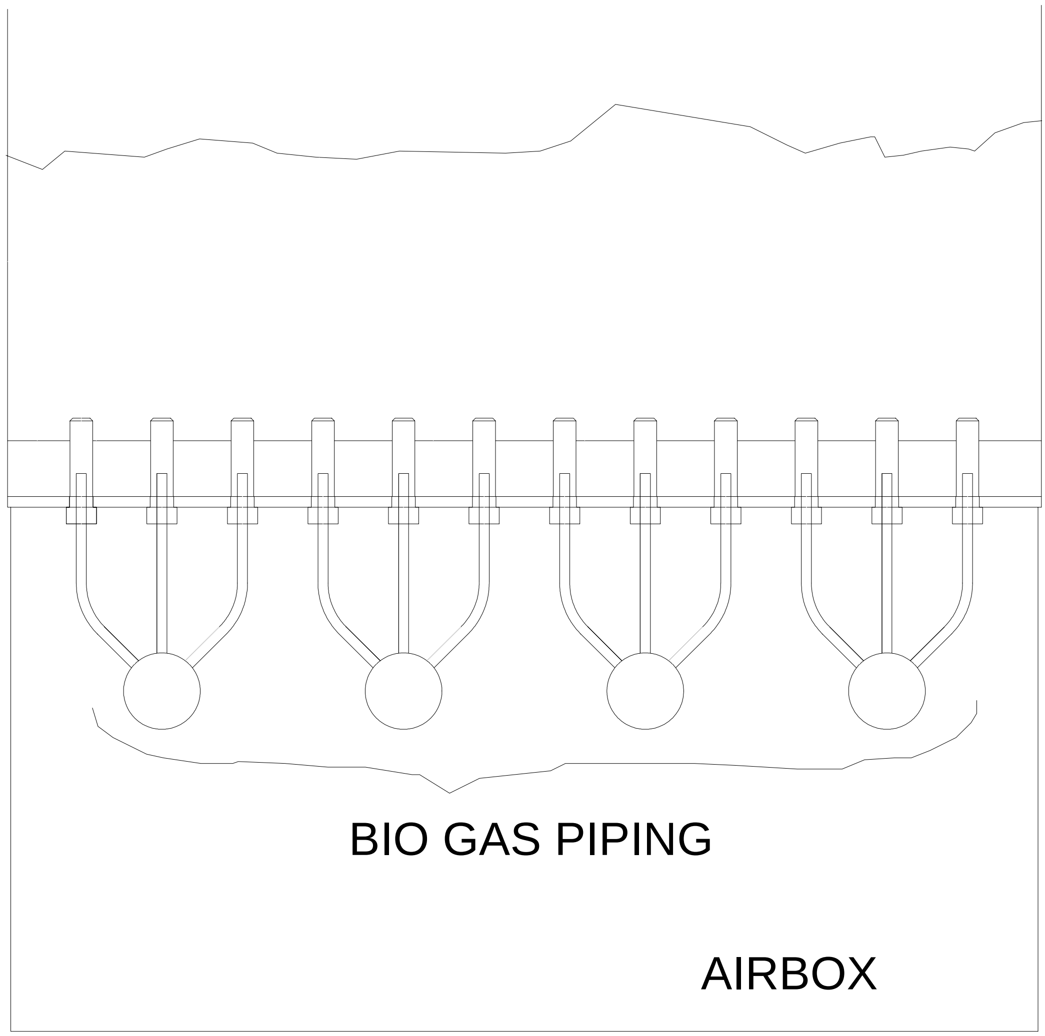

FIGURE 3. BIO GAS FEEDING ARRANGEMENT IN UNDERBED FBC BOILERS

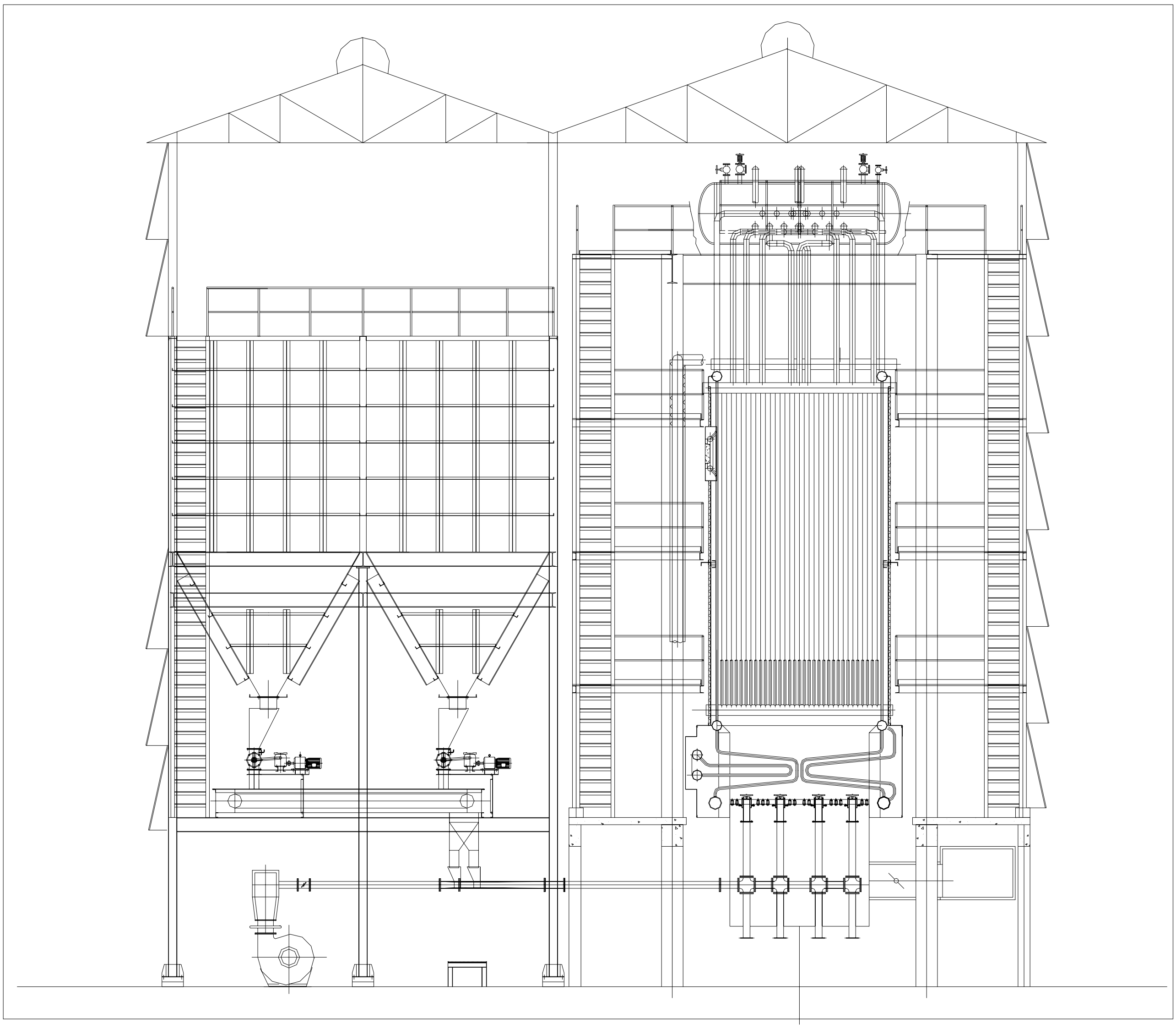

FIGURE 4. MUILT FUEL FED UNDERBED FBC BOILER WITH FUEL METERING