MULTIFUEL FLUIDIZED BED BOILER FOR SMALL-SCALE INDUSTRIAL USE : SYSTEM DESIGN

Solot Suwanayuen, Chaiyot Tangsathitkulchai, Suvit Tia, Veerapong Kritpiphat.

ABSTRACT

A project has been initiated to design and build a multifuel fluidized bed boiler for small scale industrial use. This paper describes the selection and design of the fluidized bed combustion system and the boiler to be integrated into a 2 MW steam production plant. A differentially fluidized bed furnace employing a new type of air distributor is incorporated with a conventional D-type water-tube boiler. The system is designed to combust rice hull, lignite, and other similar low-grade fuels efficiently at low combustion temperatures between 800°C and 900°C such that NO_x formation is negligible. An acceptable emission of SO_2 and particulates is to be controlled by an in-situ application of limestone and by the utilization of a special mechanically induced water-spray scrubber respectively. Other auxiliary units such as fuel feeders, air movers, and the control system have also been selected/designed so that the steam plant will work properly. After construction and installation of the system at the intended site is completed, test runs of the plant will be carried out in order to confirm the design as well as to study/evaluate its performance as well as the emission control method.

INTRODUCTION

In developing countries such as Thailand, growth of various kinds of industries is quite extensive. Most of these industries rely on fossil fuels in the form of fuel oil, lignite, natural gas and diesel oil for their energy requirements. For a combination of economic and technical reasons, fuel oil and diesel oil are used extensively for energy generation in small industries. These small industries are thus one of the main consumers of petroleum-based fuels which are not available in the country and must always be imported.

Thailand has significant lignite reserves and biomass supply sufficient to meet the energy needs of a large number of medium and small industries. It is thus one of the major goals in the government's industrial development plan to promote the use of lignite and biomass as substitute fuels for petroleum-based fuels. This would help conserve foreign exchange by reducing imports of liquid fuels and crude oils.

Difficulties arise in utilising Thailand's lignite and biomass fuels, many of which contain undesired impurities such as sulphur, moisture and ash in large proportions. The task is, therefore, to find a suitable energy generation system utilizing lignite and biomass which is technically and economically feasible as well as being environmentally acceptable.

Fluidized bed combustion technology, which is applicable to burning various types of low-grade fuels including lignite, is the most promising solution. Coals with a wide range of sulphur content can be burned without the need for stack scrubbers for removal of SO_x and NO_x. This technology has already been developed, tested and demonstrated by researchers and manufacturers in some developed countries [1-7]. High combustion efficiency and minimal gaseous pollutant emission can be maintained by this equipment.

Research and development on fluidized bed combustion processes for low-grade fuels such as lignite and biomass have also been carried out by ASEAN researchers for the past few years [8-14]. While the results so far have been promising for larger scale applications, there has as yet been no attempt outside of the laboratories. The next step is thus to demonstrate both the technical and economic feasibility of a fluidized bed energy generation system by using a prototype large enough for obtaining practical data and information necessary for the evaluation, and yet not too cumbersome for experimentation.

The general objective of this work is to promote the use of lignite and biomass as substitute fuels for the petroleum-based/fueled equipment presently needed for energy generation in small industries in Thailand, through the application of fluidized bed combustion technology.

A fluidized bed boiler plant with a capacity of 3-tons steam/hr (at 8 bars) has been designed, built and tested. The performance of the fluidized bed furnace and boiler regarding combustion and thermal efficiency and pollution control will be evaluated and optimized. In this paper the complete design of this fluidized boiler system is described.

SYSTEM DESIGN AND SELECTION

In this project a fluidized bed furnace was designed to fit into a standard open D-type water tube boiler. The water tube boiler was chosen for safety reasons as well as for ease in incorporation of a fluidized bed furnace where a good convective heat transfer rate comparable to that of the conventional radiant transfer is expected in the in-bed region.

D-type water tube boilers [2]

Water tube boilers consist mainly of tubing containing the evaporating water and the steam. By containing the pressurizd water and steam inside tubes, the mechanical stresses in the metal are substantially less than they would be in large diameter pressure vessels of other boiler types. A few of the tubes are used to form a combustion chamber by welding fins between them to form walls to contain the combustion gases. Heat transfer to the combustion chamber walls is mainly by radiation.

One of the simplest designs is the bi-drum D-type in which the combustion chamber has a D-shape cross section view (see Figure 1.) Evaporation of water to steam in the vertical pipe causes natural water circulation from the lower "mud drum" to the upper "steam drum". The boiler must be designed in such a way as to ensure that the circulation is sufficient to leave at least 10% water by volume in the steam leaving the tube bank in order to provide adequate cooling of the tube metal. The steam is then separated in the steam drum and the water, which fills the lower half of the drum, is returned to the mud drum.

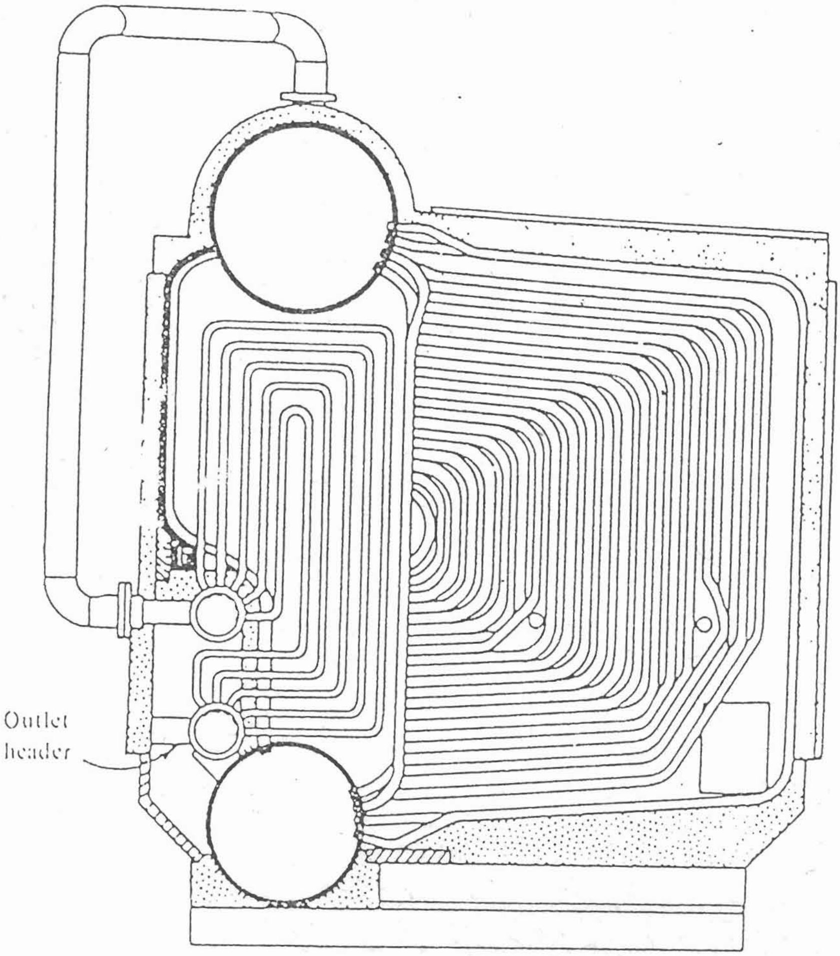


Figure 1. D-type Water Tube Boiler

In a well designed boiler, approximately 50% of the heat from combustion can be extracted by means of water or steam cooled tubes forming the radiant chamber. The combustion gas removes the remaining 50% of the generated heat, most of which is transfered to water or steam tubes as the gas passes through the boiler convective section.

The convective section is usually designed to cool the gases to within 50 K of steam saturation temperature. Typical inter-tube gas velocity in this section is about 30 m/s in the case of oil and gas firing, resulting in a convective heat transfer coefficient of about 120 W/sq.m K. For coal firing, this gas velocity is reduced to about 15 m/s in order to lower down erosion due to coal ash particles, giving a heat transfer coefficient of about 75 W/sq.m K.

Steam Plant Flow Diagram

Firstly, all necessary components are listed and combined into a proper process layout. The fluidized bed boiler system is made-up of four major units namely : feed/fuel handling unit, fluidized bed furnace/boiler, dust/ash removal system, and air movers. This layout is shown in Figure 2.

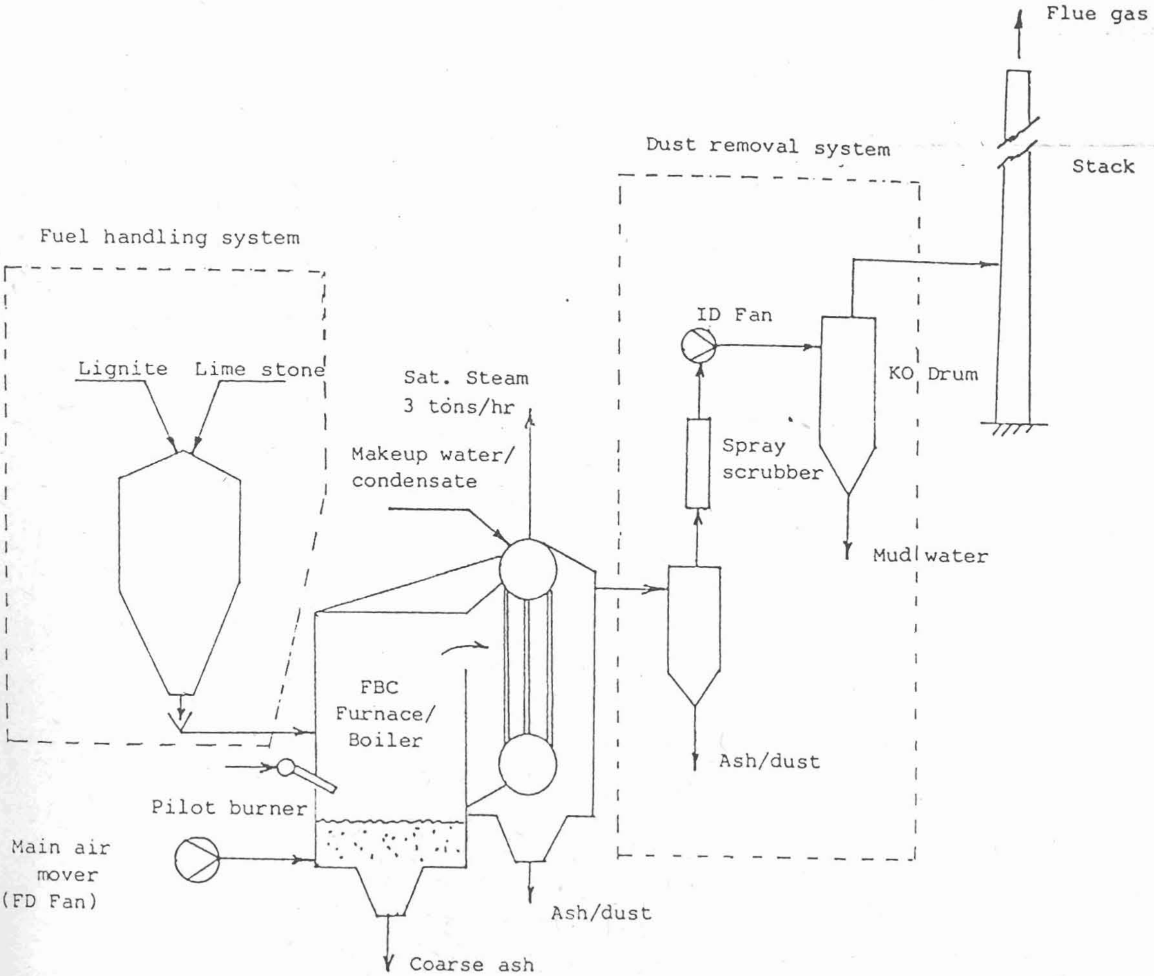


Figure 2. Steam Plant Flow Diagram

All the units given will have to be selected/designed properly. The key design procedure is the calculation for incorporating the fluidized bed furnace into the 2 MW D-type water tube boiler. In order to do this, specific design data are needed These data are given in the following section.

Design Data for Fluidized Bed Combustion System

Fuel specification : [13, 15]

	Rice Hull	Lignite
Total moisture	6	20.5%
Ash	18	11.7%
Carbon	40	59.87% D.B.
Hydrogen	5.2	4.4% D.B.
Nitrogen	2	1.26% D.B.
Sulphur	.1	3.14% D.B.
Oxygen	34.7	19.62% D.B.
Heating Value	13.4	42.2 MJ/kg D.B.

N.B : The ultimate analysis of lignite is calculated from the proximate analysis by using a method given in [16].

Operating conditions : [2, 4, 6, 17]

Combustion temperature	800 - 950°C
Excess air	30%
Fluidizing velocity	1 - 3 m/s
	(2 to 5 times min. fluidizing vel.)
Air inlet temperature	45°C
Recommended flue gas temperature	220°C
Return condensate temperature	70°C
Bed pressure drop (at MCR)	1.5 mm aq./mm static bed
Distributor pressure drop	12% of bed drop
In-bed heat transfer coefficient	280 - 350 W/sq m °K
Gas convective heat transfer coefficient	75 - 120 W/sq m °K
Carbon loss	1%
Heat loss	5%

Fluid Bed Furnace/Boiler Calculation

The principle of calculation is to do the heat balances for the furnace and the boiler which are used to check with the possible heat transferred/extracted in the bed and in the gas convective section. The in-bed heat transfer should be about the same value as the radiant transfer being substituted (see item 2 of the Design Criteria/Basis section). the total energy given to the vapourizing water/steam should amount to 2 MW.

This specific information concerning the D-type boiler will be used as design criteria, data, and as guidelines in the following procedure for integrating the fluid bed furnace with the boiler section.

Design Criteria and Basis

1. The suggested size of the steam production plant for this project was determined by the actual scale used in small industries as this gives a good-scale pilot plant required for experimentation and evaluation with reasonable investment cost. Its capacity of 3 tons steam/hr at 8 bars is thus chosen as the basis for the design. There is an accompanying advantage in that this energy generation plant can be attached to an existing factory chosen for demonstration purposes. The steam production system can then be test run under realistic conditions/situation such as actual load changes and condensate return system. A food processing plant was chosen as the installation site for the boiler plant. The system will also be available for promotion/demonstration to any type of industry after it has been proven technically, economically, and environmentally feasible to the food factory.

2. The radiant section of the conventional D-type water tube boiler will be substituted by the convective fluid bed. To ensure the proper water/steam circulation rate as well as the proper tube wall temperature in the boiler, the amount of in-bed heat transfer rate to the tube walls should be kept about equal to that of the substituted radiative mode. In the design, this criterion is met by keeping the percentage of heat transfered to the water/steam in the in-bed tubes constant at about 50% of the generated heat, similar to that of the conventional D-type system.

3. The fluidized bed boiler must be able to burn various types of fuel efficiently, especially lignite and rice hull, which have been selected as the two main fuels available within economic distance for the chosen food processing plant. Lignite and rice hull are two special materials having extremely different flowability and other related properties. Different feeding systems and a special fluidized bed must be designed so that the furnace would be able to accept both fuels.

4. The new energy generation system must produce acceptable emission levels of both particulates and toxic gas components. The steam plant and its operating conditions have to be designed to contain all types of emission within the recommended values throughout its entire range of operation.

The minimum steam production rate of 3 tons/hr at 8 bars is used as the design basis while the other criteria are used as guidelines and/or constraints for the design problems that must be met.

Calculation is usually commenced by selecting an operating fluidizing velocity within the recommended range. A simultaneous heat and mass balance can be initiated from finding the flue gas rate and then carrying on the calculation to obtain the total useful heat, the heat given off in the gas convection zone, and finally the in-bed heat release. The in-bed heat obtained should be approximately 50% of the total heat generated. Relevant operating data, properties, and actual size of the 2-MW boiler are required in this estimation. Tabulation of the results are given in Tables 1 and 2 for lignite and rice hull respectively.

The next calculation step is to check if the heat transfer rate both in the bed and in the gas convection section are in agreement with the heat obtained in the above balance. The in-bed heat transfer is governed by the fluidization properties of the bed, ie. bed particle size and bed expansion, as well as the heat transfer coefficient. In our design, a portion of the water wall within the fluidizing region is used as the heat transfer area, the height of which is the same as that of the expanded bed.

This expansion height can be adjusted to the required value by selecting proper particle size. Fine sand with the size range of 0.5 - 1.0 mm is used as the bed material. Trials using the above calculation are carried out until satisfactory results are obtained.

Finally, the bed pressure drop is required for sizing the forced draft fan. The available freeboard height in the D-type boiler is not adequate for that required above the fluid bed furnace to prevent excessive entrainment of fine bed particles and fly ash. A deflecting screen is thus needed between the combustion chamber and the convective section.

Special design consideration is given to characteristics of the fluidizing bed. The bed must be able to accept different types of fuels and provide adequate mixing to obtain a uniform distribution and good resident time within the bed. Under-bed combustion is thus ensured to sustain the bed temperature at the design level. The major effort has thus been put into the selection and design of an air distributor. A differential multi-spout distributor which produces upcoming jets at predetermined locations is thus chosen for this design for it could, in principle, provide favourable solid circulation and mixing characteristics. The drawing of the design is given in Figure 3.

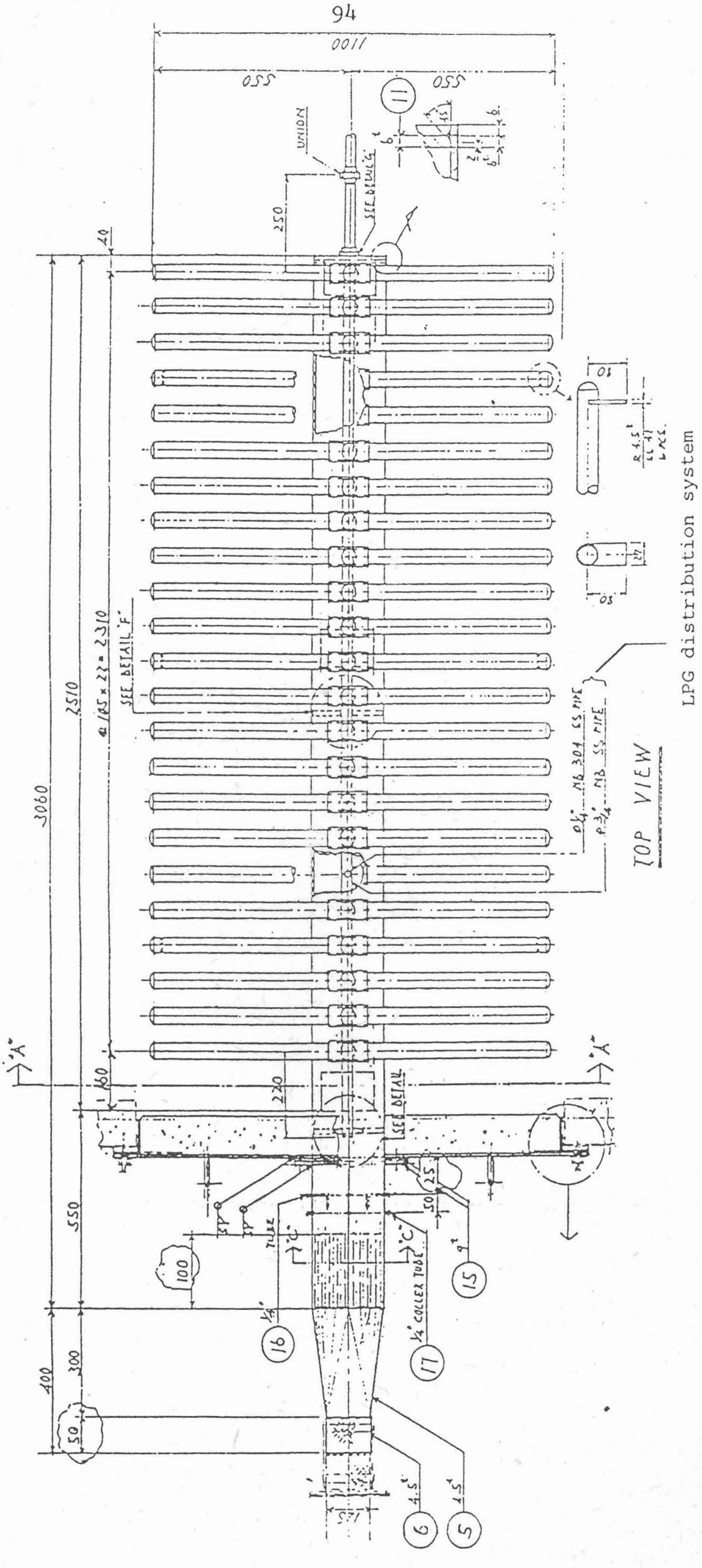


Figure 3. Differential multispout air distributor

Figure 4 shows the newly modified D-type furnace/boiler which is quite simple in design for it has no mechanical moving parts.

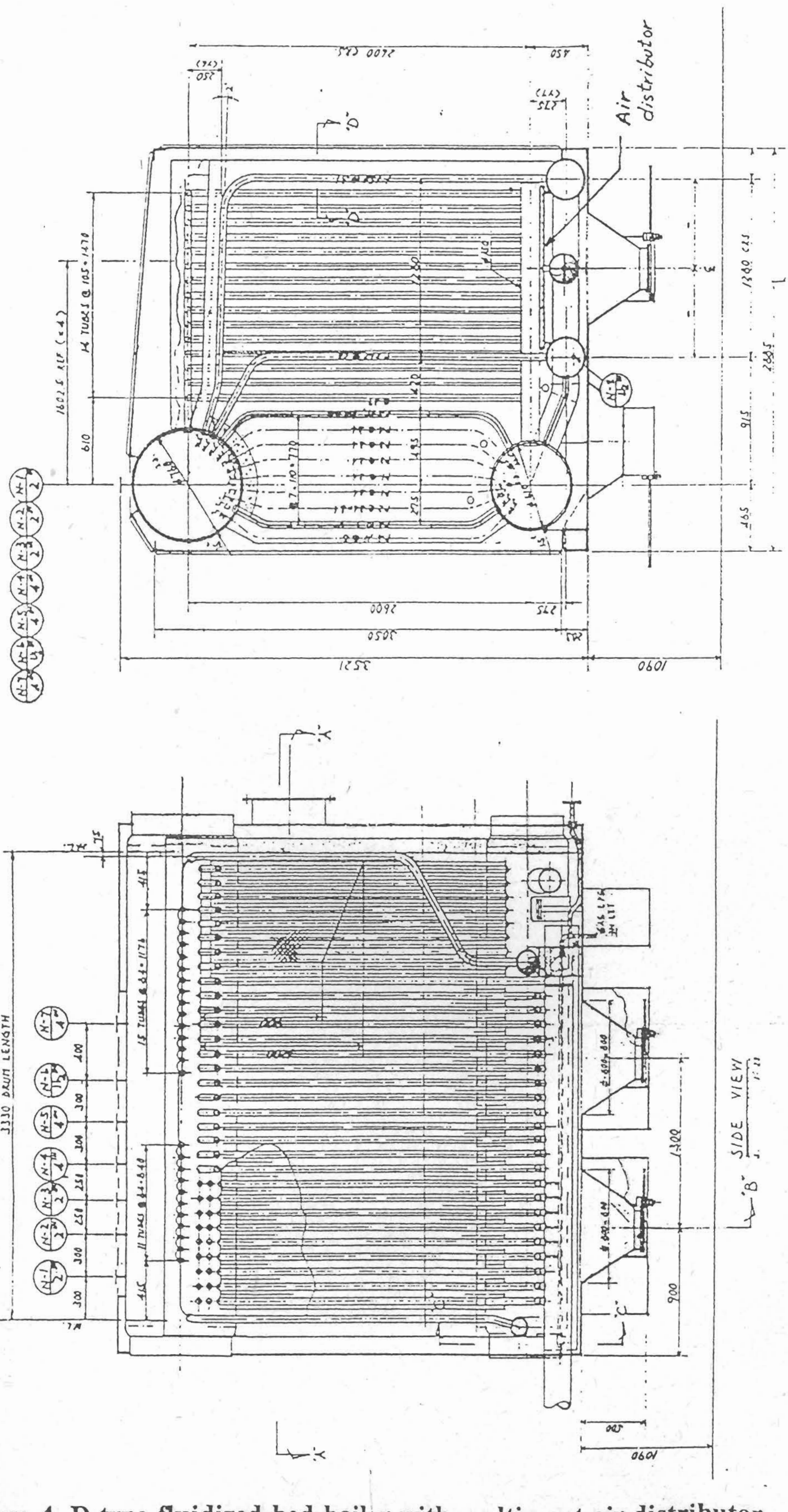


Figure 4. D-type fluidized bed boiler with multispout air distributor

Selection and Design of Feed/Fuel Handling Units

The feed handling system must be selected and designed for two types of fuels having extremely different flow characteristics namely: lignite and rice hull. It is thus decided to use separate feeding systems.

For *lignite* which has good flowability, a simple magnetic shaker is used to control its feed rate from the feed bin into the feed port directed at 45 degrees down above the fluid bed. This vibrator feeder must be able to handle feed size up to about 25 mm.

For ***rice hull*** which does not readily flow and is very light (easily entrained away in the freeboard area), above-bed feeding is not applicable, and thus a screw feeder is employed to push the fuel into the bed at a location under the fluidizing surface at a point at which a down-flow motion of the circulating solids would pull the hull deep into the bed. Since the screw is pushing against the bed pressure, an air lock device is needed at the other end. The rice hull feed bin is equipped with a rotating table and a screw-type arch breaker in order to ensure a continuous feed of rice hull of various moisture content. The details of these systems are given in Figures 5 and 6.

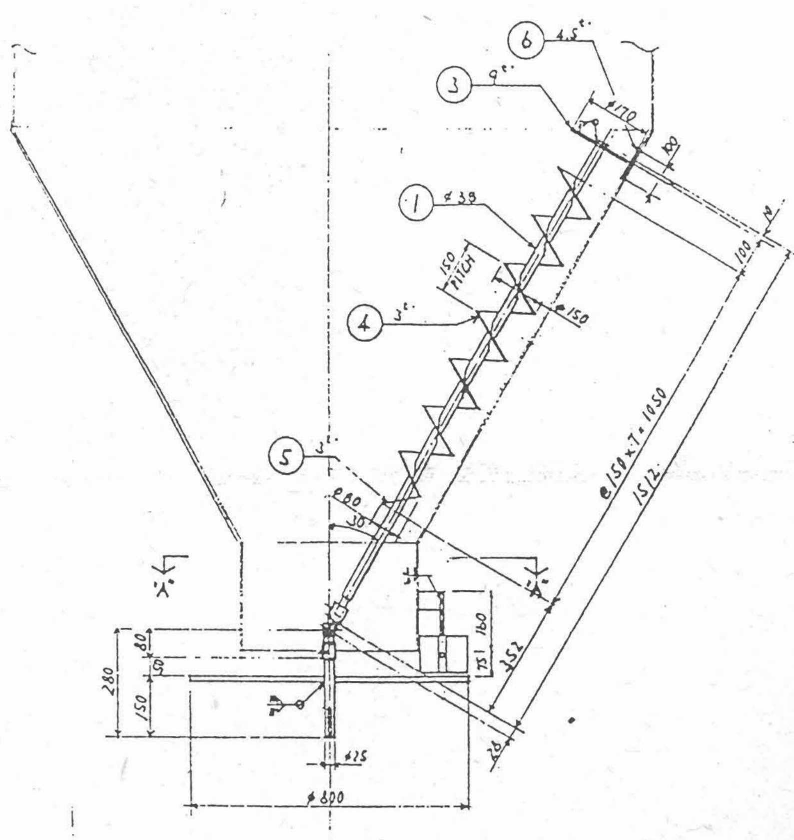


Figure 5. Rotating table and screw-type arch breaker in rice hull feed bin

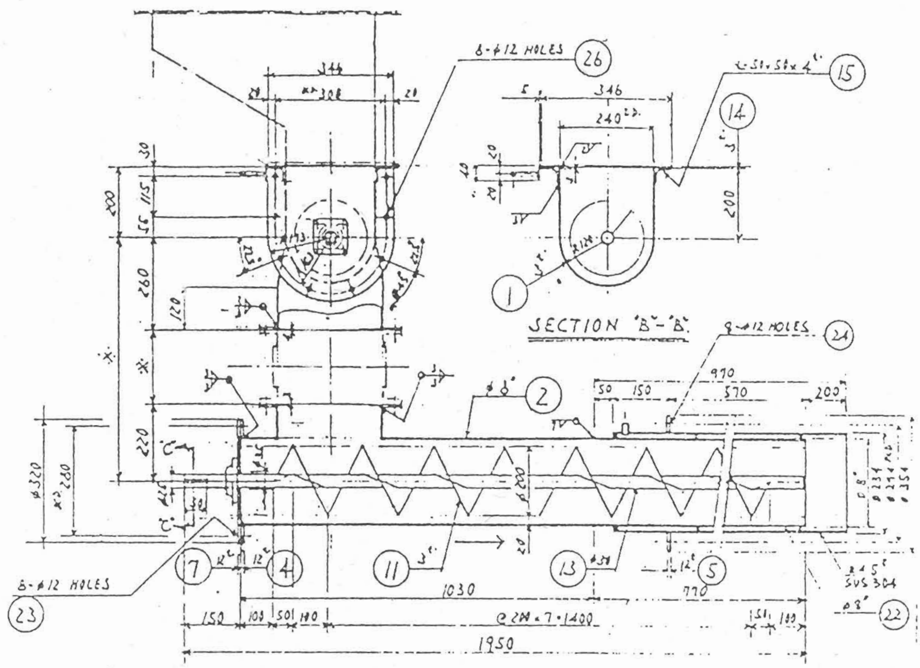


Figure 6. Rice hull screw feeder

Emission Control Systems

There are two types of emissions of major concern namely; particulates and toxic gases (Sulphur dioxide and Nitrogen oxide). Nitrogen oxide formation in the fluidized bed combustion process could be controlled to be within a negligible level by keeping the combustion temperature under 950°C. Therefore, there are only two remaining pollutants to be treated. The majority of fly ash is settled - out in the convective tube and the remaining fraction is captured in a water jacketed cyclone and in a special type of mechanically induced spray scrubber [18] consecutively. The cyclone is also used as a makeup water preheater to recover extra heat from the flue gas. Cyclone design is based on choosing proper inlet velocity and using standard/recommended dimension ratios obtained from various references [19, 20]. Table 3 [9] tabulates dimensions of industrial and model cyclones.

The scrubber consists of a water spraying system and the induced draft fan. The water spray will cool down the gas and at the same time its fine droplets will pick up the particulates.

Furthur mixing and capturing of fines are induced in the fan chamber. The wet gas is then passed through a knock out drum (see design method in [21]) to settle out water droplets before letting it into the atmosphere. The cyclone, the ID fan and the KO drum are shown in Figures 7 and 8 respectively.

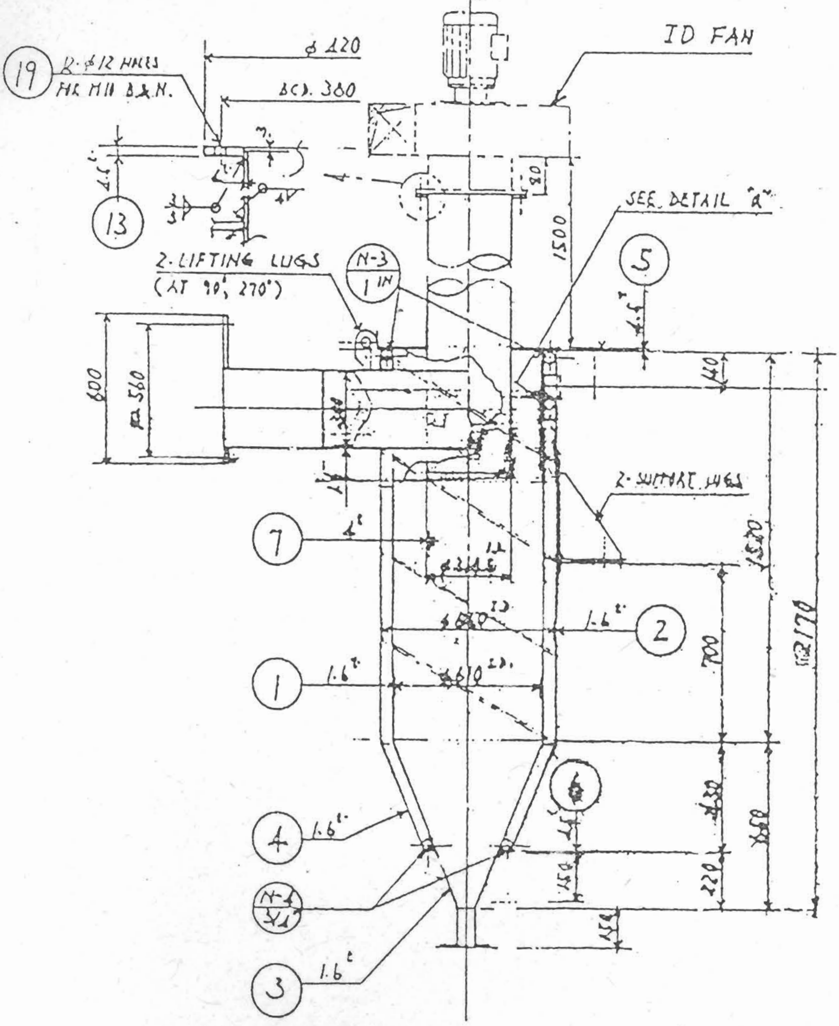


Figure 7. Water jacketed cyclone and ID fan

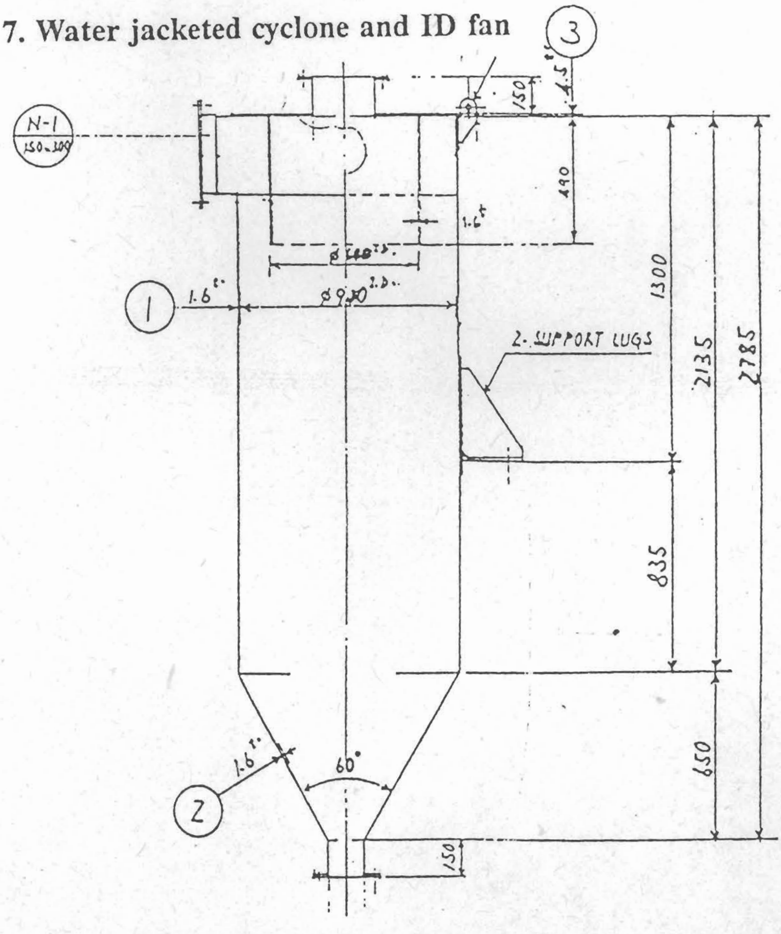


Figure 8. Water droplet knockout drum

An in - situ treatment of sulphur dioxide will be accomplished by using limestone as an absorbing medium. Properly sized limestone is to be premixed with lignite at a Ca/S ratio of 2-3 before feeding into the feed bin. Sulphur capture is expected to be up to 80 - 90% [6,17].

Air Movers

The primary air mover is a forced draft fan which is used to supply air for the combustion process. This is a high pressure fan for it must move the air through the air distributor and the fluidized bed consecutively. The minimum specification of the FD fan is about 3000 cfm at 20 - 30 in. water pressure drop. An induced draft fan is used to move all the combustion gas from the freeboard through the convective tube bank and the gas treatment system out to the atmosphere and to maintain a negative freeboard pressure of about -1 to -1/2 in.water. Its minimum capacity is about 3500 cfm at 90°C and negative pressure of about 16 in.water.

Ignition System

A premixed gas startup in which LPG is mixed with the fluidizing air during bed warmup just prior to the distributor outlets is employed (see Figure 3). The combustible gas mixture bubbling through the bed is ignited by a pilot gas burner directing its long luminuous flame constantly onto the surface of the bed. When the bed temperature is sufficiently high for an ignition of the solid fuels, the main fuel feeding can then be commenced which would increase the bed temperature sharply to the desired operating level. The system control is then ready to be changed to automatic operation.

This startup procedure is superior to a hot gas warmup method for it requires less energy as well as less warmup time [4].

Design and layout of the LPG start-up system is given in Figure 9.

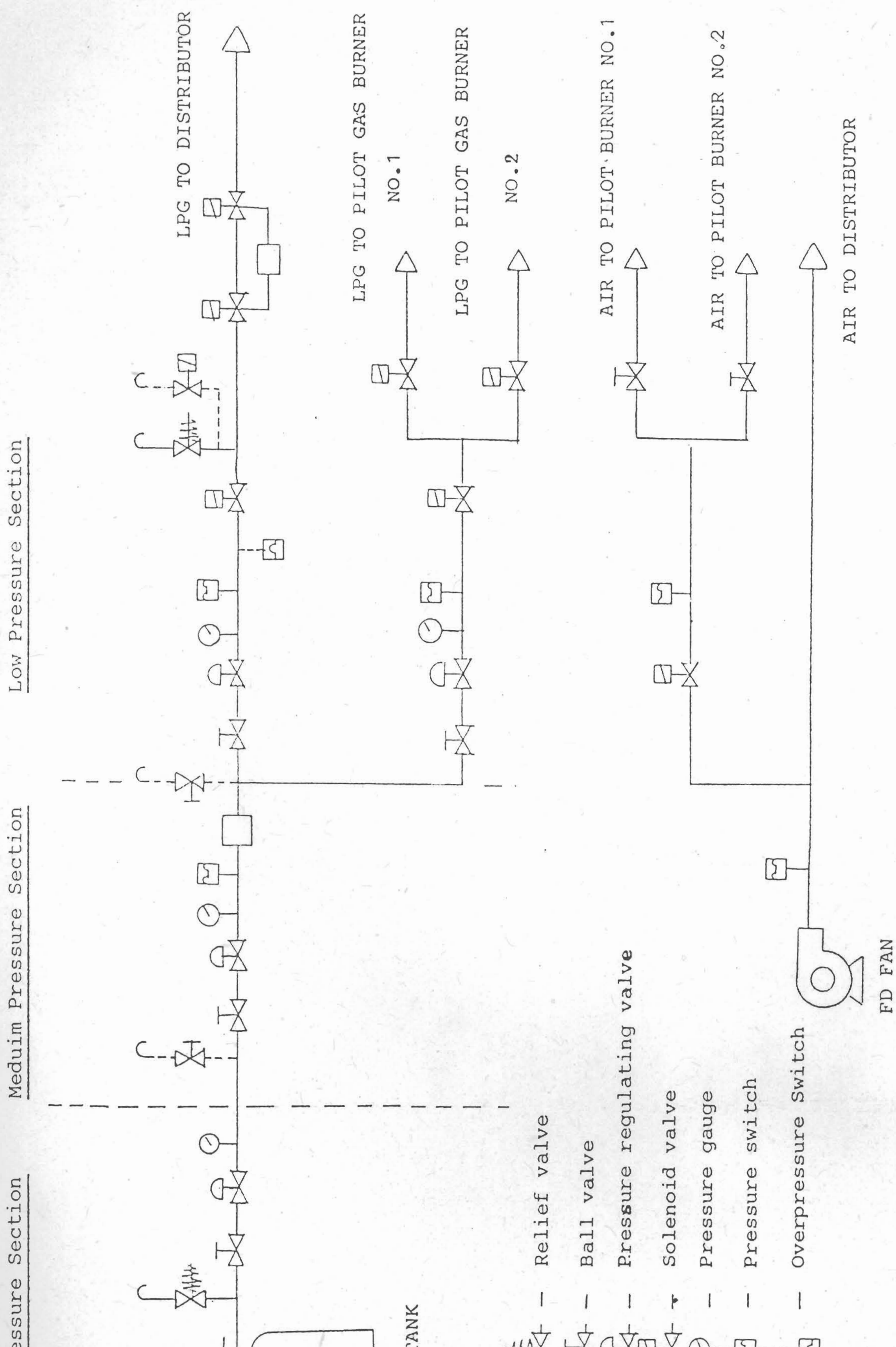


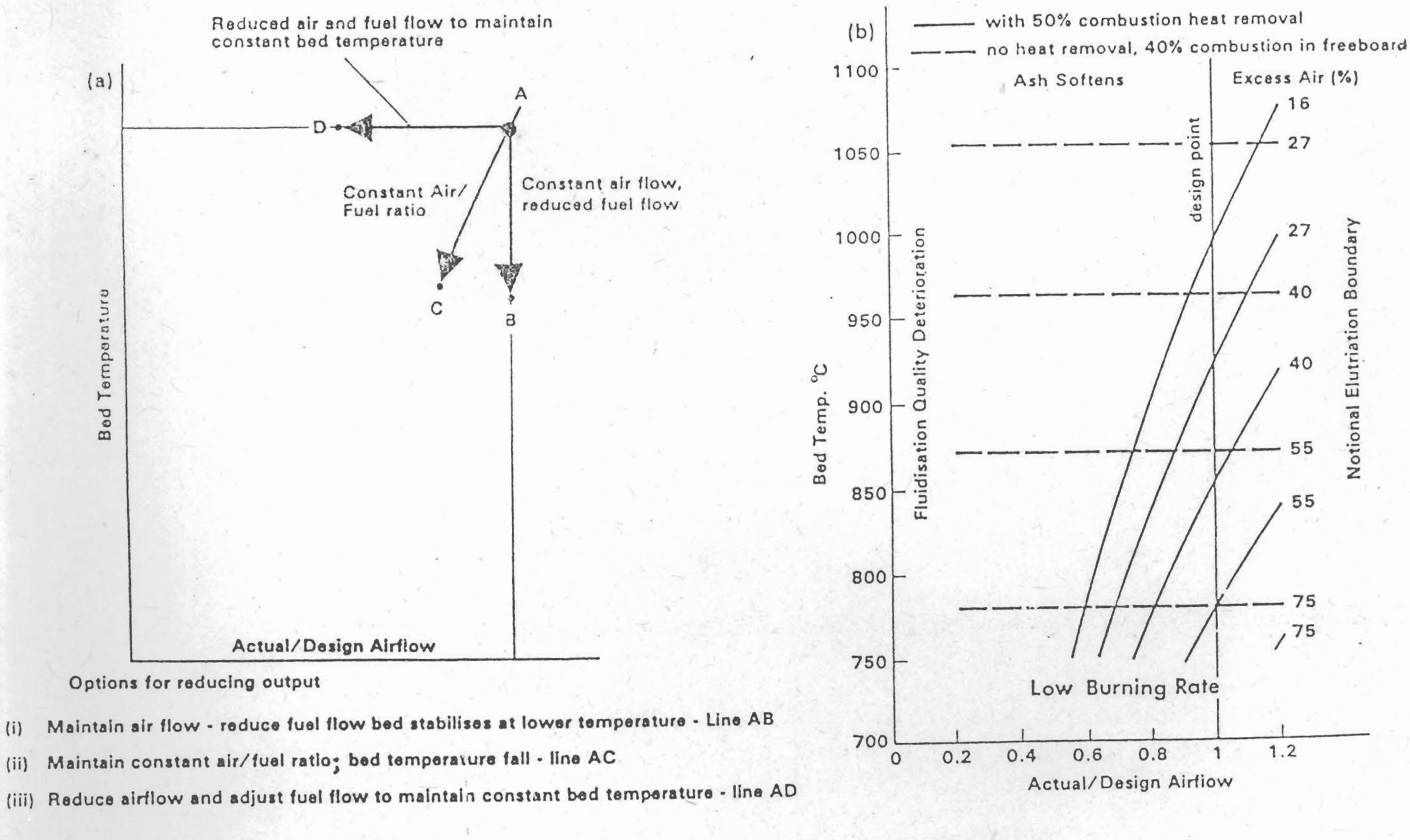
Figure 9. LPG Start-up System

Furnace Control System

Two types of furnace control schemes have been selected. In the first scheme, the bed temperature is to be kept constant. Load variation would affect the supply air rate causing changes in the amount of heat transfer. As the bed temperature responds to this effect, the feed control loop would react to stabilize the temperature. This control method is quite stable, but the combustion efficiency could be greatly affected when the air/fuel ratio is varied into an unacceptable range.

The second control scheme is used to keep the air/fuel ratio at a preset value so that the best combustion efficiency can be maintained. This method, however, would cause variation in the bed temperature which must be kept within the recommended range of 800 - 950°C to be able to combust the fuels effectively without sintering the bed material.

Figure 10 [2] demonstrates the effects of airflow on controlling bed temperature.



(a) Change of operating point diagram. (b) Operating regime map.

Figure 10. Bed temperature - airflow relationship in FBC.

CONCLUSION

A new multifuel fluidized bed boiler has been completely designed by incorporating a special type of multispout air distributor into a conventional D-type water tube boiler. The complete assembly drawing and flow diagram of the system are shown in Figures 11 and 12 respectively. The plant has now been completely fabricated and installed at a selected food processing plant in Chiang Rai Province in Thailand. Test runs of the steam plant will be carried out in order to confirm the design as well as to evaluate its performance and that of the emission control system.

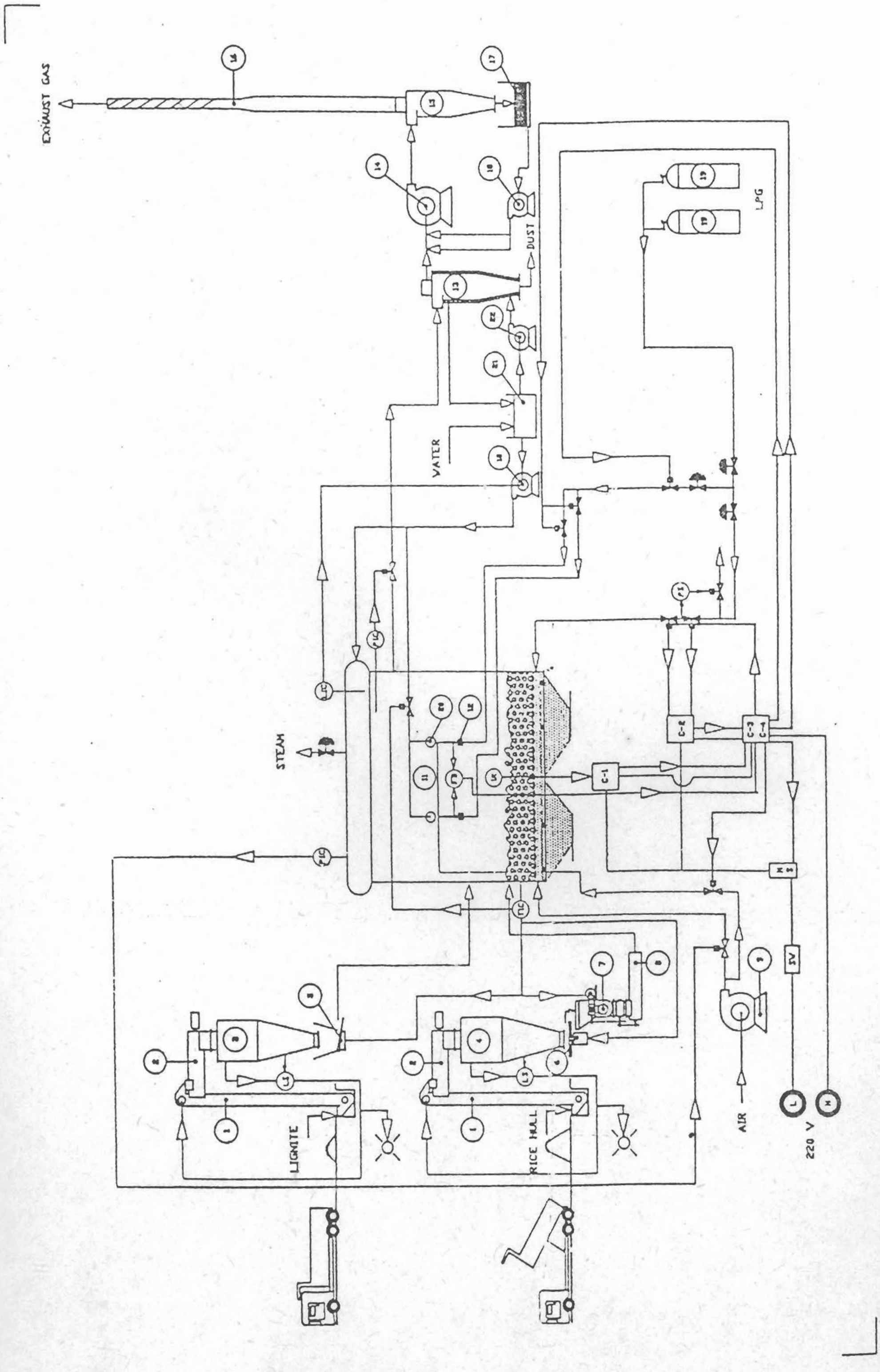
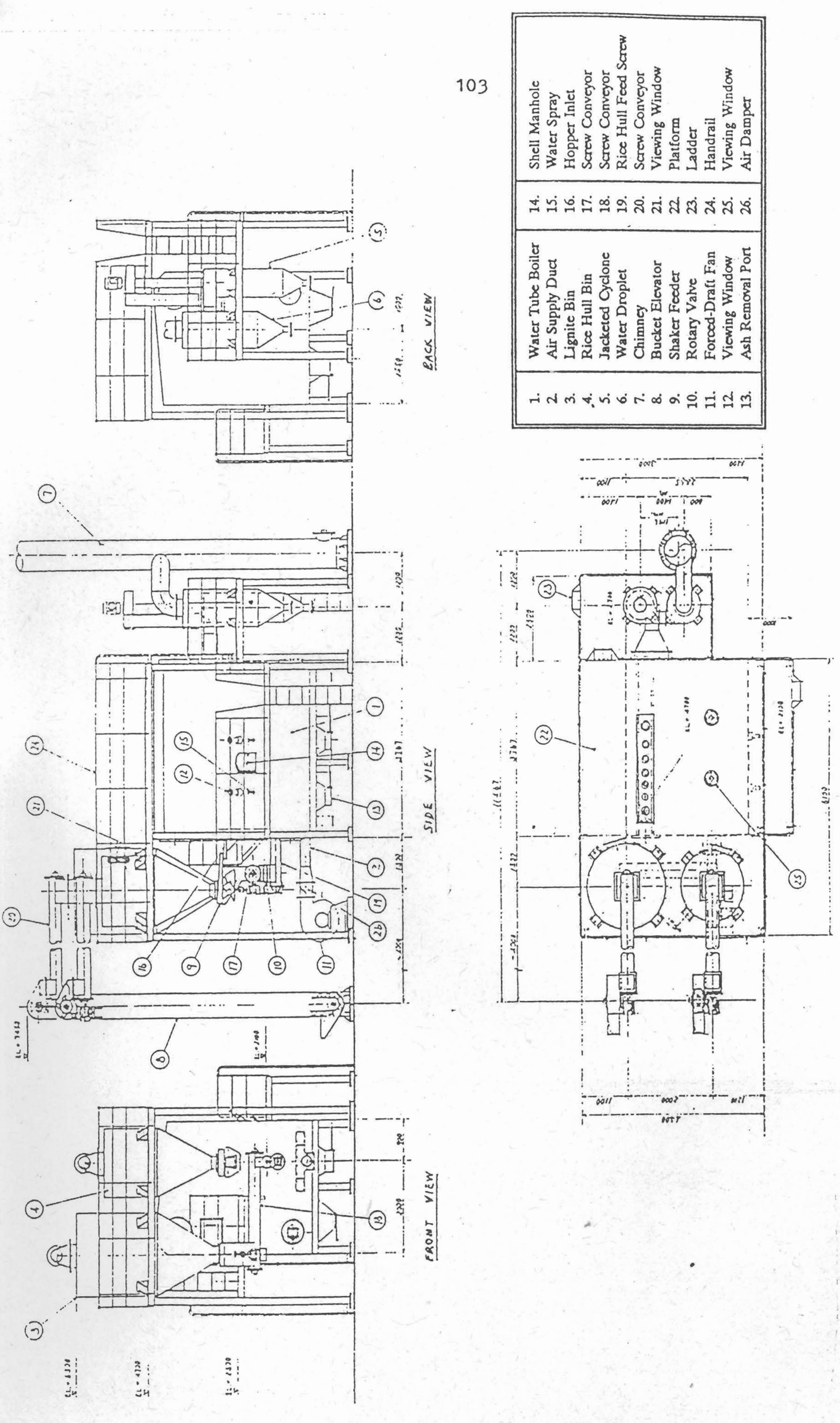


Figure 11. Flow diagram of fluidized bed boiler plant



1.	Water Tube Boiler	14.	Shell Manhole
2.	Air Supply Duct	15.	Water Spray
3.	Lignite Bin	16.	Hopper Inlet
4.	Rice Hull Bin	17.	Screw Conveyor
5.	Jacketed Cyclone	18.	Screw Conveyor
6.	Water Droplet	19.	Rice Hull Feed Screw
7.	Chimney	20.	Screw Conveyor
8.	Bucket Elevator	21.	Viewing Window
9.	Shaker Feeder	22.	Platform
10.	Rotary Valve	23.	Ladder
11.	Forced-Draft Fan	24.	Handrail
12.	Viewing Window	25.	Viewing Window
13.	Ash Removal Port	26.	Air Damper

Figure 12. Assembly drawing of fluidized-bed boiler plant

ACKNOWLEDGEMENT

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TABLE 1. FLUIDIZED BED BOILER HEAT AND MASS BALANCES RESULTS FOR LIGNITE

FUEL SPECIFICATION		
TOTAL MOISTURE	20.5	%
ASH	11.71	%D.B.
CARBON	59.87	%D.B.
HYDROGEN	4.4	%D.B.
NITROGEN	1.26	%D.B.
SULPHUR	3.14	%D.B.
OXYGEN	19.62	%D.B.
SPEC. ENERGY	24.2	MJ/kg D.B.

OPERATING CONDITIONS		
FLUIDISING VELOCITY	2	M/S (DRY AIR) AT BED TEMP.
AIR TEMPERATURE	45	DEG.C
AIR HUMIDITY	.005	DEG.C
FUEL TEMPERATURE	30	DEG.C
BED TEMPERATURE	875	DEG.C
F/GAS TEMP. EX FBC	900	DEG.C
F/GAS TEMP. BOIL/DRY IN	900.0079	DEG.C
F/GAS TEMP. EX BOIL/DRY	220	DEG.C
F/GAS TEMP. EX S/COOLER	90	DEG.C
EXCESS AIR	60	%
CARBON LOSS	1	%
BED AREA	2.2	SQ.M
HEAT LOSSES	5	%
F/G BED RECYCLE	0	%
F/G B/D RECYCLE	0	%

CALCULATED FLOWS(kg/h)		
FUEL	502.4541	
AIR (D.B.)	4870.662	
AIR (D.B.)	4895.016	
F/G (W.B.) EX BOILER/DRYER	5347.698	
F/G RECYC. TO BED	0	
F/G RECYC. TO BOILER/DRYER	0	
QUENCH WATER TO BED	-1.220703E-04	
S/COOLER WATER	291.285	
SOLID PRODUCTS	49.16722	AT 95.13597 %ASH

FLUE GAS MOISTURE CONTENT EX COMBUSTOR 5.339477 %WT.
HUMIDITY EX BOILER/DRYER 5.640659E-02 kg WATER/kg DRY AIR
HUMIDITY EX SPRAY COOLER .1139483 kg WATER/kg DRY AIR

DRY FLUE GAS COMPOSITION				
NITROGEN	79.94622	%VOL.	73.56586	%WT.
OXYGEN	7.958551	%VOL.	8.369593	%WT.
CARB.DIOXIDE	11.85962	%VOL.	17.14919	%WT.
SULP.DIOXIDE	.2356064	%VOL.	.49555	%WT.

SULPHUR EMISSIONS = 1.297521E-03 kg S/MJ GROSS HEAT INPUT

HEAT RECOVERED BY INBED TUBES = .8621828 MW
HEAT RECOVERED BY WHB = 1.197318 MW
TOTAL HEAT RECOVERED = 2.059501 MW