

FINE TUNING EXPERIENCE OF A CFBC BOILER

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Introduction

The Industrial boilers have been seeing a growth in capacity in the recent years. Current trend is to install CFBC boilers to realize better combustion efficiency. Boiler operators are now required to learn the tricks & tips of CFBC boiler operation. I share my experience on tuning a CFBC boiler during its post commissioning phase. The readers may find this case interesting with respect to the minimum instrumentation requirement for CFBC. Readers will appreciate that instrumentation has helped to tune the CFBC unit operation.

About the boiler

The CFBC boiler supplied by Chinese company has been in operation for about 3 months prior to my visit to this plant. The boiler is designed for 100% coal, 50% coal & 50% petcoke. The boiler parameters are 70 TPH, 88 kg/cm², 510 deg C and feed water temperature is 124 deg C. The design boiler efficiency is 87% with a D grade Indian coal of 36.57 % ash. The arrangement is as shown in figure 4. The boiler is provided with twin refractory cyclones. A platen SH (secondary) is placed inside the combustor. The final SH & economizers are arranged in the second pass.

CFBC working principle

The circulating fluidized bed combustion technology, CFBC, uses greater combustor superficial gas velocities than the bubbling bed combustor. See figure 1 & 2.

CFBC operates under a special fluid dynamic condition, in which the fine solids particles are transported and mixed through the furnace at a gas velocity exceeding the average terminal velocity of the particles. The major fraction of solids leaving the furnace is captured by a solids separator and is recirculated back to the base of the furnace. The high recycle rate intensifies solids mixing and evens out combustion temperatures in the furnace.

CFBC systems operate in a fluid dynamic region between that of BFB and pulverized fuel firing. This fluidization regime is characterized by high turbulence, solid mixing and the absence of a defined bed level. Instead of a well-defined solids bed depth, the solids are distributed throughout the furnace with a steadily decreasing density from the bottom to the top of the furnace.

CFBC is characterized by:

- High fluidizing velocity of 4.0 -6.0 m/s
- Dense bed region in lower furnace without a distinct bed level
- Water-cooled membrane walls.
- Optional in-furnace heat transfer surfaces located above the dense lower bed. This can be evaporator panel / SH panel in platen form.
- Solids separator to separate entrained particles from the flue gas stream and recycle them to the lower furnace. The solid separator can be water cooled / steam cooled / refractory lined. Design of solid separator can be different from manufacturer to manufacturer.
- Aerated sealing device, loop seal, which permits return of collected solids back to the furnace.

For the CFBC, gravity feed of fuel directly into the combustor has proven satisfactory for meeting the desired level of efficient mixing.

A solids separator located at the outlet of the combustion chamber separates entrained particles from the flue gas stream. The separator is designed for high solid collection efficiency with nearly 100 per cent efficiency for particles greater than 90 microns in diameter. Fuel can also be fed in the recirculation solids stream at the seal pot.

The collected solids are returned to the combustion chamber via the loop seal, which provides a pressure seal between the positive pressure in the lower furnace and the negative draft in the solids separator. This prevents the furnace flue gas from short circuiting up the separator dip leg and collapsing the separator collection efficiency. The recirculation system has no moving parts and its operation has proven to be simple and reliable. By injecting small amounts of high pressure fluidizing air into the loop seal, the solids movement back to the lower furnace is maintained.

The following are the problems experienced by the operating team

1. Efficiency of the boiler is low. The unburnt coal in fly ash is around 1.79%.
2. Boiler does not generate the rated steam at rated furnace temperature.
3. Even with a furnace temperature of 950 deg C & flue gas O₂ at 8%, the steam generation is 62 TPH.

The operating engineers shared their experience during the commissioning phase. There has been heavy air ingress in II pass roof & where economiser tubes penetrate the casing. There was shortage of ID fan capacity with all these leakages. The client had installed penthouse for the second pass & seal boxes for economiser headers. Further the seal welding of entire second pass casing to structure was done. Only after this the boiler draft problem got removed.

Review of efficiency of the boiler

At the time of visit the boiler was operating at 60 TPH with O₂% of 8%. The as-fired moisture of coal is around 14%. The GCV on air dried basis more or less matched the design GCV. Assuming effect of air infiltration is nil, the excess air for design coal worked out to be 61.2%. With an LOI of 1.79% in fly ash the efficiency was predicted to be 86.89%. A comparison of losses is given below.

Comparative efficiency performance		Design coal	Standard coal
Moisture	% by wt	14	14
Carbon	% by wt	45.17	43
Hydrogen	% by wt	0.82	2.69
Oxygen	% by wt	5.44	5.6
Sulphur	% by wt	0.55	0.47
Nitrogen	% by wt	0.17	1.05
Ash	% by wt	33.85	33.19
	total	100	100
GCV- as fired	Kcal /kg	3760	4207
ADB moisture	% by wt	7.09	8
GCV - ADB	Kcal /kg	4062	4500
HLS1, Unburnt carbon loss	%	1.07	0.94
HLS2, Total Heat loss through the ash	%	0.37	0.33
HLS3, Heat lost through moisture in air	%	0.28	0.27

HLS4, Heat lost thro moisture & H2 in fuel	%	3.6	5.76
HLS5, Heat lost through dry flue gas	%	7.29	6.91
HLS6, Radiation loss	%	0.5	0.5
Total losses	%	13.11	14.71
Therefore, Boiler efficiency,	%	86.89	85.29

My client used direct method for evaluation of boiler performance. The reasons for not achieving even these values were due to the following. In fact the same problem is faced among many boiler users. I pointed out the following facts to client.

1. There is a difference in total moisture between as received coal & as fired coal. In the input coal to coal handling plant the moisture can be at least 2-3% higher. Coal can dry up in the crushing & screening process. The boiler consumes less fuel but the weight booked is with additional moisture. Hence there is a need to establish the variation in Total moisture in raw coal & fired coal.
2. In direct method, the GCV & weight of coal should be both on the as fired basis. Taking GCV on crushed coal & weight on raw coal is not correct. Moisture & GCV estimation of raw coal can be very erroneous due to sampling error. The moisture & GCV on crushed coal is reliable since the coal is homogenized in crushing & screening process.
3. Total moisture estimation has to be done immediately after sampling. The GCV should be done on bone dry basis. If lab humidity conditions are constant in all season / in all hours air dry basis will not add error. Boiler users need to know that GCV is reported on air dried basis by lab. We need to calculate the GCV on as fired basis.
4. The coal feeding is normally varied depending on the load. This variable can affect the efficiency practically. The oxygen reduces when coal is fed. This leads to unburnt CO / hydrocarbon leaving the furnace. Relying on O₂ for air adjustment was not correct. LOI of ash is also to be watched for O₂ trimming.

Shortage of steam generation capacity & steam temperature

CFBC boilers do not have bed coils as in AFBC. The steam is generated across the entire furnace. The heat transfer coefficient is dependent on the amount of fines present in the recirculating ash. The following are the possible causes for loss of steam generation.

- Less fines in the feed itself.
- Poor performance of cyclone separator / separators
- Loop seal reversal.

In case the ash content itself is very less the boiler should be provided with fly ash recirculation arrangement. Incidentally the boiler bank ash, Economiser ash, APH ash and even ESP ash of an AFBC boiler can be a feed for CFBC boiler in order to adjust the fines content in furnace. It also helps in re-burning of ash. The presence of fines is read by the pressure transmitters placed along the height of the boiler. Here I should make a mention that there are some manufacturers do not provide this. There was hardly any head read by the pressure transmitter. See picture 1. So I went for sampling & sieve analysis of coal, bed ash & fly ash.

The table 1 showed there were hardly any fines in the feed or in bottom ash. Loop seal ash distribution more or less tallied the requirement. Figure 3 is based on extensive trials in a CFBC

unit. It could be confirmed that the cyclone performance is OK. I had advised for the change of coal size as in the AFBC boiler looking at the higher content of over size particles.

At the time of visit, the view holes in dip legs of Cyclone were opened & seen. It was found that there was improper recycling in one of the cyclones. There was reverse flow in one dip leg. See photo 1 & 2. It was calculated that the total loop seal air flow requirement should be 1000 m³/h, whereas the present roots blower capacity is 3210 m³/h and all its capacity was used up for loop seal. This was reduced gradually by opening the relief valve to 30%. The loop seal was seen working after this. The ash recycling is very important to attain higher efficiency. The carbon burn up improves with the presence of fine particulates. The working of the loop seal could be identified by the heavier airbox pressure seen in dip leg and riser leg has less airbox pressure. See picture 3, showing the inadequate dip leg pressures. See picture 4 which shows the dip leg airbox pressure is more than the riser leg side.

I left the plant insisting on the coal particle size and ash recycling arrangement required for maintaining the fines content in the furnace for improving steam generation & carbon burn up.

The second visit

After months later, the customer called up again asking for the visit. By this time the OEM had tried everything & left it to me. When the customer called up, I requested them to change the coal size first. I promised to visit only after this is done. Two days after the switch over I had visited.

Boiler performance on Coal of 8 mm top size crushed coal

- In the last two days the coal size was changed as per the recommendation given earlier. This has helped in rising the boiler steam generation without having to exceed the furnace temperature above 930 deg C. The dust load in the free board is found to rise as indicated by the free board pressure transmitter. Earlier the differential pressure between upper & lower furnace before switching over to 8 mm coal was hardly 20 mmWC. Now it is seen as 50 mmWC. See picture 1 & 2.
- The boiler was seen to generate 75 TPH with a bed temperature of 925 deg C. The loop seal temperature has reduced to 920 – 930 deg C. Earlier this was going to 950 deg C and with high excess air. The boiler exit gas temperature was more than 190 deg C.

Loop seal working

In this visit also I found that one of the loop seals was not working. Then the damper settings of air to loop seals were adjusted. The dip leg seal must be filled with material to a height more than the riser leg side. The material height at riser is fixed by the construction of the loop seal. When the bed expands beyond 600 mmWC, the material overflows to furnace. The height of the dip leg is maintained by adjusting the aeration.

- After correcting the loop seal, it was seen to contribute for dust load in free board. The bed temperatures were then seen to be within limits. The boiler was operated at 75 TPH (beyond rated capacity) without having to raise the temperature beyond 930 deg C.
- In a nut shell, the loop seal operation is very vital in recirculation of fines and this can contribute increasing the dilute bed above the dense bed.
- In fact the dip leg air flow is maintained at 0.3 m/s or less just to promote the aeration of material in dip leg.

- In riser leg the transfer is a function of the fluidizing air velocity. This is designed for 1.3 m/s. It needs modulation depending on the fine ash generation. In case the fines are increasing beyond limit and the furnace gets loaded with dust, the same can be drained from dip leg drain.

Conclusion

CFBC boilers need certain essential instrumentation for proper combustor operation & identification of a deviation. Figures 1 to 3 are provided for the interest of the CBFC owners.

Figure 1- Furnace & loop seal instrumentation

1. The air flow adjustment valve is for regulation of aeration at dip leg. Helps in proper start up. Or else it would take more time to establish the loop seal.
2. Air flow control valve at riser leg decides the transfer rate to main furnace. Excess transfer rate will lead to seal break. In adequate transfer rate will result in plugging of loop seal.
3. Air flow indications provide the operators parameters for regulation. Or else operators have to make blind adjustment. Many times loop seal will break.
4. Vent control valve is required since a twin lobe blower is used here. Or else VFD will be required.
5. Loop seal needs drain in order to control the lean bed density. Too much of dust will result in combustion temperature.
6. Drains are required for the main combustor as well. The bed ash cooler may malfunction any time.
7. Presence of adequate ash in dip leg is known by this.
8. Comparison of the pressures tells the loop seal is functioning.
9. Height of dense bed is known by this (includes drop across distributor).
10. Height of lean bed is known by this.
11. Secondary air is adjusted to complete the combustion in furnace itself.

Figure 2: Primary air system

1. Air flow meter after APH ensures the leakage air flow in APH is ignored. Moreover tube leakage is identifiable in case the damper opening increases for the same air flow.
2. As APH develops tube leakage the pressure drop across APH can be used for inference.
3. Cold air is used for coal chute flushing. This prevents the chute fires / explosions / chute clinkering.
4. Air pressure is a measurable parameter for monitoring. Damper settings are not reliable.

Figure 3: Secondary air system

1. Air flow meter after APH ensured that the leakage air flow at APH is ignored.
2. Pressure to ensure penetration is possible for CO ppm reduction is possible by choosing to close dampers optionally.
3. Valves to choose levels of secondary air ports based on FC / VM ratio.
4. As APH develops leakage the pressure drop can be used for diagnosis.

New buyers may now review the instrumentation requirement. Existing CFBC owners can review what supplement instrumentation is required for their plant.

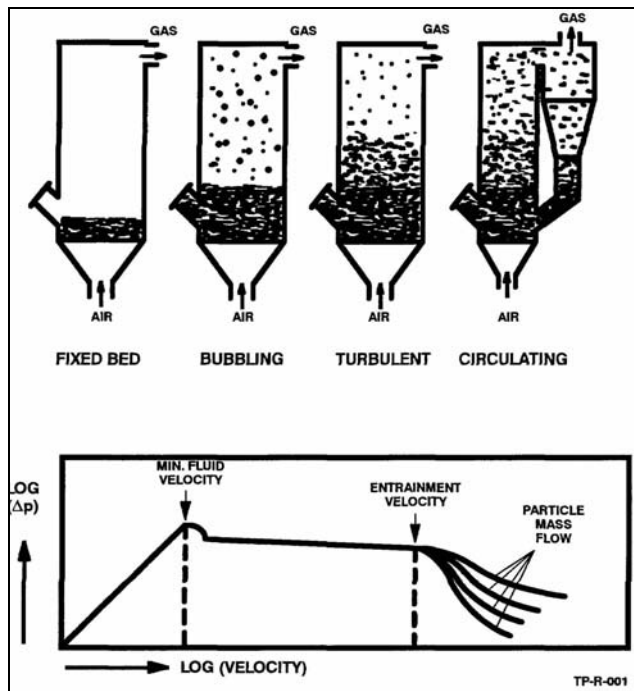


Figure 1: The principle of CFBC

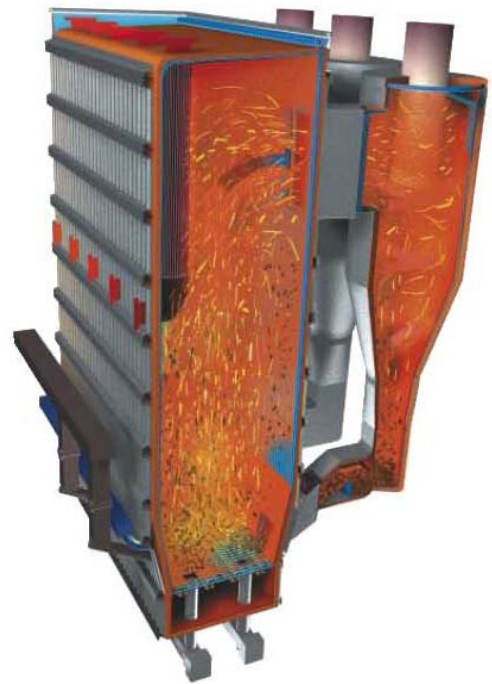


Figure 2: CFBC illustration with cyclone & loop seal.

Coal					
Top	Bottom	mean size	% wt	mean	
13	6	9.5	42.9	8	4.08
6	3	4.5	24.0	6	1.08
3	1	2	20.4	8	0.41
1	0.2	0.6	12.4	8	0.07
Mean particle size					5.65
Bed ash					
Top	Bottom	mean size	% wt	mean	
13	6	9.5	8.88	0.84	
6	3	4.5	9.47	0.43	
3	1	2	22.4	5	0.45
1	0.2	0.6	59.2	0.35	
Mean particle size					2.07
Cyclone ash					
Top	Bottom	mean size	% wt	mean	
1.5	1	1.25	0.93	0.01	
1	0.425	0.7125	12.9	3	0.09
0.425	0.25	0.3375	26.8	9	0.09
0.25	0.075	0.1625	40.7	5	0.07
Mean particle size					0.26

Table 1: Sieve analysis of coal, bed ash & loop seal ash.

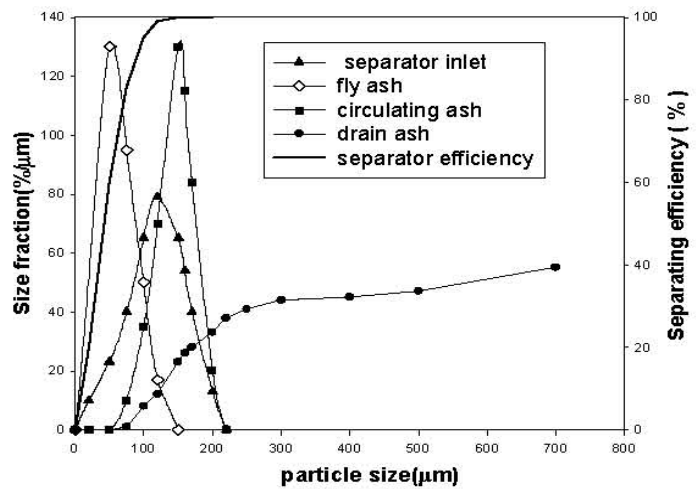


Figure 3: Typical size distribution of particles in a CFBC boiler.

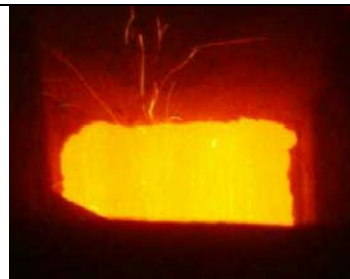


Photo 1: flow of ash in loop seal- working well.



Photo 2: Backing of ash in the next loop seal.

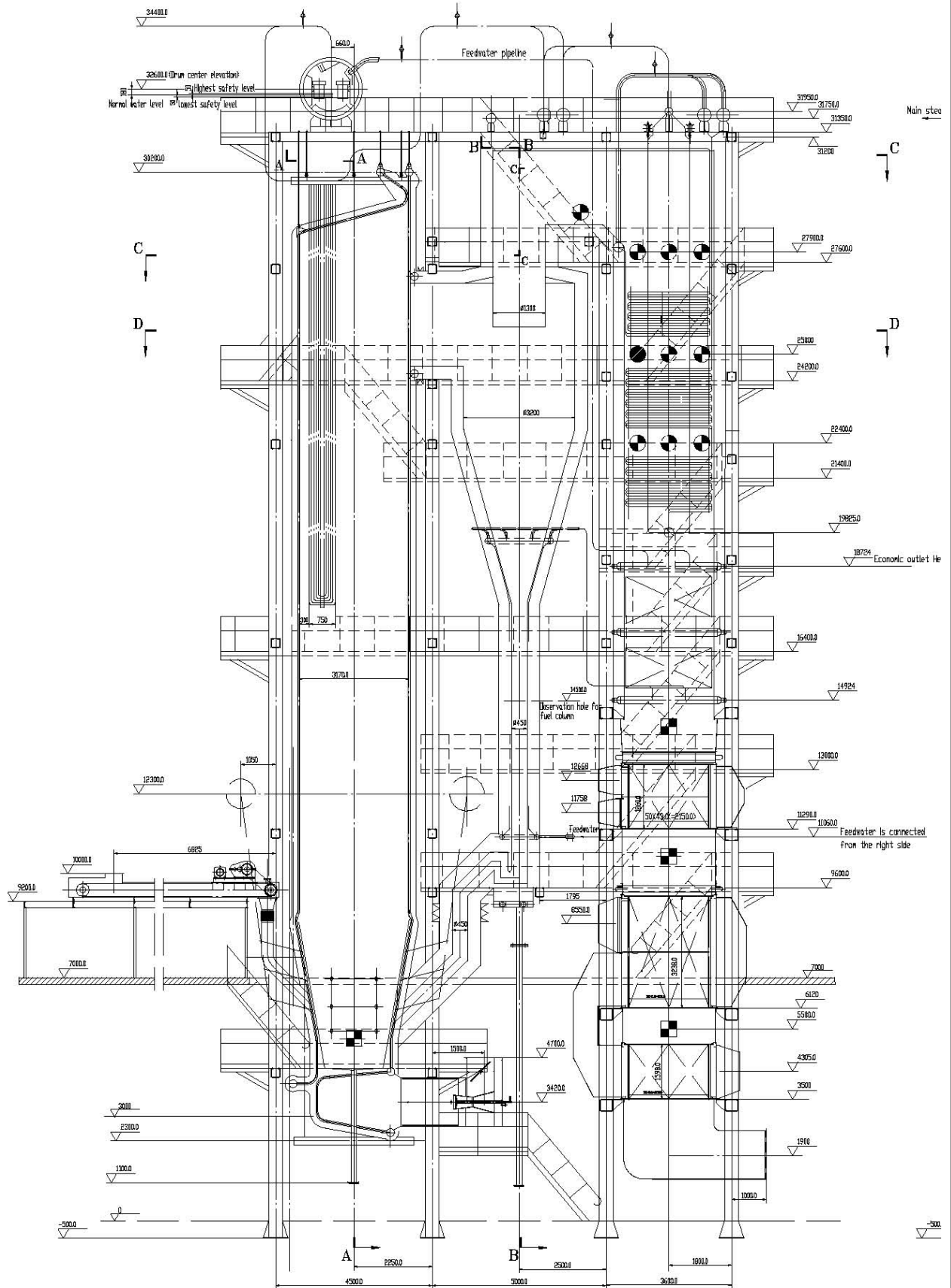
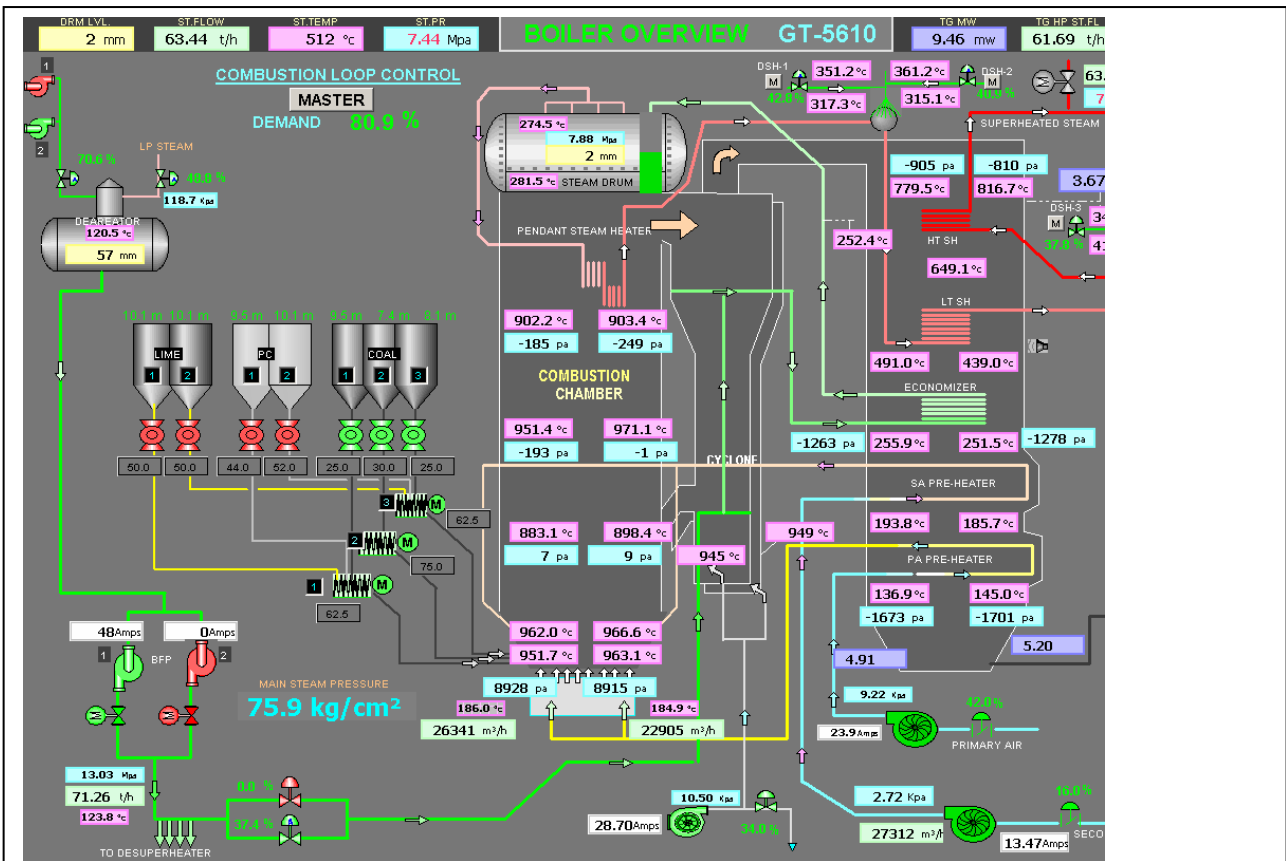
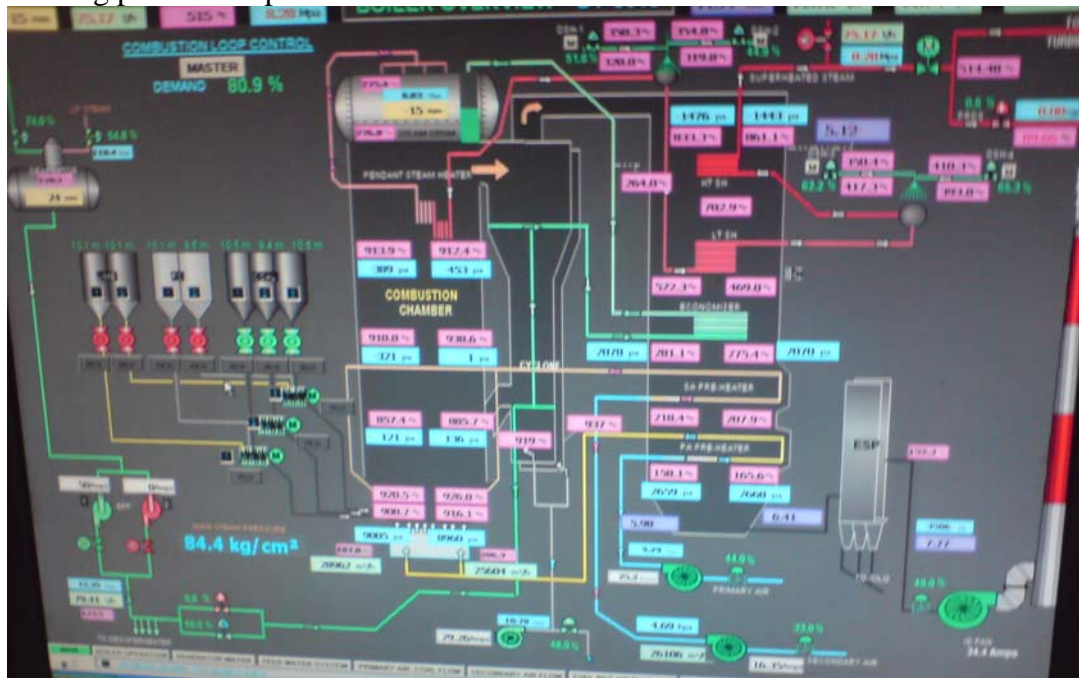


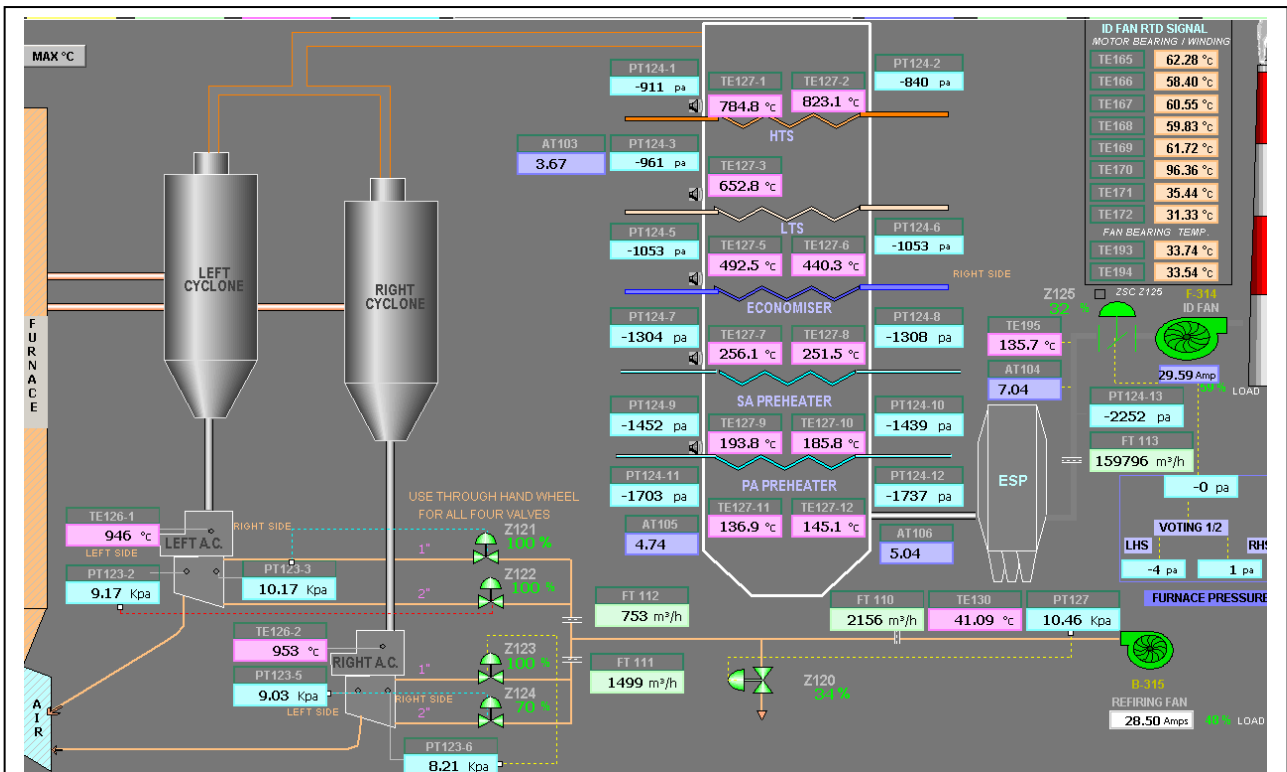
Figure 4: A view of CFBC boiler.



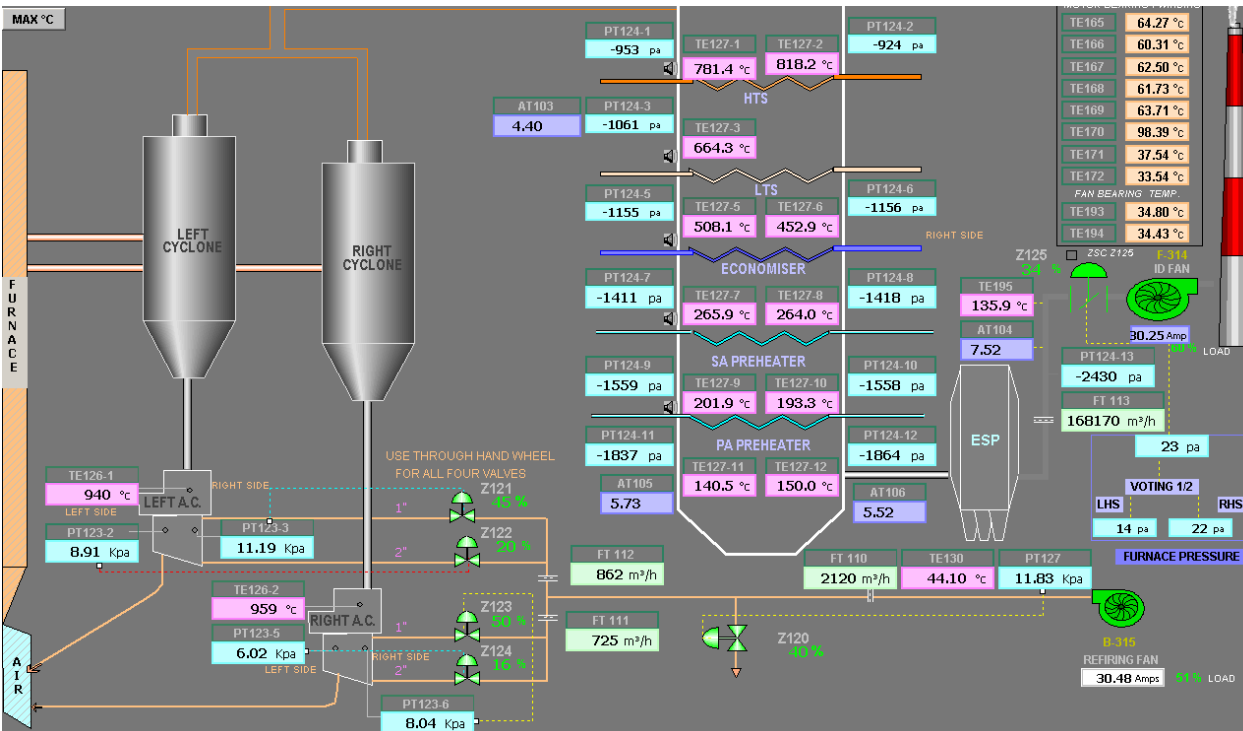
Picture 1: This is the picture of furnace at the first visit. The furnace bottom temperature is higher than the free board. The free board pressure is hardly 11 mmWC. There is considerable temperature drop in free board. Again at loop seal the temperature is more. It means combustion is taking place at loop seal.



Picture 2: After the parameters were corrected, the steam generation went to 75 TPH with furnace & loop seal temperatures at 900-920 deg C. The lean bed height is now 42 mmWC.



Picture 3: Loop seals not working before the adjustments were made. The dip leg airbox pressure is less than the riser leg side airbox pressure in right cyclone. There is no markable difference in the left cyclone either.



Picture 4: The air flows between cyclones were balanced & valves were throttled to see that there is at least 200 mmWC more pressure at the dip leg side. This picture was taken immediately after the adjustment. Within 2 hrs the boiler reached full load at a lower furnace temperature.

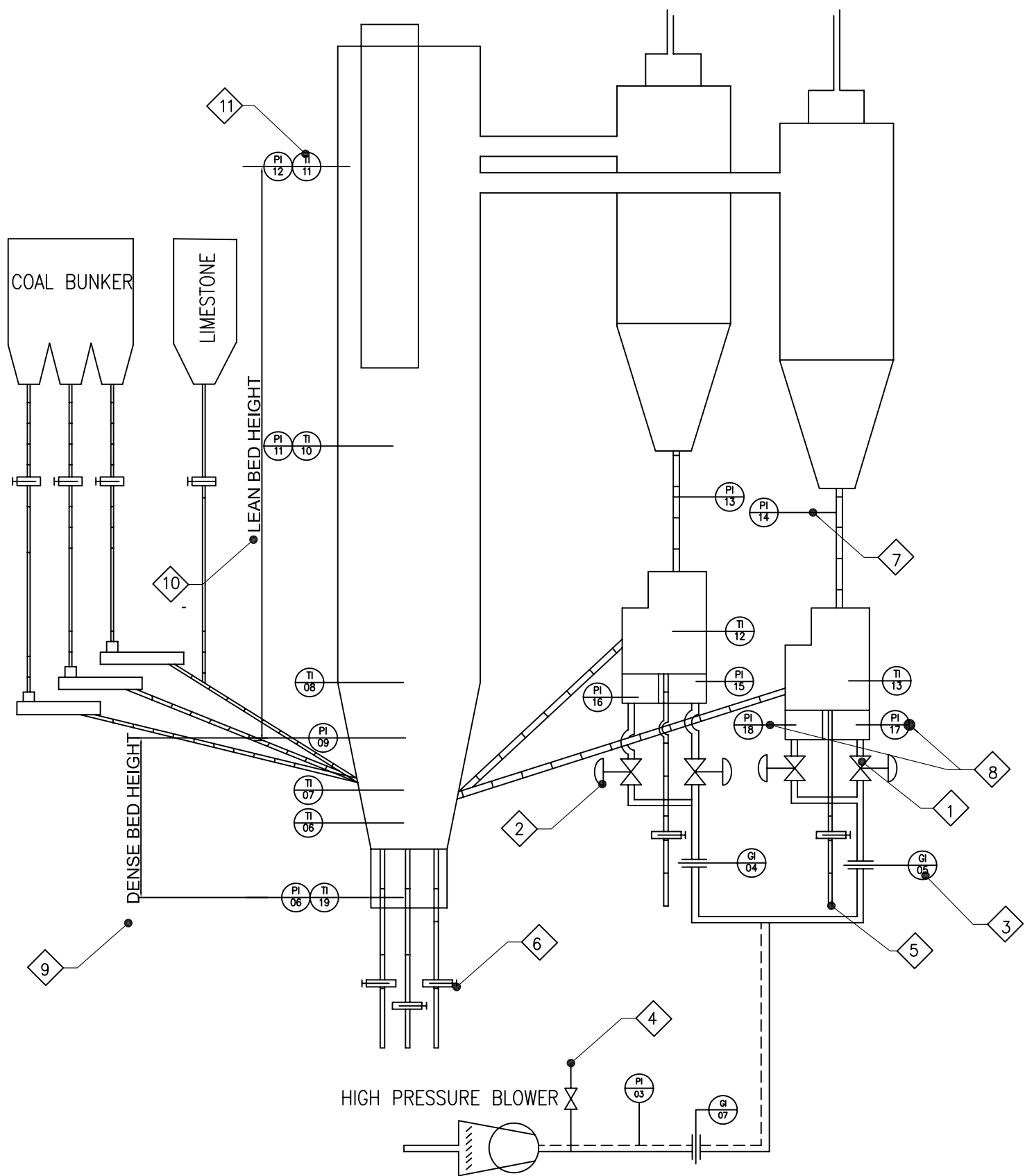


FIGURE 5: ESSENTIAL INSTRUMENTATION FOR CFBC FURNACE

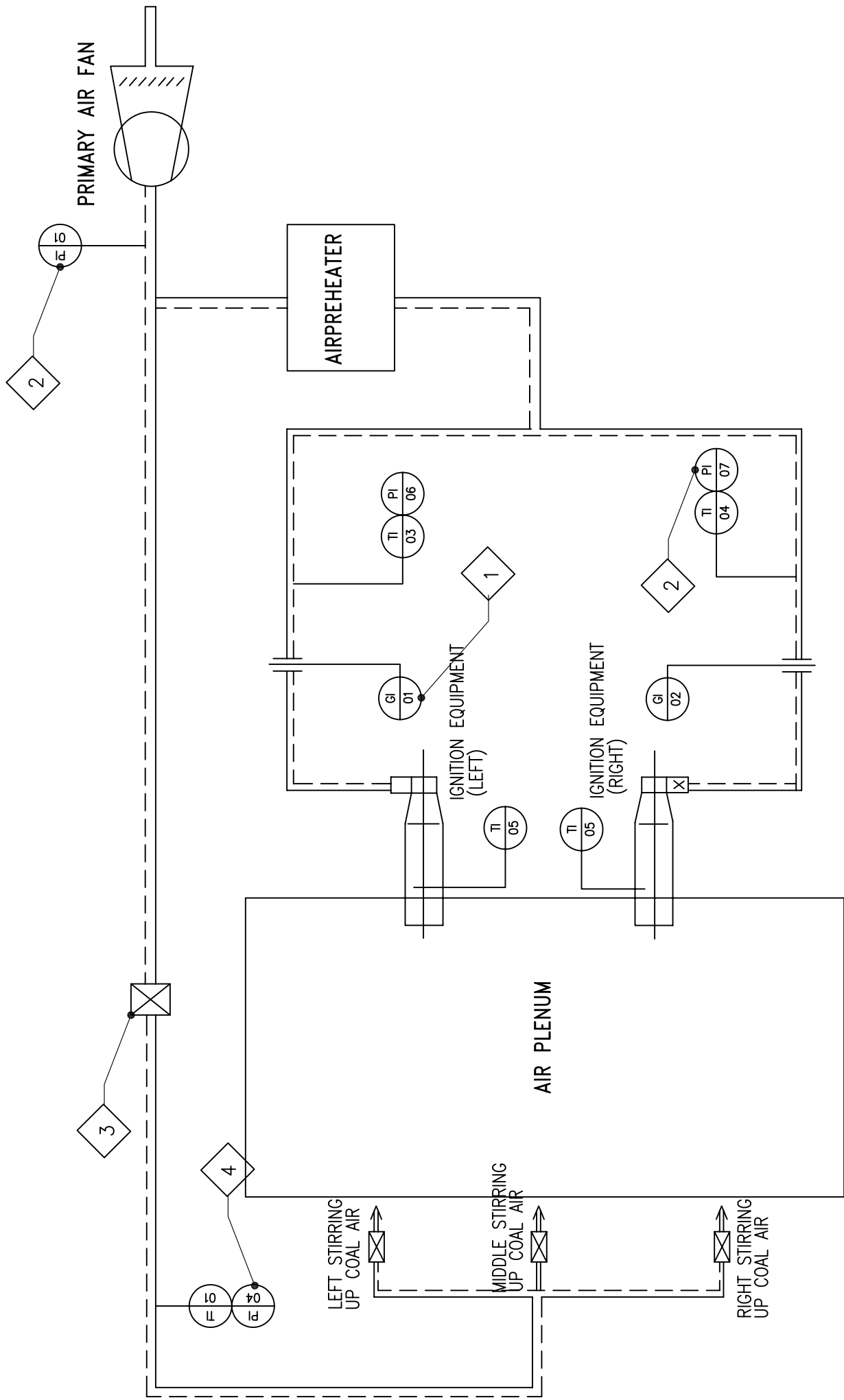


FIGURE 2: PRIMARY AIR SYSTEM CONTROLS

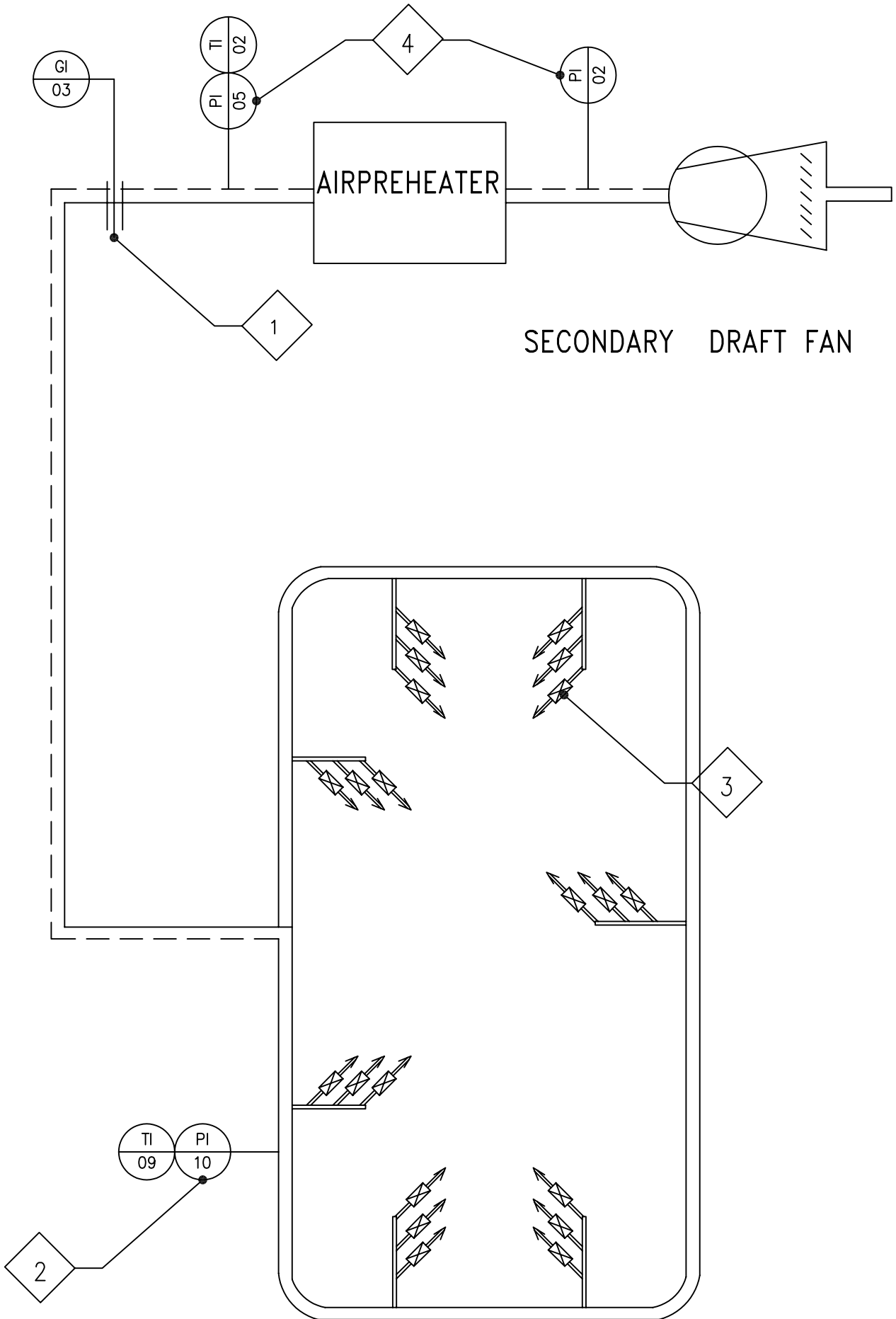


FIGURE 7: ESSENTIAL INSTRUMENTATION FOR SA SYSTEM