Status of the 200 MWe Tonghae CFB Boiler after Cyclone Modification

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Abstract

The 200MWe Tonghae thermal power plant CFB boiler (2-units) in Korea is the largest boiler to fire domestic anthracite for electric power generation. The CFB unit 1 has been operated commercially since October 1998, and the CFB unit 2, of which commercial operation will start in October 1999, is currently under initial operation. The initial operation period of the unit 1 clearly demonstrated that the full load operation was successful. However, there were apparently some rooms for optimization, particularly regarding a furnace and cyclones/sealpots temperatures and SOx emissions that were somewhat higher than expected. Therefore, the modification of cyclones to improve cyclone efficiency was performed by extension of height of the vortex finder and decrease of width of cyclone inlet duct. This modification increased cyclone separation efficiency allowed temperatures of the furnace and cyclones/sealpots and the emissions of SOx to be lower.

INTRODUCTION

The design engineering and construction project of the Tonghae thermal power plant CFB boiler (2-units) located in Tonghae, Korea, was begun by Korea Electric Power Company (KEPCO) to utilize domestic anthracite coal in early 1993. Combustion Engineering Inc. (ABB-CE) has designed a 200 MWe CFB firing Korean Anthracite fuel. In this project, KOPEC (Korea Power Engineering Company) has served as the project architectural engineering and is responsible for various balance of plant system designs and equipment procurement. Additionally, Hanjung is responsible for the boiler equipment fabrication and procurement.

The Tonghae thermal power plant firing domestic anthracite is different from recent Korean power plants. It was selected over the conventional pulverized coal boiler because of its improved efficiency of burning low quality fuels and its improved air emission capability. The two 200MWe units of Tonghae thermal power plant have been designed in such a manner that they could operate more efficiently and be able to meet the Korean environmental standards without installation of external environmental control systems. They would not need to fire supplemental fuel oil during normal operation. This plant will utilize the domestic anthracite as its fuel source and burn approximately 1.2 million ton per year. This will encourage the local coal mining industry of Korea.

The CFB unit 1 has been operated commercially since October 1998, and the unit 2, of which commercial operation will start in October 1999, is currently under initial operation. The initial operation period of the unit 1 clearly demonstrated that the full load operation was successful. However, there were apparently some rooms for optimization, particularly regarding a furnace and cyclones/sealpots temperatures and SOx emissions that were somewhat higher than expected. It was difficult to maintain the stable operation at high temperature due to the formation of clinker in the cyclones/sealpots. Therefore, the modification of cyclones to improve cyclone efficiency was performed by extension of height of the vortex finder and decrease of width of cyclone inlet duct. This modification improved the performance by lowering temperature and SOx emissions through the increase of solid circulation rate.

This paper gives a description of the unit identifying the design features and considerations. The history of operation from initial start up to the present is also discussed along with operating parameters.

POWER PLAN AND STATUS OF CFB BOILER IN KOREA

Electricity forecast and long-term power plan in Korea

Since the available domestic energy source is very limited, Korea mainly depends on imports for the most of the primary energy source. From the viewpoint of energy strategy and global environmental problem, CCT such as IGCC, FBC and FGD will be essential for the 21st century. The stringent environmental regulation has been implemented since January 1999 in Korea. KEPCO is planning to install two CCT units such as 300MW FBC or IGCC by the year 2007 and another 300MW CCT by the year 2012.

KEPCO expects that the annual growth rate of electricity demand will be 3.8% on average in the long term from 1998 to 2010. To meet future electricity demands, the power development plan requires to build additional 100 power generating units with a capacity of 40,820MW between 1998 and 2010. These facilities will comprise 15 nuclear units (14,700MW), 20 coal-fired plants (11,000MW), 22 LNG combined cycle units (8,120MW), 28 pumped storage power plants and hydro plants (3,800MW),12 oil-fired plants (2,600MW), and 3 domestic coal-fired units (600MW) including 2 units of 200MW Tonghae plants.

According to the above program, the installed capacity by 2010 will be 76,420MW. The composition of capacity will be 24,430MW(32%) nuclear, 21,300MW(27.9%) coal, 23,780MW (31.1%) LNG and oil, 6,910MW(9.0%) hydro and pump storage power. This is summarized in Table 1.

Table 1. Long-Term Electric Power Plan in Korea.

Sources / Year	1998	2000	2005	2010
Nuclear MW (%)	12,020 (27.3)	13,720 (27.3)	17,720 (27.4)	24,430 (32.0)
Coal-fired MW (%)	11,400 (25.9)	14,100 (28.1)	19,020 (29.4)	21,300 (27.9)
LNG-fired MW (%)	12,220 (27.8)	13,440 (26.7)	17,350 (26.9)	18,450 (24.1)
Oil-fired MW (%)	5,200 (11.9)	5,140 (10.2)	5,600 (8.7)	5,330 (7.0)
Hydro MW (%)	3,120 (7.1)	3,870 (7.7)	4,900 (7.6)	6,910 (9.0)
Total MW (%)	43 ,960 (100)	50,270 (100)	64,590 (100)	76,420 (100)

Commercial CFB boiler in Korea

Table 2 presents the commercial CFB boilers in operation and under construction in Korea. The boilers in operation are utility scale boilers with a capacity of 100-200 steam tons per hour. The common fuel is a bituminous coal imported from abroad. The 200MWe Tonghae CFB plant uses domestic anthracite to demonstrate the capability of anthracite burning and thus encourages the domestic coal industry. It is the largest power plant adopted beyond utility scale in Korea.

Table 2. Distribution of Commercial CFB boiler in Korea

Company (Location)	Category	Capacity (MW)	Steam (T/H)	Fuel	Start	Supplier
Oriental Chemical	Chemical	12.5	120	Bitu. Coal,	1985	Hyundai

(Inchon)				Pet. Coke		/Ahlstrom
Sunkyung (Suwon)	Textile	-	130	Bitu. Coal	1988	“
Sunkyung (Ulsan)	Textile	27	200	Bitu. Coal, Pet. Coke	1989	“
Hyundai Oil (Susan)	Refinery	-	120	Pet. Coke	1989	“
LG Chemical (Yochon)	Chemicals	25	210	Bitu. Coal	1989	“
Petrochemical Service Co. (Ulsan)	Cogen.	-	250	Bitu. Coal, Pet. Coke	1990	“
Sunil Glucose (Inchon)	Food	9.2	60	Bitu. Coal, Heavy Oil	1991	“
Dyeing Complex (Taegu)	Dye	54.1	130 x 3	Bitu. Coal	1986	Samsung/ Babcock
Jeil Sugar (Seoul)	Food	5.4	40	Bitu. Coal	1988	“
Hansol Paper (Jeunju)	Paper	23	130	Bitu. Coal	1990	“
Dyeing Complex (Pusan)	Dye	-	80	Bitu. Coal, Heavy Oil	1991	Daewoo/ B&W
Korea Energy (Ulsan)	Metal	43.5	175	Bitu. Coal	1991	Hanjung/Lurgi
KEPCO (Tonghae)	Electricity	200 x 2	693 x 2	Anthracite	1998 (1999)	Hanjung/ ABB-CE

TONGHAE CFB BOILER FEATURES

The Tonghae thermal power plant CFB boiler was designed to fire Korean anthracite by Combustion Engineering, Inc. [ABB-CE, 1994]. The Tonghae CFB combustor is shown in Fig. 1. It consists of feeding parts of coal and limestone, PA, SA and FA supplier, main combustion part (furnace, cyclones, sealpots, FBHEs and FBAC), and convective backpass.

Furnace

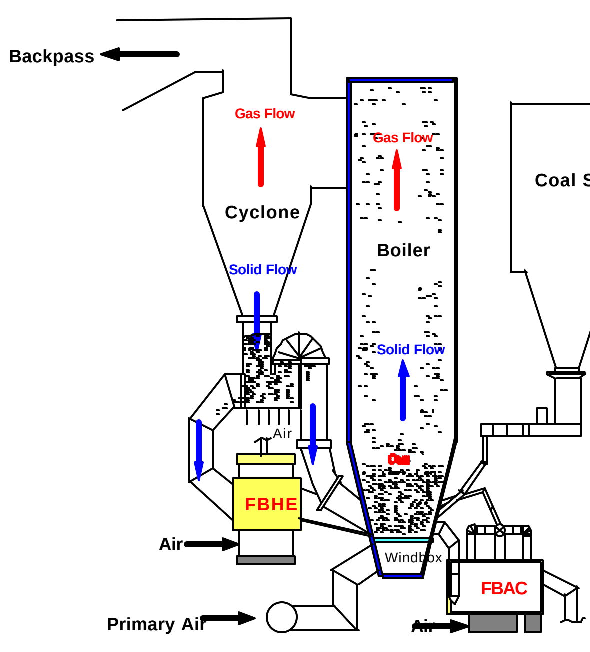

Fig. 1. Tonghae CFB Boiler Feature

Special consideration was paid to the 200MWe Tonghae thermal power plant CFB to minimize the erosion potential in the furnace. Design considerations are the use of a low fluidizing velocity, the use of specially designed tubes at the lower furnace refractory/ water wall interface with super hardened alloy coated, and the exclusion of the hanging heat exchanger surface in the furnace due to the erosiveness of the fuel. Some CFB designs have employed velocities of 6 m/sec or more, but Tonghae is operated at a much lower velocity (at about 4.6m/sec). These velocities result in lower solid impact velocities and lower solid fluidization rates; both of which will significantly lessen the furnace erosion potential.

The furnace of the Tonghae CFB (19m(W) x 7m(L) x 32m(H)) has a rectangular footprint and is significantly wider than it is deep, incorporating as an aspect ratio of more than 2:1. As all fuel feed points are aligned on the furnace front wall, the rectangular geometry was chosen to allow for good fuel mixing. Limestone is injected with the fuel in the fuel feed chutes and it is also introduced in two injection ports along the rear wall. Flue gas and solid particles exit the furnace through three openings in the upper rear wall. Solids are returned to the furnace from the cyclones and external fluid bed heat exchangers (FBHE) via the lower front wall.

Primary air is introduced to the furnace via the fluidization grate. T-style fluidizing nozzle patented by ABB-CE has relatively large openings to reduce the potential of plugging associated with many nozzle designs, while maintaining a pressure drop to preclude backsifting. Secondary air is introduced at the lower furnace along the front and rear walls. All secondary air nozzles are furnished with butterfly style dampers to maintain a steady secondary air supply-duct pressure. Secondary air is also introduced into four start-up burners.

Bottom ash is removed from the bottom of the furnace via two ash control valves (ACV). The bottom ash is introduced into a fluidized bed ash cooler (FBAC) which contains economizer and cooling water heat transfer surface. Heated fluidizing air is returned from the FBAC vents into the CFB combustor at four locations along the front wall.

Cyclones and Sealpots (Loopseal)

Three cyclone separators remove almost all of the entrained particles from the flue gas and return them, through the seal pot, to the furnace. The seal pots serve to create a pressure seal from positive pressure in the furnace to the negative pressure in the cyclone. This pressure seal prevents the flow of material back up the cyclone from the bottom of the furnace.

Fluidized Bed Heat Exchangers (FBHE)

The Tonghae unit is designed to operate at 35% load without support fuel and 30% load with minimal co-firing of the start up fuel oil. This stringent boiler turndown requirement, coupled with the difficulty to burn anthracite, has resulted in offering external fluid bed heat exchangers on the Tonghae unit. At each of the three seal pots, a stream of solids material is diverted and introduced into on FBHE through three ash control valves. As the solids from the seal pots flow over and through the FBHE heat transfer surfaces, the ash is cooled. This cooled ash is then returned to the furnace.

By placing superheat and reheat heat transfer surface in separate FBHEs into which solids can be introduced in a controlled fashion, optimum turn down control is accomplished.

Convective Backpass

The total unit heat duty is distributed in a fairly even fashion among the furnace, backpass, and FBHEs. The convective backpass contains the first stages of superheater and reheater heat transfer surfaces. The convective back pass is steam cooled as used on typical utility boiler designs.

A typical air-through, gas-over tubular air heater is located below the convective backpass economizer.

Properties of Coal and Limestone and Operating Conditions

In the Tonghae CFB, Korean anthracite is used as fuel, and which contains 39% ash, 4% VM, 53.7% FC and 3.3% MS. The coal contains low S (0.6%) and N (0.2%), and its heating value and the combustion reactivity is very low. The fraction of coal in the range of 0.1-6mm is over 95% on the design basis. Limestone used in the CFB contains 90% of $CaCO_3$ and 4.2% of $MgCO_3$ and 100% of particles smaller than 1.0mm (<0.7mm-95%, <0.5mm-90%). The proximate and ultimate analysis of the coal is shown in Table 3. The operation condition with variation of nominal rates is also shown in Table 4.

Table 3. Analyses of design coal used in the Tonghae CFBC.

Proximate analysis	wt.%	Ultimate analysis	wt.% (dry basis)
Moisture	3.3	C	54.7
Volatile Matters	4.0	H	0.3
Fixed Carbon	53.7	O	3.8
Ash	39.0	N	0.2
Heating Value (dry basis)	4600 (kcal/kg)	S	0.6
		Ash	40.4

Table 4. Operation conditions for the Tonghae CFB boiler.

#	H (m)	W (m)	L (m)	Addition air (m^3/s)						TP *	WR **
				BMCR	MGR	100% NR	75% NR	50% NR	30% NR		
1	0.0	19.05	3.35	87.22	87.22	87.22	76.3	65.58	68.34	1	1
2	0.43	19.05	3.58	14.6	14.01	10.26	4.4	4.4	4.4	1	1
3	1.37	19.05	4.09	0.93	0.93	0.93	0.93	0.93	0.93	1	1
4	1.70	19.05	4.26	9.14	9.14	9.14	9.14	9.14	7.34	1	1
5	2.44	19.05	4.66	22.19	21.75	18.94	14.54	14.54	14.54	1	1
6	4.48	19.05	5.75	32.86	31.52	23.09	9.9	9.9	9.9	1	1
7	28.53	19.05	7.09	0	0	0	0	0	0	0	1
8	32.90	19.05	7.09	0	0	0	0	0	0	0	1
9	Coal (kg/s)			30.1	29.7	27.3	20.7	14.5	7.9		
10	Lime (kg/s)			0.92	0.91	0.83	0.63	0.44	0.38		

#1: Primary air, #2: Secondary air(4points), #3: Feeder(coal and limestone) transport air, #4: Sealpot+FBHE returned air, #5: Secondary air(3points), #6: Secondary air(9points), #7: Exit, #8: Top of combustor, #9,10: coal and limestone feed rate, * TP: Tapered or not, yes=1, no=0, ** WR: [membrane wall area]/[wall area]

START UP & OPERATING EXPERIENCES

Basic guidelines for start up and operation of the Tonghae CFB boiler to complement control loop tuning and automatic controls have been prepared via some operating experience. Some changes and modifications were required to the procedure based upon the operating conditions encountered at the time. All changes in oil flow, air flow, coal flow and bed pressure drop should be done very slowly and be allowed to equilibrate and then the bed temperatures and O_2 readings become steady prior to the next step. Establishing cyclone sealpot positive pressure is to assure that no reverse flow of bed material or air/gases occurs through the cyclone sealpots, up through the cyclone and out into the back pass. To improve other operating parameters, some values and systems have been added in the combustor and boiler air/gas systems.

Start-up and Coal Firing Procedure

For the first time, the ID fan and the FAB (Fluidizing Air Blower) start to establish the normal furnace draft and operating pressure conditions with suitable bed inventory. Grease air valves in sealpots and fluidizing air valves in sealpots, FBHE and FBAC are open only to keep nozzles cool and are closed until only a minimum amount of flow is observed. The pressure gauges for the sealpots are used to determine if there is a seal in the sealpots under the condition that three ACVs on the FBHEs (evaporator, reheater and superheater) are closed. To achieve seal in the sealpots, the PA and SA start and bring to 50-80kg/s and to relatively minimum flow, and if necessary, the FBHE flow increases higher than normal flow in order to blow recycle material into the combustor.

Achieving seal in the sealpots, observing pressure taps on the sealpot for positive indications, PA flow reduces to 45-50kg/s in preparation for start up burner. The combustor differential pressure must be monitored and controlled in accordance with the unit operating procedure using the ACVs. This process is to be continued until full CFB operation is established by coal without fuel oil.

The following conditions will be needed to be met the coal firing; PA flow is 50 to 70kg/s, average lower combustor temperature is greater than 650^{o}C and cyclone outlet temperature is 975^{o}C, maximum target temperature. At the bed temperature (650-700^{o}C), which is achieved by start-up and some lance burners, the coal is fed at minimum flow rate. After confirmation of oxygen reduction at the outlet and an increase in furnace temperature, the coal feed up, the PA flow up and the oil feed down is carried out. After achieving lower combustor temperature (800 to 850^{o}C), coal, oil and PA are changed in the following increments. The amount of change in the values provided below may be slightly different from actual conditions depending on the time.

- Increase coal flow by 5 t/h (wait 4 min.)
- Remove 12kg/min of SUB oil
- Add 4kg/s of PA
- Wait 2 min. to observe effects and to permit stabilization.

If the sealpot temperature increases to 1,000^{o}C and upper furnace differential pressure is too low for circulation, then the procedure should be stopped and brought back to initial conditions for prevention of the formation of clinker in cyclones/sealpots. The coal feed up and the oil feed down is gradually performed, and ACVs of FBHE and secondary air dampers are controlled to maintain load and uniform bed temperature. In the steady-state CFB operation at full load, the achieving conditions are as follows:

- Furnace low temperature: 850-900^{o}C
- Sealpot dipleg temperature: 900-970^{o}C
- Furnace overall differential pressure (including grid pressure): 1,400-1,800 mmH_2O
- Furnace upper differential pressure (L=23.3m; from 6.9 to 30.2m): 100-300 mmH_2O
- Sealpot dipleg pressure: 500-1,000 mmH_2O

Initial Experience and Technical Problems

The initial operating period of the unit 1 clearly demonstrated that the full load was successful. However, the initial operation of the unit 1 had the following problems.

- Longer time initial heat-up of bed material
- Formation of clinker in sealpots during the initial heat-up of the bed materials
- Backsift of solid particles through the fluidizing nozzles
- Low cyclone efficiency

The above problems may be due to coal particle size distribution (PSD) and lower combustion reactivity. The coal used initial operation included finer (<0.075mm) and coarser (>6mm) particles than design PSD and is shown in Table 5. The fine particles may cause to form clinker in sealpots before the full circulation of the bed material is achieved. It is because combustion of elutriated fine particles occurred in the top of the combustor and sealpots due to the low combustion reactivity of coal and low residence time in the bed. To solve this problem, it is necessary to reduce the time for initial heat-up of the bed, which allows the circulation to be achieved quickly, and to remove the defluidization region in the sealpots. So, the lance burners to heat up the bed materials were mounted and the grease air lines in sealpots were also added to improve the fluidization.

Table 5. Particle size distribution of design and sampled coal (#1, 2, 3) in field.

Size distribution (mm)	Design PSD (wt.%)	#1-PSD (wt.%)	#2-PSD (wt.%)	#3-PSD (wt.%)
>9.5	0	1.0	0	0
5.6 – 9.5	0	14.4	5.0	24.4
4.75 - 5.6	1.0	5.1	1.2	5.1
2.8 – 4.75	2.0	12.3	2.9	11.5
2 – 2.8	16.0	7.2	2.4	4.0
1.0– 2.0	31.0	20.0	14.0	11.0
0.6 – 1.0	16.0	14.6	20.0	6.0
0.25 – 0.6	17.0	14.6	26.0	12.0
0.1– 0.25	10.0	5.8	17.9	13.6
0.075 – 0.1	2.0	3.0	3.1	2.4
<0.075	5.0	2.0	11.0	10.0

On the other hand, to prevent the backsift of solid particles through the fluidizing nozzles, the modification of T-type nozzles was completed by introducing longer and steeper orifice-tube lines.

In spite of achieving of full load operation successfully, there were apparently some rooms for optimization, particularly regarding a furnace and cyclones/sealpots temperatures and SOx emissions that were somewhat higher than expected. Therefore, the modification of cyclone to improve cyclone efficiency was performed by extension of height of the vortex finder and decrease of width of cyclone inlet duct. This modification increased cyclone separation efficiency by lowering temperatures of the furnace and cyclones/sealpots and the emissions of SOx due to the increase of circulation rate. Table 6 shows the modifications of the unit to solve the problems.

Table 6. Modifications of the device for the Tonghae CFBC

Item	Contents for modifications	Marks
Grease air line at sealpot(dipleg)	2.5"pipe – 35 places at each sealpot	Addition
Grease air line around ACVs on FBHE	1" and 1.5" – 10 place at each ACV	Addition
Window for observation at sealpot	1 window at each sealpots	New
Duct water spray nozzles at cyclone inlet	2" pipe – 3 places	New
Injection port of bed media (sand) to bed	6" pipe – 3 places	New
Injection port of bed media to sealpots	6" pipe at each sealpots	New
Solids drain line at fluidizing air line	2" nozzles – 7 places	New
Lance burner	5 places in the combustor	New
Fluidizing nozzles	Longer and steeper orifice tube	Exchange
Cyclone modification	Vortex finder and inlet width	Modification

Improved CFB performance after modification of cyclone

After the modification of cyclones, the differential pressure of upper part (ÄL=23.3m from combustor top) in the combustor, regarded as basis of complement of solid circulation, is about 190-210 mmH$_2$O, which is higher than that of unmodified upper part. The differential pressure of middle part also increases. These are resulted from the change of solid hold up in the combustor due to increase of cyclone efficiency. The axial solid hold up and pressure profiles before and after modification of cyclones are shown in Fig. 2, with predicted results by IEA (International Energy Agency) - CFBC model. The increases of solid circulation rate and solid hold up in lean phase are estimated from increase of the differential pressure. In the model calculation for the solid hold up and the pressure profiles in the combustor, the predicted results for before and after cyclone modification had good fits.

The temperature profiles before and after modification of cyclone in the combustor are shown in Fig. 3 with predictions by IEA-CFBC model. The temperature in the combustor after modification of cyclone is lower than that of before modification of cyclone although the operation temperature is somewhat different. The cyclone inlet temperature as well as sealpots temperature is also lower than before, and the stable operation and control could be achieved successfully.

The emissions of SO_2 also become to be lower, but there is still a room for optimization regarding the Ca/S mole ratio.

In Fig. 4, the calculated cumulative size fractions of discharged bottom ash, recycle ash and filter ash are depicted with sample taken from after modification of cyclone. The calculated results predict that smaller particles are more circulated, so the particles in all parts appear to be smaller after modification of cyclone. This is because of the increase of the cyclone efficiency.

Therefore, the modification of cyclone to improve separation efficiency allowed temperatures of the furnace and cyclones/sealpots and the emissions of SOx to be lower and more stable.

CONCLUSIONS

During the initial operation period, the Tonghae CFB boiler has demonstrated successfully in spite of some problems. The temperature of the combustor and the cyclones/sealpots becomes to be lower than before, and the SO_2 emissions are also reduced through the modification of cyclones. Consequently, the stable and improved operation of the Tonghae CFB boiler could be achieved although there are some rooms for optimization regarding higher unit efficiency and lower SOx emission levels.

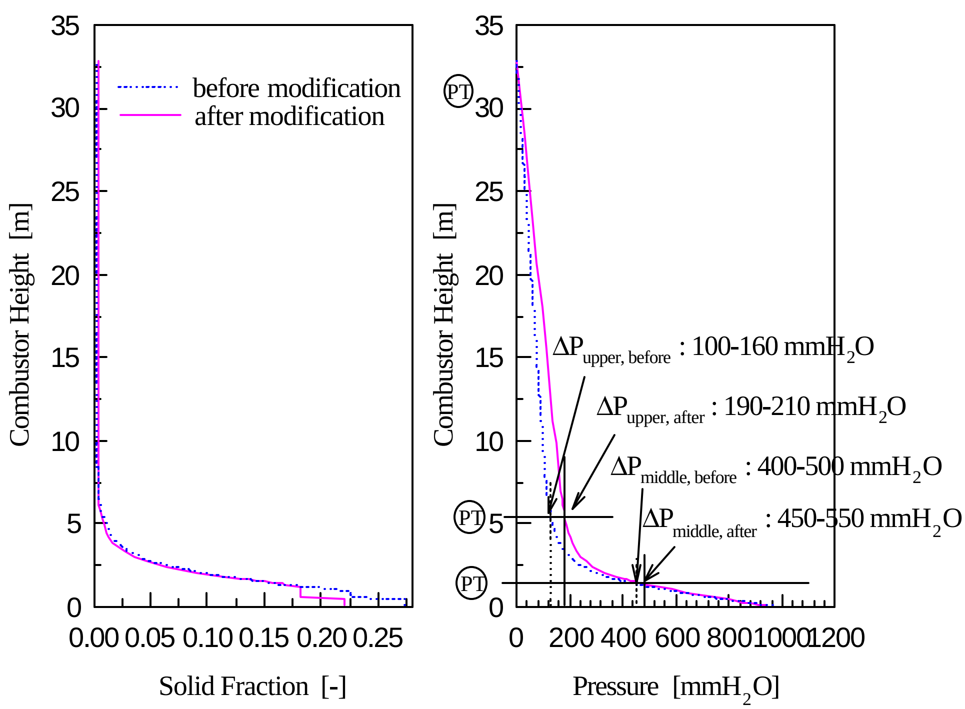

Fig. 2. Axial solid hold up and pressure profiles in the combustor

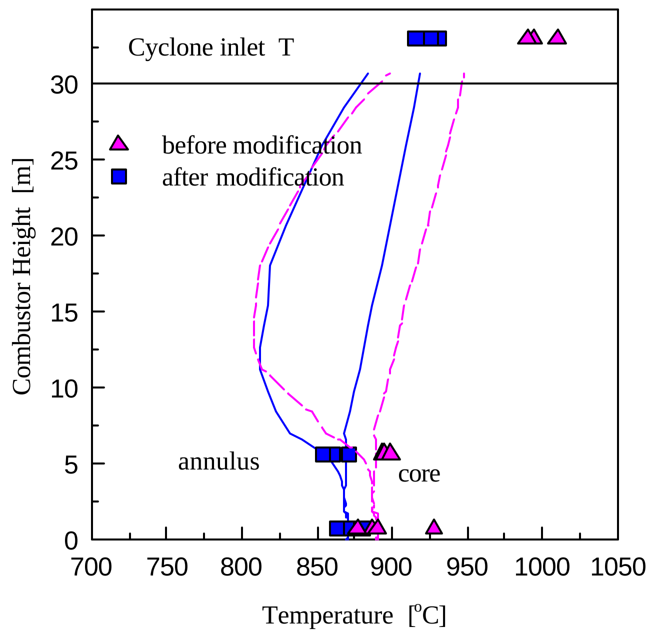

Fig. 3. Comparison of temperature profiles between before and after modification of cyclones

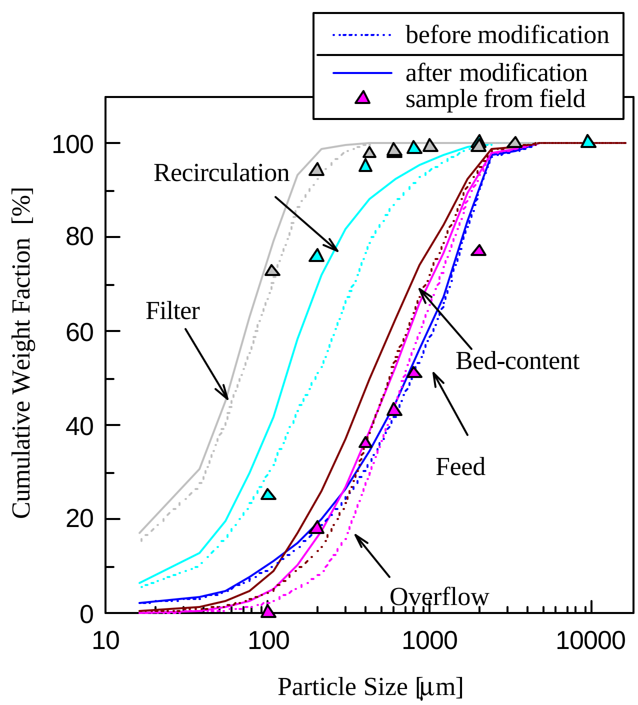

Fig. 4. Comparison of particle size distribution in the CFB boiler.

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