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Hot Gas Particulate Cleaning Technology Applied for PFBC/IGFC –The Ceramic Tube Filter (CTF) and Metal Filter－

Keywords : Ceramic tube filter (CTF), Reliability & Maintenance, Pressure Drop Performance, Metal Filter

1. Introduction

Coal is a fossil fuel abundant and widespread all over world. It is a vital resource for energy security, because the supply is stable. However, its CO_2 emission per unit calorific value is greater than that of other fossil fuels. It is necessary to develop more efficient coal utilization technologies to expand the coal utilization that meets the social demand for better environment.

The Pressurized Fluidized Bed Combustion (PFBC) combined cycle has become a subject of world attention in terms of better plant operation, improved plant efficiency, lower flue gas emission and fuel flexibility. The gas turbine, one of the most important components in the PFBC, is eager for a hot gas (approximately 650-850C) cleaning system in order to eliminate the severe erosion problem with the less thermal loss. The cyclone is most popular system for a hot gas cleaning, however, the severe damage for gas turbine blades by highly concentrated fine fly ash from PFBC boiler is reported [1].

There are several types of hot gas cleaning system, however, the rigid type ceramic filter is most promising for hot gas at a temperature of higher than 650C. The candle type, the tube type and the cross flow type of the rigid ceramic filter have been developed and tested. The candle type ceramic filters which have closed and open ends, has been developed and produced by Schmacher, Siemens-Westinghouse, LLB, Pall, etc. It was reported that the candle filter system was tested for PFBC at Tidd plant, USA [2] and was applied for the Puertollano IGCC plant, Spain [3]. The tube type filter, which has open ends and mainly uses the inner surface for filtration, has been developed and produced by Asahi Glass Company and Mitsubishi Heavy Industry etc. The Wakamatsu 71MWe PFBC combined cycle power plant, Japan is one of the representative applications of this filter system. The cross flow type raises a concern with pluggage in high dust environment. Lately, this filter has been introduced and tested at Foster Wheeler [4] and Delft University combined with the gasification process [5].

EPDC had installed Asahi Glass Ceramic Tube Filter (CTF) in the 71MWe PFBC combined cycle power plant at Wakamatsu and demonstrated for five years since 1994. Through Phase1 (Conventional PFBC using cyclones and CTF) and Phase2 (Ash Re-circulating PFBC using CTF), approximately 11,500h operation had been accumulated, where the lifetime of longest survived filter was approximately 8,000h. Many improvements were executed and demonstrated for both CTF and cyclone through both phases and the CTF process simulator was developed based on the precise plant data analysis and the sampled ash observation.

On the other hand, solid oxide fuel cell (SOFC), molten carbonate fuel cell (MCFC) and other technologies have been developed for high efficiency direct power generation [6][7]. To apply coal to fuel cells, it must be gasified and cleaned by removing impurities such as ash, sulfur compounds, halogen. IGFC (Integrated Coal Gasification Fuel Cell Combined Cycle) is a combination of gasifier that converts coal into synthesis gas, fuel cell, gas-turbine/steam-turbine. This system is expected to show much higher efficiency compared with conventional pulverized coal fired thermal power generation. Also, it is expected to be an ultimate power generation system using coal.

EPDC has installed Pall metal filter as a char filter for synthesis gas at a temperature of approximately 400C, in EAGLE (Coal Energy Application for Gas Liquid & Electricity) plant at Wakamatsu to establish the coal gasification technology for application for fuel cells (with coal feed 150 t/day pilot plant) aiming to implement the IGFC system [8].

This paper describes the reliability of filter material, the improvement of seal mechanism, the pressure drop performance, the CTF process simulator and the optimization for pulse cleaning condition using the developed simulator for Ceramic Tube Filter (CTF) as PFBC hot gas cleaning device. Further, the EAGLE project including char filter system is briefly introduced.

2. Experimental

2.1 71 MWe PFBC combined cycle power plant at Wakamatsu

Two configurations of flue gas treatment systems were examined at Wakamatsu 71MWe PFBC combined cycle demonstration power plant. Seven primary cyclones were installed at the boiler outlet to remove approximately 95% of fly ash from the boiler, and two CTF (Ceramic Tube Filter) as a hot gas extreme cleaning system were placed upstream of GT. The cyclone bypass pipe was installed between the boiler outlet and primary cyclones outlet in order to send some amount of coarser ash to the CTF. The amount of bypass gas flow was controlled with an orifice attached to the outlet of the pipe to bypass 8 or 12% of flue gas [9,10].

Two fly ash re-circulation cyclones were installed before the CTF without any primary cyclones in Phase2, aiming to recycle the relatively larger ash carried over to the fluidized bed. Therefore, fly ash smaller than approximately 200 μm in size was collected by the CTF [11]. The PFBC Phase1 and Phase2 flow diagram are illustrated in Fig.1.

2.2 CTF system for PFBC

The CTF system including the devices to measure pressure drop, is illustrated in Fig.2. The present CTF consisted basically of two pressure vessels (A and B), ceramic tube filters in the six compartments, reverse cleaning and other auxiliary equipment. The CTF pressure vessel (3.2m diameter, 16.6m height) was divided by the water-cooled tube-sheets, an inlet chamber at its top, three vertically arranged compartments (for example A1: A vessel upper compartment, A2: A vessel middle compartment, A3: A vessel lower compartment) and a hopper at the bottom.

The flue gas sent to the inlet chamber was distributed into 81 tubes. It flowed down along tubes filtrating and then was sent to GT through regenerators, ejectors and then a hot gas pipe. The filter tube supplied by Asahi Glass Company (AGC) consisted of β-cordierite filter material and metallic parts at both ends. The filters were supported by the tube-sheets and sealed. The inner diameter, outer diameter and length were approximately 140mm, 170mm and 3.06m, respectively [12].

Reverse cleaning equipment was installed in order to remove dust accumulated on the internal surface of the filters. This equipment consisted of reverse cleaning nozzles, fast control valves, regenerators and the ejector passage for heat recovery during cleaning. Compressed air was supplied as a cleaning media to the reservoir, which was automatically controlled to be about 1.5MPa higher than the process pressure. A fast pulse cleaning valve operating from closed-to-open-to-closed in 0.7 sec controlled the duration of the cleaning pluse. The time to complete the cleaning cycle through six compartments was usually 9 minutes, while a prolonged interval of up to 30 minutes was once applied successfully during a 12% bypass operation in Phase1, saving 0.5% (of gross) auxiliary power for plant operation. Two cleaning modes were executed, wherein the compartments in A vessel and B vessel were cleaned alternatively in one mode (A1-B1-A2-B2-A3-B3) and, the compartment in A vessel and then in B vessel was cleaned in sequence in another mode (A1-A2-A3-B1-B2-B3).

Pressure was measured at the inlet and outlet of CTF by resistance strain gauge PD-500GA, Kyowa-dengyo (Japan) and at the inlet and outlet of each compartment by PD-2KA, Kyowa-dengyo, to count the pressure difference across CTF (DP_{total}) and the filters in the compartment (DPc), respectively. DPc was usually defined as the pressure drop across A1 compartment, which was measured during the whole operation and recorded continuously in the DAS (Data Acquisition System). The pressure drop across the regenerators ($DP_{regenerator}$) was also monitored continuously in order to determine the amount of gas flow in the respective compartment being influenced by the accumulated ash on the filters in each compartment

2.3 EAGLE plant at Wakamatsu

EAGLE（Coal Energy Application for Gas Liquid & Electricity）plant which is consisted of gasifier, gas clean-up facilities, gas turbine and air separation unit (ASU) is illustrated in Fig.3. The specification of EAGLE plant is also summarized in Table 1.

An oxygen-brown entrained-flow gasifier with a capacity of 150 tons of dry coal per day is adopted in order to obtain high calorific value synthesis gas including high concentrations of H_2 and CO which must be suitable for fuel cells. Coal is transported by nitrogen from the upper and lower burners into the gasifier in a tangential flow pattern. Oxygen (the gasification agent) is supplied to each stage. By optimizing the distribution of coal supply to the upper and lower stages and the oxygen ratio of each stage, it is possible to obtain both high gasification efficiency and stable operation. The synthesis gas recycled from the outlet of the water scrubber is supplied to the outlet of the gasifier in order to quench slag particles. Char contained in the synthesis gas is removed by a cyclone and a filter, and recycled into the lower stage of the gasifier by N_2 gas. The gasifier enables steam to be injected from the lower stage to reduce oxygen consumption.

Cold gas clean-up is employed in order to satisfy the tolerance limits of fuel cells. Synthesis gas at a temperature of approximately 400C exits from the char filter and is heat-exchanged at the Gas/Gas Heater (GGH). Impurities such as halogens and ammonium are removed in a water scrubber, and the gas is then desulfurized in an absorber. Here, EAGLE employs methyldiethanolamine (MDEA) as the sorbent. Since MDEA has low absorptivity for carbonyl sulfide (COS), COS must be converted into H_2S in a COS converter in advance. The clean synthesis gas, which exits the MDEA absorber at approximately 40C, is heated to approximately 200C by a steam heater and GGH and supplied to the gas turbine. Part of the clean syngas is planned to send to the precise desulfurizer, where it is further desulfurized down to the tolerance limit of the fuel cell or below.

The gas turbine and generator are driven by burning clean synthesis gas in combusters. This supplies auxiliary power for the pilot plant. It is also designed so that air extracted from the gas turbine is supplied to the air separation unit which pressurized cryogenic separation method is employed. Surplus N_2 in the air separation unit is supplied to the gas turbine to reduce NO_x.

2.4 Char filter for EAGLE

The Char filter system is illustrated in Fig.4. This system is consisted of filter vessel (1.75m inner diameter, 7.48m height) which is separated by the tubesheet into clean/dirty compartments, blow back equipment and control and instruments devices. The synthesis gas at a temperature of approximately 400C and a pressure of approximately 2.5MPa is introduced into the vessel and is cleaned through the filter to cold gas clean-up.

The metal filter elements with fail safe fuse which are made of iron aluminide alloy are supported by the tubesheet and sealed. The outer diameter and length of the element are 60mm and 2,000mm respectively.

In order to remove the char captured on the outer surface of elements for continuous stable operation, a compressed nitrogen which is stored in the tank at a temperature of approximately 200C and a pressure of approximately 6MPa is automatically fed according to the pre-set condition (time duration or pressure drop across filter) through blow back valves and blow back nozzles in a reverse way. Then the char is removed from the elements to the hopper for extraction.

3. The reliability of filter material (CTF)

In the case of the filter breakage, a lot of dust including coarse particle is introduced into the gas turbine, which suffers severe damage. Thus, it is very important for the system design and maintenance to know the toughness and deterioration of the filter element.

The cordierite as filter material is considered to be stable under high temperature oxidized environment. However, it is reported that the micro-crack can be initiated by the growth of crystal grain and may weaken the body in the case of long use [13]. Moreover, the new phase might be produced by the alkali in the flue gas and then the micro-crack progressed by the reason of different thermal expansion rates between the phases [14] or the cordierite matrix could be strained [15]. Thus, the cordierite may not necessarily be stable under the flue gas environment including the corrosive agents such as alkali and/or sulfur.

The authors observed the used filter toughness decrease with the changed porosity. Then the possible deterioration mechanism was supposed that the corrosive components would attack chemically to the bonding portion in the body, which was considered to be dominant for the toughness. The specimen of the element was immersed in the H_2SO_4 solution selected as the corrosive agent. The increased porosity, the decreased thermal expansion ratio and the physical damage of the body were observed with the toughness decrease. Based on this result, the accelerated test with the gas flow of sulfur acid and/or alkali was examined to the filter material under the hot gas environment. In the case of 1% highly concentrated SO_2 gas flow (1,000h) and 100ppm SO_2 with 1% highly concentrated potassium gas flow (500h), the toughness reduction was observed with the increase of porosity and decrease of mean pore size.

The 8,000 hrs used filter was observed to be less than 4% toughness decrease compared with the virgin reference. The filter toughness decrease up to 20% would be allowed considering the stress occurred. Thus, it was estimated that the filter could survive more than several years under PFBC environment assuming linear correlation, though the other corrosive agents and the process upset must be taken into consideration. The AGC's cordierite ceramic tube filter can be applied for PFBC commercial use. Then it is desired that the proper maintenance will be periodically done, using the on site inspection tool developed by EPDC collaborated with AGC.

4. The improvement of seal mechanism (CTF)

Not only the toughness of filter material and the pressure drop stability but also the reliability of seal mechanism is very important for the hot gas cleaning system. As it is necessary to introduce coarser ash to CTF in order to stabilize the pressure drop across CTF, the gas turbine at the downstream of CTF can suffer serious damage if the dust leakage occurred caused by a poor seal mechanism [1].

The possibility of dust leakage from the joint portion of the ceramic and the metal is very much a concern, because of wider clearance during operation due to the big difference of both thermal expansion ratios. The seal mechanism between the ceramic and the metallic holder is illustrated in Fig.5. Though the various countermeasures were proposed for this problem, they were not enough. The dust leakage from both the support portion (metal/metal) and the joint portion (ceramic/metal) occurred at Wakamatsu site, however, the reliability for such seal mechanisms was much improved by the effective countermeasures.

Serious dust leakage was observed specifically for the joint portion between the ceramic filter material and the metallic holder, and was due to an unusual expansion of the clearance in between. Also the joint mat material was damaged by a process upset which carried over carbon that could burn and overheat the joint portion locally. The joint mat was changed to a material of a high thermal resistance and the gas passage resistance was also increased, by introducing a simple mechanism. Thus, it could be possible for the CTF to operate with less than 0.2mg/Nm^3 dust concentration at the outlet under PFBC condition.

5. The pressure drop performance (CTF)

The pressure drop performance across CTF is important for the system design and operation, however, it's very rare case to analyze the pressure drop behavior of the hot gas cleaning system (>800C) at the commercial size plant. In this chapter, the successful countermeasures for decrease and stabilize the pressure drop across filters and the pressure drop characteristic equation are reported.

The pressure drop across filters was confirmed to show that the original value was regained after the conditioning at every plant shutdown, even if unusually high and/or unstable pressure drop had been observed during operation [16]. This performance is most desirable feature for the hot gas cleaning system.

5.1 Reduced and statilized pressure drop across CTF

The pressure drop across filters was very high and unstable during Phase1 due to fine particle ash of 1-2 μm mean size, and then it was impossible to achieve long continuous run. The cyclone bypass line (Fig.6) that partially bypassed the seven primary cyclones was installed, based on the careful analysis for the ash particle size distribution. Then the mean particle size of CTF ash was coarsened up to approximately 10 μm (Fig.7). As the result, the pressure drop across the CTF was much reduced and stabilized, and thus an auxiliary power could be saved by 0.5% due to prolonged pulse cleaning interval [17]. The effect of coarser ash can be explained as a scratching of the surface of accumulated dust layer and less re-entrainment during pulse cleaning due to a formation of secondary particle adhering fines to the coarse one.

5.2 The pressure drop characteristic equation (CTF)

The pressure drop across the compartments (DPc) was continuously measured. It is believed that DPc does not include the drop ascribed to other equipment such as the SCB (Self Circulating Blow-down), the regenerator and the ejector. The minimum pressure drop for the compartment described as DP_{base} was observed just after the reverse cleaning. In contrast, the maximum value of DP_{max} was always obtained before the cleaning, and the pressure drop increase during pulse cleaning interval (DP_{own}) was defined as the difference of DP_{max} and DP_{base}. This study attempted to estimate DP_{base} and DP_{own} according to the D'Arcy law and Kozeny-Carman equation respectively, applying the calculated face velocity [16,18,19]. Thus, the pressure drop across A1 compartment was carefully observed and analyzed.

(1)Estimation for the base line pressure drop, DP_{base}

The base line pressure drop across the compartment (DP_{base}) can be estimated by applying D'Arcy law in both phases, using the calculated face velocity after cleaning the compartment ($V_{A1,1}$), the calculated gas viscosity and the corrected thickness/permeability ($\beta \times L/K$). Fig.8 plots the observed and calculated DP_{base}.

$$DP_{base} = V_{A1,1} \times \eta \times \{ L/K + L_i/K_i \} = V_{A1,1} \times \eta \times \beta \times L/K \qquad \cdots \text{Eq.1}$$

where $V_{A1,1}$: maximum face velocity of A1 soon after cleaning (m/s)
η : gas viscosity (Pa・s),
K : permeability across the conditioned filter material (m^2),
L : thickness of the conditioned filter material (m)
Ki: permeability across the residual dust layer during operation (m^2),
Li: thickness of the residual dust layer during operation (m)
β: coefficient (actual dust concentration/standard dust concentration)

(2) Estimation for the increasing rate of pressure drop during cleaning interval, dDPc/dt

The pressure drop increases with the increasing amount of trapped dust during the interval between reverse pulse cleaning. The reverse cleaning returns the pressure drop to the base value, which stays almost constant.

By assuming laminar flow through the layer of randomly packed ash without any spontaneous dust falling, the rate of increase in the pressure drop across the ash layer accumulated during the cleaning interval can be described by the differentiated Kozeny-Carmen equation in both phases.

$$dDPc/dt = 5(1-\epsilon) \times Sv^2 \times D \times \eta \times V_{A1}{}^2/\epsilon^3 \times \rho_s \qquad \cdots \text{Eq.2}$$

where ϵ : porosity, Sv : specific surface area (m^2/m^3),
D : dust concentration (kg/m^3),
η : gas viscosity (Pa·s),
ρ_s : true density of dust (kg/m^3)
V_{A1} : mean face velocity of A1 during the cleaning interval

$$= \{ \int_{interval} (\sqrt{\Delta P_{regenerator\ A1}})dt \;/ \sum_{i=A1}^{B3} \int_{interval} (\sqrt{\Delta P_{regenerator\ i}})dt \} \times G / A_{A1}$$

$$dL/dt = D \times V_{A1} / \{(1-\epsilon) \times \rho_s \}$$

Fig.9 plots the observed and calculated dDPc/dt, applying the calculated minimum face velocity ($V_{A1,6}$) instead of V_{A1}. As a simplification, it's also possible for estimating dDPc/dt, using the function of actual CTF dust concentration.

(3) Predicting the maximum pressure drop, DP_{max}

It is suggested that DP_{max} for A1 compartment can be predicted by using the calculated DP_{base} and dDPc/dt with applied reverse cleaning interval time (t) as the following equation:

$$\begin{aligned} DP_{max} &= DP_{base} + DP_{own} \\ &= f(\text{face velocity, gas viscosity, thickness/permeability, dust concentration}) \\ &\quad + dDPc/dt \times t \qquad \cdots \text{Eq.3} \\ &\quad + f(\text{dust concentration}) \quad (\text{as simplified}) \qquad \cdots \text{Eq.3'} \end{aligned}$$

where f(face velocity, gas viscosity, thickness/permeability, dust concentration) is basically derived from equation 1 using the maximum face velocity after the A1 compartment cleaned ($V_{A1,1}$) with corrected L/K by dust concentration and where dDPc/dt is also calculated by equation 2 using the minimum face velocity for the A1 compartment ($V_{A1,6}$).

The influence of ash particles in a particular size range must be considered in order to obtain better prediction of DP_{max} in future.

6. The optimum pulse cleaning condition (CTF)

The pressure drop across CTF is controlled to less than the allowable limit by the periodical pulse cleaning. So the pulse cleaning condition is the control parameters for the pressure drop. However, it’s very complicated to control four parameters due to the multiple compartments of the system.

Optimization of the pulse cleaning condition was not examined in the demonstration test operation at Wakamatsu due to time constraints. In this chapter, an outline of the optimum pulse cleaning condition by using the developed flue gas process simulator for Wakamatsu Phase2 system is reported.

6.1 The (reverse) pulse cleaning parameters

(1) Fast pulse cleaning valve open time: base parameter and fixed in the model
(2) Pulse cleaning pressure: base parameter and fixed in the model
(3) Pulse cleaning interval: control parameter
(4) Pulse cleaning mode: control parameter

6.2 The equivalent electric circuit model

The equivalent electric circuit model for the flue gas process from the PFBC boiler to the stack through Ash Re-circulating cyclones, CTF, GT and others was installed in the “PspiceO” (Cybernet co.), famous electric circuit simulation program. The CTF model was built based on the simplified equation for the pressure drop prediction (Eq.3’), considering the different characteristics for each compartments (upper, middle and lower).

The output from the simulator and the actual operating data were compared for the design coal and other two kinds of coal operation, which showed a good fit. Table 2 describes the observed and simulated pressure drops and their ratio during Blair Athol (BA) coal operation at 100% load.

6.3 The optimum pulse cleaning condition

The interval condition to minimize the utility consumption of pulse cleaning gas was simulated by changing the mode. This control mode was not tried during the actual plant operation, under the fixed conditions of valve opening time and pressure.

Min $Q(t) * 3{,}600 / T_{i,j}$ [kg/h}
s.t. $T_{i,j}$[s] {Pulse cleaning interval T_j at $Mode_I$ }
$DP_{total,\ max}$ (maximum pressure drop across CTF) < C : allowable limit

where,
Q(t) : utility for pulse cleaning / one pulse [kg/pulse]
$T_{i,j}$: interval time [s]

As the result, the optimum pulse cleaning condition to minimize the pressure drop across CTF and minimize the fluctuation of process pressure during cleaning was obtained.

It is possible this simulator which can optimize the pulse cleaning conditions for any kind of fuels could be applied for the purpose of system design, cost calculation and fuel selection.

Further, it’s also possible to use this simulator for a commercial plant design, by easily re-building the model fitting for the increased number of compartments and pressure vessels.

7. The plan of EAGLE project and the future perspective for hot gas cleaning

7.1 The plan of EAGLE project

The construction of EAGLE plant was completed and a coal supply has started in March 2002 following the plant commissioning. The development schedule of EAGLE project is attached as Table 3.

7.2 The future perspective for hot gas cleaning

The reliability of the filter element and seal mechanism, and the stability of the pressure drop, which are very important items of concern for the CTF under high-temperature (>650C) high-pressure PFBC environments, have been improved and verified. It’s concluded that CTF can be applied for PFBC commercial use, however, the optimum system design and further cost reduction are very much desired.

The higher system efficiency due to lower pressure drop than a system with multi-cyclones and the improved reliability of the equipment installed at the downstream due to very good performance were established by applying the reliable ceramic filter system. The PFBC combined with CTF can be operated with relatively lower running costs. The CTF would be one of the most effective measures if more severe environmental regulations, for example PM2.5, etc., were introduced [20].

Recently, the “dioxin” emission from an incinerator using refuse fuel has become a very serious problem. It may be possible to prevent “dioxin” transfer to the ash, that is difficult to treat, by separating the ash from the flue gas under high temperature at CTF. It was also reported that the candle type filter made of SiC was applied for IGCC process [3,21]. As an another possibility of a ceramic filter application, the catalyst mixtures in a filter and/or the powder injection before a hot gas filter system have been tested to eliminate pollutants in a flue gas [22]. Further, the establishment of this high temperature gas cleaning technology may encourage to develop a higher efficiency gas combined cycle plant and, therefore, an introduction to the world market would be accelerated.

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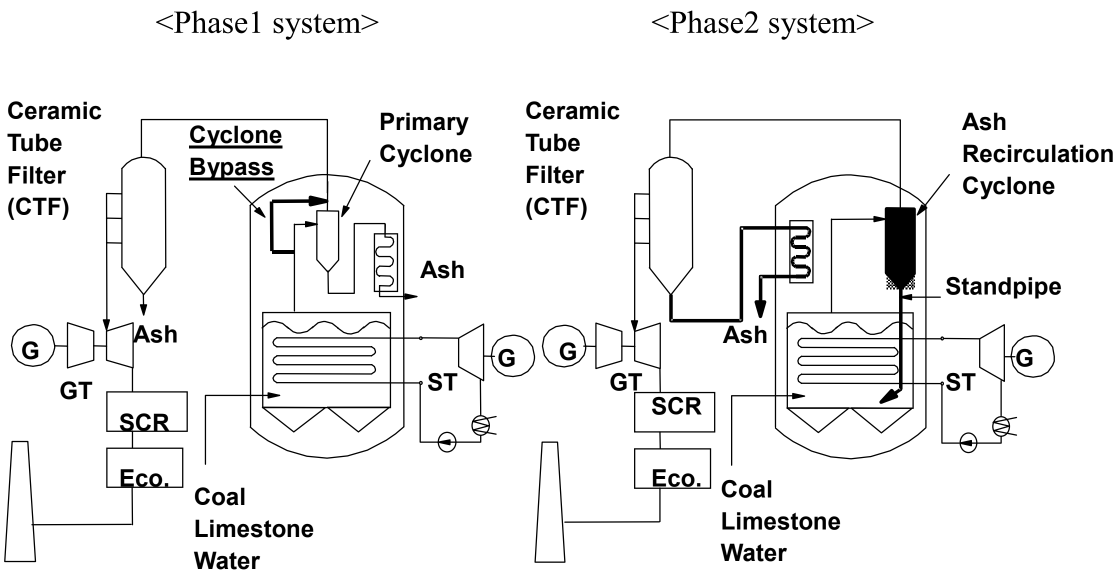

Fig.1 PFBC system flows (Phase1 and Phase2)

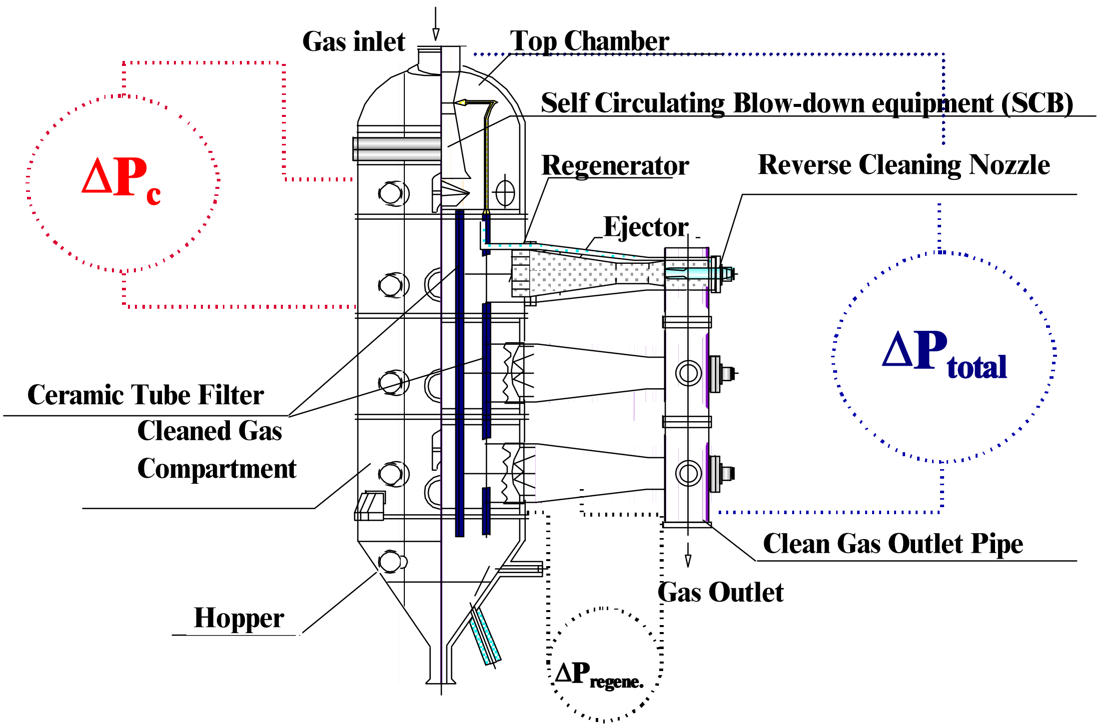

Fig.2 CTF flow diagram (for PFBC)

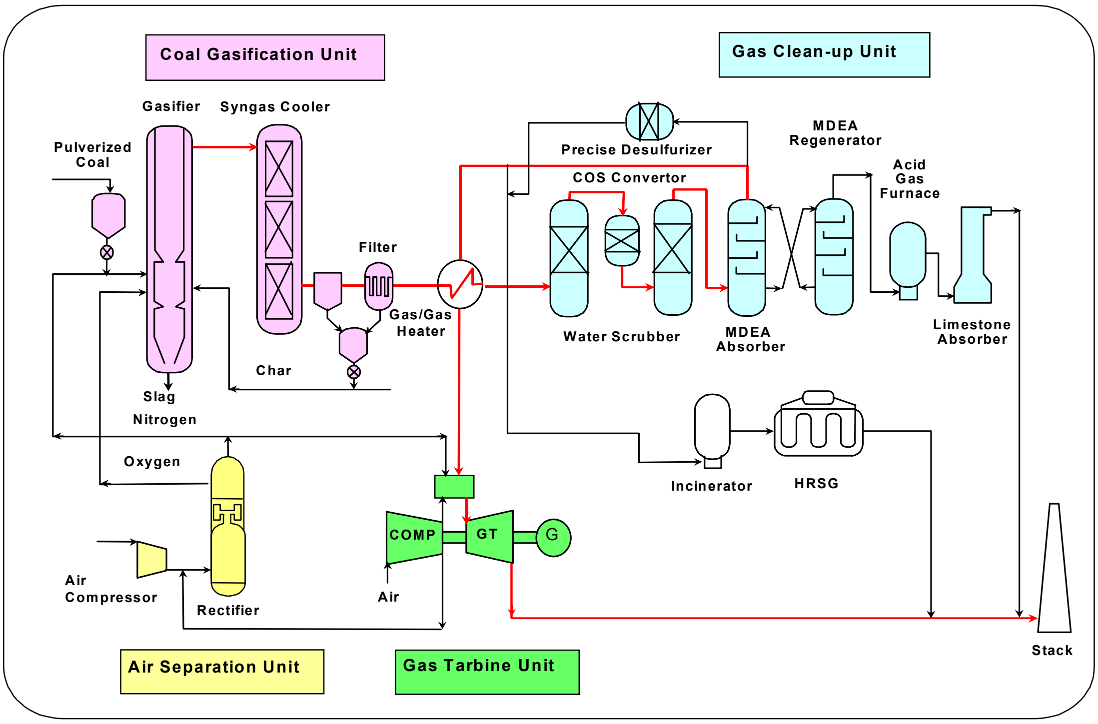

Fig.3 Flow diagram of the EAGLE pilot plant

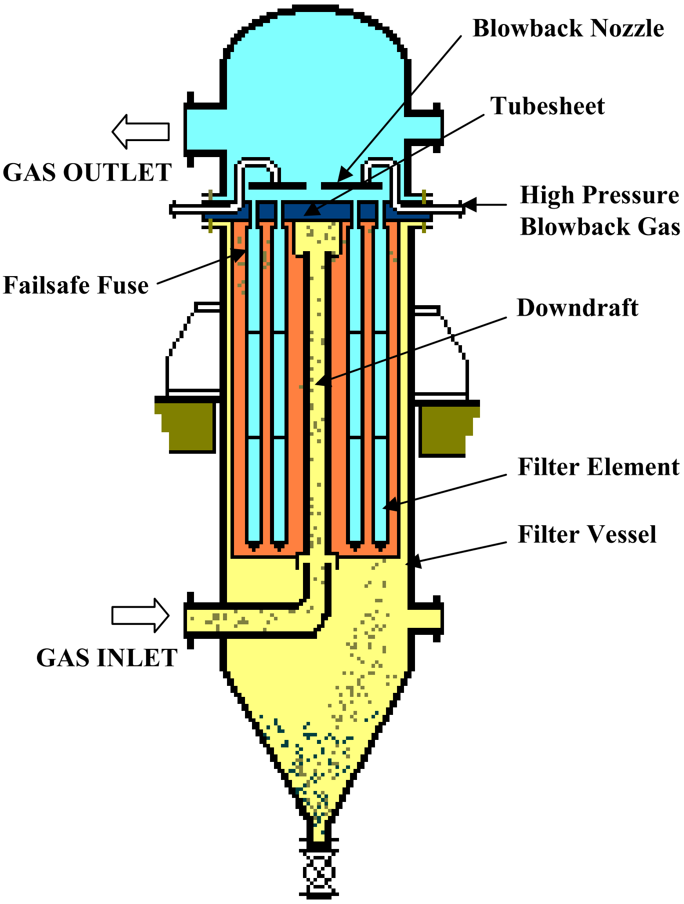

Fig.4 Char filter flow diagram (for EAGLE)

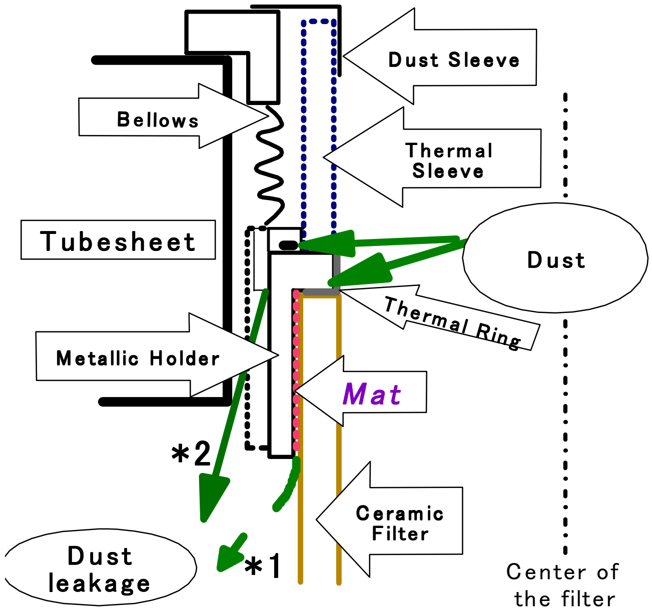

Fig.5 The CTF seal mechanism between the ceramic and the metallic holder

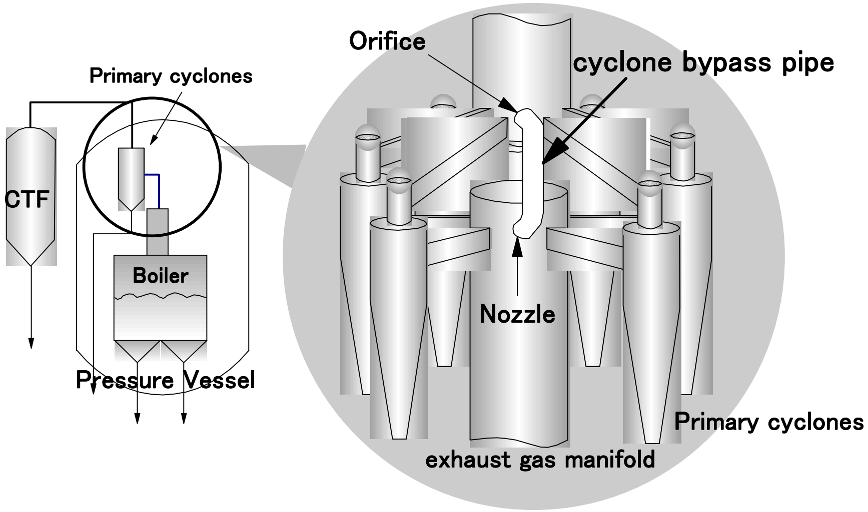

Fig.6 Cyclone bypass system during PFBC Phase1

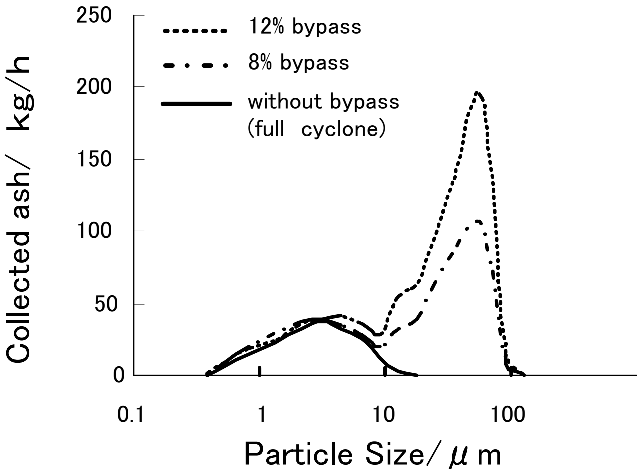

Fig.7 Ash particle size distribution during PFBC Phse1

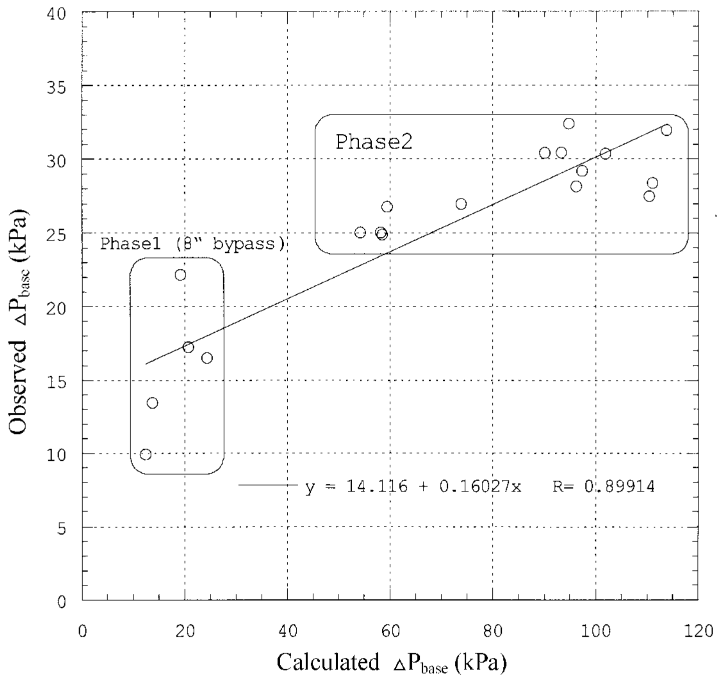

Fig.8 Observed and Calculate DP_{base} (CTF)

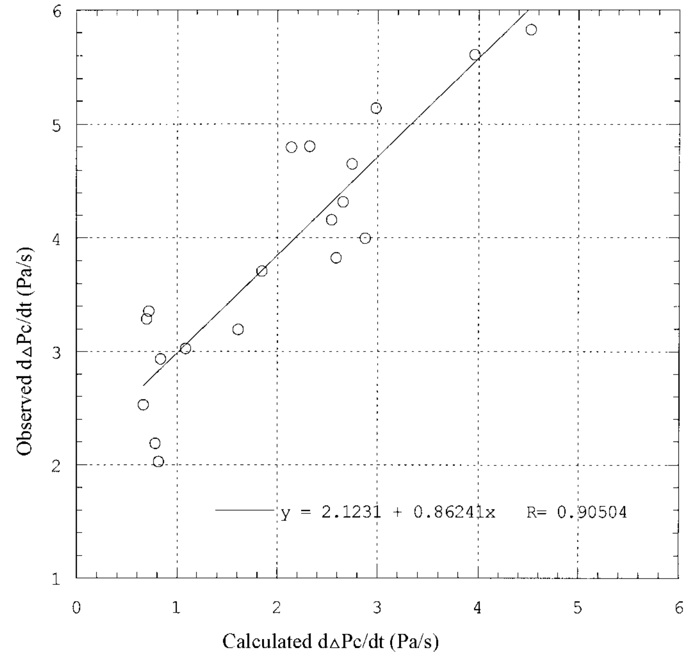

Fig.9 Observed and calculated dDPc/dt (CTF)

Table 1 EAGLE pilot plant specification

Coal gasification	Oxygen-blown entrained-flow gasifier (two-stage tangential flow type)
Coal feed	150 tons per day
Gasification pressure	26.5 ata
Gas clean-up	Cold gas clean-up using MDEA
Syngas volume	14,600 m^3 N/h (MDEA absorber outlet)
Sulfur recovery	Limestone-gypsum wet scrubbing
Air separation	Pressurized cryogenic separation
Oxygen production	4,300 m^3 N/h
Oxygen concentration	95 vol%
Air feed	20,000 m^3 N/h
Air feed pressure	13 ata
Gas turbine power	8,000 kW

Table 2 Observed and simulated pressure drop (DP_{base} and DPc) for CTF

Items		Observed	Simulated	Obs.／SIM
Press. Drop across CTF (DP_{total})	Maximum (KPa)	41.0	40.1	1.02
	Minimum (KPa)	38.5	38.0	1.01
	Mean (KPa)	39.8	39.1	1.02
Press. Drop across Compartment (DPc)	Maximum (KPa)	35.0	31.5	1.11
	Minimum (KPa)	28.0	28.1	1.00
	Mean (KPa)	31.5	29.8	1.06

Table 3 Development schedule of EAGLE project