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Demonstration of a KIER-Type CYBAGFILTER System at the Clinker Calcination Process

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Abstract−A high performance KIER-type CYBAGFILTER that combines a fabric filtration and centrifugal dust removal technology was developed to enhance the performance of conventional filtration systems. Based on the performance evaluation results obtained from a pilot-scale test and fluid dynamic computer simulation, a test CYBAGFILTER of 18,000 m^3/hr capacity was installed in the clinker calcination process of Ssangyong Cement Co. located at Yongwol, Korea. Membrane filters for surface filtration were applied and evaluated. After 12-month operation, the mean pressure drop was maintained at 70-80 mmH_2O, the collection efficiency was more than 99.8%, and the outlet dust concentration was less than 5 mg/Sm^3. With an operating pressure drop of 100 mmH_2O, the cleaning interval was much longer than that of conventional ones, promising the prolongation of filter life.

Key words: Cyclone, Bag Filter, CYBAGFILTER, Membrane Filter, Surface Filtration

INTRODUCTION

Dust particles, which are known to be among the most harmful air pollutants to the human body, are mostly generated from oil and coal combustion processes, wastes incinerators, and various manufacturing processes such as in the automobile, steel, and cement industries. In order to collect dust particles several types of dust removal devices such as fabric filters, electrostatic precipitators, cyclone collectors, and scrubbers have been used--none of which, however, can fully meet the recently reinforced air emission standards. Therefore, a hybrid type particulate collection technology consisting of more than two of these conventional removal technologies has been extensively studied [Frederick, 1980; Viner et al., 1988; Park, 1995; Helfritch and Quimby, 1991; Miller et al., 1997].

It is well known that fabric filtration gives high collection efficiency especially for fine particles compared to other dust removal methods. However, as shown in Fig. 1, a pre-dust collector such as the cyclone should be installed to reduce dust loading to the fabric filter in order to enhance the performance of the filtration system. Such an additional installation of a pre-dust collector requires additional space, cost, and sophisticated control, which is hardly acceptable.

Recently, as an alternative solution KIER has developed a newly designed particulate control unit, called a KIER-type CYBAGFILTER in this paper, that combines a centrifugal dust removal device, the so-called cyclone, and a fabric filtration system. Fabric bag filters are located at the top of the CYBAGFILTER with a cyclone at the bottom. This combination and configuration can generate 'three dimensional vortex flow' at the top of the collection chamber, which leads dust particles after dust cleaning operation to easily fall down to the bottom of the apparatus [Plucinski et al., 1989; Boericke et al., 1983].

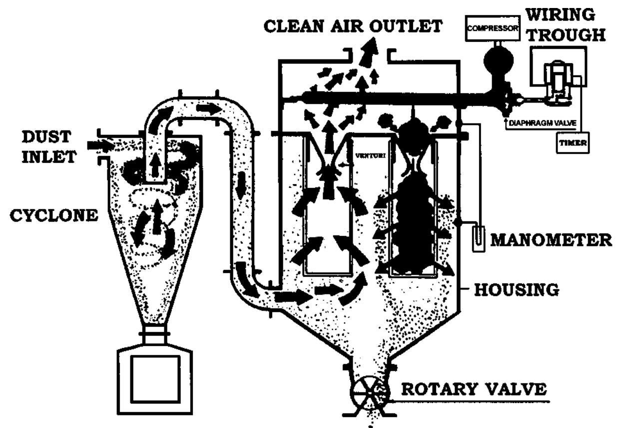

Fig. 1. Schematic diagram of a conventional bag filtration system.

In this study, for the purpose of optimal design, the flow patterns inside the CYBAGFILTER were simulated by using a computational fluid dynamics (CFD) commercial software. In order to establish the optimal operating conditions, additionally, the filtration parameters such as pressure drop, dust collection efficiency, outlet dust concentration, and fractional dust collection efficiency were

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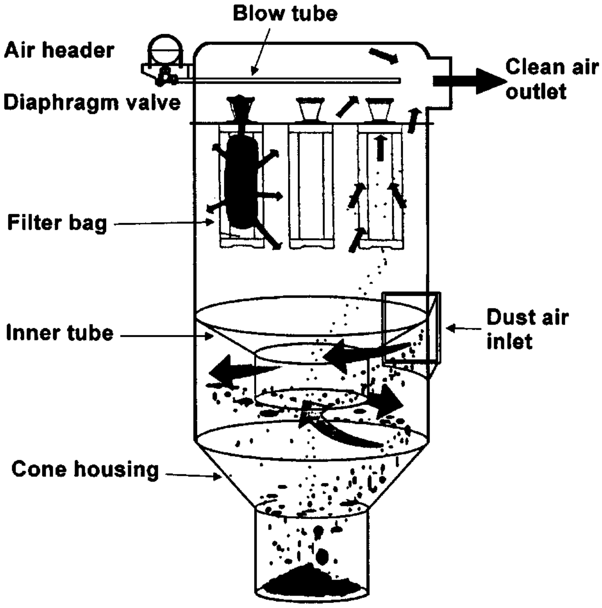

Fig. 2. Schematic diagram of KIER Type CYBAGFILTER system.

investigated based on the 12-month operation results from the CYBAGFILTER of 18,000 m^3/hr capacity installed in the clinker calcination process of Ssangyong Cement Co. located at Yongwol, Korea.

EXPERIMENTAL

1. Apparatus

As shown in Fig. 2, an inner tube was installed, which plays the role of the centrifugal outlet. The length, the diameter of the inner tube, and the angle between the inner and outer tube significantly affect the filtration performance, which has been confirmed in computational simulations and pilot-scale experiments [Kim et al., 1998, 1999; Park et al., 1999]. Based on those preliminary studies a demonstration unit of a CYBAGFILTER was installed at the Ssangyong Cement Yongwol Plant as shown in Fig. 3.

The test unit consists of dust air injection, main body, cleaning air supply, dust removal, and clean air outlet. The diameter of the CYBAGFILTER is 3,100 mm, its total height is 7,535 mm, and pulse-jet type cleaning method was applied. A fresh air damper was installed at the inlet of the test unit to prevent hot cement clinkers from directly entering into the test unit, which can be caused by abnormal operation. Whenever the inlet gas temperature goes up to a certain level, the damper will be open automatically and the fresh air will flow in. The cold fresh air will drop the temperature of the hot clinkers and eventually damage to the filter will be avoided.

Fig. 3. Photograph of CYBAGFILTER of 18,000 m^3/hr capacity.
(a) Magnification 773X (b) Size distribution.

2. Filter

Membrane filters were used for the test unit, which has been developed with the cooperation of KIER, Korea Vilene Inc., and Wooda Inc. Since the surface of the membrane filter is coated with

Table 1. Physical properties of membrane filter

Filter material	Polyester
Surface coating material	Acryl
Weight, g/m^2	570
Thickness, mm	2.0
Air permeability, cc/cm^2/sec	12-15
Tensile strength, kg/cm^2	MD: 90, CD: 240
Tensile strength, %	MD: 25, CD: 20
Bursting strength, kg_f	over 35
Heat resistance, °C	130
Pore size, mm	Max. 80 , Min. 60

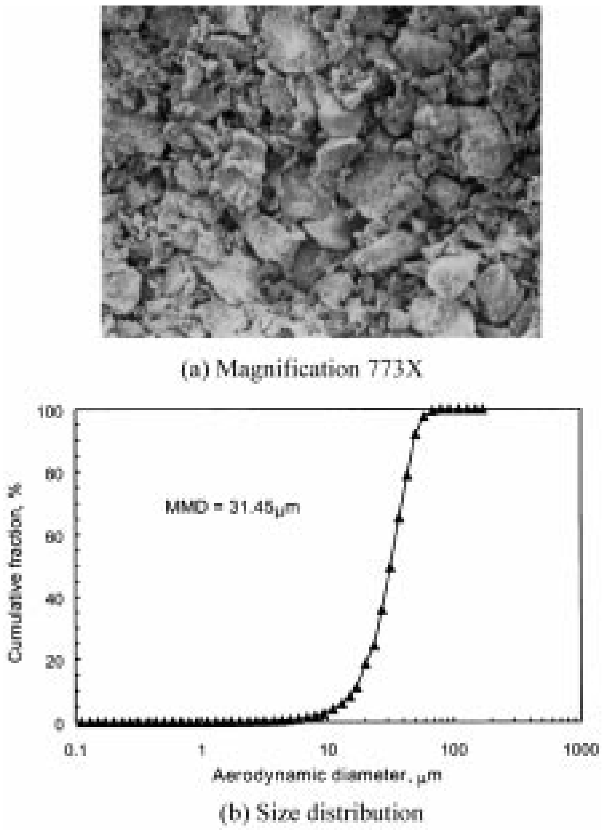

Fig. 4. Scanning electron microscope photograph and size distribution of clinker dust.
(a) Velocity magnitude (b) Velocity vector.

Table 2. Operating conditions for CYBAGFILTER

Volumetric flow rate at outlet temp., m^3/min	306
Outlet temp., °C	45
Air-to-cloth ratio, m^3/m^2	1.3
Pulse pressure, kg/cm^2	6
Pulse frequency, sec	51
Pulse time, msec	60

acryl or PTFE (Polytetrafluoroethylene, Teflon), it has microporous structure which will prevent fine particles from penetrating inside the filter; therefore, so-called 'surface filtration' will occur [Park et al., 1999]. Additionally, it has low pressure drop due to low resistance and its dust collection efficiency is above 99.9% [Brinchman et al., 1992; Son et al., 1998]. In this study acryl was used as a filter surface coating material and polyester was used as a support. Maximum operating temperature which the filter can endure is 120 °C. The diameter and length of bag filters are 156 mm and 3,300 mm, respectively. The test unit has 144 filters whose total area is 233 m^2. Physical properties of the filter are summarized in Table 1.

Fig. 4 shows a scanning electron microscope photograph and size distribution of the test dust which was generated during the transportation process of calcined clinkers. The mass median diameter (analyzed with API Aerozier) of clinker particles contained in the inlet gas was 31.45 μm. The mass concentration of clinker particles at the inlet and outlet was measured by using the Aerodynamic Particle Sizer (Model 3310A, TSI Inc.) and recorded by a data acquisition system. The collection efficiency and fractional dust penetration were calculated. The operating conditions are summarized in Table 2.

RESULTS AND DISCUSSION

1. Fluid Dynamics

The centrifugal, gravitational and inertial forces affect the flow pattern in a cyclone. The flow is a very complicated turbulent flow including strong vortex, turbulent boundary flow along the wall of the outer tube of severe streamlining curvature, flow separation at the edge of the tube slope, low Re flow, and vortex and separation at the wall of the inner tube. In order to simulate such a complicated turbulent flow more accurately, the RNG (ReNomalization Group theory based) k-ε model was employed instead of the general k-ε model. The RNG k-ε model includes the shear strain rate that the general k-ε does not have. The FLUENT/UNS™ Ver 4.2.8 code was used for computer simulation.

The magnitude and the vector field of velocity are shown in Fig. 5. A strong vortex is formed in the space between the inner and outer tube and the flow goes up along the vortex axis from the bottom. This flow merges with the flow going up from the inner tube wall to the upper outer tube wall; thus the velocity at this point will increase. The turbulent kinetic energy is also expected to be large in this area.

Fig. 6 shows the magnitude distribution of up-flow velocity. The whole areas except white-colored near the center axis represent the velocity field formed by the up-flow. The flow coming in from the inlet goes down with rotation by the centrifugal inertia, and at the slope of the cone it goes up with a vortex along the wall of the inner tube. The up-flow forms a strong vortex at the corner of junction to the outer tube wall. Such a flow pattern leads the dust particles to stay longer in the region, and consequently to settle down to the hopper. After passing the region, the up-flow changes its direction at the shell plate where the bag filters are mounted and it starts to go down with a vortex along the central axis. Most of bag filters are located in this down-flow region in which dust particles removed by cleaning fall down to the hopper more easily.

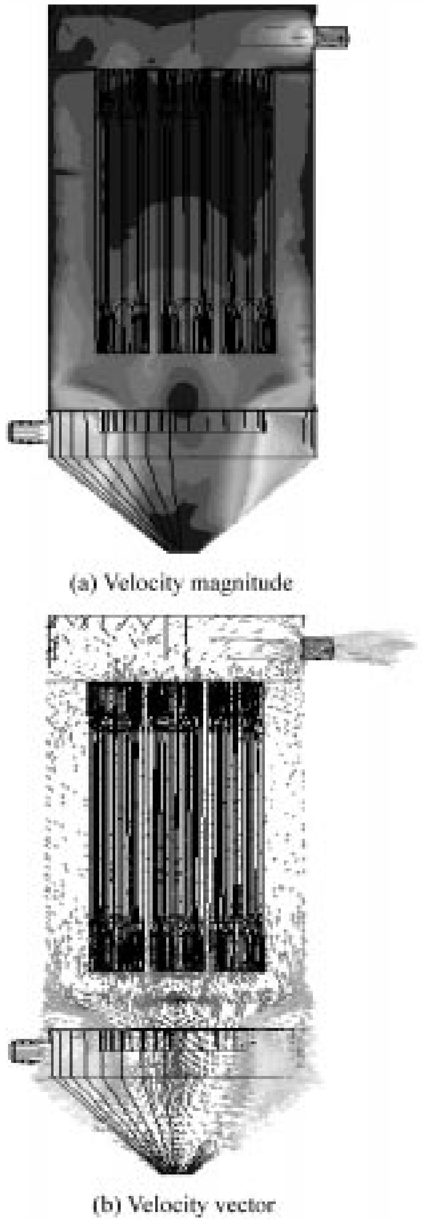

Fig. 5. Distributions of velocity magnitude and velocity vector.

Based on the above simulation results, the overall flow pattern inside the bag house is depicted in Fig. 7. At the initial stage it looks the same as a standard centrifugal dust collector, but after reaching to the shell plate a downward vortex flow along the central axis is formed.

2. Pressure Drop

The lifetime of bag filters depends on the cleaning interval. To

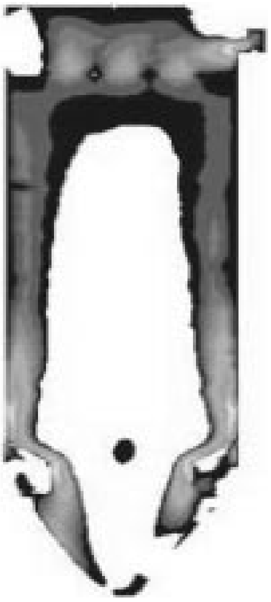

Fig. 6. Up-flow velocity magnitude characteristic distribution.

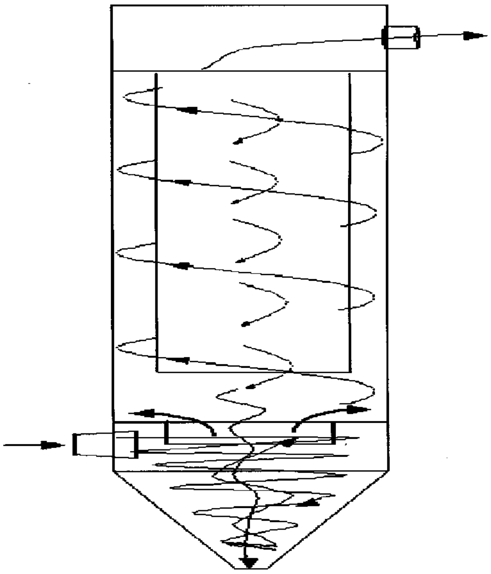

Fig. 7 Fluid dynamic of CYBAGFILTER.

prolong filter life the abrasion caused by the contact between the filter and the bag cage should be avoided by lengthening the cleaning interval. To accomplish this purpose the increasing rate of the pressure drop must be kept slow by minimizing the dust loading to

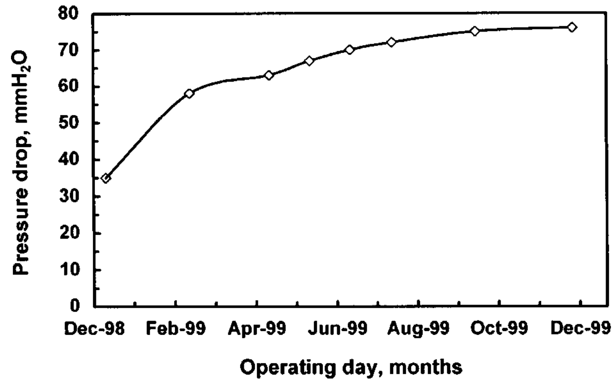

Fig. 8. The change of pressure drop along the test time.

the filter. In the case of CYBAGFILTER the filter life is expected to be much longer than that of a conventional fabric filter since 80% of the inlet dust is removed before entering the filtration part, that is, only 20% will be treated by filters.

Fig. 8 shows pressure drop characteristics of the test unit during 12-month operation. The pressure drop during the first one-month was low as 40 mmH_2O, after 7 months it was about 70 mmH_2O, after 12 months it was maintained around 80 mmH_2O. This is because the inlet dust loading was increased from 0.5 g/m^3 to 1.5 g/m^3 after Sept. 1999, which resulted in about 10 mmH_2O increase of pressure drop. This observation indicates that it took about 7 months to reach the steady state operating condition.

The performance characteristics of the conventional fabric filtration systems, which are installed at different industrial processes such as blast furnace, coke dry quenching, coke process, waste gas treatment, and plastic waste gasification, are listed in Table 3. This was measured and analyzed during 12 months [Son et al., 1995]. The pressure drop of the conventional filtration systems ranged from 100-210 mmH_2O, which is about 1.3-2.5 times higher than 80 mmH_2O of the CYBAGFILTER. As mentioned before, this is mainly due to low dust loading into filtration region compared to the conventional filtration systems. That is to say, 70-80% of the inlet dust loading is removed by the centrifugal cyclone in the lower part of the CYBAGFILTER; therefore, only 20-30% of the inlet dust loading reaches to the upper filtration part of the unit. Furthermore, membrane fabric filters were adopted to the CYBAGFILTER to prevent fine dust particles from penetrating, or depositing inside, the filters. That is another reason for the low pressure drop characteristics of the CYBAGFILTER.

From the above results, the CYBAGFILTER will prolong the filter life 2-3 times longer than conventional filtration systems for

Table 3. Performance characteristics of conventional fabric filter

Processes conditions	Blast furnace	Coke dry quenching	Coke process	Waste gas treatment	Plastic waste gasification
Face velocity (m/min)	1.0	1.4	1.5	0.5	1.2
Pressure drop (mmH_2O)	100	185	210	120	120
Inlet concentration (g/Sm^3)	0.3	-	-	-	0.5
Outlet concentration (mg/Sm^3)	10	26.5	15	20	51
Pulsing pressure (kg/cm^2)	4.5	7.0	7.0	6.0	6.0
Operating time (month)	12	12	12	12	12

the same cleaning pressure drop.

COLLECTION EFFICIENCY

Collection efficiency means the fraction collected by the filter of entering particles. The fabric filter is also characterized in terms of its penetration, the fraction of entering particles that penetrate the filter. Using the inlet and outlet particle concentrations, the collection efficiency and penetration of a filter can be calculated as follows.

$$P=\frac{C_{out}}{C_{in}}=1-E \tag{1}$$

where P and E represent penetration and collection efficiency, respectively. C_{out} is concentration at the outlet and C_{in} concentration at the inlet.

For the CYBAGFILTER tested in the present study, the inlet dust concentration was maintained at 0.5-1.5 g/m^3, and outlet concentration was about 0.1-5 mg/m^3. These values are very low compared to those of the conventional filtration systems shown in Table 3. The collection efficiency of the CYBAGFILTER, for the 12-month operation, is plotted in Fig. 9. As can be seen, the collection efficiency was about 99.75-99.92%.

FRACTIONAL PENETRATION

The fractional penetration is a very important parameter that can be used as data to predict the outlet concentration of a certain particle size. The fractional penetration of a filter is calculated as follows.

$$P_x=\frac{C_{o(x)}}{C_{i(x)}}=1-E_x \tag{2}$$

where P_x and E_x represent fractional penetration and fractional collection efficiency, respectively. $C_{i(x)}$ and $C_{o(x)}$ are the particle mass concentration of the specific particle size at the inlet and the outlet, respectively.

The most penetrating particle size (MPPS) is the particle size at which the maximum penetration occurs. Fig. 10 shows the fractional penetration measured since 1 year has passed from installing the unit. The MPPS was 1.04 μm where the penetration was 0.61%. For particles smaller than 0.7 μm and larger than 6 μm, the

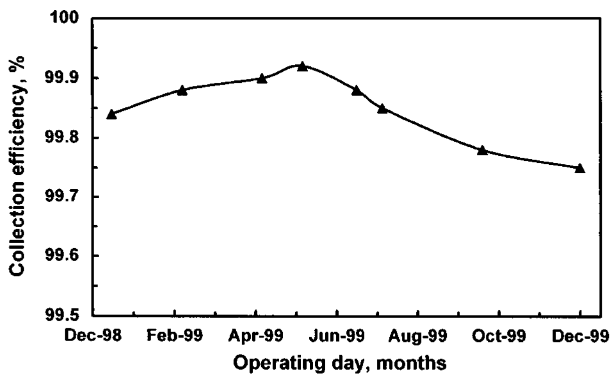

Fig. 9. The change of collection efficiency along the test time.

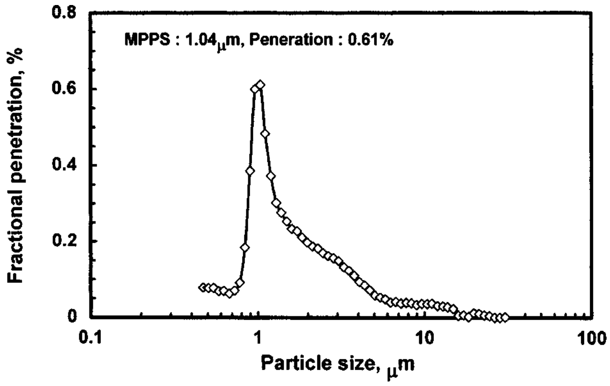

Fig. 10. Fractional penetration versus particle size.

penetration was less than 0.1%, which indicates almost 100% collection efficiency.

CONCLUSION

In this study a 12-month performance evaluation of the KIER-type CYBAGFILTER of 18,000 m^3/hr capacity installed in the clinker calcination process of Ssangyong Cement Co. located at Yongwol was conducted.

Conclusions drawn from this work are summarized as follows.

1. It was confirmed that the removed dust after cleaning falls down easily to the bottom of the CYBAGFILTER because rotating down-flow is formed along the axis as verified by the computational fluid dynamic simulation.

2. The pressure drop of the CYBAGFILTER after 12-month operation was kept as about 80 mmH$_2$O, which is 1.2-2.5 times lower than that of conventional filtration systems. This is because 70-80% of the inlet dust loading is removed by the centrifugal cyclone in the lower part of the CYBAGFILTER, so that only 20-30% of the inlet dust loading reaches to the upper filtration part of the unit. Therefore, the pressure drop is lower and the cleaning interval is longer than those of conventional filtration systems, which promises to prolong filter life.

3. Surface filtration of membrane bag filters applied into the CYBAGFILTER plays an important role in preventing fine dust particles from penetrating, or depositing inside, the filters.

4. It is expected that the CYBAGFILTER will play an important role for fine dust particle treatment as an alternative dust removal device to meet the gradually enforced dust emission regulations.

The CYBAGFILTER has a limitation of low capacity. In the future, therefore, a study should be done on the optimal design of the CYBAGFILTER module, which combines several CYBAGFILTERs in parallel to extend its capacity. The optimal CYBAGFILTER module should minimize the power usage and maximize its performance such as high collection efficiency and low pressure drop. Additionally, the centrifugal dust removal tube needs to be improved to avoid abrasion by the large particles with high velocity.

ACKNOWLEDGEMENT

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NOMENCLATURE

C_i, C_{out} : total mass concentration
$C_{i(x)}$, $C_{o(x)}$: fractional mass concentration of specific particle size
E : collection efficiency [-]
E_x : fractional collection efficiency [-]
P : penetration [-]
P_x : fractional penetration [-]

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