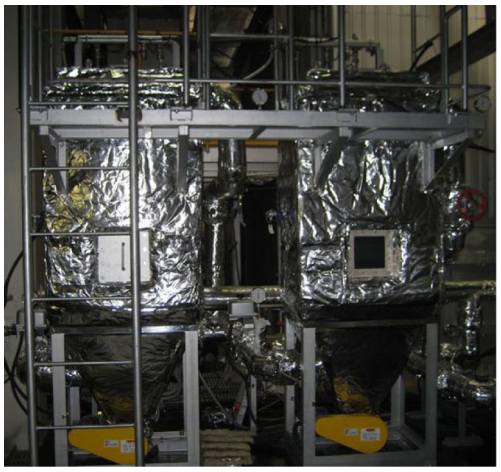
Basic Performance of HBF® (Hybrid Bag Filter) and Operation Reports for Incineration Plants



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Ahead of other competitors, MHI and Mitsubishi Heavy Industries Environmental & Chemical Engineering Co., Ltd. have developed and manufactured a practicable V-Ti catalyst-supported bag filter, the Hybrid Bag Filter® (HBF), which enables dust removal, De-HCl, De-SOx, De-NOx, and dioxins reduction (filtration, adsorption, catalytic decomposition) simultaneously. This paper describes the bench scale test results of the basic performance of HBF and also reports on the actual achievements of HBF, which prove that both pulse type HBF and reverse type HBF have very stable and favorable performance over long periods.

1. Introduction

Ahead of other competitors, we have successfully developed and manufactured[(1)-(5)] a practicable V-Ti catalyst-supported bag filter, the Hybrid Bag Filter® (HBF), which enables dust removal, De-HCl, De-SOx, De-NOx, and dioxins reduction (filtration, adsorption, catalytic decomposition) simultaneously, with achievements of practical use at 4 domestic and overseas incineration plants.

We have both pulse-type HBF, which has a higher filtration rate, and reverse-type HBF, which has a lower filtration rate.

Bag filters have been so far improved in the direction of lower temperature in order to meet the trend of tightening regulations for DXNs, Hg emission and in order to use $Ca(OH)_2$ more efficiently. A lower temperature, however, requires SGH (Steam Gas Heater) to need a lot of steam when a selective catalytic reactor is installed in later stages, thereby decreasing power generation efficiency and causing energy loss. It can, therefore, hardly be said that a lower temperature is advantageous from the viewpoint of the recent emphasis on the effective use of waste heat energy from municipal incinerators and lower Life Cycle Cost (LCC). It is important in the future to raise the temperature while maintaining DXNs removal performance.

This paper reports on the results of tests conducted from this viewpoint at MSW Incineration Plant A to evaluate the DXNs removal performance of a pulse-type HBF at a relatively high temperature (≧180°C).

Furthermore, examples of actually recorded achievements are also reported on the De-NOx and De-DXN removal performance under the long-term operation of a reverse-type HBF at MSW Incineration Plant B and the DXNs removal performance of a pulse-type HBF at MSW Incineration Plant C.

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2. Hybrid Bag Filter® (HBF)

HBFs are our original products, the functions of which have been enhanced by coating a catalyst on bag filter fibers with our unique technology to add gaseous dioxins (DXNs), VOC (DXNs precursor), and NOx reduction functions, while maintaining the conventional functions to remove other harmful substances.

That is, the HBF is an integrated flue gas treatment system for which the harmful substance removal function, necessary in disposing of exhaust gas from environmental equipment, is entirely integrated into a bag filter. **Figure 1** shows our HBF filter cloth and **Figure 2**, a conceptual diagram of the HBF functioning.

Figure 1 View of HBF filter cloth

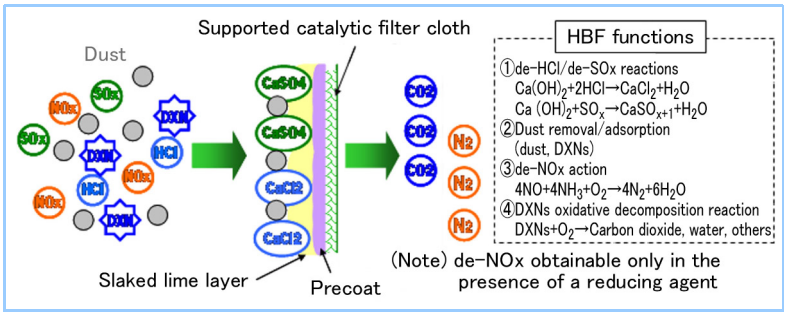

Figure 2 Schematic diagram of a catalytic bag filter

3. DXNs removal performance test

In order to investigate the above-mentioned DXNs removal performance of a pulse-type HBF at a relatively high temperature (≧180°C), the following tests were conducted, with raw gas branched off.

3.1 Test method

Tests were conducted in May – June 2010 at MSW Incineration Plant A (stoker-type, 150ton/day×3) as our delivery destination by introducing raw gas into small bag filter test equipment under normal operation. **Figure 3** shows a schematic of the test equipment. To separately evaluate the DXNs removal performance of the HBF surface sedimentary layer (dust layer) and the catalyst coated on fiber, a two-staged configuration was also tested. No. 1 is a bag filter (without any supported catalyst, hereinafter referred to as a normal BF) and No. 2, an HBF.

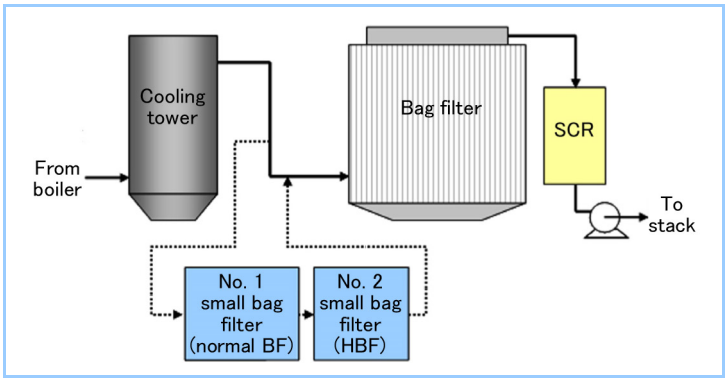

Figure 3 Schematic of test equipment

The mechanism of DXNs removal by an HBF may be based, as illustrated in Figure 2, on the removal (adsorption of gaseous DXNs and dust collection of solid-state DXNs) and catalytic oxidative decomposition reaction of gaseous DXNs that passed through the surface sedimentary layer. Taking the removal efficiency of the former as η_d and of the latter as η_c, HBF's total performance η_t is given from the following:

$$\eta_t = 1 - \frac{C_2}{C_0} = 1 - (1 - \eta_d) \cdot (1 - \eta_c)$$

In the Figure 3 test equipment, simultaneous measurement of DXN concentrations C_0, C_1, and C_2 at the entrance of No. 1 normal BF and of No. 2 HBF, and at the exit of No. 2 HBF, enables direct measurement of the DXNs removal efficiency ηd through the surface sedimentary layer and the DXNs removal efficiency η_c of the catalyst. Here, it has been confirmed beforehand that there is no difference in the DXNs removal performance obtained between the 2-stage bag filter (normally BF+HBF) and a 1-stage HBF, both marking 99.9% or more.

Table 1 shows the main specifications for HBF/BF. The amount of gas sucked in was kept constant by an inverter-controlling IDF (induced draft fan) while an automatic backwash was used at intervals.

3.2 Test conditions

Tests were conducted under the conditions of **Table 2**, taking the flue gas treatment condition at the real plant into consideration. In two-stage bag filter tests, the dust concentration of gas is of great importance when evaluating the DXNs removal performance of the surface sedimentary layer. These tests were believed to be performed in near-reality conditions because constant suction of about 3g/m^3_N during the test was observed.

The method of analyzing DXNs complied with JIS K 0311. Since the concentration of DXNs may be variable, sampling was made at one time.

Table 1 Main specifications for test equipment

Amount of gas	80-130m^3_N/h
Filtration rate	0.6-1.1m/min
Size of filter cloth	164 ϕ ×1.2m×6 strips
Backwash pressure	0.3MPa

Table 2 Test conditions

Temperature	180°C-220°C
Filtration rate	0.6-1.1m/min
Dust concentration	≒3g/m^3_N

3.3 Results and discussions

3.3.1 DXNs removal performance

Table 3 shows the test results. Here, values of removal performance η_t, η_d, and η_c were calculated from actual concentration measurements. Table 3 indicates that, under the conditions provided (filtration rate of 0.6m/min-1.1m/min, gas temperature of 180°C-220°C), independently from temperature and filtration rates, a DXNs removal performance of about 98-99% by adsorption/dust collection and of about 95-99% through oxidative decomposition of gaseous DXNs by the supported filter cloth catalyst, that is, as excellent as 99.9% or more in total, can be achieved.

As seen in Table 3, total HBF performance is less dependent upon gas temperature and the filtration rate. As mentioned above, the mechanism of DXNs removal with HBF consists of DXNs removal by adsorption and dust collection at the surface sedimentary layer growing on the filter cloth surface and oxidative decomposition of gaseous DXNs by the catalyst supported on the filter cloth. The lower the temperature, the more advantageous is the former, while the higher the temperature, the more advantageous is the latter. It is considered that, due to the combined effects of these, a high degree of DXNs removal could be achieved independently from the filtration rate and temperature.

Table 3 Results of tests on DXNs removal by HBF

Gas temperature (°C)	Filtration rate (m/min)	Performance of removal in surface sedimentary layer η_d(-)	Performance of oxidative decomposition by catalyst η_c(-)	Total HBF Performance η_t(-)	DXNs concentration at HBF exit	
					Actual measurement of concentration (ng/m^3N)	Toxicity equivalency concentration (ngTEQ/m^3N)
180	0.60	0.999	0.967	0.999	0.011	0.000014
	1.08	0.998	0.954	0.999	0.032	0.000015
200	0.69	0.993	0.978	0.999	0.027	0.000012
	1.06	0.996	0.987	0.999	0.014	0.00000081
220	0.63	0.981	0.980	0.999	0.110	0.00057
	1.09	0.977	0.990	0.999	0.090	0.0004

3.3.2 Pressure drop simulation of HBF

Along with the removal of harmful substances, the stability of the pressure drop is extremely important for a bag filter while in operation. Hence, the pressure drop of an HBF in operation was verified.

Figure 4 shows the measurement results of a pressure drop in a 24-hour continuous operation (backwash interval of 320min., backwash pressure of 0.3Mpa, filtration rate of 1.0m/min.). From these results, it was found that HBF could be used in safety because the pressure drop was always less than ΔP＝2kPa during continuous operation.

The behavior of the pressure drop at the real plant is, however, a little different from that of Figure 4 since test equipment was in a one-chamber operation while a multi-chamber is actually operated. Then, pressure drop simulation for a multi-chamber HBF operation was attempted in accordance with the basic data obtained from these tests.

Bag filter pressure drop ΔP is generally given by the following equation[6]:

$$\Delta P = \Delta P_f + \Delta P_d = (\xi_f + \xi_{d0} \cdot L_d) \cdot \mu \cdot u \qquad \cdots\cdots\cdots (1)$$

where ΔP_f is the pressure drop of the filter itself; ΔP_d, the pressure drop of the surface sedimentary layer; ξ_f, the resistance coefficient of the filter itself; ξ_{d0}, the specific resistance of the surface sedimentary layer; L_d, the dust loading; μ; the viscosity of flue gas; and u, filtration rate. L_d increases with time. However, the other parameters are constant if the temperature and filtration rate are constant.

Next, the pressure drop of a multi-chamber bag filter is examined.

If $\alpha_i = \xi_f + \xi_{d0} \cdot L_d$ is taken as No. 1 chamber's total resistance coefficient;

from equation (1), the entire pressure drop ΔP_f of the bag filter is expressed by equation (2)

$$\begin{aligned} \Delta P &= \alpha_1 \cdot \mu \cdot u_1 = \alpha_2 \cdot \mu \cdot u_2 = \cdots\cdots \alpha_8 \cdot \mu \cdot u_8 \\ &= \left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \cdots\cdots + \frac{1}{\alpha_8}\right)^{-1} \times (8u_m) \times \mu \\ &= R \times (8u_m) \times \mu \qquad \cdots\cdots\cdots (2) \end{aligned}$$

$$R = \left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \cdots\cdots + \frac{1}{\alpha_8}\right)^{-1} \qquad \cdots\cdots\cdots (3)$$

where u_m is the symbol of the average filtration rate and R, of the totalized resistance coefficient. That is, theoretically, if the average filtration rate u_m, totalized resistance coefficient R, and gas viscosity μ are known, it is possible to calculate the entire bag filter pressure drop ΔP.

From the data of Figure 4, ξ_f ＝1.21×10^9(1/m) and thenξ_{d0} ＝6.28×10^9(m/kg) can be obtained. Here, dust loading L_d(g/m^2) is approximated by:

$$\frac{dL_d}{dt} = C_d \times u \qquad \cdots\cdots\cdots (4)$$

where C_d is dust concentration (g/m^3_N).

The use of equations (1)-(4), therefore, permits a simulation of the pressure drop for a multi-chamber bag filter.

Figure 5 shows the above-based simulation results of a pressure drop for 8 chambers, gas volume≒62,000m^3_N/h (≒180t/d). This indicates how the pressure drop tends to stabilize with a growing surface sedimentary layer. A simulation calculation has found the bag filter pressure drop to stabilize somewhere around 11kPa. In other words, the finding is that even the HBF of a multi-chamber bag filter can operate stably at a pressure drop of 2kPa or less. But in the above-mentioned simulation, estimates may have been a little lower than actual performance, not taking into account the effects of clogging due to long-term operation, etc. At any rate, it is thought that a multi-chamber HBF operates stably at a pressure of 2kPa or less. In fact, no problems resulting from pressure drop (clogging) have occurred in later-described HBF achievements.

3.3.3 Hg removal

The removal of Hg was checked with this test equipment. The Hg concentration at No. 1 normal BF exit was 0.012mg/m^3_N, lower than the domestic voluntary regulation value (0.05mg/m^3_N).

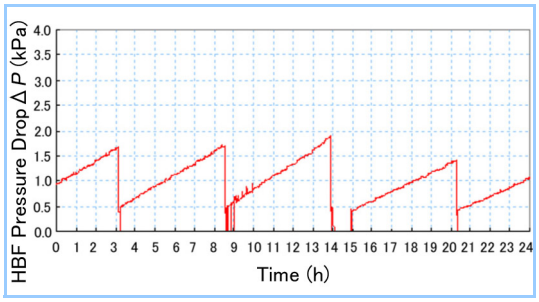

Figure 4 Pressure drop of an HBF in continuous operation (test result)

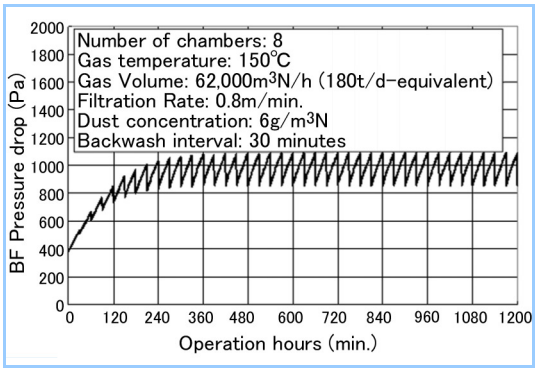

Figure 5 Simulation calculation of a multi-chamber HBF

4. Reverse-type HBF's achievements in long-term operation

MSW Incineration Plant B is a stoker-type facility to which we delivered equipment in the 1970s. This plant gradually updated its equipment from 2001, replacing electrostatic precipitators with HBFs, and now operates all three of its lines with an HBF. The HBF is a reverse-type integrated flue gas treatment system and is provided not only with de-HCl, de-Sox, and dust removal capabilities, but also with de-NOx and de-DXN (**Table 4**). As a reducing agent for de-NOx, NH_3 is supplied from upstream HBF.

Table 5 shows flue gas treatment performance measurement data as of 2009 (about three years after HBF operation started). This indicates that, even after three years of operation, not only de-HCl, de-SOx, and dust removal, but also de-NOx and de-DXNs capabilities remain favorable. With respect to de-NOx in particular, even if NH_3 was supplied at the stoichiometric ratio of some 0.6, the reaction efficiency at the HBF was favorable at nearly 100% at that time. Furthermore, DXNs emission has been significantly reduced by catalytic decomposition to become considerably lower than the domestic law's regulatory limits, proving the same effects to those of active carbon powder supplying.

Table 4 Main specifications for MSW Incineration Plant B HBF

Gas temperature (°C)	210-230
Filtration rate (m/min)	0.3
Type of catalyst	V-Ti catalyst

Table 5 MSW Incineration Plant B flue gas treatment performance measurement results

Item to be analyzed	HBF exit
Dust concentration (g/m^3_N)	Less than 0.001
HCl concentration (ppm)	1.1
SOx concentration (ppm)	Less than 1.0
NOx concentration (ppm)	39
NH3 concentration (ppm)	Less than 1.6
DXNs ($ng\text{-}TEQ/m^3_N$)	0.000078

*Everything except NH_3 is 12% oxygen-equivalent.

5. Pulse-type HBF achievements

MSW Incineration Plant C is an overseas facility to which we delivered equipment in 2000 and where normal bag filters were upgraded to HBFs in 2003. The flue gas treatment equipment in this plant is an electrostatic precipitator installed upstream of the HBF.

Table 6 shows the main specifications for HBFs at MSW Incineration Plant C and **Table 7**, the results of DXNs removal performance. According to these specifications, a sufficiently high DXNs removal efficiency has been acquired even by pulse-type HBFs for which the filtration rate is relatively fast (no de-NOx carried out).

Table 6 Main specifications for HBFs at MSW Incineration Plant C

Temperature (°C)	180
Velocity of flowing filtered fluid (m/min)	About 1.1

Table 7 MSW Incineration Plant C HBF DXN removal performance measurement results

Item to be analyzed	HBF exit
DXN ($ng\text{-}TEQ/m^3_N$)	0.0054

6. HBF effects of reducing CO_2 and LCC

As mentioned above, since the employment of our HBF allows DXNs to be removed more efficiently – even at relatively high temperatures – than by normal bag filters, it is not necessary to lower the bag filter operating temperature (to about 165°C). That is to say, the amount of steam used by flue gas heaters (SGHs) can be reduced and excessive steam may be diverted to private power generators. Hence, this section estimates how much LCC can be improved.

A case where an HBF (200°C) replaced a low-temperature bag filter (165°C) was estimated (**Figure 6**). **Table 8** shows the results of a comparative LCC calculation. As seen from this table, since an increase in bag filter temperature builds up $Ca(OH)_2$ consumption but activated carbon need not be used and the temperature width required for reheating treated gas is lessened (ΔT = 165°C→200°C to ΔT =200°C→210°C), steam could also be diverted to power generators. At the same time, the amount of water injected at the cooling tower can be made smaller by raising the bag filter temperature for a smaller volume of gas to lessen the loads on the IDF (induced draft fan).

The results showed that the LCC of flue gas treatment equipment and its surroundings as a whole could be lowered by 27.5% (by our comparison).

Furthermore, in this case, a 7.4% decrease in power consumption comes from the reduced amount of IDF power consumption and the increased power generation. If this is calculated, using the consumed/generated power-related CO_2 conversion factor in the "Manual for Improvement of Essential Equipment at a Waste Treatment Facility[7]," 7.4% fewer CO_2 emissions (by our comparison) also occurred.

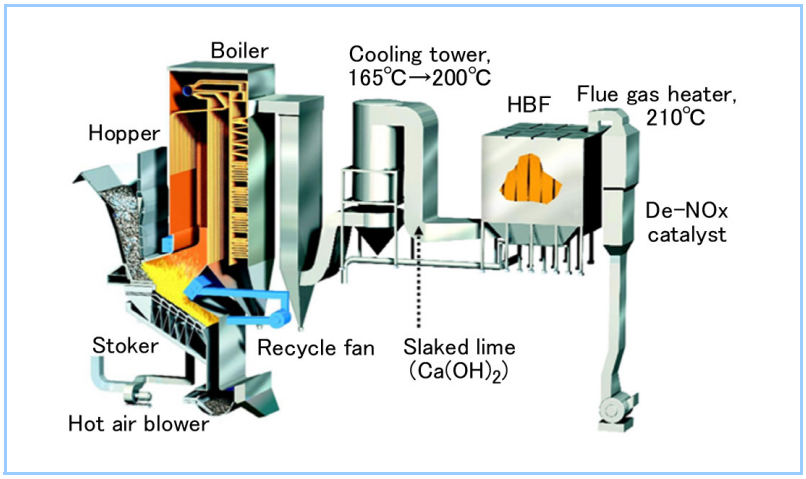

Figure 6 Example of a substituted system with HBF

Table 8 Results of comparative calculation

	Items for comparison	Low-temperature bag filter (165°C)	HBF (200°C)
①	Amount of active carbon used (%)	100	0
②	Amount of slaked lime used (%)	100	130
③	Amount of special reagent (%)	100	100
④	Filter cloth durability (life)	100	100
⑤	IDF consumed power (%)	100	97
⑥	Amount of power generated (%)	100	104
⑦	Flue Gas treatment equipment-related cost (%)*1	100	72.5

*1: Cost for ①-⑥

7. Conclusion

DXNs degradation tests by a HBF were carried out as well as to surveys of performance at an actual plant and the following results were obtained:

(1) Raw gas tests with a small HBF found pulse-type HBFs achieve an extremely high DXNs removal efficiency (99.9% or more) even under relatively high-temperature operating conditions (180-220°C, 0.6-1.1m/min). The pressure drop of the equipment in operation was also found to be stable.

(2) As for reverse-type HBFs, it was found at an actual plant that de-NOx and de-DXNs performance remained favorable enough even after three years of operation.

(3) Pulse-type HBFs also maintained reasonably high DXNs removal performance at an actual plant.

(4) Our estimations found that the use of an HBF could improve the the flue gas treatment equipment by about 27.5% (by our comparison).

(5) Our estimations found the use of an HBF could reduce CO_2 emissions from the flue gas treatment equipment by about 7.4% (by our comparison).

We found that our developed HBF, regardless of whether a reverse- or pulse-type HBF, could remove harmful substances with high efficiency. It can be said that HBFs are quite excellent in terms of effective energy utilization and CO_2 reduction as well, since they are capable of removing enough DXNs to lessen the amount of steam for flue gas reheaters and the quantity of active carbon blown in as an anti-DXNs measure.

The future is expected to be more lower-carbon/higher-efficiency power generation-oriented as well as lower LCC-oriented, moving toward the establishment of a recycling society, and HBFs may be highly effective technology, not only for newly built incinerators, but also for retrofits.

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