

## METHOD FOR TREATING ACIDIC GAS

## TECHNICAL FIELD

The present invention relates to a method for treating a  
5 harmful acidic gas, such as hydrogen chloride or sulfur oxide,  
occurring in a burning facility such as a municipal waste  
incinerator, an industrial waste incinerator, a power boiler, a  
carbonization furnace, or a private factory. Specifically, the  
present invention relates to a method for efficiently  
10 controlling the addition amount of an alkali agent for treating  
an acidic gas.

## BACKGROUND ART

An exhaust gas containing a harmful hydrogen chloride or  
15 sulfur oxide is treated with an alkali agent such as lime  
hydrate or sodium bicarbonate, then subjected to dust removing  
with a dust collector such as a bag filter (BF), and then  
discharged through a stack. The fly ash collected by a dust  
collector contains harmful heavy metals such as Pb and Cd and  
20 is therefore subjected to stabilization of these harmful heavy  
metals and then sent to landfill disposal.

Sodium bicarbonate pulverized into powder of 5 to 30  $\mu\text{m}$   
as an alkali agent for treating acidic gases has high  
reactivity compared to lime hydrate and can stably treat acidic  
25 gases, and the unreacted portion thereof is small to reduce the  
landfill disposal amount. Thus, sodium bicarbonate is an  
effective means for reducing the environmental load. As a

method for treating heavy metals, insolubilizing treatment with a chelate such as diethyldithiocarbamate is typical. This method shows high effect of fixing heavy metals in a short-term, but has a problem of re-elution of heavy metals, such as lead, by a reduction in pH due to acid rain and self-oxidation decomposition of the chelate at a final disposal site. On the other hand, in fixation of heavy metals by a phosphate compound such as phosphoric acid, a change into an inorganic mineral, i.e., into a hydroxy apatite form, is caused. The fixation is therefore excellent in long stability at a final disposal site and is a very valuable treatment method from the viewpoint of environmental protection. Furthermore, the method for treating the fly ash, treated with a sodium bicarbonate powder, with a heavy metal-fixing agent such as phosphoric acid is an effective means having an effect of reducing various environmental loads.

Meanwhile, control of the addition amount of an alkali agent such as lime hydrate or sodium bicarbonate for treating an acidic gas such as hydrogen chloride or sulfur oxide can be expected to show not only an effect of reducing the cost of acidic gas treatment but also effects of reducing the unreacted portion of the alkali agent and reducing the landfill disposal amount of fly ash.

The addition amount of the alkali agent for treating an acidic gas such as hydrogen chloride or sulfur oxide is usually feedback controlled with a PID controller based on the hydrogen chloride concentration measured with a hydrogen chloride-

measuring device of an ion selective electrode system disposed downstream of a bag filter. Unfortunately, burning facilities such as incineration facilities are usually not provided with devices for measuring acidic gas concentrations at the inlets, and the control output is adjusted by setting a parameter for PID control under the conditions not considering any variation at the inlet is unknown. However, a PID controller involves five setting items: P, I, D, lower limit of addition amount (output), and upper limit of addition amount (output), and determines the control output value by combining the setting values of each item. Consequently, a large amount of time is required to investigate appropriate control of the addition. Accordingly, in many facilities, the control by a PID controller is usually set such that the addition amount is considerably increased responding to a hydrogen chloride concentration exceeding a control set-point value (SV).

However, a common PID controller can set only a single control output upper limit. For example, when the control set-point value (SV) of the HCl concentration is set to 40 ppm, an alkali agent is added in an amount not exceeding the upper limit of the control output when the concentration of HCl becomes 40 ppm or more, which causes excessive addition of the alkali agent. The feedback control is affected by a measurement lag of an acidic gas-measuring device. The concentration of hydrogen chloride at the outlet of a bag filter is usually measured by an ion electrode method (for example, using HL-36 manufactured by Kyoto Electronics

Manufacturing Co., Ltd.). The concentration of sulfur oxide is measured by an infrared absorption method (for example, using NSA-3080 manufactured by Shimadzu Corporation). Accordingly, a long measurement lag of about 5 to 10 minutes, including the sampling time of an exhaust gas sample and the response time of the measuring instrument, is caused. This measurement lag causes a lag in the addition time of an alkali agent and leads to a failure in the treatment of acidic gases and causes excessive addition of the alkali agent.

In order to solve the problems, various control procedures have been investigated. Patent Literature 1 proposes "P + PID control" in which P is further performed in addition to usual PID control system. This is proposed as a countermeasure against sudden occurrence of an acidic gas that is difficult to be controlled by usual PID control. Patent Literatures 2 and 3 propose control systems performing both feedforward control for determining the addition amount of an alkali agent based on the acidic gas concentration at the inlet and feedback control for supplementing the addition amount of the alkali agent based on the acidic gas concentration after the treatment with the alkali agent. This control system is expected to show an effect of preventing excessive addition by feedback control and is believed to achieve stable treatment of acidic gases and have an effect of reducing the excessive addition of an alkali agent.

Patent Document 2: Japanese Unexamined Patent  
Application, Publication No. H10-165752

Patent Document 3: Japanese Unexamined Patent  
Application, Publication No. 2006-75758

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## DISCLOSURE OF THE INVENTION

### Problems to be Solved by the Invention

The control in Patent Literature 1 can respond to a sudden increase at the inlet to some extent, but the measurement lag of the measuring device is not considered. Consequently, the control cannot respond to the failure in the treatment of acidic gases due to a lag in the addition of an alkali agent caused by the measurement lag. In order to conduct the control systems of Patent Literatures 2 and 3, since many of burning facilities such as incineration facilities measure the concentrations of acidic gases only at the outlet, an additional expensive acidic gas-measuring device is required to be introduced for measuring the concentrations of acidic gases at the inlet.

By taking the conventional problems into consideration, it is an object of the present invention to provide a method for treating an acidic gas by a feedback system that does not require introduction of an additional expensive acidic gas-measuring device, while preventing the occurrence of the acidic gas due to a measurement lag involved in conventional feedback control and preventing excessive addition of the alkali agent.

### Means for Solving the Problems

(1) A method for treating an acidic gas, comprising feedback control of the addition amount of an alkali agent on the basis of a measurement signal from an acidic gas-measuring device set in a step after addition of the alkali agent to an acidic gas contained in a combustion exhaust gas, is characterized in that the method comprises a step of setting at least two ranges of acidic gas concentration slope (for example, a positive range and a negative range of the 6-second average of the latest HCl concentration slope described below); a step of setting a control set-point value of the acidic gas concentration for each of the at least two ranges of the slope (for example, 30 ppm and 40 ppm as in Example 1 described below); and a step of calculating a control output value indicating the addition amount of the alkali agent based on at least the measurement signal and the control set-point value, wherein in the step of setting a control set-point value, the control set-point value when the range of the acidic gas concentration slopes is large (for example, when the 6-second average of the latest HCl concentration slope is a positive range (in an acidic gas increasing tendency) described below) is set to be lower than the control set-point value when the range of the acidic gas concentration slopes is small (for example, when the 6-second average of the latest HCl concentration slope is a negative range (in an acidic gas decreasing tendency) described below).

In conventional PID control, for example, when the control set-point value (SV) of an acidic gas concentration is

set to 40 ppm, the control output increases after the concentration reached 40 ppm, and an alkali agent is then added. The alkali agent added reacts with the acidic gas to reduce the acidic gas concentration to 40 ppm or less, and thereby the control output decreases. Accordingly, the tendency in fluctuation of the acidic gas concentration is not considered.

In contrast, in aspect (1), since the control set-point value of the acidic gas concentration in an acidic gas increasing tendency is lower than the set-point value of the acidic gas concentration in an acidic decreasing tendency. The control output value of the alkali agent addition amount in the acidic gas increasing tendency is larger than the control output value in the acidic gas decreasing tendency.

(2) In the method for treating an acidic gas according to aspect (1), the method further comprises a step of setting one or more additional upper limits (for example, the control output addition amounts in Fig. 15, 17, or 19 described below) of the control output value in response to the acidic gas concentration (for example, the HCl concentration at the BF outlet in Fig. 15, 17, or 19 described below) between a lower limit (for example, LO [control output lower limit] (minimum addition amount of a sodium bicarbonate powder) in Fig. 15, 17, or 19 described below) and an upper limit (for example, LO [control output upper limit] (maximum addition amount of a sodium bicarbonate powder) in Fig. 15, 17, or 19 described below) of the control output value indicating the addition

amount of the alkali agent.

A Common PID controller can set only a single control output upper limit. For example, if the control set-point value (SV) of an acidic gas is constant, an alkali agent is  
5 added with the upper limit of the control set-point value as the limit, regardless of the level of the acidic gas concentration, resulting in occurrence of excessive addition. In contrast, in aspect (2), a restriction on the control output depending on a current acidic gas concentration (in a step  
10 control system described below) allows appropriate addition of an alkali agent depending on the level of the acidic gas concentration and allows a reduction of the addition amount.

(3) In the method for treating an acidic gas according to aspect (1) or (2), the acidic gas-measuring device is a  
15 hydrogen chloride concentration-measuring device in accordance with an ion electrode method.

(4) In the method for treating an acidic gas according to any one of aspects (1) to (3), the acidic gas-measuring device is a sulfur oxide concentration-measuring device in accordance  
20 with an infrared absorption method or an ultraviolet fluorescence method.

The acidic gas-measuring device used in the present invention can be operated regardless of the measuring system. The hydrogen chloride concentration can be measured by, for  
25 example, an ion electrode method or single laser absorption line spectroscopy. The sulfur oxide can be measured by, for example, an infrared absorption method or an ultraviolet

fluorescence method. Since the main object of the present invention is to reduce the measurement lag of an acidic gas, the invention is particularly effective in facilities performing feedback control by measuring an acidic gas downstream of the bag filter, accompanied by a long measurement lag, with a hydrogen chloride-measuring device in accordance with an ion electrode method or a sulfur oxide-measuring device in accordance with an infrared absorption method or an ultraviolet fluorescence method.

In addition, feedback control by measuring the hydrogen chloride concentration downstream of the bag filter in burning facilities by a laser system not involving a measurement lag has a possibility of preventing excessive addition due to feedback control. Unfortunately, the laser system has a technical problem of prohibiting JIS certification and has not been conventionally spread as a measuring device for determining the acidic gas concentration in a final exhaust gas.

(5) In the method for treating an acidic gas according to any one of aspects (1) to (4), the acidic gas concentration slope for setting the control set-point value is an average value within the latest 7 minutes.

The acidic gas concentration slope for setting the control set-point value is desirably an average value within the latest 7 minutes. The use of an average value of acidic gas slopes within the latest 7 minutes allows appropriate selection to stably treat the acidic gas.

(6) In the method for treating an acidic gas according to any one of aspects (1) to (5), the addition amount of the alkali agent is controlled using a control output calculated from a hydrogen chloride concentration and a control output  
5 calculated from a sulfur oxide concentration.

In many burning facilities such as industrial waste incinerators and private factories, high concentrations of hydrogen chloride and sulfur oxide occur. On such cases, both hydrogen chloride and sulfur oxide are the objects to be  
10 treated. Both acidic gases, hydrogen chloride and sulfur oxide, can be stably treated by, for example, adding the control output calculated based on the sulfur oxide concentration to the control output calculated based on the hydrogen chloride concentration determined by a hydrogen  
15 chloride concentration-measuring device disposed downstream of the bag filter.

(7) In the method for treating an acidic gas according to any one of aspects (1) to (6), the alkali agent for treating an acidic gas is a sodium bicarbonate powder having an average  
20 particle diameter of 5 to 30  $\mu\text{m}$ .

The alkali agent used in the present invention is preferably a sodium bicarbonate powder having an average particle diameter adjusted to 5 to 30  $\mu\text{m}$ , which particularly shows rapid reactivity with an acidic gas. The sodium  
25 bicarbonate powder shows rapid reactivity and therefore has high control responsiveness, which allows the performance of the present invention to be effectively exhibited. However,

the present invention is involved in a control procedure and can be also applied to lime hydrate. Lime hydrate having a specific surface area showing high reactivity with an acidic gas, for example, a high specific surface area of 30 m<sup>2</sup>/g or more can achieve the performance of the present invention.

#### Effects of the Invention

According to the present invention, in a feedback system that does not require introduction of an additional expensive acidic gas-measuring device, a failure in treatment of an acidic gas due to a measurement lag involved in conventional feedback control by an acidic gas-measuring device and excessive addition of an alkali agent are reduced, and it is possible to stably treat an acidic gas by efficiently adding an alkali agent.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating a structure of acidic gas treatment system 1 of adding a sodium bicarbonate powder to HCl, which is an exhaust gas in incineration facilities.

Fig. 2 is a basic structure chart of simulation reaction system 1.

Fig. 3 is a graph showing a relationship between the addition equivalent of sodium bicarbonate powder and the HCl removal rate.

Fig. 4 is a graph showing the behavior of HCl concentration at the bag filter outlet of a real machine.

Fig. 5 is a graph showing the behavior of HCl concentration at the bag filter outlet of simulation reaction system 1.

Fig. 6 is a basic structure chart of simulation reaction system 2.

Fig. 7 is a graph showing a relationship between the addition equivalent of sodium bicarbonate powder and the HCl removal rate in exhaust gas reaction.

Fig. 8 is a graph showing a relationship between the addition equivalent of sodium bicarbonate powder in the reaction on a bag filter and HCl removal rate.

Fig. 9 is a graph showing the behavior of HCl concentration at the bag filter outlet of simulation reaction system 2.

Fig. 10 is a table showing HCl concentration at the bag filter outlet and other results in each of Comparative Examples and Examples.

Fig. 11 is a graph showing the behavior of inlet HCl concentration.

Fig. 12 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl concentration in Comparative Example 1.

Fig. 13 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl concentration in Example 1.

Fig. 14 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl

concentration in Example 2.

Fig. 15 is a table showing the control setting of the step control system in Comparative Example 2.

Fig. 16 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl concentration in Comparative Example 2.

Fig. 17 is a table showing the control setting of the step control system in Example 3.

Fig. 18 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl concentration in Example 3.

Fig. 19 is a table showing the control setting of the step control systems in Example 4 and other Examples.

Fig. 20 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl concentration in Example 4.

Fig. 21 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl concentration in Example 5.

Fig. 22 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl concentration in Example 6.

Fig. 23 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl concentration in Example 7.

Fig. 24 is a graph showing the addition amount of a sodium bicarbonate powder and the behavior of outlet HCl

concentration in Example 8.

#### PREFERRED MODE FOR CARRYING OUT THE INVENTION

The present invention will now be more specifically  
5 described by embodiments, but is not limited thereto.

Fig. 1 is a block diagram illustrating a structure of  
acidic gas treatment system 1 of adding a sodium bicarbonate  
powder to HCl, which is an exhaust gas in incineration  
facilities.

10 The acidic gas treatment system 1 is composed of a  
controller 11, a sodium bicarbonate powder-adding device 12, a  
bag filter 13, and an HCl-measuring device 14. The controller  
11 calculates a control output value of the sodium bicarbonate  
powder addition amount by a PID control system based on an HCl  
15 concentration measurement signal and other factors. The sodium  
bicarbonate powder-adding device 12 adds a sodium bicarbonate  
powder to HCl in an exhaust gas based on the control output  
value of the sodium bicarbonate powder addition amount  
calculated by the controller 11.

20 The bag filter 13 removes powder dust after the reaction  
of HCl in the exhaust gas and the sodium bicarbonate powder.  
The HCl-measuring device 14 measures the HCl concentration (HCl  
concentration at the outlet of the bag filter described below)  
after the reaction of the sodium bicarbonate powder accumulated  
25 on the bag filter 13 (the sodium bicarbonate powder remained  
after the reaction with HCl in an exhaust gas is accumulated on  
the bag filter 13) with HCl after the exhaust gas reaction, and

sends an HCl concentration measurement signal to the controller 11.

The acidic gas treatment system 1 repeats the cycle described above to perform feedback control. As a result, the controller 11 controls the control output value of the sodium bicarbonate powder addition amount to an appropriate level.

The HCl concentration-measuring device 14 is a hydrogen chloride concentration-measuring device with an ion selective electrode system.

As shown in Fig. 1, the HCl concentration-measuring device 14 is preferably set so as to measure the HCl concentration (HCl concentration at bag filter outlet described below) after the reaction of the sodium bicarbonate powder accumulated on the bag filter 13 with HCl after the exhaust gas reaction. By doing so, the HCl concentration can be further precisely measured, because the sodium bicarbonate powder remained after the reaction with HCl in an exhaust gas is accumulated on the bag filter 13, and the accumulated sodium bicarbonate powder reacts with HCl after the exhaust gas reaction.

The setting of the HCl concentration-measuring device 14 is not limited to the above, and may be set at any step that is later than the addition of a sodium bicarbonate powder by the sodium bicarbonate powder-adding device 12 to HCl in the exhaust gas.

The control performed by the controller 11 will be further described in detail.

The controller 11 establishes two ranges, a positive range and a negative range, of the HCl concentration slope (concentration change per time ratio). Then, a control set-point value of HCl concentration is set for each of the two  
5 ranges.

Here, the control set-point value of HCl concentration is set such that the control set-point value for a positive range of the HCl concentration slope is smaller than that for a negative range. By doing so, the control output value of the  
10 sodium bicarbonate powder addition amount in an increasing tendency of HCl concentration can be higher than the control output value in an HCl concentration decreasing tendency.

In the HCl concentration decreasing tendency, the output value of the sodium bicarbonate powder addition amount may be  
15 also controlled to be, for example, 0.7-fold and thereby directly reduce the sodium bicarbonate powder addition amount. By doing so, the addition amount can be promptly reduced in the HCl concentration decreasing tendency, and excessive addition can be prevented.

20 A step control system will now be described as the control system in the controller 11, instead of the PID control system.

The step system is a control system for stepwise setting the control output depending on the HCl concentration.  
25 Specifically, an additional upper limit of the control output value is set in response to the HCl concentration in addition to the upper limit of the control output set in the PID control

system.

Here, in common PID control, since a single value is determined as the upper value of the addition amount of a sodium bicarbonate powder, a sodium bicarbonate powder is added within a range below the upper limit, regardless of the HCl concentration, and excessive addition is caused. Accordingly, setting of an additional control output upper value depending on a current HCl concentration by employing a step control system allows appropriate addition of an alkali agent depending on the level of the acidic gas concentration and prevention of excessive addition of the agent.

Here, an additional control output upper limit in response to an HCl concentration is set. The additional upper limit of the control output is set to be higher in a higher HCl concentration. In order to prevent the excessive addition of an alkali agent, the additional upper limit is preferably less than the upper limit of the control output value set in the PID control system (for example, LH (control output upper limit) in Fig. 15, 17, or 19 described below).

As an example of the upper limit of the additional control output, as the control output addition amount corresponding to the HCl concentration at the BF outlet [calculation input value] shown in Fig. 15, 17, or 19 described below, the additional control output upper limit is preferably set to be higher in a higher HCl concentration.

The acidic gas-measuring device used in this embodiment is not limited to the hydrogen chloride (HCl) concentration-

measuring device (HCl-measuring device 14) and may be a sulfur oxide concentration-measuring device by an infrared absorption method or ultraviolet fluorescence method.

In addition, in this embodiment, the acidic gas concentration slope for setting the control set-point value of HCl concentration is an average value in the latest 7 minutes. The use of an average value of the acidic gas slopes within the latest 7 minutes enables appropriate selection and allows stable treatment of the acidic gas.

In this embodiment, the addition amount of an alkali agent is controlled using only the control output calculated from hydrogen chloride, but may be controlled using both the control output calculated from a hydrogen chloride concentration and the control output calculated from a sulfur oxide concentration, since in many burning facilities of industrial waste incinerators and private factories, hydrogen chloride and sulfur oxide occur in high concentrations.

In this case, both hydrogen chloride and sulfur oxide are the objects to be treated. Both acidic gases, hydrogen chloride and sulfur oxide, can be stably treated by, for example, adding the control output calculated based on the sulfur oxide concentration to the control output calculated based on the hydrogen chloride concentration determined by the hydrogen chloride concentration-measuring device disposed downstream of the bag filter.

The sodium bicarbonate powder used in this embodiment is preferably a sodium bicarbonate powder having an average

particle diameter adjusted to 5 to 30  $\mu\text{m}$ , which show particularly rapid reactivity with an acidic gas. The sodium bicarbonate powder showing rapid reactivity has high control responsiveness.

5           In this embodiment, a sodium bicarbonate powder is used as the alkali agent, but any alkali agent that exhibits the effects of the embodiment can be used without particular limitation. Examples of the alkali agent other than sodium bicarbonate powder include sodium carbonate, potassium hydrogen  
10 carbonate, potassium carbonate, sodium sesquicarbonate, natural soda, sodium hydroxide, potassium hydroxide, magnesium oxide, and magnesium hydroxide. When the alkali agent is in a powder form, the powder is preferably a fine powder having a particle diameter of less than 30  $\mu\text{m}$ , in particular, 5 to 20  $\mu\text{m}$ , which  
15 shows rapid reactivity with an acidic gas. An alkali agent having a particle diameter adjusted in advance may be used, or an alkali agent having a coarse particle diameter may be added while being pulverized with a crusher installed on-site.

          In a burning facility measuring an acid gas at the inlet,  
20 feedback control by the control system described above is also an effective means, in addition to the feedforward control. Furthermore, when a denitration catalyst facility is placed downstream of the bag filter, since the exhaust gas is required to be applied at about 200°C, a thermal loss in reheating  
25 energy can be reduced by adjusting the bag filter temperature to 180°C to 230°C, resulting in economical operation.

## EXAMPLES

## Test Example 1

A simulation reaction system was established from the results of investigation with a real machine. As a first pattern, simulation reaction system 1 will be described. The results of investigation with a real machine were obtained in a municipal waste incineration facility using a sodium bicarbonate powder (Hypercer B-200 manufactured by Kurita Water Industries Ltd.) adjusted to an average particle diameter of 8  $\mu\text{m}$  in conventional control with a PID apparatus and feedback control based on the hydrogen chloride concentration measured by an ion electrode method (HL-36 manufactured by Kyoto Electronics Manufacturing Co., Ltd.).

[Simulation reaction system 1]: assumption of reaction in exhaust gas

Simulation reaction system 1 to be investigated was constructed as shown in Fig. 2 by assuming that the reaction of sodium bicarbonate and hydrogen chloride (HCl) instantly occurs in an exhaust gas.

The basic structure of simulation reaction system 1 will be described with reference to Fig. 2.

In agent injection control in an incineration facility, the addition amount of an agent (addition amount (Ag) of sodium bicarbonate powder) is determined through calculation by a control formula such as PID based on the HCl concentration (after treatment) signal of an HCl concentration-measuring device with an ion selective electrode system installed at the

outlet of a bag filter, and the determined addition amount of a sodium bicarbonate powder (acidic gas treating agent) is added to an exhaust gas (inlet HCl concentration ( $H_i$ )). The sodium bicarbonate powder added to the gas duct reacts with an acidic gas, such as HCl, in the exhaust gas to remove HCl in the exhaust gas (removed based on the HCl removal rate ( $\alpha$ )). The HCl concentration ( $H_o$ ) at bag filter outlet after this reaction is measured with the HCl concentration-measuring device with an ion selective electrode system. The measurement is accompanied by a measurement lag on the facility site, a measurement lag by exhaust gas sampling, and a measurement lag (response time) in the measurement by the ion selective electrode system to cause a control lag specific to the feedback. Accordingly, HCl measurement lag time ( $T$ ) in this simulation was set as the following formula (1):

$$T = T_1 + T_2 + T_3 \quad (1)$$

$T$ : measurement lag time of simulation reaction system

$T_1$ : lag time (sec) in the facility [set to 30 sec]

$T_2$ : exhaust gas sampling time (sec) by HCl-measuring device [set to 240 sec]

$T_3$ : 90% response time (sec) by HCl-measuring device [set to 180 sec]

Since the 90% response time (measurement lag) in the ion selective electrode system is affected by the diffusion of HCl gas into an absorbent solution,  $T_3$  was defined by the following formula (2). In this simulation investigation, the measurement lag times in the simulation were set such that  $T_1$  was 30 sec,

T2 was 240 sec, and T3 was 180 sec, based on the conditions of the facility.

$$T3 = 2.3 \times \tau \quad (2)$$

$$Y_n = Y_{n-1} + (X_n - Y_{n-1}) / \tau \times Ts \quad (3)$$

5         $\tau$ : time constant (sec)

$Ts$ : unit simulation time (= data sampling time) (sec)

[set to 0.5 sec]

$X_n$ : the current measuring device input HCl concentration (ppm)

10         $Y_n$ : the current measuring device output HCl concentration (ppm)

$Y_{n-1}$ : the last [ $Ts$  (sec) ago] measuring device output HCl concentration (ppm)

The HCl removal rate ( $\alpha$ ) by a sodium bicarbonate powder  
 15 for an inlet HCl concentration ( $H_i$ ) was estimated from the relationship between the addition equivalent ( $J$ ) of sodium bicarbonate powder and the HCl removal rate (Fig. 3) on the basis of the findings through the application of the sodium bicarbonate powder manufactured by Kurita Water Industries Ltd.  
 20 It was assumed that the reaction between an HCl concentration and a sodium bicarbonate powder instantly occurs. The addition equivalent ( $J$ ) of sodium bicarbonate powder is calculated by the following formula (4).

$$J = Ag / \{ H_i / 0.614 / 1000 / M1 \times M2 \times F / 1000 \} \quad (4)$$

25         $J$ : addition equivalent of sodium bicarbonate powder

$Ag$ : addition amount (kg/h) of sodium bicarbonate powder

$H_i$ : inlet HCl concentration (ppm)

M1: HCl molecular weight [set to 36.5]

M2: sodium bicarbonate molecular weight [set to 84]

F: exhaust gas amount ( $\text{Nm}^3/\text{h}$ ) [set to 25000  $\text{Nm}^3/\text{h}$ ]

Based on this theory, simulation was performed under the same PID control conditions as those in the real machine using a sodium bicarbonate powder "P (proportional gain) = 10%, I = 0.1 sec, D = 0.1 sec, addition amount output lower limit: 5 kg/h, addition amount output upper limit 100 kg/h". The results demonstrated that the behavior of outlet HCl concentration ( $H_o$ ) in the simulation was different from that in the real machine (Figs. 4 and 5). The outlet HCl concentration ( $H_o$ ) is calculated by the following formula (5).

$$H_o = H_i \times (1 - \alpha_g / 100) \quad (5)$$

$H_i$ : inlet HCl concentration (ppm)

15  $H_o$ : bag filter outlet HCl concentration (ppm)

$\alpha$ : HCl removal rate (%) [set based on the relationship between addition equivalent and HCl removal rate (Fig. 3)]

The comparison of changes in HCl concentration after treatment of HCl by addition of a sodium bicarbonate powder demonstrated that the rate of increase of HCl concentration in the simulation reaction system 1 was higher than that in the real machine. In further investigation while changing the parameters such as the measurement lag time, the results of the simulation did not agree with that of the real machine. Accordingly, the cause of that the rate of increase of HCl concentration in the real machine is slower than that in the simulation reaction system 1 is believed that the unreacted

sodium bicarbonate powder captured by the bag filter reacts with HCl.

#### Test Example 2

As a second pattern, simulation reaction system 2 will now be described.

[Simulation reaction system 2]: complex reaction with exhaust gas on bag filter

On the basis of the investigation results described above, the reaction of the unreacted sodium bicarbonate powder on the bag filter with HCl was incorporated into consideration, in addition to the reaction in the exhaust gas, and the reaction on the bag filter was constructed as shown in Fig. 6. The residence time of the materials captured by the bag filter is usually about 2 hours. Accordingly, in simulation reaction system 2, it was assumed that the sodium bicarbonate powder on the bag filter disappears within a prescribed time (set to about 2 hours).

The basic structure of simulation reaction system 2 will be described with reference to Fig. 6.

In agent injection control in an incineration facility, an addition amount of an agent (addition amount (Ag) of sodium bicarbonate powder) is determined through calculation by a control formula such as PID based on the HCl concentration (after treatment) signal of an HCl concentration-measuring device with an ion selective electrode system installed at the outlet of a bag filter, and the determined addition amount of a sodium bicarbonate powder (acidic gas treating agent) is added

to an exhaust gas (inlet HCl concentration ( $H_i$ )).

The HCl concentration ( $H_g$ ) after the reaction in an exhaust gas is determined from the addition equivalent ( $J_g$ ) of the sodium bicarbonate powder of the exhaust gas reaction and HCl removal rate ( $\alpha_g$ ) by the exhaust gas reaction (the following formula (6)). The addition equivalent ( $J_g$ ) of sodium bicarbonate powder of the exhaust gas reaction is calculated by the following formula (7).

$$H_g = H_i \times (1 - \alpha_g / 100) \quad (6)$$

$H_i$ : inlet HCl concentration (ppm)

$H_g$ : HCl concentration (ppm) after exhaust gas reaction

$\alpha_g$ : HCl removal rate (%) in exhaust gas reaction

[setting based on the relationship between addition equivalent of sodium bicarbonate powder in exhaust gas reaction and HCl removal rate (Fig. 7)]

$$J_g = A_g / \{H_i / 0.614 / 1000 / M_1 \times M_2 \times F / 1000\} \quad (7)$$

$J_g$ : addition equivalent of sodium bicarbonate powder in exhaust gas reaction

$A_g$ : addition amount (kg/h) of sodium bicarbonate powder

$H_i$ : inlet HCl concentration (ppm)

$M_1$ : HCl molecular weight [set to 36.5]

$M_2$ : sodium bicarbonate molecular weight [set to 84]

$F$ : exhaust gas amount ( $\text{Nm}^3/\text{h}$ ) [set to 25000  $\text{Nm}^3/\text{h}$ ]

The sodium bicarbonate powder remained after the exhaust gas reaction occasionally accumulates on the bag filter. The sodium bicarbonate powder accumulated on the bag filter reacts with HCl after the exhaust gas reaction to define the HCl

concentration ( $H_o$ ) at the outlet of the bag filter. On this occasion, the amount ( $A_s$ ) of the sodium bicarbonate powder accumulated on the bag filter was determined by subtracting the sodium bicarbonate powder amount reacted with HCl on the bag filter from the sodium bicarbonate powder accumulated by the exhaust gas reaction.

The HCl removal rate ( $\alpha_s$ ) on the bag filter was determined from the addition equivalent ( $J_s$ ) of sodium bicarbonate powder on the bag filter estimated from the sodium bicarbonate powder amount ( $A_s$ ) accumulated on the bag filter and the HCl concentration ( $H_g$ ) after the exhaust gas reaction, and the HCl concentration ( $H_o$ ) at the bag filter outlet was determined (the following formula (8)). The addition equivalent ( $J_s$ ) of the sodium bicarbonate powder on the bag filter is calculated by the following formula (9). The HCl measurement lag was set to  $T$  ( $= T_1 + T_2 + T_3$ ) as in simulation reaction system 1.

$$H_o = H_g \times (1 - \alpha_s / 100) \quad (8)$$

$H_g$ : HCl concentration (ppm) after exhaust gas reaction

$H_o$ : bag filter outlet HCl concentration (ppm)

$\alpha_s$ : HCl removal rate (%) by reaction on bag filter

[set based on the relationship between addition equivalent of sodium bicarbonate powder on bag filter and HCl removal rate (Fig. 8)]

$$J_s = A_s / \{ H_g / 0.614 / 1000 / M_1 \times M_2 \times F / 1000 \} \quad (9)$$

$J_s$ : addition equivalent of sodium bicarbonate powder on bag filter

As: sodium bicarbonate powder amount (kg/h) on bag filter

Hg: HCl concentration (ppm) after exhaust gas reaction

M1: HCl molecular weight [set to 36.5]

M2: sodium bicarbonate molecular weight [set to 84]

5 F: exhaust gas amount (Nm<sup>3</sup>/h) [set to 25000 Nm<sup>3</sup>/h]

$$As = Z_n / Ts \times 3600 \quad (10)$$

Z<sub>n</sub>: sodium bicarbonate powder amount (kg) accumulated on  
bag filter

Ts: unit simulation time (= data sampling time) (sec)

10 [set to 0.5 sec]

$$Z_n = Z_{n-1} \times (1 - 2.3 / T4 \times Ts) \quad (11)$$

Z<sub>n-1</sub>: unreacted sodium bicarbonate powder amount (kg)

T4: constant (sec) at 90% disappearance of sodium  
bicarbonate powder accumulated on bag filter

15 [set to 7200 sec]

Ts: unit simulation time (= data sampling time) (sec)

[set to 0.5 sec]

$$Z_{n-1} = (Ag / (3600 \times Ts) - Rg) + (Z_{n-1} - Rs) \quad (12)$$

Ag: addition amount (kg/h) of sodium bicarbonate powder

20 Ts: unit simulation time (= data sampling time) (sec)

[set to 0.5 sec]

Rg: sodium bicarbonate reaction amount (kg/h) in exhaust  
gas reaction

Z<sub>n-1</sub>: sodium bicarbonate powder accumulated amount (kg) on  
25 bag filter before Ts (Sec)

Rs: sodium bicarbonate reaction amount (kg/h) in reaction  
on bag filter

$$R_g = (H_i/0.614/1000/M_1 \times M_2 \times F/1000)/3600 \times T_s \times \alpha_g/100 \quad (13)$$

$H_i$ : inlet HCl concentration (ppm)

$M_1$ : HCl molecular weight [set to 36.5]

$M_2$ : sodium bicarbonate molecular weight [set to 84]

5  $F$ : exhaust gas amount ( $\text{Nm}^3/\text{h}$ ) [set to 25000  $\text{Nm}^3/\text{h}$ ]

$\alpha_g$ : HCl removal rate (%) in exhaust gas reaction

$$R_s = (H_g/0.614/1000/M_1 \times M_2 \times F/1000)/3600 \times T_s \times \alpha_s/100 \quad (14)$$

$H_g$ : HCl concentration (ppm) after exhaust gas reaction

$M_1$ : HCl molecular weight [set to 36.5]

10  $M_2$ : sodium bicarbonate molecular weight [set to 84]

$F$ : exhaust gas amount ( $\text{Nm}^3/\text{h}$ ) [set to 25000  $\text{Nm}^3/\text{h}$ ]

$\alpha_s$ : HCl removal rate (%) by reaction on bag filter

Based on this theory, simulation was performed while changing the HCl removal rates in the reaction in the exhaust gas and the reaction on the bag filter. The results demonstrated that the exhaust gas reaction and the reaction on bag filter at the HCl removal rates [exhaust gas reaction: 95%, reaction on bag filter: 75%] shown in Figs. 7 and 8 approximately agreed with the behavior (Fig. 4) of HCl concentration at the bag filter outlet in the real machine (Fig. 9). This result supports that the sodium bicarbonate powder on the bag filter reacts with HCl, resulting in a reduction in the rate of increase of HCl. In this simulation, the reaction with HCl on the bag filter was slower than the exhaust gas reaction. It is believed that this is caused by that the HCl concentration to be treated in the reaction on the bag filter is lower than that in the exhaust gas reaction, and

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the HCl removal rate is therefore low. In addition, it is believed that the sodium bicarbonate powder accumulated on the bag filter is thermally decomposed by the heat of the exhaust gas into sodium carbonate. Since the HCl removal rate of sodium carbonate is lower than that of the sodium bicarbonate powder, there is a possibility that the removing rate on the bag filter was decreased.

It is believed from the investigation results above that the reaction of a sodium bicarbonate powder with HCl in a combustion exhaust gas is a complex reaction system of the reaction in the exhaust gas and the reaction of the sodium bicarbonate powder accumulated on the bag filter. Since the behavior of the HCl concentration at the bag filter outlet approximately agreed with that in a real machine, it is recognized that the simulation reaction system 2 is effective as a tool for evaluating a control procedure using a sodium bicarbonate powder.

The results of investigation for various control procedures in the simulation reaction system 2 are shown below.

The sodium bicarbonate powders used in the following Examples 1 to 8 had an average particle diameter of 5 to 30  $\mu\text{m}$ . The HCl-measuring device 14 used in Examples 1 to 8 is a hydrogen chloride concentration-measuring device by an ion electrode method.

#### Comparative Example 1

HCl treatment was controlled using the inlet HCl concentrations shown in Fig. 11 and setting the control set-

point value (SV) of HCl treatment to 40 ppm in simulation reaction system 2 employing a PID control system "P (proportional gain) = 10%, I = 0.1 sec, D = 0.1 sec, addition amount output lower limit: 5 kg/h, addition amount output upper limit: 100 kg/h". Fig. 10 shows the addition amount of a sodium bicarbonate powder and the HCl concentrations (average, 1-hour average maximum, and instant maximum) at the bag filter outlet after the treatment with the sodium bicarbonate powder. Fig. 12 shows the addition amount of the sodium bicarbonate powder and the behavior of the HCl concentration at the bag filter outlet in this control.

#### Example 1

HCl treatment was controlled with the same PID conditions as those in Comparative Example 1 by setting the control set-point value (SV) to 30 ppm when the 6-second average of the latest HCl concentration slope was positive and setting the control set-point value (SV) to 40 ppm when the 6-second average of the latest HCl concentration slope was negative.

Fig. 10 also shows the addition amount of the sodium bicarbonate powder and the HCl concentrations (average, 1-hour average maximum, and instant maximum) at the bag filter outlet after the treatment with the sodium bicarbonate powder. Fig. 13 shows the addition amount of the sodium bicarbonate powder and the behavior of the HCl concentration at the bag filter outlet in this control.

It was demonstrated that when the HCl concentration slope is positive (increasing tendency), the setting of the control

set-point value to a low level has an effect of inhibiting occurrence of HCl peaks due to an increase in addition amount of the sodium bicarbonate powder in an HCl concentration increasing tendency. In addition, the average and 1-hour  
5 average maximum of HCl decreased. Thus, an intended effect of stably treating HCl was achieved. Unfortunately, since the addition amount of the sodium bicarbonate powder is increased compared to the conventional control (Comparative Example 1), the setting of this control is suitable for facilities that  
10 require stable treatment to an HCl concentration of, for example, 30 ppm or less.

#### Example 2

HCl treatment was controlled with the same PID conditions as those in Comparative Example 1 by setting the control set-  
15 point value (SV) to 30 ppm when the 6-second average of the latest HCl concentration slope was positive and setting the control set-point value (SV) to 50 ppm when the 6-second average of the latest HCl concentration slope was negative.

Fig. 10 also shows the addition amount of the sodium  
20 bicarbonate powder and the HCl concentrations (average, 1-hour average maximum, and instant maximum) at the bag filter outlet after the treatment with the sodium bicarbonate powder. Fig. 14 shows the addition amount of the sodium bicarbonate powder and the behavior of the HCl concentration at the bag filter  
25 outlet in this control.

When the HCl concentration slope was positive (increasing tendency), as in Example 1, an effect of inhibiting occurrence

of HCl peaks was achieved, and also HCl could be stably treated compared to the conventional control (Comparative Example 1). When the HCl concentration slope was negative (decreasing tendency), since the control set-point value (SV) was set to be  
5 higher than that in Example 1, the addition amount of the sodium bicarbonate powder was reduced, and the addition was completed at an earlier stage, resulting in a reduction in the addition amount of the sodium bicarbonate powder compared to Example 1. However, since the addition amount was higher than  
10 that in the conventional control (Comparative Example 1), the setting of this control is suitable for facilities that require stable treatment to an HCl concentration of, for example, 30 ppm or less.

Comparative Example 2 and Examples 3 to 8 will now be  
15 described. In Comparative Example 2 and Examples 3 to 8, control is performed by a step control system instead of the PID control system.

The step control system will be briefly described below. The step control system stepwise regulates the output depending  
20 on the outlet HCl concentration, unlike the PID control system. The system will be described by Comparative Example 2 (Fig. 15). When the HCl concentration is between the SV control set-point value [concentration for starting control output (above the output lower limit)] and SM1, control outputs in a range of  
25 LO to LM1 are stepwise outputted. In this step, when the HCl concentration is between SM1 and SM2, a control output of LM2 is outputted, and when the HCl concentration is SM2 or more, a

control output of LH (control output upper limit) is outputted.

In a common PID control system, the output has no limitation, and setting thereof is only LO and LH. The HCl concentration

used for control calculation from HCl slopes and the table for

determining control output are corrected with SVA1 and SVB1.

When the HCl slope is positive, SVA1 is subtracted from the HCl

concentration used in the calculation. When the HCl slope is

negative, SVB1 is added to the HCl concentration used in the

calculation. As a result, in this system, even if the HCl

concentrations are the same, the control output value

calculated when the HCl slope value is large (increasing

tendency of acidic gas concentration) is higher than that when

the HCl slope value is small.

#### Comparative Example 2

HCl treatment was controlled using the inlet HCl

concentrations shown in Fig. 11 and setting the control set-

point value (in this system, the concentration at which the

control output of an alkali agent is added to above the output

lower limit is prescribed as the SV)) to 40 ppm in simulation

reaction system 2 of a step control system. Fig. 10 shows the

addition amount of a sodium bicarbonate powder and the HCl

concentrations (average, 1-hour average maximum, and instant

maximum) at the bag filter outlet after the treatment with the

sodium bicarbonate powder. The control output addition amounts

of a sodium bicarbonate powder according to the bag filter

outlet HCl concentrations are shown in Fig. 15. In addition,

Fig. 16 shows the addition amount of the sodium bicarbonate

powder and the behavior of the HCl concentration at the bag filter outlet in this control.

In this control system, a restriction by an HCl concentration range is applied to the control output between the upper and the lower limits of the control output to allow stepwise addition of the alkali agent. As a result, the excessive addition of an alkali agent was inhibited, and the addition amount of the sodium bicarbonate powder was considerably reduced. However, the treatment level of HCl to be treated was considerably deteriorated compared to the conventional control (Comparative Example 1).

#### Example 3

In the same step control system as that in Comparative Example 2, HCl treatment was controlled by setting the control set-point value (SV) to 30 ppm when the 6-second average of the latest HCl concentration slope was positive and setting the control set-point value (SV) to 40 ppm when the 6-second average of the latest HCl concentration slope was negative. Similarly, the addition amount of a sodium bicarbonate powder and the HCl concentrations (average, 1-hour average maximum, and instant maximum) at the bag filter outlet after the treatment with the sodium bicarbonate powder are shown in Fig. 10. The control output addition amounts of a sodium bicarbonate powder according to the bag filter outlet HCl concentrations are shown in Fig. 17. Fig. 18 shows the addition amount of the sodium bicarbonate powder and the behavior of the HCl concentration at the bag filter outlet in

this control.

In this control system, the alkali agent was stepwise added as in Comparative Example 2, and an effect of reducing the addition amount of the sodium bicarbonate powder, compared to the conventional control (Comparative Example 1), was achieved. In the HCl increasing tendency, the sodium bicarbonate powder was added at an early stage considering the measurement lag. As a result, an effect of stably treating HCl was achieved. This control procedure can improve the HCl-treating level, compared to the conventional control (Comparative Example 1), and can provide an effect of reducing the addition amount and is therefore a very effective method.

In this example, when the measured value of the HCl concentration at the bag filter outlet was in a range of 40 to 50 ppm, the treatment was controlled by setting the addition amount depending on the HCl concentration. Even if the treatment in this range is controlled by PID, since the control output is restricted to 50 kg/h or less when the HCl concentration is 50 ppm or less and is restricted to 70 kg/h or less when the HCl concentration is within a range of 50 to 60 ppm, in the range of the lower limit to the upper limit of the control output, it seems that an equivalent HCl-treating effect and an addition amount-decreasing effect can be achieved.

#### Example 4

In the same step control system as that in Comparative Example 2, HCl treatment was controlled by setting the control set-point value (SV) to 30 ppm when the 6-second average of the

latest HCl concentration slope was positive and setting the control set-point value (SV) to 50 ppm when the 6-second average of the latest HCl concentration slope was negative. Similarly, the addition amount of a sodium bicarbonate powder and the HCl concentrations (average, 1-hour average maximum, and instant maximum) at the bag filter outlet after the treatment with the sodium bicarbonate powder are shown in Fig. 10. The control output addition amounts of a sodium bicarbonate powder depending on the bag filter outlet HCl concentrations are shown in Fig. 19. Fig. 20 shows the addition amount of the sodium bicarbonate powder and the behavior of the HCl concentration at the bag filter outlet in this control.

In this control system, the sodium bicarbonate powder was stepwise added as in Comparative Example 2, and the control set-point value (SV) in the HCL decreasing tendency was set to high compared to Example 3. As a result, the addition amount of the sodium bicarbonate powder was reduced, and the addition was completed at an earlier stage. Thus, an effect of reducing the addition amount compared to the conventional control (Comparative Example 1) was achieved. Furthermore, the addition amount could be reduced, while maintaining the HCl-treating level to be equivalent to that in the conventional control (Comparative Example 1). It was believed that this control system also can perform HCl treatment approximately equivalent to that of conventional control and achieves an effect of reducing the addition amount and is therefore a very

useful control method.

#### Examples 5 to 8

In order to investigate an appropriate average time of the latest HCl concentration slopes for selecting a control calculating formula under the same control conditions as those in Example 4, the investigation was performed while changing the average time of the HCl concentration slopes. Similarly, the addition amount of a sodium bicarbonate powder and the HCl concentrations (average, 1-hour average maximum, and instant maximum) at the bag filter outlet after the treatment with the sodium bicarbonate powder are shown in Fig. 10. Figs. 21 to 24 show the addition amounts of the sodium bicarbonate powder and the behavior of the HCl concentrations at the bag filter outlet in this control.

As the result of this investigation, a large HCl peak occurred when the average time of an HCl concentration slope for selecting a control formula was set to 10 minutes (Example 8). This suggests that the timing for adding a sodium bicarbonate powder was shifted by elongating the average time of the slope and that a defect occurs in this control when the average time is longer than 7 minutes. On the other hand, when the average time is 7 minutes or less, no abnormal occurrence of HCl was observed. It seemed that an average time for an appropriate HCl slope is 7 minutes or less (Examples 5 to 7).

## CLAIMS

1. A method for treating an acidic gas, comprising feedback control of the addition amount of an alkali agent on the basis of a measurement signal from an acidic gas-measuring device set in a step after addition of the alkali agent to an acidic gas contained in a combustion exhaust gas, the method comprising the steps of:

setting at least two ranges of acidic gas concentration slope;

setting a control set-point value of the acidic gas concentration for each of the at least two ranges of the slope; and

calculating a control output value indicating the addition amount of the alkali agent based on at least the measurement signal and the control set-point value, wherein

in the step of setting a control set-point value, the control set-point value when the range of the acidic gas concentration slope is large is set to be lower than the control set-point value when the range of the acidic gas concentration slope is small.

2. The method for treating an acidic gases according to Claim 1, the method further comprising the step of:

setting one or more additional upper limits of the control output value in response to the acidic gas concentration between a lower limit and an upper limit of the

control output value indicating the addition amount of the alkali agent.

3. The method for treating an acidic gas according to Claim  
5 1 or 2, wherein

the acidic gas-measuring device is a hydrogen chloride concentration-measuring device in accordance with an ion electrode method.

10 4. The method for treating an acidic gas according to any one of Claims 1 to 3, wherein

the acidic gas-measuring device is a sulfur oxide concentration-measuring device in accordance with an infrared absorption method or an ultraviolet fluorescence method.

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5. The method for treating an acidic gas according to any one of Claims 1 to 4, wherein

the acidic gas concentration slope for setting the control set-point value is an average value within the latest 7  
20 minutes.

6. The method for treating an acidic gas according to any one of Claims 1 to 5, wherein

the addition amount of the alkali agent is controlled  
25 using a control output calculated from a hydrogen chloride concentration and a control output calculated from a sulfur oxide concentration.

7. The method for treating an acidic gas according to any one of Claims 1 to 6, wherein

the alkali agent for treating an acidic gas is a sodium  
5 bicarbonate powder having an average particle diameter of 5 to  
30  $\mu\text{m}$ .