

ENVIRONMENTAL MONITORING MEASUREMENT OF THE SOOT AND DUST DISCHARGED FROM THE INCINERATOR AND INDUSTRIAL PLANTS

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Abstract: This paper describes an environmental monitor method. Here we describe a method for measuring the amount of soot and dust discharged from the plant and incinerator. The principle of method is based on the electrostatics.

When the soot and dust pass through the strong electric field, these contact to the ionized air and are charged. These induce the change in the electrostatic field near the electrode in the downstream when passing through near it and the small current occurs in the electrode. The current is proportional to the amount of electric charge of the soot and dust, and the amount of soot and dust is proportional to the charge. Thus, the soot and dust amount can be estimated from the current.

Here, a mathematical model that relates the current and the mass flow rate of the soot and dust is constructed, and a new measurement method based on the model is presented. The validity of the method is experimentally examined.

Keywords: environmental monitoring, soot and dust mass flow meter, triboelectricity

1 INTRODUCTION

The environmental problem is one of the most serious problems that we should tackle. Each organization has started the air pollution control activity. The acquisition of license of ISO14000 that clarified the standard on the effect on the environment is recognized to be important by many companies from the management ethics standpoint and they try to acquire the license. To acquire the license, it is prerequisite to continuously record, analyze and evaluate the environmental data[1].

This paper describes an online measurement method of the mass flow of soot and dust discharged from the incinerator and the industry plant. The conventional measurement methods of the gas-particle flow such as soot and dust in a pipeline and/or chimney are the optical method, the differential pressure method and the triboelectricity method[2]. Among those, the optical method is most popular, but has the serious blind problem. The measurement method of the difference pressure is same with that of gas flow measurement with orifice in a pipeline. The existence of the orifice in the pipe causes the stuffing up due to the adhesion and storage of the particle. The method is popular in the fluid flow measurement but not popular in the gas-particle flow measurement. The triboelectricity method bases on the electrical charging phenomenon of the particle by collision and friction of particles. The particle passing through a chimney collides to the wall and is charged. When the charged particle moves near the electrode, the electrical current is induced in it by the Coulomb force. The current is proportional to the amount of the charge. This method is more maintenance free than the methods above. But this method is easily influenced by the circumstances. Further some group of particles are highly charged whereas the other are low, which leads to inaccurate measurement. To improve accuracy, calibrations under each different condition are required[3]-[9].

The method presented here also employs the particle charging method. We present a new method that solves the problems in the conventional method, such as the high sensitivity to the change in circumstances and operating condition. Here we built a model that describes the relation between the electrostatic induction by the motion of the charged particle and the soot density. Employment of the model leads to the easy calibration of the measurement that fit to various measurement and operation conditions.

2 ASSUMPTIONS AND PROBLEM DESCRIPTION

Fig.1 shows how the soot moves in the flue. One soot particle in the flue collides to the another particle frequently and they are frictionally electrified. Let the shape of the particle be ball with the diameter D_p , the mass be m , the velocity be v and the electric charge be q_0 . Many such the particles exist and make a group. The group is called charged cloud and let the density of the charged particles in the cloud be n and the volume interested in be V_s . These particles collide to the particles with inverse electricity and are neutralized by which the total amount of electric charge in the cloud decrease. Let the time constant of the decrease be T_L and let the dielectric constant in the flue be $\hat{\epsilon}_1$.

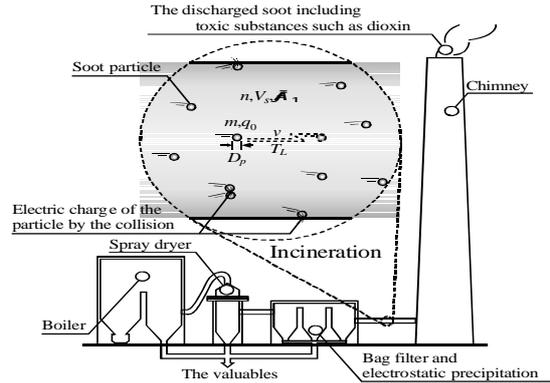


Fig.1 Behavior of the soot particle in the flue

Assume for the soot particle.

- (A1) The soot is made of the same material and the diameter is constant.
- (A2) The density of the soot particle is proportional to that of charged particle n .
- (A3) The flow of the soot is uniform.
- (A4) The density n and the time constant T are constant.
- (A5) The dielectric constant $\hat{\epsilon}_1$ is constant.

Under the assumptions above we consider the following problem:

- (P1) Consider a soot mass flow measurement method.
- (P2) Consider an easy calibration method.
- (P3) Verify the method by experiments.

3 MEASUREMENT SYSTEM

3.1 Measurement system

First consider problem (P1). Fig.2 shows the solution. In the system, (1) the soot particles are artificially charged, (2) the electric current static electrically induced appears and (3) the mass flow of the soot is calculated from the current appearance time and current amount. Thus the system has three elements the electric charger, current sensor due to the electrostatic induction, computer, correspondingly. The electric charger is located L length upper than the detecting electrode. The computer controls the charging timing and obtains the current signal and calculates the mass flow using the calibration functions.

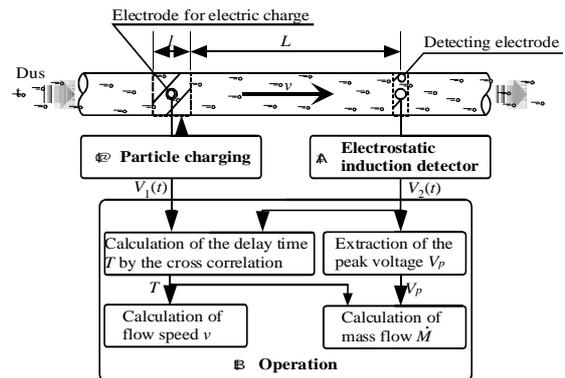


Fig.2 Measurement system

3.2 Electric charger

Fig. 3 shows an example of the electric charger. It is a pair of a line and circular plate electrodes. Let the radius of the line be r and the distance between the line and the circular plate be h . Feed the voltage V_c to the electrodes, then the electric field E appears between the electrodes

$$E = \frac{V_c}{2.30r \log(2h/r)} \quad (1)$$

Letting the vacuum dielectric constant be ϵ_0 , the saturated charge of the particle is given by

$$q_\infty = \left\{ 1 + 2 \frac{(\epsilon_1 - 1)}{(\epsilon_1 + 2)} \right\} \epsilon_0 E D_p^2 \quad (2)$$

Further, letting the charge time constant be τ , the charge of the soot in the field for t_1 is [10]

$$q_0 = q_\infty \times \frac{t_1}{t_1 + t} \quad (3)$$

Suppose $t_1 \gg \delta$, then $q_0 \approx q$. The charge q is proportional to the electric field intensity E . To charge the soot particles in the uniform amounts, the artificial charge must be enough strong so that the fluctuation due to the natural charge can be neglected. Increasing in the electric field intensity E yields the corona discharging, by which very many ions are discharged from the electrodes. The increase in the contacting frequency of the ionized air to the soot particles finally leads to the increase in the electric charge of the soot cloud. Thus the voltage V_C must be enough high to lead to the corona discharging. Fig.3 shows an example of generating the field. There are many systems and some of them are commercialized as the ionizer or as the electrostatic precipitator [11]-[13].

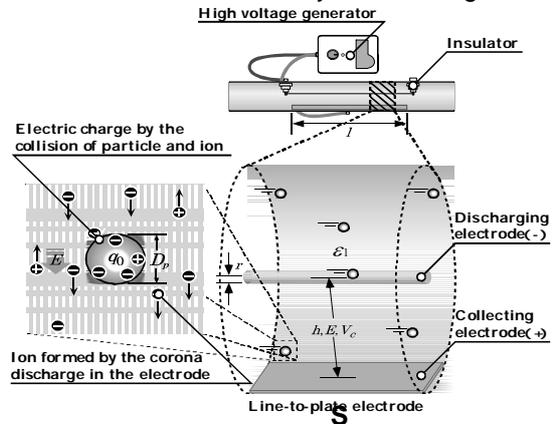


Fig.3 Structure of particle charging part and the principle

3.3 Electrostatic induction detecting element

Fig.4 shows the principle of the electrostatic induction detecting element. The element has the same structure with that of Faraday gage [14]. The electrostatic induction by the moving charged particle influences to the free electrons in the pipe, by which the electric current occurs. The current can be detected by a current to voltage converter. Even if the converter gain R_f is so high, the input impedance of the circuit is still kept high, due to the effect of the negative feedback. Thus the circuit has very low-noise characteristics.

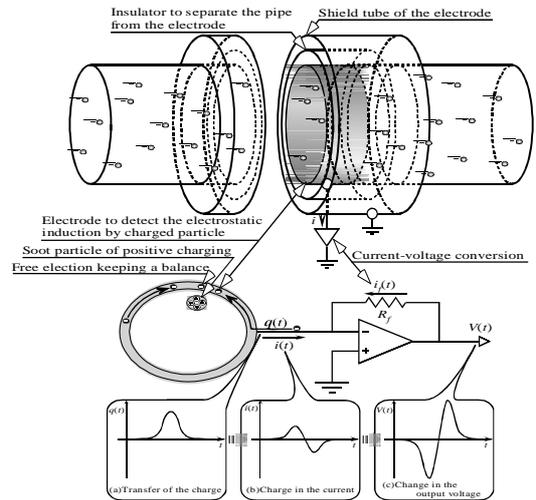


Fig.4 Structure of electrostatic induction detecting element and the principle

3.4 Signal processing element

(1) Measurement of flow velocity

The soot particles passing through the charging site are electrified by colliding the ions. The group of these particles makes an electrified cloud whose electricity is much higher than those naturally electrified. The velocity is determined by measuring the movement of the cloud Fig.5 shows the scheme of the signal processing. The pulse voltage with a constant period is fed to the electrode to generate the pulse and periodic corona ion. Synchronizing to the pulse voltage, the cloud artificially electrified and that naturally electrified alternately appears in the flue. The average velocity v of the soot particle can be calculated by dividing the length L by the delay time T to arrive the artificially electrified cloud from ion feeding site to detecting site. I.e.,

$$v = \frac{L}{T} \quad (4)$$

(2) Measurement of mass flow

We shall consider the problem (P2). First we build a mathematical model that relates mass flow and the velocity v and the magnitude of the voltage detected at the electrostatic induction detector. Fig.6 shows how the mass

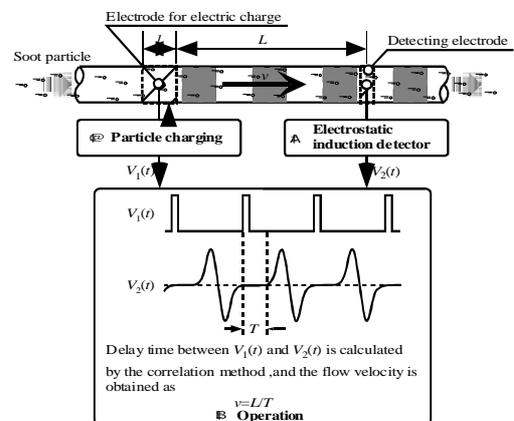


Fig.5 Estimation of the flow speed by the delay time T

flow is calculated. Consider the space near the detector in the flue. In the space all of the electrified particles induce the electron in the electrode. First the soot particle is in the charging site. Each particle is electrified and has the charge q_0 from eq.(3)(or eq.(2)). Then from Assumption (A1) and (A2), the total charge Q_0 of the group is calculated as follow;

$$Q_0 = nq_0V_s \quad (5)$$

Further from Assumption (A2), the density of the soot particle is proportional to that of the charged particles. Then by letting k be a proportional constant, the mass M of the total soot particle in the space of volume V_s is given by

$$M = knmV_s \quad (6)$$

From Assumption (A3), the soot particles in the space keep the cloud formation. In the cloud, the electric charge decreases due to the defusing and/or recombination of ions. Letting the time when the particle started at the charging site be $t = 0$, then the charge after starting can be given by;

$$\begin{cases} \frac{dq}{dt} = -\frac{1}{T_L} q \\ q(0) = Q_0 \end{cases} \quad (7)$$

The solution is given by

$$q(t) = Q_0 e^{-\frac{t}{T_L}} \quad (8)$$

The voltage output of the current-voltage converter at the time $T=L/v$ is then given by

$$V_p = -R_f \frac{dq(T)}{dt} = \frac{R_f q_0}{km} \frac{M}{T_L} e^{-\frac{T}{T_L}} = \frac{R_f q_0}{km} \dot{M} e^{-\frac{T}{T_L}} \quad (9)$$

From Assumption (A1), (A3) and (A4) the mass m , the diameter D_p of the soot particle, the proportional constant k , the length L are also constant. Further from Assumption (A5), the dielectric constant $\hat{\epsilon}_1$ is constant. Thus the following coefficient C is also constant.

$$C = \frac{km}{R_f q_0} \quad (10)$$

By using the constant C defined above and the time constant T_L , the mass flow can be given by

$$\dot{M} = CV_p e^{\frac{T}{T_L}} \quad (11)$$

The constants C and T_L are not easy to obtain theoretically, then calibrations are required to obtain these constants. Once obtained, the mass flow is calculated from V_p and T by eq.(11).

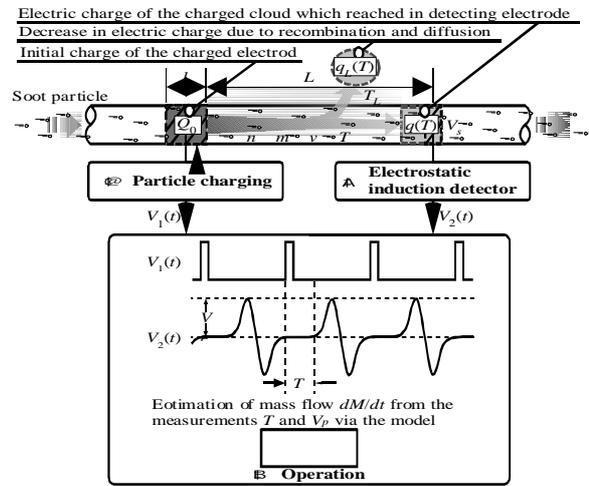


Fig.6 Estimation of the mass flow

4 EXPERIMENTAL VERIFICATION

4.1 Measurement condition

We shall consider the problem (P3). Here we measure the mass flow of the smoke from the incense sticks. We drop the ash of the incense stick so that it emits the constant amount of smoke. Since the smoke of the incense stick is an aggregate of the fine particles, when multiple incense sticks are simultaneously burnt under the same environment, the incense stick becomes the ash at the constant rate. Thus the soot generation rate from smoke can be constant. Since it is difficult to measure the accurate amount of soot generation rate of the incense stick, we include all such as carbon dioxide, steam and smoke, etc, except ash. Thus the soot generation rate (mass flow) is estimated by (original mass of incense stick – remained mass of ash)/(burn out time). Experiments were carried out under the environment of 32.1% humidity and 19.1 centigrade temperature.

4.2 Experimental system

Fig.7 shows the experimental system. The air flow was fixed by adjusting the input voltage to the fan. The smoke from the incense stick is drawn to the experimental pipe. At the electric charging site, the line and plate electrodes was employed. The voltage between the electrode was $V_C=16000V$, the distance between the electrodes $h=29mm$, the radius of the line electrode $r=0.04mm$, and the length $l=215mm$. Thus the electric field intensity was $E=5.5kV/m$. The timing of the charging was adjusted by the frequency of a function generator. The feedback register of the circuit was $R=10M\Omega$. In the experiment the number of incense sticks was increased from 1 to 9, and the range of flow velocity was from 1.3m/s to 5.9m/s with the increment of 0.23m/s in each incense stick number. The data were acquired for 20 flow velocities.

4.3 Experimental results

Fig.8(a) shows the input pulse and output voltage from the circuit when the sticks number was 5 and the flow velocity was 1.3m/s, 3.5m/s, and 5.9m/s, respectively. From Fig.8(a), the delay time is shorten in proportional to the velocity. Further in Fig.8(b) shows the output voltage when the velocity was 3.5m/s and the number of sticks were 9, 4 and 9, respectively. The output voltage increases in proportional to the number of sticks.

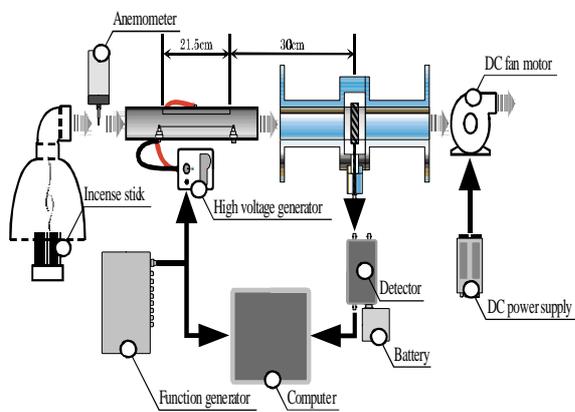
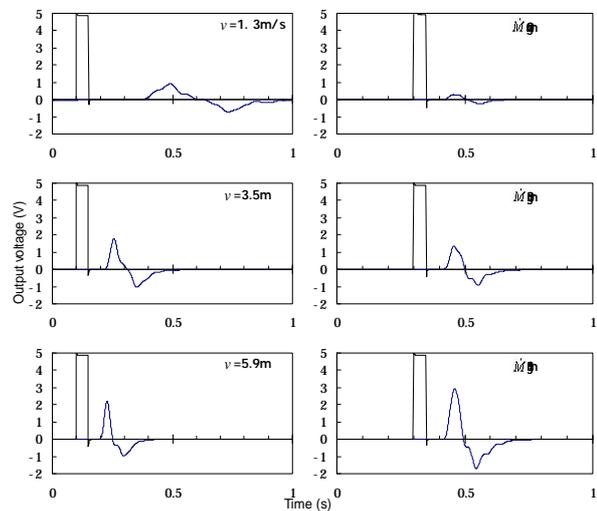


Fig.7 Experiment system



(a) Input and Output for various flow speed for the mass flow 1 mg/s
●● mass flow for the flow speed 3.5 m/s

Fig.8 Sensor output signal for various amount and speed of soot and dusts flow

Using the number of sticks, the output voltages and the delay time T , we estimated the constant C and the time constant T_L in eq.(11) by the least squares method. The constants were $C=0.44kg/sV$, $T_L=0.18s$. Thus the calibration equation is given by

$$\dot{M} = 0.44V_p e^{\frac{T}{0.18}} \quad (12)$$

From eq.(12), mass flows of 0.2mg/s (one piece incense stick burning) to 1.8mg/s (9 piece incense stick burning) were calculated for various flow velocity conditions. Fig.9 shows the average mass flow for different flow velocities. The results show accurate mass flow of the soot particle.

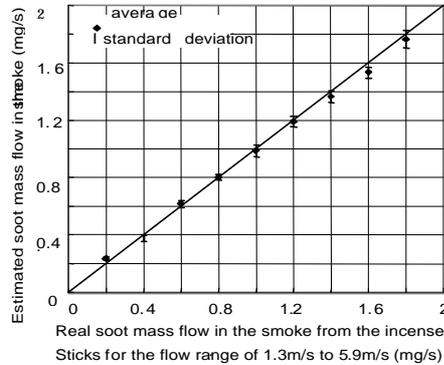


Fig.9 Real vs. Estimated soot quantity under various flow speed

5 CONCLUSIONS

Here, we newly proposed the mass flowmeter of the soot by the electrification of particles. This method artificially charges the soot particles in the upstream in the flue and detects the current induced static-electrically in the downstream. From the delay time and the current (voltage), the mass flow of the soot can be obtained. This paper clarified the followings;

- (1) The relationship between the current (voltage) which appears in the detection electrode and soot mass flow can be shown by the simple model.
- (2) By utilizing this model, soot mass flow can be measured from the detection signal by obtaining two parameters in the calibration. The validity of this method was confirmed from the experiment using the smoke from the incense stick.

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