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A Research on the Refuse Incinerators from the Viewpoint of Smoke Properties*

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The test results of the comprehensive investigations, which are carried out by the Department of Public Nuisance, the Tokyo Municipal Government, concerning the influence of the type and design principle of incinerators, operation conditions and refuse properties on the nuisances due to smoke and ash, give synthetic informations to improve the present policy of incinerator design, from the point of view of the public nuisance and also of incinerator maintenance.

For instance, the upper limit of the furnace outlet temperature, which is supposed 950°C at present, is found slightly too high, considering the content of $\text{NO} + \text{NO}_2$ discharged from the furnace, and the maintenance of air preheater located immediately behind the furnace.

Further, it is found difficult to decrease the content of organic acids even through high temperature incineration. In order to prevent the nuisances of these gases to the environment and the furnace itself, the present furnace volume design or other factors effective to decrease the content should be discussed.

1. Introduction

Recently, many municipal refuse incinerators with perfect performance are going to be built in the cities or in the suburbs not so far from the center of the cities in every country, in order to reduce the distance of refuse transportation. On the other hand, groups of apartment houses as well as the department stores are going to have their own incinerators, and special incinerators to treat special factory refuse which tends to increase.

These trends make it indispensably important to have complete information and discuss the counter-measures for the nuisances due to smoke, noise, smell or dust from the incineration plants. Without these informations, it is difficult to draw up the basic policy for public nuisance and to promote the municipal refuse treatment business with full understanding by the people.

As a part of the activities to prevent atmospheric air pollution, the Department of Public Nuisance, the Tokyo Municipal Government had a comprehensive investigation concerning refuse property,

operating condition and smoke property and ash property, as regards incinerators of various types and sizes selected in Tokyo, in 1966. Such extensive investigations which give synthetic informations are few in this country or even in foreign countries.

The objects of this paper are to publish the data from these tests and to reexamine the present design systems of refuse incinerators.

We treat in this paper only the smoke and ash properties of refuse incinerators, and omit the water pollution and noise problems, through they are equally important for public nuisance.

2. The present design system of refuse incinerators

2.1 The classification of incinerators

The furnaces of the refuse incinerators are divided into two types, the batch combustion type and the continuous combustion type, depending on the way of combustion.

The incinerators of batch combustion type usually have refuse inlets with removable doors on the top of the furnaces. From these inlets refuse is charged into the furnaces intermittently. At the bottom of the furnaces horizontal or inclined rigid burning grates are set, through which the ash is taken out. Sometimes, the combustion air is forced

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through these grates. The agitation of fire bed and the ash handling of most incinerators of this type are manual. And both the burning and sanitary conditions are sometimes extremely undesirable, and often cause public nuisance problems, though this type is attractive because of low price. So, this type of incinerators will decrease in number as big plants, and they will be limited to small incinerators.

In the continuous combustion type, the refuse is supplied to the furnaces through hoppers, transferred continuously on mechanical stokers, during which the refuse is dried and agitated and completely burned to ash, which is taken out mechanically. Continuous combustion is an indispensable condition both for effective operation of exhaust gas treatment devices and for stable control of combustion conditions.

Fig. 1 (a), (b) illustrate typical examples of the batch combustion type and the continuous com-

(a) Batch combustion type

(b) Continuous combustion type
Fig. 1 Types of incinerators

bustion type.

The heat recovery (or gas cooling) unit and the flue gas treatment apparatus, which follow the furnace, are of various types.

As a simplest flue gas treatment device, there is the shower dust collector; it is often used in combination with the batch type incinerators, though this type can collect comparatively large size dust only. Further, there are the venturi type, the multi-stage type and the Doil type scrubbers, which make use of water to catch dust. All these types are called "wet type" dust collectors. Some of them have high dust collecting efficiency, and all wet type collectors can be expected to make some degree of noxious gas absorption. But this type can not be called favorable flue gas treatment units, because of the defects, such as corrosion of the exhaust duct system due to the decrease of flue gas temperature, intricacy of water treatment units and the decline of smoke diffusion characteristics due to the gas temperature decrease.

These troubles are absent in "dry type," that is, mechanical and electric dust collectors. These two collectors are combined in the refuse incinerators of large cities. In the case of smaller cities, the mechanical types are usually adopted. In both cases, on account of the necessity to keep the flue gas inlet temperature from 250°C to 320°C to protect metals from high temperature corrosion, the water heater, gas air heater, water spray gas cooler or steam generator should be installed between the furnace and the dust collector. In case the heat recovery is important, the main part of gas cooling is carried out in the steam generator. And in other cases the water spray gas cooler plays an important role.

2.2 The basic idea of present incinerator design

1) The heat engineering design

Before designing a refuse incinerator, it is necessary to know the range of variation of refuse property—represented by such as the low calorific value—and refuse quantity to treat (The design "range" instead of design "point" is necessary for satisfactory operation of incinerators). And to decide these design range, it is necessary not only to know the present data (of four seasons) on the refuse collection area for the incinerator to be designed, but also to predict the change of population and the living standard in the area, as is usually done in city planning.

For the next stage, temperatures of various parts of the incinerator must be estimated. For example, in an incinerator illustrated in Fig. 2 (a), it is usual to set the outlet temperature of the

furnace at 750~950°C (if the temperature is lower, unresolved organic gases or tar cause unpleasant odor and other public nuisances, and if the temperature is higher, melted ash attaches in exhaust gas duct system and injures the functions of devices in the duct system). For the inlet of the dust collector, 250~320°C is usually estimated to prevent both high temperature and low temperature corrosions (as stated before). The temperature of fresh air supplied to the furnace is taken at between 200 and 250°C. The higher this temperature, the higher the grate combustion rate rises, which leads to a reduction of the size of incinerators and causes a decrease of subsidiary fuel oil consumption. But, too high fresh air temperature causes high temperature corrosion or burnout of air heater metals.

After these conditions have been determined, the means of refuse drying in the furnace is decided, and the air excess ratio for combustion is fixed, and by satisfying the heat balance in the furnace, the quantities of subsidiary fuel consumption and cooling fresh air are calculated (sometimes flue gas is used to cool the furnaces). Heat necessary to cool the flue gas exhausted from the furnace is accurately estimated for various refuse properties [Ref. (1)]. Calculated results of fresh air and flue gas volumes as well as the fuel consumption are illustrated in Fig. 2 (b).

The calculation of heat is possible only in the

Fig. 2 Characteristics of a refuse incinerator

case of continuous combustion type incinerators. For the batch type, the quantitative estimation itself is difficult, and dimensions of every part are designed empirically.

2) Design of every part of incinerators

a) Furnace

In the case of continuous combustion type, the grates are usually composed of three blocks, drying, burning and after-burning grates. Because the grate combustion rate decreases with the air preheat temperature and the calorific value of refuse, the total grate area is decided usually by the condition that the furnace keeps the designed capacity even for refuse of the previously determined lower limit quality. The value of the grate combustion rate is taken at 200 to 250 kg/m² hr, under the conditions of 250°C preheated fresh air and 600 kcal/kg refuse low calorific value [Ref. (1)].

The volume of the furnace should be decided on the contrary under the condition of treating refuse of upper limit quality. The furnace load (the heat produced by fuel in the unit volume of the furnace in unit time) is usually taken at 13~15×10⁴ kcal/m³ hr for 1000 kcal/kg refuse, though it is taken much lower when especially long flame fuels are to be burned.

In the batch combustion type, taking into account the variation of burning velocity and the lack of the air preheater, the grate combustion rate is taken at around 150 kg/m² hr, and the furnace load at between 8 to 10×10⁴ kcal/m³ hr⁽²⁾.

b) Accessory apparatus

The temperature of metal parts of the air heater, water heater, boiler and the dust collector, which are in contact with the flue gas, should be kept in the range 200~300°C. Even in the case of special steel, such as SUS 27 (Ni, 8.0~11.0%; Cr, 18.0~20.0%), it is recommended to keep the temperature under 500 or 550°C, and to pay attention to the thermal stress corrosion.

As for the water spray gas cooler, it is indispensable to design a sufficiently large cooling chamber volume, the cooling load of which should not exceed 6×10⁴ kcal/m³ hr. Further, to keep good spray condition throughout the necessary cooling load region, the application of high pressure recirculation type spray nozzles is recommended.

It is important to design the exhaust gas duct so as not to accumulate dust, not only for the purpose to keep the normal performance of equipments in the duct sys-

tem, but also to protect materials of the duct from corrosion.

In the following sections, the results of smoke tests of many incinerators including those designed to have excellent performances on the present design idea stated above are given. And based on these results the problems of the present design policy are discussed.

3. The smoke properties of refuse incinerators

3.1 General plan of the measurements

1) Types of incinerators tested

Fifteen plants in the Tokyo Municipal area are selected for the measurement, and the results of the typical 10 incinerators are listed in Table 1. In the first line the types of incinerators are listed (the names of the manufacturers of the plants are omitted). The first column of the continuous combustion type gives the results of an excellent performance incinerator newly designed, though the heat from the boiler is not utilized. The second column is an example of wrong design, which suffers much air leakage; moreover, the induced draft fan is occasionally stopped due to the erosion by water particles from the wet type dust collector. The third column shows the results of an incinerator of good performance but comparatively small capacity. Superiority or inferiority of the furnace designs can be judged from the results of furnace outlet temperature fluctuations. The temperature fluctuation of the second column furnace is considerable, and sometimes the temperature drops to lower than 750°C. The first and third column furnaces are of superior performance. So, many furnaces of these types will be manufactured hereafter.

For the batch combustion type, relatively large furnaces (1st and 2nd columns) and relatively small furnaces (3rd and 4th columns) are selected.

Three different capacity furnaces are selected from among the private incinerators.

The description or outline of each plant is also listed in Table 1.

2) Refuse property

In the municipal refuse, one which is produced from the kitchen, is called garbage, and the rest is called rubbish. To simplify and rationalize the refuse collecting system, the two refuses are collected in mixture in many cities, which is called mixed refuse. Thus, the municipal incinerators treat mixed refuse, and other private incinerators treat mainly rubbish.

The samples of refuse treated are extracted during every test, the results of which are listed in Tables 1 and 2.

As the refuse property changes with season; strictly speaking, the year-round tests are necessary for refuse incinerators. Though our measurements extended from September to March, i.e., the period which covers the most part of the season in which the air pollution is a matter of consequence, our result can be considered to give good informations as far as the public nuisance is concerned.

3) The items investigated

The operating conditions such as the temperature fluctuations of various parts of furnaces as well as the quantities of refuse are recorded. Concerning the smoke property, the concentrations of component gases, the quantities and grain size distributions, moreover, the components of dust in flue gas are measured. Further, the combustible matter content of ash, and for some incinerators the waste water property (most part of which was from the flue gas coolers or from the wet type dust collectors) are tested.

3.2 The test results

3.2.1 The concentration of noxious gases

The concentrations of noxious gases are influenced considerably by whether incineration is continued at high temperature in the furnace or not. Fig. 3 illustrates the comparison of the furnace outlet gas temperature fluctuations of the typical continuous combustion and batch combustion incinerators. We can see the distinct merit and demerit of the two combustion systems. The results of each noxious gas are as follows.

1) HCl gas: Hydrochloride gas is produced from vinyl chloride independently of the types or

Table 2 Components and calorific values of combustible matter of refuse

	%, kcal/kg					
	C	H ₂	O ₂	N ₂	S	Low calorific value
Mixed refuse	45.2 ~52.1	5.3 ~6.7	40.4 ~47.8	0.6 ~1.9	0.3 ~0.5	3300 ~5700
Rubbish	44.9 ~49.1	6.2 ~7.1	41.8 ~47.2	1.0 ~2.1	0.3 ~0.6	3500 ~5750

Fig. 3 Flue gas temperature at the furnace outlet

Table 1 List of integrated test results of smoke property of refuse incinerators
 (Smoke regulation law: Subject of regulation: Grate area, over 5 m² Discharge limit: Dust content 0.7 g/Nm³ SO₂+SO₃ 0.22%)
 (Smoke control ordinance: Subject of regulation: Grate area, from 0.5 m² to 5 m² Discharge limit: Dust content 1.0 g/Nm³ SO₂+SO₃ 0.22%)

Measurements	Municipal refuse incinerators										Private refuse incinerators		
	Batch combustion type										Department store	Recreation ground	Apartment houses
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
Outline of the plant	Continuous combustion type										Batch combustion type		
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
Operating condition	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
Refuse property	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
Property	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types
	Types	Capacity t/hr	Grate area (m ²)	Furnace vol. m ³	Subsidiary fuel	Flue gas cooling	Fresh air supply	Material	Stack	Size	Height	Top dia.	Types

Results of the

Flue gas		Stack inlet	300~320	120~130	210~340	150~200	150~200	150~200	(At collective smoke duct) 150~540	(At collective smoke duct) 280~400	160~470	(at stack) 210~300	(at stack) 240~360
Air excess ratio	Furnace outlet	—	—	1.5~2.1	1.8~2.1	—	—	—	—	—	2.6~4.3	—	1.2~2.0
	Stack inlet	—	—	2.7~4.2	2.6~2.9	2.3~9.5	3.2~7.1	—	3.5~4.0	4.9~9.9	5.4~11.4	—	4.0~10.0
Contents %		NH ₃	0.00015~0.00003	0.0003~0.0032	0.0001~0.0011	0.0060~0.0210	0.0030~0.0240	0.04~0.05	0.0009~0.0115	0.0085~0.0300	0.0001~0.0006	0.0060~0.0270	0.0007~0.0012
		HCl	0.0064~0.0238	0.0063~0.0097	0.0026~0.0180	—	—	—	0.0024~0.0045	0.0027~0.0034	0.0068~0.02510	0.0010~0.0023	0.0230~0.1140
		SO ₂ +SO ₃	0.0021~0.0062	0.0012~0.0024	0.0096~0.0310	0.0007	0.0008	—	0.0061~0.0074	0.0025~0.0035	0.0006~0.0016	0.0010~0.0026	0.0043~0.0097
		NO+NO ₂	0.0047~0.0096	0.0023~0.0042	0.0085~0.0210	—	—	—	0.0066~0.0076	0.0070~0.0382	0.0023~0.0030	0.0066~0.0127	0.0038~0.0049
		R-CHO	0.0003~0.0007	0.0012~0.0027	0.0015	—	—	—	0.0016~0.0026	0.0056~0.0079	—	0.0059~0.0095	0.0107~0.0155
		R-COOH	0.0047~0.0106	0.0090~0.0110	0.0101~0.0150	—	—	—	0.0065~0.0080	—	0.0055~0.0095	—	0.0160~0.0163
		CO ₂	—	4.2~6.7	4.9~5.9	2.2~5.2	1.8~3.5	—	3.5~5.2	1.5~3.0	0.6~2.2	—	2.8~4.2
Dust property	O ₂	—	—	13.3~16.2	13.2~14.2	12.8~18.9	16.0~18.4	—	15.1~16.0	17.0~19.0	17.5~19.4	—	15.8~19.2
	CO	—	—	0	0	0.3~0.7	0.5~0.7	—	0	0	0	—	0
	N ₂	—	—	79.6~80.0	80.0~80.9	79.9~80.0	80.0~80.5	—	79.5~80.5	79.6~80.0	79.2~80.0	—	79.0~80.0
	H ₂ O	—	—	16.3~18.0	35.0~39.9	—	25.0	—	6.7~14.9	12.7~13.8	4.9~5.8	2.4~4.4	5.5~15.6
	Dust content inlet (g/Nm ³)	1.59~1.66	0.22~0.76	0.22~0.76	2.03~3.25	0.5~0.60	0.86	—	0.30~5.71	0.19~1.41	0.42~3.95	—	0.08~1.64
	Furnace outlet	0.03~0.06	0.12~0.29	0.12~0.29	0.69~0.88	0.2~0.3	0.4~0.5	—	—	—	0.05~1.86	—	—
	Specific weight (kg/m ³)	—	3.03	—	2.62	—	—	—	2.62	2.31	2.96	2.37	3.42
	Appearance	—	—	—	0.42	—	—	—	0.44	0.47	0.31	0.38	0.46
	S ₂ O ₂	10.38	37.78	—	34.03	—	—	—	51.46	49.38	—	—	30.64
	CaO	10.84	15.41	—	12.71	—	—	—	18.23	13.29	—	—	9.97
Components %		Al ₂ O ₃	5.46	13.32	15.71	—	—	—	9.49	10.43	—	—	27.16
		Fe ₂ O ₃	1.84	6.15	7.85	—	—	—	5.09	4.63	—	—	11.80
		SO ₃	19.87	7.23	4.18	—	—	—	3.54	0.55	—	—	4.59
		Cl	—	—	—	—	—	—	3.46	1.58	—	—	2.47
		Combustible matter	12.29	5.81	14.50	—	—	—	3.68	14.47	—	—	11.56
Combustible matter in ash		14.6	14.4	—	12.6	—	—	—	14.3	—	12.5	—	—
		Water from dust collector	—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—	—	—	—	—
Dust collecting % eff.		—	—	34	—	152	48	—	—	—	70	—	—
		—	—	7.0	—	2.2	7.7	—	—	—	5.8	—	—
		above 97	45~60	—	67~83	50	55	—	—	—	77~89	—	—

operation conditions of furnaces. Table 1 shows that the concentration is high when rubbish is burned. (Some investigators concluded that sodium chloride also produces HCl in high temperature refuse combustion, but it is not clear from our results.)

The concentration of HCl in the flue gas of municipal incinerators is usually less than 200 ppm, so, attention is to be paid rather to high temperature or stress corrosion of metals. But, in case the concentration rises to 2000 ppm as in the case of incinerators of department stores, it is not permissible from the view point of public nuisance; it is hopeless to select any suitable metals. (Measured by mercuric thiocyanate method)

2) Sulphur oxides: Fig. 1 indicates that the total of ($\text{SO}_2 + \text{SO}_3$) in flue gas is less than 100 ppm (measured by JIS K 0103). As Table 2 shows, sulphur content in refuse is usually 0.05 to 0.2%, from which the concentration of sulphur oxides is estimated to be 100 to 400 ppm. The measured value is only 1/4 of the estimated. In Table 3, the sulphur content in refuse is divided into combustible and incombustible compounds (such as the family of sulphates). From this table, a half of the sulphur content is considered to be left in ash. Further, as can be seen in Tables 1 and 4, dust or fly ash especially of small size absorbs much SO_3 (SO_3 is produced in flue gases which contain much steam). By all accounts, the most part of all sulphur content in refuse is left in ash or fly ash, and about 1/4 is discharged into the atmosphere.

3) Ammonium: Ammonium is not produced

by rubbish combustion. In the case of garbage combustion, the concentration of ammonium is remarkably reduced as the furnace outlet temperature rises (Table 1). In Fig. 4, the relation between the concentration and the furnace outlet temperature is illustrated. At the furnace temperature over 750 °C, the concentration is extremely reduced. The data in Fig. 4 which indicate low concentration even at low furnace temperatures concern rubbish combustion. (Measured by Nessler method.)

4) Aldehyde: This is extremely reduced also due to high temperature incineration. (Measured by iodine method.)

5) Organic acids: The concentration of organic acids (measured as CH_3COOH) does not seem to have any distinct relation to the furnace outlet temperature. As the total content of organic acids is usually not less than 100 ppm, attention should be paid to this content as a cause of metal corrosion, just as in the case of HCl. (Measured by neutralization method.)

6) Nitrogen oxides: The content of $\text{NO} + \text{NO}_2$ increases rapidly over 900 °C furnace outlet temperature, and reaches 200 ppm at 1000 °C. (Measured by Salzmann method.)

To sum up the above, the total content of noxious gases in exhaust gases sometimes reaches 2000 ppm (mainly due to HCl) in rubbish combustion. This is not only serious in view of public nuisance, but also it renders the furnace design almost impossible due to the metal corrosion. In the case of municipal refuse incinerators, the total content can be kept under 500 ppm. But the test results showing that it

Table 3 Sulphur in refuse

	Rubbish		Municipal refuse				
	From apartment houses	From department store	Mixed refuse	Mixed refuse	Mixed refuse	Rubbish	Garbage
Total sulphur (A)	0.05	0.20	0.68	0.04	0.08	0.04	0.27
Combustible sulphur (B)	0.01	0.40	0.04	0.01	0.03	0.02	0.02
Incombustible sulphur	0.04	0.16	0.64	0.03	0.05	0.02	0.25
B/A × 100	20	20	6	25	37	50	7

Table 4 An example of dust components eliminated by dust collectors

Continuous combustion type		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	ZnO	CuO	PbO	V_2O_5	ig loss
	Electric	10.38	0.48	5.46	1.84	0.10	2.39	10.84	12.07	13.79	1.48	19.87	4.49	0.30	1.68	under 0.1	12.29
Batch combustion type	Mechanical	37.78	1.28	13.32	6.15	0.16	2.87	15.41	3.16	2.75	1.71	7.23	2.11	0.18	under 0.1	under 0.1	5.81
	Sedimentation by gravity	30.64	0.28	9.97	4.59	11.80	27.16	0.61	1.05	2.47	3.53	1.95	11.56				
Batch combustion type	Sedimentation by gravity	49.38	0.32	13.29	0.55	4.63	10.43	0.49	0.67	1.58	4.75	21.47	14.47				

is difficult to reduce organic acids even through high temperature incineration, and that nitrogen oxides are produced by high temperature incineration raised new problems for the research and design of future incinerators.

3.2.2 Dust or fly ash

The results of the measurements can be summarized as follows.

1) The dust and fly ash content in the flue gas of the continuous combustion type is nearly equal to that of the batch combustion type. But as the latter type burns a unit weight refuse with twice as much flue gas as the former, the dust produced by unit weight refuse of the latter is to be twice as much as that of the former. In Table 1, time average is taken for the dust content, but the value considerably fluctuates in the case of batch combustion type.

2) Fig. 5 illustrates examples of grain size distribution, which show that the ratio of relatively large size grains increases when the quantity of dust increases.

3) Table 1 and Fig. 6 illustrate that the electric filter and the Doil scrubber exhibit satisfactory dust collecting performance. But, as the Doil scrubber belongs to wet system, it is unfavorable for maintenance and for water treatment. Fig. 5 shows the result of measurement at the inlet and outlet of dry system dust collectors. The mechanical dust collectors always discharge nearly 0.7 g/Nm^3 (dis-

charge limit of Japanese standard) irrespective of dust content at the inlet, because, if the dust content changes, the content of larger grain size changes, but that of smaller grain size dust which can not be caught by mechanical filters remains unchanged.

Fig. 5 Grain size distribution of dust at the furnace outlet

Fig. 4 The relation between the flue gas furnace outlet temperature and the component gas concentration

Fig. 6 Dust collecting efficiency

4) The chemical contents of dust are listed in Table 4. As smaller grain size dust contains more SO_2 , dust accumulation on the metal parts should be avoided.

3.2.3 Ash from after-burning grates

The combustible matter content in ashes was 12 to 15% (Table 1). But as the heating temperature in the measurement was kept by mistake at 800°C , it is difficult to compare the result with the standard of the Ministry of Welfare⁽³⁾ (the limit of the combustible matter content in ash is 10%, under the condition of heating temperature of 650°C). But it seems probable that the measured values are nearly equal to, or a little more than, the limit. As no mechanical defect can be found in the after-burning devices, more careful operation to keep ash for enough time on the after-burning grates is desirable.

4. Design problems from the viewpoint of smoke property

4.1 Subjects for study in the future

The following problems should be solved to apply the test results in the actual design.

1) Reexamination of the test methods

As refuse is a special fuel which has not yet been studied on the scientific basis, there are many problems in the test methods. For instance, the rules for sampling should be reexamined. A reliable sampling method should be standardized by examining the relation between the volume and the sample grain size. Further, in measuring dust contents in flue gas. The present standard is based on the dry flue gas. But, considered from smoke diffusion theory, it is not proper to extend the test code for flue gas of usual fuel to the test of refuse flue gas which contains 30 to 40% steam. As the present standards for public nuisance based on the discharge contents tend to be changed to those based on environmental contents, and further, the present limit of dust content, 0.7 g/Nm^3 , is considered too loose for big cities, the new standards should be established taking this state of affairs into account.

Furthermore, the ash property is controlled at present by the combustible matter contents. Though this value seems to be important for calculating the heat balance of furnaces, the amount of soluble combustible matter which is actually noxious as land

Table 5 Content of dust discharged from dry type dust collectors

g/Nm ³		
Furnace outlet	Mechanical dust collector outlet	Electric dust collector outlet
1.4~4	→0.5~0.7→discharge	
1.2~4.4	→0.4~0.8→	→0.02~0.06→discharge

fill is only several per cent of the total combustible matter⁽⁴⁾. As the correlation between the noxious and the total combustible substance is not definite, it is desirable to establish a test standard to measure the noxious combustible substance directly.

2) Relation of gas property and furnace type

As limited incinerators in Tokyo are selected in our test, the influences of all types which exist in every city are to be examined. Especially, as to the contents of organic acids, nitrogen oxides and hydrochloric acid gas, the influences of type of furnace are important.

Above all, the following items concerning the furnace type should receive attention.

i) Whether refuse is transferred in the furnace parallel to the flue gas stream or not.

ii) Whether the combustion chamber is water cooled or not. The item i) yields the difference in heating history of refuse and in the condition of gas flame combustion in the furnace. The item ii) yields the difference in the temperature distribution in the furnace due to the difference in the furnace cooling mechanism.

A quite new type of incinerator should also be developed. For instance, if it is possible to burn chloric vinyl refuse with high temperature short flame without water vapour to produce chloric gas instead of hydrochloric acid, the selection of materials of the furnace will become easier, and our effort can be concentrated on the elimination of chloric gas.

Finally, as the result of our test showing that it is difficult to decompose organic acids at the furnace temperature, 750 to 900°C , is incredible from our experience, more discussions will be necessary to solve the problems, for instance, whether it is effective to keep flue gases longer in the furnace or not.

4.2 The treatment of chloric vinyl

Though the content of chloric vinyl in present city refuse is not so much, the frequent inspections of the content are desirable. And as to plastic refuse which is discharged from some special factories it is desirable to make some special treatments, such as to dump it in pressed packages into deep sea.

To burn chloric vinyl, it is necessary to select materials for incinerators, to devise a new blower

Fig. 7 Jet blower

such as the jet blower (Fig. 7) instead of usual induced draft turbo-blowers, to research on maintenance, as well as to investigate the forementioned special burning method and gas absorption devices. As the water treatment will also be indispensable, this method of treatment will be expensive.

4.3 The improvement of batch combustion type incinerators

As illustrated in Fig. 3, to keep up high temperature incineration is difficult for the present batch type, and it is desirable to improve their performance without greatly increasing the present cost. With the principal object set on the improvement of combustion system and labor environment, the following items are considered as actual measure.

1) The whole furnace should be contained in a steel casing to prevent the air leakage.

2) Usually, refuse is charged into the furnaces every 30 to 60 minutes, so the drop in furnace temperature in that period is inevitable. Further, owing to thick fire bed, human manipulation is necessary, which causes air leakage and makes the environment extremely unsanitary. Several measures to improve such conditions are considered. Among them, an apparatus to send refuse from the hopper into the furnace and take out ash from the furnace mechanically, as in Fig. 8, in order to reduce the time interval of sending refuse to 10~15 minutes, and to stop manual handling.

3) The flue gas air heater should not be omitted to keep high grate combustion rate.

4) As the fluctuations of flue gas volume and temperature will be decreased by means of the measures 1) to 3), the dry type dust collector can be adopted effectively, if necessary.

4.4 Temperatures of each part in incinerators

Though the temperature setting of the present design is found almost proper, there are some problems concerning the upper temperature limit at the com-

bustion chamber outlet. That is, though the limit 950°C seems to be suitable to prevent dust melting, this limit is found to be slightly higher considering the content of nitrogen oxides, as in Fig. 4. The upper limit is desirably to be slightly decreased to 900°C. This is also effective for the maintenance of the gas air heater. The increase of flue gas volume due to the cooling air is such that the decrease in the capacity of devices in the flue gas duct is unimportant. But, as stated in section 4.1, an independent conclusion must be extracted for the furnaces with water cooled walls.

Further, the measure of decreasing the content of organic acids, such as to hold flue gases longer in the furnace, must be studied and applied to the furnace design.

4.5 Dust collectors

Though the superiority of the dry system is obvious for refuse incinerators, the following are especially important points.

1) In case the mechanical filter alone is used, as dust discharge is nearly equal to the limit of the standard, it is important to design the inner cylinders of multi-cyclone as small as possible, provided that it does not cause ash choking (300 to 350 mm diameter is recommended), and to design so as to make the performance independent of the gas volume fluctuation (for instance, to put several multi-cyclones in parallel, a part of which is shut if the flue gas volume is extremely decreased, if necessary, is considered).

2) The electric filter is indispensable to keep satisfactory dust collecting performance. But, as the electric filter is still expensive, the development of simple electric filter of medium performance and of medium price is desirable especially for small cities.

5. Closing remarks

Authors are in doubt about the generality of their conclusions, as the tests were carried out on restricted conditions, though the measurements were executed on as wide scale as possible for the Tokyo Municipal Government. They fear also they possibly committed many mistakes, because a wide range of knowledge concerning mechanical, electric as well as chemical engineering is necessary to judge the results of the measurements. They hope the engineers concerned will kindly inform authors of any mistakes they found.

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Fig. 8 An example of improvement of batch type incinerator

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