PRELIMINARY STUDIES ON SMOKE FILTERING FOR A FIRE ENGINEERING LABORATORY

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ABSTRACT

Regulations on dark smoke emission and local available smoke treatment plants for chimneys and exhaust structures were surveyed. Smoke treatment methods were briefly reviewed. Three types of smoke filters, namely aluminium mesh surface panel filters, activated carbon insert induced panel filters and charcoal panel filters were investigated in a laboratory-scale rig. It is found that the effect of the studied smoke treatment plant is satisfactory. The total cost of this plant including metal housing and filters would be cheap.

1. INTRODUCTION

Air pollution has been a matter of public concern in recent years. As in other big cities, the air quality in Hong Kong (now the Hong Kong Special Administrative Region) is getting critically poor. A possible cause is the dark, black or even toxic smoke emission from vehicles and factories. This may lead to acid rain and smog as occurred in some heavy-industry cities. These are warnings that urge people to take a more serious attitude towards air pollution control. To protect the environment, the quality of the smoke generated should be improved. As there is also a demand for cleaner air, the trend of using a smoke treatment plant that purifies airborne nuisance, neutralizes toxicity and filters out dust and soot, etc. will become more important and popular.

Smoke [1,2] refers to dust or fumes; and soot, ash, grit or gritty particles emitted in smoke or steam. With regulations set up on dark smoke emission, legal action will be taken against offenders by the local Environmental Protection Department (EPD). Moreover, people should be aware that rules are getting stricter.

There are still smoke exhausts from different industrial buildings though lots of industry had been moved out of Hong Kong. Failure to comply with the regulations is believed to give [e.g. 3] unnecessary emissions of smoke, grit and dust from these buildings, causing high levels of particulate over Hong Kong. Soiling of the environment, reduction in visibility and deposition of sooty materials on buildings and clothing are likely to be resulted. Other pollutants, such as sulphur dioxide [3,4], may even lead to lung and respiratory diseases such as bronchitis and emphysema.

Smoke treatment plants should be installed to stop dark smoke emission. Building services engineers are responsible for improving this situation. The motivations should not be only for meeting those regulations and ordinances, but also for environmental protection and public health. It is therefore worthwhile to study the smoke treatment plants.

In this paper, the regulations on smoke emission are reviewed. The functions and theories of smoke treatment methods generally adopted locally are described. Experiments were carried out on the performance of some smoke filters. Application to a fire engineering laboratory in The Hong Kong Polytechnic University (PolyU) has also been considered.

2. LOCAL REGULATIONS ON SMOKE EMISSION

Dark smoke emission is one of the major factors causing air pollution. The objective of air pollution control is to reduce the negative impact of air pollution to human activities. In Hong Kong, dark smoke emission from any building is restricted by the Air Pollution Control (Smoke) Regulations [2]. It was first made [3] on 27 July 1983 under the Air Pollution Control Ordinance [1] and came into operation on 1 October 1983. The provisions were materially the same as originally provided under the repealed Clean Air Ordinance enacted in 1959. The main objective of the regulations is to set a limit on dark smoke emission from furnaces, engines, ovens, and industrial plants.

Some general information in the Air Pollution Control (Smoke) Regulations [2,3] are described as follows:

- Definition

  According to Regulation 2, "dark smoke" is determined by the measurement of Ringelmann Chart [5] or an approved device (which includes Micro-Ringelmann Chart, Miniature Ringelmann Chart, Telesmoke and Smokescope). The color of the "dark smoke" would be compared with the scale in Ringlemann Chart. If the color appears to be as dark as (or darker than) shade number 1 on the Ringelmann Chart, the smoke emitted would be defined as "dark smoke".

  "Black smoke" is defined in the International Organization for Standardization ISO 9835: 1993(E) [6] as strongly light-absorbing, particulate material suspended in the ambient atmosphere and the major contributor to black smoke is soot particles, i.e. particles containing carbon in its elemental form. Note that black smoke emission is prohibited in Hong Kong.

- Measurement of dark smoke

  Smoke is measured by authorized officers of the EPD. The Ringelmann Chart is placed at an appropriate distance [5] towards the smoke discharged from the source such as a chimney. The darkness of smoke is determined by comparing the shade of smoke to the shades on the Ringelmann Chart. If the shade is as dark as or darker than shade number 1 on the Ringelmann Chart, the smoke will be classified as dark smoke.

- Restrictions on dark smoke emission

  As mentioned in Regulation 3 [2,3], for any chimney or relevant plant that emits dark smoke, the following restrictions on duration of dark smoke emission should be followed:

  - 6 minutes in any period of 4 hours; or
  - 3 minutes continuously at any one time.

  The responsible person for the operation of any chimney or relevant plant who contravenes either of the two requirements, commits an offence and is liable to a maximum fine of $20,000. Repeated offenders would be subject to more severe punishment, including 3 months imprisonment, and an additional fine of $100 for every one quarter of an hour during the whole or any part of which such offence is knowingly and wilfully continued.

3. BRIEF REVIEW ON SMOKE TREATMENT

There are different types of smoke treatment plants available in the market. They are categorized with respect to their performances, target substances, materials and working principles. However, all smoke treatment plants are subject to the same objective, i.e. air pollution control.

As mentioned earlier, the main factor contributing to the darkness of smoke is the concentration of soot particulates. Some equipment for removing dust and soot particulates are listed in Fig. 1 [7].

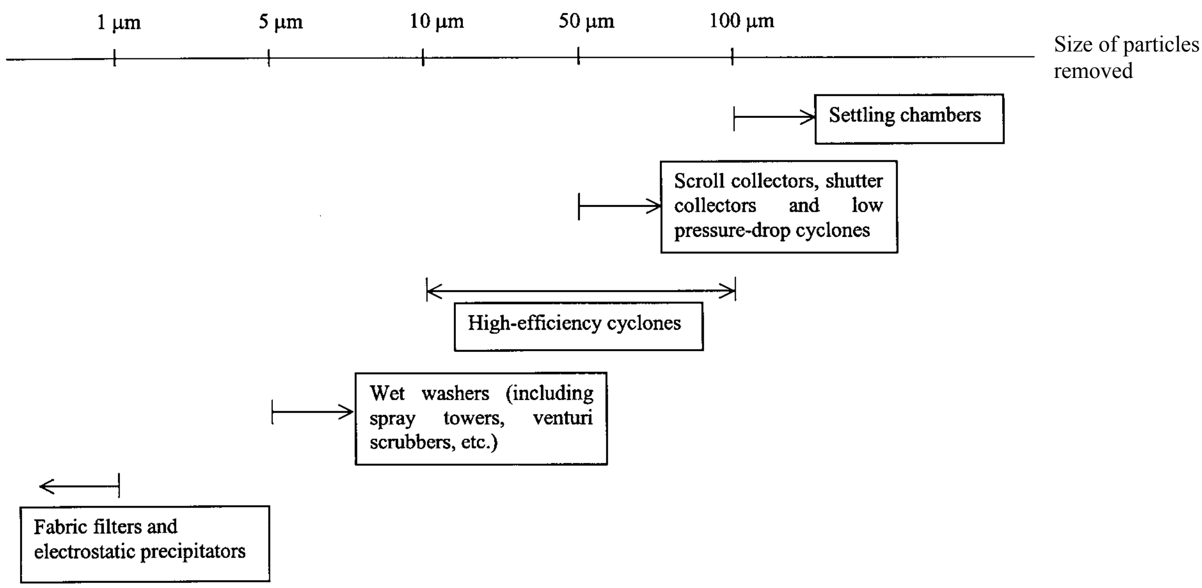

Fig. 1: Pictorial view of dust particulates removal equipment [7]

Some of them are only suitable for large-scale applications such as for tall chimneys at power generation plants. However, these criteria are not favorable for this study. Among those smoke treatment plants and devices available in Hong Kong, four types are chosen for further consideration. Information are provided by local suppliers.

- Custom mesh air filter

  This is the simplest type of air cleaning device. It functions by its mesh surface that traps and holds dust, dirt and other air contaminants. The arrestance is close to 80% for 5 μm particulate size. The advantages of this type of filter are low air resistance, easy to handle and maintain. It can be cleaned by flushing with warm or tap water. Basically, it is designed for permanent use. Filters in all sizes are available from manufacturers. Moreover, the cost of this type of air filter is cheap and the unit price is $80 to $120 depending on the size. As such filter is popular, standard size stocks are available at anytime.

  This kind of filter can be made by various types of material, such as aluminium and stainless steel. Aluminium construction is lightweight and the surface loading is minimized. However, stainless steel filters can operate at a much higher gas temperature. Although it requires more load supports, it is suitable for industrial use, especially for restaurant kitchens, because of its better corrosion resistance.

- Induced electrostatic filter

  This type of filter consists of two layers of electrostatic plastic fibres. As air passes through the grids, a static charge will be generated at these layers. In addition, a layer of expanded and corrugated aluminium is used together with a pad of special polyurethane. Being washable is one of the advantages of this filter. Its installation is also not complicated. Moreover, static electricity is naturally induced and no external power supply is needed. The dust arrestance can be up to 90%.

  For a 10” x 20” x 2” (i.e. 254 mm x 508 mm x 50.8 mm) induced electrostatic filter, the price is $2,000 and 8 weeks are required for delivery.

- Activated carbon filter

  A practical method of odour control by activated carbon has long been established. Up to 50% of the weight of the activated carbon of odours can be absorbed and retained in the vast network of extremely small pores within the body of carbon. One pound (or 0.4536 kg) of activated carbon with porous structure has a surface area of approximately 6,000,000 ft^2 (or 557,400 m^2). However, this filter is not designed for operation at high temperature. The efficiency would decrease dramatically when the gas temperature is over 50°C.

  The life cycle of activated carbon filter is not as long as the other media filters because the activated carbon functions whenever it is exposed to air. Moreover, it is recommended that the inserted activated carbon can only be washed once after certain period of operation. Further washing cannot refresh the ability of the activated carbon. Installation is as simple as the other ordinary panel filters.

  The price of this kind of filter is higher than those of the abovementioned. A panel filter of size 24” x 24” x 1” (i.e. 610 mm x 610 mm x 25.4 mm) costs $3,200, and 10 days are needed for delivery.

- Electrostatic precipitator

  This is generally regarded as one of the most efficient dust collectors [7]. It has many features which make it the only suitable choice for many applications involving fine particles and high-temperature gases. Electrostatic precipitators are used mainly for cleaning flue gases from coal-fired boiler plants, kiln gases from cement plants, and also the stack gases from municipal refuse incinerators. This type of smoke treatment plant can treat extremely high temperature smoke of up to 1,000°C, and it can deal with high volume flow requirement.

  The basic principle of electrostatic precipitation is to pass the dusty gas through a high voltage corona discharging zone, which contains a high concentration of ions. The dust particles would be attached by ions when passing through the collection zone, in which a voltage gradient is maintained, and subsequently move towards the earthed electrodes on which they are deposited and to be removed at intervals, usually by mechanical rapping.

Usually, electrostatic precipitator is supplied in a package including the prefilter, afterfilter, exhaust fan and housing. Careful installation is needed and external power supply is required for the operation of the precipitator. The price of this plant ranges from $28,000 to $32,000. Since the manufacturers are usually in the United States of America and the United Kingdom, the delivery will take about two months.

Based on the survey on local smoke treatment plants, one typical system of electrostatic precipitator is chosen to be described here. This system is suitable for restaurant kitchens and factories. The target removal substances are smoke, oil mist, dust, etc. and the size of the particulate ranges from 0.001 μm to 100 μm.

The cabinet comprises the aluminium mesh prefilter and afterfilter, ionizer and the collecting cell. The airborne particulate first passes through a mechanical prefilter that collects larger particles. The filtered air then passes through the ionizer, which imparts an electrostatic charge to the particulate. These charged particles are collected on grounded plates, and the cleaned air is then discharged out and/or re-circulated into the work environment.

4. EXPERIMENTS

Three panel filters were purchased for experimental studies:

- Filter A - Aluminium mesh surface panel filter, 610 mm x 610 mm x 50 mm thick
- Filter B - Activated carbon insert induced panel filter, 610 mm x 610 mm x 50 mm thick
- Filter C - Charcoal panel filter, 610 mm x 610 mm x 25 mm thick

Smoke cleaning efficiencies of the three filters and their combinations were tested. To examine the performance of the smoke treatment plant, three factors are concerned, namely the gas contents, optical density and smoke darkness. Different instruments were used for the measurement.

Dark smoke was generated in the smoke box, then passed through the treatment plant and delivered out. Gas contents and optical density were measured before and after treatment at the intake and exhaust points respectively of the duct works of the treatment plant. Rails were built inside the housing of the plant for inserting filters and the filters can be taken out easily for maintenance. The basic experimental setup is shown in Fig. 2.

The contents of the smoke were measured by a gas analyzer. The major gas components concerned are oxygen, carbon dioxide and carbon monoxide. The oxygen concentration y (in %), carbon dioxide concentration C (in %), and carbon monoxide level CO (in ppm) were measured automatically by the analyzer.

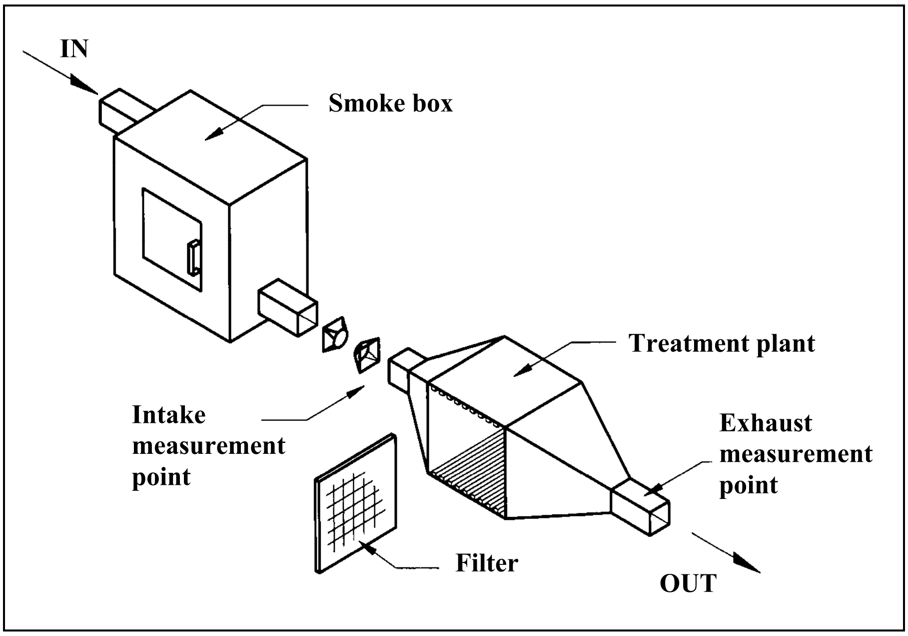

Fig. 2: The basic experimental setup

The setup for optical density measurement comprises a light source and a photo-detector. The light source applied is a laser beam. It is generally adopted because it is strong and can concentrate into a point target that is convenient for measurement. Light is received by the photo-detector which then converts the input signal, light intensity, into readable electrical voltage or current. Optical density D (in dBm^{-1}) can be calculated by the formula below:

$$D = \frac{10}{L}\log_{10}\left(\frac{I_0}{I}\right) \qquad (1)$$

where I_0 (in A) is the ambient detected current; I (in A) is the detected current when smoke passes through and L (in m) is the distance between the light source and the photo-detector.

For the optical density, particle visibility is an important factor. Particles large enough to be seen on furniture or floating in a ray of sunshine are in the size range of 50 μm or larger, although 10 μm particles can also be seen under favorable conditions.

The Ringelmann Chart was used to assess the smoke emission visually based on BS 2742: 1969 [5]. Darkness of smoke was compared with the standard shades of grey on the chart placed in a suitable position. Where possible, the general illumination of the sky should be uniform. If the sun is shining or the sky is bright on one side, the bright source of illumination should be approximately at right angle to the line of vision and not in front of or behind the observer. The shade number, namely the Ringelmann number, ranges from 0 to 4. Each shade is increased by 20% obscuration compared with the previous number. The shades of grey on the grey scale chart were obtained by cross-hatching in black on a white background so that a known percentage of the white was obscured. The Ringelmann number which most closely matches the darkness of the smoke, and the time and duration of the emission, should be noted. In favorable conditions, it is possible to estimate the smoke darkness to the nearest quarter Ringelmann number.

5. RESULTS

The experiments were basically kept under the same conditions. The ambient air temperature was 24°C. The fuel chosen for generating smoke is kerosene (50 ml) and the size of the fire container is 80 mm in height and 150 mm in diameter.

Measurements of gas contents and optical density before and after smoke treatment are listed in Table 1. A comparison of the cleaning efficiency of the filters and their combinations in percentage reduction of carbon dioxide, carbon monoxide and optical density is shown in Fig. 3.

The results for the smoke darkness determined by the Ringelmann Chart before and after treatment were observed. All the three filters were inserted in the treatment plant. It was observed that the smoke before treatment was close to shade number 4 and the treated smoke was lighter, in between shade numbers 1 and 2.

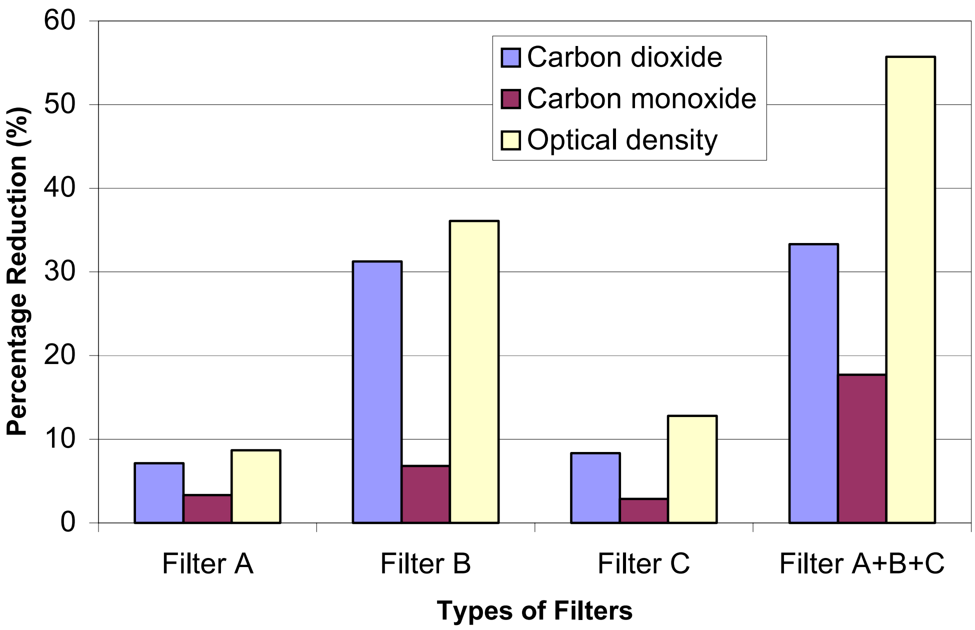

Fig. 3: Cleaning efficiency of filters for smoke treatment plant in percentage reduction

Table 1: Summary of results

	Filter A			Filter B			Filter C			Filter A + B +C		
	Intake	Exhaust	Difference / %	Intake	Exhaust	Difference / %	Intake	Exhaust	Difference / %	Intake	Exhaust	Difference / %
Temperature / °C	57	56	-1.8	56	54	-3.6	56	55	-1.8	56	54	-3.6
Oxygen concentration y / %	19.2	19.3	0.5	19.1	19.5	2.1	19.4	19.5	0.5	19.5	19.6	0.5
Carbon dioxide concentration C / %	1.4	1.3	-7.1	1.6	1.1	-31.3	1.2	1.1	-8.3	1.2	0.8	-33.3
Carbon monoxide level CO / ppm	181	175	-3.3	191	178	-6.8	175	170	-2.9	175	144	-17.7
Optical density D / dBm^{-1}	16.3	14.9	-8.6	15.4	9.8	-36	18.5	16.1	-13	16.6	7.3	-56

6. APPLICATION TO A FIRE ENGINEERING LABORATORY

The fire engineering laboratory of the Department of Building Services Engineering at PolyU was developed to carry out experiments on sprinkler, water mist systems, fire detectors and burning behaviour of materials. In certain experiments, smoke may be generated and this should be avoided in order not to pollute the environment.

When doing bench-scale experiment in such a laboratory located in the urban area, cleaner fuel should be chosen. Most of the smoke generated may not be very dark. Therefore, the above studied filtering plant is applicable. A suitable smoke treatment plant taken into account the nature of smoke generated and the capacity to be handled should be designed. The existing ductworks in the laboratory are shown in Fig. 4 and the size of the existing fan is 1 m^3s^{-1}. A smoke treatment plant can be installed at the exhaust point of the ventilation system. However, it is quite difficult to determine or eliminate the toxicity of smoke.

In conducting full-scale burning tests, there would be higher emission of dark and toxic smoke which may exceed the EPD limits and more serious problems may be encountered. A large-scale and sophisticated smoke treatment plant requiring a huge sum of investment should be installed to ensure better detection and control of both toxicity and concentration of smoke. Otherwise, the smoke darkness and toxicity from the exhaust cannot be totally reduced to meet the local regulations [2] and the health of people will be endangered. It is also one of the responsibilities of researchers to protect the environment and to ensure the health of citizens.

Thus, it may not be quite feasible to build full-scale burning facilities in the urban area, such as Hong Kong in considering the space, cost and environmental problems. Instead, careful selection on more suitable locations for installing full-scale burning facilities should be considered, such as in the remote areas in the Mainland.

7. CONCLUSIONS

A simple smoke treatment plant has been examined in this paper. The results support that this plant can reduce the pollution level to a certain extent. The optical density of the dark smoke was reduced by nearly one half when three filters were working together. Also, it is found that Filter B, the activated carbon insert induced panel filter, gives the best cleaning effect among the other filters. However, it can still be improved in order to cope with future development of the fire engineering laboratory. To achieve better performance, electrostatic precipitators and water mist systems are worth investigating in future works.

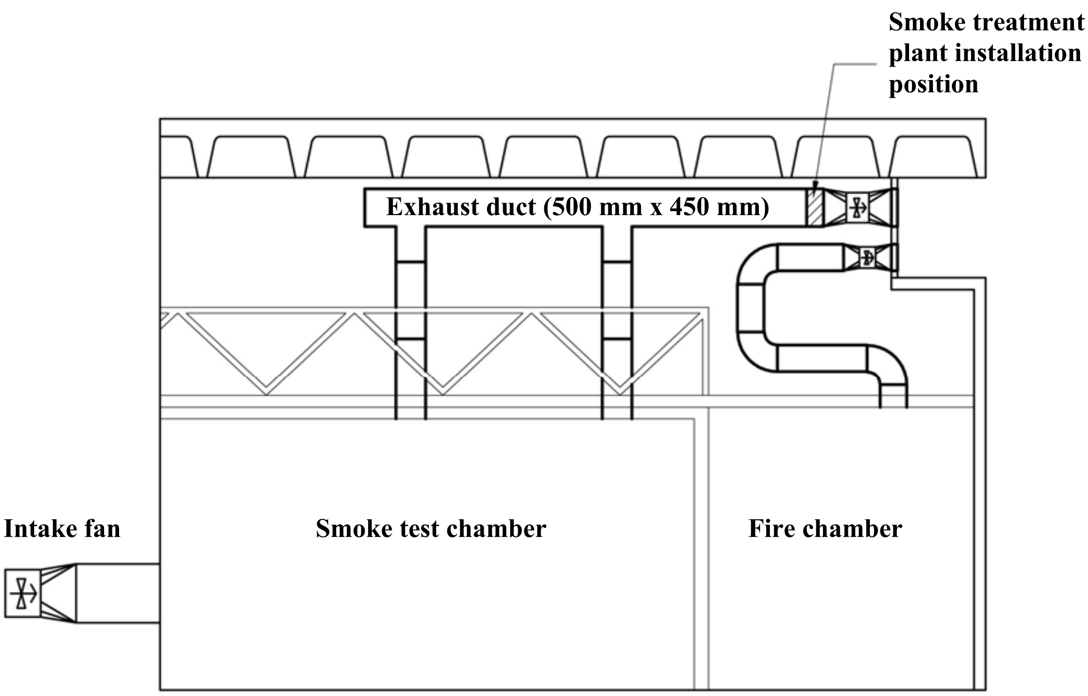

Fig. 4: Section view of the ventilation system at the fire engineering laboratory

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REFERENCES

1. Air Pollution Control Ordinance, Chapter 311 of Laws of Hong Kong, Section 2(3) of the Laws (Loose-leaf Publication) Ordinance 1990, Hong Kong Special Administrative Region, 30 June (2000).
2. Air Pollution Control (Smoke) Regulations, Chapter 311 Subsidiary Legislation C, Section 2(3) of the Laws (Loose-leaf Publication) Ordinance 1990, Hong Kong Special Administrative Region, 25 February (2000).
3. A guide to the Air Pollution Control (Smoke) Regulations 1990, Environmental Protection Department, Hong Kong, September (1991).
4. A guide to the Air Pollution Control (Fuel Restriction) Regulations 1990, Air Management Group, Environmental Protection Department, Hong Kong, March (1993).
5. BS 2742: 1969, Use of the Ringelmann and miniature smoke charts, British Standards Institution, London, U.K. (1969).
6. ISO 9835: 1993(E), Ambient air - Determination of a black smoke index, International Organization for Standardization, Geneva, Switzerland (1993).
7. C.J. Stairmand, "Equipment for air pollution control", Towards cleaner air: A review of Britain's achievements, Central Office of Information, Great Britain, pp. 22-28 (1973).