11.6 EMISSION CHRACTERISTICS OF FINE PARTICLES FROM COAL-FIRED POWER PLANTS

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Abstract: PM_{10} is one of the principal atmospheric pollutants, and it is mostly generated from coal combustion in China. These years much attention has been paid to study its formation and emission control. In this investigation, particulate emission control devices (PECDs) classification collection efficiency, particulate matter emissions and size distribution were determined experimentally at the inlet and outlet of PECDs at four different coal-fired power plants. In these power plants, one uses anthracite coal and the others use bituminous coals. Electrical Low Pressure Impactor (ELPI) with a sampling system, which consisted of an isokinetic sampler probe, pre-cut cyclone, two-stage dilution system and sample line to the instruments, were used to measure in situ. Size distribution is measured on the range from 0.03μm to 10μm in aerodynamic diameter.

Before and after all the PECDs, the particle number size distributions display the bimodal distribution which contained the fine mode and the coarse mode with a peak around 0.1μm and 1μm, respectively. On one side, the mass concentration of PM_{10} is mainly dominated by the particles which are larger than 1 μm; on the other side, the number concentration is dominated by the particles which are smaller than 0.1 μm. Before the PECDs, the mass concentration of PM_1 and $PM_{2.5}$ are about 0.6~6% and 16~24% of PM_{10}; furthermore, PM_1, $PM_{2.5}$ and PM_{10} are respectively about 0.1~0.85%, 1.7~5.7% and 14.1~35.8% of PM. After the PECDs, these numbers were changed as about 1.1~17.5%, 12~52.5%, 0.8~14.7%, 8.6~44.1% and 62~83.9%, respectively. The un-controlled emission factors and emission factors of PM are 44.15~129.32g/kWh and 0.068~1.11g/kWh, and which of PM_{10} are 6.23~38.25g/kWh and 0.042~0.72 g/kWh.

Electrostatic precipitator (ESP) collection efficiency of PM and PM_{10} is 99.0~99.89% and 98.2%~99.62%; bag-house collection efficiency is 99.94% to TSP and 99.76% to PM_{10}. The collection efficiency minimum of ESP and bag-house both appear in the particle size range of 0.1~1μm. In this size range, ESP and bag-house collection efficiency is 90.8~98.6% and 99.54%.

Time resolution of ELPI is lower than 5 seconds, which makes it is possible to measure the emission instantaneous changes such as ESP collection plate rapping and bag-house cleaning pulse. The mass and number concentration of PM_{10} will increase obviously by rapping the last electric field. The same phenomenon can be seen from emission caused by bag-house cleaning pulse operation.

The effect of the first-stage diluter temperature on particle number concentration is experimented. The results indicate that heating the first-stage dilution air to sample temperature can prevent condensation of species, such as water, sulfuric acids and some hydrocarbon compounds.

Key word: coal-fired power plants; fine particle; size distribution

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1 INTRODUCTION

PM_{10} is one of the principal pollutants of urban air in China (SEPA, 2003), and also the main factor to induce some more serious pollution phenomena, such as acid rain, air visibility depressing, global climate variety, photochemical smog and ozonosphere damage. Furthermore, fine particle matter and ultrafine particle matter are more harmful to human health than coarse ones (Pope, A. C., 1999). Many indications of health have tight relationship with the time of be exposure in certain concentration fine particles (Lidia Morawska, 2002).

Most PM_{10} of the atmosphere comes from power plants, vehicles and burning sources, always containing much toxic matter (Siegmann, 2000). According to China medium/long term predict of energy sources consumption demand (NDRC, 1998), coal is the main energy source now in China, and even till to 2020, it will account for 54% of total energy consumption. In our country, about 80% coal consumption was used by direct combustion, and main of that was consumed by power plants (about 45% of total coal consumption, and increase to 62% in 2010 by prediction). To the total emission of smoke and dust from all industries, electric power industry has taken the maximum portion (CESG, 2003). For the sake of controlling PM_{10} emission of coal-fired power plant, the key is to master its emission characteristics. In this work, we sampled from several power plants at inlet and outlet of the particulate emission control devices (PECDs), and tried to describe PM_{10} emission characteristics and the capabilities of PECDs through multifold analysis ways.

2 EXPERIMENTAL

2.1 Test conditions

Four different coal-fired power plants are measured in this work. During test run periods production equipments of these power plants are under a normal operation condition; the boiler testing load, the fuel and the burning operation mode keep invariable; the emission concentration of gaseous pollutants also keeps relatively stable (Table 1). Proximate analysis and ultimate analysis of coals are shown in Table 2. Table 3 is the component of coal gas mixed into power plants 1.

Table 1. Operational parameters and gaseous pollutants concentration during test run periods

power plants	1	2	3	4
boiler type	HG-220/100-10	HG-2023/17.6-YH4	IHI-FWSK	HG-670/13.7-10
electricity generated	50MW	600MW	600MW	220MW
testing load	80%	90%	100%	95%
PECDs type	SD65/5622 Twin chamber four-field ESP	RWD/KFH-473.32×2-4×4.5-2 Twin chamber five-field ESP	2FFA5×45M-2×128-150 Twin chamber five-field ESP	Bag-house
fuel	80% Datong bituminous coal +20%coal gas	Zhunge'er bituminous coal	60% Fuxingyou bituminous coal+40%Muguajie bituminous coal	Anthracite coal
O_2 concentration	5%	5.4%	5.5%	8.1%
NO_X concentration	408 mg/m^3	550 mg/m^3	1010 mg/m^3	460 mg/m^3
SO_2 concentration	530 mg/m^3	880 mg/m^3	1210 mg/m^3	530 mg/m^3
CO concentration	35 mg/m^3	26 mg/m^3	50 mg/m^3	Not test

Table 2. Proximate analysis and ultimate analysis of coals

power plants	fuel	Carbon (%)	Nitrogen (%)	Oxygen (%)	Hydrogen (%)	Moisture (%)	ash(%)	Volatile matter(%)	Sulfur(%)	LHV (kJ/kg)
1	Datong bituminous coal	51.59	0.78	6.82	3.95	9.8	19.75	27.14	0.29~0.37	22781
2	Zhunge'er bituminous coal	43.72	0.88	10.43	3.22	9.1	24.78	27.85	0.46-0.56	21736
3	Fuxingyou bituminous coal	49.01				9.7	22.64	26.895	0.90	20925
	Muguajie bituminous coal	48.39				9.95	22.65	27.62	1.24	20963
4	Anthracite coal	65.00	0.79	0.84	2.10	8.50	31.24	8.65	0.54	23617

Table 3. Component of coal gas

CO	CO2	N2	O2	LHV
23~25%	18%	53~56%	1~2%	2970-3300kJ/kg

2.2 Sampling system

Sampling positions are located at both the inlet and the outlet of PECDs in these power plants, which respectively represents the particle emission from boiler in non-control condition and that emitted to the atmosphere after control.

In the exhaust, the total particle matter is collected by filter drum and the apparatus is TH-800 III microcomputer dust parallel sampling meter from Wuhan Tianhong intelligence meter factory. Filter drums are baked in 105℃ ±5℃ for an hour before and after the sampling, and then put into a drier to cool until it reaches the ambient temperature to weigh. Finally the emission concentration of the total particle matter can be calculated.

The size distributions of PM_{10} are measured by Electrical Low Pressure Impactor (ELPI).

The ELPI is designed for real-time monitoring of aerosol particle mass and number size distributions (M. Moisio., 1998; Terttaliisa Lind, 2003; Thomas Ferge, 2004). The ELPI measures aerodynamic size distribution in the size range from 0.03μm to 10 μm with 12 channels. The operating principle is based on charging, inertial classification, and electrical detection of the aerosol particles. The ELPI can also be used for gravimetric measurement and chemical analysis like a conventional impactor. The response time of ELPI is less than 5 seconds, which makes it possible to support real-time measurement (Marko Marjamaki., 1999).

Because particle concentrations and gas temperatures in stack is high, diluter must be used. At present, standards are not founded for stationary sources dilution sampling. Many previous investigations had employed some forms of dilution sampling according to different research purposes (Glenn C. England., 2000). In this study, a two-stage dilution system is applied to preserve the gas and particle conditions as much as possible (Mikko Moisio, 1999). The sampling system of PM_{10} is shown in Figure 1.

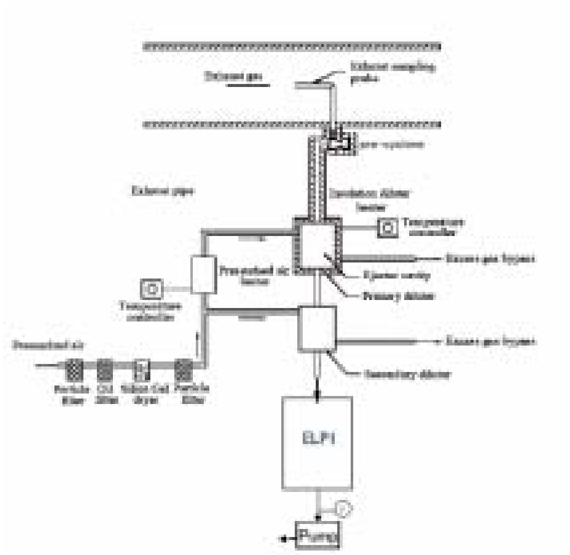


Fig 1. Sampling system of PM_{10}

The sampling system consisted of ELPI, an isokinetic sampler probe, pre-cut cyclone (cut-off diameter is 10μm), two-stage dilution system and sample line to the instruments. The operation principle of the diluter is based on an ejection type dilution. Clean and dry pressurized dilution air is conducted to the diluter through an ejector cavity. The dilution air mixes with the sample air in the ejector cavity. The dilution ratio is related to both stack pressure and dilution air pressure. In this work, the dilution ratio is about 1 to 85. All sampling lines were kept as short as possible to avoid large particle losses.

As the temperature drop includes an inevitable condensation of species with a low enough steam pressure, it is important to first lower the partial pressure of sample gas components with a clean and dry dilution airflow. The first-stage diluter heated to stack temperature. In this way, the vapor pressures of volatile components in first-stage diluter are decreased, which can prevent condensation of some species, such as water, sulfuric acids and some hydrocarbon compounds. In addition, this allows the secondary dilution with cold dilution gas without condensing the volatile components. Moreover, the secondary dilution is carried out with cold air to cool the sample.

Cleaned and dried aluminum foils were used for sampling substrates. In order to minimize particle bounce, aluminum foils were coated with a thin layer of Apiezon-L grease (Jouko Latva-Somppi., 1998).

Total PM and PM_{10} sampling follows "The determination of particulates and sampling methods of gaseous pollutants emitted from exhaust gas of stationary source" (GB/T16157-1996).

3 RESULTS AND DISCUSSIONS

3.1 Size distributions of PM_{10} at the inlet of PECDs

Figure 2 shows the number and mass distributions of PM_{10} at the inlet of PECDs.

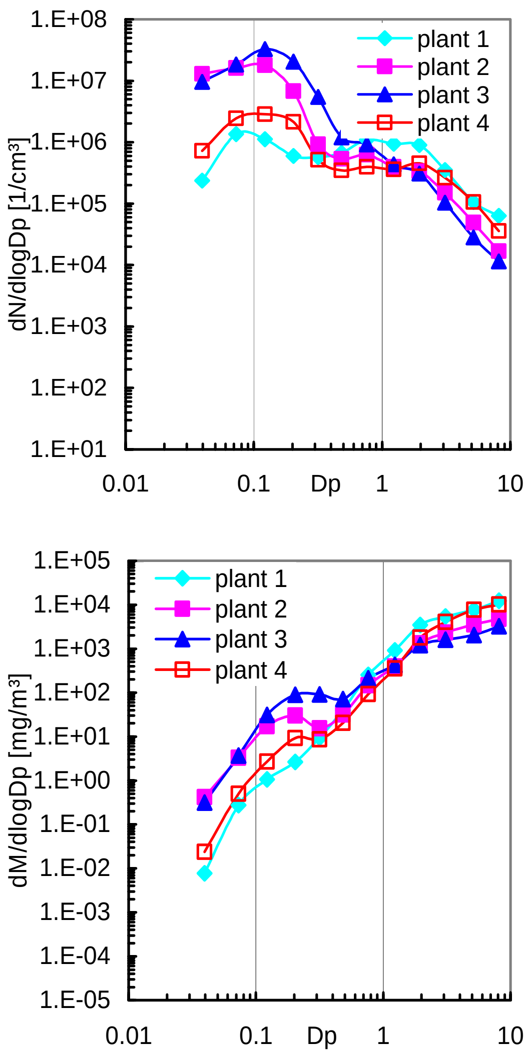


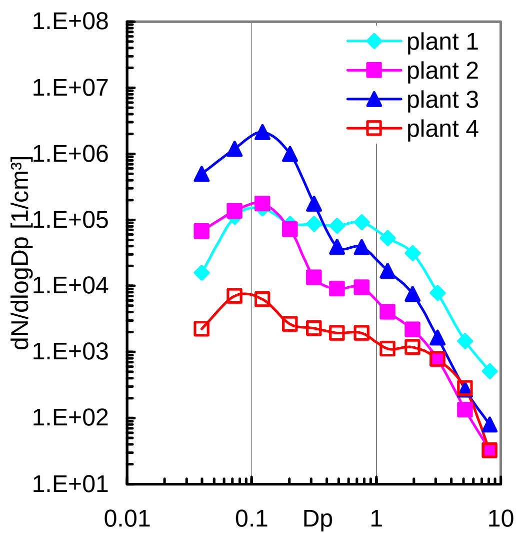
Fig 2. Size distribution of PM_{10} at the inlet of PECDs

The size distributions of particle matter form coal combustion display the bimodal distribution which contained the submicron mode and the coarse mode with a peak around 0.1µm nanometer and 1µm, respectively. The particles in the coarse mode are formed by the transformation of minerals that remain after the carbon burns away and the particle size distribution is determined by char fragmentation and coalescence of surface ash droplets. The particles in the submicron mode are formed by vaporization, condensation and nucleation of inorganic constituents in the fuel (JoAnn Slama Lighty, 2000; Yu Dunxi., 2004).

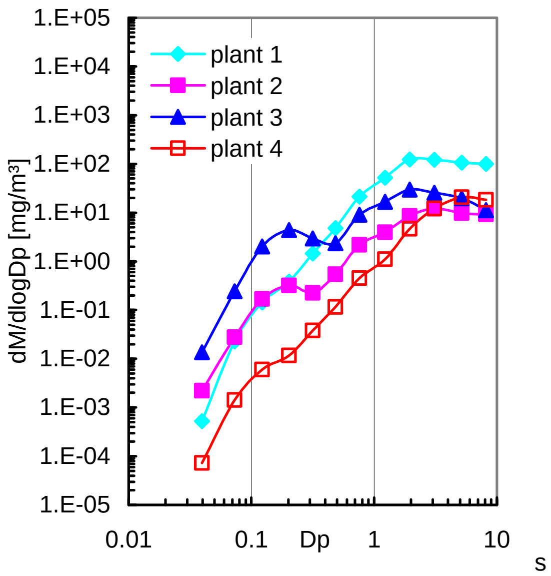
From figure 2, before all the PECDs the bimodal number size distribution can be obviously seen with a peak around 0.07~0.12µm and 0.76~1.23µm, respectively; submicron mode can be seen with a peak around 0.2µm in mass size distribution, however, the coarse mode with a peak large than 10 µm have not been seen because of exceeding over the size measurement range.

3.2 Size distributions of PM_{10} at the outlet of PECDs

Figure 3 shows the number and mass distributions of PM_{10} at the outlet of PECDs.



Number size distribution



Mass size distribution

Fig 3. Size distribution of PM_{10} at the outlet of particulate emission control devices

After all the PECDs the bimodal number size distribution can also be observed with an obvious decrease of concentration. At the same time, the mean diameters of coarse code dropped. The mean diameters of the coarse mode reduce to about 2μm~5μm in mass size distribution.

3.3 Collection efficiency of PECDs

Total collection efficiency of different particle size is shown in table 4.

Table 4. Total collection efficiency of different particle size

D_P	PM1	PM2.5	PM10	PM
Power plant 1 - ESP	90.83	95.58	98.20	99.00
Power plant 2 - ESP	98.59	99.16	99.62	99.89
Power plant 3 - ESP	95.74	96.75	98.58	99.76
Power plant 4 - Bag-house	99.54	99.72	99.76	99.94

From the table, ESPs and bag-house collection of PM are highly efficient, which reach 99.0~99.76% and 99.94%. However, collection efficiency of PM_{10} and $PM_{2.5}$ is low, though bag-house's is higher than ESP's,

The process of particle capturing could be affected by various acting force that are different with the size and type. Also the particles will have different dynamic behaviors when they were affected by different forces. To some action forces, such as inertia collision and gravity, their capture efficiency are increasing with the size increasing, but inverse to diffusion. The result is that the removal efficiency of particles is least efficient in an intermediate size range from 0.1μm ~1μm (Helble, J.J., 2000)。 The measures in the penetration of particles through PECDs are provided (Figure 4).

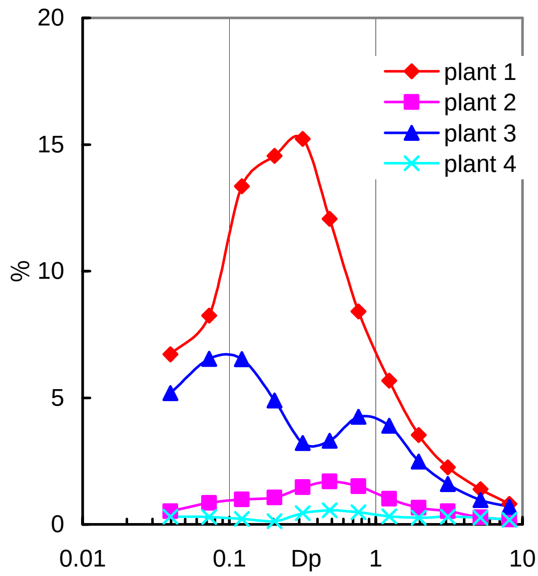


Fig 4. Penetration of PM_{10} through the particulate emission control devices

The collection efficiency minimum of ESP and bag-house both appear in the particle size range of 0.1~1μm. In this size range, ESP and bag-house penetration of PM_{10} is 1.42~9.17% and 0.46%. Therefore, it is possible to reduce the penetration in this size range by optimizing PECDs operation conditions, such as adjust the rapping cycles of ESP (Thomas Ferge., 2004).

3.4 Cumulative distribution

In china, the air pollutants emission standard only has limited value for total amount of smoke (SEPA, 2003). But in environment standard, besides TSP, we also pay more attention to the limited concentration of PM10 and PM2.5. For the sake of mastering the particle formation and emission, we gave the particulate mass size fractions of the total amount smoke with different particle size in Table 5.

Table 5. Particulate mass size fractions of total PM

Dp	Before PECDs(%)			Aftere PECDs(%)		
	PM1	PM2.5	PM10	PM1	PM2.5	PM10
Power plant 1	0.5	5.7	35.8	3.9	24.6	64.8
Power plant 2	0.4	2.9	18.4	5.0	21.1	62.0
Power plant 3	0.9	3.4	14.1	14.7	44.1	83.9
Power plant 4	0.1	1.7	16.7	0.8	8.6	71.3

From the table, the proportions of PM_{10} in total PM mass produced by coal-fired power plants is lower, but occupy the main fraction after the particulate control devices, about 62% to 84%. The un-controlled emission factors and emission factors of PM are 44.15~129.32g/kWh and 0.068~1.11g/kWh, and which of PM_{10} are 6.23~38.25g/kWh and 0.042~0.72 g/kWh.

Mass and number cumulative distribution in PM_{10} is shown in figure 5 and figure 6.

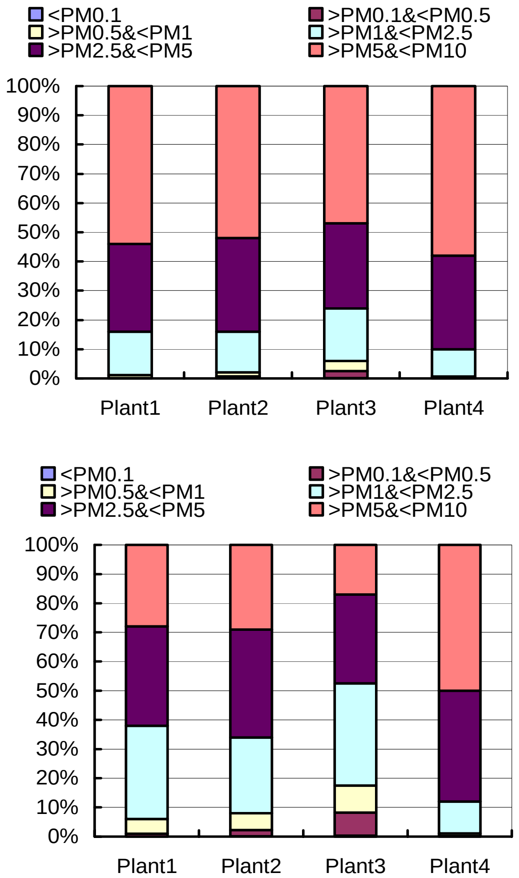


Figure 5. Particulate mass size fraction of PM_{10} before and after control devices

Figure 5 shows that the mass concentration of PM_{10} is mainly dominated by the particles which are larger than 1 μm. After both ESPs and bag-house, the mass concentration of $PM_{2.5}$ of PM_{10} are increased in evidence, and the growth degree of bag-house is smaller than ESPs. This indicates that the $PM_{2.5}$ collection efficient of bag-house is better than ESPs, as mentioned before.

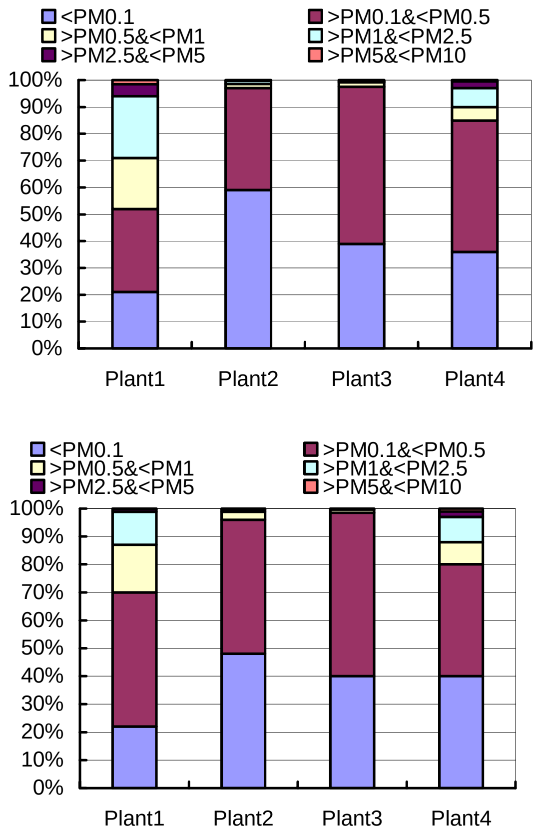


Figure 6. Particulate number size fraction of PM_{10} before and after control devices

Different from the mass concentration, the number concentration is dominated by the particles which are smaller than 0.1 μm (Eric Lipsky., 2002). Thus, though PM_{10} emissions from coal-fired power plants have lower mass concentration, the number concentration is quite higher.

3.5 Influence of PECDs operation conditions to PM concentration

Because time resolution of ELPI is lower than 5 seconds, it is possible to measure the emission instantaneous changes such as ESP collection plate rapping and bag-house cleaning pulse. Real time measurement of particulate concentration at the outlet of ESP is shown in figure 7. The test period in dashed line represent the rapping of the last electric field.

From figure 7, the mass and number concentration of PM_{10} will be affect greatly by rapping the last electric field. It possibly has two reasons. One is that the size of particles captured in the last electric field is too small, and most of them are PM_{10}; another one is that the particles re-entrainment from upstream electric field by its rapping could be captured again in the next field. When the last electric field is rapping, these re-entrainment particles will escape away. Therefore, the PM_{10} concentration in the outlet will increase obviously. The same phenomenon can be seen from emission caused by bag-house cleaning pulse operation.

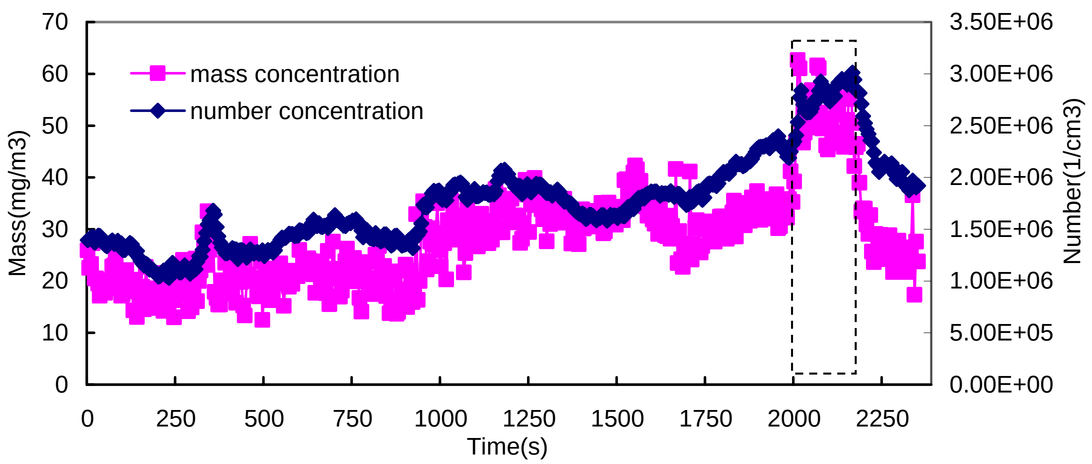


Figure 7. Real time measurement of particulate mass and number concentration at the outlet of ESP

3.6 Influence of the first-stage diluter temperature on particle number concentration

The influence of the first-stage diluter temperature on particle number concentration is experimented (Figure 8). The results indicate that heating the first-stage dilution air to stack temperature can prevent condensation of species, such as water, sulfuric acids and some hydrocarbon compounds.

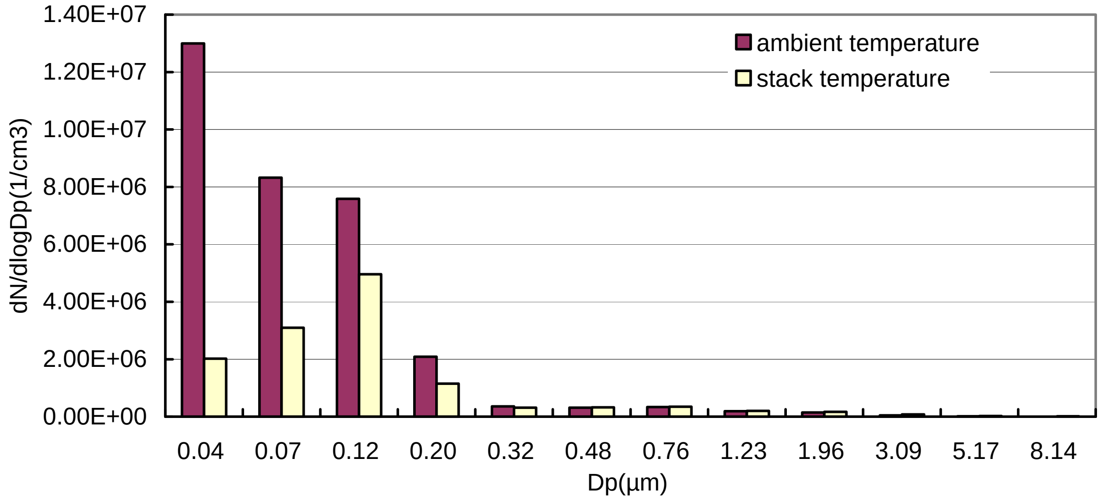


Figure 8. The influence of the first-stage diluter temperature on particle number concentration

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