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Experimental studies on effects of relate humidity variation on particles size distribution in indoor

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Abstract

In order to study the influence of related humidity on size distribution of indoor fine particles less than 2.5 μm, experiments were designed in this work as follows: a lighted incense stick was used as a more stable kind of pollutant sources in the constant temperature room, when the inhalable particles concentration in indoor reached a given value, the pollutant sources was put out, then particle size spectra in indoor were recorded in two hours. By changing the indoor relative humidity with the steam humidifier during this process, size distributions of fine particles in different relative humidity were tested. Meanwhile, samples of particles were trapped under inertial effect, and observed by FESEM (field mission scanning electron microscopy). By measuring size distributions of particles, the influence of relative humidity on the coagulation and hygroscopic growth of particles could be studied, and moreover, by observing the microscopic morphology of individual particle in different relative humidity, the probability of cohesive particulates could be studied, too. Results showed: when the indoor relative humidity was up to about 80%, the size distributions of particles changed significantly, and the number concentration of fine particles less than 1 μm decrease apparently while the number concentration of coarse particles more than 1 μm increase apparently. Excluding experimental errors of particle number concentration caused by the humidifier periodical releasing steam, the declines of number concentration of particles with sizes 0.3 ~ 0.6, 0.6 ~ 1.0, 1.0 ~ 2.5 μm became slow in turn. In addition, it was observed by FESEM that particles were likely to coagulate after resource emission, and more large particles coagulated by smaller particles were trapped when RH was more than 65%, especially when RH was up to 80%. It was illustrated that when relative humidity increased, particles absorbed moisture and grew larger, and fine particles coalesced to larger particles. The higher the relative humidity becomes, the larger the size of the particles-size spectra would be moving to.

Keywords: Fine particle; particle size distribution; coagulation; relative humidity; hygroscopic growth.

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1. Introduction

The observation and experiment show that the particles with strong hygroscopicity can grow up significantly in surroundings of larger relative air humidity and change the diameter distribution of it, so that the weather influence has been done (Andrews & Larson 1993; Berico et al., 1997; Carrico et al., 2003; Ferron et al., 1989). In addition, the hygroscopicity of particles can also affect the mechanical properties of particles also the settlement, the removal and the deposition in the respiratory system (Jones 1999; Mäkelä et al., 1997; Malm & Day 2001; Svenningsson et al., 1997). For human stay indoor mainly, the exposure levels of particles and the particles diameter distribution in indoor is more important in terms of health effects. However it's rare to see the report of it. The smaller the inhalable particle's size is, the deeper it will be locate in. Particles below 2.5 μm (PM2.5) can enter the body and be deposited on lower respiratory tract such as bronchus, then affect the health of vitals as heart and brain. In addition, the smaller the particle's size is, the bigger the specific surface area will be, the opposite surface can absorb more harmful substances (Waldman et al., 1991). Thus, the fine particles are more harmful than the coarse particles. In indoor environment, can the relative humidity cause the change of particle distribution? It provides the important theory significance in exploring the distribution law of the fine particles indoor, at the same time, it possesses the practical value for the indoor relative humidity condition is easy to control. The purpose of the experiment designed in this paper is to study the change law of the concentration distribution of the indoor fine particles as the indoor relative humidity changes, then to explore the way to control and remove the indoor fine particles.

2. Experimental method

The experiment was conducted in a laboratory with windowless and good airtight, an stable particles released resource (combustion products of a chemical incense tray) was used.

To eliminate thermal interference of environment, the temperature of the room was controlled in the range of small fluctuations by air conditioner. Different relative humidity conditions were created by the humidity controller combined with a humidifier humidity ,the way to adjust wetness was: when the measurements of the relative humidity indoor is less than the settings subtracts the return difference, the output will be started, the relay will be pull-on, and the humidifier will start to humidify. When the measurement of the humidity is greater than or equal to the settings, the output will be closed, the relay will be disconnected, and the humidifier will stop humidifying. The return difference is to prevent the relay open and close frequently, and this experiment sets 2% RH as the buffer value. Temperature and humidity sensor are set near the particle measurement sampling points, are connected to the computer and record an indoor temperature and humidity changes per minute automatically.

2.1 Experimental instrument

Temperature and humidity measurement use standard sensors produced by Swiss Rotronic Company(type number HC2S, precision ±1 %RH / 0.2 °C).Testing the number density distribution of particulate matter at different particle levels use the optical particle size spectrometer produced by American TSI Company (type number TSI 3330, detecting particle size range of 0.3 ~ 10 microns, resolution is 5% at 0.5 μm). Observing the particles

in air microphysically use the scanning electron microscope produced by German Carl Zeiss company (SUPRA 55 SAPPHIRE).

2.2 Particle source

Actually the source of fine particles indoor is complex. there are the particles entering the interior through the envelope from the outside, as well as the emission caused by indoor activities. The reference (Zhao et al., 2004) took a large number of samples from 4 families' house in Beijing, separate the particles into smoke aggregates, coal fly ash, mineral particles, biomass particles and unknown particles. Among which the character of smoke aggregates, coal fly ash and mineral particles are similar, so soot particles produced by burning incense are chosen as an experimental particle source in this paper. Through determination, the particles are mainly PM10, of which the account of PM2.5 beyonds 99.5% with main ingredient of oxide and salt of calcium and sodium and polycyclic aromatic hydrocarbons. The calcium oxides and salts in incense smoke is hygroscopic, it can reflect the change of the hygroscopic particles as the indoor relative humidity conditions changes.

For convenience of analysis, the distribution of particles is required to be stable. This experiment gets fine particles by burning a fragrant incense as a source.In order to verify the stability of the source, the experiment chose to measure the size spectrum for 23 times under a certain temperature and humidity with TSI 3330 Optical Particle Size Spectrometer. The experiments results show that the size of the particle that is released by the source is mainly under 2.5 μm, and it is distribute stably. the particle at particle size0.3~0.6 μm take up of about 93% of the total number of particles and the particle at particle size 0.6~1 μm take up of about 6% of the total number of particles. The particles more than 2.5 μm take up of only 0.107% of the total numbers. The mean square of the number density of the particle numbers under 1 μm is less than 12.7% and the maximum deviation is less than 19%. The mean square of the number density of the particle numbers between 1~2.5 μm is less than 13.7% and the maximum deviation is less than 23.8%. So the particle source can be supply to release particles under particle size 2.5 μm.

Before experiment, the particle number size distribution of original environment was measured. The number concentration of the particles at particle size 0.3~0.6 μm, 0.6~1 μm, 1~2.5 μm was five times of that in original environment. So the number concentration itself in laboratory is indecisive to experiment results. The particle number size distribution of original environment is shown in table 1.

Table 1. Particle number size distribution of original environment

Size（μm）	**0.3～0.6**	**0.6～1**	**1～1.5**	**1.5～2**	**2～2.5**
Particles number	373642	12603	1390	746	275

2.3 Experiment method

During the experiment, we set the indoor relative humidity for 35%, 50%, 65% and 50% by temperature and humidity control system, the corresponding condition are 1, 2, 3, 4. Then use the scanning electron microscopy to observe the morphology of the fine particles released by the particle source under various conditions. Use the particle size optical spectrometer to measure the number density of indoor fine particles.

The experimental details are as follows:

- The temperature control: open the air conditioning and the temperature and humidity sensor before the experiment to set the room temperature at 26 °C. A period of time later, check the indoor temperature change curve.
- The humidity control: when the indoor temperature has leveled off, open the humidifying equipment to set a certain value on the humidity controller, and then check the humidity change curve.
- The release of particles: when the indoor relative humidity has leveled off, and the average temperature gets the preset value, light the incense stick.
- The SEM sampling and the measurement of particle number density: put out the incense stick after a certain period of time, and measure the concentration of the particles continuously. Start sampling with electron microscopy when the concentration of indoor particles gets the preset value. Set up two sampling stations for comparison to eliminating the effects of sampling station. The height of sampling station is 1.1 m. Sample particles by inertial capture method for two hours. And then observe by gold-sputtering. Adjust the inlet of the particle size optical spectrometer at the same height of the sampling table to measure the number density of indoor fine particles, and record the data every minute.

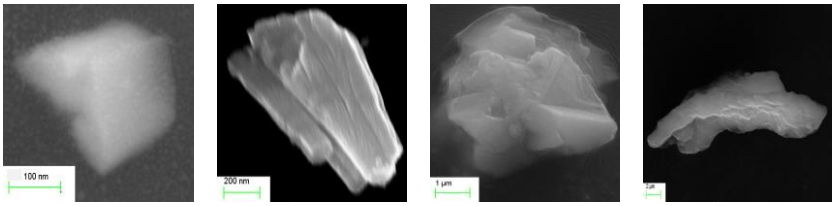
3. Analysis

3.1 Temperature and humidity control

In the course of experiments, indoor temperature and relative humidity was controled by an automatic system. Through controlling temperature and humidity, the maximum average experiment temperature is 26.88 °C and the minimum is 26.59 °C in the four conditions. Considering accuracy of measurement and requirements of the experiment temperature in the four conditions, the average indoor temperature is considered unchanged. the average relative humidity (RH%) of indoor four conditions were respectively 34.76%, 49.46%, 65.72%, 79.95%, matched with RH35%, RH50%, RH65%, RH80%. At the meantime, the indoor temperature and relative humidity stay cyclical changes, so the indoor temperature and humidity essentially unchanged within a certain range.

3.2 The shape and size of particles released from resource

Observed the smoke outline of a burning incense which is particle resource and sampled the smoke which rose toward the direction of the sampling Desk and were 200 mm away from the particle source. Fig. 1 illustrated that typical particulate matter were observed by scanning electron microscopy in RH35%.



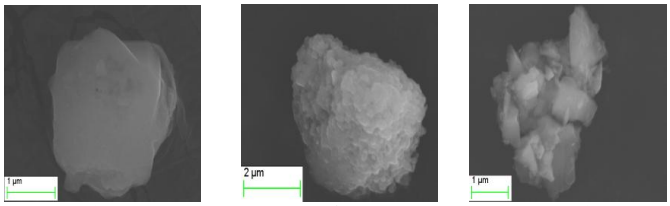
(a) I (b) II (c) II (d) IV

Fig. 1. Typical particles released from resource.

Different sizes of particle were emitted by particle source, and some typical particles in blocks, slabs, and size is below 200 nm to 10 μm showed in Fig. 1.

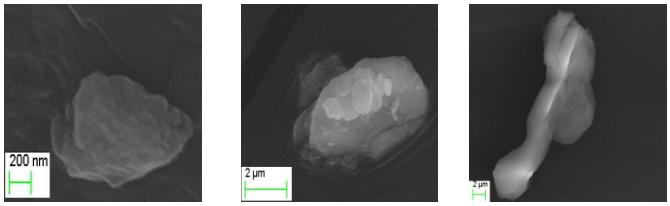
3.3 Particle morphology in the different indoor relative humidity

The sampling points were located at the horizontal distance from 1 m of particle source, 1.1 m from the ground, and took the sample countertops upwards. The sampled particles were observed by SEM in different indoor relative humidity which was shown in Fig. 2 ~ 5.



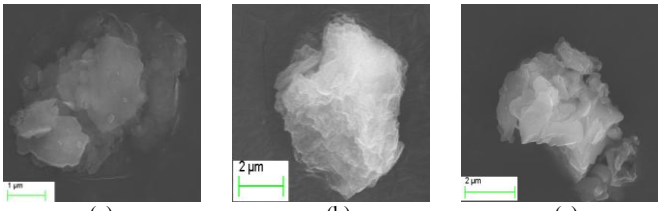
(a) (b) (c)

Fig. 2. Typical particles be observed by SEM at working condition 1 (RH35%).



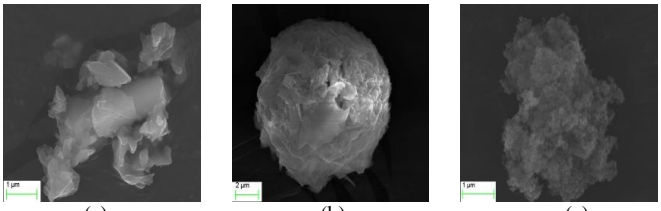
(a) (b) (c)

Fig. 3. Typical particles be observed by SEM at working condition 2 (RH50%).



(a) (b) (c)

Fig. 4. Typical particles be observed by SEM at working condition 3 (RH65%).



(a) (b) (c)

Fig. 5. Typical partcles be observed by SEM at working condition 4 (RH80%).

Fig. 2 showed a few typical particles observed by SEM at working condition 1 (RH35%). (a) showed a single block fine particles with smooth surface, within 2 μm in size, (b) showed the particles with the rough surface whose sizes were less than 3 μm, though the size of the (c) and (a) was approximate, (c) showed the particles were coagulated by the smaller particles of different sizes. At the working condition 1, the indoor fine particles and larger particles (not shown in Fig. 5) mainly showed block or strip, and a few stacked.

At the working condition 2 (RH50%) showed in Fig. 3, the observed particles were still mainly single block, similar with condition 1. Fig. 3 (a) showed a typical single fine block particles with size of less than 1 μm, (b) showed larger particles of about 4 μm that be made up of a few small particles integrated a single massive particle, (c) is irregular strip large particles with the length of 10 μm.

Fig. 4 is typical particles be observed by SEM at working condition 3 (RH65%), there are significant difference between the working condition 3 and 1; it is common for stacked-like particles and the single particle is much less. And the stacked block was looser than that seen by condition 1, such as Fig. 4 (a). Even if the particle morphology is similar, for example, comparing (b) of Fig. 4 and (b) of Fig. 3, we also can observe the appearance of particle boundary is fuzzy when the relative humidity is large, which is seems to be caused by the surface absorb water then dissolve.

When relative humidity is up to 80%, characteristics of observed particles are particularly significant. The size of particle is commonly larger. These loose stacked particles could be observed in Fig. 5 (a), it should be the morphology of the original coagulated particles when sampling by SEM in a vacuum container after the water molecules escape and become looser. (b) is a spherical coagulated particles, it should be formed by the surface tension after water absorbing, (c) is a big particles gathered by a lot of ultrafine particles below 0.1 μm, its morphology of the samples in the other condition is not found.

3.4 Particles number decay courses under different relative humidity

The number density for certain size particles is the number of them per volume.

Fig. 6 to 8 show the number decay course of particles of 0.3～0.6 μm、0.6～1 μm and 1～2.5 μm since the particle source stops producing particles.

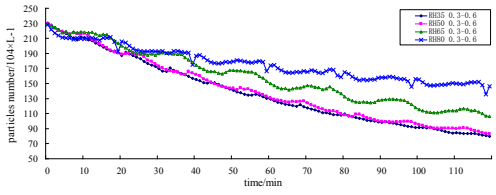


Fig. 6. Particles number decay course (0.3～0.6 μm).

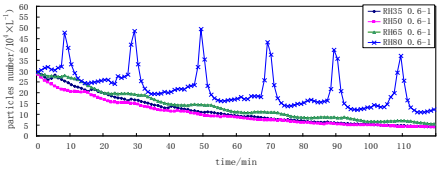


Fig. 7. Particles number decay course (0.6～1 μm).

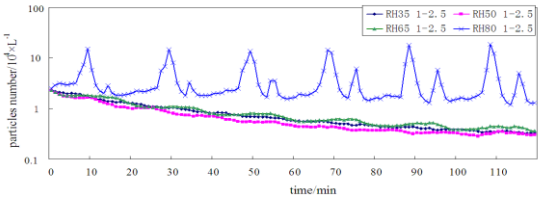


Fig. 8. Particles number decay course (1～2.5 μm).

From Fig. 6 to 8, we can know that the number density of fine particles of 0.3~0.6 μm and 0.6~1 μm all decreased over time in all kinds of conditions, that is the reason of the filtration of the air conditioner to the particles in the return air and the settlement of diffusion. The curves of particles for working condition 1 and 2 are almost the same. While the decay of condition 3 is slower. Especially for condition 4, the curve decays m slower and appears periodically jumps. Curve of particle of 0.3 ~ 0.6 μm appears cyclical trough and curve of particle of 0.6 ~ 1 μm appears cyclical peak.

That is because the working principle of the constant humidity device is to humidify the indoor air by evaporating water periodically to maintain a certain relative humidity level. Steam became super cooling in indoor air, some condenses into small droplets and some condenses with the particles as the nuclear. Scattering of small droplets may have interference on the optical spectrometer that based on the MIE theory, causes the instrument read out more particles of certain size. These small droplets can evaporate quickly, so the influence will not last so long. The periodic is match with the humidifier's work cycle and this may be the reason of the curve of particles more than 0.6um appears cyclical peak. If it is only the contribution of small droplets, it can just cause the number of particles increase periodically. Only part of the particles of certain size become bigger suddenly, can the number density of this kind of particles decreases and the number density of the particles of larger size increases. That is, in the experiment, the impact of scattering for the moisture condensed particles cause the reading of particle of 0.3 ~ 0.6 μm appears cyclical trough. The latter, that is the function of the condensation with the particles as the nuclear is that: The original particle size becomes bigger or becomes bigger by the coagulation of several smaller particles. This is the main reason of the decay of particles of 0.3~0.6 μm becoming slower in the condition of RH65% and RH80%.

Eliminating those jumping "peaks" and "bottom" data, we can conclude that the changes of particle size distribution is primary caused by moisture absorption and condensation. The change of particle size distribution caused by growth of particles is more obvious when the relative humidity indoor reach above 80%. From the data of the number density of different size particles in Fig. 6 ~ Fig. 8, we can know that: when the relative humidity indoor reach above 80%, the percentage of particles less than 1 μm decreases, and that of particles more than 1 μm increases.

4. Conclusion

1) At relative humidity range of 35% to 80%, fine particles produced by indoor source may condense in the process of production and diffusion. From the results of scanning electron microscope we know that particles of 0.3 ~ 10 μm all can coagulate.

2) The coagulation of hygroscopic particles becomes stronger when the indoor relative humidity gets 65%, it is more obvious at RH80%. The results of particle spectrometer and

electron microscopy showed that: the greater the relative humidity is, the more obvious of the condensation, and the larger size that the particles condensate into.

3) When the relative humidity indoor is more than 65%, the percentage of big particles becomes larger as the relative humidity increasing. When the relative humidity indoor get 80%, the fine particle size increased significantly.

4) When the relative humidity indoor increases, the average size of the fine particles (PM2.5) increases.

This study, mainly focused on fine particles of 0.3 ~ 2.5 μm, is important for environmental benefits. The particle source is the smoke released by burning incense which is proved to have hygroscopic ingredients. The relationship between relative humidity indoor and particle size distributions of non-hygroscopic or hydrophobic particles needs further study.

5. Acknowledgements

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References

Andrews E., Larson S.M. (1993). Effect of surfactant layers on the size changes of aerosol particles as a function of relative humidity. Environmental Science & Technology 27, 857-865.

Berico M., Luciani A., Formignani M. (1997). Atmospheric aerosols in urban area measurements of TSP and PMJO standards and pulmonary deposition assessments. Atmospheric Environment 31, 3659-3665.

Carrico C.M., Kus P., Rood M.J., Quinn P.K. (2003). Mixtures of pollution, dust, sea salt, and volcanic aerosol during ACE-Asia: Radiative properties as a function of relative humidity. Journal of Geophysical Research 108, 8650.

Ferron G.A., Oberdörster G., Henneberg R. (1989). Estimation of the deposition of aerosolized drugs in the human respiratory tract due to hygroscopic growth. Journal of Aerosol Medicine 2, 271-284.

Jones A.P. (1999). Indoor air quality and health. Atmospheric Environment 33, 4535-4564.

Mäkelä J.M., AaltoP., Jokinen V., Pohja T. (1997). Observations of ultrafine aerosol particle formation and growth in boreal forest. Geophysical Research Letters 24, 1219-1222.

Malm W.C., Day D.E. (2001). Estimates of aerosol species scattering characteristics as a function of relative humidity. Atmospheric Environment 35, 2845-2860.

Svenningsson B., Hansson H.C., Wiedensohler A., Noone K., Ogren J., Hallberg A., Colvile R. (1995). Hygroscopic growth of aerosol particles and its influence on nucleation scavenging in cloud: Experimental results from Kleiner Feldberg. In: The Kleiner Feldberg Cloud Experiment 1990. Springer Netherlands, pp 129-152.

Waldman J.M., Lioy P.J., Zelenka M. (1991). Wintertime measurements of aerosol acidity and trace elements in Wuhan, a city in central China. Atmospheric Environment 25, 113-120.

Zhao H.Y., Shao L.Y., Wang Y.B., Lü, S.L, Liu, Y.F (2004). Microscopic morphology and size distribution of indoor air PM10 in Beijing City in winter. China Environmental Science 24, 505-508.