CHEMICAL ENGINEERING TRANSACTIONS
VOL. 59, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216
DOI: 10.3303/CET1759127

Physical, Chemical and Biological Characteristics of Dust Accumulation in HVAC System

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For reducing indoor air pollution and controlling its effects, the method of sampling and experimental analysis is adopted. In addition, physical, chemical and microbial characteristics of the air conditioning system dust accumulation are discussed in details. And dust particle size distribution was determined, and by combustion oxidation - non dispersive infrared absorption method, carbonaceous materials were determined, including organic carbon (TOC), inorganic carbon (IC) and total carbon (TC). Strictly in accordance with the microbial culture methods in "Public Place Hygiene Standards of Air Conditioning and Ventilation System" issued by the Ministry of Health, the breeding situation of bacteria and fungi in different parts of the air conditioning system is analyzed. At last, the following conclusion are drawn through the above research: (1) The HVAC system, in addition to 6 sampling sections outside the fresh air, the average particle diameter of dust is between 6-20μm, and the average particle dust in the air segment size is 41.30μm. (2) The proportion of TOC, TC and IC is between 2%-7.5%, 2.5%-8.5% and 0.7%-1.2% respectively, in which the air supply pipe is the largest, and the fresh air section is the smallest. Dust associated bacteria are between 60000-210000CFU/g, the associated fungi are between 60000-140000CFU/g, and the microbial accumulation in the cold section is the most.

1. Introduction

HVAC (Heating, Ventilating and Air Conditioning) system pollution mainly includes two pollutants. One is dusts deposited in the air conditioning system pipe, filter and cooling equipment and other parts; the other is the microorganisms associated with dust in the air conditioning system (Da, et al., 2014). For controlling the deposition of particles in the air conditioning system, researchers made a large number of experimental and theoretical analysis mainly from the study of laws of particle deposition. One aim is to study the particle deposition rate and to predict the cleaning cycle of air conditioning system (Stephens and Siegel, 2013; Cucumo et al., 2016; Genco et al., 2016; De Angelis et al., 2015; Evola et al., 2015; Cannistraro et al., 2016; Mo and Zhao, 2016). For microorganisms breedings associated with the control of air conditioning system, researchers mainly studied the effects of microbial species and temperature, humidity and wind speed on microbial growth (Alghamdi, et al., 2014).
Effects of aerosol particles on indoor air quality are closely related to the concentration of indoor suspended particulate matter and particle size of particles (because it determines the parts that particles can reach the human respiratory system and the corresponding health effects). At the same time, bio chemical composition is one of the important characteristics of heavy particles. And it directly determines the harm degree of particles deposited to the human body organs and the types of diseases (Hussein, et al., 2014). Therefore, it is necessary to understand the physical, chemical and biological characteristics of dust deposited in air conditioning systems by means of actual measurements and analysis. At the same time, most of the researches focus on the particle size distribution, the types of microorganisms, and effects of three environmental parameters (temperature, relative humidity and wind speed) controlled by the air conditioning system on microbial breeding. There were no related studies on impacts of the physical and chemical characteristics of air conditioning system dust accumulation on microbial breeding and indoor air quality.

Please cite this article as: Yecong He, Min Tan, John K Tan, 2017, Physical, chemical and biological characteristics of dust accumulation in hvac system, Chemical Engineering Transactions, 59, 757-762 DOI:10.3303/CET1759127

Through this research, the status of indoor air pollution can be understood; part of the basic data of the air-conditioning system particle deposition can be acquired, which contributes to the cleaning of air conditioning system. In addition, the determination of HVAC system dust volume density provides reference data for the development of the wind pipe dust optical test instrument. And the main nutrients affecting microbial growth and the relationship between them are determined, and strategies for controlling the HVAC system microbial growth and carbon material harm are provided. More importantly, the way and cause of corrosion of equipment in air conditioning system are found and the corresponding anti-corrosion measures are provided.

2. Physical, chemical and microbiological characterization of dust deposits

2.1 Particle size distribution characteristics

Test methods and instruments:
In this experiment, the laser method is used to analyze the particle size. The instrument used is the LS230 laser particle sizer produced by Backman Company of America.
Test results:
The particle size and mean particle size corresponding to different cumulative volume percentages at each sampling point are given in table 1. In addition, the average particle diameter of 6 sampling points except for the fresh air dust is between 6-20μm and the median particle diameter is between 5-20μm. The average particle size of the dust in the air segment reached 41.30μm, while the median particle size was 89.30μm. In the air supply pipe, the average particle size of dust is only 6.51μm, and the median particle size is only 5.76μm. Along the direction of air supply, the average particle size and median particle size showed a decreasing trend.

Table 1: The particle size and mean particle size corresponding to different cumulative volume percentages at each sampling point (μm)

Sampling position	Cumulative volume percentage					
	<10%	<25%	<50%	<75%	<90%	Average particle size
1-Fresh air section	3.300	6.985	89.300	220.500	255.100	41.300
2-Return air section	4.592	8.330	15.380	29.520	83.770	16.640
3-Mixing section	4.049	7.994	16.480	36.300	108.000	17.720
4-Filter section	2.586	5.478	15.440	44.970	74.860	14.300
5-Cold section	2.778	4.478	8.086	14.600	24.790	8.297
6-Fan section	2.780	4.732	7.988	16.010	29.770	9.689
7-Air supply pipe	2.312	3.636	5.760	16.030	26.030	6.505

2.2 Carbon content in dust accumulation

Test method:
In this experiment, the combustion oxidation - non dispersive infrared absorption method was used to determine the carbon content of dust.
Test instruments:
The total organic carbon (TOC), total carbon (TC) and inorganic carbon (IC) in dust, the IL500 total organic carbon (TOC) analyzer produced by American HACH Company is used. The instrument adopts high temperature catalytic oxidation and ultraviolet persulfate oxidation technology, and the measuring range is 2ppb-10000ppm.
Pretreatment of dust samples:
First of all, use 1/10000 electron balance to take 0.1g dust sample and extract to 1000mL solution. And carry on concussion for 30min and centrifuge for 5min, and place in the test tube of 50mL. The instruments used for pretreatment are CBL ultrasonic wave instruments (C9860A) produced by CBL photoelectron and the United States Backman refrigerated centrifuges (AvantiJ-26XP). The preparation of ultra-pure water uses the ultra-pure water machine produced by the United States PALL-GELMAN Company.
Test process:
The continuous measurement of the sample is made in the experiment. If the difference of measurement results of two times was less than 2%, it is considered that the measurement results are effective, and the average values were taken as the test value. Otherwise, the measurement is continued until the difference between two results are less than 2%. The percentage of TOC, TC and IC in the dust accumulation should be the concentration measured by the TOC analyzer divided by the concentration of the extracted solution.
Test results:

The mass percentage of TOC, TC and IC in the dust at each sampling point is given in table 2. From table 2, it can be seen that, along the wind direction, the percentage of TOC, TC, IC and dust in each equipment processing section showed an upward trend. In the seven sampling points, in the wind pipe, carbon containing materials accounted for the largest proportion, in which TOC accounted for 7.34%, TC accounted for 8.46%, and IC accounted for 1.12%. In the fresh air section, the carbon containing material is the minimum, in which TOC accounted for 2.14%, TC accounted for 2.89%, and IC accounted for 0.755%. In the processing section of dust, the proportion of TOC, TC, and IC is between 2%-7.5%, 2.5%-8.5%, and 0.7%-1.2%, respectively. Some literatures have shown that the content of water-soluble carbon in PM10 in spring, summer, autumn and winter in Xi'an is 7.2%, 4.8%, 7.4% and 7%, respectively. The average value is 6.6%, which is close to the proportion of carbon content of the dust in the wind tube. This is probably because the main source of dust deposition in the wind pipe is atmospheric particulates.

Table 2: Percentage of mass fraction of TOC, TC and IC in the dust deposited at each sampling point

Sampling points	Mass percentage of various carbons			
	IC%	TC%	TOC%	TOC/IC
1-Fresh air section	0.76	2.89	2.14	2.83
2-Return air section	0.84	4.62	3.78	4.49
3-Mixing section	0.76	4.35	3.59	4.70
4-Filter section	0.99	6.01	5.02	5.09
5-Cold section	0.91	6.22	5.31	5.84
6-Fan section	1.05	7.75	6.70	6.38
7-Air supply pipe	1.12	8.46	7.34	6.55

2.3 Microbial culture

Configuration of culture medium:

Microorganisms (bacteria and fungi) culture medium preparation is referred to the standard preparation method of bacteria and fungi microbial culture medium in [GB/T1883-2002] in "Public Place Hygiene Standards of Air Conditioning and Ventilation System" issued by Ministry of Health in 2006.

Nutrient agar medium (Tryptic Soy Agar) components: protein 10g, sodium chloride 5g, beef extract 3g, agar 15g-20g, and distilled water 1000mL.

Preparation method: the above ingredients are heated and dissolved in distilled water, and the pH is corrected to 7.4, then they are filtered and packed separately. Finally, 20min autoclaving is carried out at 121 DEG C environment.

Sabouraud’s Agar components: agar 20g, peptone 10g, glucose 40g, and distilled water 1000mL.

Preparation method: the peptone, glucose and others are dissolved in distilled water, and pH value is corrected to 5.5 - 6. Then, agar is added, and 15min autoclaving is carried out at the 115 DEG C environment.

Method of culturing microorganisms:

The culture of microorganisms was carried out by using microorganism culture method in "Public Place Hygiene Standards of Air Conditioning and Ventilation System" issued by the Ministry of Health in 2006. First of all, the dust sample, with aseptic operation, is added with 100mL Tween-80 aqueous solution with concentration of 0.01%. After stirring and shaking evenly, take 1mL bacteria solution to do 10 times’ step dilution (10-1, 10-2, and 10-3 dilution). And then, they were inoculated into culture dishes, and each dish were numbered. Each dust has 3 parallel pairs of fungi and bacteria. Finally, the nutrient agar (Tryptic, Soy, Agar) inoculated with bacteria was cultured at 36 DEG C for 48 hours at a constant temperature. The Sabouraud’s agar inoculated with fungi was cultured at 28 DEG C for 5 days at constant temperature. During the period, blank samples should be set up and cultured together with test samples. If blank samples are not colonies grown, the test result is valid.

Culture results of microorganisms:

Table 3 gives the results of microbial culture at each sampling point. From the table, it can be seen that, both fungal and bacterial, have the maximum breeding numbers in the cooling section, respectively 3 times and 2 times or so of bacteria and fungi in the fresh air section. In each processing section, dust associated bacteria is between 60000-210000CFU/g and associated fungi ranges between 60000-140000CFU/g.

Table 3: The number of microorganisms in the dust deposited at each sampling point (CFU/g)

Sampling points	Bacteria	Fungus
1-Fresh air section	61700	61668
2-Return air section	91666	78333
3-Mixing section	86700	65000
4-Filter section	105000	80000
5-Cold section	205000	135000
6-Fan section	156666	91666
7-Air supply pipe	186700	100000

3. Results and discussion

3.1 Dust mean particle size and carbon content (TOC, TC, and IC)

Figure 1 shows the relationship between the average particle size in each dust processing section of air conditioning system and the mass percentage of TOC, TC and IC in the dust. From the figure, it can be seen that, with the decrease of average particle diameter, the mass percentage of TOC, TC, and IC increases, indicating that small dust particles contain high carbon volume.

According to the different assimilation principles of microorganisms on carbon sources, microorganisms can be divided into inorganic nutrient microbial microorganisms and organic nutrient microorganisms. Among them, those with photosynthesis capacity belong to inorganic nutrition, and most bacteria, fungi, and virus belong to organic nutrients (Nacke, et al., 2014). In addition, the air conditioning system is a closed system that it does not have the photosynthesis conditions. As a result, most microorganisms bred in the dust in the air conditioning system are organic nutrient microorganisms. Therefore, in order to further analyze the effect of carbon-containing matters in dust on microbial breeding, it is necessary to analyze the proportion of TOC in TC at different particle sizes.

Figure 2 shows that, with the decrease of the average particle size, the value of TOC/IC increases gradually, showing a good linear relationship between the two parts. This shows that the total organic carbon content of small particles in the dust is higher. At the same time, it can be seen from figure 2 that, in the 7 sampling points, in the dust in the air supply pipe, the ratio of TOC and IC is the largest, which is 6.55 (Ruano, et al., 2016). In the fresh air section dust, the ratio of TOC and IC is the minimum, which is 2.83. In the air conditioning system, the average value of TOC/IC is about 5.13, which further proved that the carbon containing material is mainly concentrated in the small particles.

Through the above analysis, it is known that small particles have a larger proportion of carbonaceous materials, especially TOC, which provides nutrient source for the organic nutrient type microorganisms, so the possibility of microbial breeding in small particles is greater. But the air filter in the current centralized air conditioning system has quite low filtration efficiency of small particles. For instance, the medium efficiency air filter commonly used in centralized air conditioning system, the national standards regulate that its efficiency is: for particle size greater than 1μm, the filtration efficiency of particles is between 20%-70%. However, the efficiency of air filter used in engineering practice is often low (Joppolo and Romano, 2017). The effect of HVAC air filtration systems on the concentration of microorganisms in the wind pipe is very little. In order to strengthen the indoor air quality, it is necessary to strengthen the purification of small particles.

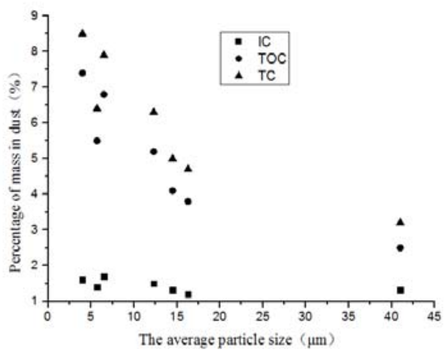

Figure 1: The relationship between average particle size and TOC, TC, IC mass percentage

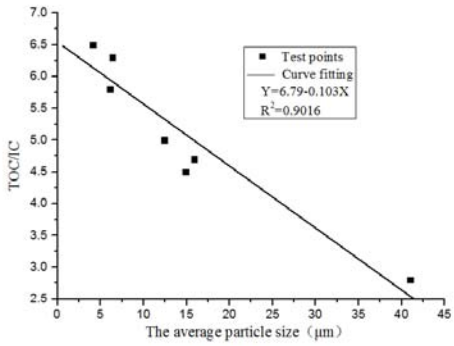

Figure 2: The relationship between the average particle size and the TOC\IC ratio

3.2 Relationship between microorganisms and mean particle size and TOC

Figure 3 shows the relationship between average particle size and the number of microorganisms. It can be seen from the figure that, as the average size increased, the number of microorganisms in the amount of dust per unit area was decreased, but in the surface cooling section with the average particle size of 8.297μm, the value is the maximum. The possible reason is: the surface cooling section, due to cooling effect, makes the condensed water generated in the wind supply air. It wets the dust on the surface cooler fin, and the dust water content becomes higher, which provides favorable conditions for the growth of microorganisms. Figure 4 shows the relationship between TOC and the breeding microorganisms in dust (Afram and Janabi-Sharifi, 2016). It can be seen from the figure that, the quantity of microorganism was positively related to the content of TOC in dust in a certain extent. The greater the TOC content is, the number of microorganisms in the dust is greater. In the same dust, the amount of bacteria is greater than that of fungi, and the correlation between the number of bacteria and TOC content in dust is more significant than that with fungi.

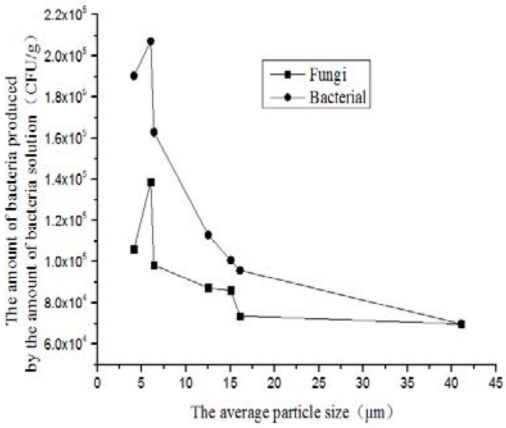

Figure 3: The relationship between average particle size and microbial quantity

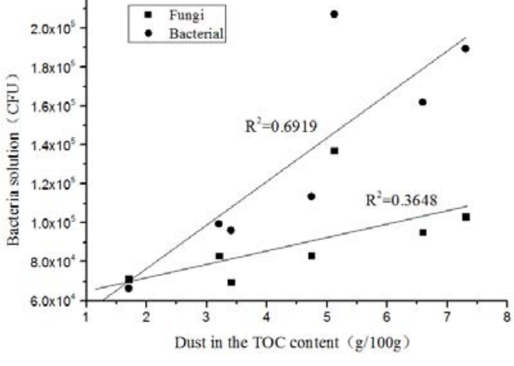

Figure 4: The relationship between TOC content and microbial quantity in dust

4. Conclusion

The average particle diameter of 6 sampling points dust except for the fresh air ranges between 6-20μm, and the average particle size of the dust in the air segment reached 41.30μm; dust sample pH value was 6.28, suitable for microbial breeding. In each processing section, the proportion of TOC, TC, and IC ranges between 2%-7.5%, 2.5%-8.5%, and 0.7%-1.2%, respectively, and the air tube is the maximum; the fresh air section is the minimum. In each processing section, dust associated bacteria ranges between 60000-210000CFU/g and associated fungi ranges between 60000-140000CFU/g, in which in the cooling section, microorganism bred in the unit dust amount is the maximum.

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