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ชื่อโครงการ THE EFFICIENCY OF CHEMICAL AGGLOMERATION IN $PM_{2.5}$ REMOVAL UNDER A CLOSED TESTING SYSTEM

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The efficiency of chemical agglomeration in $PM_{2.5}$ removal under a closed testing system

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หัวเรื่อง ประสิทธิภาพของการรวมตัวกันทางเคมีในการกำจัด $PM_{2.5}$ ภายใต้ระบบการทดสอบแบบปิด
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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อทดสอบประสิทธิภาพของสารไบโอโพลิเมอร์ในการกำจัด $PM_{2.5}$ ผ่านการเกาะรวมกันทางเคมีภายใต้ห้องทดสอบระบบปิดขนาด 6.6 ลูกบาศก์เมตร สารไบโอโพลิเมอร์ที่เลือกมาทดสอบได้แก่ เพคติน โซเดียมอัลจิเนต และแซนแทนกัม ทำการศึกษาผลของความเข้มข้นของสารเคมีรวมตัวและความชื้นภายในห้องทดสอบที่มีต่อประสิทธิภาพการกำจัด $PM_{2.5}$ ความเข้มข้นของเพคตินและโซเดียมอัลจิเนตกำหนดที่ 0.1% w/v และ 0.5% w/v และ 0.05% w/v และ 0.1% w/v สำหรับแซนแทนกัม โดยความชื้นภายในห้องทดสอบกำหนดไว้ที่ 45±3% และ 55±3% ปริมาณ $PM_{2.5}$ ที่ทดสอบควบคุมโดยการจุดธูป ทำการฉีดพ่นสารปริมาตร 10 มิลลิลิตรผ่านขวดสเปรย์ ผลการทดสอบพบว่า การฉีดพ่นเพคตินที่ความเข้มข้น 0.5% w/v ความชื้น 45% ให้ประสิทธิภาพการกำจัด $PM_{2.5}$ สูงที่สุดที่ 28.8±6.4% สำหรับโซเดียมอัลจิเนตและแซนแทนกัมให้ประสิทธิภาพสูงสุด 22.5±3.0% ที่ความเข้มข้น 0.5% w/v ความชื้น 55% และ 23.1±2.4% ที่ความเข้มข้น0.05% w/v ความชื้น 45% ตามลำดับ อย่างไรก็ตาม ผลการวิเคราะห์ความแตกต่างทางสถิติของประสิทธิภาพการกำจัด $PM_{2.5}$ ระหว่างทุกปัจจัยทดสอบยังไม่พบความแตกต่างอย่างมีนัยสำคัญที่ระดับความเชื่อมั่น 95%

Project title	The efficiency of chemical agglomeration in $PM_{2.5}$ removal under a closed testing system
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Abstract

The aim of this study was to investigate the efficacy of biopolymers in removing $PM_{2.5}$ via chemical agglomeration in a 6.6 m^3 closed chamber system. The biopolymers used in this study are pectin, sodium alginate, and Xanthan gum. Chemical concentration and relative humidity inside the chamber were assigned to examine the effect on $PM_{2.5}$ removal. Chemical agglomerants were prepared at two concentrations, 0.1% and 0.5% w/v for pectin and sodium alginate, and 0.05% and 0.1% w/v for Xanthan gum. The agglomeration testing was conducted under two different relative humidity conditions, i.e., 45±3% and 55±3%. An incense burning was used as a source of $PM_{2.5}$. 10 mL of each chemical solution were applied via a hand spray. The result showed that using pectin could give the highest removal efficiency of $PM_{2.5}$, 28.8±6.4%, which could be observed by testing at 0.5% w/v and under 45±3% RH condition. Whilst testing with sodium alginate and Xanthan gum, the highest removal efficiency of both, 22.5±3.0% and 23.1±2.4%, could be observed from applying 0.5% w/v under 55±3% RH and 0.05% w/v under 45±3% RH, respectively. However, there was no statistical difference in $PM_{2.5}$ removal efficiency when compared between all testing conditions at a confidence level of 95%.

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CHAPTER 1

INTRODUCTION

1.1 Background

People spend most of the day in indoor environments such as homes, offices, and schools. Indoor air pollutant concentrations, such as particulate matter (PM), can be found higher than those in the outdoor air, indicating a significant potential for detrimental health impacts. Possible indoor sources of PM include cooking, smoking, emissions from wood stoves and fireplaces, heating, cleaning, and other occupant activities (Cheek et al., 2020). Additionally, Outdoor air pollution such as emissions from traffic, fuel burning, and industrial can also cause indoor air pollution.

Indoor air quality (IAQ) is a growing concern for researchers and legislators in many aspects, such as long exposure times of humans to polluted indoor air, the adverse effects of some air pollutants on health and well-being, and the high diversity and chemical complexity of air in enclosed spaces (Kelly and Fussell, 2019; Hernández-Díaz et al., 2021). The amount of $PM_{2.5}$ can be used to indicate the IAQ. $PM_{2.5}$ is a particulate matter with an aerodynamic diameter less than or equal to 2.5 microns suspended in the air. It is compacted and not able to filter out by the nasal cavity, it can directly enter the lungs of the human body and remain in them, as well as it cannot easily be discharged from the body (Bai *et al.*, 2020). Until now, there are no regulatory standards for $PM_{2.5}$ in indoor environments, but certain guidelines are available. A so-called "global update" Air Quality Guidelines (AQG) was published by The World Health Organization in 2006, focusing on a $PM_{2.5}$. The value recommended for indoor air $PM_{2.5}$ is 10 $\mu g/m^3$ for the annual average and 25 $\mu g/m^3$ for the 24-h mean (Fromme, 2019). According to the announcement of the National Environment Committee issue 36 in 2010, a Thai national $PM_{2.5}$ standard is 25 $\mu g/m^3$ for the annual average and 50 $\mu g/m^3$ for the 24-h mean. A large number of particle-mass measurements of the indoor residences air were published in the scientific literature. The median/ mean values in Europe ranged from 3 to 36 mg/m^3, while in America, it ranged from 6 to 35 mg/m^3, and in East Asia, it ranged from 12 mg/m^3 in 55 urban homes in Japan in 2014 to 72 mg/m^3 in urban bedrooms in China in 2013 (Fromme, 2019b).

There are many ways to remove indoor $PM_{2.5}$, for example, portable air purifiers (PAPs), non-thermal plasma (NTP) generators, and chemical agglomeration. PAPs can reduce $PM_{2.5}$ in indoor air by between 22.6 and 92.0%. But the current evidence demonstrates that using PAP results in a short-term reduction of $PM_{2.5}$ in the indoor environment, the only downside which PAPs had is the cost (Cheek et al., 2020). Using non-thermal plasma (NTP) generators, a multi-pin corona discharge (MPCD) and a dielectric barrier discharge (DBD) generator were found to reduce $PM_{2.5}$. MPCD has a higher $PM_{2.5}$ removal efficiency. NTP produces harmful by-products such as ozone (Hernández-Díaz et al., 2021). This study centers around chemical agglomeration which is a technique that uses chemical agents to induce particle agglomeration, and reduce the amount of $PM_{2.5}$ in indoor environments. Particle agglomeration technologies are able to increase the mean particle size, which could effectively improve particle removal efficiency. The forces that used to adhesive the particle include Van der Waals force, attractive electrostatic forces, and surface tension of the liquid layer on dust particles. Chemical agglomeration is the process of agglomeration by using chemical agents in condensation. It is associated with intermolecular forces, which give the strength of the attraction between particles and chemical agents.

Chemical agglomeration is one of the most efficient methods to reduce $PM_{2.5}$. This method increased the $PM_{2.5}$ particle size due to the physical and chemical properties of the agglomeration agent which led to an improvement in the elimination process. Even though chemical agglomeration can decrease the amount of $PM_{2.5}$, it is still not a prevalent method for indoor space because chemical agglomeration is mainly used in a large-scale industrial factory that has facilities for mitigating the effect of the chemical agent. Some chemicals that are used in the industrial process cause health impacts, which makes these chemicals not appropriate for applying in indoor areas. This study focused on applying chemical agglomeration to remove indoor $PM_{2.5}$ by using chemicals that have less impact on human health and the environment. The experiment was conducted in a closed chamber under different relative humidity conditions. The chemical agents used in this study are pectin, sodium alginate, and Xanthan gum, in which each chemical desired concentration was prepared (0.05% - 0.1% w/v).

1.2 Objectives

1) To compare $PM_{2.5}$ removal efficiency of chemical agents in different solution concentrations.
2) To compare $PM_{2.5}$ removal efficiency of chemical agents in different conditions of humidity.

1.3 Research hypothesis

The hypotheses of the study on the efficiency of chemical agglomeration in $PM_{2.5}$ removal under a closed testing system are as follows:

1) The increasing of chemical concentrations resulted in a higher removal efficiency of $PM_{2.5}$.
2) The higher level of the humidity in the tested chamber resulted in a higher removal efficiency of $PM_{2.5}$.

1.4 Scope of this study

1) Three types of biopolymers including pectin, sodium alginate, and Xanthan gum with a concentration ranging from 0.05-0.1% w/v were used for $PM_{2.5}$ agglomeration.
2) The relative humidity inside the chamber was controlled at 45±3% and 55±3% humidity by using an air damper (Xiaomi Zhibai Smart Control Dehumidifier).
3) An incense burning was applied as a source of $PM_{2.5}$.
4) The test was performed in a closed chamber that size is 2 x 2 x 3 m. (6.6021m^3)

1.5 Expected benefits

1) The relationship between solution concentration and humidity that affect $PM_{2.5}$ removal efficiency in a closed chamber would be assessed.
2) The result of this study can be applied to improve the removal of $PM_{2.5}$ in a closed indoor area.

CHAPTER 2
LITERATURE REVIEW

2.1 Definition of agglomeration

Agglomeration is a process that makes the small particles in solid form combine to form a larger size. It is based on collisions and agglomeration of particles. Agglomeration of particles is a common fundamental process in many technical and industrial processes.

Particle agglomeration technology is able to increase particle size using physical and chemical methods. Common agglomeration methods include condensation-induced agglomeration, electric agglomeration, turbulent agglomeration, acoustic agglomeration, and chemical agglomeration (Sun et al., 2018).

Chemical agglomeration is the process of agglomeration by using chemical agents in condensation. It is associated with intermolecular forces, which give the strength of the attraction between particles and chemical agents. There are 3 types of intermolecular forces involving van der Waals force, valence force, and non-valence association (Lewandowski & Kawatra, 2009). In addition, the type of chemical agents can affect the agglomeration of particles due to the different chemical reactions show different particle agglomeration properties.

The chemical agglomeration of particles can improve dust removal efficiency. Efficiency has been significantly improved with increased particle diameter. At the present, chemical agglomeration is used to enhance the particle removal efficiency of dust removal technologies such as Electrostatic Precipitators (ESPs) and Fabric Filter (FFs). These technologies are very popular in industries to remove dust such as the chemical industry, mining industry, etc. Typically, industry often uses synthetic polymers as chemical agglomerants, because it has high condensation efficiency. However, synthetic polymers are not safe for human health. Biopolymer is another chemical that also capable of chemical agglomeration of fine particles and also it is not harmful to human health (Guo et al., 2017).

2.2 Biopolymers

Two different criteria underline the definition of a “biopolymer” (1) the source of the raw materials and (2) the biodegradability of the polymer. Here, a differentiation is made between

1) Type A: biopolymers made from renewable raw materials (bio-based) and being biodegradable.
2) Type B: biopolymers made from renewable raw materials (bio-based), and not being biodegradable.
3) Type C: biopolymers made from fossil fuels and being biodegradable. (Niaounakis, 2015) Biopolymers used as chemical agglomeration are shown in Table 1.

Table 2.1 List of biopolymers that are used as chemical agglomeration

Biopolymers	Characterization	Utilization	Toxicity	Reference
1. Sesbania gum	• Natural polysaccharide • High molecular weight • Lower viscosity	• Food additive • Oil • Textile • Pharmaceutical • Cosmetic	• No effect on health.	(Tang et al., 2020) (Pont, 2010)
2. Xanthan Gum	• Hetero-polysaccharide	• Food additive	• Acute effects: Inhalation of the dust and eye contact may cause irritation. May be irritating to the skin of a sensitive person.	(Emirates, 2012) (Parchem, 2017)
3. Pectin	• Natural polysaccharides • Surfactant properties	• Food additive	• On the skin: No irritant effect. · • On the eye: May have an irritating effect.	(Avantor, 2012)
4. Sodium alginate	• Natural polysaccharides • Surfactant properties	• Food additive	• No acute toxicity information	(Avantor, 2012)

5. Glycerin	- Glycerol Polymers (byproducts from the production of bio-diesel) - Nontoxic - Non-corrosive - Non-flammable liquid - Good moisture absorption capability	- Skin lotion - Soap	Acute effects: - Skin irritation/corrosion: Can be irritating to the skin. - Eye irritation: Can be irritating to the eyes. - Skin sensitization: Can be harmful if absorbed through the skin. - Respiratory irritation: Can be harmful if inhaled. Can be irritating to the respiratory tract. Avoid exposure to mist.	(Yanghao Liu et al., 2018) (Hazards, 2008)
6. Kappa-carrageenan	- Linear polysaccharide - Sulfate group and no sulfate group	- Food additive	- No acute toxicity information	(Makshakova et al., 2021) (Avantor, 2012)
7. Guar Gum	- natural polysaccharide - hydrocolloid	- Food additive - Pharmaceutical	- Not effect on health.	(Bai et al., 2019) (Pont, 2010)

From the literature review, biopolymer can be considered to be a suitable agglomerant in an agglomeration process due to its high viscosity. Moreover, biopolymer has no strong side effect on human health, then it can be utilized for indoor $PM_{2.5}$ removal. Consequently, pectin, sodium alginate, and Xanthan gum were chosen to examine the removal efficiency of $PM_{2.5}$ in this study.

Pectin and sodium alginate are natural polysaccharides with surfactant properties. Pectin and sodium alginate has not shown any effect of health toxicity. Therefore, it is safe for humans.

Xanthan Gum (XTG) is a hetero-polysaccharide. It is commonly used in many food products, as a viscosity stabilizer, and helps stabilize the product. Long-term exposure to the substance may irritate the skin and eyes (Emirates, 2012). Xanthan gum has the ability to agglomeration of fine particles.

2.3 Mechanism of chemical agglomeration

The agglomeration solution attaches to the dust particle's surface, due to the respective adhesive force. Larger particles are formed by fine particles in two different ways (Fig. 1). First, the agglomeration solution droplets are added (Fig. 1(a)), absorbing the fine particles and attaching each other to form large particles. Due to the liquid bridge force between particles, the agglomerates of fine particles are formed and agglomeration between fine particles is enhanced. Second, the agglomeration agent solution droplets contain macromolecular chain molecules with polar groups (Fig. 1(b)). These groups can adhere to particles and form stable agglomerations (Bin et al., 2018).

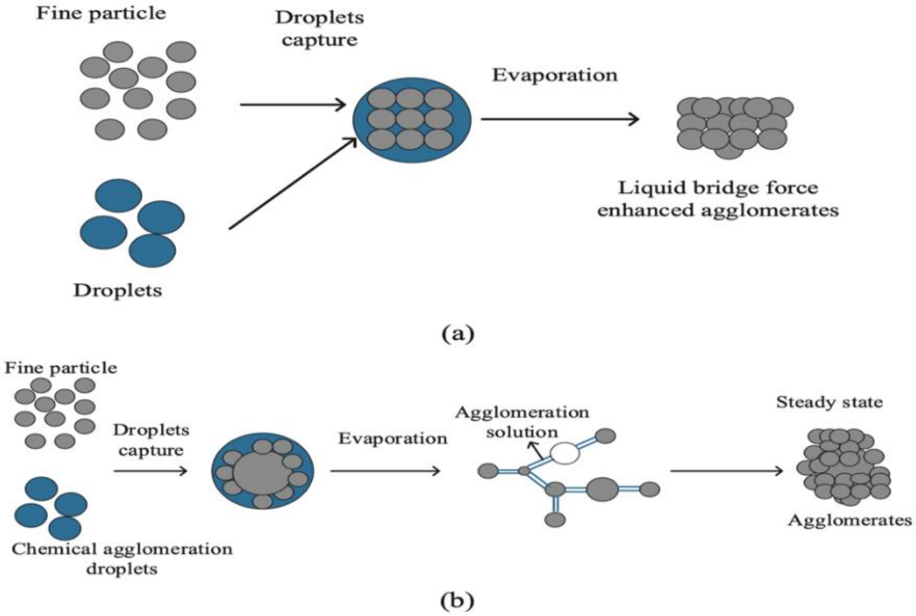


Fig. 2.1 Chemical agglomeration modes of particles

Figure 2 shows the SEM images of agglomerated particles which the smooth spheres particles can be seen before the agglomeration (a). After the chemical agents were added, agglomerates of fine particles and large particles were formed (b). After that, the particle's surfaces were not as smooth as before (c). The particles with submicron and micron sizes (d) will be attached by agglomeration agents (Bin et al., 2018).

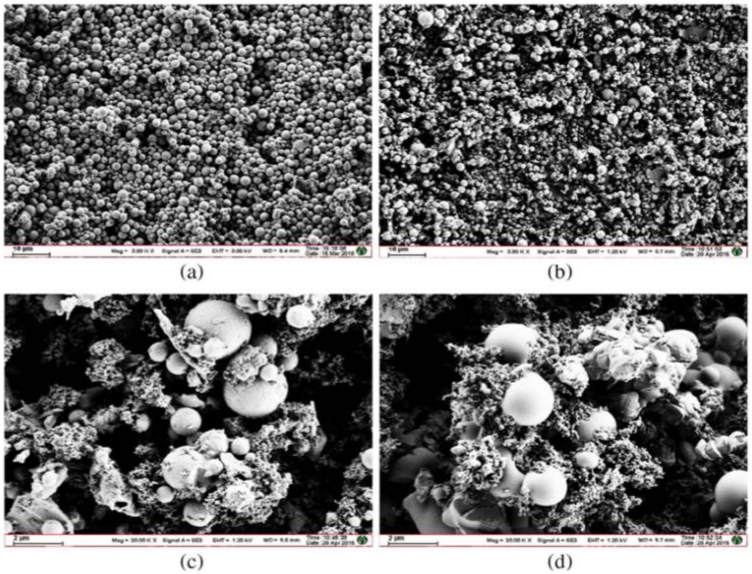


Fig. 2.2 SEM images of agglomerated particles

The previous research indicated that the chemical agglomeration process can reduce indoor $PM_{2.5}$ concentration. The agglomerant attaches to the fine particle's surface, forming a larger particle. An increase in diameter resulted in a heavier particle, which makes the particles precipitate, and decrease the $PM_{2.5}$ mass concentration.

2.4 Affecting factors of the agglomeration process

Some environmental factors have effects on the chemical agglomeration of $PM_{2.5}$ which were reported in the previous studies. Table 2.2 gives a list of related environmental factors and their effects.

Table 2.2 Environmental factor affecting chemical agglomeration of $PM_{2.5}$ under a closed testing system

Environmental factors	Effects	Reference
Relative humidity	Increasing relative humidity led to increasing particle agglomeration by means of hygroscopicity. The relative humidity has an obvious effect on the size-resolved deposition rate and coagulation coefficient for the airborne nanoparticles, which cannot be neglected. First, the impact of the RH on the size-resolved deposition rate depends on particle size. Secondly, the high initial ratio of coagulation to the total particle loss (CtTPL) tends to be associated with the high RH conditions, which may lead to the formation of nanometer-thick water films at the interface and greatly enhance the viscosities. Thirdly, the minimum time-averaged deposition rate and the maximum coagulation coefficient appear at RH ~54%; both the lower and higher RH conditions tend to enhance the deposition rate of the nanoparticles.	(Montgomery et al., 2015)
Temperature	In the chemical agglomeration process in coal combustion, testing temperatures of 120, 150, and 250 °C, and 150 °C is the optimal temperature.	(Yong Liu et al., 2016)
Potential of Hydrogen ion (pH)	In electrostatic stabilization, the surfaces of particles become charged in order to prevent their collisions. The pH of particulate suspensions is one of the keys to particle stability. For good stability, the zeta potential value should not equal to 0. In an unstable state, the particle agglomeration occurs at a higher rate, and complex agglomerates are formed (Yong Liu et al., 2016). Decreasing pH value can change the electrical properties of the agglomeration agent, which is propitious to the adsorption of particles by the formation of macromolecular chains and the agglomeration effect of particles.	(Al-Gebory & Mengüç, 2018)

Chemical concentration and Viscosity	The high chemical concentration can easily attach particles due to the probability that the collision can occur more frequently in higher concentration samples. Increasing the concentration of agglomeration solution amplifies the dust removal efficiency. By increasing the mass concentration of the agglomerant, the viscosity of the slurry and the solution droplet size expand, making it difficult to disintegrate into an aerosol which causes the spraying aerosol movement speed to decrease. An escalation in the concentration of the substance is helpful in liquid bridge bond formation between fine particles. However, the number of adsorption sites on the surface of the dust particles remains stable. As the mass concentration increases, the adsorption site is gradually occupied by polymer molecules. Weaken the liquid bridge force, so the efficiency of dust particle removal is slow or reduced.	(Y. Wang et al., 2017) (Zhou et al., 2019)
Droplet atomization performance	The size of the nozzle impacts the size of the concentrated solution droplets. A small nozzle creates a small droplet which is effective for particle agglomeration. The air pressure at the nozzle depends on the viscosity of the used solution. The increase in air pressure was beneficial to small droplet production and particle collision. Droplet fine particle collection efficiency might be greatly enhanced as well.	(Yong Liu et al., 2016)
Chamber test (Wall condition)	Chamber wall material with low static charge can interfere with experimental results. To reduce the adhesion between dust and covering material. The majority of the studies used glass and stainless-steel frames to minimize the build-up of fine particles on the wall while some studies used polymethyl methacrylate instead of both materials. Moreover, it was shown that the resuspension in rooms with	(J. J. Kim et al., 2019) (Y. Wang et al., 2017) (Fromme, 2019)

	wall-to-wall carpet was significantly higher than that in rooms with smooth flooring.	
Airflow rate	In high airflow conditions, dust removal efficiency is improved. Increasing flow speed (Fan rotational speed (RPM) and relative humidity air resulted in higher PM $_{2.5}$ removal efficiency than without airflow and dry air condition. The upward flow of the chamber air led to a higher momentum in the chamber contributing to higher particle agglomeration.(J. Kim et al., 2020)	(J. J. Kim et al., 2019) (J. Kim et al., 2020)
Surface tension	Surface tension is an important parameter of the particle's wettability. The lower the surface tension, the easier it can form a liquid film on the surface of a particle and enhancing the liquid bridge forces between the particles.	(Bin et al., 2018)

It was reported in the literature that many environmental factors were found to affect the efficiency of chemical agglomeration. Various factors can enhance the agglomeration of fine particles to produce a larger size. As a result, the amount of indoor PM$_{2.5}$ can be reduced by the deposition of larger particles. As for the testing of chemical agglomeration would be operated in a closed chamber for this study, two factors including solution concentration and relative humidity were then preliminarily selected for investigation.

A high concentration of the solution can increase the viscosity of chemical agglomerant. The viscosity also gives results in better particle adhesion efficiency. The relative humidity of the test chamber is one of the affecting factors on the adhesion of particles. The amount of water vapor in the air is also another factor of the adhesion of chemicals agglomeration with PM$_{2.5}$ within the chamber test. As a result, the removal efficiency of PM$_{2.5}$ in the indoors can be also improved. Therefore, in this study, the solution concentration and relative humidity were used as important factors to examine the removal efficiency of PM2.5 in a closed testing system.

2.5 Effects of the test chamber materials on chemical agglomeration

This research uses a laboratory simulation to study the effect of particle agglomeration in a closed system by using chemical agglomeration agents. Plastic and stainless steel has been used as a chamber to resemble a closed room environment. Plastic and stainless steel has a low static charge that decreases the link between dust and covering material resulting in low experimental error.

2.6 Source of indoor $PM_{2.5}$

Fine particles are particles with a diameter of less than 2.5 µm ($PM_{2.5}$). Sources of $PM_{2.5}$ come from combustion such as the burning of coal fuels in industrial, burning of car fuels, etc.

There are outdoor and indoor sources of fine particles. Outdoor sources come from cars, trucks, bus and off-road vehicles, and the burning of fuels. Fine particles also form from the reaction of gases or droplets in the atmosphere from sources such as power plants. These chemical reactions can occur miles from the original source of the emissions. Indoor sources come from tobacco smoke, cooking, and burning candles or oil lamps.

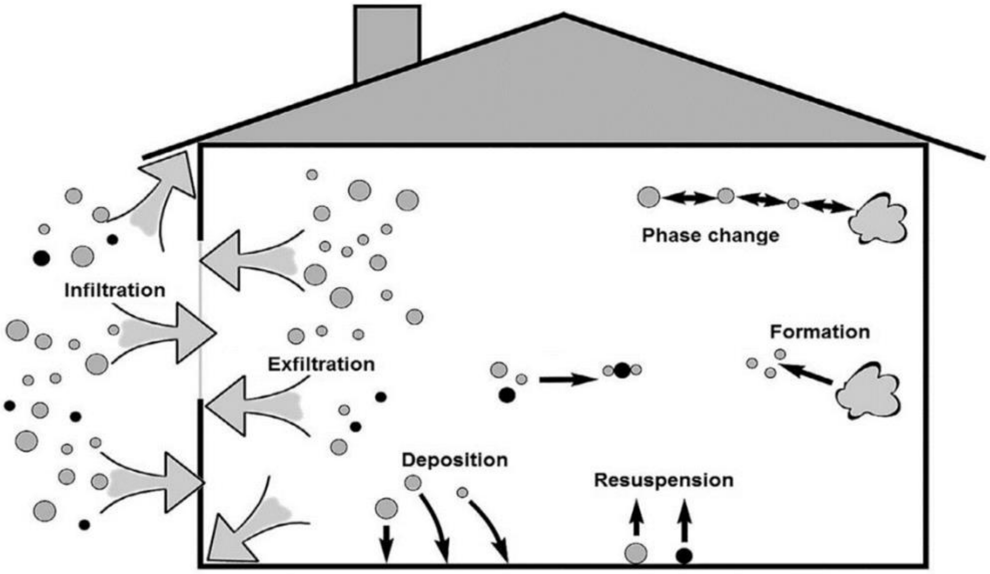


Fig. 2.3 Transport and transformation processes of particles with impact on the indoor concentration of particulate matter. Modified from Thatcher et al. (2001). Lawrence Berkeley National Laboratory. The report under contract No. DW-89938748. (Fromme, 2019)

2.7 The situation of $PM_{2.5}$ pollution in Bangkok (Thailand)

Averages 24 hours ambient $PM_{2.5}$ in Bangkok and vicinity is over the standard (50 µg/m^3) at the beginning (January to March) and the end of the year (December) from 2011-2018 (Fig. 4) (Pollution Control Department, Ministry of Natural Resources and Environment, 2017).

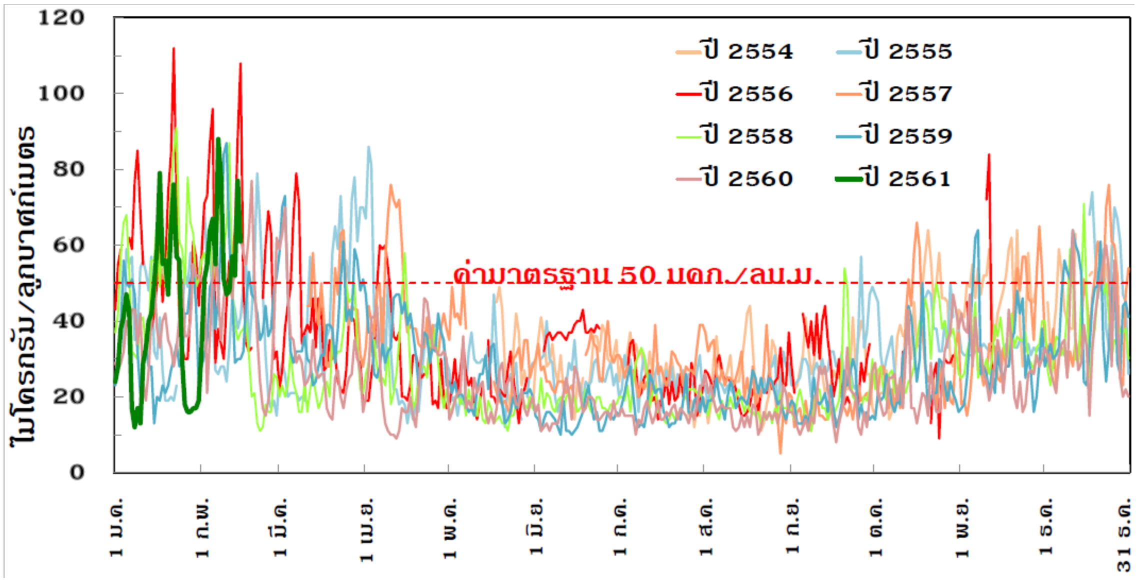
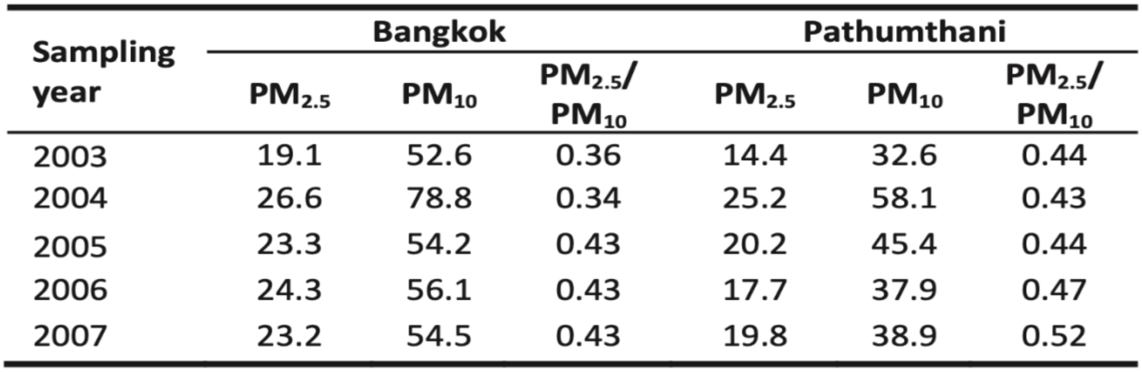


Fig. 2.4 Daily $PM_{2.5}$ mass concentrations in Bangkok areas, 2011-2018

The five common sources of $PM_{2.5}$ in Bangkok were traffic, biomass burning, secondary sulfate, soil, and aged sea salt. An annual average mass concentration of $PM_{2.5}$ in Bangkok and Pathumthani stations are shown in Table 2 (Wimolwattanapun et al., 2011). An average 24 h $PM_{2.5}$ concentration for Din Daeng (DD) stations, Jan Krasem (JK) stations, Bann Somdej (BD) stations, Bank Na (NA) stations in BMR during 2002-2003 were 69.0 ± 28.8, 40.9 ± 21.4, 41.5 ± 24.6 and 37.9 ± 18.9 µg/m^3, respectively. (Chuersuwan et al., 2008)

Table 2.3 Statistical summary of annual average mass concentrations (in µg/m^3) of $PM_{2.5}$ and PM_{10} and ratios of $PM_{2.5}$ to PM_{10}



Sampling year	Bangkok			Pathumthani		
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$/ PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$/ PM_{10}
2003	19.1	52.6	0.36	14.4	32.6	0.44
2004	26.6	78.8	0.34	25.2	58.1	0.43
2005	23.3	54.2	0.43	20.2	45.4	0.44
2006	24.3	56.1	0.43	17.7	37.9	0.47
2007	23.2	54.5	0.43	19.8	38.9	0.52

(Wimolwattanapun et al., 2011)

2.8 Exposure to $PM_{2.5}$ in Indoor Spaces

Table 2.4 shows the $PM_{2.5}$ concentration that had exceeded the recommended values in some indoor areas of some countries.

Table 2.4 Exposure to $PM_{2.5}$ in indoor areas

Indoor areas	Mass concentration of $PM_{2.5}$	Reference
$PM_{2.5}$ in Residences	A large number of particle-mass measurements in the indoor air of residences were published in the scientific literature. The median/mean values in Europe ranged from 3 to 36 µg/m^3, similar levels from 6 to 35 µg/m^3 were reported in America. In East Asia, higher concentrations were described, ranging from 12 µg/m^3 in 55 urban homes in Japan in 2014 to 72 µg/m^3 in urban bedrooms in China in 2013.	(Fromme, 2019).
$PM_{2.5}$ in Schools	Children spend a substantial portion of their days in a school, which has special furnishings and are characterized by a high density of persons per space. The average $PM_{2.5}$ ranged from 8 to 33 µg/m^3.	(Fromme, 2019).
$PM_{2.5}$ in Offices	The working adult population spends a significant amount of time each day, nearly 30%, in office rooms. An EU-wide project (OFFICEAIR) investigating 37 buildings, mainly equipped with a mechanical ventilation system, in 2012–13. 9 out of 37 buildings had a $PM_{2.5}$ concentration range between 4.7 and 38 µg/m^3.	(Fromme, 2019).

2.9 Regulation/Guideline Values

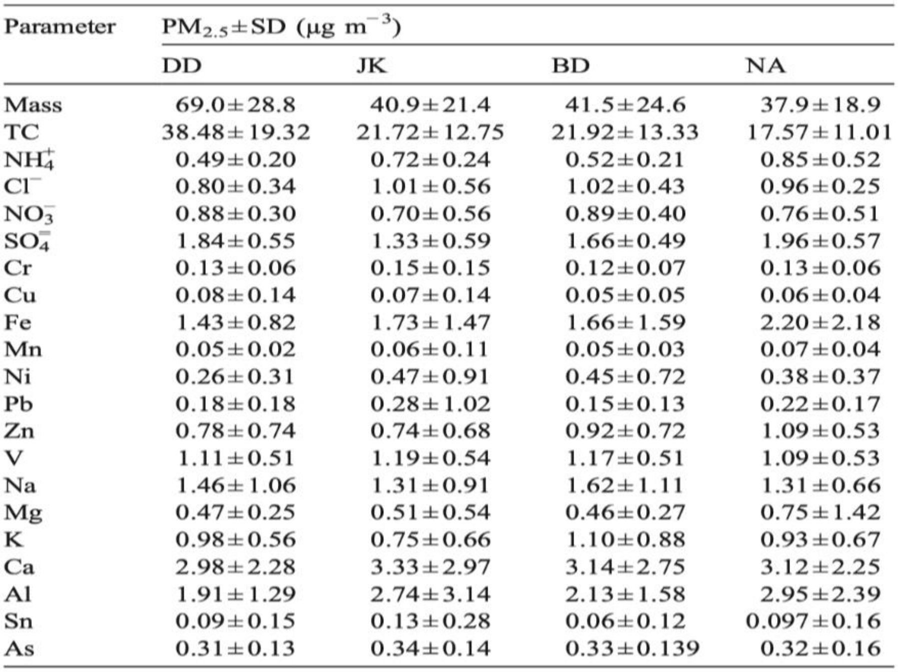
There is no evidence of a safe level of exposure to $PM_{2.5}$ or a threshold below which no adverse health effects occur. Based on the existing evidence of adverse health effects at low levels of exposure, The World Health Organization published the Air Quality Guidelines (AQG) in 2006, focusing on $PM_{2.5}$. The value recommended for indoor air $PM_{2.5}$ is 10 $\mu g/m^3$ for the annual average and 25 $\mu g/m^3$ for the 24-h mean (not to be exceeded for more than 3 days/year). According to the announcement of the National Environment Committee issue 36 in 2010, the Thai national $PM_{2.5}$ standards in the ambient are set as 25 $\mu g/m^3$ for the annual average and 50 $\mu g/m^3$ for the 24-h mean.

It was reported that the value of $PM_{2.5}$ in indoor environments has exceeded the acceptable value. The increase in $PM_{2.5}$ concentration can cause harm or adverse effects to human health. Therefore, it is necessary to reduce the amount of $PM_{2.5}$ in an indoor environment.

2.10 Chemical composition of $PM_{2.5}$

$PM_{2.5}$ samples from the 4 sampling sites (Din Daeng (DD), Jan Krasem (JK), Bann Somdej (BD), and Bank Na (NA)) measured in 2002-2003 consisted of fifteen elements as reported in Table 5. The chemical elements found in $PM_{2.5}$ were Cr, Cu, Fe, Mn, Ni, Pb, Zn, V, Na, Mg, K, Ca, Al, Sn, and As (Chuersuwan et al., 2008).

Table 2.5 Average concentrations of chemical composition found in $PM_{2.5}$ samples



Parameter	$PM_{2.5}\pm SD$ ($\mu g\ m^{-3}$)			
	DD	JK	BD	NA
Mass	69.0±28.8	40.9±21.4	41.5±24.6	37.9±18.9
TC	38.48±19.32	21.72±12.75	21.92±13.33	17.57±11.01
NH_4^+	0.49±0.20	0.72±0.24	0.52±0.21	0.85±0.52
Cl^-	0.80±0.34	1.01±0.56	1.02±0.43	0.96±0.25
NO_3^-	0.88±0.30	0.70±0.56	0.89±0.40	0.76±0.51
$SO_4^=$	1.84±0.55	1.33±0.59	1.66±0.49	1.96±0.57
Cr	0.13±0.06	0.15±0.15	0.12±0.07	0.13±0.06
Cu	0.08±0.14	0.07±0.14	0.05±0.05	0.06±0.04
Fe	1.43±0.82	1.73±1.47	1.66±1.59	2.20±2.18
Mn	0.05±0.02	0.06±0.11	0.05±0.03	0.07±0.04
Ni	0.26±0.31	0.47±0.91	0.45±0.72	0.38±0.37
Pb	0.18±0.18	0.28±1.02	0.15±0.13	0.22±0.17
Zn	0.78±0.74	0.74±0.68	0.92±0.72	1.09±0.53
V	1.11±0.51	1.19±0.54	1.17±0.51	1.09±0.53
Na	1.46±1.06	1.31±0.91	1.62±1.11	1.31±0.66
Mg	0.47±0.25	0.51±0.54	0.46±0.27	0.75±1.42
K	0.98±0.56	0.75±0.66	1.10±0.88	0.93±0.67
Ca	2.98±2.28	3.33±2.97	3.14±2.75	3.12±2.25
Al	1.91±1.29	2.74±3.14	2.13±1.58	2.95±2.39
Sn	0.09±0.15	0.13±0.28	0.06±0.12	0.097±0.16
As	0.31±0.13	0.34±0.14	0.33±0.139	0.32±0.16

(Chuersuwan et al., 2008)

2.11 Chemical composition of fine particles from incense burning

Incense burning is an indoor source of $PM_{2.5}$. Based on the integral mass balance model, the emission factors of different particulate pollutants were evaluated. The emission factors of $PM_{2.5}$ and $PM_{2.5\text{-bound}}$ chemical species such as EC, OC, metals, and ions are given in terms of their masses. (See & Balasubramanian, 2011). The major chemical compositions of $PM_{2.5}$ from 10 types of Incense burning, such as TC, OC, EC, ions, and elements mass percentages are shown in Table. 2.6 The 40 elements found in $PM_{2.5}$ are shown in Table 2.7, including Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Tl, Pb, and U. The elemental profiles were dominated by Na, Cl, and K as shown in Table 8. Major chemical compositions are mass percentages of total carbon, OC, EC, total measured ions, and total measured elements in $PM_{2.5}$ from incense burning are shown in Table 2.8 (B. Wang et al., 2006)

Therefore, various chemical constituents within the incense smoke are a good representative matter for $PM_{2.5}$ in the atmosphere. For that reason, incense burning was applied as a source of $PM_{2.5}$ in this study.

Table 2.6 Average concentrations of $PM_{2.5}$, TC, OC and EC, and mass percentage of TC, OC, EC, total measured ions, and elements in $PM_{2.5}$ from incense burning

Category	Sample ID	Total $PM_{2.5}$ ($\mu g\,m^{-3}$)	TC ($\mu g\,m^{-3}$)	OC ($\mu g\,m^{-3}$)	EC ($\mu g\,m^{-3}$)	OC/EC	TC/$PM_{2.5}$ (%)	OC/$PM_{2.5}$ (%)	EC/$PM_{2.5}$ (%)	Total measured ions/$PM_{2.5}$ (%)	Total measured elements/$PM_{2.5}$ (%)
Traditional Incense	I 1	824.9	500.6	477.9	22.8	21.0	60.7	57.9	2.8	3.4	1.0
	I 2	962.2	592.3	518.3	74.0	7.0	61.6	53.9	7.7	22.7	6.5
	I 3	2743.4	2249.2	2193.1	56.1	39.1	82.0	79.9	2.1	1.8	0.7
	I 4	1603.8	842.2	810.6	31.6	25.7	52.5	50.5	2.0	2.3	1.1
	I 5	1799.0	1384.6	1340.5	44.1	30.4	77.0	74.5	2.5	16.3	3.1
	I 6	413.0	267.8	239.2	28.6	8.4	64.8	57.9	6.9	9.3	3.8
	Average	1391.0	972.8	929.9	42.9	21.7	66.4	62.5	4.0	9.3	2.7
Aromatic Incense	I 7	233.4	183.0	139.8	43.2	3.2	78.4	59.9	18.5	10.5	3.4
	I 8	590.0	354.9	327.4	27.5	11.9	60.2	55.5	4.7	5.6	2.5
	I 9	681.4	374.2	333.1	41.0	8.1	54.9	48.9	6.0	2.4	0.7
	Average	501.6	304.0	266.8	37.2	7.7	64.5	54.8	9.7	6.2	2.2
Church Incense	I 10	6024.8	4478.4	4414.7	63.7	69.3	74.3	73.3	1.1	0.7	0.3

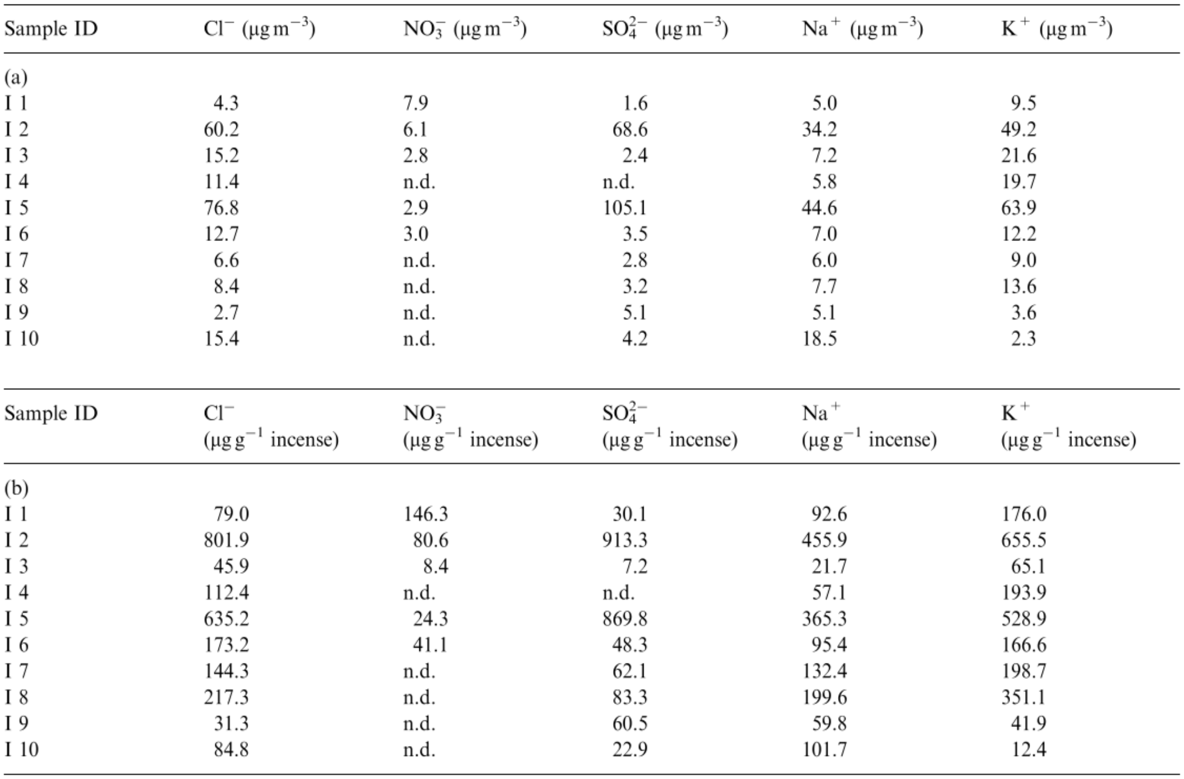
(B. Wang et al., 2006)

Table 2.7 Elemental compositions (%) of incense burning from 10 incense brands

	I 1	I 2	I 3	I 4	I 5	I 6	I 7	I 8	I 9	I 10
Na	8.44±14.88	8.27±1.11	16.36±2.30	2.76±0.23	7.94±1.21	7.03±8.41	9.12±12.22	12.18±3.01	6.39±14.14	9.01±14.16
Mg	0.70±2.83	0.77±0.23	0.99±1.12	2.12±0.50	1.25±0.23	2.46±0.51	2.62±0.72	2.34±0.51	2.26±2.48	6.38±0.81
Al	0.82±1.05	0.70±0.08	0.65±0.13	2.29±0.15	0.55±0.08	1.28±0.17	2.67±0.24	0.51±0.56	4.13±0.33	2.036±0.31
Si	0.71±0.16	0.49±0.04	0.56±0.06	1.28±0.07	0.34±0.04	0.97±0.09	1.21±0.13	1.09±0.10	3.03±0.17	3.53±0.17
P	0.00±0.28	0.00±0.07	0.18±0.04	0.00±0.15	0.00±0.07	0.00±0.16	0.02±0.23	0.00±0.17	0.08±0.34	0.07±0.26
S	2.58±0.13	1.66±0.03	2.16±0.06	2.10±0.07	0.66±0.03	1.42±0.07	6.45±0.13	4.99±0.10	21.85±0.25	6.33±0.15
Cl	25.81±0.38	46.04±0.16	30.29±0.22	37.30±0.28	44.47±0.17	41.24±0.30	33.67±0.38	32.50±0.29	23.98±0.38	61.31±0.53
K	57.42±0.38	41.38±0.10	47.33±0.19	50.78±0.21	42.84±0.11	42.47±0.21	39.50±0.27	43.83±0.23	31.84±0.27	6.15±0.12
Ca	0.00±0.96	0.00±0.66	0.00±0.76	0.08±0.82	0.00±0.68	0.00±0.69	0.26±0.66	0.08±0.71	0.52±0.56	1.18±0.08
Ti	0.00±0.80	0.00±0.09	0.00±0.29	0.07±0.32	0.02±0.10	0.11±0.33	0.21±0.56	0.02±0.41	0.15±0.76	0.06±0.78
V	0.00±0.34	0.01±0.04	0.04±0.17	0.08±0.13	0.03±0.04	0.07±0.14	0.34±0.08	0.06±0.25	0.50±0.11	0.00±0.33
Cr	0.09±0.02	0.02±0.00	0.03±0.05	0.02±0.02	0.01±0.00	0.05±0.01	0.18±0.01	0.05±0.07	0.22±0.02	0.03±0.05
Mn	0.01±0.04	0.01±0.00	0.00±0.02	0.02±0.01	0.02±0.00	0.03±0.01	0.06±0.01	0.04±0.01	0.16±0.01	0.34±0.02
Fe	0.61±0.02	0.14±0.00	0.39±0.01	0.49±0.01	1.51±0.01	1.62±0.02	1.38±0.03	0.76±0.01	1.90±0.03	2.33±0.04
Co	0.00±0.03	0.00±0.00	0.00±0.01	0.02±0.02	0.01±0.02	0.02±0.03	0.02±0.03	0.00±0.02	0.02±0.04	0.00±0.05
Ni	0.00±0.02	0.00±0.00	0.00±0.01	0.00±0.01	0.00±0.00	0.00±0.01	0.00±0.01	0.00±0.01	0.00±0.02	0.00±0.02
Cu	0.00±0.03	0.01±0.00	0.00±0.01	0.00±0.01	0.01±0.00	0.01±0.01	0.06±0.01	0.06±0.01	0.40±0.01	0.00±0.03
Zn	0.49±0.02	0.10±0.00	0.18±0.01	0.28±0.01	0.10±0.00	0.15±0.01	1.19±0.02	0.56±0.01	1.32±0.02	0.66±0.01
Ga	0.00±0.09	0.00±0.01	0.00±0.03	0.00±0.04	0.00±0.01	0.00±0.04	0.06±0.06	0.00±0.04	0.00±0.09	0.00±0.09
As	0.00±0.10	0.00±0.02	0.01±0.03	0.03±0.04	0.01±0.01	0.00±0.04	0.02±0.05	0.00±0.05	0.03±0.11	0.00±0.10
Se	0.00±0.03	0.00±0.00	0.00±0.01	0.00±0.02	0.00±0.01	0.00±0.01	0.01±0.02	0.00±0.01	0.00±0.03	0.00±0.03
Br	0.14±0.01	0.07±0.00	0.13±0.01	0.07±0.01	0.05±0.00	0.22±0.01	0.36±0.01	0.08±0.01	0.08±0.01	0.16±0.01
Rb	0.22±0.02	0.14±0.00	0.17±0.01	0.10±0.01	0.10±0.00	0.18±0.01	0.16±0.01	0.18±0.01	0.20±0.01	0.00±0.04
Sr	0.01±0.04	0.00±0.01	0.00±0.02	0.00±0.02	0.00±0.01	0.01±0.02	0.02±0.03	0.00±0.02	0.00±0.04	0.00±0.04
Y	0.00±0.06	0.00±0.01	0.00±0.02	0.00±0.03	0.00±0.01	0.00±0.03	0.00±0.04	0.00±0.03	0.00±0.05	0.00±0.06
Zr	0.01±0.06	0.01±0.01	0.00±0.02	0.00±0.03	0.00±0.01	0.01±0.03	0.00±0.04	0.00±0.03	0.00±0.06	0.00±0.07
Mo	0.00±0.09	0.00±0.01	0.00±0.03	0.00±0.04	0.00±0.01	0.00±0.04	0.00±0.06	0.01±0.04	0.00±0.09	0.00±0.10
Pd	0.00±0.11	0.00±0.01	0.00±0.04	0.00±0.05	0.00±0.02	0.00±0.04	0.00±0.08	0.00±0.05	0.00±0.10	0.00±0.10
Ag	0.00±0.14	0.00±0.02	0.01±0.05	0.02±0.06	0.00±0.02	0.01±0.06	0.00±0.10	0.02±0.07	0.00±0.14	0.00±0.14
Cd	0.09±0.14	0.00±0.02	0.01±0.05	0.01±0.06	0.00±0.02	0.04±0.07	0.00±0.10	0.00±0.07	0.00±0.13	0.00±0.14
In	0.00±0.18	0.01±0.02	0.04±0.06	0.00±0.07	0.00±0.02	0.00±0.07	0.00±0.13	0.00±0.08	0.00±0.16	0.01±0.17
Sn	0.20±0.27	0.01±0.03	0.00±0.09	0.00±0.11	0.03±0.04	0.14±0.04	0.05±0.19	0.05±0.13	0.22±0.25	0.26±0.26
Sb	0.26±0.31	0.02±0.04	0.00±0.11	0.03±0.12	0.00±0.04	0.08±0.13	0.05±0.21	0.00±0.14	0.27±0.29	0.20±0.31
Ba	1.16±1.46	0.07±0.16	0.13±0.49	0.00±0.59	0.05±0.20	0.09±0.61	0.23±1.04	0.07±0.70	0.00±1.38	0.00±1.46
La	0.00±1.84	0.00±0.21	0.27±0.65	0.00±0.76	0.00±0.25	0.21±0.79	0.00±1.32	0.34±0.93	0.00±1.79	0.00±1.90
Au	0.00±0.10	0.00±0.01	0.00±0.04	0.00±0.04	0.00±0.01	0.00±0.04	0.04±0.07	0.00±0.05	0.00±0.10	0.00±0.10
Hg	0.01±0.07	0.00±0.01	0.00±0.02	0.00±0.03	0.00±0.01	0.00±0.03	0.00±0.04	0.00±0.03	0.00±0.05	0.00±0.07
Tl	0.00±0.06	0.00±0.01	0.00±0.02	0.01±0.03	0.00±0.01	0.00±0.02	0.00±0.04	0.00±0.02	0.00±0.05	0.00±0.06
Pb	0.21±0.04	0.07±0.01	0.06±0.02	0.05±0.06	0.02±0.02	0.08±0.02	0.05±0.08	0.17±0.02	0.44±0.04	0.00±0.13
U	0.00±0.10	0.00±0.02	0.00±0.05	0.00±0.05	0.00±0.02	0.00±0.05	0.00±0.07	0.00±0.05	0.00±0.10	0.00±0.10

(B. Wang et al., 2006)

Table 2.8 (a) Average concentrations and (b) normalized emissions of inorganic ions from incense burning. (B. Wang et al., 2006)



Sample ID	Cl^- ($\mu g\,m^{-3}$)	NO_3^- ($\mu g\,m^{-3}$)	SO_4^{2-} ($\mu g\,m^{-3}$)	Na^+ ($\mu g\,m^{-3}$)	K^+ ($\mu g\,m^{-3}$)
(a)					
I 1	4.3	7.9	1.6	5.0	9.5
I 2	60.2	6.1	68.6	34.2	49.2
I 3	15.2	2.8	2.4	7.2	21.6
I 4	11.4	n.d.	n.d.	5.8	19.7
I 5	76.8	2.9	105.1	44.6	63.9
I 6	12.7	3.0	3.5	7.0	12.2
I 7	6.6	n.d.	2.8	6.0	9.0
I 8	8.4	n.d.	3.2	7.7	13.6
I 9	2.7	n.d.	5.1	5.1	3.6
I 10	15.4	n.d.	4.2	18.5	2.3

Sample ID	Cl^- ($\mu g\,g^{-1}$ incense)	NO_3^- ($\mu g\,g^{-1}$ incense)	SO_4^{2-} ($\mu g\,g^{-1}$ incense)	Na^+ ($\mu g\,g^{-1}$ incense)	K^+ ($\mu g\,g^{-1}$ incense)
(b)					
I 1	79.0	146.3	30.1	92.6	176.0
I 2	801.9	80.6	913.3	455.9	655.5
I 3	45.9	8.4	7.2	21.7	65.1
I 4	112.4	n.d.	n.d.	57.1	193.9
I 5	635.2	24.3	869.8	365.3	528.9
I 6	173.2	41.1	48.3	95.4	166.6
I 7	144.3	n.d.	62.1	132.4	198.7
I 8	217.3	n.d.	83.3	199.6	351.1
I 9	31.3	n.d.	60.5	59.8	41.9
I 10	84.8	n.d.	22.9	101.7	12.4

(B. Wang et al., 2006)

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Sampling site

All tests were performed in 2 x 3 x 2 m chamber ($6.6021m^3$) as shown in Fig. 3.1 The chamber used for testing was made of polyethylene (PE) and attached to the strain steel frame. There is one door in front of the chamber, six windows beside the chamber which would be closed when testing.

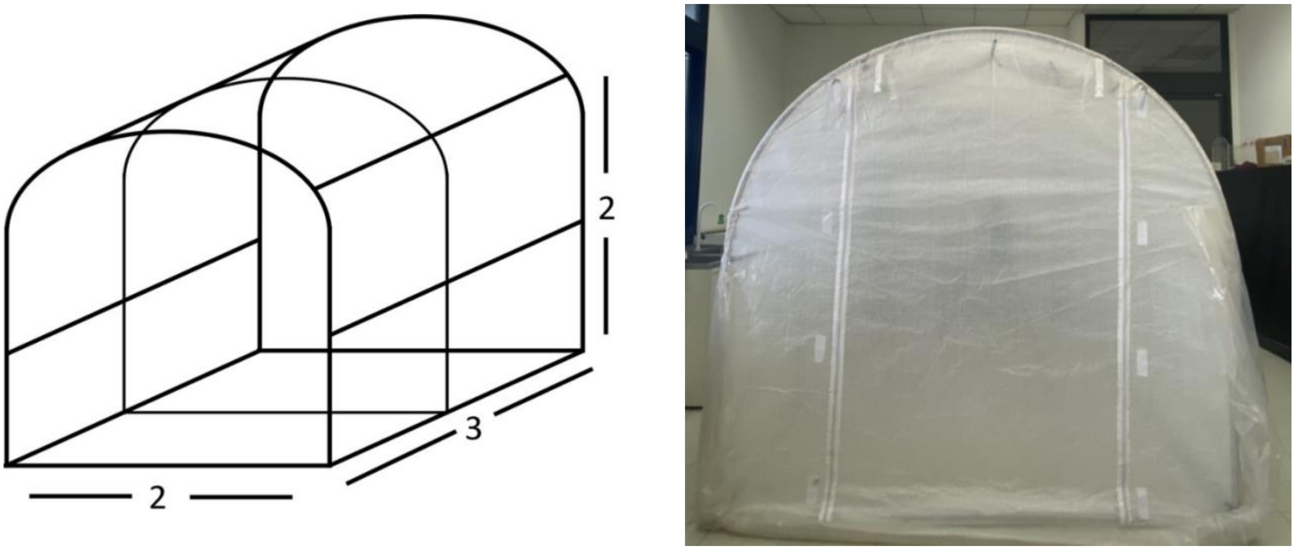


Fig. 3.1 A closed testing chamber

3.2 Experimental preparation

3.2.1) Source of $PM_{2.5}$

Incense burning was used as a $PM_{2.5}$ source. An incense was cut to a size of 2 - 3 cm to limit the amount of $PM_{2.5}$ emitted. Then, the incense was placed in a cup and put in the chamber before executing the test.

3.2.2) Chemical agents

Chemical preparation

The chemicals used for the test including xanthan gum, pectin, and sodium alginate were prepared at the concentration of 0.05-0.5%W/V, and the following equation (Eq. 1) was used for each concentration preparation.

$$(\%\ \text{weight/volume}) = \frac{\text{weight of solute (g)}}{\text{volume of solution (ml)}} \times 100 \qquad \ldots\ (\textbf{Eq. 1})$$

1) Preparation of Pectin

First, 100 mL and mixed with 0.1 g and 0.5 g of Pectin, then stirred the solution by a magnetic stirring stirrer until completely dissolved.

2) Preparation of Sodium alginate

First, 100 mL distilled water was added into a 500 mL beaker and mixed with 0.1 g and 0.5 g of Sodium alginate, then stirred the solution by a magnetic stirring stirrer until completely dissolved.

3) Preparation of Xanthan gum

First, 100 mL distilled water was added into a 500 mL beaker and mixed with 0.05 g and 0.1 g of Xanthan gum, then stirred the solution by a magnetic stirring stirrer until completely dissolved.

3.2.3) Setting the $PM_{2.5}$ monitor and environmental condition control equipment

The monitor and control equipment were placed in the chamber (as shown in Fig. 3.2) are as follows:

1) $PM_{2.5}$ was detected by aeroqual real-time monitor series 500,
2) Temperature and Humidity was measured by Temp & RH Data logger.
3) Humidity was controlled at about 45±3% and 55±3% by using Xiaomi Zhibai Smart Control Dehumidifier.
4) A fan was used to help better the dispersion of $PM_{2.5}$ in the chamber.

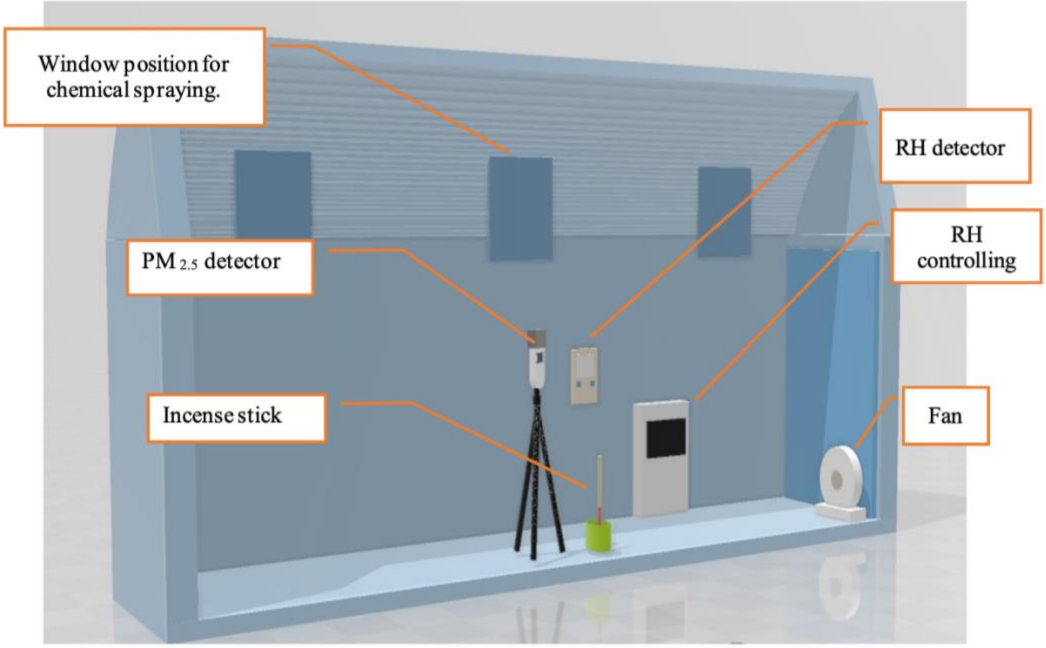


Fig. 3.2 Schematic of setting all equipment inside a closed testing chamber

3.2.4) Chamber preparation

A chamber prepared for the experiment had to be perfectly sealed to reduce the chance of $PM_{2.5}$ leakage. It also had to be cleaned before starting each testing run to avoid $PM_{2.5}$ interference from the previous experiment. The procedures of chamber preparation are as the following:

1) The leaking of the chamber was tested by lighting up the incense in the chamber and measured the amount of $PM_{2.5}$ by using aeroqual monitor series 500 for 60 minutes. The data from aeroqual series 500 was then used to plot against the time. %Decrease of $PM_{2.5}$ after finishing the leak test in the range of 10-15% could be acceptable. If not, it was necessary to fix the chamber again.
2) The chamber was cleaned by using a fan to blow $PM_{2.5}$ out of the chamber before starting the next experiment. The amount of $PM_{2.5}$ in a cleaned chamber around 20 $\mu g/m^3$ would be acceptable as the baseline ambient concentration.

3.3 Experiment design

The experiment of a total of 42 runs was performed in a closed chamber. Three types of chemical agglomerants, including pectin, sodium alginate, and xanthan gum were used. The chemicals were prepared in two different concentrations, 0.05% and 0.1% w/v for Xanthan Gum, and 0.5% and 1% w/v for sodium alginate and pectin. The relative humidity in a chamber was set at two different levels; 45±3% and 55±3%. Each agglomeration test was conducted three times. Distilled water was used as the control condition. There were 4 steps for each testing as the follows:

1) All monitor and control equipment in the chamber was turned on before start testing. Then, Xiaomi Zhibai Smart Control Dehumidifier was set at the humidity of 45±3% and 55±3%.
2) Two cm of incense was burnt completely for 12 minutes approximately as a source of $PM_{2.5}$, and the $PM_{2.5}$ measurement was started by using aeroqual series 500. After that, the door of the chamber was closed immediately.
3) The chemical agglomerants, pectin, sodium alginate, and Xanthan gum at each prepared concentrations mentioned above was sprayed into the chamber through 6 small windows on the side of the chamber.
4) $PM_{2.5}$ in the chamber was continuously measured and recorded by aeroqual series 500 for 75 minutes. After the measurement completed, the data in the internal data logger of aeroqual series 500 was transformed to the computer before starting the next experiment.

Table 3.1 Experiment design and sample number

Chemical agents / **Humidity**		**Leaking test**	**Distilled water**	**Pectin**		**Sodium alginate**		**Xanthan Gum**	
				0.1%	**0.5%**	**0.1%**	**0.5%**	**0.05%**	**0.1%**
45 ±3%	1								
	2								
	3								
55 ±3%	1								
	2								
	3								

3.4 Data collection

3.4.1) Humidity

The data from the Temp & RH Data Logger was used to check whether the humidity of the chamber was being at the setting value or not. The data was loaded into a computer via the Temp & RH Data Logger program.

3.4.2) $PM_{2.5}$

The amount of $PM_{2.5}$ was monitored by aeroqual series 500 and the data in terms of $PM_{2.5}$ concentration per minute was displayed in a computer via aeroqual series 500 programs. The collected data was taken to analyze in Microsoft Excel and was illustrated the time profile of $PM_{2.5}$ and all obtained mass concentration of $PM_{2.5}$ was then calculated %removal efficiency as expressed in the following equation:

$$\text{Removal efficiency of } PM_{2.5}\ (\%) = \frac{\rho i - \rho f}{\rho i} x 100\% \qquad \ldots \textbf{(Eq. 2)}$$

where ρi is $PM_{2.5}$ mass concentration (µg/m^3) at 12 minutes before spraying and ρf is the minimum $PM_{2.5}$ mass concentration (µg/m^3) after testing for 75 minutes.

3.5 Data analysis

The statistical analysis used for this study are as follows.

1) Descriptive Statistics was used to explain sample information of the data, including the percentage of removal efficiency, mean of the removal efficiency, and standard deviation.
2) Inferential Statistics used to analyze and to prove assumption are as follows:
    - The difference between the means of removal efficiency of $PM_{2.5}$ retrieved from using different chemical concentrations was analyzed by Paired Sample T-test at the significant level of 0.05.
    - The difference between means of removal efficiency of $PM_{2.5}$ tested under different humidity conditions was analyzed by Paired Sample T-Test at the significant level of 0.05.

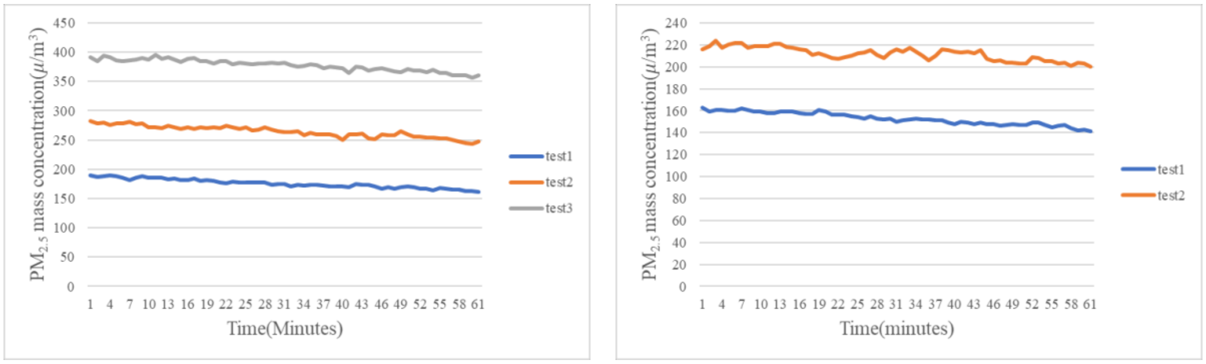
CHAPTER 4
RESULTS AND DISCUSSION

4.1 Preliminary testing of the closed chamber

Before starting chemical agglomeration, the chamber leaking had been tested and the results are shown in Table 4.1 and Figures 4.1. The PM$_{2.5}$ concentration dispersed inside the chamber without spraying the agglomeration agent gradually decreased. The result of the chamber leakage under 45±3% relative humidity (RH) for two replicates (due to time limits, only two test were completed.) was found that the average decreasing of PM$_{2.5}$ concentration in the closed chamber was about 12.1±2.0% (from 224 to 141 $\mu g/m^3$) after 60 minutes. Whilst that of under 55±3% RH was found 12.9±2.8% (from 395 to 161 $\mu g/m^3$). These decreasing rates could be acceptable for chamber preparation before agglomeration testing.

Table 4.1 PM$_{2.5}$ concentration measured for the chamber leak test

Testing condition	**PM$_{2.5}$ concentration ($\mu g/m^3$)**		**% Decrease**
	Initial	**Final**	
RH at 45±3%			
Test 1	163	141	13.5
Test 2	224	200	10.7
			Average: 12.1±2.82%
RH at 55±3%			
Test 1	189	161	14.8
Test 2	283	243	14.1
Test 3	395	357	9.6
			Average: 12.9±1.97%



(a) **(b)**

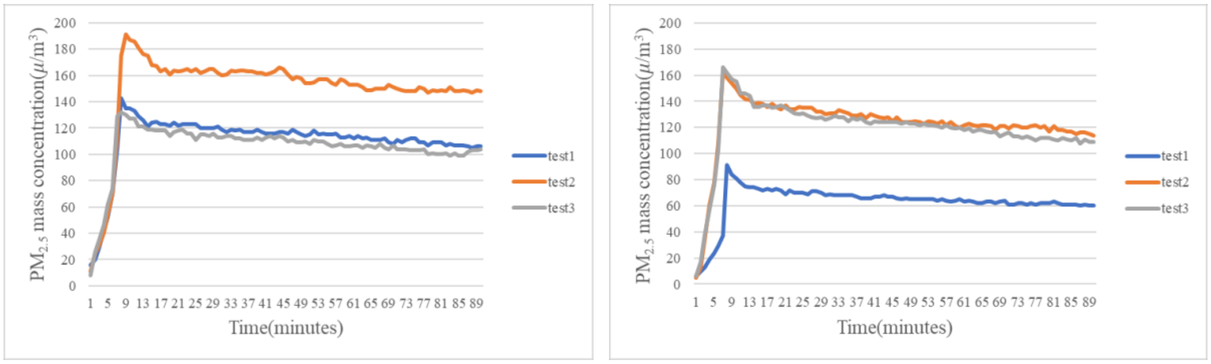
Fig. 4.1 The PM$_{2.5}$ concentration changed without spraying agglomeration agent, (a) under 45±3% RH and (b)under 55±3% RH.

4.2 The efficiency of distilled water on PM$_{2.5}$ removal

Distilled water was used to test PM$_{2.5}$ removal as the control agglomeration testing. The %removal efficiency of distilled water on the agglomeration testing of PM$_{2.5}$ is shown in Table 4.2. At each testing under 45±3% and 55±3% RH, the test was conducted three times. Figure 4.2 shows the PM$_{2.5}$ concentration decreased after spraying distilled water (started at 12 min approximately). Figure 4.3 shows the results of distilled water on PM$_{2.5}$ removal showed the average efficiency of 21.0±3.4% and 17.1±0.9% under 45±3% and 55±3% RH, respectively.

Table 4.2 The %removal efficiency of distilled water on the agglomeration testing of PM$_{2.5}$

Testing condition	**PM$_{2.5}$ concentration (μg/m^3)**		**% Decrease**
	Initial	**Final**	
RH at 45±3%			
Test 1	74	60	18.9
Test 2	141	114	19.1
Test 3	144	108	25.0
			Average: 21.0±3.4%
RH at 55±3%			
Test 1	126	105	16.7
Test 2	176	147	16.5
Test 3	121	99	18.2
			Average: 17.1±0.9%



(a) (b)

Fig. 4.2 PM$_{2.5}$ mass concentration after spray distilled water solution (a)under 45±3% RH and (b)under 55±3% RH

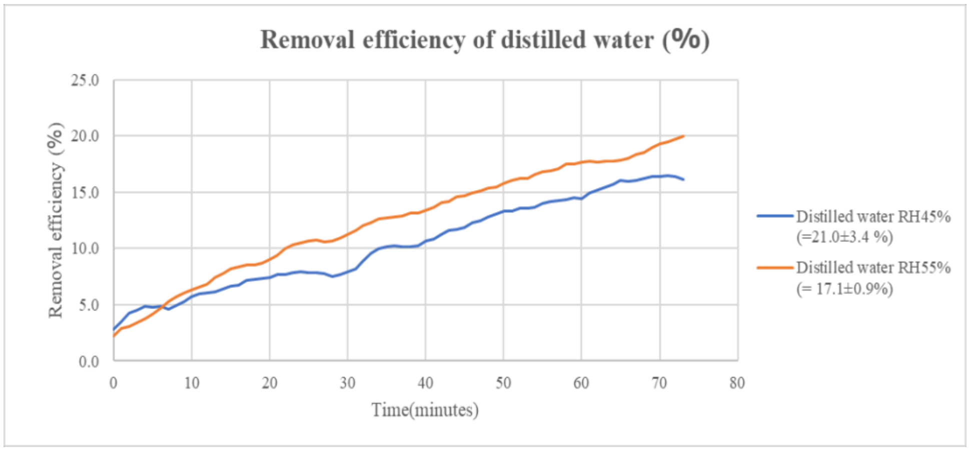


Fig. 4.3 The removal efficiency of $PM_{2.5}$ concentration after spray distilled water

Figure 4.4 shows the removal rate per 5 minutes of distilled water under 45±3% RH, $PM_{2.5}$ mass concentration was a significant decrease at 10 minutes, slowly declined until 30 minutes, and then there was slightly increased at 35 minutes and started to be steady. On the other side, under 55±3% RH, the removal rate slowly declined at first 5 minutes, increased a bit at 15 minutes, and then gradually declined until the end of observation.

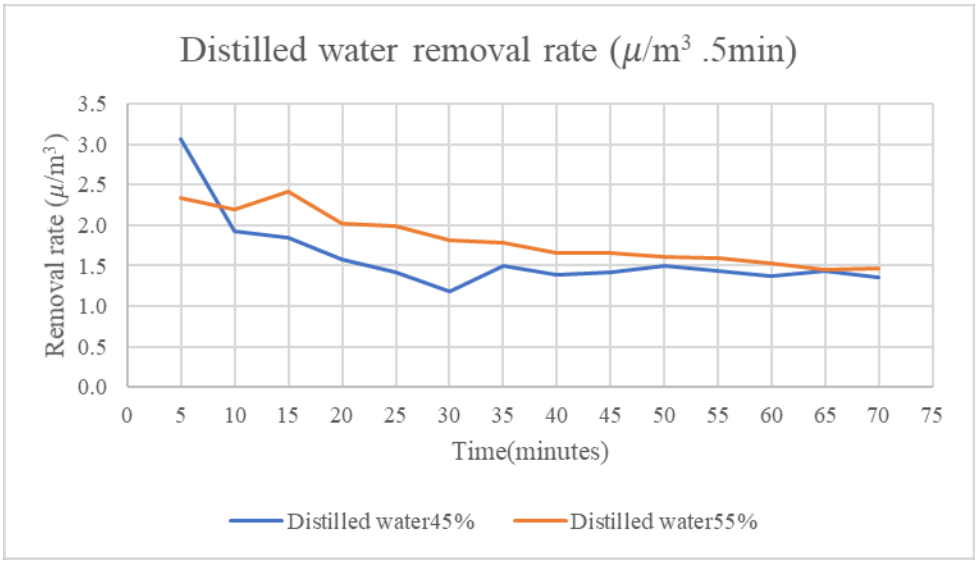


Fig. 4.4 Removal rate of $PM_{2.5}$ concentration after spray distilled water solution

4.3 The efficiency of chemical agglomeration on $PM_{2.5}$ removal

Three chemicals, i.e., pectin, sodium alginate, and Xanthan gum, were applied as chemical agglomerants in this study. The $PM_{2.5}$ concentration measured by a real-time monitoring instrument could be reported every one-minute interval, so the signal that responded to $PM_{2.5}$ in the chamber was fluctuating. Besides interpreting only, the real-time one-minute result, the moving average of the data in 5 minutes interval was calculated and used for calculating %removal efficiency and removal rate (see Appendix A and B). The results of all three chemicals on $PM_{2.5}$ removal are summarized as follows.

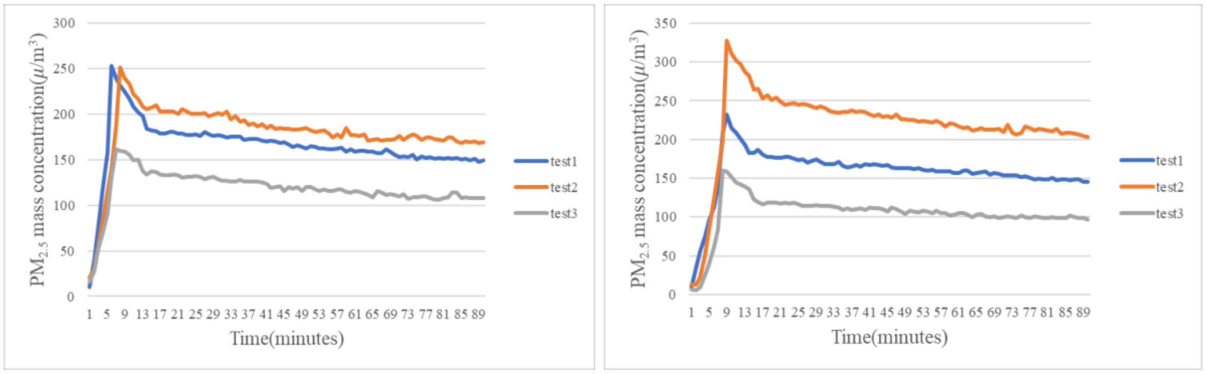
4.3.1) Pectin

Figure 4.5 shows the $PM_{2.5}$ concentration decreased after spraying 0.1% w/v pectin solution and Figure 4.6 shows the $PM_{2.5}$ concentration decreased after spraying 0.5% w/v pectin solution (started at 12 minutes roughly). Table 4.3 shows the %removal efficiency of pectin on the agglomeration testing of $PM_{2.5}$ in all testing conditions (see Appendix C). Figure 4.7 shows the removal efficiency of $PM_{2.5}$ by pectin solution in different testing conditions. The removal efficiency of pectin solutions at the defined conditions was ranged from 21.1% - 28.8%. The highest $PM_{2.5}$ removal efficiency, 28.8±6.4%, could be observed by testing at 0.5% w/v and under 45±3% RH condition. From Fig 4.6(a), $PM_{2.5}$ concentration was decreased from ~165 to 123 μ/m^3 after spraying the pectin solution. While the removal of $PM_{2.5}$ using 0.5% w/v pectin under 55±3% RH was the lowest.

From using 0.1% w/v pectin, the removal efficiency under 55±3% RH condition (28.1±2.9%) was higher than under 45±3% RH (22.4±3.0%). But for 0.5% w/v, the efficiency under 45±3% RH condition testes (28.8±6.4%), was better than that of under 55±3% RH (21.1±3.3%).

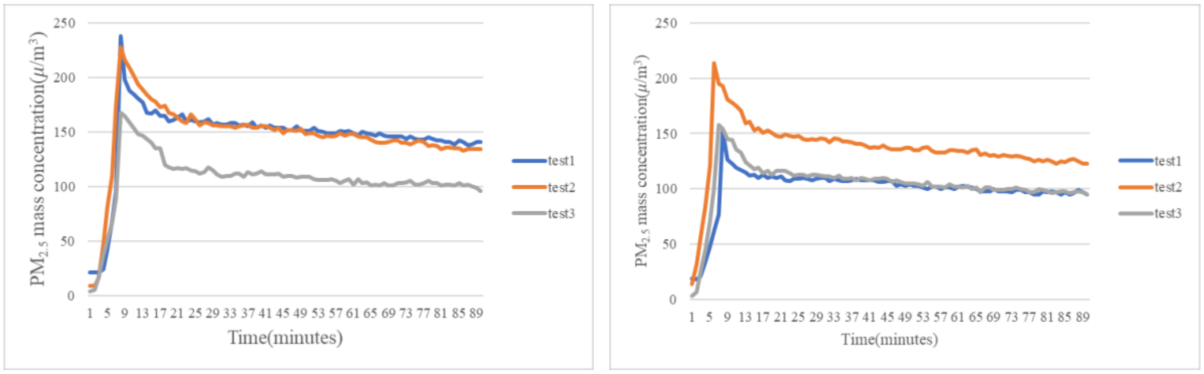
Table 4.3 The %removal efficiency of pectin on the agglomeration testing of $PM_{2.5}$

Testing condition		**$PM_{2.5}$ concentration (μg/m^3)**		**% Decrease**
Concentrations	**RH**	**Initial**	**Final**	
0.1 w/v	**45±3%**			
	Test 1	198	148	25.3
	Test 2	208	168	19.2
	Test 3	137	106	22.6
				Average:22.4±3.0%
	55±3%			
	Test 1	193	145	24.9
	Test 2	287	203	29.3
	Test 3	139	97	30.2
				Average:28.1±2.9%
0.5 w/v	**45±3%**			
	Test 1	177	138	22.0
	Test 2	189	133	29.6
	Test 3	147	96	34.7
				Average:28.8±6.4%
	55±3%			
	Test 1	115	95	17.4
	Test 2	159	123	22.6
	Test 3	124	95	23.4
				Average:21.1±3.3%



(a) (b)

Fig. 4.5 $PM_{2.5}$ concentration after spray 0.1% w/v pectin solution (a)under 45±3% relative humidity and (b)under 55±3% relative humidity



(a) (b)

Fig. 4.6 $PM_{2.5}$ concentration after spray 0.5% w/v pectin solution (a)under 45±3% relative humidity and (b)under 55±3% relative humidity

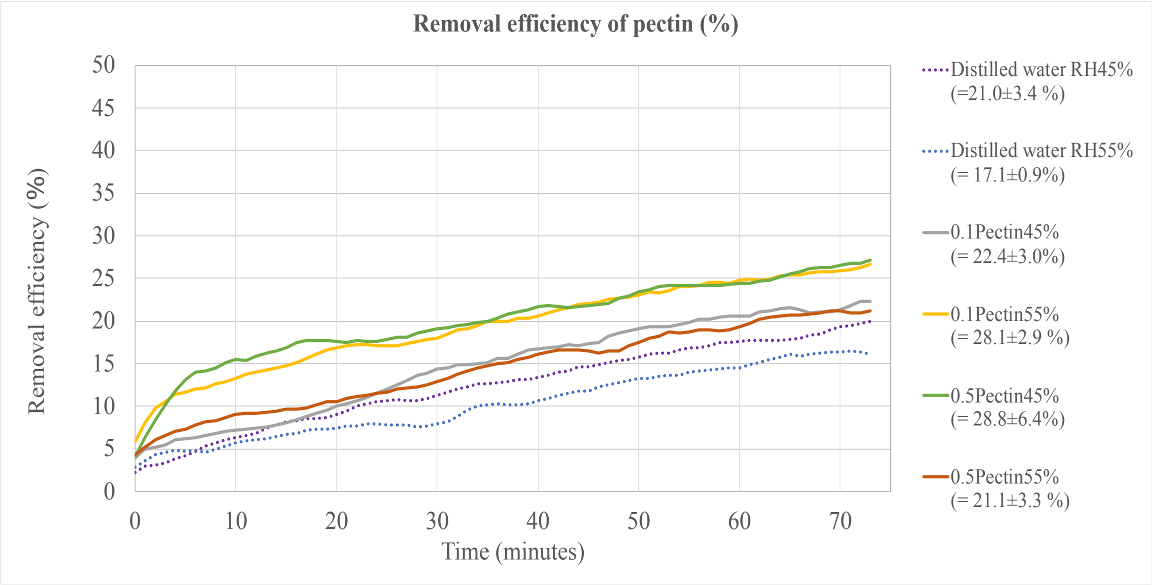


Fig. 4.7 The removal efficiency of $PM_{2.5}$ concentration after spray pectin solution

To compare the time-dependent ability of chemical agglomerant on $PM_{2.5}$ removal, the concentration decreased in every 5 minutes interval was calculated and displayed in Fig. 4.8. This figure illustrates the removal rate of $PM_{2.5}$ mass concentration per 5 minutes under all testing conditions of pectin compared with distilled water. The use of pectin as a chemical agglomerant could significantly decrease $PM_{2.5}$ at an initial stage in particular during the first 10-15 minutes. There was a significant decrease during first 10 minutes and slowly decline at 15 minutes for 0.1% w/v 55%RH, 0.5% w/v 45% RH, and 0.5% w/v 55% RH. Otherwise, there was a bit different trend for 0.1% w/v 45% RH that the removal rate rose a little bit at 15 minutes and then gradually decline after 30 minutes, this might be due to $PM_{2.5}$ retention. The removal rate of 0.1% w/v pectin 45%RH, 0.1% w/v pectin 55%RH, and 0.5% w/v pectin 45% RH were significantly higher than that of distilled water. On the other hand, the removal rate of 0.5% w/v pectin 55%RH was similar to that of distilled water.

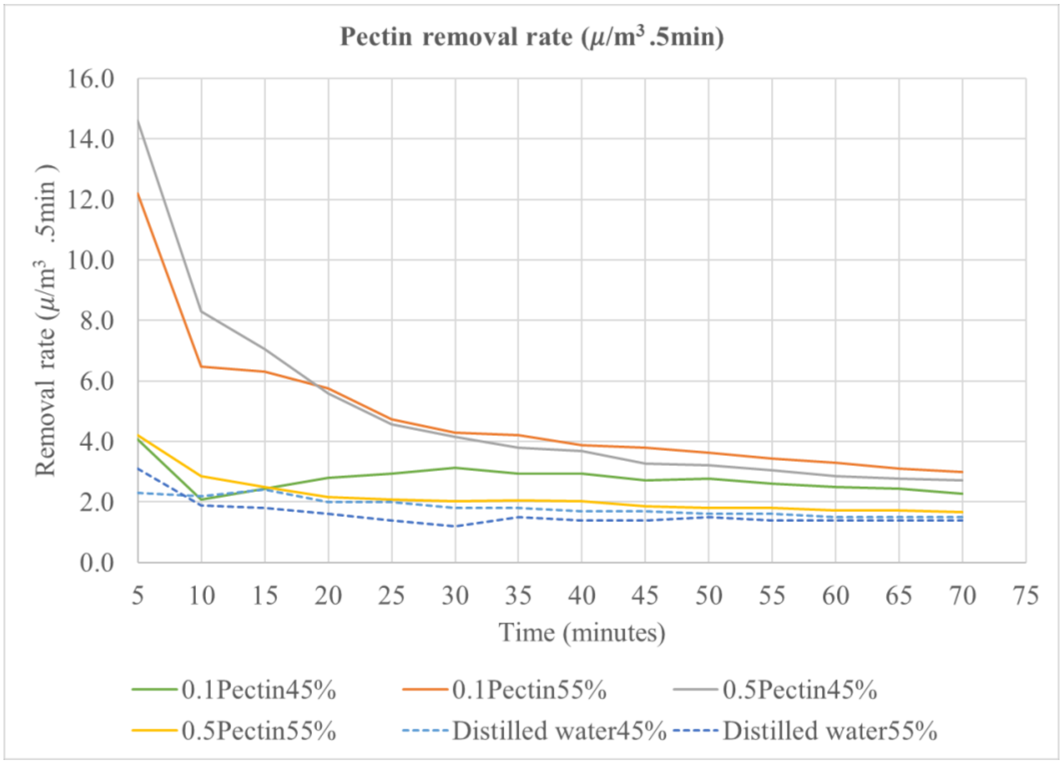


Fig. 4.8 Removal rate of $PM_{2.5}$ concentration after spray pectin solution

To examine the influence of the pectin concentration and relative humidity (n=12) on the removal efficiency of $PM_{2.5}$, the data was statistically analyzed by using paired T-test analysis (see the analysis result in Appendix D). From Table 4.4, the difference between removal efficiency applying different concentrations was not significant (p-value > 0.05). This result indicates that a 5-folds concentration increasing, from 0.1% - 0.5% w/v, could not enhance $PM_{2.5}$ removal significantly. Moreover, the difference of 10% RH was not significantly affected whether an increase or decrease of the $PM_{2.5}$ removal by pectin (p-value > 0.05) (Table 4.5).

Table 4.4 Comparison of pectin concentrations on removal efficiency $PM_{2.5}$

Humidity	**Removal efficiency**		**p-value**
	0.1% w/v	**0.5% w/v**	
45±3%	22.4	28.9	0.321
55±3%	28.1	21.1	0.165

Table 4.5 Comparison of relative humidity on removal efficiency $PM_{2.5}$ by using pectin

Concentrations	**Removal efficiency**		**p-value**
	45±3%	**55±3%**	
0.1% w/v	22.4	28.1	0.128
0.5% w/v	28.8	21.1	0.056

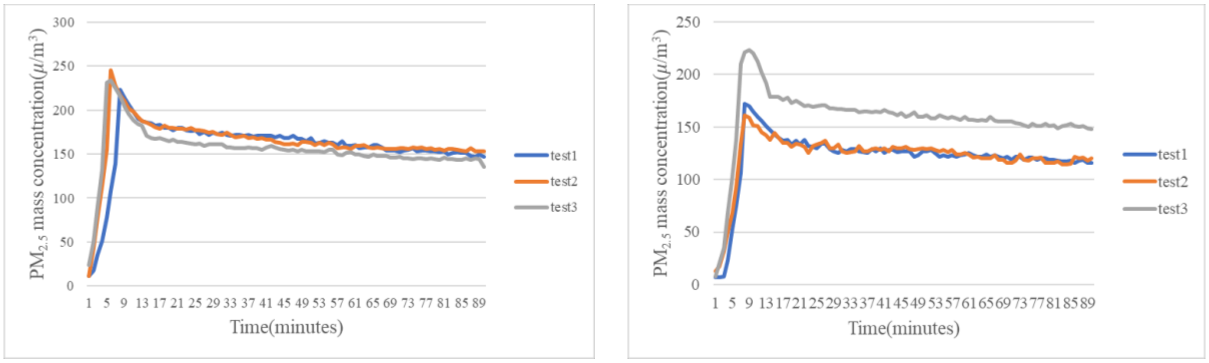
4.3.2) Sodium alginate

Figure 4.9- 4.10 shows the $PM_{2.5}$ concentration decreased after spraying 0.1% w/v and 0.5% w/v sodium alginate solution (started at 12 minutes relatively). Table 4.6 shows the %removal efficiency of pectin on the agglomeration testing of $PM_{2.5}$ in all testing conditions (see Appendix C). Figure 4.11 shows the removal efficiency of $PM_{2.5}$ by sodium alginate solution in dissimilar testing conditions. The removal efficiency of sodium alginate solutions at the bounded conditions was ranged from 21.2% - 22.5%. The highest $PM_{2.5}$ removal efficiency, 22.5±3.0%, could be observed and followed by the testing at 0.5% w/v and under 55±3% RH condition. From Fig 4.10(b), $PM_{2.5}$ concentration was decreased from ~173 to ~144 μ/m^3 after spraying the sodium alginate solution. On the other hand, the removal of $PM_{2.5}$ using 0.5% w/v sodium alginate under 45±3% RH was the lowest.

Beginning with 0.1% w/v sodium alginate, the removal efficiency under 45±3% RH condition (22.1±3.6%) was higher than under 55±3% RH (21.9±1.9%). But for 0.5% w/v, the efficiency under 55±3% RH condition testes (22.5±3.0%), was greater than that of under 45±3% RH (21.2±2.8%).

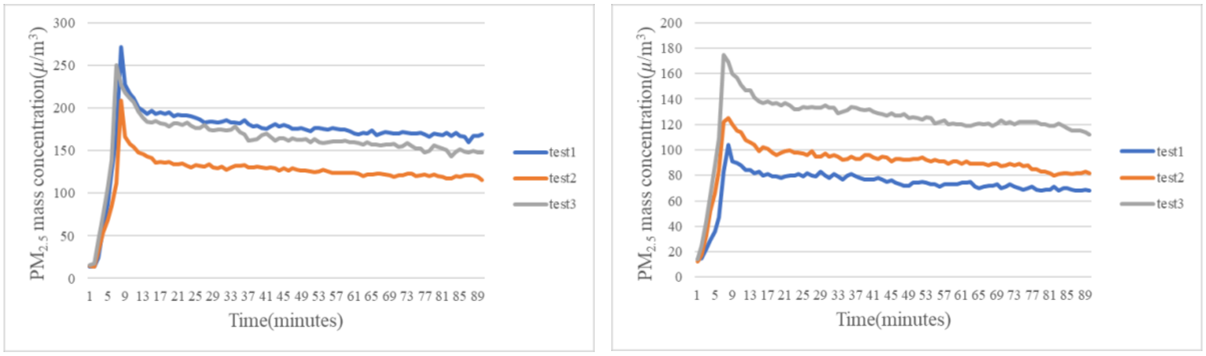
Table 4.6 The %removal efficiency of sodium alginate on the agglomeration testing of PM$_{2.5}$

Testing condition		**PM$_{2.5}$ concentration (μg/m^3)**		**% Decrease**
Concentrations	**RH**	**Initial**	**Final**	
0.1 w/v	**45±3%**			
	Test 1	188	147	21.8
	Test 2	188	153	18.6
	Test 3	182	135	25.8
				Average:22.1±3.6%
	55±3%			
	Test 1	151	116	23.2
	Test 2	142	114	19.7
	Test 3	192	148	22.9
				Average:21.9±1.9%
0.5 w/v	**45±3%**			
	Test 1	197	160	18.8
	Test 2	146	116	20.5
	Test 3	189	143	24.3
				Average:21.2±2.8%
	55±3%			
	Test 1	84	68	19.0
	Test 2	106	80	24.5
	Test 3	147	112	23.8
				Average:22.5±3.0%



(a) (b)

Fig. 4.9 PM$_{2.5}$ concentration after spray 0.1% w/v sodium alginate (a)under 45± 3% relative humidity and (b)under 55± 3% relative humidity



(a) (b)

Fig. 4.10 PM2.5 concentration after spray 0.5% w/v sodium alginate (a)under 45±3% relative humidity and (b)under 55±3% relative humidity

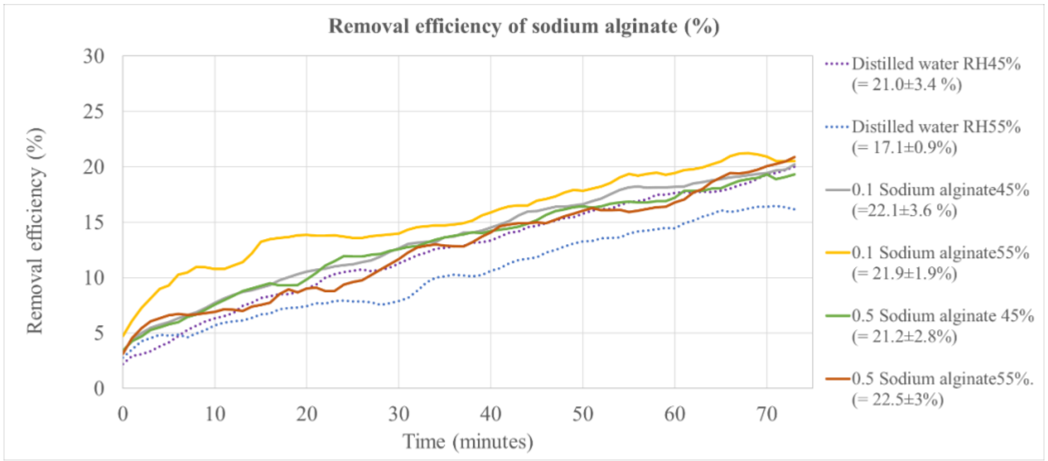


Fig. 4.11 The removal efficiency of PM2.5 concentration after spray sodium alginate solution

With regard to the time-dependent ability of chemical agglomerant on PM2.5 removal, the concentration decreased in every 5 minutes interval was calculated and exposed in Fig. 4.12. This figure exemplifies the removal rate of PM2.5 mass concentration per 5 minutes under every testing condition of sodium alginate compared with distilled water. The use of sodium alginate as a chemical agglomerant could significantly decrease PM2.5 at an initial stage in particular during the first 10 minutes. There was a significant decrease during first 10 minutes and fluctuate between 5 to 25 minutes for 0.1% w/v RH 45%, 0.1% w/v RH 55%, and 0.5% w/v RH 45%. In complete contrast, there was a bit different trend for 0.5% w/v RH 55% that the removal rate dramatically decreased at 10 minutes and gradually declined at 15 minutes, this might be due to PM2.5 retention. The removal rate of 0.1% w/v sodium alginate 45%RH, 0.1% w/v sodium alginate 55%RH, and

0.5% w/v sodium alginate 55%RH were significantly higher than distilled water. In contrast, the removal rate of 0.5% w/v sodium alginate 45% RH was lower than the removal rate of distilled water.

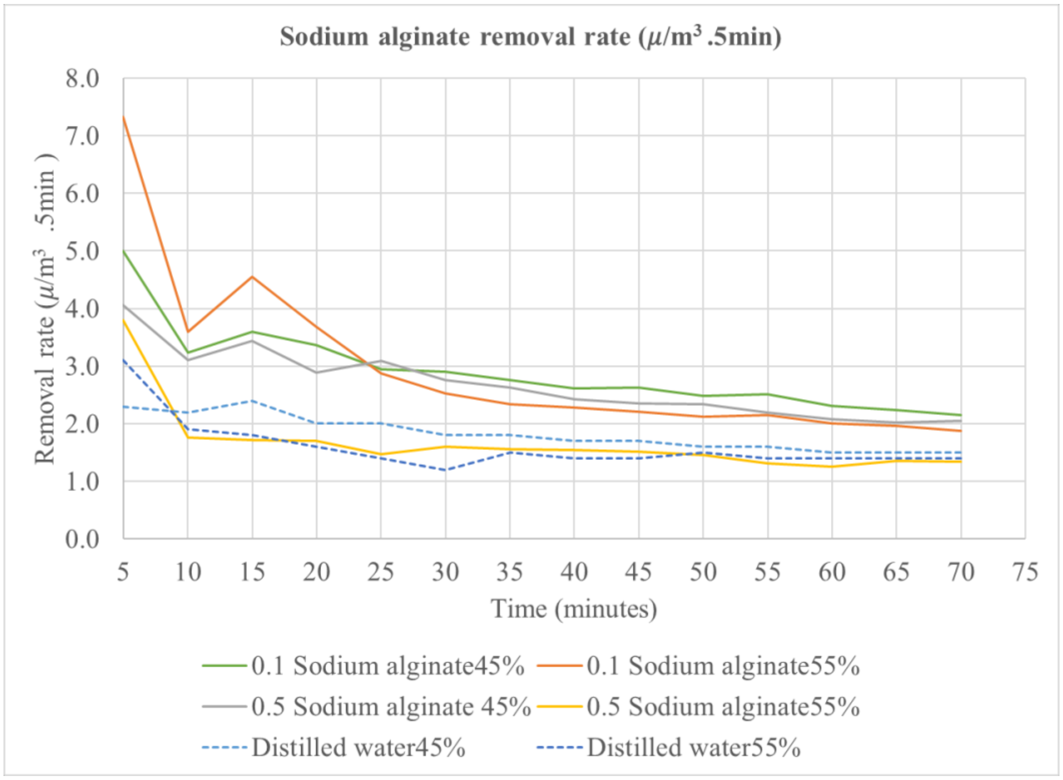


Fig. 4.12 Removal rate of $PM_{2.5}$ concentration after spray sodium alginate solution

The data of the influence of the sodium alginate concentration and relative humidity (n=12) on the removal efficiency of $PM_{2.5}$ was used to statistically analyzed by using paired T-test analysis (see the analysis result in Appendix D). Table 4.7 shows the removal efficiency was no significant difference (p-value > 0.05) when compared between difference concentrations, 0.1% w/v and 0.5% w/v. Similar to pectin, these solution concentrations did not result in the different removal efficiency of $PM_{2.5}$. From Table 4.8, the difference of RH (45±3% and 55±3%) was not significantly affected even if whether an increase or decrease of the $PM_{2.5}$ removal by sodium alginate (p-value > 0.05).

Table 4.7 Comparison of Sodium alginate concentrations on removal efficiency $PM_{2.5}$

Humidity	**Removal efficiency**		**p-value**
	0.1% w/v	**0.5% w/v**	
45±3%	22.1	21.2	0.630
55±3%	21.9	22.5	0.850

Table 4.8 Comparison of relative humidity on removal efficiency $PM_{2.5}$ by using sodium alginate

Concentrations	**Removal efficiency**		**p-value**
	45±3%	**55±3%**	
0.1%	22.1	21.9	0.924
0.5%	21.2	22.5	0.458

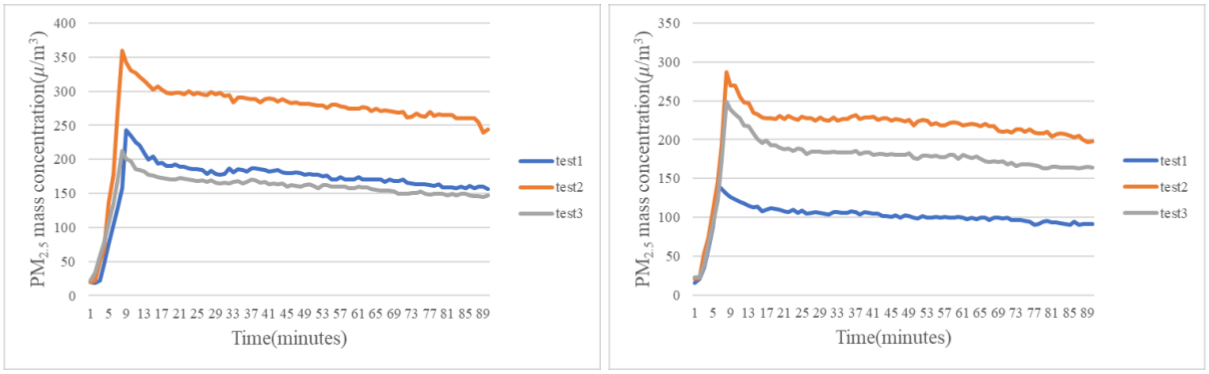
4.3.3) Xanthan gum

Figure 4.13 shows the $PM_{2.5}$ concentration decreased after spraying 0.1% w/v Xanthan gum solution and Figure 4.14 shows the $PM_{2.5}$ concentration decreased after spraying 0.5% w/v Xanthan gum solution (started at 12 minutes approximately). Table 4.9 shows the %removal efficiency of Xanthan gum on the agglomeration testing of $PM_{2.5}$ in all testing conditions (see Appendix C). Figure 4.15 shows the removal efficiency of $PM_{2.5}$ by Xanthan gum solution in disparate testing conditions. The removal efficiency of Xanthan gum solutions at the measured conditions was ranged from 20.5% - 23.1% %. The highest $PM_{2.5}$ removal efficiency, 23.1±2.4%, could be complied with testing at 0.05% w/v and under 45±3% RH condition. From Fig 4.13(a), $PM_{2.5}$ concentration was decreased from ~ 147 to $121\mu/m^3$ after spraying the Xanthan gum solution. Whilst, the removal of $PM_{2.5}$ using 0.1% w/v Xanthan gum under 55±3% RH was the lowest.

From a given condition, 0.05% and 0.1% w/v Xanthan gum, the removal efficiency under 45±3% RH condition was greater than under 55±3% RH.

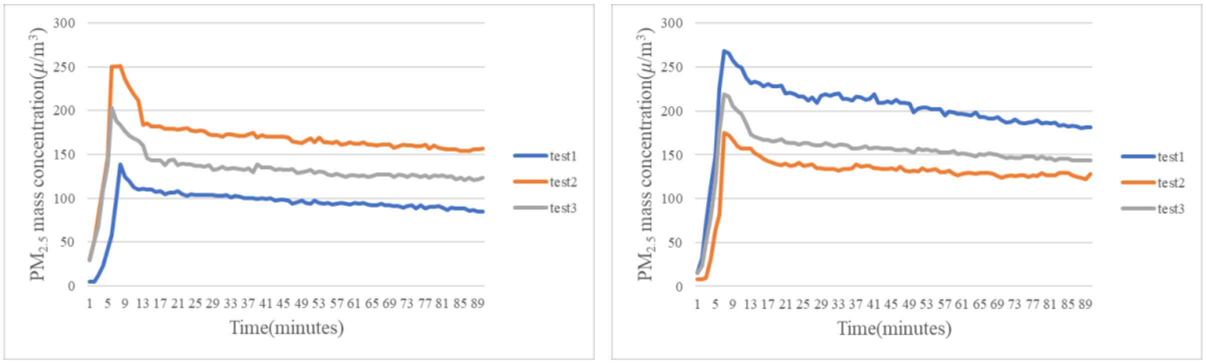
Table 4.9 The %removal efficiency of Xanthan gum on the agglomeration testing of $PM_{2.5}$

Testing condition		$PM_{2.5}$ concentration ($\mu g/m^3$)		% Decrease
Concentrations	**RH**	**Initial**	**Final**	
0.05 w/v	**45±3%**			
	Test 1	209	157	24.9
	Test 2	316	240	24.1
	Test 3	182	145	20.3
				Average:23.1±2.4%
	55±3%			
	Test 1	115	90	21.7
	Test 2	247	197	20.2
	Test 3	217	163	24.9
				Average:22.3±2.4%
0.1 w/v	**45±3%**			
	Test 1	111	85	23.4
	Test 2	184	154	16.3
	Test 3	160	121	24.4
				Average:21.4±4.4%
	55±3%			
	Test 1	232	180	22.4
	Test 2	157	122	22.3
	Test 3	173	144	16.8
				Average:20.5±3.3%



(a) (b)

Fig. 4.13 $PM_{2.5}$ concentration after spray 0.05% w/v Xanthan gum (a)under 45±3% relative humidity and (b)under 55± 3% relative humidity



(a) (b)

Fig. 4.14 PM2.5 concentration after spray 0.1% w/v Xanthan gum (a)under 45±3% relative humidity and (b) under 55±3% relative humidity

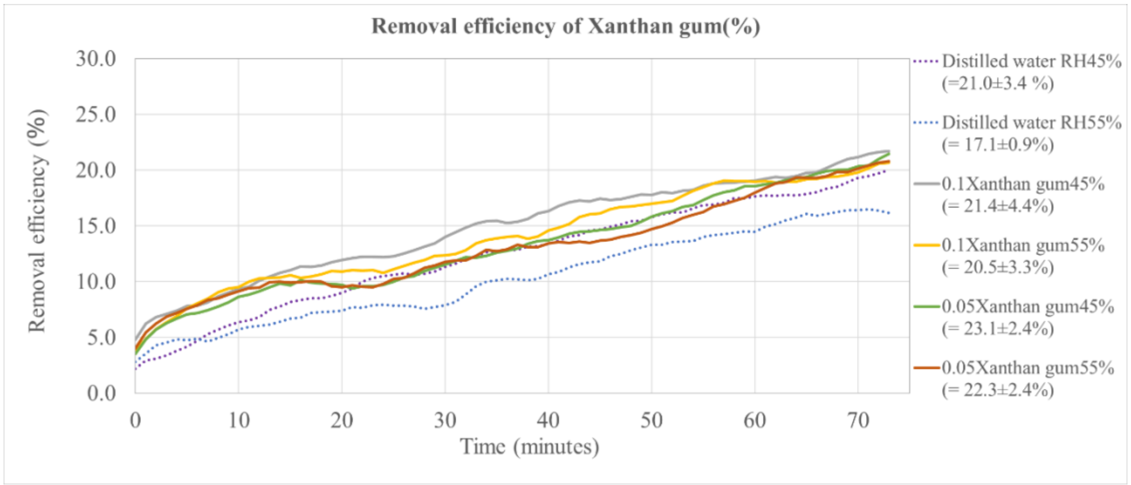


Fig. 4.15 The removal efficiency of PM2.5 concentration after spray Xanthan gum solution

To relate to the time-dependent ability of chemical agglomerant on PM2.5 removal, the concentration decreased in every 5 minutes interval was calculated and shown in Fig. 4.16. This figure demonstrates the removal rate of PM2.5 mass concentration per 5 minutes under all testing conditions of Xanthan gum compared with distilled water. The use of Xanthan gum as a chemical agglomerant could significantly decrease PM2.5 at an initial stage in particular during the first 10 minutes. There was a significant decrease during the first 10 minutes and a gradually decline at 25 minutes for 0.05% w/v RH 55% and 0.1% w/v RH 55%. In total contrast, there was a significant drop during the first 10 minutes and fluctuate between 10 to 20 minutes for 0.05% w/v RH 45%

and 0.1% w/v RH 45%. $PM_{2.5}$ retention might affect this fluctuation. The removal rate of Xanthan gum in every condition of testing was significantly higher than distilled water.

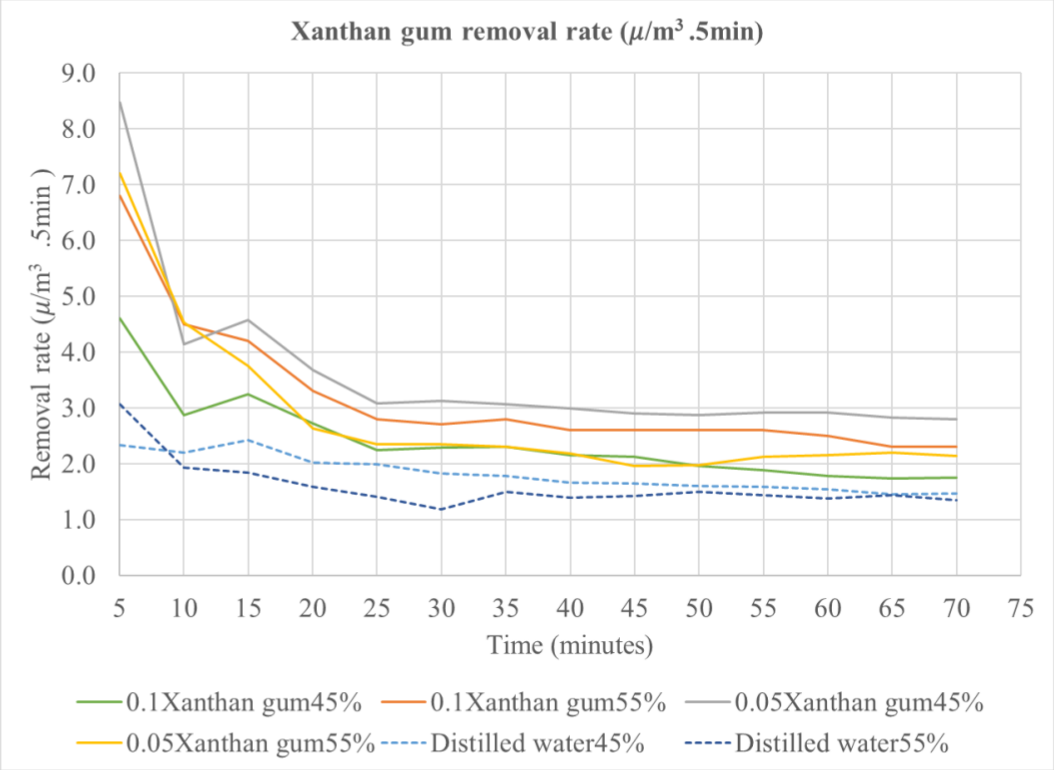


Fig. 4.16 $PM_{2.5}$ concentration after spray Xanthan gum solution

Paired sample T-test was used to analyze the influence of the Xanthan gum concentration and relative humidity (n=12) on the removal efficiency of $PM_{2.5}$ (see the analysis result in Appendix D). The difference of 2-folds concentrations raising from 0.05%-0.1% w/v was not significant on the $PM_{2.5}$ removal ($p\text{-value} > 0.05$) (Table 4.10). It indicated that these two concentrations of Xanthan gum could not give the difference $PM_{2.5}$ removal. In addition, from Table 4.11 the removal efficiency of the chemical applied under 45±3% and 55±3%RH was not significantly different ($p\text{-value} > 0.05$) which indicated that this humidity difference was not enough to change the ability of this chemical on the removal of $PM_{2.5}$.

Table 4.10 Comparison of Xanthan gum concentrations on removal efficiency $PM_{2.5}$

Humidity	Removal efficiency		p-value
	0.1% w/v	0.5% w/v	
45±3%	23.1	21.4	0.646
55±3%	22.3	20.5	0.480

Table 4.11 Comparison of relative humidity on removal efficiency $PM_{2.5}$ by using Xanthan gum

Concentrations	Removal efficiency		p-value
	45±3%	55±3%	
0.05%	23.1	22.3	0.795
0.1%	21.4	20.5	0.846

4.4 Comparison on $PM_{2.5}$ removal efficiency between different chemical agglomerants and relative humidity conditions

The %removal efficiency of $PM_{2.5}$ by all testing conditions, including spraying three chemicals and distilled water under 45±3% and 55±3% RH, are summarized in Table 4.12 and shown in Figure 4.17. Considering at 45±3% RH testing, 0.5% w/v pectin could remove $PM_{2.5}$ at the highest level (28.8±6.4%) and followed by 0.05% w/v Xanthan gum (23.1±2.4%), 0.1% w/v pectin (22.4±2.6%), 0.1% w/v sodium alginate (22.1±3.6%), 0.1% w/v Xanthan gum (21.4±4.4%), and 0.5% w/v Sodium alginate (21.2±2.8%). As for the testing at 55±3% RH, the highest removal efficiency obtained from using 0.1% w/v pectin with the value of 28.1±2.9%, and higher than those of other conditions with the sequence of 0.5% w/v sodium alginate (22.5±3.0%), 0.05% w/v Xanthan gum (22.3±2.4%), 0.1% w/v sodium alginate (21.9±1.9%), 0.1% w/v pectin (21.1±3.3%), and 0.1% w/v Xanthan gum (20.5±3.3%), respectively. All chemicals used as agglomerant could remove $PM_{2.5}$ better than distilled water for under both conditions of RH.

Table 4.12 Chemical agglomeration results in removal efficiency of $PM_{2.5}$

Chemical agents / Humidity	Distilled water	Pectin		Sodium alginate		Xanthan gum	
		0.1%	**0.5%**	**0.1%**	**0.5%**	**0.05%**	**0.1%**
45 ±3%	18.9	22.6	34.4	25.8	24.3	24.9	24.4
	19.1	19.2	29.6	18.6	20.6	24.0	16.3
	25.0	25.3	22.0	21.8	18.8	20.3	23.4
Average	21.0±3.4	22.4±3.0	28.8±6.4	22.1±3.6	21.2±2.8	23.1±2.4	21.4±4.4
55 ±3%	16.7	24.9	23.4	23.2	23.8	21.7	16.8
	16.5	29.3	22.6	19.7	24.5	20.2	22.3
	18.2	30.2	17.4	22.9	19.1	24.9	22.4
Average	17.1±0.9%	28.1±2.9	21.1±3.3	21.9±1.9	22.5±3.0	22.3±2.4	20.5±3.3

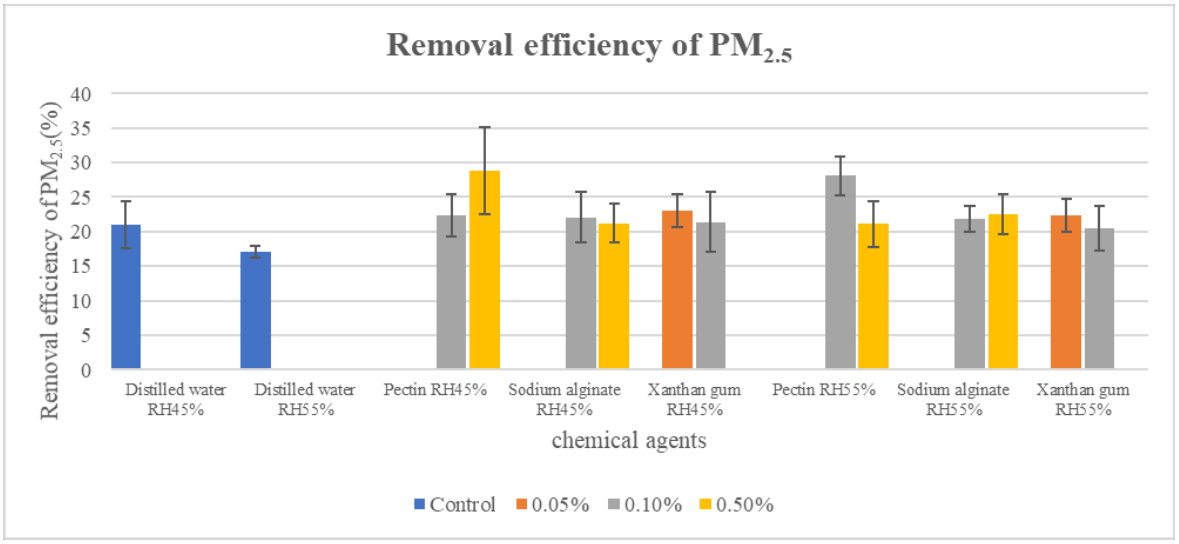


Fig. 4.17 Comparison on removal efficiency of $PM_{2.5}$ by using different chemical agglomerants

In comparison with the previous studies, the low removal efficiency (not higher than 30%) found in this study might be caused by some factors. There are many reasons that make a difference in experimental results. First, the lower initial concentration might lead to weaker coagulation. The initial $PM_{2.5}$ concentration in this study was about 200 $\mu g/m^3$ which seems to be small-scale testing when compared with those of number concentration 2.0×10^6 $1/cm^{-3}$ in the study of Bin et al.

(2018). They found that a high initial $PM_{2.5}$ concentration could result in high removal efficiency of $PM_{2.5}$ (68.1%-82.8%).

Secondly, the removal efficiency typically depends on the spray nozzle size. Bin et al. (2018) used a two-fluid atomization nozzle that was designed to generate droplets in the evaporation chamber, and the removal efficiency of sodium alginates could reach 82.8%. But for this study, the larger droplets generated by a hand spray might be difficult to enhance agglomeration. Also, Liu et al. (2016) mentioned that large droplets can weaken the agglomeration, which leads to a low removal efficiency of $PM_{2.5.}$

Thirdly, agglomeration solution volume is another effect on the removal efficiency of $PM_{2.5}$. Approximately 10 ml was used in one testing in this study which quite differed from Bin et al.'s (2018) studies. As a result, high initial $PM_{2.5}$ concentration and high volume of chemical agglomeration solution can increase adherence between chemical agglomeration agents and $PM_{2.5}$ particles, which makes the agglomeration process easily occur, and improves its $PM_{2.5}$ removal efficiency.

This study shows that the $PM_{2.5}$ removal efficiency was 12% without adding chemical agents, when using water, pectin, and sodium alginates as chemical agents, the average removal efficiency of $PM_{2.5}$ was increased to 19.1, 25.3, and 22.0 % respectively. Surprisingly, Bin et al.'s (2018) studies show that the $PM_{2.5}$ removal efficiency accounted for 62.9% without adding chemical agents, while adding water, pectin, and sodium alginates as chemical agents, the average removal efficiency of $PM_{2.5}$ rose to 68.1, 77.6, and 82.8% sequentially. In comparison between the $PM_{2.5}$ removal ability using chemical agglomeration agents and water, it clearly shows that the removal efficiency of chemical agents was greater than water.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, the experimental testing on a chemical agglomeration in a closed chamber was conducted aiming to investigate the effectiveness of chemical agglomeration on $PM_{2.5}$ removal. Laboratory experiments had been performed to compare the removal efficiency of biopolymers (pectin, sodium alginate, Xanthan gum). All study results can be concluded as the following. Our study not only offered a new technology but also a method to solve the problem of indoor $PM_{2.5}$.

The obtained results proved that chemical agglomeration using biopolymer gave an improvement of $PM_{2.5}$ removal efficiency. Pectin, sodium alginate, and Xanthan gum solutions had been investigated the ability of agglomeration $PM_{2.5}$ compared with distilled water. Among all chemicals tested, pectin could give the highest efficiency in removing $PM_{2.5}$, 28.8% decreasing by with a 0.5% w/v concentration and the test chamber condition of 55% RH. In addition, a 0.1% w/v pectin solution tested at 45% RH yielded the removal efficiency in the second sequence, with a value of 28.1%.

In comparison to the removal efficiency of $PM_{2.5}$ between chemical agglomerants and distilled water, it can be seen that the $PM_{2.5}$ removal efficiency of all chemical agents was higher than that of water. In addition, all conditions of the chemical agglomeration agents could result in a higher removal rate than the water, except the 0.5% w/v sodium alginate at 55%RH, which gives a removal rate nearly the water. Therefore, the chemical agglomeration agents could enhance the removal of $PM_{2.5}$ better than water. However, the different concentrations and relative humidity assigned for all chemicals testing could not show the statistical difference of $PM_{2.5}$ removal efficiency.

5.2 Recommendations

From the study on chemical agglomeration of $PM_{2.5}$ in a closed testing system using a hand spray bottle, some recommendations are as follows.

1) From the experiment, a high concentration of agglomeration agents trend to increase $PM_{2.5}$ removal efficiency, but this can result in high viscosity of the solutions which obstruct hand

spraying ability. Therefore, a better system to effectively produce the chemical droplets should be designed for further experiment.

2) A higher level of spraying point as well as the agglomerant volume can increase coagulation between the chemical agent and $PM_{2.5}$ extensively.
3) To get more explicit effect of relative humidity on the $PM_{2.5}$ agglomeration, higher different range should be considered.

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APPENDICES

APPENDIX A

The amount of PM$_{2.5}$ during the chemical agglomeration testing

Table A.1 PM$_{2.5}$ mass concentration when no spray chemical agglomerant

Time (minutes)	**PM$_{2.5}$ mass concentration (μg/m^3)**				
	Leak chamber testing				
	RH 45%		**RH 55%**		
	Test 1	Test 2	Test 1	Test 2	Test 3
0	163	216	189	283	391
1	159	219	187	279	385
2	161	224	188	280	394
3	161	217	189	275	391
4	160	220	188	278	386
5	160	222	186	279	385
6	162	222	182	281	386
7	161	217	185	277	387
8	159	219	188	278	390
9	159	219	185	272	387
10	158	219	185	272	395
11	158	221	186	270	389
12	159	221	183	274	391
13	159	218	184	271	387
14	159	217	181	269	383
15	158	216	181	271	388
16	157	215	184	269	390
17	157	211	180	272	385
18	161	212	181	270	384
19	159	210	180	272	381
20	156	208	177	270	385
21	156	207	176	274	384
22	156	209	179	272	379
23	155	210	177	269	382
24	154	212	177	272	380
25	153	213	177	266	379
26	155	215	177	268	380
27	153	211	178	272	380
28	152	208	174	268	382
29	153	213	175	265	380
30	150	216	175	264	382
31	151	214	171	264	378
32	152	217	174	265	375
33	153	214	172	258	376
34	152	210	174	262	379
35	152	206	173	259	378
36	151	210	172	259	373
37	151	216	171	259	375
38	149	215	171	257	374
39	148	214	171	250	372

40	150	213	169	259	365
41	149	214	175	259	375
42	148	212	173	261	374
43	149	215	173	253	368
44	148	207	171	252	371
45	148	205	167	260	373
46	146	206	170	258	370
47	147	204	167	258	367
48	148	204	170	265	366
49	147	203	171	259	371
50	147	203	170	255	368
51	149	209	166	255	368
52	149	208	166	254	366
53	147	205	164	254	370
54	145	205	168	253	365
55	146	203	167	253	365
56	147	204	165	250	360
57	144	201	165	248	360
58	142	204	162	245	360
59	143	203	163	243	357
60	141	200	161	248	360

Table A.2 PM2.5 mass concentration while using distilled water as chemical agglomerant

Time (minutes)	**$PM_{2.5}$ mass concentration ($\mu g/m^3$)**					
	Distilled water					
	RH 45%			**RH 55%**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
0	6	5	6	16	11	8
1	10	13	17	20	25	26
2	13	34	38	29	31	35
3	19	61	57	42	40	46
4	24	78	76	52	54	62
5	29	108	102	70	70	74
6	37	162	166	104	114	129
7	91	158	162	143	175	132
8	84	154	157	135	191	130
9	81	150	155	135	187	127
10	78	145	146	133	186	127
11	75	142	146	129	181	121
12	74	141	144	126	176	121
Spray	74	138	136	121	175	119
0	73	139	136	124	168	119
1	72	138	137	125	167	118
2	73	136	137	123	163	118
3	72	138	135	123	165	118
4	73	136	136	122	161	114
5	72	134	137	124	164	117
6	69	137	135	122	163	118
7	72	134	133	123	164	119
8	70	134	131	123	165	116
9	70	136	130	123	163	116
10	70	135	131	123	165	111
11	69	135	129	120	162	115
12	71	135	128	120	163	115
13	71	132	127	120	165	114
14	70	132	128	120	165	116
15	68	130	126	121	162	113
16	69	131	127	119	160	113
17	68	131	129	117	161	114
18	68	133	128	119	164	114
19	68	132	128	118	163	112
20	68	131	125	119	164	112
21	68	129	127	117	164	111
22	67	129	126	117	163	111
23	66	130	127	117	163	111
24	66	127	124	119	162	113
25	66	130	123	117	162	111
26	67	129	125	116	161	113
27	67	128	124	116	162	114
28	68	127	124	116	163	112
29	67	128	124	117	166	114

30	67	125	124	117	165	113
31	66	128	124	116	161	110
32	65	124	123	119	157	111
33	66	124	124	117	159	109
34	65	124	123	115	158	109
35	65	125	123	114	154	110
36	65	124	122	115	154	108
37	65	123	123	118	155	111
38	65	125	122	115	157	110
39	65	124	122	116	157	110
40	64	123	121	115	157	108
41	65	125	120	115	154	106
42	64	122	122	116	153	107
43	63	124	120	113	157	108
44	64	121	119	113	156	106
45	65	120	120	114	153	106
46	63	122	118	112	153	107
47	64	123	119	114	153	107
48	63	122	117	112	151	105
49	62	121	118	113	149	107
50	62	122	118	111	149	106
51	63	122	117	111	150	105
52	63	121	116	111	150	108
53	62	118	117	112	150	105
54	63	121	113	109	153	104
55	64	121	115	108	151	107
56	61	119	116	111	150	104
57	61	122	113	109	149	104
58	62	121	113	111	148	104
59	62	120	112	112	148	103
60	61	120	113	112	148	103
61	62	121	112	109	151	103
62	61	122	110	109	150	104
63	62	120	112	107	147	100
64	62	121	112	109	149	101
65	62	117	112	109	148	100
66	63	121	111	109	149	100
67	62	118	110	107	148	101
68	61	118	112	108	151	99
69	61	117	111	107	148	101
70	61	117	110	107	148	99
71	61	115	112	107	149	99
72	60	116	108	106	148	102
73	61	116	111	105	147	103
74	60	115	109	106	149	103
75	60	114	109	106	148	104

Table A.3 PM$_{2.5}$ mass concentration while using pectin as chemical agglomerant

Time (minutes)	**PM$_{2.5}$ mass concentration (μg/m^3)**											
	Pectin											
	0.1 w/v Pectin						**0.5 w/v Pectin**					
	RH 45%			RH 55%			RH 45%			RH 55%		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
0	10	21	16	10	13	7	21	9	4	19	14	3
1	40	30	28	36	13	6	21	9	5	18	32	7
2	75	54	52	56	23	10	21	16	17	21	56	25
3	119	85	70	75	51	25	24	47	37	34	84	45
4	158	115	91	96	84	40	42	81	51	48	121	71
5	253	140	130	112	123	60	68	110	67	62	214	101
6	239	187	161	137	157	83	96	175	89	77	195	158
7	231	251	160	208	198	160	238	228	168	152	193	154
8	224	239	159	232	328	159	198	216	165	126	181	145
9	217	233	155	215	311	152	188	209	159	123	178	144
10	208	222	149	209	302	144	184	201	153	119	175	136
11	202	217	150	201	298	142	181	194	148	117	171	133
12	198	208	137	193	287	139	177	189	147	115	159	124
Spray	184	205	134	183	282	136	168	184	144	112	161	121
0	182	207	137	183	264	123	167	180	140	113	153	118
1	181	210	136	187	266	120	170	178	135	110	155	119
2	179	203	134	181	253	116	165	173	135	113	151	114
3	179	203	133	178	257	118	165	174	120	110	153	116
4	180	203	133	178	251	118	160	168	118	111	151	113
5	180	203	134	176	254	118	161	166	116	110	148	116
6	179	200	133	176	249	117	163	163	117	111	147	116
7	179	205	130	177	245	118	166	160	116	108	149	116
8	177	203	131	177	246	117	160	158	117	107	148	114
9	177	200	131	175	247	118	161	166	115	109	147	112
10	178	200	132	173	245	116	160	161	114	109	148	113
11	176	200	131	174	246	114	159	156	112	110	145	113
12	180	201	129	170	245	114	160	159	113	109	144	111
13	178	198	130	172	243	114	162	158	118	108	145	113
14	176	199	131	174	241	115	157	156	115	109	144	113
15	177	201	129	171	243	114	158	156	111	110	146	112
16	176	199	127	168	241	114	157	155	109	110	145	111
17	174	203	127	168	237	114	157	155	110	107	142	111
18	175	194	126	168	236	113	158	155	110	109	146	110
19	175	198	126	171	234	112	158	154	112	108	145	112
20	175	192	128	166	236	109	156	155	112	107	143	109
21	172	193	126	164	236	111	157	156	109	107	143	109
22	173	188	126	165	238	109	155	157	113	108	142	110
23	173	190	126	167	235	110	159	154	111	109	141	108
24	173	186	126	165	237	111	154	154	112	108	141	110
25	171	189	125	168	236	109	156	155	114	108	139	109
26	170	185	123	167	232	112	154	155	111	108	137	108
27	171	187	119	168	230	111	156	154	111	108	138	109
28	170	184	120	167	232	111	154	152	111	106	137	109

29	168	185	121	166	229	110	154	154	112	106	139	110
30	169	184	116	167	230	107	154	149	109	107	137	109
31	167	184	120	164	228	112	152	152	110	107	136	106
32	164	183	118	163	232	110	152	152	110	103	136	108
33	166	183	120	163	226	107	155	151	108	104	136	106
34	164	184	116	163	226	104	152	153	109	103	137	105
35	162	185	120	163	225	108	151	148	109	104	137	105
36	165	182	120	162	225	107	151	149	109	103	135	105
37	164	180	117	163	223	106	154	149	107	103	135	104
38	162	181	116	161	224	108	151	147	106	101	137	103
39	162	182	117	160	223	107	150	145	106	100	138	106
40	161	179	116	161	222	105	149	147	106	102	134	102
41	161	174	116	159	224	108	149	146	107	102	133	102
42	162	178	117	159	221	105	149	147	105	100	133	102
43	163	174	117	159	217	105	151	149	103	101	133	101
44	159	185	115	159	221	102	150	147	105	101	135	104
45	161	177	114	157	220	103	151	148	107	100	135	102
46	159	177	116	157	217	105	149	148	102	102	134	102
47	160	176	115	160	215	105	147	146	107	103	134	101
48	160	178	113	160	216	103	150	145	103	102	133	103
49	159	171	111	156	212	100	149	145	104	101	135	100
50	159	172	109	157	213	103	148	143	101	100	136	101
51	157	173	116	158	215	104	147	141	102	98	131	97
52	157	171	114	159	213	101	149	140	101	98	132	101
53	161	172	111	155	213	100	147	140	103	98	130	101
54	159	172	112	157	213	101	146	141	101	100	131	99
55	155	173	111	156	214	99	146	142	101	98	129	99
56	153	176	110	154	210	100	146	142	103	98	131	99
57	154	172	112	154	219	101	146	140	103	98	130	100
58	153	175	107	154	209	100	144	140	104	97	129	100
59	155	178	109	154	207	99	146	139	105	99	130	101
60	150	176	109	152	209	102	144	141	102	99	129	100
61	154	172	110	153	217	100	143	142	102	97	128	99
62	152	174	110	151	215	99	143	141	103	97	127	97
63	153	174	108	148	212	101	145	137	105	95	125	97
64	151	173	106	150	214	100	144	138	103	95	126	100
65	152	172	106	148	213	99	142	137	103	98	125	99
66	151	171	108	148	212	99	142	134	101	97	126	98
67	152	174	109	151	211	100	141	136	102	98	125	96
68	151	174	114	147	214	99	141	136	102	97	123	97
69	152	170	114	148	208	99	139	135	101	95	125	98
70	150	168	108	148	209	99	142	135	103	97	124	98
71	151	170	109	147	209	102	141	133	101	95	126	96
72	149	169	108	148	208	100	138	134	102	96	127	97
73	151	170	108	148	206	99	139	134	100	99	125	98
74	148	168	108	145	204	99	141	134	99	97	123	97
75	149	169	108	145	203	97	141	134	96	95	123	95

Table A.4 $PM_{2.5}$ mass concentration while using sodium alginate as chemical agglomerant

Time (minutes)	**$PM_{2.5}$ mass concentration ($\mu g/m^3$)**											
	Sodium alginate											
	0.1 w/v sodium alginate						**0.5 w/v sodium alginate**					
	RH 45%			RH 55%			RH 45%			RH 55%		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
0	11	11	24	7	13	8	14	15	16	14	12	14
1	17	43	50	7	17	20	14	14	18	15	17	25
2	35	77	89	8	32	35	24	31	44	22	33	44
3	51	114	132	23	50	68	58	54	74	29	52	64
4	78	155	231	53	68	103	87	68	106	36	66	88
5	108	245	234	75	93	138	126	85	139	47	84	109
6	139	228	225	106	134	210	167	112	251	83	122	175
7	223	217	216	172	161	221	272	209	227	104	125	169
8	213	210	204	170	159	223	227	166	218	91	120	160
9	206	202	196	165	152	220	217	158	212	90	115	157
10	198	198	189	160	151	212	212	154	207	88	114	151
11	190	192	184	156	145	202	201	148	196	84	108	147
12	188	188	182	151	142	192	197	146	189	84	106	147
Spray	186	186	171	147	138	179	193	143	184	82	104	141
0	185	183	168	143	144	179	197	141	183	83	99	138
1	182	181	167	140	140	179	193	136	185	80	102	137
2	183	179	168	137	135	176	195	137	182	81	101	138
3	180	182	166	138	135	178	193	136	181	79	98	136
4	180	180	165	133	131	173	195	137	178	79	96	137
5	177	180	166	137	134	175	190	134	182	78	98	135
6	180	179	164	133	133	173	192	134	182	79	99	137
7	180	179	164	138	131	170	191	135	180	80	100	135
8	177	178	163	132	125	171	191	132	183	80	98	132
9	176	180	162	131	132	169	190	130	179	81	98	132
10	177	177	161	130	133	170	189	133	177	79	97	134
11	173	177	162	134	135	171	187	132	177	82	96	133
12	175	176	159	134	137	171	183	131	180	80	99	134
13	172	174	161	129	130	168	184	134	175	79	95	133
14	174	175	161	127	130	168	184	130	174	83	95	133
15	173	173	161	125	133	167	183	129	175	80	97	135
16	174	172	161	128	127	167	184	131	175	78	95	133
17	172	174	158	127	125	166	186	128	174	81	96	133
18	171	172	158	129	126	166	183	130	175	79	95	129
19	172	169	157	129	127	166	183	132	178	77	92	130
20	172	170	157	127	132	164	182	132	172	80	93	131
21	171	171	157	126	127	165	186	133	169	81	95	134
22	172	168	158	125	127	165	181	130	162	79	93	133
23	170	169	157	129	129	164	178	130	163	78	93	132
24	171	167	157	127	130	165	179	131	164	77	96	131
25	171	168	155	130	128	164	177	130	168	77	96	132
26	171	166	158	125	130	166	176	129	170	77	94	130
27	171	166	159	128	127	164	178	130	166	78	93	129
28	169	164	158	128	131	163	181	129	162	77	95	128

29	171	163	156	126	130	161	178	127	165	75	94	127
30	168	161	155	127	130	163	180	129	165	76	91	129
31	168	161	154	127	131	160	178	127	162	74	93	127
32	171	162	155	127	129	161	176	129	165	73	93	127
33	167	160	153	122	128	164	176	128	163	72	92	128
34	167	164	155	123	129	160	177	127	163	72	92	125
35	165	164	153	127	130	160	175	127	164	74	93	126
36	168	163	153	127	129	161	173	126	160	74	93	125
37	162	160	153	128	130	158	177	125	164	75	94	124
38	163	163	153	125	128	158	177	126	160	74	92	126
39	165	160	152	122	127	161	176	128	159	73	91	125
40	163	163	155	123	128	160	175	126	160	73	92	121
41	163	161	155	122	126	158	177	124	161	71	91	122
42	160	157	150	123	128	160	176	124	161	73	91	123
43	165	158	149	122	124	158	175	124	161	73	89	120
44	159	158	151	123	124	157	175	124	162	73	91	121
45	159	156	152	124	125	160	173	124	160	73	91	120
46	160	159	150	125	124	157	170	124	160	74	89	120
47	157	159	150	123	121	157	169	123	159	74	91	119
48	158	160	148	122	122	156	171	120	157	75	89	119
49	158	158	147	122	120	157	170	122	160	71	89	120
50	160	157	150	124	120	156	174	122	157	70	89	121
51	160	158	148	122	120	160	168	123	157	71	89	120
52	158	157	148	123	123	156	170	123	156	72	88	121
53	154	156	148	122	119	155	172	122	157	72	89	119
54	154	156	146	120	119	155	171	121	157	73	89	121
55	154	156	146	122	116	155	170	119	158	70	87	123
56	152	157	147	119	116	155	170	121	154	71	88	121
57	154	157	145	122	118	154	172	121	155	73	89	122
58	155	156	145	122	124	153	171	123	159	71	88	120
59	157	158	144	119	119	152	170	123	155	70	89	122
60	153	157	145	121	118	150	170	120	153	69	87	122
61	154	158	145	121	120	153	171	121	153	70	88	122
62	154	156	144	119	120	151	169	122	148	71	85	122
63	153	157	145	120	121	151	166	120	150	69	85	122
64	153	155	144	120	116	153	170	122	156	68	83	120
65	152	156	143	119	116	151	169	120	154	69	83	120
66	153	154	146	119	116	152	168	119	153	69	82	119
67	150	156	144	118	117	149	171	117	151	71	80	119
68	151	156	144	117	114	151	167	117	143	68	81	121
69	152	155	143	117	114	152	171	120	149	70	82	119
70	151	154	143	118	115	153	167	119	152	70	82	117
71	151	153	145	116	122	151	166	121	149	69	81	115
72	148	157	143	118	120	150	160	121	148	68	82	115
73	147	153	145	119	121	151	167	121	150	68	82	115
74	150	153	144	116	118	149	167	119	148	69	83	114
75	147	153	135	116	120	148	169	116	148	68	82	112

Table A.5 PM$_{2.5}$ mass concentration while using Xanthan gum as chemical agglomerant

Time (minutes)	**PM$_{2.5}$ mass concentration (µg/m^3)**											
	Xanthan gum											
	0.05 w/v Xanthan gum						**0.1 w/v Xanthan gum**					
	RH 45%			RH 55%			RH 45%			RH 55%		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
0	20	20	22	15	21	23	5	31	29	15	8	15
1	19	22	34	21	22	23	5	52	52	32	8	23
2	22	50	58	36	54	39	12	80	68	72	10	50
3	45	67	77	59	73	64	23	113	109	113	31	79
4	76	137	106	88	109	91	42	147	138	149	65	119
5	104	177	136	142	146	122	58	250	203	226	82	177
6	127	266	168	136	194	174	100	250	188	268	175	219
7	158	360	213	130	287	249	139	251	184	266	172	216
8	243	342	201	126	270	239	124	236	176	258	167	206
9	235	331	197	123	270	233	119	226	171	251	160	200
10	225	327	186	120	255	228	113	219	168	250	157	197
11	221	321	185	118	248	218	110	211	166	238	157	186
12	209	316	182	115	247	217	111	184	160	232	157	173
Spray	200	310	178	113	235	208	110	185	146	233	152	171
0	204	302	176	114	233	201	110	182	143	232	149	169
1	194	307	174	108	229	196	107	182	143	228	145	167
2	195	303	173	110	228	199	108	182	143	231	143	167
3	190	298	172	112	228	193	105	179	138	228	141	165
4	190	297	171	111	227	193	106	179	143	228	139	166
5	193	298	171	110	231	190	106	179	144	229	138	168
6	189	298	173	108	227	188	108	178	138	220	140	164
7	189	295	172	107	231	189	105	179	140	221	137	163
8	187	300	170	110	228	186	103	180	139	219	138	163
9	186	295	169	106	226	189	105	177	139	216	141	162
10	186	298	168	109	230	188	104	176	137	216	137	163
11	184	296	169	105	228	181	104	177	137	212	138	163
12	179	294	167	106	228	185	104	176	136	215	139	162
13	183	299	169	107	224	185	104	173	138	209	135	161
14	179	296	166	106	229	185	104	172	132	217	135	161
15	178	298	165	105	226	184	103	172	133	219	134	163
16	179	293	166	104	224	184	103	170	136	217	134	162
17	187	294	165	107	229	185	104	173	133	219	134	160
18	181	284	167	107	224	184	101	173	134	220	132	162
19	186	291	168	106	227	184	103	172	134	214	134	162
20	185	291	165	106	227	183	102	171	133	214	134	161
21	182	290	167	108	230	184	100	171	132	212	135	157
22	187	288	170	107	232	186	100	173	134	216	139	157
23	187	288	169	104	227	181	100	175	130	215	136	158
24	186	284	166	107	229	184	99	169	139	213	137	160
25	184	289	167	106	229	183	100	172	135	214	137	157
26	182	290	164	105	230	180	99	170	135	219	135	158
27	183	288	165	105	226	181	100	170	135	209	135	158
28	184	285	163	102	228	181	97	170	132	209	134	157

29	181	288	165	102	228	180	98	170	133	211	134	157
30	180	285	160	101	224	181	98	170	132	209	135	157
31	180	283	162	103	227	180	97	169	132	213	133	155
32	181	284	161	100	225	180	94	165	133	209	136	155
33	180	282	160	103	223	180	96	164	129	209	132	156
34	178	282	162	102	225	182	97	163	130	208	131	154
35	179	281	164	100	218	176	95	166	131	198	132	153
36	178	280	161	98	223	175	94	168	132	203	131	157
37	178	279	158	102	226	179	97	164	129	204	135	155
38	175	279	162	100	224	179	95	169	131	204	132	156
39	176	276	162	100	219	178	94	164	130	202	133	154
40	171	280	160	101	221	179	95	164	127	202	134	155
41	171	280	160	99	218	177	93	163	126	202	130	153
42	174	278	160	101	218	177	94	165	128	195	130	153
43	171	277	160	99	221	180	95	161	126	199	132	153
44	171	274	158	99	222	180	94	162	124	198	128	154
45	171	275	158	101	221	175	93	164	126	197	127	151
46	174	275	160	99	218	180	95	162	126	197	128	152
47	171	277	159	97	219	178	94	162	125	196	129	151
48	170	276	159	100	220	176	95	164	126	195	129	150
49	170	271	157	97	219	178	93	161	124	198	128	148
50	171	274	155	100	217	175	92	161	125	193	129	151
51	171	271	154	99	220	172	92	160	127	193	129	150
52	167	272	154	96	217	171	94	161	127	191	129	152
53	170	271	154	99	217	172	92	161	127	191	128	151
54	168	270	153	99	211	171	92	161	127	193	126	150
55	168	269	150	98	210	172	91	158	124	189	124	148
56	171	270	150	100	211	168	91	159	127	187	126	146
57	166	262	149	96	209	170	89	161	126	188	127	147
58	165	263	151	96	213	166	91	160	124	190	126	146
59	163	268	151	96	213	168	92	160	127	187	127	146
60	163	264	153	95	210	168	88	159	126	186	127	148
61	164	263	149	94	213	168	92	159	124	187	125	148
62	162	270	148	90	209	167	88	161	126	188	127	148
63	161	264	150	91	208	166	90	157	123	189	126	145
64	163	266	149	94	208	163	90	160	126	186	129	148
65	159	265	149	95	210	163	91	158	125	187	127	145
66	159	265	147	93	204	165	89	157	126	186	127	146
67	159	265	150	93	207	165	87	156	124	187	127	144
68	158	260	147	92	208	164	89	156	125	183	129	145
69	160	260	149	91	207	164	88	156	122	184	129	145
70	158	261	149	90	205	164	88	154	123	182	129	145
71	161	261	147	94	203	164	88	154	121	183	127	144
72	158	260	146	90	205	163	86	154	123	182	125	144
73	160	255	146	91	200	164	87	156	121	180	124	144
74	160	240	145	91	197	165	85	156	122	181	122	144
75	157	244	147	91	198	164	85	157	123	181	128	144

APPENDIX B

The moving average of $PM_{2.5}$ mass concentration in 5 minutes interval

Table B.1 The moving average of $PM_{2.5}$ mass concentration in 5 minutes interval by using distilled water

Time (minutes)	**$PM_{2.5}$ mass concentration ($\mu g/m^3$)**					
	Distilled water					
	RH 45%			**RH 55%**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
2	14.4	38.2	38.8	31.8	32.2	35.4
3	19.0	58.8	58.0	42.6	44.0	48.6
4	24.4	88.6	87.8	59.4	61.8	69.2
5	40.0	113.4	112.6	82.2	90.6	88.6
6	53.0	132.0	132.6	100.8	120.8	105.4
7	64.4	146.4	148.4	117.4	147.4	118.4
8	74.2	153.8	157.2	130.0	170.6	129.0
9	81.8	149.8	153.2	135.0	184.0	127.4
10	78.4	146.4	149.6	131.6	184.2	125.2
11	76.4	143.2	145.4	128.8	181.0	123.0
12	74.8	141.0	141.6	126.6	177.2	121.4
Spray	73.6	139.6	139.8	125.0	173.4	119.6
0	73.2	138.4	138.0	123.8	169.8	119.0
1	72.8	137.8	136.2	123.2	167.6	118.4
2	72.6	137.4	136.2	123.4	164.8	117.4
3	72.4	136.4	136.4	123.4	164.0	117.0
4	71.8	136.2	136.0	122.8	163.2	117.0
5	71.6	135.8	135.2	122.8	163.4	117.2
6	71.2	135.0	134.4	122.8	163.4	116.8
7	70.6	135.0	133.2	123.0	163.8	117.2
8	70.2	135.2	132.0	122.8	164.0	116.0
9	70.2	134.8	130.8	122.4	163.8	115.4
10	70.0	135.0	129.8	121.8	163.6	114.6
11	70.2	134.6	129.0	121.2	163.6	114.2
12	70.2	133.8	128.6	120.6	164.0	114.2
13	69.8	132.8	127.6	120.2	163.4	114.6
14	69.8	132.0	127.2	120.0	163.0	114.2
15	69.2	131.2	127.4	119.4	162.6	114.0
16	68.6	131.4	127.6	119.2	162.4	114.0
17	68.2	131.4	127.6	118.8	162.0	113.2
18	68.2	131.6	127.4	118.4	162.4	113.0
19	68.0	131.2	127.4	118.0	163.2	112.6
20	67.8	130.8	126.8	118.0	163.6	112.0
21	67.4	130.2	126.6	117.6	163.4	111.4
22	67.0	129.2	125.8	117.8	163.2	111.6
23	66.6	129.0	125.4	117.4	162.8	111.4
24	66.4	129.0	125.0	117.2	162.2	111.8
25	66.4	128.8	124.6	117.0	162.0	112.4
26	66.8	128.2	124.0	116.8	162.0	112.6

27	67.0	128.4	124.0	116.4	162.8	112.8
28	67.2	127.4	124.2	116.4	163.4	113.2
29	67.0	127.2	124.0	116.4	163.4	112.6
30	66.6	126.4	123.8	117.0	162.4	112.0
31	66.2	125.8	123.8	117.2	161.6	111.4
32	65.8	125.0	123.6	116.8	160.0	110.4
33	65.4	125.0	123.4	116.2	157.8	109.8
34	65.2	124.2	123.0	116.0	156.4	109.4
35	65.2	124.0	123.0	115.8	156.0	109.4
36	65.0	124.2	122.6	115.4	155.6	109.6
37	65.0	124.2	122.4	115.6	155.4	109.8
38	64.8	123.8	122.0	115.8	156.0	109.4
39	64.8	124.0	121.6	115.8	156.0	109.0
40	64.6	123.8	121.4	115.4	155.6	108.2
41	64.2	123.6	121.0	115.0	155.6	107.8
42	64.0	123.0	120.4	114.4	155.4	107.0
43	64.2	122.4	120.2	114.2	154.6	106.6
44	63.8	121.8	119.8	113.6	154.4	106.8
45	63.8	122.0	119.2	113.2	154.4	106.8
46	63.8	121.6	118.6	113.0	153.2	106.2
47	63.4	121.6	118.4	113.0	151.8	106.4
48	62.8	122.0	118.0	112.4	151.0	106.4
49	62.8	122.0	117.8	112.2	150.4	106.0
50	62.6	121.6	117.2	111.6	149.8	106.2
51	62.4	120.8	117.2	111.6	149.6	106.2
52	62.6	120.8	116.2	110.8	150.4	105.6
53	63.0	120.6	115.6	110.2	150.8	105.8
54	62.6	120.0	115.4	110.2	150.8	105.6
55	62.2	120.2	114.8	109.8	150.6	104.8
56	62.2	120.8	114.0	109.6	150.2	104.6
57	62.0	120.6	113.8	110.2	149.2	104.4
58	61.4	120.4	113.4	111.0	148.6	103.6
59	61.6	120.8	112.6	110.6	148.8	103.4
60	61.6	120.8	112.0	110.6	149.0	103.4
61	61.6	120.6	111.8	109.8	148.8	102.6
62	61.6	120.8	111.8	109.2	149.0	102.2
63	61.8	120.2	111.6	108.6	149.0	101.6
64	62.0	120.2	111.4	108.6	148.6	101.0
65	62.2	119.4	111.4	108.2	148.2	100.4
66	62.0	119.0	111.4	108.4	149.0	100.2
67	61.8	118.2	111.2	108.0	148.8	100.2
68	61.6	118.2	110.8	107.6	148.8	100.0
69	61.2	117.0	111.0	107.2	148.8	99.8
70	60.8	116.6	110.6	107.0	148.8	100.0
71	60.8	116.2	110.4	106.4	148.0	100.8
72	60.6	115.8	110.0	106.2	148.2	101.2
73	60.4	115.2	109.8	106.0	148.2	102.2

Table B.2 The moving average of PM$_{2.5}$ mass concentration in 5 minutes interval by using pectin

Time (minutes)	**The moving average of PM2.5 mass concentration in 5 minutes interval (µg/m^3)**											
	Pectin											
	0.1 w/v Pectin						**0.5 w/v Pectin**					
	RH 45%			**RH 55%**			**RH 45%**			**RH 55%**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
2	80.4	61.0	51.4	54.6	36.8	17.6	25.8	32.4	22.8	28.0	61.4	30.2
3	129.0	84.8	74.2	75.0	58.8	28.2	35.2	52.6	35.4	36.6	101.4	49.8
4	168.8	116.2	100.8	95.2	87.6	43.6	50.2	85.8	52.2	48.4	134.0	80.0
5	200.0	155.6	122.4	125.6	122.6	73.6	93.6	128.2	82.4	74.6	161.4	105.8
6	221.0	186.4	140.2	157.0	178.0	100.4	128.4	162.0	108.0	93.0	180.8	125.8
7	232.8	210.0	153.0	180.8	223.4	122.8	157.6	187.6	129.6	108.0	192.2	140.4
8	223.8	226.4	156.8	200.2	259.2	139.6	180.8	205.8	146.8	119.4	184.4	147.4
9	216.4	232.4	154.6	213.0	287.4	151.4	197.8	209.6	158.6	127.4	179.6	142.4
10	209.8	223.8	150.0	210.0	305.2	147.2	185.6	201.8	154.4	120.0	172.8	136.4
11	201.8	217.0	145.0	200.2	296.0	142.6	179.6	195.4	150.2	117.2	168.8	131.6
12	194.8	211.8	141.4	193.8	286.6	136.8	175.4	189.6	146.4	115.2	163.8	126.4
Spray	189.4	209.4	138.8	189.4	279.4	132.0	172.6	185.0	142.8	113.4	159.8	123.0
0	184.8	206.6	135.6	185.4	270.4	126.8	169.4	180.8	140.2	112.6	155.8	119.2
1	181.0	205.6	134.8	182.4	264.4	122.6	167.0	177.8	134.8	111.6	154.6	117.6
2	180.2	205.2	134.6	181.4	258.2	119.0	165.4	174.6	129.6	111.4	152.6	116.0
3	179.8	204.4	134.0	180.0	256.2	118.0	164.2	171.8	124.8	110.8	151.6	115.6
4	179.4	202.4	133.4	177.8	252.8	117.4	162.8	168.8	121.2	111.0	150.0	115.0
5	179.4	202.8	132.6	177.0	251.2	117.8	163.0	166.2	117.4	110.0	149.6	115.4
6	179.0	202.8	132.2	176.8	249.0	117.6	162.0	163.0	116.8	109.4	148.6	115.0
7	178.4	202.2	131.8	176.2	248.2	117.6	162.2	162.6	116.2	109.0	147.8	114.8
8	178.0	201.6	131.4	175.6	246.4	117.2	162.0	161.6	115.8	108.8	147.8	114.2
9	177.4	201.6	131.0	175.2	245.8	116.6	161.2	160.2	114.8	108.6	147.4	113.6
10	177.6	200.8	130.8	173.8	245.8	115.8	160.0	160.0	114.2	108.8	146.4	112.6
11	177.8	199.8	130.6	172.8	245.2	115.2	160.4	160.0	114.4	109.0	145.8	112.4
12	177.6	199.6	130.6	172.6	244.0	114.6	159.6	158.0	114.4	109.0	145.2	112.6
13	177.4	199.8	130.0	172.2	243.6	114.2	159.2	157.0	113.8	109.2	144.8	112.4
14	177.4	199.6	129.2	171.0	242.6	114.2	158.8	156.8	113.2	109.2	144.8	112.0
15	176.2	200.0	128.8	170.6	241.0	114.2	158.2	156.0	112.6	108.8	144.4	112.0
16	175.6	199.2	128.0	169.8	239.6	114.0	157.4	155.4	111.0	109.0	144.6	111.4
17	175.4	199.0	127.0	169.2	238.2	113.4	157.6	155.0	110.4	108.8	144.8	111.2
18	175.0	197.2	126.8	168.2	236.8	112.4	157.2	154.8	110.6	108.2	144.2	110.6
19	174.2	196.0	126.6	167.4	235.8	111.8	157.2	155.0	110.6	107.6	143.8	110.2
20	174.0	193.0	126.4	166.8	236.0	110.8	156.8	155.4	111.2	107.8	143.8	110.0
21	173.6	192.2	126.4	166.6	235.8	110.2	157.0	155.2	111.4	107.8	142.8	109.6
22	173.2	189.8	126.4	165.4	236.4	110.0	156.2	155.2	111.4	107.8	142.0	109.2
23	172.4	189.2	125.8	165.8	236.4	110.0	156.2	155.2	111.8	108.0	141.2	109.2
24	172.0	187.6	125.2	166.4	235.6	110.2	155.6	155.0	112.2	108.2	140.0	109.0
25	171.6	187.4	123.8	167.0	234.0	110.6	155.8	154.4	111.8	108.2	139.2	108.8
26	171.0	186.2	122.6	167.0	233.4	110.8	154.8	154.0	111.8	107.6	138.4	109.0
27	170.0	186.0	121.6	167.2	231.8	110.6	154.8	154.0	111.8	107.2	138.0	109.0
28	169.6	185.0	119.8	167.0	230.6	110.2	154.4	152.8	110.8	107.0	137.6	109.0
29	169.0	184.8	119.2	166.4	229.8	110.2	154.0	152.2	110.6	106.8	137.4	108.6
30	167.6	184.0	119.0	165.4	230.2	110.0	153.2	151.8	110.4	105.8	137.0	108.4

31	166.8	183.8	119.0	164.6	229.0	109.2	153.4	151.6	109.8	105.4	136.8	107.8
32	166.0	183.6	118.0	164.0	228.4	108.0	153.0	151.4	109.2	104.8	136.4	106.8
33	164.6	183.8	118.8	163.2	227.4	108.2	152.4	151.2	109.2	104.2	136.4	106.0
34	164.2	183.4	118.8	162.8	226.8	107.2	152.2	150.6	109.0	103.4	136.2	105.8
35	164.2	182.8	118.6	162.8	225.0	106.4	152.6	150.0	108.4	103.4	136.0	105.0
36	163.4	182.4	117.8	162.4	224.6	106.6	151.8	149.2	108.0	102.8	136.2	104.4
37	163.0	182.0	118.0	161.8	224.0	107.2	151.4	147.6	107.4	102.2	136.4	104.6
38	162.8	180.8	117.2	161.4	223.4	106.6	151.0	147.4	106.8	101.8	135.8	104.0
39	162.0	179.2	116.4	160.8	223.2	106.8	150.6	146.8	106.4	101.6	135.4	103.4
40	161.6	178.8	116.4	160.0	222.8	106.6	149.6	146.4	106.0	101.0	135.0	103.0
41	161.8	177.4	116.6	159.6	221.4	106.0	149.6	146.8	105.4	101.0	134.2	102.6
42	161.2	178.0	116.2	159.4	221.0	105.0	149.6	147.2	105.2	101.2	133.6	102.2
43	161.2	177.6	115.8	158.6	220.6	104.6	150.0	147.4	105.4	100.8	133.8	102.2
44	160.8	178.2	115.8	158.2	219.2	104.0	150.0	147.8	104.4	100.8	134.0	102.2
45	160.4	177.8	115.4	158.4	218.0	104.0	149.6	147.6	104.8	101.4	134.2	102.0
46	159.8	178.6	114.6	158.6	217.8	103.6	149.4	146.8	104.8	101.6	134.2	102.4
47	159.8	175.8	113.8	158.0	216.0	103.2	149.2	146.4	104.6	101.6	134.2	101.6
48	159.4	174.8	112.8	158.0	214.6	103.2	148.6	145.4	103.4	101.6	134.4	101.4
49	159.0	174.0	112.8	158.2	214.2	103.0	148.2	144.0	103.4	100.8	133.8	100.4
50	158.4	173.0	112.6	158.0	213.8	102.2	148.6	142.8	102.2	99.8	133.4	100.4
51	158.6	171.8	112.2	157.0	213.2	101.6	148.0	141.8	102.2	99.0	132.8	100.0
52	158.6	172.0	112.4	157.2	213.4	101.8	147.4	141.0	101.6	98.8	132.0	99.8
53	157.8	172.2	112.8	157.0	213.6	101.0	147.0	140.8	101.6	98.4	130.6	99.4
54	157.0	172.8	111.6	156.2	212.6	100.2	146.8	141.0	101.8	98.4	130.6	99.8
55	156.4	173.0	111.2	155.2	213.8	100.2	146.2	141.0	102.2	98.4	130.2	99.6
56	154.8	173.6	110.4	155.0	213.0	100.2	145.6	141.0	102.4	98.2	130.0	99.4
57	154.0	174.8	109.8	154.4	211.8	99.8	145.6	140.6	103.2	98.0	129.8	99.8
58	153.0	175.4	109.4	153.6	210.8	100.4	145.2	140.4	103.4	98.2	129.8	100.0
59	153.2	174.6	109.4	153.4	212.2	100.4	144.6	140.4	103.2	98.0	129.2	100.0
60	152.8	175.0	109.0	152.8	211.4	100.0	144.0	140.6	103.2	97.8	128.6	99.4
61	152.8	174.8	109.2	151.6	212.0	100.2	144.2	140.0	103.4	97.4	127.8	98.8
62	152.0	173.8	108.6	150.8	213.4	100.4	143.8	139.8	103.0	96.6	127.0	98.6
63	152.4	173.0	108.0	150.0	214.2	99.8	143.4	139.0	103.2	96.4	126.2	98.4
64	151.8	172.8	107.6	149.0	213.2	99.6	143.2	137.4	103.0	96.4	125.8	98.2
65	151.8	172.8	107.4	149.0	212.4	99.8	142.8	136.4	102.8	96.6	125.4	98.0
66	151.4	172.8	108.6	148.8	212.8	99.4	142.0	136.2	102.2	97.0	125.0	98.0
67	151.6	172.2	110.2	148.4	211.6	99.2	141.0	135.6	101.8	97.0	124.8	97.6
68	151.2	171.4	110.6	148.4	210.8	99.2	141.0	135.2	101.8	96.8	124.6	97.4
69	151.2	171.2	110.8	148.2	210.2	99.8	140.8	135.0	101.8	96.4	124.6	97.0
70	150.6	170.2	110.6	147.6	209.6	99.8	140.2	134.6	101.8	96.0	125.0	97.2
71	150.6	169.4	109.4	147.8	208.0	99.8	139.8	134.2	101.4	96.4	125.4	97.4
72	149.8	169.0	108.2	147.2	207.2	99.8	140.2	134.0	101.0	96.8	125.0	97.2
73	149.6	169.2	108.2	146.6	206.0	99.4	140.0	133.8	99.6	96.4	124.8	96.6
74	119.4	135.2	86.4	117.2	164.2	79.0	111.8	107.2	79.4	77.4	99.6	77.4

Table B.3 The moving average of $PM_{2.5}$ mass concentration in 5 minutes interval by using sodium alginate

Time (minutes)	The moving average of PM2.5 mass concentration in 5 minutes interval (µg/m^3)											
	sodium alginate											
	0.1 w/v sodium alginate						0.5 w/v sodium alginate					
	RH 45%			RH 55%			RH 45%			RH 55%		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
2	22.8	49.0	59.0	9.0	22.4	26.2	22.0	22.8	30.4	16.0	22.8	29.4
3	38.4	80.0	105.2	19.6	36.0	46.8	39.4	36.4	51.6	23.2	36.0	47.0
4	57.8	126.8	147.2	33.2	52.0	72.8	61.8	50.4	76.2	29.8	50.4	66.0
5	82.2	163.8	182.2	53.0	75.4	110.8	92.4	70.0	122.8	43.4	71.4	96.0
6	119.8	191.8	207.6	85.8	101.2	148.0	142.0	105.6	159.4	59.8	89.8	121.0
7	152.2	211.0	222.0	115.2	123.0	179.0	175.8	128.0	188.2	72.2	103.4	140.2
8	177.8	220.4	215.0	137.6	139.8	202.4	201.8	146.0	209.4	83.0	113.2	154.0
9	195.8	211.0	206.0	154.6	151.4	217.2	219.0	159.8	223.0	91.2	119.2	162.4
10	206.0	203.8	197.8	164.6	153.6	215.6	225.8	167.0	212.0	91.4	116.4	156.8
11	199.0	198.0	191.0	160.4	149.8	209.8	210.8	154.4	204.4	87.4	112.6	152.4
12	193.6	193.2	184.4	155.8	145.6	201.0	204.0	149.8	197.6	85.6	109.4	148.6
Spray	189.4	189.4	178.8	151.4	144.0	192.8	200.0	146.4	191.8	84.2	106.2	144.8
0	186.2	186.0	174.4	147.4	141.8	186.2	196.2	142.8	187.4	82.6	103.8	142.0
1	184.8	183.4	171.2	143.6	139.8	181.0	195.0	140.6	184.6	82.0	102.4	140.2
2	183.2	182.2	168.0	141.0	138.4	178.2	194.2	138.6	183.0	81.0	100.8	138.0
3	182.0	181.0	166.8	138.2	137.0	177.0	194.6	137.4	181.8	80.4	99.2	137.2
4	180.4	180.4	166.4	137.0	135.0	176.2	193.2	136.0	181.6	79.4	99.0	136.6
5	180.0	180.0	165.8	135.6	133.6	175.0	193.0	135.6	181.0	79.2	98.4	136.6
6	179.4	180.0	165.0	135.8	132.8	173.8	192.2	135.2	180.6	79.0	98.2	136.0
7	178.8	179.2	164.4	134.6	130.8	172.4	191.8	134.4	181.0	79.2	98.2	135.2
8	178.0	179.2	163.8	134.2	131.0	171.6	190.8	133.0	181.2	79.6	98.6	134.2
9	178.0	178.6	162.8	132.8	130.8	170.6	190.6	132.8	180.2	79.8	98.4	134.0
10	176.6	178.2	162.4	133.0	131.2	170.2	189.6	132.4	179.2	80.4	97.8	133.2
11	175.6	177.6	161.4	132.2	132.4	170.4	188.0	131.6	179.2	80.4	97.6	133.0
12	174.6	176.8	161.0	131.6	133.4	169.8	186.6	132.0	177.6	80.2	97.0	133.2
13	174.2	175.8	160.8	130.8	133.0	169.6	185.4	132.0	176.6	80.6	96.4	133.4
14	173.4	175.0	160.8	129.8	133.0	169.0	184.2	131.2	176.2	80.8	96.4	133.6
15	173.6	174.0	160.6	128.6	131.4	168.2	183.6	131.0	175.8	80.0	96.2	133.6
16	173.0	173.6	160.4	127.2	129.0	167.2	184.2	130.4	174.6	80.2	95.6	133.4
17	172.8	173.2	159.8	127.2	128.2	166.8	184.0	129.6	174.6	80.2	95.6	132.6
18	172.4	172.0	159.0	127.6	127.6	166.4	183.8	130.0	175.4	79.0	95.0	132.0
19	172.2	171.4	158.2	128.0	127.4	165.8	183.6	130.6	174.8	79.0	94.2	131.2
20	171.6	171.2	157.4	127.6	127.4	165.4	184.0	131.0	173.6	79.6	94.2	131.4
21	171.6	170.0	157.4	127.2	127.8	165.2	183.0	131.4	171.2	79.2	93.6	131.4
22	171.4	169.4	157.2	127.2	128.4	164.8	182.0	131.4	168.8	79.0	93.2	132.0
23	171.2	169.0	157.2	126.8	129.0	164.6	181.2	131.2	166.0	79.0	94.0	132.2
24	171.0	168.6	156.8	127.4	128.2	164.6	180.2	130.8	165.2	78.4	94.6	132.4
25	171.0	167.6	157.0	127.2	128.8	164.8	178.2	130.0	165.4	77.6	94.4	131.6
26	170.8	167.2	157.2	127.8	128.8	164.6	177.6	130.0	166.2	77.4	94.4	130.8
27	170.6	166.2	157.4	127.6	129.2	164.4	178.2	129.8	166.0	77.2	94.8	130.0
28	170.6	165.4	157.2	127.4	129.2	163.6	178.0	129.0	166.2	76.8	94.4	129.2
29	170.0	164.0	157.2	126.8	129.6	163.4	178.6	128.8	165.6	76.6	93.4	128.6
30	169.4	163.0	156.4	127.2	129.8	162.2	179.0	128.4	164.0	76.0	93.2	128.0

31	169.4	162.2	155.6	127.0	130.2	161.6	178.6	128.2	163.8	75.0	93.2	127.6
32	169.0	161.4	154.6	125.8	129.6	161.8	177.6	128.0	164.0	74.0	92.6	127.6
33	168.2	161.6	154.4	125.2	129.4	161.6	177.4	128.0	163.6	73.4	92.2	127.2
34	167.6	162.2	154.0	125.2	129.4	161.0	176.4	127.6	163.4	73.0	92.6	126.6
35	167.6	162.6	153.8	125.2	129.0	161.2	175.4	127.4	163.0	73.0	92.6	126.2
36	165.8	162.2	153.4	125.4	129.2	160.6	175.6	126.6	162.8	73.4	92.8	125.6
37	165.0	162.8	153.4	126.0	129.2	159.4	175.8	126.2	162.2	73.8	92.8	125.2
38	164.6	162.0	152.8	125.8	128.8	159.6	175.6	126.4	161.4	74.0	92.6	125.2
39	164.2	161.8	153.2	125.0	128.4	159.6	175.6	126.2	160.6	73.8	92.4	124.2
40	163.2	161.4	153.6	124.0	127.8	159.0	176.4	125.8	160.8	73.2	92.0	123.6
41	162.8	160.8	153.0	123.0	127.4	159.4	176.2	125.6	160.2	72.8	91.4	123.4
42	163.2	159.8	152.2	122.4	126.6	159.4	175.8	125.2	160.4	72.6	90.8	122.2
43	162.0	159.4	152.0	122.6	126.0	158.6	175.6	124.4	161.0	72.6	90.8	121.4
44	161.2	158.0	151.4	122.8	125.4	158.6	175.2	124.0	161.0	72.6	90.6	121.2
45	160.6	157.6	150.4	123.4	125.0	158.4	173.8	124.0	160.8	73.2	90.2	120.8
46	160.0	158.0	150.4	123.4	123.6	157.8	172.4	123.8	160.4	73.4	90.2	120.0
47	158.6	158.4	150.2	123.4	123.2	157.4	171.6	123.0	159.6	73.8	90.2	119.8
48	158.4	158.4	149.4	123.2	122.4	157.4	170.6	122.6	159.2	73.4	89.8	119.6
49	158.6	158.6	149.0	123.2	121.4	156.6	170.8	122.2	158.6	72.8	89.4	119.8
50	158.6	158.4	148.6	122.6	120.6	157.2	170.4	122.0	158.0	72.2	89.4	119.8
51	158.8	158.0	148.2	122.6	121.0	157.0	170.6	122.0	157.4	71.8	88.8	120.2
52	158.0	157.2	148.2	122.6	120.4	156.8	170.8	122.4	157.4	71.2	88.8	120.2
53	157.2	156.8	148.0	122.2	120.2	156.4	171.0	122.2	156.8	71.6	88.8	120.4
54	156.0	156.6	147.2	121.8	119.4	156.2	170.2	121.6	157.0	71.6	88.4	120.8
55	154.4	156.4	147.0	121.2	118.6	155.2	170.6	121.2	156.4	71.6	88.2	121.0
56	153.6	156.4	146.4	121.0	117.6	154.8	171.0	120.8	156.2	71.8	88.4	121.2
57	153.8	156.4	145.8	121.0	118.6	154.4	170.8	121.0	156.6	71.6	88.2	121.4
58	154.4	156.8	145.4	120.8	118.6	153.8	170.6	121.4	156.2	71.0	88.2	121.6
59	154.2	157.0	145.2	120.6	119.0	152.8	170.6	121.6	155.2	70.8	88.2	121.4
60	154.6	157.2	144.8	121.0	119.8	152.4	170.8	121.6	155.0	70.6	88.2	121.6
61	154.6	157.0	144.6	120.4	120.2	151.8	170.2	121.8	153.6	70.2	87.4	121.6
62	154.2	157.2	144.6	120.0	119.6	151.4	169.2	121.2	151.8	69.8	86.8	122.0
63	153.4	156.6	144.6	120.2	119.0	151.6	169.2	121.0	152.0	69.4	85.6	121.6
64	153.2	156.4	144.2	119.8	118.6	151.8	169.0	121.0	152.2	69.4	84.8	121.2
65	153.0	155.6	144.4	119.4	117.8	151.6	168.4	120.6	152.2	69.2	83.6	120.6
66	152.2	155.6	144.4	119.2	117.2	151.2	168.8	119.6	152.8	69.2	82.6	120.0
67	151.8	155.4	144.2	118.6	115.8	151.2	169.0	119.0	151.4	69.0	81.8	119.8
68	151.6	155.4	144.0	118.0	115.4	151.0	169.2	118.6	150.0	69.4	81.6	119.6
69	151.4	155.0	144.0	117.8	115.2	151.4	168.8	118.4	149.6	69.6	81.4	119.0
70	151.0	154.8	143.8	117.2	116.4	151.2	168.4	118.8	148.8	69.6	81.2	118.2
71	150.6	155.0	143.6	117.2	117.0	151.4	166.2	119.6	148.2	69.0	81.6	117.4
72	149.8	154.4	143.8	117.6	118.4	151.4	166.2	120.4	149.6	69.0	81.8	116.2
73	149.4	154.0	144.0	117.4	119.2	150.8	165.4	120.2	149.4	68.8	82.0	115.2

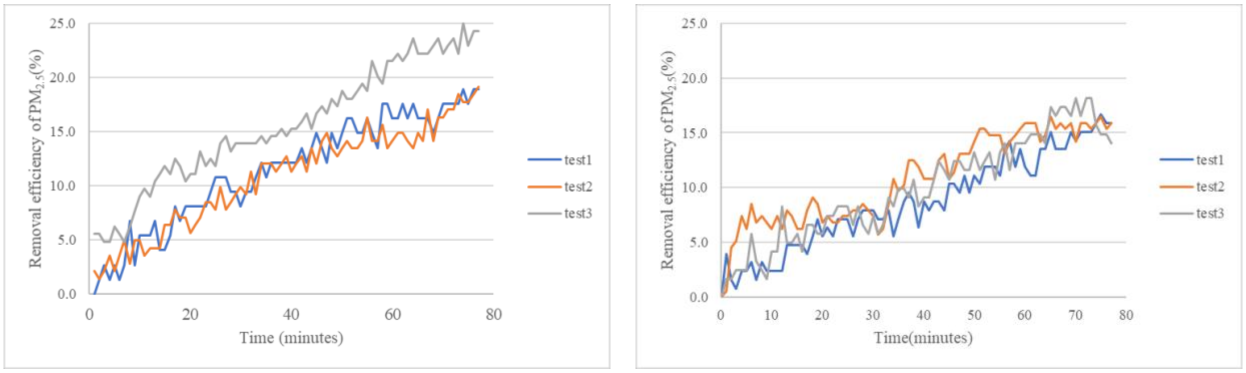
Table B.4 The moving average of $PM_{2.5}$ mass concentration in 5 minutes interval by using Xanthan gum

Time (minutes)	**The moving average of PM2.5 mass concentration in 5 minutes interval (µg/m^3)**											
	Xanthan gum											
	0.05 w/v Xanthan gum						**0.1 w/v Xanthan gum**					
	RH 45%			**RH 55%**			**RH 45%**			**RH 55%**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
2	36.4	59.2	59.4	43.8	55.8	48.0	17.4	84.6	79.2	76.2	24.4	57.2
3	53.2	90.6	82.2	69.2	80.8	67.8	28.0	128.4	114.0	118.4	39.2	89.6
4	74.8	139.4	109.0	92.2	115.2	98.0	47.0	168.0	141.2	165.6	72.6	128.8
5	102.0	201.4	140.0	111.0	161.8	140.0	72.4	202.2	164.4	204.4	105.0	162.0
6	141.6	256.4	164.8	124.4	201.2	175.0	92.6	226.8	177.8	233.4	132.2	187.4
7	173.4	295.2	183.0	131.4	233.4	203.4	108.0	242.6	184.4	253.8	151.2	203.6
8	197.6	325.2	193.0	127.0	255.2	224.6	119.0	236.4	177.4	258.6	166.2	207.6
9	216.4	336.2	196.4	123.4	266.0	233.4	121.0	228.6	173.0	252.6	162.6	201.0
10	226.6	327.4	190.2	120.4	258.0	227.0	115.4	215.2	168.2	245.8	159.6	192.4
11	218.0	321.0	185.6	117.8	251.0	220.8	112.6	205.0	162.2	240.8	156.6	185.4
12	211.8	315.2	181.4	116.0	243.6	214.4	110.8	196.2	156.6	237.0	154.4	179.2
Spray	205.6	311.2	179.0	113.6	238.4	208.0	109.6	188.8	151.6	232.6	152.0	173.2
0	200.4	307.6	176.6	112.0	234.4	204.2	109.2	183.0	147.0	231.2	149.2	169.4
1	196.6	304.0	174.6	111.4	230.6	199.4	108.0	182.0	142.6	230.4	146.0	167.8
2	194.6	301.4	173.2	111.0	229.0	196.4	107.2	180.8	142.0	229.4	143.4	166.8
3	192.4	300.6	172.2	110.2	228.6	194.2	106.4	180.2	142.2	228.8	141.2	166.6
4	191.4	298.8	172.0	110.2	228.2	192.6	106.6	179.4	141.2	227.2	140.2	166.0
5	190.2	297.2	171.8	109.6	228.8	190.6	106.0	178.8	140.6	225.2	139.0	165.2
6	189.6	297.6	171.4	109.2	228.8	189.2	105.6	179.0	140.8	223.4	138.4	164.8
7	188.8	297.2	171.0	108.2	228.6	188.4	105.4	178.6	140.0	221.0	138.8	164.0
8	187.4	297.2	170.4	108.0	228.4	188.0	105.0	178.0	138.6	218.4	138.6	163.0
9	186.4	296.8	169.6	107.4	228.6	186.6	104.2	177.8	138.4	216.8	138.2	162.8
10	184.4	296.6	168.6	107.2	228.0	185.8	104.0	177.2	137.6	215.6	138.6	162.6
11	183.6	296.4	168.4	106.6	227.2	185.6	104.2	175.8	137.4	213.6	138.0	162.2
12	182.2	296.6	167.8	106.6	227.8	184.8	104.0	174.8	136.0	213.8	136.8	162.0
13	180.6	296.6	167.2	105.8	227.0	184.0	103.8	174.0	135.2	214.4	136.2	162.0
14	179.6	296.0	166.6	105.6	226.2	184.6	103.6	172.6	135.0	215.4	135.4	161.8
15	181.2	296.0	166.2	105.8	226.4	184.6	103.6	172.0	134.4	216.2	134.4	161.4
16	180.8	293.0	165.8	105.8	226.4	184.4	103.0	172.0	133.6	218.4	133.8	161.6
17	182.2	292.0	166.2	105.8	226.0	184.2	102.8	172.0	134.0	217.8	133.6	161.8
18	183.6	290.6	166.2	106.0	226.2	184.0	102.6	171.8	134.0	216.8	133.6	161.4
19	184.2	290.0	166.4	106.8	227.4	184.0	102.0	172.0	133.2	215.8	133.8	160.4
20	184.2	288.8	167.4	106.8	228.0	184.2	101.2	172.0	133.4	215.2	134.8	159.8
21	185.4	289.6	167.8	106.2	228.6	183.6	101.0	172.4	132.6	214.2	135.6	159.0
22	185.4	288.2	167.4	106.4	229.0	183.6	100.2	171.8	133.6	214.0	136.2	158.6
23	185.2	287.8	167.8	106.4	229.4	183.6	99.8	172.0	134.0	214.0	136.8	157.8
24	185.2	287.8	167.2	105.8	229.4	182.8	99.6	171.8	134.6	215.4	136.8	158.0
25	184.4	287.8	166.2	105.4	228.2	181.8	99.6	171.2	134.8	214.0	136.0	158.2
26	183.8	287.2	165.0	105.0	228.4	181.8	99.0	170.2	135.2	212.8	135.6	158.0
27	182.8	288.0	164.8	104.0	228.2	181.0	98.8	170.4	134.0	212.4	135.0	157.4
28	182.0	287.2	163.4	103.0	227.2	180.6	98.4	170.0	133.4	211.4	134.6	157.4
29	181.6	285.8	163.0	102.6	226.6	180.6	98.0	169.8	132.8	210.2	134.2	156.8

30	181.2	285.0	162.2	101.6	226.4	180.4	96.8	168.8	132.4	210.2	134.4	156.2
31	180.4	284.4	161.6	101.8	225.4	180.2	96.6	167.6	131.8	210.2	134.0	156.0
32	179.8	283.2	161.0	101.8	224.8	180.6	96.4	166.2	131.2	209.6	133.4	155.4
33	179.6	282.4	161.8	101.6	223.6	179.6	95.8	165.4	131.0	207.4	132.8	154.6
34	179.2	281.8	161.6	100.6	222.8	178.6	95.2	165.2	131.0	205.4	132.4	155.0
35	178.6	280.8	161.0	101.0	223.0	178.4	95.8	165.0	130.2	204.4	132.2	155.0
36	177.6	280.2	161.4	100.4	223.2	178.2	95.6	166.0	130.6	203.4	132.2	155.0
37	177.2	279.0	161.4	100.0	222.0	177.4	95.0	166.2	130.6	202.2	132.6	155.0
38	175.6	278.8	160.6	100.2	222.6	178.0	95.0	165.8	129.8	203.0	133.0	155.4
39	174.2	278.8	160.4	100.4	221.6	178.4	94.8	164.8	128.6	202.8	132.8	154.6
40	173.4	278.6	160.8	100.2	220.0	178.0	94.2	165.0	128.4	201.0	131.8	154.2
41	172.6	278.2	160.4	100.0	219.4	178.2	94.2	163.4	127.4	200.0	131.8	153.6
42	171.6	277.8	159.6	99.8	220.0	178.6	94.2	163.0	126.2	199.2	130.8	153.6
43	171.6	276.8	159.2	99.8	220.0	177.8	93.8	163.0	126.0	198.2	129.4	152.8
44	172.2	275.8	159.2	99.8	220.0	178.4	94.2	162.8	126.0	197.2	129.0	152.6
45	171.6	275.6	159.0	99.0	220.2	178.6	94.2	162.2	125.4	197.4	128.8	152.2
46	171.4	275.4	158.8	99.2	220.0	177.8	94.2	162.8	125.4	196.6	128.2	151.6
47	171.2	274.8	158.6	98.8	219.4	177.4	94.0	162.6	125.4	196.6	128.2	150.4
48	171.2	274.6	158.0	98.6	218.6	177.4	93.8	162.0	125.2	195.8	128.6	150.4
49	170.6	273.8	156.8	98.6	219.0	175.8	93.2	161.6	125.4	195.0	128.8	150.0
50	169.8	272.8	155.8	98.4	218.6	174.4	93.2	161.4	125.8	194.0	128.8	150.2
51	169.8	271.8	154.8	98.2	218.0	173.6	92.6	160.8	126.0	193.2	128.6	150.4
52	169.4	271.6	154.0	98.6	216.4	172.2	92.4	160.8	126.6	192.2	128.2	150.8
53	168.8	270.6	153.0	98.2	215.0	171.6	92.2	160.2	126.4	191.4	127.2	150.2
54	168.8	270.4	152.2	98.4	213.2	170.8	92.0	160.0	126.4	190.2	126.6	149.4
55	168.6	268.4	151.2	98.4	211.6	170.6	91.0	160.0	126.2	189.6	126.2	148.4
56	167.6	266.8	150.6	97.8	210.8	169.4	90.8	159.8	125.6	189.4	125.8	147.4
57	166.6	266.4	150.2	97.2	211.2	168.8	90.8	159.6	125.6	188.2	126.0	146.6
58	165.6	265.4	150.8	96.6	211.2	168.0	90.2	159.8	126.0	187.6	126.6	146.6
59	164.2	264.0	150.6	95.4	211.6	168.0	90.4	159.8	125.4	187.6	126.4	147.0
60	163.4	265.6	150.4	94.2	211.6	167.4	90.2	159.8	125.4	187.6	126.4	147.2
61	162.6	265.8	150.2	93.2	210.6	167.4	90.0	159.2	125.2	187.4	126.4	147.0
62	162.6	265.4	149.8	92.8	209.6	166.4	89.6	159.2	125.0	187.2	126.8	147.4
63	161.8	265.6	149.0	92.8	209.6	165.4	90.2	159.0	124.8	187.4	126.8	146.8
64	160.8	266.0	148.6	92.6	207.8	164.8	89.6	158.6	125.2	187.2	127.2	146.4
65	160.2	265.0	149.0	93.2	207.4	164.4	89.4	157.6	124.8	187.0	127.2	145.6
66	159.6	264.2	148.4	93.4	207.4	164.0	89.2	157.4	125.2	185.8	127.8	145.6
67	159.0	263.0	148.4	92.8	207.2	164.2	88.8	156.6	124.4	185.4	127.8	145.0
68	158.8	262.2	148.4	91.8	206.2	164.4	88.2	155.8	124.0	184.4	128.2	145.0
69	159.2	261.4	148.4	92.0	206.0	164.2	88.0	155.2	123.0	183.8	128.2	144.6
70	159.0	260.4	147.6	91.4	205.6	163.8	87.8	154.8	122.8	182.8	127.8	144.6
71	159.4	259.4	147.4	91.2	204.0	163.8	87.4	154.8	122.0	182.2	126.8	144.4
72	159.4	255.4	146.6	91.2	202.0	164.0	86.8	154.8	122.0	181.6	125.4	144.2
73	159.2	252.0	146.2	91.4	200.6	164.0	86.2	155.4	122.0	181.4	125.2	144.0

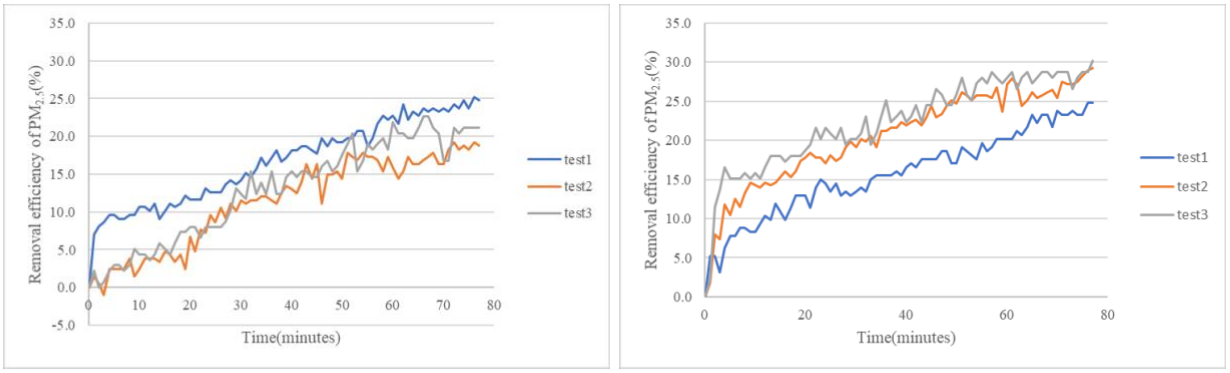
APPENDIX C

$PM_{2.5}$ removal efficiency calculated by 1-min interval monitoring data



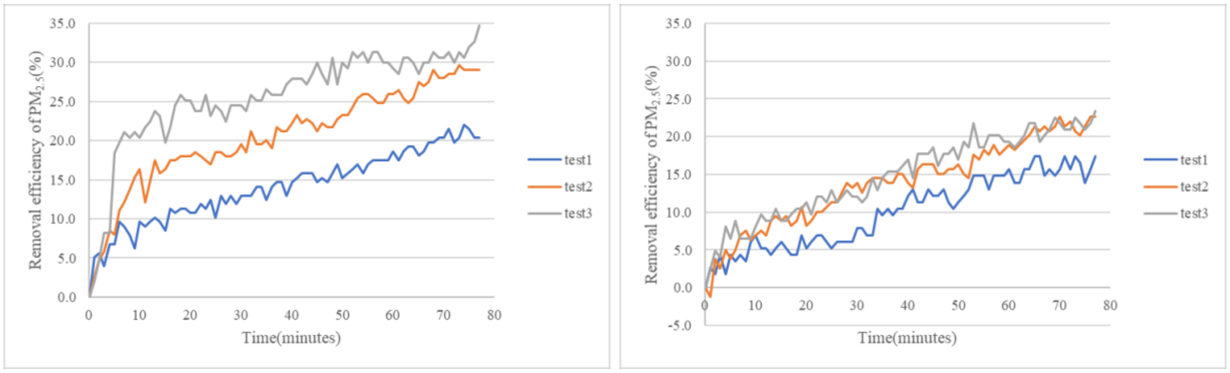
(a) (b)

Fig. C.1 The removal efficiency of $PM_{2.5}$ concentration after spray distilled water



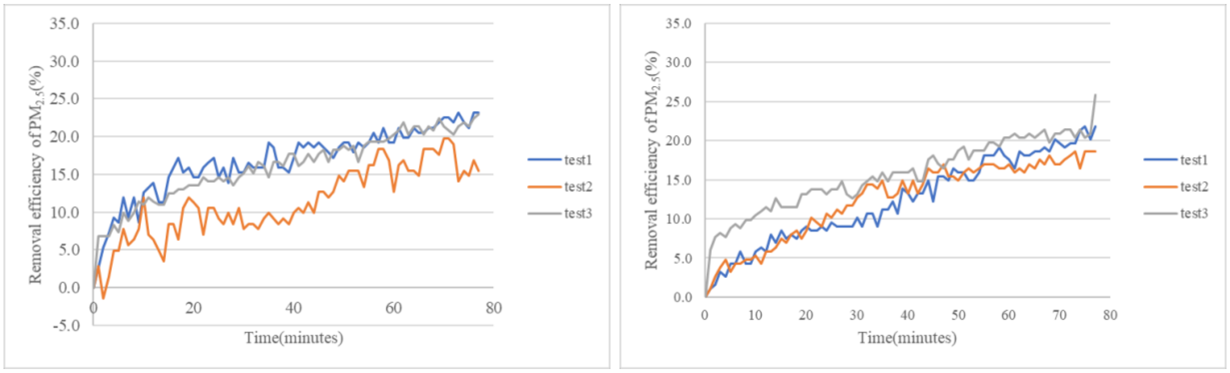
(a) (b)

Fig. C.2 The removal efficiency of $PM_{2.5}$ concentration after spray 0.1% w/v pectin (a)under 45±3% relative humidity and (b)under 55±3% relative humidity



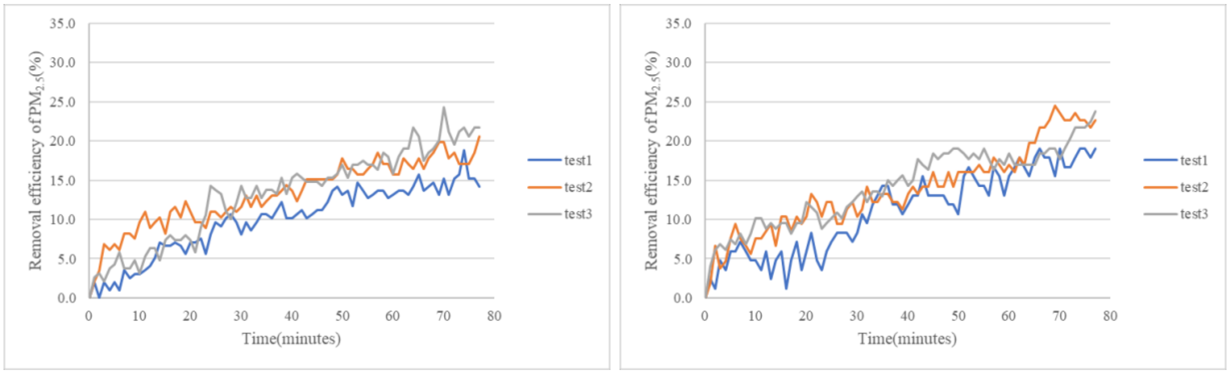
(a) (b)

Fig. C.3 The removal efficiency of $PM_{2.5}$ concentration after spray 0.5% w/v pectin (a)under 45±3% relative humidity and (b)under 55±3% relative humidity



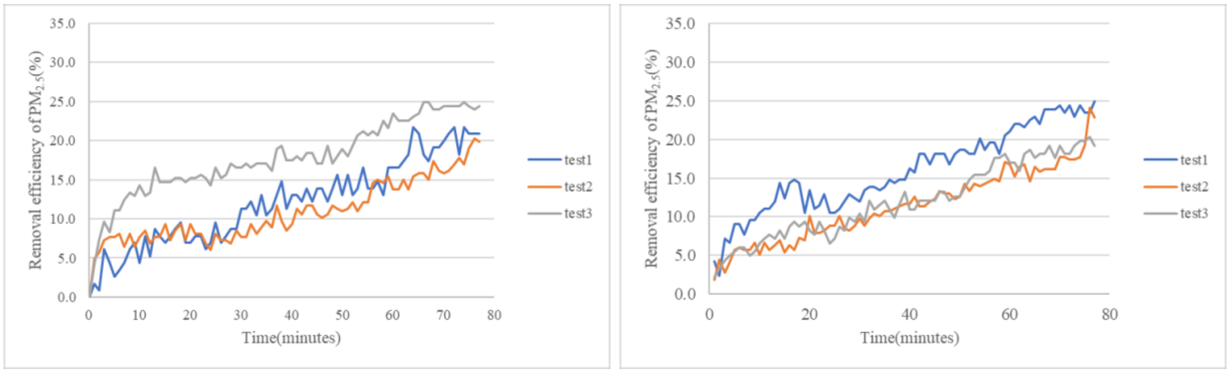
(a) (b)

Fig. C.4 The removal efficiency of $PM_{2.5}$ concentration after spray 0.1% w/v sodium alginate (a)under 45±3% relative humidity and (b)under 55± 3% relative humidity



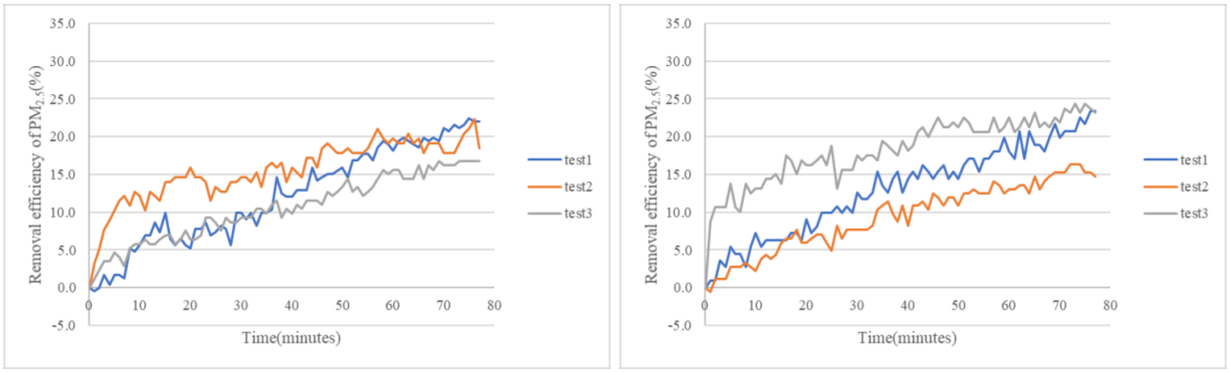
(a) (b)

Fig. C.5 The removal efficiency of $PM_{2.5}$ concentration after spray 0.5% w/v sodium alginate (a)under 45±3% relative humidity and (b) under 55±3% relative humidity



(a) (b)

Fig. C.6 The removal efficiency of $PM_{2.5}$ concentration after spray 0.05% w/v Xanthan gum (a)under 45±3% relative humidity and (b)under 55±3% relative humidity



(a) (b)

Fig. C.7 The removal efficiency of $PM_{2.5}$ concentration after spray 0.1% w/v Xanthan gum (a)under 45±3% relative humidity and (b)under 55±3% relative humidity

APPENDIX D

Statistical analysis

Table D.1 Paired Samples Test of 0.1%-0.5% w/v pectin

		Paired Differences			
		95% Confidence Interval of the Difference			
		Upper	t	df	Sig. (2-tailed)
Pectin 45%RH	0.1% w/v - 0.5% w/v	14.4258	-1.308	2	.321
Pectin 55%RH	0.1% w/v - 0.5% w/v	7.2071	.563	2	.630

Table D.2 Paired Samples Test of 0.1%-0.5% w/v sodium alginate

		Paired Differences			
		95% Confidence Interval of the Difference			
		Upper	t	df	Sig. (2-tailed)
Sodium alginate 45%RH	0.05% w/v - 0.1% w/v	15.3605	.535	2	.646
Sodium alginate 55%RH	0.1% w/v - 0.5% w/v	21.0502	2.144	2	.165

Table D.3 Paired Samples Test of 0.05%-0.1% w/v Xanthan gum

		Paired Differences			
		95% Confidence Interval of the Difference			
		Upper	t	df	Sig. (2-tailed)
Xanthan gum 45%RH	0.1% w/v - 0.5% w/v	10.1494	-.215	2	.850
Xanthan gum 55%RH	0.05% w/v - 0.1% w/v				

Table D.4 Paired Samples Test of pectin under 45%RH and 55%RH

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
0.1%w/v pectin	45%RH - 55%RH	-5.7667	3.9716	2.2930	-15.6326	4.0992	-2.515	2	.128
0.5%w/v pectin	45%RH - 55%RH	7.5333	3.2332	1.8667	-.4983	15.5650	4.036	2	.056

Table D.5 Paired Samples Test of sodium alginate under 45%RH and 55%RH

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
0.1%w/v sodium alginate	45%RH - 55%RH	.1333	2.1362	1.2333	-5.1733	5.4399	.108	2	.924
0.5%w/v sodium alginate	45%RH - 55%RH	-1.2333	2.3438	1.3532	-7.0556	4.5890	-.911	2	.458

Table D.6 Paired Samples Test of Xanthan gum under 45%RH and 55%RH

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
0.05%w/v Xanthan gum	45%RH - 55%RH	.8000	4.6861	2.7055	-10.8410	12.4410	.296	2	.795
0.5%w/v Xanthan gum	45%RH - 55%RH	.8667	6.8010	3.9265	-16.0279	17.7612	.221	2	.846

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