EFFECTIVENESS OF INFECTION CONTROL BARRIERS FOR CONSTRUCTION IN HEALTHCARE

A Thesis

by

JINYUN HUO

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Chair of Committee,	John M. Nichols
Committee Members,	Sara D. Lawhon
	Edelmiro Escamilla
Head of Department,	Joseph P. Horlen

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ABSTRACT

Aspergillosis spores enter buildings during renovation or construction. Recent research shows a causal link between new construction in existing healthcare facilities and increased infection rates in at risk patients. *Aspergillosis* is a dangerous pathogen that can lead to death, especially in immune suppressed patients, who are most at risk. Not all patients have the same risk level of infection, but infection control is an important step in the construction process, as the *Aspergillosis* spores are transmitted on dust particles, to reduce the risk of fatal infections. Infection control barriers have been largely adopted for new hospital construction at an existing facility to reduce the incidence of infections caused by construction dust borne pathogens. Previous research on construction barriers at TAMU showed that a properly placed plastic sheet barrier stopped all particle movement for a pressure differential of 105 kiloPascals measured over twenty-four hours. It is not possible to maintain a sealed barrier during all construction, although this is the most effective means of stopping dust transmission intra-building, doors are often needed to access the construction site safely. This study extends the work on the sealed barrier to introduce a small door into the sealed barrier. The door area is five percent of the wall area. The purpose of the experiment is to study the rate of particle movement, size range of one to ten microns, through the barrier with a door present under a defined set of standard air flow conditions. The door will be opened and closed at different times during the experimental period. No dust could be observed to have moved through the doorway under the present study conditions. The

results show that it is not a sufficient condition to assume that measuring air exchange rates is sufficient to determine the rate of dust movement; it appears to have an air surface velocity dependence that was not studied in this research. Future research is recommended to include the air velocity movement as a variable in the study.

DEDICATION

Thanks to my mother and father for their encouragement.

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NOMENCLATURE

These definitions are derived from the earlier research work by (Bassett, 2013):

- *AIA* American Institute of Architects
- *APIC* Association for Professionals in Infection Control
- *Aspergillus: Aspergillus spp.* and in particular *Aspergillus fumigatus* are fungi that play an essential role in recycling environmental carbon and nitrogen. Their natural ecological niche is the soil, wherein it survives and grows on organic debris. Although *A. fumigatus* is not the most prevalent fungus in the world, it is one of the most ubiquitous of those with airborne spores. The spores released into the atmosphere have a diameter small enough (2 to 3 μm) to reach deep into the lungs. Once the spores are in the air, their small size makes them buoyant, tending to keep them airborne both indoors and outdoors. Environmental surveys indicate that all humans will inhale at least several hundred *Aspergillus* spores per day. (Latge, 1999)
- *Aspergillosis: Aspergillosis* is a disease caused by the inhalation of the fungus *Aspergillus,* and usually this inhalation results in disease in people with lung diseases or weakened immune systems. The spectrum of illness includes allergic reactions, lung infections, and infections in other organs (CDC, 2012a)
- Antifungal: A drug used to treat infections caused by fungi.
- CDC: "*The Center for Disease Control and Prevention is the nation's disease prevention and wellness promotion agency, protecting people's health and safety,*

providing credible information to enhance health decisions, and improving health through strong partnerships. CDC's work encompasses a wide range of health threats, including infectious and chronic diseases, injuries, birth defects, food and water safety, bioterrorism, environmental hazards, and occupational health and safety. CDC also administers funding for state and local health departments, community-based organizations and academic institutions for a wide array of public health programs and research"(CDC, 2012b).

- Construction: can be defined as a building of structures, or the additions, alterations, expansions, reconstruction, or renovations to existing buildings. Construction may also include any maintenance, repairs or installation work to mechanical, electrical, or plumbing systems that form a part of a building system.
- Immunosuppressed: A state in which the patient's immune system is weakened due to their condition and treatment. Their body's immune system or ability to fight off infection is impaired or not effective, making the person more susceptible and vulnerable to infection. This condition is also known as being immune-compromised.
- Infection Control: Policies or procedures implemented by a healthcare facility and carried out by construction professionals to minimize the risk of spreading infections. These procedures are implemented for the protection of patients within the facility.
- Barrier: A fundamental component of infection control; barriers are the first line of defense to prevent the spread of infection within a hospital. During a time of

construction activity, barriers isolate the construction area from the treatment area.

- Nosocomial Infections: Infections contracted within the hospital that is unrelated to the patient's initial illness or injury. Nosocomial infections are also known as hospital-acquired infections. Recent research links nosocomial infections to occur during a time of construction within the healthcare facility.
- *ASHRAE* Formerly the American Society of Heating, Refrigerating and Air Conditioning Engineers. Founded in 1894, is a building technology society with more than 54,000 members worldwide. The society and its members focus on building system, energy efficiency, indoor air quality, refrigeration and sustainability within the industry.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Healthcare acquired infections are responsible for tremendous morbidity and mortality for patients at risk in hospitals. The Center for Disease Control and Prevention (CDC) estimate that approximately 10% of patients who are admitted to hospitals in United States will suffer from healthcare acquired infections. This results in millions of unwanted infections every year. Nosocomial infections and hospital acquired infections can be devastating to a patient, especially for an immunosuppressed patient, resulting in death or long term disability. Such infections include fungal and bacterial infections and are aggravated by the reduced resistance of individual patients. "*Invasive Aspergillosis is one of the most opportunistic fungal infection among immunocompromised host, with a 357% increase in death rates reported in the United States from 1980 to 1997, and the most common cause of invasive Aspergillus is Aspergillus fumigatus*" (Panckal, Imhof, Hanley, & Marr, 2006).

The trend in mortality associated with *Aspergillosis* has demonstrated an almost exponential increase, peaking in 1995 at 0.42 deaths per 100,000 of the population. Recent advances in antifungal drugs have reduced the increase in the death toll, but the disease is still persistent and problematic. Airborne transmission of the fungi can happen when the carrier of those infectious spread infected aerosol particles near the patients, or into the air handling system for the patients. Also, some micro-organisms can be brought

long distances due to air currents and can be inhaled by a high risk patient without having been in direct contact with a carrier, which is the problem associated with construction related dust. This work that deals with the movement of air particles contains specifics about infections with unknown origins (McNeail et al., 2001).

When construction work is happening in or around hospitals, there is a patient risk from the spreading of dust from the construction that may contain fungi and bacteria. Patients are risk of infection whenever they are in hospital, but there is a higher risk of infection when construction is occurring in the hospital, especially for at risk patients. Teeter (2012) notes from work by L. Old that "*more than 2 million patients admitted to acute care U.S. hospitals develop one or more nosocomial infections, and approximately 90,000 people die from complications associated with nosocomial infections, and approximately 5,000 deaths attributed to construction or maintenance related activities*." In addition to reducing the spread of infection, contractors and hospital staff need to make sure the containment of dust created by construction work is properly controlled at the source. Since 1978, construction related *Aspergillus* infections had been reported, those outbreaks of invasive *Aspergillosis* have been associated with construction activities including new construction, construction renovation and expansion. Fungal infection control is an urgent topic for both construction industry and healthcare facility management personal.

In order to make sure that patients at risk, staff and even visitors are not negatively affected by the construction work, diligent planning and strictly controlled execution during construction work are required. Current protection measures on

construction infect control including plastic sheets that separate construction work from hospital area, which is supposed to be effective with proper design. However, the barrier between construction area and hospital are not always as successful as the previous studies proved. There are still possible ways for dust from construction site to be transmitted into hospital, therefore this study will look at the movement of dust through breaks in the barrier system.

This chapter presents the problem statement, research objectives, hypothesis,

PROBLEM STATEMENT

This study addresses a research area related to the movement of dust particles from a construction area into a non-construction area. This study will measure the efficiency of a plastic barrier fitted with a door that is situated between the construction area and the hospital in stopping the transmission of dust particles. Talc is used as the substitute to dust particle

RESEARCH OBJECTIVES

The primary research area of this study is to determine the movement of dust particles in the size of 1 to 5 microns through the plastic barrier with an opening under a defined set of standard air flow conditions.

HYPOTHESIS

A test of construction barrier walls, with openings, using a differential pressure of 105 kilopascals, will showing a maximum dust flow rate of 2 μg/L in the air flow.

STUDY LIMITATIONS

The study limitations are:

- will measure particulate matter at a size of 12 micrometres using a count per square millimetre on the output filter of the test system
- restricted due to mock containments constructed at the TAMU Architecture Ranch and adjusted at the TAMU Woodshop in April 2014
- It is not known how many particles of *Aspergillus* spp. are required for the development of an *Aspergillus* infection. In part, this is because development of a patient infection is dependent not only on the number of spores, but also patient immune response to the spores.
- Talc powder is assumed to represent both the fungal spores and the dust media on which it may be transported, but this is an area for future research to determine the properties, mass, density and size of hospital dust

STUDY ASSUMPTIONS

It is assumed that

- the experiment is a measureable test resembling hospital dust transmission
- the substance utilized to imitate dust is of correct representation and size
- a study pressure of 105 kilopascals is representative of 90 metres per second wind storm, which is equivalent to fifteen pounds per square inch at two hundred miles per hour), which is higher than most recorded wind speeds in the USA, although the filtered media will reduce the impact
- the impact of the filter is assumed negligible

SIGNIFICANCE

A known relationship exists between construction activities and an increase in nosocomial infection. This study looks to see if the open door in a construction wall can be shown to present a dust transmission path.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

This study includes a literature review that looks at the background information for hospital acquired infection, considers how construction activities are involved with nosocomial infections and especially focuses on the current procedures that have been used to protect patients at risk from dust contains pathogen that are created from construction work. The chapter outlines the problem of *aspergillus* infection,

ASPERGILLUS INFECTION

Aspergillus is a group of around 200 known fungi and most of it family are known to be detrimental to human health. *Aspergillosis* is the disease caused by *Aspergillus* fungi, and there are many kinds of *Aspergillosis*. For instance, one form is allergic bronchopulmonary *Aspergillosi*s (also called ABPA) which causes allergic respiratory symptoms (wheezing and coughing), but not an actual infection. Expose to *Aspergillus* can also lead to invasive *Aspergillosis*, which may affect patients whose immune system may be compromised, such as following a transplant (Panckal et al., 2006). In this condition, the fungus invades and damages tissues in the body. Invasive *Aspergillosis* most commonly affects one organ but can also cause infections in many other organs and spread throughout the body. Patients at risk including those with chronic granulomatous disease, leukemia, cystic fibrosis, chronic obstructive pulmonary disease, severe asthmatic fungal sensitivity, HIV, AIDS, and chemotherapy and

transplant patients. According to Center for Disease Control and Prevention, 88,000 immune compromised patients died from healthcare acquired infection among two million acquired infections in hospital every year. Besides, more than half of these occurred with construction activities around the hospital.

Figure 1 shows the picture of the *Aspergillus* spores from Franzblau (2012).

Figure 1. Aspergillus spore (after David Gregory and Debbie Marshall, 2012)

Gregory and Marshall (2014) took this SEM image of *Aspergillus mould* producing spores in 2012. These authors noted *"This is a commonly found mold and airborne exposure is ubiquitous in the indoor and outdoor environments – and usually does not lead to".* Franzblau (2012) notes that *"Despite almost constant and widespread environmental exposure, this type of deep tissue infection with Aspergillus essentially never happens among persons with a normal immune system"*

This study looks at the transmission of dust particles that are capable of containing spores of *Aspergillus* that are disturbed during construction activities. The Center for Disease Control and Prevention (2014) notes that *Aspergillus* as "*a common fungus that can be found in indoor and outdoor environments and normally human beings breathe in Aspergillus spores every day without being affected. Aspergillosis is a disease caused by this fungus and usually occurs in people with lung diseases or weakened immune system."* In addition, *Aspergillus* is usually found in soils, on plants, and decaying plant matter. It also can be found in household dust, construction-building material and even on some foods items. There are lots of different types of Aspergillus, but some of the more common ones are including *Aspergillus Fumigatus, Aspergillus Flavus, Aspergillus Terreus, and Aspergillus Niger.*

ASPERGILLOSIS TREATMENT

Although the Centers for Disease Control and Prevention provide guidelines to protect patients at risk from nosocomial infection, *Aspergillosis* infection is still a tough issue for healthcare industry and the treatments of *Aspergillous* even a with significant medical expenses are not always successful. The typical questions are:

- Why have outcomes been so bad and what is the impact of early diagnosis?
- What are options for therapy?
- Is disseminated infection or severely immune-compromised?
- Can we do better in protection patient at risk?
- What's the important of role of combination therapy?
- How can management strategies improve outcome?

Table 1 shows the mortality rates from invasive *Aspergillosis* in transplant recipients from a paper by Singh and Paterson (2005).

Table 1.

Invasive Aspergillosis in Transplant Recipients (Singh & Paterson, 2005)

Type of Transplant	Incidence Range, % (Mean)	Mortality (%)
Lung	3-14% (6%)	68%
Liver	1-8 (2)	87
Heart	1-15 (5)	78
Kidney	0-4 (1)	77
Small bowel	0-10 (2)	66
Allogeneic stem cell	5-26 (10)	78-92
Autologous stem cell	2-6 (5)	78-92
Nonmyeloblative stem cell	8-23 (11)	63-67

Anaissie and Denning (2008) noted in their paper that *Amphotericin B* and *Itraconazole* are the only two antifungal agents that had been used for *Aspergillosis* treatment. However, the acute renal failure and hidden costs of toxicity indicate the treatment is not always successful and nor effective. Their data show that 212 out of 707 adult patients receiving Amphotericin B had acute renal failure, and higher mortality exists as a result of acute renal failure is 54% against 16%.

The following paper, by Bates et al. (2001), lists the key points and concerns of a 24 hour continuous infusion *Amphotericin B:*

- *Dose escalated to 2 mg/kg/d when tolerated*
- *Median duration of therapy 16 d (range 7- 72d)*
- *Infusion-related reactions is 18%*
- *>2-fold increase in creatinine is 16%*
- *Dose limited toxicity is 1/33*

Concerns (Andes, 2003; Imhof, Walter, & Schaffner, 2003) are:

- *Limited efficacy data in documented infection*
- *Poor efficacy of Amphotericin B in invasive Aspergillosis*
- *Animal models: peak serum level/MIC best predictor of outcome*

WHO IS AT RISK?

For people with a sound immune system who breathe in fungal spores or even stay for long time in contact with fungal spores or dust with fungal spores there are limited and low infection rates, but for people who born with weak immune system or

their illness lead to non-functional immune systems are more likely to develop a nosocomial infection in hospital. Such groups include:

- people living with HIV/AIDS
- organ transplant patients
- stem cell transplant patients
- cancer patients
- people taking medications that weaken their immune systems

Healthcare associated infections cost numerous lives and billions of dollars to the United States healthcare system. Hospital Acquired Infections (HAIs) facts show the impact of these infections:

- Every day in the United States 270 people die from a healthcare associated infection, which is 3 times the number of people who die in a car accident each day
- 1,737,000 people will get an HAI in the U.S. in 2012
- 40 billion dollars cost in the U.S. caused by HAIs, which is equal to the Federal Highway budget for 2014
- Healthcare associated infections are the fourth leading cause of death in the United States
- 10% of patients will get a healthcare associated infection
- On average, healthcare associated infections increase hospital stays by 8 days and HAIs keep a patient in the hospital 13 days longer

- Healthcare associated infections keep cancer patients in the hospital an average of 30 days longer

INFLUENCE OF CONSTRUCTION

Any construction system that will reduce this cost is worth investigation to provide a better health care system. Berg (2012) notes that construction related healthcare acquired infection are usually caused by fungi (most common one is *Aspergillus*). Table 2 lists the most commonly seen etiological agents from this paper.

Table 2.

Infection Agents - health care acquired

Species	Global/Regional Distribution	Pathogenicity	Typical Clinical Presentation
A. fumigatus	Ubiquitous throughout world; decomposing vegetative matter is primary ecological niche; often found in and around human dwellings in rural areas; common in the home	Most pathogenic species; isolated in ~66% of all clinical infections, but with decreased prevalence in recent years	Responsible for >90% of invasive aspergillosis cases; most rapidly growing species; also causes pulmonary disease, aspergilloma, allergic bronchopulmonary aspergillosis, may be amphotericin B resistant
A. flavus	Found in soil and decaying vegetation	Isolated in ~14% of clinical infections	Common isolate in sinusitis, skin, and invasive infections; produces an aflatoxin; may be amphotericin B resistant
A. terreus	Found in soil; Increasingly found in water supplies	Isolated in ~5% of clinical infections	Increasingly reported in invasive infection in immunocompromised hosts; resistant to amphotericin B, more susceptible to newer azoles
A. niger	Found in soil, on plants, and in food and condiments (for example pepper)	Isolated in ~5% of clinical infections	Uncommon in invasive infections; usually causes superficial infection (for example otitis externa); common colonizing isolate
A. nidulans	Found in decomposing vegetative matter	Isolated in a small percentage of clinical infections	Causes diverse infections, especially in patients with chronic granulomatous disease; may be resistant to amphotericin B
A. ustus	Found in decomposing vegetative matter	Isolated in a small percentage of clinical infections	Causes disseminated infection, otitis media, skin burn and cutaneous infections, and endocarditis

HEALTHCARE FACILITY GUIDELINES

Construction Infection prevention guidelines required construction activities around hospital area to be both effective and harmless to the patients at risk. The hospital's primary obligation is to provide for patient safety within the most risk free environment possible. Some companies have already developed their own "practice guidelines" and compete with each other to be knows as providing for the best practices in healthcare construction industry.

As an example, one such company is The Linders Health Institute, which provides ICRA/PCRA training courses. It offers courses to Architects, Engineers, Contractors, IAQ, Legal, CIH, IICRC, HVAC, including CM, PM personal. This group specifically relates to healthcare and best practices for construction of medical buildings. Some other institutions provide educational programs for healthcare infection control during construction activities.

INFECTION CONTROL PROCEDURES

The Infection control risk assessment method has the following key points for construction activities undergoing around the hospital area:

- Ensure patient safety
- Personal protective equipment
- Containment barriers
- Dust and debris control
- Anteroom construction
- Containment of infectious agents.

As noted by the AIA (2006):

"An ICRA is multidisciplinary, organizational, documented process that after considering the facility's patient population and program, which is focusing on reduction of risk from infection; Acts through phases of facilities planning, design, construction, renovation, facility maintenance, and coordinates and weighs knowledge about infection, infectious agents, and care environment, permitting the organization to anticipate potential impact"

The ICRA matrix is a published assessment method that is widely accepted by engineers and architects, and is one effective method for completing an ICRA. Although the ICRA does not have to be done as a matrix, it does help non-clinical staff understand management of patient groups without requiring specific diagnoses.

Each facility should categorize patients per group within a specific patient population. The development of the "patient risk groups" is quite relative--and the criteria are dependent on the facility's mix of patients. Nursing homes and ambulatory care delivery sites have very different populations, and risk is relative."

The key point is to stop the movement of fungi from the construction area to the ward areas for the at risk patients.

PREVIOUS STUDY

The study by Villafruela, Castroa, San Joséa, and Saint-Martinba (2012) entitled "*Comparison of air change efficiency, contaminant removal effectiveness and infection risk as IAQ indices in isolation rooms*" simulated a hospital building and focused on the risk of spreading infections from the ventilation system into the hospital building. As the nosocomial infection related morbidity and mortality is increasing and ventilation related transmission becoming a main factor of spreading infectious diseases, this research team was trying to find the correlations between the configuration of the air diffusers and the infection risk. This paper reviewed different methods and technologies in the previous studies of this problem, but because of the high expense in supporting the technology or ineffective results from the prior research study, more economy and feasible research was required to provide a more effective design of a ventilation system to help reduce this infection risk. Therefore, the main objective of this study is analysis the influence of the position of air inlets and outlets to compare the different configuration quantitatively. In this study, the research team is using a Computational Fluid Dynamics (CFD) tool for predicting the movement of the air in ventilated spaces. This study used CFD to design a ventilation systems of a simulated room in a hospital building, and the validation was based on the comparison to experimental data obtained by means of photo-acoustics spectrometry.

Three types of indices are applied to the designed ventilation system, the first one is quantifying the capacity to renew the air, second one is quantifying the capacity to remove a contaminant, and the third one is quantifying the risk of airborne infection. In

this study, the three sufficiently general indexes are used to judge the performance of a ventilation system quantitatively; they are air change efficiency and local air change index, contaminant removal effectiveness and local air quality, and infection risk. The data obtained was reviewed using a mathematical model. In the experiment, the team used three different diffusers (grille, square, swirl), and the team measured the air change efficiency ε_a^p, the infection risk $P_{I_{100}}$, and the contaminant removal effectiveness ε_{ca}^p, including one group that both considering deposition on the walls and the viability of micro-organisms ε_{cc}, and the other group only consider the deposition on the walls ε_{cb}, and the last group considered either of them ε_{cb}. Therefore the differences of these three group data can show the relations between different depositions and micro-organisms. Figure 2 shows a diagram of the model ventilation system used in their research work. The real issue here is the supply pointing directly onto the patients bed, with a dust fall rate in the typical range the ventilation arrangement is not ideal.

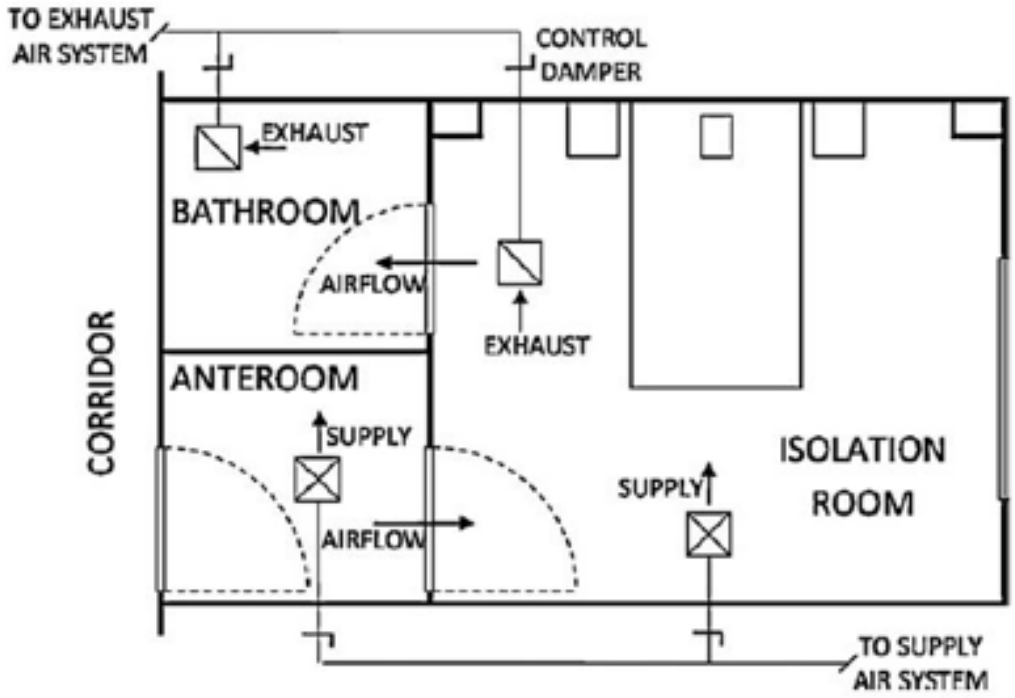

Figure 2. Diagram of the ventilation system

Table 3 shows the values of the global indices with the grille diffuser.

Table 3.

Values of the global indices for the case with grille diffusers

No.	I/O	ε_a^p	ε_{ca}	% deposition	ε_{cb}	% dead	ε_{cc}	P_{I100}
1	I13_O79	0.62	1.81	1.9	1.82	46.8	1.96	19.46%
2	I13_O8	0.58	8.99	1.7	9.10	42.0	9.40	2.77%
3	I13_Olow	0.48	0.62	2.0	0.61	48.1	0.71	43.68%
4	I13_Oup	0.57	0.93	2.2	0.93	47.6	1.03	33.72%
5	I2_O8	0.55	8.23	1.2	8.31	42.8	8.62	3.39%
6	I2_Olow	0.44	0.58	2.0	0.57	48.5	0.68	42.87%
7	I2_Oup	0.55	1.46	2.1	1.47	47.2	1.57	24.06%
8	I5_Olow	0.38	0.60	3.3	0.59	49.2	0.69	45.39%
9	I5_Oup	0.48	0.68	2.4	0.68	48.5	0.77	41.68%
10	I79_Olow	0.35	0.75	2.7	0.75	49.1	0.84	37.91%
11	I79_Oup	0.46	2.33	1.9	2.35	46.4	2.59	12.85%
12	Ilow_Oup	0.61	2.13	1.1	2.13	45.9	2.20	14.81%
13	Iup_Olow	0.54	0.44	2.6	0.44	47.6	0.76	38.45%

Table 4 shows the values of the local indices in three locations for the 13 cases with diffusers.

Table 4.

Values of the local indices in three locations for the 13 cases with diffusers

Case		V_{window}			V_{door}			V_{front}		
No.	I/O	ε_a^p	ε_{ca}^p	P_{I100}	ε_a^p	ε_{ca}^p	P_{I100}	ε_a^p	ε_{ca}^p	P_{I100}
1	I13_O79	0.55	2.20	1.95%	1.01	1.869	2.36%	1.35	2.541	1.70%
2	I13_O8	0.54	40.81	0.09%	1.00	22.04	0.18%	1.54	47.14	0.08%
3	I13_Olow	0.50	0.73	5.20%	0.93	0.635	5.95%	1.11	0.76	4.95%
4	I13_Oup	0.53	1.38	2.95%	0.96	1.068	3.86%	1.27	0.90	4.59%
5	I2_O8	0.49	20.03	0.20%	1.12	17.85	0.23%	0.97	18.05	0.22%
6	I2_Olow	0.40	0.96	3.63%	0.75	0.46	7.90%	0.76	0.40	8.88%
7	I2_Oup	0.48	1.89	2.27%	0.95	1.72	2.55%	0.94	1.76	2.45%
8	I5_Olow	0.34	0.59	6.20%	0.64	0.58	6.37%	0.71	0.43	8.72%
9	I5_Oup	0.46	0.76	5.04%	0.85	0.77	4.98%	0.86	0.60	6.47%
10	I79_Olow	0.40	0.74	5.27%	1.07	1.34	2.96%	0.74	0.99	3.89%
11	I79_Oup	0.57	5.12	0.72%	1.26	2.08	1.94%	0.89	4.77	0.77%
12	Ilow_Oup	0.48	2.04	1.93%	1.15	3.34	1.20%	1.31	2.75	1.48%
13	Iup_Olow	0.52	0.80	2.85%	1.05	0.46	4.95%	0.98	0.35	6.49%

This study data in Table 3 shows:

1. the best air change efficiency group no.1 and 12 had the air flow completely sweeping the room upon entry

2. the best contaminant removal group no. 2 and no. 5 indicated that the best way to remove contaminant is to set the air inlets in the ceiling in front of bed and the air outlet in the ceiling precisely above the patient
3. there's no significant relation between deposition of particles and contaminant change efficiency,
4. the difference between ε_{cb}, and ε_{cc}, is also very small. So there's only a relation between infection risk and contaminant removal effectiveness, ε_{cc}

The study data in *Table 4 sho*ws:

5. the researcher concluded that the relation between the local air change efficiency ε_{ca} and infection risk is significant
6. In addition, there is significant difference of infection risk from different configuration of air inlets and outlets.
7. Besides, comparing three different diffusers, there's big difference in the performance of the different configurations.

It is not enough only to consider air change efficiency to evaluate the effectiveness of the protection system for nosocomial infections, the study demonstrated that the position of air inlets and outlets, contaminant removal effectiveness, viability of the pathogens or exposure time, ε_{ct}, are related in a complex system, all of the variables can provide useful information to evaluate the effectiveness of ventilation system.

Boff, Brun, Miron, Zoppas, and Pasqualotto (2012) note that while environment air monitoring is a common practice in research institutions, not enough attention is paid to the temperature of incubation, and most of the study used room temperature, typically 20 degrees Celsius for research. This research team compared different incubation temperature on pathogenic fungi, especially *Aspergillus* species that has serious influence on the nosocomial infections. The study conducted in a Brazil hospital started in September 2010, using Andersen N-6 air sampler in ICU and hematopoietic stem cell transplantation units. Two different temperatures were used in the experiment (25 and 35-40 degrees Celsius) with observation of the fungal growth for 7 days, and using the classical mycology method to identifying the genus level.

Yeasts and mould used in the experiment all belong to *Aspergillus genus*, and environment fungi included species of cladosporium, penicillium, and trichoderma, dematiaceous fungi and sterile filamentous fungi. The quantitative results were obtained by dividing the total number of fungal colonies as shown on Figure 3.

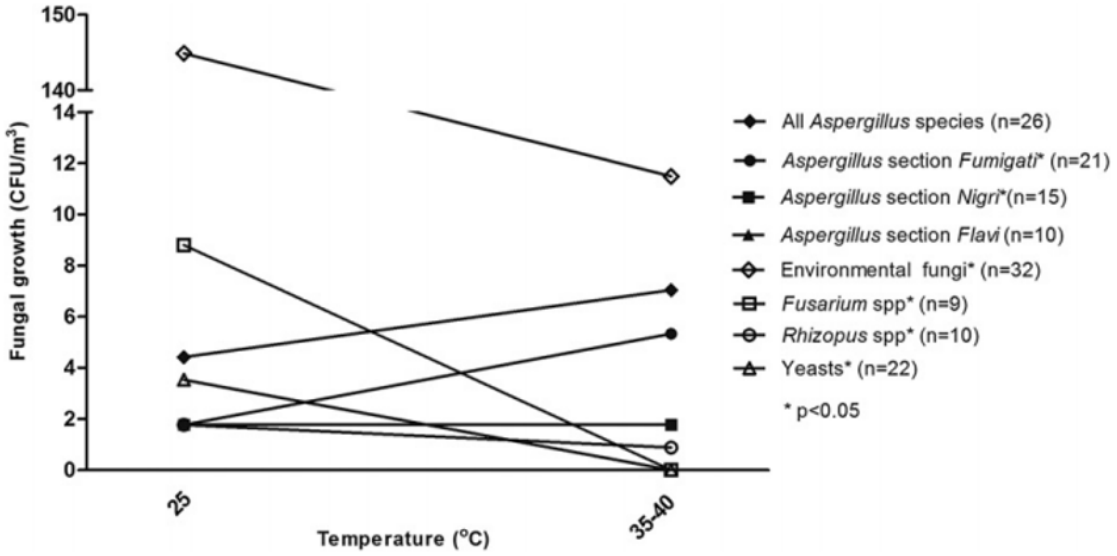

Figure 3. Fungal growth at different incubation temperatures

This study shows that *Aspergillus* section *Fumigate* grows more quickly at the incubation of 35-40C, rather than in the 25C. However not all the *Aspergillus* species are affected by temperature, *Aspergillus* section *Flavi* was not influenced by incubation temperature. Therefore, at 25C a hospital could potentially reduce the presence of *Aspergillus* section *Fumigati*, which may help control the spread of *Aspergillus* related disease in hospital.

SUMMARY

Hospital acquired infections are a problem for all people; they kill many and increase the cost of hospitals for all. The work by Boff et al. (2012) clearly points to the

computation fluid dynamics problem as the key element to understanding this problem and working towards a system that reduces the rate and number of infections.

CHAPTER III

METHODOLOGY

INTRODUCTION

The purpose of this experiment is to facilitate healthcare construction in developing a more effective barrier or inspiring new techniques to protect patient with compromised immune system and therefore reducing the risk of one of the most common nosocomial infections - *Aspergillus* infection. This experimental work is based on the previous study methods that had been used in the study entitled "*Comparison Test for Infection Control Barriers for Construction In Healthcare*" (Bassett, 2013).

The concept of this experiment is to simulate a construction site area and a hospital area with a barrier between them to testing the particle pass through. The goal of the previous research was -"*being tested is the typical plastic sheeting barrier method commonly used in hospitals during construction. The purpose is to determine how well this sheeting system upholds and maintains its barrier, and how many particles are actually transmitted through the barrier* (Bassett, 2013).

This chapter will detail the existing equipment and the changes made to the study chamber. The methodology is:

- Summarize the design of the existing equipment
- Detail the design and construction of the new wooden barrier with an opening
- Data collection
- Analysis methods

ORIGINAL EXPERIMENTAL EQUIPMENT

The original chamber used for the testing of the barriers was developed by (Bassett, 2013) who looked at the movement of dust particles through a plastic barrier sheet taped down with blue painters tape. Figure 4 shows the general arrangement.

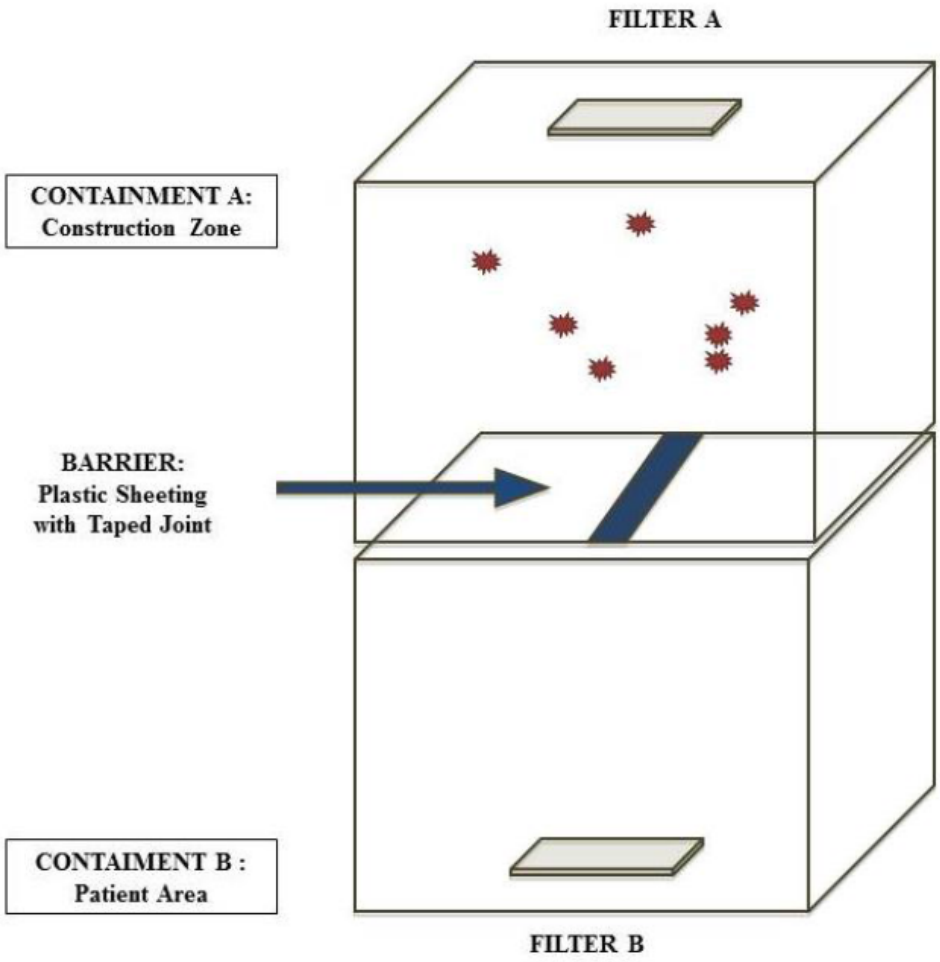

Figure 4. Containment vessel design

The rather simple plastic barrier stopped all dust movement, which was not expected due to the poor quality of the tape. Figure 5 shows the lower half of the test chamber with the plastic barrier installed.

Figure 5. Taped and sealed plastic sheeting

This experimental work will replace the plastic barrier with a simple wooden wall with a door installed in the wall. As shown in the figure above, the previous equipment is made of two-separated wood boxes with dimensions 267 mm by 304 mm by 457 mm. The chamber was constructed at woodshop of Architecture school in Texas A&M University. One of the chambers represents the hospital area, and the other represents the construction site area.

For the infection control barrier material, plastic sheeting was used with a thickness of 25.4 microns. Painters tape was also used for bond the overlap of the plastic sheeting, and fix the plastic barrier in between the two simulated boxes to simulate the infection control barrier.

The purpose of this experiment is to provide a positive air flow from upper Containment A to the lower Containment B. This allows for a measurement of particles that may have successfully passed through the barrier. An air pressure system was designed for each side of the containment vessel. A positive air pressure system is placed into the top of Containment A, where the dust will be located. This system forces air into Containment A.

Figure 6 shows a MicroGard MGA7635 air filter is inserted into the top of Containment A. Haberl (2013) suggested the use of the automotive air filters to Bassett. She selected a filter that would lay flat on the base of the lower containment vessel to maximize the chances of trapping any particulate matter that passes the barrier.

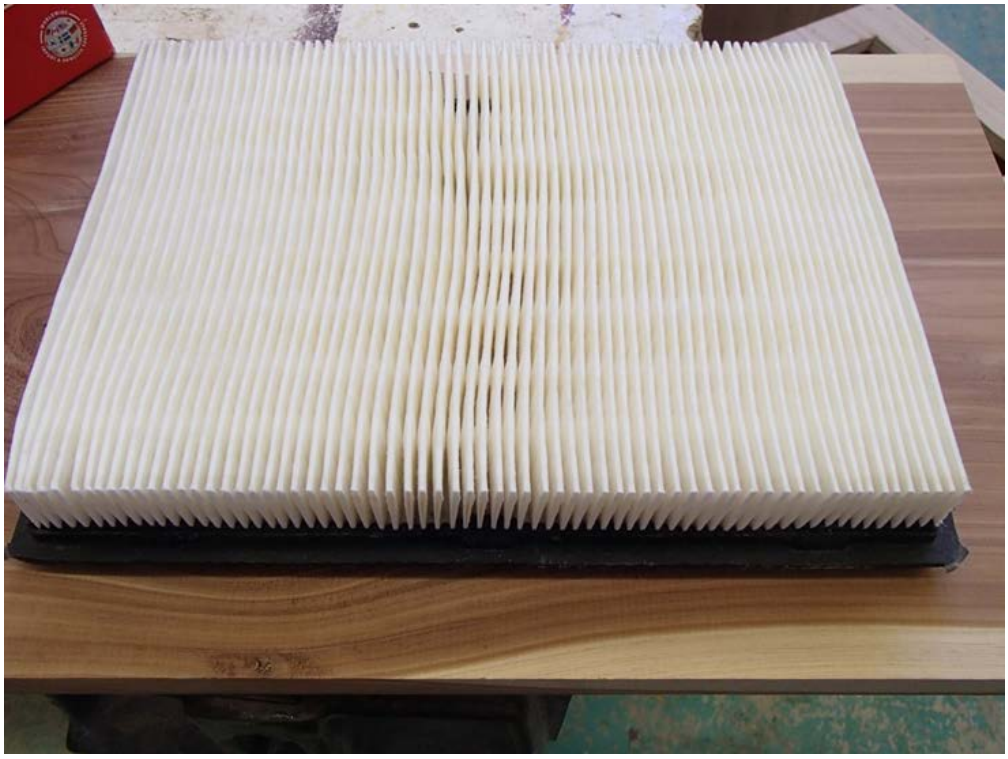

Figure 6. MicroGard MGA7635 Air Filter

This filter is lined with a rubber gasket to provide a tight seal for eliminating leakage of air. The dimensions of the filter, 248 mm by 178 mm, were cut from one face of the containment chamber A. The filter could then be tightly fit into the top of the containment chamber.

An air pressure-regulating valve controls the flow of air pushed through the filter into the containment chamber A and into the barrier to mimic airflow of a construction zone.

Containment chamber B has a filter located on the bottom face to determine the particulate matter that passed the barrier during the test. This filter would catch and trap particles that may be coming through the wall test section. The dimensions of the filter, 248 mm by 178 mm, were cut out of one face of containment chamber B. The filter could then be tightly fit into the experimental chambers.

The conceptual idea for the containment vessel is to introduce an overpressure of 105 kilo Pascals into the chamber A and measure the materials that pass through the barrier and fall onto the lower filter in chamber B. The arrangement is a vertical arrangement so that a particle that passes through the barrier should fall onto the base, which is filtered using a Microgard filter.

Figure 7 shows the pressure gauge used to measure the inlet pressure of the incoming air.

Figure 7 Pressure gauge

DESIGN OF THE WOOD BARRIER WITH AN OPENING

The simulated infection control barrier that has been used in between "construction area" and "hospital area" was originally plastic with no openings. A new barrier was constructed with a mock door covering five percent of the surface area of the wall.

A flat sheet of wood was selected for making the barrier in between the two containments. This material has to be not too thick for practical consideration, but stiff

enough to withstand the air pressure and the construction of the door. Figure 8 shows the wooden sheet selected to make the barrier.

Figure 8. Selecting the wood

Figure 9. Measuring the size of the barrier to fit in

The wood sheet is made as the same size as the flange between two boxes, which is 381 mm by 381 mm and square. Figure 10 shows the cutting of the wooden barrier.

Figure 10. Making the wood barrier

The door takes up 5% of the total barrier area. Since the total area of the barrier would be 145 by 161 mm, by calculation the door size would roughly be 6 mm by 6 mm and square. Figure 11 shows the opening constructed for the doorway.

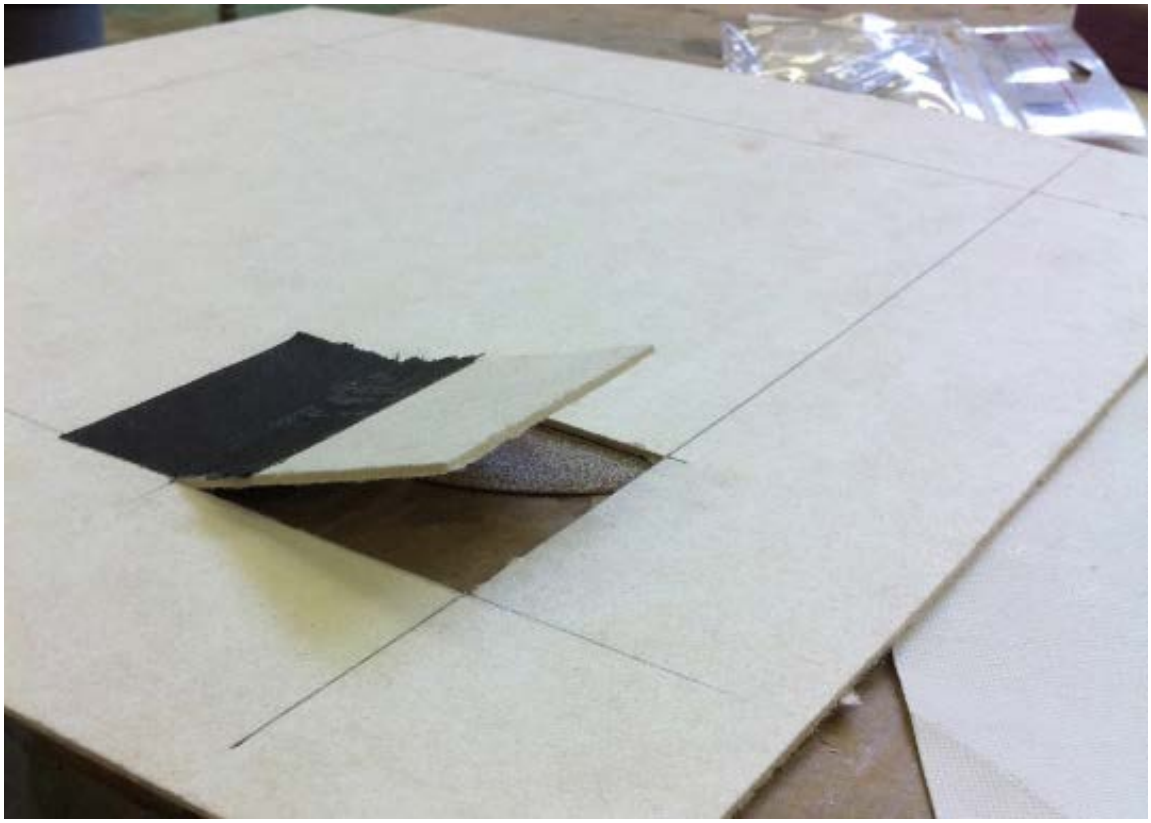

Figure 11. Making the “opening”

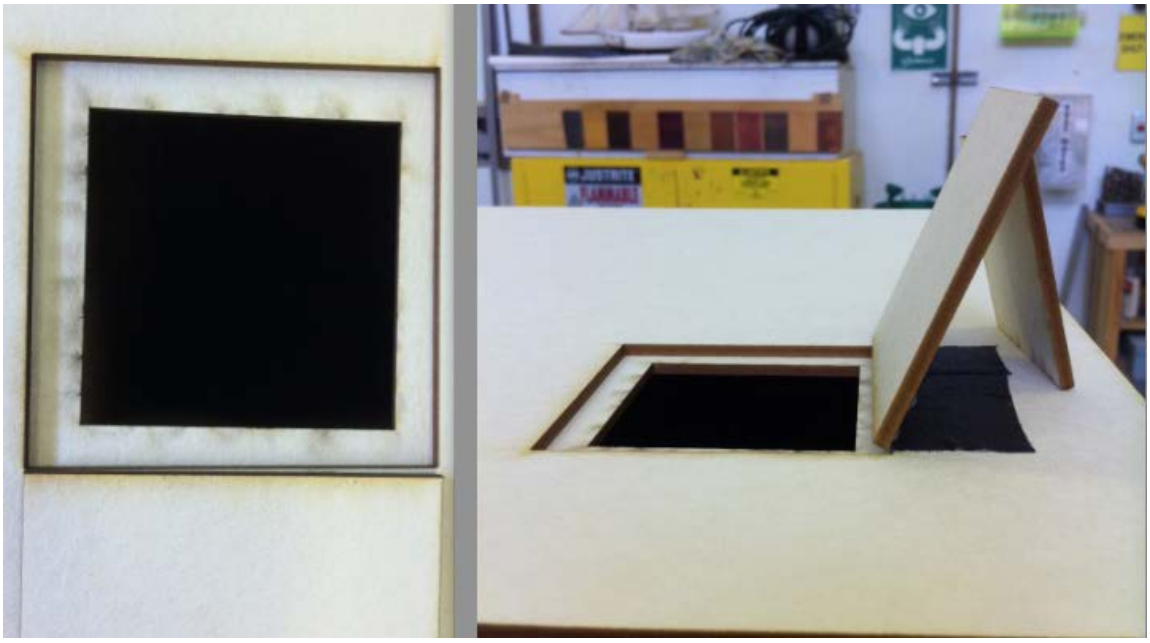

Figure 12. Making the doorframe and operating the door

A doorframe is made by cutting the same type of plywood at size of 7 mm by 7 mm, once the doorframe is set onto the wall. Black tape is used to add the “door” to the wall. A lifting wire was manufactured to make sure the door is fully closed during the experiment or open as required in the experimental protocol.

Figure 13 shows the base material used to make the door closing wire arrangement. A looped wire was heated and then stretched to form a straight thick wire able to apply the necessary load and not bend. Figure 14 shows the wire straightening and cooling.

Figure 13. Materials used to make the door closer

Figure 14. Straightening the iron wire and cool it down

After the door is ready, the iron wire to control the door open and close during the experiment is installed in the containment vessel A, as shown on Figure 15.

Figure 15. Complete work of door on the barrier

OTHER ADJUSTMENT TO THE EQUIPMENT

After the door is constructed on the barrier, a change was made to the top of the box to provide an access point to add powder during the tests. A plastic outlet was added on the construction box to fix a powder tunnel for, which can add the powder at any time during the test. This plastic tunnel has been fixed into the hole drilled on the top of the test vessel. Figure 16 shows the powder funnel prior to construction.

Figure 16. Powder funnel

Figure 17 shows the construction of the hole in the top lid of containment chamber A. The dust vessel is not in the same relative corner as the door to avoid dust short circuiting the system.

Figure 17. Drill a hole to fit the funnel on the top of box

Figure 18 shows the tools used to assemble the two chambers.

Figure 18. Material used to fixing the wood box together

Figure 19 shows the filter used in the test arrangement.

Figure 19. Filters used in the test

Four filters will be used through the whole experiment, two for each experiment (one for the top construction simulated box and the other for the bottom hospital simulated box). The top filter was used for all experiments.

The powder used by Bassett (2013) was noted by the manufacturer as being essentially cornstarch. Vitha (2013) noted the diameter at about 12 micrometres as shown on picture of a filter contaminated deliberately by Vitha with the powder. Figure 20 shows the filter contaminated with corn starch by Vitha from the study by Bassett (2013).

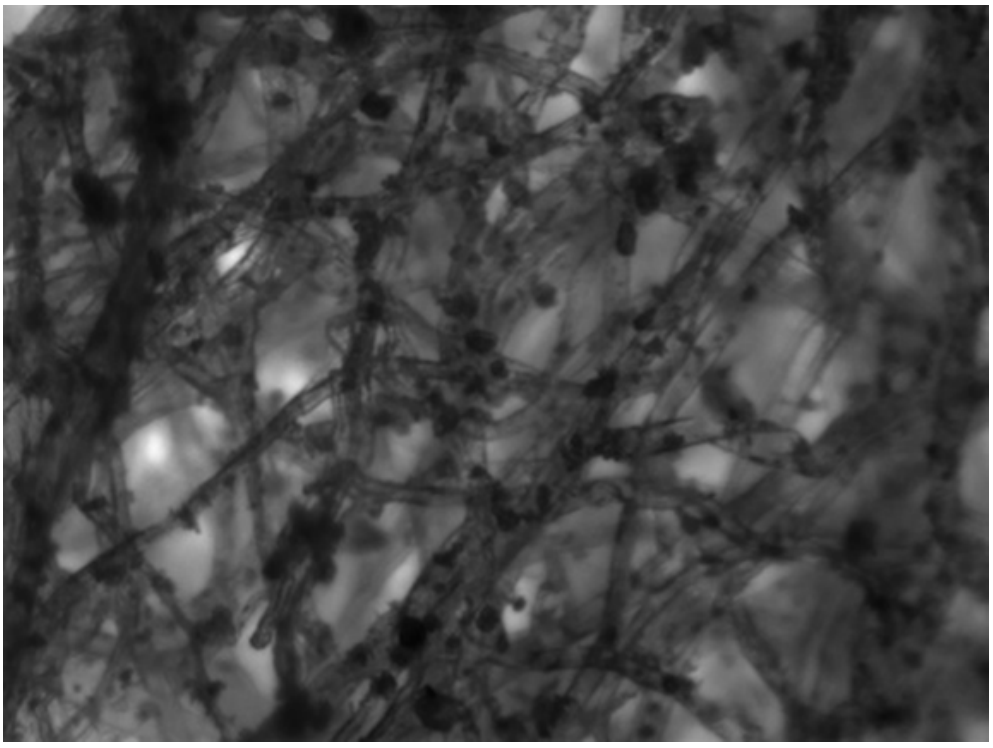

Figure 20 Picture of filter contaminated with cornstarch

Cornstarch has a grain size distribution in the range of 1 to 27 microns from recent work completed by Paterson, Hardacre, Li, & Rao (2001) on cornstarch from Australian and New Zealand. Figure 21 shows the distribution of diameters measured by these researchers.

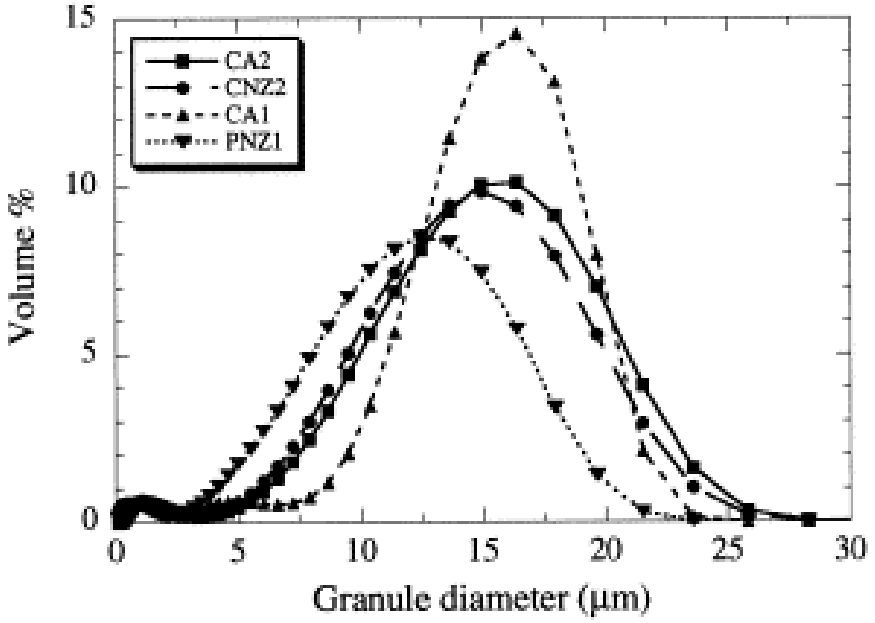

Figure 21 Cornstarch size distribution after (Paterson et al., 2001)

A sample of the powder from the same manufacturer was obtained for this set of experiments. The MDS data shows that the manufacturer has substituted talc powder for the corn starch used in the earlier powder. The reason for the change is not known.

Figure 22 shows the powder.

Figure 22. Talc Powder used in the experimental work

Three samples of Talc dust were tested by the EPA for particle size distribution. Figure 23 shows the results of the EPA analysis at three stages of manufacture, crushing, grinding and bagged. The difference in the mean size is evident in the graph. The mean size in the bagged sample is 2 to 10 micrometres (U.S. Environmental Protection Agency, 2009).

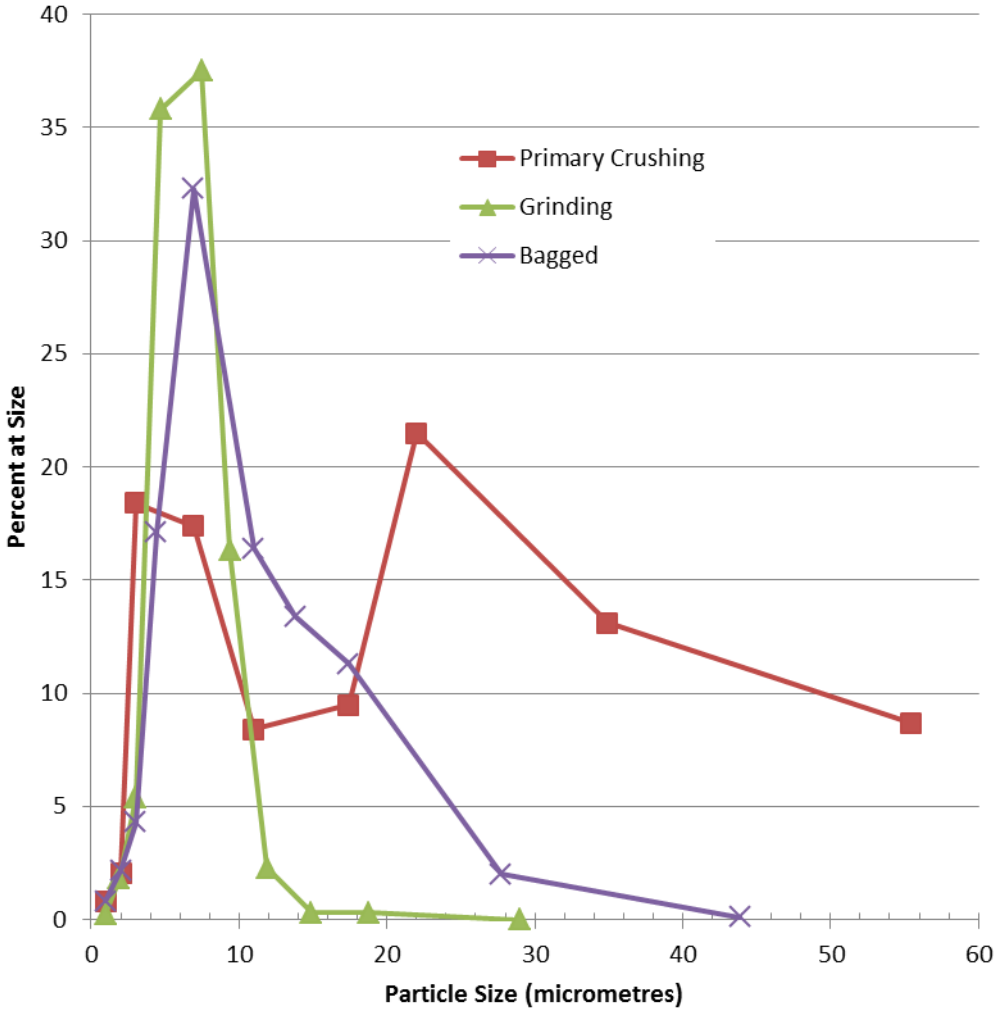

Figure 23. Talc Powder - particle size distribution

The two materials have a similar mean particle size as would be expected given the use of the materials. The corn starch has a more uniform distribution.

Figure 24 shows the two chambers assembled in the final configuration. On the top of the chamber A the powder tunnel and one iron wire control stick for the door are visible. The opening for the air inlet is shown in the center of the picture.

Figure 24. Equipment assembled

Figure 25 shows the base of Chamber B after assembly and installation of the lower filter. Two beams of wood are placed under the whole assembly to keep it off the ground so the dust from the ground will not be affects the result of the test.

Figure 25. Chamber B base view after assembly

MATERIALS LIST AND COMMENTS ON THE SELECTION

All the materials for the test equipment were sourced locally. Table 5 lists the materials and the equipment used during the tests and the construction work related to the openings on the plywood barrier.

Table 5.

Material and equipment list

Materials used in Experiment		Equipment used in Experiment	
Material	Comment	Tool	Comment
Plywood	9 mm oak (barrier)	Table Saw	Trim cut plywood
C-clamp	4 on each corner to fix the containment	Electrical scale	Measure 0.1g powder
Nails	Bostitch Air gun	Drill Press	Drill holes for minor fittings
Tape	Fix the door on the barrier	Air Pressure Regulating Valve	Supply air at 105 kPa
Powder	Talc Powder	C-clamp	Fix on the corner

Figure 26 shows the equipment used during the experimental work. Figure 27 shows the air filter used for the experiments.

Figure 26. Material used

Figure 27. Air filter shown in a flexed position

TEST PROCEDURE

Introduction

The test procedure is similar to the procedure used by Bassett (2013) when testing a fully sealed barrier. Three tests of the door system are used. The tests are numbered Test 1 to Test 3. This section outlines the test procedures. The test procedures are controlled by the access requirements for the woodshop which is only open from 8 am until 5 pm on work days.

Procedure Test Number 1

Test procedure for test number 1 is:

1. Clean two containment chambers thoroughly in order to remove the original dust exist in the containment that could effect on the final result to the test
2. Fix the two containments together with the barrier (that has the door on it) in between by using a set of C-clamps, and check the control bar works Figure 28 shows the two chambers clamped together
3. Put the filters on the top and bottom of two containments as shown in Figure 29 and Figure 30
4. Cover the top filter with cover board with a hole to fit the air flow hose, and use nails to fix it tight as shown in Figure 31
5. Weigh out 1.0 g of powder and put the powder in the top containment through the powder tunnel as shown in Figure 32 and Figure 33
6. Fix the pressure gauge on the air hose and use a cable tie to keep the air hose on all the time, and adjust the air flow as shown in Figure 34

Figure 28. C-clamp in place to hold the chambers still

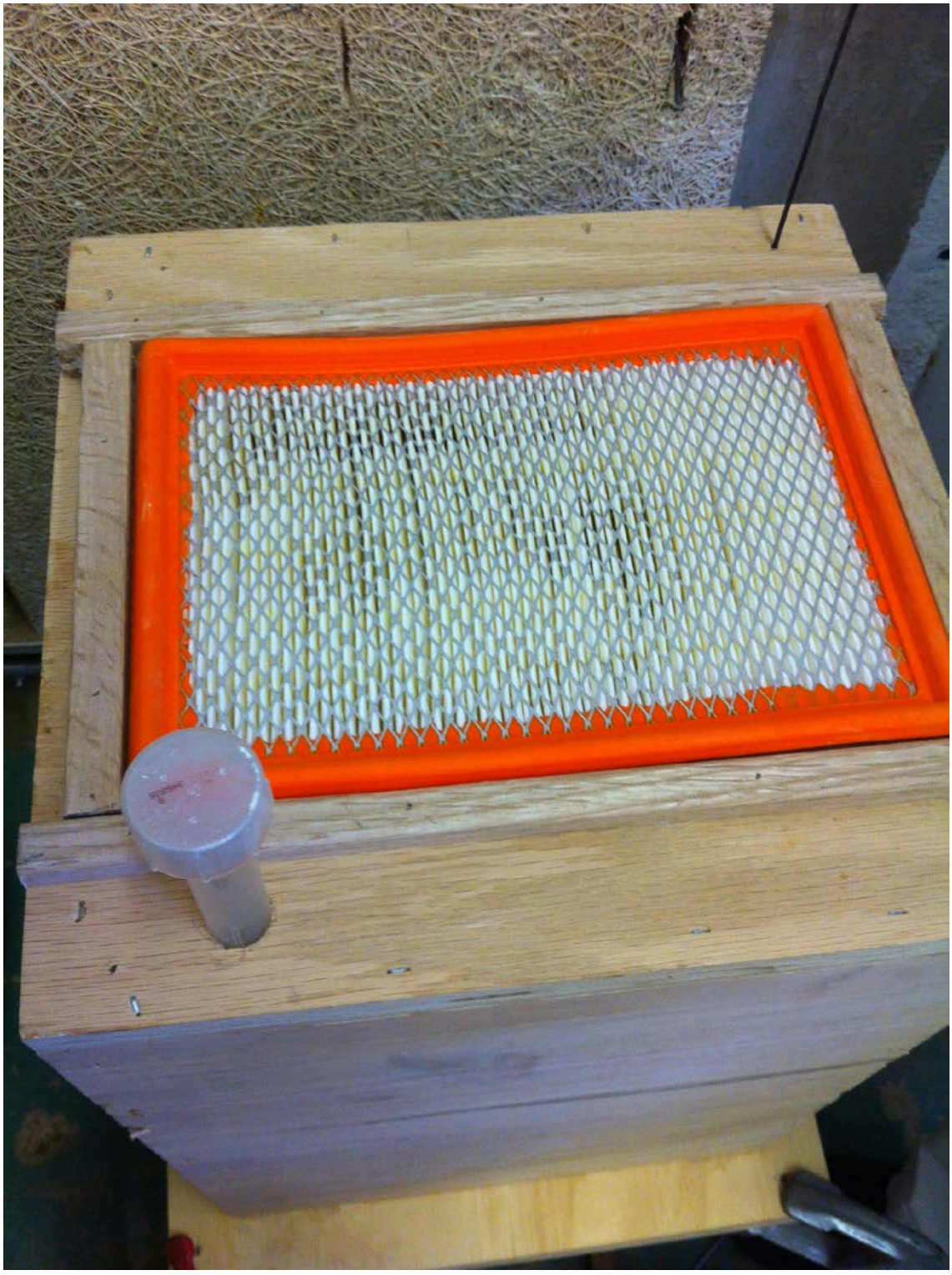

Figure 29. Top filter

Figure 30. Bottom filter

Figure 31. Fixing the cover board

Figure 32. Weigh 1.0 g powder – Sona 2007 Scale accuracy ± 0.05 grams

Figure 33. Using the powder tunnel to place the material

Figure 34. Air pressure gauge

7. Place the air supply into the top of the containment chamber A and run the test as shown in the Figure 35.

Figure 35. Test 1 Setup and in progress

The test containment vessel was placed in a quiet corner of the woodshop so it would not be disturbed during the test procedure.

Procedure Test Number 2 and 3

These two test procedures were the same as test procedure 1.

Test Protocol

The protocol for the three tests is summarized in Table 6.

Table 6.

Test Protocol for Three Tests

Description	Unit	Value
Duration Test 1	hours	72
Duration Test 2	hours	48
Duration Test 3	hours	24
Test 1 door	closed	
Test 2 door	opened	3 times in first 24 hours for 5 minutes each time
Test 3 door	opened	6 times in 24 hours with 3 minutes each time

DATA COLLECTION

Data collection uses the MicroGard filters.

ANALYSIS METHODS

A count of the particles per square metre will be made on the filters.

CHAPTER IV

RESULTS

INTRODUCTION

This chapter presents the results for the experimental work and the data analysis. The results are:

- Determination of the air exchange rate
- Test One Results
- Test Two Results
- Test Three Results
- Dust Settlement Rate Analysis
- Summary

AIR EXCHANGE RATE IN BOX

One of the key criteria for human health is an adequate supply of fresh air, this is usually expressed in air changes in a room in a certain period. A simple experiment was completed to determine the rate of supply of the air from the air vessel at the nominated supply pressure of 150 kilo Pascals. A plastic bag was used to measure the air flow rate from the air hose.

Table 7 summarizes the air flow determination rates for the test chamber.

Table 7.

Air Flow Rate Determination

Test Number	Volume Bag (L)	Time (second)	Rate of air (L/s)
1	240	210	1.1
2	240	240	1
Average	240		1.05

The volume of the test chamber A is determined from the inside dimensions 267 mm by 304 mm by 457 mm, which is 37.1 litres. The air exchange rate is 106 times per hour. The air flow rate is 1 litres/second, which given the area of the box provides an average air velocity of 12 millimetres per second.

The maximum allowable concentration of particulate matter is 150 micrograms per cubic metre of air in the USA (EPA). The total volume of air to pass through the test chamber in 24 hours is 86400 litres, which provides for a total of 0.013 grams of particulate matter at this concentration level. The supplied particulate matter is 1 gram or 77 times the legal amount.

BHP Billiton (2014) in preparing the environmental impact statement for Olympic Dam measured the dust concentrations in a rural environment at 10 micrograms per cubic metre. The BHP measurements are clean rural air and the EPA standard is the peak allowed in the USA.

A typical low velocity dust collection system to move breathable particles to the collection system requires a velocity of 9.2 metres per second to keep the fine particles in suspension.

RESULTS FOR TEST NUMBER 1

The first test is with the door closed. The test period was 72 hours. Figure 36 shows the bottom filter after three days of flow.

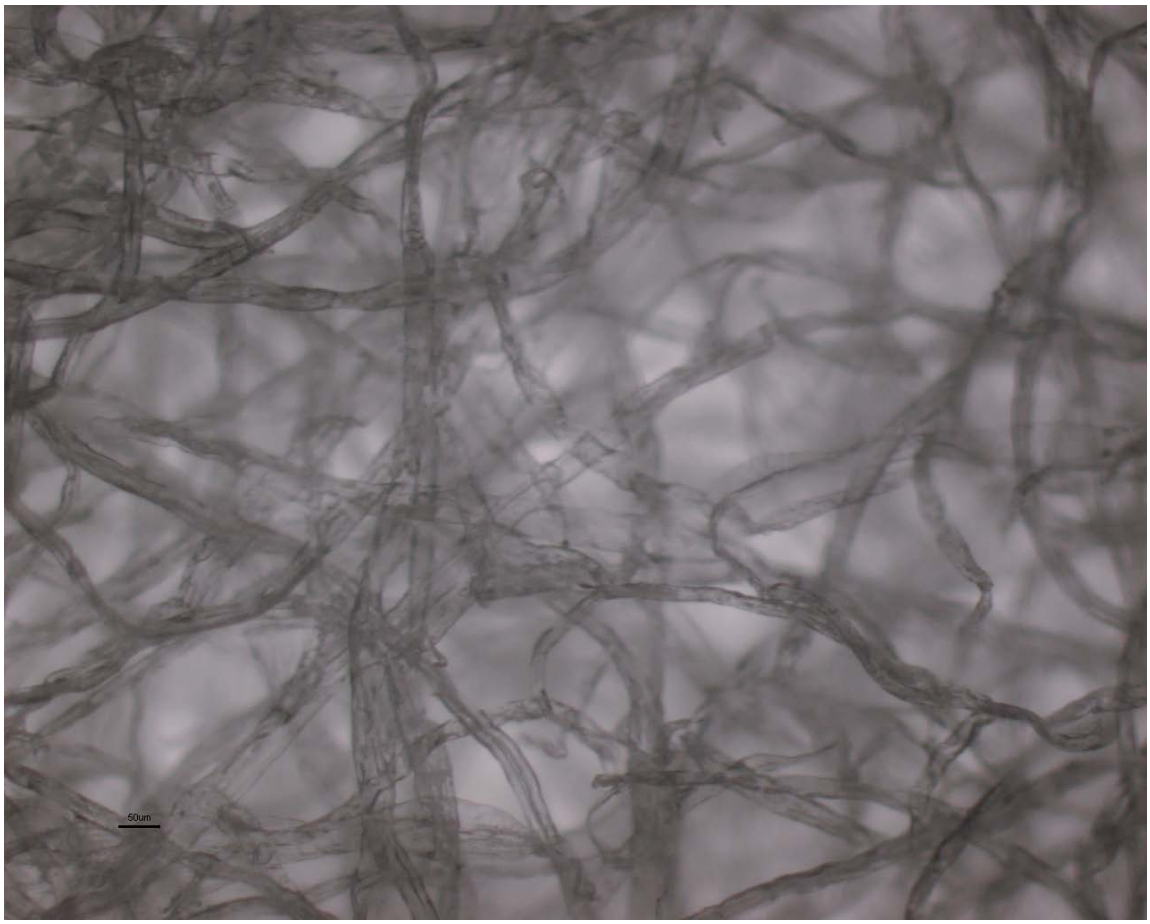

Figure 36. Test One - bottom filter optical microscope view – small scale

There are no visible particles on the filter. Figure 37 shows the filter at a higher magnification. There are no visible particles.

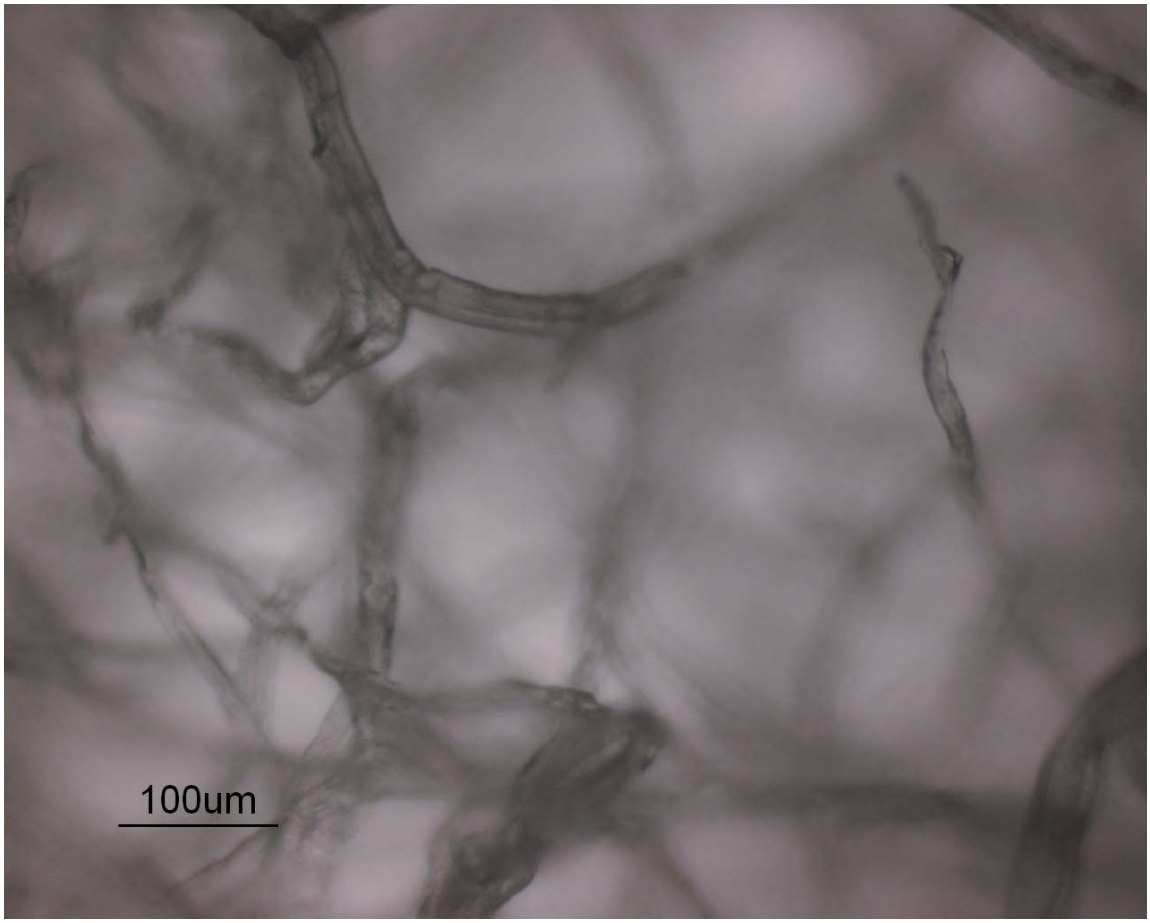

Figure 37. Test One - bottom filter optical microscope view – large scale

RESULTS FOR TEST NUMBER 2

The second test was for 48 hours, the door was opened a total of three times for a total period of 15 minutes. Figure 38 shows the second filter from the bottom of the test chamber using an optical microscope. No particles are visible.

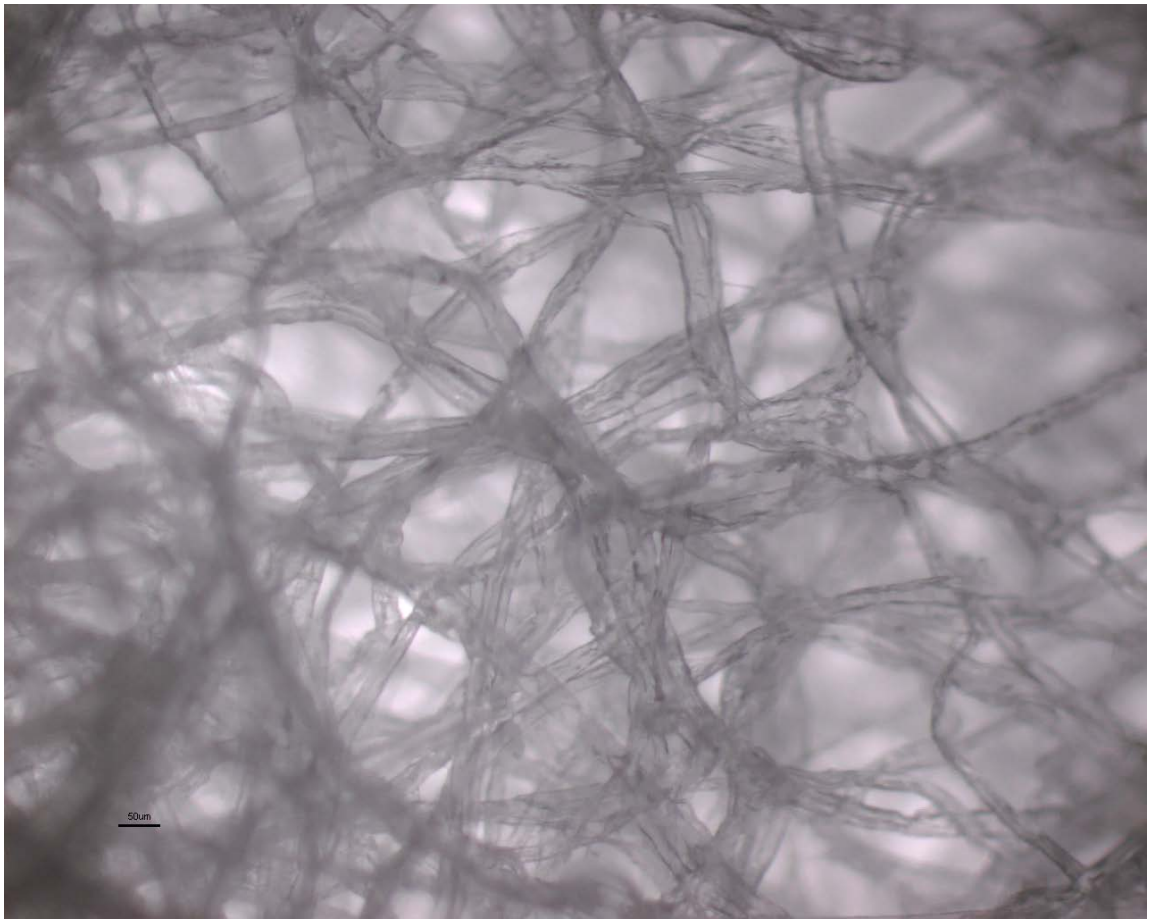

Figure 38. Test Two - bottom filter optical microscope view – small scale

Figure 39 shows the same filter at a higher magnification. No particles are visible.

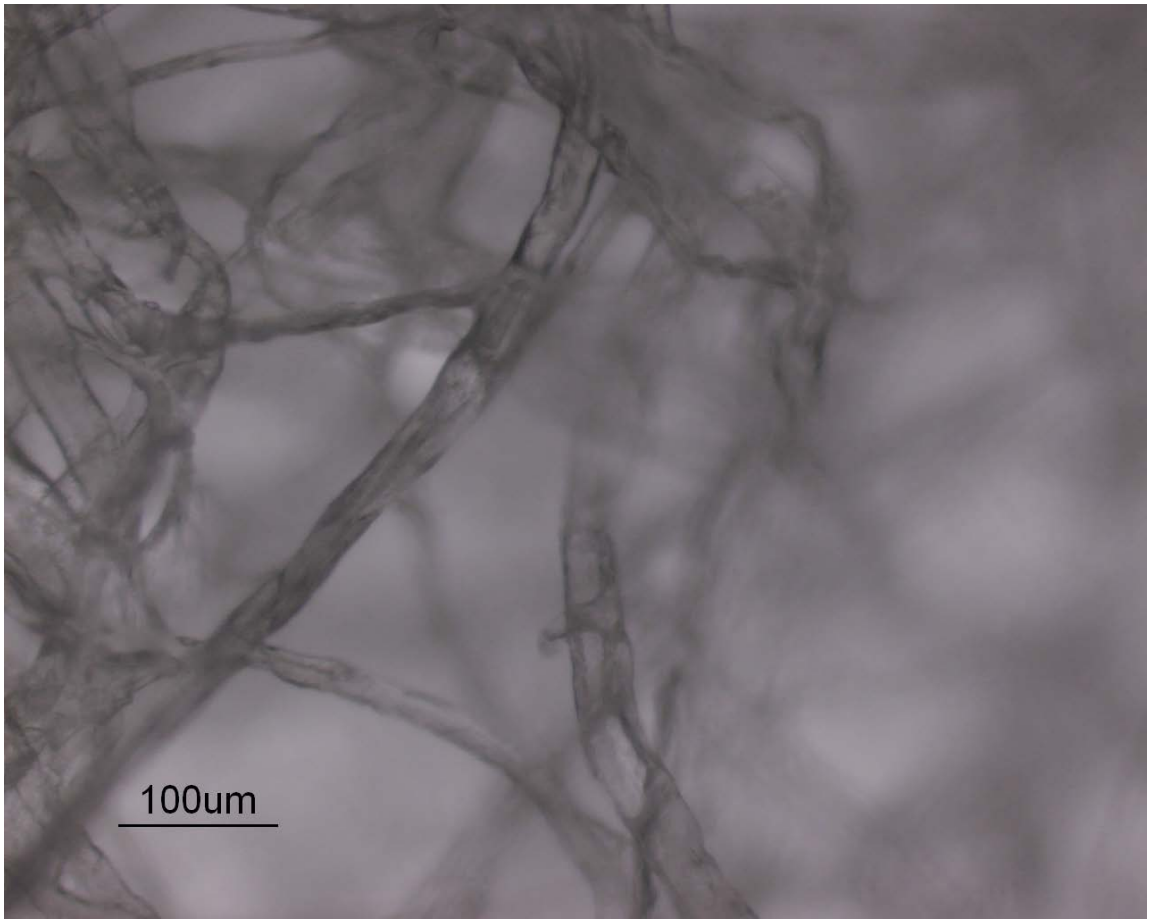

Figure 39. Test Two - bottom filter optical microscope view – large scale

RESULTS FOR TEST NUMBER 3

The third test is with the door open six times for a total of 18 minutes. The test period was 24 hours. Figure 40 shows the bottom filter after one day of flow. No dust is visible.

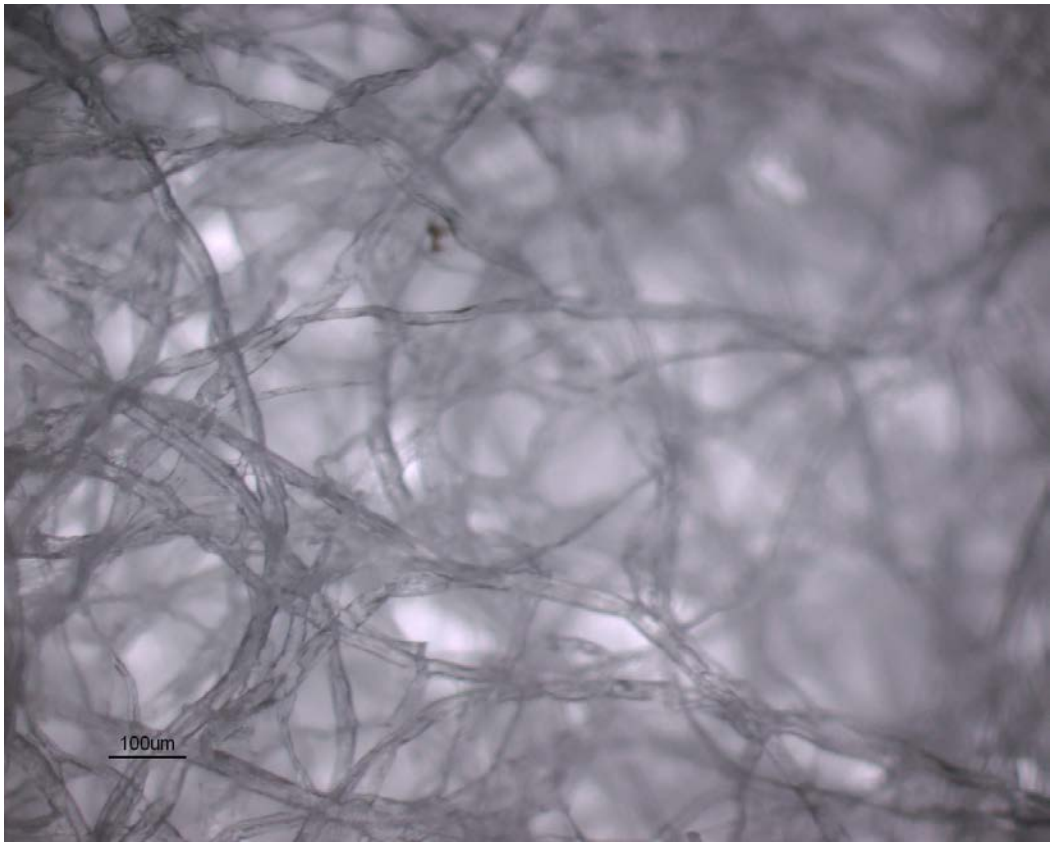

Figure 40. Test Three - bottom filter optical microscope view – small scale

Figure 41 shows the same filter at a higher magnification. No dust is visible.

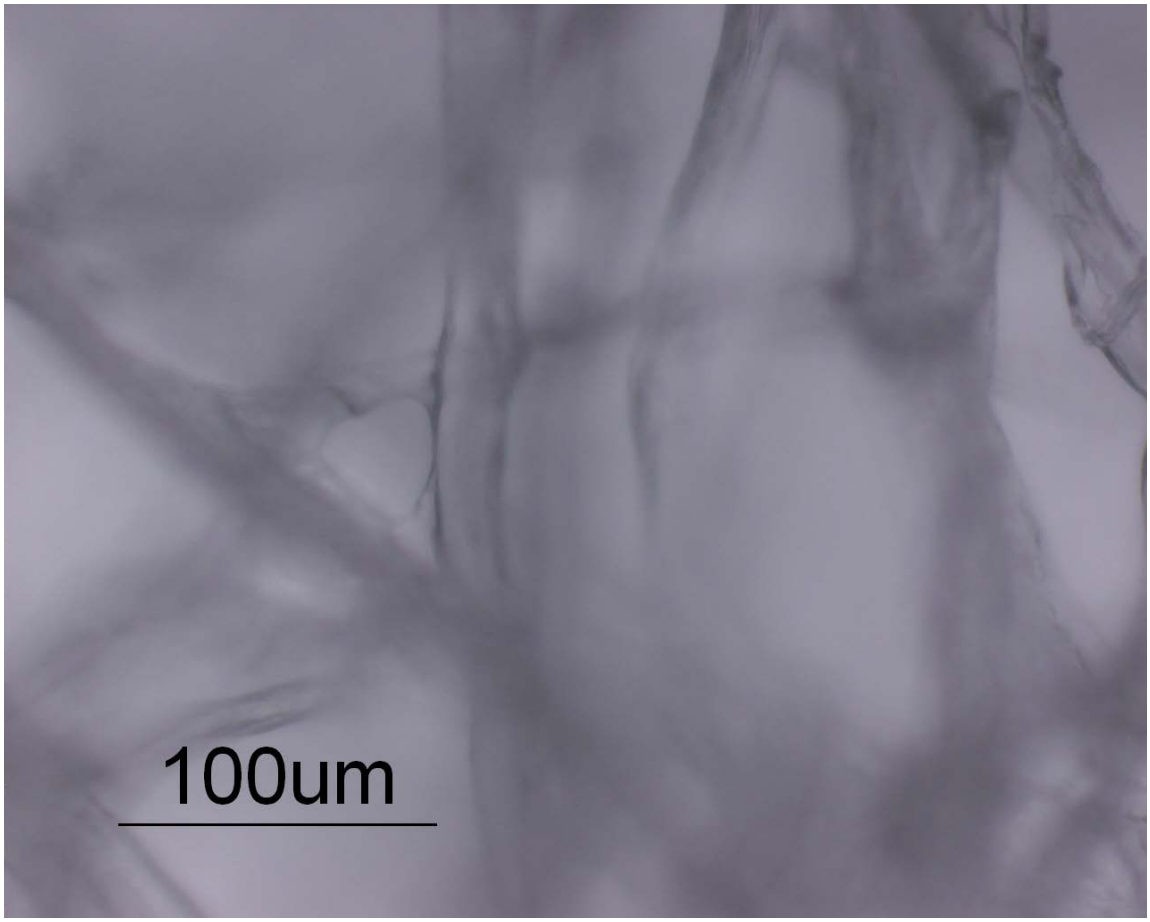

Figure 41. Test Three - bottom filter optical microscope view – large scale

SETTLEMENT RATE FOR DUST

Dust settles if suspended in air. The rate of settlement is controlled by Stokes Law. The applicable equation for settlement of particles in dry air is given in equation (1):

$$V = \frac{2r^2(\rho_s - \rho_a)g}{9\mu} \quad (1)$$

Where V is the velocity in m/s, r is the radius of the dust particle, g is 9.806 m/s. μ is the viscosity of the air, ρ_s is the density of the solid and ρ_a is the density of the air. A simple FORTRAN program was developed to determine the settling velocity for different sized talc particles in air using Stokes Law. The Reynolds number for the settlement of Talc powder in air was less than one, therefore the flow is laminar and Stokes law holds.

Figure 42 shows the settling velocity for the particle diameter range of 1 to 10 micrometres.

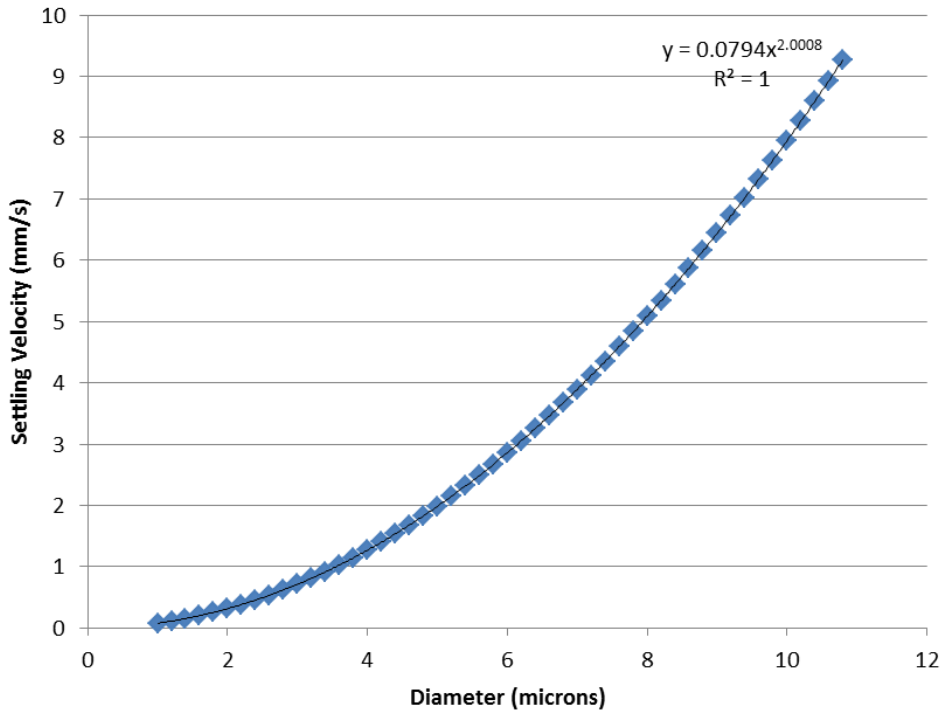

Figure 42. Stokes Law - Settling Velocities – Talc

SUMMARY

Spores are carried on dust particles. These spores can cause serious disease and death. This study has looked at the use of a test chamber to model the movement of dust through a construction wall. The results in this series of experiments show that under the standard operating conditions, no measureable dust passed through the door into the second chamber. There are different theories as to why this result is observed, but the two problems are the specific density and size of the particles is higher than naturally occurring particles and the dust movement is by air circulation alone.

CHAPTER V

CONCLUSIONS

This research expands our prior work to evaluate the effectiveness of a plastic barrier to limit the movement of dust from a construction zone next to or attached to a hospital to a clean hospital zone. Observational data suggests that increased risk of fungal disease, such as *Aspergillosis*, occurs with increased level of construction dust. The dust expected to be generated by construction is a heavy particulate matter, such as silica, gypsum or equivalent due to the nature of construction materials. The first study used a corn starch to model a dust particulate movement from a construction side to a clean side in a specially constructed chamber set. This first study found no dust movement.

This second study changed the barrier arrangement from a fully sealed plastic sheet to a wooden wall with a door representing five percent of the wall area. The door size was six millimetre square. An alternative dust material was used for this set of experiments, a talc powder. Three tests of the barrier system were made with the door in test 1 closed, in test 2, open for a total of 15 minutes in 48 hours and for test 3 the door was open for a total of 18 minutes in 24 hours. No dust was observed to move from the construction chamber to the clean chamber during the test.

An analysis of the settling velocities of the for the size and density of talc particles shows that the material will settle with a rate of 1 to 7 millimetres per second in still air. The Reynold's number for the dust settling in chamber is less than one, so the assumption of laminar flow conditions is reasonable. The air exchange rate for the

system is 106 times per hour, in excess of normal rates in a hospital setting. There appear to be a number of issues related to the experimental procedure and the results for this study. The first issue is the material used to represent the dust that moves the spores. The Talc powder may by denser than the typical house or hospital dust, although given the likely source of construction dust this would be an interesting result. The second issue is the lack of movement of the dust given the relative level of air movement.

The conclusion reached is that construction type dust is difficult to move in air systems typically used in hospitals. This conclusion points to two potential areas of future study, the composition of dust from hospital settings, the relative density and size of the dust generated in the adjacent hospital construction. The velocity of the air movement through the construction that leads to increased infection levels. Industry practice suggests a velocity of nine metres per second is required to keep particulate matter in suspension in air. This is a very high velocity for a ventilation system.

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