

COMPARISON TEST FOR INFECTION CONTROL BARRIERS FOR
CONSTRUCTION IN HEALTHCARE

A Thesis

by

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ABSTRACT

Understanding the extent of infection control measures to be taken to protect immunosuppressed and other types of patients from airborne infection agents during construction is crucial knowledge for both healthcare and construction professionals. The number of aspergillosis-related fatalities due to dust transmission during construction activity has decreased with the improvement of antifungal therapy, however the illness is particularly debilitating and the treatment is not always successful. This experimental work is the first stage in a research program to develop better dust controls for construction at existing medical facilities to reduce the incidence of dust borne fungi, such as *Aspergillus* spp.

To better protect at-risk patients from exposure to *Aspergillus* spp. and other airborne fungal infections, an experiment was conducted to determine what materials can be used to create a barrier for infection control to moderate particle transmission from the construction area to the treatment area. This study investigated the relationship between construction barriers and particle transmission. A new experimental procedure and equipment simulates the transmission of disturbed dust from construction activity across a barrier. The effective of the barrier is determined from measured particle count on filter. The results show that an effective barrier manufactured from simple and readily available building supplies stops the transmission of 12-micron dust particles under a standard set of conditions. The test provides a simple and cost effective method to compare transmission rates for dust.

DEDICATION

Thanks to my mother and father for their encouragement.

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NOMENCLATURE

- *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 occurs 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.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

The risk of nosocomial infections, or hospital acquired infections, to patients in hospital facilities has become an increasingly complex and challenging issue for the healthcare industry. As time goes on, the need for building expansion, construction, and renovation in outdated hospital structures and equipment is pressing, but one of the underlying concerns is that recent research has reported causal links between construction in health care facilities and increased infection rates. *“The U.S. National Nosocomial Infections Surveillance System released data that reveals that every year nearly 2 million patients in North America contract a nosocomial infection in a hospital and about 100,000 die as a result. Some of these infection outbreaks have been linked with hospital construction, renovation, and maintenance, which disturb mold spores and cause them to become airborne.”*(Malik, Arabzadeh, & Singh, 2008)

The theory is construction activities cause a disturbance of dust, mould, and other infectious particles, which are released into the local building atmosphere, contaminating the air and surrounding surfaces. This act of contamination is a threat to patients and has potential both to cause infections to those with serious illnesses and injuries and to people who fail to understand and follow infection control procedures (Schulster & Chinn, 2003). Schulster and Chinn provide a method based system to reduce infection

and “suggests a series of performance measurements as a means to evaluate infection-control efforts”.

For construction activities including expansion, new construction, and renovation to be put into action without compromising the health of the patients, new procedures and techniques are being implemented to better prevent environmental contamination and control infections. For new, innovative procedures to be successfully utilized, intense coordination, careful planning and diligent monitoring is required, coupled with the development of test procedures to monitor the movement of contaminated air from the construction site to the patient treatment areas. The contractor of the project plays an important role in infection control. Construction contractors are trusted to maintain a safe environment for patients and staff, yet also be efficient and functional. The procedure being tested in this study will provide a standard method to basic infection control. If construction activity is improperly contained, patients could be exposed to airborne contamination.

This research work derives from the requirements of the first major recommendation that of “*performing a risk assessment of the necessary types of construction barriers*”. A risk assessment provides a determination of quantitative or qualitative risk levels related to a defined situation and a recognized threat or defined hazard. A risk assessment works on a situation that can be termed concrete or set in place. A simple example of the procedures is summarized in the UKHSE document (Health and Safety Executive, 2002).

Construction-related nosocomial infections are preventable with the proper approaches but studies that provide specific, evidence-based information on best practices are lacking. This study will explore and determine specific infection control procedures that can reduce the transmission of construction-related infections.

PROBLEM STATEMENT

This study addresses research areas requiring improvement regarding the infiltration of dust containing *Aspergillus* during construction in healthcare facilities. Specifically, this study will measure the efficacy of barrier methods in the containment and reduction of airborne particulates similar in size to *Aspergillus* spp. spores.

RESEARCH OBJECTIVES

The primary research objective of this study is to determine the reliability of construction barriers utilized in healthcare facilities for patient protection.

HYPOTHESIS

A test of construction barrier walls using a differential pressure of 105 kilopascals can be developed that measures particulate matter at a size of 12 micrometres using a count per square millimetre on the output filter of the test system.

STUDY LIMITATIONS

This study is:

- restricted due to mock containments being constructed at the TAMU Architecture Ranch.

- self-designed and self-performed test, therefore there is room for error in the analysis.
- 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.

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 OF THE STUDY

This study seeks to understand how barrier methods can reduce particulates in air samples. Additionally this study seeks to understand how the decreasing number of aspergillosis-related fatalities spread by construction activity in healthcare facilities. As healthcare facilities age and renovations become more necessary, construction-related nosocomial infection and potential infection with *Aspergillus* becomes more of a risk. Despite the lack of increased death due to aspergillosis, *Aspergillus* remains a cause of

construction-related nosocomial infection in immunosuppressed patients. Through measureable tests it will be determined the barrier materials necessary for infection control to reduce the transmission of dust particles through walls during construction.

With proper design of infection control barriers it is proposed that the amount of dust particulates to pass through a wall can be minimized to close to zero. The expected benefits of this study could result in a decreased number of patients acquiring construction-related nosocomial infections. The results from this study will be public information and can help healthcare construction planning boards be more knowledgeable on the methods that are used prevent transmission of dust during construction.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

This literature review outlines the important role construction barriers play in protection of hospital patients with evidence-based supporting case studies. It specifically focuses on the danger of patient exposure to *Aspergillus*, commonly transmitted through dust disturbance. This paper analyzes the relationship between infection control and construction activities in healthcare facilities. Through research, data analysis and case studies, it is apparent that nosocomial infections, or hospital-acquired infections, during periods of construction in health care facilities are significantly decreased when proper control procedures are implemented. However, it is yet to be found which procedures are most successful. Research of this topic is cutting-edge and can provide critical new strategies in the world of healthcare.

CDC NOTES AND OTHER AGENCIES REQUIREMENTS

Attention to infection prevention during the construction process is becoming a factor of high consideration due to potential harm to patients (Riley, Freihaut, Bahnfleth, & Karapatyan, 2004). Agencies such as the AIA (American Institute of Architects Academy of Architecture for Health., 1997) and the CDC have set standards and requirements regarding construction-related infection control in order to prevent transmission of infectious organisms to at-risk patients, nurses, doctors, visitors and workers. State and federal governments then adopt these evidence-based standards as

their own regulations. The CDC estimates that every year more than two million nosocomial infections are acquired in U.S. hospitals, and that 88,000 of these patients die as a direct or indirect result. It is estimated that about 5,000 of these are related to ongoing construction practices within hospitals. These figures indicate that additional effort or improved methods are needed to keep immunosuppressed patients safe from construction projects. (Riley et al., 2004)

As noted by Riley et al., in 2004:

About \$10 billion a year is spent on healthcare facility construction in the US every year. Approximately 70% of the total amount is spent on renovation, and 30% is for new construction. More than ever, designers, architects, engineers, facility managers, and construction managers need to fully understand how renovations and construction projects can compromise the air quality of patients.

HEALTHCARE FACILITY GUIDELINES

Health care facilities' concerns (Sehulster & Chinn, 2003) are directly related to disease transmission by environmental pathogens (such as *Aspergillus* spp). Infection-control concerns are only heightened during construction, demolition, renovation, and repair of the facility. While health care workers and patients can contract diseases, this is especially true for immune-compromised patients. Methods of infection control during construction can provide better prevention of disease causing particle transmission and reduce infections as well as fatalities. These procedures include proper air ventilation systems, thorough disinfection of all surfaces, and ensuring water quality. An infection-

control risk assessment is encouraged before any construction activity begins that would disturb dust or water particles. This includes infection control procedures implemented to care for a disastrous event (e.g., floods, sewage break, electrical or ventilation problems, or a compromised water system). Schulster and Chinn (2003) noted:

“Infections caused by the microorganisms described in this guideline are rare events, and the effect of these recommendations on infection rates in a facility may not be readily measurable. Therefore, the following steps to measure performance are suggested to evaluate these recommendations:

- 1. Document whether infection-control personnel are actively involved in all phases of a health-care facility's demolition, construction, and renovation. Activities should include performing a risk assessment of the necessary types of construction barriers, and daily monitoring and documenting of the presence of negative airflow within the construction zone or renovation area.*
- 2. Monitor and document daily the negative airflow in ALL rooms and positive airflow in PE rooms, especially when patients are in these rooms.*
- 3. Perform assays at least once a month by using standard quantitative methods for endotoxin in water used to reprocess hemodialyzers, and for heterotrophic and mesophilic bacteria in water used to prepare dialysate and for hemodialyzer reprocessing.*
- 4. Evaluate possible environmental sources (e.g., water, laboratory solutions, or reagents) of specimen contamination when nontuberculous*

mycobacteria (NTM) of unlikely clinical importance are isolated from clinical cultures. If environmental contamination is found, eliminate the probable mechanisms.

- 5. Document policies to identify and respond to water damage. Such policies should result in either repair and drying of wet structural or porous materials within 72 hours, or removal of the wet material if drying is unlikely within 72 hours.*

The study performed for this thesis utilizes several of the procedures mentioned in the guidelines. Air handling systems within the construction zone ventilate contaminated air from the space to prevent it from traveling into the treatment area. Ventilation systems within hospital construction zones should be monitored and maintained daily. An airflow system was developed for the experiment to determine whether the air circulating within the containment would flow through the barrier and into the “treatment” area. Positive pressure was tested with this study.

“Use AIA guidelines as minimum standards where state or local regulations are not in place for design and construction of ventilation systems in new or renovated health-care facilities. Ensure that existing structures continue to meet the specifications in effect at the time of construction. Monitor ventilation systems in accordance with engineers' and manufacturers' recommendations to ensure preventive engineering, optimal performance for removal of particulates, and elimination of excess moisture.”

Disinfecting surfaces within healthcare facilities is crucial to preventing the spread of infectious organisms. To begin each test, the entire containment was thoroughly cleaned

to rid the surface of any particle that may remain. This simulated the cleaning of hospital surfaces.

Water was not an issue with the proposed study; it is however, crucial within real hospital scenarios. The following is strongly suggested within the guidelines:

“Perform assays at least once a month by using standard quantitative methods for endotoxin in water used to reprocess hemodialyzers, and for heterotrophic and mesophilic bacteria in water used to prepare dialysate and for hemodialyzer reprocessing.” In case of a disaster that would disrupt or contaminate the water system, ensure that policies are put in place for hospital workers to follow. These policies include ensuring that structural or porous materials are repaired or dried within 72 hours. If the material cannot be repaired or dried, it must be removed prior to the 72 hour mark. This is to prevent the growth of mold within walls, ceilings or floors. As mentioned previously, mold is a prime infectious particle and a danger to all immunosuppressed patients.

PREVIOUS STUDIES

An extensive literature review was conducted to aid in formulating the ideas for this paper. Analysis will derive from the fatality count of patients with Aspergillosis between 1993 and 2006 from the Center for Disease Control. APIC documents note that data has been collected portraying construction activity to be a direct influence of infection (Bartley, 2000).

Significant findings raise concern and draw attention to the fact that precautions should be taken when introducing construction into a health care environment. Patients

at risk may acquire an infection during their stay at the hospital that is unrelated to their initial illness or injury, otherwise known as a nosocomial infection. The APIC (Bartley, 2000) also states that airborne contaminants are more prominent during times of construction activity . *“Environmental dispersal of microorganisms during construction, resulting in nosocomial infections, has been described previously, and there is a solid, scientific basis for these concerns.”*

What is the source of infection? Causal factors of nosocomial infections (Riley et al., 2004) include:

- fungal contaminants
- *Disturbance of dust, mold or infectious organisms released into the air during construction can be a danger to high-risk patients (e.g., patients with debilitating infections or immunosuppression such as those that have received bone marrow or other organ transplants or patients receiving chemotherapy for cancer treatment). When the spores become airborne during repair/disturbance, they remain in the atmosphere for long periods of time due to their low settling velocities. This allows the spores to spread at a significant rate and distance.*
- Construction activity within a hospital can potentially release infection-causing particulates into the atmosphere, contaminating the air.

Contamination occurs with the disturbance of dust, which is where most disease-causing microbes, such as mold spores, can be found.

Construction activity can be anything that disturbs the hospital structure;

for example, drilling, repairs, ceiling or carpet tile removal, plumbing or mechanical repairs. These activities can potentially release mold into the air and create a concern for the spread of infection.

Without the application of infection control practices, construction activity can be potentially life threatening and create fatal infections to patients exposed to these pathogens.

IS THE MOULD PREVENTABLE

Mould can appear due to multiple situations and is extremely hard to eradicate, especially in older facilities (Lee, 2010). Water leaks, spills, poor ventilation and humidity can all spur the growth of mold. Typically growing on carpet, insulation or above acoustical ceiling tiles where plumbing is located, mold can easily go undiscovered for long periods of time. Larry Lee, the founder and owner of Pacific Industrial Hygiene LLC, gives specific types of the most dangerous molds found during construction: “Water leaks resulting in mold growth have led to life-threatening and fatal infections with environmental fungi such as *Aspergillus*, *Fusarium*, *Scedosporium*, *Zygomycetes*, and soil-borne bacteria such as *Nocardia*.”

ASPERGILLUS

This study will focus on the danger of spreading mold spores of the fungi *Aspergillus*. *Aspergillus* is a fungus naturally present in soil and dust both indoors and outdoors. The average human being inhales several hundred *Aspergillus* spores per day (Latge, 1999; Wald, Leisenring, van Burik, & Bowden, 1997).

During construction activity, dust containing *Aspergillus* spores may be dispersed when floors, walls, and ceilings are penetrated and become airborne. These spores are very small, about two to three microns, which allow them to stay suspended in the air for a long period of time and increases their chance of being inhaled (Malik et al., 2008).

Figure 1 is a photograph of the *Aspergillus* spores that are released into the atmosphere. The picture in the Melbourne, Victoria, Australia newspaper, *The Age* relates to an upgrade of the Alfred Hospital, which is noted as the busiest trauma hospital in Australia.



Figure 1 *Aspergillus* spore (after Nader, 2006)

As noted in the article,

*“In 2002, the hospital's intensive care unit had levels of *Aspergillus* two to three times higher than acceptable. The hospital said levels were now "acceptable",*

and no patient was at risk. The Alfred responded at the time by creating a separate intensive care unit with six beds for patients who had had transplants. Other patients are not believed to be at risk.”

Even the most efficient hospitals in major cities have had significant problems with the type of fungal infection, and governments are loath to discuss the problem as further noted in the article in *The Age* (Nader, 2006).

The concern with the fungus *Aspergillus* is that it happens to be one of the most common infection causing agents in hospitals and infection with this agent can be fatal for residing patients (Latge, 1999). The inhalation of *Aspergillus* spores can potentially create an infection called aspergillosis. Aspergillosis is an infection that is described as a fungal growth in the lungs that create severe symptoms including fever, chills, severe bleeding in the lungs, shortness of breath, chest pain, joint pain, and skin lesions.

Aspergillosis has a high mortality rate.

WHO IS AT RISK

Who is at risk for acquiring aspergillosis? High-risk patients particularly susceptible to obtaining aspergillosis infections during construction activity are those that are immunosuppressed, or immune-compromised. These patients are most vulnerable to acquiring a nosocomial infection during their time at the hospital due to a weakened immune system. Their immune system's ability to fight infection is "compromised" or absent making them particularly defenseless to fighting infection. For example, patients considered "high-risk" includes those with severe burn wounds, those located in the Intensive Care Unit (ICU), those who have received a bone-marrow

transplant, are receiving chemotherapy, or have received surgery. Table 1 summarizes the risk levels for Aspergillus for different categories of patient. This summary comes from the article by Bartley (2000).

Table 1

Aspergillus - Risk Levels (from Bartley, 2000)

Low Risk	Medium Risk	High Risk	Highest Risk
Office Areas	Cardiology, Echocardiography, Endoscopy, Nuclear Medicine, Physical Therapy, Radiology/MRI, Respiratory Therapy	CCU, Emergency Room, Labor & Delivery, Labs (specimen), Medical Units, Nursery, Outpatient Surgery, Pediatrics, Pharmacy, Post Anesthesia Care & Surgical Units	Any area caring for immune-compromised patients, Burn Unit, Cardiac Cath. Lab, Central Sterile Supply, Intensive Care Units, Negative pressure isolation rooms, Oncology, Operating rooms including C-section rooms

As noted, in article by Nader (2006), the problem can reach the stage of development of high risk ICU units in addition to a standard ICU unit. The issue can become very political as observed in Sydney, Australia in 1998. Figure 2 shows a plot of

the CDC data for fatality counts for Aspergillosis in the USA for the period 1993 to 2006. Fatalities recorded by the Center for Disease Control show a consistent decline in deaths related to aspergillosis from 1993 to 2006 (CDC, 2009).

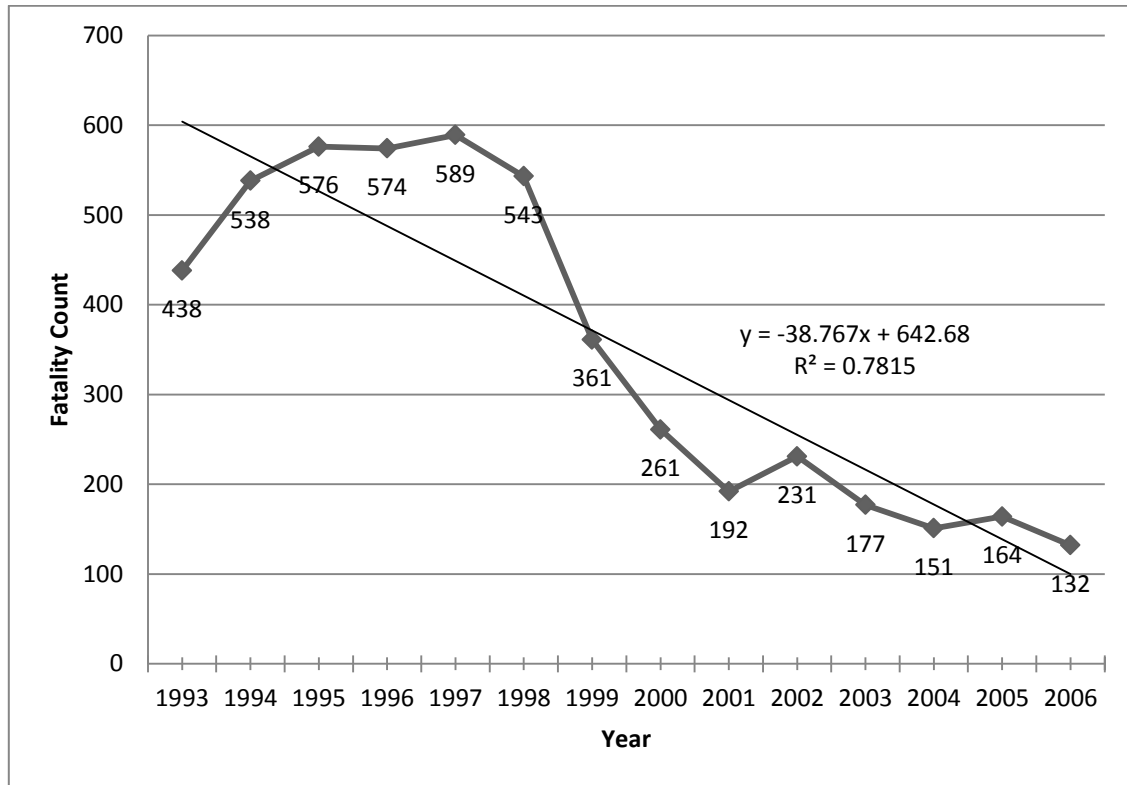


Figure 2 Aspergillosis fatalities - 1993 - 2006 in the USA

Figure 2 has a linear trend-line plotted using standard statistical techniques. The trend-line suggests a reduction in the death toll with year will continue. This pattern will need to be reviewed in a few years to determine if a population cohort exists that cannot be protected from Aspergillosis. This trend-line appears to indicate that aspergillosis is becoming less prevalent in the healthcare industry.

According to recent research, that is not the case. *Aspergillus* continues to be a serious issue to immunosuppressed patients. The reason for the decline in fatalities

recorded by the CDC may be due to the improvement of antifungal therapy used to treat *Aspergillus* infection (Latge, 1999).

Overall fatality rate due to aspergillosis may be decreasing, but the risk of acquiring aspergillosis in a hospital setting is on the rise. With the advances in modern medicine, the number of immunosuppressed patients is dramatically increasing. Chemotherapy is a perfect example. As a relatively “new” treatment that has saved many lives, advancement in chemotherapy is occurring at a fast pace. These improvements allow for a longer life span for those diagnosed with cancer. However, chemotherapy weakens the immune system. This means there is an increase in the number of patients with weakened immune systems. A higher number of immune-compromised patients allows for a higher potential that patients acquire nosocomial infections, in particular, aspergillosis.

Table 2 shows relevant data for *Aspergillus* Infection Outbreaks (Latge, 1999; Vonberg & Gastmeier, 2006). *“In 1992, aspergillosis was responsible for approximately 30% of fungal infections in patients dying of cancer, and it is estimated that aspergillosis occurs in 10 to 25% of all leukemia patients, in whom the mortality rate is 80 to 90%, even when treated. Aspergillosis is now a major cause of death at leukemia treatment centers and bone marrow transplantation and solid-organ transplantation units.”*

INFECTION CONTROL USING BARRIERS

The only way to reduce fatalities of those that acquired aspergillosis through construction-related activities is to improve infection control procedures. Infection control is defined as *“the means and measures that we diligently plan for and execute to*

assure that patients, staff and visitors are not negatively affected by the work being performed.” (Bartley, 2000)

Table 2

Mortality Data for Aspergillus Infection Outbreaks (after Vonberg 2006)

Underlying Disease	# of patients	Mortality Rate%
Hematology malignancy	299	57.6
Solid organ transplant: Kidney, Liver	44	55.9
Other immune-compromised patients High-dose steroids, Neonates, Malignancy, Chronic lung disease, ICU patient (high risk)	77	52.3
Patients without severe immunodeficiency	38	
Thoracic surgery, Cataract surgery, ICU patient (low risk), Other surgical patients		
Total	458	55%

Patients exposed to *Aspergillus* are negatively affected; in order to prevent this from occurring a successful plan for infection control must be developed and implemented. The first line of defense to eliminate the transmission of dust particles during construction is by creating and erecting a barrier system. This system separates

the construction area from the treatment area and prevents any dust from passing between the two areas.

This study will focus on the barrier system employed to prevent airborne particulates from passing through walls. Infection control is maintained by having control of dust being released into the air and preventing clean air in patient areas from becoming contaminated. To do this, physical barriers from floor to ceiling must be utilized to quarantine construction areas from the rest of the building. Depending on the danger to the patients, barriers may be flexible plastic sheeting or hard, rigid walls. All walls must be tightly sealed from floor to ceiling and checked routinely. This will ideally prevent dust movement from the construction area into the hospital hallways and rooms (Bartley, 2000).

To determine the success of a barrier, air monitoring can be performed. Air monitoring for mold particles may be performed at any time. By monitoring the particulates in the air, it can be seen if there is a change in particulate number. If a change is apparent, then the barrier may have failed. Monitoring can be done prior to construction, during construction, and post construction to determine if any changes occurred (Bartley, 2000).

CASE STUDY: HEALTH SCIENCES CENTRE IN WINNIPEG, MANITOBA

A construction infection control project was performed within a nursing station serving an active Blood and Marrow Transplant Unit (BMT) at the Health Sciences Centre in Winnipeg, Manitoba while it remained fully operational. This unit obtains patients needing blood and bone marrow transplants, or immunosuppressed patients.

These patients are at highest risk for hospital-related infection due to their suppressed and weakened immune system.

The BMT unit's nursing station was dated, and scheduled to undergo demolition, new construction, and new electrical and mechanical systems. Before construction was underway, air samples were collected from the nursing station. Airborne particulates, specifically mold, were measured to determine total concentrations in the air. Slab-to-slab containment was erected to isolate the area under renovation and a negative air pressure system was utilized. To evaluate effectiveness of containment, daily measurements of airborne particulates were taken inside AND outside of the containment as well as the rooms of the patients. Findings indicated that particulate concentrations on the exterior of the containment were constant, and similar to readings prior to construction. Mold particles were not found in patient rooms. These readings remained similar to readings prior to construction as well.

Procedures used in the renovation of the nursing unit, such as containment walls, HVAC isolation, and a negative air pressure system, were found to be effective in lowering risk of infection caused by construction. The containment and air control was deemed a success. This process is gaining recognition and becoming necessary in health care facilities undergoing construction (Pinchin Environmental, 2005).

Construction and renovation projects in health care facilities are a risk for immunosuppressed patients. Research shows that through proactive and protective methods, construction-related nosocomial infections can be reduced. This requires careful and extensive planning and implementation of proper procedures for patient

protection. The hospital should ensure that preventative measures are designated, applied and maintained consistently. Contractors working within healthcare facilities must be aware of the infection control risks associated with hospital renovation and construction projects. Construction teams must also understand the importance of working directly with the healthcare facility and strictly adhering to the detailed infection control plan. By utilizing the appropriate measures and having effective communication between the construction zone and the hospital, patient safety can be enhanced.

SUMMARY

No one should die in hospital because of airborne dust from construction. This literature review clearly documents the problem.

CHAPTER III

METHODOLOGY

INTRODUCTION

This chapter outlines the methodology used in the research program. The elements of the methodology are:

- Design of the Equipment
- Experimental Construction and Methods
- Data Collection
- Analysis Methods

The experiment mimics a hospital setting and the dust particulates that pass through infection control barrier materials when disturbed during construction. 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. This test can support the research for the possibility of creating a strong barrier or new techniques to reduce infectious particle transmission for better protection of patients.

DESIGN OF THE EQUIPMENT

A mock containment was constructed at the TAMU Architecture Ranch. The containment will test the transmission of particles through an experimental barrier. The barrier will divide the containment into two sections. Containment A represents the construction zone in which contaminated dust will be present. Containment B represents

the patient treatment area of the hospital. During this experiment we will imitate the disturbance and release of contaminated dust within Containment A, the construction zone, and determine what amount travels into Containment B, the patient area.

The barrier being tested represents the soft barriers implemented within hospitals during construction for infection control purposes. Often these barriers that separate the construction area from the patient rooms are composed of a plastic sheeting material that is sealed with tape from inside the construction zone. It is detrimental to patient protection that the seal is maintained at all times to keep air from flowing from the construction zone into the hospital treatment area. This experiment will test the plastic barrier seal. Two plastic sheets will overlap by 75 millimetres in the center of the two containments. They will then be taped together with a similar material used in hospitals. This taped joint will simulate a sealed barrier joint found in hospitals.

A substance of similar size to dust will be released within the construction zone-replicated environment, Containment A. Two air filters will be utilized. One filter will be inserted into the top of Containment A and one filter will be inserted into the bottom of Containment B. Once the containments are clean, the sealed barrier is in place, and the filters are in place, the test will begin. Using a pressure controlled air compressor, we will test the barrier's ability to withstand an air pressure of 105 kilopascals supplied through a HEPA filter system over a time span of 18 hours. This test will be performed twice.

Figure 3 shows a sketch of the theoretical basis for the containment vessel. The vessel is constructed of plywood and timber glue.

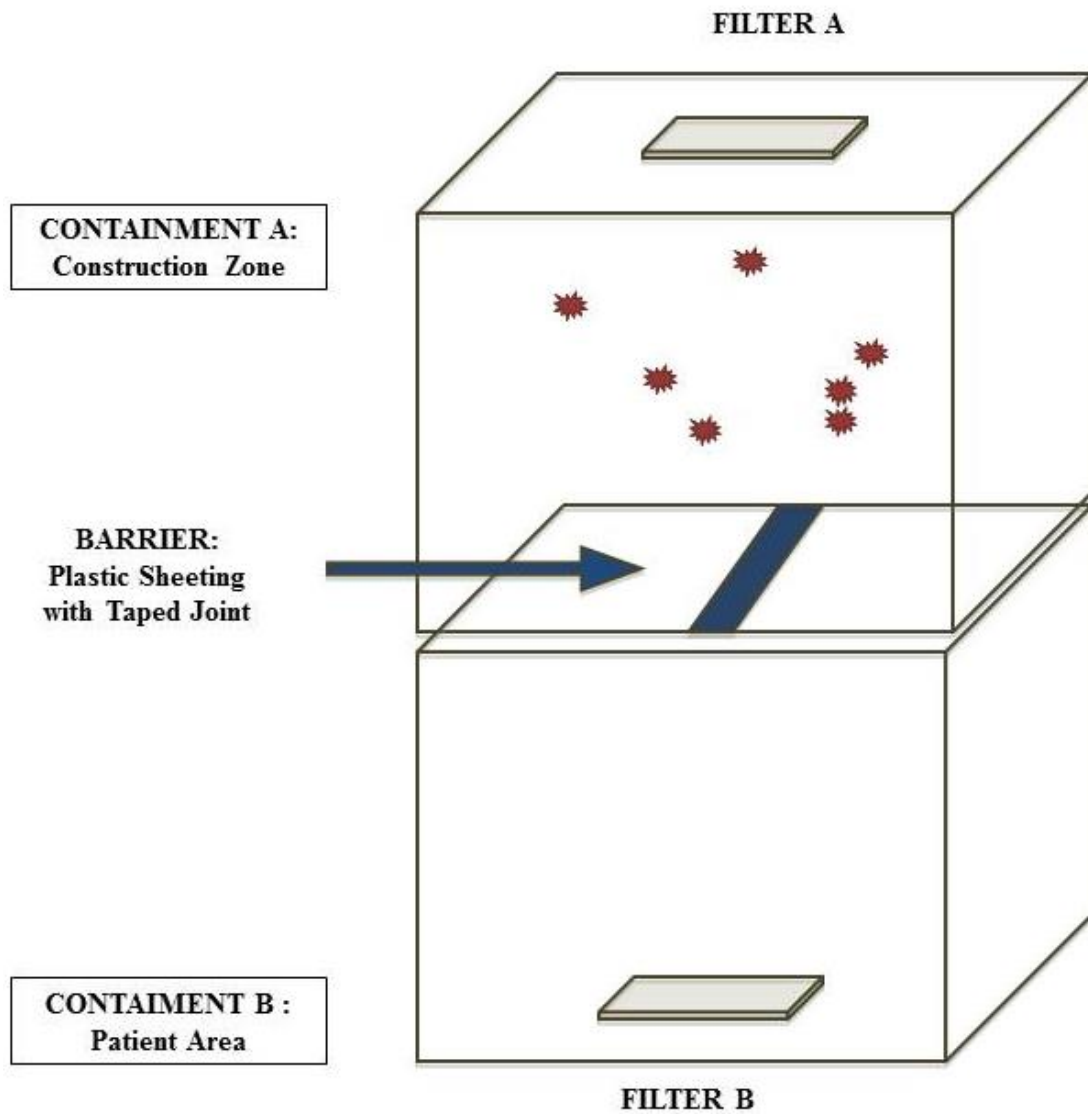


Figure 3 Containment vessel design

EXPERIMENTAL CONSTRUCTION AND METHODS

Introduction

The experimental work and procedures are:

1. Construct a containment vessel as shown in Figure 3
2. Source HEPA filters for the experiment

3. Supply an air source at 105 kPa at the inlet point
4. Provide a barrier between the two halves of the containment vessel
5. Introduce the dust media to Side A and then run an 18 hour test
6. Measure the particulate matter trapped in the filters

This section of the report details:

1. Construction of the Containment Vessels
2. Design of the Air Pressure and Filtration System
3. Materials List and Comments on the Selection
4. Simulation of the Dust Particulate Matter
5. Test Procedure
6. Suggested Changes to the Test Equipment and Procedures
7. Summary

Construction of the Containment Vessels

Two identical, separate box containments were constructed for this experiment, Containment A and Containment B. Both boxes were built using 19 mm oak plywood, each with five enclosed sides and one open face. A flange was attached to the open face of each box to extend the edges by three inches. To begin, all dimensions were determined for Containments A and B. The containment vessel has two end pieces, with dimensions shown in Figure 4.

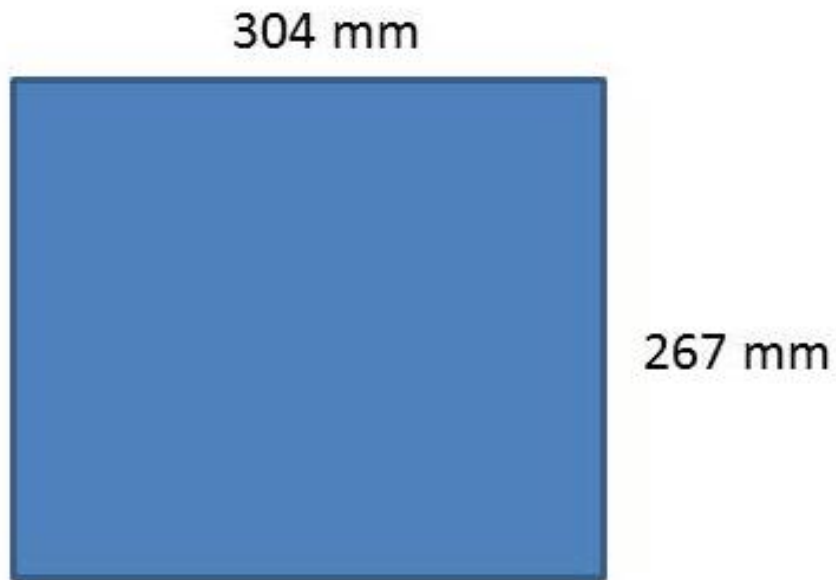


Figure 4 End piece dimensions in millimetres

There are four side plates of the type A as shown in Figure 5.

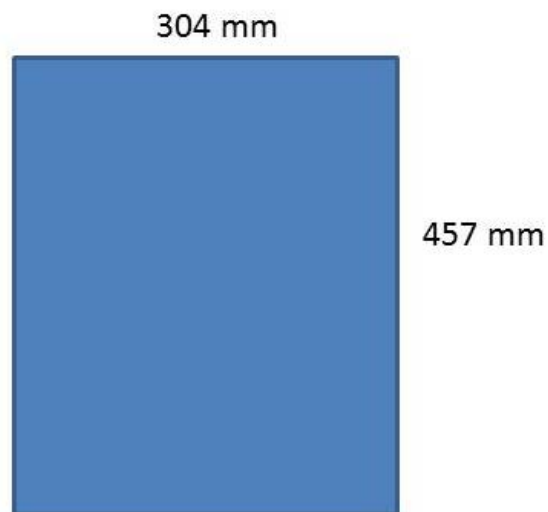


Figure 5 Side plate Type A – dimensions in millimetres

Figure 6 shows the dimensions of the side plate type B.

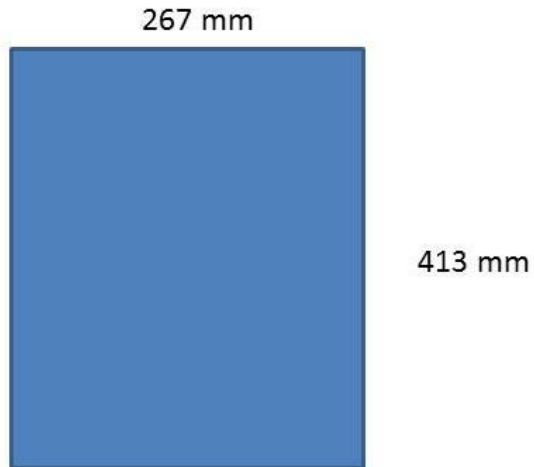


Figure 6 Side plate Type B - dimensions in millimetres

Figure 7 shows the flange plate, used to provide the edge for the barrier.

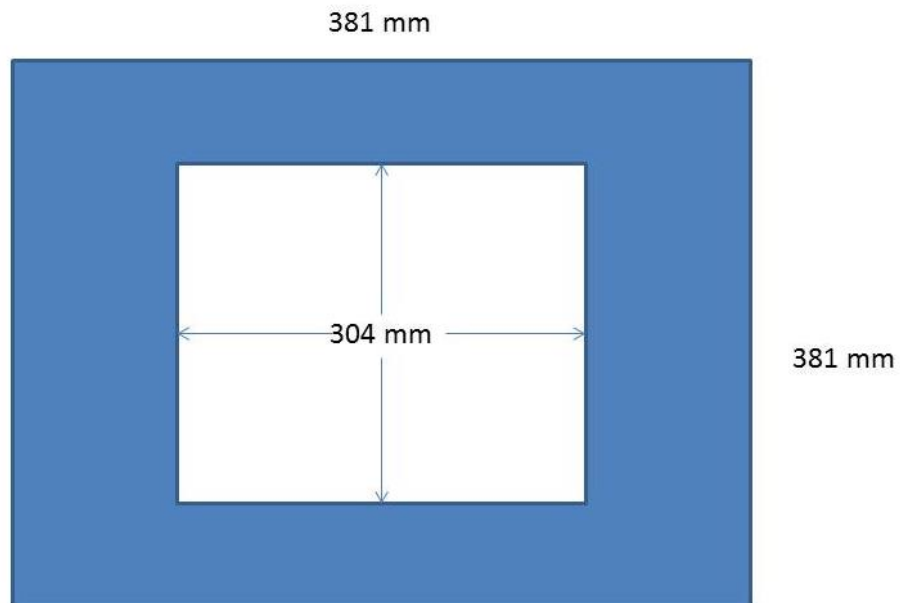


Figure 7 Flange plate - dimensions in millimetres

Plywood sheeting was cut first using a panel saw and then trimmed with a table saw. Pieces were all cut to size using the table saw. The flange pieces required an inside dimension to be cut out of the exterior dimension, posing a challenge to the construction. As a solution, Mr. Gary BS (2012) used a CNC Router to make these cuts. A CNC router is a computer-controlled device that shapes material from AutoCAD files designed and entered into the router system. After measuring, marking, and cutting appropriately, each box was assembled. This required placing wood glue along joints, then tightly securing each piece together using a nail gun. The end pieces were first connected to the bottom piece, following the side connections and the top piece. The flanges were connected to the boxes last. To seal the wood and any fibers that may conflict with the test, the insides of the boxes were coated with clear finish shellac. This process took place at the TAMU Architecture Ranch and the TAMU Woodshop, where all materials and tools were available and used to construct the containment.

Figure 8 and Figure 9 show the cutting of the plywood pieces from sheets.



Figure 8 Panel saw cutting plywood



Figure 9 Table saw fine cutting plywood

Figure 10 shows the geometric methods used in the box construction.



Figure 10 Squaring the plywood box

Figure 11 shows the non-watertight all-purpose wood glue use to join the sides.



Figure 11 Gluing the edges of the box

Figure 12 shows the boxes being tacked with nails to give the glue time to set.



Figure 12 Nail gun used to hold boxes until glue dries

Figure 13 shows a partially assembled box.



Figure 13 A partially assembled box in this case Containment A

Figure 14 shows Containment Vessel A prior to the placement of the flanges.



Figure 14 Containment A without flange piece

Figure 15 shows the two containment vessels, prior to the flange placement.



Figure 15 Containment A and Containment B without flange pieces

Figure 16 shows the flange pieces being attached to the boxes.

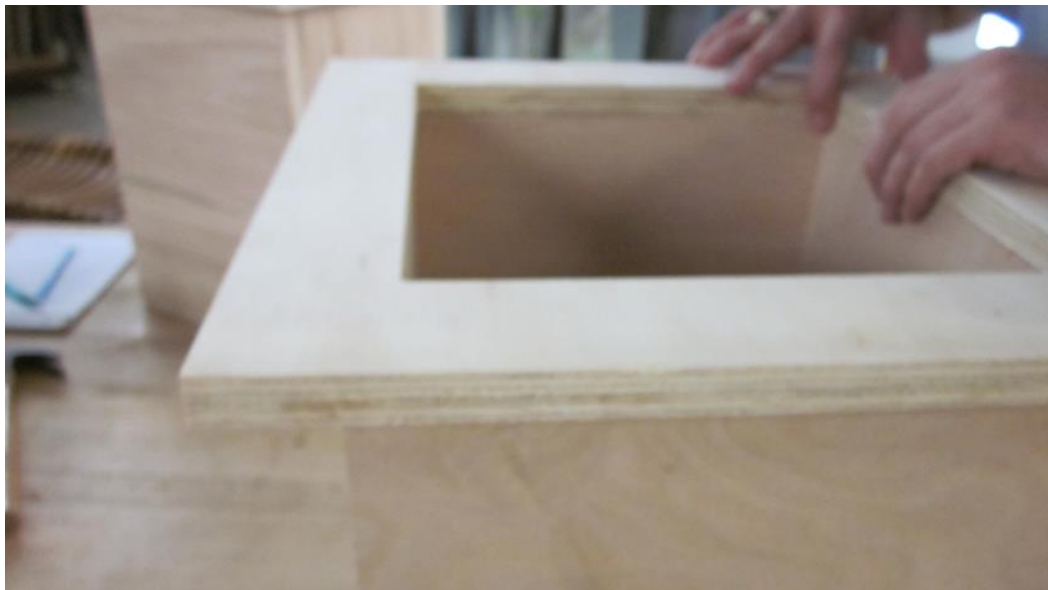


Figure 16 Flange pieces being attached to containments

Figure 17 shows the completed containment vessels.



Figure 17 Flange pieces attached to Containments A and B

Design of the Air Pressure and Filtration System

The purpose of this experiment is to direct air flow from Containment A to 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. A positive air pressure system is placed into the top of Containment A, wherein the dust will be located. This system forces air into Containment A.

To do this, a MicroGard MGA7635 air filter is inserted into the top of Containment A, as shown on Figure 18. Haberl (2013) suggested the use of the automotive air filters. A filter was selected 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 18 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 out of the top of Containment A. The filter could then be tightly fit into the top of the Containment. Using an air pressure-regulating valve, air could then be pushed through the filter into the containment and into the barrier to mimic airflow of a construction zone.

Containment B also required a filter to be located within 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 taped joint in the plastic sheeting barrier. The dimensions of the filter, 248 mm by 178 mm, were cut out of the bottom

face of Containment B. The filter could then be tightly fit into the bottom of the Containment.

Figure 19 shows the filter space being cut into the containment vessel. The cut is designed to leave the gasket outside the cut area to provide a tight seal.



Figure 19 Filter space being cut into the containment vessel

After each test, a piece of the filter would be cut, preserved, and studied microscopically to obtain a particulate count of what was transmitted through the barrier. High particulate count would indicate barrier failure.

Figure 20 shows the air filter in place in one of the containment vessels.



Figure 20 Filter fitted into place in containment vessel

The conceptual idea for the containment vessel is to introduce an overpressure of 105 kilopascals into the upper vessel and measure the materials that pass through the barrier and fall onto the lower filter. The arrangement is a vertical arrangement so that a particle that passes through the barrier will likely fall onto the base, which is filtered.

Figure 21 shows the pressure gauge used to measure the overpressure of the incoming air system.



Figure 21 Pressure gauge

Materials List and Comments on the Selection

Materials for the experiments were sourced locally in College Station. The decision to use plywood provides an impermeable and smooth wood surface for this experimental work. A powder was used to replicate the behavior of dust in the environment. The powder is a corn based starch sold under the name baby powder.

Table 3 lists the materials and the equipment used in the experimental construction and the work related to the transmission of dust particles.

Table 3 Material and Equipment List

Materials used in Experiment		Equipment used in Experiment	
Material	Comment	Tool	Comment
Plywood	19 mm oak	Panel Saw	Cut plywood
Wood	Tite-Bond Type II	Table Saw	Trim cut plywood
Glue			
Nails	Bostitch Air gun	CNC router	Cut our holes in plywood
Finish	Clear Shellac, which provides a smooth interior to the boxes	Nail gun	Temporary hold until glue sets
Plastic	25.4 micro-metres, a fairly thin plastic	Drill Press	Drill holes for minor fittings
Sheeting			
Tape	Painters sealing tape, one that does not provide a tight long term seal	Air Compressor	Supply air for the experimental work
Powder	Corn Starch Powder	Air Pressure Regulating Valve	Supply air at 105 kPa

In the development of any experimental procedure, one has to make decisions and compromises as to what is needed and what can be readily achieved. In this case the key decisions relate to the:

1. Dust source a commonly available baby powder manufactured from corn starch provided the substitute for common dust particles
2. Plastic sheeting a plastic sheeting with a thickness of 25.4 microns or in English units one thousand of an inch is a very thin plastic
3. Painters tape which has a low bond strength and likely to be the worst tape used on a construction site for a permanent seal
4. HEPA Filter a commercially available filter with the lowest cost was selected used for automotive purposes usually, but suggested by Haberl (2013)

Figure 22 shows the commonly available commercial materials used in the experimental work.



Figure 22 Materials used in experimental work

Simulation of the Dust Particulate Matter

Aspergillus spores have a size of two to three microns, and attach to dust particles as large as 25 microns (Malik et al., 2008; Wald et al., 1997). This experiment uses a commercially available cornstarch to model these dust particles.

Figure 23 shows a sample of a cornstarch powder taken from the sample used in this experimental work.



Figure 23 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 24 shows the distribution of diameters measured by these researchers.

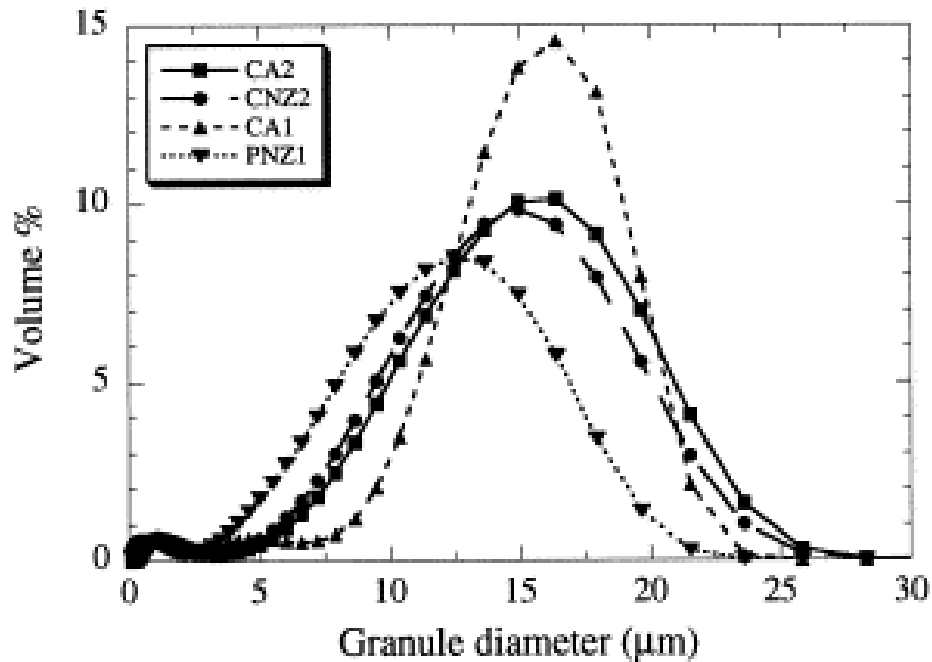


Figure 24 Cornstarch size distribution after (Paterson et al., 2001)

Vitha (2013) noted the diameter at about 12 micrometres as shown on picture of a filter contaminated deliberately by Vitha with the powder. Approximately 20.4 grams of powder will be released into Containment A prior to applying air pressure. The mass fills a small sample container typically used in a soils laboratory. The powder represents contaminated dust released by construction activity.

Further work is required on the properties of the commercially available powder as this was beyond the scope of this study. The powder clearly contains several materials.

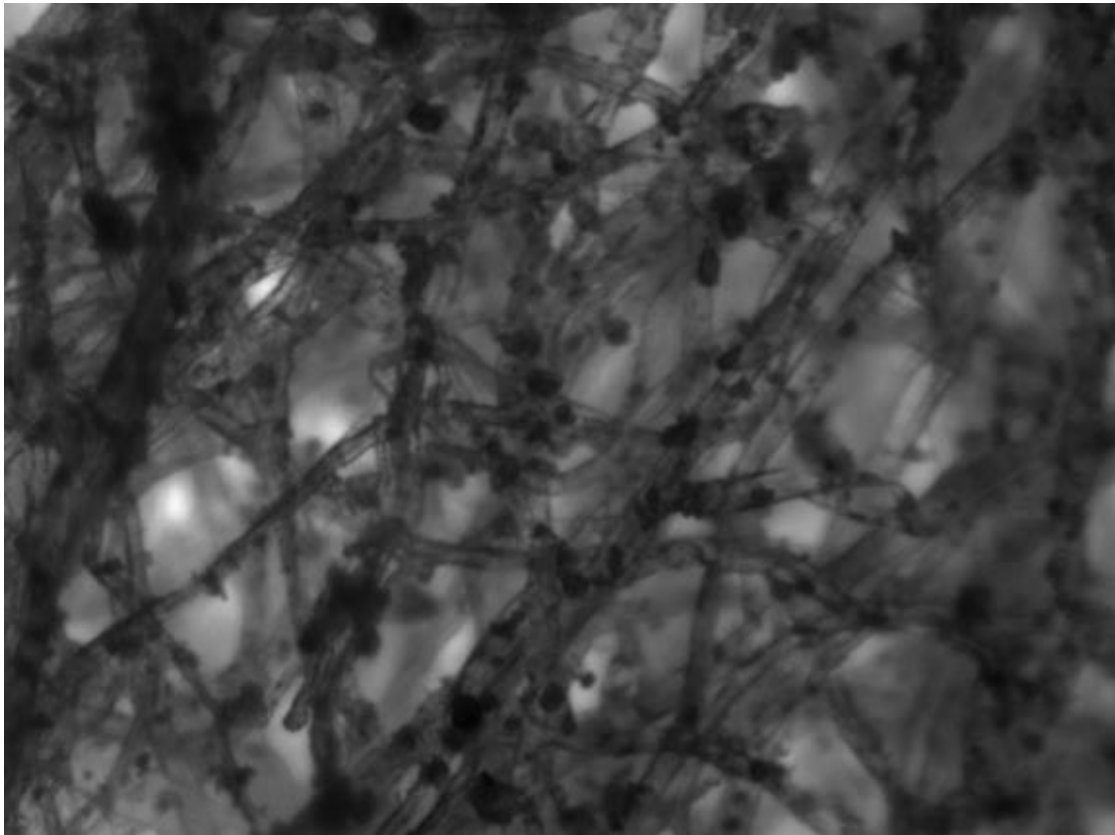


Figure 25 Picture of filter contaminated with cornstarch

Test Procedure

The test procedure is:

1. Prepare the containment vessels including the placement of the powder
2. Air Supply system
3. Apply air and then test filters

The first step in the preparation of the containment vessels is to clean the vessels to remove as much dust and other particulate matter as possible. The second step is to place and fix a sheet of plastic to the flange of the lower containment vessel; B. Figure 26 shows this step and the placement of the tape to seal the joints.



Figure 26 Placement of first plastic sheet

Figure 27 shows the placement of the second plastic strip.



Figure 27 Placement of second plastic sheet and overlap measured

Figure 28 shows the third step being the placement of the second strip and the taping of the joints.



Figure 28 Taped and sealed plastic sheeting – 75 mm overlap

The picture clearly shows the difficult problem of ensuring a tight joint with painters tape. The joint exhibits curling of the plastic and tape.

The fourth stage is sealing the top containment vessel to the bottom containment vessel. Figure 29 shows the screwed system used to ensure a tight seal.



Figure 29 Flanges secured with screws

No seal is going to be perfect given the limited resources of the experimental team. The clear purpose is to develop a repeatable test that determines if transmission is occurring and approximately at what rate. Figure 30 shows the 20.4 grams of powder placed in containment vessel A. It is placed directly onto the plastic sheeting in an approximately random fashion. Clearly, the method of placement has favoured the centre of the sheeting and the blue strip is visibly offset to one side.



Figure 30 Powder in Containment A

Figure 31 shows the seals in place after the powder added to A.



Figure 31 Containment sealed, all filters in place

One filter was retained in an unopened box to compare the particulate matter on a technically “clean” filter.

The next step is the placement of the air supply system. An Ingersoll – Rand system is used to supply filtered air to the test area, as shown in Figure 32.



Figure 32 Air delivery system

The filter on this air delivery system was changed in December 2012, in accordance with the manufacturers recommended time and procedure. Figure 33 shows the air compressor unit and filter system on the Ingersoll-Rand unit.

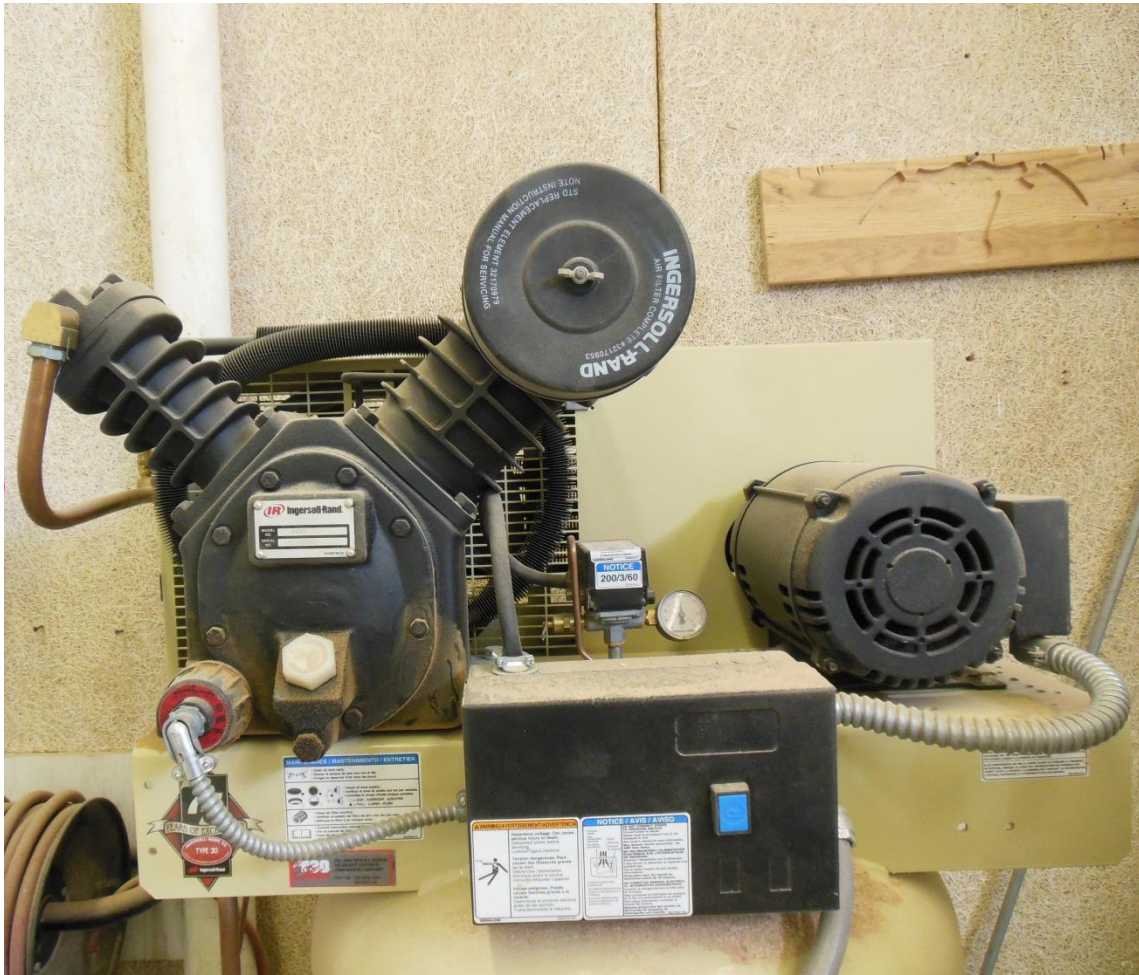


Figure 33 Air compressor unit and filter

Figure 34 provides the model details for the air delivery system. Figure 35 shows the air pressure gauge used to control the flow of air. The gauge was set to the English units of 15 psi, which is 105 kPa using standard conversion formula in the SI system (Cardarelli, 1997).

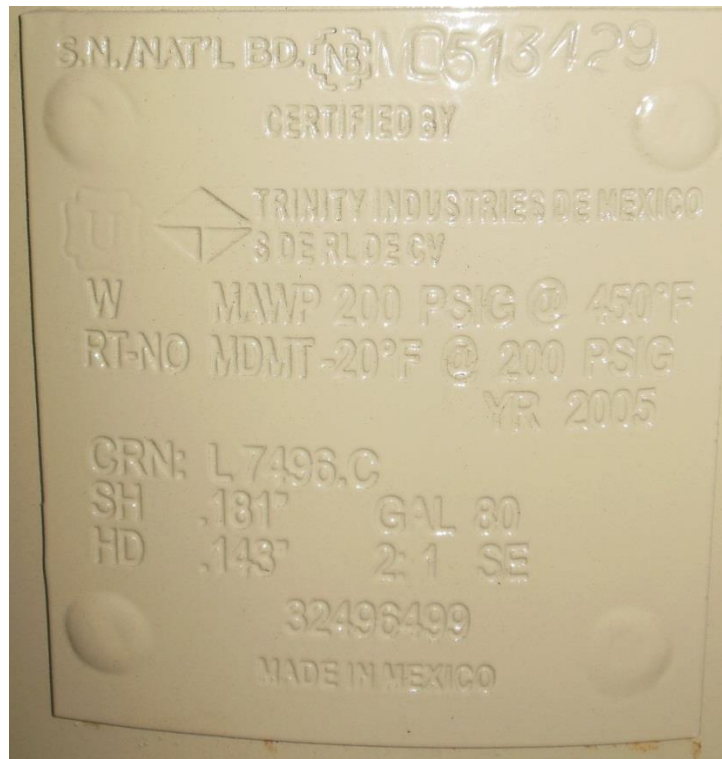


Figure 34 Model details of the air delivery system

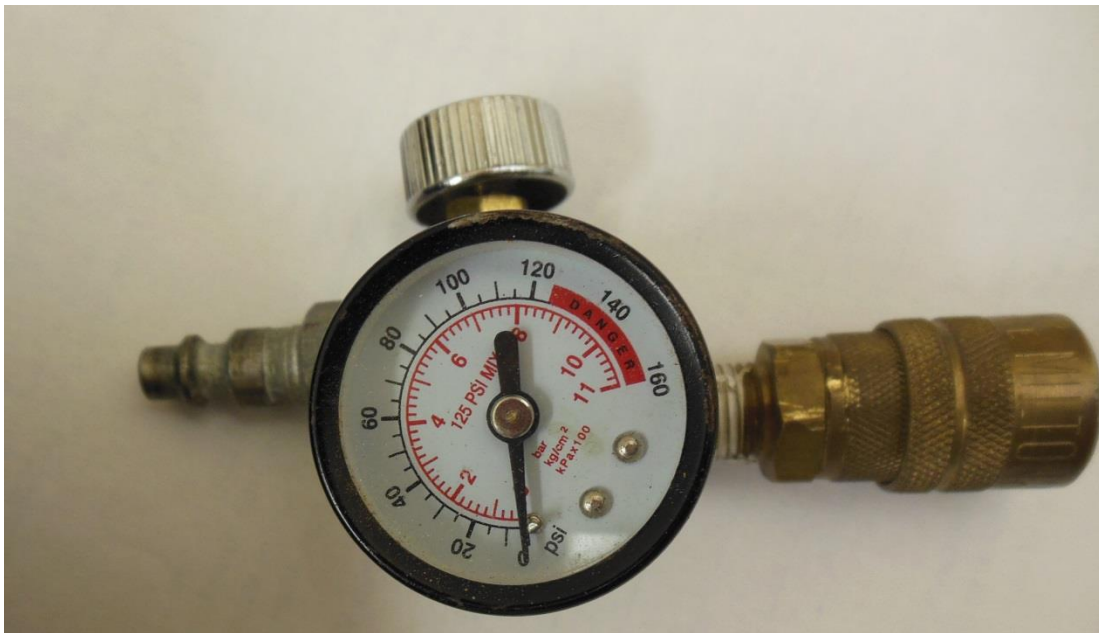


Figure 35 Air pressure gauge

The last step was the assembly of the complete unit as shown in Figure 36.



Figure 36 Assembled test unit

Tests were then run for 18 hours at the 105 kPa pressure.

Suggested Changes to the Test Equipment and Procedures

The purpose of this test was to determine if particulate matter passed the barrier under a reasonable simple test arrangement. The barrier did not permit the passage of

observable particulate matter, which does not accord with real world observations. The changes to the test that are suggested are:

1. Install fan system in the containment vessel A to model actual wind directly on the plastic barrier
2. Run the test for several days to allow drying and flutter damage to occur to the plastic sheeting
3. Better seal the exterior surfaces
4. Provide a clear viewing surface in each vessel
5. Determine the properties of the powder material
6. Repeat the test with a much finer powder, say 3 microns
7. Examine real world systems and determine the typical level of damage and the operational procedure to improve correlation of results from the experiment to the real world
8. Standardize the test
9. Determine the properties and class of the filter used in the tests
10. Improve the measurement procedure for the particulate matter that ultimately passes the filters
11. Measure the differential pressure between Vessel A and B throughout the tests
12. Measure the inlet air pressure with a greater accuracy and determine the actual volume of air per minute being placed into the system
13. Determine any leakage areas and seal them

14. Standardize the reporting and relate it to a real situation

15. Compare the test to other standard test systems

Summary

It is possible to develop a test to measure particulate transmission across a temporary construction barrier. There is room for significant improvement, but the basic procedure has been shown to work in this testing program.

DATA COLLECTION

This research program included two tests of the system. Table 4 presents the specific details of each test program.

Table 4

Test Program

Test Number	One	Two
Date	20 February 2013	21 February 2013
Start Time	2 PM	2 PM
End Time	8 AM	8 AM
Duration (hours)	18	18
Air Pressure (kPa)	105 ± 20	105 ± 20
Sample (grams)	20.4 ± 0.1	20.4 ± 0.1

After the test program was completed, the air filters were removed from the test rig as shown in Figure 37. Figure 38 shows a strip cut from the filter. The strips were bagged, sealed and carefully transported to the TAMU Microscopy Lab.



Figure 37 Filter removed after eighteen hours

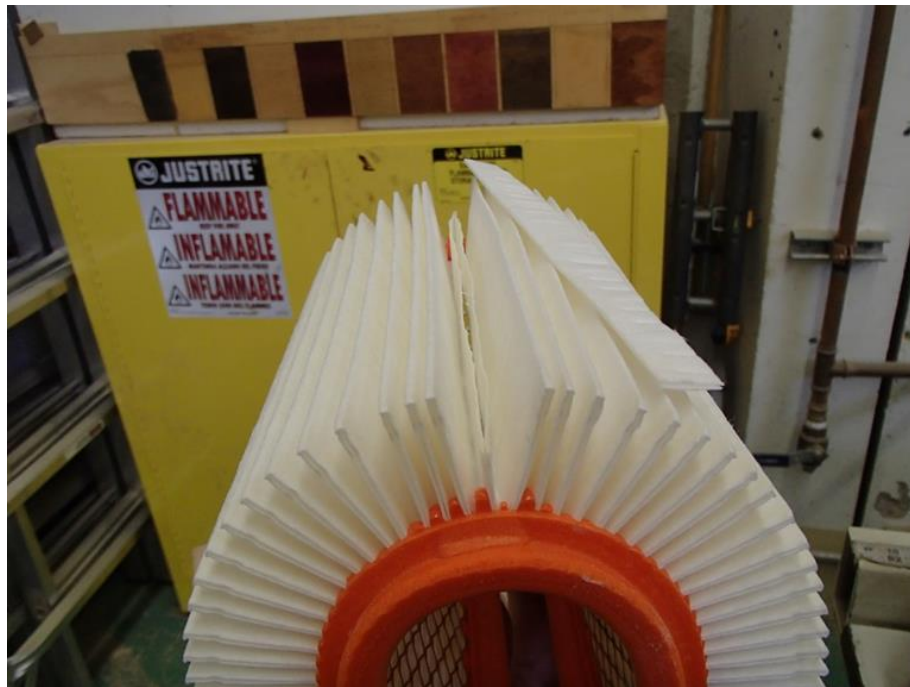


Figure 38 Filter sample removed for microscopy lab

ANALYSIS METHODS

Dr. S. Vitha of the TAMU Microscopy Laboratory examined the strips of filter fabric from the top, bottom and the clean filters under a microscope. The report from Dr. Vitha (2013) noted the procedure as:

- *Imaging the filters on our Zeiss Axiophot microscope.*
- *Initially, tested with incident polarized light, but that did not yield sufficient contrast.*
- *In the end, transmitted light (bright field) imaging worked the best.*
- *For each filter, several images were acquired using a 5x objective.*
- *In addition to the filters, the talc powder was also imaged at the same magnification.*
- *Post-acquisition, the images were converted to JPG format for more convenient viewing.”*

Dr Vitha provided the photographs used for the analysis of the results.

CHAPTER IV

ANALYSIS

INTRODUCTION

This chapter presents a summary of the photographic results and analysis of the results of the photographs. The analysis shows that a barrier can work to prevent dust.

PHOTOGRAPHIC RESULTS

On February 28, 2013, all five samples of the filters from Test One and Test Two, as well as the clean sample from an unused filter, were microscopically observed and photographed at the TAMU Microscopy Lab. The following section shows the photographs taken for each of the samples. The photographs are:

1. Clean Sample
 - a. Figure 39 shows the complete picture of the clean sample
 - b. Figure 40 shows the clean sample contaminated with powder
 - c. Figure 41 shows a section of Figure 39
 - d. Figure 42 shows a section of Figure 40
2. Test One
 - a. Figure 43 shows the input filter on the test system
 - b. Figure 44 shows the output filter on the test system
3. Test Two
 - a. Figure 45 shows the input filter on the test system
 - b. Figure 46 shows the output filter on the test system

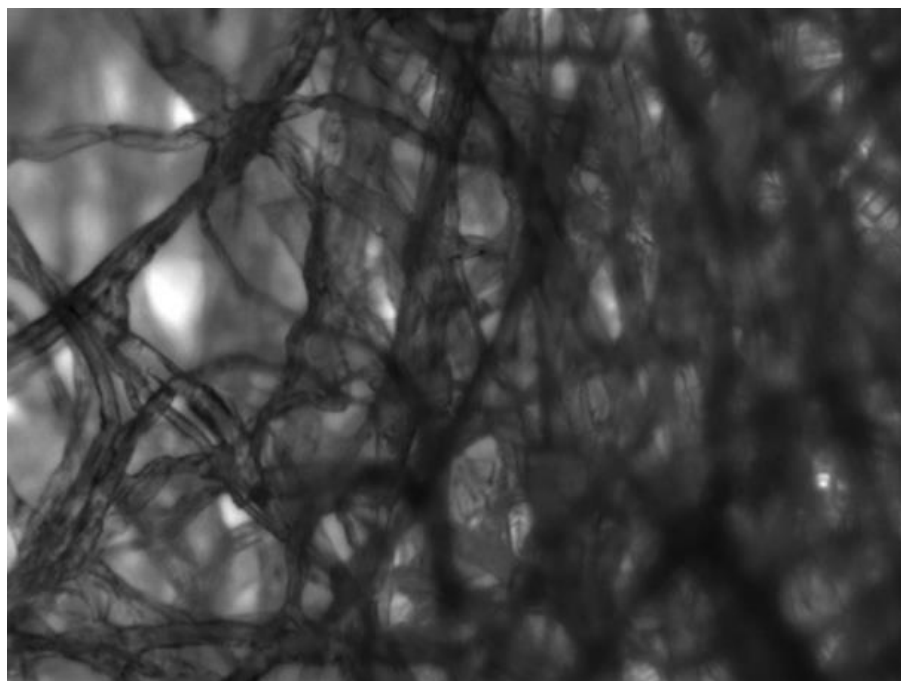


Figure 39 Clean sample - small complete picture

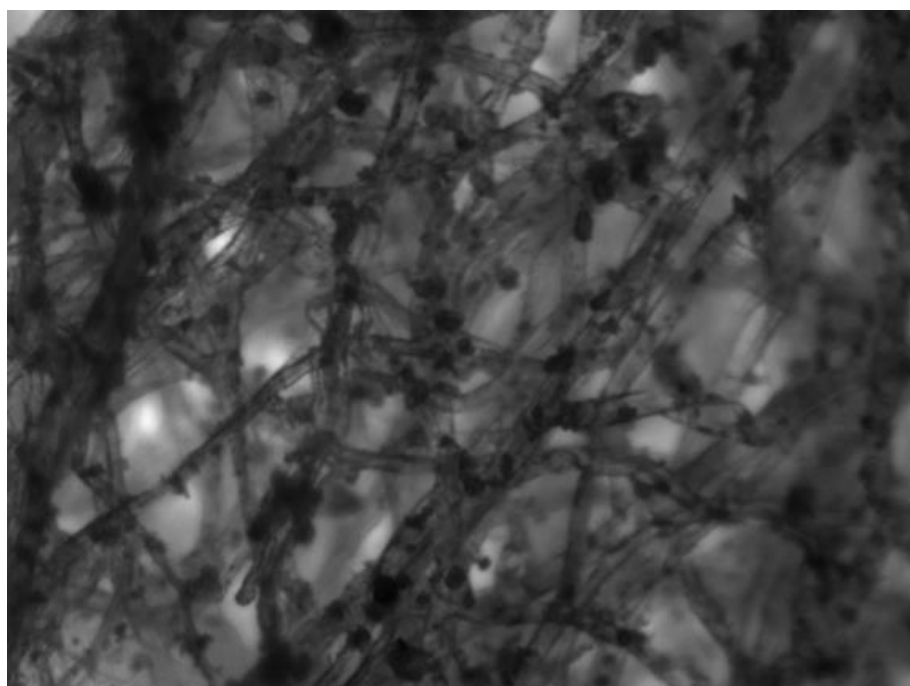


Figure 40 Clean filter contaminated with powder - small complete picture

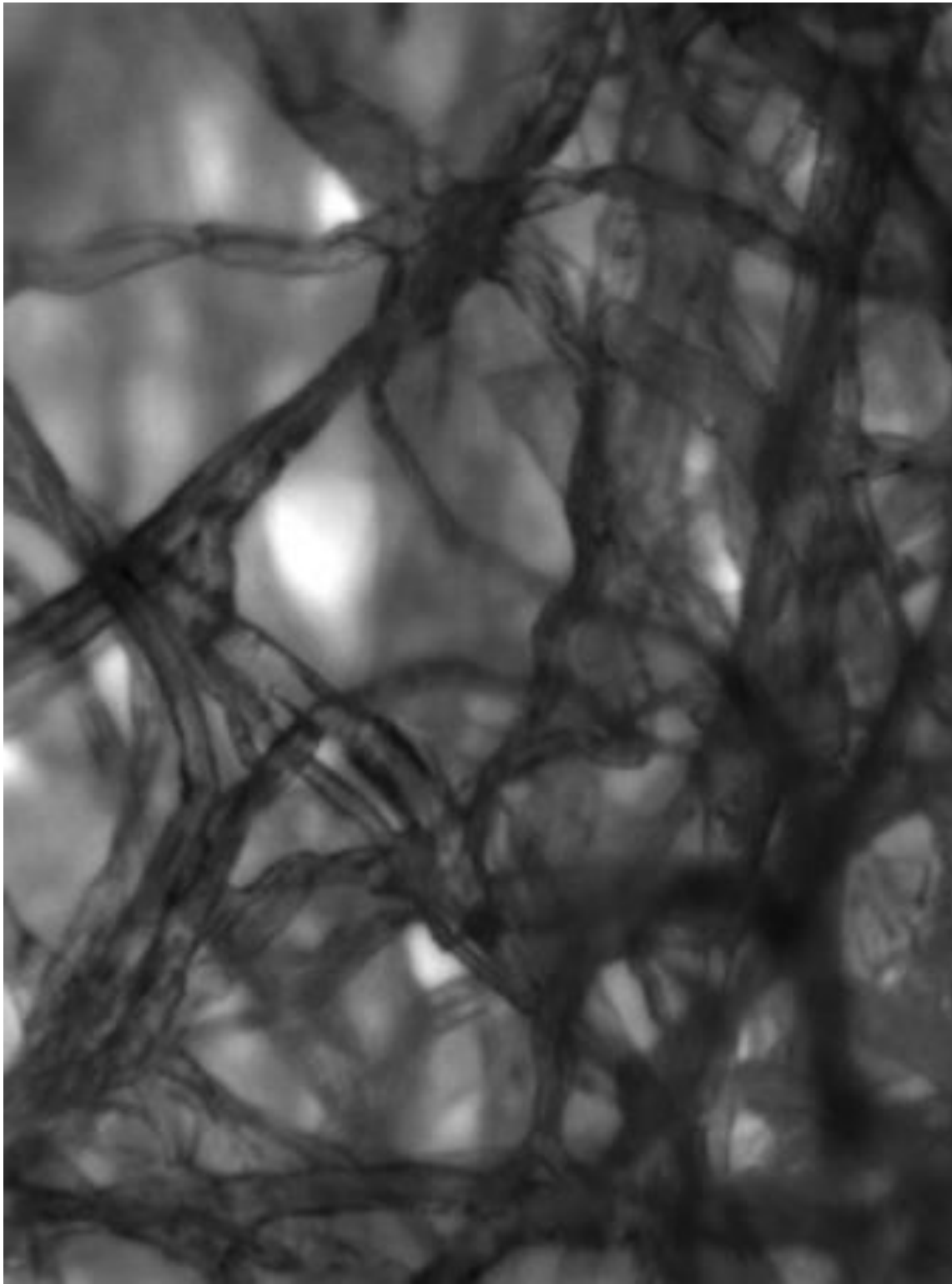


Figure 41 Clean filter - 5x magnification

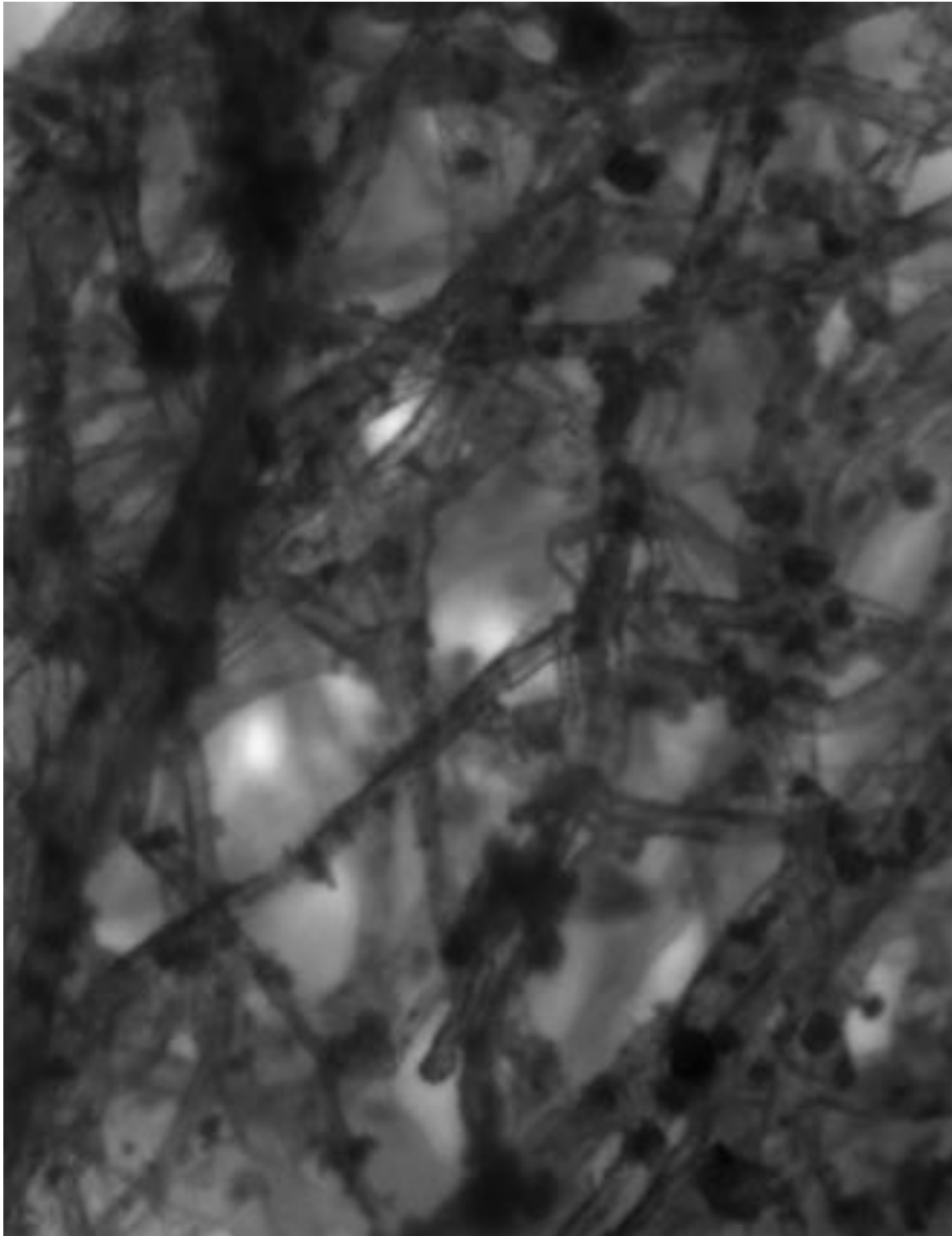


Figure 42 Clean filter contaminated with powder by Dr. Vitha

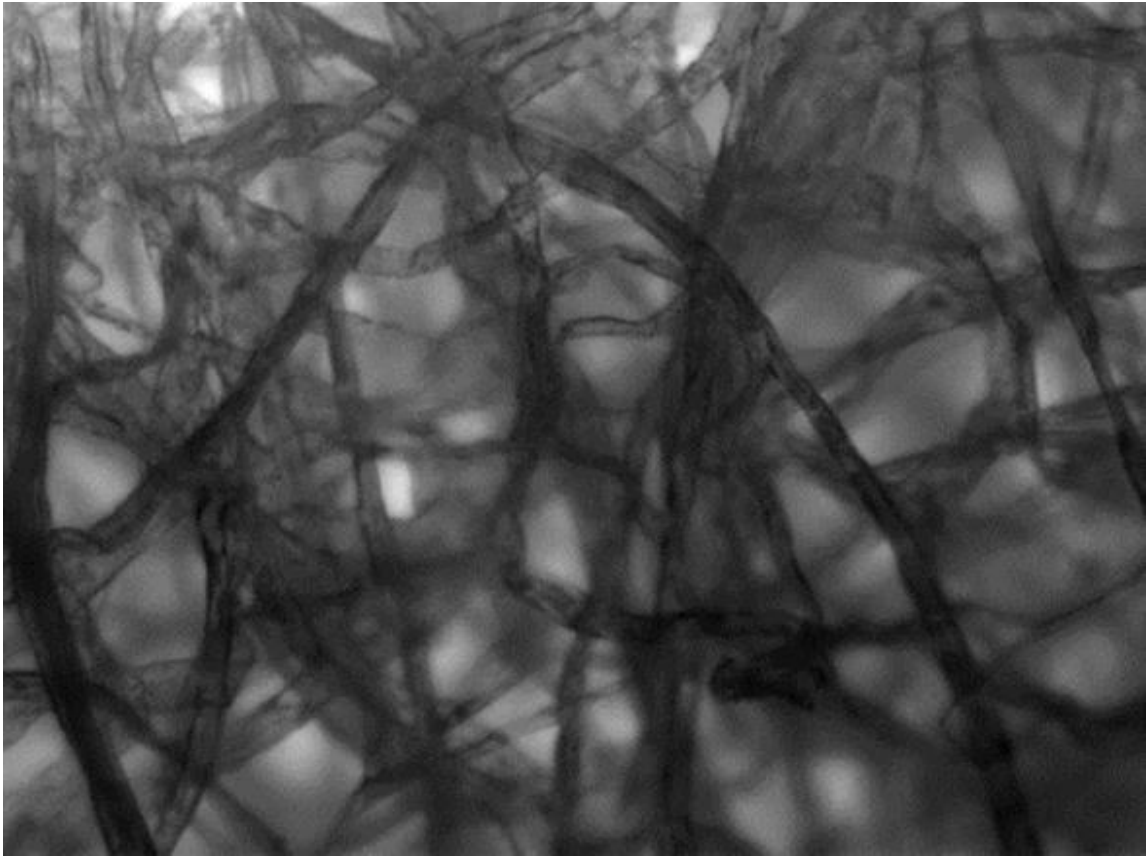


Figure 43 Test one Containment A filter

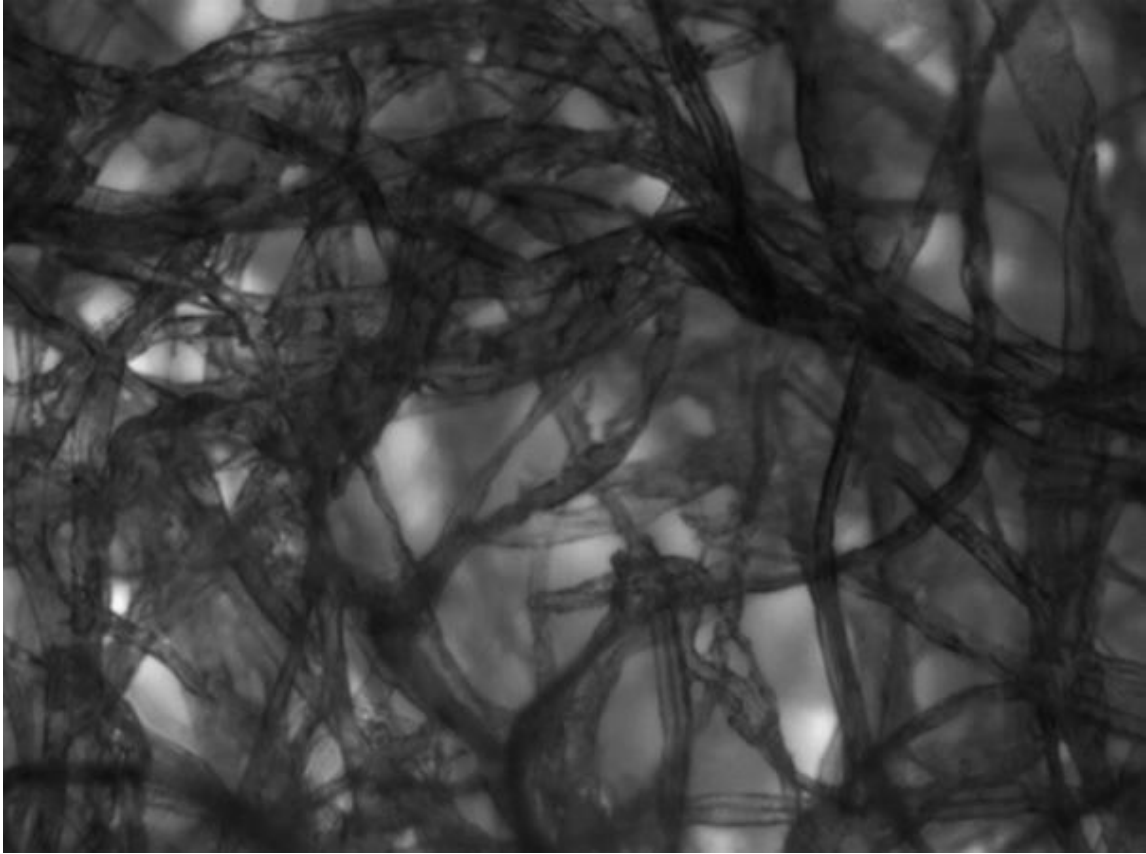


Figure 44 Test one Containment B filter

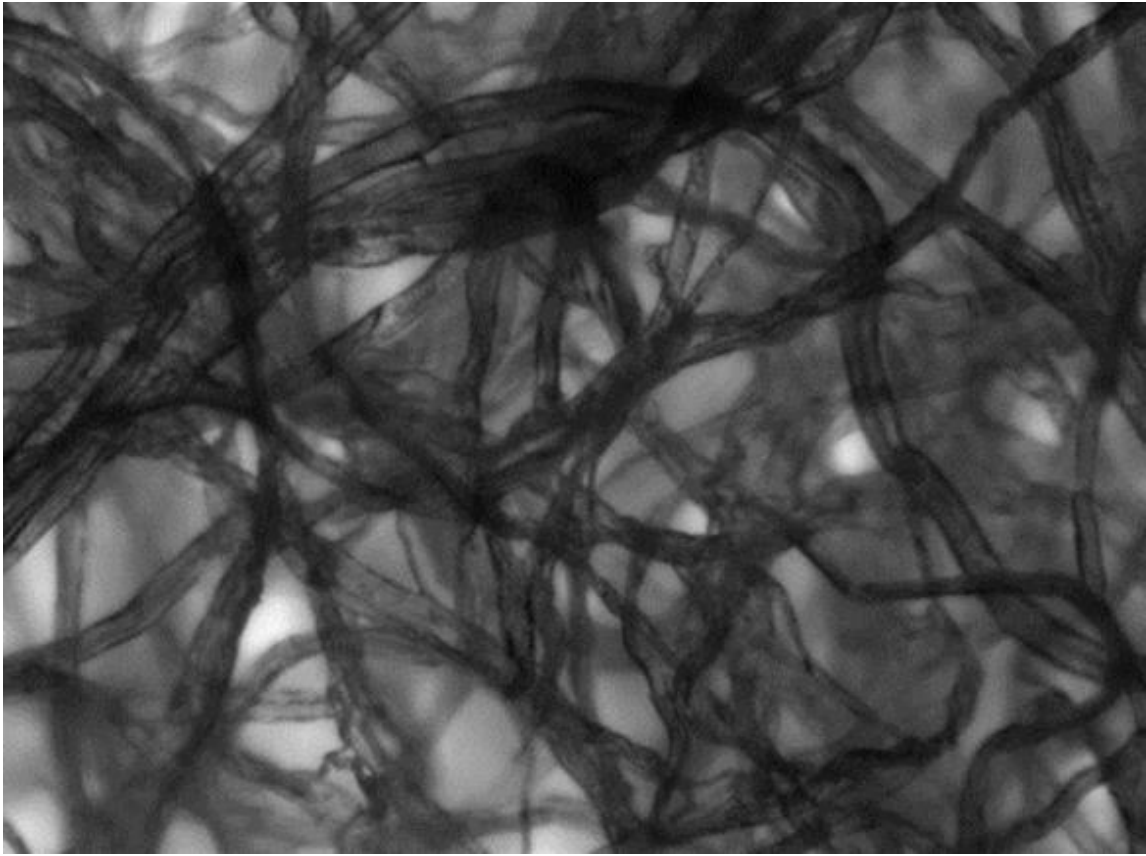


Figure 45 Test two Containment A filter

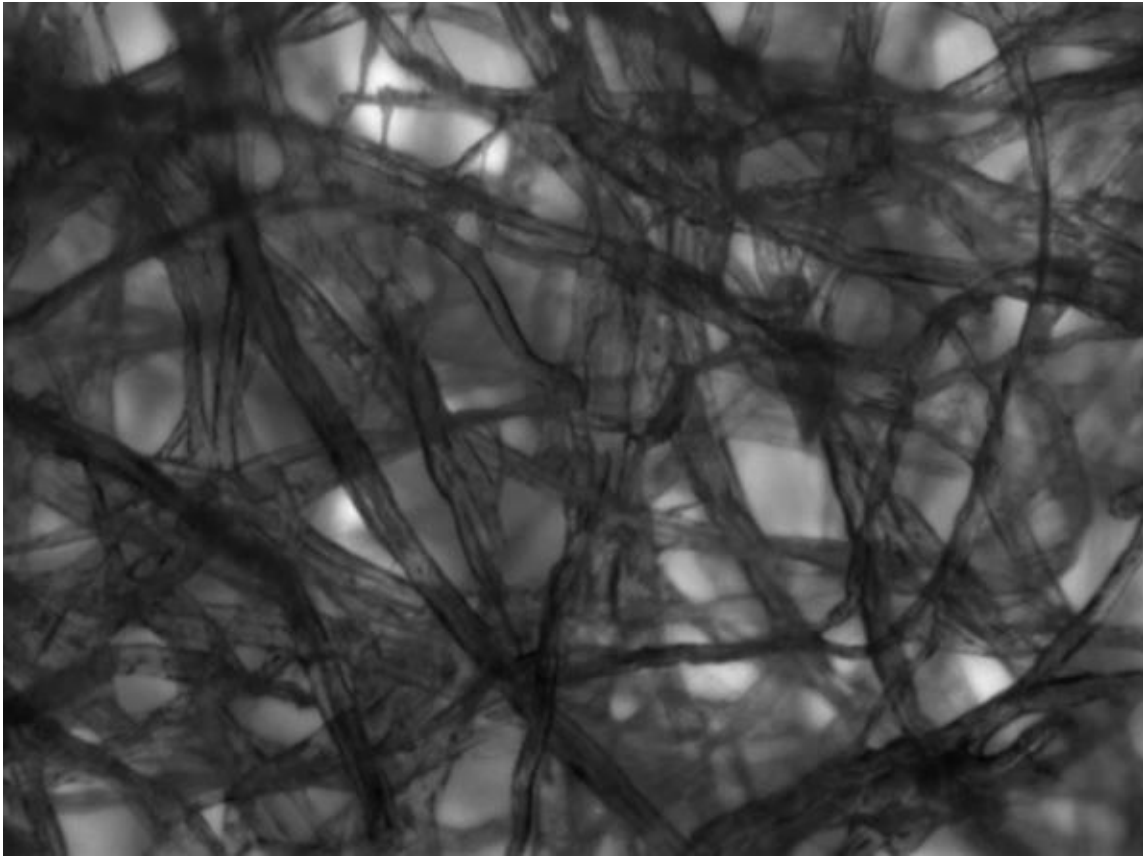


Figure 46 Test two Containment B filter

ANALYSIS OF THE RESULTS

The results show no observable movement of the powder through the barrier in either of the two tests.

The hypothesis is:

A test of construction barrier walls using a differential pressure of 105 kilopascals can be developed that measures particulate matter at a size of 12 micrometres using a count per square millimetre on the output filter of the test system.

The test clearly worked and showed no dust transmission. The hypothesis is not disproven, but further work is required to show a successful set of measurements can

occur for a barrier that does pass particulate matter. This barrier if implemented properly appears to resist dust transmission for at least 18 hours.

CHAPTER V

CONCLUSIONS

SUMMARY

This experiment supports the theory that barrier systems utilized for patient protection in hospitals today have the potential to reduce airborne particles. In this experiment, results of Test One and Test Two do not disprove the original hypothesis:

A test of construction barrier walls using a differential pressure of 105 kilopascals can be developed that measures particulate matter at a size of 12 micrometres using a count per square millimetre on the output filter of the test system.

It would be premature in the testing program to say that the hypothesis is proven. Further work and refinement of the test system is required to confirm the efficacy of the dust barrier system used in this research program.

Microscopic photos reveal no particle transmission on either test, suggesting the barrier was successful in preventing particle transmission. A standard seal procedure utilizing 1 mil Plastic Sheeting and blue painter's tape can result in zero movement of particles of the size 12 microns. Ideally, this experiment represents what could occur in a hospital setting.

With *Aspergillus* prevalent within hospitals today, research of this topic could potentially save lives. Study of particle transmission could lead to a decrease in the rate of patients obtaining nosocomial infections.

No test is perfect, but this is a start of a program to reduce dust transmission.

FUTURE RESEARCH SUGGESTIONS

Further research should focus on *why* individuals continue to obtain nosocomial infections. If soft barriers can prevent transmission of airborne particles:

- then where does the problem lie?
- Are barriers properly installed?
- Are they utilizing the correct procedure for installation?
- Are seals of barrier joints periodically checked and maintained?

Finally, ensuring the barrier remains sealed is critical. Other research suggestions to look at the broader problem are:

- Install fan system in the containment vessel A to model actual wind directly on the plastic barrier
- Run the test for several days to allow drying and flutter damage to occur to the plastic sheeting
- Better seal the exterior surfaces
- Provide a clear viewing surface in each vessel
- Determine the properties of the powder material
- Repeat the test with a much finer powder, say 3 microns
- Examine real world systems and determine the typical level of damage and the operational procedure to improve correlation of results from the experiment to the real world
- Standardize the test
- Determine the properties and class of the filter used in the tests

- Improve the measurement procedure for the particulate matter that ultimately passes the filters
- Measure the differential pressure between Vessel A and B throughout the tests
- Measure the inlet air pressure with a greater accuracy and determine the actual volume of air per minute being placed into the system
- Determine any leakage areas and seal them
- Standardize the reporting and relate it to a real situation
- Compare the test to other standard test systems

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