A STUDY OF DUST MOVEMENT THROUGH CONSTRUCTION BARRIERS

A Thesis

by

WEI ZHANG

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	John M. Nichols
Committee Members,	Edelmiro Escamilla
	Kevin T. Glowacki
Head of Department,	Joseph P. Horlen

December 2014

Major Subject: Construction Management

ABSTRACT

Airborne infection agents can and do infect patients who have a lung disease or who are coping with a weakened immune systems or in some circumstances otherwise apparently healthy people. A rise in the rate of fungal infection for a particular class of immunosuppressed patients occurred in the last few decades as the medical system improved treatment and reduced mortality rates for a number of common and previously fatal medical conditions. Fungal infection agents are opportunistic and ubiquitous. Fungal infection agents potentially derive from three sources in a hospital setting, from the air handling system, from any construction activity and from the normal hospital operations. These sources were termed Source S-AH, Source S-CA and Source S-NO for this research work respectively. Source S-AH and S-NO are always present in the hospital setting, Source S-CA requires construction activity in or near the hospital. This research work studies the movement of dust particles that can transport *Aspergillus* spore. Previous research demonstrated that a well-constructed barrier could stop the movement of dust particles from a contaminated to a non-contaminated side. However, it is not practical to completely isolate construction activity in a hospital setting from a patient cohort; the practical step is to reduce the incidence of spore movement on dust through openings in the construction barriers. This research studies the movement characteristics of dust through an opening in a construction barrier in a test rig that models a construction site in a laboratory setting. The results demonstrate movement of the dust occurs with the provision of an opening in a plastic construction wall. The filter

collection system analysis showed that the distribution of the dust did not follow a uniform pattern but showed concentrations in a few locations on the filter. The location on the filter directly beneath the door showed a five-fold total concentration when compared to an area beneath the recirculating fan inlet. The conclusion reached is the airflow direction coupled with random Brownian motion impacts on the concentration of dust particles. The hypothesis is false. Future research should be directed at understanding the physical issues of the dust movement in a room setting and developing a finite element model of the test arrangement.

DEDICATION

Thanks to my parents and my professors for their encouragement.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Nichols, and my committee members, Dr. Escamilla, and Dr. Glowacki, for their guidance and support throughout the course of this research.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. I also want to extend my gratitude to Jim Titus at the Texas A&M Woodshop; without your help and the use of your facilities this project would not be possible.

Finally, thanks to my mother and father for their encouragement.

NOMENCLATURE

AIA	American Institute of Architects
IA	Invasive Pulmonary *Aspergillosis*
IPA	Pressure
IAQ	Indoor Air Quality
ICRA	Infection Control Risk Assessment
EPA	Environmental Protection Agency
S-AH	Air Handling System - Contaminant Source
S-NO	Hospital Normal Operations - Contaminant Source
S-CA	Construction Activity - Contaminant Source
DCR	Dust Contaminated Construction Region
CR	Clean Region
CFU	Colony Forming Unit of Fungi

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION

BACKGROUND

Bassett (2013) commenced the study of dust movement through construction barriers at TAMU. This early work showed that a plastic barrier without openings effectively controlled the movement of dust from a contaminated region (DCR) to a relatively clean region (CR). Bassett's work used an experimental system developed to model air movement in a construction zone. This research work extends this earlier work to incorporate an opening into the dust barrier to model door openings into construction zones. This thesis outlines the literature review for the study, the methodology used for the experimental work and the analysis methods, the results and conclusions.

This chapter presents the problem statement, research objectives; hypothesis used for the central question and outlines the study limitations and assumptions and establishes the significance of the study. The central element to the study is to determine if dust moves through an open door at a rate that can be measured using standard experimental equipment.

PROBLEM STATEMENT

The problem statement is that a measurement can be made within ± 2 mg/L of the movement of dust particles through a model of a damaged construction wall of typical Texas construction used in real hospitals.

RESEARCH OBJECTIVE

The study's object is to test the efficacy of construction barriers utilized in healthcare facilities for patient protection from the movement of dust that can carry fungal spores.

HYPOTHESIS

A measurement can be made of the transmission of dust through a standard Texas hospital construction wall to an accuracy of 2 mg/L.

STUDY LIMITATIONS

The study limitations are:

- the Aspergillosis infection is not only caused by the number of spores, but also depends on the response of the patients' immune systems. So calculating the number of Aspergillus spores is part of the infection evidence
- the study equipment calibration is adequate
- The model box is a reasonable representation of a hospital area

The study assumptions are:

- the powder's transmission could be measured and matches the hospital dust transmission rates
- the powder's properties and size is similar to hospital dust
- to simulate the 90 meters per second wind storm, the study inlet pressure is 105 kilo Pascals, which is higher than the average wind speed data in the USA

SIGNIFICANCE OF THE STUDY

There is a rapid and continual development of hospitals throughout the world as the population ages in many areas and because of increased Gross Domestic Product for most countries. These hospitals often have ongoing construction in very limited areas of space. Figure 1 shows a typical barrier system used to limit the movement of dust between a dusty or DCR and the clean or CR areas in a hospital undergoing expansion or renovation. The issue is not that these barrier systems cannot prevent the movement of dust, they can as shown by Bassett (2013), but that openings are required that may allow the transmission of dust and spores.

Figure 1. Zip Wall System

In this study, an experiment tests the barrier method which can reduce the particulates in the air, with the introduction of an open door into the configuration. The movement of particles through a hole in the wall system is measured in the experimental

work. The result of experiment could be used to improve the environment of hospitals to reduce nosocomial infections, so that it would save more lives.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

Bassett (2013) completed the first study on the use of a containment vessel to model the movement of dust particles through a construction barrier at Texas A&M University. This prior study showed that a plastic barrier prevented the movement of dust through the test containment vessel for the nominated test conditions. Bassett recommended further work with a door in place in the barrier wall. The literature review summarizes the previous work at TAMU, considers the causes of fungal infections and looks at the problem of fungal infection control during construction activities in hospitals.

BACKGROUND

A range of nosocomial infections, or hospital-acquired infections acquired by patients during periods of construction in health care facilities is a significant and current health problem. This problem, as Bassett (2013) clearly demonstrates, arose in the last forty years as medical advancement led to a reduced patient mortality rates for diseases that suppressed the immune-system. A number of recent drug advances has reduced the rate of death in immunosuppressed patients, although it still a significant problem (Lugosi et al., 2014).

The Center for Disease Control and groups that develop standards, such as the AIA, provide guidance on the design of hospitals with the intention of reducing the

incidence of infection in hospital patients (Centers for Disease Control and Prevention, 2009, 2012, 2013, 2014; The American Institute of Architects, 2006). However, infections still occur at a rate that some consider medically unacceptable (Vonberg & Gastmeier, 2006).

DEFINITIONS

The definitions of interest in this work are:

- *Aspergillus*: *Aspergillus* spp. and in particular *Aspergillus fumigatus* are large genus of ubiquitous filamentous fungi, representing up to 40% of hospital and home fugal contamination. They play an essential role in recycling environmental carbon and nitrogen. *Aspergillus* spores are liberated in great amounts during construction and renovation work. The spores' diameter is about 2 to 3 μm, so it's small enough to reach deep into the lungs
- *Aspergillosis*: *Aspergillosis* is a kind of disease that caused by *Aspergillus*. People who suffer from lung disease or have weakened immune systems are susceptible to acquire the Aspergillosis infection
- PM2.5: Particles with diameter less than 2.5 micrometers are called "fine" particles. These particles are small enough to go deep into human lungs, causing illness. *Aspergillus fumigatus* and *Aspergillus nige*r are the common fungal types
- Infection Control: Preventing nosocomial or healthcare-associated infection is the most important part of Infection Control. Infection Control studies the factors related to the spread of infections within the healthcare setting which included

patient-to-patient, from patients to staff and from staff to patients, or among-staff. Prevention, monitoring, investigation and management are the main concerns of Infection Control

- Barrier: It's one of the main methods for infection control. They're the first defense line to prevent the spread of *Aspergillus*. During the construction activity, barriers are used to divide the hospital into two areas – construction area and treatment area.

HOSPITAL CONSTRUCTION

Every year, the healthcare construction work, including renovation and new construction, cost nearly $10 billion within the USA. Seventy percent of the work is renovation, which increases the patient cohorts risk to fungal infections from spores carried on the dust generated by the construction activities.

Healthcare facility managers, engineers and construction managers should know more about the infection control during construction so as to minimize patient risk from infections caused by airborne pathogens (Charney, 2010).

INDOOR AIR QUALITY

IAQ has become one of the most important environmental health problems for modern medicine and in homes (Riley, Freihaut, Bahnfleth, & Karapetyan, 2004). According to the study, there are two main causes of IAQ problems:

- poor or inadequate ventilation
- exposure to one or more contaminant sources in the building (Riley et al., 2004)

More than 2 million patients a year are infected in U.S. hospitals from entering hospital for another medical problem. The direct or indirect result is 88,000 unnecessary deaths. Construction and maintenance activities cause 5,000 of these deaths. IAQ is occupying an increasing part of the focus on reducing deaths in hospitals.

INFECTION CONTROL RISK ASSESSMENT

An ICRA is a process which considers the health care program, activities and the number of facility's patients. ICRA focuses on:

- reducing the risk of infection
- activities of the lifecycle including facility planning, design, construction, renovation, facility maintenance
- coordinates and weighs knowledge about infection, infectious agents, and care environment, permitting the organization to anticipate potential impact

According to the 2006 AIA Guidelines (The American Institute of Architects, 2006), there are three elements of an ICRA: design, construction and mitigation (Premier Inc., 2014).

Two important features are taken into consideration in the design of hospital areas:

- the planning should be a "long-range planning", both for new construction and renovation
- through the lifetime of the facility, "finishes and surfaces" is a new element of the design at all stages

Six aspects need to be considered during construction:

- impact of disrupting essential services to patients and employees
- determination of the specific hazards and protection levels for each patient
- location of patients by susceptibility to infection and definition of risks to each
- impact of potential outages or emergencies and protection of patients during planned or unplanned outages, movement of debris, traffic flow, cleanup, and testing and certification
- assessment of the impact and extent of external as well as internal construction activities
- determine the location of known hazards

In terms of infection control risk mitigation the following steps are recommended:

- during the construction period, the patients should be relocated, although sometimes this is difficult or problematic
- between the construction and non-construction site, a barrier or other protective methods are needed to prevent the movement of dust and other hazardous materials
- measurement of risk could mitigate the risk of patients' infection
- after all the work is complete for the barriers and other measures, the most important for the ICRA panel is the inspection of the installation of

infection control measurements and monitoring of the effectiveness of the measures throughout the construction period.

One of the widely accepted tools for assessment of risk is the ICRA matrix. It could improve the management of patient groups for non-staff without specific diagnoses. Figure 2 shows the first stage in the development of a ICRA matrix system.

TYPE A	**Inspection and Non-Invasive Activities.** Includes, but is not limited to: ▪ removal of ceiling tiles for visual inspection only, e.g., limited to 1 tile per 50 square feet ▪ painting (but not sanding) ▪ wallcovering, electrical trim work, minor plumbing, and activities which do not generate dust or require cutting of walls or access to ceilings other than for visual inspection.
TYPE B	**Small scale, short duration activities which create minimal dust** Includes, but is not limited to: ▪ installation of telephone and computer cabling ▪ access to chase spaces ▪ cutting of walls or ceiling where dust migration can be controlled.
TYPE C	**Work that generates a moderate to high level of dust or requires demolition or removal of any fixed building components or assemblies** Includes, but is not limited to: ▪ sanding of walls for painting or wall covering ▪ removal of floorcoverings, ceiling tiles and casework ▪ new wall construction ▪ minor duct work or electrical work above ceilings ▪ major cabling activities ▪ any activity which cannot be completed within a single workshift.
TYPE D	**Major demolition and construction projects** Includes, but is not limited to: ▪ activities which require consecutive work shifts ▪ requires heavy demolition or removal of a complete cabling system ▪ new construction.

Figure 2. Type of Construction Project Activity, after Premier Inc. (2014)

The second stage is to identify the patient risk groups. Figure 3 shows an analysis of a simple hospital into the risk groups of interest to the development of an ICRA.

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 ▪ Laboratories (specimen) ▪ Medical Units ▪ Newborn Nursery ▪ Outpatient Surgery ▪ Pediatrics ▪ Pharmacy ▪ Post Anesthesia Care Unit ▪ Surgical Units	▪ Any area caring for immunocompromised patients ▪ Burn Unit ▪ Cardiac Cath Lab ▪ Central Sterile Supply ▪ Intensive Care Units ▪ Negative pressure isolation rooms ▪ Oncology ▪ Operating rooms including C-section rooms

Figure 3. Patient Risk Groups, after Premier Inc. (2014)

The third step is the development of the infection control matrix. Figure 4 shows a sample of the infection control matrix.

	Construction Project Type			
Patient Risk Group	**TYPE A**	**TYPE B**	**TYPE C**	**TYPE D**
LOW Risk Group	I	II	II	III/IV
MEDIUM Risk Group	I	II	III	IV
HIGH Risk Group	I	II	III/IV	IV
HIGHEST Risk Group	II	III/IV	III/IV	IV

Figure 4. Classes of Patient Precautions, after Premier Inc. (2014)

When the project is belongs to Class III or Class IV, infection control approval will be required for the hospital areas affected during the work. The fourth stage is the development of the required infection control procedures for each class of patient. Figure 5 shows a sample set of procedures.

	During Construction Project	Upon Completion of Project
CLASS I	1. Execute work by methods to minimize raising dust from construction operations. 2. Immediately replace a ceiling tile displaced for visual inspection	1. Clean work area upon completion of task.
CLASS II	1. Provide active means to prevent airborne dust from dispersing into atmosphere. 2. Water mist work surfaces to control dust while cutting. 3. Seal unused doors with duct tape. 4. Block off and seal air vents. 5. Place dust mat at entrance and exit of work area 6. Remove or isolate HVAC system in areas where work is being performed.	1. Wipe work surfaces with cleaner/disinfectant. 2. Contain construction waste before transport in tightly covered containers. 3. Wet mop and/or vacuum with HEPA filtered vacuum before leaving work area. 4. Upon completion, restore HVAC system where work was performed.
CLASS III	1. Remove or Isolate HVAC system in area where work is being done to prevent contamination of duct system. 2. Complete all critical barriers i.e. sheetrock, plywood, plastic, to seal area from non work area or implement control cube method (cart with plastic covering and sealed connection to work site with HEPA vacuum for vacuuming prior to exit) before construction begins. 3. Maintain negative air pressure within work site utilizing HEPA equipped air filtration units. 4. Contain construction waste before transport in tightly covered containers. 5. Cover transport receptacles or carts. Tape covering unless solid lid.	1. Do not remove barriers from work area until completed project is inspected by the owner's Safety Department and Infection Prevention & Control Department and thoroughly cleaned by the owner's Environmental Services Department. 2. Remove barrier materials carefully to minimize spreading of dirt and debris associated with construction. 3. Vacuum work area with HEPA filtered vacuums. 4. Wet mop area with cleaner/disinfectant. 5. Upon completion, restore HVAC system where work was performed.
CLASS IV	1. Isolate HVAC system in area where work is being done to prevent contamination of duct system. 2. Complete all critical barriers i.e. sheetrock, plywood, plastic, to seal area from non work area or implement control cube method (cart with plastic covering and sealed connection to work site with HEPA vacuum for vacuuming prior to exit) before construction begins. 3. Maintain negative air pressure within work site utilizing HEPA equipped air filtration units. 4. Seal holes, pipes, conduits, and punctures. 5. Construct anteroom and require all personnel to pass through this room so they can be vacuumed using a HEPA vacuum cleaner before leaving work site or they can wear cloth or paper coveralls that are removed each time they leave work site. 6. All personnel entering work site are required to wear shoe covers. Shoe covers must be changed each time the worker exits the work area.	1. Do not remove barriers from work area until completed project is inspected by the owner's Safety Department and Infection Prevention & Control Department and thoroughly cleaned by the owner's Environmental Services Dept. 2. Remove barrier material carefully to minimize spreading of dirt and debris associated with construction. 3. Contain construction waste before transport in tightly covered containers. 4. Cover transport receptacles or carts. Tape covering unless solid lid. 5. Vacuum work area with HEPA filtered vacuums. 6. Wet mop area with cleaner/disinfectant. 7. Upon completion, restore HVAC system where work was performed.

Figure 5. Required Infection Control Precautions by Class, after Premier Inc. (2014)

ASPERGILLUS

Aspergillus is a fungus who normally lives in soil, where it widely distributed and is often present in dust. *Aspergillus* spore has a diameter from 2 to 3 μm. Each spore is small enough to reach the lung alveoli. Their small sizes also keep spores airborne both indoors and outdoors, although dust carrying the spores can settle tolerably quickly in air as shown in the analysis by Bassett (2013).

The spores are not normally harmful to a person who has a normal immune function as shown in Figure 6. It plays an essential role in the environment which can recycle carbon and nitrogen. However, people who have lung disease or have weakened immune status are susceptible to *Aspergillus* infection.

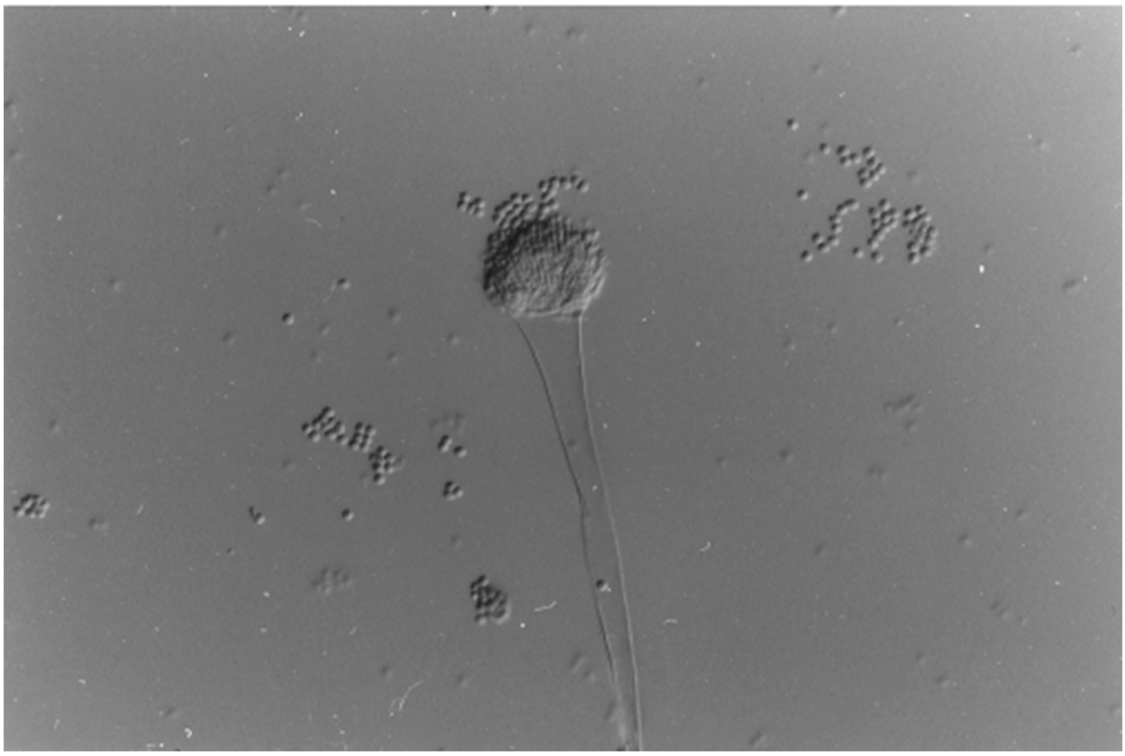

Figure 6. Light Microscopy of Typical *Aspergillus Fumigatus,* after Latge (1999)

Recently, *Aspergillus fumigatus* has become the most prevalent airborne fungal infection agent. It causes many severe and fatal invasive infections especially in the developed countries. As Latge (1999) notes:

"*In 1992, invasive infections (IA) was responsible for approximately 30% of fungal infections in patients dying of cancer, and it is estimated that IA occurs in 10 to 25% of all leukemia patients in whom the mortality rate is 80 to 90%, even when treated.*"

WHO IS AT RISK?

The risk of Aspergillus infection depends on the overall health of a patient. It also depends on the extent of the exposure to the moulds that cause the infection in the patient. The Mayo Foundation for Medical Education and Research. (2014) provides an excellent summary of the risks, provided in total, as follows:

- Weakened immune system: This factor affects the infection risk most. For example, the patients who need to have immune-suppressing drugs when they are after undergoing transplant surgery - especially bone marrow. Some certain cancers of the blood are at the highest risk. People who have later stage AIDS are also at high risk.
- Low white blood cell level: In immune system, white blood cells are the most important role. They are also called neutrophils, fighting fungal infections is their duty. Chemotherapy, an organ transplant or leukemia would lower the neutropenia level. This makes the patients at higher risk of invasive Aspergillosis.

- Lung cavities: *Aspergillus* can develop in the cavities. Cavities are the air spaces in the lungs. When the patients whose cavities are damaged by radiation or by serious lungs, they are at risk.
- Asthma or cystic fibrosis: Asthma or cystic fibrosis relate to higher rate of an allergic response to *Aspergillus* spores. People with lung diseases under long-standing treatment or hard to control are easy to get infected.
- *Ankylosing spondylitis*: This is a kind of uncommon lung disease. People with this disease are easier to infect *Aspergillosis,* especially the man who smoked.
- Long-term corticosteroid therapy: The long-term corticosteroid users have more probability of infection, and different underlying diseases as well as the drugs are being used will affect the probability.
- A hospital stay: People under treatment in the hospital often have immune system, this will increase the risk of infection. When the hospital need renovation or expansion, the construction activities will produce many dust, the *Aspergillus* will release into the dust. The surfaces in the hospital such as ceilings, stairs and air conditions exist many spores.
- Genetic makeup: Some genetic problems will also increase the risk of *Aspergillosis*.

PREVIOUS STUDIES

Significant research activity has shown that there's a direct relationship between the risk of nosocomial infection for hospital patients and construction. Malik, Arabzadeh,

and Singh (2008) note that "*Data released by the U.S. National Nosocomial Infections Surveillance System show that every year nearly 2 million patients in North America contract an infection in a hospital and about 100,000 die as a result of their infection.*"

One technique to reduce the movement of unwanted materials from a construction to a non-construction site is an access barrier. Access barriers range from the simple available at a local hardware store, such as the ZIPWALL system shown in Figure 1. The very real issue is not the ability of the barriers to resist dust movement, but the need for access from one side to the other side of the wall. This movement results in the disturbance of fungal spores (Reboux et al., 2014) which cause fatal infections in some patient groups. This French research team looked at a 10-year survey of fungal aero-contamination in a French hospital. The conclusions from the study were summarized as

- *Firstly, an alarm threshold of 40 cfu/m3 makes it possible to keep the staff alert without warning them too often (12 times in 10 years, representing only 2.3% of weeks with alarm alerts).*
- *Secondly, whenever A. fumigatus is detected in the Haematology ICU, reinforcement of preventive measures and biocleaning should be implemented.*
- *Finally, monitoring does not prevent all IA cases, but the absence of surveillance could possibly reduce staff vigilance and consequently increase the risk of IFI.*

Nichols (2014) reviewed the data published by this French research team. The data from French paper has been further analyzed using three alternate statistical techniques. The first technique is a simple regression of the count data for the number of diagnosed infections per month for the 69 months. Figure 7 plots the number of diagnoses per month presented as a count histogram.

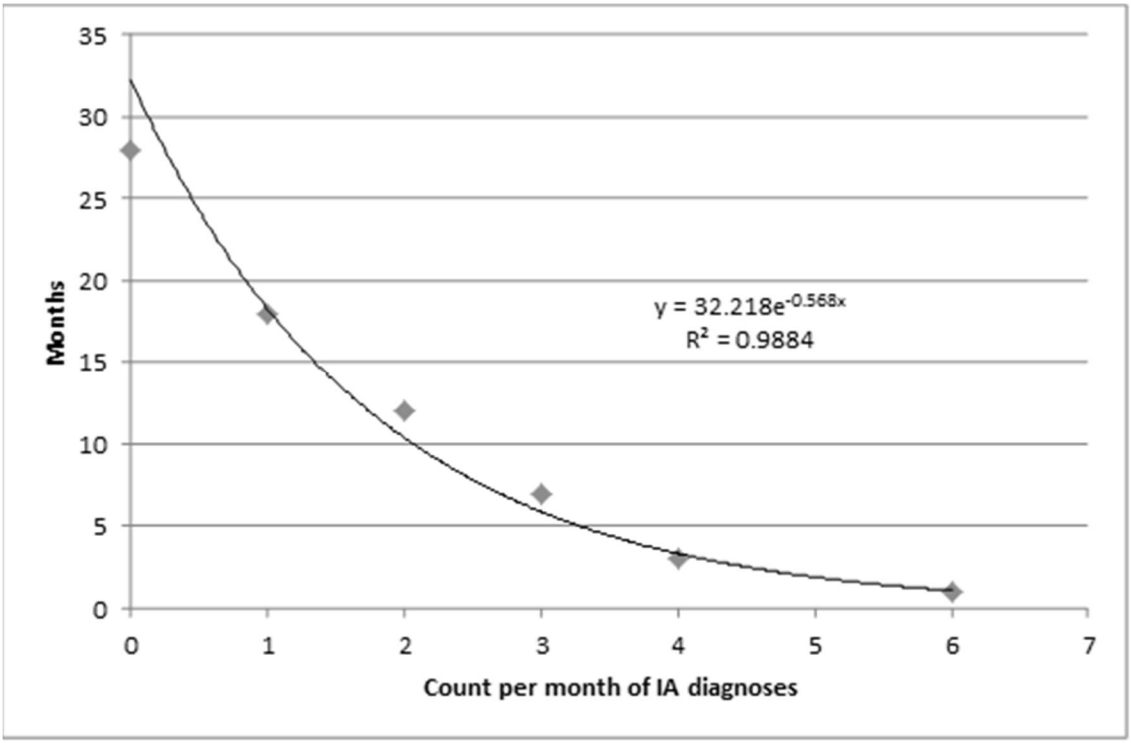

Figure 7. Invasive *Aspergillus* Diagnoses per Month – Count of the Months from 2007 to September 2012.

The result shows a clear statistical model underlies the infection rate, although the model is not normally distributed. Whilst the months with 6 IA diagnoses have a low probability of occurrence they are not rare. One trigger could be the actual incidence of

an IA infection as well as a spore count. As Nichols noted, Kordzakhia (1998) developed a technique using Fast Fourier transforms to review mortality data for earthquakes. Using this technique for this data, the first step is to determine the standard statistical data for the monthly counts for the invasive *Aspergillus* diagnoses, which has a mean value of 1.2. The mean value is subtracted from each of monthly data points to establish the residual data. The second step in the analysis is to complete a Fast Fourier transform of the residual data. The result from a standard Fast Fourier transform analysis of the residual data is shown on Figure 8.

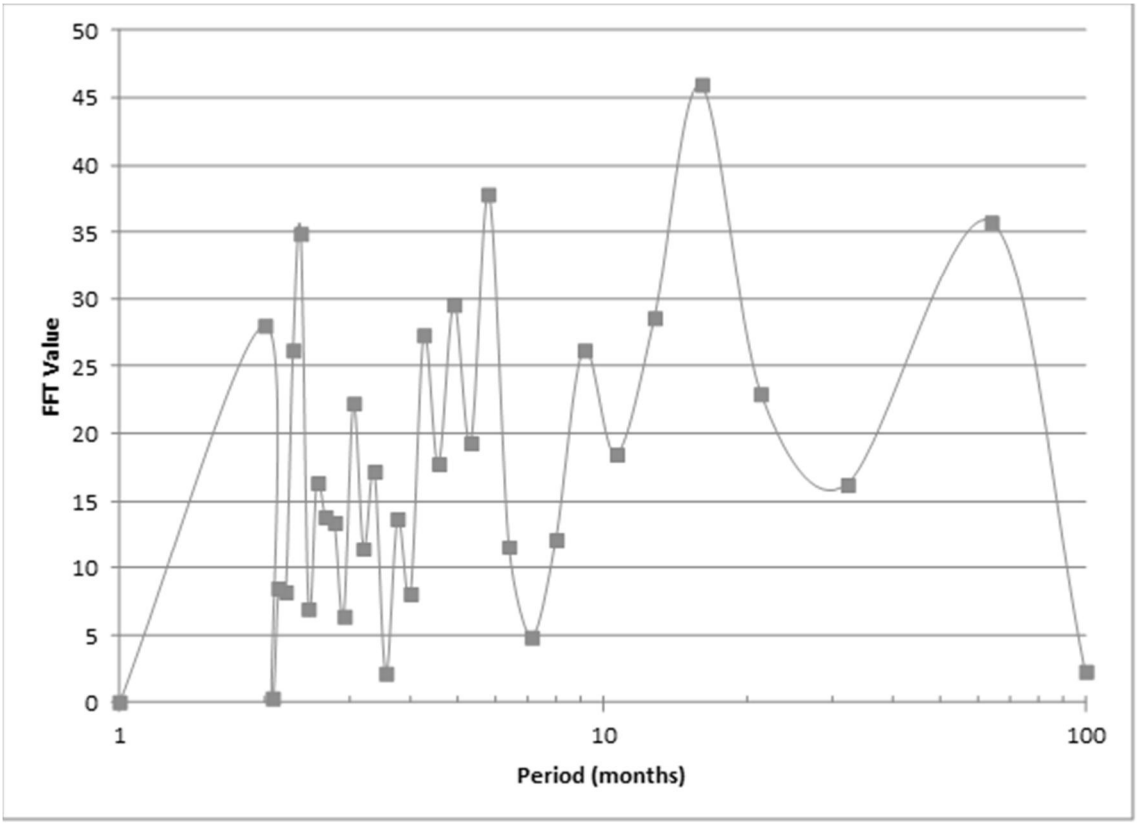

Figure 8. FFT of the Monthly Count Data for Invasive *Aspergillus D*iagnoses

The data was kept to the first 64 months; an alternative of padding the 69 points to the 128 needed for a longer FFT was not undertaken for this data by Nichols. Figure 8 represents a plot of the period rather than the frequency, where the period is the inverse of the frequency. The results show a solid peak on an annual basis, a peak at six months and a peak at two months. The annual peak could be related to weather changes or the construction activity noted in the Reboux paper. The two month peak is interesting and one that requires further analysis of the complete data sets. The conclusions from the original paper really point to the problem of attempting to contain IA infections. The two sets of conclusions point to the need for further research on the design of hospitals. Nichols then used a third technique of counting the time gaps between invasive *Aspergillus* diagnoses. The data from the paper has been counted in terms of the time between diagnoses, so an invasive *Aspergillus* diagnoses in April and another in May is coded as one, a diagnoses in April and the next in June is coded as two and one in April and the next in July to December is coded as three. No results were higher than a 3.

This simple analysis provides a further review of a tragic problem. The issue appears to be caught between the issue of hospital design and infection control. It is interesting to observe that TAMU's Construction Science Department's students read for a Bachelor of Science in Construction Science, but students are not required to take courses in building hospitals and infection control issues, yet these graduates will build many major hospitals or have built many already (Texas A&M University Office of the Registrar, 2014).

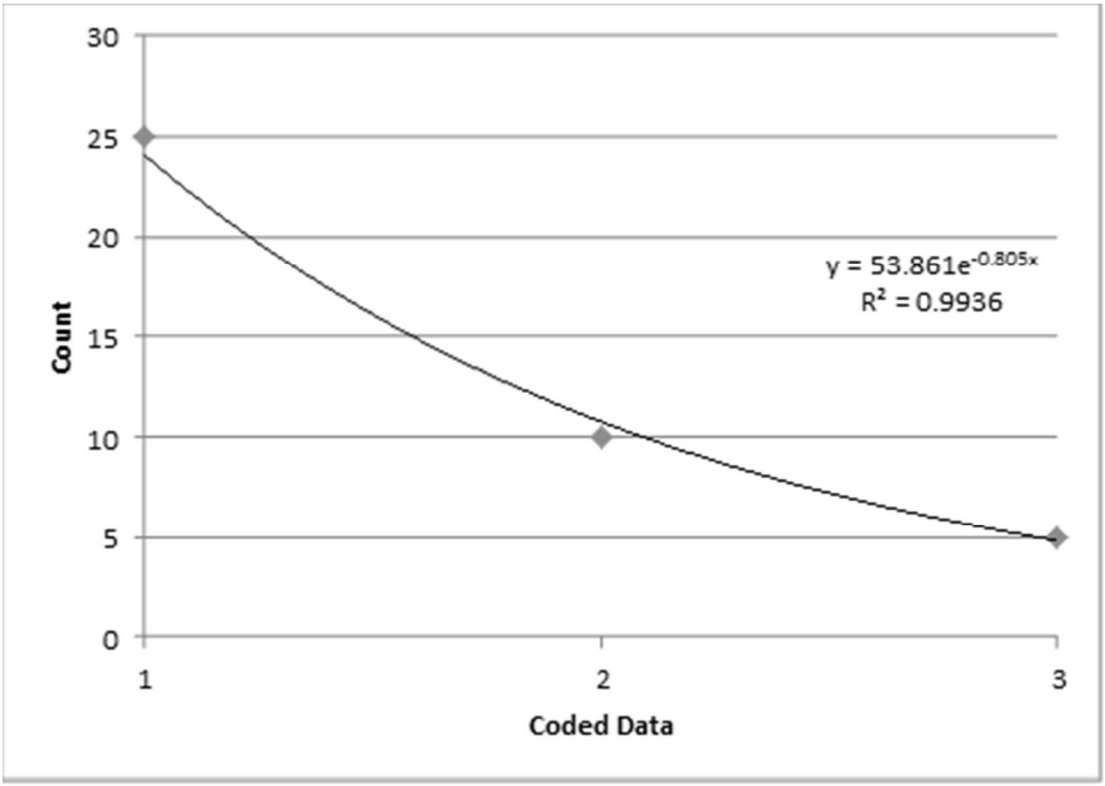

Figure 9. Data for the Interval between Reported Invasive *Aspergillus* Diagnoses

Oren, Haddad, Finkelstein, and Rowe (2001) wrote on an IA problem that occurred between 1995 and 1998. During extensive hospital construction and indoor renovation, a nosocomial outback of invasive pulmonary *Aspergillosis* occurred in acute leukemia patients treated in a regular ward that has only natural ventilation. The observed infection rate was 50%. In another ward, during an on-going construction period, an extremely high incidence rate of invasive pulmonary *Aspergillosis* in acute leukemia patients undergoing intensive chemotherapy was observed by the research team. This team used a specialized air-handling system capable of excluding *Aspergillus*

spores, such as high-efficiency particulate air (HEPA) filtration with or without laminar airflow ventilation. There are three basic types of flow recognized in a fluid or air flow. Laminar flow is where the air travels in a regular fairly undisturbed stream, this usually occurs at low velocity flows. The accepted method for determining the type of flow (Streeter & Wylie, 1979) is the use of the Reynold's number, Re. The formula for the Reynolds number for a duct is:

$$\mathrm{Re} = \rho \frac{du}{\upsilon} \tag{1}$$

Where, ρ is the density of the fluid in kg/m^3, d is the diameter or characteristic length of the pipe or duct, u is the velocity in m/s and υ is the kinematic velocity in m^2/s. A typical range of flow conditions for different flow types is shown in Flow Conditions Description. There is theoretically no upper limit to the turbulent flow, but flows in hospital ventilation systems would be best as laminar flows.

Table 1

Flow Conditions Description

Flow Type	Reynold's Number Lower Limit	Reynold's Number Upper Limit
Laminar	0	2300
Transitional	2300	4000
Turbulent	4000	-

Air sampling, with a slit impactor using impaction on a rotating agar plate, was used to estimate the number of *Aspergillus* spores in different areas in different periods. Counts were obtained from regular rooms of regular wards where acute leukemia (AL) patients were hospitalized during construction periods. The result showed that the intensive chemotherapy method reduced the incidence rate of invasive pulmonary *Aspergillosis*. While keeping patients in a special ward with air filtration through a HEPA system eliminated invasive pulmonary *Aspergillosis* completely.

In the period of 2003 to 2004, major renovation work was carried out in a Florentine hematology unit in Italy, thus increasing the risk of fungal, particularly *Aspergillus*, infections, mainly in patients with acute leukemia during severe neutropenia related to aggressive chemotherapy. Pini, Faggi, Donato, Sacco, and Fanci (2008) studied this problem, the first purpose of the study is to highlight possible risk situations for patients; the second purpose is to correlate any *Aspergillus* infections with the fungal burden.

As noted in the paper:

- looked at two hematology wards on the first floor of a Florentine hospital
- made both a qualitative and quantitative evaluation of fungal burden in the air
- the result showed that in the restricted access rooms:
    - the total mycotic burden was always low
    - the *Aspergillus* burden was even lower

The conclusion reached was the level of environmental isolation (entrance limited to a minimum number of people, a ban on opening windows and so on) was valid. In the study, the *Aspergillus* spore was the most frequently isolated species, but there were no cases directly ascribable to this species.

High concentrations of *Aspergillus* fumigatus occurred along the corridor between wards, coinciding with or immediately after the renovation work. There are extremely low concentrations of *Aspergillus* fumigatus and no case of invasive *Aspergillosis* was documented in the study results. In conclusion, this study suggests a *possible relationship between environmental fungal contamination in hematologic patients and the incidence of invasive Aspergillosis, and also underlines the importance of environmental surveillance*.

Fournel et al. (2010) studied airborne Aspergillus during hospital construction works over 30 months. This study showed the impact of HEPA filters on the concentration of fungi spore or CFU. These authors showed that there was no significant risk associated with construction that could be measured using standard statistical tests as acceptable confidence levels. The results how the efficiency of the HEPA filter in the removal of fungal spores from the air, which is the best indicator a air safe for compromised patients. Table *2* summarizes the key data from the study.

Cornet et al. (1999) results are interested and repeated here: *1,047 air samples and 1,178 surface samples were collected from January 1996 to December 1997. Significantly more air samples were positive for Aspergillus species during the period of building renovation than during the periods before and after renovation in a unit without*

a protected air supply adjacent to the building work area (51.5% vs 31.7%; odds ratio [OR], 2.3; 95% confidence interval [CI95], 1.4-3.7; P<.001). A major increase in the frequency of positive air samples was also found in another adjacent unit that was protected with HEPA filtration alone (from 1.8% to 47.5%; OR, 48.9; CI95, 12-229; P<107). In addition, in this unit, the mean count of Aspergillus conidia in positive air samples increased significantly during construction (4 colony-forming units [CFU]/m3 to 24.7 CFU/m3; P=.04) and the proportion of positive surface samples showed a significant increase during renovation (from 0.4% to 9.7%; OR, 28.3; CI95, 3.4-623; P=104). However, none of 142 air samples collected during renovation in the area protected with laminar airflow plus HEPA filtration showed Aspergillus conidia.

Table 2

Fournel Data for a Florentine Hospital

Air Handling System	Before Work			During Work		
	Positive Culture	Test N	Ratio	Positive Culture	Test N	Ratio
None	58	93	0.62	53	95	0.56
HEPA filtration	0	134	0.00	2	234	0.01
Plasmair	42	248	0.17	85	497	0.17
Aspergillus airborne contamination	100	475	0.21	140	826	0.17

Manuel and Kibbler (1998) provide a summary of the epidemiology and prevention of invasive *Aspergillosis*. This article summarizes the key methods of acquiring the infection and some thoughts on treatment.

BASSETT TEST METHOD AND EQUIPMENT

Bassett (2013) developed a simple test to measure the movement of dust particles through a barrier construction wall. This research showed that a barrier was effective in preventing the movement of dust, which is taken as an indicator for movement by fungal spores. The test arrangement is shown in Figure 10.

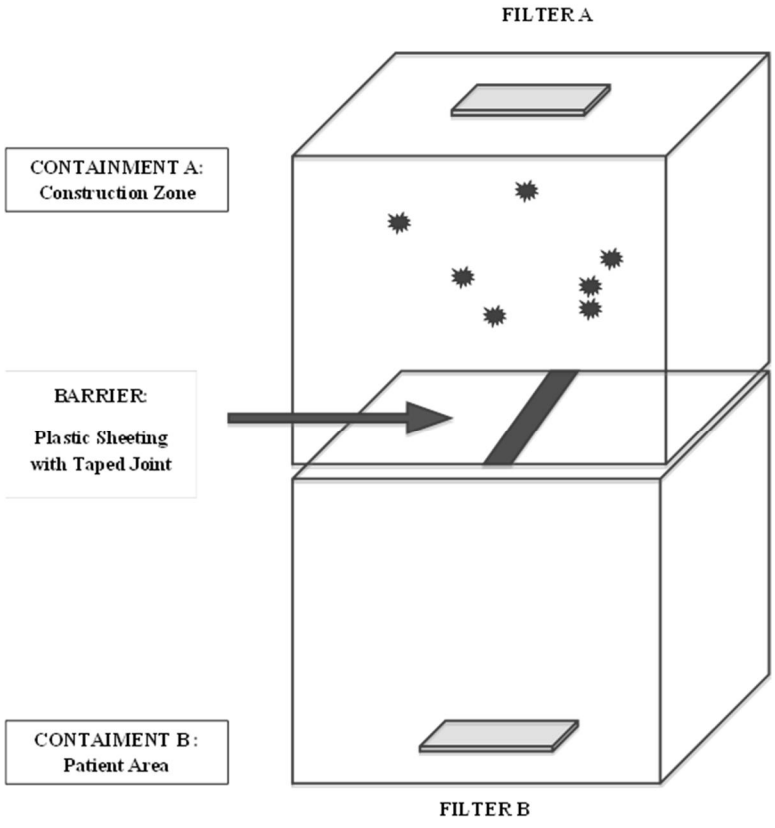

Figure 10. Test Arrangement from Bassett (2013)

TYPES OF BARRIERS

Construction activities disturb dust, the dust released into the atmosphere can act as a transport mechanism for fungal spores. Such contamination raises the risk of infection. In the development of the construction work, the non-construction site areas should be isolated from the construction work.

A project that is small or short duration may generate minimal dust, although not always.

Bartley (2000) provides an excellent summary of the guidelines for projects during construction. The typical findings are:

- projects could use fire-rated plastic sheeting
- should be sealed at full ceiling height with at least 2-foot overlapping flaps for access to entry
- if the project produces moderate to high level of dust, there should be a
    - rigid
    - dust-proof
    - fire-rated barrier walls, such as drywall
- barrier walls require caulked seams
- A large, dusty project needs
    - a place for people to change clothing
    - tool store
    - thus there should be an entry vestibule
        - the entry area needs gasketed door-frames

        - for the full perimeter of walls and wall penetrations, tight seals should be maintained
    - Before construction of the rigid impervious barrier, a temporary plastic barrier should be provided.
    - After the barrier construction is complete, cleaning of the area is needed to minimize dust levels
    - plan of barrier removal to minimize dust dispersal

WALL OPENINGS

The Occupational Safety and Health Standards (Occupational Safety and Health Adminstration, 2014) definition of an opening is:

Opening means a gap or void 30 inches (76 cm) or more high and 18 inches (48 cm) or more wide, in a wall or partition, through which employees can fall to a lower level.

A wall that is 3.44 metres high and 22 metres in length with an opening of 0.76 m by 0.48 m has an opening area of about 5% of the total area.

STANDARDS

There are two key standards for the design of hospitals and the ventilations system. Facility Guidelines Institute. (2010) publish the standard guidelines for the design of health care facilities, these include the ventilation requirements. Charney (2010) provides an excellent series of articles on the safety problems and solutions for modern hospitals. The critical and unaddressed issue is the organizational aspects of hospital construction (Liu, Borman, & Gao, 2014).

SUMMARY

Effective barriers to the movement of fungal spores are plastic sheeting, HEPA filters and HEPA filters combined with laminar air flow.

CHAPTER III

METHODS

INTRODUCTION

This chapter outlines the methods used for the experimental work and the analysis techniques for the data collected by the study. The purpose of this work is to use the Bassett (2013) test system to investigate the movement of dust through a door introduced into a construction barrier. The sections cover equipment design, experimental methods and data collection.

EQUIPMENT DESIGN

The original equipment was developed by (Bassett, 2013) and is shown schematically in Figure 10. The original equipment used by Basset was modified to include a five percent opening in the barrier wall. No other changes were made to the system for this first simple test. No dust passed through the doorway during an 18 hour test that was observable on the filters (Vitha, 2014).

Figure 11 shows the modifications made to the test equipment to provide for the transmission of dust particles. The key point is that in order to eliminate dust the equipment must first allow the transmission of dust under laminar type flow conditions.

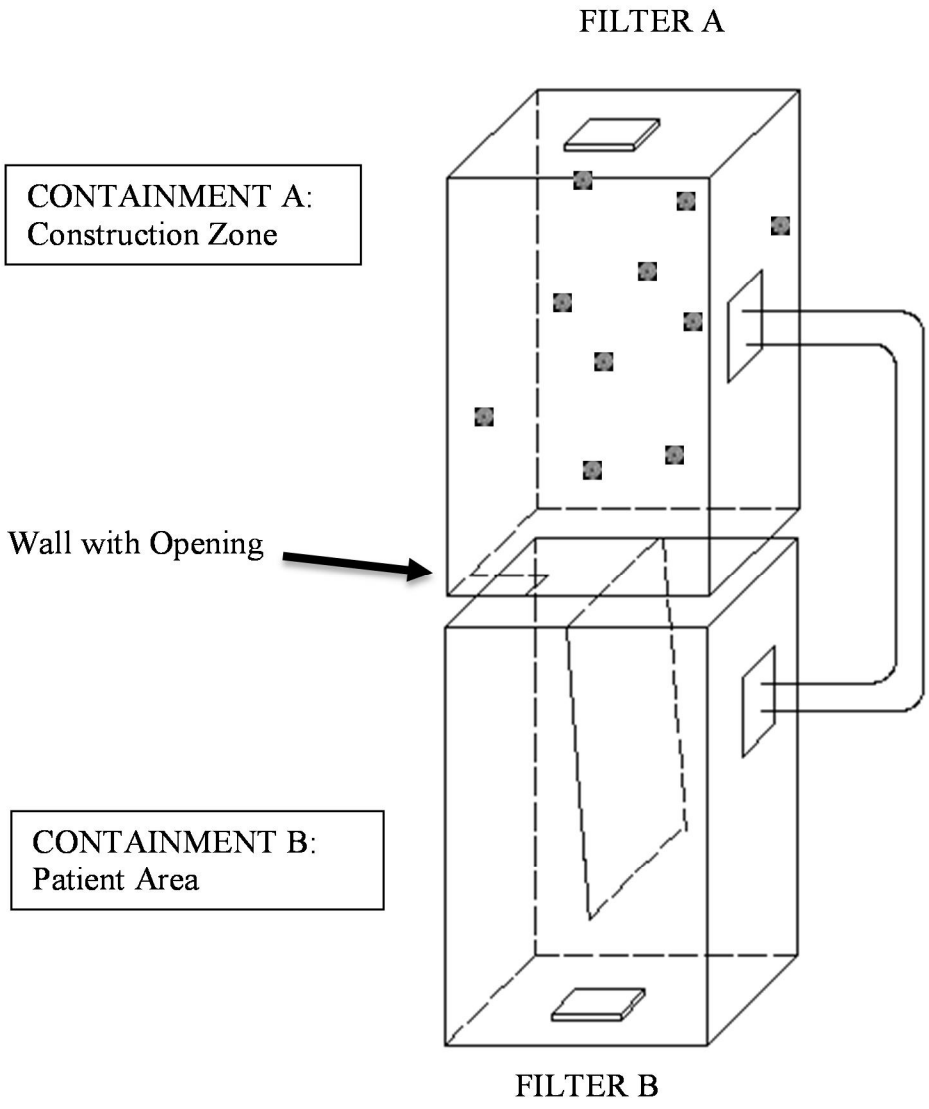

Figure 11. Containment Vessel Design

The revised design is still based on a two Containment A and Containment B vessel with:

- Containment A simulates the construction site into which dust will be released, termed the S_CA
- Containment B simulate the non-construction area of the hospital where patients will be treated here, termed the S_NO
- between the two containments, there is a wall with an opening which is used for simulate the real wall, the door has an opening area of 5% of the model wall
- A fan and a duct are used for simulate the air flow condition in the hospital, to overcome the problem of no movement
- A wall in Containment B will be used to help direct the airflow and prevent short circuiting of the stream.

Figure 12 shows the plan for the wall opening.

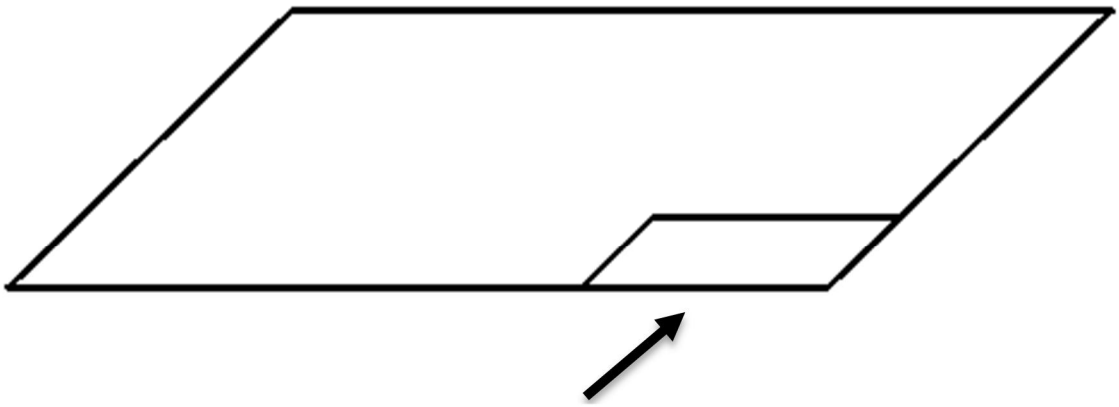

Figure 12. Wall with an Opening

EXPERIMENTAL CONSTRUCTION

The containment vessels are the same as the Bassett Test Arrangement. Figure 13 shows end piece of the units. All dimensions are in mm and the construction is 12 mm plywood.

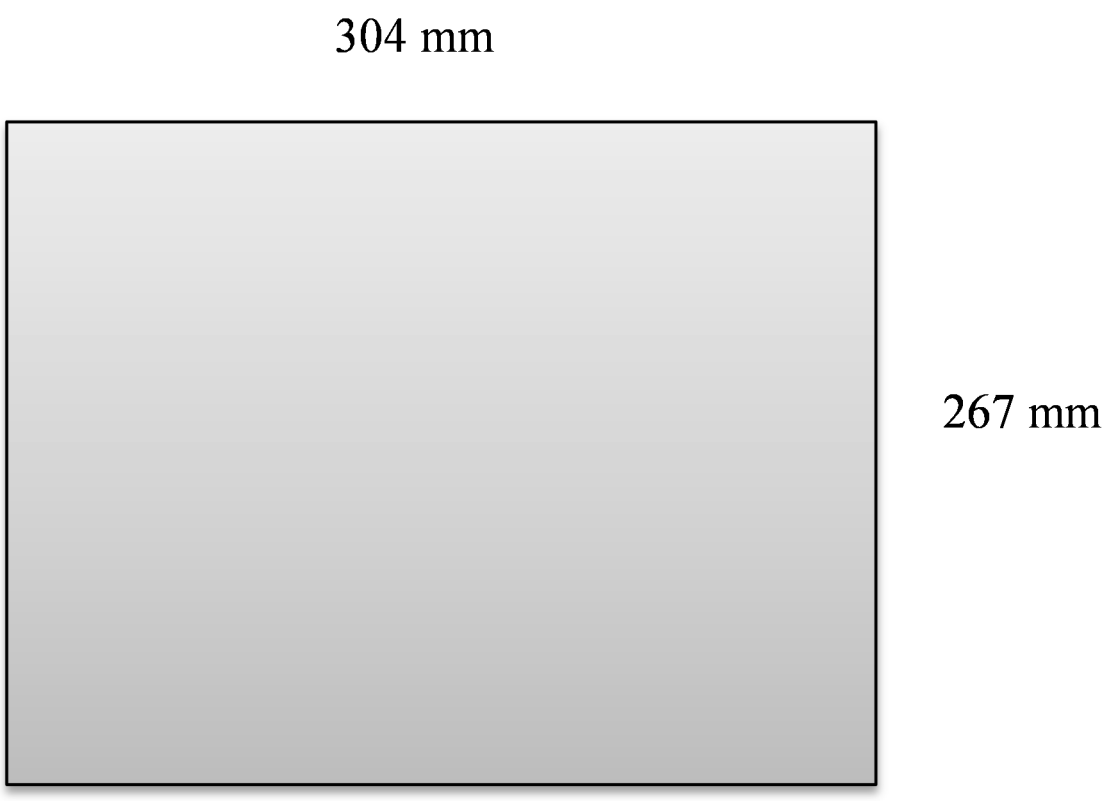

Figure 13. End Piece Dimensions

Figure 14 shows side plate A for the containment vessel.

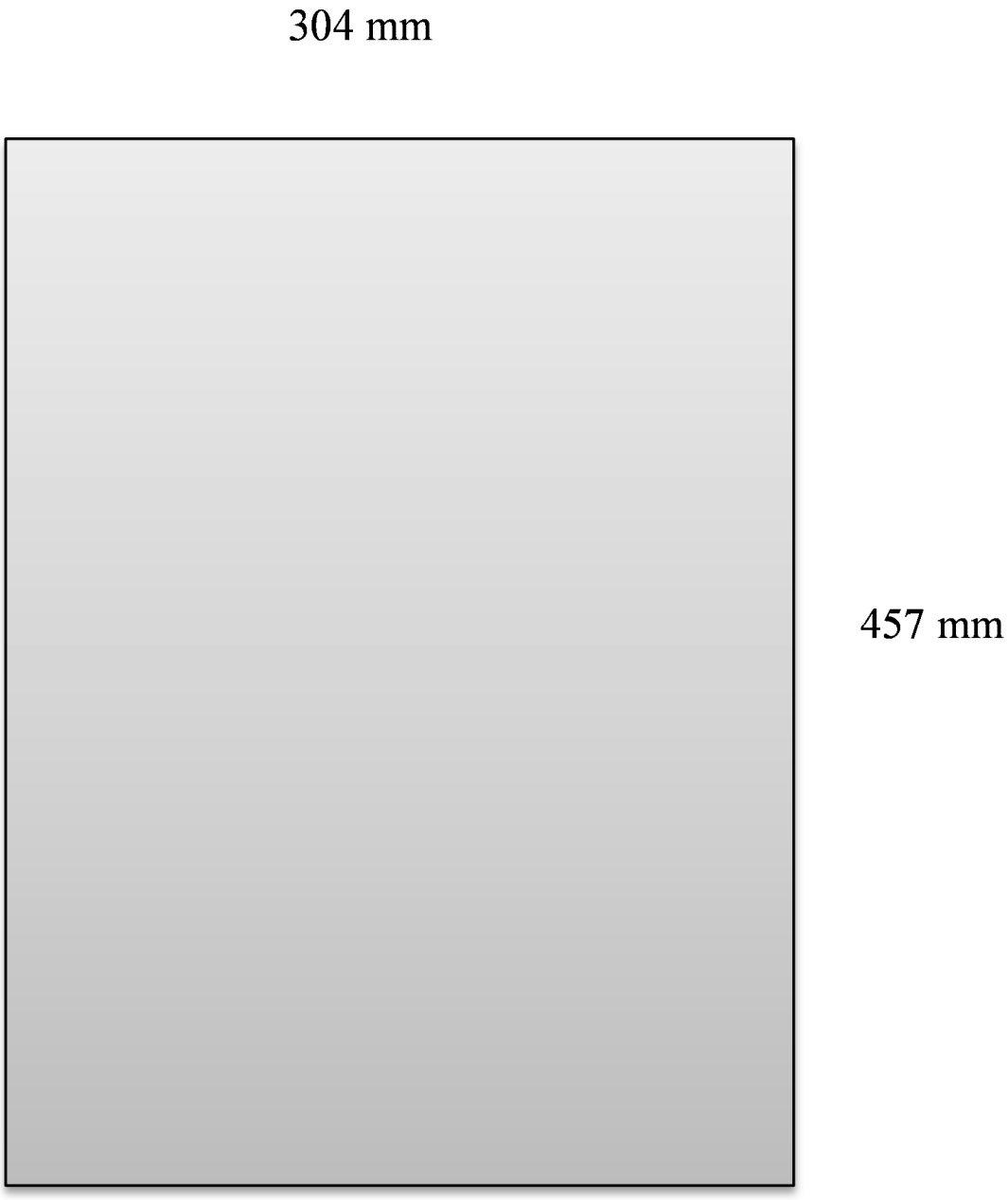

Figure 14. Side Plate A

Figure 15 shows the side plate B for the containment vessel.

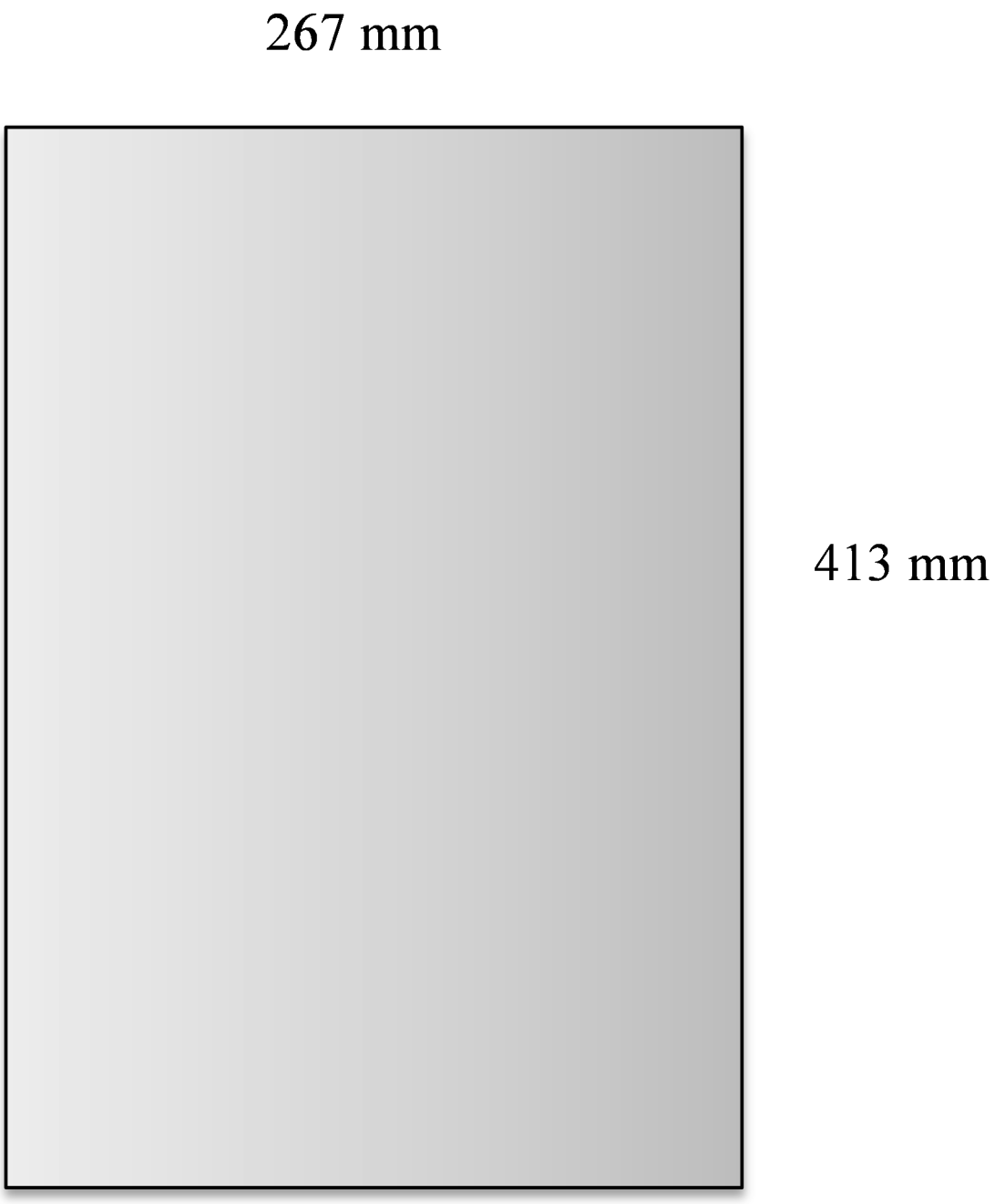

Figure 15. Side Plate B

Figure 16 shows the flange used to hold the wall located between the two containment areas.

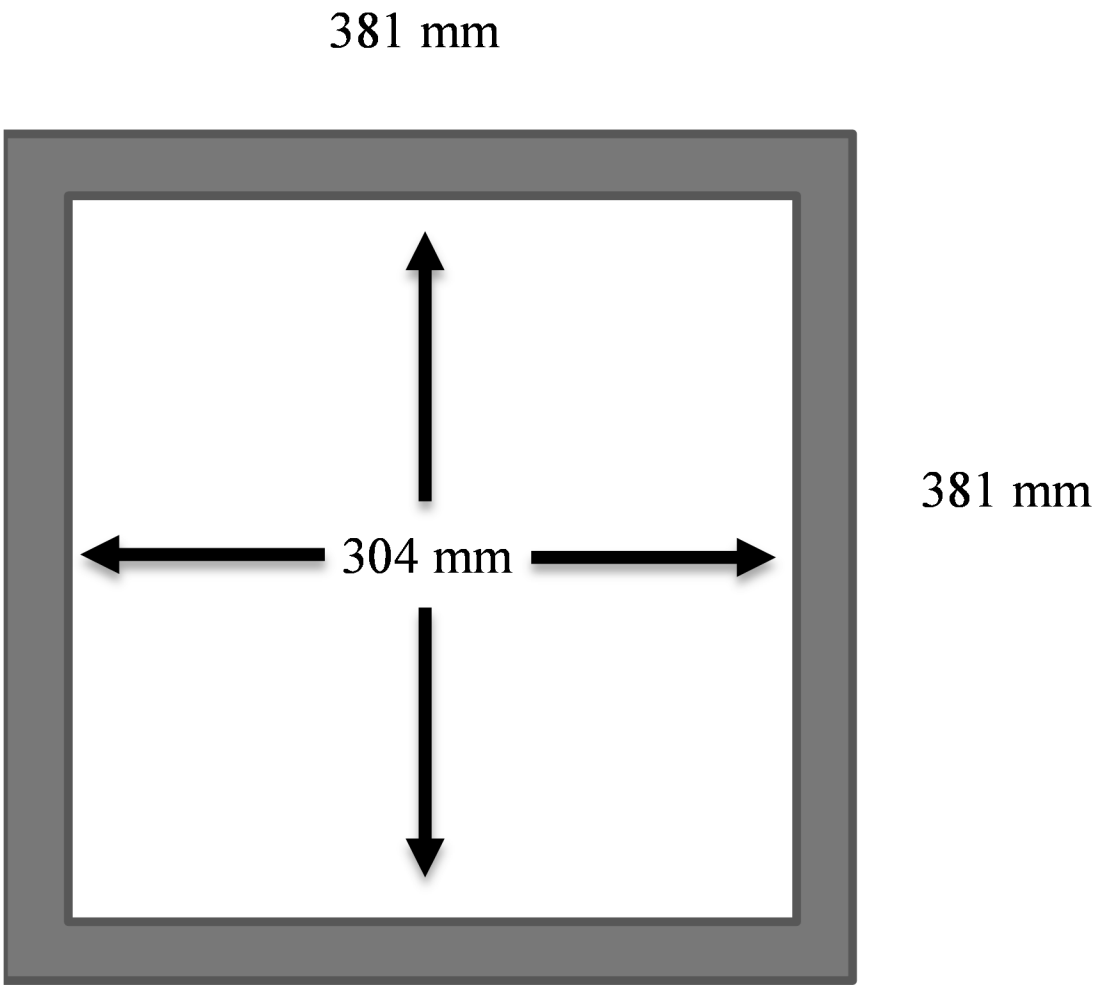

Figure 16. Flange Plate

Figure 17 shows one of the containment vessels prior to the current set of modifications. The fan used for the circulation flow is shown in the picture.

Figure 17. Containment Vessel

Figure 18 shows the sketch of the wall and opening to be placed between the two flanges on the containment vessels. In real hospital, the airflow is more complex than it was in Bassett Test Arrangement. For simulating the airflow, a fan and a duct is placed between the two containments.

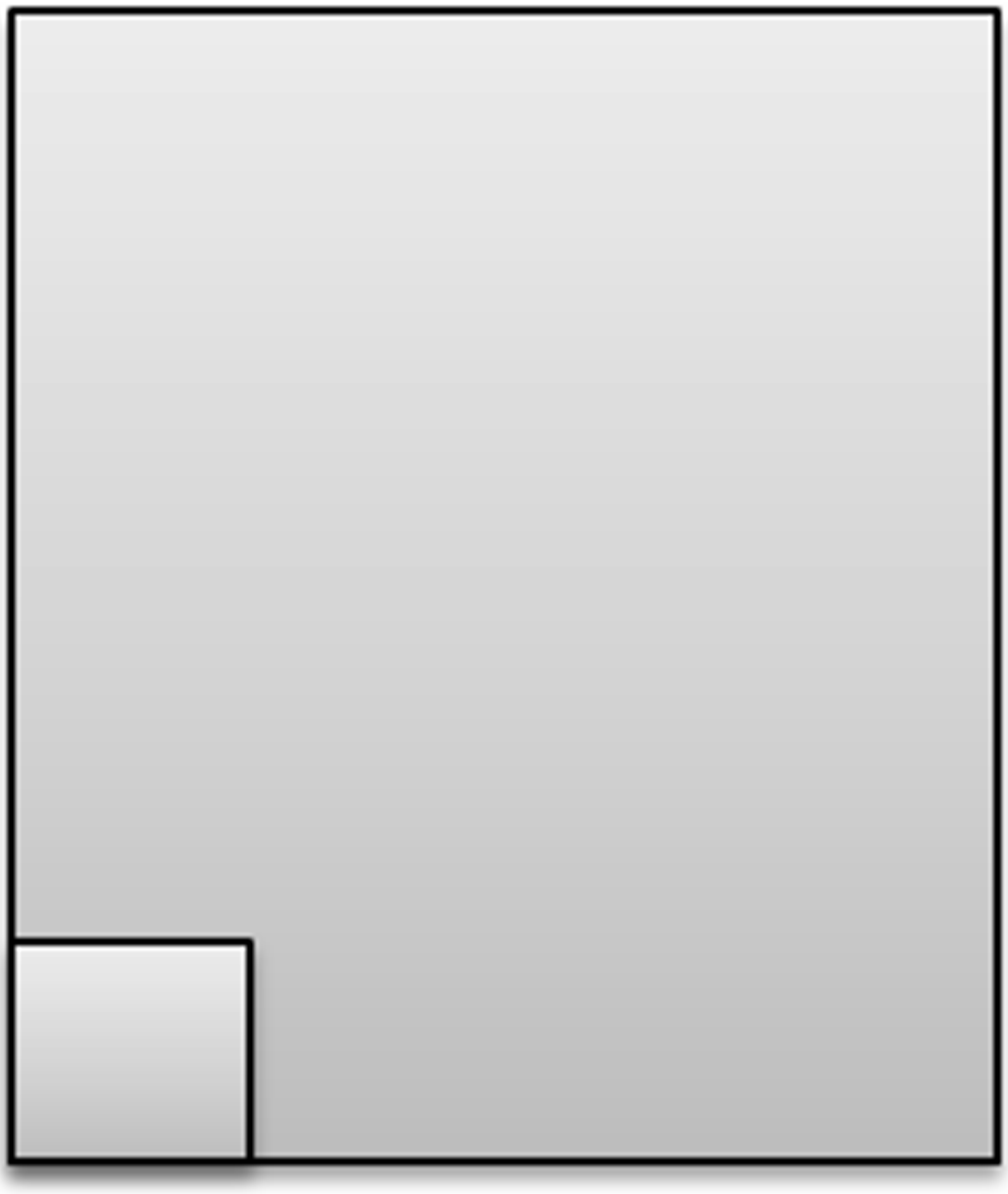

Figure 18. Sketch of Wall with Opening

Figure 19 shows the fan used to generate a circulation in the chambers.

Figure 19. Fan

Figure 20 shows the preparation work to the hole required for the fan placement.

Figure 20. Drilling a Hole in the Containment Vessel for the Fan

Figure 21 shows fan mounted on the vessel.

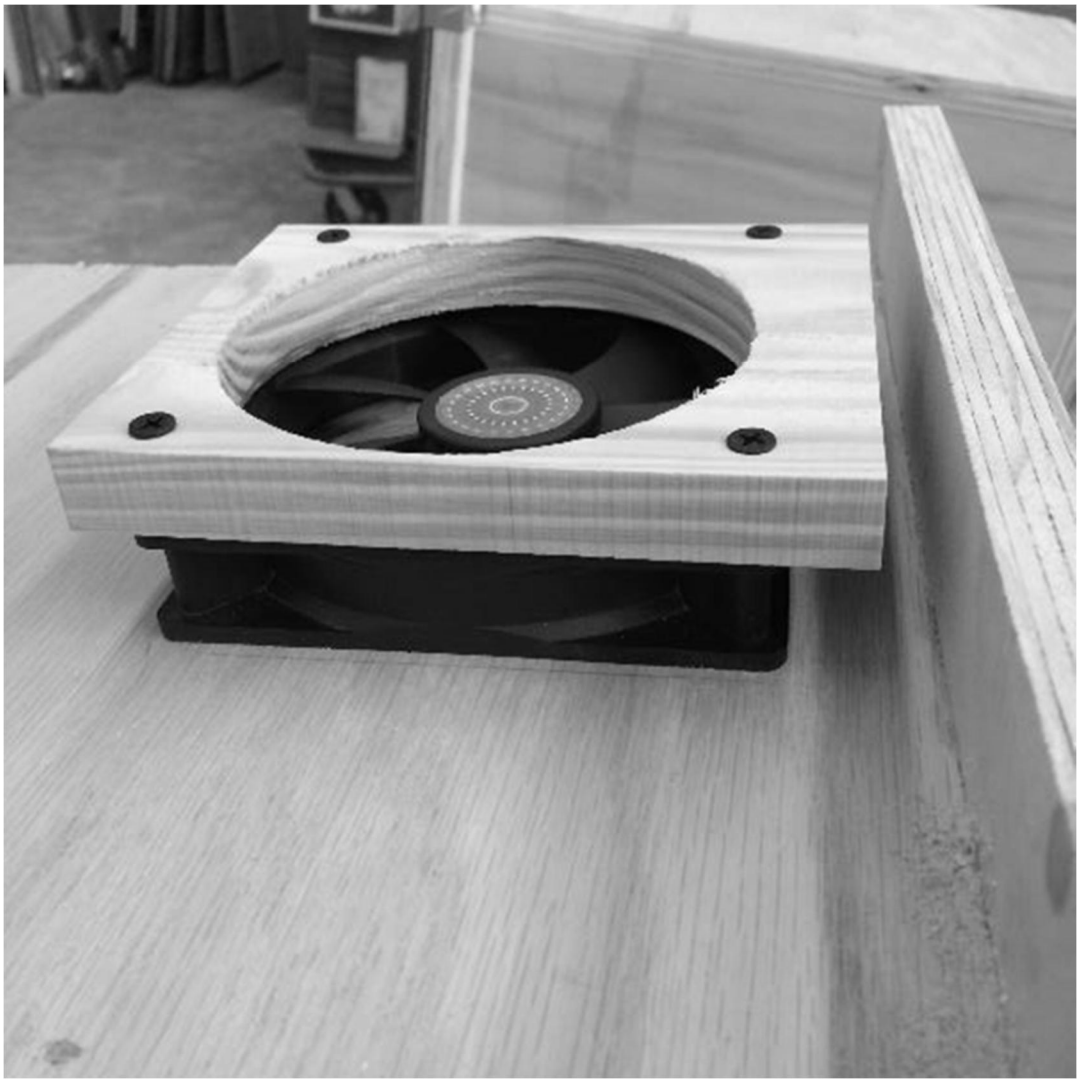

Figure 21. Connection between the Fan and the Containment

The fan is a Rocketfish RF 120 Fan operating at 12 V and 0.16 amps. The fan has a rated duty point of 44 cubic feet per minute or 20.76 litres per second (Rocketfish Inc., 2014).

Figure 22 shows cutting of the pipe for the tube that connects the two containment vessels. The tubing has a diameter of 75 mm.

Figure 22. Cutting the Tube

Figure 23 shows the containment vessels assembled for the testing.

Figure 23. Fan and Duct System

Figure 24 shows the baffle plate used in the Containment B to mitigate the problem of short circuiting of the air current.

Figure 24. Wall in Containment B Vessel

Figure 25 shows an approximate idea of the likely air flow within the containment vessels. It is considered that a simple circulation pattern will develop in containment A, due to the two directions of the inflows.

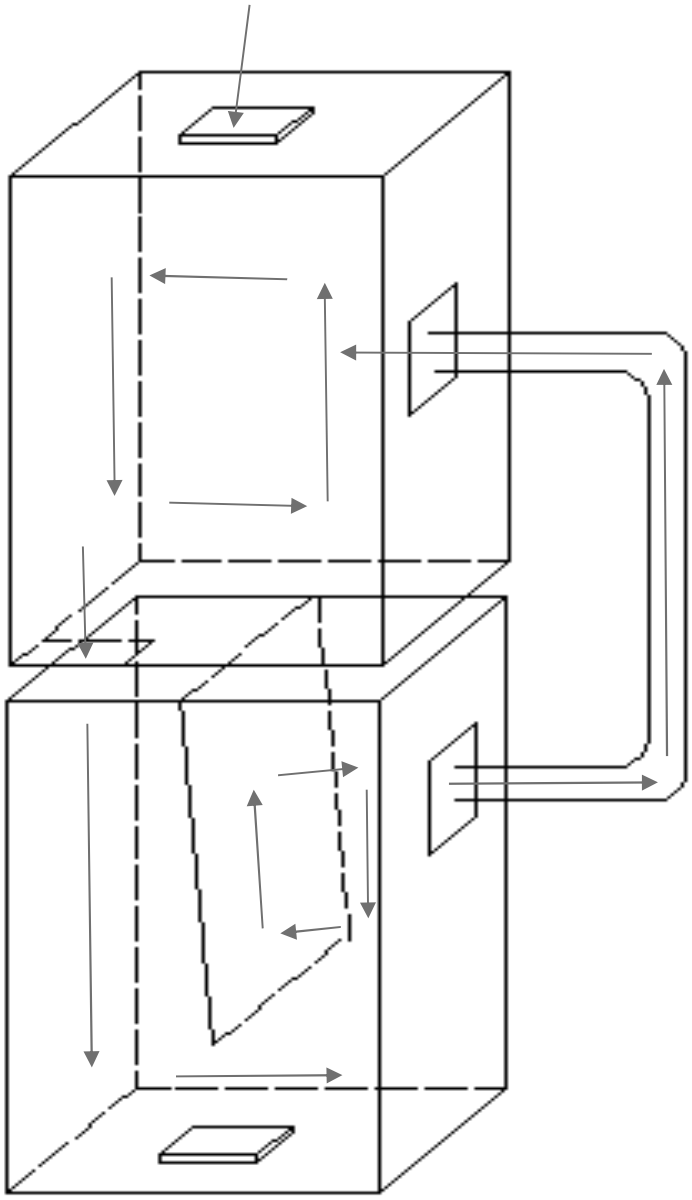

Figure 25. Airflow in the Containment Vessel

Figure 26 shows air pressure gauge used to monitor the inlet air pressure.

Figure 26. Pressure Gauge for Inflow Air

Figure 27 shows the FRAM filter used for the experimental work. The filter is capable of trapping the dust particles used for the experimental work. FRAM group data shows a 5 micron minimum size with a 99% capture efficiency rate.

Figure 27. Filter used in the Experiments

Figure 28 shows the talc powder used as the dust substitute for the experimental work. Bassett (2013) also used the Gold Bond brand, but her sample contained corn starch, this sample contains talc powder. The reason for the change in the brand configuration is not known.

Figure 28. Powder and the Scale

EXPERIMENTAL METHOD

Bassett (2013) tested for a period of between 18 and 24 hours as a result of the constraint imposed by the lab safety rules. The containment vessel is assembled and clamped into position.

The experimental steps are:

- determine the flow rate for the supply side air stream
- place the filters into the correct locations and seal gaskets
- connect the power and ensure circulation between the chambers
- measure the dust to be used for the experimental work
- place the dust inside the containment A using the delivery spout
- seal all edges
- turn on the air to the correct pressure
- test for 18 to 24 hours

Figure 29 shows measurement of 1g of the dust powder.

Figure 29. Measurement of the Dust Mass

Figure 30 shows the placement of the dust in the corner of containment vessel A.

Figure 30. Powder in Position in the Containment Vessel A

The powder needs to be moved by the air stream through the door and onto the air filter in containment B.

Figure 31 shows the air delivery system.

Figure 31. Air Delivery System and Filters

The filter on this air delivery system was changed in December 2012, in accordance with the manufacturers recommended time and procedure. Figure 32 shows the air compressor unit and filter system on the Ingersoll-Rand unit.

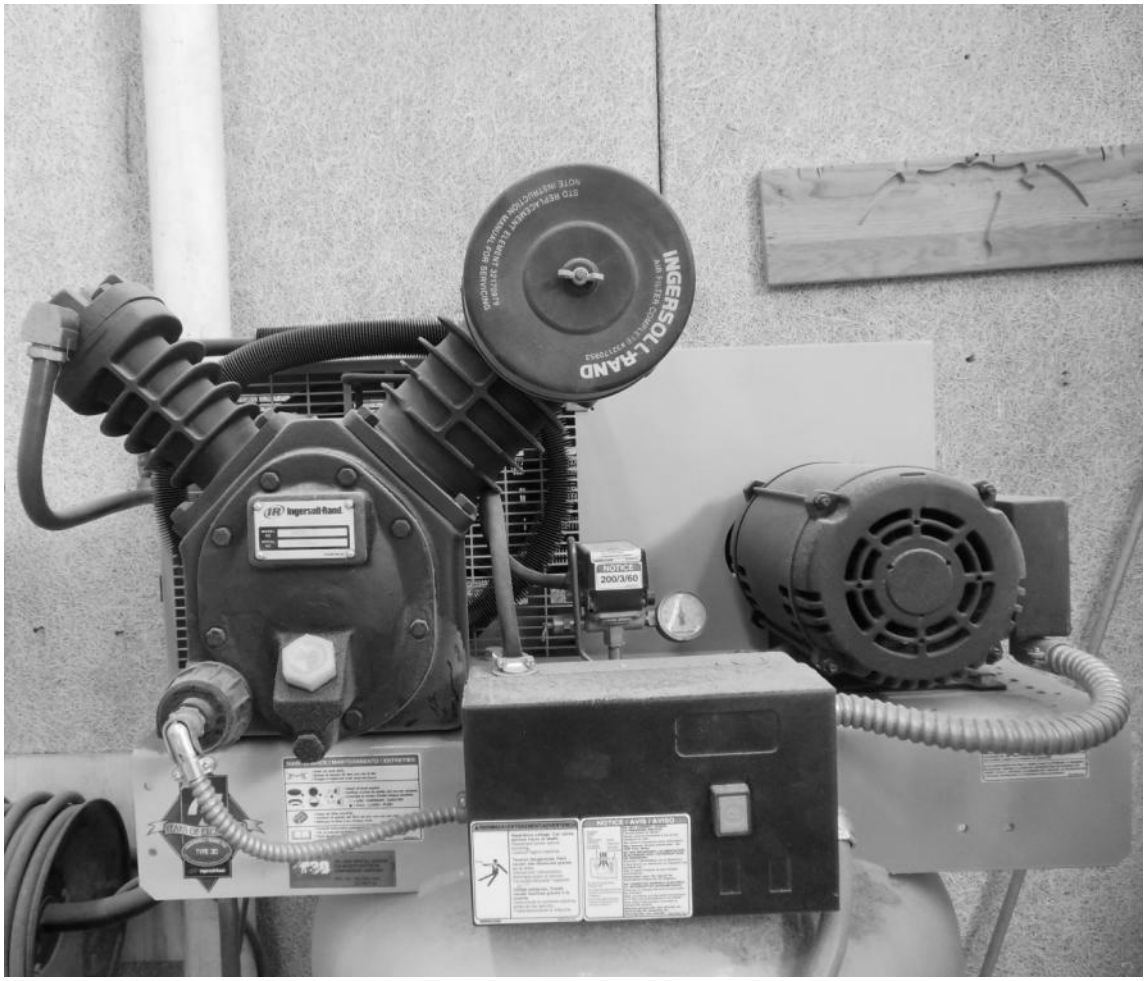

Figure 32. Air Compressor Unit and Filter

Figure 33 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 33. Model Details of the Air Delivery System

Figure 34 shows the completed and assembled unit.

Figure 34. Experimental System set up for Test Run

DATA COLLECTION

This research program included three tests of the system. Table 3 presents the specific details of each test program.

Table 3

Test Program

Test Number	One	Two	Three
Date	26 May 2014	27 May 2014	28 May 2014
Start Time	10 AM	2:00 PM	5:00PM
End Time	10 AM	2:00 PM	5:00 PM
Duration (hours)	24	24	24
Air Pressure (kPa)	105 ± 20	105 ± 20	105 ± 20
Sample (grams)	1.0 ± 0.05	1.0 ± 0.05	1.0 ± 0.05
Arrangement	Open door – no fan	Open door – no fan	Open door fan

At 10:00 am on May 27, 2014, both of the filters were removed and the filter on the bottom was put in a box carefully and taken to the TAMU Microscopy Lab. The first filter was marked as #1. This procedure was repeated for the two subsequent tests number #2 and #3. The containments were cleaned after each test.

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 (2014) 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

RESULTS

INTRODUCTION

This chapter summarizes the results for the experimental work including the photographs and numerical work. The analysis shows that for:

Test 1 and Test 2:

- Opening a door does not lead to dust movement as the first two tests showed no dust movement

Test 3:

- Installing the fan and the baffle, which increased the circulation led to the movement of dust onto the bottom filter

TESTS ONE AND TWO RESULTS

All samples were delivered to the TAMU Microscopy Lab in a sealed bag. Test 1 and 2 showed no movement of dust from the containment vessel A to containment vessel B. The equipment was then modified to include the circulation fan.

TEST THREE RESULTS

Two filters are used for the tests. Filter A is used to clean the inlet air, filter B is used to test for the presence of dust in the outlet air stream. Figure 35 shows the filter arrangement for test 3.

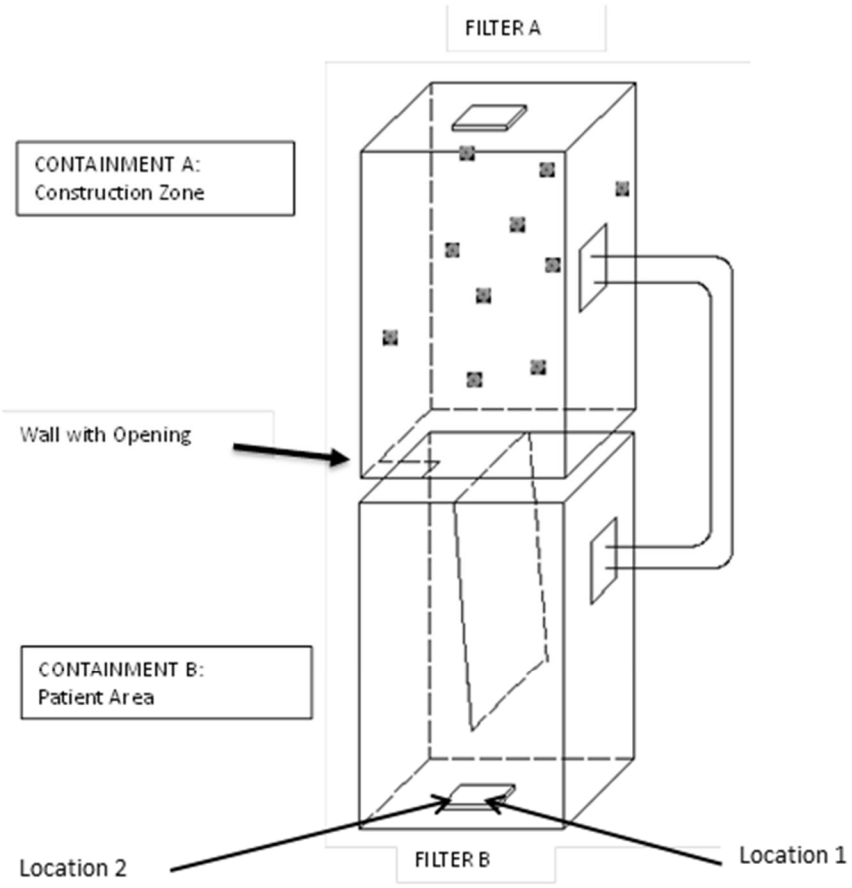

Figure 35. Filter Arrangement for Test Three

The first observation from the filter B from the third test was that the particle density was not uniform across the filter. Two locations were selected to test the particle density. Figure 36 shows the approximate location of the density tests sites. Location 1 is located immediately below the intake for the circulation fan and Location 2 is immediately below the doorway with a air stream moving downwards.

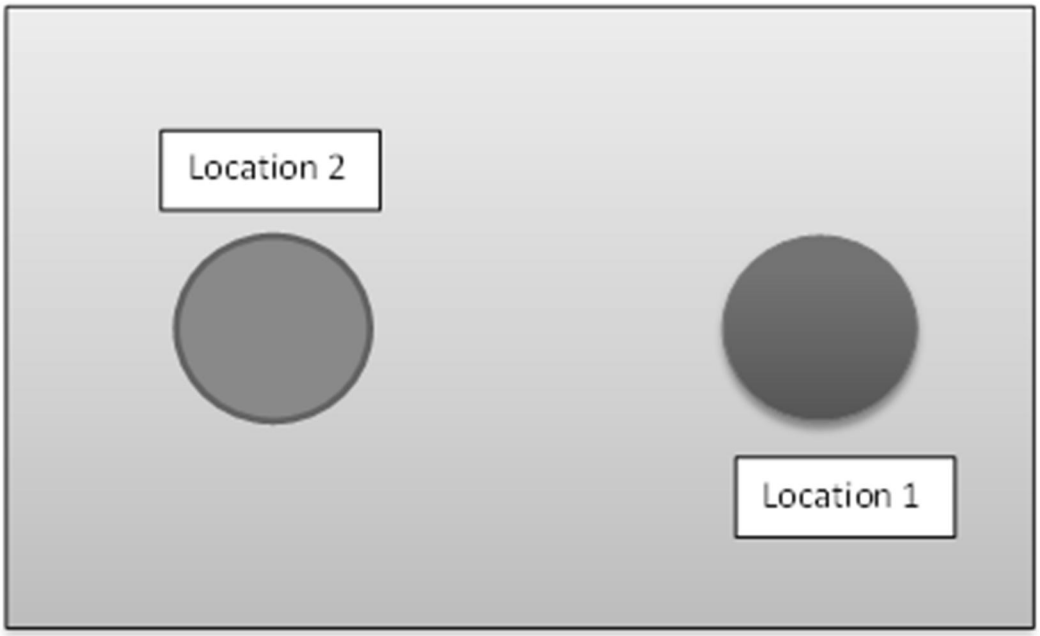

Figure 36. Particle Density Test Sites

Four spots, termed A to D, were used for the density of talc particles are each of the two locations. A count was made at each spot of the total number of visible particles and the area of the count site was determined in square millimetres. At each spot three heights were selected for the counting, at the top of the filter, in the middle of the filter and at the bottom of the filter. A series of photographs of the filter data is shown in this chapter.

Figure 37 shows a photograph of location 1, spot A on the top of the filter.

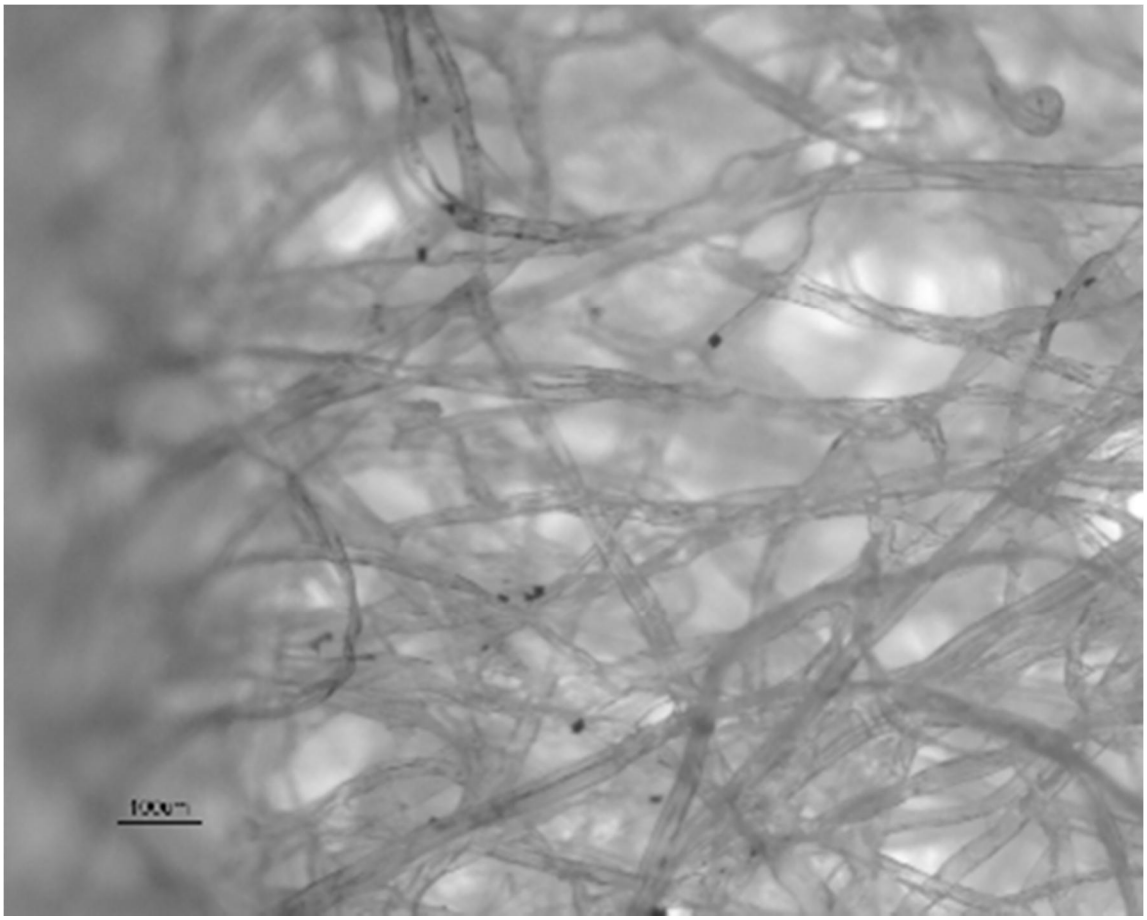

Figure 37. Location 1 at Top A

This photograph shows a number of particles in the 10 micron range, as would be expected.

Figure 38 shows a photograph of location 1, spot B on the top of the filter.

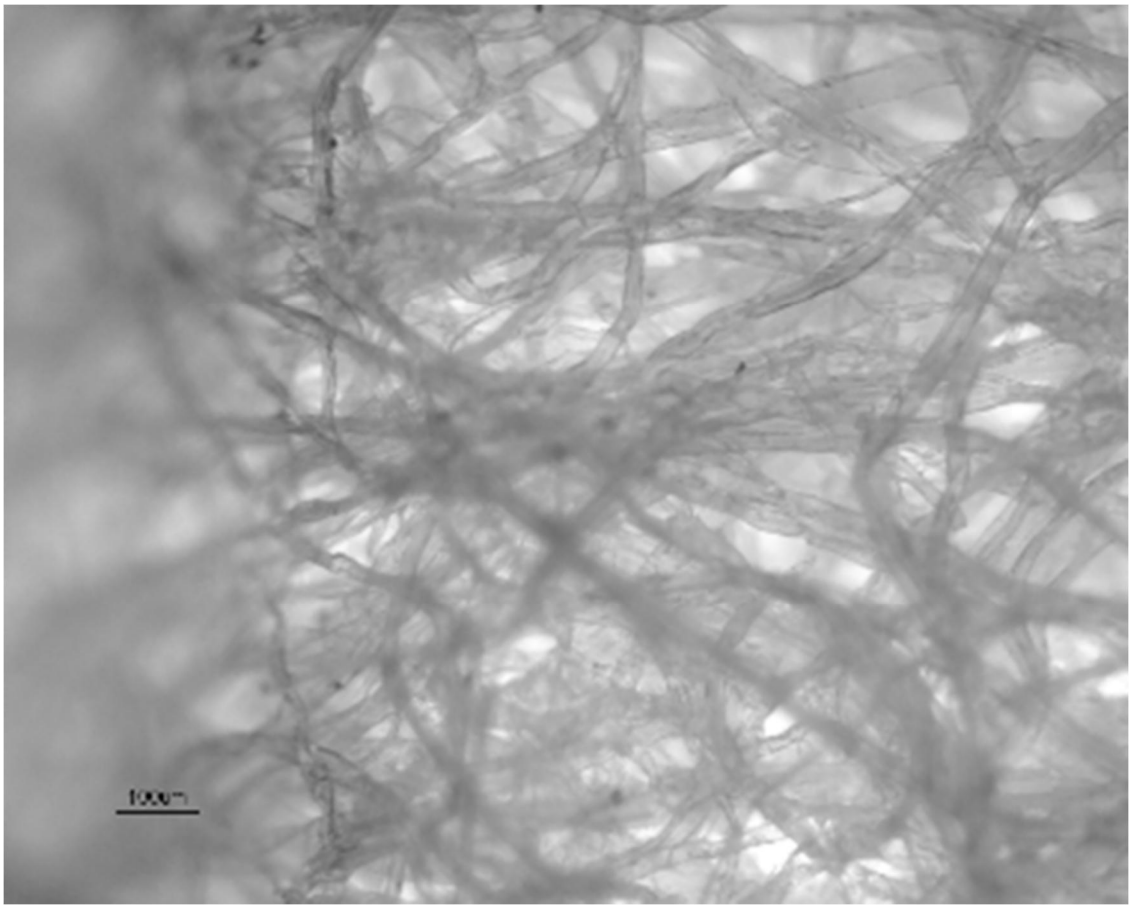

Figure 38. Location 1 at Top B

This shows some scattered particles.

Figure 39 shows a photograph of location 1, spot C on the top of the filter.

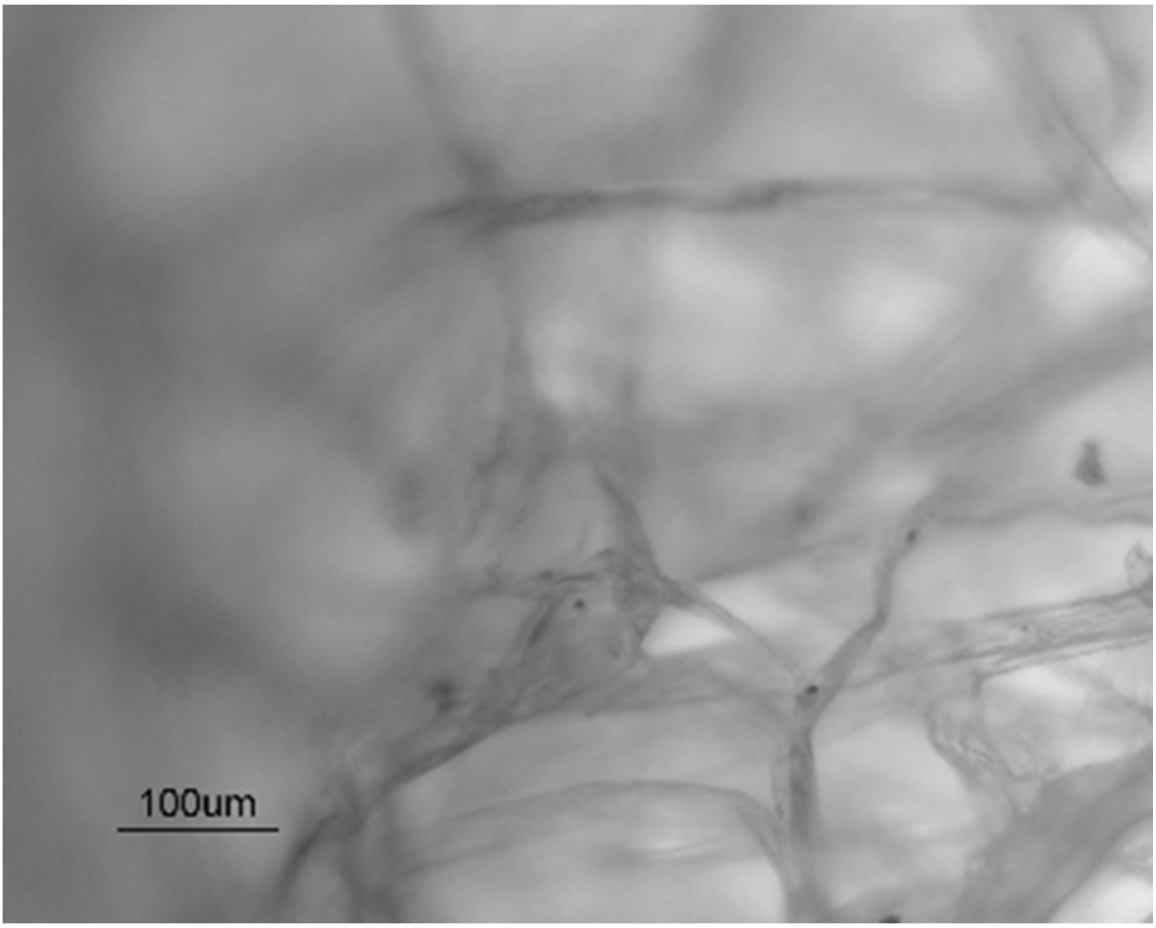

Figure 39. Location 1 at Top C

This photograph shows a few particles. The smallest measureable particle in this picture is approximately 4 microns in diameter.

Figure 40 shows a photograph of location 1, spot D on the top of the filter.

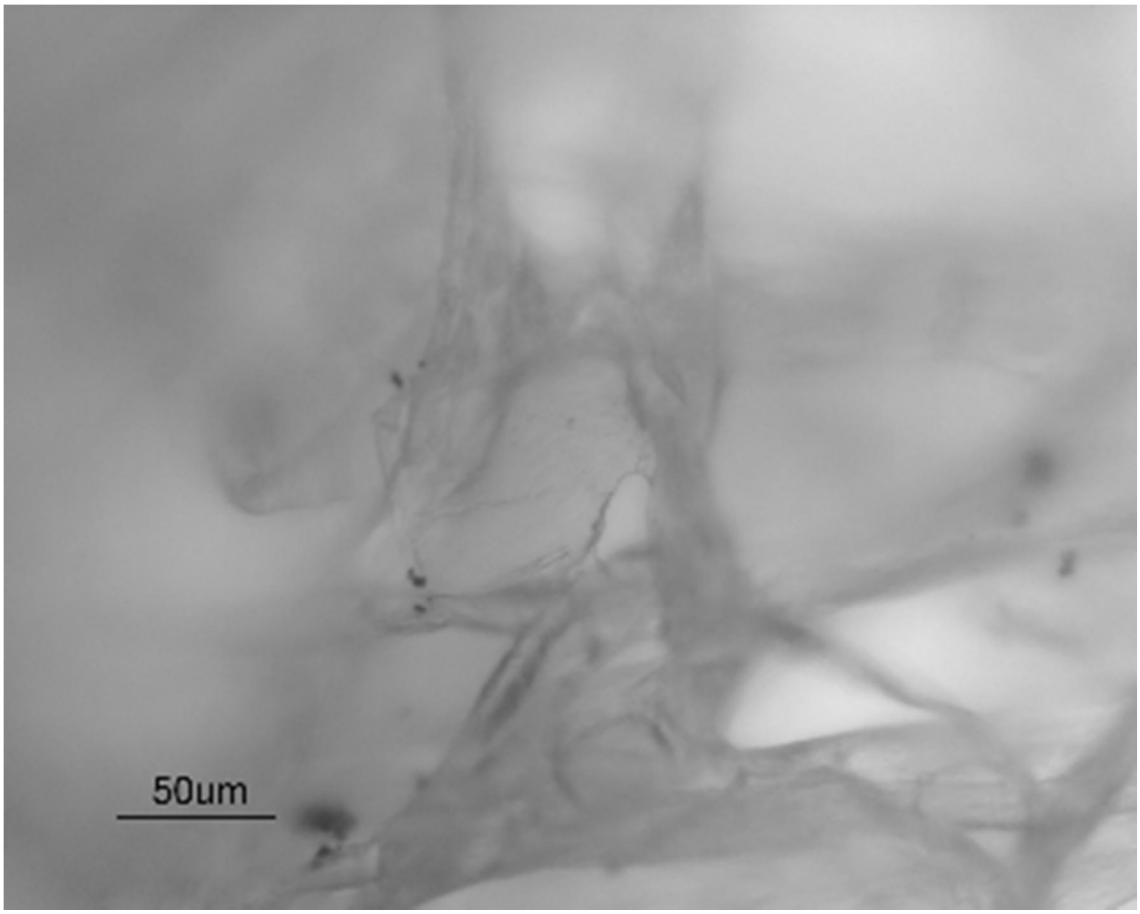

Figure 40. Location 1 at Top D

Figure 41 shows a photograph of location 1, spot A on the middle of the filter.

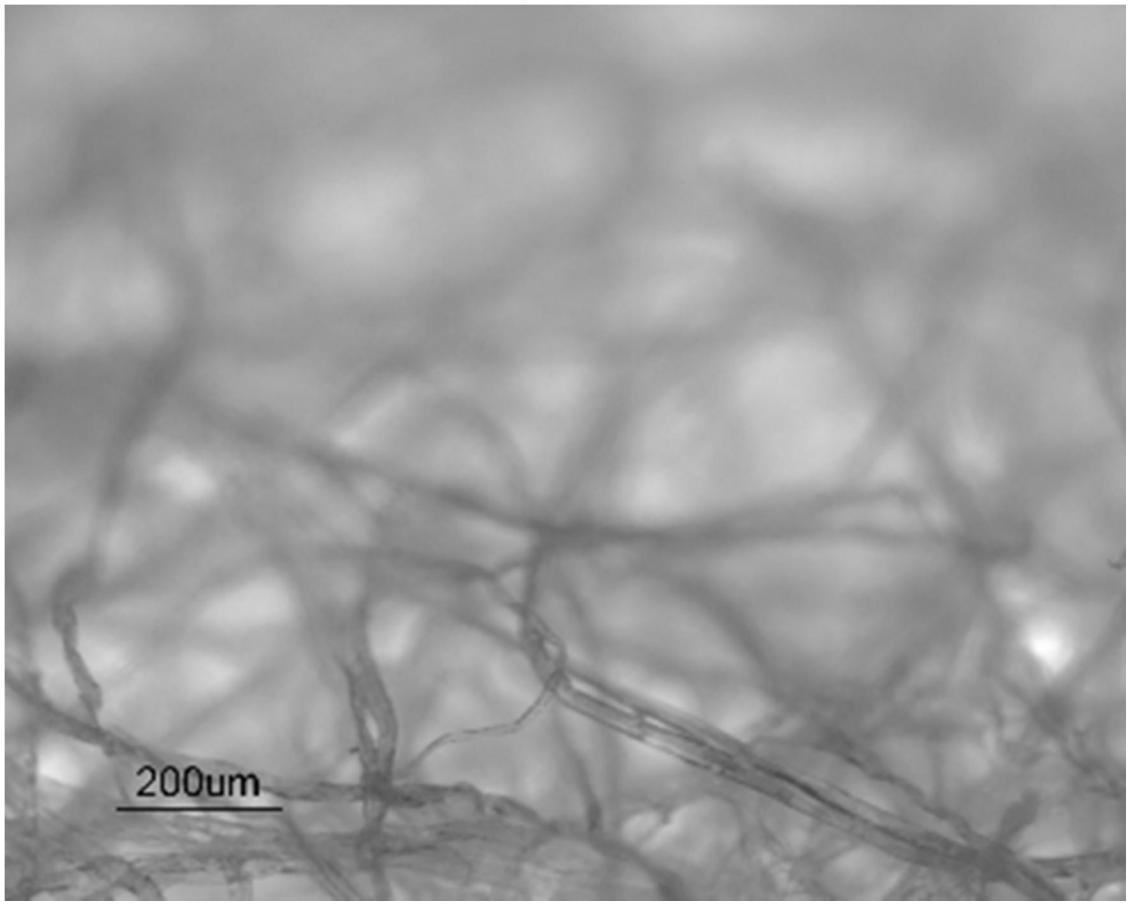

Figure 41. Location 1 at Middle A

Figure 42 shows a photograph of location 1, spot B on the middle of the filter.

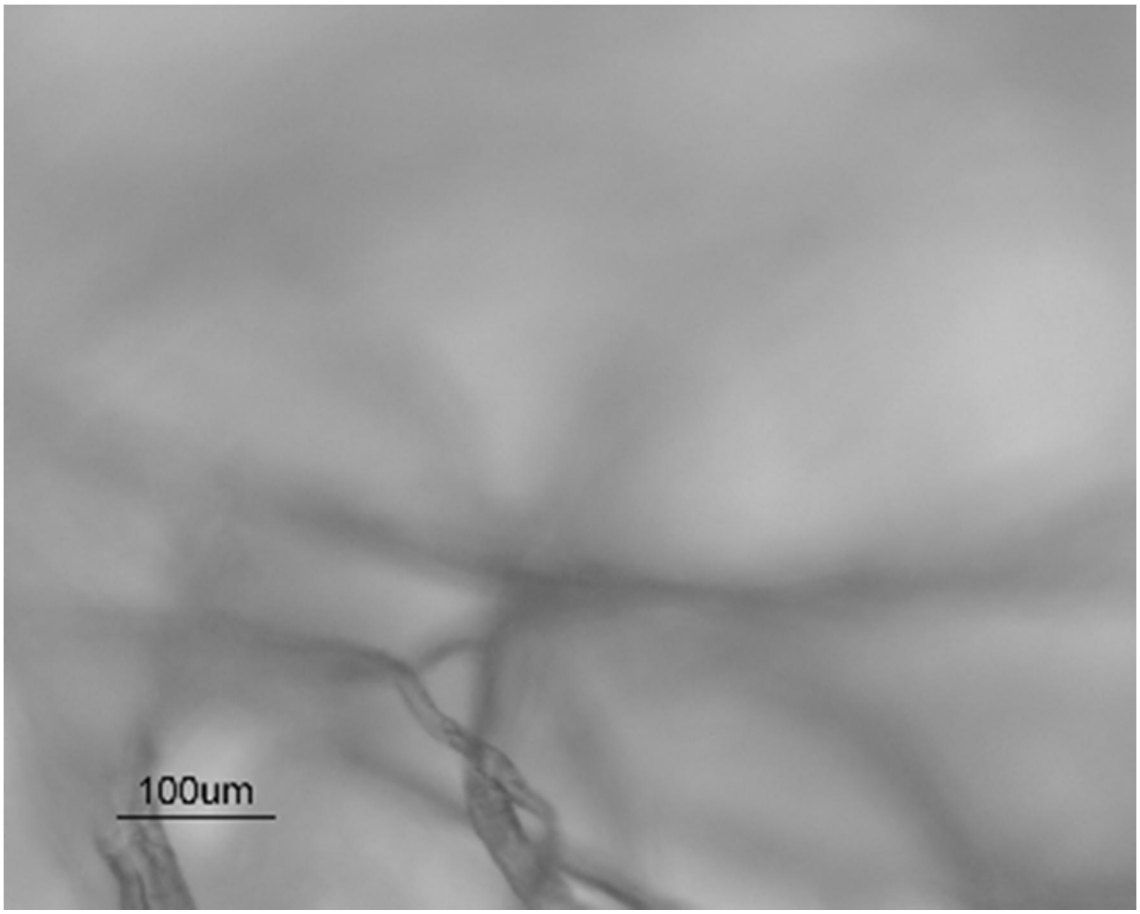

Figure 42. Location 1 at Middle B

Figure 43 shows a photograph of location 1, spot C on the middle of the filter.

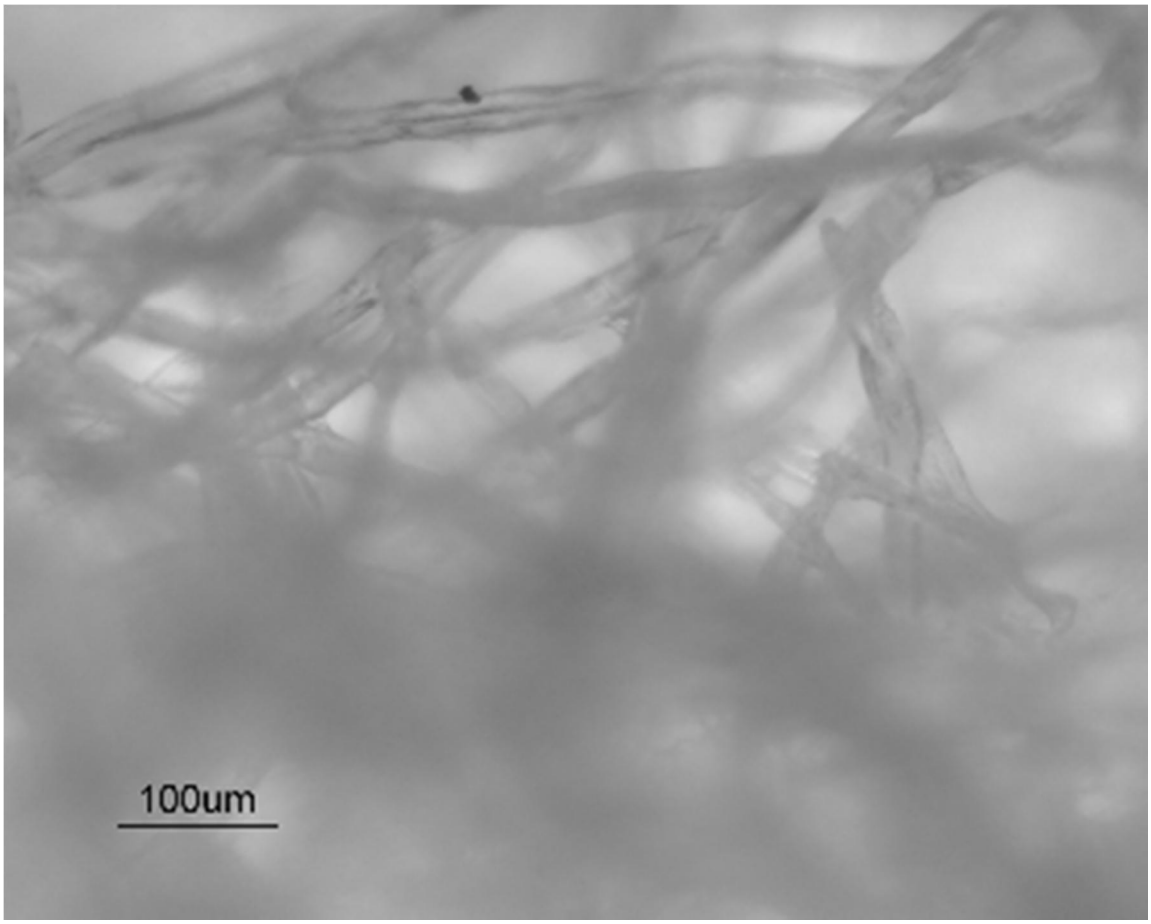

Figure 43. Location 1 at Middle C

Figure 44 shows a photograph of location 1, spot D on the middle of the filter.

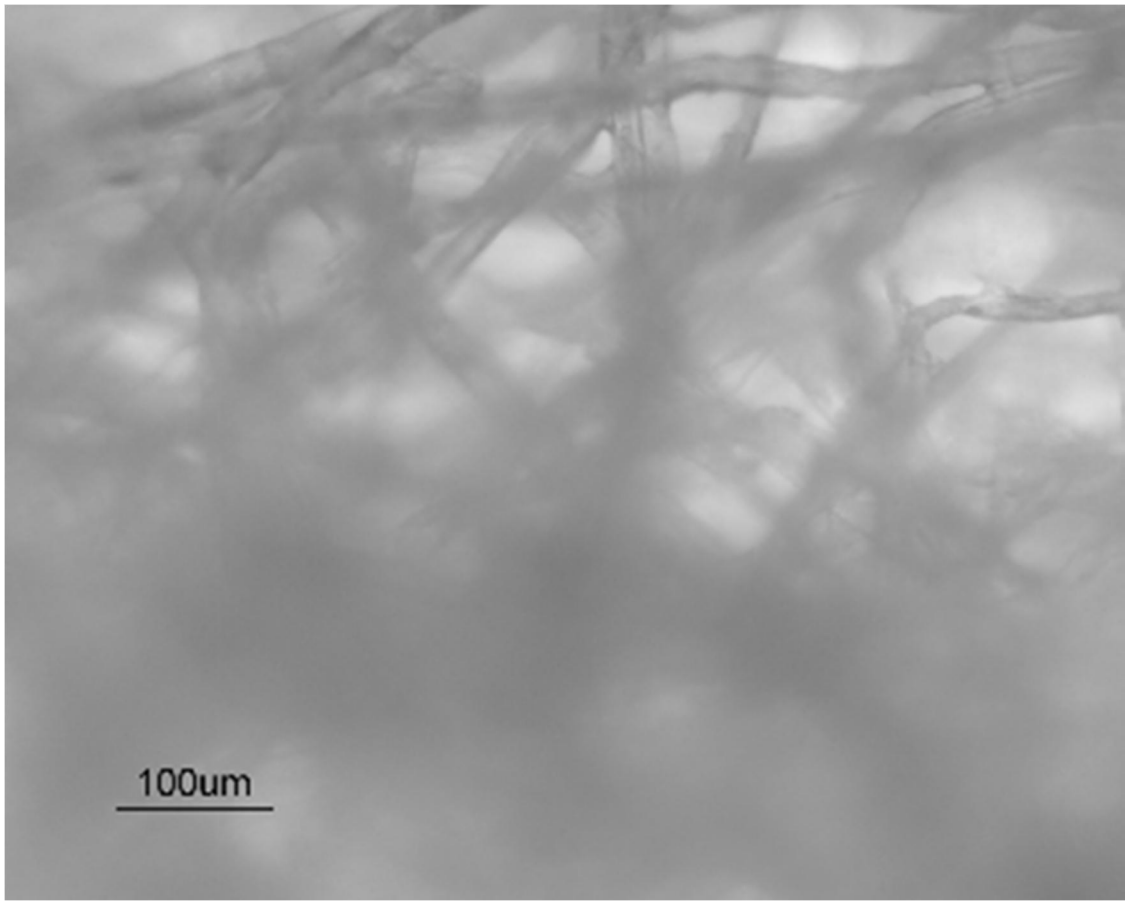

Figure 44. Location 1 at Middle D

Figure 45 shows a photograph of location 1, spot A on the bottom of the filter.

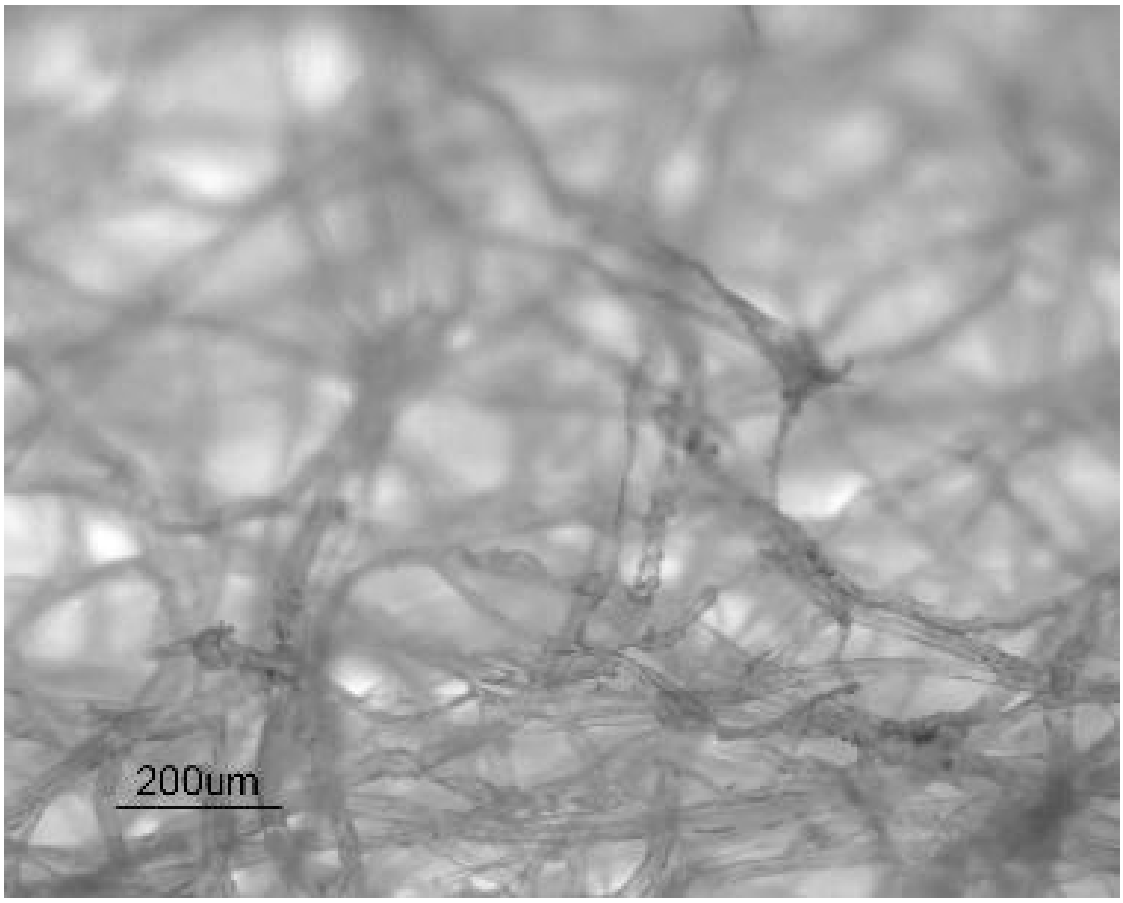

Figure 45. Location 1 at Bottom A

This photograph shows the density of some particles in particular areas of the image.

Figure 46 shows a photograph of location 1, spot B on the bottom of the filter.

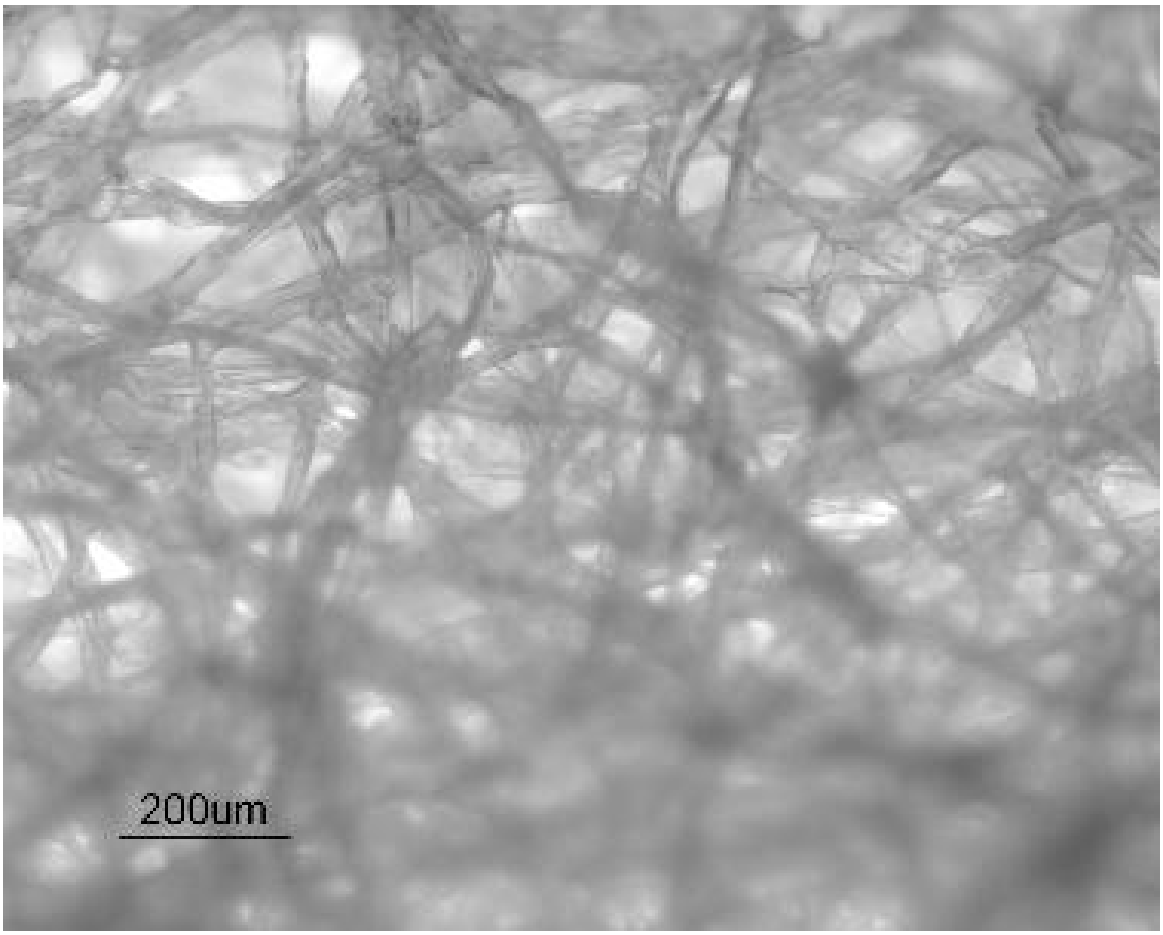

Figure 46. Location 1 at Bottom B

Figure 47 shows a photograph of location 1, spot C on the bottom of the filter.

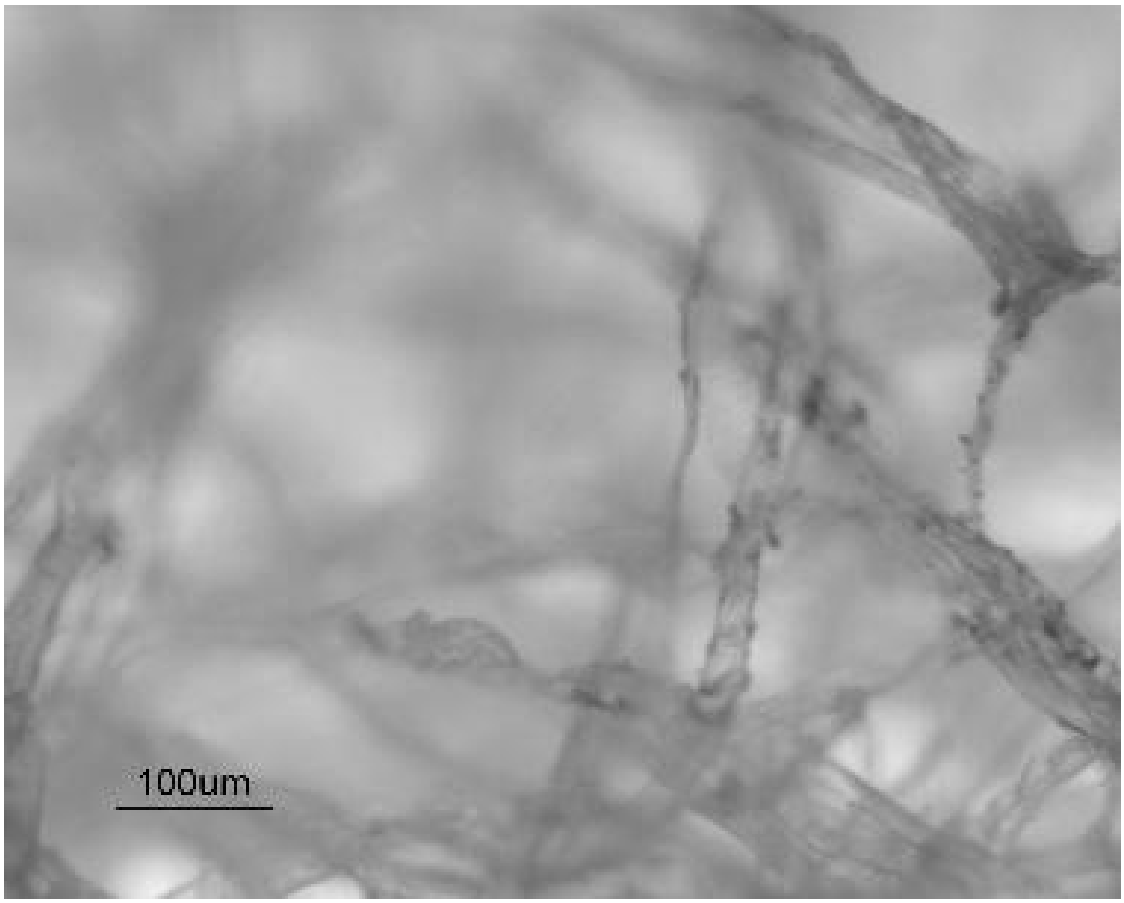

Figure 47. Location 1 at Bottom C

This image shows small particles adhering to the filter material.

Figure 48 shows a photograph of location 1, spot D on the bottom of the filter.

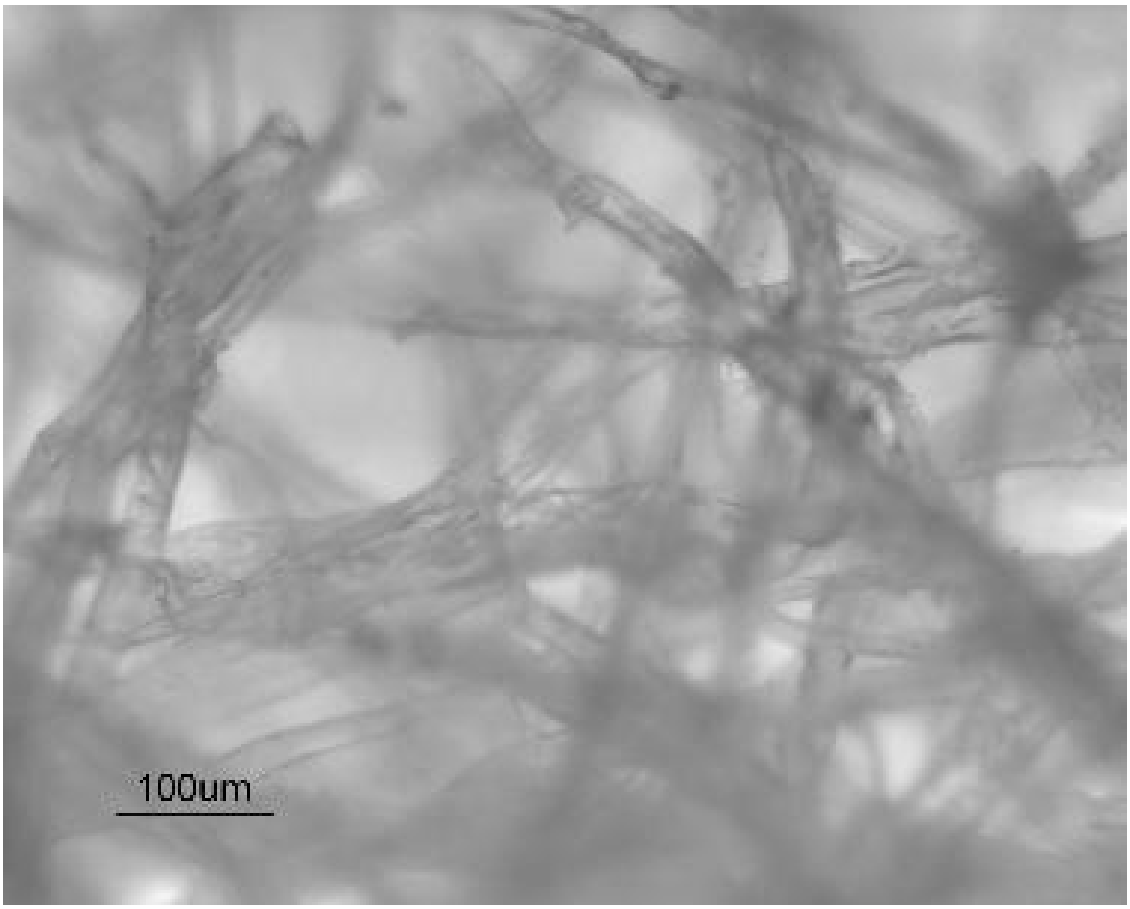

Figure 48. Location 1 at Bottom D

Figure 49 shows a photograph of location 2, spot A on the top of the filter.

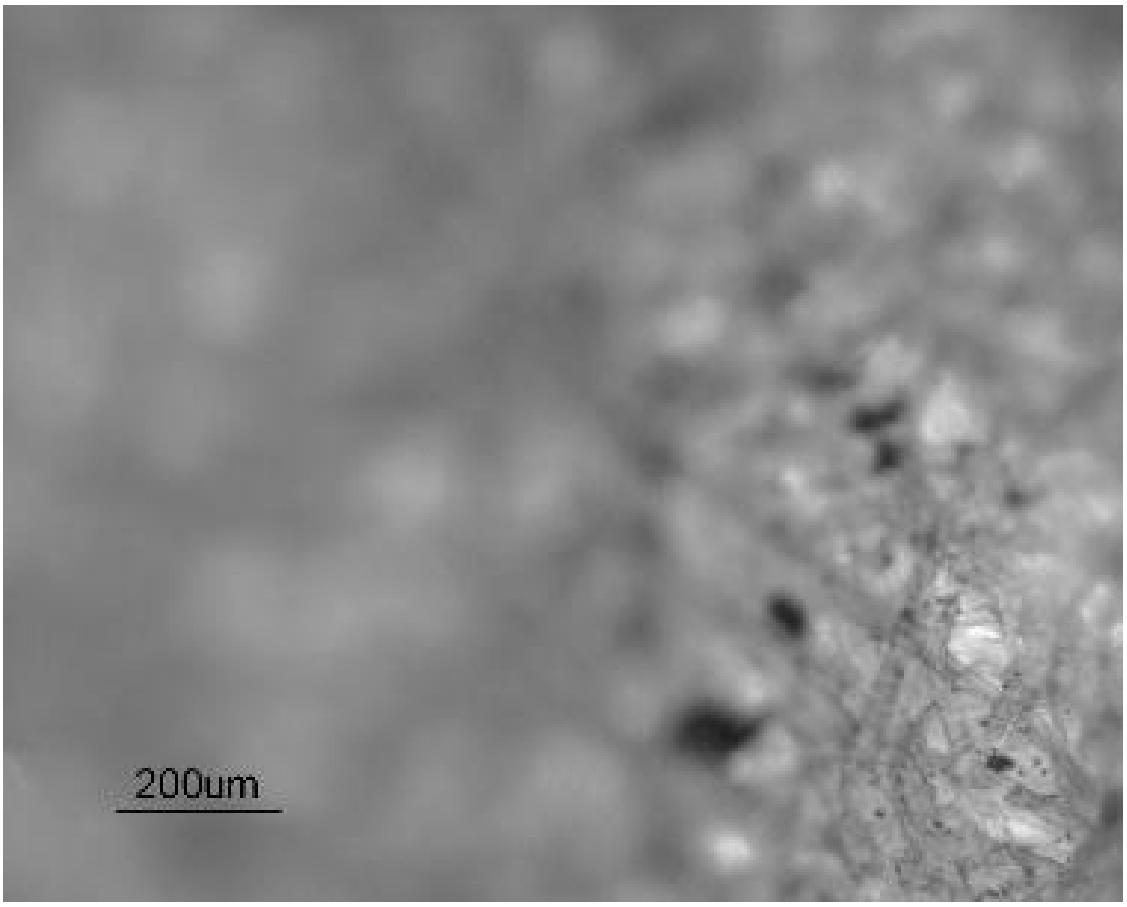

Figure 49. Location 2 at Top A

This photograph shows some large, but a significant number of small particles in the image area.

Figure 50 shows a photograph of location 2, spot B on the top of the filter.

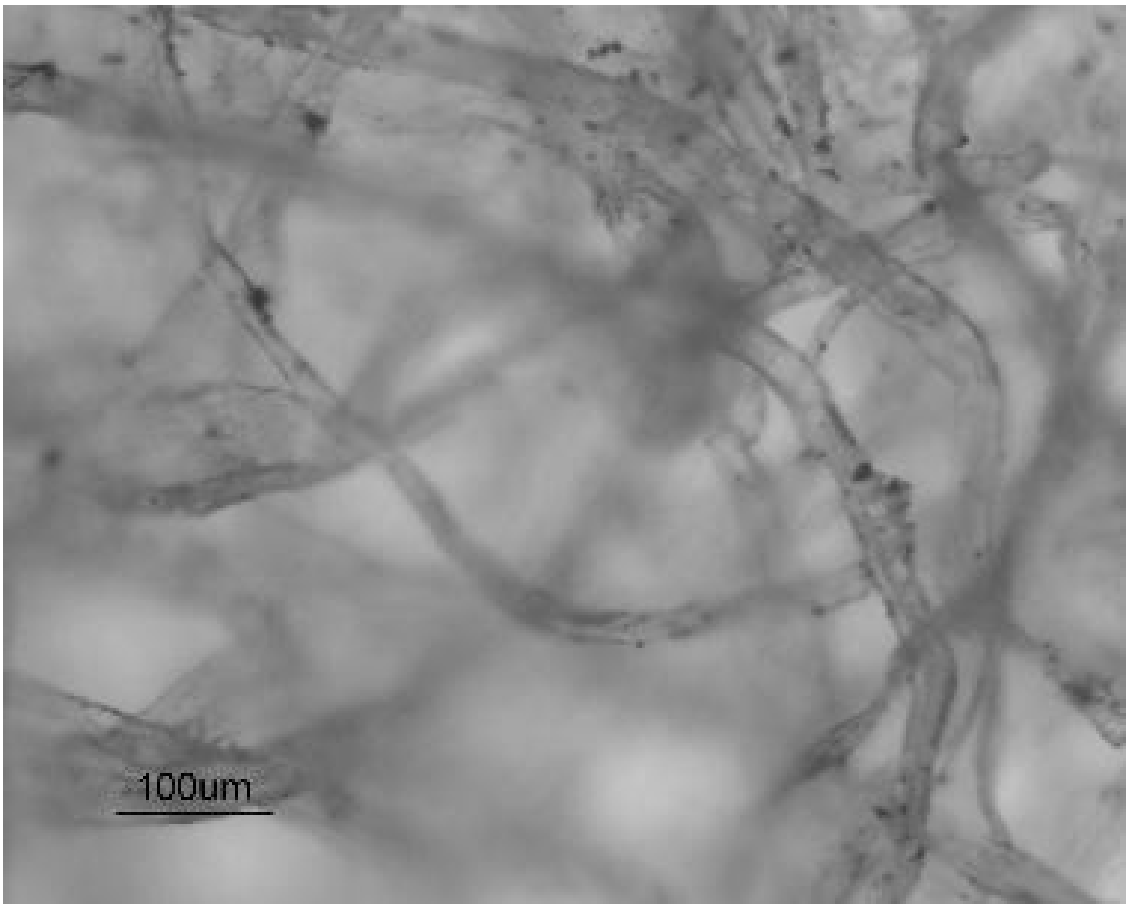

Figure 50. Location 2 at Top B

Figure 50 shows a photograph of location 2, spot C on the top of the filter.

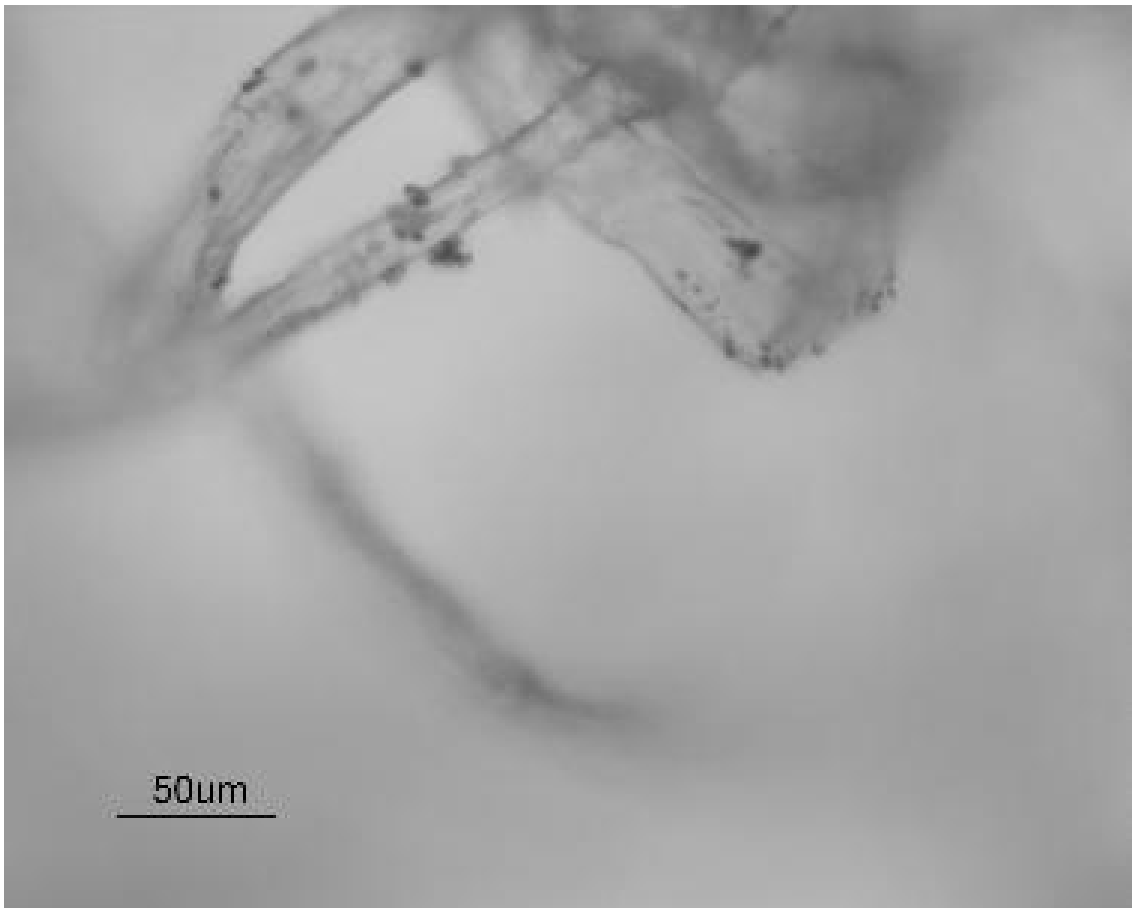

Figure 51. Location 2 at Top C

Figure 52 shows a photograph of location 2, spot D on the top of the filter.

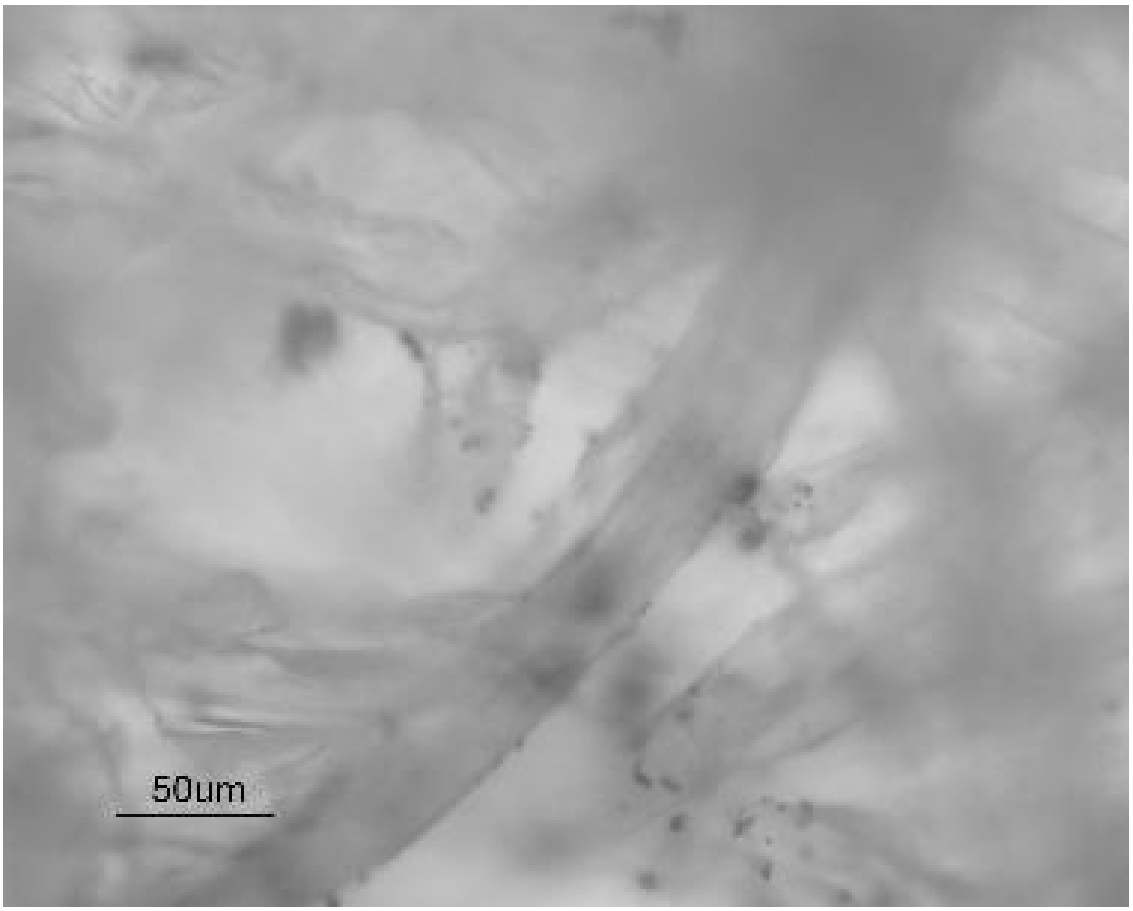

Figure 52. Location 2 at Top D

Figure 53 shows a photograph of location 2, spot A on the middle of the filter.

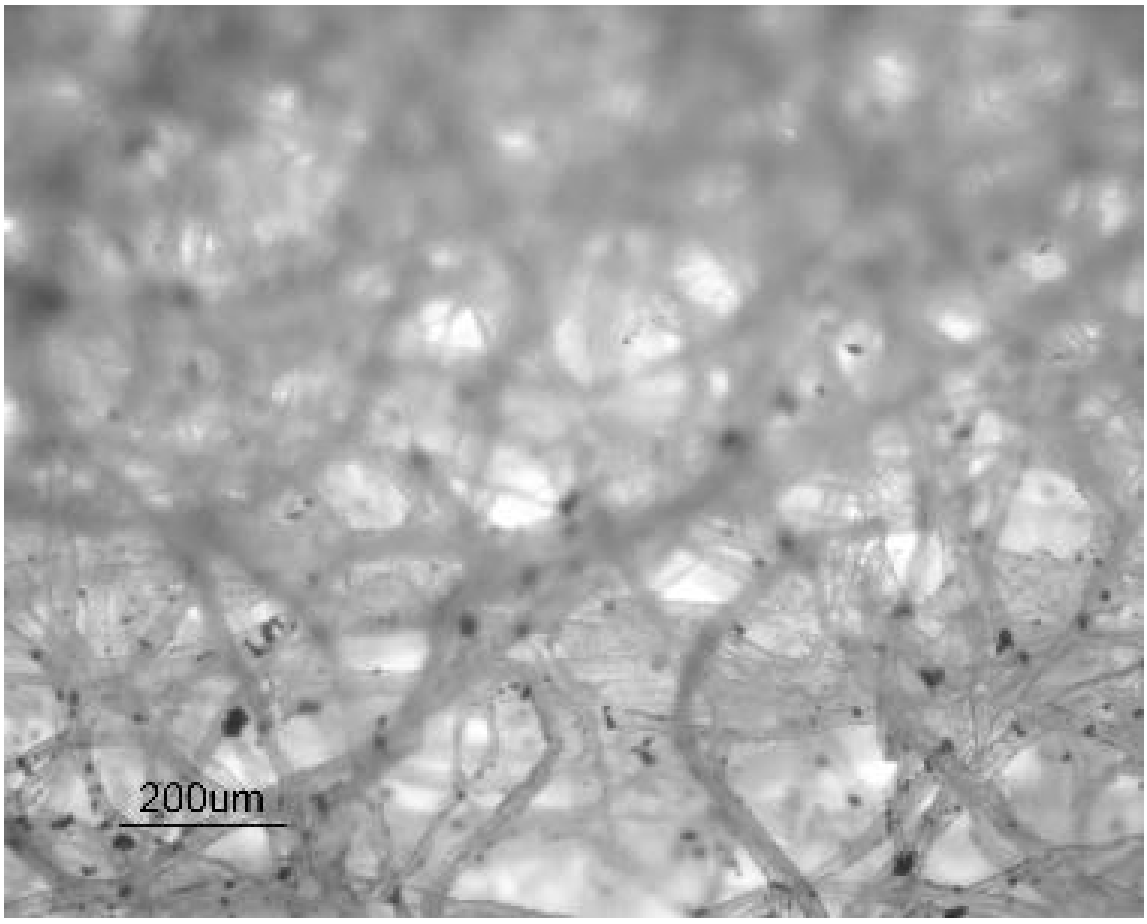

Figure 53. Location 2 at Middle A

Figure 54 shows a photograph of location 2, spot B on the middle of the filter.

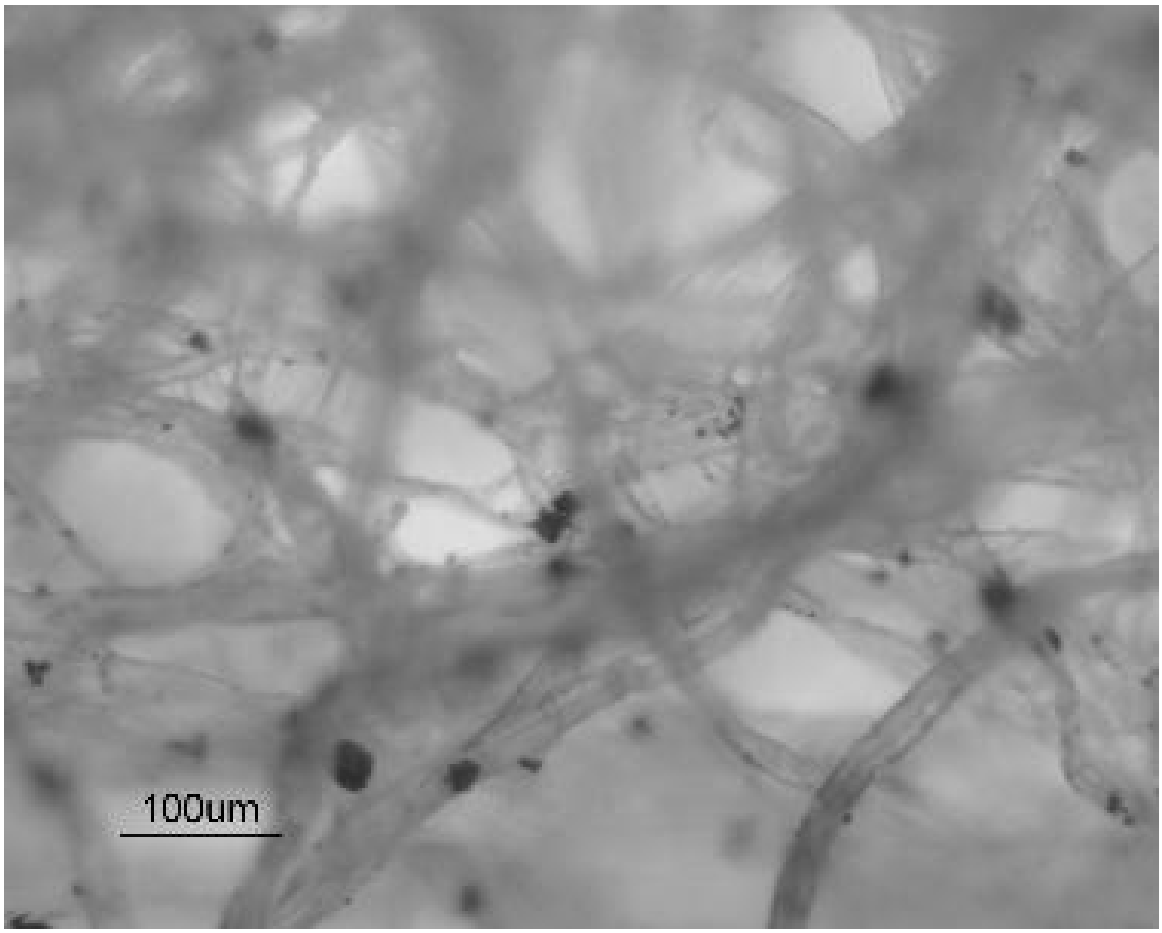

Figure 54. Location 2 at Middle B

Figure 55 shows a photograph of location 2, spot C on the middle of the filter.

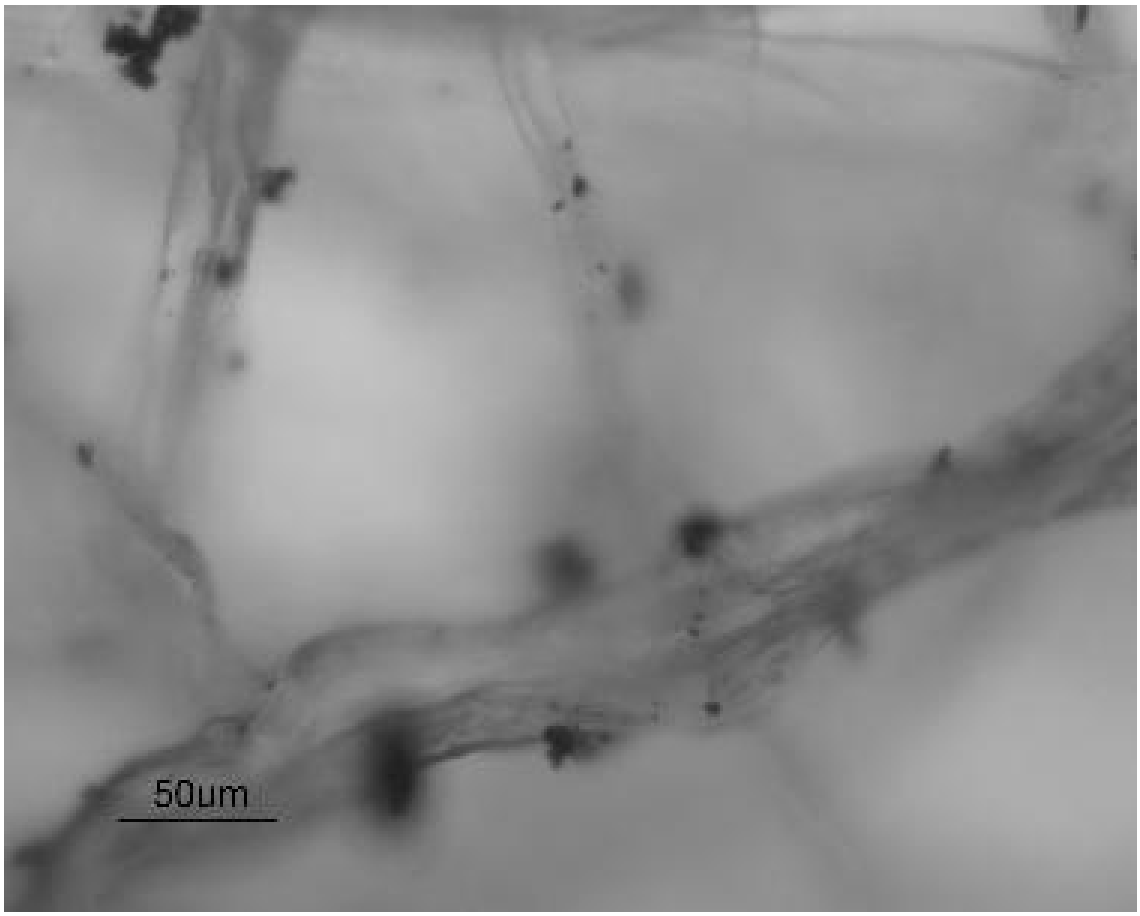

Figure 55. Location 2 at Middle C

Figure 56 shows a photograph of location 2, spot D on the middle of the filter.

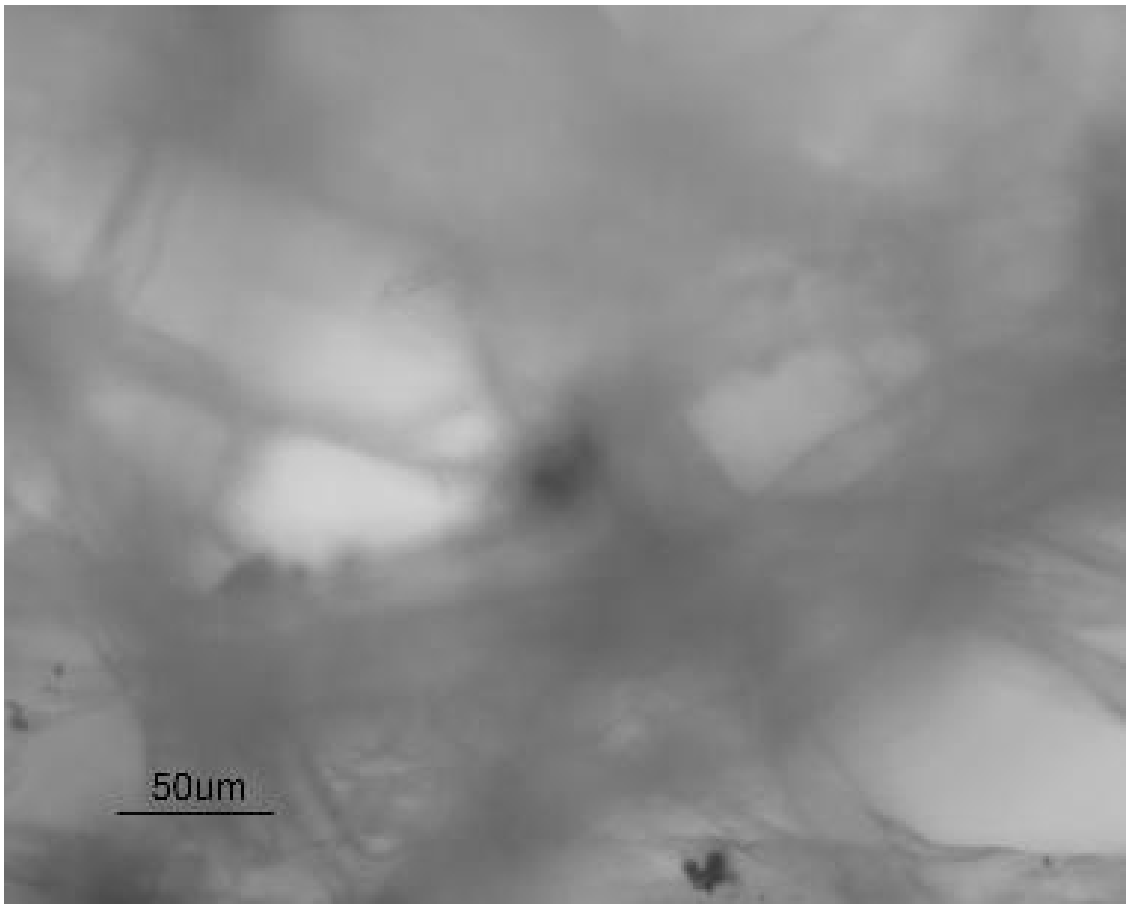

Figure 56. Location 2 Middle D

Figure 57 shows a photograph of location 2, spot A on the bottom of the filter.

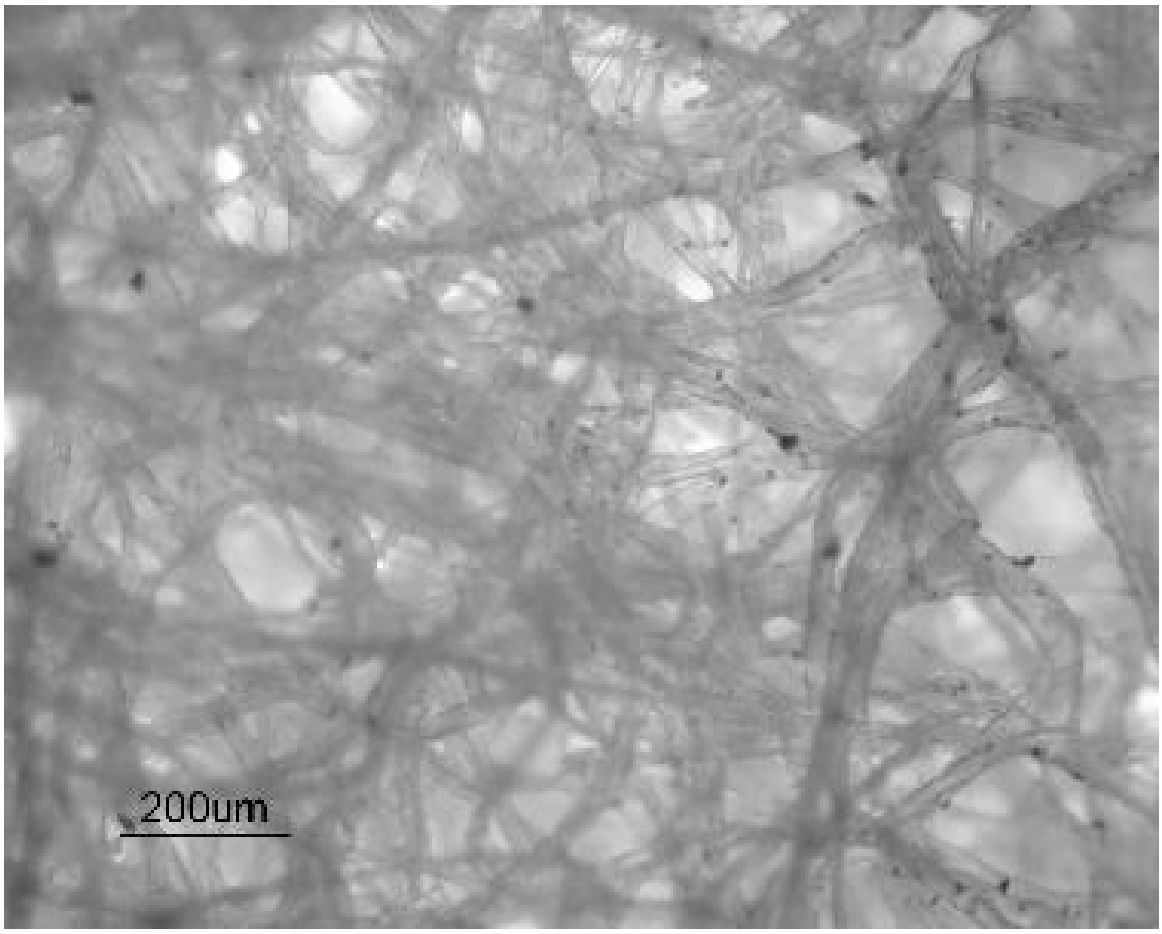

Figure 57. Location 2 at Bottom A

Figure 58 shows a photograph of location 2, spot B on the bottom of the filter.

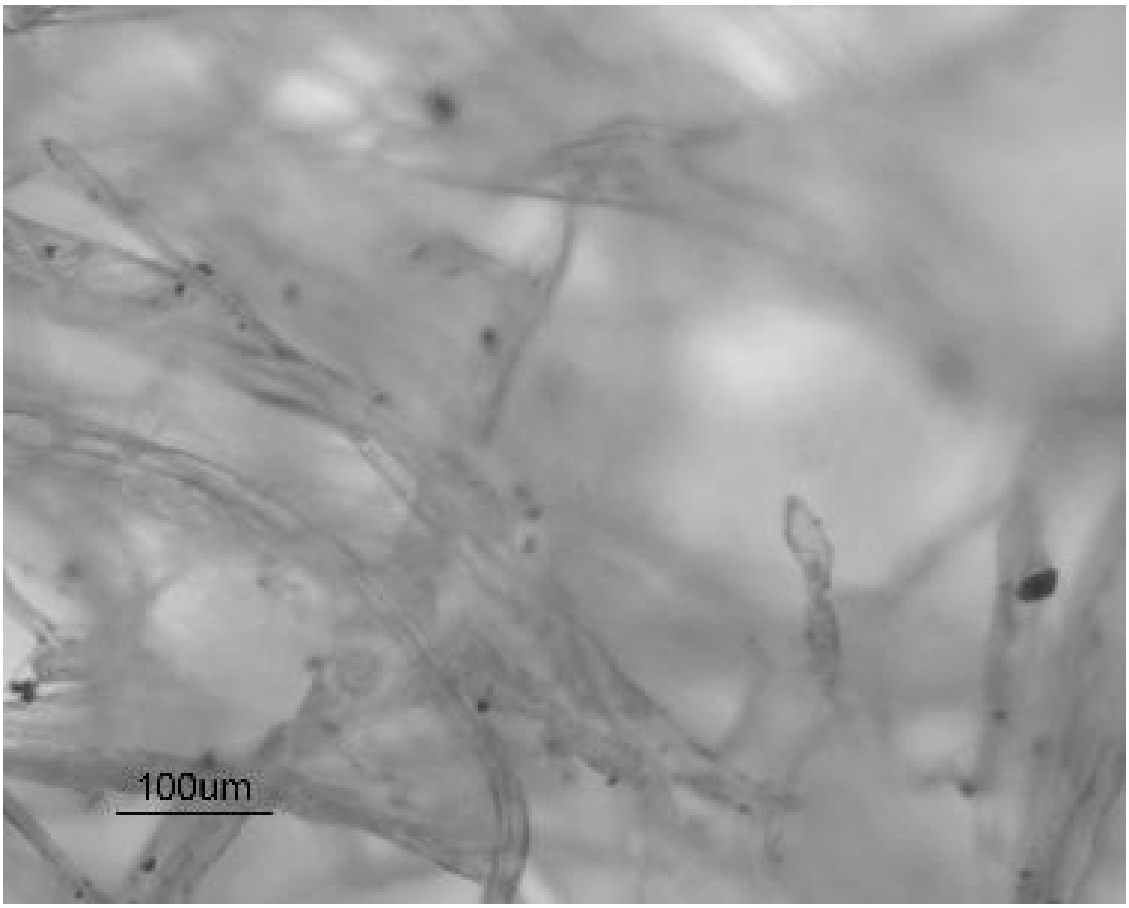

Figure 58. Location 2 at Bottom B

Figure 59 shows a photograph of location 2, spot C on the bottom of the filter.

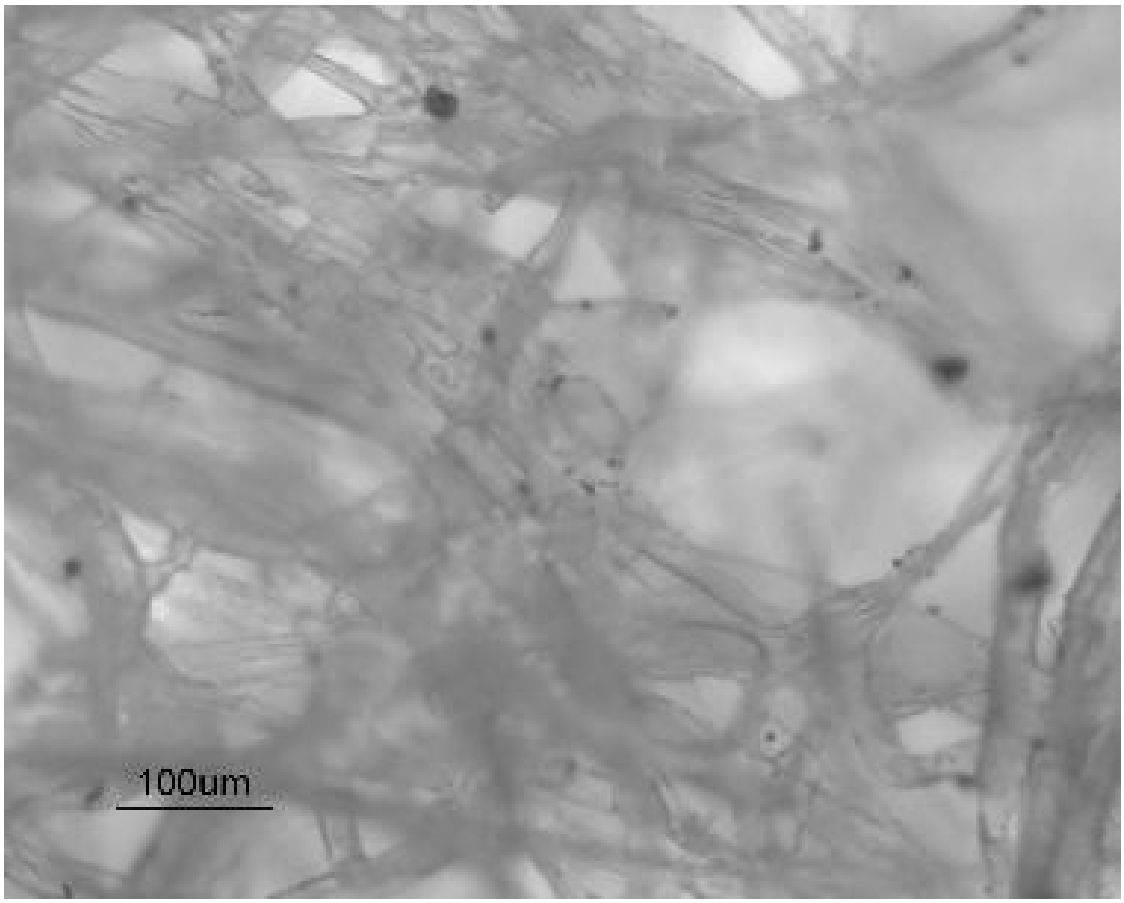

Figure 59. Location 2 at Bottom C

Figure 60 shows a photograph of location 2, spot D on the bottom of the filter.

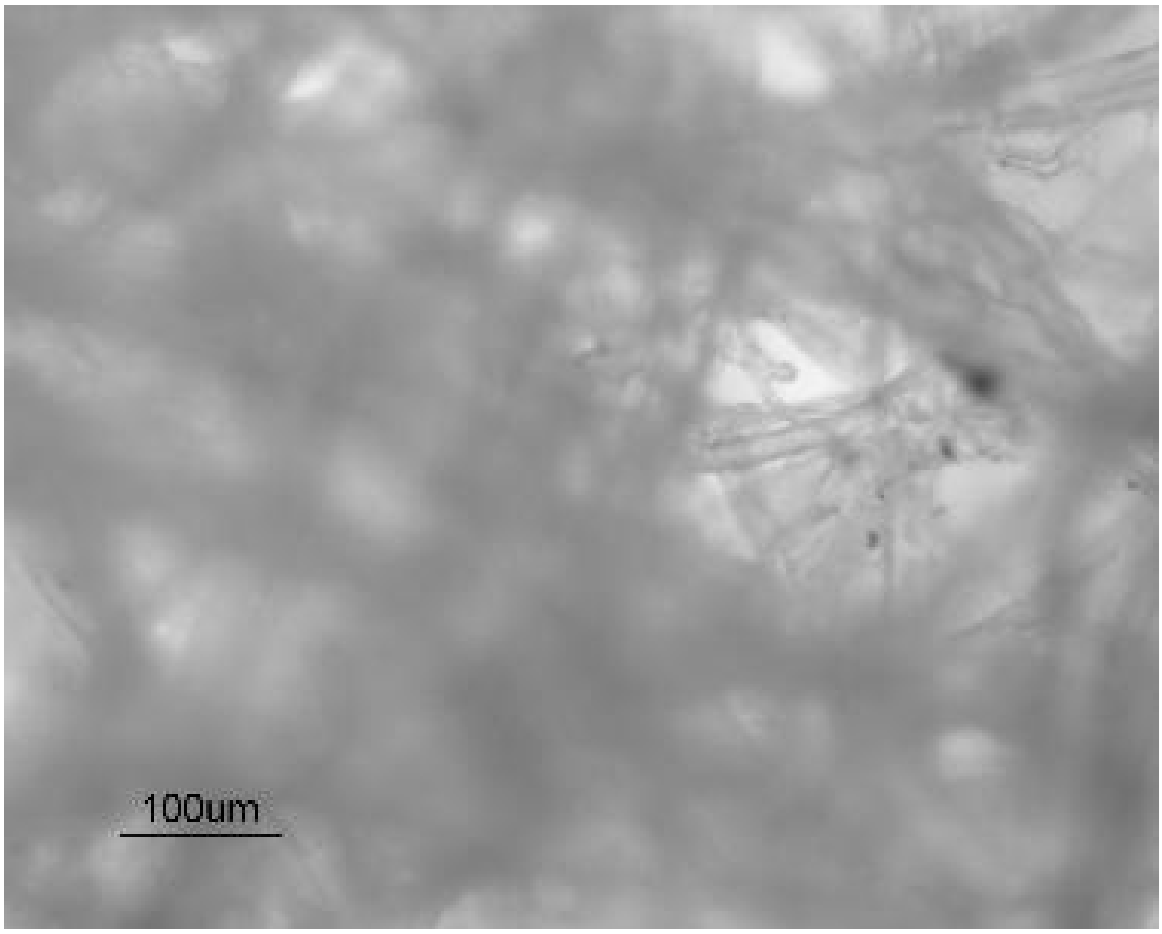

Figure 60. Location 2 at Bottom D

The photographs show a difference in the density of particles in different parts of the filter.

ANALYSIS

The dust concentration was determined at the 24 locations shown in the photographs. Table 4 summarizes the dust data for filter location 1.

Table 4

Dust Concentrations on the Filter at Location 1

Height on the filter	Spot location	Number in photograph	Number per square millimeter	Mean	Variance
Top	A	23	42.83	26.54	106.42
	B	15	27.93		
	C	9	16.76		
	D	10	18.62		
Middle	A	1	1.86	0.93	0.87
	B	0	0		
	C	1	1.86		
	D	0	0		
Bottom	A	6	11.17	12.1	25.14
	B	4	7.45		
	C	11	20.48		
	D	5	9.31		

Table 5 summarizes the dust data for location 2.

Table 5

Dust Concentrations on the Filter at Location 2

Height on the filter	Spot location	Number in photograph	Number per square millimeter	Mean	Variance
Top	A	13	24.21	28.4	12.79
	B	16	29.8		
	C	14	26.07		
	D	18	33.52		
Middle	A	55	102.42	51.68	1040.98
	B	30	55.87		
	C	16	29.8		
	D	10	18.62		
Bottom	A	22	40.97	37.24	117.9
	B	24	44.69		
	C	24	44.69		
	D	10	18.62		

Figure 61 shows the location 1 dust concentrations. The numbers 1 to 4 on the graph correspond to the four spots A to D.

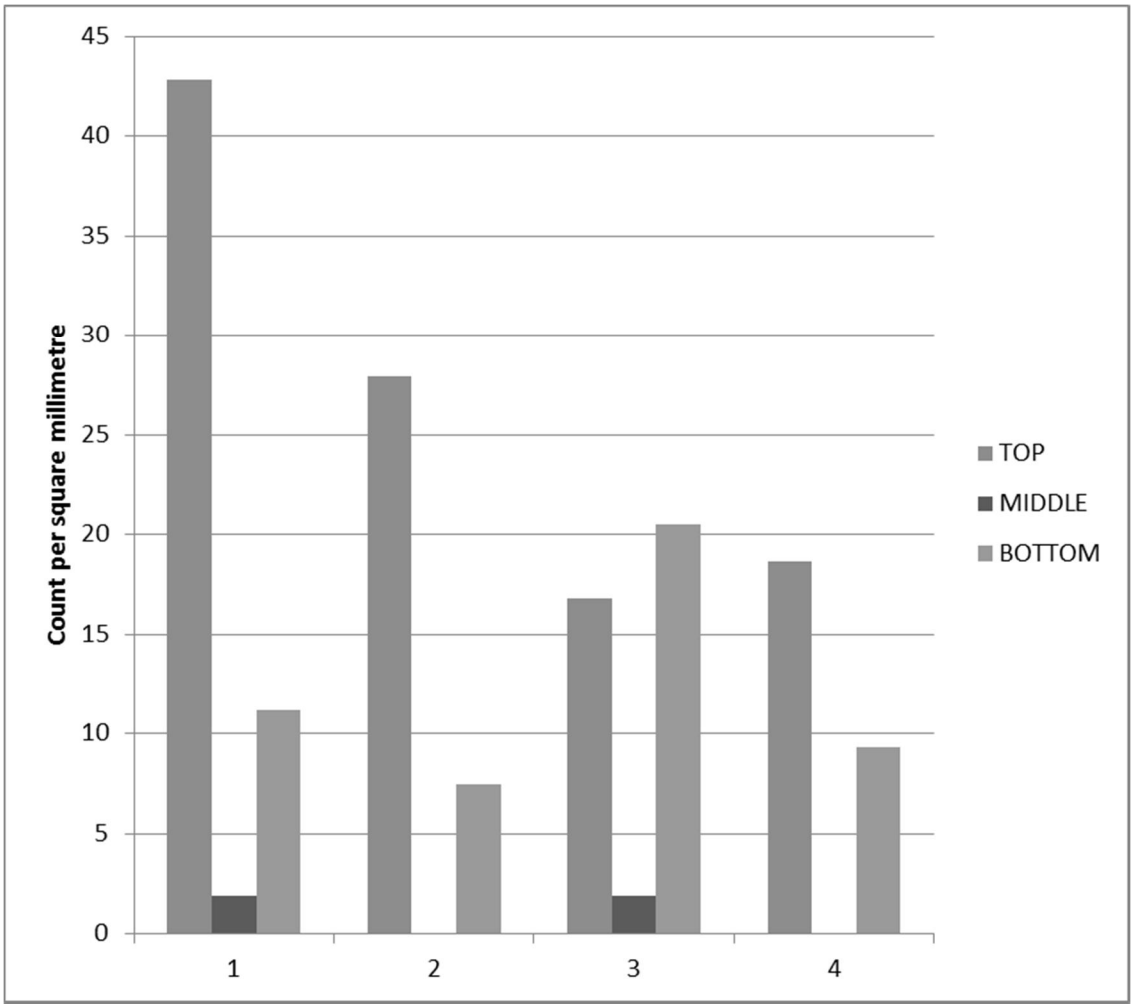

Figure 61. Dust Concentrations at Point A (1) to Point D (4) at Location One

The dust concentration is higher on the upper and lower surfaces; there is probably a sound physics reason for this distribution that warrants further study.

Figure 62 shows the location 2 dust concentrations. The numbers 1 to 4 on the graph correspond to the four spots A to D.

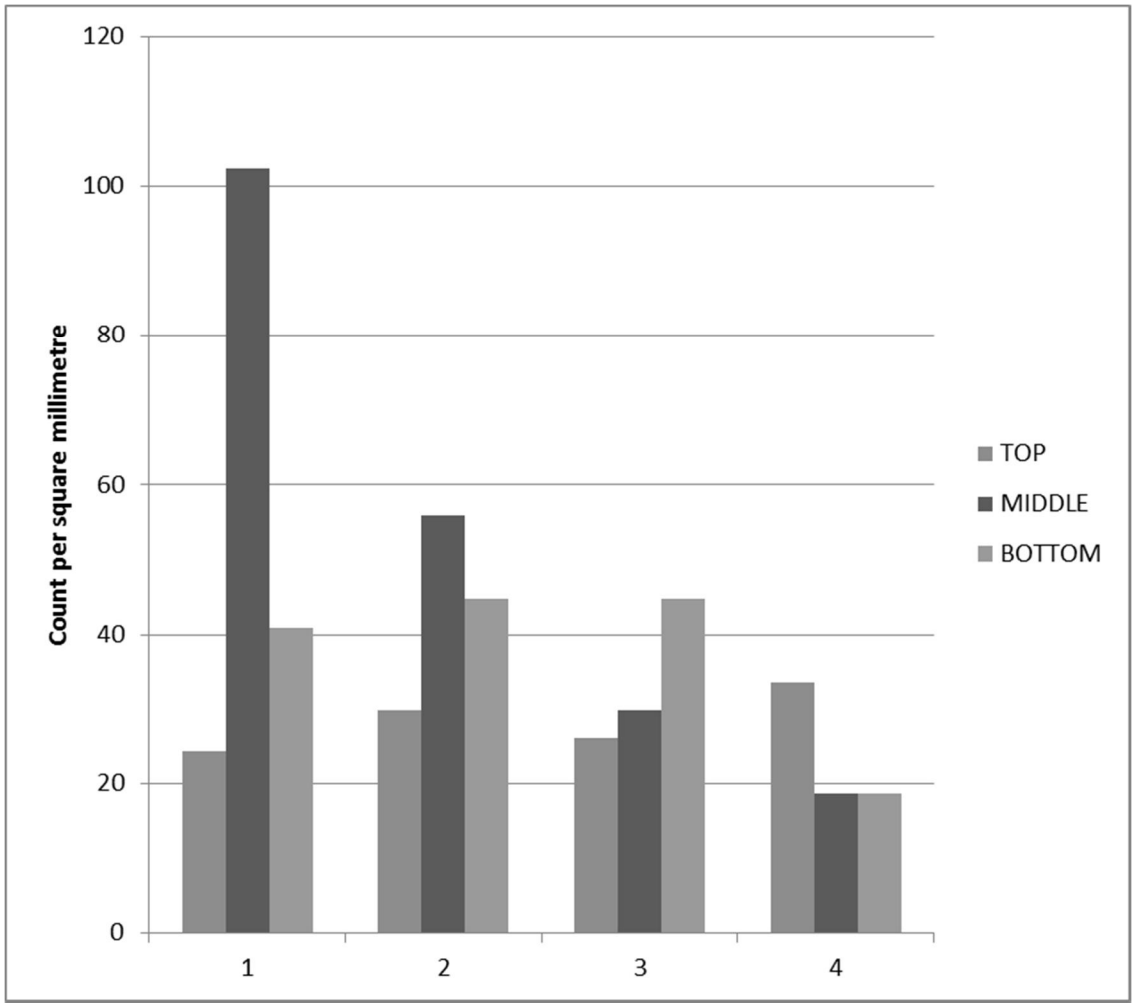

Figure 62. Dust Concentrations at Point A (1) to Point D (4) at Location Two

Figure 63 shows the dust concentrations for the two locations for the top data. A Student's t Test analysis of the data shows that the two groups of numbers are drawn from the same population set (Johnson, 2000).

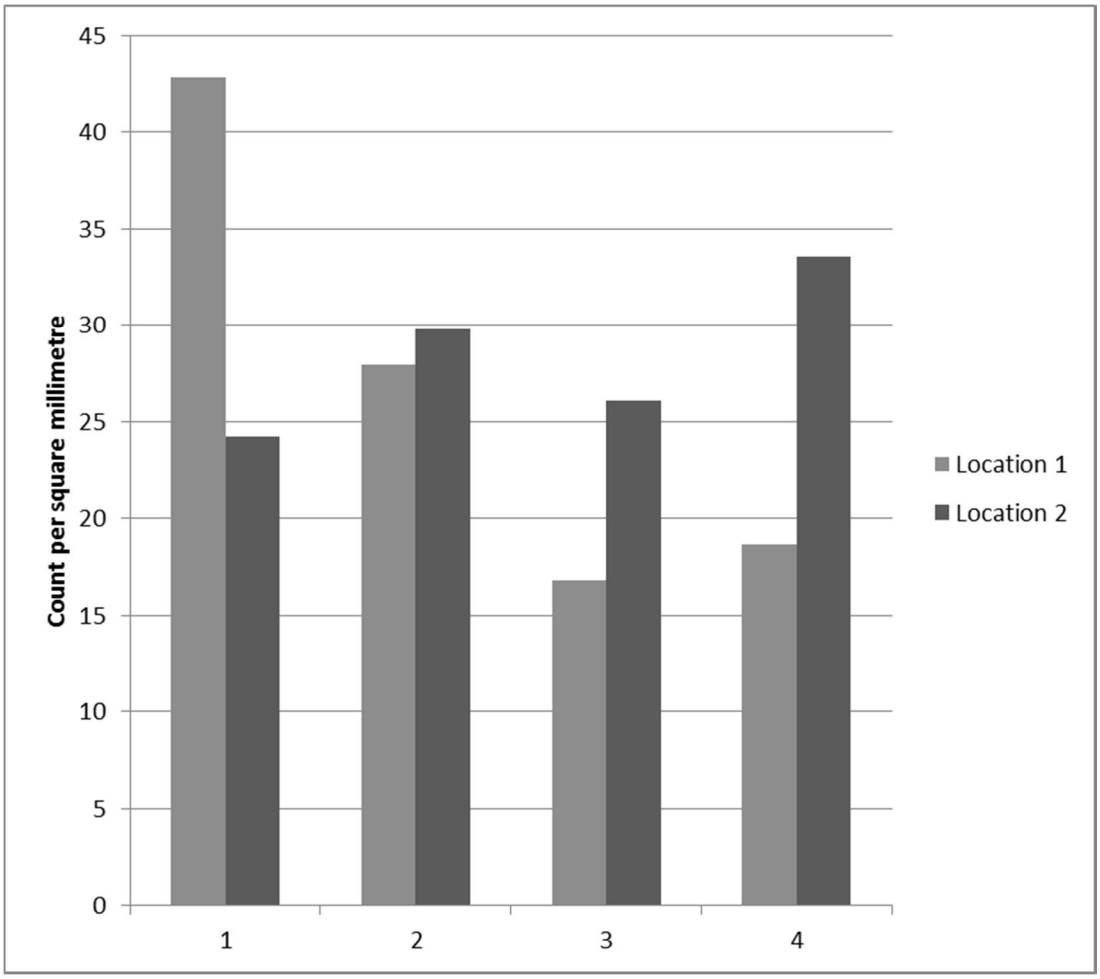

Figure 63. Dust Concentrations at Point A (1) to Point D (4) for Top

Figure 64 shows a comparison of the dust concentrations for the two locations for the middle segments of the filters. A Student's t Test analysis of the data shows that the two groups of numbers are drawn from the same population set at the $p < 0.03$ level assuming one tail.

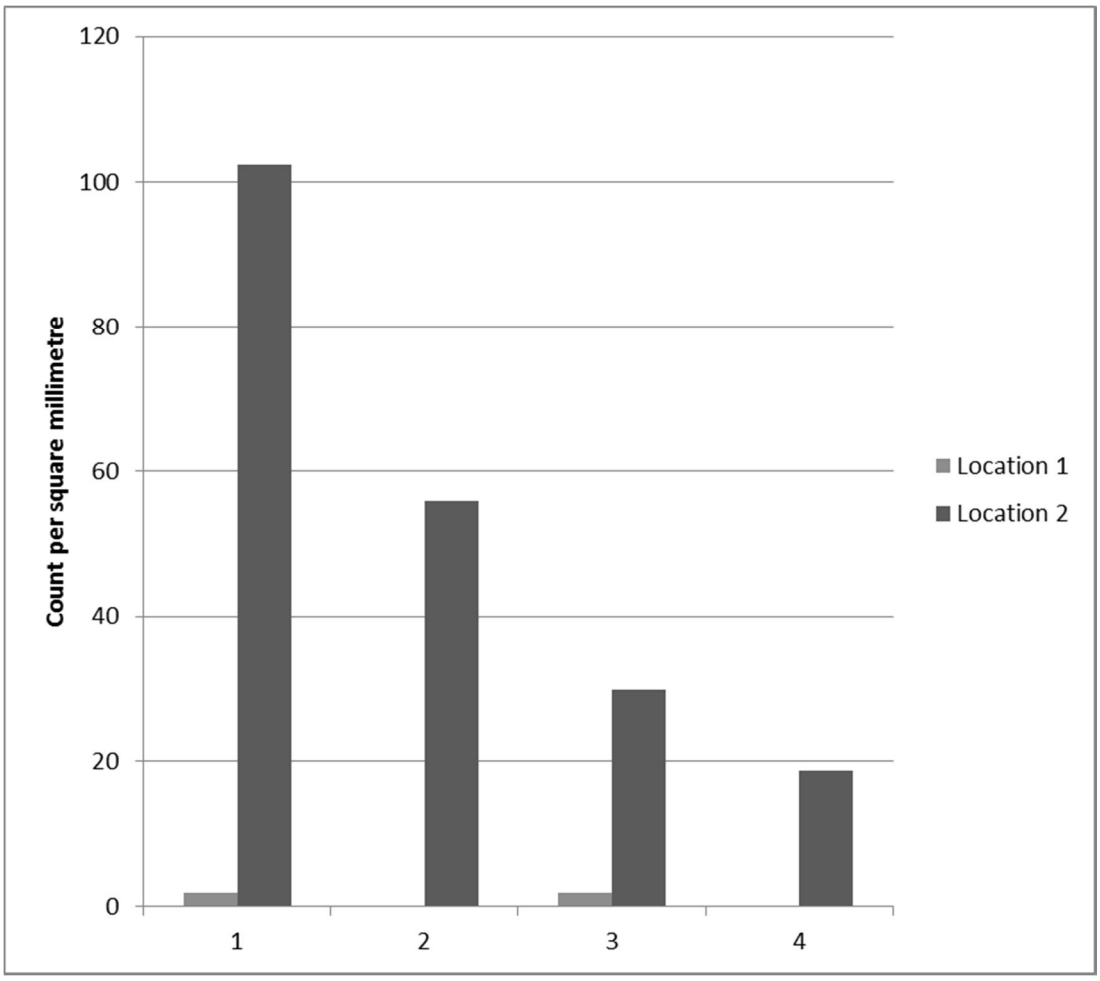

Figure 64. Dust Concentrations at Point A (1) to Point D (4) for Middle

Figure 65 shows a comparison of the dust concentrations for the two locations for the middle segments of the filters. A Student's t Test analysis of the data shows that the two groups of numbers are drawn from the same population set at the $p < 0.02$ level assuming one or two tails.

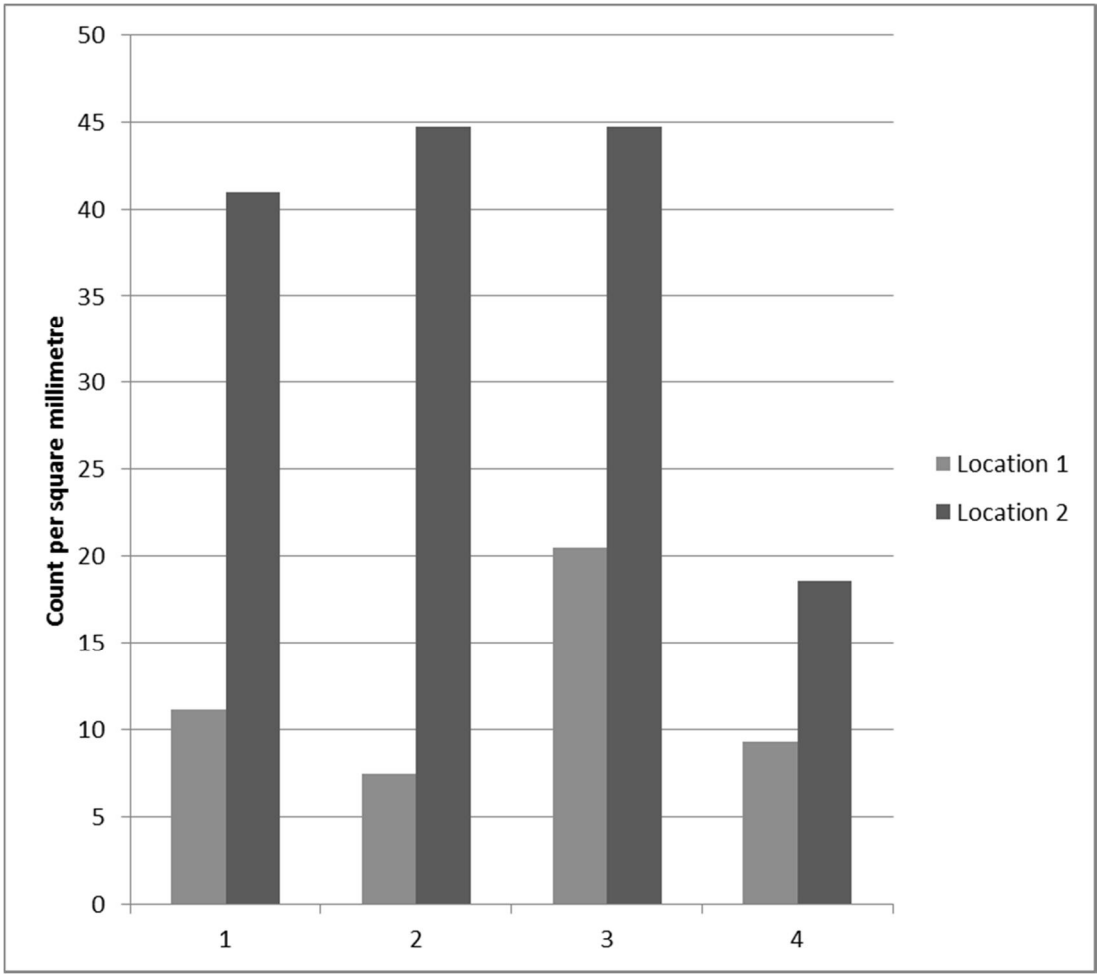

Figure 65. Dust Concentrations at Point A (1) to Point D (4) for Bottom

Figure 66 shows the dust concentrations at each of the twelve sample locations tagged as spot location A to D and three heights top, middle, and bottom.

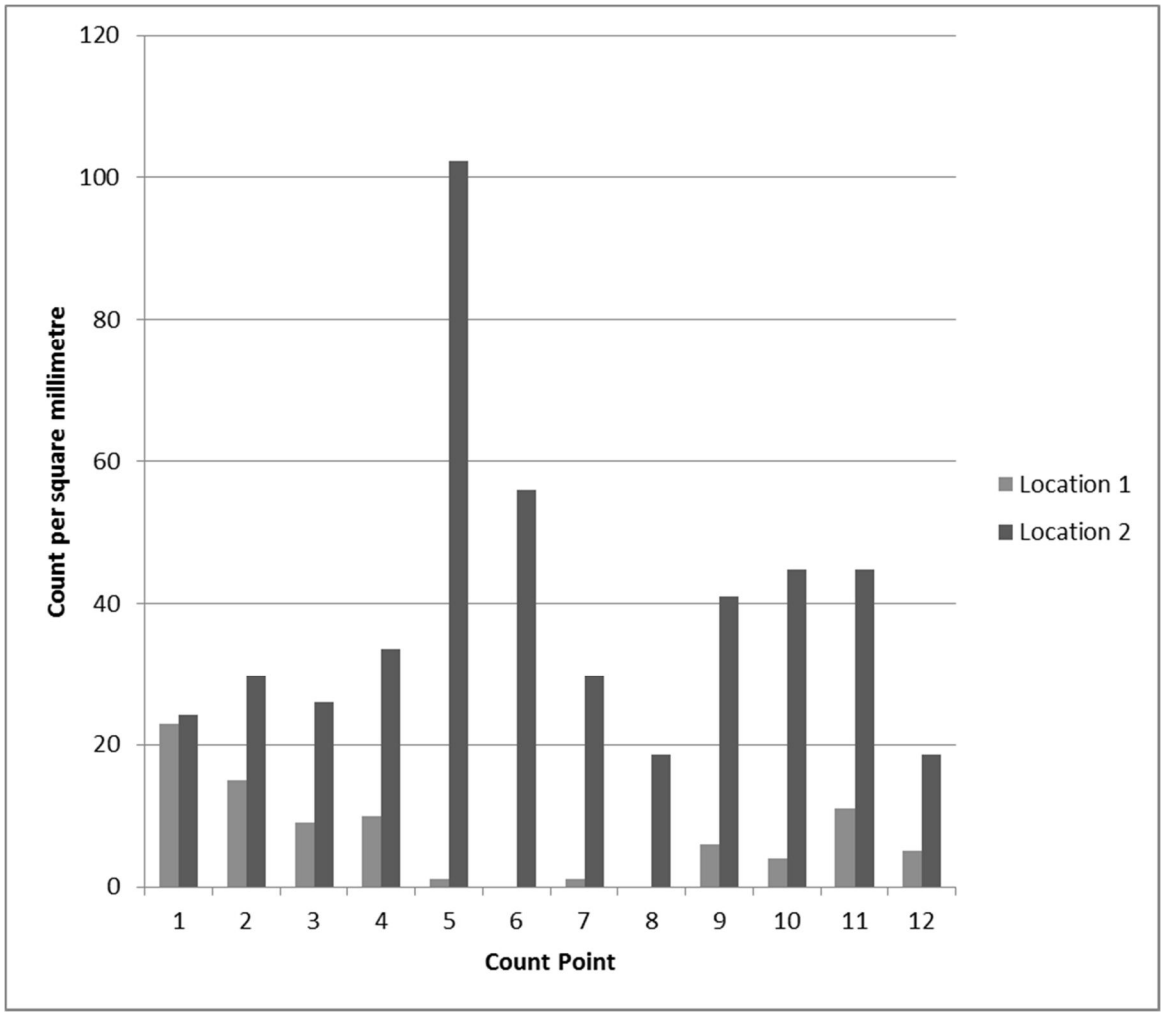

Figure 66. Dust Concentrations at the Twelve Points on each of the Two Locations

A Student's t Test analysis of the data shows that the two groups of numbers are drawn from a different population set at the $p < 0.0002$ level assuming one tail. The particulate matter had a concentration of about 0.3 particles per square millimetre per

hour for location 1 and 1.6 particles per square millimetre per hour for location 2. The minimum measured particle size in the photographs was 0.3 microns. The estimated particulate load for the 24 hours on the filter for the low estimate at location 1 is 351,000 particles and for high estimate for location 2 is 1.8 million particles. This assumes a surface are of 48,800 square millimetres for the filter and the rates per square millimetre per hour observed at the two locations. This represents between 0.2 and 1 particle per litre of air flowing in the circulation system. The air flow velocity in the tube is approximately 1.1 m/s.

SUMMARY

There is a clear difference in the concentrations of dust at the two locations. Location 2 immediately beneath the door way has a mean concentration level that is 5 times as high as location 1 beneath the air intake for the circulation fan. The hypothesis is clearly false.

CHAPTER V

CONCLUSIONS

This research study continues the study of the movement of particulate matter between construction and non-construction zones in a hospital setting. The original research looked at the movement of particulate matter through a simple but complete plastic barrier. A simple two chamber test arrangement was developed in the earlier research to model the clean and dirty sides of a hospital construction area. The original work showed that the movement of dust through the barrier was improbable for the test arrangement.

This current research introduced a door into the plastic wall to model a real construction zone where people and goods pass from one side of the barrier to the other for the usual reasons. Dust in the form of talcum type powder is used to model the movement of the particulate matter that is known to increase the incidence of invasive Aspergillosis in immune compromised patients. A doorway with an area equal to five percent of the wall area was introduced into the original test system. Two tests were completed using this arrangement, with the result that no particulate matter was observed in the filters in the clean chamber after a test period of 24 hours.

The standard test arrangement was modified to introduce a recirculating fan system to increase the air flow between the chambers. A twenty four test of this system showed movement of the dust particles from the dirty to the clean chamber. Two

locations were chosen on the outlet filter to test the differences in the concentrations of dust on the filters.

Location 1 is immediately beneath the intake point for the circulating fan, the dust concentration rate was determined at 0.3 particles per square millimeter per hour. Location 2 immediately below the doorway had a dust concentration rate of 1.6 particles per square millimetre per hour. Clearly the movement of dust through the doorway is unacceptable at these rates. The hypothesis is false as the flow rate particulate matter is determined with a significantly greater accuracy than postulated as the base error rate.

Further research should consider

- testing the powder and comparing the properties to average dust particulate matter
- determine the properties of the filters used in the tests
- develop a finite element model of the chamber
- test the particulate matter rates and sizes in outside air 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

REFERENCES

Bartley, J. M. (2000). APIC State-of-the-Art Report: The role of infection control during construction in health care facilities. *American Journal of Infection Control, 28*(2), 156-169

Bassett, A. J. (2013). *Comparison test for infection control barriers for construction in healthcare.* MSc (Construction Management) (Master's Thesis), Texas A&M University, College Station.

Cardarelli, F. (1997). *Scientific unit conversion: a practical guide to metrication* (M. J. Shields, Trans. First ed.). London: Springer-Verlag.

Centers for Disease Control and Prevention. (2009). National vital statistics system Retrieved 10 April, 2014, from http://www.cdc.gov/nchs/nvss/mortality/historical_gmwki.htm

Centers for Disease Control and Prevention. (2012). Fungal diseases - Aspergillosis. Retrieved 10 April, 2014, from http://www.cdc.gov/fungal/aspergillosis/

Centers for Disease Control and Prevention. (2013). What is public health? Retrieved 10 April, 2014, from http://www.cdcfoundation.org/content/what-public-health

Centers for Disease Control and Prevention. (2014). Aspergillosis Retrieved April 10, 2014, from http://www.cdc.gov/fungal/diseases/aspergillosis/index.html?s_cid=cs_748

Charney, W. (2010). *Handbook of modern hospital safety*. Bacon Rouge: CRC Press.

Cornet, M., Levy, V., Fleury, L., Lortholary, J., Barquins, S., Coureul, M., Deliere, E., Zittoun, R., Brücker, G., & Bouvet, A. (1999). Efficacy of prevention by high - efficiency particulate air filtration or laminar airflow against Aspergillus airborne contamination during hospital renovation. *Infection Control and Hospital Epidemiology, 20*(7), 508-513

Facility Guidelines Institute. (2010). *Guidelines for design and construction of health care facilites*. Chicago, IL: The Facility Guidelines Institute.

Fournel, I., Sautour, M., Lafon, I., Sixt, N., L'Ollivier, C., Dalle, F., Chavanet, P., Couillaud, G., Caillot, D., Astruc, K., Bonnin, A., & Aho-Glélé, L.-S. (2010). Airborne Aspergillus contamination during hospital construction works: Efficacy of protective measures. *American Journal of Infection Control, 38*(3), 189-194

Johnson, R. A. (2000). *Probability and statistics for engineers*. Upper Saddle River: Prentice Hall.

Kordzakhia, N. (1998, June 1998). [Fast Fourier Transform analysis of statistical data].

Latge, J. P. (1999). Aspergillus Fumigatus and Aspergillosis. *Clin Microbiol Rev, 12*(2), 310-350

Liu, L., Borman, M., & Gao, J. (2014). Delivering complex engineering projects: Reexamining organizational control theory. *International Journal of Project Management, 32*(5), 791-802

Lugosi, M., Alberti, C., Zahar, J., Garrouste, M., Lemiale, V., Descorps-Desclère, A., Ricard, J., Goldgran-Tolédano, D., Cohen, Y., Schwebel, C., Vésin, A., Timsit, J., & Azoulay, E. (2014). Aspergillus in the lower respiratory tract of immunocompetent critically ill patients. *Journal of Infection, 69*(3), 284-292

Malik, O., Arabzadeh, H., & Singh, J. (2008). *Controlling hospital-acquired infections, role of industrial hygienists*. Falls Church, VA: American Industrial Hygiene Association.

Manuel, R. J., & Kibbler, C. C. (1998). The epidemiology and prevention of invasive aspergillosis. *Journal of Hospital Infection, 39*(2), 95-109

Mayo Foundation for Medical Education and Research. (2014). Diseases and conditions: Aspergillosis - risk factors Retrieved May 27, 2014, from http://www.mayoclinic.org/diseases-conditions/aspergillosis/basics/risk-factors/con-20030330

Nichols, J. M. (2014). Discussion on: A 10-year survey of fungal aerocontamination in hospital corridors: a reliable sentinel to predict fungal exposure risk? *Manuscript submitted for publication to Journal of Hospital Infection*

Occupational Safety and Health Adminstration. (2014). Safety and Health Regulations for Construction - Sec. 1926.500(b) definitions Retrieved 10 April, 2014, from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10756

Oren, I., Haddad, N., Finkelstein, R., & Rowe, J. M. (2001). Invasive pulmonary aspergillosis in neutropenic patients during hospital construction: before and after chemoprophylaxis and institution of HEPA filters. *American Journal of Hematology, 66*(4), 257-262

Pini, G., Faggi, E., Donato, R., Sacco, C., & Fanci, R. (2008). Invasive pulmonary Aspergillosis in neutropenic patients and the influence of hospital renovation. *Mycoses, 51*(2), 117-122

Premier Inc. (2014). Infection control risk assessment (ICRA) Retrieved March 24, 2014, from https://www.premierinc.com/quality-safety/tools-services/safety/topics/construction/icra.jsp

Reboux, G., Gbaguidi-Haore, H., Bellanger, A. P., Demonmerot, F., Houdrouge, K., Deconinck, E., Bertrand, X., & Millon, L. (2014). A 10-year survey of fungal aerocontamination in hospital corridors: a reliable sentinel to predict fungal exposure risk? *Journal of Hospital Infection, 87*(1), 34-40

Riley, D., Freihaut, J., Bahnfleth, W., & Karapetyan, Z. (2004). *Indoor air quality management and infection control in health care facility construction.* Paper presented at the Proceedings of the CIB World Building Conference, 2004, Toronto, Canada. CIB: pg. (1-10)

Rocketfish Inc. (2014). Rocketfish - 120 mm case fan Retrieved 6 July, 2014, from http://www.rocketfishproducts.com/products/computer-accessories/RF-120FAN.html

Streeter, V. L., & Wylie, E. B. (1979). *Fluid mechanics*. New York, NY: McGraw Hill.

Texas A&M University Office of the Registrar. (2014). Academic catalog: fall 2014 Retrieved 6 July, 2014, from Texas A&M University website: registrar.tamu.edu/General/Catalog.aspx

The American Institute of Architects. (2006). *Guidelines for the design and construction of health care facilites*. Washington, DC: AIA.

Vitha, S. (2014). [Microscopic work on filters for the study of particulate movement in an enclosed chamber]. Texas A&M University.

Vonberg, R. P., & Gastmeier, P. (2006). Nosocomial Aspergillosis in outbreak settings. *Journal of Hospital Infection, 63*(3), 246-254