DESIGN, MANUFACTURE AND TEST A NOSE/MOUTH FILTER FOR USE DURING

THE HARMATTAN

By

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Science in Mechanical Engineering and that to the best of my knowledge, it contains no material which has been accepted for the award of any other degree of the university or any other university, except where due acknowledgement has been made in the text.

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ABSTRACT

The Harmattan is characterized by massive suspension and deposition of large quantity of Sahara soil dust particles (density □□ 2,650 kg/m^3 and diameter 2□ 0.5□m) in West Africa during the months of November to March each year (Sunnu, 2006). Inhalation of the dust aerosols has been shown to cause adverse effects on human respiratory systems. Even though there are a lot of imported respirators in the local market which are used for various purposes, there is none designed specifically for the Harmattan dust. The purpose of this study is to design, manufacture and test a mouth/nose filter (mechanical respirator) for use during the Harmattan period. To achieve this objective of filtering the dust aerosols, four (4) different locally made filters were tested using an experimental test rig set up to simulate the inhalation of the Harmattan dust. The test was carried out at a constant flow rate of 8.22l/min where the salient filter design parameters such as pressure drop, penetration, efficiency and quality factor were observed. The results suggest that the tri-ply of calico, felt and twill is appropriate to be used as mouth/nose filter for the Harmattan dust particles owing to the fact that it had the highest efficiency of 80%, the lowest aerosol penetration of 20%, a pressure drop of 47.67 Pa and a filter quality of 0.0337.

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DEDICATION

To Agbeko T. Tamakloe, Osami N. Adorsu and to Senyo K. Ocloo.

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U_0	Face velocity
d_f	Fiber diameter
f	Friction factor
d_h	Hydraulic diameter of a pore
□	Kinematic viscosity of air
U	Mean velocity
N_0	Particle number concentration entering the filter
N_L	Particle number concentration leaving the filter
□p	Pressure drop
q_F	Quality factor
□	Single fiber collection efficiency
□	Solidity
t	Thickness of filter
□	Viscosity

Q	Volumetric flow rate
A	Cross sectional area
AC	Alternative current
DC	Direct current
DOP	Dispersed oil particulate
E	Overall efficiency
HEPA	High efficiency particulate air
NIOSH	National Institute for Occupational Safety and Health
P	Penetration
PM	Particulate matter
R_e	Reynolds number
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

This chapter contains the background, motivation, objectives and methodology of the research. It discusses dust aerosols and filtration of clean air.

1.1 Background

Aerosols or airborne particles are present in our environment either by nature or through human activities, they come in many forms such as dust, mist, fume, smoke and fog (Sunnu, 2014).The West African atmospheric environment is not immune to aerosols, thus naturally, the dry season months from November to March, is characterized by massive suspension and deposition of Saharan soil dust particles (Sunnu, 2006). The presence of the dust aerosol in the West African region creates an opalescent atmosphere during this period (Sunnu, 2006). The dust invasions are sustained by the northeast trade winds, which blow across the Sahara Desert towards the Gulf of Guinea and beyond, in northeasterly direction during this period. This dusty wind phenomenon is locally called the Harmattan (Sunnu, 2006).This massive dust invasion makes it virtually impossible for human, industrial, commercial or domestic activities to go on effectively without filtration.

Atmospheric air filtration is a widely used process in that clean air is needed for air compressors, for combustion in vehicles and for air conditioners among others. In processing industries, filtration plays a vital role by preventing hydraulic control systems for instance to seize abruptly (Sutherland, 2008). The performance of some industrial machines such as blowers, air compressors, and gas turbine engines may reduce significantly if their intake air is not well filtered. In the health sector, health professionals wear surgical masks during surgery as they attend to patients to prevent micro-organisms, viruses and bacteria contamination. Mechanical air purifying and chemical cartridge respirators are used to protect individuals exposed to contaminated air as they breathe in air.

However, there is no filter designed specifically for the Harmattan dust which is a heavily suspended dust aerosol. Aerosol filtration has seen enormous advancement in the past decades based on customer's increasing demand for small size, high efficiency, and low pressure drop of a filtration system. Emission regulation also drives the evolution of filter media technology as well as filter configuration optimization. It is anticipated that the demand for clean tidal air can only become stronger for human health protection and sustainable growth. Since filtration systems are to be challenged by different aerosol contaminants in different environment in the real world, developing robust filtration technology with better flexibility and functionality without significantly increasing the cost is expected to be the future trend.

At this point, a thorough understanding of aerosol behaviour is of great importance while finding means to remove particles from suspensions of the Saharan dust in the tidal air. Aerosol filtration has been a long-standing topic for both academic research and industrial practice for environment and equipment protection (Chuanfang, 2012). Aerosol filtration is a very complex process but fundamental theories are well established regardless of the still existing gaps between theory and experiment. Chen (1955) has made significant contribution to filtration theory, where he established a semi-empirical screen model to account for interference effect of neighboring fibers. His model is considered as one of the milestones of aerosol filtration theory. His work also covered aerosol removal mechanisms through direct interception, Brownian diffusion and the force of inertia impaction, which is critical to designing air filters with low pressure drop and high filtration efficiency that is practiced routinely today.

1.2 Motivation

There have been genuine interests in aerosol properties lately because of proofs of the harmfulness of contaminated airborne particulate matter (Wilson and Spengler, 1996). Studies performed over the Harmattan periods of 1997 to 2009 showed that the average daily particle diameter, number and mass concentrations observed in the representative peak Harmattan periods are 1.57±0.54μm, 50±25 particles/cm^3 and 1,130±994 μg/m^3 respectively (Sunnu, 2012). Furthermore, the corresponding average daily particle diameter, number and mass concentrations observed during the months of January-February called the background Harmattan over the twelve seasons are respectively, 1.31±0.31 μm, 32±12 particles/cm^3 and 576±429 μg/m^3.In the light of these results, Sunnu (2012) suggested the design of ambient air filters for nose and mouth, engines and clean environment during the Harmattan.

Respiratory related ailments remain widespread all over the world, as they infect half of the world's population. (Jimoh, 2012). Inhaling contaminated air, which may well contain particularly aggressive substances, often causes health conditions such as flu, emphysema, headaches, eye irritation, coughing, dizziness, and the build-up of toxins in the bloodstream. Aerosol particles enter the body through the mouth and nose, and are gradually deposited on the bronchial mucous membrane. At the early stage of deposition, the bronchial membrane itself is able to provide protective counteractions in the form of sputum and coughing. This physical adjustment becomes impossible as a result of repeated inhalation of particulates and their inevitable deposits over an extended period. As a consequence, the functions of the bronchi become abnormal.

Functional deterioration of the lungs will affect the heart adversely, leading to heart disease. This somewhat over-dramatic representation nevertheless highlights the need for clean air for all human activity (Sutherland, 2008).

According to the World Health Organization (Ramadan, 2011), particulate matter affects more people than any other pollutant (WHO, 2008). PM 2.5 is especially dangerous as the particles are able to travel deep into the bronchioles region of the lungs and can result in serious health risks. It is therefore observed from the above that the design and manufacture of a mouth/nose filter to filter these Harmattan particles is essential.

1.3 Objective

The overall goal of this work is to design and manufacture suitable nose/mouth filter for removing aerosol particles from air.

Specific Objectives

i. To select suitable materials for the filters ii. To design a nose/mouth filter (mechanical respirator) capable of filtering aerosols greater or equal to 2±0.5µm diameter iii. To produce prototype samples iv. To construct a test rig for testing of the filters

v. To test the samples

1.4 Methodology

In order to achieve the above objectives the following methods were used

- Literature review on existing air filters (respirators) in the system
- Designing the filter using standard procedures

- Setting up experiment to test the various filter combinations using a test rig
- Collecting Harmattan dust using soft brushes
- Manufacturing the filter by sewing , using a sewing machine

1.5 Structure of thesis

This thesis is organized into five (5) chapters. Chapter one includes background, motivation, objectives and methodology. Chapter two contains literature review of aerosol, filtration, single fiber theory, filter materials, pressure drop, penetration and efficiency, types of respirators and test performed on respirators. Chapter three presents the methodology (design and test), after which, results and discussions ensued in chapter four. Finally chapter five presents the conclusion and recommendations of the research.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews literature that relates (generally) to aerosols and filter design including aerosols, filtration, single fiber theory, filter materials, pressure drop, penetration, efficiency and types of respirators.

2.1 Aerosol

An aerosol is a collection of solid or liquid particles suspended in a gas. The term aerosol includes both the particles and the suspending gas, which is usually air. Particle size ranges from about 0.002 to more than 100μm (Hinds, 1999). The Centre for Diseases Control and Prevention, an American organization through NIOSH Aerosol Research (2010) described it as a suspension of tiny particles or droplets in the air, such as dusts, mists, or fumes. These particles may be inhaled or absorbed by the skin, and can sometimes cause adverse health effects (CDC-Aerosols-NIOSH, 2010).

2.2 Filtration

The process of air filtration is the separation of particles from carrier suspending fluids by the use of porous media. Sieving is only one of the several mechanisms by which filters remove particles from a fluid (Chen 1955). Zhang (2004) also asserted that filtration consists of an air stream passing through a fibrous filter in which particles or gases in the flow may be collected by one of the following particle capture mechanisms: interception, inertial impaction, or diffusion.

In their quest to take away dust particles from gases (air), engineers have developed filtering devices in which the pores are several orders of magnitude larger than the particles which are trapped. By developing theories which consider several mechanisms of particle capture in addition to sieving (Rubenstein, 1977), they have successfully predicted the effectiveness of particle removal by filters (Rubenstein et al, 1977). In any filtration system, three (3) elements namely, the fluid medium, the aerosol particles in the fluid which are assumed to be spherical, and the filter itself are worth considering (Rubenstein et al, 1977).

2.3 Mechanisms of Aerosol Particle Capture in Fiber Filters

Rubenstein et al (1977) also assumed that the aerosol particles stick to the filter upon contact in dealing with mechanisms of aerosol particle capture in fiber filters. These mechanisms by which a fiber can remove dispersed particles from an air stream are namely Direct interception, Inertial impaction, Gravitational deposition, Brownian diffusion and Electrostatic attraction.

It is important to describe the velocity field surrounding the strand or fiber before commencing the analysis of the mechanisms of particle capture. Even though this description could be done mathematically (Chen 1955; Pich 1966), it is sufficient to describe the velocity field graphically using stream lines as indicators of flow direction (Figure 2.1).

Billings (1966) agreed with the assumptions for single fiber filter model as follows.

- The fibers are sufficiently far apart, so that the fluid flow in the vicinity of a given fiber can be adequately represented by flow near an isolated fiber i.e., interfiber interference or fiber crossing effects are neglected.(the fluid streamlines near a fiber are not displaced significantly by presence of the other fibers)

- The particles approaching a surface do not interact with or distort the flow to produce additional hydrodynamic lift or drag
- The particles always adhere on contact, i.e., effective contacts surface migration, and re-entrainment are neglected and it is assumed that a particle sticks to the fiber upon contact and is also filtered from the suspended gas.

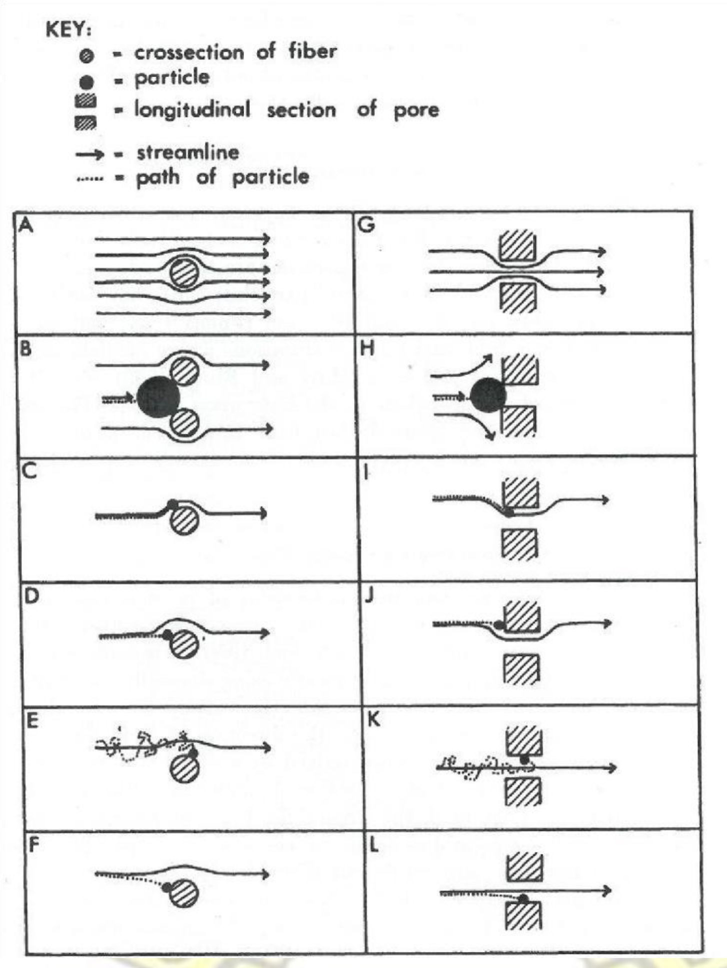

Figure 2.1 Diagram of: A, flow around a fiber; B, sieving; C, direct interception; D, inertia impaction; E, Brownian diffusion; F ,gravitational deposition ;G, flow through a pore; H sieving; I, direct interception; J, inertia impaction; K, Brownian diffusion; & L, gravitational deposition.

2.3.1 Direct interception

This filtration mechanism occurs when a dust particle moves with the airstream and at some point becomes attracted to the media fibers, leaves the airstream and attaches itself to the fibers. This occurs when a dust particle follows a gas streamline that happens to come within one particle radius of the surface of a fiber. Figure 2.2 shows the phenomenon of interception. The particle hits the fiber and is captured because of its finite size. Thus, for a given size particle, certain streamlines will result in capture of the particle while other streamlines will not.

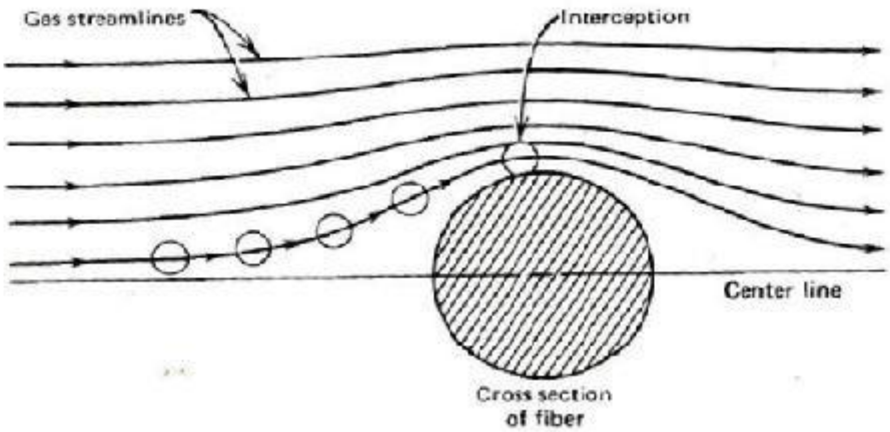

Figure 2.2 Filtration mechanism due to interception (Hinds, 1999 pp 192)

2.3.2 Inertial impactions

When a particle, because of its inertia, is unable to adjust quickly enough to the abruptly changing streamlines near the fiber and crosses those streamlines to hit the fiber and attaches itself to the fiber , Inertial impaction is said to have occurred. Figure 2.3 shows the inertial impaction mechanism. The streamlines of a fluid around the fiber are curved (Sarsah, 2012). Particles with a finite mass and moving with the flow may not follow the streamlines exactly due to their inertia (Sangkhamanee, 2009). If the curvature of a streamline is sufficiently large and the mass of a particle is sufficiently high, the particles may deviate far enough from the streamline to collide with the media surface.

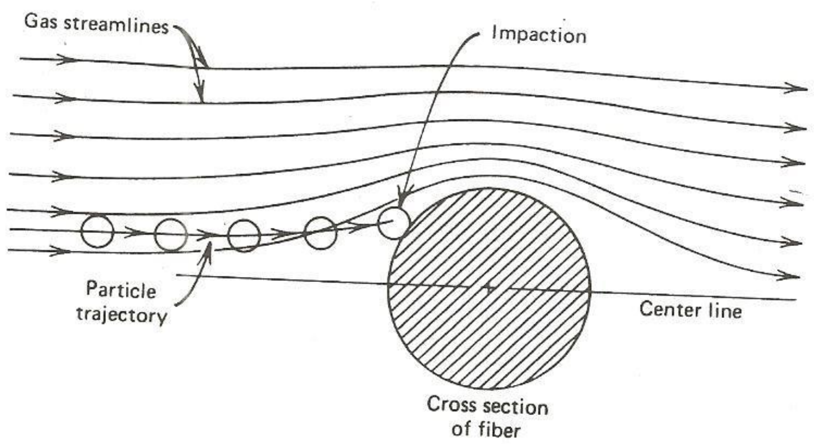

Figure 2.3 Filtration mechanism due to impaction (Hinds, 1999 pp 193)

2.3.3 Gravitational Deposition

Particles will settle with a finite velocity in a gravitational force field. When the settling velocity is sufficiently large, the particles may deviate from the streamline. Under downward filtration conditions, this would cause an increase collection, due to gravity. When flow is upward, this mechanism causes particles to move away from the collector, resulting in a negative contribution to filtration.

2.3.4 Brownian diffusion

Brownian motion is the irregular wiggling motion of an aerosol particle in still air caused by random variations in the relentless bombardment of gas molecules against the particle. Diffusion of aerosol particles is the net transport of these particles in a concentration gradient. Filtration by Brownian diffusion occurs when small particles collide with the air molecules and move in an erratic path (Brownian movement).

The path allows for the small particle to come in contact with the media and stay attached as shown in Figure 2.4.

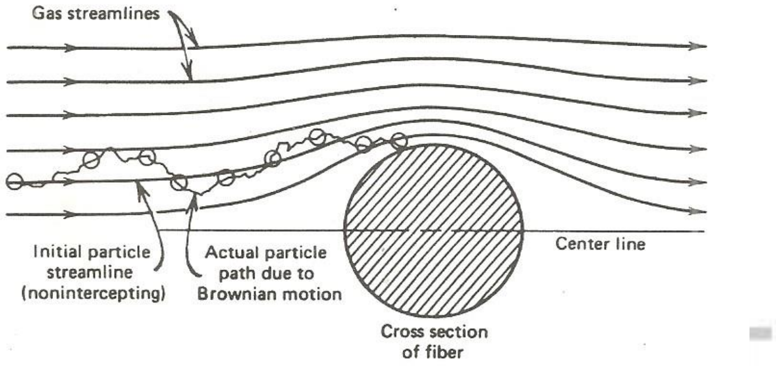

Figure 2.4 Filtration mechanism due to diffusion (Hinds, 1999 pp 194)

2.3.5 Electrostatic attraction

It is an efficient method of removing dust and other small particles from air over a particle size range from about 10 to 0.01 microns (Willeke, pp 192). The principle involved, as shown in Figure 2.5 is that of passing the air through an ionizer screen where electrons colliding with air molecules generate positive ions which adhere to dust and other small particles present, giving them a positive charge, which then enter a region filled with closely spaced parallel metal plates alternatively charged with positive and negative voltages. Positive plates repel the charged particles which are attracted by and retained on the negative plates by electrostatic forces.

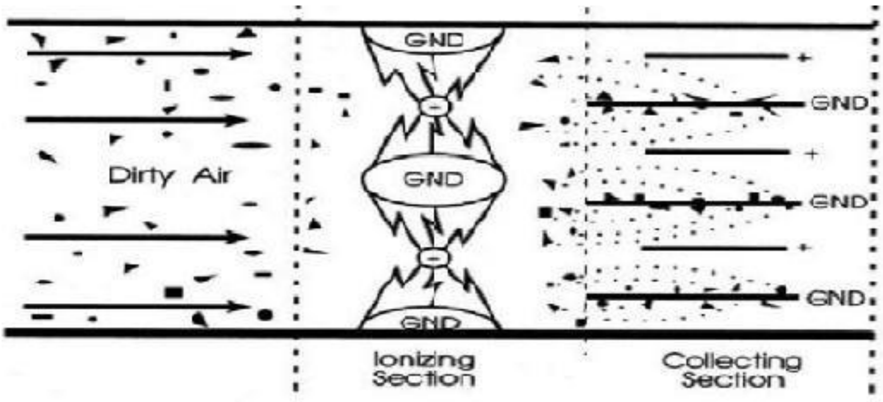

Figure 2.5 Principle of electrostatic attraction (willeke, pp 192)

2.4 Bouncing and Re-entrainment phenomenon

In constant flow, adhesion forces are usually strong enough to hold on to a particle if the particle initially was captured. However there are circumstances where particles do not stay attached to the filter media. Bouncing and re-entrainment are two conditions where the adhesion forces between the particle and the filter media are overcome by other forces (Brown, 1993).

Bouncing is often observed after inertial impaction. This is because the velocity of the particle, and therefore the kinetic energy, is higher than in other conditions. For direct interception on the contrary, the flow velocity and therefore the particle velocity is low at proximity to the filter media where the direct interception occurs. This results in small chances for bouncing of the particle (Brown, 1993).

Re-entrainment of a particle means that the particle leaves the filter media after it has settled. In a steady flow this is not likely to happen, but if the flow alters or other particles or larger clusters of particles are hitting already deposited particles reentrainment can occur. If this happens the particles receive enough energy from the altering flow or transfer energy from other particles to annul the adhesion forces and the deposited particle is able to re-enter the flow (Brown, 1993).

2.5 Formation of filter cake

The forces and mechanisms mentioned earlier create filtration by capturing free particles in a flow and deposit them on a filter media. The media itself usually have a good ability to capture particles. The dust particles suspended in the gas are captured in the pores of the filter media, which creates smaller opening for penetration and even better filtration efficiency. After a while the particles start gathering on the top of the filter and a filter cake is formed. Figure 2.6 shows the formation of a filter cake step by step. With the increase of the filter cake thickness the pressure difference over the filter also increases. The pressure difference contributes to the force causing re-entrainment. When these forces are sufficiently strong particles will re-enter the flow, often in larger lumps creating a hole in the filter cake. Such holes are called pinholes and are often hard to close when first opened (Lee et al, 1977).

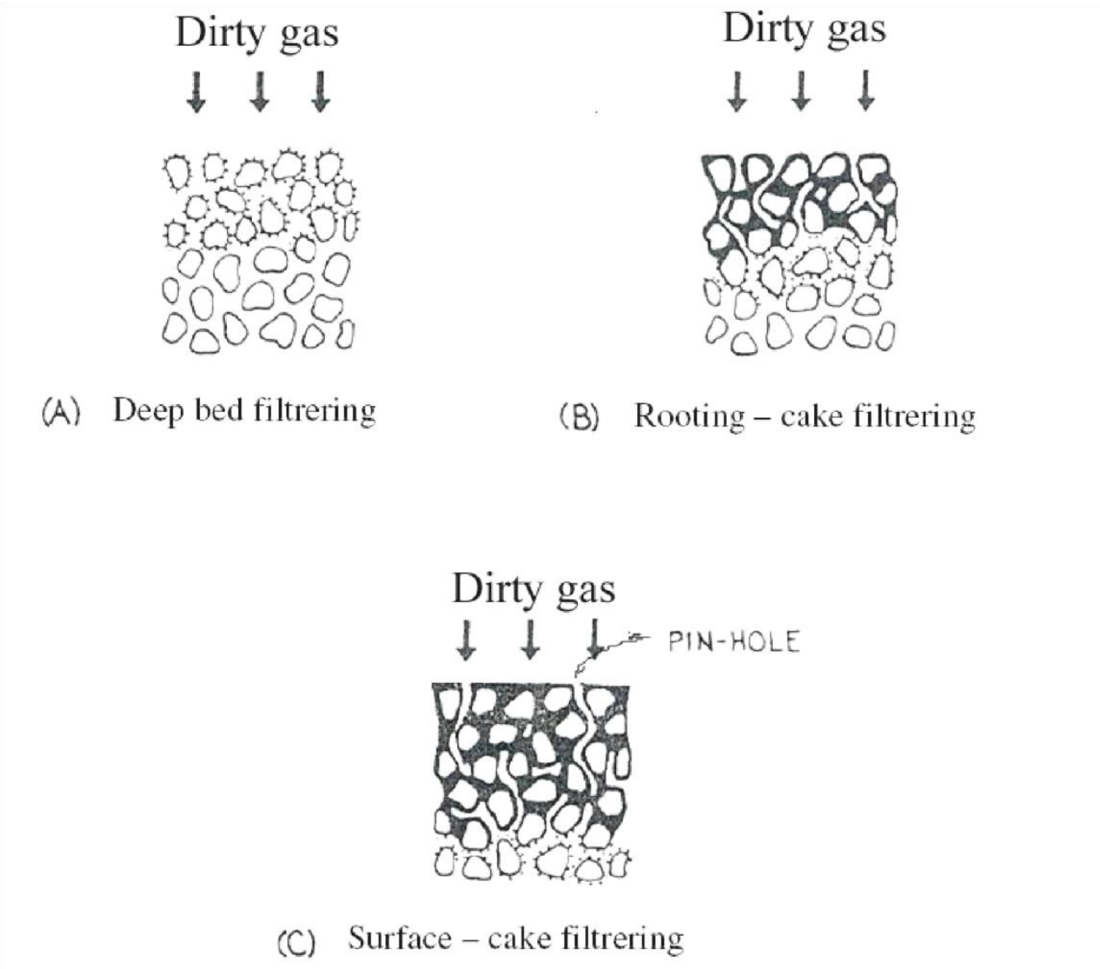

Figure 2.6 Filter cake phases (Lee et al, 1977)

2.6 Theoretical consideration of filter design parameters

This section discusses filter design variables including filter media, pressure drop, penetration, filtration velocity, filter quality and overall efficiency as follows.

2.6.1 Fabric or type of filter media

The Elsevier Handbook of Filter Media has a precise definition of a filter medium:

"A filter medium is any material that, under the operating conditions of the filter, is permeable to one or more components of a mixture, solution or suspension, and is impermeable to the remaining components".

Porous membrane filters are mostly made from natural fiber cellulose (cotton or viscose), glass, polyamide (nylon), natural fiber protein (wool), polyvinyl chloride, fluorocarbon (Teflon), and silk among others. Table 2.1 gives the comparative rating of some fabric filter materials

Table 2.1 Comparative rating of some fabric filter materials

		Comparative rating	
parameters	**cotton**	**viscose**	**polyester**
Comfort			
Moisture regain	Good	**Very good**	poor
Thermal protection	Good	**Very good**	poor
Air permeability	Very good	**Good**	poor
softness	good	**Very good**	poor
smoothness	poor	**Good**	Very good
Static dissipation	Good	**Very good**	poor
Aesthetics drape	good	**Very good**	poor
luster	poor	**Very good**	Very good
Crease recovery	poor	**poor**	Very good
uniformity	poor	**Very good**	good
Utility performance antipilling	good	**Very good**	poor

Table 2.1 shows that cotton or viscose could be the preferred choice for a respirator design owing to the following reasons:

- Natural fiber cellulose is soft, comfortable and is also an excellent type of material in ventilation type collectors.
- As shown in table 2.1 air permeability of viscose is good (breathing), drapes well and has high antipilling properties
- Cotton is Readily available, cheap and used everywhere

2.6.1.1 Woven materials types

 Plain

In plain weave, as shown in Figure 2.7, the threads that run lengthwise which are technically called warp and the threads that go across the length named weft are aligned in such a manner that their patterns cross one another. It is woven such that at one time the weft thread crosses the warp threads by going over it, and the next time it goes under, and vice versa (Wikipedia, n.d.).

Figure 2.7: structure of plain material on an optical microscope

Twill

In this type of weave (Figure 2.8) the weft thread goes over one or more warp threads and then under two or more warp threads and so on, with an offset between rows to create a diagonal pattern characteristics (Wikipedia, n.d.).

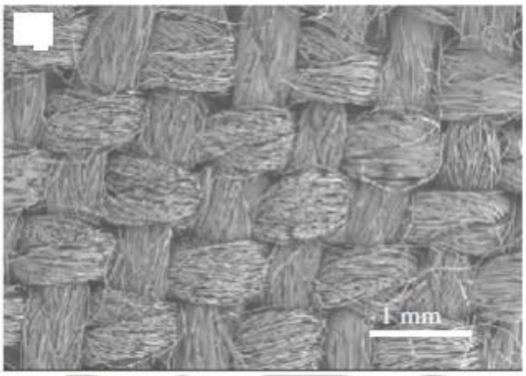

Figure 2.8: Scanning electron microscope image for a twill weave, after Benesse et al., 2006

2.6.1.2 Non-woven fabric

As shown in Figure 2.9, these fabrics are made up of web structures bonded together by intertwining fibers or strands mechanically, thermally or chemically. They normally come as flat and porous pieces of materials (Nonwoven.Fabric.Wikipedia, n.d).

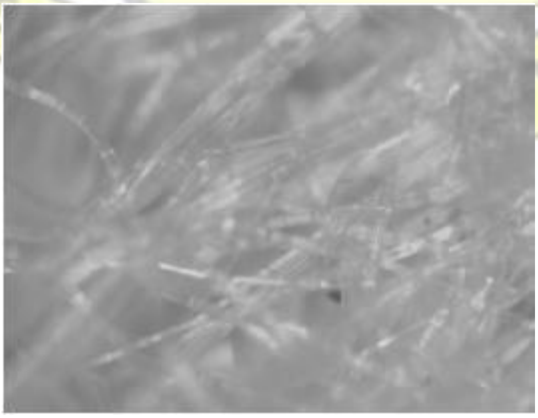

Figure 2.9: structure of a non-woven material viewed on an optical microscope

2.6.2 Pressure drop

This is the resistance to airflow, across a filter caused by the combined effect of each fiber resisting the flow of air past it. The pressure drop represents the total drag force of all the fibers (Hinds, 1999).

For the pressure drop across a woven fabric, Holman (1992) suggested the following analysis:

Reynolds number: $$R_e = \frac{U d_h}{\nu} \qquad \text{Eq. (2.1)}$$

Where:

$U \equiv$ Mean velocity of flow $d_h \equiv$ Hydraulic diameter of a pore

$\nu \equiv$ Kinematic viscosity of air

The pressure drop (Δp) of the flow through a duct over the thickness of the fabric is related to the friction factor f through Darcy's formula.

$$\Delta p = f \frac{t}{d_h} \rho \frac{U^2}{2} \qquad \text{Eq. (2.2)}$$

Where **t** is the thickness of the fabric and ρ is the air density (Holman, 1992)

2.6.3 Penetration

During particle filtration there will always be some particles that penetrate the filter. However, the filters can be optimized to create a little penetration as possible and thereby increase the filtration efficiency, if the mechanisms of the penetration are known.

In Figure 2.10 considering fiber length per unit volume of filter as

$$l = \frac{\alpha}{\pi a^2} \qquad \text{Eq. (2.3)}$$

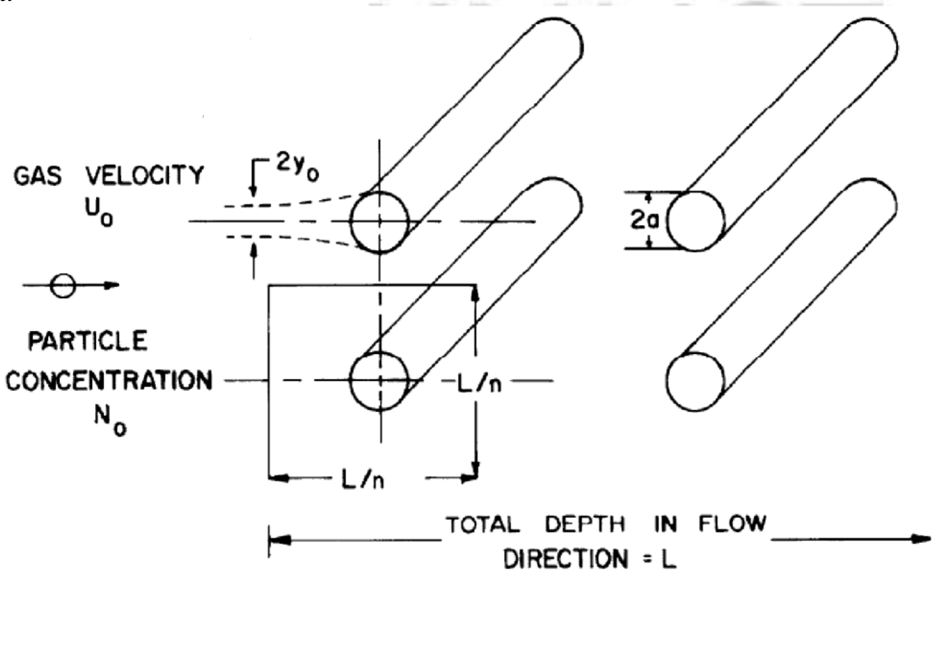

Figure 2.10: isolated fiber model of aerosol fiber, after Billings (1966)

With l : The fiber length per unit volume of filter

a: The radius of the yarn or fiber in (m)

α: The packing density which is a dimensionless quantity ($0.01<\alpha< 0.3$), for fibrous filter (hinds, 1999), and assuming that all fibers are perpendicular to the flow and the particle concentration is uniform at every distance from the filter entrance.

Let $2y_o$ be the width of the fluid approaching the fiber from which all particles are removed. The change of concentration (particulate/cm^3) in the direction of flow is

$$-\frac{dN}{dx} = 2y_oNl \qquad \text{Eq. (2.4)}$$

Where N denotes particle concentration and x is the distance through the filter in the direction of flow. The fraction of aerosol particles penetrating the filter (penetration) can be obtained by integrating $N=N_o$ at $x=0$ to $N=N_L$ at $x=L$

$$-\frac{dN}{dx} = 2 y_o N l \qquad \text{Eq. (2.5)}$$

$$\ln\left(\frac{N_o}{N_L}\right) = \left(\frac{y_o}{a}\right)\left(\frac{2L\alpha}{\pi a}\right) \qquad \text{Eq. (2.6)}$$

After introducing the fiber length per unit volume of filter from equation (2.3), the ratio of the outlet to the inlet aerosol particle concentration is calculated as $\left(\frac{N_L}{N_o}\right)$ and it is known as the filter penetration $P = \left(\frac{N_L}{N_o}\right)$.

Having obtained the penetration and taking the definition of efficiency which is the fraction of particles approaching the fiber in the region defined by the projected area of the fiber that are ultimately collected on the fiber i.e. $E = \frac{y_o}{a}$ Eq. (2.7)

Where y_o is stream tube height from which all particles are removed and a is the fiber radius

Then equation (2.6) becomes $\ln\left(\frac{N_o}{N_L}\right) = E\left(\frac{2L\alpha}{\pi a}\right)$ Eq. (2.8)

Hence the filter efficiency is $E = \frac{a}{2L} \ln \left(\frac{N_o}{N_L} \right)$ Eq. (2.9)

This shows that the efficiency could be determined knowing filter depth (L), fiber radius, *a* and solidity α.

According to Hinds (1999) air-cleaning equipment, characterized in terms of its penetration, P which is the fraction of entering particles that exit or penetrate the filter could be written as follows

$$P = \frac{N_L}{N_0} = 1 - E \qquad \text{Eq. (2.10)}$$

Where E is experimentally expressed as $E = \frac{N_o - N_L}{N_o}$ Eq. (2.11)

Where N_o :Concentration or number of aerosol dust particles entering the filter

N_L :Concentration or number of aerosol dust particles leaving the filter

At high efficiencies, large changes in penetration are associated with small changes in efficiency. For example, penetration changes by a factor of 10 when efficiency changes by less than 1%, from 99 to 99.9%.

2.6.4 Air to cloth ratio or filtration velocity

The velocity of the air at the face of a filter, just before the air enters, is called the face velocity, U_0.

$$U_0 = \frac{Q}{A} \qquad \text{Eq. (2.12)}$$

Where Q is the volumetric flow rate through the filter and A is the cross-sectional area of the filter exposed to the entering airstream. The air velocity through highefficiency filters is usually quite low, about 0.1 m/s (10 cm/s). Because of the low velocities used, it is often necessary to pleat the filter material to obtain a large filter area in an element of convenient size (hinds, 1999).

2.6.5 Filter quality

The best filter is the one that gives the highest collection efficiency with the least pressure drop possible. A useful criterion for comparing different types of filters and filters of different thickness is the filter quality q_F.The greater the value of (q_F), the better the filter. Comparisons ofq_F must be made for the same face velocity and test aerosol particle size (Hinds, 1999).

A good respirator filter is the one with high efficiency and a reasonably low air resistance. Therefore, it is worth noting that to rank respirators, the filter quality using penetration and pressure drop (high efficiency and least pressure drop) must be considered. Filter quality is usually expressed by the "quality factor (q_F)," which relates the aerosol penetration by the filter to the pressure drop across it and is usually used as the indicator of filter performance (Han, 2000)

$$q_F = \frac{-\ln(1/P)}{\Delta p} \qquad \text{Eq. (2.13)}$$

Where P is the penetration (%), Δp is pressure drop across filter in Pa and q_F the quality factor in Pa^{-1}

2.6.6 Overall Efficiency (E)

In general, measurement of particle and fiber charge is difficult in practice, and is not usually done as part of the experimental determination of fiber efficiency. Capture by gravitational deposition is negligible because of the small particles concerned in filtration. The three remaining mechanisms of diffusion, impaction and direct interception form the basis of the mechanical theory of filtration. These mechanisms have received the majority of theoretical and experimental study (Billings, 1966).

To find the collection efficiency of homogeneous fibrous media, Brown (1993) suggested the formula shown below

$$E = 1 - \exp\left(-\frac{4\alpha\eta t}{\pi d_f (1-\alpha)}\right) \qquad \text{Eq. (2.14)}$$

Where t is the filter thickness in μm, E is the overall efficiency, η is the single fiber collection efficiency, α is the packing density (dimensionless) and d_f is the fiber diameter in meter.

Here the single fiber collection efficiency η is expressed as a function of the efficiencies calculated for each of the different capture mechanisms considered for a single fiber. It can therefore be calculated as follows:

$$\eta = 1 - \left[(1-\eta_d)(1-\eta_i)(1-\eta_r)\right] \qquad \text{Eq. (2.15)}$$

Where

□: Single fiber collection efficiency

$□_d$: Single fiber Diffusion efficiency

$□_i$: Single fiber inertial efficiency

$□_r$: Single fiber Interception efficiency

To get the appropriate expression of a single fiber efficiencies depending on each filtration mechanism, Benesse et al (2006) proposed that one should have an excellent understanding of the parameters of the filter structural (fiber diameter, filter porosity and thickness of the strands, etc.) and filtration conditions such as flow velocity and particle size. Figure 2.11 shows that with increased dust particle size diameter, interception and inertia impaction filtration mechanisms dominate, whereas Brownian diffusion is dominant with a decrease in particle size (Air purifiers: filter efficiency, 2001).

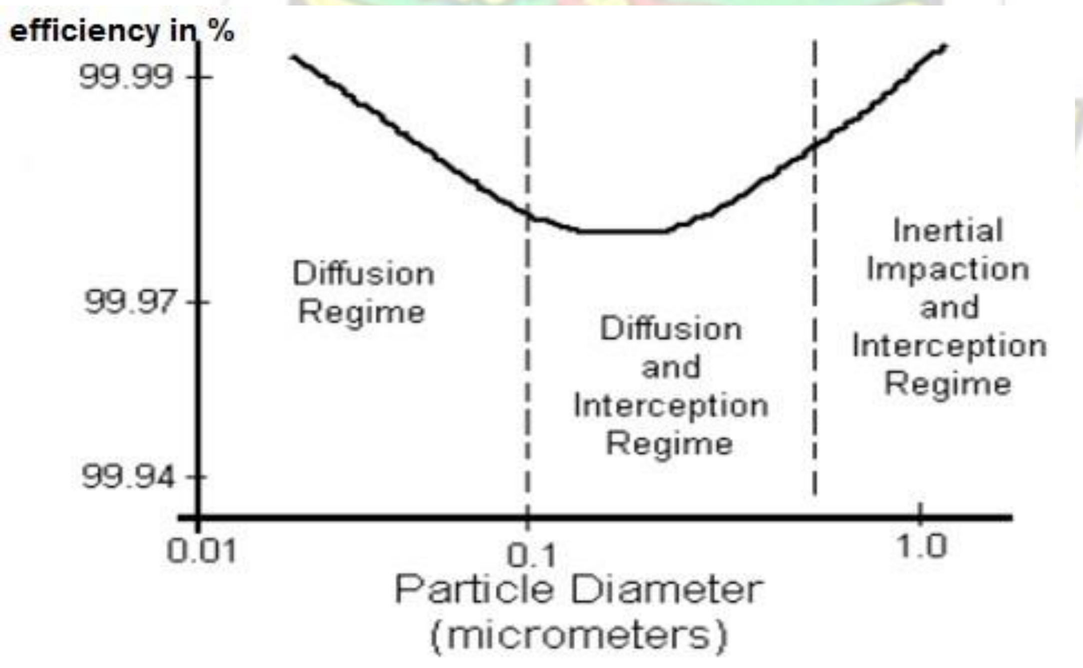

Figure 2.11 Filter efficiency vs. particle size

2.7 Application of aerosol filters

Aerosol filters have a lot of applications and this section documents their usage in various industries.

2.7.1 Respirators

Respiratory equipment is used throughout the world to provide personal protection from a variety of noxious gases, vapours and aerosol hazards which could cause harm and even death to humans. Inhaling wood dust, chemicals, coal dust, pesticide spraying, wall and wood paints, pollen, etc., can cause aerosol transmissible illness such as cold, diphtheria, delicate respiratory conditions and swine flu. In contrast, surgical nose and mouth masks have not traditionally provided dust aerosol protection to the wearers but have been used to keep mouth generated particles from harming a patient in a healthcare situation. A simple surgical respirator shown in Figure 2.12 (a) can collect aerosol particles just like a regular air filter but with very low air flow coming to the mask. In Figure 2.12 (b) an elastomeric half face piece cartridge air purifying respirator was shown.

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(a) Face mask (b) Cartridge respirator

Figure 2.12 Typical nose/mouth filters seen in the market, after Chuanfang (2012).

The cartridge respirator can be stretched to give careful protection against multiple hazards. It can handle not only dust and mist, but also micro-organisms, viruses and bacteria. The cartridge filter normally has multiple layers for different functionalities as shown in Figure 2.13. The removal of agents like micro-organisms, viruses and bacteria is brought about by the physical adsorption property of the agents onto activated charcoal layer with the filter. The layer has an extraordinary large surface area, as high as 300-2000m^2/g . Further, increased protection can be achieved by impregnating the charcoal with substances such as copper oxide which reacts chemically with these agents (Verdegan et al, 2007).

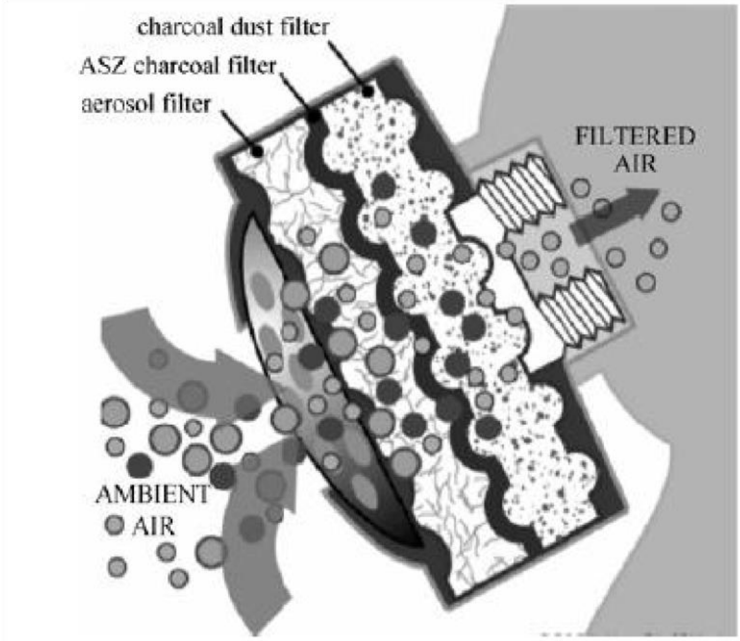


Figure 2.13 Illustration of cartridge filter structure, after Chuanfang (2012).

2.7.2 Bag house collectors

Bag house collectors are air contamination control devices that remove particles out of air or gas freed from coal-fire and cement plants, steel mills and food manufacturing companies, etc. As shown in Figure 2.14, the filter medium of the majority of baghouses is a long, cylindrical bag (or tube) which is made up of woven or felted fabric (Baghouse-dust-collectors, 2003). The dirty gas enters the baghouse through hoppers which are large funnel-shaped containers used for storing and dispensing particulate (Baghouse, 2003).

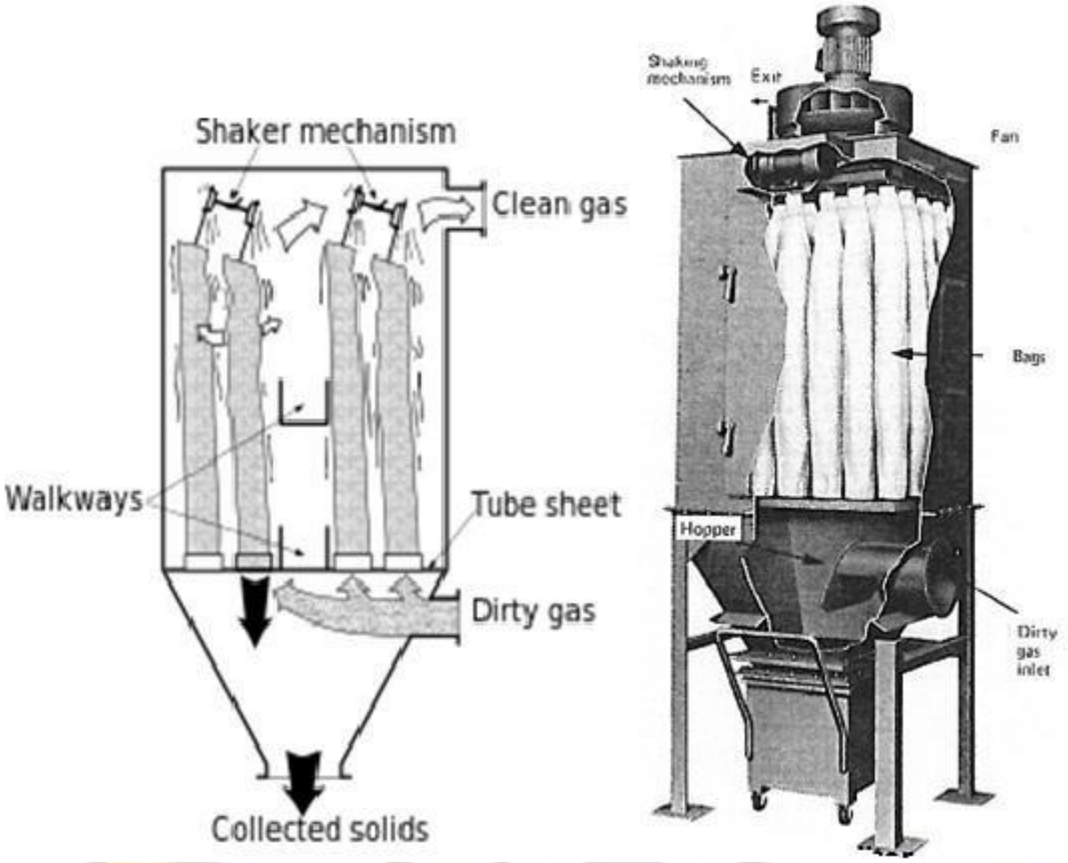


Figure 2.14 Bag filter (Matteson & Orr, 1987)

2.7.3 Oil Bath Filters

This type of filter was used in vehicles until the introduction of paper filters in the 20th century. The general principle of oil bath filters is that incoming air is sucked downwards through the filter system towards the bowl containing a reservoir of oil as illustrated in Figure 2.15. The airflow has to make an abrupt change in direction from travelling downwards towards the oil pool before routing back upwards to the filter outlet (Vintagetractorengineer, 2009). The direction of the air changes easily, however due to inertia forces, any dirt carried in the air is unable to make the turn so it continues straight onto the oil where it is trapped (Vintagetractorengineer, 2009).

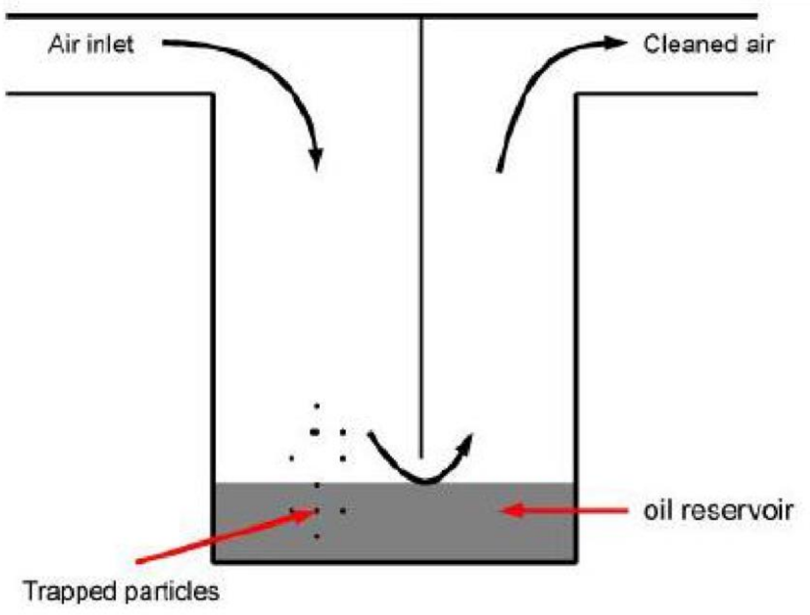


Figure 2.15 An oil bath filter

2.8 Types of respirators

This section discusses the various types of respirators available in the market which are most widely used.

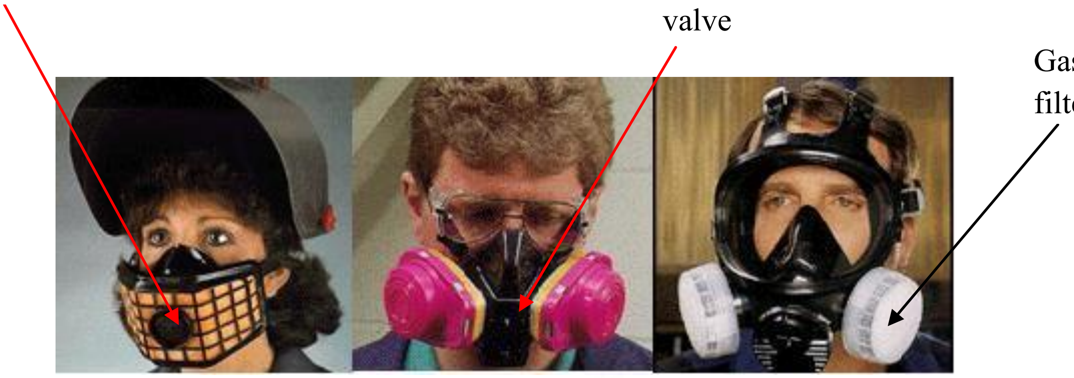
2.8.1 Surgical mask

Health professionals usually wear surgical mask during surgery or other health related activities to prevent bacteria contaminations from either health workers to patients or from the patients to health workers. Modern surgical masks (Refer to Figure 2.16) are made from paper or other non-woven material, and should be discarded after each use for they are presumed to be contaminated. The design of the surgical masks depends on the mode; usually the masks are 3 ply/3 layers (Surgical mask, 2012). This 3 ply material is made from a melt blown which is a process for producing fibrous webs or articles directly from polymers or resins using highvelocity air or another appropriate force to attenuate the filaments. The melt blown is placed between non-woven fabric, the melt-blown material acts as the filter that stops microbes from entering or exiting the mask (Hygiene Mask-kk. Industrial machines Pvt Ltd, 2014).

Figure 2.16 Typical 3-ply surgical masks

2.8.2 Air-purifying and chemical cartridge respirators

Chemical cartridge respirators use a cartridge to remove gases, and other vapors from breathing air by adsorption, absorption, or chemisorptions. A typical organic vapor respirator cartridge is a metal or plastic case containing from 25 to 40 grams of sorption media such as activated charcoal or certain resins (Safety Saves, 2008). The service life of the cartridge varies but it is based, among other variables, on the carbon weight and molecular weight of the vapor and the cartridge media, the concentration of vapor in the atmosphere, the relative humidity of the atmosphere, and the breathing rate of the respirator wearer (Respirator-WIKI2.Wikipedia, 2015).



a) Particulate Respirators

b) Combination Respirators

c) Gas and vapour Respirators

Figure 2.17 Air purifying respirators

Particulate respirators shown in Figure 2.17a) capture particles in the air, such as dusts, mists, and fumes do not protect against gases or vapours, generally become more effective as particles accumulate on the filter and plug spaces between the fibers and filters should be replaced when user finds it difficult to breathe through them. Combination respirators shown in Figure 2.17b are normally used in atmospheres that contain hazards of both particulates and gases and have both particulate filters and gas/vapor filters. Gas and vapor respirators shown in Figure 2.17c are normally used when there are only hazardous gases and vapors in the air, use chemical filters (called cartridges or canisters) to remove dangerous gases or vapors. Gas and vapor respirators do not protect against airborne particles, instead they are made to protect against specific gases or vapors.

2.8.3 Mechanical Respirators

The mechanical filter respirators shown in Figure 2.18 capture particulate matter when contaminated air is passed through the filter material. They are often made of Wool, plastic, glass, cellulose, and combinations of two or more of these materials.

Figure 2.18 Mechanical respirators

2.9 Summary of the chapter

This chapter defined aerosols as dispersion of minute particles or droplets in the air which when inhaled may cause adverse health effects. It goes on to elaborate on filtration and its mechanisms such as interception, inertia impaction and diffusion. Filter design parameters including types of filter media, pressure drop, penetration, filtration velocity, filter quality and overall efficiency were explained, whiles application of aerosol filters and the various types of respirators such as surgical mask, mechanical respirators, etc., were also discussed.

CHAPTER 3

METHODOLOGY

The dry season months from November to March, is characterized by massive suspension and deposition of Harmattan aerosol that we breathe. Sunnu et al (2006) observed that the Harmattan dust average size range from 0.89 to 2.43 μm and the mass concentrations range from 168 to 1331μg $/m^3$. The high concentration of dust particles during the Harmattan may have detrimental effects on the human respiratory system (lungs) and may lead to eye irritation, coughing and catarrh. This chapter presents the filter design for use during the Harmattan and its test.

3.1 Design

This section explains the process and procedures employed for the manufacture of the filter (mouth/nose mask). A respirator must protect its wearer and correctly fit against the face of the user so that the inhaled air is drawn through the filter not through gaps between the user's face and the respirator. The process for the manufacturing begins with selection of conceptual designs, drawing of models, selecting of materials and construction of model.

3.1.1 Concept generation

Two concepts were chosen for consideration and the final model design was inspired from these concepts.

Concept 1: Foldable 3-panel design

Concept 2: Simple unvalved respirator with metal nose bridge

3.1.2 Computer aided design drawing

After a design has been selected, the next step is to get dimensions for the drawing including contact area, centre filtering area and straps.

3.1.2.1 Contact Area

To get the contact area some critical dimensions were taken on the human face. These dimensions were taken by measuring 21 Ghanaians at random using a measuring tape.

These dimensions are the distance from the dorsum of the nose to the chin and from the middle of the jaw to the tip of the mouth.

As shown in Figure 3.1 the distance from the dorsum (middle of the nose curve) of the nose to the chin and from the middle of the jaw to the tip of the mouth have been measured. It follows therefore that the average contact area is approximately equal to $14000 mm^2$ which was used to size the filter.

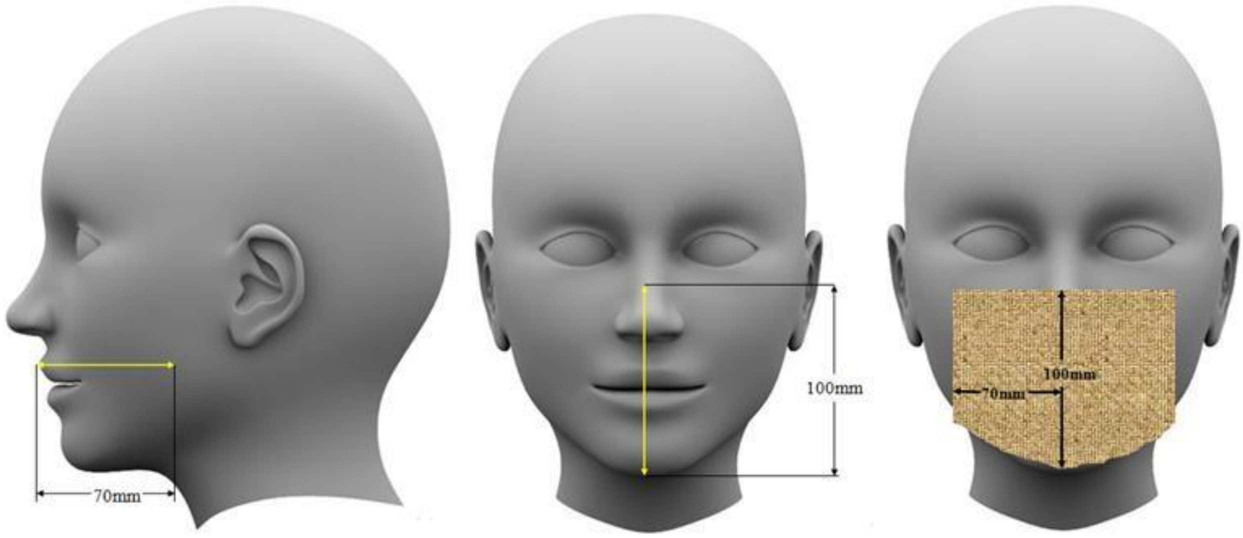


Figure 3.1 Contact area

3.1.2.2 Drawing

The dimensioning was based on information obtained whilst measuring the contact area. The model drawing of the design was drawn using Auto Cad application as shown in Figure 3.2.

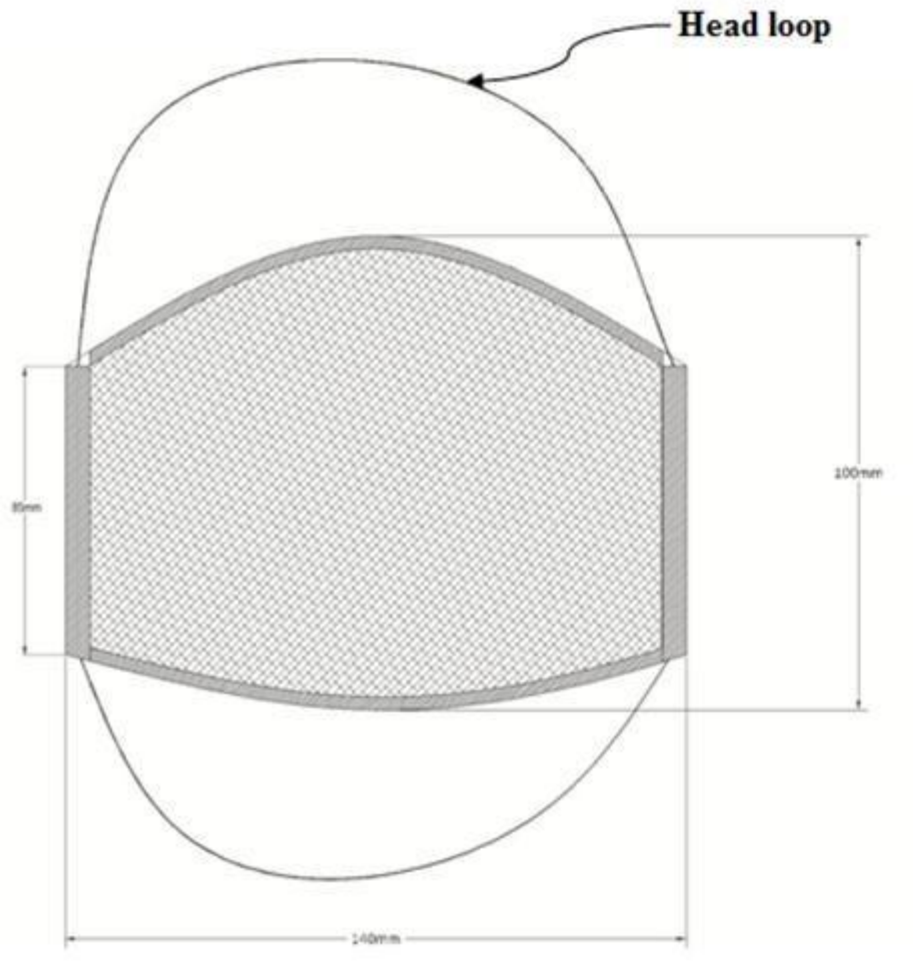


Figure 3.2 Auto Cad drawing of the nose/mouth mask

3.1.3 Material

Fabric filtration is a widely accepted method for particulate emissions control. Woven and non-woven materials are typical examples of fabric filters that may be used for clean air for breathing. Figure 3.3 shows a twill weave, felt and calico which were the materials used to design the filter.

Figure 3.3 Material chosen for design

3.1.4 Methodology for the manufacturing

This section talks about equipment and tools used in the manufacture of the nose/mouth mask as shown in table 3.1. Additionally, the sequential steps needed in the production are also described.

Table 3.1 Equipment, tool and materials

Equipment	Tools	Materials
Industrial sewing machine	Pair of scissors	Felt fabric
	Tape measure	Calico fabric 2x2
	Rule	twill fabric
	Pencil	elastic twin
	Needle and thread	

The steps needed in the production were as follows:

- Ironing of both calico and twill fabrics for an accurate measurement to be taken
- Measurement of the fabric with the required measuring instruments
- Cutting out of the materials according to the shape required
- Joining , sewing and stitching of all cut pieces together

3.2 Test on the filter

The type of filtration used during the test was such that, the particle laden gas (aerosol) flows through the fabric, leaving the dust retained by the fabric. In this study, four (4) filter combinations were manufactured for testing which are as follows:

i. 2x2 twill weave plied with a plain weave sewn together as shown in Figure 3.4 ii. Twill weave, felt (filter medium) and plain weave which are plied and sewn together as shown in Figure 3.5 iii. A tri-ply of Calico, felt and twill weave as indicated in Figure 3.6 iv. A tri-ply of calico, felt and plain weave as shown in Figure 3.7

Figure 3.4 Plain and twill weave

Figure 3.5 Plain, felt and twill

Figure 3.6 Calico, felt and twill

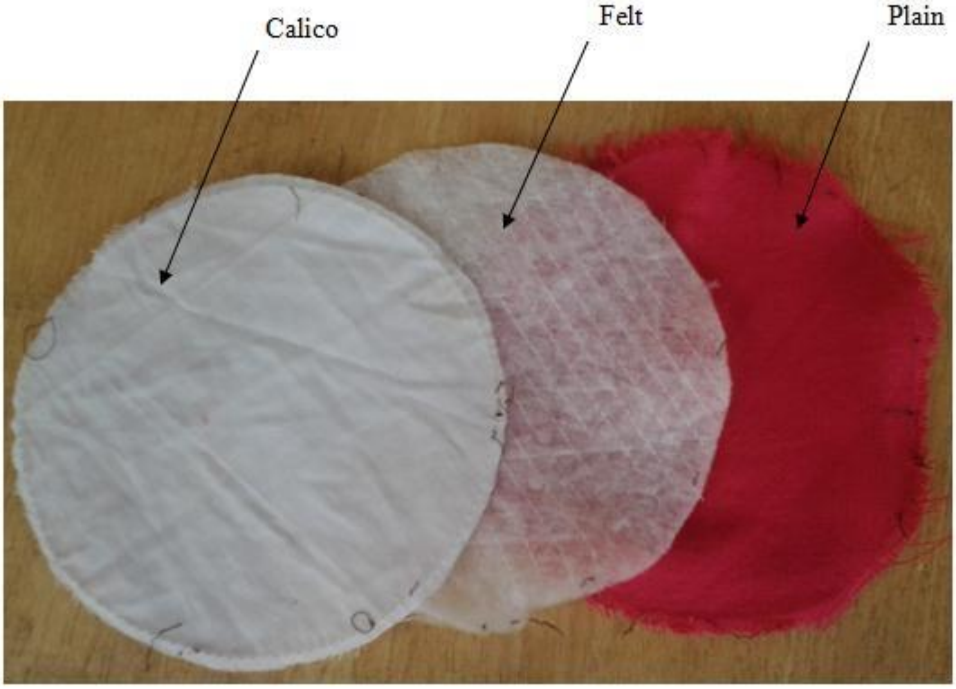


Figure 3.7 Calico, felt and plain

Experiments were conducted using the set-up shown in Figure 3.13, which is aimed at determining the suitable filter to use during the Harmattan period amongst the filters alluded to earlier. The set-up consists of:

- **An aspirator**

  The device shown in Figure 3.8 is a 12V, D.C car air conditioning fan/blower which was used as an aspirator (suction device)

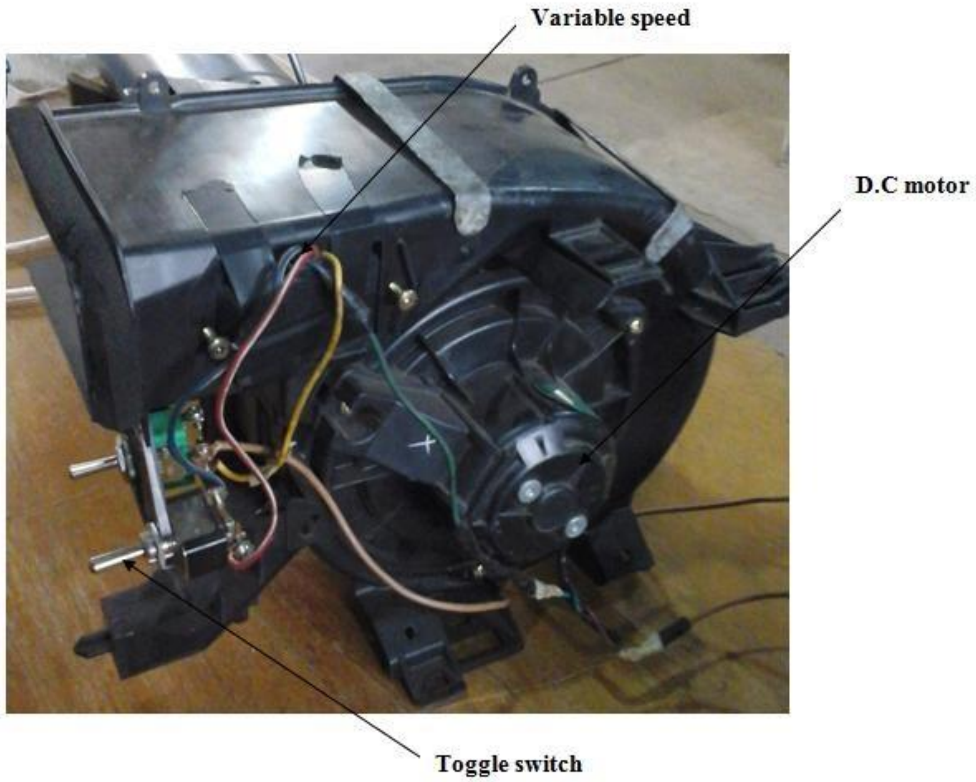


Figure 3.8 Aspirator

- **A rectifier**

It consists of a UPS transformer, a bridge rectifier (Wheatstone bridge) and a capacitor. The rectifier is basically used to convert A.C to D.C (see Figure 3.9).

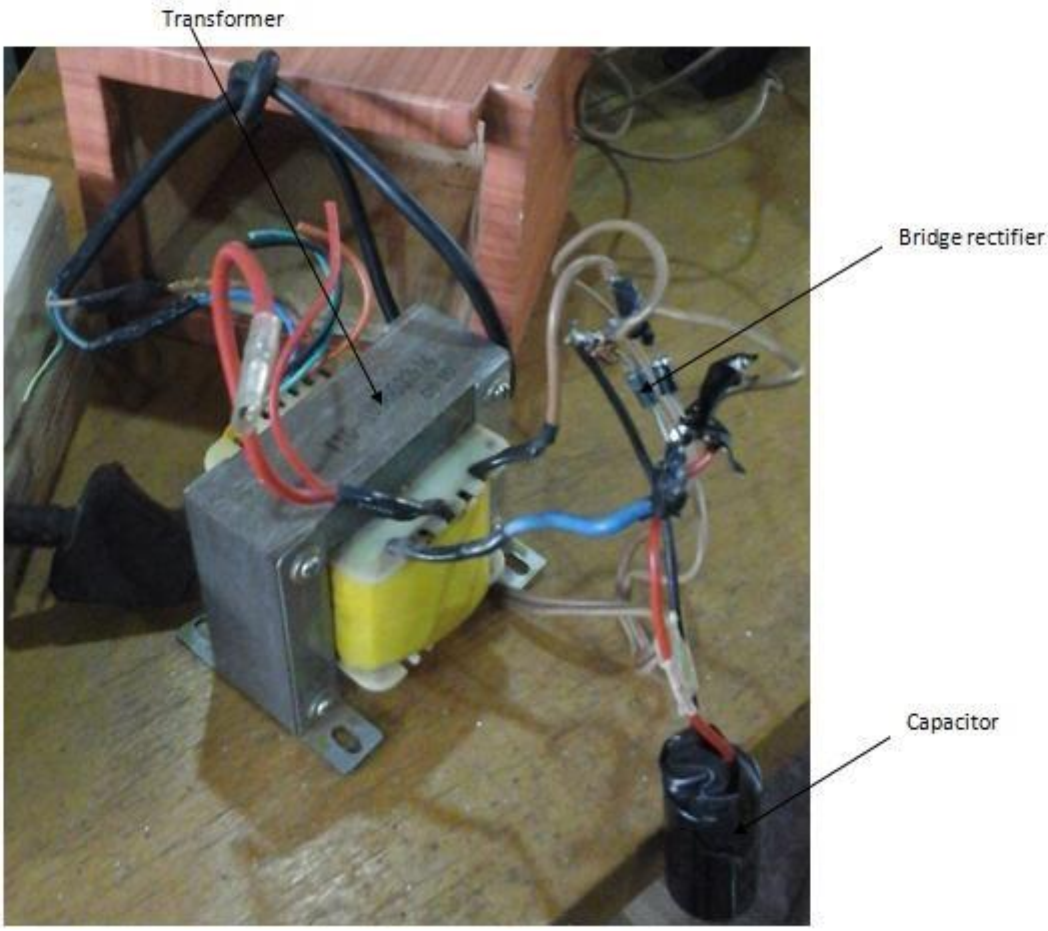


Figure 3.9 A rectifier

- **The pipe conduit**

A 50 mm P.V.C pipe of 61 cm long on which two (2) 6 mm holes were drilled on the centre line where two rubber hoses are fixed to measure the pressure across the filter. The latter is held in a filter holder incorporated in the pipe as shown in Figure 3.10.

Figure 3.10 Pipe conduits and filter holder assembly

- **Manometers**

As shown in Figure 3.11 a well type manometer was used to find the pressure drop across the filter. The velocity of flow and the rate of flow were measured using a pitot tube which was connected via hoses to an inclined manometer.

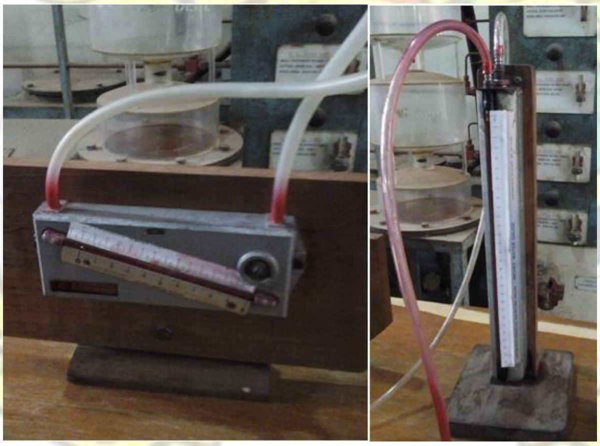


Figure 3.11 Manometers

- **Control valve**

Figure 3.12 shows a gate valve which was used to control the flow of air through the conduit.

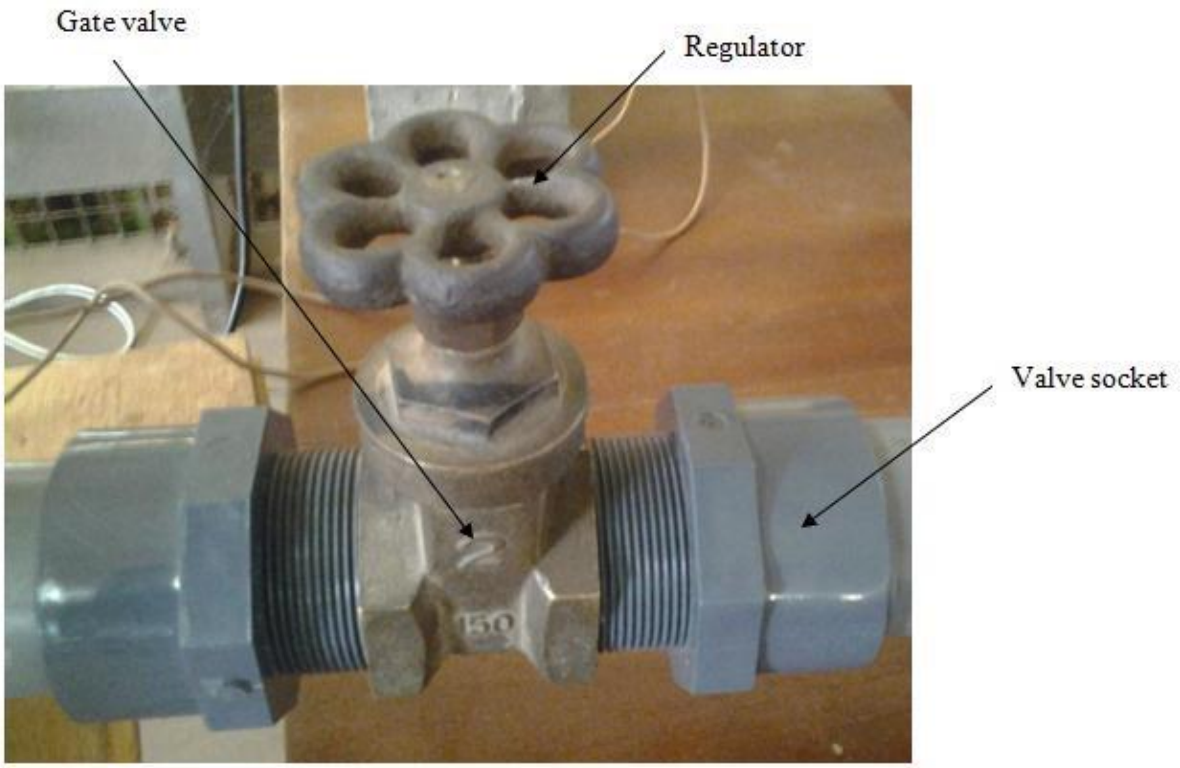


Figure 3.12 Gate valve

Figure 3.13 shows the experimental set up which comprises the aspirator, rectifier, pipe manometers and Pitot tube amongst others. The set –up was mounted on a platform which is about 90 cm above the ground.

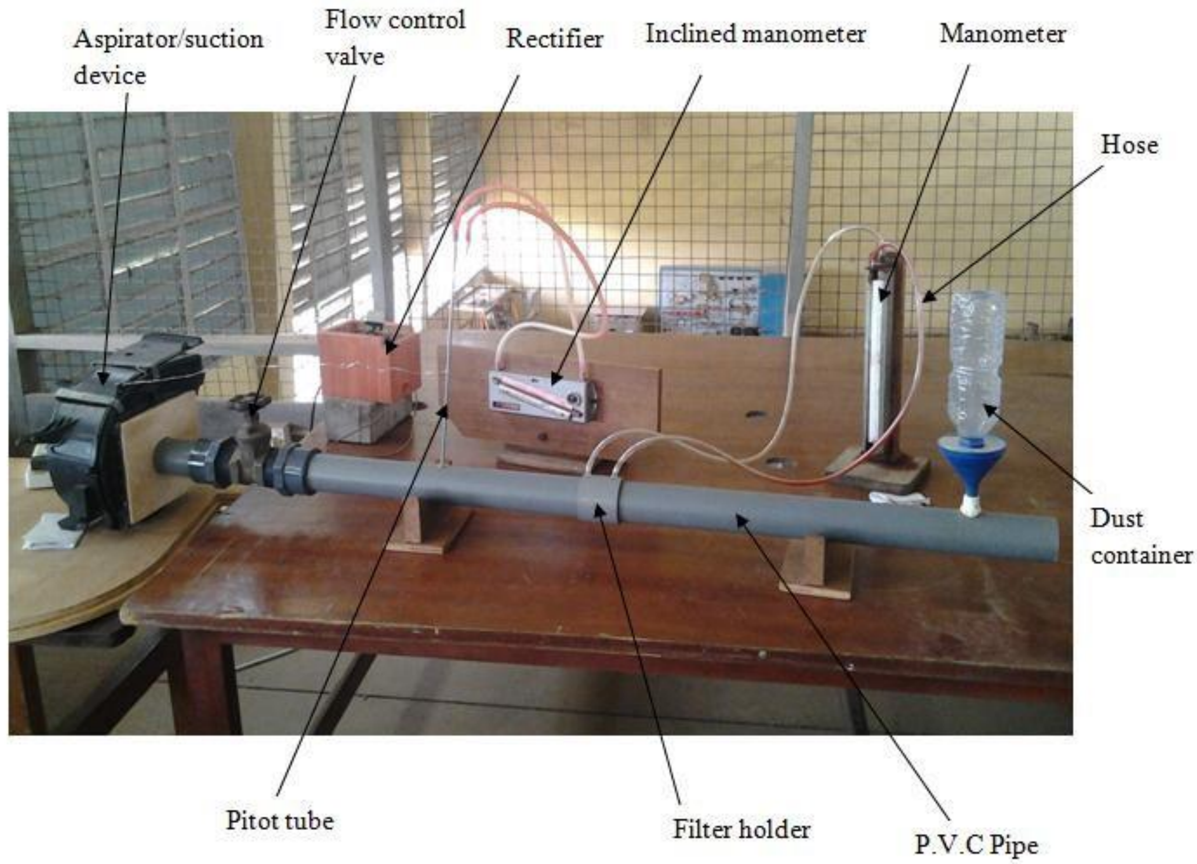


Figure 3.13 Test rig set -up

The schematic diagram of the set-up is shown in figure 3.14.

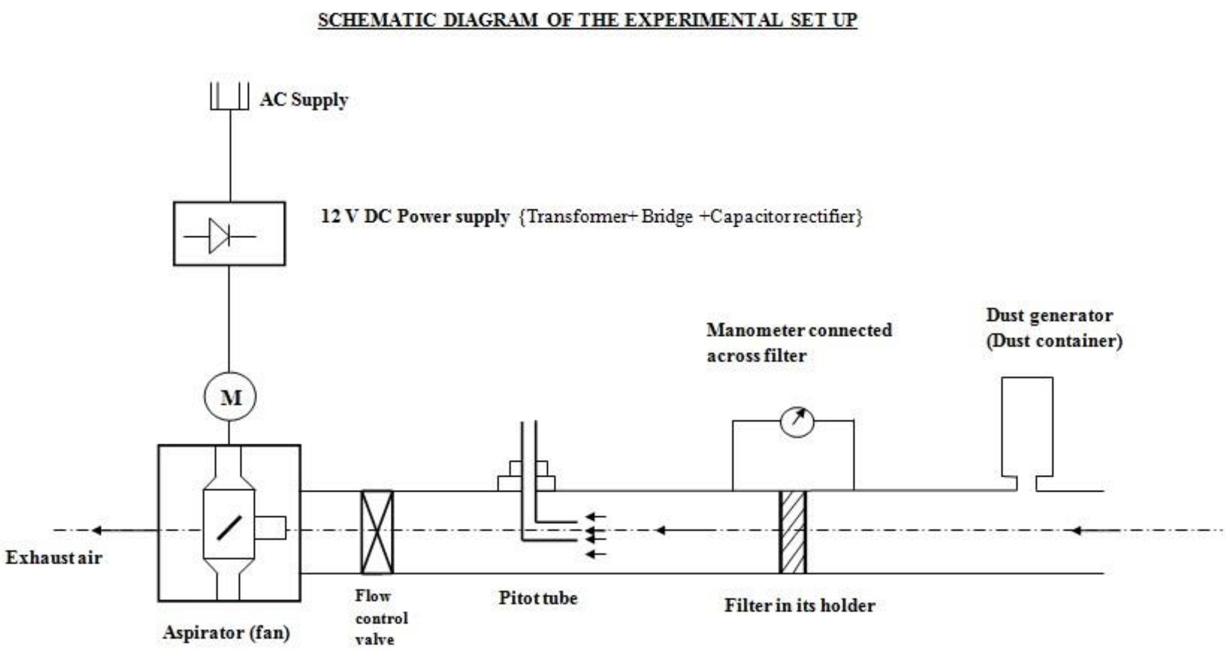


Figure 3.14 Schematic Diagram of the Test Rig

3.3 Experimental Procedure

The dust used for this experiment was collected from three different sources. Namely

- Settled dust collected from the roof top of the new blocks from December 21 to December 23, 2014.
- Settled dust collected from January 15, 2015 to January 21, 2015 on window louvers from the northern region.
- Settled dust collected from the louvers of few buildings in Ho (V/R) from February 9, 2015 to March 19, 2015.

The valve was set such that the flow rate remains at a constant value of

8.2 *l*/min throughout the test, since the goal of the study is to manufacture the best respirator for breathing during the Harmattan.

The experimental procedure is segmented in 2 major steps:

Step1: a certain quantity of dust was weighed using a microbalance.

Step2: the various test parameters were obtained as follows.

- **Velocity**

This is measured using the Pitot tube. After reading h , the following formula is used to find the velocity $V = C_d \sqrt{2gh}$ where

C_d : Pitot factor, 0.98 engraved on the Pitot tube

V :Velocity (m/s)

h:Pressure difference (m)

- **Flow rate**

$Q = A \times V$

A : cross sectional area of filter (m^2) which normal to velocity

Q : Volumetric rate m^3/s

- **Pressure drop across filter**

This is measured using the well type manometer

$\Delta p = \Delta h \rho_L g$

Δ_P: Pressure drop (Pa)

Δh: Liquid level in the manometer (m)

ρ_L: Density of the manometric fluid (kg/m^3)

- **Penetration (P) and efficiency (E)**

These two parameters were determined using a sample calculation shown below:

Mass of container (before) =17.4 g

Mass of container + dust =20.5 g

$\therefore$Mass of dust (before) = 3.1 g Mass

of filter (new) = 8.8kg After the

system is run, Penetration (P), Efficiency (E) and Filter quality are determined as follows;

Mass of filter +dust = 9.2 g

$\therefore$Mass of dust retained by filter = 9.2-8.8 = 0.4 g

Mass of dust left in pipe = 2.6 g

$\therefore$Mass of dust entering filter, which we may denote N_0

N_0 = mass of dust (before) –mass of dust left in pipe

$N_0 = 3.1 - 2.6 = 0.5$ g

Mass of dust that may enter the nostrils, N_L

$N_L = N_0$ - mass retained by filter

$N_L = 0.5\text{g} - 0.4\text{ g} = 0.1$ g

Therefore Penetration, P

$$P = \frac{N_L}{N_0} \times 100 = \frac{0.1}{0.5} \times 100 = 20\%$$

And

$$E = \frac{N_0 - N_L}{N_0}$$

$$E = 1 - \frac{N_L}{N_0}$$

$$E = 1 - P$$

$$E = 1 - 0.2$$

$E = 80\%$

- **Filter quality**

The best filter is the one with the greatest value of q_F

$$q_F = \frac{\ln(1/P)}{\Delta p}$$

q_F : Quality factor (Pa^{-1})

P : Penetration (%)

Δ_P: Pressure drop (Pa)

3.4 Sample design calculations

In this section, data obtained from theory and experiment were used to calculate the various filter design parameters

3.4.1 Filtration velocity

Filtration velocity is defined as the velocity of air at the face of a filter, just before the air enters.

$$V = \frac{Q}{A}$$

Where Q is the volumetric flow rate through the filter, $Q = 1.37 \times 10^{-4}\ m^3/s$ and

A is the area of the filter , $A = 1.963 \times 10^{-3} m^2$

3.4.2 Penetration

Penetration is defined as the fraction of particles entering, that exit or penetrate the filter.

$$P = \frac{N_L}{N_o}$$

Here N_L is the dust aerosol concentration upstream the filter and N_o is the dust aerosol downstream.

3.4.3 Pressure drop

It is the resistance to the air flowing through the structure of the filter, Δp. It represents the total drag force of all the fibers.

3.4.4 Collection efficiency

Collection efficiency is the ratio of the number of particles actually collected by a fiber in one second to the number that would have passed through an imaginary outline of the fiber in one second. It is defined in connection with the penetration as

$$E = 1 - \frac{N_L}{N_o}$$

3.4.5 Quality factor

Filter quality is normally expressed by the quality factor (q_F), which relates the penetration by the filter to the pressure drop across it. It is a useful criterion for comparing different types of filters and filters of different thickness. It is defined as

1

CHAPTER 4

RESULTS AND DISCUSSIONS

The results of the designed, manufactured and tested filter are presented in this chapter.

4.1 The filter

Figure 4.1 shows the outer, inner and side views of the filter designed with an elastic head loop to aid wearing. The designed filter is a tri-ply of twill-felt-calico of oval shape.

Figure 4.1 The designed filter

4.2 Results of the test

4.2.1 Test performed on the plain-twill filter

The results of the test performed on the plain and twill 2-ply filter at a constant flow rate of $1.37\times10^{-4}\ m^3/s$ or $8.2\ l/\min$ are presented in table 4.1

Table 4.1 Results of the test performed on the plain-twill filter

Time (min)	Speed[V] (m/s) x 10^{-2}	Flow rate[Q] (L/min)	Pressure drop,[ΔP] (Pa)	Quality factor,[q_F] (Pa^{-1}) x 10^{-3}
1	7	8.2	39.73	17.4
2	7	8.2	47.67	14.5
3	7	8.2	55.62	12.4
4	7	8.2	59.59	11.6
5	7	8.2	63.57	10.9
6	7	8.2	67.54	10.2
7	7	8.2	67.54	10.2
8	7	8.2	71.51	9.6
9	7	8.2	71.51	9.6
10	7	8.2	71.51	9.6
11	7	8.2	71.51	9.6
12	7	8.2	75.48	9.2
13	7	8.2	75.48	9.2
14	7	8.2	75.48	9.2
15	7	8.2	75.48	9.2

Using table 4.1, graphs of pressure drop in Pascal against time (Figure 4.2) and quality factor which is a useful criterion for comparing different types of filters and filters of different thickness in Pa^{-1} against time (min) shown in Figure 4.3, were plotted to see the behavior of the filter as far as these filter design parameters are concerned. Also a comparison is made between quality factor and the pressure drop as indicated in figure 4.4.

Figure 4.2 describes the pressure drop (the resistance to the air flowing through the structure of the filter), which varies linearly with time within the first minute until 40 Pascal and increases gradually to 65.54 Pa, remains constant at that value for a minute. From the latter it increases a bit to 71.51 Pa, remains at that value for about 3 minutes and finally plateau at a constant value of 75.48 Pa for the remaining of the test. The graph of the quality factor shown in figure 4.3 shows that the quality factor of the plain-twill 2-ply filter starts from 0.0174 Pa^{-1}, and decreases exponentially to reach 0.0092 Pa^{-1}.

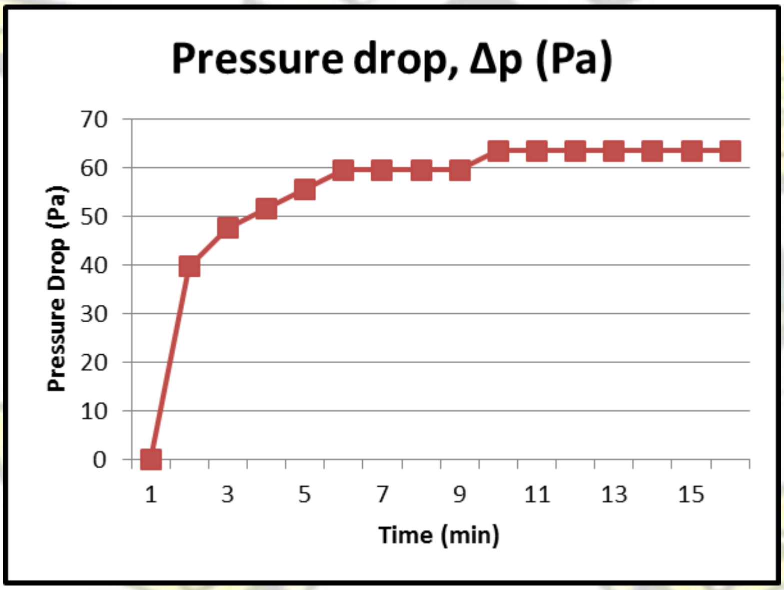


Figure 4.2 Pressure drop against time for plain-twill filter

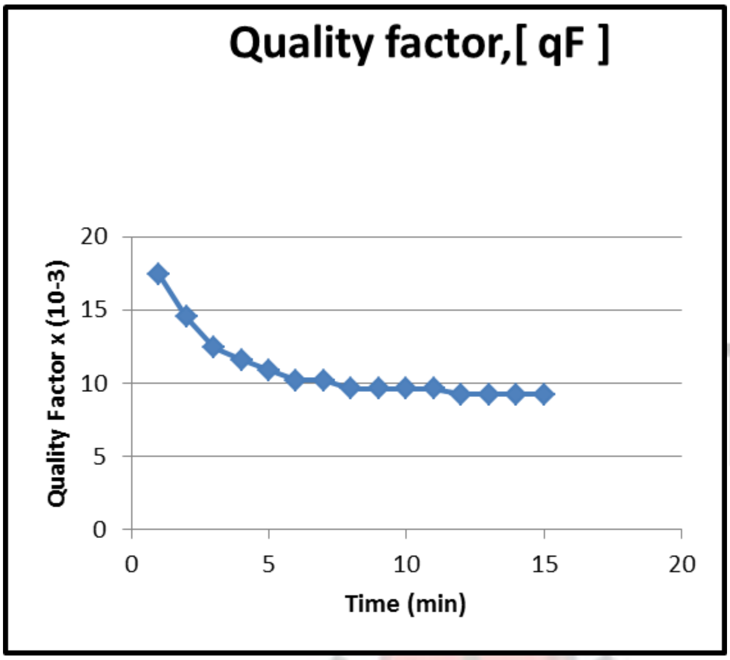


Figure 4.3 Quality factor against time for plain-twill filter

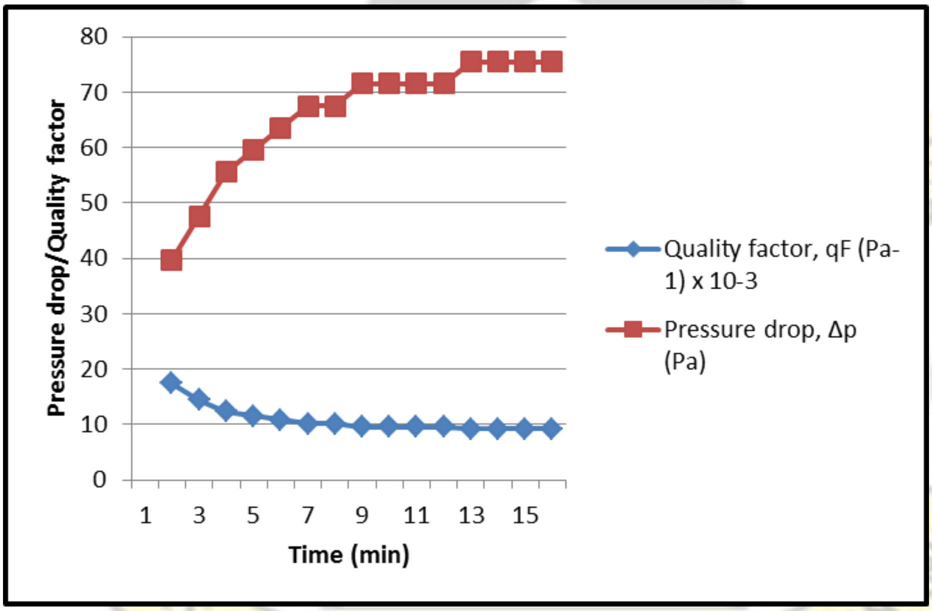


Figure 4.4 Pressure drop compared to quality for plain-twill filter

4.2.2 Test performed on the calico-felt-plain filter

The results of the test performed on the calico, felt and plain filter at a constant flow rate of $1.37\times10^{-4}\, m^3/s$ or $8.2l/\text{min}$ are presented in table 4.2

Table 4.2 Results of the test performed on calico - felt - plain filter

Time (min)	Speed[V] (m/s) x 10^{-2}	Flow rate[Q] (L/min)	Pressure drop, $[\Delta P]$ (Pa)	Quality factor, $[q_F]$ (Pa^{-1}) x 10^{-3}
1	7	8.2	39.73	24.6
2	7	8.2	47.67	20.5
3	7	8.2	51.65	18.9
4	7	8.2	55.62	17.6
5	7	8.2	59.59	16.4
6	7	8.2	59.59	16.4
7	7	8.2	59.59	16.4
8	7	8.2	59.59	16.4
9	7	8.2	63.57	15.4
10	7	8.2	63.57	15.4
11	7	8.2	63.57	15.4
12	7	8.2	63.57	15.4
13	7	8.2	63.57	15.4
14	7	8.2	63.57	15.4
15	7	8.2	63.57	15.4

In order to see the behavior of calico-felt-plain filter with respect to the filter design parameters during the test, plots of the pressure drop (Pa) and quality factor (Pa^{-1}) are plotted against the time (min) as shown in figures 4.5 and 4.6.

In figure 4.5 the pressure drop after varying linearly with respect to time, increases gradually from 40 Pa to 59.59 Pa, remains constant at that value until the 9^{th} minute, took a slight increment to 69.57 Pa and remains constant through the 10 to 16^{th} minutes of the experiment. The graph of the quality factor which is shown in figure 4.6 indicates that the new calico-felt-plain filter has a quality of 0.0246 Pa^{-1}, however as time goes on this value decreases gradually until it reaches 0.0154 Pa^{-1}.

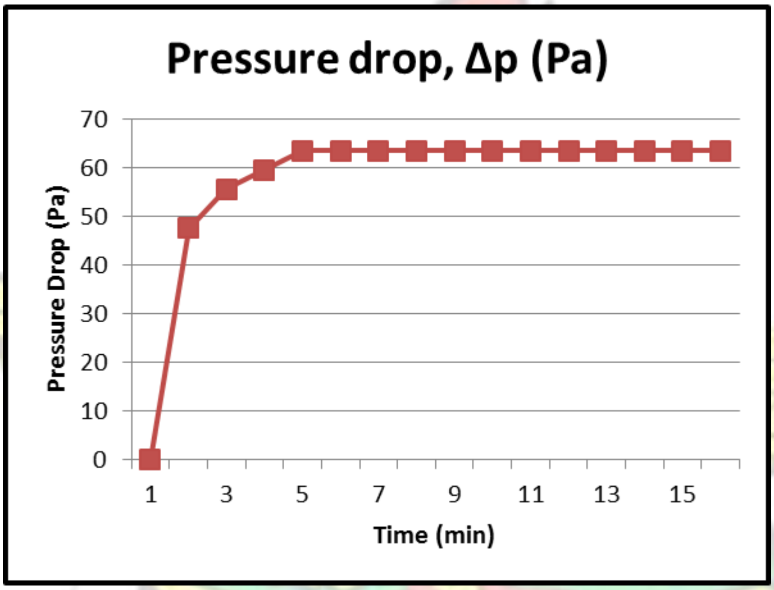


Figure 4.5 Pressure drop against time for calico-felt-plain filter

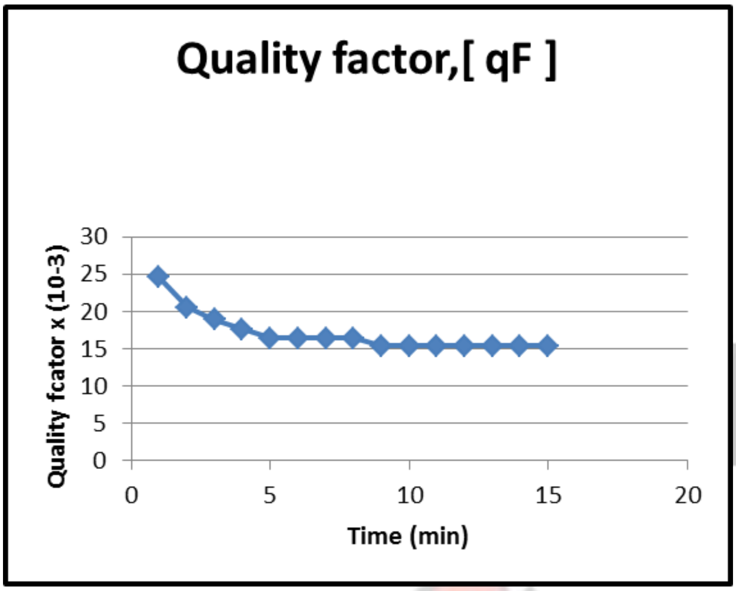


Figure 4.6 Quality factor against time for calico-felt-plain filter

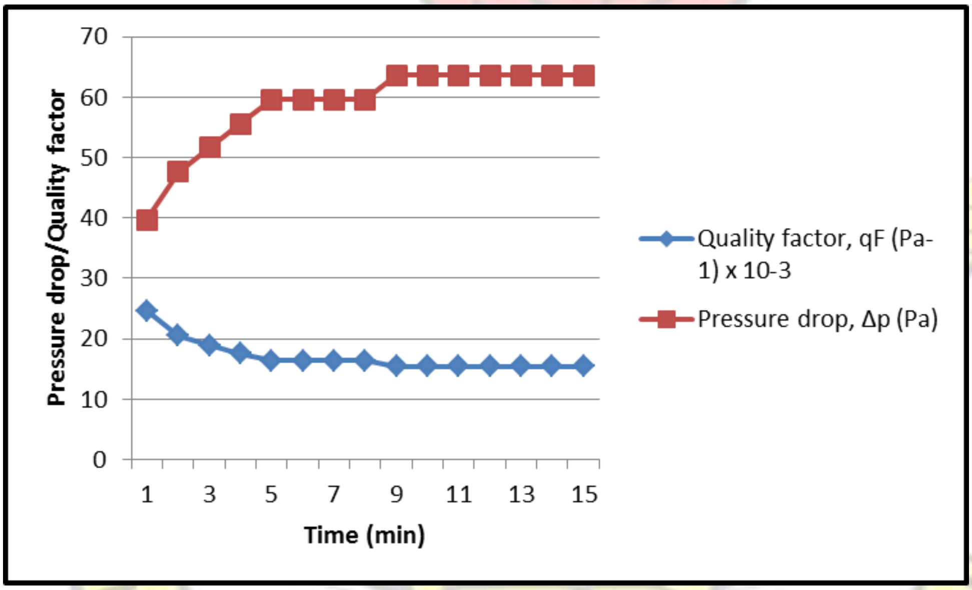


Figure 4.7 Pressure drop compared to quality for calico-felt-plain filter

4.2.3 Test performed on the calico-felt-twill filter

The results of the test performed on the calico-felt-twill filter at a constant flow rate of $1.37 \times 10^{-4}\ m^3/s$ or $8.2 l/\text{min}$ are presented in table 4.3

Table 4.3 results of the test performed on the calico-felt-twill filter

Time (min)	Speed[V] (m/s) x 10^{-2}	Flow rate[Q] (L/min)	Pressure drop, (ΔP) (Pa)	Quality factor,[q_F] (Pa^{-1}) x 10^{-3}
1	7	8.2	47.67	33.7
2	7	8.2	55.62	28.9
3	7	8.2	59.59	27.0
4	7	8.2	63.57	25.3
5	7	8.2	63.57	25.3
6	7	8.2	63.57	25.3
7	7	8.2	63.57	25.3
8	7	8.2	63.57	25.3
9	7	8.2	63.57	25.3
10	7	8.2	63.57	25.3
11	7	8.2	63.57	25.3
12	7	8.2	63.57	25.3
13	7	8.2	63.57	25.3
14	7	8.2	63.57	25.3
15	7	8.2	63.57	25.3

Figures 4.8, 4.9 and 4.10 were drawn using table 4.3.In Figure 4.8, the pressure drop after a linear variation with time within one minute, increases gradually from 47.67 Pa to 63.57 Pa, for the period 2-5 minutes it remains at 63.57 Pa till the end of the 16 minutes. The quality factor shows in figure 4.9 starts from 0.0337 $Pa^{-1}$and decreases gradually to 0.0253 Pa^{-1}. It is shown in figure 4.10 that from 0-5 minutes as pressure increases the quality factor decreases. After 5 minutes pressure remains constant at 63.57 Pa while the quality factor remains constant at $25x10^{-3}$/Pa from 5-16 minutes.

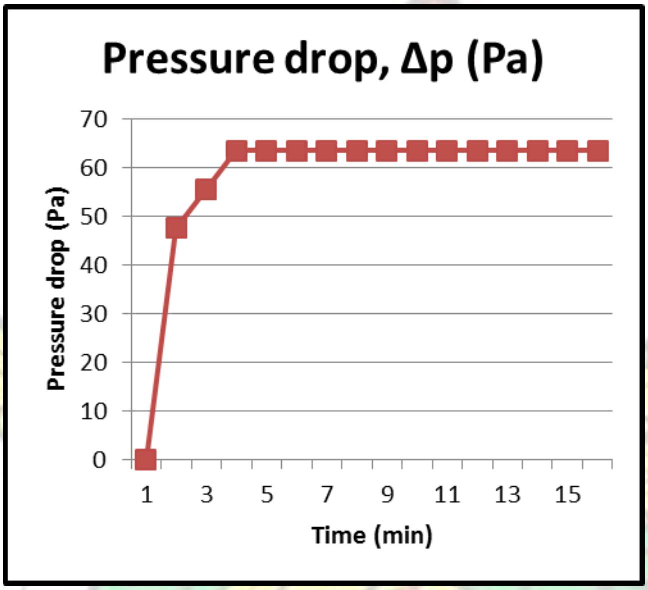


Figure 4.8 Pressure drop against time for calico-felt-twill filter

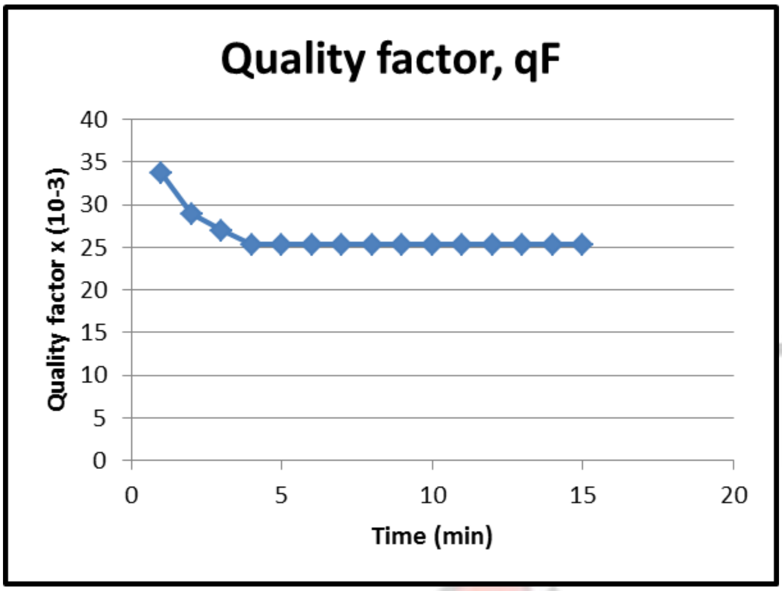


Figure 4.9 Quality factor against time for calico-felt-twill filter

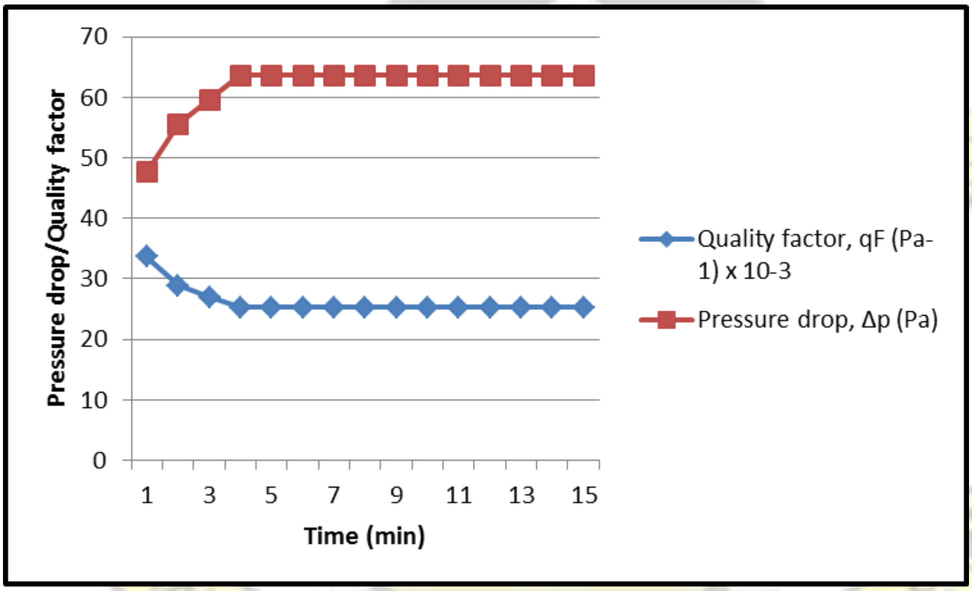


Figure 4.10 Pressure drop compared to quality for calico-felt-twill filter

4.2.4 Test performed on the twill-felt-plain filter

The results of the test performed on the twill-felt-plain filter at a constant flow rate of $1.37 \times 10^{-4}\ m^3/s$ or $8.2\ l/\min$ are presented in table 4.4.

Table 4.4 Results of the test performed on the twill, felt and plain filter

Time (min)	Speed[V] (m/s) x 10^{-2}	Flow rate[Q] (L/min)	Pressure drop,(ΔP) (Pa)	Quality factor,[q_F] (Pa^{-1}) x 10^{-3}
0	0	0	0	-
1	7	8.2	47.67	10.7
2	7	8.2	55.62	9.2
3	7	8.2	63.57	8.0
4	7	8.2	63.57	8.0
5	7	8.2	63.57	8.0
6	7	8.2	63.57	8.0
7	7	8.2	63.57	8.0
8	7	8.2	63.57	8.0
9	7	8.2	63.57	8.0
10	7	8.2	63.57	8.0
11	7	8.2	63.57	8.0
12	7	8.2	63.57	8.0
13	7	8.2	63.57	8.0
14	7	8.2	63.57	8.0
15	7	8.2	63.57	8.0

In Figure 4.11, the pressure drop after varying linearly with respect to time, increases gradually from 47.67 Pa to 63.57 Pa, and remains constant through the remaining of the experiment i.e., 5-16 minutes. The graph of the quality factor which is shown in Figure 4.12 indicates that for this filter the quality factor from the first minutes to the fourth minutes decreases gradually from 0.0107 $Pa^{-}1$ to 0.008 Pa^{-1}. The quality factor then remains constant at 0.008 Pa^{-1} for the rest of the experiment (4-16 minutes).In figure 4.13, from 0-3 minutes as pressure increases the quality factor decreases. After 3 minutes pressure remains constant at 63.57 Pa while the quality factor remains constant at 11 $x10^{-3}$/Pa from 3-16 minutes.

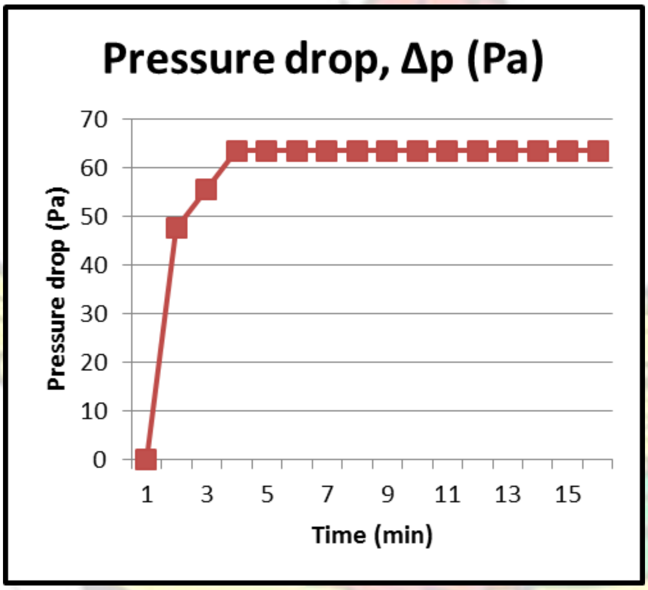


Figure 4.11 Pressure drop against time for twill-felt-plain filter

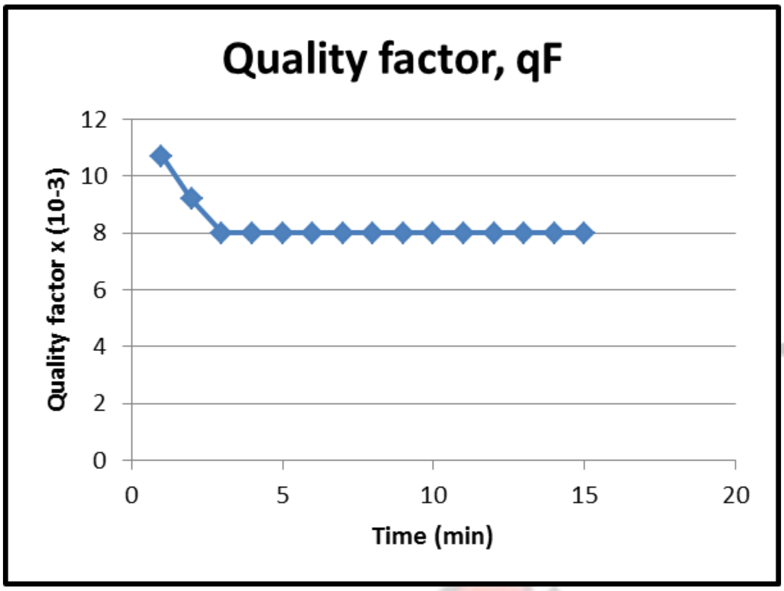


Figure 4.12 Quality factor against time for twill-felt-plain filter

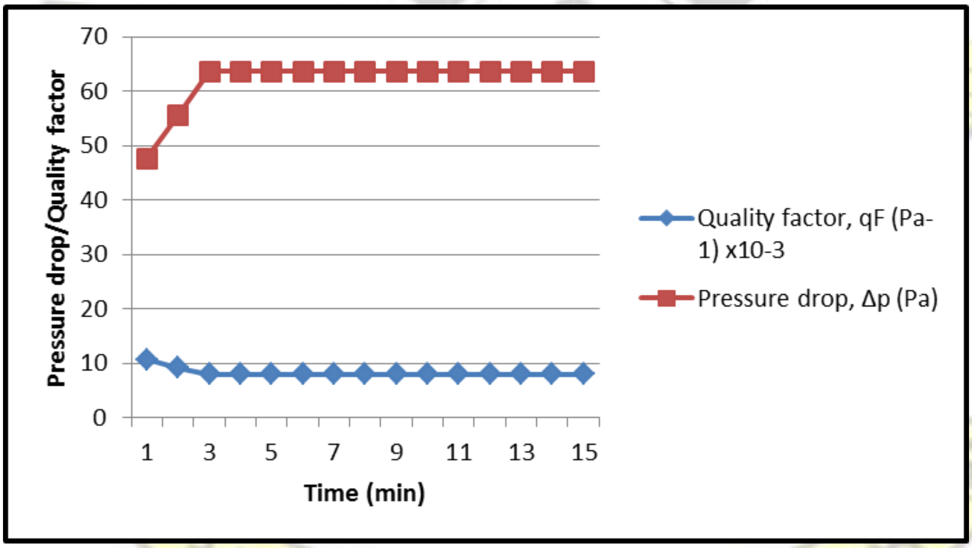


Figure 4.13 Pressure drop compared to quality factor for twill-felt-plain filter

Figure 4.14 shows a graph which maps the relationship between the efficiency and the penetration from empirical values obtained for all the filters under test. Here it is observed that plain-twill filter had a penetration of 50% hence a collection efficiency of 50% (calculations leading to 50% shown in appendix 1).The calico-felt-plain filter a penetration of 37.5% with 62.5% efficiency. Additionally calico-felt-twill filter recorded 20% penetration which translates into a collection efficiency of 80% and finally plain-felt-twill had a penetration of 60% with an efficiency of 40%.

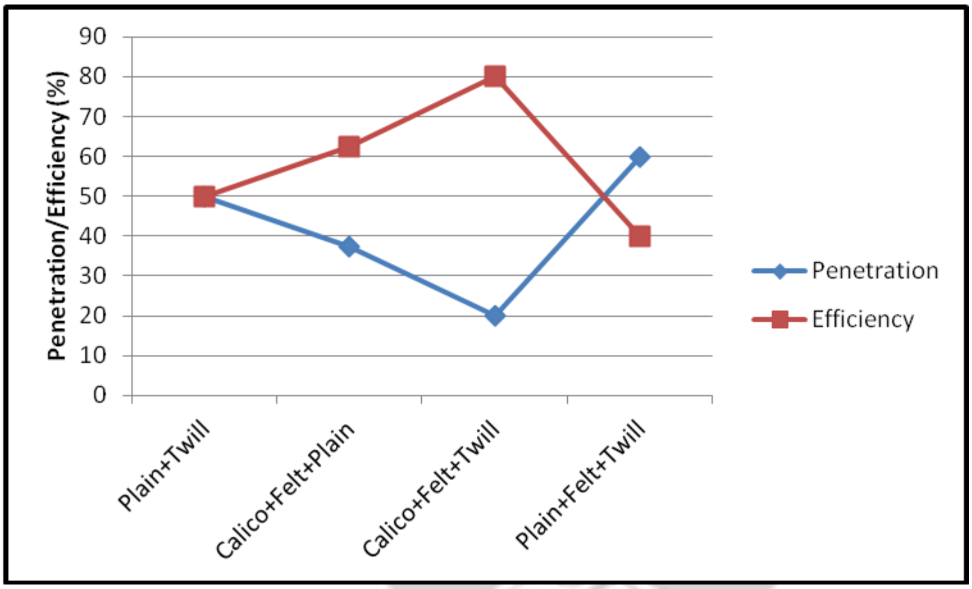


Figure 4.14 Relationship between the efficiency and the penetration for all the filters under test

4.3 Discussions

It was observed that for all the filters, the pressure drop which is the resistance to the air flowing through the structure of the filter, increases gradually to maximum value of 67.54 Pa, and remains constant through the remaining of the experiments. This shows that the pores of the nearest fibers get blocked quickly by so doing increase the resistance to air flow through the filter air passages i.e. as more and more aerosol dust get captured by the filters. When the value of the pressure drop remains constant for the remaining of the experiment, it is an indication that the filter was run to clogging. The particular phenomenon observed at the 9th minute in Figures 4.2, 4.5 and 4.7 where the pressure remained constant for some time and increased again slightly is termed re-entrainment. This means the particles receive enough energy from the altering flow or transfer energy from other particles to annul the adhesion forces and the deposited particle is able to re-enter the flow hence re opening the pores.

For the calico-felt-plain filter the clogging occurred earlier i.e. around the 9th minute which indicates the presence of a non-woven material which has increased the thickness of the filter thus enhancing its capacity to capture aerosol dust. Owing to these, the filter penetration was lower than that of plain-twill to about 12.5% and consequently gives calico-felt-plain collection efficiency of 62.5 %.(see appendix 1 for calculations leading to the determination of 62.5%).

The filter twill-felt-plain even though it run to clogging after 3 minutes, has a penetration of 60% hence an efficiency of 40% which shows that the deposited particles were able to re-enter the flow during the period of the test and were not able to be captured by the plain material placed after the felt material.

Calico-felt-twill had a penetration of only 20% hence an efficiency of 80% which was the highest amongst all the filters

The graph of quality factor (which is a useful criterion for comparing different types of filters and filters of different thickness) against time shows that the quality of all the filters decreases with time which shows that all filters lose their quality as more particles deposit. This indicates that filter masks should not be used forever because as they grow they lose their quality and become less effective.

Figure 4.14 titled relationship between efficiency and penetration shows that under the same conditions of flow i.e. same volumetric rate of flow the lower the penetration the higher the efficiency. Owing to all that was mentioned above, it was clear that the best and most efficient filter amongst the 4 filters is calico-felt-twill which had a collection efficiency of 80%, the lowest penetration of 20%, highest quality of 0.0337.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The following gives the conclusion of the test performed on the filter designed to protect the population against the Harmattan dust.

5.1 Conclusion

Four (4) nose/mouth masks were designed, manufactured and tested in this work to mitigate the challenge of inhaling dust aerosols which deposit massively during the Harmattan. The 4 filters were tested at a rate of $8.2l\ /\text{min}$.

To achieve the goal of this work which premise was laid in the above paragraph, the following were done:

- Plain & twill weaves, calico and felt materials were chosen
- The mask was designed and manufactured
- Harmattan dust of particle diameter grater or equal to $2 \pm 0.5\,\mu m$was collected and used during the test
- The filter performance test set up was built to get the most efficient filter

It was found out that the try-ply of calico-felt -twill filter had the lowest penetration of 20% which translates to an efficiency of 80%, with a pressure drop and quality of 47.67 Pa and 0.0337 respectively. It has hence been sanctioned the most efficient filter in this research.

It was also important to note that mechanical respirators or ambient filters could be made locally to suit exactly the need of the indigenes.

5.2 Recommendations

The recommendations from this thesis are as follows;

- This work has been done using only one constant volumetric flow rate. It is important to study the performance of the filters under various flow rates to determine the behaviour of the filter under these conditions.
- Filters should not be used for a very long period because from the test it was observed that as more dust aerosols get captured the quality of the filter keeps reducing.
- These locally made filters should be compared to the imported filters which are mostly made up of paper filters.

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APPENDIX 1

PLAIN + TWILL

Mass of container (before) = 17.4 g

Mass of container + dust = 20.5 g

Mass of dust (before) = 3.1 g

Mass of filter (new) = 8.6 g

After Running the System

Mass of filter + dust = 9 g

∴ Mass of dust retained by filter = 9 g – 8.6 g = 0.4 g

Mass of dust left in pipe = 2.3 g

N_o = mass of dust (before) – mass of dust left in pipe

= 3.1 g – 2.3 g = 0.8 g

$N_L = N_o$ – mass retained by filter

= 0.8 g – 0.4 g = 0.4 g

$$P = \frac{N_L}{N_o} = \frac{0.4}{0.8} \times 100 = 50\%$$

E = 1 – P = 50%

$$q_F = \frac{\ln(1/P)}{\Delta p} = \frac{\ln 39}{1.7350} = 0.0174\,Pa^{-1}$$

CALICO + FELT + PLAIN

Mass of container (before) = 17.4 g

Mass of container + dust = 20.5 g

Mass of dust (before) = 3.1 g

Mass of filter (new) = 8.3 g

After Running the System

Mass of filter + dust = 8.8 g

$\therefore$Mass of dust retained by the filter = 8.8 g – 8.3 g = 0.5 g

Mass of dust left in pipe = 2.3 g

N_o = mass of dust (before) – mass of dust left in pipe

= 3.1 g – 2.3 g = 0.8 g

N_L = N_o – mass retained by filter

= 0.8 g – 0.5 g = 0.3 g

$$P = \frac{N_L}{N_O} = \frac{0.3}{0.8} \times 100 = 37.5\%$$

E = 1 – P = 100 – 37.5 = 62.5 %

$$q_F = \frac{-\ln(1-P)}{\Delta p} = 13937.73.5 = 0.0246 Pa^{-1}$$

CALICO + FELT +TWILL

Mass of container (before) = 17.4 g

Mass of container + dust = 20.5 g

Mass of dust (before) = 3.1 g

Mass of filter (new) = 8.8 g

After Running the System

Mass of filter + dust = 9.2 g

$\therefore$Mass of dust retained by filter = 9.2 g – 8.8 g = 0.4 g

Mass of dust left in pipe = 2.6 g

N_o = mass of dust (before) – mass of dust left in pipe

= 3.1 g – 2.6 g = 0.5 g

$N_L = N_o$ – mass retained by filter

= 0.5 g – 0.4 g = 0.1 g

$$\therefore P = \frac{N_L}{N_O} \times 100 = \frac{0.1}{0.5} \times 100 = 20\%$$

E = 1 – P = 100 – 20 = 80%

$$q_F = \frac{-\ln(1-P)}{\Delta p} = 471\ 20.67 = 0.0337\,Pa^{-1}$$

PLAIN + FELT + TWILL

Mass of container (before) = 17.4 g Mass

of container + dust = 20.5 g

Mass of dust (before) = 3.1 g

Mass of filter (new) = 9.1 g

After Running the System

Mass of filter + dust = 9.3 g

∴ Mass of dust retained by filter = 9.3 g – 9.1 g = 0.2 g

Mass of dust left in pipe = 2.6 g

N_o = mass of dust (before) – mass of dust left in the pipe

= 3.1 g – 2.6 g = 0.5 g

N_L = N_o – mass retained by filter

= 0.5 g – 0.2 g = 0.3 g

$$P = \frac{N_L}{N_o} = \frac{0.3}{0.5} \times 100 = 60\%$$

E = 1 – P = 100 – 60 = 40%

$$q_F = \frac{-\ln(1-P)}{\Delta p} = \frac{471}{60.67} = 0.0107\,Pa^{-1}$$

APPENDIX 2

CALCULATIONS

- VELOCITY

$V = C_D\sqrt{2gh}$

$h = 2.588 \times 10^{-4}m$, it represents the height of the liquid column in the manometer

$C_D = 0.98$, Pitot factor

$V = 0.98\sqrt{2 \times 9.81 \times 2.588 \times 10^{-4}}$

$= 0.698 m/s \approx 0.7 m/s$, which represents the filtration velocity

- CROSS SECTIONAL AREA OF THE PIPE

$$A = \frac{\pi D^2}{4}$$

$$= \frac{\pi \times 0.05^2}{4}$$

$$= 1.963 \times 10^{-3} m^2$$

- FLOW RATE $Q = AV$

$$= 1.963 \times 10^{-3} \times 0.0698$$

$$= 1.37 \times 10^{-4} m^3/s$$

$$= 8.225 L/\text{min}$$

- PRESSURE DROP

$\Delta P = \rho g h$, where h represents the liquid rise in well type manometer

$$= 810 \times 9.81 \times 5 \times 10^{-3}$$

$$= 39.73 Pa$$