UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEVELOPMENT OF FILTER TEST RIG TO DETERMINE FILTER EFFICIENCY BASED ON THREE DIFFERENT ANGLE

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Mechanical Engineering Technology (Refrigeration and Air Conditioning System) with Honours

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2018

DECLARATION

I hereby, declared this report entitled "Development of Filter Test Rig to Determine Filter Efficiency based on Three Different Angle" is written by me and is my own effort and that no part has been plagiarized without citations.

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APPROVAL

This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Refrigeration and air conditioning system) with Honours. The member of the supervisor is as follow

…………………..

(Amir Abdullah bin Muhamad Damanhuri)

ABSTRAK

Komponen utama dalam penapis udara bagi Unit Pengendalian Udara (AHU) adalah untuk menangkap pencemaran udara daripada udara luar dan bagi ruang dalaman. Kebanyakan manusia memilih penapis berlipat sebagai pilihan utama dalam AHU dan sebagai pra penapisan. Keberkesanan penapis dan kejatuhan tekanan di penapis udara menunjukkan dengan pelbagai sudut penapis. Matlamat dalam penyelidikan ini adalah reka bentuk dan fabrikasi prototaip rig ujian penapis dengan mengikut standard ASHRAE 52.2 dan EN 779. Penapis yang berkesaan akan ditentukan dengan meletakkan penapis yang bersudut 30°, 60° dan 90° dalam rig ujian. Susunan serat yang tidak teratur dalam penapis akan lebih berkesan untuk mengeluar pencemaran udara dan menyebabkan kejatuhan tekanan akan menurun ketiba-tibaan dalam proses ketika kek debu mencapai ketinggian yang tetap. Ketebalan kek debu akan menambah berkesanan dan kejatuhan tekanan dalam penapis. Kadar aliran udara adalah $600m^3/h$ hingga $6000m^3/h$ dan rig ujian berbentuk U adalah mengikuti standard ASHRAE 52.2. Oleh itu, reka bentuk rig ujian berbentuk U dengan saiz 610mm (T) x 610mm (L) dan kiraan formula yang kadar aliran udara adalah 0.64m/s hingga 4.48m/s. Kelajuan kipas dalam eksperimen adalah 1986.5rpm. Keberkesanan penapis yang paling tinggi adalah sudut yang 90°. Walaupun sudut 60° ada keputusan yang paling banyak berbezaan dalam kejatuhan tekanan dan kebolehtelapan, tetapi sudut 90° ada halaju yang tinggi daripada sudut 60°. Jadi, kejatuhan tekanan dan kebolehtelapan penapis udara akan menerus meningkat dan menurun masing-masing dari point bermula. Kesimpulannya, kita boleh mengatakan sudut 90° lebih berkesan daripada sudut 60° bahawa ia boleh menangkap lebih banyak habuk dalam masa bermula.

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ABSTRACT

The main component of air filter in Air Handling Unit (AHU) is to trap the air contaminant in air and supply to space. Most people will choose pleated filter as the main type of filter in AHU and also as pre-filter. The efficiency and pressure drop of the filter can be shown in difference filter angle. This study aim to design and fabricate the prototype of air filter test rig based on ASHRAE standard 52.2 and EN 779. The efficiency of air filter in the test rig placed in 30°, 60° and 90 of angle also are determined. Heterogeneous of fiber arrangement in air filter will more effective to remove air contaminant and cause the pressure drop will suddenly decline in the middle of process when the dust cake reached certain high. Also, the thickness of dust cake will increase the efficiency and pressure drop of air filter. The air flow rate is $600m^3/h$ until $6000m^3/h$ and the U-shape of air filter test rig based on ASHRAE 52.2 standard. Hence, the test rig had been design in U-shape with the size of 610mm (H) x 610mm (W) and the formula to calculate the air flow range is 0.64m/s until 4.48m/s. The fan speed in this experiment is 1986.5rpm. The highest efficiency of air filter angle is 90°. Although the angle of 60° had the largest difference of pressure drop and permeability, but the angle of 90° had the high face velocity than 60° in starting point. Hence, the pressure drop and permeability of air filter will keep increase and decrease respectively after starting point. In conclusion, we can said that angle of 90° is more efficiencies than angle 60° to trap the air contaminant at the starting point.

DEDICATION

I am very appreciate my beloved parents that they teach me a lot of things around the world. They encouraged me all the ways when I face problem in studies. In this project, I am also appreciate my supervisor that is Mr. Amir Abdullah bin Muhammad Damanhuri for his willing to guide me all the way until I can done this project.

ACKNOWLEDGEMENT

First of all, I would like to express my sincere acknowledgement to my supervisor Mr. Amir Abdullah bin Muhammad Damanhuri for his mindful supervision and guidance that have guided me in accomplishing this thesis. His wides knowledge in this study area had moved this project become succeed. Also, I would like to express my gratitude to Mr. Izzat, the technician of Lab FYP & innovation HVAC and Mr. Zahirulza"lm, the technician of Studio Analysis HVAC for their assistance to borrow the instrument and open the lab on time. Besides that, I am grateful to my housemates and beloved friend as their company and support me all the time in the work on this project. Finally, I also would like to thanks a lot to my family who had been supported and encourage me all the time. Without the spirit and support that I received thought this path, possibility this projects will not be completed successfully.

Thank you.

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LIST OF ABBREVIATIONS, SYMBOL AND NOMENCLATURES

AHU   - Air Handler Unit

MERV   -Minimum Efficiency Reporting Rate

HEPA   - High Efficiency Particular Air

ULPA   - Ultra Low Penetration Air

PM   - Particular Matter

ASHRAE - American Society of Heating, Refrigerating, and Air Conditioning Engineers

EN   - European Standard

VOCs   - Volatile Organic Compound

IAQ   - Indoor Air Quality

SBS   - Sick Building Syndrome

HVAC   - Heating Ventilation and Air Conditioning

TES   - Thermal Energy Storage

CCWS - Water Cooled Water Chilled System

>   - More than

<   - Less than

CFM   - Cubic Feet per Minutes

mm   - Milimeter

µm   - Micrometer

fpm   -Feet per Minutes

Pa   - Pascal

m/s   - Meter per Seconds

m^3/s   - Meter Cubic per Seconds

m^3/h   - Meter Cubic per Hours

°   - Degree

°C   - Degree Celsius

K   - Kelvin

g   - Grams

CHAPTER 1

INTRODUCTION

1.1   Introduction

Air-conditioning system is a system that provide cooling and comfortable condition for human. That are included component evaporator, compressor, expansion valve and condenser. For large central system, Air Handler Unit (AHU) is the main component to supply cool air to every single room by ducting. In order to provide great comfort for human in such large space, the humidity, temperature and fan speed needed to control by the evaporator, blower and air filter inside the AHU. However, the main important component in AHU to provide clean air in a space is air filter. The air contaminant will be trapped by air filter. So that, air filter had classified into its standard by each pressure drop and efficiency.

AHU is one of the component that used a lot of filter. Whatever it used washable/reusable filter, pleated filter, electric filter, deep plated filter and electronic air filter (Hutten., 2016). But, most of the company will choose pleated filter as the main type of filter for AHU and also as pre-filter. The main filter is choose in difference class which is based on the human required. The function of air filter is used to remove the air contaminant from outdoor air and maintain the quality of indoor air. Nowadays, Indoor air quality is become the main issue that effect the human health. Although, the chemical composition in air can not remove by air filter, but the dust or micro-particles can be trapped by filter to improve the quality of indoor air. Particular Matter (PM) in the air will effect human body health (Mendell et al., 2011) . This is due to some smallest size of PM will penetrate our lung and go inside our blood.

1.2   Problem Statement

Technology and industry are growing faster and cause people ignore to care our environment. Some of people also point out that the concentration of air particle in indoor

is higher than outdoor air (Yu et al., 2009). That also means air conditional system must be maintain time by time to make sure people inside the condition can received good air quality. In order to make sure people had received good air quality, change or wash the air filter periodically is a must. This is due to the air contaminant and dust in the air will trapped by air filter. This will cause the efficiency of air filter become lower and the velocity of wind blow also decrease. The efficiency of air filter can be determined by last longer filter had withstand and the pressure drop between the filter. So that, people can estimate the time for AHU from the efficiency of air filter in this experiment. Usually, the filter placed in AHU is in 90° or vertical. Hence, this study will focus on the different angle of air filter.

1.3 Objective

This study come out with several objective:

(i) To design and fabricate the prototype of air filter test rig with using Solidwork based on ASHRAE standard 52.2 and EN 779.

(ii) To determine the efficiency of air filter in the test rig placed in 30°, 60° and 90° of angle.

1.4 SCOPE

This research will focus on fabricate the prototype of air filter test rig and calculate the efficiency of air filter in different angle. The air filter test rig will be fabricate based on the standard ASHRAE 52.2 and EN 779 to choose the suitable fan power. Test powders has been used as a dust in this research and the filter will choose low efficiency filter which is MERV 5-8. This is due to the size of test powder is about 8-12μm and the size of filter can be blocked is approximately to the size of powder (Chen et al., 2015). This can increase the accuracy of the data taken. The environment temperature for this experiment is about 25°C. In addition, the air flow rate that supply by fan is 800 CFM and the range of air velocity is 150 to 1500 feet per minute (fpm) which in the range of calculation with ASHRAE and Europe standard. Also, the Particular Matter (PM) will be recorded. Last, angle of filter that had been placed is to determine whether there have any change of pressure drop between the filter and effect the efficiency of filter.

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1.5 Significant of Study

AHU and centralization system consist air filter. The maintenance of air filter is necessary when used it in some time. The reason of maintenance air filter is to maintain the good air quality supply to indoor and reduce the energy consumption to fan. The air contaminant indoor contain dust, mould spore, cigarettes, Volatile Organic Compound (VOCs), $PM_{2.5}$ and PM_{10} (Yu et al., 2009).These air contaminant may penetrate our lung and go inside our blood due to the smallest size of PM (World Health Organization Europe., 2013). In this case, it show that the important of air filter inside the air conditioning system in indoor. The energy consumption of fan can be reduced by decreasing the pressure drop.

Dust holding capacity is the amount of dust that air filter can filtered out. The dust holding capacity related to the efficiency of air filter when test it from clean to dirty condition and the efficiency of air filter will show out the performance of air filter whether it reached. However, the penetration of dust to the filter correlate to the dust holding capacity and filter performance. This is due to some of the smallest dust which can not fully blocked by air filter although the air filter had high dust holding capacity. Air filter in AHU normally is place in vertical. So, this study focused on the place of filter in different angle and verified the effect of efficiency and performance of air filter.

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CHAPTER 2

Literature Review

2.1 Introduction

This chapter will discuss about the purpose of air filter for industry and living life and also discuss the design air filter test rig related to the research. In industry, the air filter is use to supply the air to clean room and other specific condition space. In living life, air filter is most use in air purification machine like the brand Coway, Sharp and Dyson which is very popular nowadays in market. From this chapter, it will more focus on the selection of air filter, design of air filter test rig and angle of air filter placed. For the topic selection of air filter, it is important to choose the air filter according to its classification of air filter, efficiency and resistance of air flow. Classification of each air filter in market like MERV, HEPA and ULPA which is very convenient for people to choose the suitable filter based on its function. By the way, the efficiency of air filter also related to the air filter that have been chosen and the arrangement of the filter according its classification. The resistance of air flow is one of the factor that affecting the filter pressure drop (Wang et al., 2016) and also effect the amount of heat generated by fan motor. For the topic of design test rig, the idea of design the test rig is come from the research and product of Germany company TOPAS. Both design is according to standard of ASHRAE 52.2. The main aim of this research is the angle of air filter placed. The angle of filter placed in the test rig is use to investigate whether the angle will affect the efficiency of filter in a long time. Lastly, the effect of Indoor Air Quality (IAQ) is also related to the air filter. The air filter can block the unwanted contaminant in the air in order to supply clean and fresh air to human or space.

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2.2   Indoor Air Quality

In a few years, the government of Malaysia encourage the revolution industry in order to reach the vision 2020. However, the cost of people have to pay is the air quality was going down years by years. Based on Millet (2016) claim that people spend about 80%-90% of time in indoor. Furthermore, computer games and working place in office will increase the staying time in indoor. Besides that, the result of research Indoor PM2.5 in an urban zone with heavy wood smoke pollution shows than the chemical in air particles in indoor is higher than outdoor (Jorquera et al., 2018). This is due to the chemical substance that had been used by people like formaldehyde, mold spore and other which is trapped inside indoor environment. From both research, they are show that the important of air filter device in indoor to remove the harmful air contaminant. So, the indoor air quality (IAQ) become more concern by the people. By the way, the poor IAQ will let the Sick Building Syndrome (SBS) occur and the health of people inside the building will be effected. To increase indoor air quality, the contaminant of air needed to filter by air filter machine and circulate air from outside also can increase the quality of air. Last but not least, positive pressure of indoor air can be used to „push‟the air from indoor to outdoor negative pressure.

2.2.1   Sick Building Syndrome (SBS) and Health Effect

Sick Building Syndrome (SBS) is a health problem when people stay inside the building or environment. However, this health problem will be disappear when people stay outside the building in a few days. The cause of SBS may be involved in temperature, humidity and increased air contaminant (Bernstein et al., 2010). SBS of temperature may due to the lowest temperature will let people feel too cold and can not work in normal speed and highest temperature also will let people feel too hot and uncomfortable due to lot of sweat come out from body. High humidity not only let the people‟s skin become wrinkled, but also help the mold grow inside the building and let the IAQ become worse.

Our air contains a lot of chemical, mold spores and Particular Matter (PM). The chemicals exist in our air such as formaldehyde, Tobacco Smoke and other. Volatile Organic Compounds is also known as VOCs is the basic chemical component of the formaldehyde and other like benzene and perchloroethylene. Besides that, VOCs also

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made become family product in our daily life, like rug, paint, oven cleaners, drycleaning fluids and home furnishings (Murray et al., 2010). Furthermore, there have some study show that occupants will be complained when the VOCs level is 3000 mg/m^3 or higher. The syndrome of formaldehyde is rhinitis, nasal congestion, rash, pruritus, headache, nausea and vomiting. Tobacco smoke has been identified that have more than 4000 chemical components in the cigarette. With a lot of chemical component inside the cigarette, it have a lot of effect to second hand smoke, children and adult. For second hand smoke, it will cause disease and premature death for children and adults who do not smoking, while for children, children will face varies respiratory symptoms, more severe asthma and delayed lung growth. Adult will face the symptoms is difficult inhalation, lung cancer and cardiovascular disease (Bernstein et al., 2010).

Mold spores is one of the factor that will cause the IAQ decrease. Mold spores always occur in the place which have high humidity ratio. Besides that, damp carpets or ceiling tiles is the idea place for mold to grow. This is because that place is poor insulation and low air ventilation indoor (Air et al., 2009). In the research of WHO, they point out the effect of mold spores will let the people have the problem of respiratory symptoms, allergies, asthma and perturbation of the immune system (Mendell et al., 2011). Moreover, Particular Matter (PM) is air particles that exist in our surrounding like a simple household activities such as smoking, cooking and cleaning, open burning in space heaters, candles and incense, and people walking around. When these indoor sources did not control well, the indoor PM may become more than outdoor and this determined from the research that shows the median indoor and outdoor PM2.5 concentrations of 44.4 and 41.8 mg/m3, respectively (Jorquera et al. 2018). For the health effect, Most of the research show that the concentration of PM will be effect the grow of lung for children, lung cancer and respiratory infection (Paulin & Hansel., 2016; Robert et al., 2007; Srimuruganandam & Shiva Nagendra., 2010). According to the WHO estimated that about 800,000 premature deaths each year and it rank 13th leading that cause of dead in the worldwide(Anderson et al., 2012).

2.3   Sources of Contaminant

Air that we had breathed got a lot of air particles which can not blocked by our nose hair and mucus. VOC is one of the chemical component that we can not blocked.

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VOC can be emitted from our living live things that is paints, carpets, flooring, insulation materials, adhesives, office supplies, cleaning products, and office machines (Redlich et al.,1997). From the most of the source, the research show that the main emitted VOC are formaldehyde and paint. Formaldehyde can be emitted from particleboard, fiberboard, and plywood which is the material to build up the home furniture (Bernstein et al., 2010). From the statement above, the concentration of VOC in indoor is more than outdoor due to the emitted formaldehyde from furniture. Paint is use to decorate or protect our home wall and furniture, but it also another main sources of emitted the VOC to our surrounding. In the same research, it also concluded that about 65.2% of the VOCs emitted in the first 4 h, and about 99% of the VOCs were released to indoor air after 10 days (Yu et al., 2009). The source of Particular Matter (PM) can be divide into organic and inorganic matter. For inorganic matter, it consist of chemical compound like SiO_2, SO_4^{2-} and NO_3^- while organic matter such as organic carbon and elemental carbon which emitted from soil dust, vehicle emission, coal combustion, secondary aerosols, industrial emission and biomass burning (Liu et al., 2015). Besides that, mold spores, bacteria and fungi are come from outdoor air transfer into indoor air. However, the mold would like to grow in high humidity level with poor insulated and low air ventilation place such as bathroom and the bedroom which near to toilet (Air et al., 2009). Bacteria can come from many source like pets, soils, plants and even from outdoor air, while the sources of fungi only can transfer from outdoor air (Millet., 2016).

2.3.1   Particular Matter

Particular matter (PM) divided into 3 category based on its diameter of particles that is 2.5-10μm ($PM_{2.5}$-PM_{10}) is classified "Coarse", less than 2.5μm (<$PM_{2.5}$) is classified "Fine" and the last one less than 0.1μm (<$PM_{0.1}$) is classified "ultrafine" particles (Anderson et al., 2012; World Health Organization Europe., 2013). From the source of contaminant that had stated above, we know that the source of PM divide into organic matter and inorganic matter (man-made). Based on the research of WHO stated that the PM contains chemical constituents (sulfates, nitrates and ammonium), inorganic ions (ions of sodium, potassium, calcium, magnesium and chloride, organic and elemental carbon), particle-bound water, metal (cadmium, copper, nickel, vanadium and zinc), polycyclic aromatic hydrocarbons (PAHs) and biological components (allergens and

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microbial compounds) (World Health Organization Europe., 2013). In addition, the research also states that the 0.1-1µm of diameter of PM can easily transfer in a long range and remain in the atmospheric for days or weeks. From the Figure 2.1 shows the average concentration of $PM_{2.5}$ in worldwide 2005.
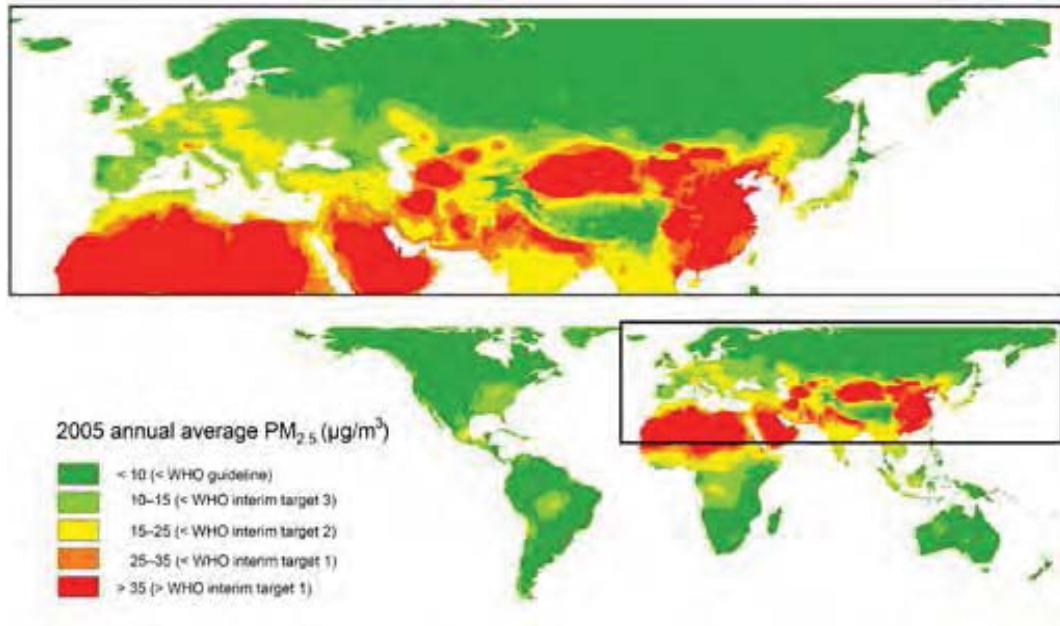

Figure 2.1: Average concentration (µg/m3) of PM2.5 worldwide, 2005(World Health Organization Europe 2013).

2.3.2   Filtration Strategies

In AHU system, the equipment that had placed inside the AHU in Malaysia are damper, pre-filter, main filter, cooling coil and blower. However, filter can divided into two as mention in equipment that is pre-filter and main filter. The function of pre-filter is to block the large air particles, while main filter is to block the micro or nano air contaminant. If just put the main filter only in AHU, filter can not withstand in a long time and cause to spend more money to exchange that expansive filter. In addition, pre-filter also can put in more than one layer to get the clean air. So, it is important to choose the right pre-filter depend to the environment. Figure 2.2 shows the AHU system.
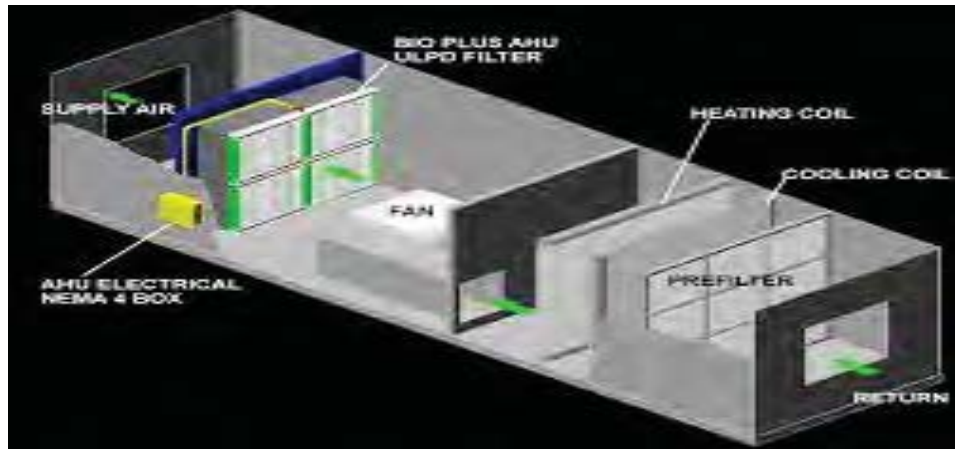
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Figure 2.2: AHU system. (Source: http://gasairsystems.com/HVAC%20System.htm)

Air filter got a lot of size depend on product design in market nowadays such as square, rectangular and cylinder (Hutten., 2016). Besides that, the material inside the air filter is a main component to block the dust, mold or other air contaminant. Below table 2.1 shows the material inside the air filter.

Table 2.1: Properties of fiber material. (Hutten., 2016)

Generic name	Maximum temperature °C (°F)		Physical resistance					Chemical resistance				
	Continuous	Intermittent	Dry heat	Moist heat	Abrasion	Shaking	Flexing	Mineral acid	Organic acid	Alkalies	Oxidizing	Solvents
Cotton	80 (180)	–	G	G	F	G	G	P	G	F	F	E
Polyester	135 (275)	–	G	F	G	E	E	G	G	F	G	E
Acrylic	235 (275)	140 (285)	G	G	G	G	E	G	G	P	G	E
Modacrylic	70 (160)	–	F	F	F	P – F	G	G	G	G	G	G
Nylon (polyamide)	115 (240)	–	G	G	E	E	E	P	F	G	F	E
Nomex³	205 (400)	230 (450)	E	E	E	E	E	P – F	E	G	G	E
Polypropylene	95 (200)	120 (250)	G	F	E	E	G	E	E	E	G	G
PTFE (fluorocarbon)	260 (500)	290 (550)	E	E	P – F	G	G	E	E	E	E	E
Fluorocarbon	230 (150)	–	E	E	P – F	G	G	E	E	E	E	E
Vinyon	175 (350)	–	F	F	F	G	G	E	E	G	G	P
Glass	290 (550)	315 (600)	E	E	P	P	F	E	E	F	E	E
Wool	100 (215)	120 (250)	F	F	G	F	G	F	F	P	P	F

E, excellent; F, fair; G, good; P, poor.
³Du Pont de Nemours International S.A. trademark.
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2.4 Air Filter

Air filter is the component place in HVAC system and other machine that need to remove the unwanted contaminant like dust in air to avoid indoor air quality (IAQ) problem and may harm the component in HVAC system. In order to block the contaminant in air that have some type of filter which is exist in market nowadays. That are HEPA,

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