JOURNAL OF MARINE SCIENCES & ENVIRONMENTAL TECHNOLOGIES
Vol. 2, Issue No.1 (June-2016)

ISSN: 2413-5267

Nano Fibers in Dust Collection Systems

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إستخدام ألياف النانو في نُظم جمع الغبار

الصادق صالح الرجيبي[1] و فاطمة حديد[1] و ميلود يونس[2] و عبدالباسط زروقه[2]

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Abstract

The cement industry has developed in productivity and technology as well. In such an industry, the emission of great amounts of undesirable dust to the atmosphere as an associated product takes place. In the cement industry dust collectors with different technologies are in use. The most common type is that fabricated from textile polymers. In the last decade, nano-technology was introduced for the fabrication of such filters. This type of filter can be used to separate particles of different sizes. In this work, Nano-technology for the production of textiles used for filters for dust collectors is considered and compared with other types of dust collectors. The tensile force for textiles prepared by the application of nano-technology to be used in the proposed dust collectors in the cement industry is estimated. This force is found to be two times that found in other collectors and shows higher efficiency by about 70%. The most disadvantage of applying this technology, for the time being, is the relatively high cost of fabrication. Work is in progress to reduce the cost of fabrication and hence to use such textiles in dust collectors in the cement industry. Finally, the application of nano-technology for preparing dust collectors will lead to a better environment by reducing air pollution.

***Keywords**: Filter efficiency, Nano fiber filter media, Dust collectors, High modulus and strength.*

الملخص

شهدت صناعة الإسمنت تطورا كبيرا من الناحية الإنتاجية والتقنية حيث تنبعث كميات ضخمة من الغبار في الجو كمنتج مصاحب غير مرغوب فيه. كما أنه في صناعة الإسمنت يتم استخدام مجمعات للغبار بتقنيات مختلفة من أبرزها المصفيات المنسوجة التي يتم تصنعيها من خيوط البوليمر المنسوجة. وشهد العالم في السنوات العشر الأخيرة تطورا كبيرا في المصفيات باستعمال تقنية النانو. ويمكن استعمال هذا النوع من المصفيات لفصل الجسيمات بأحجام مختلفة. وفي هده الدراسة تم التعرض إلى تقنية النانو في إنتاج الخيوط المصنعة لمصفيات الغبار ومقارنة جودة وكفاءة المصفيات في صناعة الإسمنت للحالتين. وتم احتساب قوة الشد للخيوط المنسوجة باستعمال تقنية النانو للمصفيات المقترح استعمالها في صناعة الإسمنت، وقد بلغت جودتها ضعف المصفيات العادية وحققت كفاءة أفضل بمقدار70%. ويعيب استعمالها في الوقت الحاضر الارتفاع النسبي لتكلفتها ولا يزال العمل جارٍ لإيجاد طرق لتخفيض تكلفة الإنتاج للمصفيات المصنعة بتقنية النانو لاعتمادها في مصانع الإسمنت، الأمر الذي سيؤدي إلى بيئة أفضل وحل معضلة أساسيه في صناعة الإسمنت بالعالم العربي والتي تتمثل في خفض نسبة انبعاث الملوثات الصناعية للهواء الجوي.

***الكلمات الدلالية:** كفاءة المرشح، مصفيات مصنعة بتقنية النانو، مجمعات الغبار، قوة الشد للخيوط.*

1. Introduction

Cement industry is one of the most important industries in urban life. It is the most important source of air pollution by dust. Cement is made by blending different raw materials and exposure to high temperatures for configure the precise chemical proportions of lime, silica, alumina and iron in the final product known as (Cement Clinker). Although a huge production of these factories carries with it a lot of risk to the environment and human dramatically. Follows the process of producing huge quantities of cement dust generated from production processes as the withdrawal that appear dense white, this dust has many flaws, especially on the atmosphere and the neighborhoods surrounding the plant, both in terms of its spread air or penetration by rain surface water due to the softness of this dust, these particles are ranging from (20-100 microns). Dust collectors are used in many processes to either recover valuable granular solid or powder from process streams or to remove granular solid pollutants from exhaust gases prior to venting to the atmosphere. Dust collectors may be of single unit construction, or a collection of devices used to separate particulate matter from the process air. They are often used as an air pollution control device to maintain or improve air quality. Mist collectors are often used to improve or maintain the quality of air in the workplace environment. Fume and dust collectors are used to remove sub micrometer size particulate from the air. They effectively reduce or eliminate particulate matter and gas streams from many industrial processes (Duda, 1976). In this study concentration on filters, and studying how can keep it longer life and high efficient by reinforced fabric. Fabric collectors use filtration to separate dust particulates from dusty gases. They are one of the most efficient and cost effective types of dust collectors available and can achieve a collection efficiency of more than 99% for very fine particulates.

Nanotechnology is the engineering of functional systems at the molecular scale. This covers both current work and concepts that are more advanced. In its original sense, nanotechnology refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, high performance products. Nanotechnology Filtration Systems are necessary to get less use of compressed air required for cleaning the filter, electrical power to do so and fuel consumption. Thomas Green discusses features Nano fibers with other fibers in terms of diameter ranging from 0.07 to 0.15 microns, and the thickness of the surface layer of a 0.1 to 0.5-micron pore size (Green, 2006). Also, can be enhanced by adding materials such as carbon, glass, and Kevlar fibers to the polymer composed of composite materials that have superior structural characteristics of the most important high modulus and strength to weight ratios and mechanical properties that make them good and effective in many applications. Of the most important applications that have implemented the technology of composite materials are filtration systems and medical fields and Science tissues, such as ships and aircraft industries. There have been many research applications to target that got the patents could be clarified in the U.S. as shown in Figure (1) (Huang *et al*., 2003).

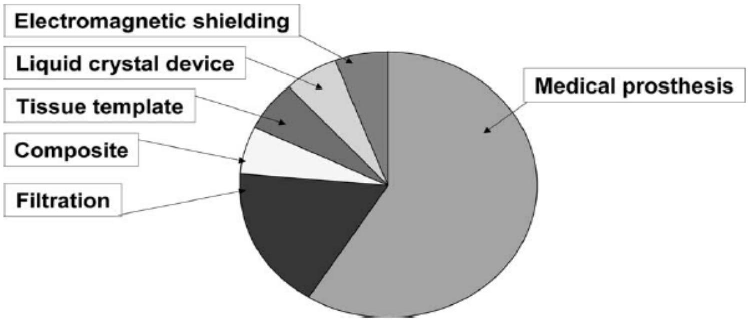

Figure 1. Application fields targeted by US patents on electrospun nano fibers (Huang *et al*., 2003)

Electro spinning may emit some polymers smells bad or even harmful, so it should be conducted operations inside the rooms with a good ventilation system. In addition, there are several criteria affect the process of transformation of the polymer to the nano fibers, including properties of polymer solution such as viscosity, flexibility, conductivity and surface tension or the characteristics of the changes, including the hydraulic pressure in the capillary tubes or the distance between the tip and the surface of the complex, and the standards of the surrounding circumstances, including temperature, humidity and speed of the air in the room. Production of fibers have very small diameters measured in nano is done to control the viscosity of the polymer solution for being the main factor for it. This means that the diameter increases with increasing concentration of the polymer. High voltage also increases the diameter of the fiber that is highly elastic. This defect for electro spinning add to that the non-uniform diameters may be overcome by controlling the temperature. As well as the interface of this method there are many problems such as grains and pores of the fiber to be overcome to control the polymer concentrations and temperatures and proportions of the solvent used. Generally, the perspective fields of application can be summarized in Figure (2).

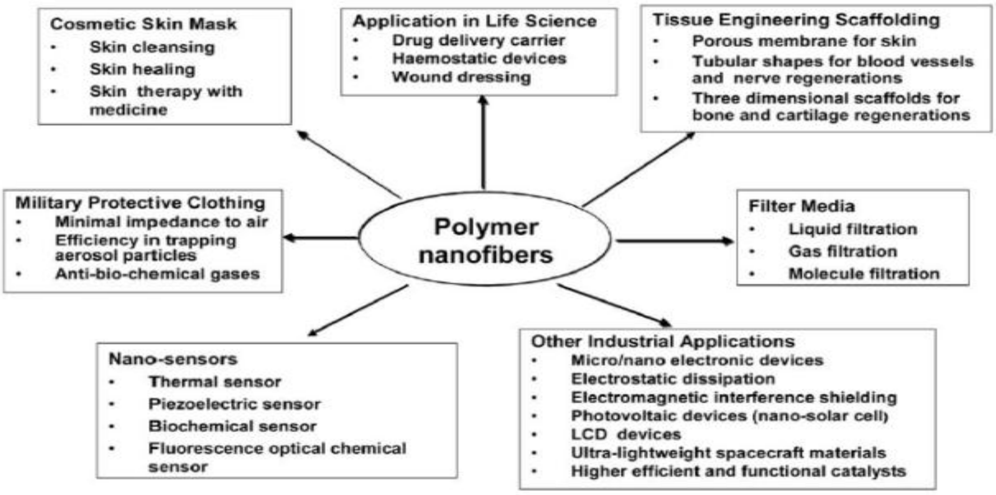

Figure 2. Potential applications of electro spun polymer nano fibers (Huang *et al*., 2003)

Jaroszczyk *et al.* (2008) have ongoing research to develop technology for nano fibers for use in systems demobilization because it gives the dust cake a homogeneous distribution of dust to achieve high efficiency. Good quality nano fiber layering results in uniform dust cake distribution (Figure 3. a and b) resulting in high efficiency. The basic understanding of the filtration mechanisms are not well known at the nano fiber scale. The classical fluid dynamics mathematical models used in the Continuum region of the filtration process do not apply to the slip flow that takes place around nano fibers. This region, described by large Knudsen numbers, requires a different approach such as the Lattice-Boltzmann method. Table (1) describes the major parameters of engine air filtration, while Table (2) shows classification of filtration process in nano fiber filter media. The ratio of nano fiber diameter to cellulose fiber diameter is approx. equal to 1:130.

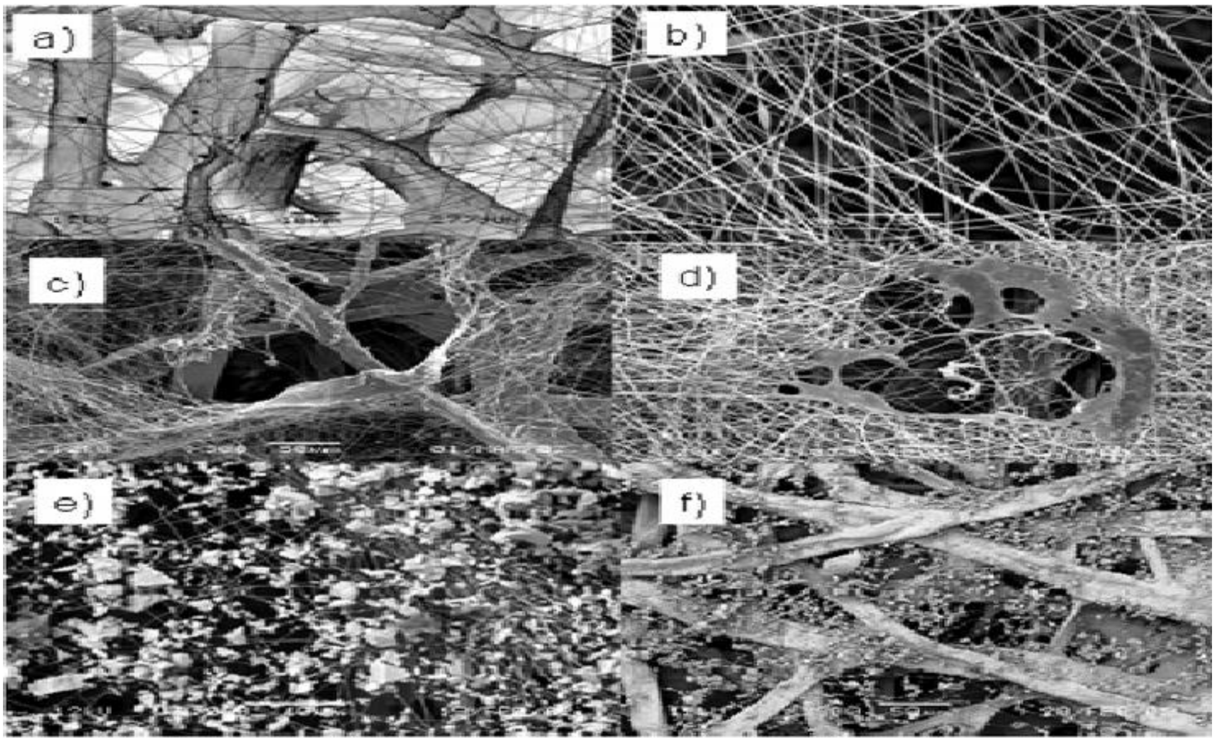

Figure 3. Uniform (a and b), non-uniform (c and d), and dust cake distribution (e and f)

Table 1. Classical engine air filtration

Dimensionless Number	*Range of value*	*Conditions*
Reynolds (*Re*)	0.0007-20	d_f=1-100μm, v=1-300 *cm/s*
Knudsen (K_n)	0.013-0.0013	d_f=1-100μm
Stokes (*Stk*)	0.004-651,000	d_f=1-20μm,dp=1-200μm
		v=1-100 *cm/s*, ρ_p=2.65 g/cm^3

Table 2. filtration with nano fibers.

Free molecule	*Transition*	*Slip flow (Cunningham)*	*dimensionless Number*
$K_n > 10$	K_n=10-0.25	K_n<0.25	*Re*<0.0007
d_f< 65 nm	d_f = 65-400 *nm*	d_f>400 nm	*Stk*<0.004

Fiber diameter is the main variable responsible for filter efficiency and pressure drop. The efficiency would increase even more drastically when nano fibers are utilized, pressure drastically increases with decreasing fiber diameter in the classical region of filtration. Efficiency increases rapidly with decreasing fiber diameter. Pressure drop significantly increases with decreasing fiber diameter since it is a function of $1/d_f$, in this region, until the free molecule regime is reached where pressure drop is a function of $1/d_f^2$,the larger the Knudsen number, the lower the pressure drop. When dust deposits form on nano fibers, this benefit of low-pressure drop diminishes with increasing amounts of deposited dust. Moreover, nano fibers capture very fine particles. The pressure drop increases more rapidly for this compacted dust cake. Nano fibers are very good collectors of small particles; a very dense dust would be formed them resulting in drastic pressure drop increase. Therefore, a careful analysis of filter dust operational conditions is necessary before any decision concerning the filter media is made. There are several theoretical models that are useful in making this decision equation (1). Löffler (1970) predicted the increase of pressure drop with time.

$$\Delta P_{dl} = \Delta P_m + \frac{\mu.\ v^2\ .\ t.\ c\ .E_f}{(1-\varepsilon_d).\ \rho_d.\ k_{DC}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

where; ΔP_{dl} = pressure drop of dust- loaded filter element, ΔP_m = media pressure drop, E_f = filter efficiency, μ = air dynamic viscosity, v = air velocity, t = filtration time, C= dust concentration, k_{DC} = dust cake permeability, ρ_d= dust density, and ε_d = porosity of the dust cake.

Pressure drop in this case increases linearly with time and dust concentration and with the square of velocity. Because the air permeability decreases for dust cakes formed by fine dusts, pressure drop should increase for these dusts. This equation does not include structural changes of the filter caused by dust deposited inside the filter media.

2. The Use of Fiber in Industrial Environments

Graham *et al.* (2002) discuss the theoretical filtration benefits of small fibers in air filtration applications, a process for making nano fibers, and real-world applications that demonstrate the practical usage of nano fiber based filter media. Filters containing three different media varieties were tested: a cellulose media, a cellulose/synthetic blended media, and a cellulose media with a nano fiber treatment. had been observed. The nano fiber/cellulose composite media maintains a lower pressure drop as compared to the other two media varieties tested. Nano fiber Filter Media in Cabin Air Filtration of Mining Vehicles in test and comparison in Table (3). Results of the study are presented in Table (4). It can be seen that a significant increase in filter efficiency was observed with the installation of the composite filters, thus providing an improvement in worker protection. Two gravimetric particle sampling devices were used on a Caterpillar 992G wheel loader.

Table 3. Media specifications for mining cab study

Filter	*Basis Weight*	*Permeability*	*Thickness*
Cellulose	67 $lb/3000ft^2$	58 *ft/min* at 0.5 in *w.g.*	0.013"
Cellulose+ Nano fibers	67 $lb/3000ft^2$	40 *ft/min* at 0.5 in *w.g.*	0.013"

Table 4. Filter performance comparison in 992G wheel loader cab

Filter	*Outside Dust mg/m³*	*Inside Dust mg/m³*	*Dust Reduction %*
Cellulose			
Submicron	0.031	0.01	68
Respirable	0.441	0.06	86
Cellulose+ Nano fibers			
Submicron	0.037	0.003	92
Respirable	0.361	0.025	93

3. Improvement of Filters Dust Collection Systems

The main objective is to design a filter to be used in removing dust dumped to atmospheric environment. Polymeric materials exhibit mechanical properties which come somewhere between (viscous and elastic) and hence they are termed viscoelastic. In addition, when the applied stress is removed the materials have the ability to "recover" slowly over a period of time these effects can also be observed in metals but the difference is that in plastic they occur at room temperature whereas in metals they only occur at very high temperature. Been studying the possibility of improving the basic material, (polypropylene) have been added in each of the fiber glass and carbon fiber as material of improved properties. Composite materials that can tolerate high stresses and pressure for a long time before damaged and before stopping to work, because the carbon fiber is best than glass fiber or another additive material in the stresses and age, and was proposed to use carbon fiber, but at a rate of 1% CF to polypropylene. Carbon fibers, which are a new breed of high strength materials are mainly

ISSN: 2413-5267

used as reinforced in composite materials such as carbon fiber reinforced plastic. Carbon fiber offer the highest specific modulus and highest specific strength of all reinforcing fibers, the strength and modulus are outstanding compared to other materials, and compressive strength of carbon fibers is lower than of inorganic fibers but still higher than that of polymeric fibers. Compressive properties dictate the use of carbon Composites in many structural applications. Recently a lot of research has been done on compressive properties and morphology of carbon fibers. Carbon fiber composites are ideally suited to applications where strength, stiffness, lower weight, and outstanding fatigue characteristics are critical requirement. Carbon fibers also have good electrical conductivity, thermal conductivity, and low linear coefficient of thermal expansion. The two main sectors of carbon fiber applications are high technology sector, which includes aerospace and nuclear engineering, and the general engineering and transportation sector, which includes engineering components such as bearings, gears, cams ..etc. and automobile bodies. However, the requirements of two sectors are fundamentally different. The large scale use of carbon fibers in aircraft and aerospace is driven by maximum performance and fuel efficiency, while the cost factor and the production requirements are not critical. The use of carbon fibers in general engineering and surface transportation is dominated by cost constraints, high production rate requirements, and generally less critical performance needs.

In More Complex Models it may be seen that the simple Kelvin model given an acceptable first approximation to creep and recovery behavior but does not account for relaxation. The Maxwell model can account for relaxation but was poor in relation to creep and recovery. It is clear therefore that some compromise may be achieved by combining the two models. It can be seen that although the exponential response predicted in these models are not a true representation of the complex viscoelastic response of polymeric materials, the overall picture is, for many purposes, an acceptable approximation to the actual behavior. Maxwell model with Kelvin model will be applied for composite materials (1% CF + 99% PP). In this case the stress –strain relation is given by the following mathematical model:

$$\varepsilon(t) = \frac{\sigma_o}{\xi_1} + \frac{\sigma_o t}{\eta_1} + \frac{\sigma_o}{\xi_1}.\left(1 - \exp(\frac{\xi_2}{\eta_1} t)\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

From this the strain rate may be obtained as:

$$\acute{\varepsilon} = \frac{\sigma_o}{\eta_1} + \frac{\sigma_o}{\eta_2}.\exp(\frac{\xi_2}{\eta_2 t}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where, $\eta_1, \eta_2, \xi_1, \xi_2$ are the model constants.

The creep curve and *isochronous* graphs are plotted to find the model constants and applying mathematical model Eqns. (2, and 3) (Crawford, 1998).

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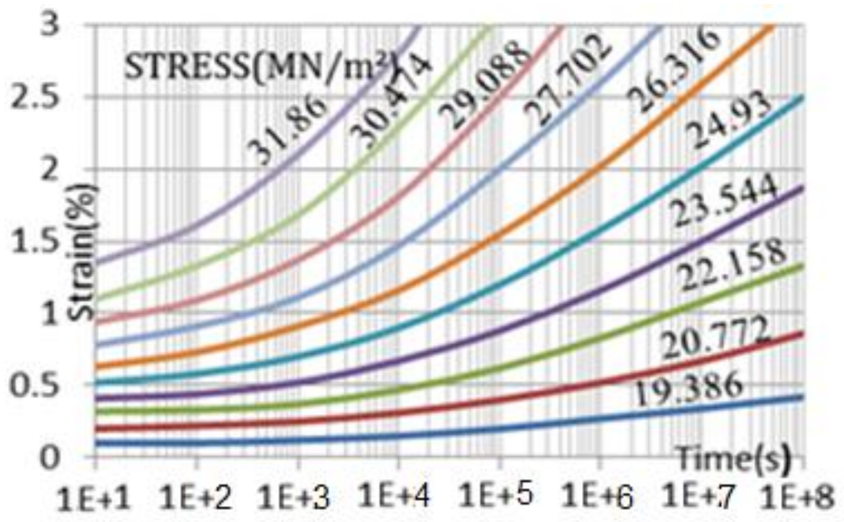

Figure 4. Creep curve for composite 1% CF, and 99%PP

For composite material 1% CF, and 99%PP the design tensile strength is derived from creep curve and plotted in Figure (5) by application on equations (3, and 4).

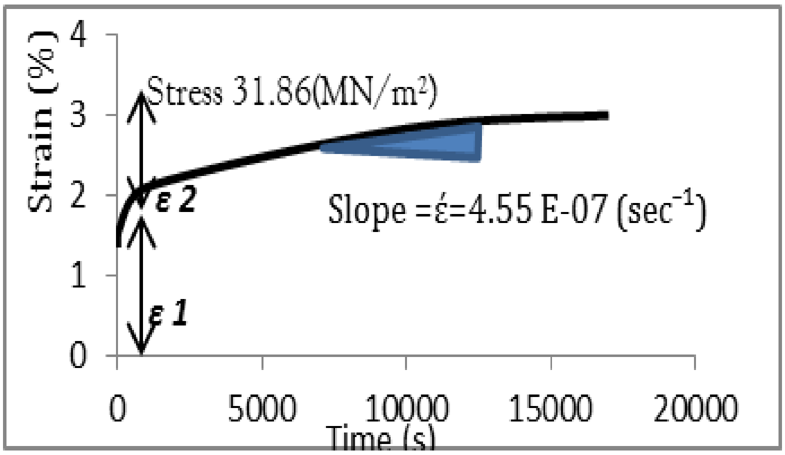

Figure 5. Calculation of model constants

ε_1=1.62%, and ε_2=0.88%,

ξ_1=1966.67 (*MN/m²*), η_1 = 7.02exp(+07) (*MN.s/m²*),

ξ_2 = 3620 (MN/m²), η_2 = 4.90exp(+08) (*MN.S/m²*).

The stress four composite materials have been increased drastically to the levels reaching to the value of the stress more than 30 *MN/m²*, so the 1% CF and 99% PP composite material has higher stress leading to a considerable improvement of loading and efficiency.

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4. Choosing The Filter MERV

MERV stands for (Minimum Efficiency Reporting Value). MERV ratings are used to gauge the ability of the filter media to remove particles from the air and is a reliable standard for measuring the efficiency of the filter. The MERV rating of a filter describes its effectiveness. The MERV scale ranges from 1 to 16, and measures a filter's ability to remove particles from 0.3 to 10 microns in size. Cellulose blend and spun bond polyester filters are not adequate for weld fume filtration. Typically, the minimum for weld fume extraction is MERV 13 or greater. The quality of the return air suffers when the filters MERV value is not adequate for the particulate being collected. Filters with higher ratings not only remove more particles from the air, but also remove the smaller particles that are most concerning for worker protection as shown in Figure (6).

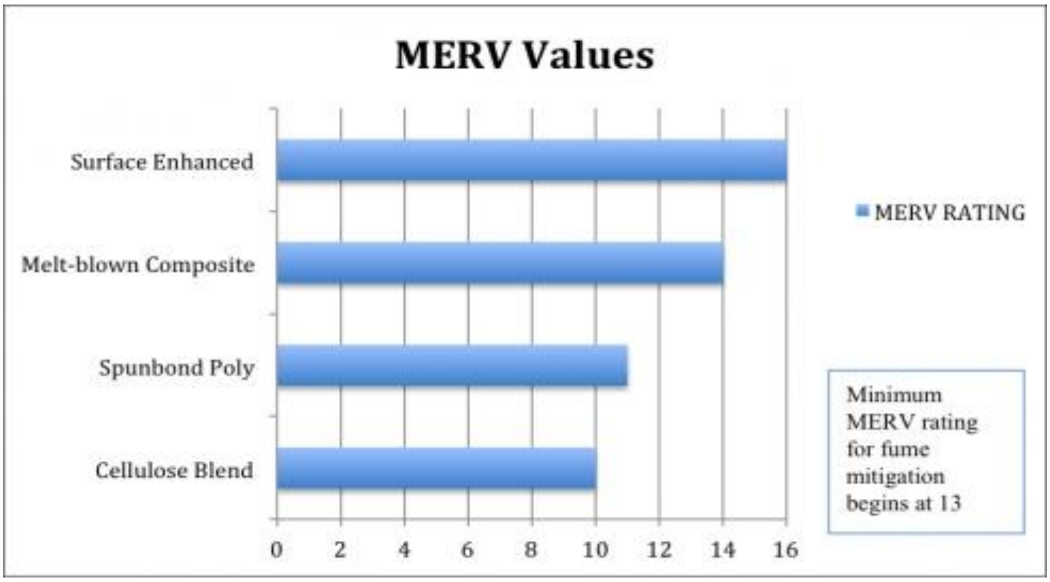

Figure 6. MERV ratings are used to gauge the ability of the filter media.

Choosing the type of filter depends on the field and work requirements and standards to be achieved, experience and most importantly achieve the highest efficiency at the lowest cost always the mean target.

5. Conclusion

Dust collection systems using reinforced materials based on polypropylene has promising future. Improvement of 30% of efficiency is achieved. Applications of dust collection systems using reinforced materials in cement industries is investigated in this paper where creep curve of the blend is mathematically modeled.

ISSN: 2413-5267

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