Experimental Investigation of Powder Holding Capacities of H13 and H14 Class Activated Carbon Filters Based on En 779 Standard

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Abstract**—**The use of HEPA filters for air conditioning systems in clean rooms tends to increase progressively in pharmaceutical, food stuff industries and in hospitals. There are two standards widely used for HEPA filters; the EN 1822 standards published by the European Union, CEN (European Committee for Standardization) and the US based IEST standard (Institute of Environmental Sciences and Technology. Both standards, exhibit some differences in the definitions ofefficiency and its measurement methods. While IEST standard defines efficiency at the grit diameter of 0.3 µm, the EN 1822 standard takes MPPS (Most Penetrating Particle Size) as the basis of its definition. That is, the most difficult grit size to catch up. On the hand, while IEST suggests that photometer and grit counters be used for filter testing, in EN 1822 standard, only the grit (grain) counters are recommended for that purpose. In this study, powder holding capacities of H13 and H14 grade materials underthe EN 779 standard are investigated experimentally by using activated carbon. Measurements were taken on an experimental set up based on the TS 932 standard. Filter efficiency was measured by injecting test powder at amounts predetermined in the standards into the filters at certain intervals. The data obtained showed that the powder holding capacities of the activated carbon filter are high enough to yield efficiency of around 90% and that the H13 and H14 filters exhibit high efficiency suitable for the standard used.

Keywords**—**Activated Carbon Filters, HEPA Filters, Powder holding capacities

I. Introduction

THERE are particles of varieties of sizes suspended in the air. Their sizes may vary from as small as far below 1 micrometre to as large as over 200 micrometre. If we think of a period at the end of sentence to have a size of 500 microns, we see that over 2 million particles with diameters of 0.3 microns will be found on a the period. Under the best light conditions, it is possible to see with naked eyes, particles of sizes up to 10 microns. The fact that human hair has a diameter of 59 microns helps us to figure out the size of a micron. While blood cells have the size of 14 microns, tuberculosis bacilli have the size ranging between 2 to 6 microns in length and 0.5 micron in width.The thread soft wool is relatively large in size. As for ash, we find it appearing in several sizes varying from 1/10 micron to 50 microns. By considering that a particle size of 10 microns is the smallest size that can be seen with naked eyes under the best conditions of light, we come to conclude that among the ten million particles in air, only one can be seen with naked eyes. When looking in terms of weight, we find that, 20% of the particles show that at least 90 % of the total (mass) is covered by weight. On the other hand, over 99% of the particles have diameters less than 0.5 microns. Particles carrying viruses and germs should also be considered to be these small particles[1]. Therefore, it is necessary to put these minute particles in the atmosphere and in areas where people live under control as they both increase environmental pollution and endanger human health. This controlling activity named as air filtration technique, is conducted by using powder collection and environmental pollution controlling systems for outdoor environment and by using filters of different precisions for indoor cleansing[2].

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II. Air Filtration Techniques

The wide variations of the particle sizes in the atmospheric air together with the different environments subjected to such particles necessitate the availability of different filtration methods in order to achieve the required cleansing. Filtration methods are classified based on the nature and the type of particles such as large particles, small particles, solid particles, liquid particles etc. they are generally available in one or several of the five principles listed below;

- Elimination method
- Precipitation
- Electrostaticsedimentation
- Viscous impingement
- Diffusionand stopping, preventing method[3].

A. Elimination Method

This involves elimination of all particles of sizes of 10 microns or larger from the air by introducing filtering holes of sizes smaller than 10 microns.

B. Sedimentation

This is the removal of the airborne particles from the air as a result of gravity.

C. Electrostatic Sedimentation

In order to hold particles under this principle, electrical forces are used. The particles loaded electrically from an ionization source are passed through an electrically loaded parallel platethe particles are drawn through opposite charged plates. In electrostatic filters, dust accumulation formed as a result of smaller particles trapping larger particles is drawn through the plates towards other filters which are governed by impingement or diffusion principles. In filters cleansed with water, sticking matter is generally found on them and hence periodic water cleansing is needed.

D. Viscous Impingement

Impingement refers to the way a particle separates from the air whereas viscous is used to explain how the particle is prevented from reuniting with the air after its initial separation. When an airborne particle approaches an obstacle, the air continues flowing around the obstacle while the particle cannot stopand collide with the obstacle and hence get it separated from the main air stream. Here the obstacle is a filter fibre. Due to the fact that molecular power alone is not enough in driving the particle to the obstacle, sticky adhesives are applied thereby preventing the particle from resorting back to air. This principle is mostly valid for heavier particles and applied on front and course filters.

E. Diffusionand Stopping, Preventionmethod

Small and very light particles tend to follow the air stream. However; under some conditions, when they move in the direction of flow, they are prevented by molecular attractive forces existing between the particles and the obstacle. This phenomenon is termed as stopping principle. Substantially low air speeds such as 0.1-0.2 m/s are required for this to occur.

F. Diffusion Principle

Particles smaller than a micron tend to move randomly. This is known as Brownian motion and this causes internal molecular forces. In large particles total molecular forces cannot initiate such a motion. It is possible to catch up particles undergoing such a random motion by introducing tight celled barriers into the way the particles pass.

III. Properties Required For An Air Filter

An air filter is expected to have the following useful properties.

• Resistance against air flow
• Dust holding capacity
• Efficiency

Filters are designed in such a way that these properties are able to achieve the expected optimum performance[4].

A. Resistance Against Air Flow

Every filter creates resistance against air flow. And this is recorded as pressure drop in the filter expressed as Pascal (N/m^2) or inch/ mm water column. Generally, the resistance of filters operating based on the viscous impingement principle is lower than that of the filters under diffusion/stopping principles. As filter resistances increase with the use of filters, not only initial pressure drops are important but also the final pressure drops need to be specified. When this value is reached the filter must be replaced[5].

B. Dust Holding Capacity

This is the amount of dust recommended to be held by a filter up to the end of its ultimate resistance. Based on this definition, it is clear that powder (dust) holding capacity of a filter determines its lifespan and that it is the important factor that specifies the quality of the filter. The cost of filtered air is determined by the dust holding capacity of the filter used and its resistance against the air flow[6].

C. Efficiency

Regardless of being simply understood, efficiency can hardly be defined.Defining efficiencies of filters from different classes in different aspects will simplify our work. If it is assumed that there are 100 grams of dust in air stream, and if a filter can take up 80 of those grams, then it means that this filter has 80% of dust holding efficiency. According to the viscous impingement principle, efficiency of operating filters is designated based on the weight of the dust held on the filters (weight arrestance). However; 97 % of the total weight of atmospheric particles forms 1% of the total number of particles. For this reason, it is not possible to use the term efficiency in terms of dust weight for filters that separate smaller particles. For dry and surface widened filters as well as other diffusion filters the term dust spot efficiency is used. The efficiency in question is determined with a test by using atmospheric air within which minute carbon impurities always exist. In this case dust spot efficiency means the capability of filter to sieve out the airborne impurities in the air. Even for high efficiency filters such as HEPA filters, the dust spot efficiency becomes insufficient. The efficiency of such filters is specified after injecting particles having diameter sizes of 0.01 to 2 microns into the air to be cleaned and then counting their numbers on the clean air side of the filters. This measurement is done with 0.001% accuracy[7].

IV. Filter Classifications Based On Performance

Filters are classified after conducting tests on their respective performances. With this aim, EN 779 and EN1822 standards prepared by CEN and those recommended by the USare used.

The first air filter test standard was published by the ASHRAE (American Society of Heating,Refrigerating and Air-Conditioning Engineersin 1968. This standard has progressively been updated by taking filter’s real operating conditions into account.

Prior to testing, filters should be relieved of the effects of electrostatic forces. To remove these effects from the fibers, the filters are exposed to diesel fume for several hours (Gustavsson, 2003). In this way the filters become relieved of the electrostatic effects.

Under the European norms, filter performance classification is done with respect to the EN 779 (particulate air filters for general ventilation) and EN 1822 (high efficiency particulate filter testing) standards.

Under the EN 779 standard coarse filters are categorized based on the mean weight average of the synthetic dust held and grouped at G1-G4 classes; while medium and fine filters are classified based on the average percentage of dust holding efficiency under M5 and M6 classes as well as at F7-F9 intervals. (Table-1)

TABLE I
CLASSIFICATION OF COARSE AND FINE FILTERS (EN 779-2012)

Grup	Sınıf	ΔP_{max} (Pa)	$\%\mathrm{A_m}$	$\%\mathrm{E_m}$	% Asgari verim
Kaba	G1	250	$50 \leq A_m < 65$		
	G2	250	$65 \leq A_m < 80$	-	-
	G3	250	$80 \leq A_m < 90$	-	-
	G4	250	$90 \leq A_m$	-	-
Orta	M5	450	-	$40 \leq E_m < 60$	-
	M6	450	-	$60 \leq E_m < 80$	-
İnce	F7	450	-	$80 \leq E_m < 90$	35
	F8	450	-	$90 \leq E_m < 95$	55
	F9	450	-	$95 \leq E_m$	70

According to the EN 779 standard published in 2012, in the particulate holding test, synthetic particles (DEHS liquid, Di-ethyl Hexyl-Sebacat) of the sizes ranging at 0,2-3 μmare injected into clean flowing air at the rate of 0.944m^3/h. Here, the flow of clean air per unit square meter may vary between 0.24 and 1.5 m^3/h but generally 0.944 m^3/h is used.As soon as the test starts, pressure drop and particulate holding efficiency are recorded.The amount of particles collected during the tests is measured and the particle holding efficiency calculated.The amount of particles collected at the end of the tests is weighed on the filter and calculated. If the ratio of the particle weight held on the filter to the weight of the particles entering the filter is less than or equal to 0.9, then the filter is a coarse filter. This ratio is at the same time mean average (Am). By using Table 1, the class belonging to this Am filter can be determined. However; if the weight ratio is larger than 0.9, the test specimen will fall into either medium or fine filter. Classification of the medium or fine filters is done by using measurements with the help of an optic particle counter.Particle measurement by using the optic counter is done on the basis of sending laser beam into the air filter which gets into contact with the particles after which its direction is changed. The diverted laser beam is collected into a detector and then its presence is felt by a sensor. In this the position and size of the particulate collected by the filter becomes vivid. In medium and fine filters, the particle collecting efficiency for particulates having the diameter size of 0.4 μm is determined by measurement using optic particulate counter. According to the results of this measurement, if the ratio of the number of particles collected to that entering the filter lies at (Em) 0.4≤ Em <0.8, then the filter concerned is understood to be of the medium quality. With respect to the measurement results, the medium class filter lies at M5 or M6 categories. If the calculated ratio is greater than or equal to 0.8 (Em ≥0.8) then the filter is termed as the fine filter which, according to the Table falls at the interval of F7-F9. The minimum efficiency on Table 1 is described as the efficiency at the beginning of the filtration process or the particle holding efficiency during the tests where both efficiencies for a specimen can never be smaller than the minimum efficiency.

In filtering micro scale particles, EN 1822 standard is applied. In this standard, the filters consist of EPA (Efficiency Particulate Air filter), HEPA (High Efficiency Particulate Air Filter and ULPA (Ultra Level Particulate Air Filter). (Table 2).

The minimum efficiency for the whole filter value on Table-2 is obtained by screening every point on the filter by using optic particulate counter and analysing the results; localized value refers to the minimum efficiency obtained after screening every point on the filter and analysing the result of each point separately. Leakage term refers to the number of particles passing the filter without being trapped by the filter[8].

TABLE II
CLASSIFICATION OF PRECISION FILTERS (EN 1822-2009)

	Whole filter value			Localvalue	
Group	Filter class	Holding Efficiency %	Leakage %	Holdin g Effic. %	Leak. %
EPA	E10	85	15	-	-
	E11	95	5	-	-
	E12	99.5	0.5	-	-
HEPA	H13	99.95	0.05	99.75	0.25
	H14	99.995	0.005	99.975	0.025
ULPA	U15	99.9995	0.0005	99.997 5	0.0025
	U16	99.99995	0.00005	99.999 75	0.0002 5
	U17	99.999995	0.000005	99.999 9	0.0001

Particle holding test for precision filters is done based on the EN 1822 standard. The particle holding test makes use of theMPPS particles (Most Penetrating Particle Size) whose sizes range at 0.1-0.3 μm. To accomplish this, DEHS liquid of the MPPS size is injected into the air where the particulate counters on the front and back of the filters, locally, count the number of particles entering and leaving the filters. The number of particulates measured locally and the local particulate holding efficiency are then calculated. By analysing the results of the local particulate efficiency, the whole filter particle trapping efficiency is calculated. By making use of the lowest local efficiency and the whole filter efficiency, the precision filter class can be determined. For instance, a precision filter with the minimum local particle trapping efficiency of 94% and all- filter particle trapping efficiency of 96% is in E11class[9].

V. EXPERIMENTS AND FINDINGS

A. Particle Trapping Experimental Set

What is expected from an air filter is trapping a large number of small particles by creating low pressure drop conditions. Actually, the objective of filtering is to obtain clean air; that is air with no particles.In order to measure this feature of the filter, particle trapping experiments were conducted. The developed particle trapping set consists of four parts (Figure-1). The first part is pre-filtration and regulator system, pressure loss has been used as shown in the experimental set for particle filtration and adjusting the air flow rates. With the help of the liquid housing which forms the second part of the experimental, calcium carbonate (CaCO3) nano-particles are blown and sent to the mixing chamber. In the mixing chamber, homogeneous mix is obtained. The no-load operating line in the third section has been purposely designed to allow fixing and removal of the test specimen when the system is running. The last section is the filter specimen test section on which a rotametre is fixed to measure volumetric rate of the air passing the filter[10].

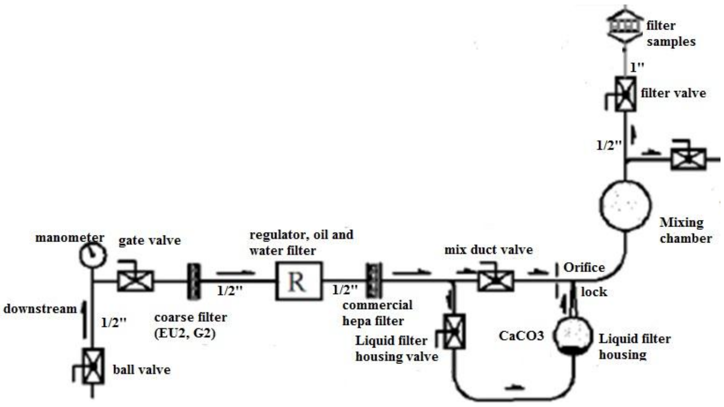

Fig.1 Schematic View Of Particle Trapping Experimental Set

Fig.2 Particle Trapping Experimental Set

Throughout the experiment the liquid bearing system was always open (Figure-2). Even at the time when the filter test specimens were being weighed, the liquid bearing system was operated by feeding the no-load line with air having particulates. And it is for this reason that homogeneously distributed particle concentration was achieved.

Liquid filter bag housing system is a name given to the status where solid particles of certain sizes behave like liquid.That is, pressurised gas passes through the solid particles forming the medium. In this case solids start to show liquid characteristics. In addition, their densities decrease without affecting the structure of the particles. This phenomenon is known as housing[11].

In order for the particles coming out of the liquid housing to be able to mix thoroughly an orifice is mounted onto a transparent hose where quick connection of air and the liquid housing has been pre-set (Figure-3a). Liquid house was formed of two hemispherical plastic bowls where one bag has small perforations on the air inlet section. Below the perforations was placed an H13 class HEPA filter so that the particles were prevented from pouring down. Air inlet conduit was well sealed with a transparent hose. The top part where particles eject a pipette was inserted through a hole drilled on the upper spherical bowl. The pipette was placed in such a way that it comes right to the orifice outlet where air gushes out (Figure -3a).Very small solid particles were blown away with air in the liquid housing causing formation of nan-particulate air.

Mixing chamber was improvised by joining two transparent funnels mouth to mouth with adhesives.The edges of the funnels were mounted with a transparent hose and sealed securely to avoid leakage (Figure-3b).

In order to monitor pressures recorded in liquid housing and on the mixing chamber one manometer was located for each part (Figure-3c).

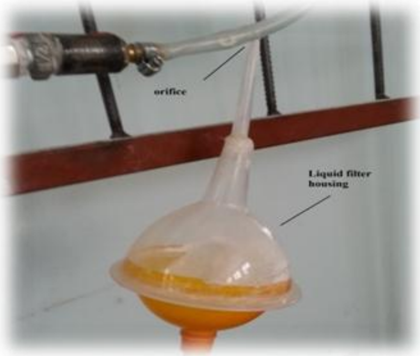

Fig.3a Liquid Filter Housing System And Orifice

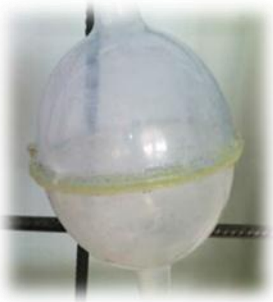

Fig.3b Mixing Chamber Fig. 3c Manometers

B. Preparation Of Filter Specimens

The filter specimens were cut by preparing a pattern in a way that they can be fixed. To achieve homogeneity, at least 5 cm distance from the filter edges was left when the specimens were cut. To make sure that the filters are centred easily and to avoid filter ripping, the corners coinciding with bolts were removed. (Figure-4a). In addition, care was taken to avoid the filter specimens surpassing the flanges (Figure-4b). To prevent the HEPA filters from deforming and bursting as a result of pressure spikes, chrome-nickel wires were wrappedon either side of the filters (Figure-4a).

Fig. 4a Chrome-Nickel Wire Wound H13 Class HEPA Filter Used In The Experiment

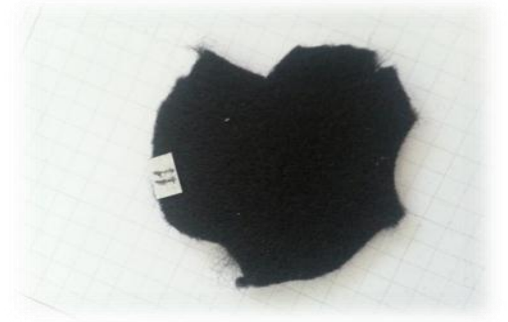

Fig. 4a Activated Carbon Filter Used In The Experiment

Fig.4b H13 Class HEPA Filter On The Flange

C. Particle Trapping Experiments

The activated carbon filter, H13 and H14 classes HEPA filters used in the particle trapping experiment were fixed onto flanges as shown on Figure 4-b. To achieve perfect water tight feature, gaskets were placed onto the specimens. And over the gaskets, flanges were fixed. The specimen constrained in between two flanges was pinned down with bolts. A rotametre was attached at the hose exit to measure the air flow rate passing through the filter (Figure -5)

Fig. 5 Filter Used In The Experiment Seen Mounted On The Flange

The pressure on the gate and universal valves at the inlet of the experimental set was adjusted gradually so that it maintains the value of 1.5 bars. The regulator was opened slowly so that air could enter the liquid housing and the mixing channel. Inside the air channel, calcium carbonate ($CaCO_3$) reacted with air and got into the mixing chamber where homogeneous $CaCO_3$ nano-particulate air was obtained. The homogeneously distributed $CaCO_3$ nano-particles propagated into the water from the idle (no-load)operating line. The experimental set was thus operated for 2 to 3 minutes in order to achieve steady operating condition. After the system has acquired steady regime, the regulator was gradually throttled to close the valve that allows passage of the particles. Then the filter valve was opened incrementally to allow$CaCO_3$nano-particles arrive to the filter specimen. The manometer on the liquid housing side was set at 0,2 bar (Şekil-3c). As for the manometer on the line at the mixing chamber, it was first set at 0.2 bar, then raised to 0.4 bar and finally adjusted to 0.6 bar. The $CaCO_3$nano-particles were blown over the filters for five minutes. After that the filter exit valve was closed and the orifice line valve opened; then the idle operating valve was opened and finally the filter valve was closed. As the system continues operating, the amount of particles passing through the filter specimen was weighed on a precision scale. Consequently; the 5-minute section of the experiment was accomplishedin this way.

The same procedures were repeated for 10, 15 and 20-minute intervals, weighed on the precision scale and filter efficiency calculated (Figure -3).

TABLE III
PARTICLE HOLDING CAPACITY OF ACTIVATED CARBON FILTER

F.No	W1 (gr)	W2 (gr)	P1 (bar)	P2 (bar)	V (l/min)	A %	T (min)
1	0.2281	1.5211	0.2	0.2	50	85	20
2	0.1672	1,2232	0.2	0.2	50	86	15
3	0.1102	0.9226	0.2	0.2	50	88	10
4	0.0612	0.5926	0.2	0.2	50	90	5
5	0. 4612	2.9117	0.2	0.4	75	84	20
6	0.3507	2.3921	0.2	0.4	75	85	15
7	0.3015	2,1025	0.2	0.4	75	86	10
8	0.2012	1.5926	0.2	0.4	75	87	5
9	0.6825	3.5552	0.2	0.6	125	80	20
10	0.6020	3.2508	0.2	0.6	125	82	15
11	0.4528	2.8572	0.2	0.6	125 l	84	10
12	0.3828	2.5578	0.2	0.6	125	85	5

Fig.6 Activated Carbon Filters That Have Trapped Particles

The above mentioned procedures were also applied to H13 and H14 class HEPA filters for 5, 10 and 15 minute-intervals, weight dimensions taken on precision scale and filter efficiency calculated (Figure-4).

TABLE.IV
PARTICLE HOLDING EFFICIENCY OF H13 CLASS HEPA FILTER

	W1	W2	P1	P2	V	A	T
1	0.0352	3,2232	0.2	0.2	100	98.90	15
2	0.0242	2.8245	0.2	0.2	100	99.14	10
3	0.0152	1.8235	0.2	0.2	100	99.16	5
4	0.0382	3,2532	0.2	0.4	150	98.82	15
5	0.0272	2.8535	0.2	0.4	150	99.04	10
6	0.0182	1.9935	0.2	0.4	150	99.08	5

Fig.7 H13 Class HEPA Filters That Have Trapped Particles

TABLE V
PARTICLE TRAPPING EFFICIENCY OF H14 CLASS HEPA FILTER

F.N.	W1	W2	P1	P2	V	A	T
1	0.0272	3,1232	0.2	0.2	100	98.90	15
2	0.0252	2.8265	0.2	0.2	100	99.14	10
3	0.0132	1.8265	0.2	0.2	100	99.27	5
4	0.0302	3.2532	0.2	0.4	150	99.07	15
5	0.0258	2.8545	0.2	0.4	150	99.11	10
6	0.0175	1.9955	0.2	0.4	150	99.13	5

Fig. 8 H14 Class HEPA Filter That Has Trapped Particles

Abbreviations

F.N.: Filter Number
W1: Particle weight held by a filter (gr)
W2: Total particle weight during the tests (gr)
P1 : Liquid housing pressure (bar)
P2 : Mixing chamber pressure (bar)
V : Volumetric flow rate (litre/min)
A : Filter efficiency (%)
T : Test interval (minutes)

VI. RESULTS

In this study, particle trapping performances of H13 and H14 class HEPA filters and activated carbon filter under various operating pressure conditions were investigated experimentally under the light of EN779 standard.

The measurements taken in this study were taken on an experimental set that complies with the TS 932 standard. The data obtained show that the dust holding capacity of activated carbon filter is high enough to achieve efficiency of about 90% and that H13 and H14 filters exhibit worthwhile efficiency that is suitable with the existing standards.

In the particle trapping tests, non-toxin calcium carbonate ($CaCO_3$) was used as nano-particles. In blowing these materials the liquid housing was benefitted from. The developed experimental set was found fairly successful showing high performances when operated under varying pressure drops and during particle trapping.

Care should be taken after the particle trapping tests not to straighten the filter specimens or positioning them in way that will cause the trapped particles to flow away.

The valves used during the tests need to be opened and closed gradually. Otherwise, the liquid inside the manometers may vanish with the air, filter may burst and even water tight feature may get impaired and leakage may develop due to pressure spikes. (Figure-8).

Fig.9 Punctured HEPA Filter

Bolt-nut fasteners were used in fixing the filters onto the flanges.Due to the tedious nature of tightening and loosening the bolts during the tests, it is recommended that the flanges be made large enough; weld the bolts on the flanges and use of butterfly nuts.

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