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QUALITY ASSESSMENT OF NONWOVEN AIR FILTERS USED IN FERTILIZER FACTORIES

تقييم جودة أقمشة مرشحات الهواء الغير منسوجة المستخدمة فى مصانع الأسمدة

BY

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خلاصه - فى هذا البحث امكن انشاء جهازين لقياس كفاءة الترشيح وهما جهاز ترشيح الغازات وجهاز الليزر . كفاءة الترشيح امكن قياسها لعديد من أقمشة المرشحات الغير منسوجة. وقد وجد أن هنالك اتفاق كبير بين كفاءة الترشيح المقاسة على كلا الجهازين . خواص الأداء الضرورية لتقييم جودة أقمشة مرشحات الهواء امكن اختيارها وترتيبها بعناية حسب درجة أهميتها . طرق التقييم المختلفة مثل المتوسط الحسابى والمتوسط الهندسى والمتوسط التوافقى والمتوسط الأسى ومساحة الشكل المتعدد الأضلاع ورقم الجودة وايضا دالة الرغبة العامة امكن استخدامها لتقييم جودة أقمشة مرشحات الهواء بدقة .

ABSTRACT - Two experimental techniques used to evaluate fabric filtration efficiency. Gas filtration apparatus and another apparatus used optical techniques based on laser doppler velocimeter are constructed. The filtration efficiency have been measured for a wide varity of non-woven filter fabrics. Excellent agreement has been found between the two techniques. The necessary performance characteristics of air filter fabrics could be selected and arranged carefully in decreasing order of importance. In this paper several methods are used to assess the quality of some nonwoven fabrics as air filters similar to those filters used in the fertilizer factory. Complex evaluation of quality methods have been applied to determine the best filter which can be used in fertilizer factories. Quality assessment methods such as arithmetic mean, geometric mean, harmonic mean, exponential mean, polygon area, quality number and generalized desirability function can be used for assessing the quality ranking of air filter fabrics accurately.

I. INTRODUCTION

Filters are commonly used in the industrial purposes and for protecting the environment from the pollution. Filters can be classified as one of two types, based on the way in which the fibres are held in place. In the first type, the packed filter (nonwoven filter), the fibres are loosely packed into a substantial volume, presenting a fairly long path a long which the air must pass on its way through the filter. This type of filter has wide use in air conditioning applications and other applications where the dust loading, or particle - number concentration, is relatively small. In the second type of filter (woven or knitted filters), called the single layer filter, fibres are woven into a thin layer of cloth. Bag filters are the typical example of this type of filter [1]. Filter fabric is one of the most important types of industrial fabrics. Fluid mechanics forms the principal foundation of air pollution control theory. Fluids may be either liquids or gases.

Each filter must fulfil the necessary requirements according to the different end uses such as filtration process of cement, acids, salts, oils, sugar, milks and so on. This makes the technology of these filters difficult to be studied in general. Safety, it could be said that each filter can be considered as a special fabric with respect to the type of material and the method of manufacture.

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Generally, the fertilizer company is using two types of filters, e.g. air filters and liquid filters. But the present study concerned with the most important filter used in air compressor (Talkha II). This is because air compressor needs a huge amount of very pure air per unit time in order to the ideal processes can be carried out successfully.

As far as filtration is concerned, the amount of dust particles passing through a filter medium is of major importance for various products. If the pore size is large, a higher mass of dust will be expected to pass through the filter fabric, while if the pore size is small, there will be higher dust retention and a low mass of dust will pass through. And the need for a simple filtration apparatus is an important factor in determining the resultant gas and dust permeability of filter fabrics.

In Selecting a filter fabric for fertilizer factories, one must consider the different characteristics of the fabric as they relate to the type of application. For example, for air filter fabrics, the main property to consider is mechanical resistance [1]. For filtration systems, essentially two characteristics are important: the air permeability coefficient and the particle retention capacity of the filter, expressed by geometrical ratios between characteristic particle dimensions of the soil to be retained and a characteristic opening of the fabric [2].

Different characteristics have been proposed for evaluating the filtration performance of air filter fabrics: filtration efficiency, pressure drop, fabric porosity, pore size and fabric thickness [3-5].

Many research works have been studied filter characteristics individually. But the present work concerned with the complex assessment of the filter characteristics e.g. Filtration efficiency, pressure drop, air permeability, porosity, fabric weight, bursting strength and specific work of rupture.

The object of this paper is to study the performance of domestic nonwoven fabrics similar to those imported filters used in the factory. This will lead to improving the filtration efficiency and durability of air filters using domestic fabrics which saves a lot of hard currency and insure the supply of these filters from the Egyptian market.

2. EXPERIMENTAL WORK

2.1 Fabric Preparation:

Fabrics of different weight per unit area and thickness were produced by using different numbers of layers of parallel - laid webs and different amounts of needling. The various filter samples are listed in Table I.

2.2 Filtration Efficiency Test:

2.2.1 Gas Filtration Apparatus (Weighting method):

The measurement of filtration efficiency of fabrics is the main object of this work. This is because there is no apparatus in Egypt or in the market available to measure the filtration efficiency. Then it was necessary to build an apparatus. This apparatus was designed to measure both the filtration efficiency and air permeability with a similar manner to the Shirley air permeability tester. The designed apparatus is capable of measuring the air permeability at high pressure drops and rate of air flow which is not possible by using Shirley air permeability tester.

Figure (1) shows a schematic diagram of the apparatus. Air is drawn from the atmosphere through the pipe (1) by the action of a blower (8), then passes through

Table 1 : Specifications of Filter Fabrics

Fabric	Type of Fibres	Thickness, mm	Weight per/unit area,g/m^2	Fabric Density, g/cm^3
1	40% acrylic/44% polyester/ 6% cotton /5% nylon/5% wool	4.3	310.6	0.0722
2	100% acrylic	6.62	270.5	0.0409
3	33% wool/ 33% cotton/ 34% acrylic	6.05	647.1	0.1070
4	100% polyester	2.6	164.4	0.0632
5	88% polyester/12% wool	4.6	586.9	0.1276
6	50%acrylic/50% polyester	8.22	445	0.0541
7	100% polyester	4.6	117.5	0.0373
8	88% polyester/12% wool	1.2	235.1	0.1959
9	wool/acrylic/nylon/polyester	4.8	404.6	0.0843
10	80% polyester/20%fibran	7.45	864.5	0.1160
11	" " " "	9.0	1158.6	0.1287
12	" " " "	7.75	898.8	0.1160
13	" " " "	5.72	871.4	0.1523

line A or B according to the type of test. Air flows through line A for air permeability test (in this case valve B is closed). On the other side, air flows through line B for measuring filtration efficiency.

In this test valve A is closed and air flows through line B. A regulator (9) is is used to get a dry air in the system. A flowmeter (10) is used to measure the rate of air flow. The pressure gauge (11) measures the air pressure in the line. A dust feeding device (13), feeds the system with a constant amount of dust. This dust is mixed with the air flow. The sample (5) acts as a filter, which prevents the coarse particles of dust and permits the fine ones to pass through. The fine particles are accumulated on the surface on the filtration paper (12). The pressure drop across the fabric sample is measured by the manometer. The following operating conditions were kept constant: 15 cm^2 area of test filter and 70 cm^3/sec rate of air flow.

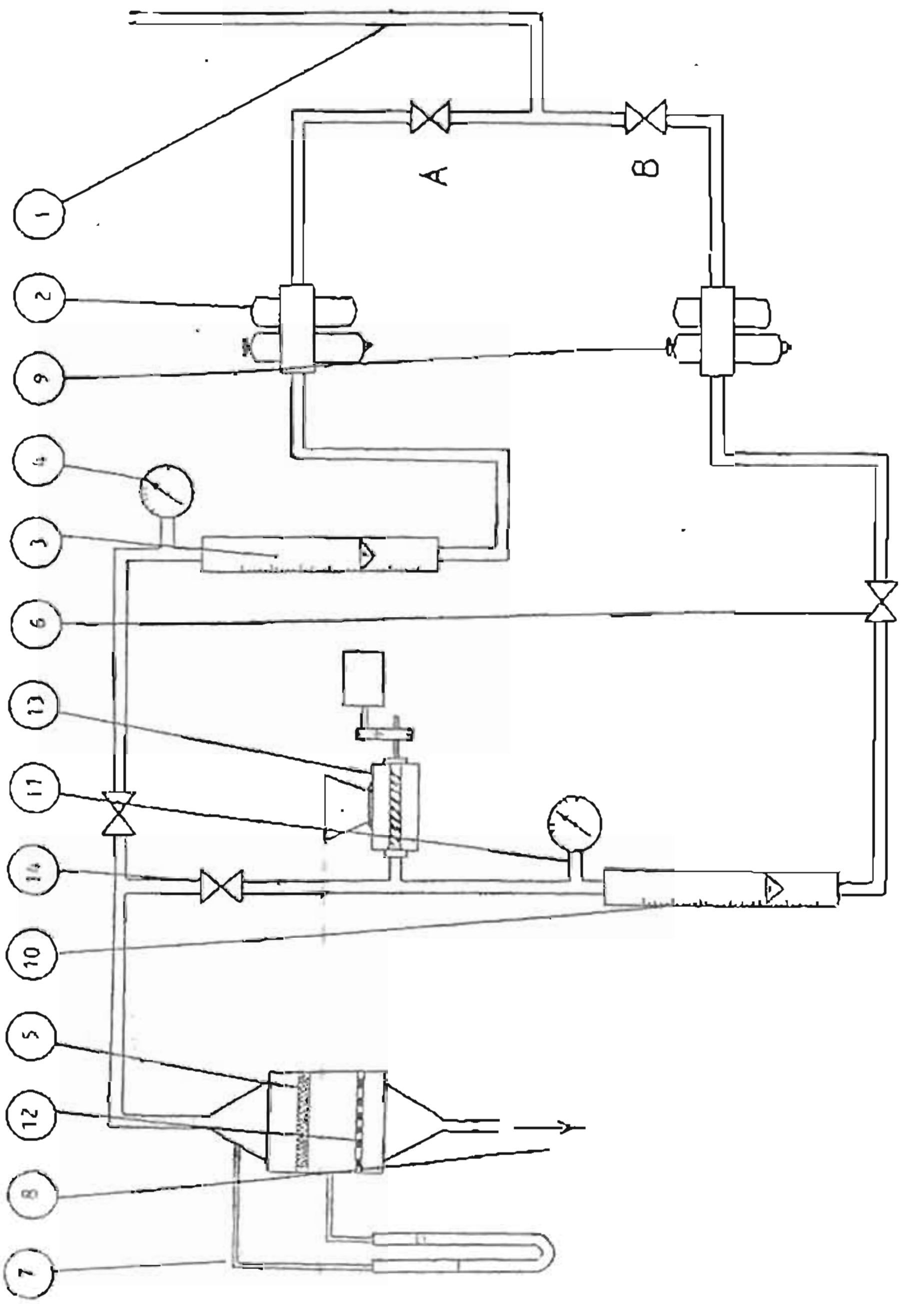

Figure 1 . A Schematic diagram of gas filtration apparatus

2.2.2. Laser Technique (optical method):

Optical techniques based on laser doppler velocimeter are applied to evaluate filtration efficiency by measuring particles concentration before and after the tested filter [6]. There are three detectors located at selected spacings behind the receiver aperture as shown in Fig. (2). This method has several potential advantages for obtaining the size and velocity of particles [6].

A moduler fluid flowing system has been constructed to allow the visualization concept. It consists of a two rectangular channels (3X3X100, 3X3X80 cm) made of plexiglass, and dust supplying system as demonstrated in Fig. (3). Dust feeding system aspirates dust from the container to the ejector in order to obtain a homogeneous mixture of dust and air. By means of a suction at the other side, the flow of air and dust passes through the filter fabric.

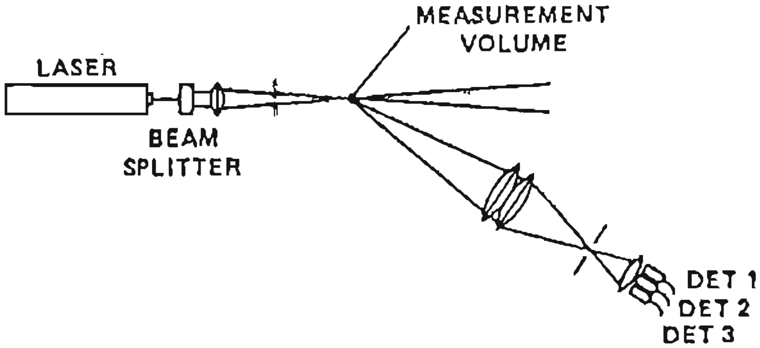

Figure 2 . Optical Schematic for an LDV and the P/DPA

3. RESULTS AND DISCUSSION

From such study, performance properties of air filters can be divided into two groups : positive properties such as filtration efficiency, air permeability, porosity, bursting strength and specific work of rupture; and negative properties such as pressure drop and weight per unit area. The results of both positive and negative relative characteristics (Y_1 - Y_7) of each property could be listed in Table II. Selection of the best fabric is difficult enough without using special methods for assessing the quality such as complex characteristics or generalized desirability function.

3.1. Complex Characteristics:

Complex characteristics of quality assessment may be determined [7] by calculating the arithmetic mean (A), geometric mean (G), exponential mean (E), polygon area (P) and quality number (Q) of the relative characteristics (Y_1 - Y_7) as given in Table II.

3.2. Generalized Desirability Function:

Generalized desirability function (D) can be calculated [8-10] by the geometric mean of the individual charcteristics of the desirability (di) as follows:

$$D = (d_1 \cdot d_2 \cdot d_3 \cdot \ldots d_7)^{1/7}$$

where $di = \exp (- \exp - Zi)$; $Zi = a + b X i$

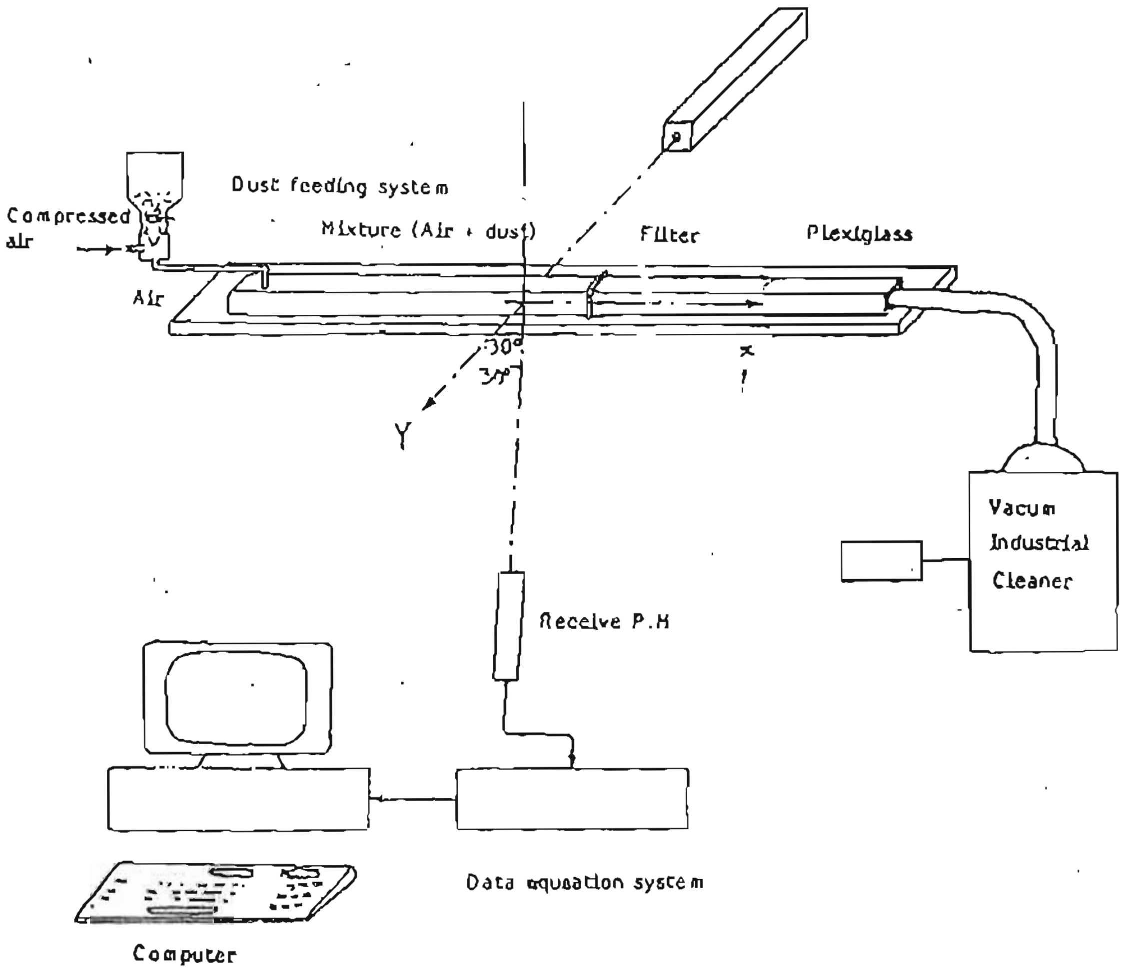

Figure 3. Fluid Flowing System

Table II : Typical Relative Characteristics of Filter Fabrics

Fabric Property	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Filtration efficiency, %	90.0100	95.0800	98.3900	84.3100	98.0300	70.8100	85.4500	86.1000	88.1000	93.4500	70.4100	78.3700	97.1200
Relative value, y1	0.9148	0.9664	1.0000	0.8569	0.9963	0.7197	0.9050	0.9091	0.8954	0.9498	0.7156	0.7965	0.9871
2. Pressure drop, mm of water	4.0000	4.2500	7.3300	5.8000	9.5000	4.0000	2.6000	20.6000	3.0000	14.0000	18.6000	12.8000	10.0000
Relative value, y2	0:6500	0.6118	0.3547	0.4483	0.2737	0.6500	1.0000	0.1262	0.8667	0.1857	0.1398	0.2031	0.2600
3. Air permeability, ft3/ft2.min	369.5000	310.0000	305.0000	265.0000	253.0000	358.5000	752.7000	280.0000	497.5000	310.0000	186.5000	198.0000	272.0000
Relative value, y3	0.4909	0.4119	0.4052	0.3251	0.3361	0.4763	1.0000	0.3720	0.6610	0.4119	0.2478	0.2631	0.3614
4. Porosity, %	94.3500	96.5000	91.8900	95.1800	90.6900	95.7300	97.3000	85.7100	93.2100	91.2900	90.3400	91.2900	88.5700
Relatie value, y4	0.9697	0.9918	0.9444	0.9782	0.9321	0.9839	1.0000	0.8809	0.9580	0.9382	0.9285	0.9382	0.9103
5. Fabric weight, g/m2	310.6000	270.5000	647.1000	164.4000	586.9000	445.6000	171.5000	235.1000	404.6000	864.5000	1158.6000	898.8000	871.4000
Relative value, y5	0.5292	0.6079	0.2541	1.0000	0.2801	0.3694	0.9588	0.6994	0.4064	0.1902	0.1419	0.1829	0.1887
6. Bursting strength, kg	21.9000	30.3000	17.9000	9.3000	153.3000	54.2000	20.7000	44.8000	28.3000	102.6000	143.6000	19.2000	42.8000
Relative value, y6	0.1430	0.1970	0.1170	0.0609	1.0000	0.3530	0.1350	0.2920	0.1840	0.6700	0.9370	0.1250	0.2790
7. Sp. work of rupture, g/tex	0.6768	0.1893	0.0549	0.2000	1.6074	0.0819	0.1592	1.7614	0.2443	0.8020	0.5782	0.4430	0.1472
Relative value, y7	0.4210	0.1180	0.0340	0.1240	1.0000	0.0510	0.0990	0.7850	0.1520	0.4990	0.3600	0.2760	0.0920

Z_i - dimensionless characteristics which Z = 1.5 for the best sample and Z = 0 for the worse ones;
a,b - constants and
X_i typical properties of each sample.

Therefore, the values of D can be easily calculated and the fabrics can be ranked according to its quality as listed in Table III.

3.3. Rank Agreement:

The selected fabric samples are to be ranked using the six methods of quality assessment (A,G,E,P,Q and D). The coefficient of concordance (w) among the different methods is equal to 0.88. The final rank of each sample is set out in Table III.It could be noticed that the fabric NO.7 and fabric No. 12 has the best and worse quality respectively. For checking the best Fabric, the overall efficiency (Y) and quality index (I) can be calculated [11] as follows:

$$Y = L_n [1/(1-m)] / \Delta p \text{ ; and}$$

$$I = -100 \log f / \Delta p$$

where m- fractional efficiency ;Δp - pressure drop, and
f- fractional penetration.

3.4. Optical System

The purpose of using this experimental technique is to produce a steady two phase flow of air and dust through a filter. This is to measure the concentration of dust before and after the filter by means of optical techniques. These optical methods are based on Laser Doppler Anemometry (LDA) [12]. These techniques have the advantage of not disturbing the flow.

The size and velocity histograms are presented in Fig. (4). The results of the calculations performed are presented to the right of the size histogram. They include:

Probe Width- This is the actual diameter of the optical volume as measured during data acquistion. All size histogram bins are normalized to this value to obtain the corrected bin counts.

Probe Area- The projected area of the probe volume normal to the velocity sensitive direction. The probe area is calculated from the geometry of the receiver (which influences the length of the probe) as well as the probe width. The probe area is used to determine particle flux and number density.

Probe Volume - Actual volume of the optical probe calculated from the above values. This quantity is useful to insure that the probe volume meets the requirements of particle number density.

Fluid Flow rate - The total volume of all particles measured (using corrected counts) divided by the run time. This gives the average value during the data acquisition.

Fluid Volume Flux - The fluid flow rate divided by the probe Area. This gives the average volume flux through the probe during the data acquisition.

Number Density - The total number of particles divided by the volume of gas phase which passed through the probe during data acquisition. To determine this, the bin count for every size class is firstly adjusted by the ratio of the mean particle velocity for that size class to the overall mean relocity. The adjusted bin

Table III : Quality ranking of Fabrics

Assessment Method	Fabric Sample												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Arithmetic mean(A)	0.5884	0.5578	0.4442	0.5456	0.6883	0.5148	0.7280	0.5807	0.5891	0.5493	0.4958	0.3978	0.4398
Rank	4.0000	6.0000	11.0000	8.0000	2.0000	9.0000	1.0000	5.0000	3.0000	7.0000	10.0000	13.0000	12.0000
Geometric mean(G)	0.5103	0.4420	0.2907	0.3719	0.5867	0.3934	0.5294	0.4818	0.4766	0.4569	0.3779	0.3061	0.3281
Rank	3.0000	7.0000	13.0000	10.0000	1.0000	8.0000	2.0000	4.0000	5.0000	6.0000	9.0000	12.0000	11.0000
Expontional mean(E)	0.6190	0.6036	0.5066	0.6800	0.7380	0.5500	0.7838	0.6165	0.6330	0.5890	0.5470	0.4440	0.4950
Rank	4.0000	7.0000	11.0000	6.0000	2.0000	9.0000	1.0000	5.0000	3.0000	8.0000	10.0000	13.0000	12.0000
Polygon area (P)	0.5475	0.2850	0.4650	0.3970	1.2570	0.7020	1.6030	0.8805	1.0204	0.6850	0.4790	0.3560	0.3950
Rank	4.0000	6.0000	11.0000	7.0000	2.0000	8.0000	1.0000	5.0000	3.0000	9.0000	10.0000	13.0000	12.0000
Quality number (Q)	2.3840	2.4610	1.9890	3.9170	3.8680	2.1960	4.7190	1.9300	2.7890	1.9270	2.1710	1.6310	1.7890
Rank	6.0000	5.0000	9.0000	3.0000	2.0000	7.0000	1.0000	10.0000	4.0000	11.0000	8.0000	13.0000	12.0000
Desirability function(D)	0.6280	0.6120	0.5550	0.5680	0.6630	0.5730	0.6470	0.5370	0.6140	0.5980	0.4730	0.4970	0.5310
Rank	3.0000	5.0000	9.0000	8.0000	1.0000	7.0000	2.0000	10.0000	4.0000	6.0000	13.0000	12.0000	11.0000
Rank Totals	24.0000	36.0000	64.0000	42.0000	19.0000	48.0000	8.0000	39.0000	22.0000	47.0000	60.0000	75.0000	70.0000
Final Rank	4.0000	5.0000	11.0000	7.0000	2.0000	9.0000	1.0000	6.0000	3.0000	8.0000	10.0000	13.0000	12.0000
Overal Efficiency (Y)	0.5759	0.7037	0.5633	0.3193	0.4124	0.3078	0.8647	0.1092	0.7095	0.1947	0.0655	0.1196	0.3547
Quality Index (I)	25.0100	30.7800	24.4600	13.8700	17.9500	13.3700	37.5500	4.7400	30.8200	8.4600	2.8400	5.1900	154100

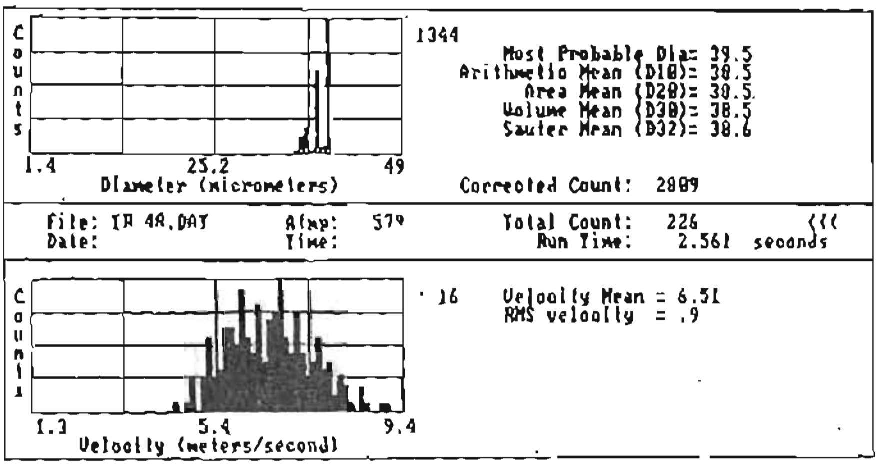

Fig. (4. .a) Flux / Number density before original filter

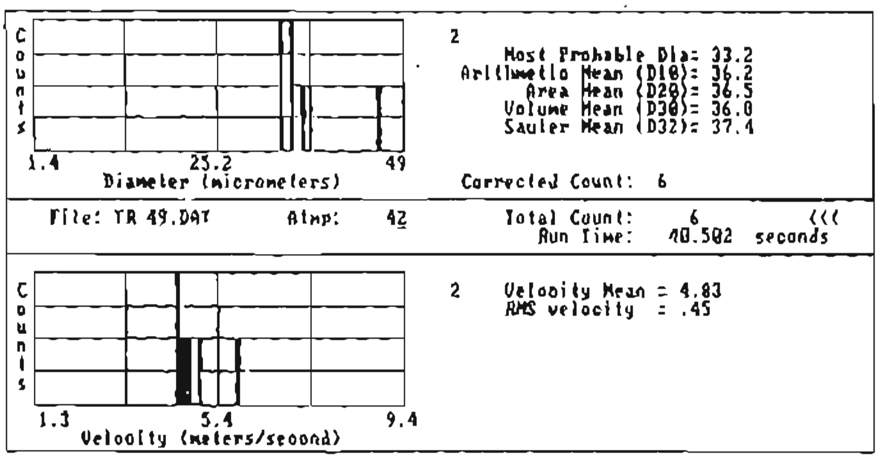

Fig. (4. .b) Flux / Number density after original filter counts are summed for all size classes. Consequently, gas phase volume is determined by sweeping the probe area at the overall mean velocity for the sample run time.

From the previous data, the filtration efficiency is calculated. Simillar results are obtained for both optical and weighting methods. Correlation coefficient of filtration efficiency between the two methods is shown in Fig. (5).

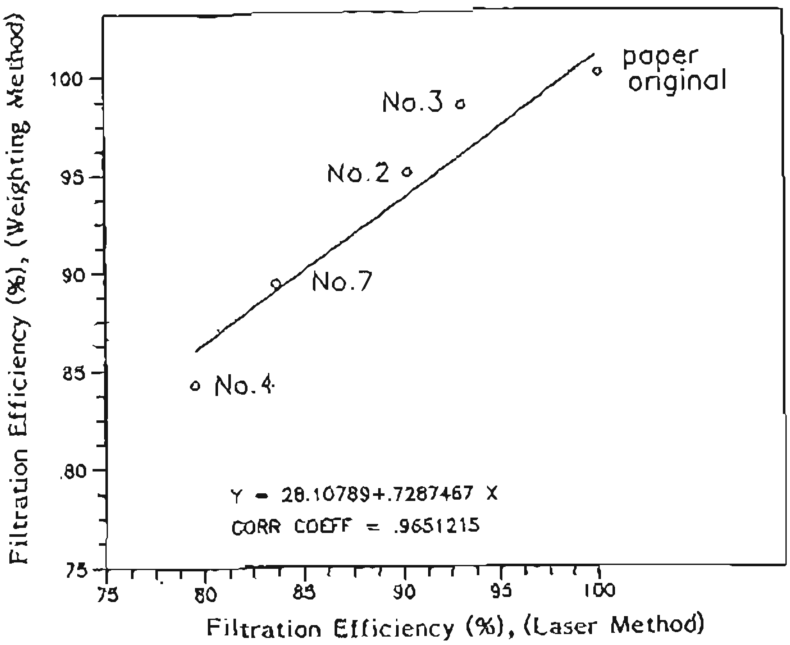

Figure 5. Correlation coefficient between filtration efficiency measured by laser and weighting methods

4. CONCLUSION

From the work described in this paper the following conclusions have been deduced:

1. A new simple and efficient apparatus was established on the basis of constant rate of air flow for measuring the filtration efficiency of filters.

2. Laser technique can be successfully used in determination the filtration efficiency of air filters.

3. The results obtained from the two apparatuses are in a good agreement.

4. performance properties of air filter fabrics could be selected and arranged carefully in decreasing order of importance.

5. Methods of quality assessment such as arithmetic mean, geometric mean, exponential mean, polygon area, quality number and generalized desirability function can be used for assessing the quality ranking of air filter fabrics.

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