Eng. & Tech. Journal, Vol.31, Part (A), No.8, 2013

Experimental Comparative Study on the Performance of Single and Multi-Stage Dry Air Filters

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Received on: 22/2/2012 & Accepted on: 6/12/2012

ABSTRACT

An experimental study on the effect of filter types, relative humidity and using two stage filters on the weight efficiency and pressure drop across the filter was carried out, to complete the study a test rig is designed and built, the rig consist of three sections air duct, of 30 cm ×30 cm cross sectional area, with overall length of 220 cm. Six types of air filters are used in a single stage filters; namely spongy, polyester, synthetic one and two layer aluminum filters. A molten Aluminum powder dust (Type Aluxite No. 25, 98% less than 35 microns and 2% less than 10 microns) is used. In two stage filters study the bag filter is used as a secondary filter while the primary can be any type of the five filters mentioned above. The study shows that the spongy filters gives a maximum efficiency when is used as a single stage filter as compared with the other filters type. Increasing of working environment relative humidity improves the weight efficiency for both single and two stage filters. Two stage filters can improved the filtration process, it is found that the combination of spongy filter and bag filters give a maximum of weight efficiency of about 92% when the relative humidity equals to 90% . Space distance between two stage filters affect the weight efficiency, it is found that the best distance between the spongy filter and bag filter is between 15 to 20 cm.

Keywords: Filters efficiency, two stage filters. Pressure drop across the filters.

دراسة عملية لمقارنة اداء المرشحات الأحادية وثنائية المراحل

الخلاصة

أجريت عمليا دراسة تأثير نوع مرشح الهواء الأحادية والثنائية المراحل ورطوبة المحيط النسبية على كفاءة المرشح الوزنية وهبوط الضغط خلال المرشحات. تم تصميم وبناء جهاز مختبري يتكون من مجرى هواء بأبعاد 30 cm× 30 cm ويتكون مجرى الهواء من ثلاثة مقاطع وبطول كلي يساوي 220 cm. أجريت الدراسة على خمسة أنواع من المرشحات كمرشحات أحادية

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المرحلة هم المرشحات الأسفنجية و البوليستيرية والصناعية والمرشحات المصنوعة من الألمنويم احادية وثنائية الطبقة. أستخدم غبار قياسي (من نوع Alxite No.25 والمتكون من غبار الالمنيوم 98% بقطر اقل من 35 microns و 2% بقطر يساوي 10 microns). في المرشحات ثنائية المراحل استخدم المرشح الكيسي كمرشح ثانوي دائما في حين ان المرشحات المذكوره اعلاه استخدمت كمرشحات رئيسة.
بينت الدراسة أن المرشح الاسفنجي يتميز بأعلى كفاءة وزنية عند استخدامه في مرحلة ترشيح احادية. وكذلك أن زيادة الرطوبة النسبية تحسن من كفاءة المرشحات لكلا مرحلتي الترشيح. وكذلك تبين ان مرحلتي الترشيح تزيد من كفاءة الترشيح،واعطى المرشح الاسفنجي- المرشح الكيسي أعلى كفاءة وبمقادر 92% عندما كانت الرطوبة النسبية تساوي 90%. وكذلك اتضح ان المسافة بين المرشحين في مرحلتي الترشيح لها تأثير واضح على الكفاءة الوزنية، وكانت افضل مسافة بين المرشحين بحدودcm 15-20.

INTRODUCTION

The concept of *indoor air quality* (IAQ) is not new subject, it is as far back as the early 1800s , the publication at that time suggest the ventilation as the solution for improving the IAQ [1]. When the new science of air cooling came along, the introducing outdoor air through the cooling systems was used to improve IAQ. Outdoor air is not necessarily ‘‘better’’ than indoor air, and simple ventilation is not enough, so, it must also control humidity; temperature; gaseous, particulate, bacterial and allergen contaminants of outdoor air; as well as air movement within occupied spaces in order to provide a comfortable and healthy environment [2]. The control of air purity, by cleaning the supply air, is one of the factors that can improve the human comfort, some air cleaning devices are designed to be installed in the ductwork of a central heating, ventilating, and air-conditioning (HVAC) system to clean the air in the whole building, and these devices are called air filters. Three characteristics of proper filter selection and performance are: efficiency, resistance to airflow, and dust-holding capacity. Efficiency measures the ability of the filter to remove particles from the air stream. Minimum efficiency during the life of the filter is the most meaningful characteristic for most filters and applications. Resistance refers to the static-pressure drop across the filter at a given face velocity. Dust-holding capacity defines the amount of dust an air filter can hold when it operates at a specified airflow rate to some maximum resistance value [3]. Evaluating filter types requires data on efficiency, resistance during filter loading and dust-holding capacity at various pressure drops. These items can directly affect the fan’s ability to move air at varying resistances, which can lead to higher fan brake horsepower requirements and greater energy use.

Studies have shown that re-circulated air tends to have a larger proportion of lint than does outdoor air, but proper filtration might reduce dust and lint in the space, resulting in lower housekeeping costs. Tengfei (Tim) Zhang, etal [4]. They have used both measurement and computational fluid dynamics (CFD) modeling to investigate the flow interaction between an air conditioner and a portable air cleaner to purify indoor gaseous pollutants. It was found that better air purification efficacy during the air conditioner running under the cooling mode as compared with the heating mode. The location of pollutant source does not much impact to air cleaning when indoor air is well circulated. However, the pollutants released at the low level of a room such as

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from the floor are found being slightly easier extracted and removed by a portable air cleaner. Fulin Wang et al. [5] have proposed a model that can estimate filter resistance using estimated air-conditioner indoor unit air flow rate, which is tightly related to filter fouling conditions. Two sorts of value were used as inputs to estimate air flow rate. One is the power consumed by the fan in the indoor unit of a room air-conditioner and the other is the thermal performance of a room air-conditioner. For the room air-conditioners with real-time indoor unit fan power consumption is available, fan power consumptions are used as inputs to estimate filter resistance. It was found that the maximum and average difference between estimated and measured filter resistance were 12.72% and 5.89% when using the fan power consumption as inputs. When using the air-conditioner thermal performance data, the maximum and average estimation errors were 13.12% and 5.96%.

A.F. Miguela [6] has developed a model to predict the permeability and performance of a fibrous filter in dynamic regime. Besides the mass loading of the aerosol particles, this model took into account the structural characteristics of the filter, the size of the loading particles and the filtration velocity. This study was performed with sodium chloride and alumina aerosols in the size range of 0.5 –1.3 μm and 0.8–6 μm, respectively, and filtration velocities of 2, 5 and 15 cm/s. The relative air humidity was controlled in the range of 32–90%. It was observed that the permeability and the performance of tested filter were not only influenced by the size of aerosol particle and mass loading of particles but also by the particle hygroscopicity and air humidity, through the interdependence of this quantities with cake particle density.

The weight efficiency (it is a measure of its ability to remove dust from the air), pressure drop through single and two -stages filters and the distance between filters are studied experimentally in present work for different types of dry filters, as well as, the effect of dust concentration and the outdoor relative humidity on the filter efficiency are studied. A test rig is built to achieve with different types of measurement and instrumentation.

APPARATUS SETUP AND TEST PROCEDURES

The main part of the apparatus is an air duct, which consist of three parts, the cross sectional area of the duct is 30 cm × 30 cm. The first part is a galvanized steel duct of 45 cm long which is used as a control climate duct in addition to hold a dust injector at its entrance. While the second part is a wooden duct of 75 cm long; the function of this part is to hold the test filter through a slide gate at the top of the duct. The third part is also a galvanized steel duct of 100 cm long. A variable speed axial fan is mounted at the end of this part, the fan is used to draught the air, Figures (1-a) and (1-b) show the schematic of apparatus configuration and apparatus configuration respectively,.The dry bulb temperature and relative humidity of draught air are controlled by an electrical heater and humidifier, through the control climate duct. The steam injector consist of water vessel(with safty valve) in the form of cylinder of 100 mm in diameter and 400 mm length, an electric heater of 0.5 kW capacity is immersed through the water in the vessel, the amount of steam injected is controlled manually through steam valve. Ten electrical heaters each 0.5 kw in capacity are distributed through the control chamber to ensure good temperature distribution through the air,

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the heater's capacity is controlled by variable transformer while air temperature is controlled by thermostat that inserted through air duct.

The dust injector, consist of a dust chamber in the form of cylinder of dimension of 50 mm x 100 mm and an air nozzle, an air compressor that can produce a pressure of 5 kPa maximum is used, the compressed air is supplied through the dust chamber, that contains 20 g of standard dust. The dust is injected through the control section in the form of pulls, the time between each pulls is about three minutes, while the time required to injected all dust mass is about 30 min.

TESTED FILTERS AND INJECTED DUST

Six common types of air filters, with specification shown in Table(1), are tested. A 30 cm × 30 cm cross sectional area of each type of filters mentioned above is contained in a wood frame as shown in figure 2, while figure 3 shows the bag filter..

The molten Aluminum powder dust is used in this work (Type Aluxite No. 25, 98% less than 35 microns and 2% less than 10 microns) [7].

TEST PROCEDURES

The filter performance is tested as a single stage filtration, as well as a double stage filtration. The bag filter is used a secondary filter always in a double stage filtration, while the primary filter can be any type of the remaining four filters mentioned in Table(1). The pressure drop through dirty filters is measured using a water U tube manometer in step of 5 min along the experiment period.

The dry and wet bulb temperature of draught air are measured using a type K thermocouples, connect to a selector switch, the selector switch is connected to a digital thermometer.

The filter weight efficiency can be calculated by taken the mass of clean filter, and then taken the mass of dirty filter at the end of the experiment period, while the mass of injected dust used in this work is 20 gram. Equation 1 is used to calculate the weight efficiency;

$$\eta = \frac{w_2 - w_1}{w_d} \times 100\% \qquad \ldots(1)$$

η is the filter weight efficiency (%) w_1, w_2 and w_d are the mass of clean filter, dirty filter and injected dust respectively (grams)

RESULTS AND DISCUSSION

Figure (4) show the effects of relative humidity on the filter weight efficiency for the five types of filters, namely, spongy, polyester, synthetic one and two layer aluminum filters. It can be seen from the figure that as the relative humidity increases the filter efficiency increases also, due to increasing of the adhesion effect between the dust particles and filters fibers on one hand and between the dust particles its self which leads to increase the overall volume of dust particles on the other hand. The figure indicates that single layer aluminum filter has less efficiency as compared with another

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filter; this is due to its relatively low porosity, while spongy filter has the maximum weight filter. Also it can be seen from the figure that spongy filter shows less impression by relative humidity due to its high weight efficiency.

Figure(5) shows the effect of filter operating time on the pressure drop across the five types of filters. It can be seen that the less efficient filter; namely aluminum filter has a less pressure drop, and the high efficient filter has a maximum pressure drop , this is due to the filter porosity which affect the pressure drop and holding efficiency. The figure also show that as the operating time increases the pressure drop increases due to partially blockage of filter porosity. The filtration efficiency can be improved by using two stage filters; figure (6) shows the effect of relative humidity on the weight efficiency for two stage filters, the primary is the spongy filter, while the secondary one is a bag filter. It can be seen from the figure that the weight efficiency affects slightly as compared with the efficiency of single filter efficiency. This is due to that spongy filter has a high efficiency in capturing dust particles thus adding supplementary filter has no effect on the filter weight efficiency. Figure (7) shows the effect of relative humidity on the two stage filter efficiency, namely primary polyester filter and secondary bag filter. It can be seen from the figure that the two stage filter efficiency improved as compared with the weight efficiency of a single polyester filter, especially for the relative humidity range from 20 to 60%, while for the relative humidity more that 60% the relative humidity has less effect on the two stage filters.

Figure (8) shows the effect of relative humidity on filter efficiency of primary two layers aluminum filter and secondary bag filter as a two stage filters. It can be seen from the figure that the weight efficiency of the two layers aluminum improved significantly as the bag filter is used, this is due that the overall porosity of the two stage filter increases which lead to improve the capture of dust particles. Figures (9, 10 and 11) show the pressure drop across the two stage filters, namely spongy-bag, polyester-bag, and two layers aluminum – bag filters, respectively. It can be seen from figure (9) that the pressure drop across bag filter reduces as it is used as a secondary filter, this is due to collection of most dust particles by spongy filter, which means that bag filter stays partially clean during the operating time, while the overall pressure drop increase as compared with that for single stage spongy filter. Figures (10 and 11) show the same behaviors, but for different filters, as that mentioned for Figure (9).

Figure (12) shows the effect of space distance between the spongy and bag filter in two stage filters combination. It can be seen from the figure that the space distance has a significant effect on the weight filter efficiency, when the distance between the two filters equal to zero the weight efficiency is about 78%, as the space distance increases the weight efficiency increases, the best space distance between the two filters seems to be about 15 to 20 cm, as the space distances increases more than 20 cm, the weight efficiency reduces rapidly.

CONCLUSIONS

- Spongy filters have a high efficiency as compared with other filter types, due to high porosity of spongy filter, this lead to increase the pressure drop across the filter. The maximum weight efficiency of spongy filters is about 88% when the environment relative humidity is about 75%.

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- Relative humidity of the working environment increases the weight efficiency of the all type of filters that studied in this work. While it has a little effect on the weight efficiency of the two stage (spongy and bag filters).
- Using two stage filters can improved the overall efficiency of filtrations, especially for the filters that have low porosity, namely single and two layers aluminum filters. The combination of spongy filter and bag filters give a maximum of weight efficiency of about 92% when the relative humidity equals to 90%.
- Space distance between two stage filters affect the weight efficiency, it is found that the best distance between the spongy filter and bag filter is between 15 to 20 cm.

Table (1) Filters specifications.

No.	Filters type	Symbo	Thickness mm	Application	Features
1	Spongy two layers filter	1	25	Highly used for cleaning in take air in window type air conditioner.	Low coast, self-supporting, Easy installation
2	Polyester filter	2	6	High recommended cleaning in take air.	Low coast, self-supporting, Easy installation safe handling
3	Synthetic filter	3	25	Used in industrial and commercial building where more dust accumulation is required	High dust holding capacity low resistance filters and it can be washed by air or regular water.
4	Aluminum two layers filter	4	6	Used for the collection of big particles of duct it used for corrosive atmospheres	High dust holding capacity, low resistance filter
5	Aluminum one layers filter	5	18		
6	Bag filter	6	—	Bag filter inserts consisting of robust metal front frames and filter bags of high quality glass fiber filaments for the separation of fine dust down to particulars or aerosols.	

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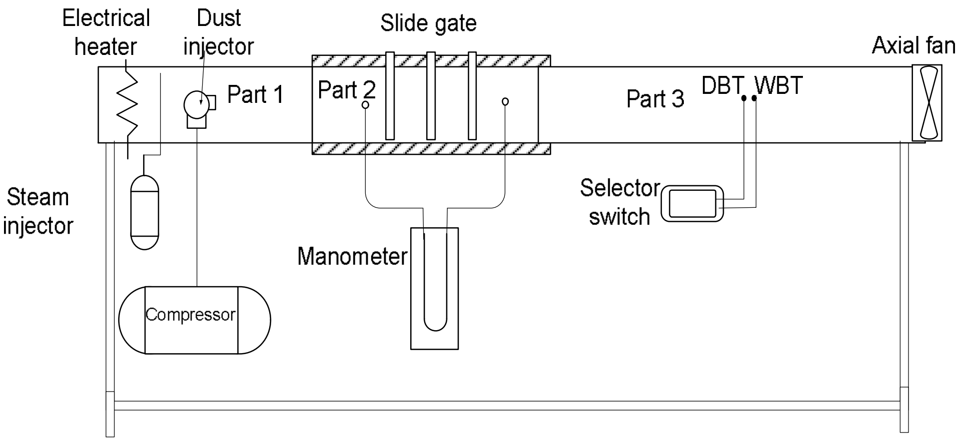

Figure (1 –a) Schematic of apparatus configuration.

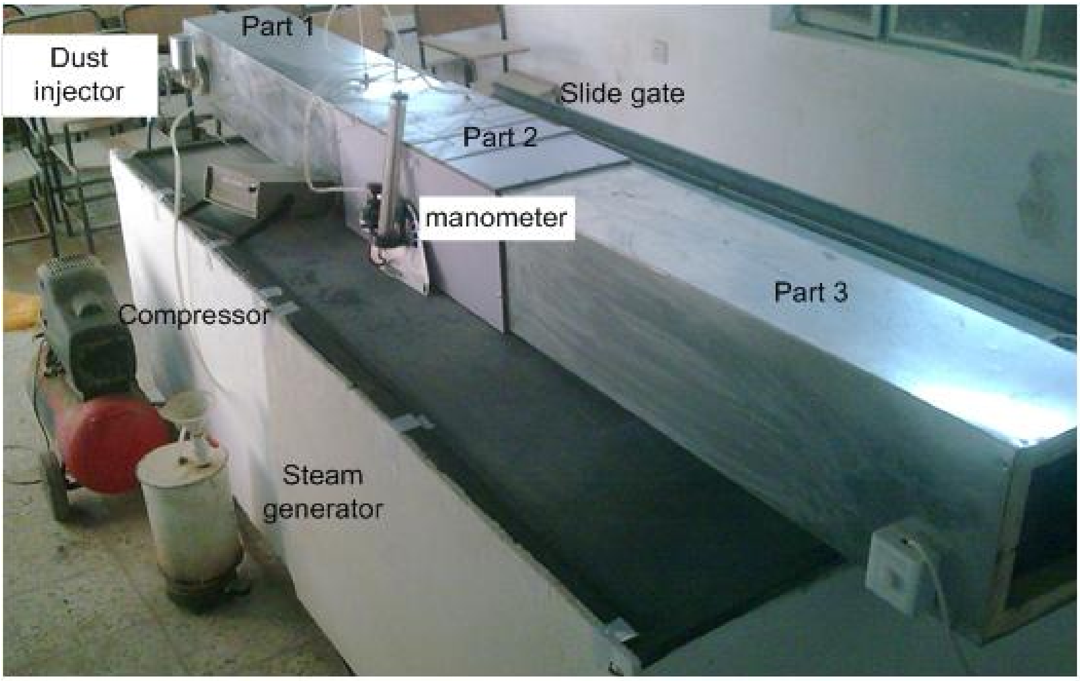

Figure (1 –b) Apparatus configuration.

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Figure (2) Filter fram.

Figure (3) Bag filter.

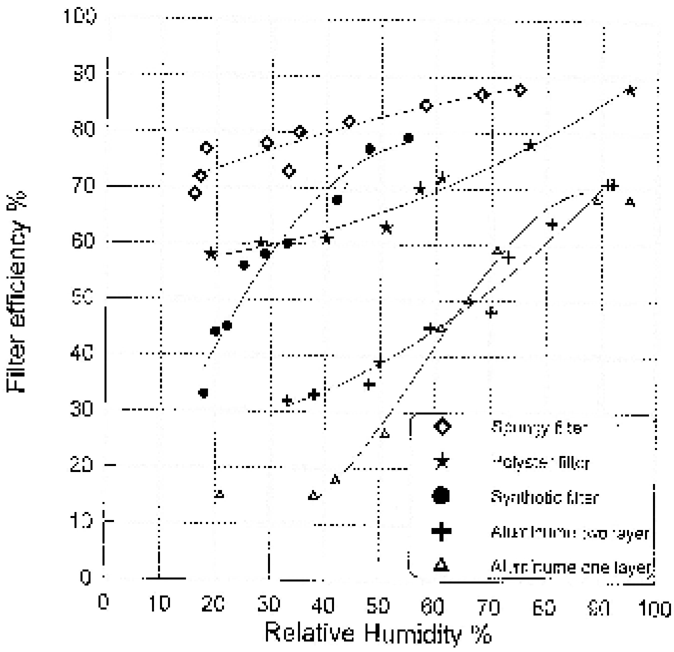

Figure (4) Effect of relative humidity on the weight efficiency of five types of filters.

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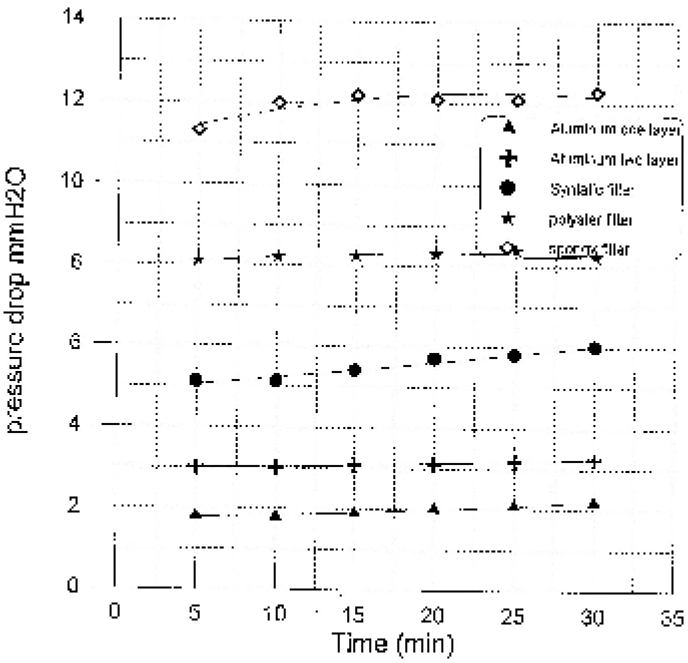

Figure (5) Effect of operating time on the pressure drop (Δ p) across the filter.

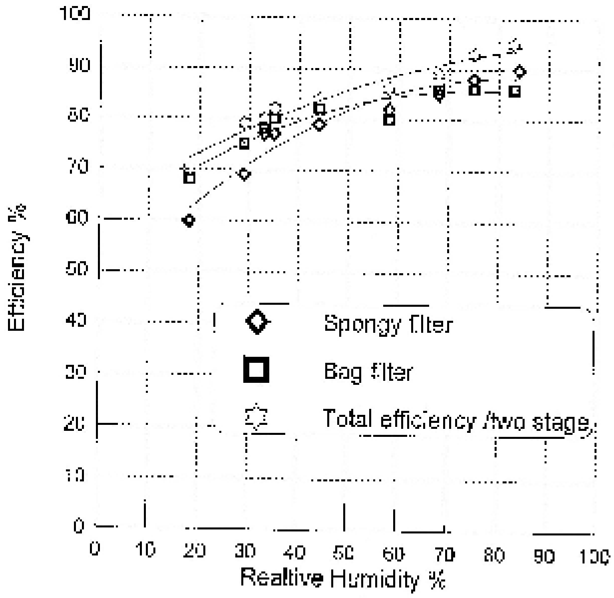

Figure (6) Effect of the relative humidity on the weight efficiency for two stage filter, spongy filter used as primary filter and Bag filter as secondary filter.

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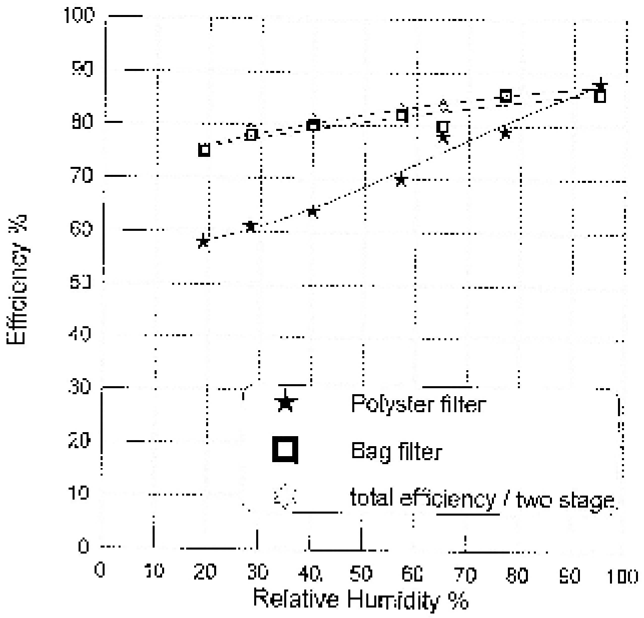
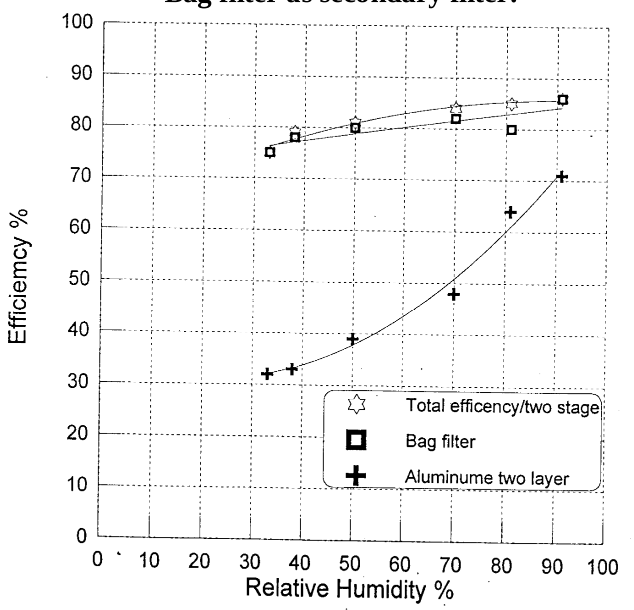


Figure (7) Effect of the relative humidity on the weight efficiency for two stage filter polyester filter as primary filter and Bag filter as secondary filter.



Figure(8) Effect of the relative humidity on the weight efficiency for two stage filter, aluminum two layer filter as primary filter and Bag filter as secondary filter.

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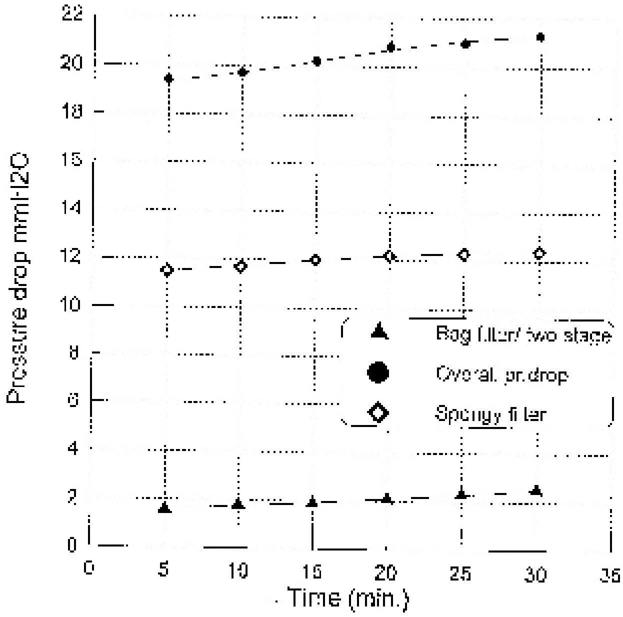

Figure (9) Effect of operating time on the pressure drop (Δ p) across the filter on two stage (by using spongy filter as primary filter and Bag filter as secondary filter).

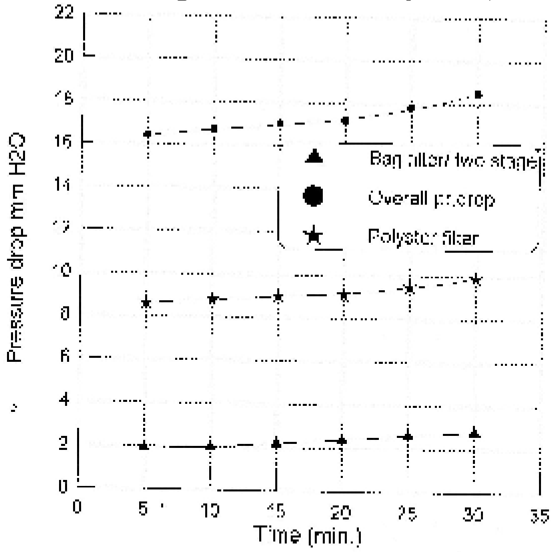

Figure (10) Effect of operating time on the pressure drop (Δ p) across the filter on two stage (by using polyester filter as primary filter and Bag filter as secondary filter).

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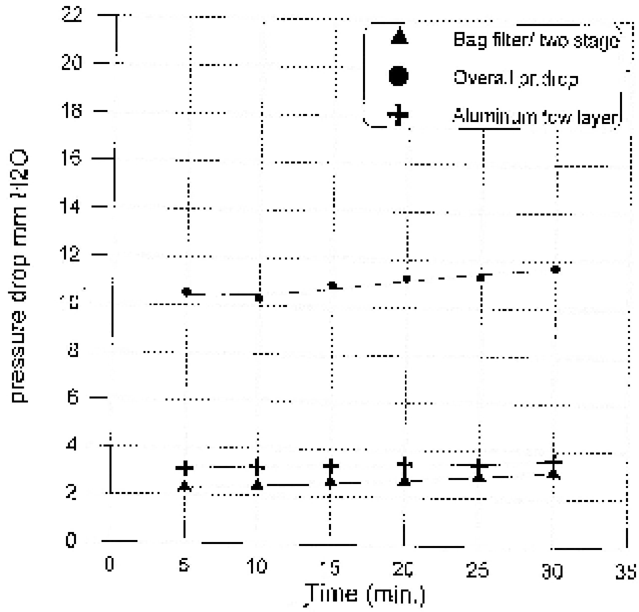

Figure (11) Effect of operating time on the pressure drop (Δ p) across the filter on two stage (by using aluminum two layer filter as primary filter and Bag filter as secondary filter).

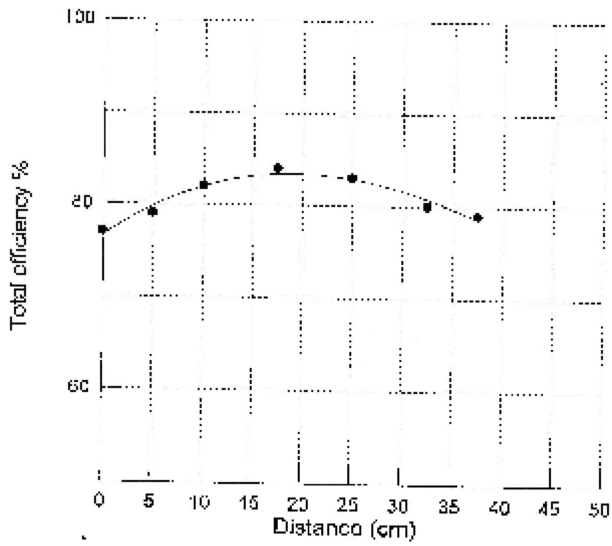

Figure (12) the relation between the total efficiency of the system(two stages by using spongy filter as primary filter and bag filter as secondary) and the distance between primary and secondary filter.

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