Filtration of Solid Pollutants from Air

Prof. Dr. Manal H. AL-Hafidh

Islamic University College, Najaf, Iraq

Refrigeration & Air-conditioning Technical Engineering Department

manal.hadi@iunajaf.edu.iq

recieved 12/1/2018
accepted 2/3/2018

ABSTRACT:-

Theoretical and experimental investigations are concerned with the removal of tobacco and cement aerosol from air stream using a packed bed filter. Four different types of packing were used (glass beads, Raschig rings, plastic wire mesh and glass wool). A glass column with 6.4 cm inside diameter and 75 cm height was used. The packing height is varied (3-15) cm, Reynold's number ranges (0.1-564) based on packing diameter.

Mathematical model of penetration for different types of packing are presented.

Glass wool and Raschig rings show better efficiency for capturing the aerosol compared with the plastic wire mesh and glass beads packings. The penetration was observed to decrease with higher grain porosity of packing and with higher specific gravity of the pollutant. The results show that, increasing the concentration of the pollutant entering the filter increases the accumulated weight in the filter bed causing to close the filter after 3.5 hours in the case of glass beads packing while it is 1 hour in the case of using Raschig rings packing.

A comparison was made between the theoretical calculation and the experimental results which showed good agreement.

KEY WORDS

Air pollution, glass beads, Raschig rings, plastic wire mesh and glass wool, tobacco and cement aerosol.

INTRODUCTION

During last few decades indoor air quality has finally received much deserved scientific attention. Although considerable progress has been made in our knowledge about indoor pollution and its sources, the problem is still not completely understood. The unique

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

individuality of each indoor environment (i.e. construction, inhabitants, habits, etc.) implies further research difficulties and indoor ambiences also differ between regions as well as between continents. Despite that, the problems of poor indoor air that modern societies face are similar for many countries around the world. It is certainly necessary to continue with research efforts. In particularly associations between indoor air quality and health impacts need to be better addressed as so far much of the knowledge is derived from outdoor exposure studies.

Previously, consideration has been given to the force acting on an isolated particle moving relative to fluid and it has been seen that the frictional drag can be expressed in terms of a friction factor which is in turn a function of the particle Reynold's number. The forces on the particle were found for different particle Reynold's number. **[Burson and Keng, 1967], [Morsi, 1975]**.

An expression for the efficiency of collection of a single sphere was derived theoretically taking into account diffusion as well as direct interception using the equation for the flow field around an isolated sphere in the viscous regime ($Re<<1$) **[Kimura and Shirato, 1984] [Lee and Lue, 1980]**

[Zimwara et al., 2012], [Devi et al., 2017] examines various impacts of cement manufacturing companies on environmental and health aspects by using of appropriate technology and computer modeling. Analysis of gas stack emissions was done for a cement manufacturing company in Zimbabwe where compliance was investigated. Emissions samples were randomly selected at various points within the company and concentration of various emission constituents were analyzed

SO_2 emissions data are tracked by the National Emissions Inventory (NEI). The NEI is a composite of data from many different sources, including industry through the CEM program, EPA models, and numerous states, tribal, and local air quality management agencies. Different data sources use different data collection methods, and many of the emissions data are based on estimates rather than actual measurements. For major electricity generating units, most data come from CEMs that measure actual emissions. For other fuel combustion sources and industrial processes, data are primarily from state, local, and tribal air quality management agencies and are estimated primarily using emission factors. Emissions from on-road and non road sources were estimated using EPA-approved models, often using state-supplied model inputs **[Lu et al., 2010], [Kurtulus, 2012], [U.S.EPA, 2015].**

Tobacco smoke is one of the most significant indoor sources of air pollution. There is no doubt that tobacco smoke causes various adverse health effects; voluminous literatures have been dedicated to this topic. The adverse effects of smoking have been widely recognized for

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

several decades, but only recently public concerns have focused on indirect exposures to tobacco smoke. The concentration of 15 elements in various brands of cigarette tobacco and cigarette wrapping paper were determined using instrumental neutron activation analysis. The paper of some of the brands contains higher concentrations of toxic elements than the tobacco. The cigarette filter and the ash were also analyzed to determine the adsorption of toxic elements on the filter and their transference in smoke. The toxic effects of some of the elements have been briefly discussed **[Ahmad et al., 2007].**

This research is concerned with the removal of tobacco and cement aerosol from air stream by using packing bed filters of glass beads, Raschig rings, plastic wire mesh and glass wool and to obtain the efficiency of the four types of packings. Mathematical models of penetration for different types of packing are presented.

EXPERIMENTAL STUDY

The packings were selected as follow:

1- 0.6 cm glass beads.

2- 0.635 x 0.635 cm Ceramic Raschig rings.

3- 0.1 cm plastic wire mesh.

4- 0.00254 cm glass wool **[Brady, 1971]**.

The packed bed column was made of Pyrex glass tube of 6.4 cm inside diameter, 7.62 cm outside diameter and 75 cm height. An air distributor used which was made of Pyrex glass contained 14 circle holes each of 0.074 cm diameter.

The schematic drawing of the experimental apparatus is shown in **Fig.(1).** To measure the pressure drop across the packing and air distributor, two tappings 0.48 cm diameter were used one below the air distributor and the other on the top of the packing. These tappings were connected to an inclined manometer. A technique was adapted to ensure measurement immediately below the packing and before any settlement takes place. The air was dried to prevent agglomeration of pollutant aerosols due to moisture and the dryer was filled with anhydrous calcium chloride as a drying agent. Screw conveyer was used **Fig.(2)** to introduce pollutant particles into the air stream and its speed was controlled by a regular and located at a distance of 22 cm upstream the filter to ensure that the particle reaches its terminal speed before reaching the filter bed. A calibrated rotameter ranged from 5.55 x 10^{-5} to 111.11x10^{-5} m^3/s was used for measuring the air flow rate. A cascade impactor was used **Fig. (3)** to obtain

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

the entering and leaving cumulative weight and particle size distribution. To measure and check the sizes and shapes of small and medium size particles, a measuring projector were used which enlarged the shadow image of the tested object projected on a ground glass screen. **Figures (4 and 5)** show the size distribution for Tobacco and Cement pollutant respectively at the inlet of the bed.

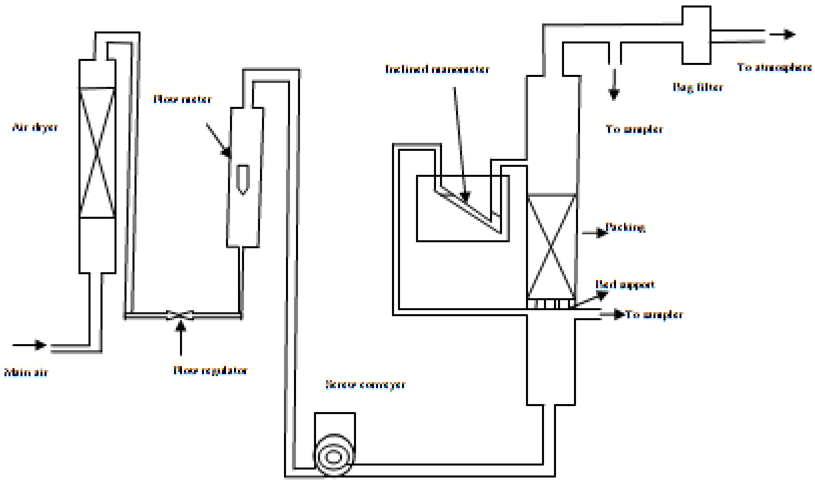

Fig. 1 Schematic diagram of the experimental apparatus

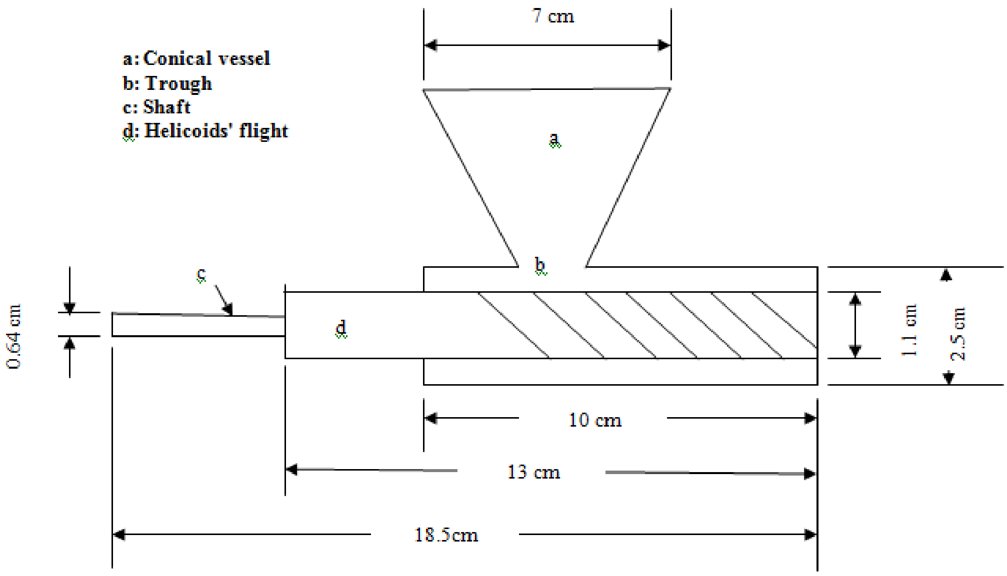

Fig. 2 Screw conveyer

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

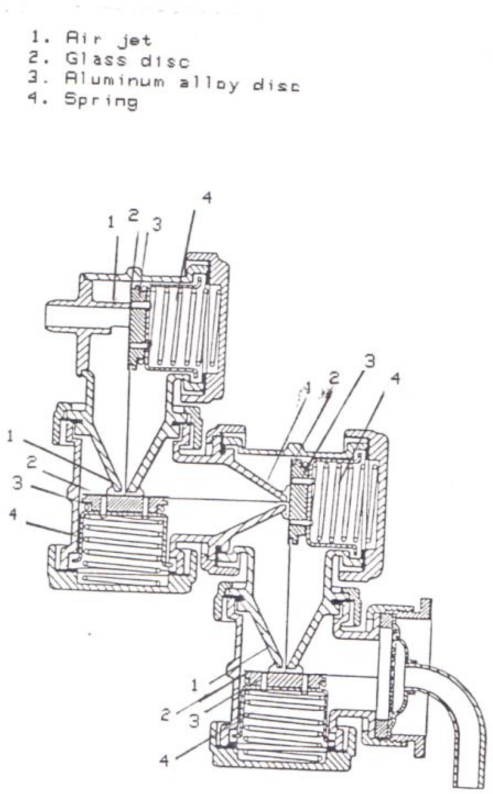

Fig. 3 Cascade impactor

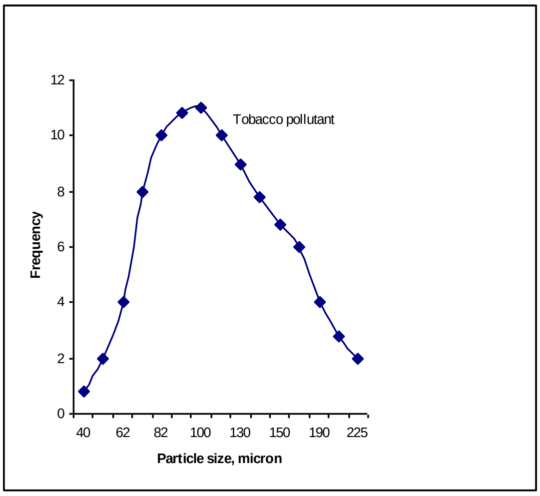

Fig. 4 Tobacco particle size distribution

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

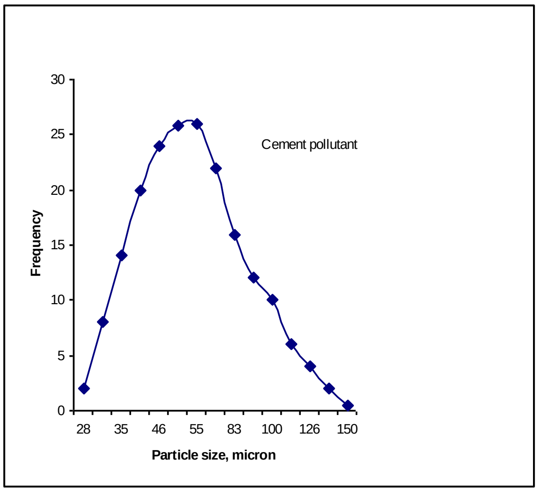

Fig. 5 Cement particle size distribution

MATHEMATICAL MODEL

The porosity of the packing was determined by measuring the volume of a certain amount of packing in a graduated cylinder and filling, the voidage was obtained with a measured volume of water (water method).

$$e = \frac{Volume\ of\ voidage}{Total\ volume\ occupied\ by\ the\ packing} \quad (1)$$

Where e= Bed voidage cm^3.

The density method used for measuring the porosity of glass wool.

$$e = 1 - \frac{\rho_b}{\rho_p} \quad (2)$$

Where ρ_b= Bulk density g/cm^3.

ρ_p=Packing density g/cm^3.

The inlet and outlet concentrations of Tobacco and Cement particles are obtained by determining the weight of particles per certain volume entering and leaving the bed through the sampling instrument (cascade impactor). The equivalent diameter of Raschig rings is calculated by the following equation **[Richardson et al., 1961]**:

$$d_p = \frac{6}{\emptyset_s\ S} \quad (3)$$

$\emptyset_s$ is the shape factor. For Raschig rings $\emptyset_s = 0.3$, $d_p = 1.27\ cm$.

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

S=Specific surface of packing particles cm^{-1}.

The pressure drop per unit height of packing is plotted against superficial air velocity for a given packing height and packing type **Figs (6 - 9)**.

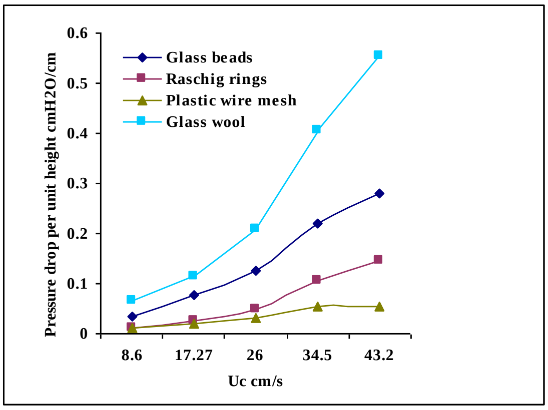

Fig. 6 Pressure drop for 3 cm packing

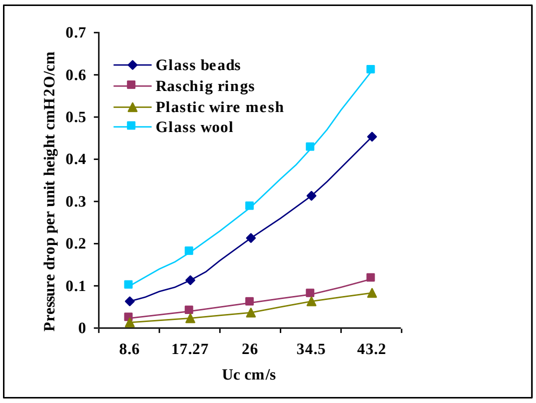

Fig. 7 Pressure drop for 5 cm packing

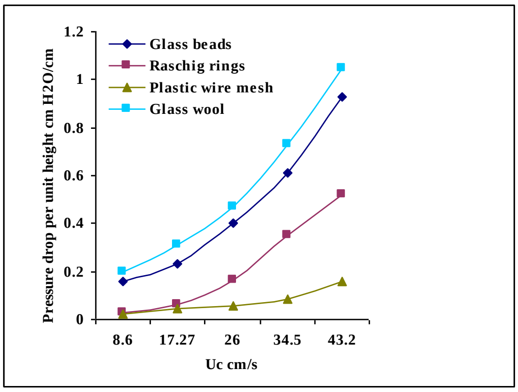

Fig. 8 Pressure drop for 10 cm packing

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

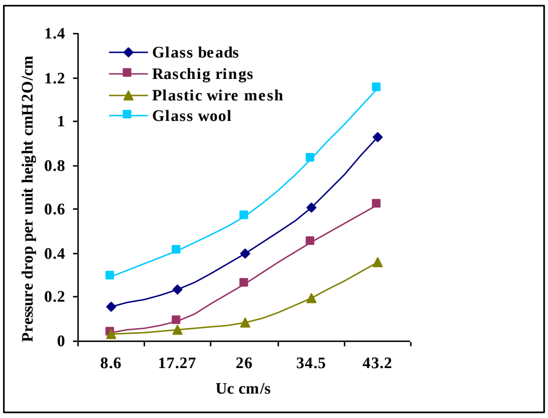

Fig. 9 Pressure drop for 15 cm packing

The penetration is expressed in term of inlet and outlet concentration as **[Latif and smith, 1980] and [Lee and Liu, 1982]**.

$$P = \frac{C_o}{C_i} \quad (4)$$

Where

C_o=Outlet concentration g/m^3

C_i= Inlet concentration g/m^3

Calculations for the performance of the filter are based on the mathematical models of **[Latif and smith, 1980] and [Lee and Liu, 1982]**.

RESULTS AND DISCUSSION

Penetration of Aerosol Particles

Figures (10 - 13) represent semi-log graph for the variation of overall penetration with bed height, and **Figures (14 - 17)** show the individual penetration with bed height at constant velocity for a given type of packing and aerosol. It is clear that the penetration decreased exponentially as bed height increases for all types of packing. The Raschig rings packing shows a minimum penetration for most superficial velocities. Glass beads and plastic wire mesh have higher penetration than other packings. As air velocity increases plastic wire mesh packing indicates better collection efficiencies relative to glass beads packing. In general the order of efficiencies of packing types for capturing aerosol at velocity range 8.6-43.2 cm/s and column height 3-15 cm is respectively:

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

(a) Raschig rings.

(b) Glass wool.

(c) Plastic wire mesh.

(d) Glass beads.

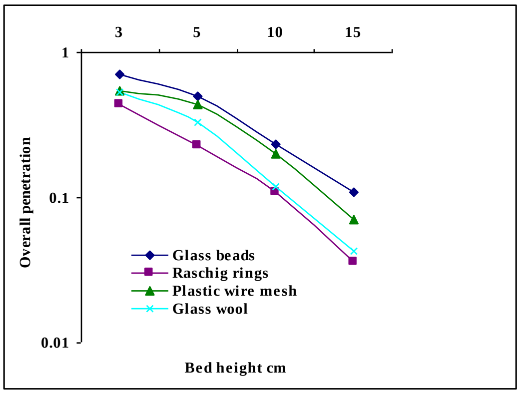

Fig. 10 Bed height effect on overall penetration of Tobacco pollutant at Uc=34.5 cm/s

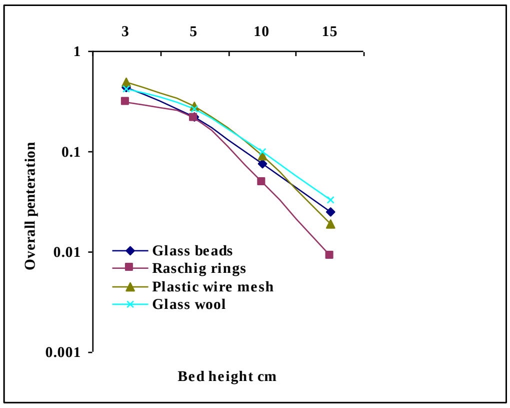

Fig. 11 Bed height effect on overall penetration of Cement pollutant at Uc=34.5 cm/s

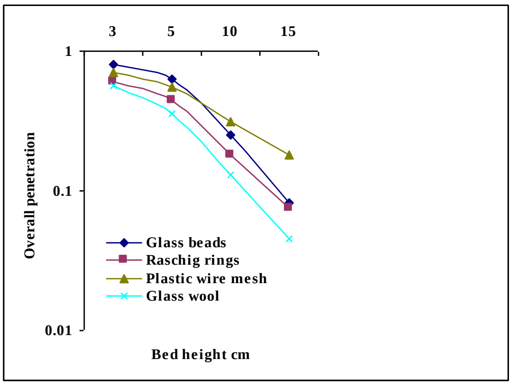

Fig. 12 Bed height effect on overall penetration of Tobacco pollutant at Uc=17.27 cm/s

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

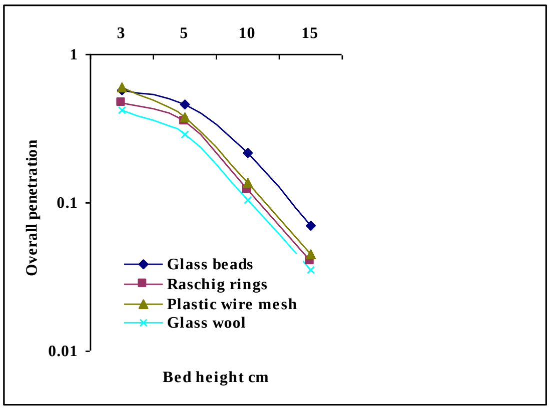

Fig. 13 Bed height effect on overall penetration of Cement pollutant at Uc=17.27 cm/s

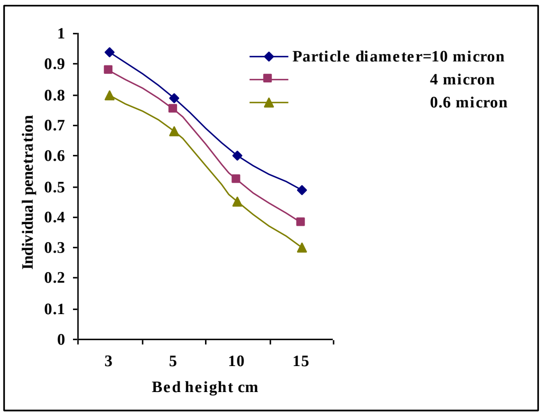

Fig. 14 Glass beads bed height effect on individual penetration of Tobacco pollutant at Uc=17.27 cm/s

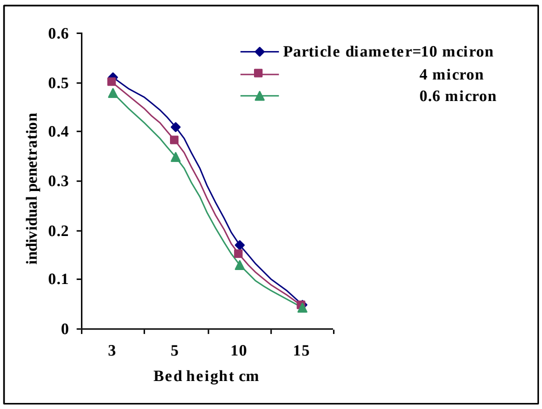

Fig. 15 Raschig rings bed height effect on individual penetration of Tobacco pollutant at Uc=8.6 cm/s

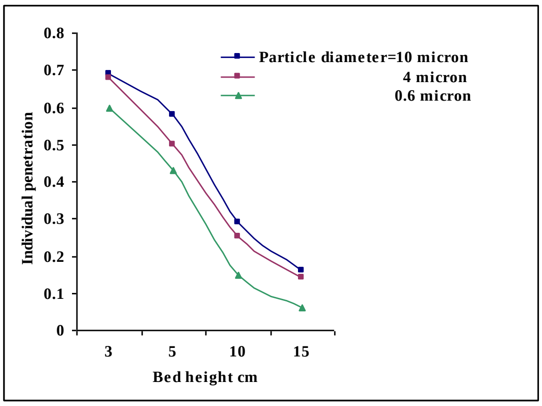

Fig. 16 Glass beads bed height effect on individual penetration of Cement pollutant at Uc=8.6 cm/s

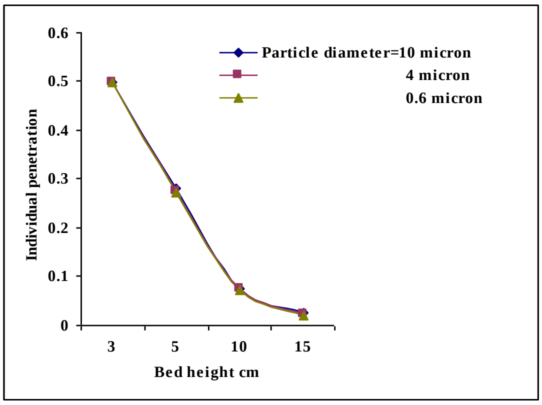

Fig. 17 Raschig rings bed height effect on individual penetration of Cement pollutant at Uc=26 cm/s

The effect of velocity on the overall penetration for all types of packings is shown in **Figures (18 - 21)** For Tobacco pollutant and **Figures (22 - 25)** for Cement pollutant respectively.

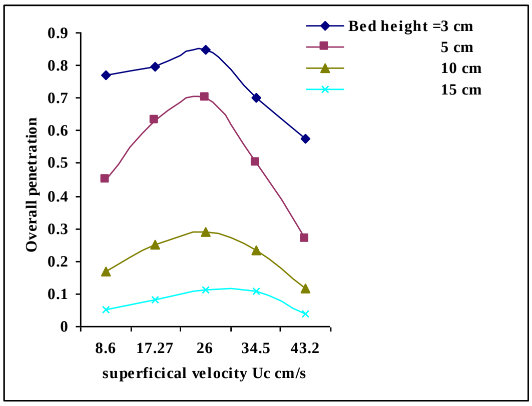

Fig. 18 Velocity effect on overall penetration of Tobacco pollutant for glass beads packing

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

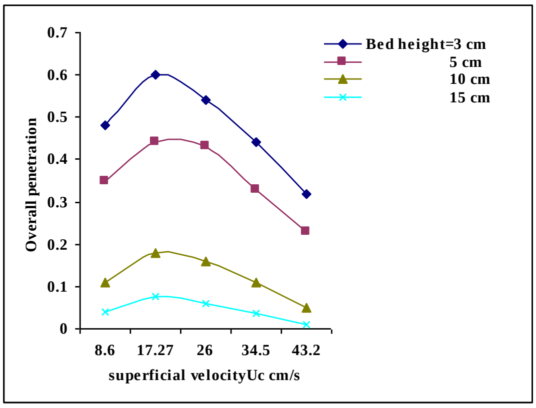

Fig. 19 Velocity effect on overall penetration of Tobacco pollutant for Raschig rings packing

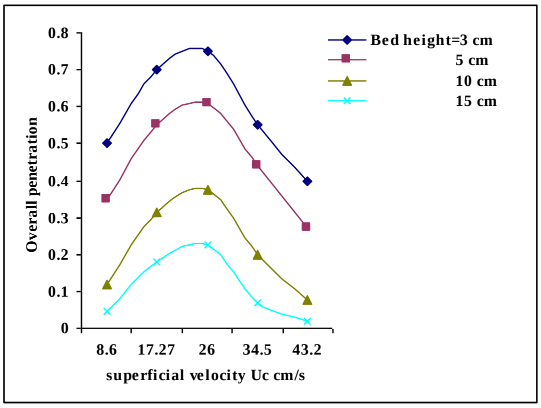

Fig. 20 Velocity effect on overall penetration of Tobacco pollutant for Plastic wire mesh packing

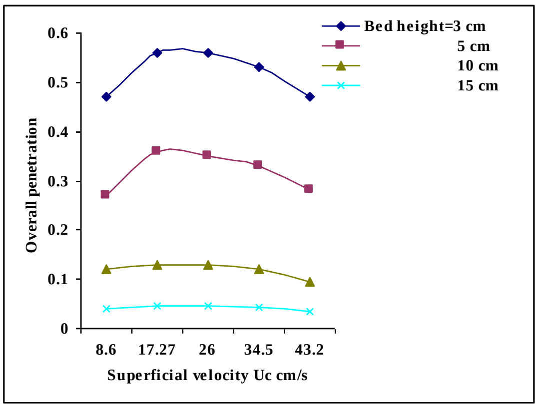

Fig. 21 Velocity effect on overall penetration of Tobacco pollutant for Glass wool packing

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

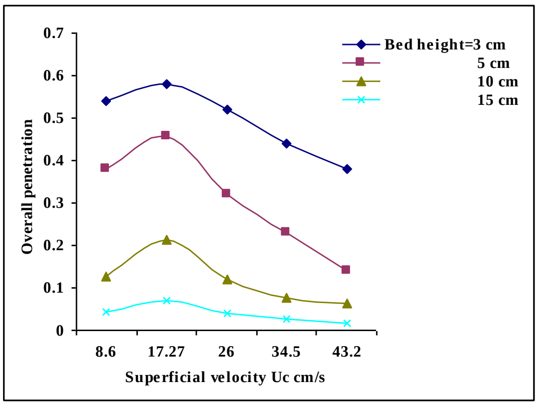

Fig. 22 Velocity effect on overall penetration of Cement pollutant for glass beads packing

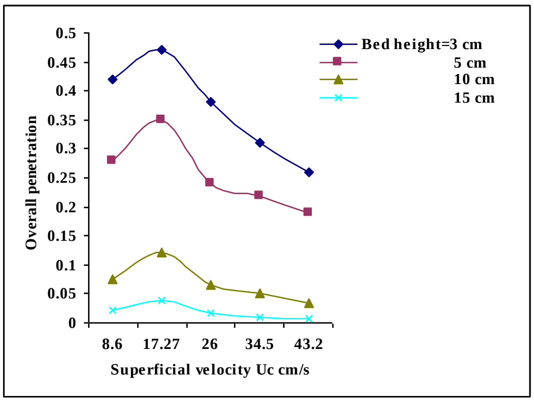

Fig. 23 Velocity effect on overall penetration of Cement pollutant for Raschig rings packing

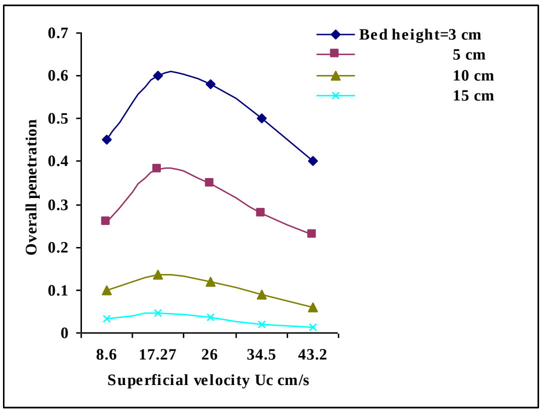

Fig. 24 Velocity effect on overall penetration of Cement pollutant for Plastic wire mesh packing

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

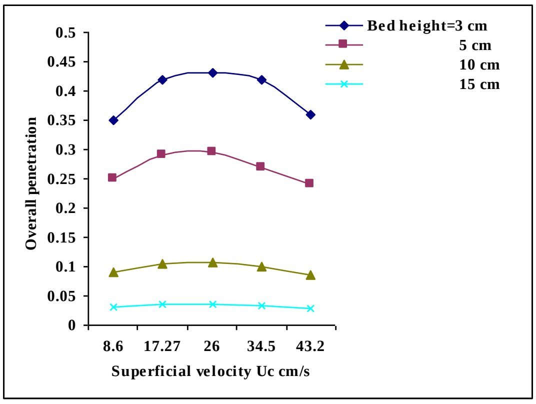

Fig. 25 Velocity effect on overall penetration of Cement pollutant for Glass wool packing

Individual penetration versus aerosol particles size for a given air velocity, packing height and type are plotted in **Figures (26 and 27)**. These figures indicate that penetration is higher for lower specific gravity pollutant under similar other conditions, so throughout the experiments, Tobacco give a poorer filter quality than cement pollutant.

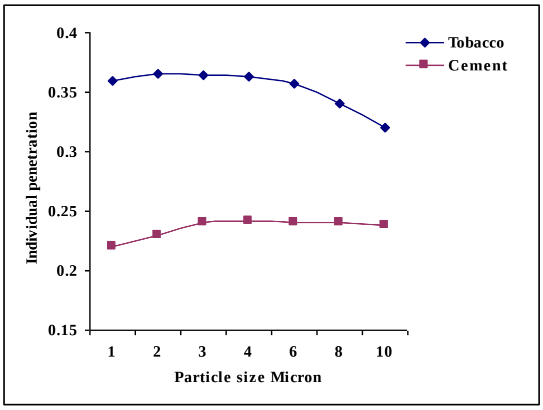

Fig. 26 Individual penetration through Raschig rings Bed for L=5 cm, Uc=34.5 cm/s

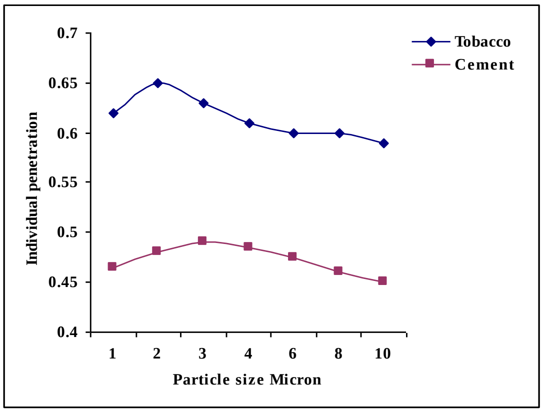

Fig. 27 Individual penetration through Plastic mesh Bed for L=3 cm, Uc=43.2 cm/s

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

The variation of the overall penetration of different types of pollutants with the superficial velocity is shown as semi-log graph in **Figures (28 - 31)** respectively.

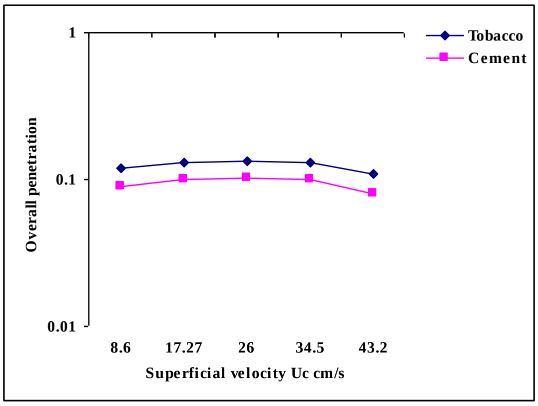

Fig. 28 The variation of the overall penetration with the superficial velocity for different types of pollutants and for Glass wool with L=10 cm

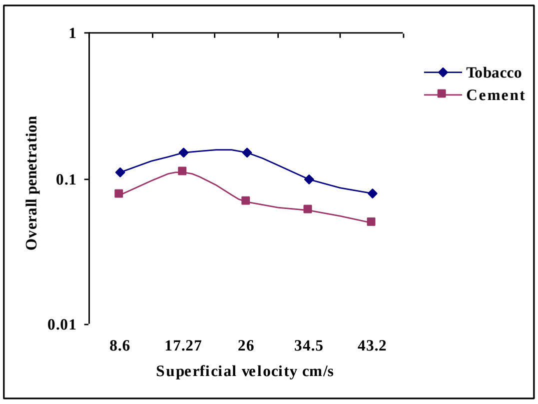

Fig. 29 The variation of the overall penetration with the superficial velocity for different types of pollutants and for Raschig rings with L=10 cm

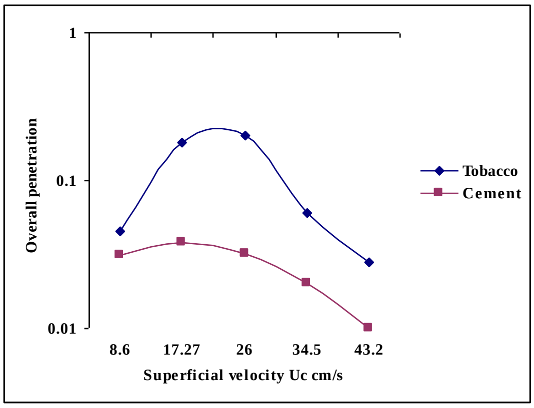

Fig. 30 The variation of the overall penetration with the superficial velocity for different types of pollutants and for Plastic mesh with L=15 cm

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

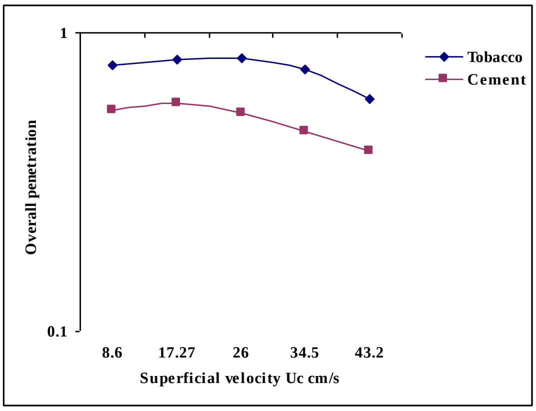

Fig. 31 The variation of the overall penetration with the superficial velocity for different types of pollutants and for Glass beads with L=3 cm

Figures (32 and 33) show the weight of particles accumulated in the filter bed at a certain time for cement pollutant with the packing of Raschig rings and glass beads respectively. These figures indicate that the accumulation of particles is build up in the filter bed as time increases, and becoming heavier in the bottom of the bed, the particles penetrate upward between packing particles. As time increase the accumulation of particles in the pores reaches saturation point, no further accumulation can take place and at this stage filter efficiency becomes zero. After this stage the results of the accumulation of great amount of particles in filter bed and the decrease in pores size caused the velocity of air to increase. The accelerated air will carry the particles from filter bed which cause to decrease the weight of particles accumulated in the filter bed and the pore size will increase again.

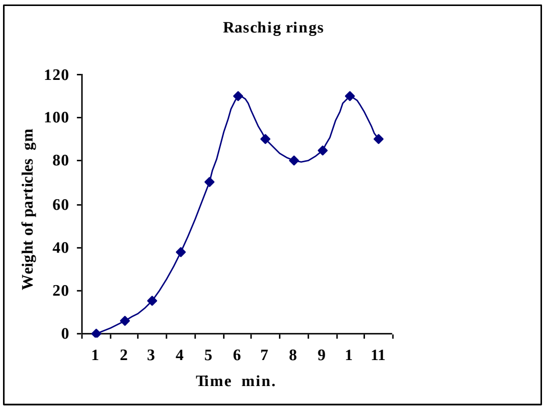

Fig. 32 Accumulation of Cement particles in filter bed

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

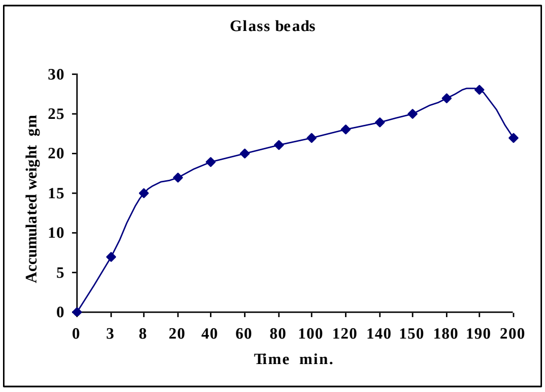

Fig. 33 Accumulation of Cement particles in filter bed

A comparison of theoretical and experimental calculation of Δw (difference between inlet and outlet weight of pollutant in filter bed) versus air velocity are shown in **Figures (34 and 35)** for glass beads and Raschig rings packings respectively.

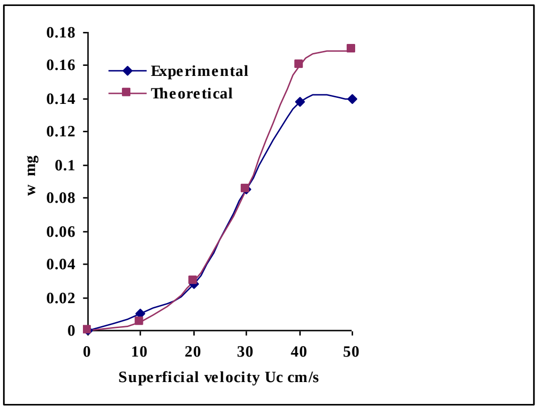

Fig. 34 Effect of velocity on Δw for cement pollutant and for Glass beads of L=3 cm and for a time =15 min.

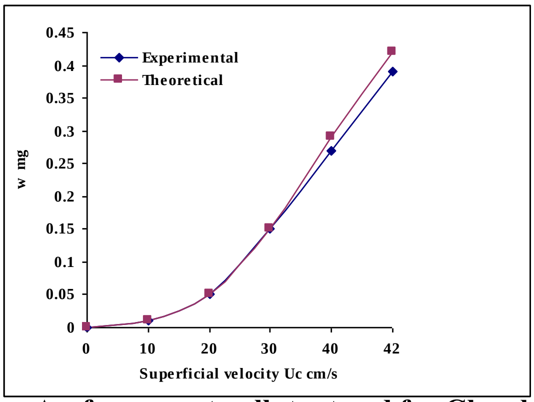

Fig. 35 Effect of velocity on Δw for cement pollutant and for Glass beads of L=3 cm and for a time =15 min.

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

The variation of accumulated weight of particles with time of accumulation for a given type of packing and bed height is represented by the following equations for Cement pollutant using DGA curve fitting program.

$W = -0.4656 + 0.92235\ T - 0.02357\ T^2 + 3.8896 \times 10^{-4}\ T^3 - 3.86387 \times 10^{-6}\ T^4 + 2.228465 \times 10^{-8}\ T^5 - 6.79638 \times 10^{-11}\ T^6 + 8.37668 \times 10^{-14}\ T^7$. For glass beads

$w = -0.29542 + 0.893982\ T - 0.067702\ T^2 - 0.001284\ T^3 + 0.000001\ T^4$. For Raschig rings

Where T= Time of accumulation of pollutant in filter bed.

CONCLUSIONS

The following major conclusions can be drawn from the experimental and theoretical study:

- The penetration decrease exponentially as the bed height increases for all types of packing and pollutants investigated.
- The order of efficiencies of the different packing types for capturing Tobacco or Cement aerosol are: (a) Raschig rings, (b) Glass wool, (c) Plastic wire mesh and (d) Glass beads.
- The overall and individual penetration velocities (at a given packing height) exist for all types of pollutants and all types of packing studied.
- The penetration is higher for pollutant of lower specific gravity under similar other conditions.
- Accumulation of particles in filter bed increases with time until it reaches a saturation point, then the accelerated velocity of air due to decrease of pores size causes to carry a large amount of particles from filter bed and these stages will be repeated.
- Although the porosity of glass beads packing is less than that for Raschig rings, the accumulation of particles on Raschig rings is more due to its surface area.

مجلة العلوم والتطبيقات الهندسية
Journal of Science And Engineering Application
ISSN 2521 - 3911

- Although the glass beads packing efficiency is less than that of Raschig rings packing, the glass beads packing filter can be used for a time much more than that for Raschig rings filter.

REFERENCES

1- Burson J.H. and Keng E.Y.H., Particle dynamics in centrifugal fields, Journal of Powder Technology, Vol. 1, P 305, 1967.

2- Morsi S. A. and Alexander A. J. An investigation of particle trajectories in two-phase flow systems, Journal of Fluid Mechanics, Vol. 55, Issue 2 , pp. 193-208, 1972.

3- Michael, D. H., and Norey, P. W., Particle Collision Efficiencies for a Sphere, Journal of Fluid Mechanics, Vol. 37, Part 3, pp. 565-575, 1969.

4- Lee K.W. and liu B.Y.H., Experimental Study of Aerosol Filtration by Fibrous Filters, Journal of Air Poll. Cont. Assoc., Vol. 1, P. 35, 1982.

5- Zimwara D., Mugwagwa L., Chikowore T.R, Air pollution Control techniques for the Cement manufacturing industry: a case study for zimbabwei.

6- Devi K.S., Vijaya V., Lakshmi and Alakanandana A., Impacts of Cement Industry on Enviroment – an Overview, Asia Pacific Journal of Research, *www.apjor.com* Vol: I. Issue LVII, November 2017.

7- Lu Z., Streets D. G., Zhang Q., Wang S., Carmichae G. R. l, Cheng Y. F., Wei C., Chin M., Diehl T, and Tan Q., Sulfur dioxide emissions in China and sulfur trends in East Asia since 2000, Atmos. Chem. Phys., Vol., no.10, P. 6311–6331, 2010.

8- Kurtulus Ozcan H., Long Term Variations of the Atmospheric Air Pollutants in Istanbul City, Int. J. Environ. Res. Public Health, Vol.9, P. 781-790, 2012.

9- U.S. EPA (United States Environmental Protection Agency). 2015. 2011 National Emissions Inventory, Version 2, technical support document Draft report.
https://www.epa.gov/sites/production/files/2015-10/documents/nei2011v2_tsd_14aug2015.pdf (PDF), (371 pp, 16.1MB).

10- Ahmad S., Chaudhry M. , Qureshi I., Journal of Radio analytical and Nuclear Chemistry, Volume 54, Issue 1-2 , 2007.

11- Latif, B.A.J.; Smith, J.W. Oxidation of Hydrogen Sulfide to Elemental Sulfur on an Activated Carbon Bed in the Presence of Iron (III) Chlo- ride Aerosol; Powder Technol. Vol. 27, P. 143-148, 1980.

12- GEBHART J., ROTH, C.; STAHLHOFEN, W. Filtration properties of glass bead media for aerosol particles in the 0,1 – 2 µm size range. Journal of Aerosol Science, Vol. 4, no. 5, P. 355-371, 1973.

13- Brady G.S., Material Hand book, 10^{th} edition, Mc Graw Hill, 1971.

14- Richardson J.F., Newitt, D.M., , and Gliddon B.J., Hydraulic Conveying of Solids in Vertical Pipes, J.Trans., Inst. Chem. Engrs., Vol, 39, P. 93-100, 1961.

15- Casella C.F. and Co Ltd. London, Instrument Leaflet 3018/TE, Cascade impactor, Leaflet 930/3 Ref. T 1320012.