PERFORMANCE OF HEPA FILTER MEDIUM UNDER ACCIDENTAL CONDITIONS IN NUCLEAR INSTALLATIONS

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ABSTRACT

High Efficiency Particulate Air filters (HEPA Filters) are the main components in ventilation or confinement system for the retention of radioactive particles in nuclear installations. During abnormal conditions or accidents (e.g. fire accident, criticality in a nuclear fuel cycle facility and LOCA in power reactors) the resulting heat, smoke and humidity affect to a large extent the performance of HEPA filters. As a part of a research programme aims at the evaluation and improvement of the performance of HEPA filter media during abnormal conditions, the effect of elevated temperatures up to 400 °C on the resistance of medium to penetration of water under pressure has been investigated. The test results showed that the resistance of the medium to penetration of water decreases with increase in temperature and thermal exposure time. This could be attributed to burnout of the organic binder used to improve the resistance of the medium to the penetration of water. The results also showed that at 400 °C the resistance of the medium to the penetration of water disappeared. This was confirmed by inspection of the filter medium samples after exposure to high temperature using a scanning electron microscope. The inspection of the medium samples showed that the organic binder in the medium was deformed and finally collapsed at 400 °C. Also, a best estimate model for the relation of filter medium resistance to water penetration under elevated temperature has been implemented. The results of this study can help in establishing a regulatory operating limit conditions (OLCs) for HEPA filter operation at high temperatures conditions in nuclear installations.

KEYWORDS: High temperature; HEPA filter medium; Water resistance; High pressure

INTRODUCTION

The functions of the ventilation and air cleaning system (VACS) in nuclear installations (reactors or fuel cycle facilities) are: to ensure an adequately safe environment for the operators and the public by confinement of radioactive materials (RAM) under – ve pressurizing conditions., to maintain specified conditions within the process volumes, and to maintain subsequent discharges within prescribed limits. It is equipped with an air cleaning system which collects radioactive aerosols. The air cleaning system must be capable of protecting the plant personnel and environment against contamination with radioactive materials. This is accomplished mainly by High Efficiency Particulate Air (HEPA) filter. A HEPA filter is defined by (1,2) as a filter having : (a) a minimum particle removal efficiency of not less than 99.97 % for 0.3 micron particles, (b) a maximum pressure drop, when clean, of 250 Pascal when operated at rated airflow capacity, and (c) a rigid casing extending the full depth of the medium. Fig. (1) Shows a schematic diagram for a ventilation and air cleaning system of a nuclear fuel processing installation in which a typical exhaust air system is implemented (3). In nuclear facilities, HEPA filters are usually arranged in banks or arrays in a nuclear ventilation system and generally contain a paper media. The filter medium is approximately 0.381 mm thick and is constructed from ultra fine glass fibers which are held together with an organic binder (4, 5). The small fiber and high packing density of the media allow for the efficient collection of submicron particles (6). The filter media is pleated to provide a large surface area to volume flow rate. Corrugated separators are often employed to strengthen the filter pack and prevent the media from collapsing (7). The most common design is a box filter cell where the pleated media is placed in a rigid square frame constructed of wood or metal box packs with approximately 60 cm height and width and 6 to 30 cm length (8). Box seal the media to the frame using polyurethane, or other commercially available adhesive.

Many events or accidents in nuclear facilities can cause perturbations to the conditions with which the ventilation system has to deal. The following list of accidents is of highly potential occurrence:

- fires in cells and glove-boxes, involving liquid or solid combustible materials;
- explosions in cells, glove-boxes and other equipment in nuclear fuel cycle facilities;
- criticality accidents;
- attack of filters by chemicals;
- fire in ducts;
- failure of one or several of the components constituting the ventilation and air cleaning protective systems (heaters, scrubbers, etc.);
- explosions or fires resulting from the mixture of fresh air with unburned combustibles generated by fires.
- LOCA accidents in power reactors.

The safety significance of these events is determined by the challenges or impacts arising to the air cleaning system components. As in the case of reactors, failures in protective systems seem to be the most probable accidents, although their consequences in fuel cycle facilities, compared with reactors, appear generally to be less severe. According to operational safety experience gained from many countries concerning the safety of nuclear facilities, it was found that wide range of types and magnitude of potential fires and chemical explosion in glove boxes are most significant (8). A set of source term parameters for solvent fires and explosions defined from different countries are shown in Table (1) (8).

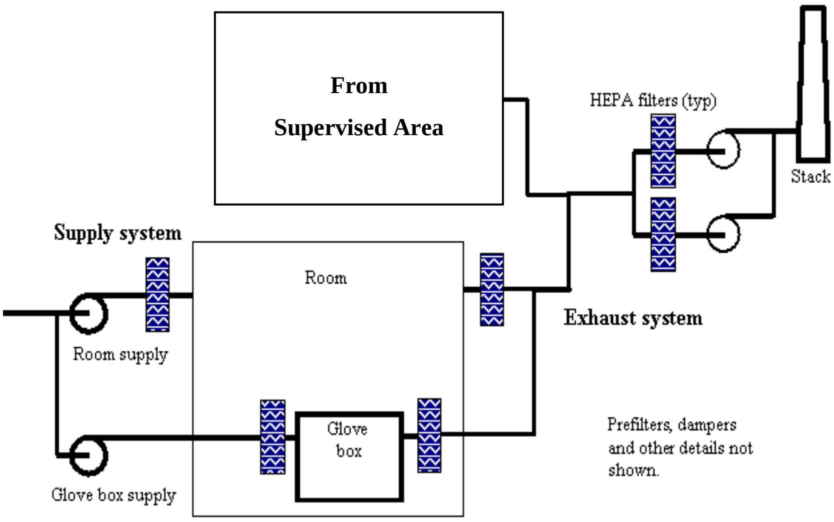


Fig.1: Nuclear facility ventilation and air cleaning system simplified schematic, diagram.

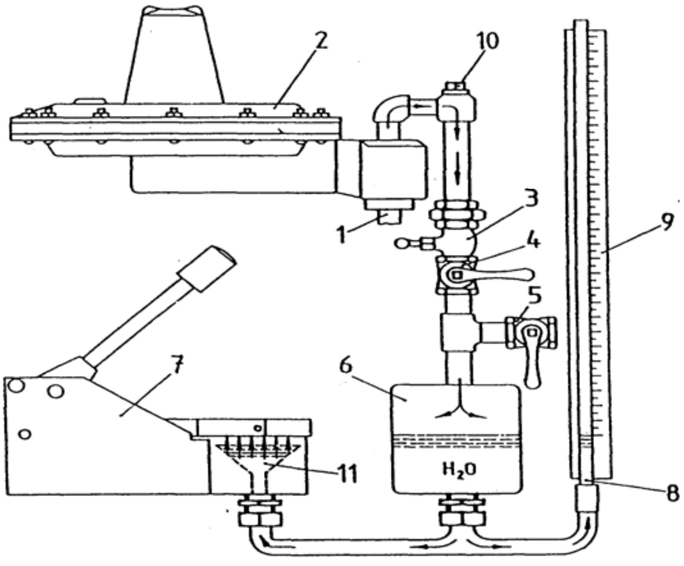
In the case of an accident, these filters could be exposed to - operating conditions extremely different from those typical of normal service. A loss of coolant, a fire, or a tornado depressurization could challenge HEPA filters at their service locations by exposing them to high differential pressures, high flow rates, high relative humidity, and high temperature.

In order to protect the operators and environment against contamination, the reliable performance of the HEPA filters must be ensured not only during normal operation but particularly during accident situations. To fulfill this task, the behavior of filters under such hypothetical accident conditions must be known. Many investigations have been carried out to simulate the effects of a number of individual challenges, and more information is available on the behavior of filters during many of the published scenarios (9 – 33). High humidity might be present along with elevated temperature as a result of fire extinguishing or a loss of coolant accident. In the interest of nuclear safety, the investigations of the behavior of HEBA filters or other air cleaning system components under such conditions are of great importance. In this context, an experimental investigation program has been designed to study the behavior of HEPA filters at elevated temperatures and at high humidity. As part of this study, the effect of elevated temperature on the resistance of filter medium to penetration of water under pressure was investigated. The test was performed for the conventional and high strength filter media samples after exposure to elevated temperatures, for different thermal exposure times, to find out whether the medium degrades with increasing temperature and time. The results of this study can help in establishing a regulatory operating limit conditions (OLCs) for HEPA filter operation at high temperatures conditions in nuclear installations.

EXPERIMENTAL PROCEDURE

Measurements were performed with circular filter medium samples. The samples were exposed to high temperatures for different exposure times in a laboratory oven at fuel safety department NCRSC . Medium resistance to penetration of water was subsequently measured and recorded before and after thermal challenge. Testes were performed in accordance with Mil – F – 0051079D (34) , using an apparatus shown in Fig.(2). The test apparatus was constructed in the mechanical engineering department, Shoubra Faculty of Engineering, Benha University. Initial test results indicated that the media retained a minimum value of water penetration resistance at 400 ^{o}C. At this temperature the media resistance to water penetration was time independent, below 400 ^{o}C, exposure time up to 6 hrs became relevant. Therefore the tests were performed with filter media in the range from room temperature up to 400 ^{o}C, and for thermal exposure time up to 6 hrs. To represent the material as fully as possible five test specimens from different portions of the medium were tested and the average values were listed to obtain each data point. To determine the effect of heating on the structure of filter medium, samples of the filter medium after exposure to high temperatures were inspected using a scanning electron microscope.

Test Conditions:
Sample diameter: 70 mm
Temperature range: up to 400 ^{o}C.
Exposure time: up to 6 hours



1. Compressed air inlet
2. Pressure regulator
3. Needle valve.
4. Shut - off cock.
5. Exhaust cock.
6. Water reservoir.
7. Specimen holder.
8. Glass manometer.
9. Manometer scale.
10. Plug

Fig. 2: Schematic diagram of the test apparatus used for measurements of water Penetration resistance of filter medium.

RESULTS AND DISCUSSION

The results of this test are shown in Tables 1 and 2 and represented in Figs. 3 and 4. From these tables and figures it could be seen that the resistance of the medium to penetration of water increases slightly with increase in temperature, passing through a peak at about 130 °C for conventional and high strength filter media. The increase of resistance to penetration of water is probably caused by chemical reactions of the organic matter which lead to thermal hardening effect (35). As the temperature was increased further, the resistance to water penetration decreased and finally disappeared at 400 °C.

The effect of exposure time on the resistance to penetration of water of the medium for different temperature challenges is shown in Figs. 3 and 4 and Tables 1 and 2. From these figures and tables, it could be noticed that at 100 °C, the resistance to penetration of water of the medium increases with the increase in exposure time up to 2 hrs. Under these conditions the resistance to penetration of water is about 110 % of the room temperature value. For a thermal exposure time

Raising the temperature above 200 °C, the medium resistance to penetration of water decreases with an increase in thermal exposure time as is shown in tables. (2 and 3). This could be explained due to burnout of the organic matter. The resistance to water penetration of the conventional and high strength filter medium drops to about 70 % and 35 % at 300 °C, and to about 45 and 30 % at 400 °C, respectively compared with the corresponding values at room temperature after thermal exposure time of 6 hours.

Examination of the new conventional and high strength filter media samples showed that the binder is clearly visible between fibers as a translucent webbing between the fibers. At temperature up to 130 °C no meaningful alterations were observed even after thermal challenge for 6 hours. As the temperature increases up to 350 °C, the decomposition of the media binder increases with increase in temperature and thermal exposure time. At 400 °C it could be noticed that most of the binder has been lost after 30 minutes and the micro fibers appear clean. Some scanning electron microscope photographs of the examined media samples are shown in Figs. 5-12.

Table 1: Effect of temperature and exposure time on the resistance of conventional filter medium to water penetration

Temperature (°C)	Filter Medium Water Penetration Resistance (kPa)					
	Exposure Time (hr)					
	1	2	3	4	5	6
Room Temperature	3.8	3.8	3.8	3.8	3.8	3.8
100	4.07	4.4	4.06	4.03	4.01	3.9
200	3.89	4.2	3.54	3.35	3.3	3.15
300	3.25	3.2	2.86	2.72	2.6	2.53
400	2.63	2.34	1.92	1.88	1.78	1.7

Table 2: Effect of temperature and exposure time on the resistance of high strength filter medium to water penetration

Temperature (°C)	Filter Medium Water Penetration Resistance (kPa)					
	Exposure Time (hr)					
	1	2	3	4	5	6
Room Temperature	5.67	5.67	5.67	5.67	5.67	5.67
100	5.9	5.95	5.9	5.72	5.7	5.65
200	6.4	6.5	5.8	5.65	5.48	5.4
300	4.6	3.3	2.5	2.2	2.05	1.95
400	2.8	2.1	1.8	1.75	1.65	1.6

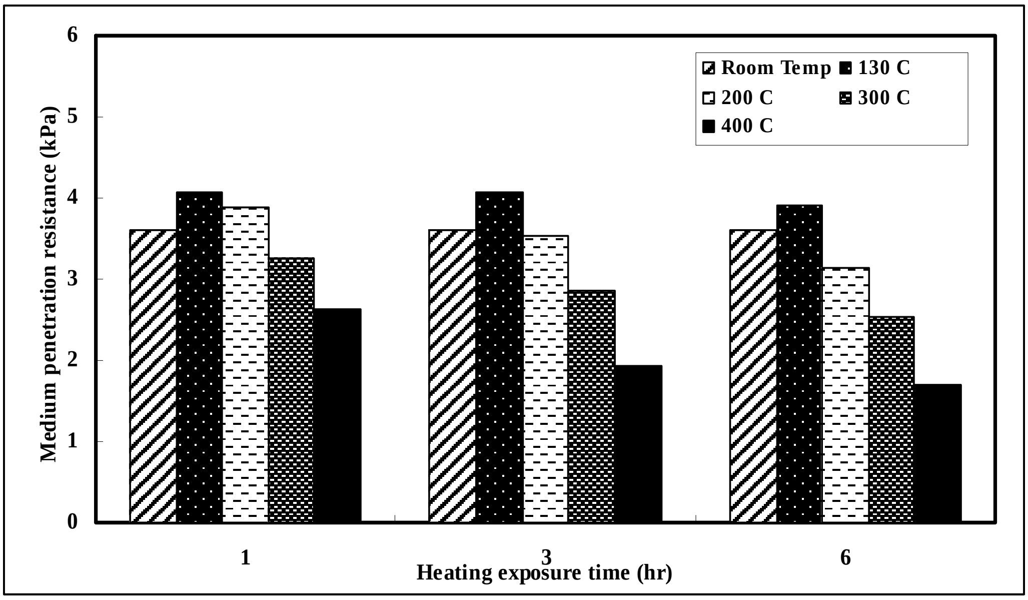


Fig.3: Effect of temperature and exposure time on the resistance of conventional filter medium to water penetration.

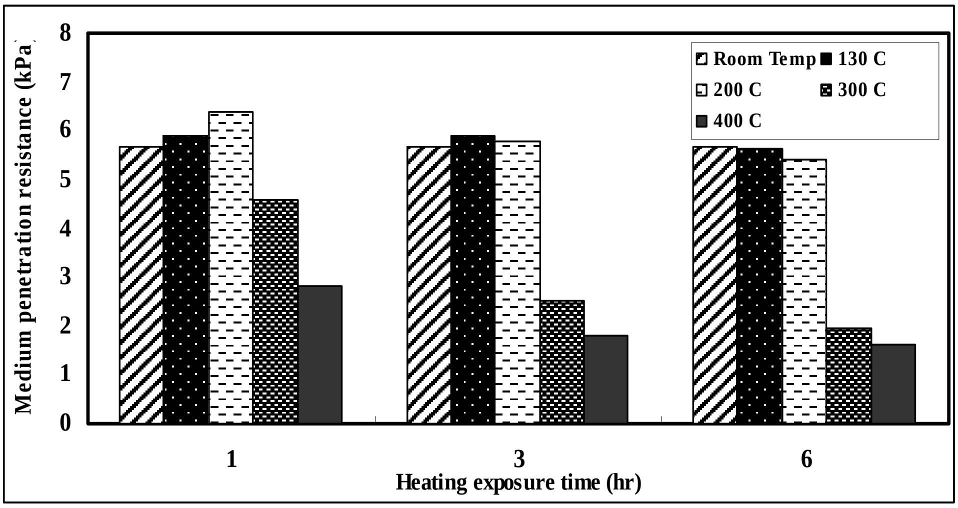


Fig 4: Effect of temperature and exposure time on the resistance of high strength filter medium to water penetration

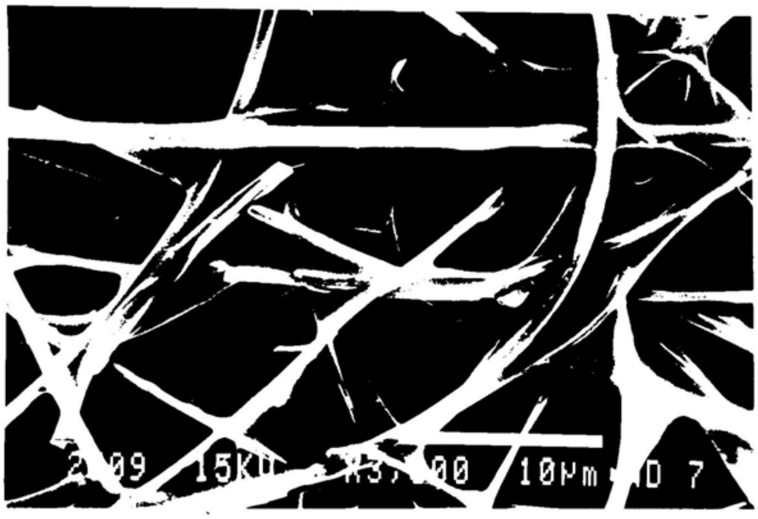


Fig.5: Scanning electron photograph of a reference conventional filter medium sample

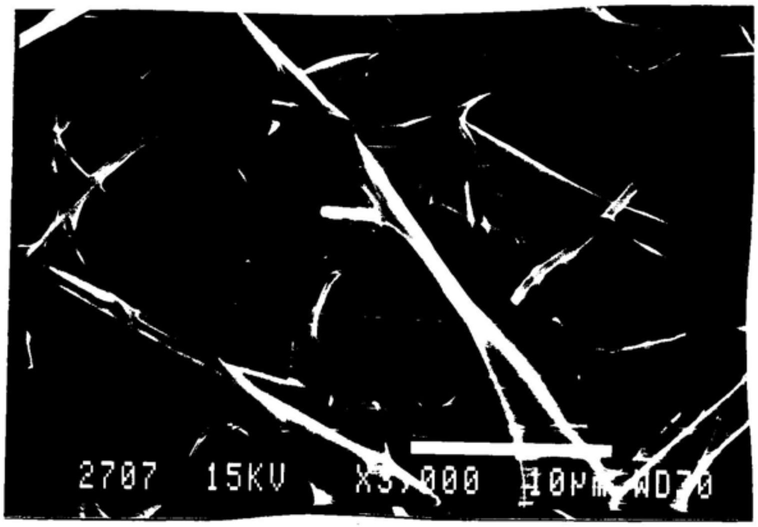


Fig.6: Scanning electron photograph of conventional filter medium sample heated at 250 °C for 1 hrs.

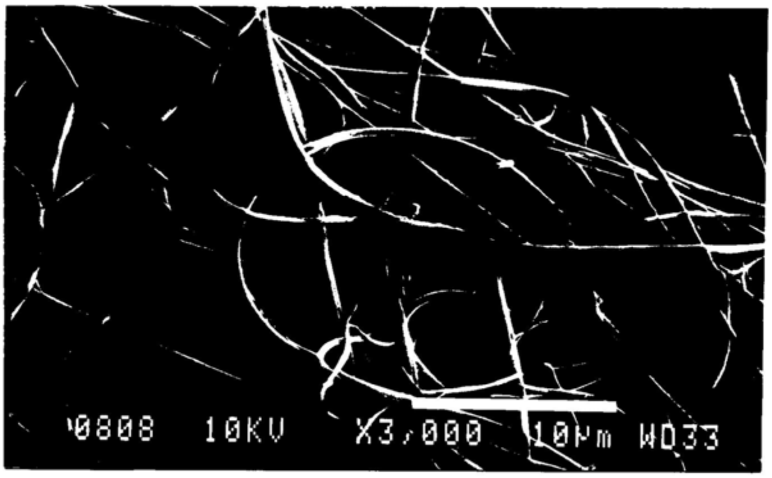


Fig.7: Scanning electron photograph of conventional filter medium sample heated at 250 °C for 3 hrs.

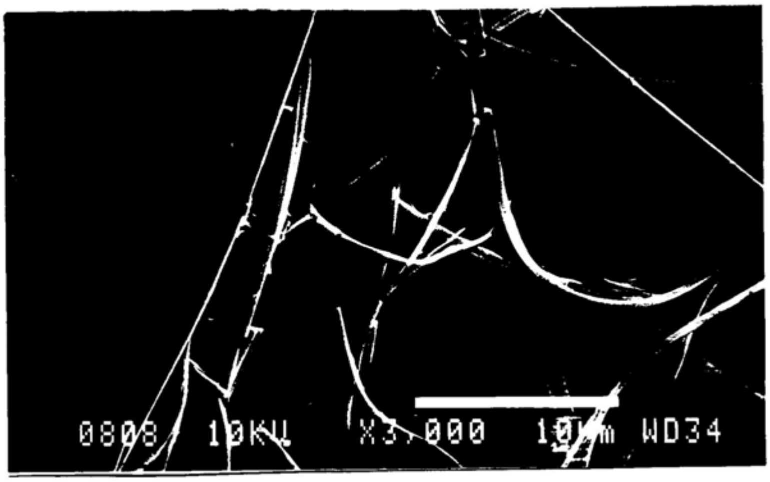


Fig.8: Scanning electron photograph of conventional filter medium sample heated at 250 °C for 6 hrs.

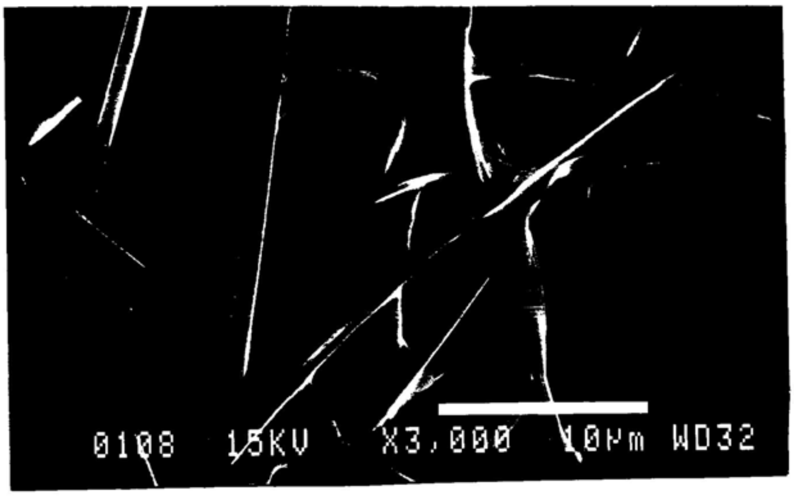


Fig.9: Scanning electron photograph of a reference conventional filter medium sample

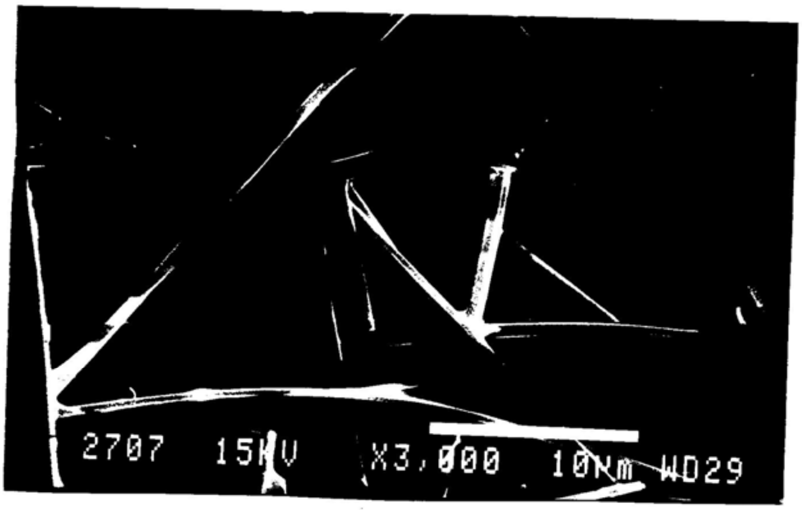


Fig.10: Scanning electron photograph of conventional filter medium sample heated at 200 °C for 1 hr.

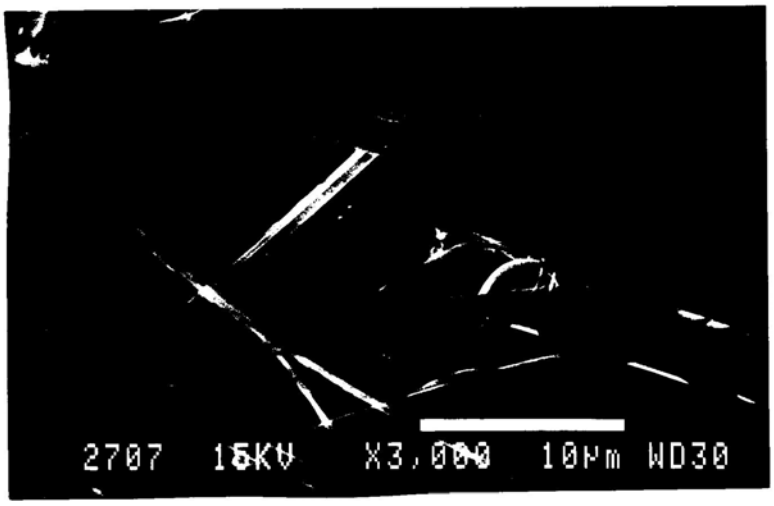


Fig.11: Scanning electron photograph of conventional filter medium sample heated at 300 °C for 1 hr.

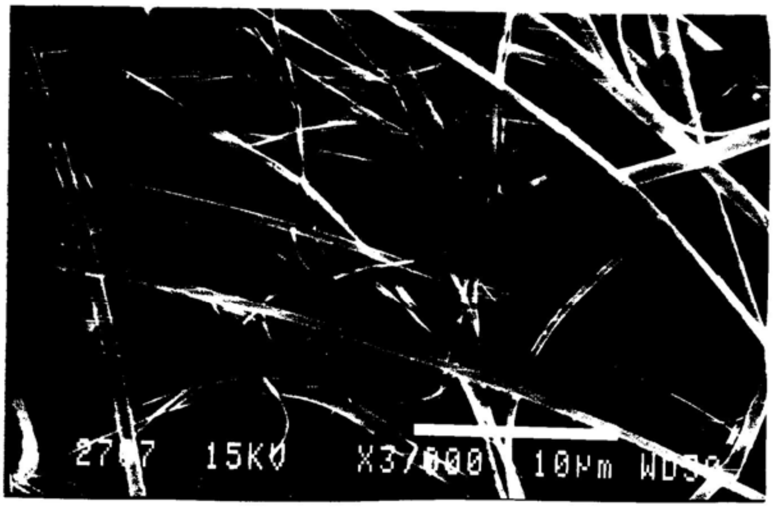


Fig.12: Scanning electron photograph of conventional filter medium sample heated at 400 °C for 1 hr.

Using Origin® 6.1 the best fitting model for the prediction of filter medium resistance values to water penetration and temperature could be given by:

$$R = -\ 0.00002\ T^2 + 0.0035\ T + 3.8175 \qquad (1)$$

Where: R is the filter medium resistance (kPa), and T is the temperature in °C

Fig.13 depicts the graphical representation of Eq.1. compared to experimental investigations, it is seen from the figure that there is a good and best estimate simulation for the medium filter resistance with temperature. This means that, Eq.1 can give a best estimate representation for HEPA filter resistance to water penetration under high temperature.

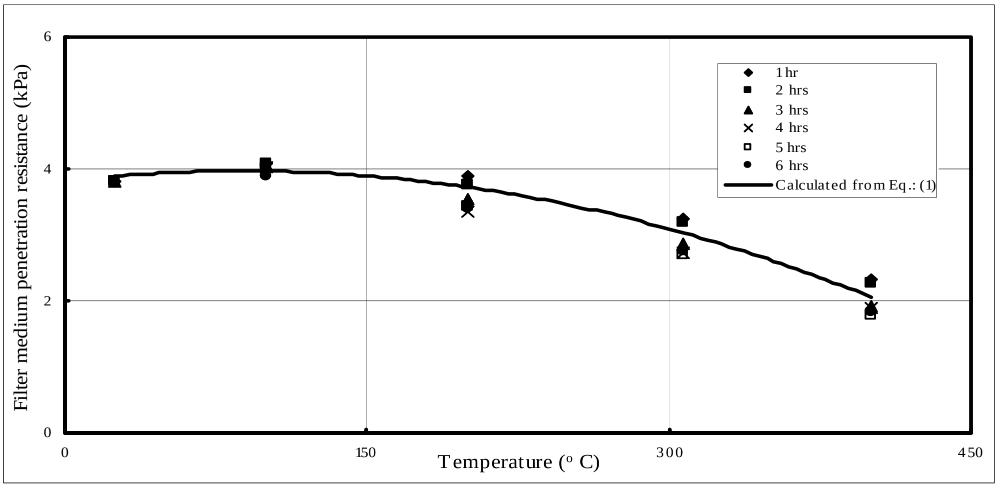


Fig.13: A comparison of the best estimated model calculation
vs. experimental investigation

CONCLUSIONS

As a result of static exposure to elevated temperatures up to 400 °C, the resistance of HEPA filter medium to penetration of water decreases with the increase in temperature and thermal exposure time. This was due to burnout of the organic matter used to improve the medium resistance to penetration of water. At 400 ^oC, the medium exhibited essentially no degree of resistance to penetration of water as a result of complete burnout of the organic binder. Filter medium resistance to water penetration has been correlated by the Equation: $R = - 0.00002\ T^2 + 0.0035\ T + 3.8175$, which gave a best estimate representation for HEPA filter medium resistance to water penetration performance under postulated accidental conditions in nuclear installations. The results of this study can help in establishing a regulatory operating limit conditions (OLCs) for HEPA filter operation at high temperatures conditions in nuclear installations.

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