

Ultrasonic Cleaning and Re-use of HEPA Filters in Nuclear Fuel Manufacturing Facility

C. K. ASNANI, K. RAMACHANDRAN, G. V. S. N. SARMA
and A. P. KULKARNI

Nuclear Fuel Complex, ECIL PO, Hyderabad

ABSTRACT

In the nuclear industry, High Efficiency Particulate Air (HEPA) filters are used as an important engineering safeguard to prevent the potential release of airborne radioactive particulates into the environment during the plant operations. These filters have high efficiency (99.97%) in removing particulate matters in the sub-micron range and are widely used in the entire fuel cycle from the stage of mining/milling to nuclear waste management operations. Nuclear Fuel Complex (NFC) at Hyderabad manufactures nuclear fuel for all the commercial nuclear power reactors in the country. The fuel is in the form of high density Uranium dioxide (UO_2) pellets clad in Zircalloy-4 tubes. Many chemical and metallurgical processes are employed for the production of UO_2 pellets starting from the raw material magnesium diuranate (MDU). HEPA filters are used for final filtration of off-gases from these processes as well as the working areas/plants. Each fully loaded HEPA filter contains around 3–5 kgs of uranium bearing fine powder, which needs to be recovered as it is a costly material. Normally, HEPA filters are used once-through, as suitable technique for non-destructive decontamination has not been developed. This has resulted in a large accumulation of loaded HEPA filters at NFC, which is a cause for concern. The reuse of the HEPA filters depends on the extent of decontamination achieved. As the conventional cleaning techniques are found to be ineffective, the decontamination of HEPA filters presents a challenging problem. Therefore, development work was taken up at NFC to evolve a suitable decontamination technique for HEPA filters. A state-of-the-art ultrasonic decontamination technique using commercial acetone has been developed at NFC. The technique offers a suitable non-destructive method to ensure removal of uranium fines from the filter media completely and thereby rendering the HEPA filter suitable for reuse. The observations and results of this development work are presented in this paper.

Key Words : HEPA filters, ultrasonic cleaning, nuclear fuel manufacturing facility.

INTRODUCTION

Nuclear Fuel Complex (NFC) at Hyderabad manufactures nuclear fuel for all the commercial nuclear power reactors in the country. The fuel is in the form of high density Uranium dioxide (UO_2) pellets clad in Zircalloy-4 tubes. Many chemical and metallurgical processes are employed for the production of fuel pellets starting from

the raw material magnesium diuranate (MDU). The stringent regulatory criteria for the release of airborne radioactive particulates into the environment from nuclear operations have necessitated use of HEPA filtration systems. At NFC, HEPA filters are used in the uranium powder and pellet producing plants for off-gas final filtration. Apart from their high efficiency (99.97%) in removing particulate matters in the sub-micron range, they offer very low flow resistance (i.e., a pressure drop of less than 25 mm wg at the rated air flow). A standard HEPA filter has a face dimension of 610 x 610 mm and a depth of 292 mm having an air handling capacity of 1700 CMH⁽¹⁾. The filter medium used in a HEPA filter is a continuous sheet of paper of around 30 meters length and 572 mm width. The thickness of the paper is around 0.4 mm. The filter paper is made of a combination of cellulose, asbestos, glass, and ceramic fibers. The fiber diameter ranges from 0.5 to 0.75 microns. Small quantities (less than 8%) of certain additives are also added to impart strength and water repellency. The sub-micron fibers of the filter paper are in random distribution and orientation. The particles in an air stream follow a tortuous path while passing through the paper and get trapped by interception, inertial and diffusion mechanisms. The filters are removed from the filtration system when they get loaded (corresponding to a pressure drop of 75mm wg). Each loaded HEPA filter contains around 3 to 5 kgs of UO₂ powder.

Presently, there is no suitable method known to remove the fine UO₂ powder from the HEPA filters. Conventional decontamination methods such as high pressure water jet spraying and mechanical tapping cannot adequately remove the uranium particulate matter in the micron and sub-micron size range. In fact the water from the high pressure jet spraying system does not even totally wet the filtering medium inside the HEPA filters.

In order to achieve a better contact of the cleaning medium with the filters, decontamination trials using ultrasonic cleaning technique were taken up at Centralized Decontamination Facility at NFC.

EXPERIMENTAL

Fig. 1 schematically shows the unit used for carrying out the trials.

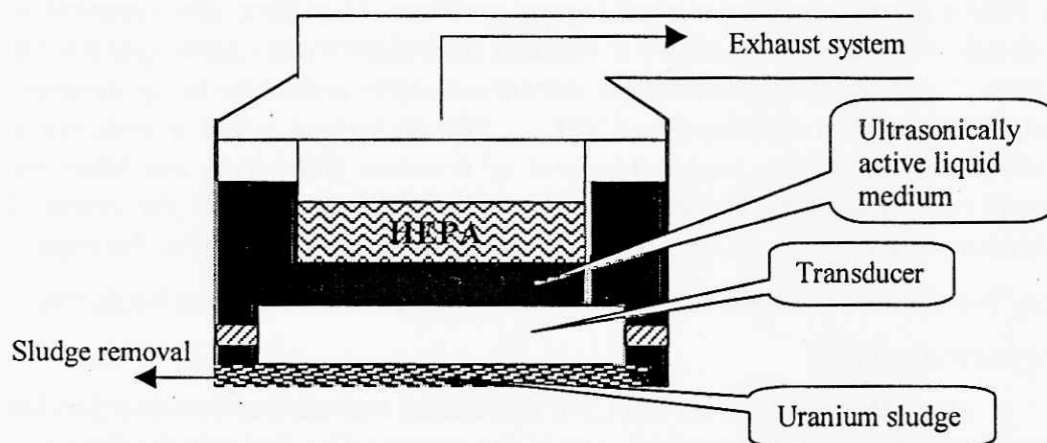


Fig. 1 : Schematic diagram of the ultrasonic cleaning unit

The unit mainly consists of:

i) Treatment/cleaning tank

SS-304 tank having a capacity of 1000 liters for holding the transducers at the bottom and for containing the liquid medium along with the HEPA filter.

ii) Ultrasonic generator and transducer

Ultrasonic power supply generator which supplies electrical energy at 30 kHz ultrasonic frequency. The ultrasonic generator converts a standard electrical frequency of 60 Hz into the high frequencies required in ultrasonic transmission, generally in the range of 20 to 80 kHz.

Piezoelectric ultrasonic transducer for converting the electrical energy from the generator into vibrations. Piezoelectric transducers are made up of several components. The ceramic (lead zirconate) crystal is sandwiched between two strips of tin. When voltage is applied across the strips, it creates a displacement in the crystal, known as the piezoelectric effect. When these transducers are mounted to a diaphragm (wall or bottom of the tank), the displacement in the crystal causes a movement of the diaphragm, which in turn causes a pressure wave to be transmitted through the aqueous solution in the tank.

iii) Ventilation

The ventilation system consists of a canopy over the treatment tank and the exhaust duct from the canopy is connected to a water scrubber, a centrifugal blower and a chimney 6 meters above the roof level.

MECHANISM OF CLEANING

Ultrasonic cleaning (Figure 2) involves the cycle of formation, growth and collapse of micron-size bubbles due to alternating positive and negative pressure waves in a solution. This process is called cavitation [2].

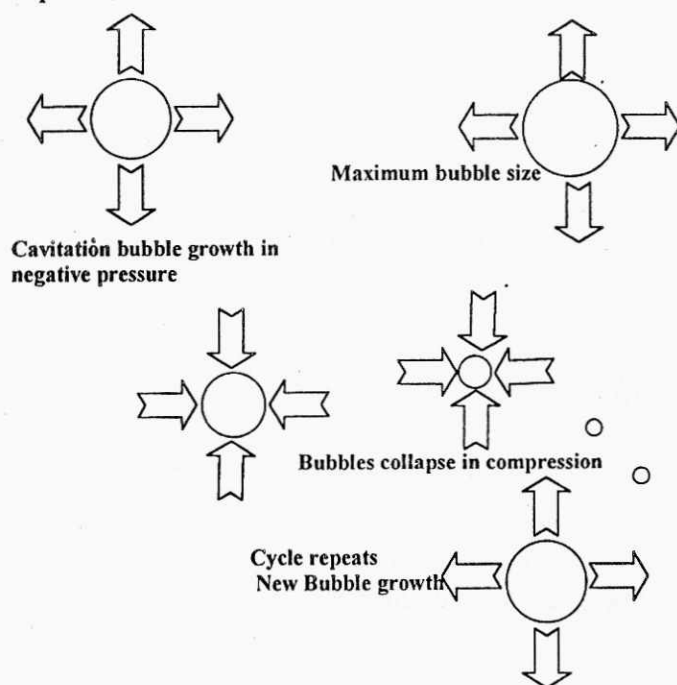


Fig. 2 : Cavitation and implosion during ultrasonic cleaning

The violent collapse of the cavitation bubbles results in implosions, which cause shock waves to be radiated from the sites of the collapse. The intensity with which cavitation takes place in a liquid medium varies greatly with the colligative properties of that medium, which include vapor pressure, surface tension, viscosity, and density. The surface tension and the vapor pressure characteristics of the cleaning fluid play the most significant roles in determining cavitation intensity and, hence, cleaning effectiveness. The energy required to form a cavitation bubble in a liquid is proportional to both surface tension and vapor pressure. Thus, the higher the surface tension of a liquid, the greater will be the energy that is required to produce a cavitation bubble, and consequently, the greater will be the shock-wave energy that is produced when the bubble collapses. In the same manner, when the vapor pressure of a liquid is low, as is the case with cold water, cavitation is difficult to produce but becomes easier as the temperature is increased.

Selection of cleaning medium

Table 1 gives the properties of some of the commonly used cleaning solutions.^[3]

Table 1 : Properties of some commonly used cleaning solutions

Liquid	Vapour Pressure (mm Hg)	Viscosity (centipoise)	Surface tension (N/m)	Specific gravity	Exposure Limits (ppm)
Water (at 70°C)	20	0.43			-
Acetone(20°C)	180	0.33	0.024	0.79	1000
Kerosene	5	2.40	0.028	0.82	200
Petrol	300	0.56	0.022	0.72	Carcinogenic

Based upon their colligative properties and safety considerations, water (at 70°C) and acetone (at room temperature) were selected as the two different media for carrying out the trials.

Ultrasonic cleaning process

- i) The HEPA filter was weighed before loading into the ultrasonic tank.
- ii) The tank was filled with around 500 liters of the cleaning solution. For the water as the medium, the temperature was maintained at around 70°C by steam heating. Acetone trials were conducted at room temperature.
- iii) The HEPA filter was immersed into the cleaning medium in the tank and the ultrasonic generator is started.

- iv) For initial trials, the residence time of the HEPA filter in the ultrasonic cleaning tank, was kept around 4 hours. Subsequently, with more trials and experience, the residence time was standardised to 2 hours.
- v) After removal from the ultrasonic bath, the filters cleaned with acetone were subjected to 4 hours of atmospheric drying. The filters cleaned with water as the cleaning medium were subjected to hot air drying for 16 hours.
- vi) Dried HEPA filters were weighed and were visually examined. The acetone cleaned HEPA filters were additionally subjected to online differential pressure and filtration testing.

RESULTS & DISCUSSION

Table 2 lists the results of the ultrasonic cleaning trials of the HEPA filters with water (at 70°C) and acetone (at room temperature) as the cleaning media.

Table 2 : Results of ultrasonic cleaning trials of HEPA filters

S. No.	Cleaning Medium	Weight (kgs) before cleaning	Weight (kgs) after cleaning	Weight change(kgs)
1	Water at 70°C	15.5	14.0	1.5
2	”	17.0	15.2	1.8
3	”	13.2	11.3	1.9
4	”	17.5	16.0	1.5
5	”	17.0	15.1	1.9
6	Acetone	15.7	10.5	5.2
7	”	15.2	9.4	5.8
8	”	15.7	10.0	5.7
9	”	15.0	10.5	4.5
10	”	15.0	10.3	4.7
11	”	15.6	10.0	5.6
12	”	15.5	11.5	4.0
13	”	16	11.8	4.2
14	”	15.8	10.8	5.0

The HEPA filters that were cleaned with water (at 70°C) were found to contain residual uranium, which could not be recovered. The acetone cleaned HEPA filters were found to be visually as clean as unused HEPA filters and had a final weight of around 10 kgs, which is around the same as that of unused HEPA filters. The acetone washed HEPA filters were fixed online in the plant ventilation system to carry out the pressure differential test. The pressure differential test is a standard test for in-place leak testing of HEPA filters.^[4] The differential pressure of these decontaminated filters

was around 20 mm wg which is similar to that of new HEPA filters. To check the integrity of the filter medium, an additional test in the form of the downstream (after HEPA) air sampling to measure the radioactivity levels during plant operation was carried out. The samples showed negligible radioactivity, well below the permissible levels.

The uranium bearing sludge collected from the tank bottom was dried at room temperature and the residual cake was analyzed and found to contain around 84% uranium. This residue can be recycled as a feed material to the UO₂ powder producing plant at NFC.

CONCLUSIONS

HEPA filters can be successfully cleaned and re-used using ultrasonic cleaning technique with acetone as the liquid medium. This helps in easy recovery of valuable uranium bearing powder and at the same time reduces new filter procurement. It also contributes in reducing the storage/disposal of such bulky used and contaminated filtering medium.

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