Characterization of a Highly-Efficient Aerosol Filtration System ◇

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In any radioactive ion beam facility based on the production of uranium fission products (as planned for the EURISOL project [1]) the vacuum system has to be treated as contaminated with radioisotopes, potentially including long-lived α emitters (e.g. in cases when ^{238}U is used as fission source). Therefore exhaust gases from vacuum pumps have to be treated with special care in order to guarantee release of radioactivity to the environment within legal limits. Thus a reliable concept to store and purify those gases has to be part of the radioprotection concept of any RIB facility. The present report describes tests of a filter system for vacuum pump exhaust gases specifically designed to remove quantitatively aerosol components from vacuum exhaust gases prior to their release to the environment.

A first series of measurements was performed under standard laboratory conditions aiming at studying the sedimentation behaviour of aerosol particles in gas storage vessels operated at underpressure. A setup as depicted in Fig. 1 was realized in a conventional laboratory in Garching (i.e. not fulfilling clean-room specifications). Two gas storage vessels of 4 liters volume each were connected with each other as shown in the figure. Dust particles with typical sizes between 0.1 μm and 2 μm were used for the tests. Diagnostics of the aerosol concentration as a function of the particle size was performed by a commercial opto-electronic particle counter, operating on the basis of detecting the scattering of (diode laser-generated) light off the aerosol particles. Since the particle detector module contained also a vacuum pump, a pressure gradient in the gas storage vessels could be adjusted for the tests. In order to maintain a constant pressure gradient during extraction of the stored gas, clean air (filtered by the lateron tested Ni membrane filter) was flown into the storage volume.

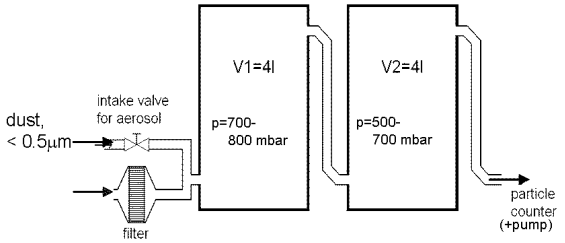

Fig. 1: Setup used to study the sedimentation behaviour of aerosol particles in gas storage vessels operated at underpressure.

After flooding the gas volumes for a few minutes with a stream of aerosol-loaded air, the inlet valve was closed and the system remained untouched for a variable period of time in order to allow for gravitational sedimentation prior to extraction of the gas using a constant pressure gradient. During extraction via the particle counter the extracted aerosol particle rate was measured as a function of the aerosol particle size ranging from 0.1 μm up to particles larger than 2 μm.

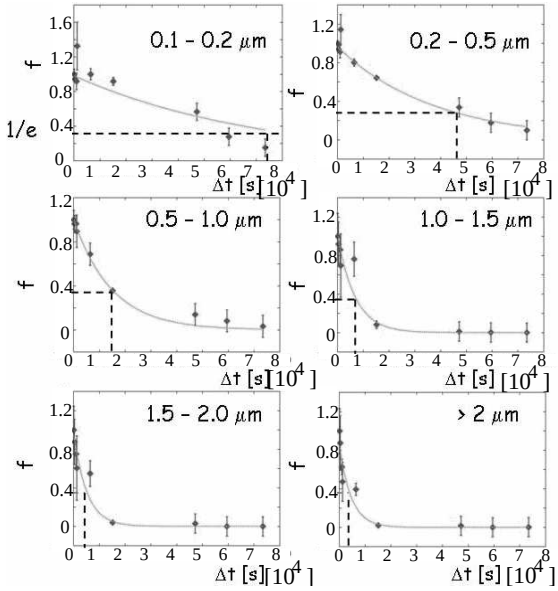

Fig. 2: Time characteristics of the aerosol extraction from a gas storage volume after gravitational sedimentation during Δt as a function of the particle size. The setup used is depicted in Fig. 1. Dashed lines denote Δt to reach the f/e level.

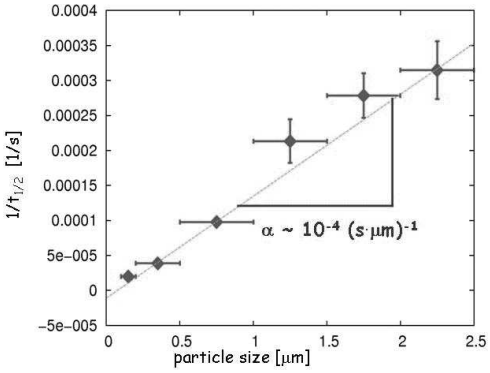

Fig. 3: Time dependence of the gravitational sedimentation process of aerosols in a stored gas volume which is extracted under vacuum conditions. Plotted is the 'sedimentation constant' λ according to the exponential fit to the data shown in Fig. 2 as a function of the extracted particle size.

Since the number of initially loaded particles could not be measured directly, a normalized differential measurement scheme was applied during the extraction procedure: already during loading of the volumes a 10s measurement provided the starting value of the extracted particle number $N(t_0)$. Then the measurement of the extracted particle number was performed after a variable sedimentation time Δt. Fig. 2 displays the resulting normalized ratios $f = N(t_0 + \Delta t)/N(t_0)$ as a function of the sedimentation time Δt, where $f(t_0) = 1$. As already intuitively expected, the larger the particle size the lower the fraction of extracted particles for a given sedimentation time due to the more efficient gravitational sedimentation process. In order to quantify this behaviour, an exponential fit was applied to the data according to

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$N(t_0 + \Delta t) = N(t_0) \cdot exp(-\lambda(t_0) + \Delta t))$. In this way the time characteristics of the sedimentation process can be quantified by the 'sedimentation constant ' λ describing the time to reach the 1/e level of the fraction of extracted particles. When we plot λ as a function of the particle size as shown in Fig. 3, we realize a linear dependence of the 1/e - sedimentation time as a function of the particle size, resulting in a slope constant $\alpha = 10^{-4}/s \cdot \mu$m.

The presently most efficient commercial aerosol filter available (according to the manufacturer) is given by an all-metal nickel in-line gas filter (type Wafergard III from Mykrolis-Entegris [2]). Its housing assembly has been optimized to minimize outgassing by minimizing the weld area. According to specifications the downstream cleanliness is < 1 particle/ft^3 larger than 0.01 μm. The specified particle retention rate is larger than 99.9999999% removal of all particles (referenced at the most penetrating particle size). Fig. 4 shows the Ni membrane filter module as used in our measurements.

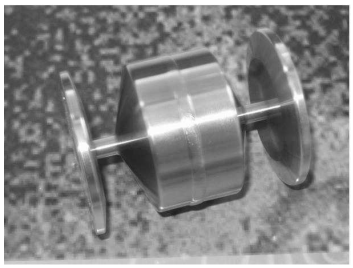

Fig. 4: All-metal Nickel membrane filter specified for 99.9999999% particle removal efficiency as used in our performance characterization tests.

When aiming at a reliable quantitative study of the aerosol particle production of typical roughing vacuum pumps as well as of the filtration efficiency of the Ni membrane filter, it soon turned out the the achievable air quality in a conventional laboratory will not allow for reliable measurements due to the uncontrolled pollution by a huge number of dust particles in the room air volume. A quantitative and controlled particle loading of the tested filter assembly requires a dedicated aerosol generator with absolutely clean air as carrier gas. Such experimental conditions can only be guaranteed under clean-room conditions which as usually not available in a nuclear physics laboratory environment. Therefore our further studies on the characterization of the vacuum exhaust filter system were performed in cooperation with the development division of one of the European market leaders in clean-room technology, the company M+W Zander in Stuttgart/Germany. They granted us access to their ultra-clean room laboratory together with the appropriate aerosol generation and detection technology.

The first series of measurements was conducted in a clean room of class ISO 3 (corresponding to a particle concentration of 1 particle/ft^3 at 0.5 μm particle size). The aerosol contents in the exhaust gas of two different roughing vacuum pumps was characterized, namely a membrane pump (model Vacubrand MD4) and a scroll pump (model Edwards XDS 10). Both pumps were connected to a vacuum recipient (4 liter volume) and operated at different pumping speeds, while the distribution of the aerosol particle sizes in the exhaust gas was analyzed

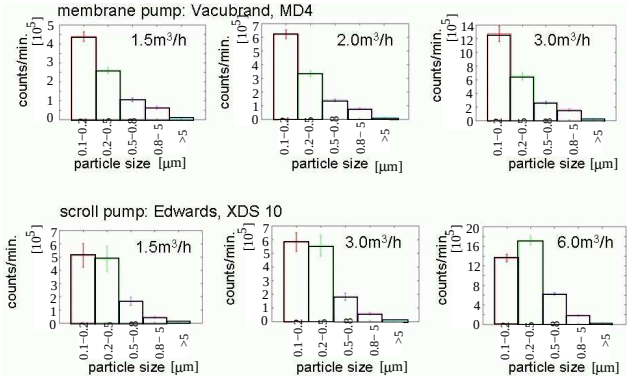

Fig. 5: Distribution of aerosol particles detected in the exhaust gas of two roughing vacuum pumps (upper line: membrane pump type Vacubrand MD4, bottom line: scroll pump type Edwards XDS 10). Both pumps were operated at different pumping speeds.

As it turns out (see Fig. 5), the dominant fraction (>50%) of aerosol particles in case of the membrane pump is provided by small sizes between 0.1 μm and 0.2 μm independent of the pumping speed. For the scroll pump under investigation particle sizes between 0.2 μm and 0.5 μm contribute almost equally as the smaller ones between 0.1 μm and 0.2 μm, even dominating at the largest pumping speed. Together particles with a size smaller than 0.5 μm account for about 80% of all detected aerosols. In general it can be concluded that rather independent of the pumping speed small particle sizes <0.5μm dominate the aerosol production.

Thus the appropriate test conditions could be chosen for the characterization of the filter efficiency of the Ni inline gas filter displayed in Fig. 4. An aerosol particle generator capable of producing $8{\cdot}10^9$ particles/minute with sizes between 0.1μm and 0.2 μm (corresponding to the exhaust gas situation) was connected to the inlet of the filter module, while the filtered gas flow was analyzed at the outlet by a particle detector. Since the particle detector can only resolve a maximum of 10^5 particles per minute, the initial particle production rate was determined by downscaling the volume flow from the aerosol generator by a factor of 10^{-5} via a controlled admixture of pure air. During a measurement time of 100 minutes 5 particles were detected behind the Ni membrane filter. This translates into an excellent filtration efficiency of $5{\cdot}10^{-12}$, even exceeding the manufacturers' specification of 10^{-9}. Thus this type of Ni membrane filter clearly qualifies as a highly efficient device to remove aerosol particles from stored vacuum exhaust gases prior to their release to the environment.

In conclusion our test measurements confirmed the feasibility of a vacuum exhaust handling system that, besides a reduction of radioactivity via temporal storage in decay tanks held at constant underpressure, also enables to quantitatively avoid the release of aerosol particles into the environment by using an efficient Ni membrane filter assisted by a slow release of the stored gas.

References

[1] http://www.ganil.fr/eurisol/Final_Report.html and: http://www.eurisol.org/site01/plaquetteEurisol_300807.pdf
[2] Wafergard is a registered trademark of Mykrolis Corporation