Pressure loss of air filters for general ventilation at high relative humidity or exposed to water droplets

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In anticipation of DIN EN 779:2012 (particulate air filters for general ventilation) and the associated introduction of a minimum efficiency, once more a intense discussion was triggered about the benefit of the performance data of filters determined in the laboratory, in particular compared to operational data. For example, the suitability of the test dust and the decreasing electret effect of synthetic filter materials [1] were discussed.
In addition, essential differences exist also with the climate conditions, comparing the standardized conditions according to DIN EN 779 or also ISO 11155-1 (vehicle interior filters) with the actual operating conditions.
Therefore, some first systematic attempts were carried out to indicate the effect of high humidity on pressure loss during the exposure to different dusts, as well as the influence of water droplets on the pressure loss. Furthermore, fraction separation efficiencies were measured for relevant operating conditions.

1. Motivation

The basic sense and purpose of standardization is illustrated by an overview article by Ripperger [2]: “Standards are means for the unification of tangible and intangible assets. So they also offer recognized solutions for constantly recurring tasks. One goal of standardization is to promote the national and international exchange of goods and services...” So it is not the primary purpose to depict “the reality”.

On the other hand, the standard-compliant measurement may not be seen completely independently from the actual conditions in practical applications, since new media and filter elements are being developed specifically in view of the classification of the standard.

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Current standards of air filtration provide rather non-specific guidelines for the climate conditions in the test channel:

DIN EN 779:2012 (filters for general ventilation)
> Room air or outside air; no information about the temperature
> Relative humidity should be < 75%

ISO 11155-1 (vehicle interior filters)
> Climate conditions: temperature 23°C +/- 5°C; humidity 55% +/- 15%

Fig. 1 shows the measured values of relative humidity (location Mülheim/Germany in 2011) in a cumulative representation. It can be seen that values of relative humidity ≤ 30% are only present approx. 1% of the year and values of relative humidity ≤ 70% only up to 30% of the year. This means on the one hand that a test channel without climate control would only be allowed to be used at certain times and, on the other hand, that for 70% of the year, conditions prevail that the standard does not allow for.

Moreover, with condensed humidity (fog), sea spray or rain, the problem can appear that water droplets themselves deposit on the filters. In this case, it results in a sticking together of the already deposited dust and leachings, which partially leads to a drastic increase of pressure loss. In particular in coastal regions and with offshore locations of gas turbines, crystalline salt particles or salt dissolved in water droplets are transported in the air and can also reach the turbine blades [3]. Fouling and corrosion thereby caused lead to a reduction in the performance and/or of the life-time of the gas turbine. Due to the good water solubility of sea salt, water that passes through the filter can also wash off already deposited particles again and transport them into the turbine [4]. These effects are not taken into account in EN 779:2012, which is used also to test coarse and fine dust filters for the supply air of gas turbines.

2. Test procedure

Exposure of the filter media to test dust A2 and NaCl is done in a test channel according to DIN 71460, already

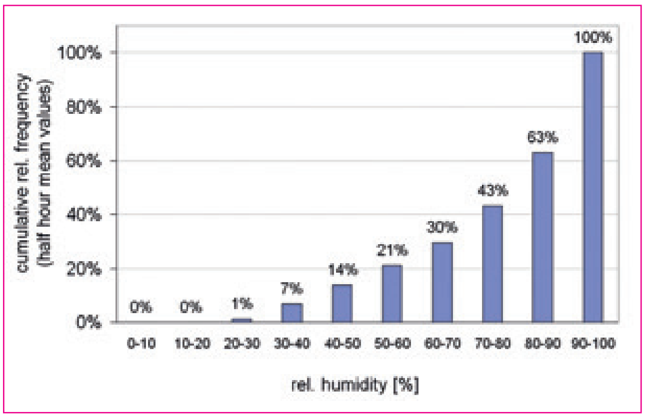

Fig. 1: Measured values of relative humidity (location Mülheim in 2011, provided by the Institute for Energy and Environmental Technology, Duisburg)

Fig. 2: Extended test channel at the University of Duisburg-Essen

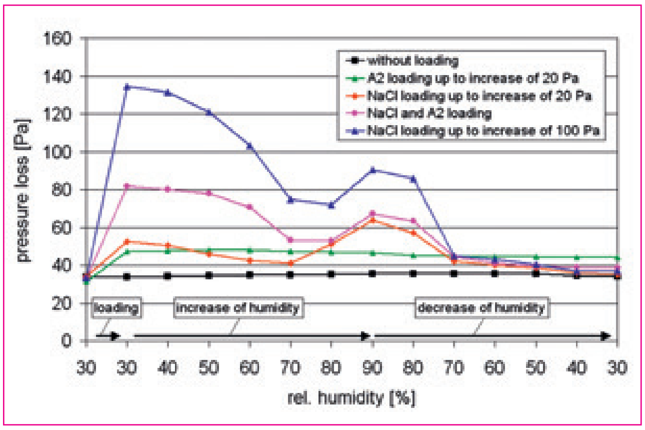

Fig. 3: Media test (filter surface area: 600 mm x 300 mm, volume flow: 80 m^3/h, T: 23°C)

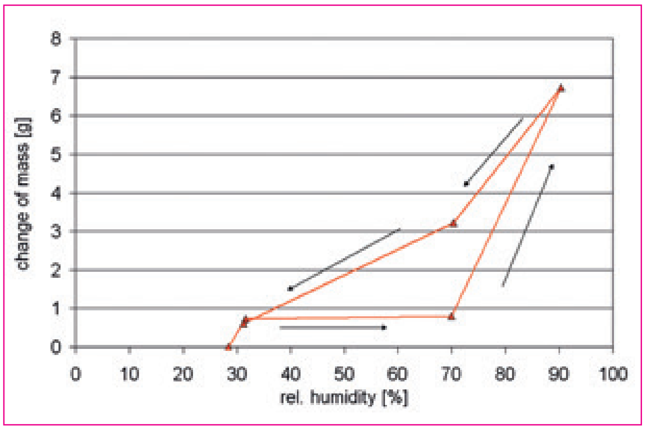

Fig. 4: Media test (filter surface area: 600 mm x 300 mm, volume flow: 80 m^3/h, T: 23°C)

described several times, at the Department of Nanoparticle Process Engineering at the University of Duisburg-Essen [6] (see Fig. 2). For the supply of A2, a rotating brush aerosol generator (RBG 1000, from Palas GmbH) is used. The generation of the NaCl aerosol is done by atomisation of an aqueous salt solution with an aerosol generator AGK 2000 (from Palas) with downstream diffusion dryer. A Welas 2300 aerosol spectrometer (from Palas), operating according to the scattered light principle, is used as the particle measuring instrument (Welas measurement => scattered light - latex spheres - equivalent diameter). The temperature of the volumetric air flow during the measurements is 23°C, and the relative humidity varies between 30% and 90%. Through the existing climate components, the temperature can be adjusted precisely to +/- 1.0 K and the relative humidity to +/- 2%. The mean velocity is approximately 15 cm/s.

3. Test results

In Fig. 3 the pressure loss is shown as a function of rel. humidity for different loading situations of the filter medium. Here, the pressure loss of the filter medium without any loading shows no dependence on humidity. In the second test series the unloaded filter medium is exposed to the A2 test dust until an additional pressure loss of approx. 20 Pa is present (new => 30%); the rel. humidity is slowly increased in steps of 10%. From 90% onwards it is reduced stepwise again. Also here, no dependence on the rel. humidity can be identified. If this test is carried out after separating NaCl particles in the filter media, one obtains first a continuous reduction of the pressure loss up to values of rel. humidity of approx. 70%. With a further increase of humidity to values of 90%, there is a substantial increase of pressure loss to more than 60 Pa, which, however, decrease to the original value by reducing the rel. humidity back to values of 30%. This behaviour of the pressure loss according to variation of the humidity is also to be found after concurrent loading with A2 and NaCl, as well as in the case of higher NaCl loading.

In Fig. 4 the hysteresis dependent on variation of humidity can be seen more clearly. Here the increase of the mass deposited on the filter is shown as a function of the rel. humidity. At a rel. humidity of 30%, approx. 1 g of dry salt particles are separated at first. From 70% onwards, the mass on the filter considerably increases and above the deliquescence point of 76% rel. humidity, solution droplets are present. After the reduction of the rel. humidity to 30%, the same mass is measured again as directly after the separation of salt particles.

To explain the identified changes of the pressure loss and in particular to be able to recognize the influence of humidity on the separated particles, SEM images have also been executed (Dr. Notthoff). Fig. 5 shows on the left side the formation of dendrites between the fibres through small salt crystals. These are no longer visible after moisture variation. Big solution droplets have formed predominantly at the fibre crossing points and after renewed drying, big salt crystals were present (Fig. 5 right side).

Fig. 6 depicts the result if, at the same time, A2 and NaCl are separated. In the dry state (30% rel. humidity) A2 and NaCl particles are present side by side. After moisture variation, predominantly bigger mixing particles appear at the fibre crossing points.

Though the present test results show a pressure dependence of the loaded filters

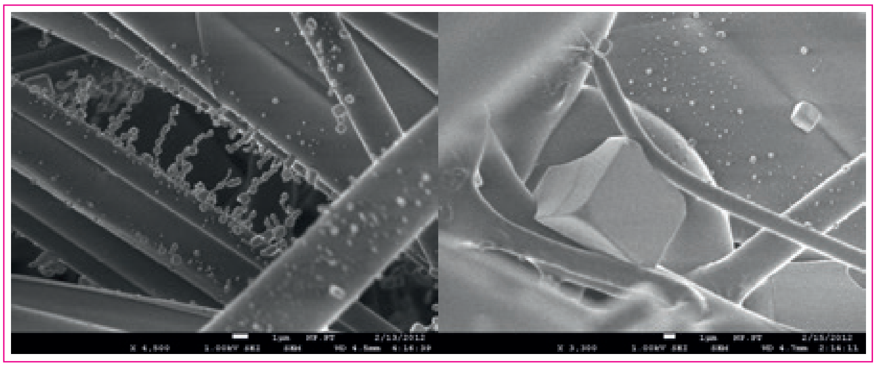

Fig. 5: Media test + NaCl exposure without/with moisture variation

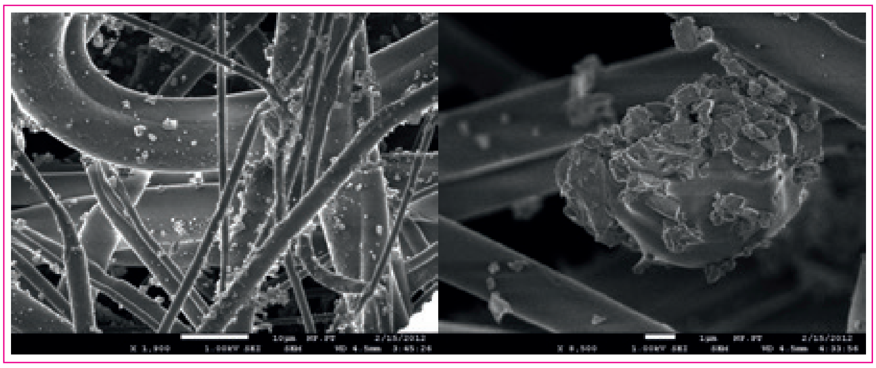

Fig. 6: Media test + NaCl/A2 exposure without/with moisture variation

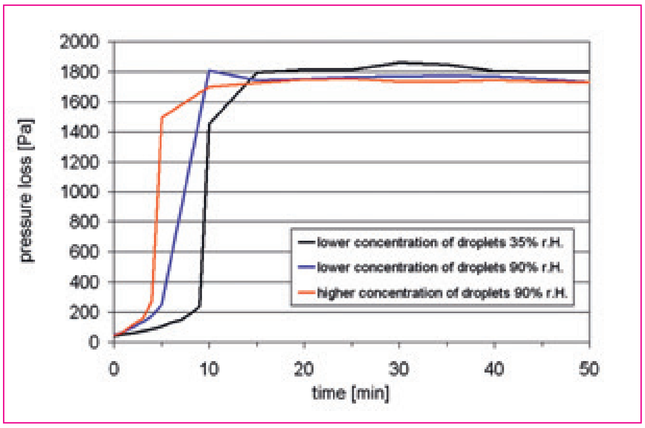

Fig. 7: Media test with water droplets (volume flow: 80 m^3/h, T: 23°C, filter surface area: 600 mm x 300 mm)

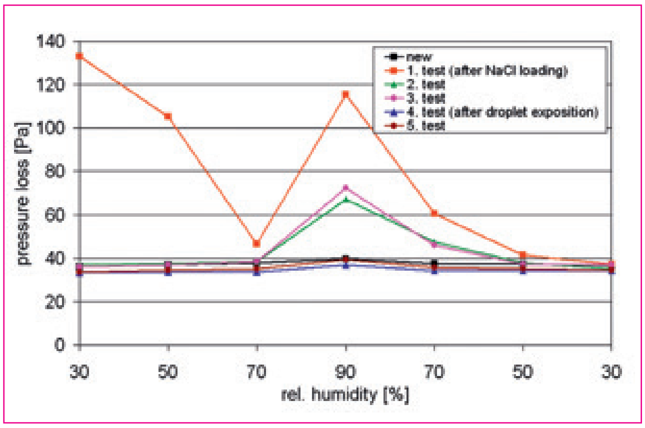

Fig. 8: Media test with water droplets

depending on the particle characteristics, extremely high pressure losses (known from some operating data) have not been ascertained. Therefore, another test series has been carried out, where finely dispersed water droplets are added into the test channel. The results are summarised in Fig. 7. After a very short time, the pressure loss rises from 25 Pa to a maximum value of 1800 Pa. This pressure value can be considered as a saturation state of the filter. It is independent of the rel. humidity in the channel and also does not change with a significant increase of the fed droplet number concentration (realised by an increase to an inlet pressure of 2 bar for the atomizer).

Fig. 8 once more indicates the pressure loss as a function of the rel. humidity. After loading with NaCl and spraying with water droplets (4th test), the pressure loss shows no more dependence on humidity. As the weighing of the filter has also illustrated, the salt is flushed out of the filter by the first application with water. The pressure loss and the filter mass achieve nearly the initial value. In Fig. 9 the pressure loss is displayed as a function of rel. humidity. These tests have been carried out on compact filters of fibreglass materials already used to protect gas turbines at locations close to the ocean. The pressure loss at this compact filter was similar to those measured at the filter media mentioned above.

Fig. 10 represents exemplarily the resulting fractional separation efficiency (with DEHS as test aerosol) in new condition, after variation of rel. humidity or application with Isopropanol (IPA). A series of individual tests have been carried out on a filter medium. It was pre-treated with Isopropanol (IPA) and charged with NaCl particles or water droplets. The results of these individual measurements can be summarised as follows: The fractional separation efficiency in new condition decreases significantly after IPA treatment. After humidity treatment or charging with water droplets the curves of the resulting fractional separation efficiencies lie between those of the curves for material in new condition and after IPA treatment and is dependent on the exposure time at higher values of rel. humidity or the intensity of the droplet exposure, respectively.

Conclusion:

Initial test data show:

> The variation of relative humidity causes a significant change of pressure loss if NaCl is present as loading aerosol.

> If additional water droplets are applied, then the pressure loss rises extremely. Existing particle layers may be washed away.

=> The transferability of performance data according to standardized tests is also limited concerning the influence of the humidity.

Literature:

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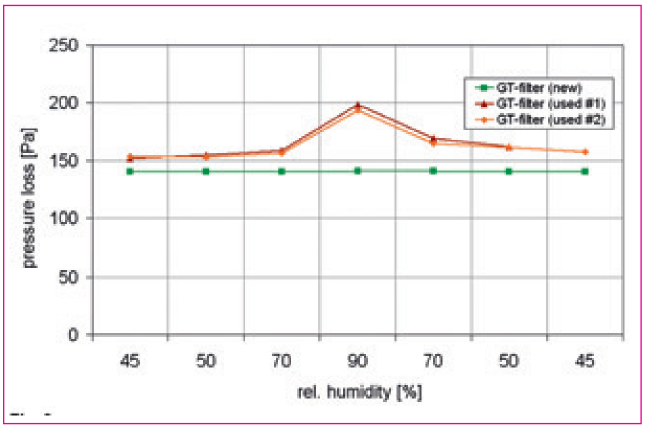

Fig. 9: Pressure loss measurements of used gas turbine filters (carried out on the HVAC test bench according to DIN EN779-2012 [5] and provided by the Institute for Energy and Environmental Technology, Duisburg

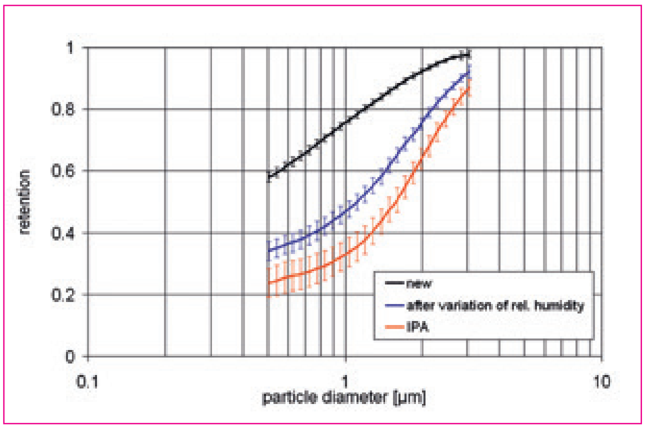

Fig. 10: Fractional separation efficiencies of the tested filter media (DEHS test aerosol)