ACTRIS recommendation for aerosol drying

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Humidity control

One particular problem during summertime or in warm and humid atmospheres is the high dew point temperature of the air. If this dew point exceeds 20-25°C, as in tropical or subtropical regions, water may condensate in the aerosol sampling lines or hydrophilic particles grow significantly in size and change their properties. The philosophy of long-term observational networks (WMO-GAW, EMEP, EUSAAR, ACTRIS) is, therefore, to limit the relative humidity (RH) in aerosol instrumentation to a maximum of 40% when determining physical and optical properties. Below 40% RH, the hygroscopic growth is limited and usually causes less than 10% diameter change compared to dry conditions.

Ambient dew point temperature

The choice of measures to dry a sample aerosol at an observation site depends on the difference between the maximum occurring ambient dew point temperature and the temperature under which the measurement is usually performed. In-situ physical and optical aerosol measurements are preferably made in an air-conditioned laboratory around 23 °C+/-2 °C. Assuming an indoor temperature of 21 °C, the following decisions might be made as an example:

<u>Ambient dew point temperature below 7°C</u>

Here, drying is not necessary because the RH in the sampling lines at room temperature will always be lower than 40%. A temperature difference of 14 K between the indoor and outdoor environments is sufficient to decrease RH far enough. The ambient temperature and RH are, for example, 7 °C and 100%, respectively, with a dew point of 7 °C. In this case, the RH of the aerosol at room temperature of 21°C is 40%.

<u>Ambient dew point temperature between 7 and 21°C</u>

In this range, the aerosol flow needs to be dried at least upstream of each instrument, because RH can exceed 40% in the sampling lines at room temperature. The ambient temperature and RH are, for example, 25 °C and 73%, respectively, with a dew point of 20 °C. The RH of the aerosol at room temperature would then be 93%, with no condensation occurring in the sampling pipes.

Ambient dew point temperature above 21°C

In this case, RH would always exceed 100% in the sampling lines at room temperature of 21 °C. This worst-case would lead to condensation of water in the sampling lines and may even damage instrumentation. Therefore, the main aerosol inlet flow has to be dried before entering the room. The ambient temperature and RH are, for example, 30°C and 65%, respectively, at a dew point temperature of 23°C. The RH would theoretically amount to 108% at room temperature, so that condensation would occur.

Drying technology

We present four possibilities drying the aerosol sample flow to a RH below 40%. Each of these options has their advantages and disadvantages. The choice might depend on the requirements of the measurement program and/or the technical facilities at the observation site.

Membrane dryers

Membrane dryer are elastic tubes based on water vapor-permeable polytetrafluoroethylene (PTFE). Commercially available membranes are products such as Nafion® or Gore-Tex® tubes. Nafion is a sulfonated tetrafluoroethylene and works as permeable membrane in which water vapor molecules are transported. Gore-Tex is a porous fluoropolymer membrane which has roughly one billion pores per cm^2. The small pore size enables water vapor molecules to pass through. Liquid water, however, cannot penetrate because of the hydrophobic nature of the membrane. In both types, the transport of water vapor is driven by the gradient of its partial pressure across the tube membrane. The air flow to be dried inside of the tube will reach an equilibrium RH if the residence time is sufficiently long. This final RH of the air flow is limited by the dew point temperature of the surrounding purge gas. To sufficiently dry an air flow, the dew point temperature of the purge gas should be below -20 °C. In practice, only Nafion driers are commercially available to dry air flows. These dryers consist of either a single Nafion tube or of a bundle of up to 100 individual tubes. While single tube types can be recommended to dry aerosol flows of approximately 1 l/min, bundle dryers should be used with care. The total flow rate used in a bundle dryer can be higher. The flow rate, however, is limited by the pressure drop of the bundle dryer. In addition, particles losses due to diffusion need to be taken into account. By design, the bundle Nafion dryer acts as a diffusion battery so that losses of particles smaller than 0.05 µm are significant. Moreover, the entrance of the bundle dryer acts as an impactor for coarse particles larger than 1 µm. The bundle Nafion dryers are, thus, only recommended for the particle size range 0.05-1 µm.

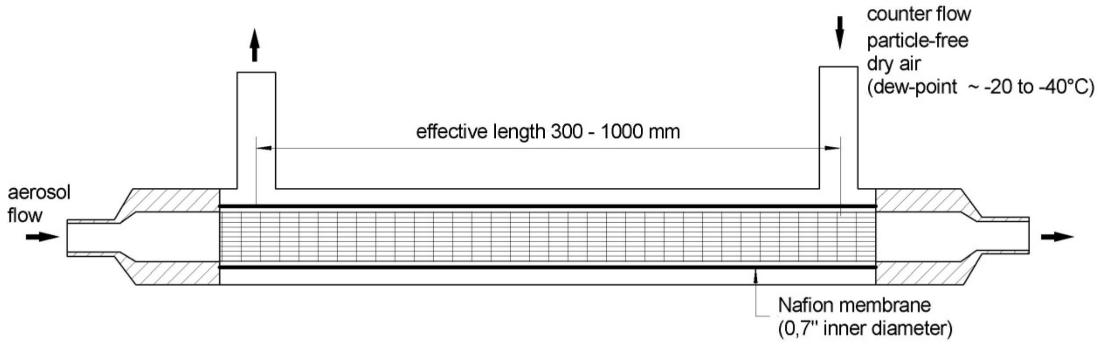

Figure 1: Sketch for aerosol dryer with low particle losses based on a Nafion membrane with 0.7 inch inner diameter

Alternatively, custom-designed Nafion dryers can be considered. Figure 1 illustrates the construction of a single-tube Nafion dryer with minimum pressure drop and particles losses. Here, a Nafion tube with inner diameter of 12 mm is used. Basically, the pressure drop and particle losses are very low in this device.

Advantage:

- A Nafion dryer does not need regular maintenance. The membrane only needs exchange when the drying efficiency drops.

Disadvantage:

- Purge air with a dew point temperature below -20 °C needs to be made available at the measurement site. This requires additional costs for an external compressed air system including adsorption dryer and filters.

<u>Diffusion dryers</u>

Diffusion dryers are widely used and available in commercial as well as custom-built designs. The principle is that a stainless steel screen forms an aerosol tube, and is surrounded by silica gel spheres. When the aerosol passes through the metal screen tube, water vapor is adsorbed by the silica.

Advantage:

- Inexpensive construction and use. However, the silica needs to be replaced and/or regenerated once saturated with water. The aerosol flow rate through the diffusion dryer may typically be on the order of a few l/min. The higher the flow rate the more often the silica needs to be exchanged.

Disadvantage:

- Labor-intensive use, especially in environments with high ambient dew point temperatures.

- Enhanced losses by diffusion. The equivalent length to calculate the losses by diffusion is much longer than the actual length (Wiedensohler et al; 2012).

An automatic diffusion dryer for long-term operation at humid environments is shown in Figure 2. The entire dryer is housed in cabinet and can be placed on roof the measurement laboratory or container. The aerosol enters the cabinet and is fed to one of two parallel stainless steel columns with an inner diameter of 70 mm and a total length of 800 mm. Each of these columns has one or more stainless steel mesh tubes surrounded by silica gel. The first column is used for aerosol drying, while the second column is regenerated at ambient pressure by dry air with a low dew point temperature, preferably below -20 °C. During regeneration, dry air is flushed through the column separated from the atmosphere.

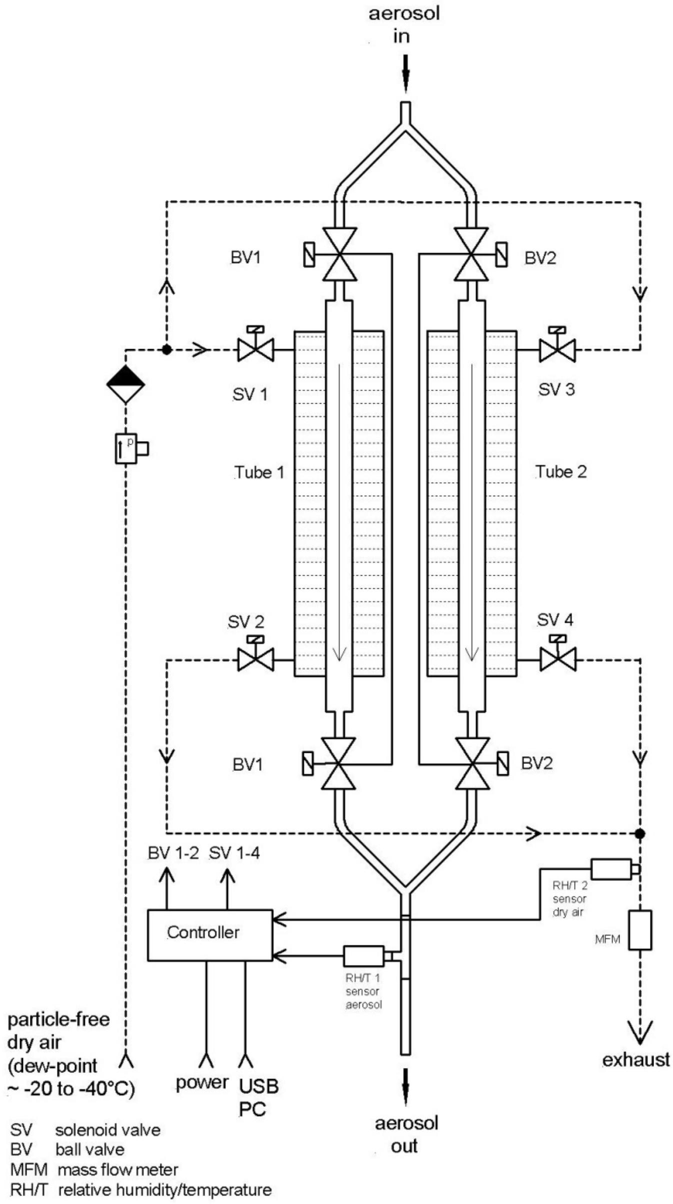

Figure 2: Sketch for a regenerative silica-based diffusion dryer (Tuch et al., 2009)

The temperature and RH of the dried aerosol and the currently regenerating column are continuously measured. The columns are switched if the RH of the dried aerosol increases above a certain threshold. For this purpose, each column can be shut at the top and bottom by motor-actuated ball valves. This generates the silica gel of the first column while the second is used to dry the aerosol.

<u>Drying by dilution</u>

Dilution of an aerosol sample with particle-free dry air is another possibility to reduce a critical RH. This method requires the continuous provision of particle-free dry air. The method also introduces several uncertainties into the system. First, the mixing between sample and zero air usually induces turbulences that causes some associated particle diffusion losses. This issue might be of secondary importance if the measurement is limited to accumulation mode particles, i.e. particles at the upper and lower end of the particle size distribution can be ignored. Secondly, the dilution ratio needs to be monitored with great accuracy to prevent propagation of the associated error into all measured ambient concentrations. However,

Advantage:

- The advantage here, diluting the aerosol is simple.

Disadvantage:

- Continuous provision of particle-free dry air and constant monitoring of dilution ratio required.
- If the ambient aerosol concentration is already low such as, e.g., in a tropical rainforest, dilution might be not considered.
- Potential particle losses due to turbulences.

Drying by heating

Heating an aerosol sample leads to a reduction of RH in the sampling line. It is insufficient to heat only the aerosol flow while keeping the instrument at room temperature, because the dew point temperature will remain unchanged. In case that both the aerosol flow and the instrument can be heated to reduce RH, a modest heating might be applied to reach a temperature that is at maximum 10 K above ambient temperature, but not higher than 40°C.

Advantage:

- Heating has no real advantage.

Disadvantage:

- Heating of the aerosol flow may irreversibly change the sample by evaporating the most volatile particulate species. For this reason, we discourage heating of aerosol sampling flow. Only a heated whole air inlet can be considered to evaporate cloud and fog droplets or to prevent accumulation of ice at the inlet.