FILTERS:
ADSORPTIVE GAS FILTERS

Key words: Adsorptive filters, gas, filter efficiency, adsorption capacity

1. SCOPE
The aim of this method is to measure the filter efficiency and the adsorption capacity of adsorptive filters for different gases of low concentration in air. The measurements are carried out by means of a specified test equipment.

The method also includes measurement of the pressure drop.

2. FIELD OF APPLICATION
This method is especially intended for testing the adsorptive material of a filter, but complete adsorptive filters can also be tested.

3. REFERENCES
ISO 5221 Guide to methods of measuring airflow rate in air handling ducts.

4. DEFINITIONS

Adsorption
The function of the filters, to reduce the amount of a specified gas in the set gas stream will in the following be referred to as "adsorption". Irrespective of the physical or chemical mechanism which is the basis for the function, the definition adsorption will be used.

Sample gas
The sample gas is the volatile substance which is added to an airflow to obtain a gaseous pollutant. This pollutant is to be removed by the adsorption filter.

Filter efficiency
The filter efficiency refers to the ability of the filter to remove the sample gas from the airstream. The filter efficiency, E, is calculated according to the following expression.

\[ E(t) = \frac{C_1 - C_2(t)}{C_1} \]

where

- \( C_1 \) = the concentration of sample gas before the filter at the point of time \( t_0 \) or \( t_F \) (ppm) (constant during the test)
- \( C_2(t) \) = the concentration of sample gas after the filter at the point of time \( t \) (ppm)

Filter efficiency curve
The filter efficiency curve describes the filter efficiency as a function of time.

Adsorption capacity
The adsorption capacity is the mass of sample gas \( m_A \), which the filter can adsorb per unit mass of filter, stated in percent

\[ x_A = \frac{m_A}{m_{filter}} \times \frac{q}{C_1} \times \frac{x}{100} \times \frac{E(t)}{dt} \%
\]

or

\[ x_A = \frac{m_A}{m_{filter}} \times 100 \%
\]

where

- \( q \) = airflow rate [m³/s]
- \( t \) = measuring time [s]
- \( x \) = conversion factor [mg/m³]
- \( m_A \) = mass of adsorbed sample gas [g]
- \( m_{filter} \) = total mass of filter used in the test [g]

Measuring time
The measuring time at the start of the measurement is \( t_0 \) [s]. The measuring time at the end of the measurement is \( t_F \) [s] (\( t_F \) is defined as the time when \( C_2(t)/C_1 = 0.95 \)).

Pressure drop
The static pressure drop \( \Delta P_{stat} \) [Pa] which originates from the flow across the filter media.

5. SAMPLING
A test sample is either an adsorptive filter without any kind of accessories or a complete filter with frame and filter holder.

The test sample must be packed by the producer/distributor in a plastic cover or similar, to protect it from gases which might be adsorbed by the filter.

6. METHOD OF TEST
6.1 Principle
The major purpose of this Nordtest method is to determine the filter efficiency and adsorption capacity of the adsorptive filter for different volatile gases.
In the test a constant amount of sample gas is injected into the airstream through a spreader. After dilution and mixing the gas passes through the filter cassette containing the sample object.

To determine the filter efficiency, air is continuously drawn into a gas analyser through measuring hoses from a point after the filter. The filter efficiency is calculated from the concentration of gas before and after the filter.

The adsorptive capacity is calculated from the filter efficiency curve.

The pressure drop as a function of the exhaust airflow shall be measured before the test of the filter efficiency.

6.2 Apparatus

The test is performed with an apparatus according to the description below, see Figure 1. The numbers in the figure refer to the numbers below. Case B is not described in the figure.

A. If the sample gas which is being used consists of a liquid at room temperature, the following equipment may be used.
   1. A syringe to inject liquid into a hot airstream
   2. An airpump to create the airstream
   3. A small oven to heat the airstream
   4. A cooler to cool the concentrated airstream

B. If the sample gas is gaseous the following may be used:
   A bottle with concentrated sample gas. The bottle shall be provided with a reduction valve, a manometer, a flowmeter and a massflow controller for delivery of a constant amount of sample gas.

C. The following description is valid for both cases A and B.
   5. An L-valve to control admission of the concentrated airstream to the filter cassette. When the valve is open, the gas stream passes through the filter cassette.
   6. A spreader, through which the sample gas is injected into the duct.
   The spreader can be made as a type of X-fitting with holes distributed to correspond to the area of cross section. Figure 2 shows the holes that were made for the sampling probe.

7. A small fan in front of the spreader.
8. Mixing device which consist of guide plates and a perforated plate to ensure that the sample gas is being distributed evenly through the cross section.
9. A straight duct on each side of the filter cassette. The straight ducts are used for measuring the pressure drop across the filter cassette and creating a mixing area, to give the gas enough time to be sufficiently mixed.
10. Sampling probes for sampling before and after the filter cassette. The holes in the probe should be distributed to correspond to the area of cross section. See Figure 2.
11. A filter cassette with an internal diameter of 125 mm in which the filter to be tested is mounted, see Figure 3. The filter cassette is used only when the adsorptive material of the filter is to be tested. When a complete filter is to be tested, a suitable airtight adapter must be used.
12. Airflow measuring device, possibly equipped with a pressure meter, placed at the end of the testing equipment.
13. Analysing equipment (e.g. FID), including a pump and tubing of nonadsorbing material (e.g. PTFE), for determination of the concentration of sample gas in the air. It is practical to use a sample exchanger for suction of air to the gas analyser.
14. Equipment to measure the pressure drop across the filter cassette.
15. Data logger or printer which registers the temperature, humidity and the concentration of sample gas after the filter continuously or at intervals during the test.

The temperature and relative humidity of air passing through the filter must be controlled and measured. This is done either by controlling the temperature and RH in a climate chamber, or by means of a suitable air treatment apparatus combined with insulating the test equipment to avoid heat loss.

It is important to check that the sample gas is uniformly distributed in the duct before the filter. This is done by traversing through the cross section. A difference of max 5 % medium content in the cross section is permitted.

6.3 Preparation of Test Samples

Before testing, the filter is conditioned by placing it in an oven or conditioned directly in the apparatus at 90 °C for at least 16 hours to set it to “zero”, which means that the filter is emptied of moisture and any volatile pollutant. After that, the filter is mounted in a special filter cassette (when only the material is to be tested) with the diameter $\varnothing = 125$ mm, see Figure 3.
6.4 Procedure

6.4.1 Pressure drop

The static pressure difference, \( \Delta P_{stat} \), shall be measured in the duct 5 \( D_e \) upstreams and downstreams from where the filter cassette is mounted, at nominal face velocities of 50 \%, 100 \% and 200 \% of the face velocity used in the test.

The pressure drop shall be measured with and without the test sample to calculate the pressure drop due to the test sample.

6.4.2 Measurement of filter efficiency

The analysing equipment is started. Make sure to follow the instructions for the gas analyser, especially the warm up period.

Air distribution is started. The air distribution is set at the required parameters, the temperature and RH at X ppm by means of the corresponding measuring and adjusting apparatus. The required parameters depend on what environment the filter will be used in. (A standard case and example are given in Appendix 1, Test conditions.) After this test run under stable conditions the concentrated sample gas is turned off by closing the valve (5).

After conditioning according to 6.3 the filter cassette is mounted, and clean air (without sample gas) is passed through the filter. The background level of adsorbable gas which is being adsorbed by the filter is the difference of the measured content before, \( C_{1B} \), and after, \( C_{2B} \), the filter. If the background level differs by more than 2 \% of the concentration \( C_1 \) the test must be interrupted. When the humidity balance is achieved in the filter the test can start.

The sample gas is turned on by opening the valve (5). This point of time \( t_0 \) simultaneously indicates the beginning of the "filter efficiency curve". The exposure continues until the condition of the incoming and outgoing sample gas concentration in the filter cassette reaches the value \( C_2(t)/C_1 = 0.95 \). This point of time \( t_F \) defines the end of the "filter efficiency curve".

During the test, airflow, temperature and relative humidity are registered. The tolerance value for temperature and humidity is observed. The measuring interval is shown in 6.6. After determining the last measured value, the incoming concentration is determined by changing measuring hose (10) or by using a sample exchanger. For the following calculations the lower registered value of the incoming concentration is to be used. If the registered incoming concentration differs by more than 5 \% from the concentration determined in the beginning, the measurement result is considered invalid.

6.4.3 Calculation of filter efficiency and adsorptive capacity

The filter efficiency, \( E \), is calculated according to the following expression.

\[
E(t) = \frac{C_1 - C_2(t)}{C_1}
\]

If the gas analyser is not specific for the sample gas, compensation of the background level (which is not being adsorbed) must be done using the following:

\[
C_1 = C_{1measured} - C_{2B} \\
C_2(t) = C_{2measured(t)} - C_{2B}
\]

The adsorptive capacity is calculated with reference to the "filter efficiency curve", which ends at the time \( t_F \) when \( C_2(t)/C_1 = 0.95 \).

The mass of sample gas \( m_{tot} \) to which the filter has been exposed during the test is obtained by \( m_{tot} = C_1 * x * q * t_F / 1000 \) [g].

The factor \( x \) implies the conversion of the concentration from ppm to the mass/volume unit mg/m\(^3\).

The factor \( x \) is different for every substance and can be calculated using the following equation:

\[
x = \frac{M}{V_m} \quad [mg/m^3]
\]
where

\[ M \] is the molecular weight of the sample gas

\[ V_m \] is the molar volume dms/mole at the actual temperature

An example with toluene gives the following conversion factor \( x \):

\[ \text{If } V_m = 24.1 \text{ dm}^3/\text{mole} \ (20 \ ^\circ\text{C}) \text{ and } M_{\text{toluene}} = 92 \text{ g/mol} \to x = 3.8 \text{ mg/dm}^3 \]

The mass of sample gas \( m_{\text{tot}} \) is represented in the diagram by the area \( F = 100 \cdot t_F \). The mass of adsorbed sample gas \( m_A \) is represented by the area \( F_A \).

\( F_A \) is calculated by numerical integration of the surface below the 'filter efficiency curve'. See Figure 4.

The mass of adsorbed Sample gas \( m_A \) is calculated by

\[ m_A = m_{\text{tot}} \cdot \frac{F_A}{F} \ [g] \]

To obtain the adsorption capacity, \( m_A \) is divided by the weight of the filter material.

\[ x_A = \frac{m_A}{m_{\text{filter}}} \cdot 100 \ [%] \]

![Filter efficiency curve](image)

**Figure 4. Filter efficiency curve**

### 6.5 Expression of results

#### 6.5.1 Pressure drop

The pressure drop shall be plotted versus the flowrate.

#### 6.5.2 Filter efficiency and adsorption capacity

A summary of the results can be presented according to the example shown in Appendix 2.

### 6.6 Accuracy

#### 6.6.1 Measuring and control device for the air flow, temperature and relative humidity

The instruments to be used are to be calibrated and shall guarantee a maximum control and measuring inaccuracy less than ±3 % for airflow, ±1 °C for temperature and ±3 % for the relative humidity RH.

The measuring interval shall be the same as for the gas analysis, see below.

#### 6.6.2 Measurement of pressure

The pressure difference is to be measured with a micro manometer with an inaccuracy less than ±2 % of the measured value.

#### 6.6.3 Gas analysis

The measuring range of the gas analyser must for every mixture of sample gas cover the present concentration range. A set limit at \( \leq 5 \ % \) of the incoming concentration \( C_1 \) must be guaranteed. The instruments must be calibrated with at least two defined gas concentrations in this range. The measuring inaccuracy shall amount to \( \leq 3 \ % \ C_1 \).

Two conditions must be fulfilled for the measuring interval:

- Between two measurements the downstream concentration \( C_2 \) must not change by more than 5 % of the upstream concentration \( C_1 \).
- The measuring interval is set to maximum 5 minutes.

### 6.7 Test report

The test report shall include the following information, if relevant:

a) Name and address of the testing laboratory

b) Identification number of the test report

c) Name and address of the organisation or the person who ordered the test

d) Purpose of the test

e) Method of sampling and other circumstances (date and person responsible for the sampling)

f) Name and address of manufacturer or supplier of the tested object

g) Name and other identification marks of the tested object

h) Description of the tested object

i) Date of supply of the tested object

j) Date of the test

k) Test method

l) Conditioning of the test specimens, environmental data during the test (temperature, air pressure, RH, sample gas, concentration etc.)

m) Identification of the test equipment and instruments used

n) Any deviation from the test method or special phenomena noted during the tests

o) Test results (use SI units)

p) Inaccuracy or uncertainty of the test result

q) Date and signature.
Test condition

**Standard case**

When it is considered that the environment of the filters is not harsh, the filters whose performance is to be compared should be tested according to the standard case, which means the following parameters:

- Temperature 20 °C, RH 30 %, face velocity 0.4 m/s, sample gas toluene, concentration 10 ppm, thickness of the filter 20 mm (if it is optional).

**Kitchen range hood case**

The required parameters are the following:

- Temperature 30 °C, RH 80 %, face velocity 0.4 m/s, sample gas toluene, concentration 10 ppm, thickness of the filter 20 mm (if it is optional).
### Summary of results

<table>
<thead>
<tr>
<th>Filter type (pellets or mat)</th>
<th>Type designation firm</th>
<th>Filter holder during the test</th>
<th>Thickness of the filter (mm)</th>
<th>Weight of the filter (kg/m²)</th>
<th>Temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Face velocity (m/s)</th>
<th>Sample gas</th>
<th>Concentration (ppm)</th>
<th>Filter efficiency 5 min after start (%)</th>
<th>Adsorption capacity (%)</th>
<th>Pressure drop at face velocity used (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated carbon (pellets)</td>
<td>EX 1, Carbon AB</td>
<td>Filter cassette</td>
<td>20</td>
<td>12.2</td>
<td>20</td>
<td>30</td>
<td>0.4</td>
<td>Toluene</td>
<td>10</td>
<td>80</td>
<td>4.5 %</td>
<td>80</td>
</tr>
</tbody>
</table>