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# Test methods for evaluating degradation of characteristics of cleanable filter media

*Méthodes d’essais pour l’évaluation de la dégradation des propriétés des medias filtrants décolmatables*

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# Foreword

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The committee responsible for this document is ISO/TC 142, *Cleaning equipment for air and other gases*.

# Introduction

The main purpose of using cleanable filter is, of course, to separate dust particles from dirty gases. They are usually designed to be usable for as long as two years to four years. However, it is very hard to design and/or select filter media properly, since their important characteristics of collection performance and residual pressure drop change with operation time. Physical and chemical properties of filter media, such as degradation in tensile strength, tenacity and so on, also change with time. Those changes can damage filter media and this can result in the breakage of bag filters and leakage of dust to the atmosphere. Hence the evaluation of these performances is also important for the rational design and the selection of appropriate filter media. ISO 11057:2011 has been published to meet the demand for the evaluation of filtration characteristics.

Changes in physical and chemical properties of filter media are caused by many factors, such as heat, corrosive gases, and mechanical reasons like clogging weave openings and increasing size of weave openings, the combination of those factors and so on (see Annex A). These changes are mostly adverse effects to filter media. Degradation proceeds very slowly, and thus, it takes a long time before recognizable and/or measurable change appears. Furthermore, the appearance of change depends on the combination of causes and fibre material. These facts are the main reason why mechanism of property changes has not been well understood despite its practical importance.[1]-[13] Hence, the characterization or evaluation methods for filter media have not been established yet[14][15] (see Annex B).

Nevertheless, there are demands for the establishment of a guideline for systematic characterization and evaluation of property change of filter media with respect to their relevant long-time operation not only from manufacturers of filter media, but also from producers and users of filter installations, especially the users treating combustion exhaust gases.

To evaluate degradation of filter media in a laboratory, it is important that experiment can be done in a relatively short time period by using controllable single or a small number of variables, i.e. causes of change.

Furthermore, it is important that the resulting effects are measureable. From this point of view, heat intensity is controllable by changing heating temperature and the intensity of corrosive gas is also controllable by changing gas concentration. Thus, their effect is expected to be accelerated. Of course, the effects can be evaluated by the degradation of tensile stress.

Evaluation of property change of filter media by corrosive gases can be done by contacting filter media with those corrosive materials in any phases, i.e. gas, liquid and solid state. Testing by dipping filter media into a solution of corrosive materials is easy and the resulting effects are expected to be obtained in a short period of time. Chinese Standard, GB/T 6719:2009 adopts this method.[16] Solid state testing can be carried out by hard contact of filter media but it will take a long time and it is very hard to control the intensity of corrosiveness.

Testing under the gaseous state takes much longer than a liquid type test but the intensity of corrosiveness is controllable and it is much easier than the test under the solid state. Furthermore, test temperature and gas conditions except corrosive gas concentrations, are similar to the actual operation condition of filtration, which is suitable (see Annex B). Hence, in this International Standard, test methods for evaluating degradation characteristics of cleanable unwoven filter media with synthetic fibre by heat and corrosive gases are standardized because they are most widely used for bag filtration.

The major objective of this International Standard is to specify the testing method to assess the relative change of physical performances of new and used cleanable filter media for industrial application, by exposing it in hot and/or corrosive gas conditions [17][18].

# Test methods for evaluating degradation of characteristics of cleanable filter media

## 1 Scope

This International Standard specifies a standard reference test method useful to assess the relative degradation characteristics of cleanable filter media for industrial applications under standardized simulated test conditions. The main purpose of testing is to obtain the information about relative change of properties of filter media due to exposure to the simulated gas conditions for a long time. The main target of this International Standard is the property change of nonwoven fabric filters because they are frequently used under similar circumstances to the test gas conditions described in this International Standard.

The results obtained from this test method are not intended for predicting the absolute properties of full scale filter facilities. However, they are helpful for the design of a bag filter and selection and development of appropriate cleanable filter media, and for the identification of suitable operating parameters.

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4606, *Textile glass — Woven fabrics — Determination of tensile breaking force and elongation at breaking by strip method*

ISO 13934-1, *Textiles — Tensile properties of fabrics — Part 1: Determination of maximum force and elongation at maximum force using the strip method*[1]

ISO 29464:2011,*Cleaning equipment for air and other gases — Terminology*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 29464:2011 and the following apply.

**3.1**
**aged filter sheet**
filter sheet exposed under simulated hot and corrosive gas conditions for a preset period of time to evaluate the change of filter properties

**3.2**
**air permeability**
gas volume flow rate per unit filtration area at pressure drop of 124,5 Pa

**3.3**
**average gas concentration**
mean concentration of test gases during the exposure

---

[1] This International Standard replaced ISO 5081, *Textiles — Woven fabrics — Determination of breaking strength and elongation (Strip method).*

**3.4**
**batch type exposure chamber**
chamber in which filter sheets are exposed to stationary test gas mixture

**3.5**
**chemical degradation**
degradation of chemical properties of filter media by the interaction with test gases

**3.6**
**cleanable filter**
filter designed to enable the removal of collected dust by appropriate technique

[SOURCE: ISO 29464:2011; 3.1.77]

**3.7**
**continuous-flow-method**
exposing method of filter sheet, which is exposed in a continuous flow of test gas mixture

**3.8**
**corrosive gas**
chemicals which react with filter media and change its chemical and physical properties

**3.9**
**degradation**
change in physical and chemical performances of filter media by the interaction with corrosive gases

**3.10**
**elongation**
incremental change in length of test specimen by tensile test

**3.11**
**elongation at maximum load**
incremental change in length of test specimen at maximum load in tensile test

**3.12**
**elongation ratio**
ratio of elongation of test specimen to its initial length between holders or its percentage

**3.13**
**elongation ratio at maximum load**
ratio of elongation of test specimen at maximum load in tensile test to its initial length between holders

**3.14**
**exposure chamber**
chamber to expose test filter sheet to corrosive gases

**3.15**
**filter media**
material separating particulate matter from gases and characterized by its separating structure and its structural and/or textile-technological characteristics

**3.16**
**flow-through type replacement**
method to replace test gas in the batch type exposure chamber by introducing test gas continuously to the chamber

**3.17**
**initial load**
initial load applied on the test specimen at the start of tensile test

**3.18**
**length between holders**
length between holders of top and bottom holding chucks positioned at the start of the tensile test

Note 1 to entry: See Figure 3.

**3.19**
**load**
tensile strength of test specimen observed in the tensile test

**3.20**
**non-continuous-flow-method**
exposing method of filter sheet, which is exposed in still test gas mixture

**3.21**
**nonwoven fabric**
filter media using fabric made from long fibres, bonded together with each other by chemical, mechanical, heat or solvent treatment

**3.22**
**number of replacement**
number of test gas replacement for whole heating space volume of the test chamber

**3.23**
**replacement of gas**
exchange gas to maintain test gas concentration within certain concentration range

**3.24**
**retention of tensile strength**
ratio of tensile strength of the test specimen subjected to thermal and/or acid gas exposure to that of the test specimen without the exposure

**3.25**
**strip method**
method of implementing tensile test with holding whole width of the test specimen with a holding device

**3.26**
**tensile speed**
speed to pull a test specimen in tensile test

**3.27**
**tensile strength**
value of the maximum load divided by the width of test specimen

**3.28**
**test gas**
gas which may cause changes in physical propertied of filter media to be used for tensile test

**3.29**
**vacuum replacement**
method to replace test gas in the batch type exposure chamber by the use of vacuum

**3.30**
**thermal exposure**
expose filter media at an elevated temperature to accelerate the change of its physical properties

**3.31**
**woven fabric**
filter media using a fabric formed by weaving

## 4 Symbols and abbreviated terms

| | | |
|---|---|---|
| $A$ | total surface area in a filter media | $(\mathrm{m}^2)$ |
| APA | nonwoven fabric with Aromatic Polyamide fibres | |
| $C$ | gas concentration | $(\mathrm{mg} \bullet \mathrm{m}^{-3})$ |
| $F(A)$ | constant related to total surface area of filter media | $(\mathrm{N} \bullet \mathrm{mm}^{-1})$ |
| Glass | fabric with Glass fibres | |
| $K$ | effective reaction constant | $(\mathrm{s}^{-1})$ |
| $k$ | reaction constant | $(\mathrm{m}^3 \bullet \mathrm{mg}^{-1} \bullet \mathrm{s}^{-1})$ |
| $L_1$ | length of specimen | (mm) |
| $L_2$ | length between holders | (mm) |
| $L_3$ | length of holder | (mm) |
| MD | machine direction | |
| $P$ | load | (N) |
| $P_{\mathrm{max}}$ | maximum load | (N) |
| $p$ | pressure | (Pa) |
| PI | nonwoven fabric with Polyimide | |
| PPS | nonwoven fabric with Polyphenylene Sulfide | |
| PTFE | nonwoven fabric with Polytetrafluoroethylene | |
| $Q$ | flow rate of test gas | $(\mathrm{l} \bullet \mathrm{min}^{-1})$ |
| $q$ | air permeability of filter | $[(\mathrm{cm}^3 \bullet \mathrm{s}^{-1}) \bullet \mathrm{cm}^{-2}]$ |
| $S$ | tensile speed | $(\mathrm{mm} \bullet \mathrm{min}^{-1})$ |
| $T$ | temperature | (°C) |
| TD | transverse direction | |
| $t$ | exposure time | (s),(h) |
| $V$ | volume of the exposure chamber | (l) |
| $w$ | width of holder | (mm) |
| $\delta$ | elongation | (mm) |
| $\delta_{\mathrm{max}}$ | elongation at maximum load | (mm) |
| $\varepsilon$ | elongation ratio | (%) |
| $\varepsilon_{\mathrm{max}}$ | maximum elongation ratio | (%) |
| $\tau$ | tensile strength | $(\mathrm{N} \bullet \mathrm{mm}^{-1})$ |

| | | |
|---|---|---|
| $\tau_0$ | tensile strength of the filter media without exposure | $(\mathrm{N{\bullet}mm^{-1}})$ |
| $\Delta\tau$ | tensile strength difference between after and before exposure | $(\mathrm{N{\bullet}mm^{-1}})$ |

## 5 Principle

Physical performance of filter media mostly degrades with time because of long time exposure under severe gas conditions, such as hot and/or corrosive gas conditions. When filter media is exposed to hot and/or corrosive gas atmospheres such as NOx, SOx, HCl and moisture etc., those gases are considered to interact with materials in fibres and thus affect crystallinity and/or other bonding of molecules in fibres, i.e., they decompose fibre in the media to some extent. Hence, these conditions result in irreversible damage to media and weaken physical performances like tensile strength, elongation and so on.

Details of the above mentioned process have not been understood well yet, but tensile strength after filter media is exposed to corrosive gases and/or high temperature is expressible by the following formula with the assumption that degradation reaction between corrosive gas and some reactive component in a fibre is pseudo linear.

$$\tau(0) - \tau(t) = \Delta\tau = F(A)\left[1 - \exp(-Kt)\right] \qquad (1)$$

where

| | |
|---|---|
| $T(t)$ | tensile strength of filter media; |
| $F(A)$ | unknown constant related to total surface area of filter media; |
| $K$ | effective reaction constant and is related to the degradation of media. |

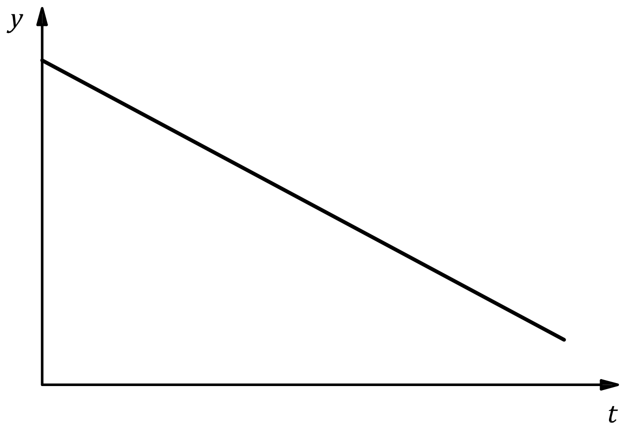
The first derivative of Formula (1) becomes,

$$\frac{d\Delta\tau}{dt} = -\frac{d\tau}{dt} = KF(A)\exp(-Kt) \qquad (2)$$

Similar formula can be obtained applying Hooke’s law between tensile strength and elongation as:

$$\frac{d\Delta\delta}{dt} \propto KF(A)\exp(-Kt) \qquad (3)$$

Formula (2) and Formula (3) suggest that a straight line is obtained when the logarithm of first derivative of tensile strength of filter media and elongation is plotted against exposure time *t* in a semi-log paper, as shown in Figure 1. The slope of the line in Figure 1 gives *K* [see the details of the derivation of Formula (2) and Formula (3) in Annex C].



**Key**

$t$ exposure time (h)

$y$ $lg(-d\tau/dt)$

**Figure 1 — Relation between gradient of tensile strength of filter media and exposure time to corrosive gas**

The degradation process is usually very slow, and thus, measurable changes in the physical properties (like tensile strength and elongation) usually appear after filter media has been exposed for a very long time period. Hence, it shall be accelerated by some means to evaluate the effect through an experiment.

In this International Standard, degradation is accelerated by exposing filter media to a higher corrosive gas concentration and higher gas temperature.

## 6 Test specimen, equipment and test procedure

### 6.1 General

The test specimen, equipment and procedure at each step shall be chosen so as to ensure good reproducibility and repeatability of the test. The equipment to prepare the samples for the measurement generally consists of the following main components: gas supply system; exposure chamber and heating system; exhaust gas treatment unit; vacuum pump; and gas analysing system. Figure 2 shows a schematic diagram of the equipment.

The test shall be carried out using the following three steps:

Step 1: Preparation of filter sample sheets for gas exposure

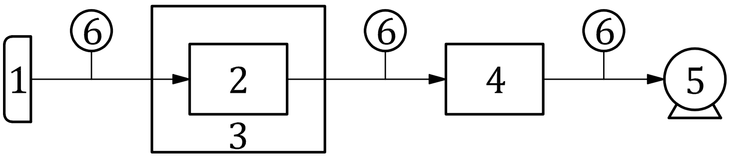
> Air permeability of filter sample sheets for gas exposure shall be similar, so as to obtain reliable data (described in 6.2). Air permeability of filter media with a size defined in 6.2.3 shall be measured and suitable sheets selected based upon the measured air permeability.

Step 2: Exposure of sheets

> Sheets selected at Step 1 shall be exposed to thermal and/or corrosive gas conditions (described in 6.3 and 6.4).

Step 3: Tensile test

> Tensile specimens of machine direction (MD) and transverse direction (TD) shall be cut from exposed sheets. Then tensile strength and elongation of specimens shall be measured by the scheme described in Clause 7.



**Key**

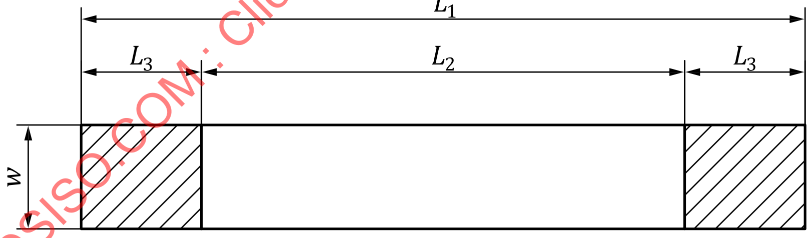
1 gas supply
2 exposure chamber
3 heating system
4 gas treatment
5 vacuum pump
6 gas analysis

Figure 2 — Schematic diagram of equipment to prepare sample for physical performance test

## 6.2 Preparation of sheets for gas exposure

### 6.2.1 Shape and size of tensile specimen

A rectangular shape without shoulders between holders shall be adopted in tensile tests as shown in Figure 3, since filter media is soft and porous. Hence the size of the sheet of filter media to expose shall be large enough for the tensile test to obtain reliable and reproducible data. According to the results shown in Annex D, the measured tensile strength of nonwoven filter media with a rectangular test sheet does not depend on the width of holder $w$, in the range from 20 mm to 50 mm and length between holders $L_2$, from 80 mm to 120 mm (see Annex D). Hence, in this International Standard, a rectangular shape with $w$ = 25 mm width and $L_2$ = 100 mm in length between holders shall be adopted and other dimensions are determined as $L_3$ = 50 mm, $L_1$ = 200 mm.



**Key**

$L_1$ length of specimen
$L_2$ length between holders
$L_3$ length of holder
$w$ width of holder

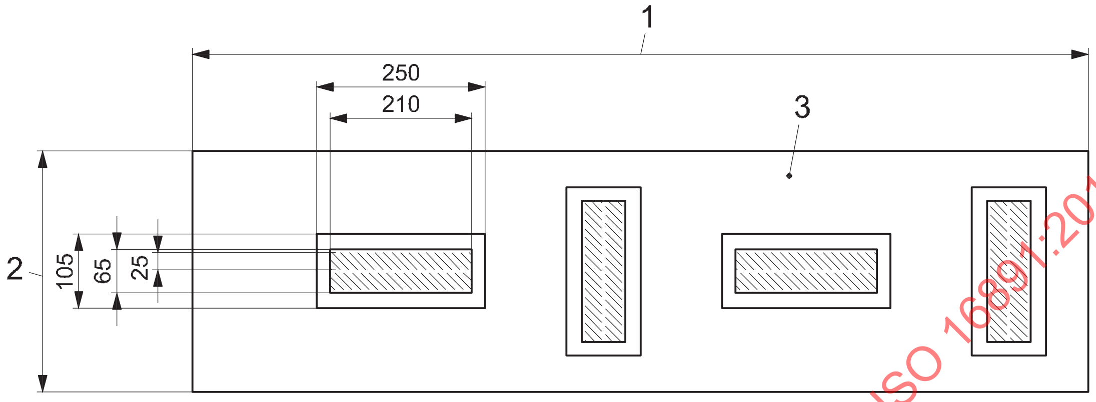
Figure 3 — Shape of tensile specimen

### 6.2.2 Sample sheet for exposure

To deteriorate every filter sheet equally, test gases shall have contact with all fibres in the filter for the whole exposure period. Therefore, a continuous-flow-through type of test gas flow shall be adopted. Here, in the continuous-flow-method, the test gas flow through sheets during whole the exposure period is the same as during actual bag filter operation. Test gases used for the exposure are corrosive except $O_2$, and, thus, it is important to minimize gas consumption not only because of the cost of gas but also for safety reasons. The sample sheet holder and flow rate for the exposure is specified in 6.3.

Based on these considerations, the size of the sheet to be exposed to test gases was determined as 105 mm × 250 mm, in which test gas flows through the central part with an area of 65 mm × 210 mm, which shall be large enough to cut two tensile test specimens of 25 mm × 210 mm, as shown in Figure 4. Sample sheets shall be cut with the size of 105 mm × 250 mm in the central part of the filter media roll with at least four sheets for each direction.

Dimension in mm



**Key**

1 MD

2 TD

3 filter media

Figure 4 — Preparation of sample sheet for test gas exposure

### 6.2.3 Selection of sample sheet through air permeability measurement

The tensile strength of a specimen strongly depends on the structure of the specimen. Nonwoven filter media is composed of bonded entangling fibres. They distribute uniformly macroscopically but not microscopically because of manufacturing mechanism and it results in the unevenness of packing density or mass of fibres. Unevenness of fibre distribution in the filter, i.e. filter structure, can change physical properties such as tensile strength and/or elongation, air permeability and so on. In this sense, it is essential to eliminate filter media with different structures from the test to avoid the fluctuation of measured data due to the unevenness of filter structure. Hence, by sample sheets with similar structure shall be selected before they are exposed to test gases structure. However, it is difficult to select from the product information about the media given by manufacturer, i.e. it is usually limited to mean value of air permeability and mass of fibres per unit area of the filter. However, air permeability of filter media is the same when the filter structure is the same. This means that filter media with similar structures show a similar air permeability so that air permeability can be used for the selection of filter media with a similar structure. Hence at least four sample sheets for gas exposure shall be selected according to the air permeability of each sheet. Air permeability of each sheet shall be within ±10 % from the mean air permeability of the filter media specified by the manufacturer.

### 6.2.4 Filter media for exposure

In the range of this International Standard, any nonwoven filter media made of synthetic fibres can be used for the test, since degradation is evaluated by the change of tensile strength and elongation of the media.

## 6.3 Sample preparation

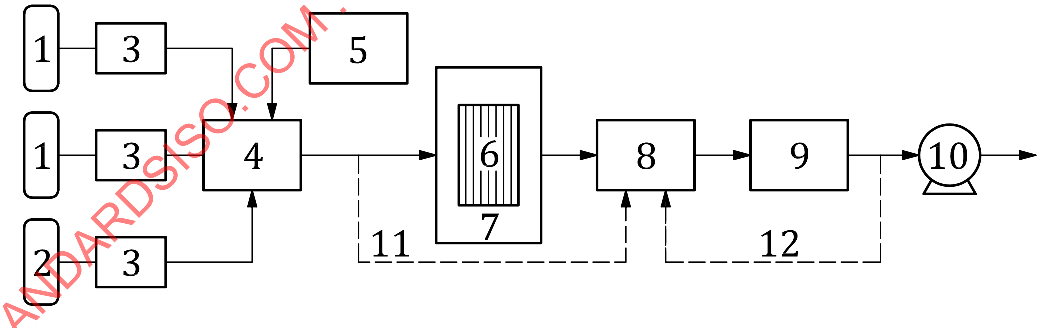
### 6.3.1 Exposure system

In the practical bag filtration, hot and/or corrosive gases, of course, flow through filter media and thus, every fibre in the filter is exposed to corrosive gas at the same concentration so that degradation takes place evenly regardless of the location in the filter, i.e. not only its surface but also its inside.

The purpose of exposing filter media to hot and/or corrosive gas conditions is to accelerate the change of physical performances of the media by satisfying certain contact between every fibre in the filter media and corrosive gas, i.e. to prepare an aged filter sample. To meet these requirements, a gas temperature and through type chamber shall be adopted for the sample sheet exposing method. This is a continuous-flow-through method and the test gas flows continuously in and out the chamber. The sample sheets are placed in the chamber like a barrier to block the test gas flow rate. Hence, the test gas flows through the inner space of the media and thus contacts with all fibres during its passage through the sheets. Since contact time between fibres and the test gas is short even at a very slow gas stream, the consumption of test gas by the interaction with fibres is considered to be small because of the low reaction rate. Therefore, the test gas concentration change from inlet concentration is considered to be small. Outlet test gas shall be exhausted directly to the atmosphere after an appropriate de-toxifying treatment, i.e. a circulating-gas type exposure system shall not be adopted, since some unknown gas components, which have some side effects, can be produced by the interaction between test gas and filter media.

Figure 5 shows an example of a continuous flow through system. It is composed of a gas supply unit, heating and exposure unit, gas concentration monitoring unit and exhaust gas cleaning unit. Test gases and balance gas are fed from gas cylinders. Moisture is generated by heating. Their flow rates, especially test gases with small flow rates, shall be precisely controlled by mass-flow-controllers to maintain test gas concentration constant. After they are mixed well at the mixing box, they are introduced to the exposure chamber in a heating system. Inlet concentration of the test gas shall be measured before and during the exposure.

NOTE Test gases are a potential hazard. If test gases leak, corrosion of material occurs and thus special care is needed.



**Key**

| | | | |
|---|---|---|---|
| 1 | test gas | 7 | heating system |
| 2 | balance gas | 8 | gas analyzer |
| 3 | mass flow controller | 9 | gas treatment device |
| 4 | mixing box | 10 | pump |
| 5 | moisture generator | 11 | gas line for inlet gas concentration measurement |
| 6 | expose chamber with filter sample sheets | 12 | gas line for gas concentration measurement for exhaust gas |

**Figure 5 — Example of continuous flow through type setup for exposure test**

Figure 6 shows an example of an exposure chamber which is placed in the heating system. The chamber to install the sample case (shown in Figure 7) shall be an airtight box with inlet and outlet pipes and temperature sensors. The sample case is composed of a case and a frame plate, and shall have the capacity to hold a maximum of eight filter sample sheets and separators. The sample sheets with MD and TD shall be piled up as described in 6.3.1. A separator sheet shall be inserted between each pair of adjacent sample sheets to prevent direct interaction between fibres in different sample sheets. The frame plate shall be placed on the top of the pile. Then, they shall be slid into the case and pressed to the case by screws to prevent the leakage of test gas from the periphery and the entanglement of fibres in different sheet (as shown in Figure 7). Then, the sample case shall be fixed to the chamber by pressing down the lid of the chamber. Materials used for the chamber and the sample case shall have an excellent corrosion and adsorption resistance against the test gases. Furthermore, separator sheets shall be non-cohesive with the test sample sheet material and of a suitable thickness, such as a PTFE sheet with 1 mm thickness.

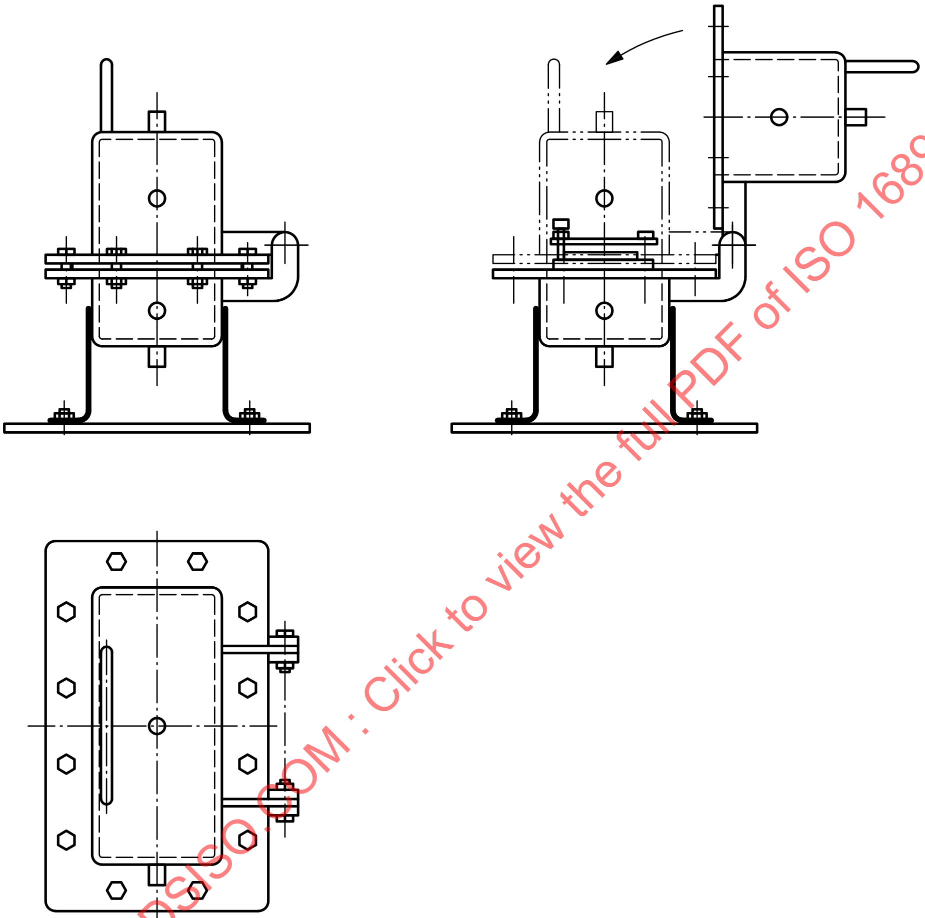
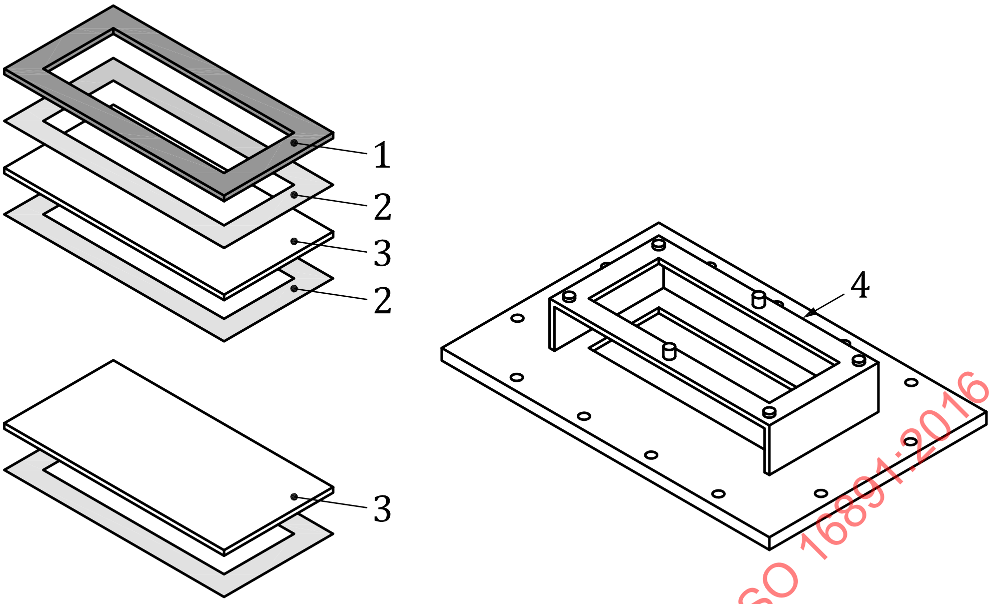


Figure 6 — Exposure chamber



**Key**

| | |
|---|---|
| 1 | frame plate |
| 2 | separator |
| 3 | sample filter sheets |
| 4 | sample case |

**Figure 7 — Details of sample case**

A chamber other than the flow-through-type chamber can be used for the sample preparation if it is an equivalent type of apparatus by comparison with the standard reference apparatus (see Annex E).

A comparison shall be performed with the standard reference apparatus according to the procedure specified in this International Standard: three filter media shall be tested on both apparatus simultaneously (same location and same time) under the same test conditions.

### 6.3.2 Heating system

The heating system, inside which the exposure chamber is placed, is used for heating the chamber. It shall be capable of heating up to the higher temperature than the maximum exposure temperature. The temperature of the system shall be controlled within test temperatures ±1 %. However, control accuracy of ±5 % can be adoptable through the negotiation between stakeholders when the suitable temperature measuring device with required accuracy is not commercially available.

### 6.3.3 Test gas supply system

Any type of gas supply system may be used as far as specified gas composition and flow rate are maintained during the exposure test. Examples of gas supply system are shown in Figure E.4.

### 6.3.4 Gas analyzer

Outlet concentration of the test gas shall be measured by an appropriate instrument, either continuously or intermittently, to keep the concentration constant during the exposure and also to determine the accurate gas concentration.

### 6.3.5 Gas treatment device

Gases used in this test are corrosive and are harmful even at low concentration. Therefore, appropriate gas treatment such as absorption or neutralization shall be performed before they are released to the atmosphere. Gas concentration after treatment shall be monitored occasionally for safety.

## 6.4 Exposure conditions and procedures

### 6.4.1 Exposure conditions

#### 6.4.1.1 Composition of test gas

Exposure of corrosive gas shall be chosen so as to be appropriate for the usage of the filter media from Table 1. However, test gas and its concentration (other than listed in Table 1) may be chosen after negotiation between stakeholders.

**Table 1 — Gas composition for exposure**

| Exposing gas | Gas composition |
|---|---|
| $N_2$ | $N_2$: 100 % (only for thermal exposure) |
| $NO_x$ | $NO_2$: 0,1 %; $O_2$: 10 %; $N_2$: balance |
| $SO_x$ | $SO_2$: 0,1 %; $N_2$: balance |
| | $SO_2$: 0,1 %; moisture: 20 %; $N_2$: balance |
| HCl | HCl: 0,2 %; $N_2$: balance |
| | HCl 0,2 %; moisture 20 %; $N_2$: balance |
| Mixed gas 1 | $NO_2$: 0,1 %; $SO_2$: 0,1 %; HCl: 0,2 %; $O_2$: 10 %; $N_2$: balance |
| Mixed gas 2 | $NO_2$: 0,1 %; $SO_2$: 0,1 %; HCl: 0,2 %; $O_2$: 10 %; moisture: 20 %; $N_2$: balance |

#### 6.4.1.2 Gas temperature

Temperature of exposure gas shall be determined about 10 % higher than the service temperature of filter material in the practical filtration operation but it shall be lower than its softening temperature. However, the test temperature may change after negotiation between stakeholders.

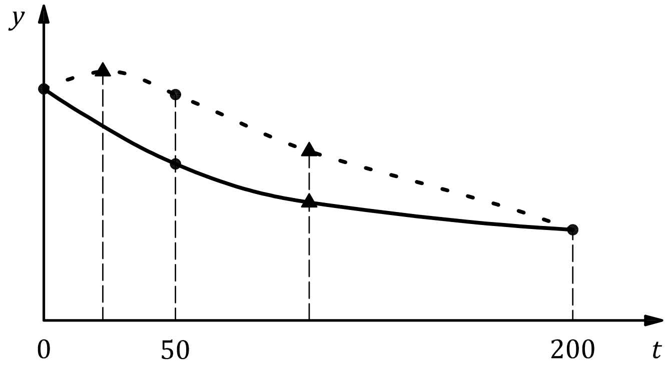
The service temperature and the recommended test temperature of filter materials are summarized in Annex F.

### 6.4.2 Exposure period and number of exposure

According to Formula (1), tensile strength changes exponentially with exposure time (shown as solid line in Figure 8); but it is empirically known that tensile strength often has a short maximum as the exposure starts and then decreases with time (shown as dotted line in Figure 8).

Hence, the exposure period and number of exposures shall be specified as three exposures with periods such as 50 h and 200 h and one exposure with a period of time less than 50 h or between 50 h to 200 h.

However, the number of exposures and length of exposing period may be changed after negotiation between stakeholders.



**Key**

| | |
|---|---|
| ● | required measuring point |
| ▲ | selective measuring point |
| $t$ | exposure time (h) |
| $y$ | $\tau(t)$ or $\delta_{max}(t)$ |

Figure 8 — Trend of experimental degradation

### 6.4.3 Attachment of filter sample sheets in the sample case

At first, four sample sheets with similar permeability are selected for each direction of filter media MD and TD, i.e. eight sample sheets in total, according to the procedures described in 6.2. Then, selected sample sheets and separators shall be piled up alternately and among sample sheets, MD and TD shall also be alternated. The frame plate shall be placed on the top of the pile. Then, they shall be slid in the sample case and pressed to the case by screws to prevent the leakage of test gas from the periphery but not screwed too firmly to avoid the entanglement of fibres in neighbouring sheets. The sample case shall be fixed to the chamber by pressing down the lid of the chamber. Materials used for the chamber and sample case shall have an excellent corrosion and adsorption resistance against test gases.

### 6.4.4 Implementation of the exposure

a) Assembly of the system: Install the sample case into the heating system and connect all units such as the gas supply system, exposure chamber and heating system, exhaust gas treatment unit, vacuum pump and gas analysing system.

b) Adjustment of test gases: Mix the calculated amount of individual test gas according to Table 1 in 6.4.1.

c) Residual gas in the exposure system shall be replaced completely by $N_2$ gas before test gases are introduced to the system and it is recommended to feed the test gas at a higher rate, such as 5 l/min, for the first hour to ensure the contact of test gas to all fibres surface in the sheets.

d) Gas exposure: After checking for leaks and preheating the chamber, introduce the test gases listed in Table 1 and flow them through the sample sheets at (1 ± 0,1) l/min. Outlet gas concentration shall be monitored continuously. When test gas concentration change is detected, it shall be corrected by changing the flow rate of the particular gas.

e) Ending procedure and taking out sample: Switch off the heater of the system when the predetermined exposure time has passed. Then stop feeding the test gas and increase the balance gas flow rate to avoid the further performance changes and to cool down the exposure chamber to room temperature.

After the chamber cools down to room temperature, take out test sample sheets.

# 7 Tensile strength measurement of exposed specimen

## 7.1 Tensile test device

The tensile test shall be carried out by the strip method described in ISO 4606 and ISO 13934-1.

A tensile test device can be chosen from any one of the following three types: a constant rate elongation type, a constant rate tension type, or a constant rate loading type.

## 7.2 Preparation of a tensile test specimen

The tensile test specimen shall be prepared according to the strip method, i.e. two pieces with $L_1$ = 200 mm in length and $w$ = 25 mm in width shall be prepared by cutting the sheet and, then one piece shall be chosen as a tensile test specimen and the other shall be kept as a reserve.

## 7.3 Method of tensile test

The tensile strength of the specimen shall be measured using the following procedures.

a) Fixing the tensile specimen: The tensile test specimen shall be fixed to a holder without causing observable damage to the specimen (as observed with naked eyes) or slipping in the tensile test holder. The specimen shall be automatically held with an air chuck, a hydraulic chuck, or a screw action tool. The holder surface shall be smooth and even. However, in the case of a holder incapable of tightly holding the tensile specimen, a holder having a line marked surface, a notched surface or a waved surface can be used. In the case of using a manual holder with a screw action tool, confirm strictly in advance that there is no slippage during the tensile test.

   NOTE 1 Alternatively, torque without causing slippage is determined in advance and the tensile test is carried out at the predetermined torque or more, such as 30 N·m. In the case of using air chuck or hydraulic chuck, the pressure at the holder surface is 0,4 MPa or over of gauge pressure. Loading-elongation (stress-strain) curve (see Figure 9) is observed for the judgment of sliding.

   NOTE 2 In the case of tightly holding the tensile specimen, using a lining at the holding part of the sample can avoid any slippage. Materials suitable for the prevention of slippage include paper, felt, leather, plastic and sheet gum.

b) Direction of tensile: The direction of tensile test shall be in MD and TD of the tensile test specimen.

c) Number of tensile test specimen: The number of tensile test specimen shall be at least 4 in MD and TD, respectively, under the same exposure conditions.

d) Tensile test temperature: The tensile test temperature is room temperature.

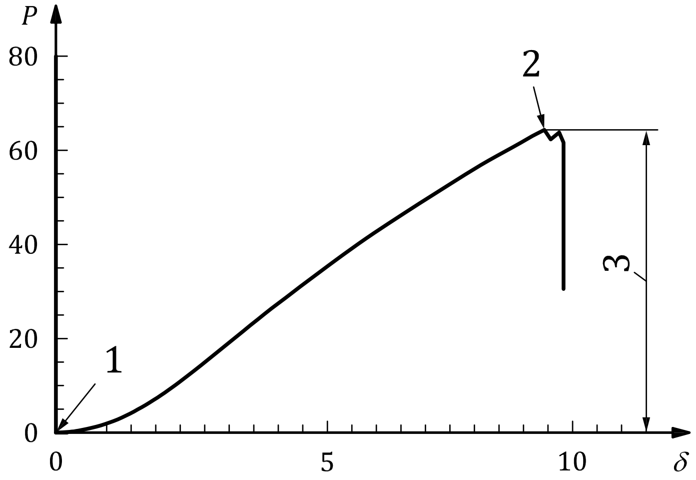
e) Length between holders: The length between holders shall be 100 mm.

f) Tensile speed: The tensile speed shall be 100 mm × $\text{min}^{-1}$ for nonwoven fabric.

g) Test specimen is subjected to above mentioned conditions until failure.

h) Determination of tensile characteristics: Tensile strength $\tau$ and elongation ratio at maximum load shall be calculated by obtaining maximum load $P_{\text{max}}$ and elongation at maximum load on the basis of load – elongation curve (see Figure 9). The starting point of elongation is a point when an initial load has been applied.

i) Tensile strength and elongation shall be measured only when the failure takes place at the middle part of the specimen. When failure takes place near the holder, stop the test and a tensile test with the reserved specimen shall be carried out.



**Key**

$\delta$ elongation (mm)

$P$ load (N)

1 starting point of elongation

2 maximum load $P_{max}$ (N)

3 elongation at maximum load $\delta_{max}$(mm)

**Figure 9 — Load-elongation (stress- strain) curve**

### 7.4 Characterization of the degradation

a) Tensile strength: The tensile strength is calculated from the obtained maximum load by Formula (4).

$$\tau = \frac{P_{max}}{w} \tag{4}$$

b) Retention: The retention of tensile strength given by a ratio of tensile strengths before and after exposure is calculated by Formula (5).

$$\text{Retention of tensile strength} = \frac{\tau}{\tau_0} \tag{5}$$

where

$\tau_0$ is the tensile strength of a virgin filter media, i.e., without test gas exposure.

The elongation ratio at maximum tensile load is calculated by Formula (6) from obtained elongation at maximum load.

$$\varepsilon_{max} = \frac{\delta_{max}}{L_2} \tag{6}$$

where

$L_2$ is the length between holders before tensile test (mm).

NOTE Arithmetical mean of determined values is adopted as the test result.

## 8 Test report

The report shall include at least the following information.

a) References: test certificate number, date of issue, location and name of laboratory, name of operator

b) Filter media

   1) Filter media: material (web, scrim), type of media, lot number

   2) Properties of filter media: mass per unit area of media, thickness, specified air permeability, and tensile strength in MD and TD by the manufacturer

c) Permeability of candidate sample sheets and selected sample sheets for gas exposure

d) Gas exposure

   1) Type of exposure system: continuous-flow-type

   2) Exposed gases: name of gases and composition

   3) Exposing condition: gas flow rate, temperature, duration of exposure

   4) Number of sample sheets exposed

e) Data of tensile test device

   1) Tensile test device: Identification of device

   2) Type of tensile (constant rate elongation, constant rate tension or constant rate loading), maximum tensile strength (load cell)

   3) Holder: type of clipping (air, hydraulic, screw action), size of holder, form of surface of jaw, force of clipping, prevention for slippage, interval between holders

   4) Tensile rate

f) Results of tensile strength test

   1) ID of specimen of tensile strength test

   2) Direction of strength: MD or TD

   3) Specimen dimensions for each tensile test sheet: width and length

   4) Maximum tensile strength: load, tensile strength (=load per unit width) and retention

   5) Elongation of specimen at maximum tensile load: elongation between chuck jigs and elongation ratio to the initial length of test sheet

   6) Arithmetical means of the strength and elongation

g) Other comments

An example of test report is shown in Annex H.

# Annex A

(informative)

# Causes and results of degradation of fabrics

Filter media used in a bag filter degrade due to many causes and their appearances and effects are different from each other. It is important to know the relation between cause and result before discussion of the evaluation method. Causes and resultant appearances are listed in Table A.1 [1] to [5] [7][9][20][21].

Table A.1 — Degradation of fabric, causes and results

| **1 Thermal degradation** | | |
|---|---|---|
| Cause | Results | Remarks |
| Meltdown or burn-out | Sudden break | Rapid pressure drop decrease |
| Change of fabric quality | Break at too much external force | Slow degradation of strength |
| Formation of micro crack | | |
| Shrinkage of fabric | Break by abrasion | Contact with retainer |
| Elongation of fabric | | Generation of creases |
| **2 Chemical degradation** | | |
| Cause | Results | Remarks |
| Corrosion by alkali and acid<br>Hydrolysis<br>Reaction with gas and etc. | Break at too much external force | Slow degradation |
| **3 Mechanical degradation** | | |
| Cause | Results | Remarks |
| Abrasion with retainer | Break at too much external force | Mass loss by abrasion |
| Abrasion with dust | | |
| Collision with housing | | Rapid and local abrasion |
| Collision between fabric | | |
| **4 Clogging weave openings** | | |
| Cause | Results | Remarks |
| Moistening | Shut down the system | Rapid pressure drop increase |
| Penetration of dust | Break of media | Slow pressure drop increase |
| **5 Increasing size of weave openings** | | |
| Cause | Results | Remarks |
| High pulse pressure | Shut down the system | Drag force increase with filtration velocity |
| Increase of dust load | Break of media | Enhanced dust penetration |
| Increase of fabric weight | | |

# Annex B
(informative)

## Possible evaluation method for characteristic change of fabrics

Characteristic change of filter media is due to many causes, as described in Annex A. There are many possible evaluation methods for those changes and their practical effectiveness. The following are possible evaluation methods and their characteristics [1] to [5],[8] to [15].

**Table B.1 — Possible evaluation methods for characteristic change of filter media**

| **Phase of test** | **Solid** | **Liquid** | **Gas** | |
|---|---|---|---|---|
| Contact method | Insert or attach agent into the specimen | Dip the specimen into a liquid | Flow gaseous agent through the specimen | Put specimen into a container with gaseous agent for a certain time period |
| Agent concentration | — | High | Low | Low |
| Concentration stability | — | Changes with time | Steady | Changes with time |
| Remarks | Influence appears at the place where solid agent contacts with filter media | Can produce different products at gas phase contact | Similar condition to actual filtration.<br>Waste gas treatment is necessary | Refill or exchange of agent and waste gas treatment are necessary |
| Experimental period and cost | Uncertain period<br>Low cost | Short period<br>Low cost | Long period<br>High cost | Long period<br>High cost |

**Table B.2 — Comparison of degradation mechanism with chemical analysis**

| **Filter media type** | **Strong acid solution immersion**<br>90 °C × 90 h | | | **Acid gas exposure**<br>200 °C × 1000 h | | |
|---|---|---|---|---|---|---|
| | 1,0N HCl | 1,0N $H_2SO_4$ | 1,0N $HNO_3$ | HCl 0,2 % | $SO_2$ 0,1 % | NO 0,05 % |
| PPS* | No change | No change | Oxidation C = O<br>Nitration -$NO_2$ | Unknown/ Slight change | — | Oxidation<br>C = O, C-O<br>$SO_2$, SO |
| | (-) | (-) | (+) | (++) | (-) | (++) |
| PI* | Hydrolysis | Hydrolysis | Hydrolysis<br>Nitration -$NO_2$ | — | — | Oxidation<br>Aromatic Ring |
| | (++) | (+) | (++) | (-) | (-) | (+) |
| APA* | Hydrolysis | dissolution | Hydrolysis<br>Nitration -$NO_2$ | — | — | Oxidation<br>C-O |
| | (++) | (+) | (++) | (-) | (-) | (+) |
| PTFE* | — | — | — | — | — | — |
| | (-) | (-) | (-) | (-) | (-) | (-) |

* The upper row of each material shows change of chemical structure; the lower row shows strength retention.

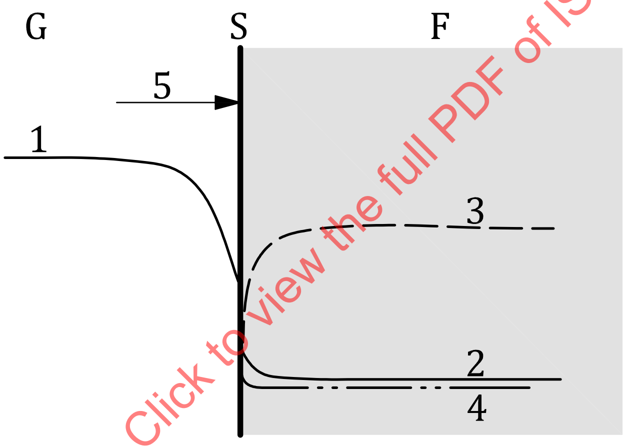
# Annex C
(informative)

# Theoretical consideration of degradation mechanism

Degradation of filter media is caused by the reaction between fibres and reactive gas in the exposure chamber. Although its mechanism has not been understood yet, some kind of interaction or reaction between gas and fibre will take place and it is expected to be related to the degradation of filter media.

It can be understood using the following simplified model. Reaction between gas and fibres in filter media can be considered to proceed uniformly and slowly at any place in the media so that the phenomenon can be considered by any single fibre in the media.

In this calculation, pseudo linear reaction between reactive component A in a fibre and reactive gas B is assumed. Their concentration profiles near the fibre surface are shown in Figure C.1.



**Key**

| | | | |
|---|---|---|---|
| G | gas | 1 | concentration profile of reactive gas B in gas phase, $C_{Bg}$ |
| S | surface of fibre | 2 | concentration profile of reactive gas B in fibre, $C_B$ |
| F | fibre | 3 | concentration profile of reactive component A in fibre, $C_A$ |
| | | 4 | concentration profile of product AB in fibre, $C_{AB}$ |
| | | 5 | diffusion of gas component B |

**Figure C.1 — Concentration profiles of reactive gas B and fibre component A**

This reaction can be thought to proceed as follows:

Reactive gas B first moves to a fibre surface and adsorbs on the fibre surface and penetrates into the fibre and it reacts with A and makes product AB as:

$$A + B = AB \tag{C.1}$$

The kinetic formula for the reaction is

$$\frac{dC_{AB}}{dt} = -\frac{dC_A}{dt} = KC_AC_B \tag{C.2}$$

By making following assumptions, Formula (C.2) is simplified.

Assumption 1: Gas B is adsorbed until its saturation for a given temperature and does not change with time.

Assumption 2: Consumed amount of B in the fibre is supplied from gas surrounding the fibre.

Assumption 3: Reaction between A and B takes place in a thin layer in the fibre. At the beginning, it takes place at the fibre surface layer because of slow reaction.

From Assumption 1, $C_B$ = constant

Hence, Formula (C.2) becomes the next formula by introducing effective reaction constant $K = kC_B$.

$$\frac{dC_{AB}}{dt} = -\frac{dC_A}{dt} = KC_A \tag{C.3}$$

From the above formula, the next differential formula is obtained.

$$-\frac{dC_A}{C_A} = Kdt \tag{C.4}$$

Integrate Formula (C.4) with initial condition at t = 0, $C_A = C_A\,(0)$ results:

$$C_A(t) = C_A(0)\exp\left(-Kt\right) \tag{C.5}$$

Since reaction between A and B is assumed to be a pseudo-linear reaction, thus the reacted amount of B in molar basis is the same as A consumed. Hence, total molar amounts of reacted A and B are given by the following formula:

$$\Delta M_A\left(t\right) = \Delta M_B\left(t\right) = F\left(A\right)\left[1 - \exp\left(-Kt\right)\right] \tag{C.6}$$

Here, $F(A)$ is a constant related to total surface area in a fibre media $A$.

If tensile strength of the filter before it is exposed to the reactive gas can be assumed to be proportional to the amount of reactive material A in the filter material as:

$$\tau\left(0\right) \propto M_A\left(0\right) \tag{C.7}$$

After filter media was exposed, the amount of A decreased, $\Delta M_A\,(t)$, and then, tensile strength at time = $t$, can be expressed as:

$$\tau\left(t\right) \propto M_A\left(0\right) - \Delta M_a\left(t\right) \tag{C.8}$$

Hence, deducted tensile strength can be expressed by the following formulae:

$$\Delta\tau\left(t\right) = \tau\left(0\right) - \tau\left(t\right) \propto M_A\left(0\right) - \left(M_A\left(0\right) - \Delta M_A\left(t\right)\right) = \Delta M_A\left(t\right) \tag{C.9}$$

$$\Delta\tau\left(t\right)\propto\Delta M_A\left(t\right)=F\left(A\right)\left[1-\exp\left(-Kt\right)\right] \tag{C.10}$$

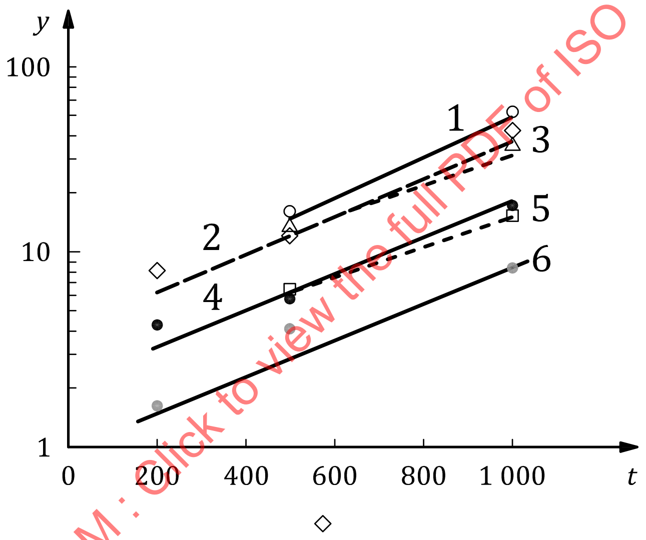
According to Hooke’s law, applied tensile strength to a body $\tau$ is proportional to the elongation of the body $\delta$ as:

$$\tau\propto\delta \tag{C.11}$$

Hence, $\Delta\delta(t)$ can be expressed by the following formula:

$$\Delta\tau\left(t\right)\propto\tau\left(t\right)-\tau\left(0\right)\propto\delta\left(t\right)-\delta\left(0\right)=\Delta\delta\left(t\right)\propto1-\exp\left(-Kt\right) \tag{C.12}$$

Formula (C.10) and Formula (C.12) suggest that deducted tensile strength and elongation are related to the mass reacted in the filter media. Figure C.2 contains experimental data replotted from Figure G.6 and shows linear relations between logarithm of $\Delta\tau$ and exposure time $t$ regardless of filter material and reactive gases.



**Key**

| | | |
|---|---|---|
| $t$ | exposure time | (h) |
| $y$ | relative tensile strength $(\tau(0)-\tau(t))/\tau(0)$ | (N•mm−1) |
| 1 | PPS felt exposed to NO gas 500 ppm | ○ |
| 2 | PPS scrim exposed to NO gas 500 ppm | ◇ |
| 3 | PI felt exposed to NO gas 500 ppm | △ |
| 4 | PPS felt exposed to HCl 2000 ppm | ● |
| 5 | PTFE felt exposed to NO gas 500 ppm | □ |
| 6 | PPS felt exposed to $SO_2$ gas 1 000 ppm | ● |

**Figure C.2 — Experimental correlation of relative decrease of tensile strength with exposure time**

# Annex D
(informative)

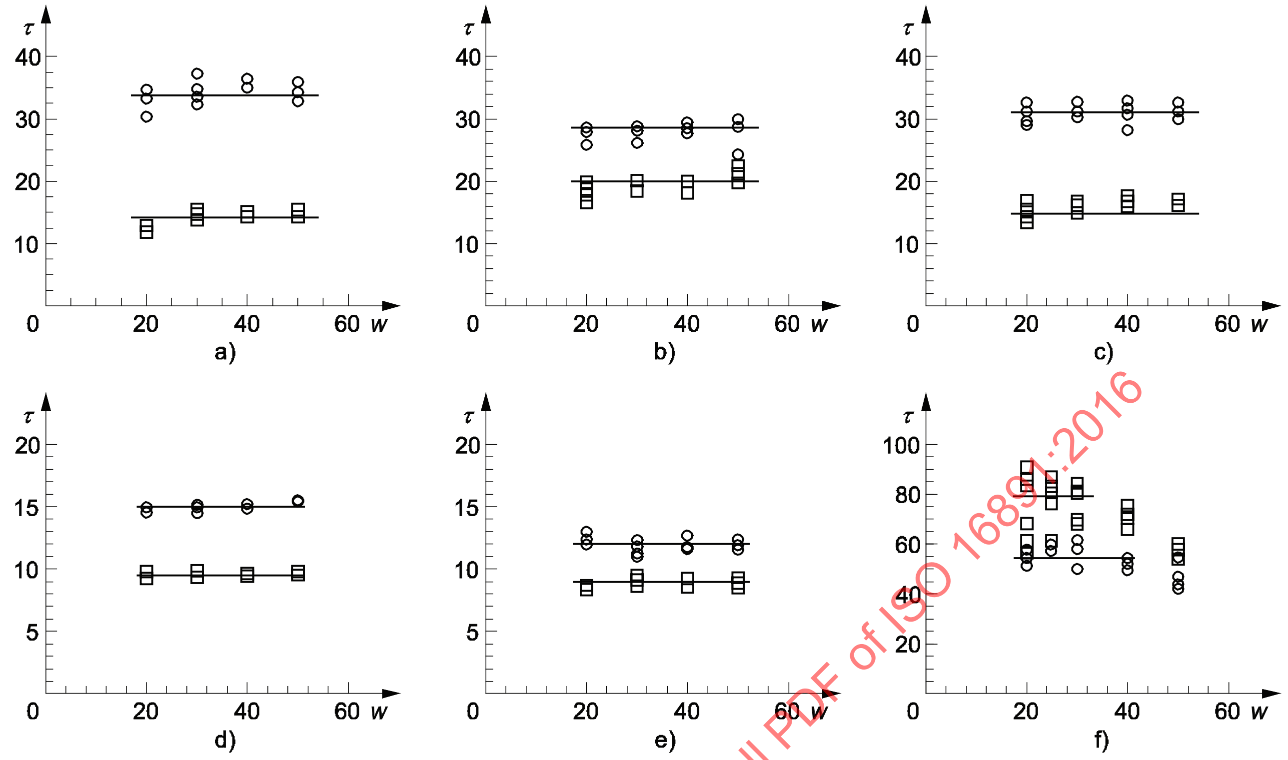
# Determination of specimen size

## D.1 Effect of specimen width on measuring tensile strength

Figure D.1 shows tensile strength of different virgin filter media measured at room temperature, without thermal exposure. Tensile strength $\tau$ is measured at different specimen width from 20 mm to 50 mm for both machine direction (MD) and transverse direction (TD).

For nonwoven fabric with polymer fibres, measured strengths show little difference with change of specimen width. Hence, it can be concluded that measured tensile strength is not affected by specimen width in tested width range. Any width between 20 mm to 50 mm is adoptable but narrower width is recommended because absolute value of tension becomes larger for wider specimen width, i.e. requiring a larger tension testing machine for higher capacity.

However, the result of woven fabric with glass fibre was different. It probably depends on width.



**Key**

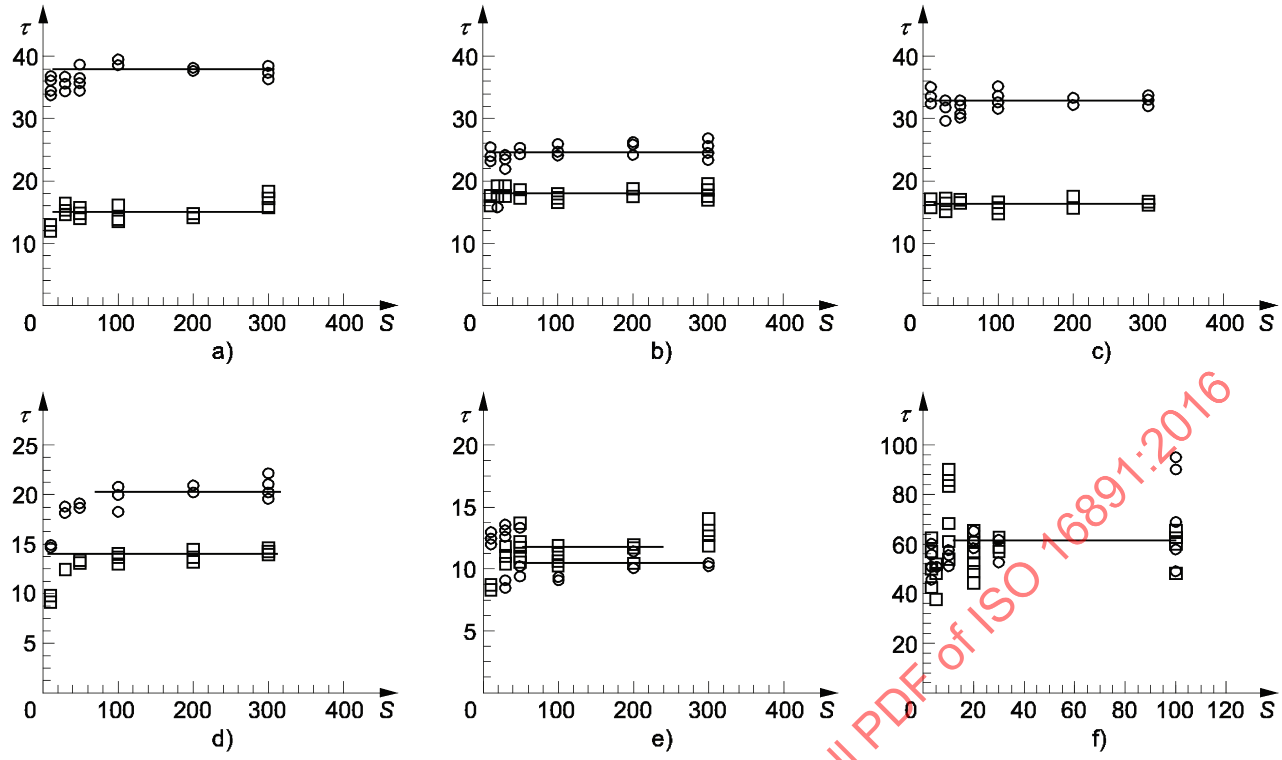
| | | | |
|---|---|---|---|
| w | width of specimen (mm) | a) | PPS |
| τ | tensile strength(N•mm$^{-1}$) | b) | PI |
| ○ | TD | c) | APA |
| □ | MD | d) | PTFE |
| | | e) | glass coated PTFE |
| | | f) | glass fabric |

NOTE Filter media without thermal exposure.

Figure D.1 — Effect of specimen width on measuring tensile strength

## D.2 Effect of tensile speed on tensile strength

Tensile speed has a potential to affect the measured value of tensile strength. Hence, it was tested at different tensile speeds for different filter media of width 20 mm at room temperature. Figure D.2 shows the results. As seen from the figure, measured tensile strength does not change for nonwoven fabric for speeds faster than 100 mm•min$^{-1}$ but does change for woven fabric with glass fibres. Hence, it is recommended to adopt around 200 mm•min$^{-1}$.



**Key**

$S$ tensile speed (mm•min$^{-1}$)
$\tau$ tensile strength (N•mm$^{-1}$)
○ TD
□ MD

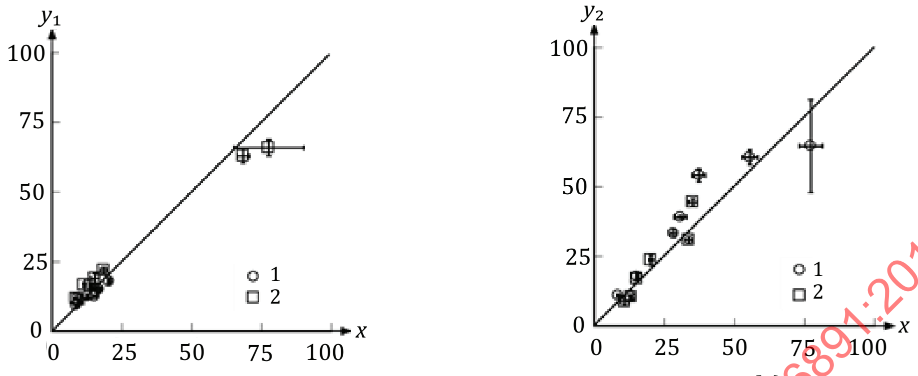
a) PPS
b) PI
c) APA
d) PTFE
e) glass coated PTFE
f) glass fabric

NOTE Filter media without thermal exposure.

Figure D.2 — Measured tensile strength at different tensile speed

## D.3 Effect of length between holders on measuring tensile strength

Tensile strengths of virgin fabrics with different length between holders were measured with two different testing machines at room temperature. Figure D.3 shows the comparison of experimental results. Figure D.3 a) compares measured strength for machine direction (MD) with lengths of 80 mm and 120 mm and Figure D.3 b) compares strengths for TD with lengths of 100 mm and 120 mm. As seen from Figure D.3 a), the effect of specimen length for MD is small except for larger strength because of length and machine, but for TD measured strength for 100 mm specimen gives larger values than those for 120 mm, especially larger strength. No significant differences were observed between testing machines.



a)

b)

**Key**

| | |
|---|---|
| a) | comparison of tensile strengths in MD between different machines |
| b) | comparison of tensile strengths in TD between different machines |
| $x$ | tensile strength for 120 mm length between holders (N•mm$^{-1}$) |
| $y_1$ | tensile strength for 80 mm length between holders (N•mm$^{-1}$) |
| $y_2$ | tensile strength for 100 mm length between holders (N•mm$^{-1}$) |
| ○ | tensile test by using machine A |
| ☐ | tensile test by using machine B |

**Figure D.3 — Tensile strength of virgin fabric with different length between holders**

# Annex E
(informative)

# Experimental setup for gas exposure

## E.1 General

Two methods are considered to have potential for the preparation of aged filter sheet for tensile testing, i.e. continuous-flow-through method and non-continuous gas exposure method. The former refers to the method where test gas flows through the sample sheets continuously, and thus, the test gas contacts with all fibres along its passage through sheets. From this reason, the former has been adopted in this International Standard. Note that it is expected to consume large amount of test gas even at a small flow rate.

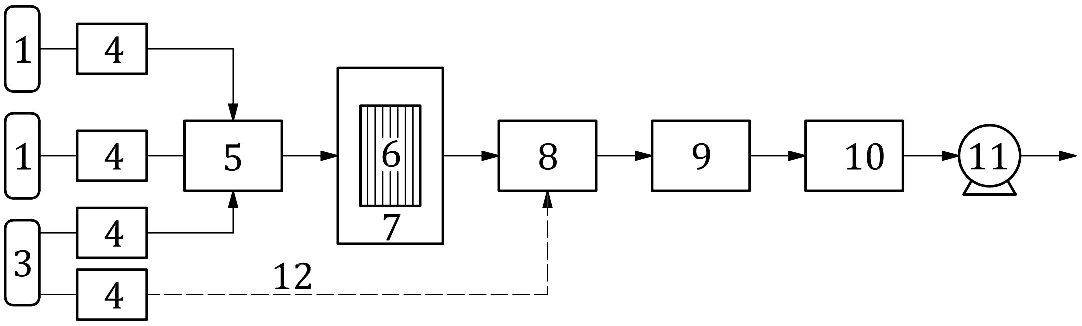
In the latter method the sample sheets are exposed in a chamber filled with test gas but with no gas movement except natural convection. Theoretically, a chamber of this method has no limitation on space and the shape of the chamber as long as it can store sample sheets in which all fibres will surely have contact with the test gas.

Filter sheets are either hung or put in the chamber. Since test gas is consumed only by the interaction with filter media, total consumption of test gas is expected to be relatively small. However, because of no gas movement in the chamber, contact between the test gas and fibres in the sheet is accomplished only by Brownian diffusion of test gas. Hence, it is supposed to have difficulty in achieving homogeneous interaction behaviour throughout the sample sheet, i.e. inside and outside of the sheet during the whole exposure period even if diffusion is active at a high temperature. Furthermore, it is better to be replaced occasionally to maintain test gas concentration within tolerable concentration range, since test gas concentration changes with exposure time.

In this Annex, typical setups for continuous and non-continuous flow methods are described, and test gas preparation methods are also introduced.

## E.2 Continuous-flow-method

Figure E.1 shows an example of experimental setup for a continuous-flow-method. In Figure E.1, the system uses a FT-IR analyzer to measure test gas, because it is capable of measuring $NO_x$, $SO_x$, and HCl concentration by a single instrument. When outlet concentration is measured intermittently, a measuring instrument other than FT-IR analyzer can be used. Note that some techniques require gas sampling for the measurements.



**Key**

| | | | |
|---|---|---|---|
| 1 | test gas 1 | 7 | heating system |
| 2 | test gas 2 | 8 | gas diluter |
| 3 | balance gas | 9 | gas analyzer (FT-IR) |
| 4 | mass flow controller | 10 | gas absorber (alkaline solution like NaOH) |
| 5 | mixing box | 11 | suction fan |
| 6 | expose chamber | 12 | emergency dilution line for higher test gas concentration |

NOTE 1 Monitoring of leakage of $NO_x$, HCl, $SO_2$ gases are needed for indoor use.

NOTE 2 The suction fan can be used if necessary.

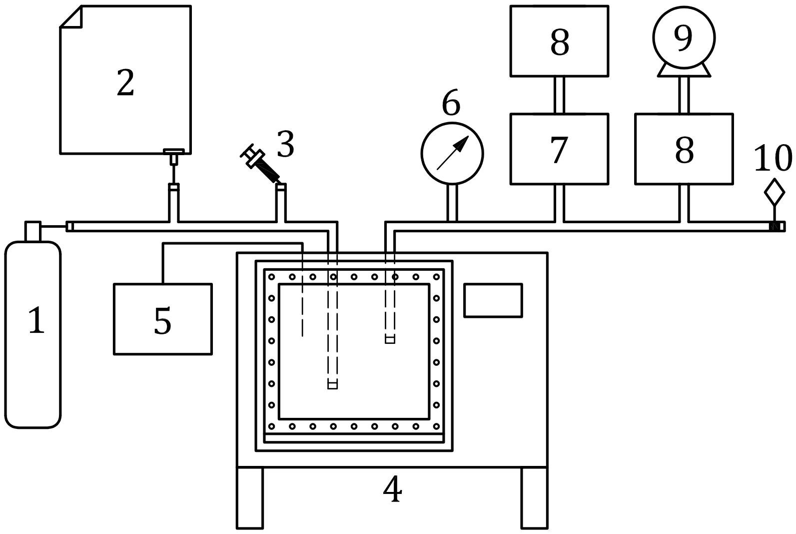
NOTE 3 Measuring instrument other than FT-IR analyzer can be used as long as it measures test gas concentration continuously.

**Figure E.1 — Example of continuous flow type experimental setup**

## E.3 Non-continuous-flow-method

Figure E.2 shows an example of experimental setup for the non-continuous-flow-method. It is composed of a test gas supply system, heating and exposure chamber. The chamber is the main part of the system and is an airtight structure. Material used for the chamber should have an excellent corrosion and absorption resistance against test gases. The test sample holder is prepared inside the chamber. It is also to be made of a sufficiently rigid and excellent corrosion-resistant material with smooth surface finished not to damage test samples. Since exposure time is at the maximum of several hundred hours, the volume of the chamber is required to be big enough to store at least several sheets of test filter media vertically without touching neighbouring sheets. Also, the size of each sheet shall be large enough to make several test specimens. In this type of method, fulfilment of new test gas is necessary to be repeatedly performed after the remaining gas is evacuated at vacuum to ensure the certain contact of test gas with every fibre in the sheet. Gas concentration in the chamber changes, i.e. decreases by the interaction with fibre material with exposure time and thus replacement of test gas is needed before test gas concentration becomes less than the recommended concentration.

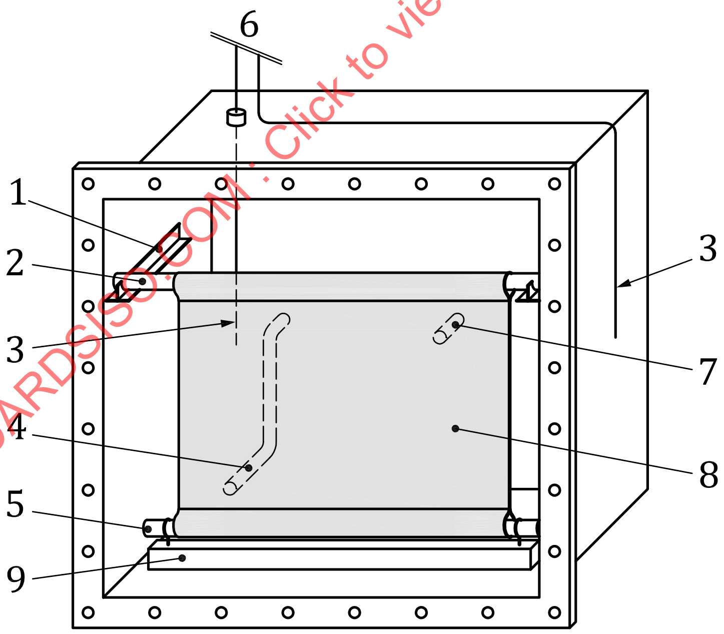
Figure E.3 shows examples of exposure chambers by replacement method. In the figure, the sheet of filter sample is hung from the top and bottom bars.



**Key**

| | | | |
|---|---|---|---|
| 1 | $N_2$ gas cylinder | 6 | pressure gauge |
| 2 | test gas supply bag | 7 | gas analyzer |
| 3 | injection site of water | 8 | gas absorber |
| 4 | heating system | 9 | vacuum pump |
| 5 | thermometer | 10 | safety valve |

**Figure E.2 — Example of experimental setup of replacement method**



**Key**

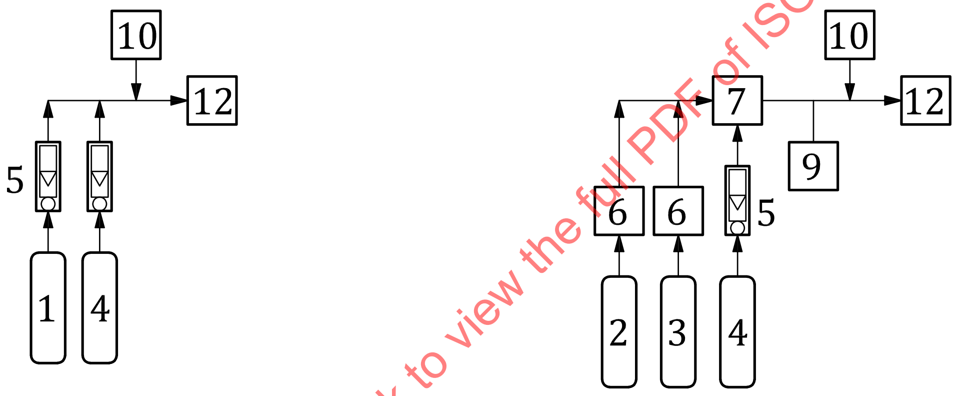
| | | | |
|---|---|---|---|
| 1 | sample holder | 6 | thermometer |
| 2 | rod | 7 | gas outlet |
| 3 | thermocouple | 8 | test sample |
| 4 | test gas inlet | 9 | weight |
| 5 | rod | | |

**Figure E.3 — Example of exposure chamber**

Figure E.4 shows examples of a test gas supply unit. In Example 1, test gas is already prepared and cylindered at the factory. Hence, in this system, only balance gas is necessary for the preparation and cooling-down period of the exposure. For Example 2, a high concentration test gas such as $NO_2$, $SO_2$ and HCl is used. Hence, test gases are to be fed accurately through the mass flow controller according to the exposure condition. Since corrosive gases are usually very reactive, especially with $O_2$ and/or water, test gas concentration changes rapidly because of the reaction so this method may be better than the other methods. For Example 3, gases are mixed in the same way as Example 2 but prepared gas is stored in a container; but this method is not good if a large amount of test gas is required.

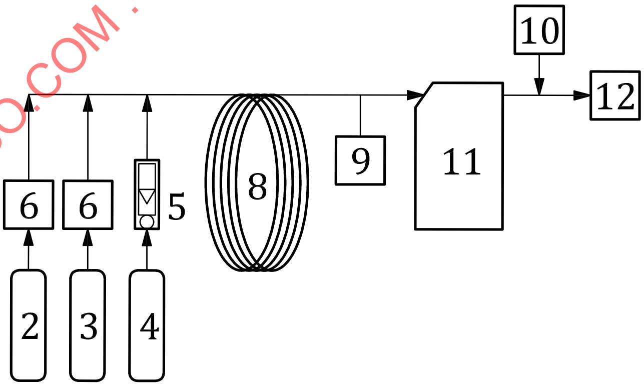
Also, test gas flow rate is important. Gas concentration does not change in a practical bag filter system because of large flow rate. It is also true that gas concentration shall not change within a sample sheet, but it happens because of the interaction between corrosive gases and filter media if the flow rate is set at too low a rate to save test gas consumption. Hence, it is determined appropriately so as not to change so much downstream in the exposure chamber. The outlet concentration shall be monitored continuously and, when change is detected, appropriate measures shall be taken to correct concentrations.

When moisture addition is necessary, it is added to the chamber using the liquid phase, i.e. water, through an appropriate device such as injection syringe, etc.



A) Example 1

B) Example 2



C) Example 3

**Key**

| | | | |
|---|---|---|---|
| 1 | mixed test gas | 7 | mixing tube |
| 2 | test gas 1 | 8 | mixing box |
| 3 | test gas 2 | 9 | gas analyzer |
| 4 | balance gas | 10 | $H_2O$ generator |
| 5 | flow meter | 11 | test gas container |
| 6 | mass flow controller | 12 | exposure chamber |

**Figure E.4 — Example of a device to prepare test gas**

# Annex F
(informative)

# Service temperature of filter materials

The service temperature of bag filters depends not only on material used, but also on physical and chemical properties of dust and surrounding gas. Furthermore, it also depends on the country and area used. Hence, appropriate values were determined based on a literature survey[19][20][21] and by hearing from suppliers of fibre materials and they are summarized in Table F.1.

Table F.1 — Service temperature and Test temperature

| **Temperature** / **Fibre material** | **Service temperature** (°C) | **Recommendation for test** (°C) |
|---|---|---|
| Polypropylene | 95 | |
| Polyamide | 110 | |
| Homo polymer Acrilic | 130 | 145 |
| Polyester | 150 | 160 |
| Polyphenylene Sulfide | 190 | 220 |
| Aromatic Polyamide | 200 | 220 |
| Polytetrafluoroethylene | 260 | 260 |
| Polyimide | 260 | 280 |

# Annex G
(informative)

# Examples of measured data of fabric at different circumstances

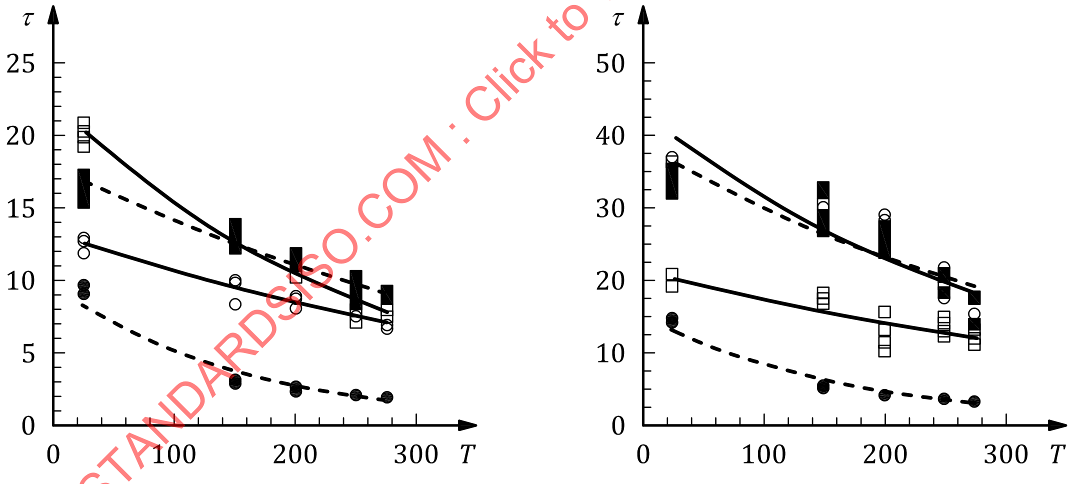
## G.1 General

The thermal property of the materials used for bag filters is one of the key factors influencing the lifetime of bag filters operating at a high temperature [7]. The change or degradation of mechanical properties of the filter media under thermal exposure is characterized to estimate the thermal durability of the bag filter.

Therefore, the method for laboratory test characterizing mechanical property of filter media exposed thermally was studied to standardize the testing method for thermal durability.

## G.2 Effect of temperature on tensile strength of virgin media

Figure G.1 shows the tensile strengths of the virgin material for machine (MD) and transverse (TD) directions without the heat exposure, when the tensile test was performed at a prescribed temperature in the air. The width of test piece was 20 mm. The tensile strength of all samples decreased as the test temperature of the tensile test increased. Especially, strength of the glass fibre fabrics measured at 150 C decreased to about 1/5 to 1/4 of measured strength at room temperature. The degradation by heat was remarkable in the glass fibre fabrics and the strength decreased drastically.



a)    b)

**Key**

$T$ temperature at which tensile tests were carried out (°C)

$\tau$ tensile strength (N•mm$^{-1}$)

a) MD

b) TD

○ PPS

□ PI

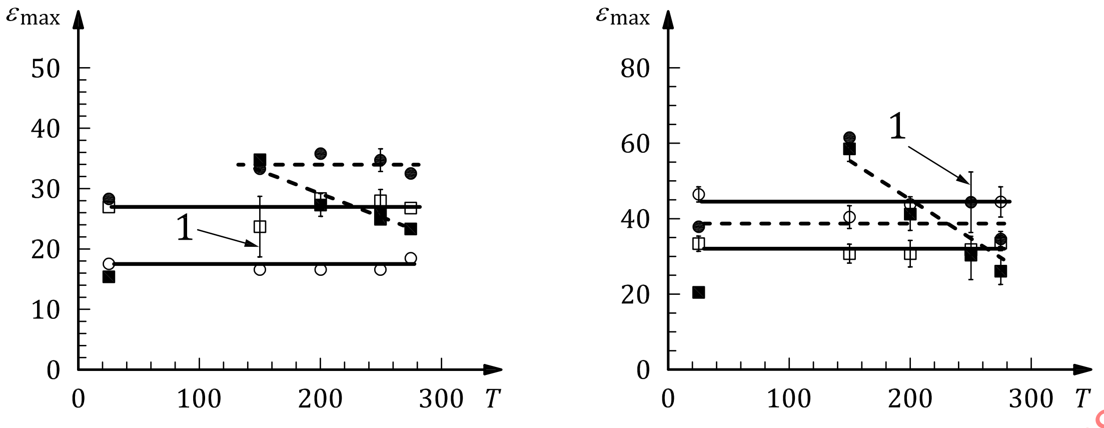
■ APA

● PTFE

NOTE Filter media without thermal exposure.

**Figure G.1 — Tensile strength of virgin filter media at different test temperature**

Figure G.2 shows the elongation at different temperature. The elongation for MD seems to decrease slightly with temperature but the tendency is not clear. The temperature dependency of elongation is small.



a)

b)

**Key**

| | |
|---|---|
| $T$ | temperature at which tensile tests were carried out (°C) |
| $\varepsilon_{max}$ | maximum elongation ratio (%) |
| a) | MD |
| b) | TD |
| 1 | error bar of the measurement |

| | |
|---|---|
| ○ | PPS |
| □ | PI |
| ● | APA |
| ■ | PTFE |

NOTE 1 Filter media without thermal exposure.

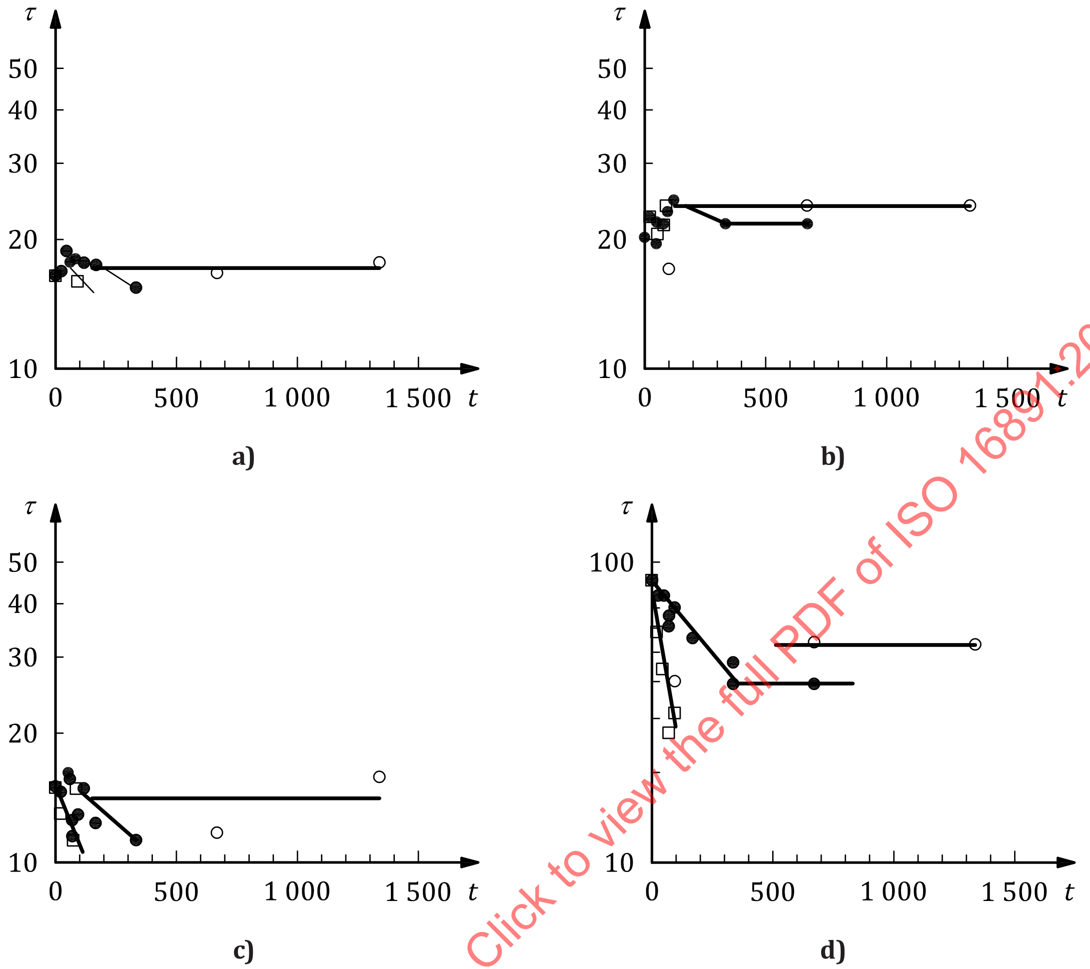
NOTE 2 Error bar of the $\varepsilon_{max}$ measurements means standard deviation.

**Figure G.2 — Elongation of virgin filter media at different test temperature**

## G.3 Effect of exposure time on mechanical properties measured at room temperature

Figure G.3 shows the changes in tensile strength of the filter materials exposed at different temperatures 150 °C, 200 °C and 250 °C and different periods. The tensile tests after high temperature exposure were carried out at a room temperature. The exposure time dependence is obviously different with the materials and the exposing temperature. That is, the strength decreased with the exposure time and the rate of decrease at a higher exposing temperature was larger.

The strength rise was observed in APA (Aromatic polyamide) and PI (Polyimide, not shown). This result seems to have the contradictory trend against the strength at the test temperature shown in Figure G.1. It is thought that difference of the tensile test temperature causes the variation of the strength in polymer felts. As for the polymer felts exposed at a high temperature for about 100 h, the strength is thought to recover when it cools down to the room temperature. Therefore, the temperature of the tensile test is extremely important in the evaluation of the heat degradation characteristic.



**a)** **b)** **c)** **d)**

**Key**

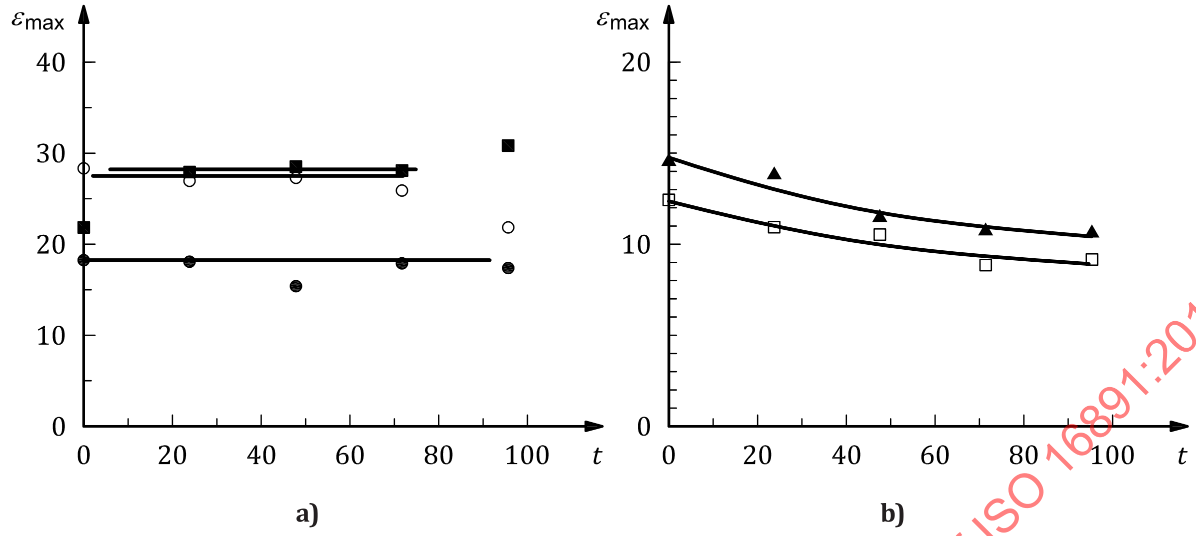
| | |
|---|---|
| *t* | exposure time (h) |
| τ | tensile strength (N•mm$^{-1}$) |
| ○ | exposure at 150°C |
| ● | exposure at 200°C |
| □ | exposure at 250°C |

| | |
|---|---|
| a) | APA |
| b) | PI |
| c) | PTFE |
| d) | glass fabric |

NOTE Tensile tests of filter media after thermal exposure were carried out at a room temperature.

**Figure G.3 — Relation between tensile strength of filter materials measured at room temperature and exposing time at high temperature**

Figure G.4 shows the variation of the maximum elongation $\varepsilon_{\max}$ (=$\Delta L/L_2$) with the exposure time *t* at temperatures of 250 °C. The elongation ratios of polymer felts were almost constant, whereas those of glass fabrics decreased. The mechanical properties of the glass fabrics were influenced more by the exposed temperature in comparison with the polymer felts.



**Key**

| | | | |
|---|---|---|---|
| *t* | exposure time (h) | ○ | PPS |
| $\varepsilon_{max}$ | maximum elongation ratio (%) | ■ | PI |
| a) | polymer felts | ● | APA |
| b) | glass fabrics | ▲ | glass fabric A |
| | | □ | glass fabric B |

NOTE Tensile tests of filter media exposed at 250 °C for given duration were done at a room temperature.

**Figure G.4 — Variation of tensile strain with exposing time**

## G.4 Effect of exposure time on mechanical properties measured at high temperature

Figure G.5 shows variation of the tensile strength measured with exposure temperature. As shown in the figure, behaviours to the exposure time are mostly similar. Especially, the strengths of the glass fabrics and PTFE did not change with exposure time at every temperature. But the strengths of plastics