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Methods for sampling and analysis of fire effluents

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National foreword

This British Standard is the UK implementation of ISO 19701:2013. It supersedes BS ISO 19701:2005 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee FSH/16, Hazards to life from fire.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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ISBN 978 0 580 69706 7

ICS 13.220.01; 13.220.40

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 April 2013.

Amendments issued since publication

Date	Text affected

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INTERNATIONAL STANDARD

ISO 19701

Second edition
2013-04-01

Methods for sampling and analysis of fire effluents

Méthodes d'échantillonnage et d'analyse des effluents du feu

Reference number
ISO 19701:2013(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 19701 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 3, *Fire threat to people and environment*.

This second edition cancels and replaces the first edition (ISO 19701:2005).

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Introduction

The analysis of fire gases for use in toxic hazard and life threat assessment and other purposes (e.g. impact on the environment) is a great challenge for the analyst. Fire atmospheres are by nature hostile environments. Temperatures in excess of 1 000 °C are common, the gas phase can contain many corrosive, toxic, irritant or combustible species together with relatively large quantities of condensable water.

These properties are largely incompatible with most instrumental analytical methods where a "clean" sample is required. This poses many problems both for the qualification and quantification of the chemical species and particulates in fire atmospheres. In presenting a sample to the measuring instrument that it will tolerate, it can be necessary to filter particulates and remove other species. Losses in the sampling train must therefore be quantifiable and taken into account in the final analysis.

Techniques also exist for measuring chemical species *in situ;* this will be the subject of a future document.

The methods described in Clause 5 have been used successfully by a number of laboratories. Studies of repeatability and reproducibility of many of the methods covered in this International Standard have been taken from AFNOR NF X70-100-1[1] and AFAP-3.[2]

For methods that involve a commercial instrument, uncertainty in the measured values may be estimated from the manufacturer's data and other information, e.g. allowance for losses in the sampling process. For other methods, uncertainty in the measured values can occur through a variety of reasons, such as sensitivity to the strength of reagents or the visibility of a colourimetric end point. In these cases, it is assumed that best practice by qualified personnel is applied.

This International Standard is structured as follows.

— Clause 1 describes the scope of this standard

— Clause 4 describes methods of sampling.

— Clause 5 describes analytical methods for gases in fire atmospheres:

— Annex A provides information on techniques that were found not suitable with fire effluents.

— Annex B briefly describes the use of aspirated chemical colour-change tubes.

— Annex C is a summary of the main instrumental methods available for fire gas analysis, expanding the information provided under the clauses for each individual chemical species.

— Annex D presents a method for continuous measurement of HF concentration using ion selective electrode.

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Methods for sampling and analysis of fire effluents

SAFETY PRECAUTIONS — Due consideration must be given to the fact that both the fire gases for analysis and many of the reagents used for their analysis can be toxic and/or present serious health hazards. It is assumed throughout that the procedures described in this document will be carried out by suitably qualified professional personnel, adequately trained in the hazards and risks associated with such analyses and aware of any safety regulations that may be in force. Consideration must also be given to the safe and ecologically acceptable disposal of all chemicals used for analyses. This can require extensive treatment prior to release of the waste into the environment. Again, it is assumed in this document that the personnel responsible for the safe disposal of such reagents are suitably qualified and trained in these techniques and are aware of the regulations which may be in force.

1 Scope

This International Standard presents a range of sampling and chemical analytical methods suitable for the analysis of individual chemical species in fire atmospheres. The procedures relate to the analysis of samples extracted from an apparatus or effluent flow from a fire test rig or physical fire test model and are not concerned with the specific nature of the fire test.

This International Standard doesn't cover aerosols (detailed in Reference [3]) and FTIR technique (detailed in Reference [4]). The gases of environmental interest, such as PAH, dioxins, furans, endocrinal disturbers, will be developed in a future document by ISO TC92/SC3.

2 Normative references

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

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 apply.

4 Methods of sampling

4.1 General considerations

Sampling is perhaps the most critical part of the procedures for analysis of gases in fire effluents. Whereas sampling and analysis are commonly in use for many gaseous species in other fields, sampling from fire atmospheres presents unusual and difficult problems.

The sample presented to the analyser shall be as representative as possible of the test atmosphere, without having been changed by the sampling system. The sampling procedure should influence the test atmosphere as little as possible (e.g. by depletion of the test volume). The sampling procedure should be as uncomplicated as possible, while incorporating all necessary features detailed in this International Standard. The sampling procedure shall be capable of operating with minimal blockage in the sampling lines, melting or other disruption of probes, and without allowing condensation of the species for analysis.

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IMPORTANT — It is important to appreciate that the overall accuracy of the analysis of fire effluent species is significantly dependent on the sampling procedures adopted, in particular the quantification of losses in probes, sampling lines, and filtering systems.

4.2 Concentration and volume fraction

The concentration of fire effluent or of a toxic gas is its mass divided by the volume in which it is contained. For a fire effluent the typical units are $g.m^{-3}$.However, for a toxic gas, concentration is usually expressed as a volume fraction at T = 298 K and P = 1 atm, and is expressed in terms of $\mu L.L^{-1}$ (equivalent to $cm^3/m^3 = 10^{-6}$).

NOTE 1 The concentration of a gas at a temperature, T, and a pressure, P can be calculated from its volume fraction (assuming ideal gas behaviour) by multiplying the volume fraction by the density of the gas at that temperature and pressure.

NOTE 2 Volume fractions of toxic gases used to be expressed in terms of "ppm by volume" but "ppm" is a deprecated term and therefore "$\mu L.L^{-1}$" is now used.

4.3 Special considerations

There are many factors that have a direct influence on the specific type of sampling methodology selected to ensure that a suitable sample is presented to the analyser. For example, consideration shall include the range of concentrations anticipated, the limits of detection, reactivity of the species of interest, presence of interferences, and peak and average concentration values. Sampling of the extremely complex atmosphere produced during combustion requires a very thorough evaluation and assessment of all potential factors that might affect optimum conditions for sample collection and analysis.

The large number of different products frequently encountered in fire effluents often requires the use of a variety of sampling procedures and approaches to ensure accurate identification and quantification of combustion products. The selected sampling procedure also depends on the instrumentation and analytical procedures available for the specific species being measured.

Sampling may involve either continuous, online analysis (e.g. non-dispersive infrared) or non-continuous batch sampling (e.g. evacuated flask or bubbler samples). Batch-type sampling can be further subdivided into two categories:

a) "Instantaneous", or "grab";

b) Average, or integrated.

Although there is no sharp distinction between categories a) and b), it is generally understood that grab samples relate to samples taken over a short time period (i.e. usually less than 1 min), whereas integrated samples are usually taken over a longer time period (i.e. a substantial portion of the total test period).

In some cases, continuous or semi-continuous online or frequent instantaneous sampling can be well suited for following the rapidly changing combustion environment and will provide a representative concentration profile. Frequently however, the minimum detectable limit of the species of interest requires larger sample volumes than can be taken with these techniques. If this analytical limitation exists, it is necessary to carry out the sampling over a longer period. While using longer sampling periods permits the analysis of lower concentrations, this approach has some limitations. For example, these types of samples permit a determination only of the integrated average concentration obtained over the sampling period and do not discern any abrupt change in the evolution of the species of interest. However, abrupt concentration changes can also be missed with instantaneously obtained samples, if samples are not taken frequently enough.

When batch-sampling procedures are used, it is essential to specify sampling frequency, the starting time of each sample and the total sampling time. This information is essential in order to ensure proper evaluation of the data in conjunction with other fire properties that are being monitored (e.g. heat release, temperatures, mass loss, smoke evolution, flame spread).

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Test fires can be classified as “small” (laboratory or “bench” size), “intermediate” or “large” (usually full-scale). The sampled gases can be hot or near room temperature. It is generally necessary to extract the gases from the test atmosphere through suitable tubing using a suction pump. Stainless steel tubing, as short as possible, is often used. In the case of the production of hot gases, the sampling line shall be heated to at least 100 °C. Several analytical methods require a dry, particulate-free sample. Glass wool may be used (in most cases) as a particulate filter, with another trap of a drying agent (e.g. calcium sulfate or calcium chloride) for removing moisture. The traps should be located just before the analyser and after any heated sections of sampling tubes. Simple cold traps are often insufficient to remove the quantity of moisture present in fire effluents; however, they can be useful in conjunction with other filters and traps. The individual sampling and analytical system being used dictates flow requirements and the necessity for moisture removal. Precautions should be taken to minimize the volume of the filtering systems to reduce sampling time.

With the exception of hydrogen fluoride (HF), acid gases shall be sampled using glass, epoxy-lined or PTFE tubes to minimize losses due to reactivity and condensation on the tube surfaces. For hydrogen fluoride, tubes lined with PTFE shall be used (glass and glass-lined tubes are unsuitable). For species that are relatively reactive and prone to losses, sampling lines shall be as short as possible, and shall be heated to a sufficient temperature to avoid condensation. Hydrogen chloride (HCl) and hydrogen bromide (HBr) can be adsorbed onto soot particles as well as gas sampling lines (including PTFE lines).

For organic materials (e.g. acrolein), unlined stainless steel tubing is suitable but the sampling lines shall be heated to avoid condensation. Particulate traps, although usually necessary, can be avoided in some cases and instrument requirements should be checked in this regard.

The location and size of sampling probes is influenced by the size of the test apparatus and the requirements of the analytical system. The positioning of sampling probes in specific apparatus, however, is beyond the scope of this International Standard. In general, the possibility of the stratification of gases in chambers without good mixing shall be considered and sampling too near the wall of a test chamber should be avoided.

Calibration of the entire sampling and analysis system, rather than just the analysis system, is recommended in order to ensure that any losses in the sample route can be allowed for. All calibrations should, therefore, take into account such factors as gas leakage (both into and out of the sampling lines) and the adsorption of gases onto probes, sampling lines, filters and other components. Calibration gases are often obtainable in cylinders; however, it is advisable that the concentration stated by the supplier be verified by an independent analysis. This is especially true of reactive gases such as HCl and HF, which can decay over relatively short time periods even in a closed cylinder. The calibration gas shall be introduced at the sampling probe and allowed to travel the same course as a test gas, through filters and traps if present, to the analyser or sampling medium.

4.4 Sampling using gas-solution absorbers

Absorption of gases in solution by the use of gas-washing bottles, bubblers, impingers, etc. all rely on the same principle. The test atmosphere is drawn or pushed through the absorbing media at a measured rate for a specified period of time. At the end of the sampling period, the solution is analysed for the species of interest (e.g. the chloride ion for absorption of hydrogen chloride gas in water). Assuming 100 % efficiency

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(see discussion below), it is possible to calculate the concentration of the species in the gas phase, as measured in the solution. A typical equation for calculating concentrations is presented in Formula (1):

$$\rho_G = \frac{\rho_S \times V \times (m_G / m_S)}{q \times t} \quad (1)$$

where

ρ_G is the gas concentration;

ρ_S is the solution concentration;

V is the volume, expressed in litres, of solution;

m_G/m_S is the ratio of atomic or molecular weights for the gaseous species, G, and solution species, S, if different, e.g. HCl/Cl);

q is the rate of gas flow, expressed in litres per minute, through the impinger;

t is the time, in minutes of gas flow.

The volume fraction of the gas, X_G, can be calculated by dividing the concentration by the density d, of the gas at the ambient temperature and pressure. This density can be found, assuming ideal gas behaviour, as follows:

$$d = \frac{M_G}{H} \quad (2)$$

$$X_G = \rho_G \frac{H}{M_G} \quad (3)$$

where

M_G is the molar mass of the gaseous species, G;

H is the gaseous volume occupied by 1 mol of an ideal gas at the relevant ambient pressure (P) and temperature (T).[H = 8,314 J.K-1.mol-1 × 1 mol × T/P]

EXAMPLE Suppose that the measured solution concentration of chloride ion (Cl^-) was 0,006 g × dm^{-3} in 0,025 dm^3 of solution, the ambient thermodynamic temperature was 293,15 K, the ambient pressure was 1 bar (10^5 Pa = 10^5 J × m^{-3}), and the flow rate of gas was 0,25 dm^3/min for 2 min. Then the gas concentration of hydrogen chloride is given by:

ρG = [0,006 g.dm^{-3} x 0,025 dm^3 x (36,461 / 35,453)] / [0,25 dm^3/min x 2 min]

ρG = [0,00015 g x 1,028] / 0,50 dm^3

ρG = 0,0003084 g.dm^{-3} = 308,4 mg.m^{-3}

The volume fraction of hydrogen chloride is given by:

X_G = 308,4 mg.m^{-3} x (8,314 J.K^{-1}.mol^{-1} x 293,15 K / 105 J.m^{-3}) / 36,461 g.mol^{-1}

X_G = 308,4 mg.m^{-3} x 0,02437 m^3.mol^{-1} / 36,461 g.mol^{-1}

X_G = 0,0002061 = 206,1 µL/L

The volume of the absorber solution and the total flow of gas directly affect the ratio of the gas and solution concentrations. For a given gas concentration, the smaller the solution volume and/or the larger the gas volume sampled, the higher the solution concentration. The choice of sampling conditions

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is dictated by the requirements of the analytical technique, including the volume and sampling rate tolerated, expected concentration of gas in the test atmosphere, necessity for frequent sampling, etc.

The efficiency of absorption of a gas in liquid is affected by the following:

a) Solubility of the gas in the solution;

b) Physical characteristics of the absorber;

c) Ratio of gas flow rate to solution volume.

Generally, absorption efficiency is estimated empirically by allowing the flow of a known concentration of the gas of interest through a series of impingers and measuring the "break-through" from the first impinger (i.e. whatever is collected in the other traps). Another check on the efficiency of a given flow/impinger system is to conduct a series of experiments with a known concentration of gas, using different impingers and various flow rates. In practice, however, the choice of apparatus is limited, and gas flow rates and trapping solution volumes are based on Formula (1), taking into account the known characteristics of the analysis methods.

There are basically four types of gas-solution absorbers: simple gas-washing bottles (including midget impingers), spiral or helical absorbers, packed glass-bead columns and fritted bubblers. The gas-washing bottles, or impingers, function by drawing the gas through a tube (usually with a constricted opening), which is immersed in the trapping liquid/solution. This type is most suitable for highly soluble gases because contact time between solution and gas is short and bubble size is relatively large. For less soluble species, the other absorbers offer longer contact time and/or smaller bubble size (which increases relative surface contact). The spiral or helical absorbers are built in specialized shapes to allow a long contact time. The flow rate in these bubblers is limited because of the possibility of trapping solution over-flow with high flow rates. Packed glass-bead columns allow increased gas/liquid contact by dispersing the bubbles through a bed of glass beads. Flow rates can be higher than for the spiral absorbers.

The fritted bubblers contain a sintered or fritted disc on the gas inlet tube to disperse the gas into fine bubbles (the size of the bubbles is dependent on the porosity of the frit). It is necessary to exercise caution in using such bubblers so that frothing does not occur and so that the coalescence of the fine bubbles does not defeat the purpose of the frit. Also, it is necessary to filter smoky atmospheres (containing particulates or liquid aerosols) before drawing them through a fritted bubbler in order to prevent clogging of the frit (which occurs very easily). Such clogging can also occur from the build-up of wax-like deposits. Certain gas species (e.g. HCl) can be absorbed onto a filter, especially if particulates have also been trapped on the filter.

Note that very soluble gases, such as HCl and HF, can cause water to be sucked back along the sampling tube. With these gases, it is often necessary to include an empty bubbler to act as a liquid trap.

4.5 Sampling using solid sorption tubes

Solid sorption tubes are an alternative method to gas-solution absorbers for sampling certain gases from fire effluents. Following sampling, the species of interest is desorbed in water and its analysis can then be performed in a way similar to that for aqueous solution absorbers.

The advantages of solid sorption tubes over solution absorbers are

a) Ease of handling,

b) Compactness,

c) High absorption efficiency,

d) Ability to be located directly at the point of sampling.

This latter advantage can have dramatic consequences in the measurement of HF, HCl and HBr in fire effluents because these species are easily lost to the inside surfaces of sampling lines. With solid sorption tubes (except in areas of extreme heat), a sampling line is not necessary before the sorption tube itself. All

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associated hardware (e.g. valves, flow meters and pumps) can be located behind the tubes, even far from the sampling point. This ensures that the sample is as representative as possible of the fire atmosphere.

Much experience has been gained through using solid sorption tubes, for example in the field of atmospheric sampling and for staff exposure monitoring in the workplace. Similar tubes have been re-examined for potential use in sampling fire effluents. Two studies [5],[6] were carried out using solid sorbents to measure certain gases in real building fires. These tubes were located in portable sampling boxes carried by the firemen who were actually fighting the fire. Tubes of similar design, containing activated charcoal, have been used to sample HF [7] and HCN.[8] Tubes containing flake sodium hydroxide for the absorption of acid gases have also been described.[9] A procedure for successive (e.g. every 3 min or 5 min) sampling with tubes at one location without removing or replacing tubes has been described for sampling gases in full-scale fires.[8]

Calculation of the original gas concentration (e.g. HCl) from the representative species recovered in the desorbent solution (e.g. Cl^-) is the same as that described for solution absorbers, except that the solution volume is the volume of desorbent liquid. In practice, a small aliquot, rather than the entire quantity, of the desorbent solution is often used for the analysis so it is necessary to take this factor into account.

The same considerations that apply to solution absorbers, with respect to inefficient absorption, breakthrough and the relationship of volume sampled to gas and solution concentration, also apply to the use of solid sorbents. Instead of bubble size, it is the particulate size of the absorbent that is important (large particles offer less surface area per unit volume and more opportunity for channelling, smaller particles can cause the tube to plug when sampling moist gas). The tubes should be small enough (typically 100 mm long, 6 mm OD) such that two tubes can easily be placed in series to allow for the possibility of "breakthrough" from the first tube.

Solid sorption tubes are subject to plugging due to soot collection. This can be recognized during sampling by a decrease in sample flow rate. The same flow rate should be maintained over the duration of sampling using a constant flow device; otherwise, an error is introduced in the calculation of gas concentration. A glass wool plug loosely packed into the inlet of the tube reduces the tendency to blocking from soot.

Thermal desorption of the adsorbed sample is also possible; the sample tube is heated in an inert gas stream thus driving off the sample without the need for a liquid solution stage.

4.6 Sampling for spectrometric or spectrophotometric analysis

The uses of spectrometric analysis [direct mass spectrometry (MS)] and spectrophotometric analysis [both non-dispersive infrared (NDIR) and Fourier transform infrared (FTIR)] have become quite widespread in recent years. FTIR techniques in particular are becoming more prominent.[9], [10], [11] The continuous measurement by means of NDIR analysis (e.g. for CO and CO_2) is now so common that several different companies manufacture commercial instruments designed for this purpose.

For two of the methods (direct MS and FTIR), it is important that the fire effluents be free from particles before they are introduced into the analyser. The filter used, which is often placed at the junction of the sampling line and the test chamber, shall be inert so it does not react with any of the gases of interest. A stainless steel filter unit containing a glass-fibre filter (e.g. Whatman multigrade GMF150[1)] micro-filter, 1 µm, 47 mm in diameter) has been found suitable. The sample line and the filter (and for FTIR also the absorption cell) are heated to a temperature above 120 °C (120 °C to 150 °C has been found to be suitable), in order to prevent liquid water from forming, to prevent water-soluble gases (e.g. HCN and the acid gases) from dissolving and other gases from condensing.

When a filter is used, it is necessary to check the extent to which the species of interest have been retained by the filter. If retention occurs, it is necessary to correct the measured concentrations. The amount of retained material is dependent principally on the type and capacity of the filter used, the nature of the species and the volume of gas passing through the filter.

1) The Whatman GMF150 filter is an example of a suitable product available commercially. This information is given for the convenience of users of ISO 19701 and does not constitute an endorsement by ISO of this product.

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4.7 Sampling using gas bags

Sampling with gas bags can be used for most analytical methods. The test atmosphere is pumped, or allowed to flow under pressure, into a gas bag at a measured constant rate for a measured time period, thus obtaining a known volume of sample in the bag. It is necessary to filter the fire effluents before passing into the bag; simple in-line glass wool filters for particulates, and calcium chloride filters for moisture, have been found effective. However, a calcium chloride absorbent removes water vapour and water-soluble gases. At the end of the sampling period, the bag may be stored before it is connected to the analyser; but it is important to appreciate that storage times in bags should be kept to a minimum, preferably less than 1 h. Gases such as HF and HCl can dissolve in condensed/trapped water and this reduces the concentration presented to the analyser.

Bags shall be gas-tight and inert and those with a lining of polyvinylfluoride (PVF) are recommended.

Table 1 summarizes the analytical methods and types of sample required for each method described in this International Standard.

Table 1 — Type of sampling for the analytical methods described

Gas	Analytical Method	Type of sample for analysis
Carbon monoxide (CO)	NDIR	gas
Carbon dioxide (CO_2)	NDIR	gas
Oxygen (O_2)	Paramagnetism	gas
Hydrogen cyanide(HCN)	Colourimetry (Chloramine T) Colourimetry (picric acid) HPIC	solution solution solution
Hydrogen chloride (HCl) Hydrogen bromide (HBr)	ISE HPIC titrimetry	solution solution solution
Hydrogen fluoride (HF)	ISE HPIC Online ISE	solution solution solution
Nitrogen oxides (NO_x)	Chemiluminescence	gas
Nitrogen dioxide (NO_2)	HPIC	solution
Nitrogen monoxide (NO)	Gfx-IR	gas
Acrolein (2-propenal)	Colourimetry HPLC GC-MS	solution solution gas
Formaldehyde (Methanal)	Colourimetry HPLC	solution solution
Acetaldehyde (Ethanal)	HPLC GC-MS	solution solution
Total aldehydes	Colourimetry	solution
Sulfur dioxide (SO_2)	HPIC	solution
Carbon disulphide (CS_2)	GC-MS, GC/FPD	gas
Hydrogene Sulphide (H_2S)	HPIC GC/FPD	solution solution
Ammonia (NH_3)	Colourimetry HPIC Titration	solution solution solution
Antimony compounds	AAS or ICP	solution
Arsenic compounds	AAS or ICP	solution
Phosphorus	ICP	solution
Phosphates	Colourimetry HPIC	solution solution

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Table 1 *(continued)*

Gas	Analytical Method	Type of sample for analysis
Phenol	HPLC GC-MS	solution gas
Benzene	HPLC GC-MS	solution gas
Toluene (Methylbenzene)	HPLC GC-MS	solution gas
Styrene (Phenylethene)	HPLC GC-MS	solution gas
Acrylonitrile	GC-MS	solution
Formic acid	HPIC HPLC	solution solution
Hydrocarbons (total)	FID	gas

5 Analytical methods for fire gases

5.1 Carbon monoxide by non-dispersive infrared spectroscopy (NDIR)

5.1.1 Application and limitations

The method provides a continuous analysis/monitoring capability for carbon monoxide. The analysers are commonly self-contained instruments and include sample pumps, sample filtering, analysis hardware and electronics. Direct readout of carbon monoxide concentration is usually provided (either digital or analogue) together with an output for connecting recording devices. Instruments providing carbon monoxide and carbon dioxide analyses in the same case are available.

5.1.2 Sensitivity and selectivity

Instruments are available for measuring carbon monoxide from below 1 µl/l to 50 000 µl/l (5 %) and more with a common resolution of 0,1 % of the selected range. Interferences with nitrogen compounds, water and carbon dioxide have been described.

5.1.3 Other considerations

Multi-range instruments are available to cover all concentrations likely to be encountered in fire effluents, which will normally be over the range 500 µl/l to 50 000 µl/l. The method is non-destructive and the sample can be “passed on” for analysis of other compounds, taking into account that some components of the sample, e.g. particles, acid gases and water, can be lost in filtering and sampling.

5.1.4 Analysis principles

NDIR instruments operate by passing a beam of infrared (IR) radiation of a fixed wavelength through the sample. The IR wavelength used is that which is in a main spectroscopic absorption region for carbon monoxide (and which is not absorbed significantly by other species). The absorption of the radiation is a measure of the concentration of carbon monoxide in the internal gas sample cell. Refinements may include a “double beam” system that can compensate for interfering species and other effects.

5.1.5 Procedure

See Clause 4 for principles of sampling and C.2 for general principles of the method. However, for the analysis of carbon monoxide by NDIR, the specific information in 5.1.6 to 5.1.10 is relevant.

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Normally, the instruments have only to be powered and the sampling line attached. It is usually convenient to set one concentration range within which the analysis is carried out and, therefore, it is desirable that the recording system used (e.g. data logger) has sufficient resolution for the chosen range.

5.1.6 Sampling

It is essential that the sample stream entering the instrument be treated to remove particulates and vapours condensable under ambient conditions. Simple in-line glass wool and calcium chloride filters have been found to be effective. Sample flow rates on the order of a few litres per minute are common and where the sampling point is many metres away from the instrument, a separately pumped, heated sample line with a higher flow rate can be used with the instrument sample port "teed" into this.

5.1.7 Analysis

There is no requirement for additional analytical procedures.

5.1.8 Calibration

Calibration is achieved through the introduction of standard (preferably certificated) gas mixtures and "zero gas" (which may be high-purity nitrogen) as provided commercially in pressurized cylinders. It is desirable to calibrate the instrument by introducing the sample both at the inlet port and at the remote sampling point. On multi-range instruments, it is usually possible to calibrate on the lowest range if more than one range is to be routinely used. However, calibration within the range to be used for measurement is recommended. It should be noted that the ambient concentration could vary significantly from these values depending on location. It is, therefore, important to recognize that a significant ambient reading can be obtained at the beginning of a fire experiment due to local conditions. The calibration and the analysis of the fire effluents shall be carried out using the same flow-rate through the analyser.

5.1.9 Calculations

There are no calculations required; the carbon monoxide concentration is obtained by direct readout or (more usually) through a connection to an electronic recording apparatus.

Note that some instruments have a nonlinear scale but have the electronic output corrected to provide a linear signal. This linear signal ranges between fixed values and usually does not take account of the selected concentration range.

5.1.10 Repeatability and reproducibility

Regarding the similarity of measurement technique, repeatability and reproducibility have been estimated as equivalent to CO_2 by NDIR (see 5.2.10).

For determination of CO yields according to AFAP-3[2] during combustion of PMMA at 800°C, Repeatability has been estimated as 14 % and reproducibility as 26 %.[12] These values include repeatability and reproducibility of the fire model.

5.2 Carbon dioxide by non dispersive infrared spectroscopy (NDIR)

5.2.1 Application and limitations

NDIR provides a continuous analysis/monitoring capability for carbon dioxide. The analysers are commonly self-contained instruments and include all sampling, pumping, sample filtering, and analysis hardware and electronics. A direct readout of the carbon dioxide concentration is usually provided (either digital or analog) together with an output for connecting recording devices. Instruments providing carbon dioxide and carbon monoxide analyses in the same case are available.

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5.2.2 Sensitivity and selectivity

Instruments are available for measuring carbon dioxide from below 1 µl/l to 200 000 µl/l (20 %) and more, with a common resolution of 0,1 % of the selected range. Interferences with nitrogen compounds and water have been described.

5.2.3 Other considerations

Multi-range instruments are available to cover all concentrations of carbon dioxide commonly encountered in fire effluents, which normally are in the range 500 µl/l to 200 000 µl/l. The method is non-destructive and the sample can be "passed on" for analysis of other compounds, taking into account that some components of the sample, e.g. particles, acid gases and water, can be lost in filtering and sampling.

5.2.4 Analysis principles

NDIR instruments operate by passing a beam of infrared (IR) light of fixed wavelength through the sample. The IR wavelength used is that which is in a main spectroscopic absorption region for carbon dioxide (and which is not absorbed significantly by other species). The absorption of radiation is a measure of the concentration of carbon dioxide in the internal gas sample cell. Refinements may include a "double beam" system that can compensate for interfering species and other effects.

5.2.5 Procedure

See Clause 4 for principles of sampling and C.2 for general principles for this method. However, for the analysis of carbon dioxide by NDIR, the specific information in 5.2.6 to 5.2.11 is relevant.

The instruments usually have only to be powered and the sampling line attached. It is usually convenient to set one concentration range within which the analysis is carried out and it is therefore desirable that the recording system used (e.g. data logger) have sufficient resolution for the chosen range.

5.2.6 Sampling

It is essential that the sample stream entering the instrument be treated to remove particulate and vapours condensable under ambient conditions. Simple in-line glass wool and calcium chloride filters have been found to be effective. Sample flow rates of the order of a few litres per minute are common and where the sampling point is many metres away from the instrument, a separately pumped, heated sampling line with a higher flow rate can be used with the instrument sample port "teed" into this.

5.2.7 Analysis

There is no requirement for additional analytical procedures.

5.2.8 Calibration

Calibration is achieved through the introduction of a standard (preferably certificated) gas mixtures and "zero gas" (which may be high-purity nitrogen) as provided commercially in pressurized cylinders. It is desirable to calibrate the instrument by introducing the sample both at the inlet port and at the remote sampling point. On multi-range instruments, it is usually desirable to calibrate on the lowest range if more that one range is to be routinely used. A useful check is the concentration of ambient carbon dioxide (350 µl/l to 355 µl/l in 1997) following a zero gas check. However, it should be noted that the ambient concentration can vary significantly from these values depending on location. It is, therefore, important to recognize that a significant ambient reading can be obtained at the beginning of a fire experiment due to local conditions. The calibration and the analysis of the fire effluents shall be carried out using the same flow-rate through the analyser.

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5.2.9 Calculations

There are no calculations required: the carbon dioxide concentration is obtained by direct readout or (more usually) through a connection to an electronic recording apparatus.

Note that some instruments have a nonlinear scale but have the electronic output corrected to provide a linear signal. This linear signal ranges between fixed values and does not usually take account of the selected concentration range.

5.2.10 Repeatability and reproducibility

For determination of CO_2 yields according to AFNOR NF X70-100-1, repeatability has been estimated as 8 % and reproducibility as 21 %, for a yield of around 0,15 kg/kg.[1] These values include repeatability and reproducibility of the fire model.

For determination of CO_2 yields according to AFAP-3[2] during calcinations of Zinc carbonate at 800°C, repeatability has been estimated as 16 % and reproducibility as 28 %.[12] These values include repeatability and reproducibility of the fire model.

5.2.11 Trueness

Trueness of the method has been determined according to AFAP-3[2] during calcinations of Zinc carbonate, with the hypothesis of a raw formula of $3(Zn(OH)_2).2(ZnCO_2)$ and considering the release of all carbonate into CO_2. Theoretical yield is 0,160 kg/kg. Value found (average of 3 determination) was 7,3 % lower than theoretical value.

5.3 Oxygen by paramagnetism

5.3.1 Application and limitations

This method provides a continuous analysis monitoring capability for oxygen. The analysers are commonly self-contained and include sample filtration, analysis hardware and electronics. Sample pumping may be built-in or provided externally. Direct readout, often by digital display, of oxygen concentration is usually provided together with an output for connecting recording devices.

5.3.2 Sensitivity and selectivity

Most instruments operate in the range 0 % to 100 % but may be able to switch ranges to cover narrower concentration ranges, typically 0 % to 25 %. A resolution of 0,1 % oxygen is common. Some instruments can also provide a “differential” reading, i.e. the change from a set starting value. No significant interference is likely but other paramagnetic compounds, e.g. nitrogen dioxide and carbon monoxide, can give a weak interference.

5.3.3 Other considerations

The advent of oxygen-depletion calorimetry has placed new demands on the sensitivity, selectivity and stability of the paramagnetic oxygen analyser. Most heat-release-rate measurements using this technique require a measurement accuracy of 0,02 % oxygen, usually over the range 15 % to 21 % oxygen.

5.3.4 Analysis principles

Oxygen exhibits the property of paramagnetism (i.e. concentrating/attracting an applied magnetic field) because of the electron arrangement in its molecule. Practical instruments utilize this property by measuring the movement of a body placed in a magnetic field, with the oxygen-containing sample flowing around the body.

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5.3.5 Procedure

See Clause 4 for principles of sampling and C.3 for general principles of the method. However, for the analysis of oxygen by paramagnetism, the specific information in 5.3.6 to 5.3.10 is relevant.

The instruments usually have only to be powered and the sampling line attached.

5.3.6 Sampling

It is essential that the sample stream entering the instrument be treated to remove particulates and vapours condensable under ambient conditions. Simple in-line glass wool and calcium chloride filters have been found to be effective. In order to protect the delicate mechanism in the measuring cell, sample flow-rates are usually very small, e.g. a few millilitres per minute, in comparison to the normal practical sampling rates required from the fire atmosphere, so a suitable internal by-pass is usually fitted.

5.3.7 Analysis

There is no requirement for additional analytical procedures.

5.3.8 Calibration

Calibration is achieved by the introduction of standard (preferably certificated) gas mixtures and "zero gas" (which may be high-purity nitrogen) as provided commercially in pressurized cylinders.

A useful check is to utilize the ambient oxygen concentration in dry air (20,9 %), this accuracy being adequate for many purposes. When used for oxygen depletion calorimetry, this accuracy for calibration is acceptable as the measurements involve a difference of oxygen concentration from ambient. However, it should be noted that other factors, such as location and atmospheric conditions, could affect the ambient concentration of oxygen. For example, at a relative humidity of 50 %, the ambient oxygen concentration is reduced from that of dry air to approximately 20,6 %.

5.3.9 Calculations

There are no calculations required; oxygen concentration is by direct readout or (more usually) through connection to electronic recording apparatus.

NOTE Some instruments have a nonlinear scale but have the electronic output corrected to provide a linear signal. This linear signal ranges between fixed values and does not usually take account of the selected concentration range.

5.3.10 Repeatability and reproducibility

No data has been collected yet. Nevertheless, the technique is at the basis of oxygen-depletion calorimetry and confidence in oxygen concentration produced is estimated fewer than 10 %.

5.4 Hydrogen cyanide

5.4.1 Hydrogen cyanide by colourimetry (Chloramine T)

5.4.1.1 Application and limitations

These are covered in 5.4.1.2 and 5.4.1.3.

5.4.1.2 Sensitivity and selectivity

This technique is capable of measuring 0,05 µg cyanide ions in the aliquot taken.

Small negative interferences arise from nitriles, oxides of nitrogen and sulphide.

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5.4.1.3 Other considerations

A concentration of 0,01 M sodium hydroxide for the trapping medium prevents breakthrough of hydrogen cyanide in fritted bubblers but does not influence the pH during the colourimetric analysis procedure.

During the colour development, there is a 10 min "window" between 25 min and 35 min during which the blue colour is stable, allowing analysis of multiple samples simultaneously. The solutions containing HCN have been found to be unstable over time. The solutions shall be analysed on the same day as the sample is obtained.

It should be noted that visual comparison of colour hue and intensity could be used as a guide to concentration (i.e. without the use of a spectrophotometer) but such assessments can be relatively subjective and are affected by such factors as colour-blindness and other sight defects.

5.4.1.4 Analysis principles

Cyanide (CN^-) in the test solution, is converted to cyanogen chloride (CNCl) by reaction with chloramine T at pH 7. The CNCl then forms a blue dye on addition of 4-pyridinecarboxylic acid-pyrazolone reagent, which is measured in a spectrophotometer at a wavelength of approximately 638 nm (corresponding to the maximum absorbance of the standard solution); see Reference [13].

5.4.1.5 Procedure

See Clause 4 for principles of sampling and C.4 for general principles of the method. However, for the analysis of hydrogen cyanide by chloramine T colourimetry, the specific information in 5.4.1.6 to 5.4.1.9 is relevant.

5.4.1.6 Sampling

Pump the fire atmosphere through a fritted bubbler containing 20 ml of 0,01 M sodium hydroxide at 0,4 l/min for 4 min to 5 min and record the total volume sampled. These sampling parameters may be varied if necessary to suit conditions. Copper sampling tubes are unsuitable. Flow measurements will contribute to the overall uncertainty in the determination.

5.4.1.7 Analysis

5.4.1.7.1 Reagents

Analytical grade reagents should be used where possible. Water used should be quality 3 as defined in ISO 3696:1987.[14]

5.4.1.7.1.1 **Absorbing solution,** 0,01 M sodium hydroxide

5.4.1.7.1.2 **Phosphate buffer,** pH 7.2

Add 19,8 g sodium hydrogen phosphate to 300 ml distilled water and adjust to pH 7,2 with potassium dihydrogen phosphate solution (ρ = 200 g/l). Make up volume to 500 ml with distilled water.

5.4.1.7.1.3 **Chloramine T solution,** ρ = 1 g/l

Dissolve 0,1 g chloramine T in 100 ml distilled water. Prepare freshly each day.

5.4.1.7.1.4 Pyridine-pyrazolone solution

Mix 1-phenyl-3-methyl-5-pyrazolone (0,3 g in 20 ml dimethyl formamide) with 4-pyridiene carboxylic acid (1,5 g in 20 ml 1 M NaOH; adjust pH to 7,0 with 1 M HCl). Adjust final volume to 100 ml with distilled water. The solution is stable for up to five weeks if refrigerated.

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5.4.1.7.1.5 Stock cyanide solution, ρ approximately 1 000 µg/ml CN^-

Dissolve 1,29 g potassium cyanide in 500 ml 0,01 M sodium hydroxide.

5.4.1.7.1.6 Standard cyanide solution, ρ = 2,0 µg/ml CN^-

Add 1 ml stock solution (5.4.1.7.1.5) to 0,01 M sodium hydroxide contained in a 500 ml volumetric flask and make up to volume. Prepare freshly each day.

5.4.1.7.2 Protocol

To a boiling-tube, add an aliquot of test solution containing up to 4,0 µg CN^-. Add 0,01 M sodium hydroxide (if necessary) to give a total volume of 4 ml. Then add in turn with shaking

— 1,8 ml phosphate buffer,

— 0,8 ml chloramine T (leave 5 min to react),

— 1,8 ml pyridine-pyrazolone solution.

Read absorbance at approximately 638 nm (corresponding to the maximum absorbance of the standard solution) in a 1 cm cell against a reagent blank solution, 30 min exactly after the addition of the chloramine T solution (see 5.4.1.7.1.3).

5.4.1.8 Calibration

Prepare calibration standards containing 2,0 µg and 4,0 µg CN^- using 1 ml and 2 ml aliquots of the standard cyanide solution (5.4.1.7.1.6). Prepare at least two more calibration solutions to cover the range of concentrations required. Make up the volume to 4 ml with 0,01 M sodium hydroxide and develop the colour as described above. Standards should be included with each set of analyses.

5.4.1.9 Calculations

Compare the absorbance of the test solutions with that obtained for the calibration standards and calculate concentrations in the test atmosphere using Formula (4):

$$\rho_{HCN} = \frac{\rho_{CN} \times V_{as} \times 1{,}038}{V_{ta} \times e} \tag{4}$$

where

ρ_{HCN} is the hydrogen cyanide concentration, expressed in grams per litre of atmosphere;

ρ_{CN} is the cyanide ions concentration in the absorbing solution, expressed in grams of cyanide ions per litre of the solution;

1,038 is the conversion factor from CN to HCN, equal to 27/26;

V_{as} is the total volume, expressed in litres, of absorbing solution;

V_{ta} is the volume, expressed in litres, of the test atmosphere sampled;

e is the collection efficiency of the trapping system, experimentally determined using a train of two traps.

5.4.1.10 Repeatability and reproducibility

No data has been collected yet.

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5.4.2 **Hydrogen cyanide by colourimetry** (picric acid)

5.4.2.1 Application and limitations

These are covered in 5.4.2.2 and 5.4.2.3.

5.4.2.2 Sensitivity and selectivity

This technique is capable of measuring 2 µg/ml cyanide ions.

Interferences arise from acetone and other ketones. Washing flasks with acetone is prohibited with this technique.

5.4.2.3 Other considerations

Sample solutions containing HCN have been found to be unstable over time. It is recommended that the solutions be analysed within 24 h of the collection of the sample. It should be noted that visual comparison of colour hue and intensity could be used as a guide to concentration (i.e. without the use of a spectrophotometer) but such assessments can be relatively subjective and are affected by such factors as colour-blindness and other sight defects.

5.4.2.4 Analysis principles

Cyanide (CN^-) in the test solution, trapped in the form of an alkaline cyanide, forms a red derivative of isopurpurate when added to a picric acid reagent, the absorbance of which is measured in a spectrophotometer at a wavelength of approximately 480 nm (corresponding to the maximum absorbance of the standard solution).

5.4.2.5 Procedure

See Clause 4 for principles of sampling and C.4 for general principles of the method. However, for the analysis of hydrogen cyanide by picric acid colourimetry, the specific information in 5.4.2.6 to 5.4.2.11 is relevant.

5.4.2.6 Sampling

Pump the fire atmosphere through a fritted bubbler containing 20 ml of 0,1 M sodium hydroxide at 0,4 l/min for 4 min to 5 min and record the total volume sampled. These sampling parameters may be varied if necessary to suit conditions.

5.4.2.7 Analysis

5.4.2.7.1 Reagents

Analytical grade reagents should be used where possible. Water used should be quality 3 as defined in ISO 3696:1987.[14]

5.4.2.7.1.1 **Absorbing solution**, 0,1 M sodium hydroxide

5.4.2.7.1.2 Colourimetric reagent

Dissolve 50 g of sodium carbonate in distilled water. Add 250 ml of a 1,2 % picric acid solution (commercially available with analysis certificate). Adjust final volume to 1 000 ml with distilled water. The solution is stable for several months if kept in a brown flask.

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5.4.2.7.1.3 **Stock cyanide solution**, ρ approximately 800 µg/ml CN^-

The solution can be prepared from potassium cyanide dissolved in sodium hydroxide (0,01 M). The exact concentration of the solution has to be checked before use, as potassium cyanide is not stable and oxidation can occur.

5.4.2.7.1.4 **Standard cyanide solution**, ρ approximately 40 µg/ml CN^-

Add 5 ml stock solution (5.4.2.7.1.3) to distilled water contained in a 100 ml volumetric flask and make up to volume. Prepare freshly each day.

5.4.2.7.2 Protocol

To a flask or Erlenmeyer, add an aliquot of test solution of between 1 ml and 20 ml. Add 30 ml of colourimetric reagent and make up to 50 ml with 0,1 M sodium hydroxide.

Make a sample blank solution by adding to a flask or an Erlenmeyer 1 ml of test solution and 50 ml of 0,1 M sodium hydroxide. This is to allow for the fact that the sample itself can contain colouring, which interferes with the analysis.

Place the flasks or Erlenmeyers for 10 min in a water-bath kept at 90 °C ± 2 °C.

After cooling to ambient temperature, read the absorbance at approximately 480 nm (corresponding to the maximum absorbance of the standard solution) in a 1 cm cell against a reagent blank and the sample blank. If the absorbance measured is higher than the calibrated range, dilute the test solution using 0,1 M sodium hydroxide and repeat the analysis.

5.4.2.8 Calibration

The reagent blank and standard solutions are prepared in accordance with Table 2.

Table 2 — Preparation of reagent blank and standard solutions

Parameter	CN concentration in µg/ml					
	Reagent blank	Standard solution				
		2,4	4,8	7,2	9,6	12
	Volume of reagent added ml					
Standard cyanide solution	0	3	6	9	12	15
0,1 M sodium hydroxide	20	17	14	11	8	5
Colourimetric reagent	30	30	30	30	30	30

Develop the colour as described in 5.4.2.7.2. Standards should be included with each set of analyses.

5.4.2.9 Calculations

Compare the absorbance of the test solutions with those obtained for the calibration standards and calculate solution concentrations using Formula 4, in 5.4.1.9.

5.4.2.10 Repeatability and reproducibility

Repeatability and reproducibility were estimated in a mixture issued from trapping fire effluents from various materials in 0,1 M NaOH solution.[1] For concentration around 8 mg/l, repeatability has been estimated as 7 % and reproducibility has been estimated as 21 %. For concentration around 32 mg/l, repeatability has been estimated as 4 % and reproducibility has been estimated as 23 %.

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5.4.2.11 Trueness

Values found during interlaboratory trial were compared with technique by high performance ion chromatography (HPIC). Results were comparable for low concentration (at about 8 mg/l) at less than 13 % and for high concentration (at about 32 mg/l) at less than 4 %.

5.4.3 Hydrogen cyanide by high performance ion chromatography (HPIC)

5.4.3.1 Application and limitations

These are covered in 5.4.3.2 and 5.4.3.3.

5.4.3.2 Sensitivity and selectivity

This technique is capable of measuring within the range of 0,05 µg/ml to 50 µg/ml as cyanide ions in solution. For measurement of higher concentrations, accurate dilution of the sample solution is necessary.

This technique is specific to cyanide ions in aqueous solution. An alkaline eluent shall always be used for separation and detection to ensure the cyanide ions exist in the anionic form.

This method allows measurement of hydrogen sulphide simultaneously (see 5.14.1).

5.4.3.3 Other considerations

A glass syringe with a PTFE-tipped plunger is recommended for use during injection to avoid unnecessary reactions with the rubber materials often present in the plungers of plastic syringes. Certain types of columns have been found to be sensitive to the fire-effluent solution in that they can quickly become clogged. The solution should be filtered before injection onto the column. It is often necessary to regenerate the columns regularly.

In routine usage, it has been proven that HPIC separating columns are subject to accelerate aging of solid phase. A special care has to be done checking no degradation of analytical conditions.

5.4.3.4 Analysis principles

The separation is carried out on an anion exchange column followed by Amperometric detection with a silver-working electrode. A silver chloride reference and a stainless steel counter electrode are fitted in the cell.

5.4.3.5 Procedure

See Clause 4 for principles of sampling and C.5 for the general principles of the method. However, for the analysis of hydrogen cyanide by HPIC, the specific information in 5.4.3.6 to 5.4.3.11 is relevant.

5.4.3.6 Sampling

The following procedure has been found suitable; see AFNOR NF X70-100-1[1] and AFNOR NF X70-100-2.[15] Pump the fire atmosphere through a non-fritted then a fritter impinger, containing 75 ml and 150 ml, respectively, of 0,1 M sodium hydroxide, at 2 l/min for 20 min and record the total volume sampled. These sampling parameters may be varied if necessary to suit conditions. Copper sampling tubes are unsuitable.

5.4.3.7 Analysis

5.4.3.7.1 Reagents

Liquid chromatography grade reagents should be used where possible.

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5.4.3.7.1.1 Absorbing solution, 0,1 M sodium hydroxide.

5.4.3.7.1.2 Eluents, consisting of 0,1 M sodium hydroxide, 0,5 M sodium acetate or 0,5 % ethylene diamine.

5.4.3.7.1.3 Stock cyanide solution, ρ approximately 1 000 µg/ml CN^-.

Dissolve 1,25 g potassium cyanide in 500 ml 0,1 M sodium hydroxide.

5.4.3.7.1.4 Standard cyanide solutions

Dilute stock cyanide solution in 0,1 M sodium hydroxide contained in volumetric flasks and make up to volume in order to obtain several standard solutions. Prepare freshly each day.

5.4.3.7.2 Protocol

Flow rate should be set at 1 ml/min. The applied voltage setting is zero volts.

Direct analysis of the unknown solution can be carried out. The sample injection volume is 25 µl and it is advisable to inject at least 10 times the volume to fill the sample loop completely.

5.4.3.8 Calibration

Standard cyanide solutions are injected into the system and a chart recorder or an integrator monitors the detector response. The peak area monitored is directly related to the concentration of each standard solution. A calibration curve is then prepared.

5.4.3.9 Calculations

Compare the peak area of the test solution corresponding to cyanide ions with those obtained for the calibration curve and calculate atmospheric concentrations using Formula 4, in 5.4.1.9.

5.4.3.10 Repeatability and reproducibility

Repeatability and reproducibility were estimated in a mixture issued from trapping fire effluents from various materials in 0,1 M NaOH solution.[1] For concentration around 7 mg/l, repeatability has been estimated as 4 % and reproducibility has been estimated as 18 %. For concentration around 33 mg/l, repeatability has been estimated as 2 % and reproducibility has been estimated as 9 %.

5.4.3.11 Trueness

Values found during interlaboratory trial were compared with technique by colourimetry (picric acid), see 5.4.2. Results were comparable for low concentration (at about 7 mg/l) at less than 13 % and for high concentration (at about 33 mg/l) at less than 4 %.

5.5 Hydrogen chloride and hydrogen bromide

5.5.1 Hydrogen chloride and hydrogen bromide by ion selective electrode (ISE)

5.5.1.1 Application and limitations

These are covered in 5.5.1.2 and 5.5.1.3.

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5.5.1.2 Sensitivity and selectivity

This technique is capable of measuring 5 µg/ml of hydrogen chloride or hydrogen bromide in the test solution. However, mixtures of bromide and chloride will produce strong positive interference. Sulphide ions will also produce a strong positive interference.

If both bromide and chloride ions are present in the same test solution, then a total hydrogen halide concentration can be measured and expressed as halide equivalents, as the sensitivities to Cl^- and Br^- are equal.

5.5.1.3 Other considerations

Hydrogen cyanide, phosphates and total phosphorus can be quantified in the same test solution.

5.5.1.4 Analysis principles

Hydrogen chloride and/or bromide is collected in 0,01 M sodium hydroxide contained in fritted bubblers. Halide ions in the test solutions are measured by a determination of the electrode potentials with halide-selective and reference electrodes; see Reference [16].

5.5.1.5 Procedure

See Clause 4 general sampling requirements and C.7 for general principles of the method. However, for the analysis of hydrogen chloride and hydrogen bromide by ISE, the specific information in 5.5.1.6 to 5.5.1.10 is relevant.

5.5.1.6 Sampling

Pump the fire atmosphere through a fritted bubbler containing 20 ml of 0,01 M sodium hydroxide at 0,4 l/min for 4 min to 5 min and record the volume of test atmosphere sampled. These sampling parameters may be varied if necessary to suit conditions.

5.5.1.7 Analysis

5.5.1.7.1 Reagents

Analytical grade reagents should be used where possible.

5.5.1.7.1.1 Absorbing solution, 0,01 M sodium hydroxide

5.5.1.7.1.2 Standard chloride solution, approximately 200 µg/ml, equivalent to 5,6 µmol/ml

Dissolve 0,329 6 g sodium chloride in 1 000 ml 0,01 M sodium hydroxide.

5.5.1.7.1.3 Standard bromide solution, approximately 450 µg/ml equivalent to 5,6 µmol/ml

Dissolve 0,669 8 g sodium bromide 1 000 ml 0,01 M sodium hydroxide.

5.5.1.7.2 Protocol

Chloride and/or bromide in the solution are quantified against calibration standards (for example, 200 µg/ml Cl^-, equivalent to 5,6 µmol/ml Cl^-) according to the procedure specified by the manufacturer of the ISE instrument.

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5.5.1.8 Calibration

Prepare calibration standards with the 0,01 M sodium hydroxide solution used as trapping medium. Generally, standards up to 5,6 µmol/ml are used. For everyday use, conditioning/calibration of the ISE is carried out with a single specified standard.

5.5.1.9 Calculations

For an ISE used as a halide analyser, the concentration of hydrogen chloride and/or hydrogen bromide in the test atmosphere is calculated from Formula (5):

$$\rho_{HX} = \frac{\rho_X \times V_{as} \times \frac{M_{HX}}{M_X}}{V_{ta} \times e} \tag{5}$$

where

ρ_{HX} is the hydrogen halide concentration, expressed in grams per litre of atmosphere;

ρ_X is the halide ions concentration in the absorbing solution (chloride or bromide), expressed in grams of halide ions per litre of the solution;

$\frac{M_{HX}}{M_X}$ is the conversion factor from halide ion to hydrogen halide, equal to 1,028 for chloride (36,45 / 35,45) and 1,013 for bromide (80,9 / 79,9);

V_{as} is the total volume, expressed in litres, of absorbing solution;

V_{ta} is the volume, expressed in litres, of the test atmosphere sampled;

e is the collection efficiency of the trapping system, experimentally determined using a train of two traps.

5.5.1.10 Repeatability and reproducibility

No data has been collected yet.

5.5.2 Hydrogen chloride and hydrogen bromide by high performance ion chromatography (HPIC)

5.5.2.1 Application and limitations

These are covered in 5.5.2.2 to 5.5.2.3.

5.5.2.2 Sensitivity and selectivity

This technique is capable of measuring within the range of 0,05 µg/ml to 50 µg/ml as chloride or bromide ions in solution. For measurement of higher concentrations, accurate dilution of the sample solution is necessary.

This technique is specific to chloride and bromide ions in aqueous solution. Co-elutants can interfere with the accuracy of the results.

Other anions can also be analysed by this technique with appropriate trapping solutions.

Details on method sensitivity and selectivity can be found in Reference [17].

5.5.2.3 Other considerations

0,1 M sodium hydroxide may be used as the trapping solution. This will trap a wider range of anions and may allow longer storage of samples.

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5.5.2.4 Analysis principles

The separation is carried out on an anion exchange column followed by conductimetric detection. It is necessary to use chemical or electrochemical suppression.

NOTE Hydrogen bromide can be also detected using a UV-visible detector. In this case, chemical or electrochemical suppression is not needed.

5.5.2.5 Procedure

See Clause 4 for principles of sampling and C.5.1 and C.5.2 for general principles of the method. However, for the analysis of hydrogen chloride and hydrogen bromide by HPIC, the specific information in 5.5.2.6 to 5.5.2.11 is relevant.

5.5.2.6 Sampling

The following procedure has been found suitable; see AFNOR NF X70-100-1[1] and AFNOR NF X70-100-2.[15] Pump the fire atmosphere through a non-fritted then a fritted impinger, containing 75 ml and 150 ml, respectively, of distilled water, at 2 l/min for 20 min and record the total volume sampled. These sampling parameters may be varied if necessary to suit conditions.

5.5.2.7 Analysis

5.5.2.7.1 Reagents

Liquid chromatography grade reagents should be used where possible.

5.5.2.7.1.1 Absorbing solution, distilled water or 0,1 M sodium hydroxide

5.5.2.7.1.2 Eluents, consisting of 0,001 7 M sodium hydrogen carbonate and 0,001 8 M sodium carbonate

5.5.2.7.1.3 Stock chloride or **bromide solution** ~1 000 µg/ml Cl^- or Br^-

Dissolve sodium chloride (0,82 g) and/or bromide (0,64 g) in 500 ml distilled water.

5.5.2.7.1.4 Standard chloride or **bromide solution**

Dilute stock chloride or bromide solution in distilled water contained in a volumetric flask and make up to volume in order to obtain several standard solutions. Prepare freshly each day.

5.5.2.7.2 Protocol

The sample flow rate should be set at 2 ml/min.

Direct analysis of the unknown solution can be carried out. The sample injection volume is 25 µl and it is advisable to inject at least 10 times the volume to fill the sample loop completely.

5.5.2.8 Calibration

Standard chloride or bromide solutions are injected into the system and the detector response is monitored by a chart recorder or an integrator. The peak area monitored is directly related to the concentration of each standard solution. A calibration curve is then prepared for the chloride and/or bromide.

5.5.2.9 Calculations

Compare the peak area of the test solution corresponding to chloride and bromide ions with those obtained for the calibration curve and calculate concentrations in the test atmosphere using Formula (5) in 5.5.1.9.

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5.5.2.10 Repeatability and reproducibility

Repeatability and reproducibility were estimated in a mixture issued from trapping fire effluents from various materials in water solution.[1]

For hydrogen chloride, for concentration around 4 mg/l, repeatability has been estimated as 15 % and reproducibility has been estimated as 35 %. For concentration around 37 mg/l, repeatability has been estimated as 6 % and reproducibility has been estimated as 17 %. For concentration around 78 mg/l, repeatability has been estimated as 5 % and reproducibility has been estimated as 16 %.

For hydrogen bromide, for concentration around 2 mg/l, repeatability has been estimated as 6 % and reproducibility has been estimated as 15 %. For concentration around 34 mg/l, repeatability has been estimated as 4 % and reproducibility has been estimated as 15 %.

5.5.2.11 Trueness

Trueness of the method has been determined according to AFNOR NF X70-100-2[15] fire model. This determination has been performed using reference PVC at known quantity, with the hypothesis of conversion of chloride present in the polymer exclusively into hydrogen chloride. Theoretical yield of HCl is 0,584 kg/kg. Value found (average of 3 determination) was less than 1,1 % different from theoretical value.

5.5.3 Hydrogen chloride and hydrogen bromide by titrimetry

5.5.3.1 Application and limitations

These are covered in 5.5.3.2 to 5.5.3.4.

5.5.3.2 Sensitivity and selectivity

This technique is capable of measuring within the range over 4 µg/ml as chloride or bromide ions in solution. For measurement of high concentrations, accurate dilution of the sample solution is necessary.

This technique is specific to chloride and bromide ions in aqueous solution. Important concentrations of hydrogen cyanide or sulphide ions can interfere. Details on method sensitivity and selectivity can be found in Reference [17].

5.5.3.3 Other considerations

Depending on proportions between Cl^- or Br^-, specific corrections may apply if both ions are present. The salts produced by precipitation reaction have different solubilities, according to Formula (6):

$$\frac{(K_s)_{AgBr}}{(K_s)_{AgCl}} = 5\times10^{-3} \tag{6}$$

There is a good separation, with error below 5 % when the bromide and chloride mass concentrations are such that:

$$0{,}1 \le \frac{[Cl^-]}{[Br^-]} < 5 \tag{7}$$

However, in other cases, measurement is less accurate due to precipitation of the two halides.

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5.5.3.4 Analysis principles

Chloride and bromide ions in an acid solution form a precipitate with silver ions (from a $AgNO_3$ solution) according to the following reactions:

$$\begin{aligned} Ag^+ + Cl^- &\rightarrow \underline{AgCl} \\ Ag^+ + Br^- &\rightarrow \underline{AgBr} \end{aligned} \tag{8}$$

The titration method is carried out by measuring variations in potential U using a combined silver electrode. The end of the reaction is indicated by a jump in potential caused by a sharp increase in the concentration of free silver ions. The equivalent measurement point for all chloride and bromide ions in solution is precisely determined on the potential curve U as function of the volume of $AgNO_3$ added to the solution.

If both of these ions are present in analysed solution, then the first jump in potential is associated with bromide ions and the second with chloride ions.

5.5.3.5 Procedure

See Clause 4 for principles of sampling and C.9 for general principles of the method. However, for the analysis of hydrogen chloride and hydrogen bromide by titrimetry, the specific information in 5.5.3.6 to 5.5.3.9 is relevant.

5.5.3.6 Sampling

The following procedure has been found suitable; see AFNOR NF X70-100-1[1] and AFNOR NF X70-100-2.[15] Pump the fire atmosphere through a non-fritted then a fritted impinger, containing 75 ml and 150 ml, respectively, of distilled water, at 2 l/min for 20 min and record the total volume sampled. These sampling parameters may be varied if necessary to suit conditions.

5.5.3.7 Analysis

5.5.3.7.1 Reagents

5.5.3.7.1.1 Nitric acid, in around 69 % solution

5.5.3.7.1.2 Silver nitrate, solution with a known concentration c_{AgNO3} ranging between 0,02 mol/l and 0,10 mol/l

5.5.3.7.2 Protocol

Take a volume V_1, in millilitres, of the solution to be analysed and add a sufficient volume of nitric acid to obtain a final pH less than 2. Stir the mixture and titrate with appropriate silver nitrate solution. Plot the potential curve U as function of the volume of $AgNO_3$ added to the solution and determine the equivalent measurement volume V_{eq} for each jump in potential.

It is suitable to confirm association of jump potentials with chloride and bromide ions by addition of a known aliquote of each of these ions.

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5.5.3.8 Calculations

If only one jump in potential is observed and confirmed to be associated with chloride ions by addition, the total mass, in milligrams, of HCl released during the test is equal to:

$$HCl(mg) = c_{AgNO_3} \times V_{eq} \times \frac{V}{V_1} \times M_{HCl} \quad (9)$$

where

c_{AgNO_3} is the concentration, expressed in moles per litre, of the silver nitrate solution;

V_{eq} is the volume of silver nitrate used at the inflexion point of the jump in potential corresponding to the chloride ions, expressed in millilitres;

V is the volume of the solution to be analysed, expressed in millilitres;

V_1 is the volume of the test sample, expressed in millilitres;

M_{HCl} is the molar mass of HCl (36,45 g/mol).

If only one jump in potential is observed and confirmed to be associated with bromide ions by addition, the total mass, in milligrams, of HBr released during the test is equal to:

$$HBr(mg) = c_{AgNO_3} \times V_{eq} \times \frac{V}{V_1} \times M_{HBr} \quad (10)$$

where

c_{AgNO_3} is the concentration, expressed in moles per litre, of the silver nitrate solution;

V_{eq} is the volume of silver nitrate used at the inflexion point of the jump in potential corresponding to the bromide ions, expressed in millilitres;

V is the volume of the solution to be analysed, expressed in millilitres;

V_1 is the volume of the test sample, expressed in millilitres;

M_{HBr} is the molar mass of HBr (80,9 g/mol).

If two jumps in potential are observed and confirmed to be associated respectively with bromide and chloride ions by additions, the interpretation is more complex and two cases are possible.

<u>Case 1:</u>

$$0,1 \leq \frac{[Cl^-]}{[Br^-]} < 5$$

The total mass, in milligrams, of HBr and HCl released during the test is equal to:

$$HBr(mg) = c_{AgNO_3} \times V_{eq1} \times \frac{V}{V_1} \times M_{HBr} \quad (11)$$

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$$HCl(mg) = c_{AgNO_3} \times \left(V_{eq2} - V_{eq1}\right) \times \frac{V}{V_1} \times M_{HCl} \quad (12)$$

where

c_{AgNO_3} is the concentration, expressed in moles per litre, of the silver nitrate solution;

V_{eq1} is the volume of silver nitrate used at the inflexion point of the first jump in potential corresponding to the bromide ions, expressed in millilitres;

V_{eq2} is the volume of silver nitrate used at the inflexion point of the second jump in potential corresponding to the bromide and chloride ions, expressed in millilitres;

V is the volume of the solution to be analyzed, expressed in millilitres;

V_1 is the volume of the test sample, expressed in millilitres;

M_{HCl} is the molar mass of HBr (80,9 g/mol).

Case 2:

$$\frac{\left[Cl^-\right]}{\left[Br^-\right]} \leq 0{,}1 \quad \text{or} \quad \frac{\left[Cl^-\right]}{\left[Br^-\right]} > 5$$

In this case, the direct titrimetric method cannot correctly measure the amounts of chloride and bromide ions. The measurement can be achieved using titrimetry by adding a known quantity of the minor halide and then subtracting this added halide from the result of the measurement.

5.5.3.9 Repeatability and reproducibility

Repeatability and reproducibility were estimated in a mixture issued from trapping fire effluents from various materials in water solution.[1]

For hydrogen chloride, for concentration around 4 mg/l, repeatability has been estimated as 8 % and reproducibility has been estimated as 10 %. For concentration around 16 mg/l, repeatability has been estimated as 2 % and reproducibility has been estimated as 10 %. For concentration around 165 mg/l, repeatability has been estimated as 3 % and reproducibility has been estimated as 4 %.

For hydrogen bromide, for concentration around 7 mg/l, repeatability has been estimated as 9 % and reproducibility has been estimated as 34 %. For concentration around 16 mg/l, repeatability has been estimated as 4 % and reproducibility has been estimated as 15 %.

5.6 Hydrogen fluoride

5.6.1 Hydrogen fluoride by an ion-selective electrode (ISE)

5.6.1.1 Application and limitations

The method described has been successfully and reliably used for the analysis of hydrogen fluoride in fire atmospheres as described in AFNOR NF X70-100-1[1] and in References [2],[18] and [19].

5.6.1.2 Sensitivity and selectivity

This technique is capable of measuring 0,1 µg/ml of hydrogen fluoride in the test solution.

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The nature of the fluoride-selective electrode (lanthanide fluoride) and the buffer solution makes this method very specific for hydrogen fluoride.

Hydroxide ion and some metal ions can interfere, but addition of an ionic strength/pH-adjuster buffer compensates for these.

5.6.1.3 Other considerations

Sampling equipment shall be non-reactive to HF. Losses are minimal compared to other techniques.

A trapping medium of approximately 1 M sodium hydroxide contained in non-fritted impingers has been successfully used.

Lanthanide Fluoride (LaF) crystal surface of ISE is subject to aging, inducing degradation of sensitivity. Laboratory has to take care of this aspect and ISE need regular care by polishing crystal surface. Similar care concerns reference electrode.

5.6.1.4 Analysis principles

The test solution is buffered at pH 6 to pH 8 with HCl (6 mol/l) and fluoride ions measured by determination of the electrode potentials with fluoride selective and reference electrodes. Fluoride selective electrode is made of Lanthanide Fluoride (LaF) crystal. Reference electrode commonly used is classical Ag/AgCl electrode specific to complex solutions.

5.6.1.5 Procedure

See Clause 4 for general sampling requirements and C.7 for general principles of the method. However, for the analysis of hydrogen fluoride by an ISE, the information in 5.6.1.6 to 5.6.1.11 is relevant.

5.6.1.6 Sampling

Because of the reactivity of HF, sampling lines, probes etc. should be constructed from non-reactive materials (e.g. PTFE).

5.6.1.7 Analysis

5.6.1.7.1 Reagents

Analytical grade reagents should be used where possible.

5.6.1.7.1.1 Acetic acid for analysis

5.6.1.7.1.2 **Total ionic strength activity buffer** (TISAB), pH 5,5 as supplied by an electrode manufacturer or as prepared

Dissolve 37 g potassium chloride, 68 g sodium acetate and 36 g cyclohexylenediaminetetraacetic acid (CDTA) in water. Adjust to pH (5 ± 0,2) with hydrochloric acid. Dilute to 1 l.

5.6.1.7.1.3 **Stock fluoride solution,** ~100 µg/ml F^-

Dissolve 0,221 1 g sodium fluoride (dried at 105 °C for 2 h) in deionised water and dilute to 1 l.

5.6.1.7.1.4 Standard fluoride solutions

Dilute stock fluoride solution by adding known amounts (up to 12,5 ml) to 25 ml of the TISAB solution and make up to 50 ml with water, to obtain several standard solutions. Table 3 gives an example of the calibration curve data.

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5.6.1.7.2 Protocol

Fluorine in the solution is quantified against calibration standards according to the procedure specified by the manufacturer of the ISE instrument.

5.6.1.8 Calibration

The calibration standards are prepared with two solutions having F^- concentrations of $1{,}9 \times 10^{-1}$ µg/ml and $1{,}9 \times 10^{2}$ µg/ml. Table 3 shows the calibration solutions which have been found to be suitable for a range of fluorine concentrations.

Table 3 — Preparation of fluorine calibration solutions

Reagent	Concentration of calibration solution µg/ml				
	$1{,}9 \times 10^{-2}$	$1{,}9 \times 10^{-1}$	1,9	$1{,}9 \times 10^{1}$	$1{,}9 \times 10^{2}$
	Volume of reagent added ml				
Solution with $1{,}9 \times 10^{2}$ µg/ml fluoride	—	—	0,2	2	20
Solution with $1{,}9 \times 10^{-1}$ µg/ml fluoride	2	20	—	—	—
Water	18	0	19,8	18	0
Buffer solution	20	20	20	20	20

The calibration is not linear, but logarithmic for large variations of concentrations, due to Nernst law.

5.6.1.9 Calculations

The concentration of hydrogen fluoride in the test atmosphere is calculated from Formula (13):

$$\rho_{HF} = \frac{\rho_F \times V_{as} \times 1{,}053}{V_{ta} \times e} \tag{13}$$

where

ρ_{HF} is the hydrogen fluoride concentration, expressed in grams per litre of atmosphere;

ρ_F is the fluoride ions concentration in the absorbing solution, expressed in grams of fluoride ions per litre of the solution;

1,053 is the conversion factor from F to HF, equal to 20/19;

V_{as} is the total volume, expressed in litres, of absorbing solution;

V_{ta} is the volume, expressed in litres, of the test atmosphere sampled;

e is the collection efficiency of the trapping system, experimentally determined using a train of two traps.

5.6.1.10 Repeatability and reproducibility

Repeatability and reproducibility were estimated in a mixture issued from trapping fire effluents from various materials in 1 M NaOH solution.[1] For concentration around 1 mg/l, repeatability has been estimated as 7 % and reproducibility has been estimated as 25 %. For concentration around 357 mg/l, repeatability has been estimated as 2,5 % and reproducibility has been estimated as 6 %.

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5.6.1.11 Trueness

Values found during interlaboratory trial were compared with technique by colourimetry (SPADNS) presented in AFNOR NF X70-100-1.[1] Results were comparable for high concentrations (at about 350 mg/l) at less than 2 %. Colourimetric method (SPADNS) is not suitable for low concentrations and is not considered in the present standard. This method allows repeatability around 6 % for high concentrations.[1]

5.6.2 Hydrogen fluoride by high performance ion chromatography (HPIC)

5.6.2.1 Application and limitations

See 5.6.2.2 and 5.6.2.3.

5.6.2.2 Sensitivity and selectivity

This technique is capable of measuring within the range of 0,05 µg/ml to 50 µg/ml as fluoride ions in solution. For measurement of higher concentrations, accurate dilution of the sample solution is necessary.

This technique is specific to fluoride ions in aqueous solution. Co-elutants can interfere with the accuracy of the results.

Other anions can also be analysed by this technique with appropriate trapping solutions.

Details on method sensitivity and selectivity can be found in Reference [17].

5.6.2.3 Other considerations

Glass materials are not suitable because of the reactivity of HF. Non-reactive materials and equipment (e.g. PTFE or other plastics such as PVC and PE) shall be used. One M sodium hydroxide may be used as the trapping solution. This will trap a wider range of anions and can allow longer storage of samples. A 0,1 M sodium hydroxide solution may be used for low HF content solutions.

5.6.2.4 Analysis principles

The separation is carried out on an anion exchange column followed by conductimetric detection. Chemical suppression shall be used.

5.6.2.5 Procedure

See Clause 4 for principles of sampling and C.5.1 and C.5.2 for general principles of the method. However, for the analysis of hydrogen fluoride by HPIC, the specific information in 5.6.2.6 to 5.6.2.10 is relevant.

5.6.2.6 Sampling

The following procedure has been found suitable; see AFNOR NF X70-100-1[1] and AFNOR NF X70-100-2.[15] Pump the fire atmosphere through three non-fritted impingers, each containing 75 ml of 1 M sodium hydroxide, at 2 l/min for 20 min and record the total volume sampled. These sampling parameters may be varied if necessary to suit conditions.

5.6.2.7 Analysis

5.6.2.7.1 Reagents

Liquid chromatography grade reagents should be used where possible.

5.6.2.7.1.1 **Absorbing solution,** 1 M sodium hydroxide

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5.6.2.7.1.2 Eluents, 0,000 3 mol/l sodium hydrogen carbonate and 0,002 7 mol/l sodium carbonate

5.6.2.7.1.3 Stock fluoride solution, ~1 000 µg/ml F^-

Dissolve 1,10 g sodium fluoride in 500 ml distilled water.

5.6.2.7.1.4 Standard fluoride solutions

Dilute stock solution in distilled water contained in volumetric flasks and make up to volume in order to obtain several calibration solutions. Prepare freshly each day.

5.6.2.7.2 Protocol

The sample flow rate should be set at 1,5 ml/min.

Before injecting the sample into the chromatograph, it is important that it be neutralized to avoid interferences with the F^- peak. Neutralization should be carried out with sulphuric acid or with pH adjustment cartridges.

Direct analysis of the unknown solution can be carried out. The sample injection volume is 25 µl and it is advisable to inject at least 10 times the volume to fill the sample loop completely.

5.6.2.8 Calibration

Standard solutions of fluoride are injected into the system and a chart recorder or an integrator monitors the detector response. The peak area monitored is directly related to the concentration of each standard solution. A calibration curve is then obtained.

5.6.2.9 Calculations

Compare the peak area of the test solution corresponding to fluoride ions with those obtained for the calibration curve and calculate atmospheric concentrations using Formula (13) in 5.6.1.9.

5.6.2.10 Repeatability and reproducibility

Repeatability and reproducibility were estimated in a mixture issued from trapping fire effluents from various materials in 1 M NaOH solution.[2] For concentration around 1,03 mg/l, reproducibility has been estimated as 25 % (no repeatability was calculated). For concentration around 2,11 mg/l, reproducibility has been estimated as 17 % (no repeatability was calculated). For concentration around 14,8 mg/l, repeatability has been estimated as 6,1 % and reproducibility has been estimated as 8,1 %.

5.7 Oxides of nitrogen

Oxides of nitrogen are reactive species. There are a lot of equilibriums between them, depending on temperature and oxygen concentration. For example, nitric oxide (NO) reacts with oxygen to form nitrogen dioxide (NO_2). Depending on concentration, it should be assumed that the conversion of NO into NO_2 could be slow enough and neglected. Nevertheless, the user of analytical techniques described hereunder for nitric oxides has to take care of these considerations to interpret the result of its measurement and a possible deviation between gas expected and gas analysed.

5.7.1 Oxides of nitrogen by chemiluminescence

5.7.1.1 Application and limitations

Continuous or delayed analysis of oxides of nitrogen (NO_x) is possible, and the analysers are self-contained units containing all sampling, analysis and electronics hardware with direct readout of nitric oxide (NO) or combined NO and nitrogen dioxide (NO_2) from which the NO_2 concentration is estimated

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by difference. However, other nitrogen compounds can be detected as NO_x. The use of specifically designed modern instruments is recommended, even if some interference can occur.

5.7.1.2 Sensitivity and selectivity

Typical sensitivities routinely achievable are less than 1 µL/L NO_x. Nitrogen-containing compounds other than NO_2 can be detected as NO_x. In the NO_x "mode", background interferences can be higher than 10 % of the reading.

In terms of selectivity, some interference can occur during the chemiluminescence analysis of NO_x in fire effluents.

— There are five main oxides: N_2O, NO, N_2O_3, NO_2 and N_2O_5 and chemical equilibriums between them. The measurement with a chemiluminescence apparatus represents, then, not solely the sum of NO + NO_2.

— H_2O, CO, CO_2, O_2 and HNO_3 have been shown to interfere significantly in the chemiluminescence analysis of nitrogen oxides in fire effluents. These interferences can be positive or negative, depending on the gases concerned. In the case of a delayed analysis with a sample collected in a gas bag, these interferences have been shown to decrease as the fire effluents (gas of interest and interfering gases) are diluted. Quantification of these interferences can be achieved only by separate analysis of the individual components using the same instrument.

5.7.1.3 Other considerations

Instruments with a molybdenum-based NO_2 to NO converter are recommended, as older instruments which use a carbon-based converter actually increase interferences and require periodic replacement of the carbon material.

Practical use of the instruments has shown that some drift of calibration can occur over relatively short time intervals (i.e. over the period of a fire test) and allowance should be for this. The use of oxygen as opposed to air in the ozone generator will lead to greater linearity and increased signal strength. Adoption of this procedure, however, requires oxygen-tolerant materials in the pumping systems.

Concentrations of both NO_2 and NO can be derived and it should be noted that these species are often required to be separately analysed, as the entity "NO_x" has limited value in toxic-hazard assessment.

5.7.1.4 Analysis principles

Chemiluminescence refers to the light emitted when nitric oxide (NO) reacts with ozone. Nitrogen dioxide (NO_2) is produced, a small proportion of which is in an electronically excited state which, on decaying, emits light with a wavelength of between approximately 0,6 µm and 3,0 µm.

The light intensity is measured by a photomultiplier and is proportional to the concentration of NO in the sample. NO_2 does not exhibit chemiluminescence and if analysis of NO_2 is required, the whole sample is passed through a "converter" where the NO_2 is reduced to NO. The resulting signal is then from both the original NO content and the NO_2 content, the latter being obtained by difference.

5.7.1.5 Procedure

The instruments normally need only to be powered for a short period to allow the converter to achieve the required temperature and to stabilize the electronics. A separate twin pumping system may be utilized for sample inlet and for the chemiluminescence detector when operated at low pressure.

See Clause 4 for principles of sampling and C.8 for general principles of the method. However, for the analysis of nitrogen oxides by chemiluminescence, the specific information in 5.7.1.6 to 5.7.1.11 is relevant.

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