

Measurements of particles from residential combustion of solid fuel – Nordic basis for a new coming CEN standard



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Summary

Increased concentrations of particulate matter in the ambient air can be related with death from lung cancer and cardiopulmonary disease. Residential biomass combustion is common in the Nordic countries and an important source to particles in the ambient air. To ensure a future sound air quality, residential biomass combustion is one of the sources it is urgent to control. Biomass combustion is a renewable energy source and consequently has an important place in a sustainable development. However, inefficient biomass combustion causes emissions of particles from incomplete combustion. This includes soot, condensable organic particles (tar drops), and char particles. At the same time particles originating from the inorganic material in the fuel (ash particles) are emitted. From today's residential appliances these inorganic particles are emitted even at efficient combustion.

Particulate emissions from residential solid biofuel combustion measured in a specific measurement point can be affected by several parameters, e.g. temperature, pressure, dilution during sampling, and losses in the sampling system. There are two main ways to measure particulate emissions from residential combustion. First particles can be sampled in warm flue gas, in the chimney, i.e. above dew point of the gas. Secondly, a dilution tunnel can be used, thus cooling the flue gas, besides diluting. The lower the temperature in the measurement point is, the more components are in liquid phase, and thus measured as liquid particles. Consequently, more compounds are in liquid phase at sampling in dilution tunnel compared with sampling in warm flue gas. Dilution with room-tempered air decreases the temperature of the flue gas and thus condensation is enhanced.

Within CEN/TC 295/WG5, i.e. European committee for standardization, technical committee 295 working group 5 –Test methods, work on a new common particulate test method was initiated year 2005. The starting point was four different national methods for measurements of particles. (The national methods are for U.K., Norway, Austria, and Germany.) The objective of the work presented in this report is to give a Nordic influence on the ongoing work on a common European method for measurements of particles during residential combustion of solid fuel. In the long-term this method will contribute to better control of the environmental performances of the residential combustors and of emission levels. The work reported has been performed during year 2006, and consist of two main parts:

- I) A Nordic work-shop with purpose to exchange experiences from different kinds of particle measurements methods, and give common Nordic input on the draft standard for particulate emissions.
- II) Participation in the process of developing a common European method for measurements of particulate emissions from residential solid combustion within CEN.

The work-shop was kept small (9 participants) and focused on technical aspects of particulate measurement. The measurement methods applied and situation within the Nordic countries Denmark, Finland, Norway and Sweden country were discussed. Possible experimental research needs were identified, e.g. investigate possibilities to apply the particulate emission test method developed within TC 295/WG5 on residential solid fuel boilers tested according to EN 303-5. Other examples of ideas identified was comparisons of different particulate measurement methods, and the need of a precyclone (PM10 or PM2.5) for different fuels and burn rates. Besides common Nordic research needs other business were discussed. It was agreed on the need for Nordic cooperation within the standardisation process, not only within CEN/ TC 295, but as well within CEN/TC 57.

The work financed by the Nordic Council of Ministers Working Group Sea and Air has resulted in exchange of experiences of measurements of particulate emissions, identification of common research needs and common interests in the standardization work concerning particulate emissions from residential solid biofuel combustion. A Nordic work-shop about methods for measurement of particulate emissions has been performed, thus resulting in a first common Nordic effort in this area within CEN/TC 295/ WG5. Most of the Nordic remarks on the preliminary draft for particle measurement method were accepted, or partly accepted, and a few remarks will be investigated experimentally, and discussed in the next meeting of TC 295/WG5.

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Introduction

Particulate air pollution has been associated with death from lung cancer and cardiopulmonary disease [1, 2]. In Europe particulate matter in the ambient air is regulated through EU directive 1999/30/EC of 22 April 1999 [3]. The 24-hour limit value for PM₁₀, i.e. particulate matter less than 10 µm in size, is 50 µg/m³. The corresponding annual limit value is 40 µg/m³. The three largest sources to particulate matter in the ambient air in Europe are industry, residential combustion and transport [4]

Residential biomass combustion is common in the Nordic countries and an important source to particles in the ambient air. In Sweden particle emissions from residential biomass combustion is in level with the particle emissions from traffic [5]. To ensure a future sound air quality, residential biomass combustion is one of the sources it is important to control as biomass combustion is a renewable energy source and consequently has an important place in a sustainable development.

Particles from residential biomass combustion

The particulate emissions depend on the combustion conditions, thus a combination of appliance type, chimney, fuel and firing behaviour. There are two main sources of primary particles from residential biomass combustion:

1. Particles from incomplete combustion. This includes soot, condensable organic particles (tar drops), and char particles.
2. Particles originating from the inorganic material in the fuel – ash particles.

Particles from incomplete combustion are emitted at inefficient combustion conditions, and can be minimized through optimising the combustion conditions with respect to temperature, mixing and residence time. However, particles from the inorganic ash components in the fuel are emitted no matter the combustion conditions, from today's residential appliances. Besides the primary particles emitted from the chimney, gaseous components from the combustion flue gas might form secondary particles in the ambient air. Secondary particles can be made up of nitrates from gaseous nitrogen oxide emissions, sulphates from sulphur dioxide and condensed organic compounds.

Measurement of particles

The flue gas emitted from residential biomass combustion is comprised of a mixture of different kinds of particles and gases that are potentially particle formers. The particle concentration measured in a certain measurement point might be affected by several parameters (which sometimes are connected to each other), e.g.:

- **Temperature.** The lower the temperature in the measurement point, the more components are in liquid phase, and thus are measured as liquid particles.
- **Pressure.** If the partial pressure of a vapour in the flue gas is higher than the saturation vapour pressure nucleation might occur, which means that particles are formed.
- **Dilution.** Dilution with room-tempered air decreases the temperature of the flue gas and thus condensation is enhanced. On the other hand, dilution with heated air decreases the partial pressure and thus the condensation of potential particle decreases.
- **Losses.** Particles might be lost in the sampling system through e.g. diffusion and thermophoresis.

At present there are different national standards and methods used for particle measurements during residential biomass combustion in the Nordic countries [6 – 9]. In Europe there are additional standards used [e.g. 10]. There are mainly two ways to perform particle measurements:

1. In the chimney, i.e. above the dew point of the flue gas.
2. In a dilution tunnel, i.e. below the dew point of the flue gas.

The two main ways of measurements may cause confusion since they lead to different particle compositions and concentrations. Sampling in the chimney means measurement of ash, soot, and liquid particles with dew point above the sampling point. Measurement in dilution tunnel means a lower temperature and thus more liquid particles. Measurement in the chimney implies less equipment as it does not require a dilution tunnel. However, particle concentration in dilution tunnel gives better values for source contributions to ambient levels of particles.

Work on particulate emission test method within CEN/TC 295/WG5

The work reported here has the process of developing a common European method for measurement of particulate emissions at residential solid combustion within CEN as a starting point. Therefore brief background information about this is presented here. Within CEN/TC 295/WG5, i.e. European committee for standardization, technical committee 295 working group 5 –Test methods, it was decided to start to work on a new common particulate test method at the meeting 17 February 2005. The starting point is a draft standard technical specification (TS) containing four different national methods for measurements of particles, together with methods for nitrogen oxides and organic gaseous carbon, at residential solid combustion (The national methods are for U.K., Norway, Austria, and Germany.) Eventually (at the meeting 17 November 2005) Mr. Gaegauf, Switzerland, is selected to be responsible for the development of a common draft standard for particulate emission test. At a meeting 7 February 2006 Gaegauf introduces the problem of the determination of particulate emission, and the particulate emission test method is discussed. It is decided that Gaegauf will develop a detailed draft standard within the next months. The project contract from the Nordic Council of Ministers, Working Group Sea and Air for the work presented here was received 19 May 2006.

Objective

The objective of the project proposed is to give a Nordic influence on the coming CEN standard technical specification for measurements of particles during residential combustion of solid fuel. In the long-term this standard will contribute to a better control of the environmental performances of the residential combustors and of emission levels.

Method

The work reported has been performed during year 2006, and consist of two main parts:

1. A Nordic work-shop with purpose to exchange experiences from different kinds of particle measurements methods, and give common Nordic input on the draft standard for particulate emissions.
2. Participation in the process of developing a common European method for measurements of particulate emissions from residential solid combustion within CEN.

Results and discussion

The main part of the work performed is related to the work-shop. Therefore this result will be presented first. The second part of the project, i.e. participating in the process of developing a common method for measurements of particulate emission is of course related to the work-shop as well. However, as this is of certain interest in the work performed it is presented separately.

Work-shop

VTT, DTI and SINTEF were invited by SP to a Nordic work-shop on particle measurement at testing of residential wood stoves (Appendix 1). The purpose of the work-shop is to exchange experiences from different kinds of particle measurements methods, and discuss the Nordic implementation of the new coming measurement-method in the CEN-standard developed within CEN/TC 295 WG5. The

measurement methods applied and situation within each country were discussed. Possible experimental research needs were identified. Participation in the work-shop was limited to 4 persons/country. It was up to the invited institutions/companies to circulate the invitation to selected persons within each country. The participants were allowed to be from other organisations than those specified.

The work-shop participants were 9 persons, from the organisations invited and from University of Kuopio, in Finland. The minutes from the work-shop, including participants list is presented in Appendix 2, and summarised here. At the work-shop current situation in each country was presented and can be found in appendix 3-6.

Current situation in Denmark

Measurement methods. In Denmark, particulate emissions from residential biofuel combustion are measured at the DTI by use of accredited methods, and a few other methods. Methods covered by current accreditations of DTI's energy laboratory are according to: VDI 2066 Blatt 2 [11], EN 13284-1 [12], VDI 2066 Blatt 5 [13], NS 3058 [9], EN 303-5 (reference 14, a standard for residential boilers that specify that particulate emissions need to be measured but not how), MEL 02 [15] (Danish Environmental Agency Guideline), ISO 9096 [16], and ISO 10155 [17]. The methods used for measurement of the particulate emission in these standards have sampling of particles on filters in common, that mean: Extractive, isokinetic sampling and gravimetric determination of mass. In connection with testing according to VDI 2066 Blatt 2 and EN 303-5, particles are sampled in-stack in a filter cartridge made of stainless steel or titanium. The cartridge is stuffed with glass wool or/and quartz wool. The method is tested practically for dust load in the range from 1 to 1000 mg/m³. For dust concentration less than 20 mg/m³ a backup plane filter has to be used in combination with the stuffed filter cartridge. Alternative to the filter cartridge an extraction filter thimble can be used. The typical sample flow rate is 4 m³/h. At sampling according to VDI 2066 Blatt 5, particles are sampled in-stack by means of a cascade impactor (0.5-15 µm). If the dust contains more than 15 % particles (by mass) larger than 10 µm it is advisable to use a preseparator upstream of the impactor. The preferable dust load without preseparator is 10 to 500 mg/m³ and with preseparator it is 200 to 5000 mg/m³. The typical sample flow rate is 1 m³/h. In connection with testing according to the Norwegian method NS 3058 thus out-stack sampling on plane filter is applied and sampling is performed in a dilution tunnel. More information about NS 3058 appears from chapter "Current situation in Norway" In the following methods sampling in stack or outside stack with heated filter and probe is applied: EN 13284-1, MEL 02, and ISO 9096. MEL 02 is an elaboration EN 13284-1 prepared by the Danish Environmental Agency.

Methods used besides accredited standards: Petersen Column, LAS-X particle sizer/counter, and SMPS particle sizer/counter. Petersen column is a device for measurement of aerosols containing solid and liquid particles, developed for tary flue gases. The column has one filtering step and two washing steps. Tests have shown that it collects more than 99 % of organic components in gases with boiling point equal to benzene or higher. LAS-X particle sizer/counter has a range of 100 nm to 7.5 µm, divided into 16 size fractions. SMPS particle sizer/counter used is the model for ultrafine particles, thus measuring in the range 3-1000 nm.

Political attention in Denmark. During recent years there has been more and more focus on air pollution caused by residential combustion of solid fuel in Denmark. A wide range of initiatives in order to minimize the residential air pollution have been initiated. The Danish EPA finances ongoing projects about wood smoke and health effect corresponding to approximately 370 000 euros (appendix 7). Another example is that the public can find advises about how to use their stoves in a non-polluting way at a website about air pollution [18] focusing on wood smoke. In 2005 an investigation of particulate air pollution in Denmark [19], and a field study on emissions from stoves [20] were published. Both reports conclude that the residential combustion of solid fuel cause a substantial contribution to the local air pollution, almost half of the total emissions of PM_{2.5} in Denmark are from residential biofuel combustion. An example of an ongoing project connected to residential solid fuel

combustion is “Evaluation of the volume of bad chimneys for residential solid fuel stoves and boilers – regulations and proposals for solutions”, initiated by the Danish Environmental Agency. Another initiative from the Danish government is an agreement about an additional effort against particulate air pollution from residential heating. This effort include an “Agreement about Scrapping of Older Stoves and Boilers”, additional information on correct firing and testing of particle filters for woodstoves and boilers in practice.

Current situation in Finland

In Finland there has been a national interdisciplinary research program called FINE Particles - Technology, Environment and Health from year 2002 to 2005 [21]. The program had four main areas: Releases and processes, Measurements, Outdoor and indoor fine particles –health impacts, and Environmental and other impacts of fine particles. Total budget was 26 million euros, from which 50 % from the Finnish energy agency. Other financiers were Academy of Finland, Ministry of Transport and Communications and Ministry of the Environment. The FINE program involved close to 60 companies and over 20 research groups. VTT and University of Kuopio were among the participating research groups.

At VTT an ELPI (electrical low-pressure impactor) is used as counter/sizer. It measures number of particles in the range 0.007-10 μm (12 size fractions). Flue gas is diluted with particle-free and dry pressurized air before measurement in ELPI. Ejector dilutors in two steps (first step diluted) are used, alternatively a porous tube dilutor developed within the Fine project. To protect the measurement system from particles larger than PM10 a pre-cyclone is used upstream of ejector dilution system. For measurements of particle mass size distribution a DLPI (Dekati low-pressure impactor) is used. At VTT particulate emissions from the following residential appliances have been characterized within the FINE program: wood stoves, slow heating residential appliances, wood chips burners, sauna stoves, industrial boilers, district heating boilers, oil burners.

At the University of Kuopio, formation of particle emission from residential biofuel combustion is studied through measurements and modelling. Particles are measured by filter sampling, and sizer counters SMPS and ELPI. Three approaches are used for sampling and dilution:

1. Sampling from exhaust through a dilution system (ejector dilutors, porous tube dilutors or fine particle sampler)
2. Dilution tunnel technique (partial flow dilution, ISO 8178)
3. Hood dilution (full dilution + secondary dilution system)

Current situation in Norway

Test methods used for dust (i.e. particles in hot flue gas) and particles in Norway are NS 3058 – Smoke emission (particulate) and the Austrian method for dust Article 15a [23]. Particulate emissions standards were made year 1994 (NS 3058-1, NS 3058-2 and NS 3059). Since 1997 it is required that all stoves installed in Norway have been tested for particulate emission according to the Norwegian standard. During testing according to NS 3058 the mass of fuel charge per m^3 of the fire box volume is defined. The reason is to avoid the manufacturers to claim that their appliances are to be used at smaller heat outputs than what can be expected from the users, and thus get lower emissions at testing than in practical use. Each fuel log is standardized in NS 3058-1. It is of fir wood and rectangular in shape, more instructions of the size is specified in the standard. The standard includes testing at four burn rate categories. Particles are sampled on a plane filter, out stack of a dilution tunnel. In NS 3059 the calculations of weighted mean values from the test results of different burn categories are described and emission limits from this weighted mean values are specified as:

- Catalyst-equipped wood heaters, ≤ 5 g particulate matter/kg (dry wood)
- Non-catalyst wood heaters, ≤ 10 g particulate matter/kg (dry wood)

The burn categories used in the Norwegian standard are a result of an investigation of user habits in Norway, as well as the corresponding weighing factors.

Current situation in Sweden

Particulate matter in the ambient air is regulated in Sweden. However, particulate emissions from residential combustion are not regulated in the building regulations. The annual residential biofuel combustion in Sweden is 12-13 TWh. The number of wood and pellets stoves and insets are together 1 100 000, and the residential biofuel boilers are 260 000. Approximately 60 % of the residential biofuel boilers are of old-type technique.

Year 2000 to 2003 there has been a national frame project called Biofuel Health and Environment performed in Sweden [22]. Total budget was about 3.3 million Euros, and the work was divided between 25-30 university research groups, research institutes and companies. SP was responsible for characterization of gaseous and particulate emissions from residential wood and pellets boilers.

Examples of results from this work are:

- Large possibilities to decrease the emissions by changing from old-type wood boilers without heat storage tank to modern wood boilers with heat storage tank or pellets burner/boilers.
- The variations in emissions are large. Consequently emission data needs to be further investigated with respect to real conditions at people's home.
- Particle size distributions showed that the particulate emission was dominated by size less than 1 μm , both with respect to mass and number of particles. The particles contained mainly potassium sulphate and potassium chloride at favourable combustion conditions.

Recently there have been field studies of emissions from residential biofuel stoves and boilers performed.

During testing of residential boilers particles are measured at boiler testing according to EN 303-5, using method EN 13284-1 as a basis. At testing of stoves and insets according to Norwegian standard NS 3058 (as described earlier: dilution tunnel, out stack measurement), and at testing of pellets stoves for voluntary P-mark, using EN 13284-1 as a basis. Particle sampling described in EN 13284-1 is out stack on warm gases at larger boilers, and it is primarily a method for lower concentrations and higher flows than for residential combustion.

Research needs identified

The discussion about common research needs resulted in an idea list:

- a. Investigate possibilities to apply the particulate emission measurement suggested in CEN/TC 295 WG5 N70/2006 on residential solid fuel boilers EN 303-5
- b. Investigate the need for a pre-cyclone (PM10 or PM2.5), for different solid fuels and different burn rates
- c. Investigate the state of cleanliness of the dilution tunnel and the PM measured on blank filter
- d. Compare particulate emission measured in dilution tunnel with particulate emission measured by dilution of raw flue gas through porous tube
- e. Parallel measurements of particulate matter
 - 13284-1
 - VDI2066 in stack
 - NS3058, part 1 and 2, for fuel charge according to EN13240
 - DIN standard? 70 °C
- f. Bio keymark, investigate the interest of manufacturers?

Common question and activities

Besides common Nordic research needs other business were discussed. It was agreed on the need for Nordic cooperation within the standardisation process, not only within CEN/ TC 295, but as well

within CEN/TC 57. At present there is a standard method for testing of residential boilers which specifies that particles are to be measured, but not the method to be used. Consequently the following activities were decided:

- a. Send Nordic comments on Preliminary draft of EN TS on particulate emission test method to C. Gaegauf and M. Benzi (CEN/TC 295/WG 5 N 70/2006).
- b. Harmonize or revise EN 303-5. Within TC 57. Next meeting is expected spring 2007. Make a letter to raise the question in the Nordic countries.

Nordic input on the preliminary draft of EN TS on particulate emission test method

The preliminary draft of Technical Specification on particulate emission test method discussed, i.e. document CEN/TC 295/WG 5 N 70/2006 can be found in appendix 8. The method resembles the Norwegian method for measuring particulate emissions with respect to many parts. The draft was discussed at the work-shop and it resulted in a document with common Nordic input sent in to the secretariat of CEN/TC 295/WG 5, see appendix 9. Besides a number of small remarks common general remarks found were summarised as:

- Blank test prior to measurements is suggested. Particulate matter sampled on blank filters should not exceed 1mg/h. Gas velocity 5.5 m/s is suggested during blank tests.
- Measurements of gas emissions are to be performed with forced draught according to standard. The experimental set-up in figure 1 means problems with keeping the draught constant simultaneously with constant volume flow in the dilution tunnel. => Gas emissions and particulate emissions need to be performed separately.
- Particles might be lost in the sampling system. Especially particles larger than 10 µm might be lost to a high degree through inertial deposition. Pre-cyclone with a cut-off at 10 µm might be a solution, but it needs more work to define a pre-cyclone, because cut-size depends on flow velocity, which is not fixed in the method.
- High burn rates (e.g. typically 4-10 kg dry fuel per hour in Finland) require a very powerful fan. We suggest that a larger diameter (than 150 mm) of the dilution tunnel is used in these cases.
- Emission should be stated as [mg particulate matter per kg dry fuel supplied] or [mg particulate matter per MJ fuel supplied]. If particulate concentration per m³ is needed this may be calculated from burn rate if combustion is good. However if combustion is poor, it is necessary to use dilution ratio. In this case using CO₂ may be a problem due to limited accuracy of analyzers below 1 % CO₂, and it should be allowed to use a CO measurement instead since this is often more accurate. However special attention should be given in case of to unstable CO values.
- Add in the Scope: This method applies to fuel loads set in other national standards as well.

At the meeting of TC 295, WG5 in November, the preliminary draft method had been modified for smaller remarks from the Nordic countries as well as from other countries, prior to the meeting. General remarks were discussed, and the following was agreed concerning the Nordic general remarks:

- Blank tests need to be performed but are probably not necessary prior each measurement. Work is needed on how often the blank tests need to be performed. Sintef in Norway will perform blank test on a dilution tunnel which has been used for about a year and compare with blank test for an entirely new dilution tunnel.
- The Nordic countries indicated that there might be practical problems with fulfilling the demand for constant volume flow at particle sampling simultaneously with the demands of chimney draught for measurement of gaseous emissions. Consequently, there might be a need for separate measurements of particulate emissions and gaseous emissions. Mr. Gaegauf will investigate this problem experimentally, and inform TC 295/WG5 about the results. The group agreed that if it is possible to perform measurements of particle emissions and gaseous

emissions simultaneously, and fulfil the demands in the standards, this is preferable. The question will be discussed at next meeting, with experimental results as a background.

- The need for a preseparator was discussed. There was an agreement that it is not needed for residential wood combustion, however it might be necessary at higher burn rates or for certain fuels. Mr. Gaegauf will take this in consideration in the description of the method.
- The Nordic suggestion to use larger diameter (than 150 mm) of the dilution tunnel for cases with high burn rates (more than 4 kg dry fuel per hour) was accepted.
- Because of lack of time, the question about how to calculate particulate emissions was not discussed. Mr. Gaegauf will be reminded about this remark.
- “This method applies to fuel loads set in other national standards as well” in the scope was not accepted, as it is already permitted to use several fuel loads in a number of European standards, which is mentioned in the scope, and national standards should be avoided in favour of European standards.

Conclusions

The work financed by the Nordic Council of Ministers Working Group Sea and Air has resulted in exchange of experiences of measurements of particulate emissions, identification of common research needs and common interests in the standardization work concerning particulate emissions from residential solid biofuel combustion. A Nordic work-shop about methods for measurement of particulate emissions has been performed, thus resulting in a first common Nordic effort in this area within CEN/TC 295/ WG5. Most of the Nordic remarks on the preliminary draft for particle measurement method were accepted, or partly accepted, and a few remarks will be investigated experimentally, in Switzerland, and discussed in the next meeting of TC 295/WG5.

Further work

The development of a common European method for measurement of particulate emissions at residential solid combustion within CEN continues. During year 2006 a draft standard on particulate emission test method has been produced after the preliminary draft discussed in this report. Discussion of details and demonstration of the experimental equipment will be performed at the next meeting of CEN/TC 295/ WG5, in February 2007. For the Nordic countries it is important to continue to be a part of the development process, build up equipment for the new method according to the standard and to make comparisons with earlier used methods for particulate emissions. However, from year 2007 there is no common Nordic project so common Nordic efforts will probably be very limited. But at national level there are experimental work direct supplementary to the project reported here performed during 2006 to 2007

- In Denmark: project Quality assurance of small biofuel combustors, 80 000 Danish Kr, financing from the Danish Energy Agency, project journalnr.: 33036-0071
- In Sweden: Particle measurement for residential biofuel boilers –Influence of different methods, ca 80 000 Danish Kr (100 000 Swedish Kr), financing from the Swedish Energy Agency, project nr: 30207-1.

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- [12] EN 13284-1, Stationary Source Emission – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method
- [13] VDI 2066 Blatt 5, Particulate Matter Measurement, Dust Measurement in Flowing Gases, Particle Size Selective Measurement by Impaction Method – Cascade Impactor
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- [15] MEL 02: Danish Environmental Agency Guideline, Måling af emissioner til luften, Bestemmelse af koncentrationen af total partikulært materiale i strømmende gas
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Appendix 1 –Invitation to the work-shop

Nordic work-shop on particle measurement at testing of residential wood stoves

25-26 October 2006 at SP Swedish National Testing and Research Institute

Financial support from the Nordic Council of Ministers, working-group sea and air



VTT, DTI and SINTEF are invited to a Nordic work-shop on particle measurement at testing of residential wood stoves. The purpose of the work-shop is to exchange experiences from different kinds of particle measurements methods, and discuss the Nordic implementation of the new coming measurement-method in the CEN-standard developed within CEN/TC 295 WG5. The measurement methods applied and situation within each country will be discussed. Possible experimental research needs will be identified as well as the information need of the manufacturers and sellers.

Each country is invited to participate with maximum 4 persons. The participants might also be from other organisations than those specified. It is up to the invited institutions/companies to decide and to circulate this invitation to selected persons within each country.

Please register your participation in this work-shop to Linda Johansson at SP, tel: +46 33 16 55 01 or e-mail: linda.johansson@sp.se Deadline for registration: 6 October 2006

Preliminary agenda

25 October

- 11:00 Start. Presentations of the participants
Background information (SP)
- 12:00 Lunch
- 13:00 Presentations of the current situation in each country (15 min per country + discussion)
- 14:30 Coffee
- 14:45 A tour at the SP Energy Technology laboratory
- 15:15 Nordic input on the draft CEN-standard for particle measurements
- 16:30 End of first day

26 October

- 08:30 Experimental research needs on particle measurements
- 09:30 Coffee
- 09:45 Information needs of Nordic manufacturers and sellers of residential combustion devices
- 10:30 New common questions and activities
- 11:30 Summary of the work-shop
- 12:00 Lunch
- 13:00 End of the work-shop

Appendix 2 –Minutes from the work-shop

Minutes from Nordic work-shop on particle measurement at testing of residential wood stoves, 25-26 October at SP



Participants

Kim Winther and Uwe Zielke, Danish Technological institute, Denmark
Heikki Oravainen and Raili Taipale, VTT, Finland
Jarkko Tissari, University of Kuopio, Finland
Asbjörn Östnor, Sintef, Norway
Lennart Gustavsson, Henrik Persson and Linda Johansson, Sweden

Summary

1. The current situations in each country were presented according to overhead-slides attached.
2. The preliminary draft of EN TS on particulate emission test method, CEN/TC 295/WG5 N 070/2006 was discussed. Nordic input on the draft was sent to the working group. This input is attached.
3. Research needs identified:
 - a. Investigate possibilities to apply the particulate emission measurement suggested in CEN/TC 295 WG5 N70/2006 on residential solid fuel boilers EN 303-5
 - b. Investigate the need for a pre-cyclone (PM10 or PM2.5), for different solid fuels and different burn rates
 - c. Investigate the state of cleanliness of the dilution tunnel and the PM measured on blank filter
 - d. Compare particulate emission measured in dilution tunnel with particulate emission measured by dilution of raw flue gas through porous tube
 - e. Parallell measurements of particulate matter
 - 13284-1
 - VDI2066 in stack
 - NS3058, part 1 and 2, for fuel charge according to EN13240
 - DIN standard? 70 °C
 - Bio keymark, investigate the interest of manufacturers?

How proceed?

- Every country looks for national financing.
 - Nordic (Nice, Nordic Council of Ministers Energy, Nordic Council of Ministers, Sea and Air,... *(Responsible: Lennart Gustavsson, Linda Johansson)*
 - EU *(Responsible: Heikki Oravainen)*
4. Common question and activities
 - a. Send Nordic comments on Preliminary draft of EN TS on particulate emission test method to Christian Gaegauf and Monica Benzi (CEN/TC 295/WG 5 N 70/2006). *(Responsible Linda Johansson)*
 - b. Harmonize or revise EN 303-5. Within TC 57. Next meeting is expected spring 2007. Make a letter to raise the question in the Nordic countries. *(Responsible: Kim Winther)*

Appendix 3 -Presentation of the current situation in Denmark



Particle measurements in DK

Accredited methods
Other methods



Kim Winther

INDUSTRI OG ENERGI



Methods covered by current accreditations of DTI

VDI2066 Blatt 2
EN13284-1
VDI 2066 Blatt 5
NS3058
EN303-5
MEL 02
ISO 9096
ISO 10155

INDUSTRI OG ENERGI



Other methods used by DTI

Petersen Column
LAS-X particle sizer/counter
SMPS particle sizer/counter

INDUSTRI OG ENERGI



VDI 2066 Blatt 2

Range 1-1000 mg/Nm³
Sample flow rate 4 m³/h or 12 m³/h
Iso-kinetic sampling
IN-stack filter cartridge
Filter material: quartz wool
Back up plane filter used below 20 mg/Nm³

INDUSTRI OG ENERGI



EN13284-1

Range <20 mg/Nm³
IN-stack or OUT-stack plane filter
Sample flow rate 1-3 m³/h IN-stack
Sample flow rate 1-20 m³/h OUT-stack
Iso-kinetic sampling
Filter material depending on temperature: paper, glass fibre or PTFE
Back up filter not used

INDUSTRI OG ENERGI



VDI 2066 Blatt 5

Cascade impactor
Range <100mg/m³
Particle size 0,5-15µm (best <3 µm)
IN-Stack impactor
Sample flow rate 3m³/h at 600 mBAR suction pressure
Iso-kinetic sampling
Plate material: metal
Back up filter allways used

INDUSTRI OG ENERGI



NS3058

Dilution tunnel
Range 20 g/kg dry wood (approx 1600 mg/Nm³ at 13% O₂)
Particle size: total mass
OUT-Stack plane filter
Sample flow rate ?
Gas velocity measured with pitot tube
Filter material: 1 µm porosity
Back up filter not used

INDUSTRI OG ENERGI



EN303-5

Similar to VDI 2066 Blatt 2
Range up to 150 mg/Nm³ at 10% O₂
IN-Stack filter cartridge
Sample flow rate 1-3 m³/h
Iso-kinetic sampling
Filter material: glass- and quartz wool
Back up filter not used

INDUSTRI OG ENERGI

MEL 02 (Danish Environmental Agency Guideline)

Based on EN13284-1
No dilution tunnel
Range <50 mg/Nm³
IN-Stack or OUT-stack plane filter
OUT-stack must be used when gas is saturated or contains droplets
Sample flow rate not specified
Isokinetic sampling
Filter material: quartz fibre
Back up filter not used

INDUSTRIØG ENERGI

ISO 9096

Similar to VDI 2066
IN-stack or OUT-stack
Range 0,005 – 10 g/Nm³
Plane filter or filter thimbles
Filter material quartz fibre

INDUSTRIØG ENERGI

ISO 10155

Calibration of AMS (Automatic Monitoring Systems)
Range 1-1000 mg/Nm³
Particle size
Stack
Sample flow rate
Sampling
Filter material
Additional filter

INDUSTRIØG ENERGI

Petersen Column

Device for measurement of aerosols containing solid and liquid particles (tary flue gases)
Method developed by Danish Teknologisk Institut for collection of solid, liquid and gaseous components in gasses. Included in Technical Specification CEN/TS 15439 for tar measurement. The column has one filtering step and 2 washing steps. Tests have shown that it collects more than 99% of organic components in gasses.

INDUSTRIØG ENERGI



INDUSTRIØG ENERGI

LAS-X particle sizer/counter

Laser Particle Sizer) which har a range of 100 nm til > 7,5 µm and separates particles in 16 size fractions.

Work best with low concentrations and should therefore be used in a dillution tunnel.

INDUSTRIØG ENERGI

SMPS particle sizer/counter

Scanning Mobility Particle Sizer, which measures ultra fine particles from 3 – 1000 nm

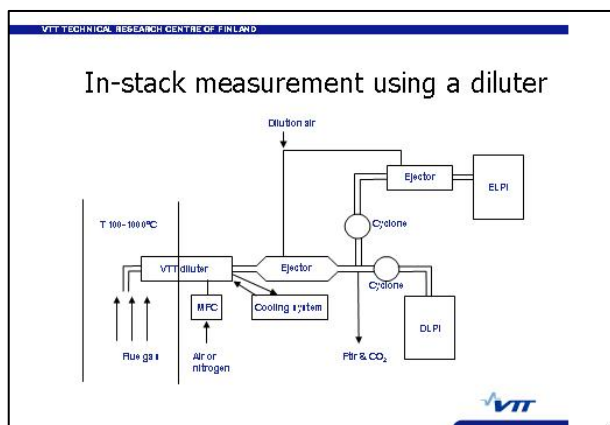
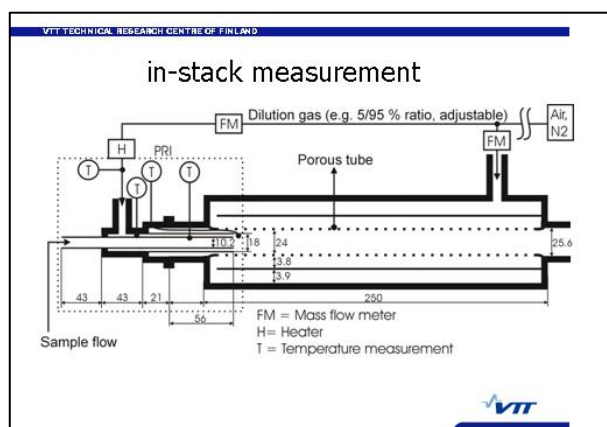
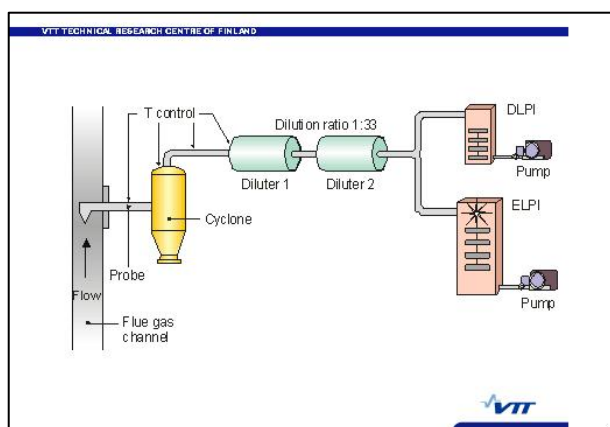
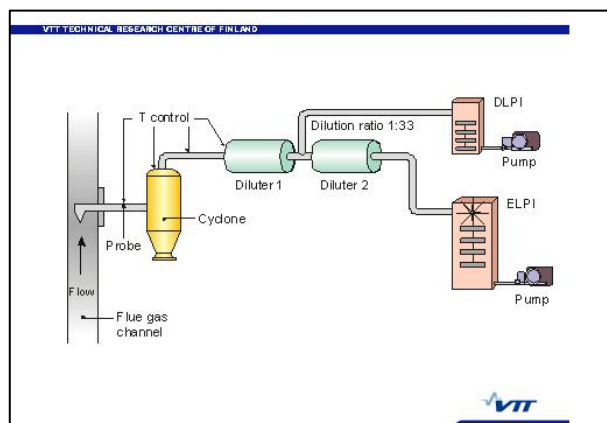
Work best with low concentrations and should therefore be used in a dillution tunnel.

INDUSTRIØG ENERGI

Appendix 4 -Presentations of the current situation in Finland

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

Fine particle measuring at VTT Jyväskylä



What we have measured so far

- wood stoves
- SHRA (kakelungar)
- wood chip burners
- pellet burners
- sauna stoves
- industrial boilers
- district heating boilers
- oil burner



TSP according SFS 3866/ISO 9096

This is used to determine also moisture content of flue gases and is used when calculating ELPI-results for dry flue gases.

Or moisture of flue gases is got from FTIR-measurement

University of Kuopio
 Department of Environmental Sciences
Fine Particle and Aerosol Technology Laboratory
 KUOPIO, Finland



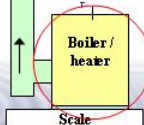
Research areas for RWC (UKU)

- **Formation of particle emission**
 (measurements and modelling)

Combustion appliance and technique

Fuel (ash content)

Operational way (batch and log size)



Boiler / heater

Scale

Projects: PIPO, PIHI-MALLI, BIOPOR





- Behaviour of particles in exhaust gas
- Reduction techniques
- Dilution into ambient air
- Environmental and health effects

Projects: PÄVÄ, LÄPI, NÄPES, PUPO-terveys, (PIPO)

Sampling and dilution techniques for particles (1)

- direct from exhaust gas
 - o Ejector diluters
 - o Porous tube diluters
 - o Fine Particle Sampler

Projects: PUPO, PIPO, HILA

Sampling and dilution techniques for particles (2)

- Dilution tunnel technique

(Partial flow dilution ISO 8178)

Projects: PUPO-terveys, PIPO

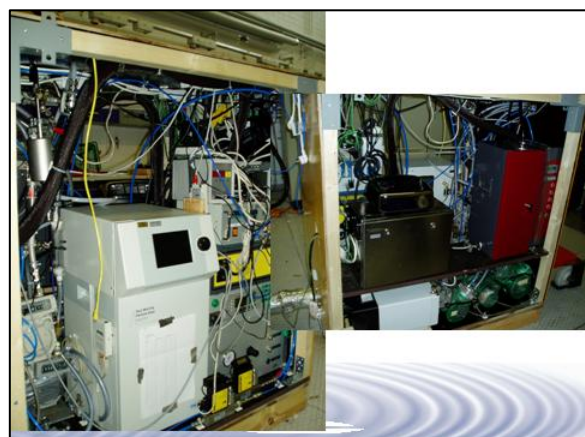
Sampling and dilution techniques for particles (3)

- Hood dilution (full flow + secondary dilution technique)

Projects: PUPO, PIPO

Current situation
University of Kuopio

- Main dilution techniques used
 - Partial flow dilution tunnel
 - Porous tube diluter + ejector diluter
- Main factors for particle measurement
 - Dilution ratio
 - definition
 - condensated material
 - Losses
 - Filter (artefact)



Thank You!



Appendix 5 -Presentation of the current situation in Norway

Test methods for dust and particles

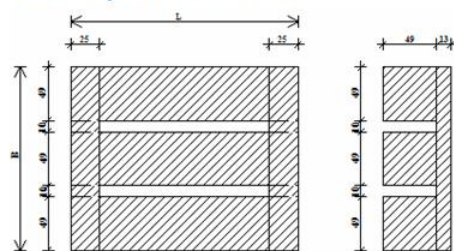
- NS 3058 – Smoke emission (particulate)
- The Austrian method for dust Article 15a.
- Draft Technical Standard on Particulate emission test method (TC 295 WG 5, document N 70/2006)

Particulate emission in Norway

- Standards made in 1994 (NS 3058-1, NS 3058-2 and NS 3059)
- Required for all stoves installed in Norway since July 1997

NS 3058-1 Fuel charge

- Test load
 - $112 \pm 11 \text{ kg/m}^3$ of the fire box volume



NS 3058-1 Burn rate categories

Tabell 1: Belastningsområder
Table 1: Burn rate categories

	Midlere brenselforbruk i kg/h Average burn rate in kg/h			
	Belastningsområde 1 Burn rate category 1	Belastningsområde 2 Burn rate category 2	Belastningsområde 3 Burn rate category 3	Belastningsområde 4 Burn rate category 4
Klasse 1 Grade 1	< 0,80	0,80–1,25	1,26–1,90	> 1,90
Klasse 2 Grade 2	< 1,25	1,25–1,90	1,91–2,80	> 2,80

NS 3058-2 Dilution tunnel

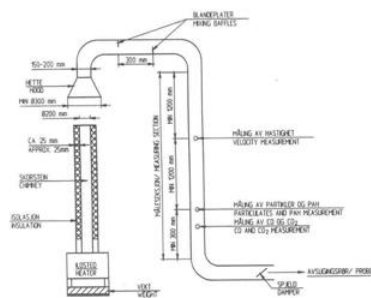
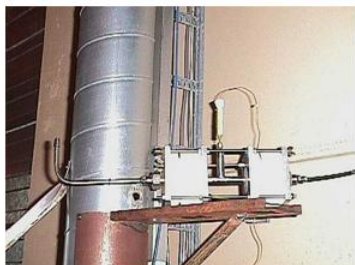


Figure 2: Utytningstunnel med ildsted og skorstein
Figure 2: Dilution tunnel with wood heater and chimney



NS 3058-2 Filter holders

- Made of polytetrafluoroethylene (PTFE) or stainless steel



NS 3059 Requirements

- Weighted mean value
 - Catalyst-equipped wood heaters
 - $\leq 5 \text{ g/kg (dry)}$
 - Non-catalyst wood heaters
 - $\leq 10 \text{ g/kg (dry)}$

Calculation of smoke emission:

Calculation of smoke emission (E _{SO2})				
Filter name	Sum over kg/h	Particulate Emission kg/h	Weighted mean [1]	[kg]
NS3058-2-1	1.05	0.27	0.706	35.3
NS3058-2-2	1.27	0.27	0.215	44.3
NS3058-2-3	0.23	0.23	0.288	15.6
NS3058-2-4	0.25	0.45	0.033	1.2

Total weighted particulate emission:

Sum over kg/h	
4.35	[kg/h]
3.15	[kg dry wood]
0.16	[g/kg]

Appendix 6 -Presentation of the current situation in Sweden

Current situation in Sweden –particles from residential biomass combustion

Particles from residential biofuel combustion –One of three large sources to ambient air particles, besides traffic and long-distance transport.

Regulations on particle concentrations in ambient air

No regulations for particulate matter from residential boilers and stoves

Research project Biofuel Health and Environment =>
Knowledge about concentrations, particle size distributions, and chemical content,

Nordic work-shop on particle measurement at testing of residential wood stoves



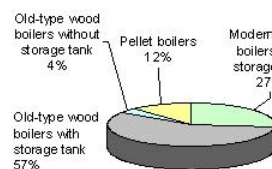
SP Swedish National Testing and Research Institute

Residential biofuel combustion in Sweden

- 12-13 TWh per year
- Wood and pellets stoves and insets: 1 100 000
- Boilers fired with wood and pellets: 260 000



SP Swedish National Testing and Research Institute



Ämnesportering sömning 2003.xls, Räddningsverkets webbplats, www.raaddningsverket.se

Small-scale combustion in Sweden, fuel comparison

	Oil	Wood pellets	Oat energy grain
Density (kg/m ³)	850	650	540
Heating value (kWh/kg)	11	4.8	4.2
Volume equivalent to 1 m ³ oil	1.0	3.0	4.1
Price (Swedish Kr)	8500 kr/m ³	2200 kr/ton	860 kr/ton
Price, Kr/kWh	0.91	0.46	0.20



SP Swedish National Testing and Research Institute

Research Project Biofuel Health and Environment

Biofuel Health and Environment is a frame project financed by the Swedish Energy Agency.

```

graph LR
    Emissions --> AmbientAir[Ambient air]
    AmbientAir --> HealthEffects[Health effects]
    SynthesisProject[Synthesis project] --> AmbientAir
    
```



- Year 2000 - 2003
- ~3.3 million Euro
- Totally 25-30 participating Universities, Research Institutes, and Companies

<http://www.itm.su.se/bhm>



SP Swedish National Testing and Research Institute

Examples on conclusions from Biofuel Health & Environment

The residential biofuel boilers in Sweden are dominated by old-type wood boilers with high emissions => There are large possibilities to decrease the emissions by changing to modern boilers and install heat storage tanks

The variations in emissions are large. => emission factors for particles need to be further investigated with respect to real conditions at people's home. *Recently performed work*

Particle size distributions => Particle emissions are dominated by size less than 1 µm (submicron). Both with respect to number and mass

Particle content at favourable combustion conditions: potassium sulphate and potassium chloride



SP Swedish National Testing and Research Institute

Recent examples of results from field studies

Wood boilers (25 cases)

- Fuel, moisture content 15 ± 6 %, except for two cases with 24 % & 29 %
- Median modern boiler had somewhat lower emissions than median old-type
- Only a few boilers fulfilled emission limits (OGC) used at testing at laboratory

Wood stoves and insets (20 cases)

- Fuel, moisture content 10 – 18 %, one exception 24 %.
- Emissions from new (newer than 1999) stoves and insets showed lowest values except for two cases
- Particle emissions ranged from 20 to 180 mg/MJ_{fuel} supplied
- New stoves and insets fulfil emission limits (OGC and/or CO) even at field conditions, with start-up emissions included



SP Swedish National Testing and Research Institute

Emission limits

Regulations*

- Boilers
 - Wood: Max 150 mg OGC/m³ flue gas at 10 % O₂ (heat storage tank recommended)
 - Pellets: Max 100 mg OGC/m³ flue gas at 10 % O₂
- Stoves and insets
 - Max 0.3 % CO at 13 % O₂

Voluntary

- P-mark
 - Particle demand included for pellets stoves: 100 mg dust/m³ flue gas at 10 % O₂
- Swan label
 - Wood boilers: 70 mg dust/m³ flue gas at 10 % O₂
 - Pellet boilers: 40 mg dust/m³ flue gas at 10 % O₂
 - Stoves, etc: 1-15 g/kg dry fuel

*Boverkets byggregler, BFS 1993:57 med ändringar till och med 2006:12, avsnitt 6:741



SP Swedish National Testing and Research Institute

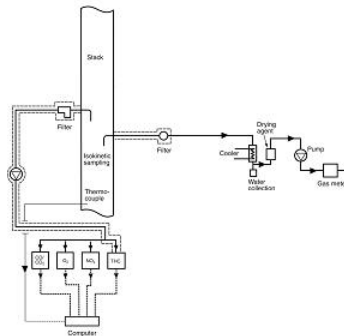
Particle measurements performed at testing

- Boilers tested according to EN303-5
 - Particle measurements based on EN 13284
- Stoves and insets
 - Particles measured for products tested according to Norwegian standards
 - Particles measured for pellets stoves tested for P-mark, particle measurements based on EN 13284



SP Swedish National Testing and Research Institute

Particle measurements according to EN13284



SP Swedish National Testing and Research Institute

Appendix 7 – Summary of Danish projects on health effects from wood smoke financed by the Danish EPA

- Review-studie af den videnskabelige litteratur om sundhedseffekter af forurening fra brænderøg, herunder særligt partikler. Gennemføres af Danmarks Fødevareforskning. Budget ca. 200.000 kr.
- Toksikologiske effekter af brænderøg (in vitro studier = i reagensglas). Gennemføres af Afdeling for Miljø- og Arbejdsmedicin, Institut for Folkesundhedsvidenskab, Københavns Universitet. Budget ca. 150.000 kr.
- Toksikologiske effekter af brænderøg (in vivo studier = i dyremodeller). Gennemføres af Afdeling for Miljø- og Arbejdsmedicin, Institut for Folkesundhedsvidenskab, Københavns Universitet. Budget ca. 350.000 kr. Forventes igangsat i 2007.
- Nye målinger af luftforurening i brændeovnskvarterer og fra skorsten, samt forbedret kortlægning af eksponering med brændeovnsrøg. Gennemføres af DMU, Afdeling for Atmosfærisk Miljø. Budget ca. 1 mio. kr.
- Forbedrede emissionsopgørelser og vurdering af tiltag til reduktion af emissioner fra brændeovne og -kedler. Gennemføres af DMU, Afdeling for Systemanalyse med input fra Teknologisk Institut og Miljøstyrelsen. Budget ca. 400.000 kr.
- Vurdering af omfanget af dårlige skorstene fra private brændeovne og -kedler, regelgrundlag og løsningsmuligheder. Gennemføres af Force Technology. Budget ca. 200.000 kr.

Appendix 8 – Preliminary draft of particulate emission test method

CEN/TC 295/WG 5
Residential solid fuels burning appliances
Test methods



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

2006 - 09 - 27
CEN/TC 295/WG5 N 70/2006

PRELIMINARY DRAFT OF EN TS ON PARTICULATE EMISSION TEST METHOD

by Mr C. Gaegauf

ENEA



SECRETARIAT:
CTI - Italian Thermotechnical Committee
Monica Benzi

CTI - Italian Thermotechnical Committee
Via Scarlatti 29
I-20134 Milan
phone: +39 02.266.265.20 fax: +39 02.266.265.50
email: benzi@cti2000.it

Determination of particulate emission from solid fuel burning appliances

1 Introduction

European legislation limited the airborne particulate in the member states in 2005. The limit for total suspended particulates in the ambient air is 50 µg/m³. This threshold can just be exceed 35 days each year. Thus authorities have to reduce the various particulate emission sources in order to meet the European clean air requirements.

Residential solid fuel burning appliances are one of the potential sources contributing to the total suspended particulates in ambient air. The major fractions of the particulates in the wood combustion process for example are submicron-sized with aerodynamic diameters of less than 1 micron, typically in the range of 30 to 300 nm. These nanoparticle fractions can act as respiratory irritants since they behave like gaseous effluents penetrating deeply into the human respiratory tract.

In many countries in Europe the regulation on particulate emissions of solid fuel burning is expected to become stricter. A common European standard on test method determining particulate emissions is crucial to support innovative, environmental friendly products and supplying the authorities with facts and figures on the solid fuel burning appliances. A common European test method prevents trade barriers, which is a key issue of the European economic market.

2 Scope

This Technical Standard describes a method to determine the particulate emission in the flue gas from a solid fuel burning appliance in accordance with hEN 12809 (residential boilers), hEN 13815 (cookers), hEN 13299 (inset appliances and open fires), hEN 13240 (roomheaters), EN 14785 (pellet roomheaters) and EN 15250 (slow heat release appliances). The fuel is loaded manually or by automatic feeding devices. The method is based on gravimetric particulate matter measurement in a dilution tunnel. The dilution tunnel parameters are kept in similar ranges for temperature and dilution ratio for different appliance burn rates.

3 Normative references

text

4 Terms and definitions

For the purposes of this Technical Specification, the following terms and definitions apply:

4.1 Test cycle

Test run with a test fuel load.

4.2 Test cycle duration

Elapsed time between loading of the test fuel and the loss of the total fuel load mass less ash.

4.3 Burn rate

The mass of test fuel burnt per hour based on fuel dry.

4.4 Particulate emission

Particulate matter of various shape, structure and density emitted in a test cycle of a solid fuel burning appliance.

4.5 Particulate mass

The total particulate mass of all particulate material emitted in a test cycle. The particulate mass is determined gravimetrically after removal of uncombined water with the particulate sampling train.

4.6 Dilution tunnel

Sampling duct which combines all appliance exhaust gases with ambient dilution air.

4.7 Constant volume sampling

Method to sample exhaust gases diluted with ambient air at constant flow rate.

4.8 Extraction fan

Fan installed in the dilution tunnel downstream of the emission sampling section to carry diluted gases of the test rig.

4.9 Dilution tunnel flow volume

The total volume of the diluted gas in the dilution tunnel during a test cycle.

4.10 Dilution tunnel gas flow rate

Flow rate of the diluted gases in the dilution tunnel.

4.11 Emission sampling section

Section in the dilution tunnel where the particulate emission sampling train is attached.

4.12 Particulate emission sampling train

Apparatus to withdraw part of the dilution tunnel gas to determine the particulate mass.

4.13 Filters

Filter appropriate to collect the particulates in the sample gas.

4.14 Particulate emission sample gas volume

The total volume of gas collected during a test cycle in the particulate emission sampling train.

4.15 Particulate emission sampling train gas flow rate

Gas flow rate in the particulate emission sampling train.

4.16 Portion of dilution tunnel to sampling train gas volume

The portion of the dilution tunnel gas flow volume to the particulate emission sampling train gas volume sampled during a test cycle based at standard conditions without water vapour.

4.17 Dilution ratio

The dilution ratio is defined as the volume ratio of the total diluted flow and the undiluted flue gas at standard conditions based on dry.

4.18 Particulate emission factor based on fuel mass

Mass of particulate emission based on unit mass of test fuel based on dry [mg/kgdry].

4.19 Particulate emission factor based on net heating value of fuel

Mass of particulate emission based on net heating value of test fuel based on dry [mg/MJ].

4.20 Particulate emission rate

Mass of particulate matter emitted per unit time [g/hr].

4.21 Particulate emission concentration

Mass of particulate emission based on unit volume flue gas dry related to a given oxygen content in the flue gas [e.g. mg/mn3 @13% O2].

4.22 Standard condition

Volume of gas @ 273 K (0°C) and 1'013.25 hPa

5 Test method

5.1 Principle

The appliance is installed on the test rig according to the EN-Standards. The flue gas at the exhaust of the EN-Standard measuring section is collected in a cowl and mixed with ambient air in the dilution tunnel. The diluted gases are kept at constant flow. A sample of the diluted flue gas is withdrawn (isokinetically; research is on the way to approve the necessity) through the sampling train in which the particulate matter is collected on a filter and backup filter in series. The filter holders are maintained at a temperature of 35°C. The mass of the particulate matter collected is determined of each test cycle conducted in accordance to the EN-Standards.

The particulate emission can be calculated as particulate emission factor (mg/kg fuel dry or mg/MJ), particulate emission rate (g/hr) or particulate concentration in the flue gas volume (e.g. mg/m³ @ 13vol% O₂).

5.2 Apparatus

5.2.1 Dilution tunnel

A typical dilution tunnel test rig configuration is shown in figure 1.

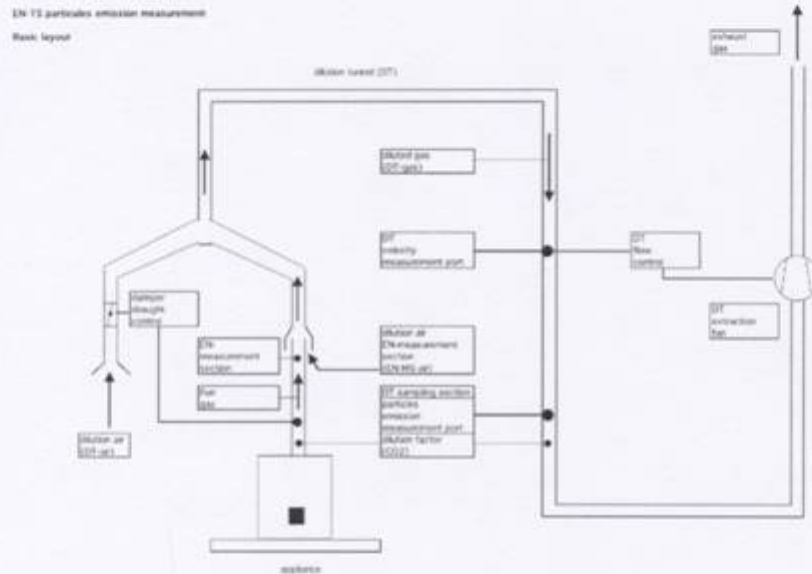


Figure 1 Typical dilution tunnel test rig facility to determine particulate emission parallel to EN-test

5.2.1.1 Layout of dilution tunnel ducts

The nominal diameter of the ducts shall be designed such that the dilution tunnel gas flow is in the range of 3...10 m/s at dilution ratios of less than 20. Table 1 gives some indication of the duct layout.

Table 1 Dilution tunnel figures for typical wood heat appliances operating at burn rates up to 3 kg/hr fuel dry with a mean oxygen content in the flue gas of 13 vol%.
Test fuel beech (18% moisture, 13.9 MJ/kg fuel as fired).

Nominal duct diameter 150 mm							
burn rate kg fuel dry/h	fuel load kW	flue gas flow dry m ³ /h	flue gas temperature °C	DT gas flow m ³ /h	DT-gas velocity m/s	DT- temperature °C	dilution ratio –
1	4.72	11.6	180	160	3.0	32.0	13.8
1.5	7.08	17.4	200	211	4.0	35.3	12.1
2	9.43	23.2	220	317	6.0	35.1	13.7
3	14.15	34.8	250	527	10.0	35.7	15.2

5.2.1.2 Collecting cowl

The collecting cowl is designed to collect the total flue gas of the appliance tested. The cowl shall be of corrosion-resistant steel, with its large end having a minimum entry opening diameter of 450 mm, and an exit diameter capable for coupling to the nominal duct diameter. The cowl shall be placed axially above the measuring section outlet.

5.2.1.3 Connectors

All connectors shall be made of seamless or longitudinally seamed stainless or corrosion-resistant steel with the designed nominal diameter. The connector nearest the cowl shall be 500 mm ± 100 mm long, the connector between the bends shall be 2000 mm ± 10 mm long and the connector between the downstream bend and the sampling section shall be 2400 mm ± 10 mm long.

NOTE Connectors may be constructed from more than one length of duct.

5.2.1.4 Bends

There shall be at least two 90° bends upstream from the sampling location. The bends shall be of stainless or corrosion resistant steel and shall have the nominal inside diameter with a nominal centreline radius of 300 mm to fit the ducts.

NOTE Segmental (lobster back) bends are permitted.

5.2.1.5 Emission sampling section

The emission sampling section shall be joined to the connector after the downstream bend and shall be one continuous length of either stainless or corrosion-resistant seamless or longitudinally seamed steel tube not less than 2400 mm long with the designed nominal diameter. The distance from the upstream end to the Pitot tube position shall be 1500 mm ± 10 mm and the distance from the upstream end to the emission sample port location shall be 2100 mm ± 10 mm.

5.2.1.6 Extraction fan

An extraction fan shall be fitted after the sampling section, and shall carry exhaust products clear of the test area. The system shall incorporate a means of adjusting the flow rate through the dilution tunnel, and be capable of maintaining a flow rate meeting the required dilution ratio at the maximum burn rate.

5.2.1.7 Component assembly

The bends, connectors and sampling section shall be fitted so that they can be removed easily for cleaning.

5.2.1.8 Flow measuring device

A standard Pitot tube of a known coefficient or an alternative device of at least equal accuracy. The Pitot tube shall be installed within 2 mm of the centre of the velocity traverse section, and shall point directly upstream within 2° of the axis of the dilution tunnel.

5.2.1.9 Differential pressure gauge

A pressure measuring device for measuring the Pitot tube velocity head to within ± 1 Pa.

5.2.1.10 Dilution tunnel temperature monitoring

A temperature system for measuring the temperature in the dilution tunnel with a range up to 200°C with an accuracy of ± 1.0 K shall be installed at the sampling section.

5.2.2 Particulate emission sampling train

Apparatus for the collection of emissions (see figure 2). This shall include the following components.

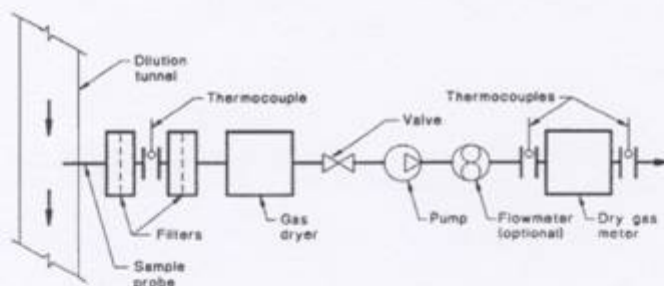


Figure 2 A typical arrangement of particulate emission sampling train used with the dilution tunnel

5.2.2.1 Sampling probe

A probe of seamless stainless steel of a nominal internal diameter of approx. 10 mm and a length of 300 mm to 600 mm (with one end cut-off at right angles, as shown in figure research is on the way to approve whether this set up is feasible; see point 5.2.). The sampling port shall have means for positioning the probe end in the centre of the sampling section of the dilution tunnel.

5.2.2.2 Particulate matter filter

There are two filters placed in series with a filter and back up filter. The filters shall not be changed during a test cycle. The filter diameter shall be such, that the particulate mass sampled over a test

cycle is sufficient in relation to the tare weights of the filter membranes in order to meet the required accuracy.

5.2.2.3 Filter holders

The two filter holders for the filter and back up filter are constructed of stainless steel and capable of retaining filters described in clause 5.2.4.1. The filter housing shall be heated to $35^{\circ}\text{C} \pm 2 \text{ K}$. Seals shall be incorporated to prevent sample gas bypassing the filters and to prevent air ingress to the filter housing.

5.2.2.4 Filter coupling

The first filter shall be coupled as close as is practicable to the end of the sample probe. The second filter assembly shall be coupled as close as is practicable to the first filter assembly so that the filter membranes are not more than 100 mm apart.

5.2.2.5 Filter housing temperature monitoring

A system for measuring the filter housing temperature with a range up to 50°C with an accuracy of $\pm 0.5 \text{ K}$.

5.2.2.6 Drying system

Equipment shall be capable of reducing the moisture content of the sample gas to less than 1.5 % moisture by volume. If carbon dioxide is measured in the sampling train do not use silica gel as desiccant but anhydrous calcium-sulphate, calcium-chloride or magnesium-perchlorate (needs to be approved).

5.2.2.7 Dry gas meter

A suitable instrument for measuring dry gas volume of the sampling train with a calibrated accuracy of $\pm 1 \%$ of the volume sampled. The dry gas meter is installed downstream of the pump to have ambient pressure condition for the sample gas metering.

5.2.2.8 Sampling gas temperature measurement

A system for measuring the average temperature of the sampling gas passing through the dry gas meter over the range 10°C to 50°C to within $\pm 0.5 \text{ K}$.

5.2.2.9 Pressure gage

Device to measure the pressure in the sampling train line.

5.2.2.10 Indicating gas flow meter

Device to indicate the gas flow in the sampling train line with a range of $0.01 \dots 0.06 \text{ m}^3/\text{min}$.

5.2.2.11 Pump

The pump shall be airtight and maintain a flow rate up to $0.06 \text{ m}^3/\text{min}$ through the sampling train. The pump is capable of extracting the gas sample at the required rate against the resistance imposed by the sample probe, filters, dryer and connecting tubes. The pump is installed upstream of the dry gas meter.

5.2.3 Dilution ratio measurement

The ratio of the dilution tunnel gas flow and the appliance flue gas flow can be measured by the carbon dioxide (CO₂) concentration in the flue and the dilution tunnel gases. The ratio of the CO₂ concentration in the dilution tunnel and the flue gas defines the dilution ratio. The EN-Standards provide CO₂ monitoring in the flue gas. An additional carbon dioxide analyser for the CO₂ monitoring in the dilution tunnel can be installed at the emission sampling train exhausts. The carbon dioxide analyser shall be capable to measure CO₂ in the range of 0.05...5 vol% with an accuracy of $\pm 0.01\%$.

5.2.4 Reagents

5.2.4.1 Filters

Glass fibre filters to fit the filter holders, without organic binders and having at least 99,95 % collection efficiency on 0,3 mm dioctylphthalate smoke particles.

NOTE The Gelman A/E 41631 filter has been found to be acceptable for this purpose.

5.2.4.2 Desiccant

As desiccant silica gel (with indicator), anhydrous calcium sulphate, calcium chloride or magnesium perchlorate shall be used. If carbon dioxide in the sampling train is measured do not use silica gel since it absorbs CO₂ but use ~~anhydrous calcium sulphate, calcium chloride or magnesium perchlorate~~ (to be approved).

5.2.4.3 Acetone

Use general purpose reagent grade acetone.

5.2.5 Instrumentation

5.2.5.1 Ambient temperature measurement system

A system which measures ambient temperatures in the range 10°C to 40°C with an accuracy of $\pm 1.0^\circ\text{C}$.

5.2.5.2 Ambient air pressure measurement system

An instrument capable of measuring ambient barometric pressure within ± 3 hPa

6 Test procedure

6.1 Preparation

6.1.1 Dilution tunnel

The dilution tunnel shall be clean at the commencement of the test cycle.

6.1.1.1 Cowl

Locate the dilution tunnel cowl centrally over the EN-measuring section terminal of the test rig. Adjust the extraction fan damper or extraction fan speed to obtain the required gas velocity in the dilution tunnel.

6.1.1.2 Induced draught

Measure the draught induced by the dilution tunnel on the EN-measurement section without operation of the measuring section fan. Adjust the distance between the cowl and the terminal so that the induced draught is less than 1.25 Pa.

6.1.1.3 Dilution tunnel flow rate

Place the Pitot tube at the centroid of the sampling section. Adjust the exhaust fan damper to the desired velocity to maintain the desired dilution ratio. Once a constant velocity is obtained at the centroid of the duct, perform a velocity traverse. Calculate the total gas flow rate.

6.1.1.4 Velocity measurement

After obtaining velocity traverse results that meet the flow rate requirements choose a point of average velocity and place the Pitot tube at that location in the duct. Mount the Pitot to ensure no movement during the test cycle and seal the port holes to prevent air leakage.

6.1.2 Emission sampling train

During preparation and assembly of the sampling train all openings where contamination can occur, shall be covered.

6.1.2.1 Filters

Condition the filters by drying them for 24 hours in a desiccator containing the desiccant. Remove and weigh them within 1 minute to the nearest 0.01 mg using the balance. A tweezer or a clean surgical gloves shall be used when placing the weighed filters in the filterholders.

6.1.2.2 Probe and filter holder

Rinse the probe and filter holder assemblies (upstream of the front filters) with acetone to remove moisture before desiccating.

Desiccate the filters, filter gaskets and the probe/filter holder assemblies (upstream of the front filters), for 24 hours at ambient condition (temperature and pressure) in a desiccator. Weigh each component. Record results to the nearest 0.1 mg. During each weighing, the period for which the components are exposed to the laboratory environment shall be less than 2 minutes. The filter gaskets can be weighed in sets to be used in each filter holder and kept in an identified container (glass or polyethylene petri dishes) at all times except during sampling and weighing. The filter holder section between the front and second filter need not be dessicated or weighed.

6.1.2.3 Leak-check

A pre-test leak-check of the sampling train shall be carried out with a vacuum of 170 Pa. A post-test check at the conclusion of each test cycle shall be done with the greatest vacuum measured during the test cycle.

6.1.2.4 Drying system

Weigh the desiccant containers with the desiccant then assemble to the sampling train.

6.1.2.5 Sampling probe

The probe inlet shall be positioned at the dilution tunnel centroid. Block off the duct openings to prevent air leakage.

6.1.2.6 Pump

Set the pump at the required sampling train gas flow.

6.1.2.7 Filter holders

Maintain the filter holder temperature such that the sampling gas temperature is in the range of $35^{\circ}\text{C} \pm 2 \text{ K}$.

6.2 Measurement

6.2.1 Test cycle

The appliance is installed according to the EN-standard. It is conditioned either with a pre-test or a precedent test cycle.

Record the dry gas meter reading of the emission sampling train at the beginning and the end of the test cycle.

The test fuel load shall be added to the appliance within 1 minute of starting emission sampling train pump.

Check visually that the cowl is collecting all of the flue gas exhausts. If it is not adjust the dilution tunnel flow rate.

During the test cycle make periodic adjustment to keep the sampling train and dilution tunnel flow rate at the required level.

The dilution tunnel temperature shall not be less than 25°C .

Do not change filters during the test cycle.

The sampling train pump shall be shut off when the scales indicate that all but 50 gramm of the test fuel load excluding calculated ash has been burnt.

6.2.2 Collecting of particulate material

6.2.2.1 Probe and filter holders

When the sampling probe is cool, wipe the external surfaces of the probe to make sure that particulate material cannot contaminate the sample during the subsequent probe cleaning.

Desiccate the filters, filter gaskets and probe at ambient condition (temperature and pressure) for at least 24 hours. Weigh each component. Report the results to the nearest 0.1 mg. Filters and filter gaskets may be weighed directly without a Petri dish. They may be weighed in pairs (front and back filters and front and back filter gaskets from same filter train) to reduce handling and weighing

errors. During each weighing, the components shall not be exposed to the laboratory atmosphere for longer than two minutes.

6.2.2.2 Filters

Remove filters from filter holders by use of a tweezer or a clean surgical glove. Place them in an identified, clean Petri dishes which tare weight are defined. Carefully transfer all particulate material or filter fibres to the Petri dishes. Cover the Petri dishes before they are moved to the balance.

6.2.3 Determination of sample particulate masses

6.2.3.1 Filters

Dry the filters in the Petri dishes in a desiccator at ambient condition (temperature and pressure) for at least 24 hours. Allow them to stabilize to a constant mass. Weigh them to the nearest 0.1 mg within 1 minute of removal from desiccator.

6.2.4 Determination of water content in the sample gas

Weigh the desiccant containers.

7 Calculations

7.1 Volume of gas sampled in the emission sampling train

7.1.1 Volume of gas sampled

Calculate the volume of dry gas sampled during the test cycle at standard condition from equation (1).

$$VSG_{ndry} = VSG_{stdry} \frac{273}{273 + TSG_m} \frac{pSG_m}{1013.25} \quad [mn3] \quad (1)$$

Nomenclature:

VSG_{ndry} total volume of dry gas sampled in the sampling train at standard condition during the test cycle [mn3]

VSG_{stdry} total volume of dry gas sampled in the sampling train during the test cycle [m3]

TSG_m mean temperature of the gas sampled in the sampling train during the test cycle [°C]

pSG_m mean pressure of the gas sampled at the inlet of the dry gas meter during the test cycle [hPa]

7.1.2 Moisture content of gas sampled

7.1.2.1 Volume of water vapour

Calculate the volume of water vapour in the gas sampled from equation (2).

$$VWV = vWV \cdot MWV \quad [mn3] \quad (2)$$

Nomenclature:

VWV volume of water vapour sampled during test cycle [m³]

vWV specific volume of water vapour (vWV = 1.24 m³/kg water vapour)

MWV mass of water sampled during test cycle [kg]

]

7.1.2.2 Moisture content

Calculate the moisture content in the gas sampled from equation (3) which is equal to the moisture content in the dilution tunnel gas.

$$MCDT = \frac{VWV}{VWV + VSG_{dry}} \cdot 100 \quad [\%] \quad (3)$$

Nomenclature:

MCDT moisture content in the dilution tunnel gas [%]

VWV volume of water vapour sampled during test cycle [m³]

VSG_{dry} total volume of dry gas sampled in the sampling train at standard condition during the test cycle [m³]

7.2 Volume of gas in the dilution tunnel

7.2.1 Volume of gas with water vapour

Calculate the volume of the gas with water vapour in the dilution tunnel during the test cycle from equation (4).

$$VDT_{at} = vDT \cdot areaDT \cdot \Delta t \cdot 3600 \quad [m^3] \quad (4)$$

Nomenclature:

VDT_{at} total volume of gas in the dilution tunnel with water vapour during the test cycle [m³]

vDT mean gas flow velocity in the dilution tunnel [m/s]

areaDT area of the dilution tunnel duct [m²]

Δt test cycle duration [h]

7.2.2 Volume of gas dry

Calculate the volume of the dry gas in the dilution tunnel during the test cycle from equation (5).

$$VDT_{dry} = VDT_{at} \cdot \frac{100 - MCDT}{100} \quad [m^3] \quad (5)$$

Nomenclature:

VDT_{dry} total volume of dry gas in the dilution tunnel during the test cycle [m³]

VDT_{at} total volume of gas in the dilution tunnel with water vapour during the test cycle [m3]

MCDT moisture content in the dilution tunnel gas [%]

7.2.3 Volume of gas dry at standard condition

Calculate the volume of the dry gas at standard condition in the dilution tunnel during the test cycle from equation (6).

$$VDT_{ndry} = VDT_{atdry} \cdot \frac{273}{273 + TDT_m} \cdot \frac{pDT_m}{1013.25} \quad [m3] \quad (6)$$

Nomenclature:

VDT_{ndry} total volume of dry gas in the dilution tunnel at standard condition during the test cycle [mn3]

VDT_{atdry} total volume of dry gas in the dilution tunnel during the test cycle [m3]

TDT_m mean temperature of the gas sampled in the dilution tunnel during the test cycle [°C]

pDT_m mean pressure of the gas sampled in the dilution tunnel during the test cycle [hPa]

7.3 Portion of dilution tunnel to sampling train gas volume

To calculate the factor for the appliance particulate emission the portion of dilution tunnel and sampling train gas volume need to be known (equation 7).

$$RATIO_{VDT-VSG} = \frac{VDT_{ndry}}{VSG_{ndry}} \quad [-] \quad (7)$$

Nomenclature:

RATIO_{VDT-VSG} portion of dilution tunnel and sampling train gas volume

VDT_{ndry} total volume of gas in the dilution tunnel at standard condition [mn3]

VSG_{ndry} total volume of dry gas sampled in the sampling train at standard condition [mn3]

7.4 Dilution ratio

To calculate the dilution ratio of the appliance flue gases in the dilution ratio apply equation (8).

$$RATIO_{DT-FG} = \frac{CO2DT_m}{CO2FG_m} \quad [-] \quad (8)$$

Nomenclature:

RATIO_{DT-FG} dilution ratio of the appliance flue gases [-]

CO2DT_m mean concentration of carbon dioxide in the dilution tunnel during the test cycle [vol%]

CO2FG_m mean concentration of carbon dioxide in the flue gases during the test cycle [vol%]

7.5 Total particulate mass sampled

To calculate the total particulate mass collected in the sampling train apply equation (9).

$$m_{tot} = m_{F1} + m_{F2} + m_u \quad [\text{mg}] \quad (9)$$

Nomenclature:

m_{tot} total mass of particulate material collected in the sampling train [mg]

m_{F1} mass of particulate material collected on the filter and backup filter [mg]

m_u mass of particulate material from filter holder, filter gaskets and probe upstream backup filter [mg]

7.6 Total particulate mass emitted

To calculate the total particulate mass emitted by the appliance during the test cycle apply equation (10).

$$PM_{total} = m_{tot} \cdot \frac{VDT_{ndry}}{VSG_{ndry}} \quad [\text{mg}] \quad (10)$$

Nomenclature:

PM_{total} total particulate mass emitted by the appliance during the test cycle [mg]

m_{tot} total mass of particulate material collected in the sampling train [mg]

VDT_{ndry} total volume of dry gas in the dilution tunnel at standard condition

VSG_{ndry} total volume of dry gas sampled in the sampling train at standard condition

7.7 Particulate emission factor based on fuel mass

Calculate the particulate emission factor based on fuel mass dry from equation (11).

$$PM-EF_{mass} = \frac{PM_{total}}{m_{fueldry}} \quad [\text{mg/kg}] \quad (11)$$

Nomenclature:

$PM-EF_{mass}$ particulate emission factor based on fuel mass dry [mg/kg]

PM_{total} total particulate mass emitted by the appliance during the test cycle [mg]

$m_{fueldry}$ mass of fuel batch of the test cycle based on dry [kg]

7.8 Particulate emission factor based on fuel net heating value

Calculate the particulate emission factor based on fuel net heating value based on fuel dry from equation (12).

$$PM-EF_{dry} = \frac{PM_{total}}{m_{fuel,dry} \cdot NHV_{fuel,dry}} \quad [mg/MJ] \quad (12)$$

Nomenclature:

$PM-EF_{dry}$ particulate emission factor based on fuel net heating value dry [mg/MJ]

PM_{total} total particulate mass emitted by the appliance during the test cycle [mg]

$m_{fuel,dry}$ mass of fuel batch of the test cycle based on dry [kg]

$NHV_{fuel,dry}$ Net heating value of test fuel [MJ/kg]

7.9 Particulate emission rate

Calculate the particulate emission rate from equation (13).

$$PM-ER = \frac{PM_{total}}{\Delta t} \cdot 3.6 \quad [g/hr] \quad (13)$$

Nomenclature:

$PM-ER$ particulate emission rate [g/hr]

PM_{total} total particulate mass emitted by the appliance during the test cycle [mg]

Δt test cycle duration [s]

7.10 Particulate emission rate

Calculate the particulate emission rate from equation (14).

$$PM-ER = \frac{PM_{total}}{\Delta t} \cdot 3.6 \quad [g/hr] \quad (14)$$

Nomenclature:

$PM-ER$ particulate emission rate [g/hr]

PM_{total} total particulate mass emitted by the appliance during the test cycle [mg]

Δt test cycle duration [s]

7.11 Particulate emission concentration

To calculate the appliance particulate emission concentration apply equation (15).

$$PM-CON = \frac{PM_{total}}{VDT_{dry}/RATIO_{VDT-FG}} \quad [mg/mn3] \quad (15)$$

Nomenclature:

PM-CON particulate emission concentration in the flue gases [mg/mn3]

PM_{total} total particulate mass emitted by the appliance during the test cycle [mg]

VDV_{dry} total volume of dry gas in the dilution tunnel at standard condition [mn3]

RATIO_{VDV-FC} dilution ratio of the appliance flue gases

To calculate the appliance particulate emission concentration related to a standard oxygen content in the flue gas (e.g. 13 vol% O₂) apply the following equation (16):

$$PM-CON_{stand} = PM-CON \cdot \frac{(21 - O2_{mean})}{(21 - O2_{stand})} \quad [mg/mn3] \quad (16)$$

Nomenclature:

PM-CON particulate emission concentration in the flue gases [mg/mn3]

O₂_{mean} mean oxygen concentration in the flue gases of the appliance during the test cycle [vol%]

O₂_{stand} standard oxygen concentration to relay emission concentration in the flue gases (e.g. 13 vol%)

Appendix 9 – Nordic input on the draft of particulate emission test method

Nordic input on the preliminary draft of EN TS on particulate emission test method – CEN/TC 295/WG5 N 70/2006

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Borås, Sweden 26 October 2006

Specific remarks

1 Introduction, line 2: Change “total suspended particulates” to “PM10 (Particulate Matter less than 10 µm)”

4.4. Add “Particulate matter = Solid and condensible matter”

4.4 and 4.5. Add units.

4.5. Change “material” to “matter”

5.2.2.3 and 6.1.2.7. The filter holder temperature should be between 20 °C and 35 °C. (It is not necessary to heat it.) The filter holder shall be made of stainless steel or polytetrafluorethylene (PTFE).

6.1.2.1. The filters should be weighted to the nearest 0.1 mg (not 0.01 mg).

7.4 Equation 8: Change places of numerator and denominator

7.9 and 7.10 seem to have the same content

General remarks

- Blank test prior to measurements is suggested. Particulate matter sampled on blank filters should not exceed 1mg/h. Gas velocity 5.5 m/s is suggested during blank tests.
- Measurements of gas emissions are to be performed with forced draught according to standard. The experimental set-up in figure 1 means problems with keeping the draught constant simultaneously with constant volume flow in the dilution tunnel. => Gas emissions and particulate emissions need to be performed separately.
- Particles might be lost in the sampling system. Especially particles larger than 10 µm might be lost to a high degree through inertial deposition. Pre-cyclone with a cut-off at 10 µm might be a solution, but it needs more work to define a pre-cyclone, because cut-size depends on flow velocity, which is not fixed in the method.
- High burn rates (e.g typically 4-10 kg dry fuel per hour in Finland) require a very powerful fan. We suggest that a larger diameter (than 150 mm) of the dilution tunnel is used in these cases
- Emission should be stated as [mg particulate matter per kg dry fuel supplied] or [mg particulate matter per MJ fuel supplied]. If particulate concentration per m³ is needed this may be calculated from burn rate if combustion is good. However if combustion is poor, it is necessary to use dilution ratio. In this case using CO₂ may be a problem due to limited accuracy of analyzers below 1% CO₂, and it should be allowed to use a CO measurement instead since this is often more accurate. However special attention should be given in case of to unstable CO values.
- Add in the Scope: This method applies to fuel loads set in other national standards as well.

