# Sampling Exhaust Gases of Thermal Processes with Continuous, Automatic Adjustment to Isokinetic Conditions

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## Introduction

Emissions of polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) should be sampled isokinetically according to VDI guidelines [1,2,3]. The sampling error can be reduced by using an automatic sampling system, especially for processes with fluctuations in the volumetric flow rate of exhaust gases and dust as well as soot gases. Isokinetic conditions during the whole sampling interval is maintained at different sampling points.

## Materials and Methods

Isokinetic sampling of PCDD/F emissions with an automatic sampling system was carried out at sampling points under different conditions. The selected sampling sites were at the following locations:

1. in the stack gas downstream of a baghouse filter at about 60 °C at a secondary aluminium smelting research pilot plant,
2. in the flue gas of a wood incinerator at a temperature range of 140 to 250 °C.
3. in the flue gas of a rotary furnace at a temperature range of 150 to 600 °C at a secondary aluminium research pilot plant.

PCDD/F were sampled with the cooled probe method according to VDI guidelines 3499 connected to the automatic sampling system MRU4000 of GSM, Neuss, Germany (formerly Ströhlein company). In the following the operating with the automatic sampling system is described. Isokinetic condition is defined by equivalence of the velocities of sampled gas and exhaust gas:

$$v_{exhaustgas} = v_{samplegas} \qquad (1)$$

The gas sample should be sucked through the sampling train with a sample gas flow rate of about 1.5 m³/h (using impinger). The determination of the velocity of the exhaust gas requires some related data for the operation. Ambient air pressure $p_{atm}$ [hPa] is determined with a manometer. The water content $f_n$ [kg/m³] of the exhaust gas is assessed in a control unit before sampling. The weight is determined of an U-glass filled with calciumhydroxide before and after sucking 10 L of exhaust gas.

The volume parts of the gas components are measured with an gas analyzer or they are estimated. The temperature $T_d$ [K] of the exhaust gas is determined with a thermocouple installed in the orifice. The static pressure $p_{st}$ [hPa] and dynamic pressure $p_{dyn}$ [hPa] in the duct are measured by a pressure head. These parameters are needed to determine the density of the dry flue gas under standard conditions $\rho_n$ [kg/m³] and the velocity of the gas $v$ [m/s]. $\rho_n$ is determined from the volume parts of the gas components $\omega_i$ [%(v/v)] and the density of a gas component under standard conditions $\rho_{n,i}$ [kg/m³]. The $\rho_{n,i}$ is the ratio of the relative moleculare weight of a gas component $M_{r,i}$ [kmol/kg] and its molar standard volume $V_{mn,i}$ [m³/kmol].

$$\rho_n = \sum \frac{\omega_i}{100\%} \cdot \rho_{n,i} \qquad (2)$$

$$\rho_{n,i} = \frac{M_{r,i}}{V_{mn,i}} \qquad (3)$$

where i denotes $CO_2$, $O_2$, CO, $N_2$. The density of carbon dioxide, oxygen, carbon monoxide and nitrogen is 1.977 kg/m³, 1.429 kg/m³, 1.250 kg/m³ and 1.251 kg/m³ under standard conditions, respectively. $\rho_n$ is converted into the density of flue gas including water vapor under standard conditions $\rho_{n,f}$. The standard density of water $\rho_{n,w}$ is 0.804 kg/m³.

$$\rho_{n,f} = \frac{\rho_n + f_n}{1 + \frac{f_n}{\rho_{n,w}}} \qquad (4)$$

With $\rho_{n,f}$ the gas density of flue gas $\rho_{pt,f}$ [kg/m³] is calculated as

$$\rho_{pt,f} = \rho_{n,f} \cdot \frac{273.15}{1013} \cdot \frac{(p_{atm} + p_{st})}{T_d} \qquad (5)$$

The velocity of the exhaust gas is determined according to

$$v = \sqrt{200 \cdot \frac{p_{dyn}}{\rho_{pt,f}}} \qquad (6)$$

A nozzle diameter $d$ [m] must be selected, which is suitable to achieve a standard sample gas flow rate of about 1.5 m³/h. The calculations are done by the control unit.

$$V_n = v \cdot \frac{\pi}{4} d^2 \cdot 3600 \cdot \frac{(p_{atm} + p_{st})}{T_d} \cdot \frac{273.15}{1013} \cdot \frac{\rho_{n,w}}{\rho_{n,w} + f_n} \qquad (7)$$

**Results and Discussion**

The automatic sampling system performs a continuous adjustment to the velocity of the exhaust gas. Using a fixed nozzle diameter at varying exhaust gas velocities, the flow rate is regulated with the control unit. The sampling train described above is applicable for an isokinetic sampling according to the guideline VDI 2066. Figures 1-3 show the adjustment of the measured $V_{n\ measured}$ [m³/h] to the calculated standard sample gas flow rate $V_{n\ calculated}$ [m³/h] at different sampling sites. The calculated standard sample gas flow rates are calculated with the formulas above using the corresponding relationship. The measured standard gas flow rate is obtained from the gas volume meter. The regulation difference, which is the error between

the measured and calculated sample gas flow rate is less than 5 %. The regulation difference $\Delta\overline{V}$ is evaluated with equation 8. The sample gas flow rate was adjusted continuously and automatically by a regulating valve controlled by a microprocessor. All relevant physical data of the flue gas for the calculation of the desired sample gas flow rate were registered each minute.

$$\Delta\overline{V} = \frac{\sum_{1}^{j} \frac{\left|V_{n\,calculated} - V_{n\,measured}\right|}{V_{n\,measured}}}{j} \qquad (8)$$

The cleaned flue gas in the duct downstream of the baghouse filter had a nearly constant standard sample gas flow rate during the sampling time (Fig. 1). The gas flow rate of the sampling system is approximately 2.5 m³/h during the sample time. Normally a sampling system by manual adjustment is sufficient. But the automatic system responded quickly to a short deviation in the duct. Isokinetic conditions were always met.

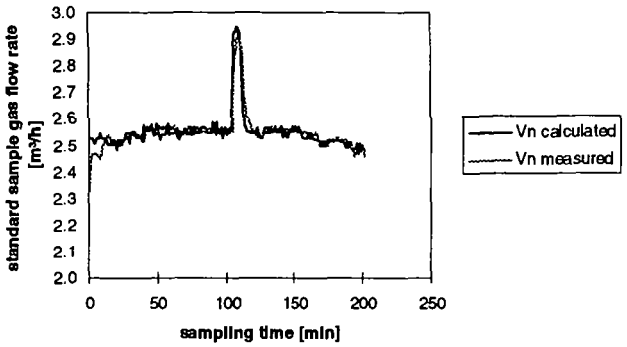


Figure 1: Measured and calculated standard sample gas flow rate after a baghouse filter.

Figure 2 shows the maintenance of isokinetic conditions and is typical for the process of the wood incinerator. After feeding wood into the incinerator, the temperature in the incinerator increased within three minutes from 140°C to 250°C. The dry wood started to burn immediately because a blower operated automatically for 10 min. A standard sample gas flow rate peak of 2.50 m³/h was observed.

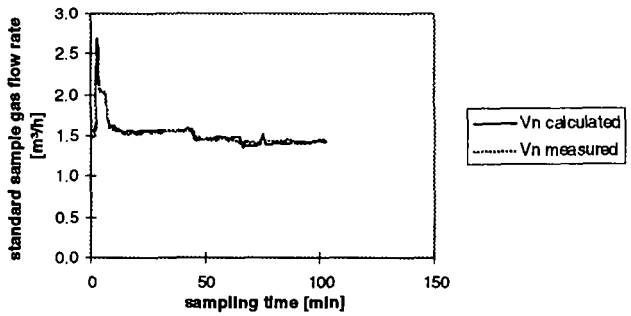


Figure 2: Measured and calculated standard sample gas flow rate after a wood incinerator.

The velocity of the gas increased to 7 m/s and resulted in the high standard sample gas flow rate in the startup of the process (see equation 7). The standard gas flow rate is related to the velocity in the exhaust gas. After this period a complete combustion was achieved and the temperature at the sampling point remained at 200 °C. Then the blower was switched off. The velocity in the exhaust gas decreased from 7 to 4 m/s and changed to 3 m/s during the burnout of the wood.

Intensive fluctuations of the sample gas flow rate, resulting from the extreme process conditions, are shown in Figure 3. The sample gas flow rate indicates the progress of the process. The output of the burner in the rotary furnace changed several times between 20 % and 100 % and therefore the temperature of the exhaust gas varied from 150 °C to 600 °C. The main reason for the different standard sample gas flow rate is the change in temperature of the exhaust gas. The temperature influences the density of flue gas and consequently the velocity in the duct and thereby the standard sample gas flow rate. If the temperature in the duct moves in the range of 450 °C, as in this case, $T_d$ in equation 7 is predominating the standard sample gas flow rate $V_n$. The automatic sampling system responds to changes of the process parameters in the duct. The adjustment of the measured and calculated standard sample gas flow rate is maintained during the whole sampling time. Therefore, a continuous isokinetic and representative sampling is possible.

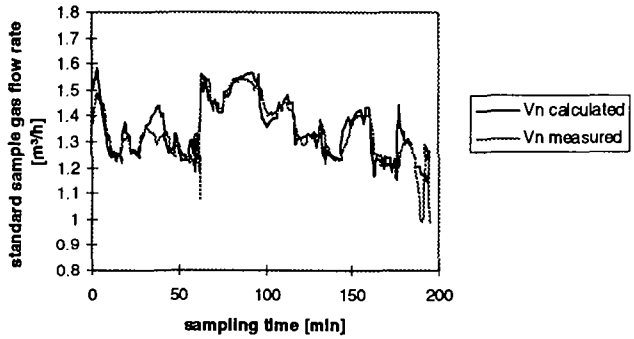


Figure 3: Measured and calculated standard sample gas flow rate after a rotary furnace.

**Acknowledgments**

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**References**

1. VDI 2066 Blatt 1 Messen von Partikeln: Staubmessungen in strömenden Gasen; Gravimetrische Bestimmung der Staubbeladung; **1975.**
2. VDI 2066 Blatt 1 Messen von Partikeln: Manuelle Staubmessung in strömenden Gasen; Gravimetrische Bestimmung der Staubbeladung; Filterkopfgeräte (4 m³/h, 12 m³/h), **1975.**
3. VDI 3499 Messen von Emissionen - Messen von Reststoffen, Messen von polychlorierten Dibenzodioxinen und -furanen im Rein- und Rohgas von Feuerungsanlagen mit der Verdünnungsmethode, Bestimmung in Filterstaub, Kesselasche und in Schlacken; **1990.**