Biomass for Energy and Industry, 10th European Conference and Technology Exhibition
June 8–11 1998, Würzburg (Germany)

DETERMINATION OF AVERAGED POLLUTANT CONCENTRATIONS FROM FURNACES BY CONTINUOUS MEASUREMENT OF THE FLUE GAS FLOW

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ABSTRACT: The common method to measure emission data is to analyse the concentrations of emissions and O_2 in the flue gas and to calculate the data in mg/Nm^3 at a standard O_2-concentration. With this method, instantaneous data as a function of the time during the test can be calculated, e.g. CO(t). For a correct comparison of different tests, *average* concetrations are necessary. If the flue gas flow is not constant, an information on the instantaneous *mass flow* is needed for a correct calculation of average data.
The aim of the present project was to develop a method to determine the integrated amount of pollutants, which corresponds to a correctly averaged concentration. Therefore, the concentrations of CO, CO_2, O_2 and NO_X are analysed *and* the flue gas velocity is continuously measured to calculate the *instantaneous mass flow* of the pollutants. The mass flow is then integrated over the test period and divided by the total flue gas volume to get an averaged value in mg/Nm^3:

$$\overline{CO} = \frac{\int CO(t) \cdot \dot{V}_{FlueGas}(t)dt}{\int \dot{V}_{FlueGas}(t)dt}$$

The method has been applied for test bench experiments and for on-site measurements in large plants. The data have been calculated with and without the information of the flue gas flow. It is shown that errors made by data evaluation without the flue gas flow can be in the order of 10% – 40% if the flue gas flow varies. However the error is zero for constant flue gas flow. Without measurement of the flue gas flow, the data have to be averaged before normalizing to a given O_2 reference value to minimize the error.
Keywords: Standardization, averaging, flue gas flow measurement.

1. INTRODUCTION

The common method to receive emission data of wood furnaces is to measure the instantaneous concentrations of emissions and O_2 in vol.-% or vol.-ppm in the flue gas [1]. This data are calculated to mg/Nm^3 at a standard O_2-concentration, e.g. CO in mg/Nm^3 at 11 vol.-% O_2. If the heating value of the fuel is known, the data can also be transformed to a concentration in mg/MJ heat input. Both calculations are valid for instantaneous data and the concentrations are therefore a function of the time during the test of the furnace, e.g. CO(t).
For the comparison of different furnaces and the comparison with emission standards, average concetrations must be calculated from the measured data. If the flue gas flow is constant, correct average concentrations can easily be calculated from the instantaneous concentrations. However, for manual wood furnaces the flue gas flow can vary in a wide range during the test due to the start up and the shut down periods [2]. In automatic furnaces the flue gas flow varies according to the heat demand. For varying flue gas flow, a correct calculation of average pollutant concentrations is not possible without an information of the instantaneous mass flow of flue gas.
The aim of the present project was to develop a method to measure the integrated amount of pollutants, which corresponds to a correctly averaged concentration [3, 4]. It should be possible to use the method for test bench conditions for stick wood boilers and also for on-site measurements of large combustion plants.

2. METHODS FOR EMISSION EVALUATION

The following measurement procedures can be used for the determination of correctly averaged emission data:

- Dilution tunnel
- Continuous measurement of the air flow
- Continuous measurement of the flue gas flow.

The three methods aim in the determination of averaged emission data which could theoretically be determined by the collection of the whole flue gas during the relevant measurement period [4]. The dilution tunnel is a convenient method to determine emissions from wood stoves on a test bench. However it cannot be applied for on-site measurements or for larger furnaces. As an alternative, either the inlet air flow or the flue gas flow can be measured continously.

In the present work, the flue gas flow has been measured continously and used for the averaging of emission data. The detailed formula for the calculation of averaged emission concentration is given in Table I (formula A). Furthermore a simplified formula is proposed which leads to a minor error (formula A_{simp}).

If the flue gas volume cannot be measured, either formula B or C has to be used. Formula B represents the method „1st calculation of instantanous concentrations to a standard O_2 level and 2nd calculation of averaged concentration" while formula C describes the method „1st calculation of averaged concentrations and 2nd calculation of concentration at a standard O_2 level".

As it is shown in the results, method C leads to smaller errors than method B.

Table I: Different methods for the determination of emission data according to [4]

Method A (Reference):

Correct determination of averaged CO concentration with continous measurement of the flue gas flow

$$\overline{CO}_{gew\_norm} = \frac{21}{100\ A\ \lambda_{norm}} \frac{\int CO(t)\, \dot{V}_{A\,tr}(t)\, dt}{\int \dot{V}_{A\,tr}(t)\, dt} \left[\frac{100 \int \dot{V}_{A\,tr}(t)\, dt}{\int \left[[CO(t)] + [CO_2(t)] \right] \dot{V}_{A\,tr}(t)\, dt} + \left(A - 1 - \frac{\int [CO(t)]\, \dot{V}_{A\,tr}(t)\, dt}{2 \int \left[[CO(t)] + [CO_2(t)] \right] \dot{V}_{A\,tr}(t)\, dt} \right) \right]$$

Method A_{simp}:

Simplified determination of averaged CO concentration with continous measurement of the flue gas flow

$$\overline{CO}_{gew\_norm} = \frac{\overline{\lambda}}{\lambda_{norm}}\ \overline{CO}_{gew} = \frac{21}{A\ \lambda_{norm}} \frac{\int CO(t)\, \dot{V}_{A\,tr}(t)\, dt}{\int \left[[CO_2(t)] + [CO(t)] \right] \dot{V}_{A\,tr}(t)\, dt}$$

Method B:

Determination of averaged CO concentration without continous measurement of the flue gas flow

(1st calculation of standardized concentrations, 2nd calculation of average data)

$$\overline{CO}_{norm} = \frac{21}{A\ \lambda_{norm}} \int \frac{CO(t)}{[CO_2(t)] + [CO(t)]}$$

Method C:

Determination of averaged CO concentration without continous measurement of the flue gas flow

(1st calculation of average concentrations, 2nd calculation of standardized data)

$$\overline{CO}_{norm} = \frac{\overline{\lambda}_{arith}}{\lambda_{norm}}\ \overline{CO}_{arith} = \frac{21}{A\ \lambda_{norm}} \frac{\overline{CO}_{arith}}{\left[\overline{CO_2}(t)_{arith}\right] + \left[\overline{CO}(t)_{arith}\right]}$$

3. DETERMINATION OF AVERAGED EMISSION DATA BY CONTINOUS MEASURING OF THE FLUE GAS FLOW

The concentrations of CO, CO_2, O_2 and NO_X are analysed continuously. Furthermore the flue gas velocity is continuously measured to calculate the instantaneous mass flow of the the species. The mass flow, e.g. of CO, is integrated during a whole batch (for a manual furnace) or during the whole test period (from a few minutes to a whole season) and then divided by the total flue gas volume during the test period. The result is an integrated emission value in mg/Nm^3. The principle of the calculation is as follows (details see Table I and Ref. [4]):

$$\overline{CO} = \frac{\int CO(t) \cdot \dot{V}_{FlueGas}(t)dt}{\int \dot{V}_{FlueGas}(t)dt} \quad \textbf{(1)}$$

The method has been applied for stick wood furnaces and for an automatic under stoker furnace [4]. Furthermore, the method has been implemented for measurements in a 1 MW combustion plant for urban waste wood and it has been used to determine averaged emission data during a whole heating period [5]. Figure 1 shows the principle of the measurement on a test bench for boilers.

A system with differential pressure has been used for the measurement of the flue gas flow. The sample probe consists of four measurement locations in the chimney for averaging the flow distribution (Annubar tube).

Since the dry flue gas volume is needed for the calculation of averaged data (see Table I) and the wet flue gas flow is measured by Annubar, an information of the H_2O content in the flue gas is also needed. For this purpose the H_2O can be measured continously. If the fuel composition is known, the H_2O content in the flue gas can also be calculated from the the water content in the fuel. It has been shown, that this simplification leads to a far smaller error than a simplified averaging without an information on the flue gas flow [4].

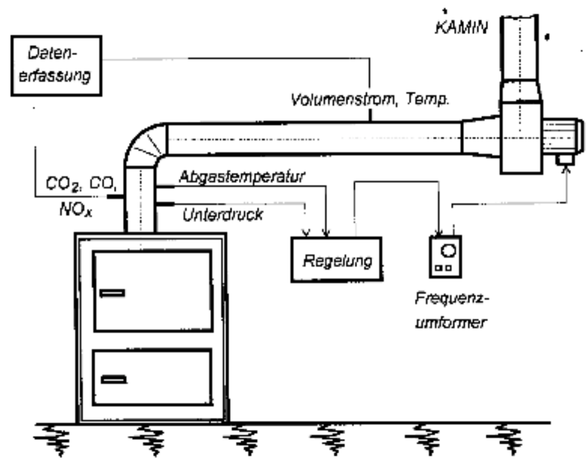

Figure 1: Test bench with continous measurement of flue gas flow with pressure drop (Annubar) [4].

4. RESULTS

The collected data from the different tests have been evaluated with and without taking into account the continuously measured flue gas flow.

The results indicate that without measuring the flue gas flow, the concentrations have to be averaged *before* they are calculated to a certain O_2 reference value to minimize the error of the evaluation (see Table II). The opposite, first calculation to an O_2 standard and then averaging the concentrations, leads to greater errors [6, 7].

Furthermore it is shown, that errors made by common data evaluation without the instantanous flue gas flow can be as large as 10% – 40%, if the flue gas flow varies for instance in a stick wood furnace. The error becomes zero if the flue gas flow is constant.

Table II: Differences **Δ** of the simplified calculation methods A_{simp}, B and C in comparison to the correct determination method A for stationary combustion and whole batch process [4, 5].

Difference Δ to A	$A_{simp.}$ [%]	B [%]	C [%]
Average Δ stationary	– 0.3	+ 23.6	+ 8.5
Average Δ batch	– 0.1	+ 57.8	+ 10.2
Max. Δ stationary	– 0.4	+ 80.9	+ 39.1
Max. Δ batch	– 0.3	+ 196	+ 41.5

5. CONCLUSIONS

In wood furnaces the flue gas flow can usually vary in a wide range due to a batch wise operation (manual fed furnaces) or due to changing heat demand (automatic furnaces). Therefore the varying mass flow of the flue gas has to be measured continously for a correct determination of averaged pollutant concentrations. It has been shown that the continous measurement of the flue gas flow is an appropriate method for the correct determination of averaged pollutant concentrations for test bench and for on-site measurements.

If emissions are measured without a continous information on the flue gas flow, the data have to be averaged before normalizing to a given O_2 level to minimize the error in comparison to a correct determination.

ACKNOWLEDGMENT

This work has been carried out in cooperation with TIBA AG Bubendorf and has been funded by the Swiss Federal Office of Energy.

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