Online monitoring of flue gas emissions in power plants having multiple fuels

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Abstract: This paper introduces an online monitoring application for flue gas emission measurements. The monitoring is conducted by analytical redundancy by estimating the monitored measurement variables. The estimated variables are CO_2, H_2O, flue gas flow and combustion air flow. Additionally, SO_2 content in the flue gas can be estimated with certain limitations. The monitoring method is based on physical combustion modeling and is therefore boiler structure and fuel independent. The model is valid for multiple fuels as long as the fuel flow measurements, fuel properties and flue gas O_2 measurement are available. The estimates can further be improved by flue gas CO measurement. The monitoring method was successfully tested in an industrial wood, peat, bark and slurry fired power plant. The results verify that the method is able to automatically separate sensor faults and process disturbances.

Keywords: Process monitoring, estimation, mass balance, power plant, sensor diagnostics, flue gas

1. INTRODUCTION

There is an increasing demand to protect environment from harmful emissions. As energy production is a major source of harmful emissions, authorities have set further tightening emission limits also to power plants. In European Union, the flue gas emissions, i.e. SO_2, NO_x and dust, are restricted e.g. by Large Combustion Plant (LCP) directive, Integrated Pollution Prevention and Control (IPPC) directive and their future replacement Industrial Emission Directive (IED) that is coming into effect in 2016. In parallel, European Union Emission Trading System (EU ETS) aims at reducing greenhouse gas emissions, especially CO_2 emissions. These directives and systems not only control the emission levels but also set requirements for the reliability of emission measurements in power plants. Therefore, the reliability of emission measurements is getting an increasing attention in the future.

The required measurement reliabilities of emission monitoring systems are described in (EN 14181) by Quality Assurance Levels (QAL) 2–3 and in Annual Surveillance Tests (AST) procedures. There, the correctness of measurements is assured by regular calibrations carried out by external specialists. However, the reliability of sensors might be deteriorated e.g. due to fouling and wearing, and without any actions these inaccuracies might not be observed for a while. Therefore, quality control of emission sensors should also be carried out between the calibrations to provide environmentally efficient operation of the combustion processes.

Fault detection procedures applied in sensor diagnostics are based on redundant information where the readings from the monitored sensors are compared with reference values. The reference values can be generated either by hardware redundancy from redundant sensors or by analytical redundancy generated by models. Hardware redundancy in emission measurements is hardly a solution mainly due to high investment and maintenance costs. Therefore, analytical redundancy is preferable if it is able to provide decent estimates. The analytical redundancy can be generated by data based models or physical models. In flue gas emission monitoring, there are some publications of data based emission estimates, e.g. Ruusunen & Leiviskä (2004); Ruusunen (2013), Yap & Karri (2011) and Shakil *et al.* (2009). Additionally, there are quite a few publications covering monitoring of NO_x emissions and emission monitoring of internal combustion engines, which are out of scope of this article. However, the validity and applicability of data based models are often case and fuel specific and require maintenance. On the other hand, there are physical combustion models, which are typically based on energy and and/or mass balances and are used to estimate some features, especially fuel moisture contents or heating values. However, to authors' knowledge there are no publications covering emission monitoring based on physical combustion models that are fuel quality and quantity independent.

After the redundant information for sensor signal is generated, the inconsistency between actual measured data and reference data indicates fault either in the diagnosed signal or some value used in the generation of the reference information. The faulty signal is identified by generating a model chain where redundant information is generated by using different measurements as source data and the inconsistency appears in so called parity relations where the faulty signal is applied. The estimates can also be utilized in data reconciliation applications, e.g. presented in Huovinen *et al.* (2012).

This paper introduces an online monitoring method for flue gas emission measurements. The monitoring is conducted by analytical redundancy by estimating the monitored measurement variables. The combustion air flow estimate and flue gas estimates (CO_2, H_2O, SO_2, and flue gas flow) are based on physical combustion modelling. The model is derived to be applicable with multiple fuels to gain

applicability in challenging and versatile combustion environments. The method was successfully tested in an industrial wood, peat, bark and slurry fired boiler, and the results are presented and commented after model derivation.

2. MODELLING OF THE COMBUSTION

In this section, the model for estimating the combustion variables is presented. The model is derived to be applied with multiple fuels to gain generality and exploitability. The foundation of the model is element balance equations that can be solved analytically. Unfortunately, some effort is needed to scale the measured and a priori information to required forms and to calculate the estimates from these scaled variables. After that, however, the estimates provide physically relevant information that connects several separate measurement signals to form an entirety. The analytical solution enables exploitation of the method with minor calculation power in any real computational environment.

The idea of the combustion model is to calculate the desired estimates according to measurement and a priori information. The main a priori information for this model are fuel chemical compositions, which are expressed in form of $C_x H_y O_z N_v S_w$, where C stands for element carbon, H hydrogen, N nitrogen, and S sulphur. Moreover, the fuel moisture and ash contents must be known for all fuels. When this a priori information is gathered together with fuel flow measurement and flue gas oxygen measurement information, which is one of the most reliable flue gas measurements and inexpensively duplicable, the main components of flue gas flow can be estimated. Moreover, the estimates can be further improved by CO measurement that reduces the proportion of CO_2 in the flue gas.

The principles of equations presented in this section can be found in books covering combustion, e.g. in Van Loo & Koppejan (2008), but according to author's knowledge, the derived analytical solution has not been published previously.
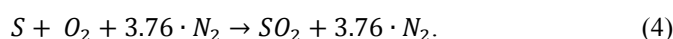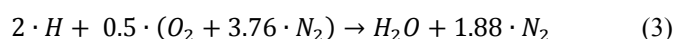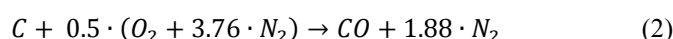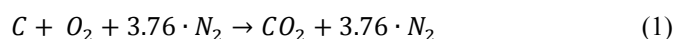
Table 1. Nomenclature

Symbol	Description	Unit
n	Amount of substance	mol
M	Molecular mass	kg/mol
m	Mass	kg
p	Pressure	Pa
R	Universal gas constant	J/(mol·K)
ρ	Density	kg/m³
T	Temperature	°C
$r_{F,k}$	Ratio of molecular flow of fuel k over molecular fuel flow	-
x	Molecular ratio of C to C	-
y	Molecular ratio of H to C	-
z	Molecular ratio of O to C	-
v	Molecular ratio of N to C	-
w	Molecular ratio of S to C	-
r_{Air}	Oxygen-to-fuel mole ratio	-
λ	Molecular air factor	-
η	Proportion of water vapour in air	-
γ	Molecular ratio of H_2O to combustion	-
X	Volume ratio	-
φ	Measured air moisture content	-

Table 2. Indexes

Symbol	Description
k	Fuel k, i.e. $k \in \mathbf{N}$
daf	Dry, ash free
st	Stoichiometric
FG	Flue gas
l	Gas component, i.e. $l = O_2, CO$
NTP	T = 0 °C & p = 101 325 Pa
me	Measurement
est	Estimate

2.1 Balance equations

The main chemical reactions in combustion environment having over stoichiometric conditions can be presented as

$$C + O_2 + 3.76 \cdot N_2 \rightarrow CO_2 + 3.76 \cdot N_2 \tag{1}$$

$$C + 0.5 \cdot (O_2 + 3.76 \cdot N_2) \rightarrow CO + 1.88 \cdot N_2 \tag{2}$$

$$2 \cdot H + 0.5 \cdot (O_2 + 3.76 \cdot N_2) \rightarrow H_2O + 1.88 \cdot N_2 \tag{3}$$

$$S + O_2 + 3.76 \cdot N_2 \rightarrow SO_2 + 3.76 \cdot N_2. \tag{4}$$

Based on the chemical reactions (1–4), the main flue gas components are carbon dioxide (CO_2), water (H_2O), nitrogen (N_2) and sulphur dioxide (SO_2). Typically, some carbon monoxide (CO) is also present due to incomplete combustion despite the excess air feed which can be seen in oxygen (O_2) content in the flue gas. By combining this information, the overall chemical reaction formula of combustion of multiple fuels ($k \in \mathbf{N}$) can be described as

$$\sum_k \left(r_{F,k} \cdot C_{x_k} H_{y_k} O_{z_k} N_{v_k} S_{w_k} \right)$$
$$+ r_{Air} \cdot (O_2 + 3.76 \cdot N_2 + \eta \cdot H_2O) + \gamma \cdot H_2O \rightarrow$$
$$b \cdot CO + c \cdot CO_2 + d \cdot H_2O + e \cdot O_2 + f \cdot N_2 + h \cdot SO_2, \tag{5}$$
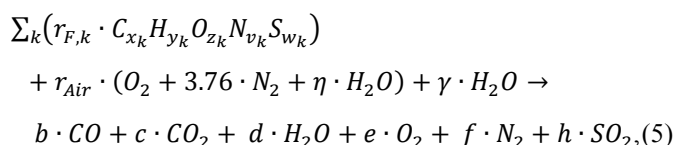
of which some of the symbols and indexes are described in Table 1 and 2, respectively. The parameters b, c, d, e, f, and h determine the molecular proportions of the flue gas, and their values are solved later in this section. Ashes, dust and unburned material are not stated in (5) but must be considered when measured and a priori information is converted to required form of (5). From (5), the element balance equations for C, H, O, N, and S, can be described, respectively, as

$$\sum_k (r_{F,k} \cdot x_k) - (b + c) = 0 \tag{6}$$

$$\sum_k (r_{F,k} \cdot y_k) + 2 \cdot r_{Air} \cdot \eta + 2 \cdot \gamma - 2 \cdot d = 0 \tag{7}$$

$$\sum_k (r_{F,k} \cdot z_k) + r_{Air} \cdot (2 + \eta) + \gamma$$
$$- (b + 2 \cdot c + d + 2 \cdot e + 2 \cdot h) = 0 \tag{8}$$

$$\sum_k (r_{F,k} \cdot v_k) + 2 \cdot 3.76 \cdot r_{Air} - 2 \cdot f = 0 \tag{9}$$

$$\sum_k (r_{F,k} \cdot w_k) - h = 0 \tag{10}$$

In (10) it is assumed that all the sulphur is reacted to SO_2. The validity of this assumption is process and process condition dependent, i.e. any SO_2 removal actions deteriorates this approach. However, this parameter can be omitted by setting w_k to zero.

From (5), the concentrations of O_2 and CO in the flue gas can be represented by molecular ratios

$$X_{O_2} = e/(b + c + d + e + f + h) \qquad (11)$$

$$X_{CO} = b/(b + c + d + e + f + h). \qquad (12)$$

The equations (11–12) can be fixed with the flue gas composition measurements by balances

$$X_{O_2,me} - X_{O_2} = 0 \qquad (13)$$

$$X_{CO,me} - X_{CO} = 0 \qquad (14)$$

which actually connects the balance equation (5) to reality.

By solving the equations (6–10) and (13–14) simultaneously while setting the other variables as parameters, the formulas for flue gas coefficients, i.e. parameters b, c, d, e, f, and h, and therefore flue gas composition and oxygen-to-fuel mole ratio r_{Air} can be calculated analytically. The analytical solution as such provides mathematically exact results, but the calculation results, however, are not necessarily correct due to incorrectness of input parameters and assumptions made when deriving the calculations.

2.2 Calculation of model input parameters

In this subsection, the input parameters needed to exploit the balance calculus are presented. The molecular flow of fuel k over total molecular fuel flow can be presented as

$$r_{F,k} = \dot{n}_{k,daf}/\Sigma_k \dot{n}_{k,daf}, \qquad (15)$$

where

$$\dot{n}_{k,daf} = \dot{m}_{k,daf}/M_k, \qquad (16)$$

in which $\dot{m}_{k,daf}$ can be calculated by reducing the respective fuel moisture and ash contents from the measured fuel mass flows. The molecular mass M of fuel k can be calculated by

$$M_k = x_k \cdot M_C + y_k \cdot M_H + z_k \cdot M_O + v_k \cdot M_N + w_k \cdot M_S. \quad (17)$$

The external moisture content that is fed to the boiler in the form of fuel moisture and steam from soot blowing system can be considered as

$$\gamma = \Sigma_k(r_{F,k} \cdot n_{H_2O,k}/n_{C,k}) + r_{steam}, \qquad (18)$$

where $n_{H_2O,k}$ is the molecular amount of water in 1 kg of moist fuel k and $n_{C,k}$ is the respective amount of carbon. Additionally, the r_{steam} stands for relative amount of soot blowing steam compared to total molecular fuel flow, which can be presented as

$$r_{steam} = \dot{m}_{steam,me}/(M_{H2O} \cdot \Sigma_k \dot{n}_{k,daf}), \qquad (19)$$

where $\dot{m}_{steam,me}$ stands for measured mass flow of steam fed to the boiler.

The air humidity can be taken into account by calculating the molecular ratio of air moisture to dry air by equation

$$\eta = (\varphi \cdot p_h')/(p_{tot} - \varphi \cdot p_h'), \qquad (20)$$

where φ is measured air moisture content, p_h' saturation pressure of water vapour in measured combustion air temperature, and p_{tot} measured pressure of moist air.

2.3 Model outputs: Combustion air

In this subsection, the combustion air estimates that can be generated based on element balance calculus are derived. The stoichiometric (st) air requirement of fuel k can be expressed as

$$r_{Air,st,k} = x_k + y_k/4 + w_k - z_k/2. \qquad (21)$$

Then, the overall excess air ratio can be calculated as

$$\lambda = r_{Air}/\Sigma_k r_{Air,st,k}. \qquad (22)$$

The dry air and air moisture mass flows can be calculated by equations

$$\dot{m}_{air,dry} = 4.76 \cdot r_{Air} \cdot M_{air} \cdot \Sigma_k \dot{n}_{k,daf} \qquad (23)$$

$$\dot{m}_{air,H_2O} = \eta \cdot r_{Air} \cdot M_{H_2O} \cdot \Sigma_k \dot{n}_{k,daf}, \qquad (24)$$

whose sum is the total moist air mass flow. Next, the mass flow can be converted to volume flow by multiplying it with relevant gas density derived from ideal gas law, i.e.

$$\rho_{gas} = p_{gas} \cdot M_{gas}/(R \cdot (T_{gas} + T_{NTP})). \qquad (25)$$

Finally, the volume flow of combustion air can be estimated by equation

$$\dot{V}_{Air,est} = \dot{m}_{air,dry}/\rho_{Air} + \dot{m}_{air,H_2O}/\rho_{H_2O}. \qquad (26)$$

2.4 Model outputs: Flue gas properties

In this subsection, the flue gas estimates that can be generated based on element balance calculus are derived. The main outputs of the combustion model are the flue gas compositions and flue gas volume flow. The flue gas composition can be solved from equations (13–14) and (27–30)

$$X_{CO_2,est} = c/(b + c + d + e + f + h) \qquad (27)$$

$$X_{H_2O,est} = d/(b + c + d + e + f + h) \qquad (28)$$

$$X_{N_2,est} = f/(b + c + d + e + f + h) \qquad (29)$$

$$X_{SO_2,est} = h/(b + c + d + e + f + h). \qquad (30)$$

Additionally, the mass flows (kg/h) of flue gas components can be calculated by equations

$$\dot{m}_{CO} = b \cdot M_{CO} \cdot \Sigma_k \dot{n}_{k,daf} \qquad (31)$$

$$\dot{m}_{CO_2} = c \cdot M_{CO_2} \cdot \Sigma_k \dot{n}_{k,daf} \qquad (32)$$

$$\dot{m}_{H_2O} = d \cdot M_{H_2O} \cdot \Sigma_k \dot{n}_{k,daf} \qquad (33)$$

$$\dot{m}_{O_2} = e \cdot M_{O_2} \cdot \Sigma_k \dot{n}_{k,daf} \qquad (34)$$

$$\dot{m}_{N_2} = f \cdot M_{N_2} \cdot \Sigma_k \dot{n}_{k,daf} \qquad (35)$$

$$\dot{m}_{SO_2} = h \cdot M_{SO_2} \cdot \Sigma_k \dot{n}_{k,daf}. \qquad (36)$$

The total flue gas volume flow (Nm³/h) can be calculated by

$$\dot{V}_{FG,est} = \sum_l \dot{m}_l / \rho_l, \tag{37}$$

where l includes CO, CO_2, H_2O, O_2, N_2, and SO_2.

2.5 Converting the estimates to measurement formats

Before comparing the derived estimates with respective process measurement information, the estimates must be converted to standard forms. These standard gas compositions are component specific. For H_2O, there is typically no conversion, so the estimate is valid as such, i.e.

$$X_{H_2O,est,norm}(\%) = 100 \cdot X_{H_2O,est}(-). \tag{38}$$

The O_2 is typically presented as volume concentration in dry flue gases according to equation

$$X_{O_2,est,norm}(\%) = 100 \cdot X_{O_2,est}(-) \cdot f_{H_2O}, \tag{39}$$

where

$$f_{H_2O} = 100 / \left(100 - X_{H_2O,est,norm} \right). \tag{40}$$

The other gas components are typically normalized to some reference O_2 content, i.e. $X_{O_2,ref}(\%)$. According to IED directive, the standardised O_2 content is 6 % for solid fuels, 3 % for combustion plants other than gas turbines and gas engines using liquid and gaseous fuels, and 15 % for gas turbines and gas engines. The O_2 normalization can be made

$$f_{O_2} = \left(20.95 - X_{O_2,est,norm} \right) / \left(20.95 - X_{O_2,ref} \right). \tag{41}$$

The CO_2 and N_2 proportions can be then normalized as

$$X_{l,est,norm}(\%) = 100 \cdot X_{l,est} \cdot f_{H_2O} \cdot f_{O_2}, \tag{42}$$

where l includes CO_2 and N_2. The rest of the estimated gases are typically presented in the form of mg/Nm^3, which can be achieved by equation

$$X_{l,est,norm} = \theta_l \cdot X_{l,est} \cdot f_{H_2O} \cdot f_{O_2}, \tag{43}$$

where l includes CO and SO_2 and θ_l stands for gas specific unit conversion coefficient.

The flue gas volume flows are typically normalized as

$$\dot{V}_{FG,est,norm} = \dot{V}_{FG,est} / f_{H_2O}. \tag{44}$$

3. ESTIMATION RESULTS

The theory presented in Section 2 was tested in an industrial installation. This section introduces the setup briefly and concentrates on estimation results.

3.1 Process description

The test process was an industrial 200 MW$_{th}$ BFB (Bubbling Fluidized Bed) boiler producing energy for a paper mill. The main fuels of the boiler are woody biomass, peat, bark and slurry. The woody biomass consists mainly of chipped logging residues, wood, stumps, and saw dust. The bark and slurry comes from the neighbouring paper mill. Roughly 2/3 of the slurry is primary waste and 1/3 biological waste from waste water purification process.

There are a 2000 m^3 storage for woody biomass, a 2000 m^3 storage for peat and a 5000 m^3 storage for bark at the site. The storages also stabilize fuel quality changes. After these storages, there are two parallel 100 m^3 fuel feeding silos before the boiler, which are fed from fuel specific storages and through a slurry flow line from the waste water treatment process. All the fuel mass flows are measured separately before the fuel feeding silos, and these measurements are used as model inputs. With typical fuel mixtures, the capacity of the silos provides some 30–40 minutes operation at full boiler load.

Emission monitoring system of the plant and respective measurements fulfil the requirements of LCP directive.

3.2 Trial run setup

There are four types of fuels involved in the process, i.e. wood, peat, bark and slurry. Table 3 presents fuel element compositions that are used in the calculations, which are taken from literature and fit within the ranges that are typically presented for such fuels. Fuel moisture contents are rough estimates of typical values at the plant, and these values also fit with the literature values. Fuel compositions and especially moisture contents, however, are known to vary to a significant extent from fuel batch to another, but the average values tend to remain somewhat stable primarily due to stabilizing effect of fuel storages. Therefore, all the values of Table 3 are kept constant during the estimation period.

Table 3. Fuel element compositions and moistures

Element composition (m-%, d.b.)	Wood	Peat	Bark	Slurry
C	49.8	53	57.5	45
H	6.4	5.5	7.1	5.75
S	0.05	0.2	0.05	0.05
N	1.45	1.7	0.5	0.4
O	41.8	34.1	32.35	28.8
Ash	0.5	5.5	2.5	20
Water	50	50	60	77

The estimations and subsequent calculations were carried out in Matlab© environment. These results were conducted off-line, but the calculations can as well be done on-line.

3.3 Estimation results

Next is presented estimation results in a case that lasted 1 000 hours. The time resolution of calculations was 1 hour. Fig. 1 describes the basic conditions during the period. Upper diagram points out the estimated fuel power during the period, which was calculated indirectly from steam power. The graph illustrates that fuel power was mainly some 50–75 % of boiler nominal capacity. Lower figure presents the estimated fuel power proportions of the four fuel feeds. It can be seen that woody biomass dominated the fuel feed, slurry flow was minor but stable and the peat and bark flows fluctuated to significant extent.
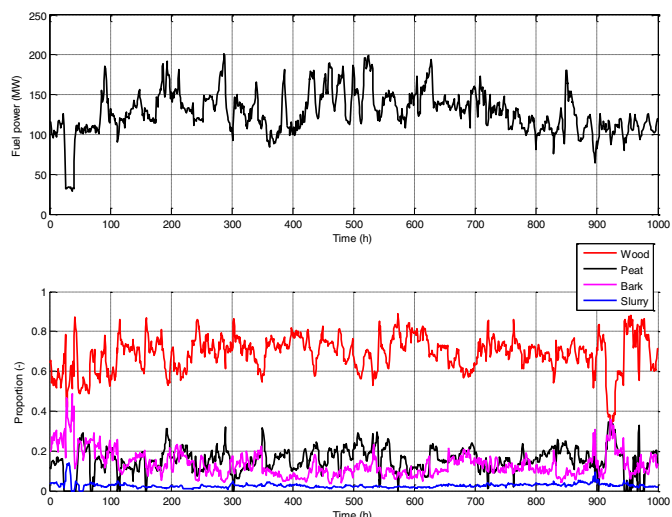
Fig. 1. Estimated total fuel power (upper) and proportions of fuel powers of total fuel power (lower).

Fig 2. illustrates flue gas O_2 and CO contents during the period. The raw measurements without compensations were fixed in equations (13) and (14). As the O_2 signal is uncompensated as such, the measured and estimated O_2 curves in Fig. 2 are the same. However, the measured and estimated CO signals differ slightly but to a noticeable extent due to errors in flue gas H_2O estimation that is used to compensate the CO estimate according to equation (40). Moreover, it can be seen that there is a significant raise in O_2 measurement at the beginning of the period which was caused by a process disturbance. The raise will affect the other estimates by oxygen compensation equation (41).

Fig. 3 and 4 demonstrate the estimation results. There, the flue gas moisture content compensations for estimated variables are calculated with use of flue gas moisture content estimate. Hence, an error in flue gas moisture content estimate will immediately disturb the other estimates accordingly. Fig 3. presents the measured and estimated air (upper) and flue gas (lower) flows.
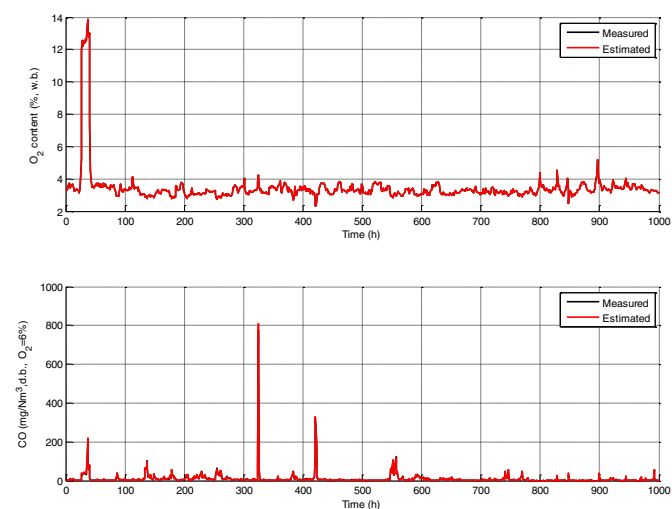

Fig. 2. Process measurements that are used as inputs in estimation calculus: O_2 (upper) and CO (lower).
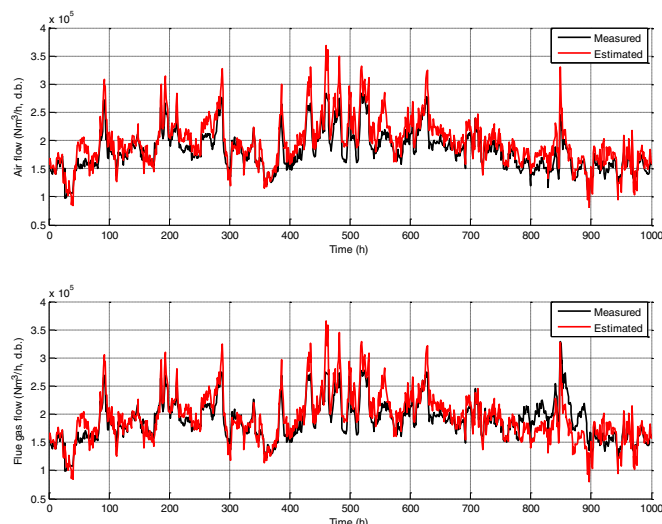

Fig. 3. Measured and estimated air (upper) and flue gas (lower) flows.
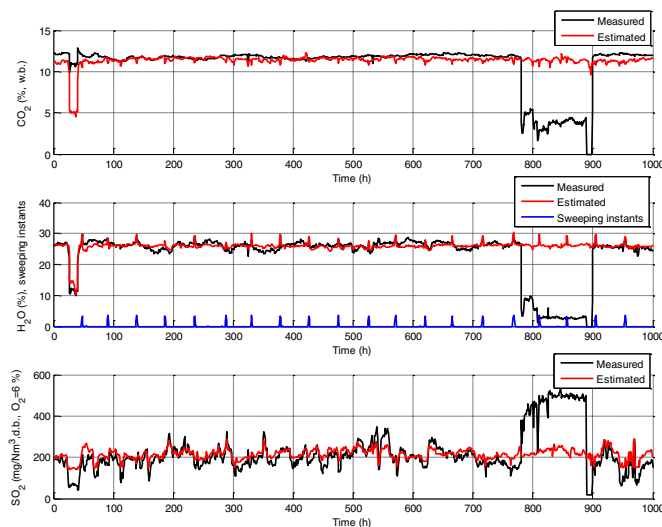

Fig 4. Measured and estimated flue gas CO_2 (upper), H_2O (middle) and SO_2 (lower) contents. Middle figure also shows time instants when steam assisted soot blowing was active.

It can be seen in Fig. 3 that the estimates fit quite well with the measurements. The most of the inconsistencies can be seen in both the air and the flue gas flows at the same time, which indicates that the actual fuel flows were different than measured. However, the similarity between air and flue gas flows is somewhat disturbed between time period 800–900, where the flue gas flow is significantly underestimated. The reason can be seen in Fig. 4, which demonstrates the measured and estimated flue gas contents, i.e. CO_2 (upper), H_2O in addition to boiler soot blowing instances (middle), and SO_2 (lower). There, the CO_2 and H_2O measurements drop significantly while the SO_2 peaks. This was caused by a failure in measurement device that provided the CO_2 and H_2O signals. As a result, the disturbed measurement signal also reflected to presented SO_2 signal via H_2O compensation. As can be seen, the estimates are likely to provide somewhat correct estimates also during the failure, which is highly beneficial from plant operation, diagnostics and emission reporting point of views. It should also be noticed, that the

estimations succeed to recognise the abnormal process behaviour at the beginning of the run by providing fairly correct estimates. This feature enables the plant operators to differentiate the sensor malfunctions and abnormal process behaviours.

4. DISCUSSION

The major benefit of the presented flue gas estimation model is that it enables to connect several measurements before and after the boiler to form an entirety, which enables on-line anomaly detection, sensor diagnostics and drifting prevention. These prospects can be achieved with any fuel combination, as long as fuel flows and their chemical compositions and moisture contents are known. The major drawback is that these values, i.e. fuel compositions and moisture contents, do change constantly. Fortunately, some of these changes can be recognised, as these effects are indicated in several variables. Additionally, the fuel storages stabilize fuel quality changes, but trends remain. Therefore, some adaptive feature would improve the performance of the proposed estimation model. On the other hand, fuel storages might also cause errors to estimates, as the volume changes in storages deteriorate the simultaneousness of measurement before and after the boiler. Indication of this behaviour can be seen when estimation errors in both flue gas and air flow estimates increase synchronously. This could also be taken into account by adding energy balance to the calculations.

It was pointed out that the presented estimation method is able to recognise process anomalies and sensor malfunctions. The sensor malfunctions can, however, occur also in sensors that provide inputs to the model. Additionally, the fuel element properties and especially fuel moisture contents might change. As the analytical solution provides mathematically correct results, the estimates satisfy the balances also with false information. As a result, all the estimates are incorrect with false input information. If the error in the input signal is significant, the disadvantageous effect can be seen as increased estimation error in several or all the estimated variables. False information in O_2 and CO measurements and fuel properties affect primarily the estimates about flue gas compositions whereas false information in fuel flows primarily disturbs combustion air and flue gas flow estimates. Still, the interpretation of results might require some expertise but the results indicate a change in some variables.

The estimates presented in this paper also benefit other emission variables (i.e. NO_x, HCl, etc.) which are typically monitored, presented, and supervised in normalized conditions by O_2 and H_2O compensations. Therefore, the monitoring of these compensation variables also increases indirectly the reliability of these reported emission measurements.

5. CONCLUSIONS

The need for monitoring is evident; process anomalies and sensor faults must be detected and identified. This paper presented a balance calculation method to estimate combustion air and flue gas flows and flue gas composition (CO_2, H_2O, SO_2, and N_2) in any over stoichiometric combustion environment having one or multiple fuels. Based on physical characteristics of combustion, the analytical solution provides interpretable results in various process conditions and low CPU requirement in computational environments. The method was tested in an industrial BFB boiler having wood, peat, bark, and slurry as fuels. The test results indicated the applicability of the method in this challenging process environment. Currently, the method is applied on-line at the power plant described in this article, and the method is to be applied at two boilers of a coal fired power plant and at a waste incineration plant in the near future. The method should, however, be further developed to adapt to significant fuel flow and especially fuel moisture content variations.

ACKNOWLEDGEMENTS

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