Environmental and energetic aspects of variable biomass quality fed to a steam boiler

***Miroslav Variny*[1,2]*, Otto Mierka*[1,2]**

[1]*Faculty of chemical and Food Technology, Slovak University of Technology, Radlinského 9, 812 37 Bratislava 1, Slovak republic*

[2]*GRUCON s.r.o., Nezábudková 24, 821 01 Bratislava 2, Slovak republic*

miroslav.variny@stuba.sk

Abstract

Combusted biomass in steam boilers in paper mills stems mainly from internal sources but it also may be purchased from outer ones, contributing to its variable moisture, composition and lower heating value (LHV). Available process data from an industrial application were processed yielding simple biomass LHV calculation estimation to help the online M&T purposes. This has not been possible in the past due to unreal LHV values obtained by laboratory analyses of biomass samples. We also paid attention to varying flue gas SO_x content that strongly influences the risk of flue gas duct low temperature corrosion that has been confirmed by inspection during boiler overhaul. Measures were proposed to eliminate its occurrence after the necessary low temperature flue gas duct part repair.

Key words: *biomass moisture, lower heating value, thermal efficiency, stack losses, low temperature corrosion*

Súhrn

Parné biomasové kotle v papierenskom priemysle spaľujú biomasu pochádzajúcu najmä z výrobného procesu (kôra, nekondičné štiepky, piliny...), avšak v menšej miere sa palivová biomasa môže nakupovať zvonka, čo prispieva k jej premenlivému zloženiu, vlhkosti a výhrevnosti. Analyzovali sme prevádzkové údaje z priemyselného biomasového parného kotla s cieľom získať jednoduchú koreláciu medzi nimi a aktuálnou dolnou výhrevnosťou biomasy. Získaná korelácia pomôže pri vyhodnocovaní aktuálnej tepelnej účinnosti kotla a na účely M&T, čo vzhľadom na nereálne hodnoty účinnosti po použití výhrevností zistených laboratórne nebolo doteraz možné. Merané zloženie spalín vykazuje značne premenlivý obsah SOx, práve kvôli meniacej sa kvalite spaľovanej biomasy, čo komplikuje prevádzku kotla s cieľom vyhnúť sa nízkoteplotnej korózii spalinového traktu. Táto bola pri obhliadke počas odstávky kotla potvrdená a navrhli sme opatrenia na jej spomalenie, resp. minimalizáciu jej opätovného výskytu po nutnej oprave nízkoteplotnej časti spalinového traktu kotla.

Kľúčové slová: *vlhkosť biomasy, dolná výhrevnosť, tepelná účinnosť, komínové straty, nízkoteplotná korózia*

Introduction

Biomass continues to play an important role in heat and power production both in industrial and residential sector. Large biomass fired steam boilers are traditionally found in pulp and paper industry [1, 2]. The power sector tests the possibility for biomass cofiring in coal boilers [3,4,5], or together with other kinds of fuels [2] however the economically acceptable share of cofiring does not exceed 20 % at present. Biomass can replace a part of fuel needs in other industrial sectors as well, for example as supplementary fuel in lime kilns [6], either by direct feeding of various sludges or using gas produced by biomass gasification [7].

Short and long term monitoring of boiler performance is very important when striving towards economically feasible boiler operation. Several techniques are implemented to reach this goal. Cafaro et al. [8] apply thermoeconomic method to analyze the decay of selected power plant key components performance over time. The obtained results allow for following trends over a time period of more than 500 days. Valero and Lozano present a similar study in [9], by applying fundamental approach to performance monitoring and costs assignment in a coal fired power plant located in Spain based on theory of exergetic cost. Analysis of several steady state operation data allowed them to identify the flue gas recuperator as a piece of equipment with the most significant performance decay, with exiting flue gas temperature above 200 instead of around 150 °C and leaking air. If the fuel composition varies significantly even over shorter time period, online fuel quality analysis is necessary to be conducted to proceed with any boiler or power plant performance studies.

SOx emissions from steam boilers and other industrial devices (furnaces…) directly impact their safe operation area regarding low temperature corrosion [10-12], as their flue gas content even in a few ppms rises its dewpoint by tens of °C. Verhoff [10] and Banchero [11] presented decades ago simple equations that can be used for a quick dewpoint estimation in praxis. Ibler [12] provides dewpoint charts for various fuels and air excess values. The study by Ciukaj and Pronobis [5] provides analysis of flue gas dewpoints from boilers co-combusting coal and biomass in Czech republic and Poland, the reported flue gas dewpoint rise compared to water vapor dew point reached almost 90 °C. We documented the impact of neglecting the low temperature corrosion risk in an anthracite calcination process study [13] where it led to extensive corrosion of flue gas fan and stack. For steam boilers, the study [1] recommends that “it makes more sense to preheat the feed water to close to the acid dew point before it enters the economizer. This allows the economizer to be designed so that the flue gas exiting the economizer is just barely above the acid dew point.” For situations with varying fuel quality and sulphur content preheating the water to varying temperatures may become problematic and usually “a somewhat higher flue gas temperature is acceptable to provide an extra safety margin”.

Keeping all those issues in mind we decided to conduct a performance study of an industrial biomass fired steam boiler, fed by biomass with variable composition to demonstrate the impact of such situation on boiler operation reliability and efficiency.

Biomass boiler and the related cogeneration unit layout

The object of our study is an industrial 100 MW_t steam boiler located in a paper mill in Slovakia. Its layout together with the RES-based cogeneration unit is depicted in **Fig. 1**. Apart from biomass, natural gas is used in the boiler as supplementary fuel in power burners, ensuring the temperature in the combustion chamber stays above certain minimum value when combusting low quality biomass. In extreme cases the NG consumption exceeds 50 MW_t. Frequent changes in biomass quality put stress on boiler operators; boiler automation is only on moderate level so the operators have to adjust the combustion air flow and NG to power burners flow manually, often multiple times per hour, seeking both for efficient boiler operation and for keeping NO_x and CO emissions below upper environmental limits.

Biomass quality is estimated by sampling and laboratory analysis once per one or two weeks. Obtained data can thus neither be used for reliable long term boiler thermal efficiency estimation nor for operational analyses and Monitoring and Targeting purposes. Applying the laboratory lower heating value data to monthly or yearly balances one gets a wide unrealistic spread of boiler thermal efficiencies, ranging from 70 up to 110 %. A simple easy to be used operational biomass lower heating value estimation procedure is thus needed to ensure reliable and economically feasible boiler operation and to help the plant technologist in balancing procedures, including correct estimation of produced steam price.

As a frequent measure in large steam boilers, combustion air is preheated to above 200 °C in rotary regenerator, utilizing waste heat content of flue gas leaving the boiler, thus reducing fuel consumption and increasing boiler thermal efficiency. Originally the cold ambient air should pass firstly through a steam preheater to ensure a certain minimum temperature of air entering the regenerator in order to prevent low temperature corrosion occurrence on flue gas side. The steam preheater broke down in 2012 and since then cold air passes to regenerator without preheat. Boiler operators confirmed that since then the flue gas to stack temperature dropped from around 200 to around 150 °C, thus seemingly increasing the boiler thermal efficiency (and saving steam to steam preheater which has been considered as an excellent steam saving measure at that time). However the flue gas dewpoint when combusting sulphur-containing fuels often exceeds 150 °C and such situation may lead to extensive regenerator and stack corrosion if continuing for longer time. Thus we also concentrated on this issue, striving to verify the initial assumption of corrosion risk by flue gas dewpoint range estimation and proposing measures to remedy this situation.

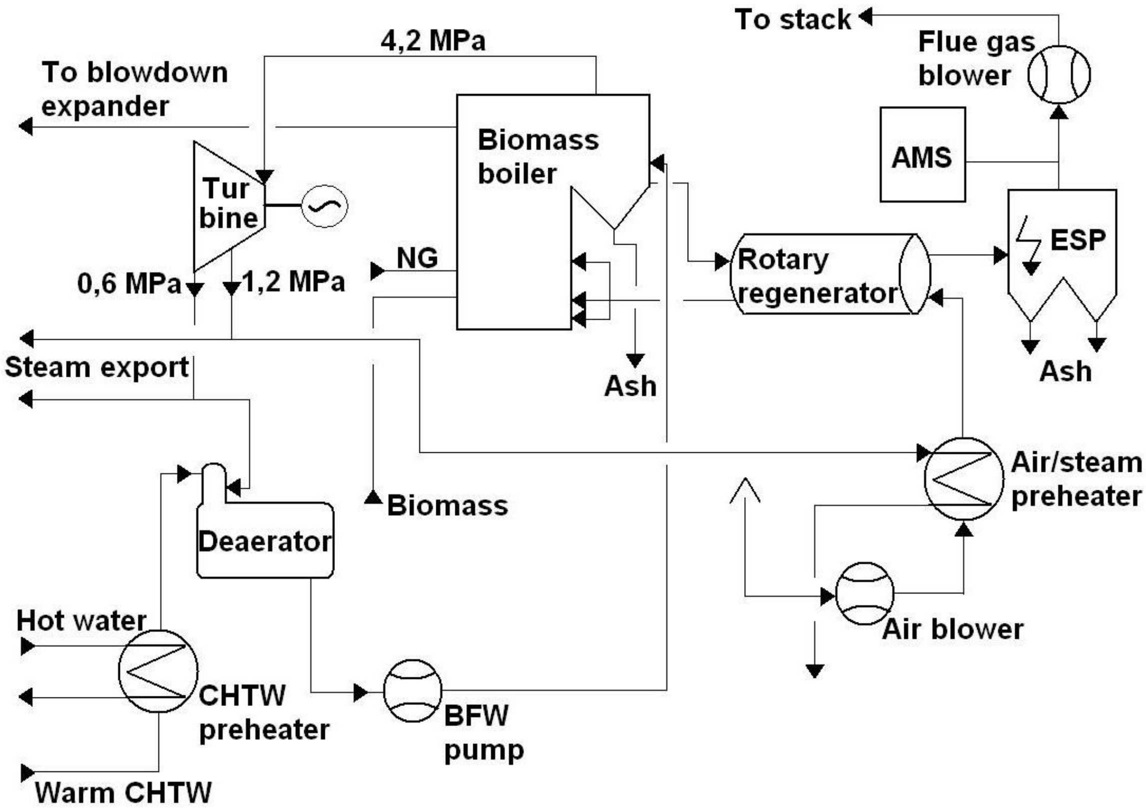

Figure 1 Schematic depiction of the RES-based cogeneration unit understudy

Available process data and calculation model

Outputs of process sensors incorporated in the calculation model include following:

- mass flow of combusted biomass, boiler feedwater and produced steam
- volumetric flow of NG to power burners; that of combustion air and flue gas
- temperature of ambient air, air after steam preheater, produced steam and flue gas to stack
- pressure of produced steam
- oxygen content in flue gas measured above combustion chamber
- oxygen, CO and SO_x content in flue gas to stack (AMS) on dry basis

Any online data characterizing biomass quality are missing. Initial estimates subject to iterative calculations thus include biomass moisture and hydrogen content. Due to the lack of any process data, fix oxygen content of 45 % wt. in biomass combustible matter has been assumed. Ash from boiler has been considered for simplicity as inert which, on our request, has been confirmed by laboratory thermogravimetric analysis. Other assumptions relating to boiler heat balance are as follows:

- constant natural gas composition and LHV
- constant ambient air moisture
- 1,5 MW as fix radiation heat losses from boiler surface
- 18,95 GJ/t as constant value of dry biomass combustible matter LHV

Balancing and calculation procedure is depicted in **Fig. 2**. It includes two iterative cycles leading to successive hydrogen and water content in biomass estimation that in turn impacts the biomass LHV and boiler thermal efficiency in the end. The calculations also yield among other results the flue gas dew point values. The mentioned calculation procedure has been applied to process data in form of one hour averages available for appr. 1,5 year period. Results for shorter periods with stable boiler operation have been graphically processed and are shown and discussed in the next chapter.

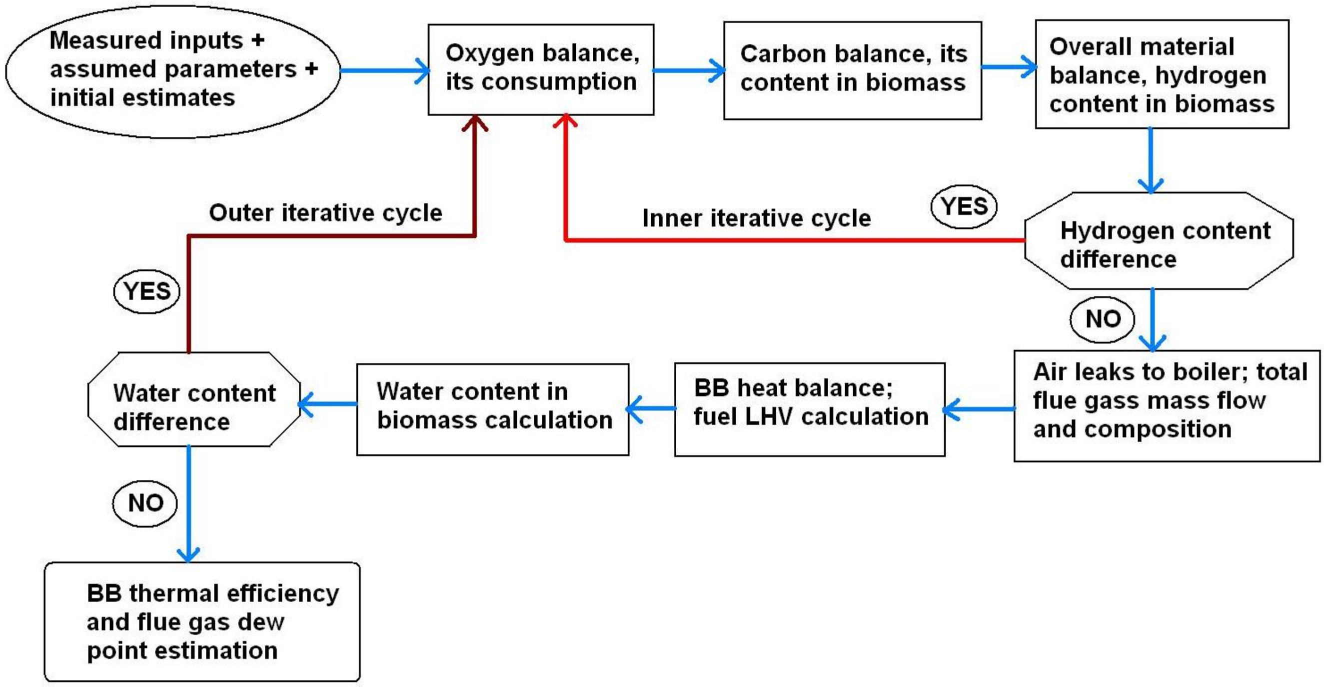

Figure 2 Calculation procedure

Results and discussion

The priority of performed calculations was to formulate a simple relationship between online values of combusted biomass LHV and actual values of process variables. On obtaining the biomass LHV it has been plotted against the relative combustion air to biomass mass low ratio and the result is shown in **Fig. 3** with the combustion air mass flow being recalculated to oxygen content in wet flue gas of 4,5 % vol. The idea behind was simple: the drier the biomass is the higher is its LHV and also more combustion air is needed to combust one ton of such biomass. Thus, some relationship between those two parameters must exist. As can be seen in that figure, the data trend is almost linear and can be fitted with linear relationship (1) without significant loss of accuracy.

$$LHV = -0{,}33 + 1{,}668.\frac{\dot{m}_{air}}{\dot{m}_{biomass}} \quad [GJ/t] \tag{1}$$

Such relationship can, in our opinion be used more generally, for hardwood based biomass that is combusted with appr. 40 % air excess (corresponding to 4,5 % oxygen content in wet flue gas). For higher or lower air excess it will deliver incorrect values but via simple material balance the air mass flow can be recalculated to given range and thus correct LHV value is obtained.

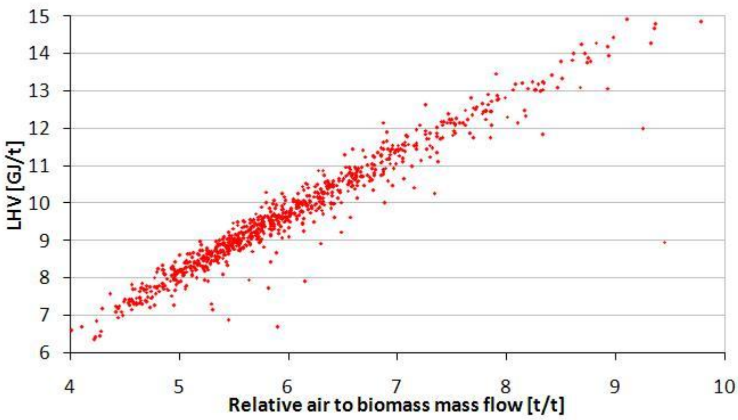

Figure 3 Biomass LHV trend

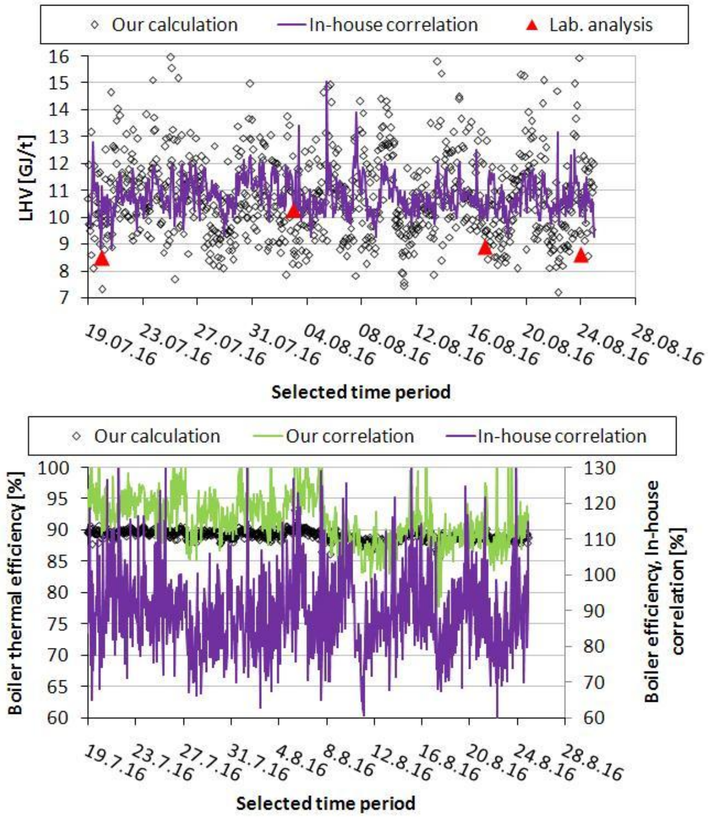

Figure 4 Comparison of biomass LHV and boiler thermal efficiency obtained by our calculation model, by model fitting with linear LHV relationship and by in-house correlation

The boiler technologist developed an alternative method for online biomass LHV estimation, based on correlation of rotational biomass feeders speed that further will be referred as "in-house correlation". Available process data included the biomass LHV resulting from the in-house correlation, so we could compare the results of our calculations with those data as well as with (scarcely available) LHV estimated by laboratory analysis. Such comparison is shown in **Fig. 4**. Obviously, the laboratory LHV values in the selected time period tend to lie below both our and in-house correlation data and lead to boiler thermal efficiencies around or above 100 %. Boiler thermal efficiency data resulting from the LHV in-house calculation tend to vary in a wide interval (70 to 110 %) that in our opinion makes the in-house correlation less trustworthy.

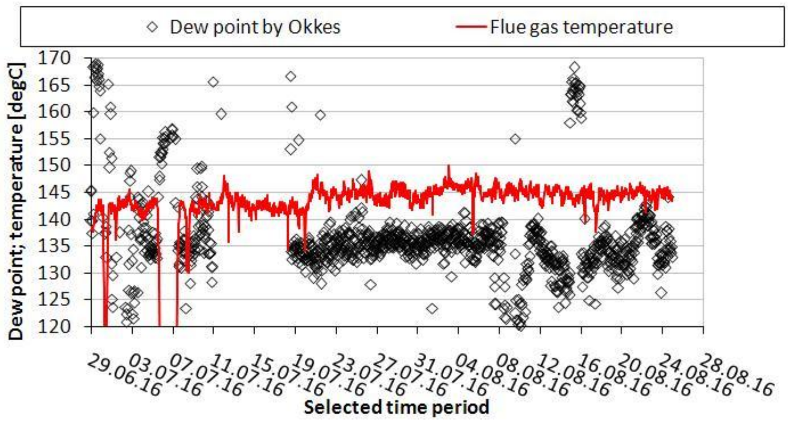

Figure 5 Calculated flue gas dew point vs. flue gas to stack temperature

On the other hand, data resulting from using the relationship (1) indicate a quite narrow and reasonable boiler thermal efficiency interval of 85 to 95 %. We believe the relationship (1) can be further improved; however it is questionable whether it would contribute to LHV estimation preciseness since there are some doubts about the correctness of biomass mass flow measurement. Thus we recommended the plat operators to stick with (1) at the moment since it represents a significant improvement in actual LHV estimation and to return to (1) and refine it only after this issue has been dealt with.

Attention has been paid to flue gas dew point estimation, using process data from flue gas automatic monitoring system and calculation procedure by Okkes [11]. Resulting data are depicted in **Fig. 5**. Frequently appearing dew point values of 135 °C correspond to SOx content in the flue gas of appr. 5 to 10 ppm. The depicted time period represents the trends during the analyzed 1,5 year period well – most of the time the estimated dew point is lower by around 10 °C than the flue gas to stack temperature, but short periods occur where it is otherwise. It must be said that even with dew point lower than flue gas temperature there is some risk of low temperature corrosion on the cold end of recuperator. In a situation where cold air is led to the recuperator without preheat the recuperator wall temperature is lower by several tens of °C than that of flue gas and it is exactly there where the weak acid from flue gas will condense. Safe boiler operation requires combustion air preheat prior to recuperator to at least 60 °C, preferably to at least 80 °C – a measure that is a standard in refinery furnaces and boilers combusting sulphur containing gaseous or liquid fuel as well as in coal boilers. The existence of severe recuperator corrosion has been later confirmed by visual inspection during boiler overhaul.

In order to ensure future safe boiler operation, following measures were recommended:

- immediate recuperator repair
- immediate repair of steam air preheater; alternatively replacing it by hot water heater as hot water is available in excess in the given paper mill
- identification of high sulphur content biomass source and either eliminating it from biomass fed to the boiler or combust it at certain regular intervals that allows the boiler operators to adjust air preheat to higher temperature in before

Incorporation of waste heat for air preheat instead of steam improves the boiler operation economics and should therefore be economically attractive for plant managers. Estimated installation costs including auxiliaries amount to 600 ths. euro and the resulting single payback period calculated solely from steam saving lies around 7 years.

Conclusions

Analysis of variable quality biomass fed steam boiler has revealed significant negative impact of such situation on boiler performance estimation possibility and operation reliability. Variable biomass moisture and lower heating value disables the online boiler M&T as laboratory LHV analyses are scarce and the in-house developed online LHV correlation does often yield unreal boiler thermal efficiencies. One of the results of our calculations is a simple actual biomass LHV estimation relationship using available boiler process data and its superiority above the laboratory and in-house LHV estimation has been sufficiently proven. Another issue relates to boiler operation reliability that is threatened by severe low temperature corrosion of the boiler rotary regenerator. As analyzed, current state cannot be changed and low temperature corrosion will occur again even if the regenerator undergoes repair, unless the air steam preheater is set into operation again. As an alternative, air preheater utilizing hot water instead of steam can be installed; replacement of steam by cheap hot water heat leads to financial savings and contributes to future sustainable preheater operation.

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