The influence of co-firing of biomass on heating surfaces in coal fired boilers in PGE Energia Ciepła S.A.Power Plant in Kraków

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Abstract

This work describes the slagging and fouling problem in boiler OP-380 related to biomass co-combustion in PGE Energia Ciepła Power Plant in Kraków. Examination period last 206 days and starts on 19.06.2014 till 23.01.2015. Biomass was co-fired with coal on average level of 23% by weight, and fuel was mix of agro-biomass: pellet from sunflower husk (87%) and pellet from herbaceous residues (13%). The main parameter which have been analyzed to determine progress of slagging and fouling process was heat load of boiler OP-380 parts. Following elements were examined: I^{st}, II^{nd} and III^{rd} level of primary and secondary steam superheaters, evaporator and feed-water preheater. Furthermore, temperature and pressure of flue gases were analyzed. Work consist photography of damages on heated surfaces. Final result indicate that most damages (90%) done during biomass co-firing are caused by steal oxidation (overheat) of pipes material. Overheat is a result of slagging and fouling of I^{st} and II^{nd} level secondary steam superheaters which takes over less heat as their should. For that reason to keep output parameters of secondary steam, more heat must be provided into the boiler. In consequence, other elements takes over more heat as it is necessary. Rest of damages are result of aggressive compounds in flue gases, such as alkali compounds. Moreover, investigation point out that co-burning biomass on level 15-20% do not have direct influence on corrosion damages of superheaters. However, increasing share of biomass in feedstock up to 40% provoke occurrence of corrosion damages on wider scale.

Keywords: *coal, biomass, co-firing co-combustion, slugging, fouling, corrosion, power plant.*

1. Introduction

One of the main sources of energy used for electricity generation is coal which is responsible for approximately 40% of the total power produced globally. Moreover, as it is well known, coal-fired power plants are major sources of CO_2 emission that contribute to anthropogenic climate change. Coal is a source of 9538 (TWh/year) of energy [1]. It is hardly to imagine source of power so huge to cover those needs. All types of renewable technology have their limits and disadvantages (Table 1). To be more precise, electricity generation from renewable sources nowadays is on the level of 21.1% in which 16% is hydro energy (excludes electricity generation from pumped storage). However, capacity of energy produced from water is on minor level. Other renewables include geothermal, solar, wind, tide/wave/ocean, biofuels, waste and heat combined together giving 7.1% of worldwide electricity generation. Electricity is moreover produced from natural gas (22.9%), nuclear power (10.6%) and oil (4.1%) [1].

Table 1. Advantages and disadvantages of renewable energy sources, adapted from [2]

Renewable energy source	Advantages	Disadvantages
Passive solar	No fuel costs, renewable, non-polluting	Only works in daylight, not efficient when clouds present, power output is low
Photovoltaic solar	No fuel costs, renewable, non-polluting	Only works in daylight, not efficient when clouds present, power output is low, high initial costs, energy needs to be stored
Hydro-electric	No fuel costs, renewable, non-polluting	Need correct location, changes in the environment, destroy ecosystems and can displace people, expensive to construct
Wind	No fuel costs, renewable, non-polluting	Need a windy location, environmental noisy, high maintenance costs due to metal stress and strain
Wave	No fuel costs, renewable, non-polluting	High maintenance due to the power of waves, high establishment costs
Biomass	Produces less harmful greenhouse gases, can be sustainable, can be used for different purposes	Takes a lot of space, not entirely clean, expensive, not easily transported

Nothing indicates drastic changes in terms of fuel usage for power generation. Renewable energy sources are eco-friendly but from economical point of view they appear much worse. Most of the existing power plants were built to produce electricity from anthracite or lignite. Furthermore coal is very well distributed on our planet which allows many countries to be producers and users simultaneously. It is also energy safety guarantor. Coal can deliver energy at a cost of between $1 and $2 per MMBtu compared to 6 to 12 per MMBtu for natural gas and oil [3] which gives the first place for cheapest energy source. Especially United States (246.643 Mt), Russia (157.010 Mt), China (114.500 Mt) and India (94.445 Mt) have enormous coal reserves [4]. Is it possible to co-fire biomass with those huge amounts of coal on global scale? What are advantages, disadvantages and why people are interested in co-combustion of biomass?

It is assumed that with binding law regulation in Poland, prices of electricity and financial mechanisms the most favored sources of renewable energy is biomass. Mainly residual wood from wood industry, but also cultivation of fast growing energy crops, agricultural or food industry residuals or biogas [5]. Biomass is seen as a highly flexible resource which can increase energy source diversification. Furthermore already existing power plants are suitable for burning biomass and those which are not, can be easily adapted for it. The main objective of this work is to study slagging and fouling process during biomass co-fire in boiler OP-380 (scheme on Fig.1) installed in PGE Energia Ciepła S.A. Power Plant in Kraków and find solution to avoid this issue.

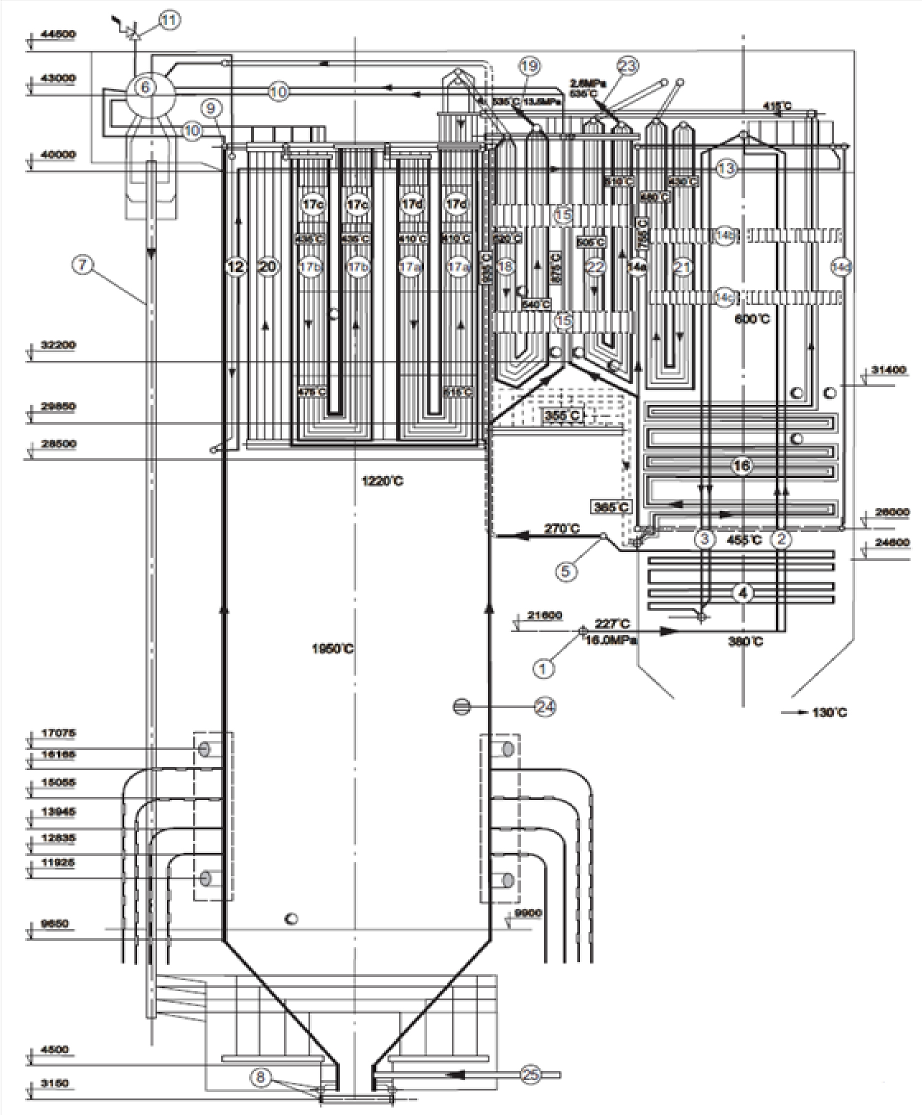

Figure 1. Scheme of boiler OP-380, adapted from [6]

Elements description		
1. Feed water inlet	11. Steam drum safety valve	17. Fence IInd superheater
2. Rising rack pipes	12. Fresh steam wall superheater	18. End IIIrd superheater
3. Down falling rack pipes	13. Ceiling superheater	19. Outlet of fresh steam to the turbine
4. Heating coil pipe	14. Fresh steam Ist superheater	20. Secondary steam wall superheater
5. Outlet chamber of water heater	a. Front wall of IInd course	21. Secondary steam middle superheater
6. Steam drum	b. Side walls of IInd course	22. Secondary steam end superheater
7. Down falling pipes	c. Side walls of IInd course	23. Outlet of secondary steam
8. Lower screen chambers	d. Back wall of IInd course	24. Air inlet (OFA nozzle)
9. Upper screen chambers	15. Side superheaters of middle course	25. Exhaust gases recirculation inlet
10. Connecting pipes	16. Convection superheater	

1. Co-firing technology

Co-firing or co-combustion, is the process in which two types of fuel are burned in the same boiler [7]. Despite that many types of fuel can be mixed, upper mentioned terms are mostly related to the burning of coal with solid biomass. The number of fuel types used together is not limited. The greatest advantage of co-firing is that already existing power plants can be used to co-combustion new mixture. In many cases new fuel is more environmental friendly and cheaper in the same time, for example agricultural residues. Often biomass is co-fired in already existing coal-fired power plants instead of building new blocks. Co-firing advantages [8]:

- Considering that co-burning is realize in already existing coal-fired power plants, implementation can be achieved in short time and with low investment cost.
- Rural areas can gain economically benefits from the production of biomass.
- According to European Union Legislation biomass is CO_2 neutral, thus biomass co-combustion will not increase greenhouse effect and help reduce global CO_2 emission.
- Co-firing of biomass allows obtaining subsidies in countries where government offers them for replacing fossil fuels with clean technologies.
- Usually biomass fuels have fewer sulfur and nitrogen content than coal, hence emissions of SO_x and NO_x are reduced.
- Landfilled biomass residues are one of the main sources of greenhouse gases, methane which is released during rotting is 21 times more potent as carbon dioxide in terms of global warming impact [7].
- Co-combustion is one of the most efficient way to utilize biomass in power industry. Average efficiency of biomass power plant is in the 20 to 25% which is almost half lower for the considerable coal units. In the same time biomass co-firing at a 3-5% (w/w) causes a decrease in boiler efficiency less than 1% [7].

2. Description of boiler OP-380 from PGE Power Plant in Kraków

Table 2. Boiler OP-380 parameters, adapted from [9]

Parameter	Value
Circulation	Natural
Furnace type	Tangent
Maximum efficiency	105.6 (kg/s)
Temperature of fresh steam (outlet)	540 (^oC)
Pressure of fresh steam (outlet)	13.9 (MPa)
Temperature of secondary steam (outlet)	540 (^oC)
Pressure of secondary steam (outlet)	2.65 (MPa)
Temperature of feed water	227 (^oC)
Boiler efficiency	91%
Fuel type	Hard coal
Fuel Heating value	21 (MJ/kg)

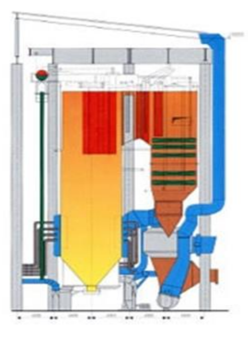

Table 2 show general parameters of boiler OP-380. Boiler OP-380 was produced by RAFAKO S.A. (PBG Group). Data was collected from coal fired boiler OP-380 with steam output of 105 (kg/s) which is equal to 380 (t/h). Boiler has two-courses shape with tight packed membrane walls. Circulation of working medium occurs in natural way. Feedstock is coal which is introduced by four mill sets.

1. Methodology

Method of determination ratio of heat transfer and theoretical value of heat transfer

To define slagging and fouling of given heat surface element, necessary is to find value of theoretical thermal load for this element. Comparing obtained value with real thermal load it is possible to determine level of slagging and fouling given part. Theoretical value is determined by using temperature flue gases coefficient, whereas to compare both values of thermal load the coefficient of heat transfer is used.

Temperature flue gases coefficient and theoretical thermal load

Temperature flue gases is ratio between real flue gases temperature on intermediate superheater or before convectional superheater (depends on analyzed element) and nominal temperature based on mass flow of agent flowed by given heated surface. It is correction coefficient for nominal thermal load, which is dependent only on mass flow of agent. If flue gases temperature increase on intermediate superheater and before convectional superheater, that indicate about decreased heat transfer by working substance, which is caused by slagging and fouling of boiler. From that reason temperature flue gases coefficient is implemented, by given formula:

$$\varphi_{fg,i} = \frac{T_{r,i}}{T_{n,i}} \quad (-)$$

$\varphi_{fg,i}$ – flue gases temperature coefficient i, (–),

$T_{r,i}$ – real temperature of flue gases, (K),

$T_{n,i}$ – nominal temperature of flue gases, (K).

Theoretical thermal load of heated surface include impact of changing mass flow agent as well as influence of changing flue gases temperature in the middle course for thermal load of given element. This value is equal to thermal load, with which device should work in given conditions and furthermore it is template used to calculate heat transfer coefficient. Equation:

$$Q_{t,i} = \varphi_{fg,i} \cdot Q_{n,i} \quad (kW)$$

$Q_{t,i}$ – theoretical thermal load of element i, (kW),

$\varphi_{fg,i}$ – flue gases temperature coefficient i, (–),

$Q_{n,i}$ – nominal thermal load of element i, (kW).

Heat transfer coefficient:

Heat transfer coefficient is percentage ratio of real thermal load of this element to theoretical value of temperature load calculated by taking into account mass flow agent amount and temperature coefficient. He allows to determine percentage difference of thermal load between real value occur in real time and theoretical value which should occur in given conditions (agent mass flow and flue gases temperature). Coefficient of heat transfer is defined by formula:

$$\xi_i = \frac{Q_{r,i}}{Q_{t,i}} \cdot 100\% \quad (\%)$$

ξ_i – heat transfer coefficient of element i, (%),

$Q_{r,i}$ – real thermal load of element i, (kW),

$Q_{t,i}$ – theoretical thermal load of element i, (kW).

3. Results and discussion

4. Conclusions

The effect of biomass co-firing on slagging and fouling of heated surfaces in boiler OP-380 installed in PGE Energia Ciepła S.A. Power Plant in Kraków have been presented in this work. Main parameter which was analyzed was heat load. Correlation between slagging process and decreased parameter of heat load has been described. The following elements of the boiler were taken into account: feed-water heater, evaporator, primary steam Ist level superheater, primary steam IInd level superheater, primary steam IIIrd steam superheater, secondary steam Ist level superheater, secondary steam IInd level superheater, secondary steam IIIrd level superheater.

To verify used methodology and determine changes of amount of exchanged heat three examination periods were set: reference period, early phase of slagging and fouling and final phase of slagging and fouling. Quantity of exchanged heat was dependent on boiler exploitation time and boiler technical condition.

Biomass co-firing is a technology used worldwide. Mostly it is applied in power plants designed for coal burning, not for biomass co-combustion. Slagging and fouling process is common and exist in industry. To prevent from damages of superheaters parts caused by overheating, there must be designed system which warn power plants operators long before critical temperatures. That may be obtain by set of following states of heat transfer coefficient: acceptable, alert and critical; for each boiler part. With mentioned system overheats could be easily reduced by implementation of response of soot blowers in alert states. Optimization of soot blowers work is very important since economic reasons. However, there are limitation of that solution. After continuously biomass co-firing, at some stage, slagging and fouling process is so expanded that soot blowers cannot deal with contaminations. Then unit must be stopped and cleaned mechanically. For the boiler OP-380 the service break occurred after 7 months.

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