REDUCTION OF NO_X EMISSION BY SECONDARY-AIR REDISTRIBUTION

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ABSTRACT

Till the beginning of 2008 NOx emission limit value for large solid-fuel-fired furnaces was 650 mg/m3. Since the beginning of 2008 it was lowered to 600 mg/m3 for large furnaces from 50 MW to 500 MW fuel-energy input. Since the beginning of 2016 only 200 mg/m3 of NOx will be allowed in flue gas emitted from furnaces between 300 MW in 500 MW of fuel-energy input. This level of NOx emissions can in most cases be attained by combination of primary and secondary measures for NOx reduction. NOx formation is targeted by primary measures while secondary measures are used for NOx removal from flue gas.

The goal of the paper is to present the enhancements of primary measures on boiler 3 of Power plant Ljubljana. This enhancements cover redistribution of secondary air between respective burner nozzles. Currently the redistribution enabled operation of boiler 3 with emissions below the future limit value of 200 mg/m3.

POVZETEK

Do konca leta 2007 je v Sloveniji mejna emisijska vrednost NOx za velike kurilne naprave na trdna goriva znašala 650 mg/m3, od začetka leta 2008 naprej 600 mg/m3 za velike kurilne naprave z vhodno toplotno močjo od 50 MW do 500 MW. Od začetka leta 2016 dalje bo v dimnih plinih velikih kurilnih naprav med 300 MW in 500 MW na izstopu v ozračje smelo biti le še 200 mg/m3 NOx. Tako nizke emisije iz kotlov na trdna goriva je mogoče doseči s kombinacijo primarnih in sekundarnih ukrepov za redukcijo emisije NOx. S primarnimi ukrepi se omejuje nastajanje NOx pri zgorevanju, sekundarni ukrepi pa obsegajo postopke za izločanje NOx iz dimnih plinov oziroma denitrifikacijo.

Tokratni prispevek je namenjen predstavitvi nadgradnje primarnih ukrepov na kotlu 3 Termoelektrarne Toplarne Ljubljana, ki zajema prerazporeditev sekundarnega zraka med posamezne šobe gorilnikov. Trenutno so z omenjeno nadgradnjo in pod določenimi ostalimi pogoji emisije NOx kotla 3 že pod bodočo mejno emisijsko vrednostjo.

1. INTRODUCTION

Boiler 3 was put into operation in 1984. It produces 270 t/h of superheated steam at a pressure of 95 bar and a temperature of 535 ° C. Imported brown coal is used as fuel with calorific value of about 19 MJ/kg and wood-chips. The boiler has four mills. Each mill is preparing coal dust and blows it into the furnace through three burner nozzles. Due to the relatively high quality of coal and addition of grate for wood-chips co-firing most of the time two mills are in operation while two are in reserve.

Before year 2000 combustion air was supplied only to the burners of mills that were operating. The air was divided into the primary air for cooling mills, secondary air, which was supplied below and above the burners and tertiary air that was injected into the boiler hopper. Only flows of primary and secondary air were measured.

In year 2000 the original burners were replaced by more modern-design burners allowing for better mixing of combustion air with coal dust. From then on secondary air is fed to each burner nozzle respectively. Its flow can be distributed among nozzles with manual dampers. Above the burners over-fire air was added.

Due to the installation of grate for co-firing of wood mass, which can supply up to 25% of input energy to the boiler, hopper-air supply needed to be modified. Since the hopper air is used also for cooling the grate it is evenly distributed throughout the horizontal cross section of the furnace. Measurements of hopper-air flow were installed.

In 2012 coal dust distribution measurements were added to the coal-dust ducts and motor-driven dampers for secondary-air distribution to burner nozzles. Motorized dampers show to be a substantial step forward in optimization of secondary air distribution. Air distribution among burner nozzles now automatically adjusts to the distribution of coal dust.

Since the beginning of 2016 only emissions of 200 mg/m^3 of NO_x will be permitted for large combustion facilities with fuel-energy input between 300 MW and 500 MW. Considerable effort is done to reduce the NO_x emissions below this threshold by employment of primary measures. In this way large investment in de-NO_x reactor could be avoided.

2. NOX FORMATION IN COAL-DUST FIRING SYSTEMS

NO accounts for about 95% of all nitric oxides referred to as NO_x. There are three main mechanisms of NO formation [1]: thermal NO, prompt NO and NO formed from nitrogen components contained in the fuel.

During coal dust combustion these three processes are not equivalent. The results of previous research show that the nitrogen content in coal affects the concentration of nitrogen oxides in flue gases. Coals containing 1% nitrogen compared to coals containing 2% nitrogen cause about 50 % lower NO_x emissions. It turns out that during coal combustion gaseous compounds are the main source for nitrogen oxides formation. Nitrogen bound in the gaseous compounds is more prone to oxidation than nitrogen which is bound in the solid structure of coal. Nitrogen content in volatile compounds of coal is a very important fact from the point of view of NO_x emissions. Larger share of volatiles which is characteristic for bituminous coals does not directly cause increased emissions of NO_x. The impact is only indirect because the greater amount of volatiles leads to higher flame temperature which first forces more nitrogen to vaporize and then promote the oxidation of nitrogen contained in the fuel and also of nitrogen contained in air. If conditions are very unfavorable up to 50% of nitrogen from gaseous compounds in the coal may be converted to NO.

The actual amount of nitrogen oxides from gaseous compounds is actually related to the way air and fuel are mixed, to the distribution and level of flame temperatures and to the stoichiometric combustion conditions. NO formation from in nitrogen compounds contained in coal is lower in fuel rich conditions. NO formation is also reduced by the presence of other nitrogen compounds due to other chemical reactions and N_2 formation. While in this mechanism flame temperature is not so important as the it is during the formation of thermal NO it is nevertheless necessary to avoid flame-temperature peaks.

Conditions established in the furnace after employment of primary measures for reduction of NOx emissions are in contradiction with optimal-combustion conditions. Side effects are expected to emerge [2]: increased content of unburned matter in ash and slag may appear, superheated steam temperature may drop, exiting flue gas temperature may increase, increased corrosion and flame instability may occur etc.

After primary measures for reduction of NOx emissions are employed other measures to limit or eliminate side effects may be also unavoidable.

3. COMBUSTION AIR DISTRIBUTION SYSTEM OF BOILER 3

Currently combustion air is fed to the boiler at three respective locations. Reasons for this are explained in the following paragraphs.

3.1 Air for wood-chips combustion

Screw conveyor speed determines the wood-chips mass flow fed to the boiler. From screw conveyor wood chips drop onto the chain conveyor and then into the funnel-shaped opening on top of air duct. Wood chips are then blown into the furnace. Speed of air at wood-chips nozzle needs to be sufficient to carry the wood chips over the furnace to the opposite wall where they fall on the grate. The grate is moving towards the wood-chips nozzle. Grate air is divided to three zones: drying, combustion and post-combustion. Air flow for each respective zone can be controlled separately.

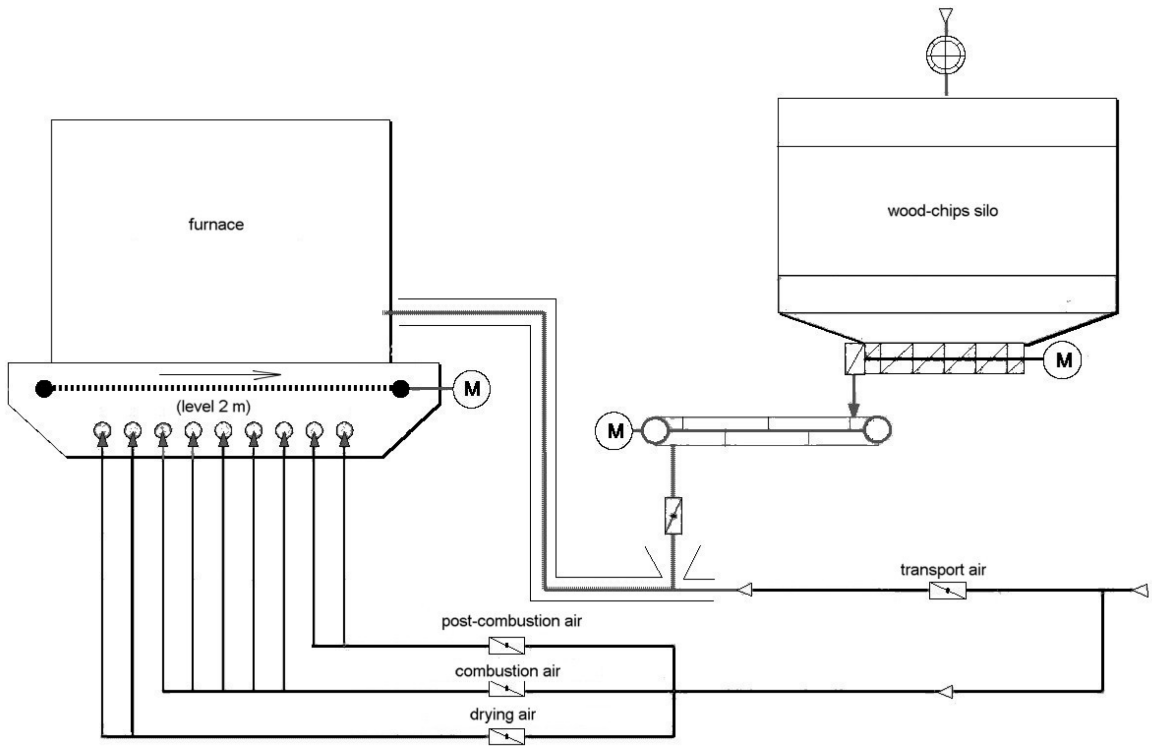

Figure 1: Wood-chips-combustion air for

Grate supplier did not provide detailed instructions regarding air-flow for respective grate zone. Therefore air flows needed to be determined by trial and error procedure. Excessive air flow caused small wood particles to fly through the furnace not having time to burn completely. On the other hand if there was not enough air wood chips and unburned coal particles did not burn completely on the grate. Before the grate installation unburned coal particles (slag) fell directly to water below the hopper causing excessive boiler losses.

3.2 Air for coal-dust combustion

Burner nozzles are located at 14 m to 16 m level of the furnace. Air for coal combustion is divided to primary and secondary air.

Before employment of primary measures for reduction of NO_x emissions primary air was used for cooling coal mills. Therefore its mass flow used to be was much bigger than nowadays. Primary air promotes thermal NO_x formation since it enters the furnace mixed with coal dust and causes excessive flame temperatures. If addition of air is gradual flame temperature is lower and NO_x formation is reduced. Due to this mechanism cold recirculated flue gas (CRFG) is now used for cooling coal mills.

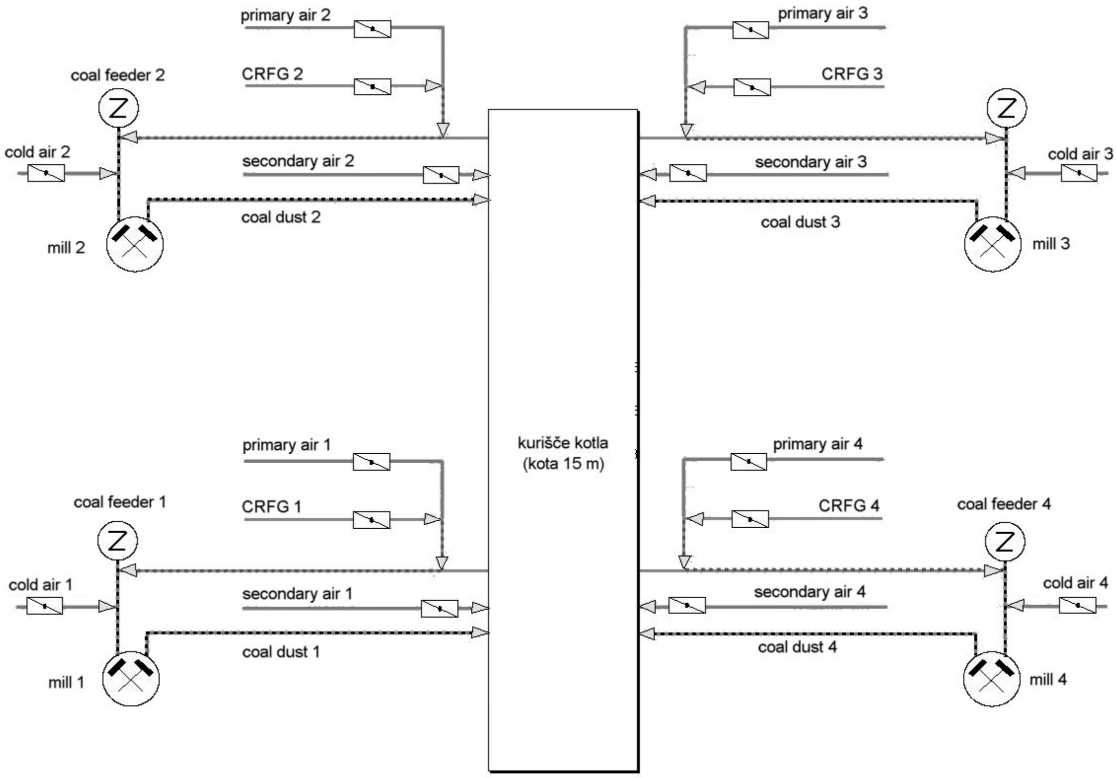

Figure 2: Combustion air for coal

Secondary air enters the furnace through the outer ring of each burner nozzle (Figure 3) and surrounds the coal dust that enters the furnace through the core of the burner.

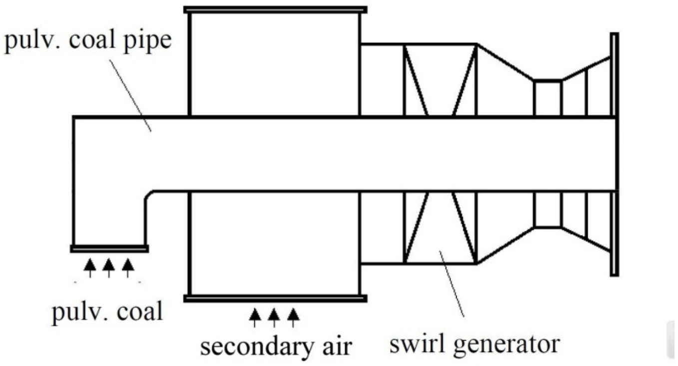

Figure 3: Burner nozzle

Calorific value of currently used imported coal is higher than calorific value of coal that was originally used. Besides wood-chips cofiring provides additional energy input. Due to these facts most of the time only two coal mills are in operation while two remain in reserve. Burner nozzles coupled to mills that are not in operation can be used for combustion air supply if necessary. Therefore there are many different air distribution options available and our task was to find the optimal one.

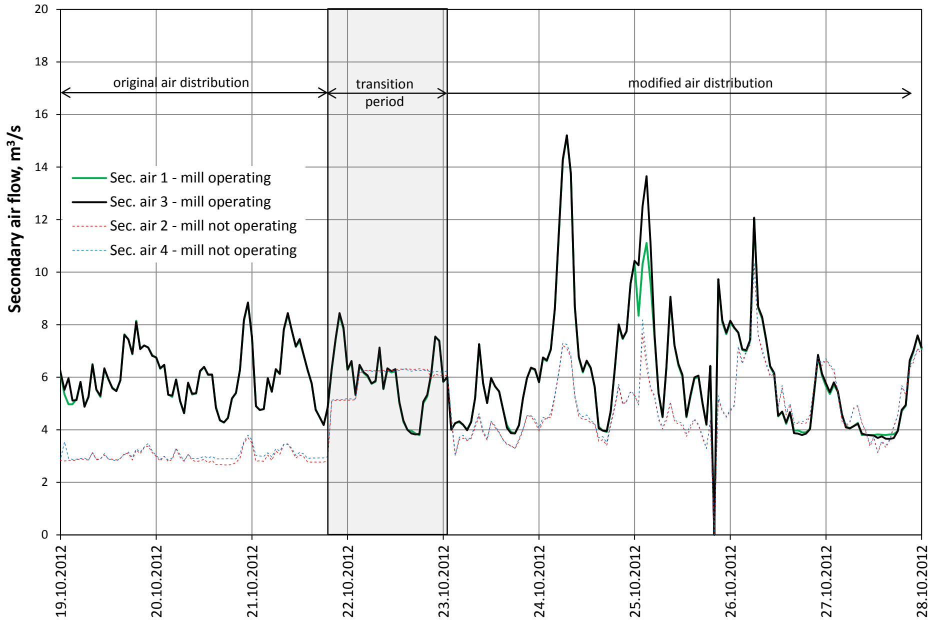

Figure 4: Transition to new secondary air distribution

Before and after the modification of secondary air distribution total secondary air flow is proportional to total coal-feeders' load. To illustrate the modification of secondary air distribution period from October 19 to October 28 2012 is presented (Figure 4). Graph is divided to three periods: period with original secondary air distribution, transition period and period with new secondary air distribution. Originally majority of secondary air was fed to burners coupled to mills in operation. After the transition period secondary air flow to burners coupled to mills out of operation was gradually increased while air flow to burners of operating mills was gradually decreased.

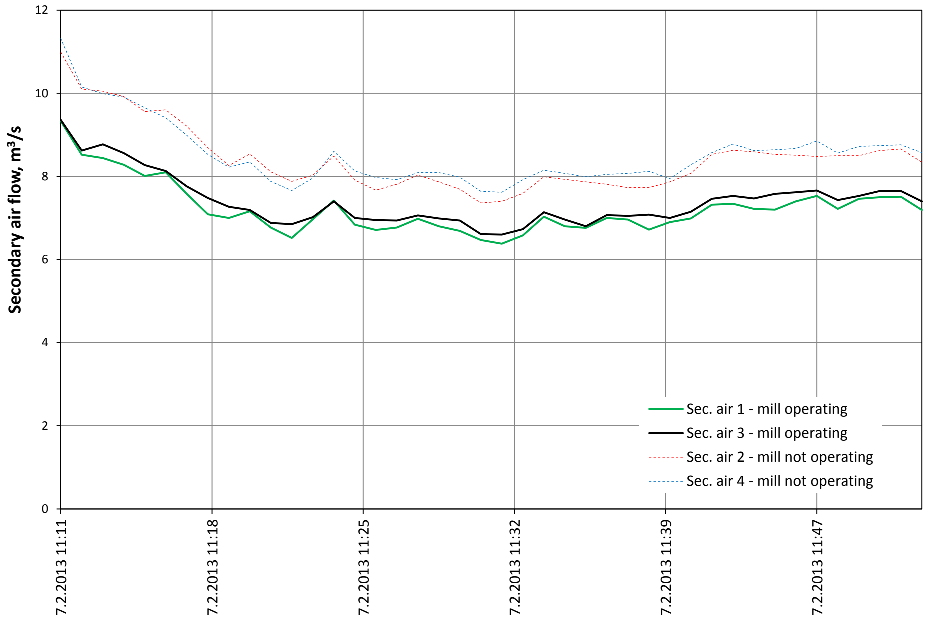

Figure 5: Current secondary air distribtion

Currently non-operating burners receive even more air than operating burners which is shown on Figure 5 (February 7 2013). Majority of air enters through the upper burner nozzle to increase the air velocity and penetration into the flame.

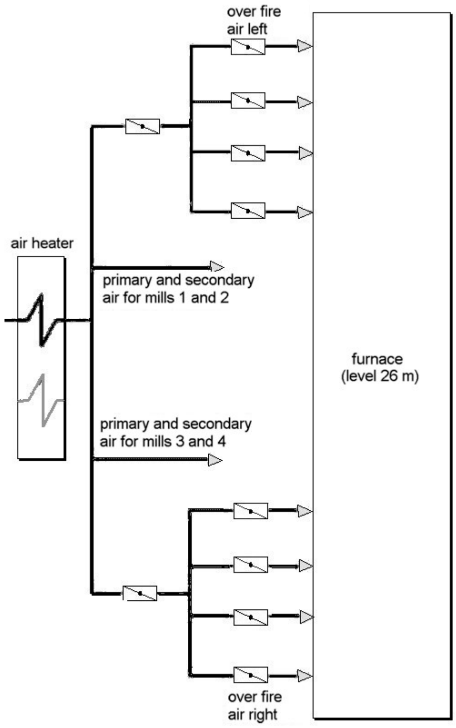

Figure 6: Over-fire air

Approximately 10 m above upper burner nozzles over fire air (OFA) is fed to furnace through eight nozzles: four located on the left and four on the right side of the boiler. OFA flow for each boiler side is measured and can be controlled from control room. Each of eight nozzles can be open or closed respectively. During next summer stoppage modification of OFA fire air distribution system is planned to further optimize the combustion and decrease NO_x emissions.

4. MONTHLY EMISSIONS OF NOX

Figure 7 shows monthly NO_x emissions of boiler 3 from February 2012 to February to February 2013. Boiler was out of operation from the beginning of June till the end of September. It is evident that the level of NO_x emissions after the stoppage is significantly lower than before the stoppage. Since monthly NO_x emissions are dependent on average boiler load the most relevant comparison can be done if the same months of different years are compared. In February 2012 monthly NO_x emissions were 304 mg/m^3 while in February 2013 they were only 211 mg/m^3, almost one third or 100 mg/m^3 lower.

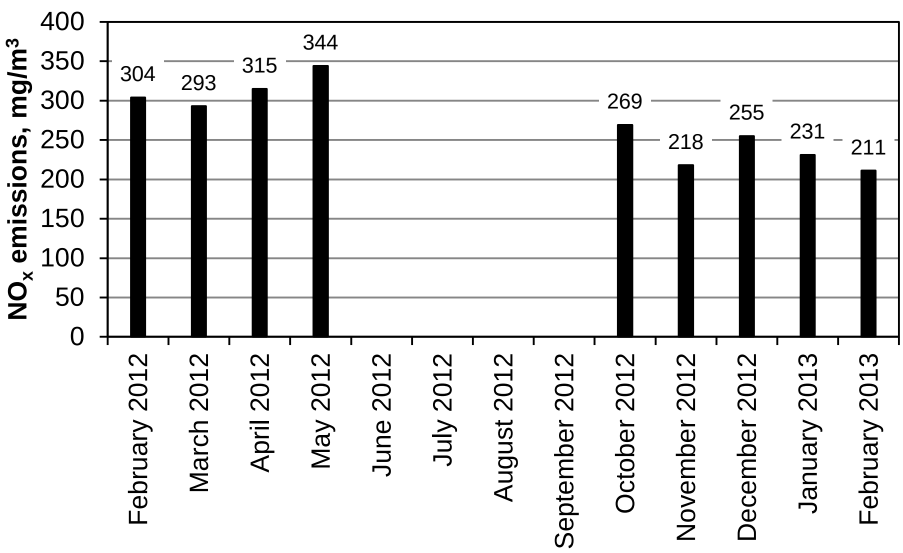

Figure 7: Monthly NO_x emissions

5. CONCLUSION

By optimizing the firing systems of existing solid-fuel fired furnaces including fuel choice, fuel preparation and combustion system redesign fuel energy can be exploited in more efficient manner and emissions of harmful gases can be reduced to levels that seem to be reachable only by employment of the most sophisticated solutions used in new furnaces.

6. LITERATURE

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