HARMFUL EFFECTS OF AIR LEAKAGE INTO PULVERISED-COAL FIRED BOILER

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ABSTRACT

The paper presents the reasons and consequences of uncontrolled air on the operation of steam boilers with dust firing i.e. combustion of coal crushed into powder. This type of combustion is more advanced than the combustion of solid fuels of larger granulation. It enables achieving higher output and efficiency. Several conditions must be fulfilled to enable quality combustion. One of these conditions is the optimum fuel to air ratio. This condition can be met if good control over the allocation of combustion air to the burner nozzles is possible. Usually it is possible to achieve from the perspective of installed measurement and control equipment but a major obstacle to this is an entry of uncontrolled air into the boiler. This makes it impossible to maintain optimum conditions for quality combustion.

POVZETEK

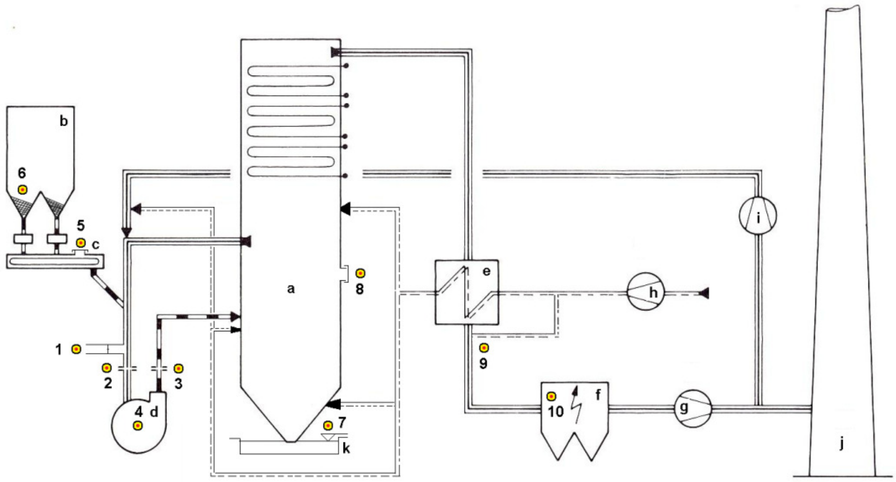
V prispevku so predstavljeni vzroki in posledice nenadzorovanega vdora zraka v kotel. Obravnavani so parni kotli s premogovo prašno kurjavo oziroma zgorevanjem trdnih goriv zmletih v prah. Prašna kurjava z zgorevanjem v prostoru je naprednejša od zgorevanja v plasti ali na rešetki. Omogoča doseganje večjih toplotnih moči in višjih izkoristkov kotlov. Za kvalitetno zgorevanje mora biti izpolnjeno več pogojev. Eden od pogojev je optimalno razmerje goriva in zgorevalnega zraka. Ta pogoj je mogoče izpolniti v primeru dobrega nadzora nad razporejanjem zgorevalnega zraka med gorilnike oziroma šobe gorilnikov. Večinoma je s stališča vgrajene merilne in regulacijske opreme to možno izvajati, vendar veliko oviro pri tem predstavlja nenadzorovan vdor zraka v kotel, zaradi katerega je količina nadzorovanega zraka manjša. To neposredno onemogoča vzpostavitev optimalnih pogojev za zgorevanje.

1. INTRODUCTION

Periodical tests of steam boilers with pulverised-coal firing in Slovenian power plants have led to many interesting and useful insights. Uncontrolled air intrusion into any furnace or burner has always a negative connotation though it is not always clear why. The remainder of this paper is to present some of these negative impacts in the case of steam boilers with pulverised-coal firing.

2. EVENTUAL AIR-LEAKAGE LOCATIONS

Oxygen is always needed for combustion. In most cases oxygen contained in surrounding air is used. Mixing of air and fuel should be made in a controlled manner and the air ratio should be kept as optimal as possible. Ideally all the air needed for combustion should be supplied in a controlled manner with no uncontrolled intrusion or leakage of air into the boiler. Due to the fact that steam boilers in thermal power plants are usually very large it is difficult to ensure absolute tightness. There are always locations where uncontrolled air penetrates into the boiler. Boilers' manufacturers assume that 10% to 20% of air enters in an uncontrolled manner. Figure 1 shows a simplified scheme of a steam boiler with some auxiliary equipment. Locations of possible air leakage are marked.



	Steam boiler and attendant machinery		Locasions of uncontroled air intrusion
a	steam boiler	1	air flap for fresh-air mill colling
b	coal hopper	2	joint of mill casing, inlet side
c	coal feeders	3	joint of mill casing, outlet side
d	coal mills	4	mill's gates and other clearances in the housing
e	air heaters	5	inspection openings on feeders housings
f	electrostatic precipitators	6	too low level of coal in the coal hoppers
g	induced draft fans	7	too low level of sealing water at boiler's hopper
h	forced draft fans	8	inspection openings in the furnace and flue gas ducts
i	cold gas recirculation fans	9	poor air heaters sealing
j	stack	10	electrostatic precipitator housing and flue duct joints

Figure 1: Simplified scheme of a steam boiler with auxiliary equipment

3. EFFECTS OF AIR LEAKAGE

3.1 Air leakage into the furnace and flue gas duct

3.1.1 Increased stack loss

Combustion control maintains the oxygen content in flue gas at a predetermined level related to the boiler's load. Oxygen measurement is located in the flue gas duct just before the air heater. If the air leakage occurs in the furnace or the flue duct before oxygen measurement, boiler control reduces the controlled-air supply. Combustion air is heated in air heaters using the flue-gas heat. If due to air leakage controlled-air flow is reduced, flue-gas temperature at air-heater exit and stack loss are increased.

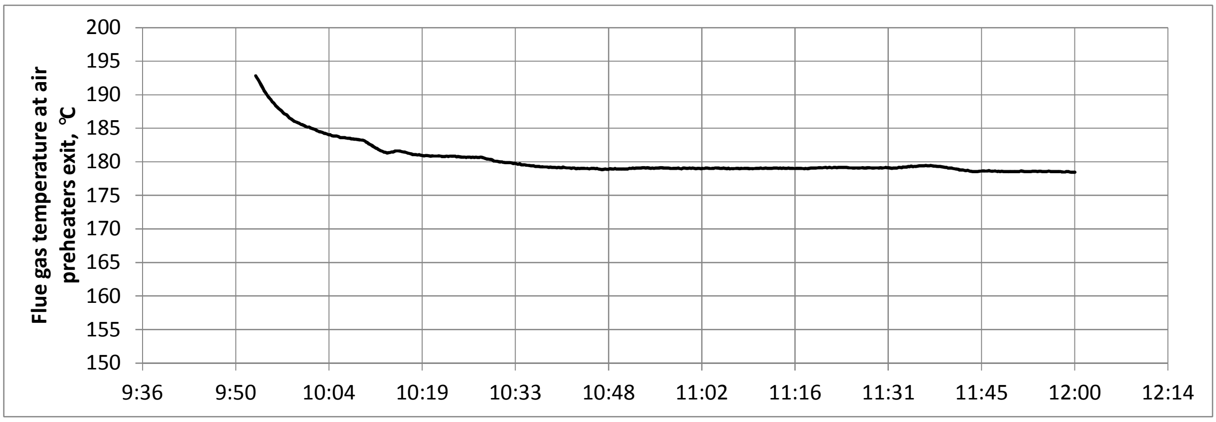


Figure 2: Flue gas temperature at air-heater exit

The diagram in Fig. 2 shows flue gas temperature after the air heater. Temperature record was made after closing the mill gate. Prior to closing the gate was open due to mill outage [1]. Before the start of recording flue gas temperature was exceeding 200 °C. After closing the mill gate the temperature stabilized below 180 °C. A similar effect is caused by air leakage at any location from 1 to 8 indicated in Fig. 1. Increase in temperature of flue gas depends on the extent of air leakage, which is further dependent on the size of the opening and the pressure difference between the ambient pressure and pressure inside the device. Locations where the most extensive leakages occur are on the suction side of the mills (Fig. 1, locations 1, 2, 4, 5, 6) since there is a maximum difference between the ambient pressure and inside pressure. Leakage-air temperature depends on location and is always relatively low (20 °C to 50 °C) compared to the temperature of air exiting the air heater (200 °C to 300 °C). Due to its low temperature the uncontrolled air has a high density. Mass flow rate of uncontrolled air can thus be large and may have unexpectedly large impact on boiler operation.

3.1.2 Increased loss due to unburned substances in ash and slag

Combustion air must be mixed with fuel in a controlled manner at predefined moment and location [2], [3], [4]. Certain conditions need to be met to ensure complete combustion: adequate temperature, proper concentration of oxygen and other reactants, sufficient duration of these conditions for fuel particle to complete the combustion. Boilers with pulverised coal firing have extremely large furnaces. Volume of the furnace can exceed 50000 m^3 (e.g. dimensions 23×23×95 m). Combustion of coal dust is divided into several phases. Each phase of has its own requirements. If they are not met the loss of unburned substances in the slag and fly ash are increased. Consequently the boiler's efficiency is deteriorated. Fuel may not burn completely due to inadequate conditions for combustion caused by air leakage into the boiler. The reason for increased loss by unburned substances may, besides air leakage, also be fuel particle size, fuel composition, etc.

3.1.3 Increased emissions of CO and NO_x

Primary measures for reduction of NO_x emissions focus on staging of the combustion air supply [5]. To achieve low NO_x emissions the combustion air should be supplied gradually and in a controlled manner into the furnace. Primary air is mixed with fuel particles before entering the furnace and that is why it easily reacts with them. Heat formation during combustion is very intense if there is a lot of primary air. Consequently the high flame temperature is causing excess formation of thermal NO_x [4], [6]. Any air leakage at locations 1 to 6 (Fig. 1) increases primary air flow and promotes the formation of thermal NO_x.

On the other hand, a lack of oxygen in some locations in the furnace promotes the incomplete combustion i.e. increases CO emission.

3.2 Air leakage in air heater and electrostatic precipitator

3.2.1 Air heater

Air leakage in the air heater has no influence on the combustion. It affects the power plants efficiency due to increased power consumption of forced and induced draft fans. Due to air leakage larger quantities of air and flue gas need to be transported. In some extreme cases forced draft fans need to operate full power all the time. Up to 50 % of air supplied by forced draft fans may migrate into the flue gas due to air leakage in the air heater. Induced draft fans therefore need more power to transport this unnecessary amount of flue gas mixed with air through the electrostatic precipitator, desulphurisation unit and stack. Air leakage may occur even in well-sealed air heaters if the difference between the air and flue gas pressure is excessive i.e. if the pressure of combustion air is too high.

3.3 Electrostatic precipitator

Air leakage into the flue gas duct and electrostatic precipitator also has no effect on the combustion itself and boiler efficiency. But it causes increased power consumption for induced draft fans and therefore affects overall plant efficiency. This location is not very common but it can occur due to poorly sealed openings in the precipitator housing or due to wear of precipitator housing material.

4. MODELLING EFFECTS OF AIR LEAKAGE

To illustrate the effects of air leakage at various locations of the boiler software package IPSEPro 5.0 was employed. Results of modelling are shown in Fig. 3.

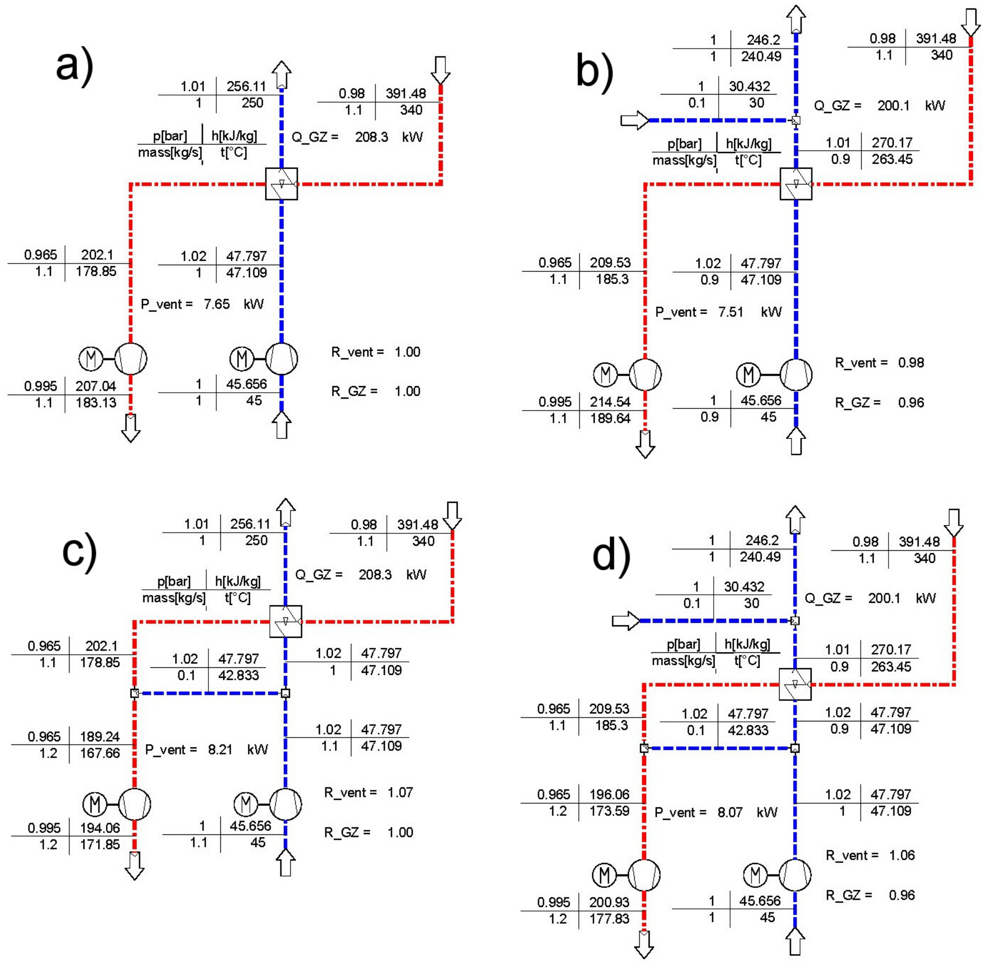


Figure 3: Modelling uncontrolled air leakage

Type of leakage	Rel. heat flow in air heater	Rel. fan power
a) no leakage	1,00	1,00
b) air leakage in furnace	0,96	0,98
c) air leakage in air heater	1,00	1,07
d) air leakage in air heater and furnace	0,96	1,06

In the model each leakage represents 10 % of the total combustion air. The impact on fans power consumption and heat recovery in air heater is presented with ratios R_vent and R_GZ. In example d, which is the worst case scenario, air is leaking into the furnace as well as into the air heaters. In total 20 % of combustion air enters the boiler in an uncontrolled manner. Recovery of heat from flue gases is reduced by 4 %. At the same time the consumption of power for driving fans is increased by 6 %.

5. CONCLUSIONS

Laboratory for Heat and Power at the Faculty of Mechanical Engineering cooperates with Slovenian thermal power plants for decades. Cooperation consists of monitoring, maintaining and improving the efficiency of their operation. Plants and their main components incuding steam boilers are tested periodically. Sometimes deteriorated performance of steam boilers was detected with no obvious reasons. More detailed analysis of the results often revealed that the anomalies were associated with the combustion air.

Air leakage adversely affects the efficiency of the boiler and power plant. It also causes increased emissions of harmful gases CO_2, CO and NO_x. Measures to avoid and prevent air leakage are in most cases relatively cheap while having significant financial and environmental effects.

6. REFERENCES

[1] KUŠTRIN, Igor, SEKAVČNIK, Mihael, SENEGAČNIK, Andrej, MORI, Mitja. Thermal Tests of 125 MW Unit: Operation Optimization: Power Plant Trbovlje (December 2011). Ljubljana: Faculty of Mechanical Engineering, 2012 (Slovene text).
[2] Smoot L. D. (editor), Fundamentals of coal combustion, Elsevier, Amsterdam, 1993.
[3] Rayaprolu K., Boilers for power and process, CRC Press, New York, 2009.
[4] Joos F., Technische Verbrennung, Springer, Berlin, 2006.
[5] Hill S.C., Smoot D., Modeling of nitrogen oxides formation and destruction in combustion systems, Progress in Energy and Combustion Science, vol. 26, 2000, pp.417–458.
[6] Ribeirete A, Costa M. Impact of the air staging on the performance of a pulverized coal fired furnace. Proceedings of the Combustion Institute, 2009; vol. 32(2), pp.2667–73

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