SIMPLIFIED COMBUSTION-AIR FLOW CONTROL

Igor Kustrin
igor.kustrin@fs.uni-lj.si
Janez Oman
janez.oman@fs.uni-lj.si
Faculty of Mechanical Engineering, University of Ljubljana

Abstract: The described method can be applied whenever a damper or valve is used for controlling the fluid flow. Usually separate devices are used for measuring and controlling the flow: for example pressure differential device for measuring and damper or valve for controlling. Two examples of controlling combustion-air flow for a coal-dust fired steam boiler show how, with sufficient accuracy, dampers can be used for both. In large scale units such an approach reduces investment costs due to avoiding the need for expensive measuring equipment and improves the reliability of air flow control due to avoiding the usual problems with clogging of the impulse lines or problems with poor calibration of differential pressure transmitters.
Keywords: Combustion, Damper, Reliability, Differential pressure, Control

1. INTRODUCTION

In cooperation with Faculty of Mechanical Engineering of Ljubljana one of Slovene power plants (PP1: 232 MWth, 124 MWe) introduced effectively this method on two coal fired steam boilers while the other plant (PP2: 125 MWe) is planning to introduce it. Details of both examples are presented in the paper.

In order to use a damper for a measuring device the relation between the air flow and the openness of the damper must first be determined. It can be done by means of a reference measurement: for example Pitot tube or any other kind of pre-calibrated tube or probe. The relation between volume flow and openness or position of a damper depends on type and size of a damper as well as on design of the driving mechanism. Besides the openness of the damper, the air pressure and temperature measurements are needed for accurate mass flow calculation.

2. DESCRIPTION OF FIRING SYSTEM

In 2003 and 2004 PP1 upgraded firing systems of two steam boilers. Boilers were erected in 1967 and equipped with obsolete firing systems producing NO_x emissions of about 550 to 750 mg/m^3. There are four coal pulverizers per boiler. Two or three are in operation while one or two remain in reserve.

Figure 1- Old and new burner nozzles

During the reconstruction old nozzles (Fig. 1: left) were replaced with new Low-NO_x nozzles (Fig. 1: right). Now there are only two round nozzles per burner instead of three rectangular nozzles. This enables easier coal dust distribution between nozzles. Oil burner operating during startups is seen in the rectangular opening below the lower nozzle. New nozzles are designed specially for the Indonesian coal used in PP1. Coal dust enters the furnace through the inner section of the nozzle. Secondary air enters the furnace through the outer ring. Both streams exit the nozzle in a swirl-like motion rotating in opposite directions. Coal-dust mixes with combustion air not before the burning zone.

Besides the replacement of burners additional modifications of the firing system were done. (Fig. 2) Before the reconstruction secondary-air flow was controlled on-site by manual dampers. Openness of these manual dampers depended on the operator yet there was a tendency not to adjust them very often. Mill's outlet temperature was controlled remotely by adjusting the cooling or primary air flow. Cold recirculated flue gas was used to control mill-inlet temperature. This kind of temperature control resulted in too high an air-ratio, hence large flue-gas losses, low boiler efficiency and large NO_x emissions. Sometimes mixture of coal dust and air self ignited in the ducts connecting the pulverizer and the burner due to excess oxygen content. This was causing damage to ducts and decreasing plant's reliability.

Secondary air was distributed above the upper nozzle, below the lower nozzle and between the nozzles. Air flow to respective nozzles was not known since the only air-flow measurement was located before the forced draft fans. Due to air leakage in air heaters mass flow of controlled air actually entering the boiler was lower than the measured mass flow. Hot-air collector (ring around boiler) was not present before the reconstruction and therefore pressure losses in hot-air ducts leading to respective burners were different. Combustion-air was therefore more or less randomly distributed among burners.

Before the reconstruction the decision was made not to install the over fire air (OFA). OFA is very common when introducing primary measures for NO_x reduction. There were three main reasons for this decision:

- avoiding additional investment costs,
- the fact that there are never all burners in operation and "OFA" can enter the furnace through those burners,
- furnace is relatively low (short) and the efficiency of OFA was questionable.

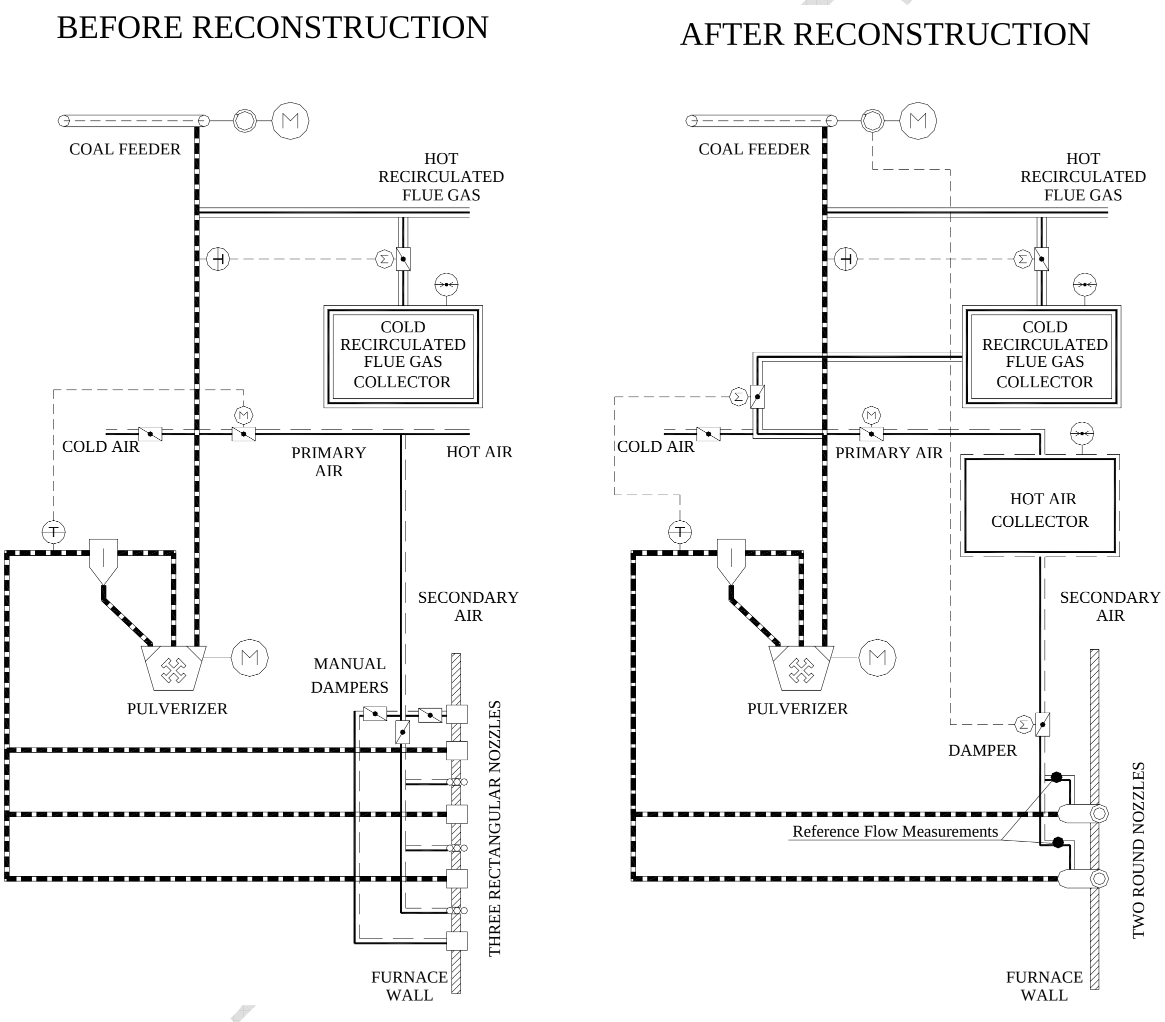

Figure 2- Firing systems before and after reconstruction

After the reconstruction cold recirculated flue gas is used to control mill's outlet and inlet temperatures. For this reason more powerful fans driving cold recirculated gas were installed. Hot air is not used for temperature control any more. It is used only as secondary air. Remotely controlled dampers are used for adjusting secondary-air flow. One damper controls air flow to both nozzles. Air flow is adjusted according to coal-feeder load. Due to the new hot-air collector forming a ring around the boiler equal air-pressure is assured for all burners. The required pressure in hot-air and cold-recirculated-flue-gas collectors is maintained by fans.

Before the reconstruction there was practically no air-flow measurement. For efficient reduction of NO_x emissions air-flow measurements are essential. The obvious choice would be to install conventional pressure differential devices (PDD) or some other kind of flow measuring equipment into the air ducts leading to burners. But this option was not appreciated due to extensive investment costs, lack of space for the installations and possibility of frequent failures. The other option was to adopt the unconventional method described in this paper requiring practically no investment costs and eliminating probable difficulties with pressure-difference measurements.

Power plant PP2 has similar arrangement of the firing system but differently designed burners and dampers. It has six mills and burners. Each burner is equipped with two rectangular nozzles. Due to different design of dampers the relation of air flow-damper position is different as in PP1 (Fig. 5 and Fig. 6).

3. COMPARISON OF METHODS FOR AIR-FLOW CONTROL

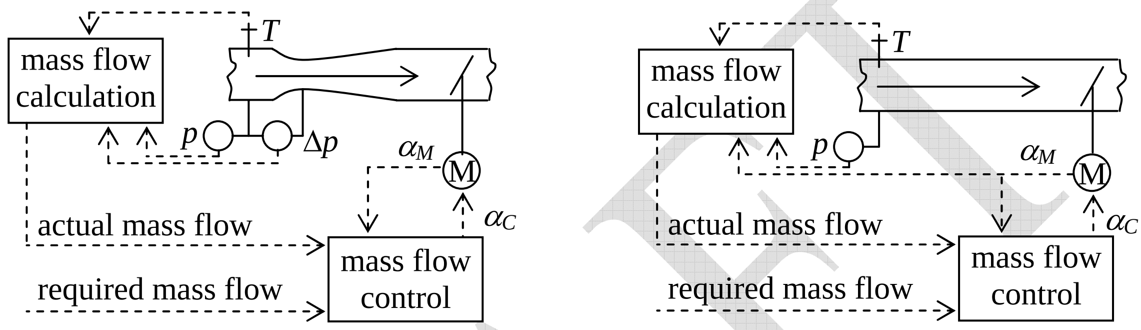

Figure 3- Conventional and simplified method for air-flow control

Figure 3 schematically shows conventional method using PDD for measuring actual mass flow and simplified method presented in this paper. There is no pressure differential device and no measurement of pressure difference Δp required for the simplified method. Pressure difference measurement is very often the cause for malfunctions. Measurements of damper openness α_M, air temperature T and pressure p are needed for both methods. Initial reference measurements of mass flow are usually required for both methods. Conventional method rarely complies with all the requirements from EN ISO 5167 and needs reference measurements to calibrate the mass flow measurement. Simplified method needs reference measurements to determine the relation between volume flow and damper openness. The furnace pressure measurement which is needed for mass flow calculation in the case of simplified method (see chapter 6.2) is normally not required since during normal boiler operation it is constant and can be entered as such.

4. DESIGN OF DAMPERS

Figure 4 schematically shows differences in designs of dampers in PP1 and PP2. PP1 has one single-blade butterfly type damper and PP2 has two single-blade butterfly type dampers per duct. Driving mechanisms are differently designed as well. In PP1 50 % openness corresponds to an angle of 45° while in PP2 50 % openness corresponds to an angle of less than 45°. In fact the nonlinearity of flow-openness relation is in PP2 compensated for with the design of driving mechanism which is evident from the results of reference measurements (Fig. 6).

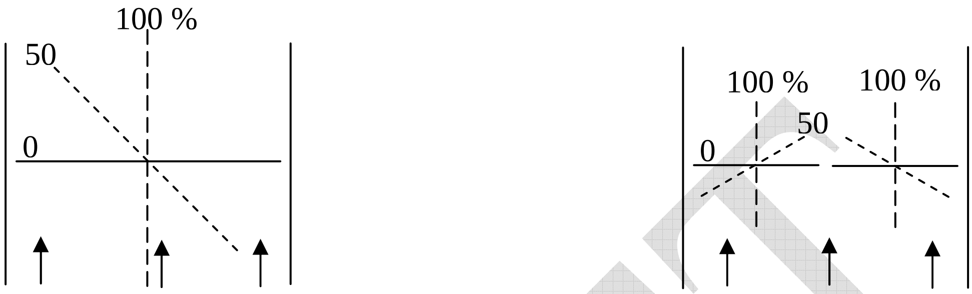

Figure 4- Dampers' design in PP1 and PP2

5. REFERENCE MEASUREMENTS

To establish the dependence of volume flow on damper openness reference measurements were carried out during the period of test operation. At each pre-selected damper position hot-air volume flow was measured by traversing air ducts leading to nozzles (Fig. 2). Pre-calibrated cylindrical differential pressure probe was used since this type of probe can be easily inserted into the hot-air duct through the ball-valve.

5.1 Conditions during reference measurements

- Reference conditions (hot air pressure and temperature, furnace pressure) were measured with permanently installed instrumentation and kept constant for the duration of reference measurements.
- Damper openness was adjusted to 8 to 10 pre-selected positions according to permanently installed instrumentation. For each damper position hot-air velocity in the duct was measured. Each duct's cross-section was numerically divided into five equal rectangles. Measuring points were located in centers of the rectangles. Mean velocity in the duct was calculated as an arithmetic average of the five measured velocities.

5.2 Results of reference measurements

Figure 5 and Fig. 6 show results of reference measurements for both power plants. The shape of curve representing the flow-openness relation depends on the design and size of a damper and driving mechanism. The shape of curve is not important since any shape can be approximated by an equation. Nevertheless it is more convenient if the relation is close to linear. It would be even more convenient if all curves were identical but this is almost impossible to expect. Not all ducts are of the same length nor they have equal number and shape of bends. Therefore pressure losses are different and so are volume flows. Yet it does not represent a problem since modern computer-controlled equipment can be programmed. Experience from PP1 showed that even though the flow-openness relations are different only one function (bold curve) can be used for all dampers.

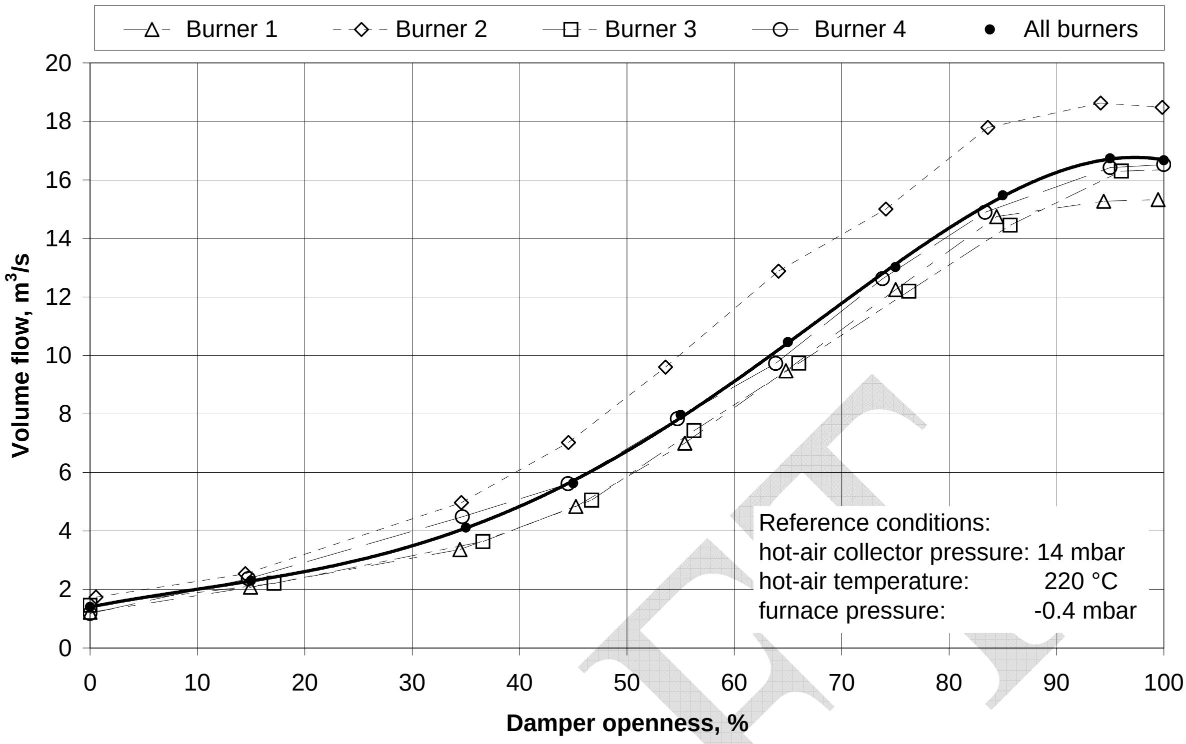

Figure 5- Volume flow in relation to damper openness in PP1 (Kustrin et al. 2004)

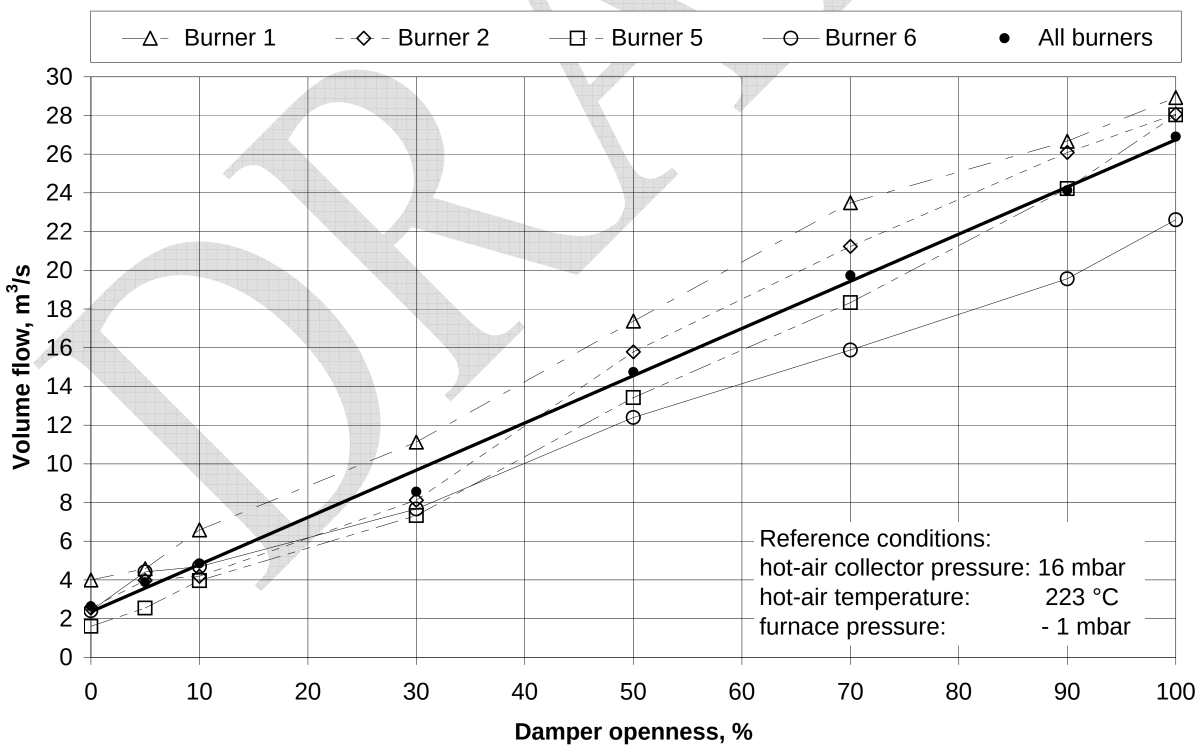

Figure 6- Volume flow in relation to damper openness in PP2 (Kustrin et al. 2006)

It was impossible to carry out reference measurements on two of six air ducts in PP2 due to lack of space. It was assumed that the flow-openness relations of the remaining two ducts do not differ significantly from the others.

6. CALCULATION PROCEDURES FOR CONVENTIONAL AND SIMPLIFIED METHOD

6.1 Conventional method

Unless the PDD is manufactured and installed according to EN ISO 5167 usually the following method for mass flow calculation is applied:

$$\dot{m}_{PDD} = k\sqrt{\Delta p \cdot \rho}\,, \tag{1}$$

where k is a PDD constant determined by reference measurements, Δp is PDD pressure difference and ρ is air density:

$$\rho = \rho(T, p) \tag{2}$$

which depends on measured temperature T and pressure p.

6.2 Simplified method

For the simplified method the following relation is used:

$$\dot{m}_{damper} = \rho \cdot \dot{V}_{damper} \tag{3}$$

where ρ is air density and $\dot{V}_{damper}$ is the actual volume flow through the damper. It can be calculated by:

$$\dot{V}_{damper} = \dot{V}_{ref}\sqrt{\frac{p - p_{furnace}}{p_{ref} - p_{furnace,ref}}}\,, \tag{4}$$

where $\dot{V}_{ref}$ is volume flow at reference conditions (pressure and temperature) during reference measurements when the relation between volume flow $\dot{V}_{ref}$ and damper openness α was determined:

$$\dot{V}_{ref} = \dot{V}(\alpha)\,, \tag{5}$$

In general air pressure is not equal to reference pressure but depends on boiler load. The reference volume flow $\dot{V}_{ref}$ through the damper is therefore multiplied by the square root taking this into account. Other variables in the Eq. (4) are: p is air pressure, p_{ref} is reference air pressure, $p_{furnace}$ is furnace pressure and $p_{furnace,ref}$ is reference furnace pressure. Actual mass flow through the damper $\dot{m}_{damper}$ is therefore:

$$\dot{m}_{damper} = \rho \cdot \dot{V}_{ref}\sqrt{\frac{p - p_{furnace}}{p_{ref} - p_{furnace,ref}}}\,, \tag{6}$$

In most cases furnace pressure is constant and can be entered as such into the equation.

7. CONCLUSIONS

In cooperation with Faculty of Mechanical Engineering of Ljubljana one of Slovene power plants introduced effectively the method presented in the paper on two coal fired steam boilers while another power plant is planning to introduce it.

The method can be applied whenever damper or valve is used for controlling the fluid flow. Usually separate devices are used for measuring and controlling the flow: for example pressure differential device for measuring and damper or valve for controlling. Two examples of controlling combustion-air flow for a coal-dust fired steam boiler show how, with sufficient accuracy, dampers can be used for both. Such an approach reduces the investment costs due to avoiding the need for expensive measuring equipment and improves the reliability of air flow control due to avoiding the usual problems with clogging of the impulse lines or problems with poor calibration of differential pressure transmitters.

Initial reference measurements are needed anyway: pressure differential devices usually need initial reference measurements (calibration) since they are usually not manufactured and installed according to all requirements from EN ISO 5167 and dampers need initial reference measurements to determine the relation between the volume flow and the openness of the damper. The determined relation remains unchanged until a major reconstruction of ducts, dampers or burner nozzles is done. In this case a new set of reference measurements is needed.

If pressure differential devices i.e. Venturi nozzles or tubes are used usually measurements of small pressure differences are needed. Impulse-lines-cleaning system must be operated regularly to prevent impulse lines clogging with dust and moist from air. Differential pressure transmitters prone to zero drifting also frequently cause malfunctioning.

Only simple measurements of air temperature, air pressure and damper openness are needed if the presented simplified method is applied. These measurements are anyway needed for normal boiler operation and are usually well maintained.

Operating experiences show excellent results. Since the employment of the method the operation of hot air control is error free and NO_x emissions are effectively reduced below the required limit.

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