Application of cascade control in the process of flue gas desulfurization of thermal power plant

Goran Kvascev, Zeljko Djurovic, Avram Avramovic

Abstract—**The paper presents the use of cascade control for the needs of an efficient flue-gas desulphurization process in the thermal power plant TE KO Drmno. A system for reducing the content of sulfur oxides (SO2) in flue exhaust gases - desulphurization has been implemented within two thermal power plants units. The technological process, control structure, implementation of cascade control, and plant operation results are presented. By applying the proposed control structure, the efficient operation is achieved of the entire system in terms of the regulations of the European Commission in terms of emissions of sulfur oxides and particles, but also electricity consumption and energy efficiency. The goals that the plant was supposed to meet were achieved, as well as the economic justification of the entire project.**

Index Terms— **Flue-gas desulphurization, thermal power plant, cascade control**

I. INTRODUCTION

In the Republic of Serbia, within the PE "Electric Power Industry of Serbia" (EPS), 34,896 GWh of electricity is produced annually, based on ten-year average. The electricity generation capacities owned by EPS have a total capacity of 7,855 MW and consist of 22 thermoblocks, 49 hydro units, and one reversible hydro power plant with 2 units. About 70% of production comes from thermal power plants and about 30% from hydropower plants. As fuel in thermal power plants, coal from surface mines is mostly used, i.e. lignite, whose average annual production ranges from 37 to 40 million tons of coal.

Lignite is a solid fuel that contains a high percentage of sulfur. Combustion of sulfur-containing fuel produces sulfur dioxide SO_2, as a dominant product of its oxidation, and sulfur trioxide SO_3 (in the amount of several percent of SO_2), as well as other oxides sulfur, which have no greater significance. Sulfur oxides SO_2 and SO_3 have been recognized as the most common and most dangerous gases of anthropogenic origin, with a serious negative impact on human health and vegetation, primarily creating acid rain. Therefore, it is of special interest to reduce the emission limit values (ELVs) of sulfur oxides to an acceptable level, which will not be harmful to the environment and the health of the population.

In the Republic of Serbia, based on our conditions, ELVs are defined by several criteria:

- whether plants are fired by solid, liquid, or gaseous fuels,
- whether plants are small, medium, or large (in terms of power),
- whether plants are old or new.

In the Republic of Serbia, based on: "Uredba o graničnim vrednostima emisija zagađujućih materija u vazduhu iz postrojenja za sagorevanje" ("Sl. glasnik RS", br. 6/2016) [1], the emission limit values, ELVs, for sulfur dioxide are expressed in mg/normal m^3 as function of power of plant, and which are applied to old plants, are given in the Figure 1.

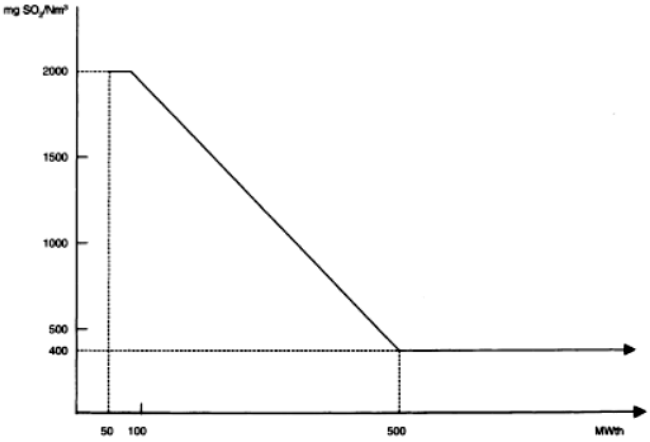

Fig. 1. Emission limit values, ELVs, for sulfur dioxide in mg/normal m3, which are applied to old plants as function of power of power plant

For plants with a thermal power of 100 to 500 MWth, the emission limit values for sulfur dioxide are calculated according to:

$$y = -4x + 2400$$

where: x - thermal power of the plant (MWth), y - emission limit value for SO_2 (mg SO_2/normal m^3).

For plants with a thermal power of more than 500 MWth, a desulphurization rate of at least 94% must be achieved.

On the other hand, observing the *National Plan for the Reduction of Emissions of Major Pollutants from Old Large Combustion Plants* [2] (*Nacionalni plan za smanjenje emisija*

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glavnih zagađujućih materija koje potiču iz starih velikih postrojenja za sagorevanje), which clearly defines the maximum emissions of sulfur oxides, it is clear that these goals have not yet been achieved. If we take as an example the TE KO Drmno B1/B2 units, for which the maximum emission of 7,957.03 tons per year is defined according to the plan [2], and compare with the data that over 95,000 tons of SO_2 were emitted during the previous year, it is clear that it is necessary to provide a plant for processing sulfur oxides, i.e. flue-gas desulphurization system. Such a system has been put into operation during the past period. Tests, final adjustments of control loops, and obtaining the necessary approvals for work are in progress.

II. FLUE-GAS DESULPHURIZATION TE KO DRMNO

According to the conclusions of the Study "*Directions of optimal reduction of sulfur oxide emissions from thermal power plants of the Electric Power Industry of Serbia*" [3], TE KO Drmo B1/B2 was chosen as the first thermal power plant where the construction of such a plant is planned. The flue gas desulphurization plant in TE KO Drmno is the first desulphurization system in Serbia to be operational, and it started operating on October 23, 2020. Based on previously accepted analyzes, the wet limestone / gypsum process was defined as the reference desulphurization process.

Process Overview

The process of flue gas desulfurization consists of several chemical processes that are essential for understanding and applying the control system, which is presented in Figure 2:

- The SO_2 in the flue gas is absorbed into the circulating slurry
- Circulating slurry containing calcium sulfate ($CaSO_4$) and precipitated limestone
- Add some limestone into absorb to supply alkalinity and calcium ions (Ca ++) source
- Add air into absorb for Oxidized SO_2 to sulphate (SO_4).
- Solution sulfate ion and calcium ion reaction precipitated gypsum ($CaSO_4 * 2H_2O$)
- The precipitated gypsum is separated from the slurry water is removed. This results in solid by-product from the process. Slurry liquid return.

The process schematic is shown in Figure 3, which shows the thermal power plant that was upgraded by the flue-gas desulphurization subsystem, and which consists of three main parts:

- Absorber – within which the process of Absorption, Oxidation, and Neutralization (shown in Figure 2) takes place
- Absorbers preparation
- Gypsum dehydration

The most important process takes place in the Absorber, where the main control structures are located. It is necessary to control the flow of an absorber with the control valve in order to make chemical reaction to be successful and efficient. This can be achieved by adding limestone into the absorber to ensure alkalinity. Constant alkalinity produces a successful and efficient flue-gas desulphurization process. As the absorber system is large in volume, and the time constants are also large (on the order of 15 minutes), it is extremely important to accurately add limestone slurry. This is main task for the control system, to work efficiently and precisely. For this control structure, cascade control is proposed, with the outer loop according to alkalinity (with reference pH value), and an inner loop for control of a flow of limestone slurry.

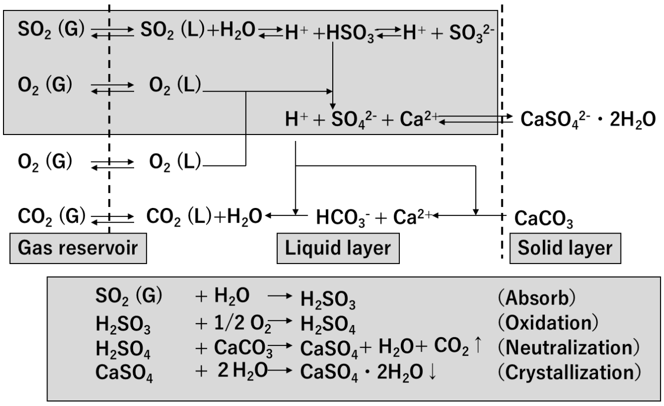


Fig. 2. Chemical Process Overview

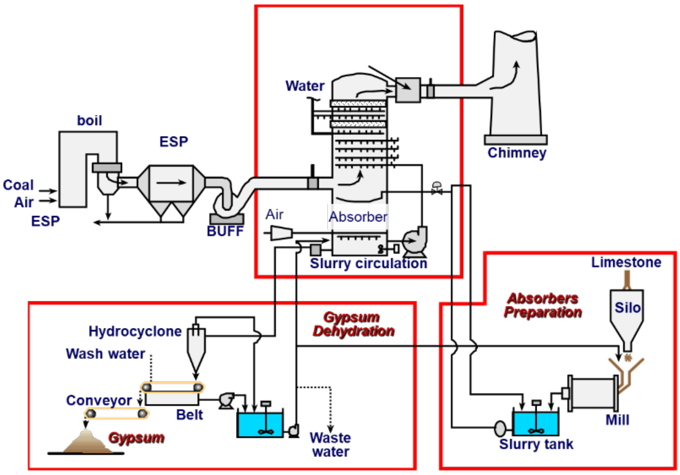


Fig. 3 FGD Process schematic

Figure 4 shows a process flow diagram (PFD):

- flue gases: when the flue gas system is running: VDG → ODG inlet valves → Buster fan → Absorber → New chimney
- flue gases: when the flue gas system is not working: VDG → Bypass valves → Old chimney
- air: when the air sealing system is running: Air sealing fan → Heater → Valve closed
- process water: when the process of flushing the absorber inlet with water in case of emergency is in progress: Process water tank → Flushing water pump in case of emergency → Flushing water tank → Flue gas duct spraying

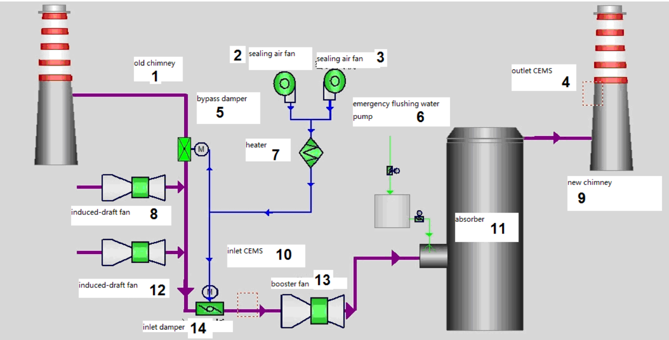


Fig. 4 Process flow diagram, 1-old chimney, 2,3-sealing fans, 4-outlet CEMS, 5-bypass damper, 6-emergency flushing water pump, 7-heater, 8,12-induced-draft fans, 9-new chimney, 10-inlet CEMS, 11-absorber, 13-booster fan, 14-inlet damper

III. CONTROL LOOPS

Figure 5 shows the simplified P&I diagram shown on DCS SCADA system - Absorber picture. Measurements, state of actuators (valves, pumps, and actuators), as well as controls within control loops are presented. Control valve (measured position: 2TJ39S001) is responsible for alkalinity (pH measurement marked as 2TD40A001 and 2TD40A002). The flow of liquid limestone slurry through this pipe is marked as 2TJ39F001. As the system for measuring the pH value needs to be maintained at regular time intervals, a double measurement is planned, so the value of one probe is taken as main and another as spare, which gives a regular measurement in full time.

Within this research, a cascade control structure was proposed, with the use of PI / PID controllers, shown in Figure 6. Simpler control procedures did not give satisfactory results, observing a testing period of 6 months.

Cascade control structure consists of two loops:

- The outer loop controls the alkalinity (pH value) of the PID controller - the pH value is controlled by setting the flow of the internal PI controller. Alkalinity measurements is achieved by sensors
- Internal PI control loop - controls the reference flow from the outer loop through control valve 2TJ39S001, and measured flow of limestone slurry – 2TJ39F001

PI/PID controllers are tuned using the SRT method [4], measuring the response in the open loop in the nominal mode of plant. In the first version, the control of the PID controller in the external loop was set without differential action, however, after testing, it was necessary to introduce significant differential action for two reasons: faster elimination of disturbances and problems due to jamming of the control valve due to longer periods without moving the actuator.

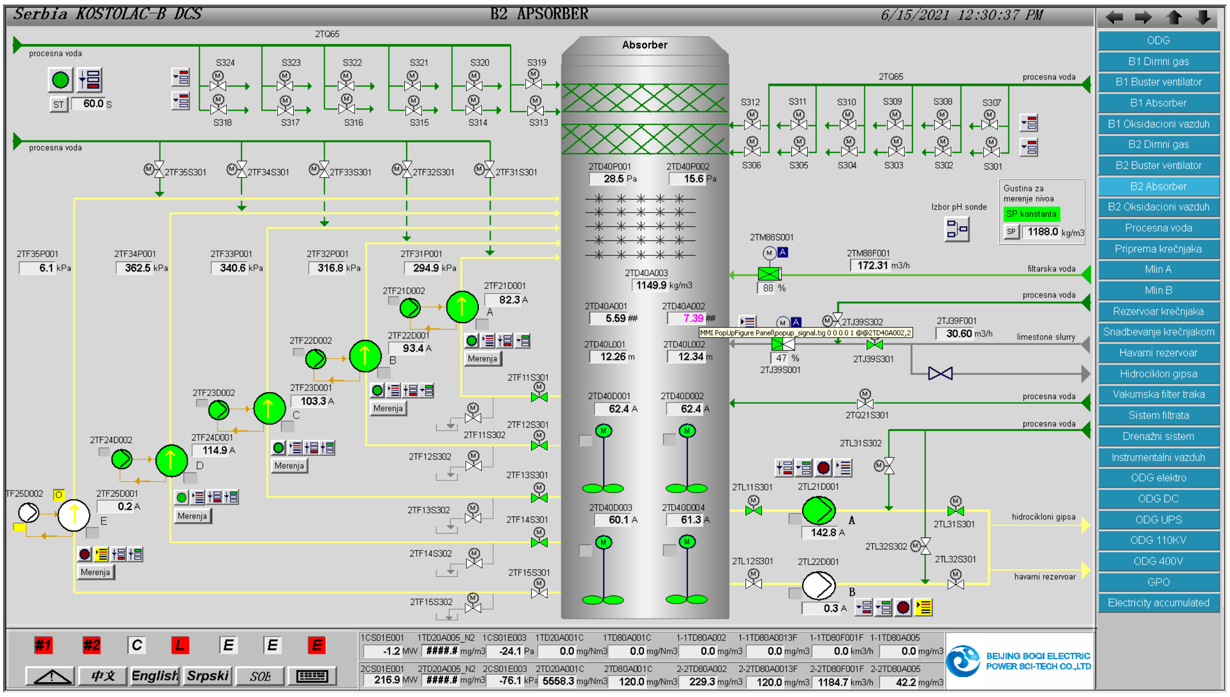


Fig. 5 SCADA control system – P&I diagram

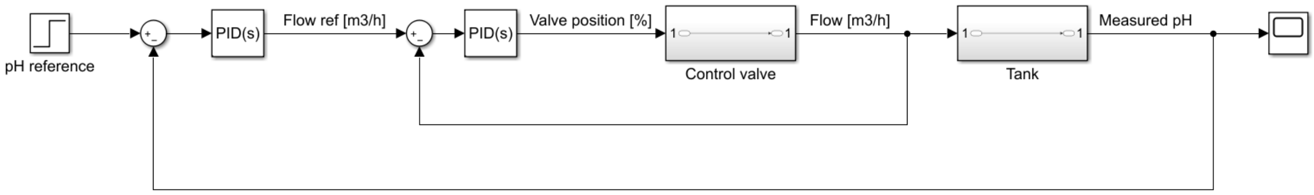
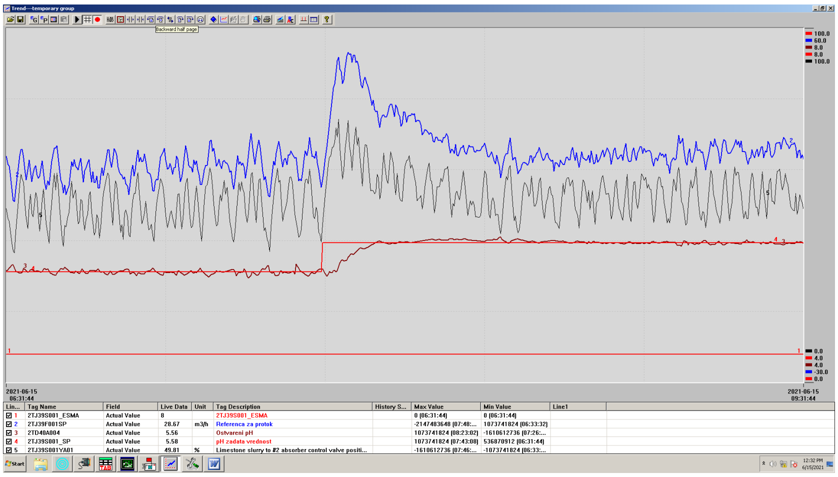


Fig. 6 Proposed cascade control structure

IV. MAIN RESULTS

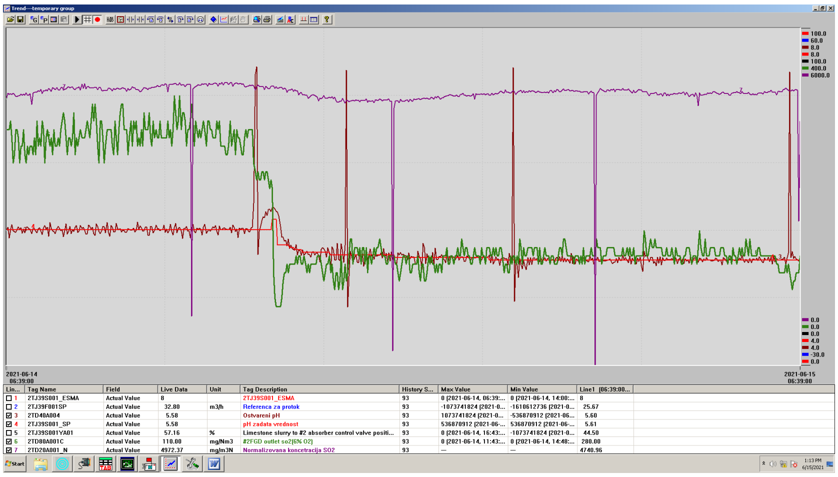
Figures 7 and 8 show the measurements from the plant after the final testing in the nominal regime. Figure 7 shows satisfactory results of control the alkalinity (pH value) with a rise time of about 10 minutes with a step change of the reference value. The measured flow in inner loop is almost same as flow reference.

Observing the measured values in the real environment, it can be concluded that the control of the plant operates within the specified standards. The emission of sulfur oxides SO_2 does not exceed the value of 250 mg/Nm^3, measured in 24 hours time range. Considering that the inlet concentration of SO_2 is in the range of about 5000mg/Nm^3, it can be confirmed that the efficiency of the desulfurization process is more then 99%.



Lin...	Tag Name	Field	Live Data	Unit	Tag Description	History S...	Max Value	Min Value	Line1
☑ 1	2TJ39S001_ESMA	Actual Value	8		2TJ39S001_ESMA		0 (06:31:44)	0 (06:31:44)	
☑ 2	2TJ39F001SP	Actual Value	28.67	m3/h	Referenca za protok		-2147483648 (07:48:...	1073741824 (06:33:32)	
☑ 3	2TD40A004	Actual Value	5.56		Ostvareni pH		1073741824 (08:23:02)	-1610612736 (07:26:...	
☑ 4	2TJ39S001_SP	Actual Value	5.58		pH zadata vrednost		1073741824 (07:43:08)	536870912 (06:31:44)	
☑ 5	2TJ39S001YA01	Actual Value	49.81	%	Limestone slurry to #2 absorber control valve positi...		-1610612736 (07:46:...	-1073741824 (06:33:...	

Fig. 7. Control performance pH control loops - 3h time scale: pH reference value – red color, pH measured value – brown color, flow reference – blue color, valve position – gray color



Lin...	Tag Name	Field	Live Data	Unit	Tag Description	History S...	Max Value	Min Value	Line1 (06:39:00...
☐ 1	2TJ39S001_ESMA	Actual Value	8		2TJ39S001_ESMA	93	0 (2021-06-14, 06:39:...	0 (2021-06-14, 14:00:...	8
☐ 2	2TJ39F001SP	Actual Value	32.80	m3/h	Referenca za protok	93	-1073741824 (2021-0...	-1610612736 (2021-0...	25.67
☑ 3	2TD40A004	Actual Value	5.58		Ostvareni pH	93	1073741824 (2021-0...	-536870912 (2021-06...	5.60
☑ 4	2TJ39S001_SP	Actual Value	5.58		pH zadata vrednost	93	536870912 (2021-06-...	536870912 (2021-06-...	5.61
☐ 5	2TJ39S001YA01	Actual Value	57.16	%	Limestone slurry to #2 absorber control valve positi...	93	0 (2021-06-14, 16:43:...	-1073741824 (2021-0...	44.50
☑ 6	2TD80A001C	Actual Value	110.00	mg/Nm3	#2FGD outlet so2(6% O2)	93	0 (2021-06-14, 11:43:...	0 (2021-06-14, 14:48:...	280.00
☑ 7	2TD20A001_N	Actual Value	4972.37	mg/m3N	Normalizovana koncetracija SO2	93	—	—	4740.96

Fig. 8 Control performance of Absorber unit - 24hours time scale: pH reference value – red, pH measured value – brown, SO_2 inlet concentration [mg/Nm^3] – violet, SO_2 outlet concentration [mg/Nm^3] – green

V. CONCLUSION

The paper presents the application of the cascade control structure of desulphurization in the thermal power plant TE KO Drmno. By applying the proposed control structure, the efficient operation of the entire system was achieved in terms of meeting the regulations of the European Commission, which is shown through the data obtained in the actual operation of the plant. Possible improvements consist of the introduction of feedforward control depending on the boiler load, as well as the measured input values of sulfur oxide.

ACKNOWLEDGMENT

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