Effective use of wastewater in electrostatic precipitators

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Abstract The paper presents the results of research conducted in industrial conditions on the injection of treated wastewater (or water) from the wet flue gas desulphurization (WFGD) installation before the electrostatic precipitator (ESP) for flue gas cleaning from pulverised coal boiler (PC-boiler) feed by hard coal. The installation uses the waste heat of the flue gas to eliminate the injected liquid by completely vaporizing it. At the same time contributing to the increase of ESP efficiency by conditioning the flue gas. The tests were carried out on an installation with an injection capacity of a maximum of 6m^3/h of liquid (treated wastewater, process water or mixture of both), into the flue gas stream with an average value of approx. 125,000 Nm^3/h. During the tests it was confirmed that the conditioning liquid evaporates. No increase in the concentration of typical pollutants in the exhaust gases, in particular SO_2, HCl, HF, NH_3, was found, as at the temperatures at which the injection process takes place (about 200°C). A decrease in the dust concentration downstream of the ESP was observed as a result of favorable changes in the properties of the dust-gas medium after the injection of the conditioning liquid. The obtained results show that the presented installation for injection of treated sewage into the flue gas duct before the ESP enables the elimination of the sewage stream. In addition, it will improve the operation of the electrostatic precipitator without the need for significant and costly modernization, which is particularly important for the existing industrial facilities (e.g. power plants). Additionally, it is possible to reduce other pollutants (NOx, mercury) by adding appropriately selected liquid additives.

Keywords: Electrostatic precipitator, Wastewater injection, Flue gas conditioning

1 Introduction

The article presents the results of research on the injection of conditioning liquid, in the form of treated industrial wastewater or its mixture with water, into the flue gas channel before the electrostatic precipitator. The hot flue gas can therefore be a source of waste heat for the elimination of the industrial wastewater stream. Given the worldwide trend towards zero-emission wastewater management in industrial plants, the proposed solution may help to achieve this goal [1-4]. On the other hand, it is known [5-8] that the process of humidifying the exhaust gas before the ESP has a positive effect on its operation and increases the collection efficiency as a result of:

- reducing the volume flow of the dedusted exhaust gases by lowering their temperature, and thus reducing the exhaust gas velocity in the electrostatic precipitator chamber,
- increasing the humidity of the flue gas, which leads to a decrease in the resistivity of ashes with high resistivity (which is important for the operation of electrostatic precipitators - elimination of the back corona),
- favorable change in dust properties at the inlet of the ESP (due to the mechanical agglomeration, the share of heavy metal-rich submicron dusts decreases and, consequently, the dust emission may be expected to decrease).

An example of a source of industrial wastewater is the WFGD installation (wet flue gas desulphurization installation) in power plants. Crude sewage from this source is characterized by a high content of chlorides, sulphates, heavy metals, suspended solids (mainly gypsum), nitrogen compounds, and moreover, they contain a large load of organic compounds. This makes it necessary to expand the sewage treatment plant or build the so-called evaporators in order to meet all the requirements for sewage treated by national regulations and BAT conclusions [9, 10]

Accordingly, it has been proposed to inject a liquid consisting of wastewater or a mixture of wastewater and water into the flue gas duct upstream of the electrostatic precipitator for the simultaneous conditioning of the flue gas and removal of the wastewater stream. It is a solution that is particularly suitable for use in existing facilities in order to meet the increasingly stringent exhaust gas cleanliness standards without the need for costly modernization of the dust collector, and at the same time eliminate at least part of the waste water stream from WFGD.

2 Description of the facility and injection installation

The installation for the injection of conditioning liquid into the flue gas upstream of the electrostatic precipitator works with a water boiler (WP-120 type) fired with hard coal. A two-pass, three-zone horizontal electrostatic precipitator is used for dust removal.

Upstream of the ESP, a flue gas conditioning installation has been built, consisting of the following basic elements:

- compressed air supply system,
- process water and treated wastewater supply system,
- conditioning liquid injection system (10 injection lances with the necessary fittings and pneumatic nozzles of Laval type).
- system of automatic regulation of the conditioning installation operation.

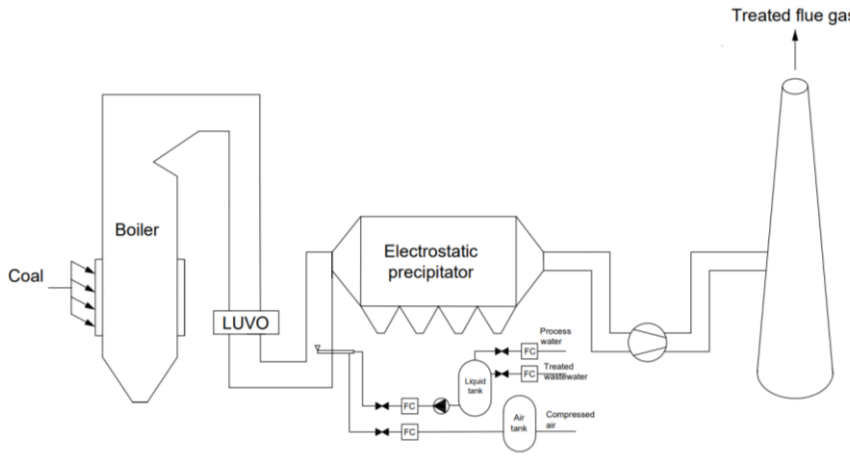

Fig. 1. Diagram of the installation for injection of conditioning liquid into the flue gas duct before the ESP

The conditioning liquid is supplied to the installation, which is a mixture of process water and pre-treated sewage from the wet flue gas desulfurization installation. The basic operating parameters of the flue gas conditioning system are shown in Table 1.

Table 1. Basic operating parameters of the exhaust gas conditioning installation

No.	Parameter	Unit	Value	
			min	max
1.	Stream of conditioning liquid	m^3/h	2	6
2.	Pressure of the conditioning liquid	bar	2.6	6
3.	Spraying air stream	Nm^3/h	1,750	2,400
4.	Spraying air pressure	bar	3.5	6

The conditioning liquid injection system consists of 10 injection lances, 5 for one exhaust gas string. Lances are used to inject liquid using compressed air in order to produce sufficiently fine liquid droplets and their complete vaporization before entering the electrostatic precipitator. For this purpose, spraying nozzles mounted at the end of the lances were used, working in the system of internal mixing of the liquid-air mixture.

The installation is equipped with an automatic regulation system in order to maintain the set parameters of the conditioning liquid injection depending on the current parameters of the exhaust gases before the ESP. The amount of injected liquid is selected by the control system on the basis of the measured flue gas temperature before the installation and the calculated acid dew point temperature for the current flue gas composition. The parameters of the sprayed liquid and air (streams and pressures) are maintained by the automatic control system at the level ensuring the appropriate size of the sprayed liquid droplets (the so-called Sauter diameter below 55 μm).

3 Description of the research

The influence of the conditioning liquid injection on the dust concentration downstream of the electrostatic precipitator (automatic dust meter), the chemical composition of exhaust gases (FTIR Gasmet DX 4000 analyzer) and the properties of the fly ash precipitated in the dust collector (particle size analyzes, chemical composition analyzes of the collected samples) were investigated. For this purpose, three series of measurements were performed for the parameters determined by the boiler operation (125 MWt), each time starting with "zero" measurements, i.e. without liquid dosing:

- series I: process water injection into flue gas (no wastewater addition). During the injection, the concentration of H_2O, HF, NH_3 and HCl was measured and the indications of the measuring equipment in the facility were monitored. Samples of fuel, process water from the liquid tank and ash samples from the electrostatic precipitator (3 zones) were taken.
- series II: injection of a mixture of process water and treated wastewater (20% by weight), measurement of the concentration of H_2O, HF, NH_3 and HCl, indications of the measurement equipment at the facility, sampling of the process liquid from the liquid tank, ash samples from the electrostatic precipitator (3 zones).
- series III: injection of treated wastewater (100%) into the flue gas, measurement of the concentration of H_2O, HF, NH_3 and HCl, indications of the measuring equipment at the facility, collection of media samples.

For all three measurement series, the same parameters of liquid injection were maintained with a volume flow of 3.2 m^3/h, and the air stream to the installation was kept at 2,400 Nm^3/h. During the research, the dust concentration was continuously measured in the cross-section behind the electrostatic precipitator (DURAG D-R 290 photometric dust meter).

During the measurements, coal with the parameters given in Table 2 was burned.

Table 2. Results of elemental analysis of fuel

No.	Parameter	Unit	Value
1.	Calorific value	kJ/kg	23,800
2.	Heat of combustion	kJ/kg	27,055
3.	Total moisture	%	10.4
4.	Ash, in working condition	%	15.8
5.	Sulfur, in working condition	%	0.44
6.	Carbon, in working condition	%	61.6
7.	Hydrogen, in working condition	%	3.5

4 The results of the research

The results of the three series of tests of the injection system are presented in the following subsections.

4.1 Process water injection tests into the exhaust gas - series I

The results from series I of measurements obtained from the boiler monitoring system and the measurements of flue gas parameters made with the FTIR analyzer are shown in Fig. 2.

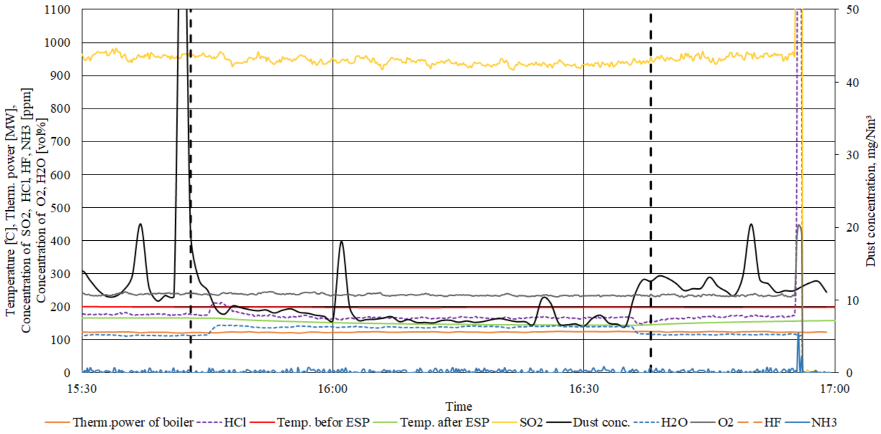

Fig 2. Boiler operation parameters and concentration measurement results for series I

The analysis of the results of measurements of pollutants in the exhaust gas confirms that the injection of process water has no effect on the concentration of SO_2, HF, HCl and NH_3 in the exhaust gas. The process water injection into the flue gas caused an increase in the water vapor content from 5.3% to 6.2%, a decrease in the dust concentration in the flue gas (Table 3) and a reduction in flue gas temperature in the measurement section from 166 to 148°C.

Table 3. Dust concentration in the flue gas under reference conditions*, series I

Lot No.	Conditioning liquid	No injection, mg/m^3_{ref}	With injection, mg/m^3_{ref}	Reduction of emission, %
I	Process water	18	12	33

* reference conditions: dry gas at a temperature of 273.15 K, and a pressure of 101,3 kPa, calculated for oxygen content in the flue gas O_2 = 6 vol-%.

The ash samples from the ESP were tested for grain composition and the content of chlorine, sulphates and mercury, and the obtained results are summarized in Fig. 3 and Table 4, respectively.

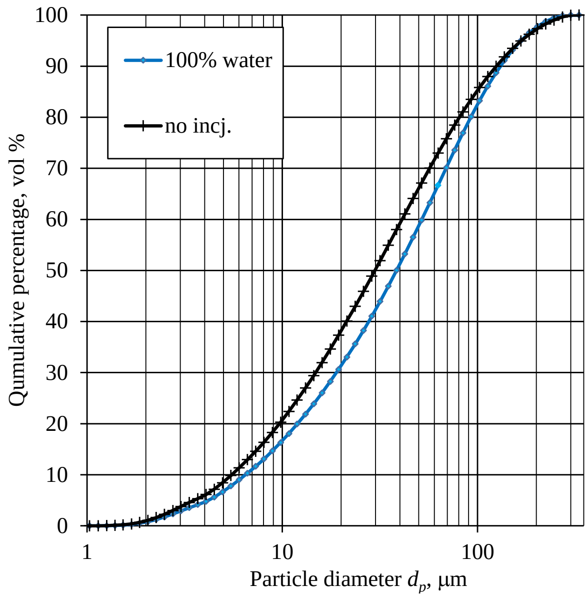

Fig 3. Particle size distribution of dust samples from the ESP zone I, series I

Fig. 3 shows a shift in the dust grain composition towards larger particle diameters during water dosing. Dust samples collected in the first zone of the ESP were analyzed due to the fact that the largest stream of dust mass is removed there. Table 4 summarizes the results of the analysis of the chemical composition of ash from under the electrostatic precipitator.

Table 4. Content of chlorine, sulphate and mercury for fly ash samples from the ESP, series I

No.	Identified component	Unit	Value	
			No injection	Process water
1.	Chlorides (Cl)		442	514
2.	Sulphates (SO_4^{2-})	mg/kg	1,118	1,160
3.	Mercury (Hg)		0.541	0.388

During series I, no effect of injection of process water on the chemical composition of the ash was observed.

4.2 *Water and sewage mixture injection tests (20%) - series II*

The results from the series II measurements obtained from the boiler monitoring system and the measurements of flue gas parameters made with the FTIR analyzer are shown in Fig. 4.

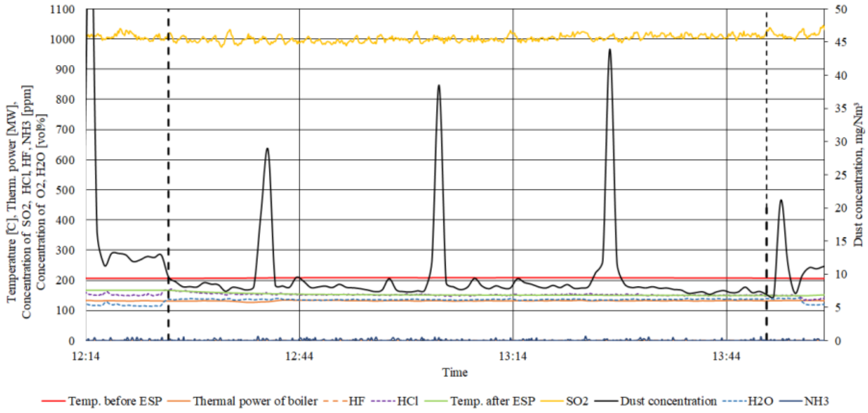

Fig 4. Boiler operation parameters and concentration measurement results for series II

There was no observed effect of liquid injection into the channel on the concentration of SO_2, HF, HCl and NH_3 in the exhaust gas, while an increase in water vapor content in the exhaust gas and a decrease in dust concentration (Table 5) and exhaust gas temperature downstream of the electrostatic precipitator were observed.

Table 5. Dust concentration in the flue gas under reference conditions, series II

Lot No.	Conditioning liquid	No injection, mg/m^3_{ref}	With injection, mg/m^3_{ref}	Reduction of emission, %
II	20% of sewage treated	22.5	13.8	38

The test results of ash samples are shown in Fig. 5 (grain composition) and in Table 6 (chemical compositions).

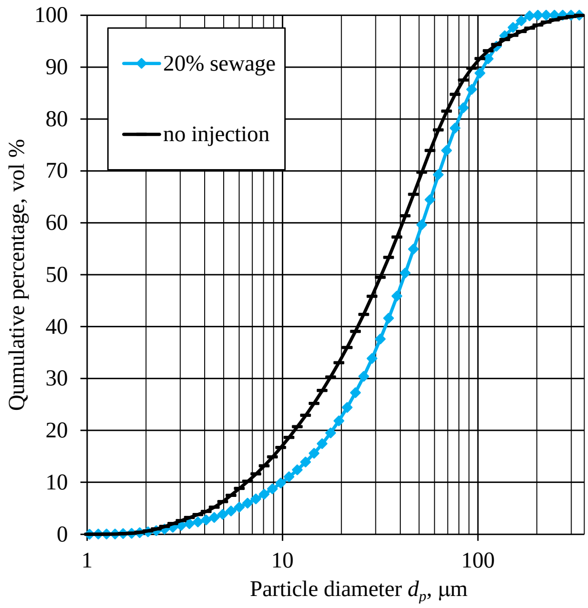

Fig 5. Particle size distribution of dust samples from the ESP zone I, series II

Fig. 5 shows the shift of the dust grain composition towards larger particle diameters during dosing of the conditioning liquid (20% of wastewater).

Averaged ash samples from the ESP were tested for the content of chlorine, sulphates and mercury. The results for the collected samples are summarized in Table 6.

Table 6. Content of chlorine, sulphate and mercury for fly ash samples from the ESP, series II

No.	Identified component	Unit	Value	
			No injection	20% sewage
1.	Chlorides (Cl)		96.7	748
2.	Sulphates (SO_4^{2-})	mg/kg	878	1,112
3.	Mercury (Hg)		0.269	0.307

In the case of injection of a 20% solution of sewage into the flue gas channel before the ESP, no effect of the injection on the mercury content in the ash was observed, while the concentration of sulphates and chlorine in the ash increased, which is related to the high content of chlorine in the supplied liquid (4,245 mg/dm^3). Due to the use of fly ash as an additive to concrete mixes, the concentration of chlorine in the ash should be kept at <0.1%.

4.3 *Purified sewage injection tests - series III*

The results from the series III measurements obtained from the boiler monitoring system and the measurements of flue gas parameters performed with the FTIR analyzer are shown in Fig. 6.

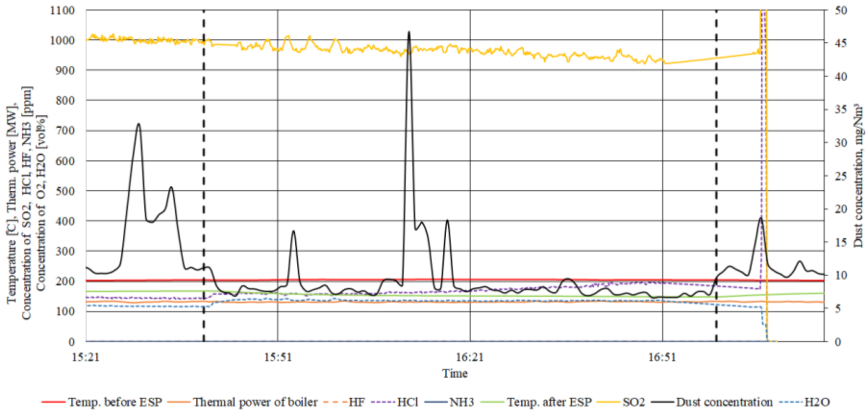

Fig 6. Boiler operation parameters and concentration measurement results for series III

As in the previous measurement series, no effect of liquid injection into the channel on the concentration of SO_2, HF and NH_3 in the exhaust gas was observed. On the other hand, for HCl, a slow increase in the concentration of HCl in the flue gas occurred during the injection of treated sewage. However, due to the lack of determination of the chlorine content in the fuel, this effect cannot be clearly ascribed to the injection of sewage into the exhaust gas channel. Again, an increase in the water vapor content in the flue gas and a decrease in dust concentration (Table 7) and flue gas temperature downstream of the ESP were observed.

Table 7. Dust concentration in the flue gas under reference conditions, series III

Lot No.	Conditioning liquid	No injection, mg/m^3_{ref}	With injection, mg/m^3_{ref}	Reduction of emission, %
III	100% treated sewage	17.8	13.7	24

The test results of ash samples are shown in Fig. 7 (particle size compositions) and in Table 8 (chemical compositions).

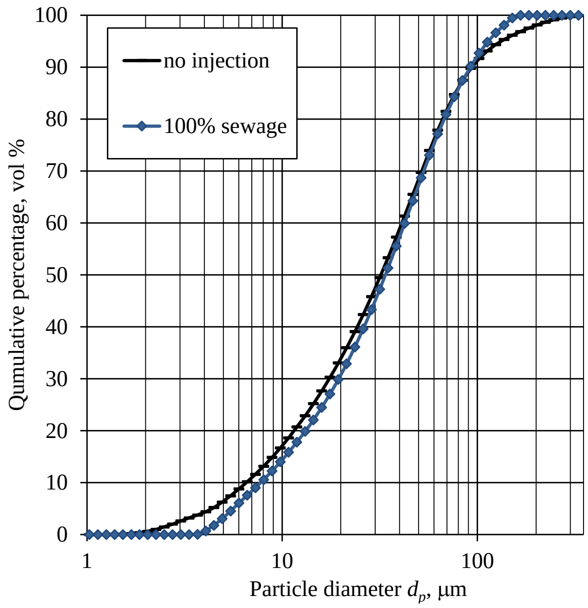

Fig 7. Particle size distribution of dust samples from the ESP zone I, series III

Fig. 7 shows no significant shift in the dust grain composition during the dosing of the conditioning liquid (100% of wastewater) and without dosing the liquid.

The averaged ash samples from the ESP were tested for the content of chlorine, sulphates and mercury and the results are summarized in Table 8.

Table 8. Content of chlorine, sulphate and mercury for fly ash samples from the ESP, series III

No.	Identified component	Unit	Value	
			No injection	100% sewage
1.	Chlorides (Cl)		96.7	7,952
2.	Sulphates (SO_4^{2-})	mg/kg	878	1,480
3.	Mercury (Hg)		0.269	0.298

In the case of injection of 100% of sewage into the flue gas channel upstream of the ESP, no effect of injection on the mercury content in the ash was observed, while the concentration of sulphates and chlorine in the ash increased, which is related to an even greater content of chlorine in the supplied sewage (18 530 mg/dm^3).

5 Summary and conclusions

During the described tests, the exhaust gas stream with a value in the range of 125,000 Nm^3/h, treated wastewater originating from WFGD process water or a mixture thereof was injected. It was found that as a result of the processes taking place at the injection point, the conditioning liquid evaporates, which contributes to the temperature drop at the electrostatic precipitator inlet. The remaining compounds in the wastewater settle on the fly ash particles, forming agglomerates, and are precipitated with the main dust stream in the dust collector. There was no evidence of an increase in the concentration of standard pollutants in the exhaust gas leaving the dust collector, in particular SO_2, HCl, HF and NH_3. The reason for the increase in HCl concentration in the exhaust gas for series III has not been explained

Each time, the injection of the conditioning liquid caused a decrease in the dust concentration in the cross section downstream of the electrostatic precipitator, the largest decrease, amounting to 38%, was recorded for series III. The values obtained during the operation of the injection system are significantly below the expected value of 25 mg/m^3 (in reference condition) for the tested object. This gives the user of the installation the possibility of flexible adaptation to the changing parameters of the coal burned (which is currently the case very often) in order to meet the applicable dust concentration standards.

The parameters of the ash precipitated in the ESP changed depending on the composition of the injected conditioning liquid. The injection of process water practically does not change the chemical composition of the ash. The injection of liquids containing treated sewage increased the concentration of sulphites and chlorine in the fly ash. In the case of injection of 100% of treated sewage, the permissible content of chlorine in the ash from the electrostatic precipitator of $<0.1\%$ was exceeded. It is connected with the presence of significant amounts of the mentioned components in the supplied sewage. It is necessary to optimize the process parameters so as not to cause unacceptable deterioration of the parameters of the ash with commercial value.

Conditioning of exhaust gases by liquid injection improves the operation of the dust collector without the need for deep and costly modernization. It is particularly important for the existing energy facilities, which should maintain the desired cleanliness of exhaust gases without the need to incur unjustified financial outlays. Additionally, it is possible to reduce other pollutants (NOx, mercury) by adding appropriately selected liquid additions [11, 12], which will be the subject of the planned tests on the described installation. Moreover, the obtained results show that the injection of treated sewage into the flue gas duct before the dust collector allows for their removal in the amount determined each time for a given object. This may eliminate the need to expand the sewage treatment plant or build the so-called evaporators, in order to meet all the requirements for sewage treated by national regulations and BAT conclusions.

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