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Installations for cleaning exhaust fumes from dust–gas pollutants

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Abstract
This article shows the methods and techniques that are used for cleaning exhaust fumes from dust–gas particles. The pollutants come from a complicated electricity production process in a thermal power station, whose main fuel is a hard coal or a brown coal. In the recent years, using purification installations has been the result of changing regulations in the field of environmental protection and increasing public awareness. The methods are aimed to reduce nitrogen oxides, sulphur oxides and dust emissions to the environment, not exceeding the emission limit values for individual chemical compounds.

1. INTRODUCTION

Applicable regulations and standards relate to environmental protection and determines limit of physical quantity characterising the pollutants emission, which results from the combustion process [Theodore…2008]. The current guidelines mainly achieve to check three parameters [The regulation of the Minister for the Environment of 30th October…2014]. The regulations in Poland have determined the upper end for the emission of chemical compounds such as nitrogen oxides, sulphur oxides and dust to the environment, depending on the power of the boiler. Minister of Environment published regulation with schedules relating to the emission standards for devices with a nominal heat output of not less than 50 MW [The regulation of the Environment Minister of 4th November…2014].

Pollutions are also generated during the electricity production in the form of dust–gas particles. In order to protect the environment and to fulfil the applicable standards and regulations regarding permissible nitrogen oxides, sulphur oxides and dust emission in the surroundings, it was necessary to implement exhaust fumes cleaning installations in current power units [Czajkowska….2018].

2. CHEMICAL COMPOSITION OF EXHAUST GAS FUMES

Electricity production starts from supplying fuel inside the boiler in the form, for example, hard coal or lignite dust. Fuel combustion takes place in specially constructed power boiler, which produces the water vapour with high temperature and high pressure. In the first step, the chemical energy from the fuel is transformed into the thermal energy of water vapour. In the next step, the water vapour goes to the energy turbine, where comes another transformation of thermal energy into mechanical energy (expansion of water vapour propels the energy turbine). Finally, the obtained mechanical energy is supplied to the generator in which the last process of converting it into electrical energy takes place. The thermal power plant should be built in a way to ensure the highest possible efficiency of individual transformation [Zaporowski…2015].

As mentioned earlier, a side effect of electricity production is the generation of the dust-gas particles. Most of the chemical compounds included in the polluted exhaust fumes are dangerous to human health and noxious for the natural environment. The dusting medium included chemical compounds such as hydrogen fluoride (HF), carbon tetrachloride (CCl_4) and oxides (X_aO_b), in particular carbon monoxide (CO), sulphur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen dioxide (NO_2) [Brzezińska….2018]. In the thermal power plants, installations are built for protecting environment and preventing over-normative emission of dust–gas pollutants to the surroundings.

3. UNION STANDARDS AND REGULATIONS OF THE ENVIRONMENT MINISTER RELATING TO ENVIRONMENT PROTECTION

The European Commission has developed an energy policy (commonly known as 3x20 package) for countries belonging to the European Union, which have been included as goals of the Green Paper. The objectives of the policy relate to reducing the harmful greenhouse gases emissions to 2020 by at least 20% compared to 1990. In addition, the part of energy obtained from renewable energy sources will be increased by 20% to 2020. Energy policy is also focused on [Green Paper…2006]

- increasing energy efficiency,
- improving energy security
- extending the area of renewable energy to biofuels,
- developing competitive sectors on the energy market (reference to the area of fuels and electricity),
- minimising the impact of the energy sector on the natural environment.

The destructive impact of industrial development on the environment and climate change gives the opportunity to look at particular assumptions admitted by the European Union in order to counteract these harmful factors [Action Plan…2006]. Burning of raw materials and fossil fuels emits many harmful chemical compounds. Pollutants that have a negative impact on the natural environment are present in exhaust fumes. The European Commission created the energy and climate package, analysed the current situation and considered the implementation of specific activities aimed at improving the current EU situation [IEA…2016].

The Directive 2010/75/UE of European Parliament and the Council from 24 November 2010 on the issue of industrial pollution caused the realisation of key changes in Polish law, regarding environmental protection regulations [DIRECTIVE …2010]. The most important changes relate to the introduction of exacerbations in the regulations concern to maintain the standards of emission pollution from industrial concerns. Mainly, the Industrial Emissions Directive (IED) indicates the reduction of sulphur dioxide, nitrogen oxides and dust formed in combustion processes [Rutkowska-Subocz…2018]. The following are the two regulations of Environment Minister in Poland, which relate to environmental protection, that limit the emission of dust–gas pollutions:

- The Regulation of Environment Minister of 30 October 2014, on the requirements for the measurement of emission volumes and water amount [The Regulation …2014].
- The Regulation of Environment Minister of 4 November 2014, on the pollutants emission limits for certain types of installations, combustion plants and equipment incineration or waste incineration plants [The Regulation …2014].

Implementation of individual modernisation and revitalisation of thermal power plant could it possible to fulfil the requirements in order to preserving emission limits of dust–gas pollutants, which are included in the following EU regulations.

4. FLUE GAS DESULPHURISATION

The wet flue gas desulphurisation method (FGD) is based on water humidification in the chamber, which contains a factor allowing absorption of sulphur dioxide in a liquid. The exhaust gases are cooled to a temperature within (50 ÷ 60) °C, during the desulphurisation process [Galos…2016]. This method is one of the first and oldest methods to eliminate sulphur compounds from fumes. Intense moisturising of air needs the equipment that is used to remove water from the device. It should also be reheated flue gas; this allows to clean fumes from other harmful compounds into the electrostatic precipitator.

In the dry FGD method, a sorbent is fed into the combustion chamber. Substances that are capable of absorbing harmful sulphur dioxide are called a sorbent. Calcium oxides and limestone are most often used as a sorbent [Wardak…2015]. The process starts after blowing the sulphide-absorbing substance to the combustion zones. The desulphurisation phase occurs only at the specified optimum temperature inside the chamber.

In the semi-dry desulphurisation method, water vapour with sorbent suspension is introduced into very hot flue gas stream. In this method, sodium bicarbonate is used as a sorbent, as a sulphide-absorbing agent [Wardak…2015]. The chemical reaction occurs during exponential contact of the sorbent with polluted exhaust fumes, which involving the combination of sulphur oxides with an absorbing agent. In addition, as a result of the very high temperature inside the chamber, the water evaporates at the same time. The final product of the desulphurisation process is dry.

These above-mentioned methods have characteristic advantages and disadvantages (Figures 1 and 2); further selection of the best FGD technique is required from the enterprise's possibilities and the used boiling factor. The semi-dry desulphurisation is characterised by a lower consumption of water, which is used during the sulphide removal process while maintaining the final product in a dry form. However, the final form of the obtained combustion

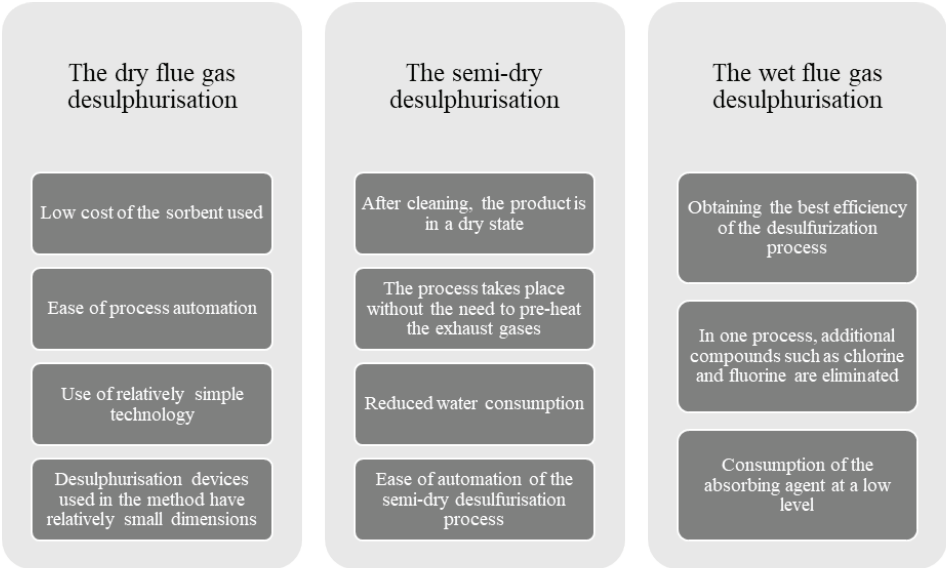

Figure 1. The advantages of flue gas desulphurisation methods

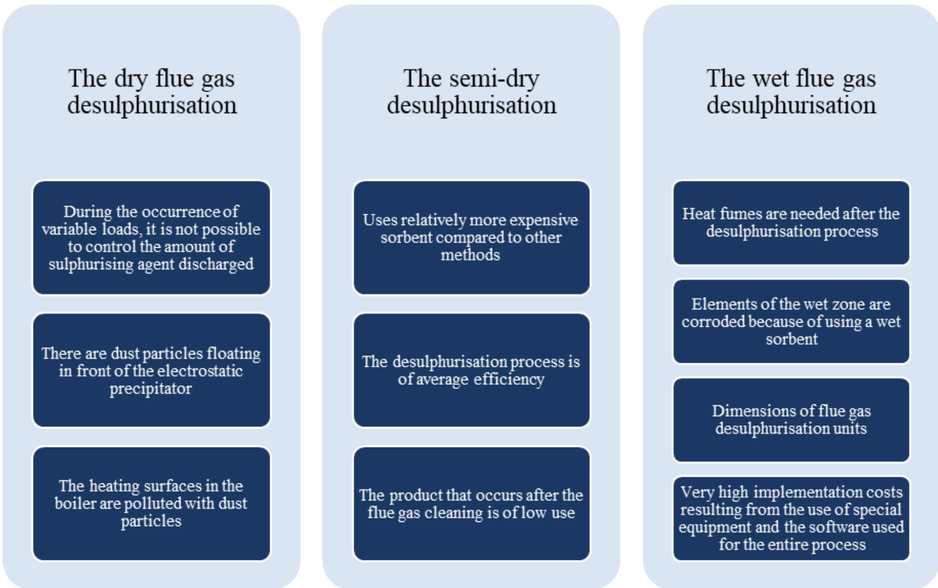

Figure 2. Disadvantages of sulphide exhaust purification methods

dust in the semi-dry desulphurisation method has rarely used for other purposes. In addition, the sulphide-absorbing factor used exceeds the price compared with that used in the dry desulphurisation method.
The wet FGD method was invented and developed as the first method of purification exhaust fumes from sulphides. Today, this method has been replaced by the other two techniques because of the highest implementation costs and the necessity of the using equipment. The dry method is characterised by lower desulphurisation efficiency in comparison with the other two exhaust purification methods; however, employers mainly use dry desulphurisation for economic reasons.

The dry FGD method is characterised by low implementation and operation costs; in addition, the sorbent used is of the lowest price compared to the sorbents used in other desulphurisation methods. In the power industry, because of the lowest degree of efficiency cleaning process, the dry method is gradually being replaced by semi-dry desulphurisation of flue gases.

5. DENITROGENISING COMBUSTION GASES

The reference document BREF entitled "Reference Document on Best Available Techniques for the

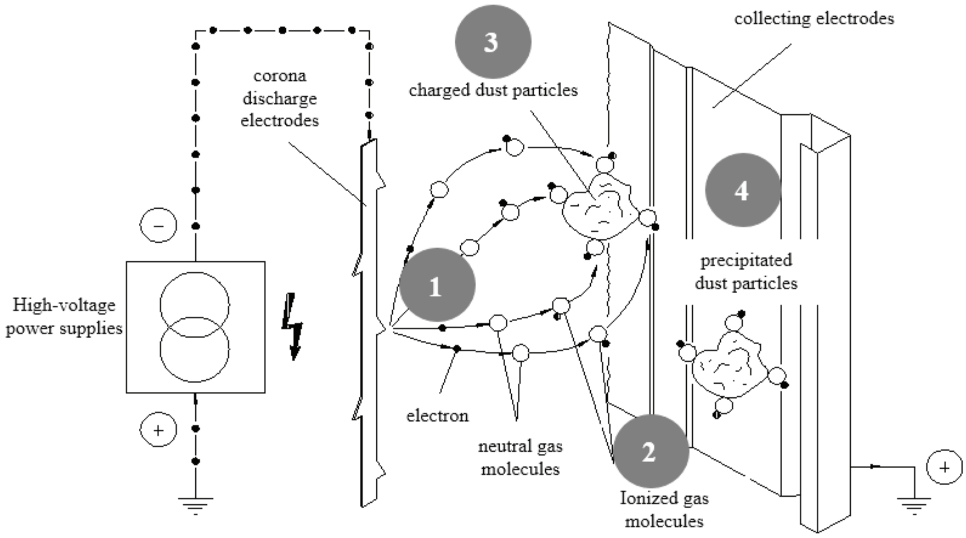

Figure 3. The scheme of electrostatic precipitator operation (1, the active space between corona discharge electrodes and collecting electrodes; 2, molecules of exhaust fumes are ionised; 3, dust particles are charged by negative ions; 4, the dust is deposited on the collecting electrodes)

Manufacture of Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers" specifies that selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR) and their combination are the best available methods for denitrification of exhaust gases alongside primary methods [Best Available Techniques … 2016].
The principle of exhaust gases denitrification of nitrogen oxides by the SNCR method is based on the use bringing the reagent to the fumes and the next reaction of nitrogen oxides with ammonia or carbamide. The use of this technique allows the inhibition of not only the reduced NO_x emission but also the emission of the reagent NH_3 (ammonia) and CO_2 to the environment. The achievement of appropriate and optimal conditions is the basic and the most important issue in ensuring the efficiency of the SNCR method. The SCR installation is used to operate in „high dust" environment; it is designed to work in a dusty and sulphated environment, that is, the exhaust route directly behind the boiler and before the electrostatic precipitator. SNCR does not increase the exhaust flow resistance (it does not require changing the fans of exhaust fumes), what is important in the next purification of flue gas by electrostatic precipitators. Another advantage is the ability to correct and control the symmetry of combustion and the temperature distribution of the exhaust gases in the chamber by the operator, thanks to the ultrasonic temperature measurement system in the chamber furnace built for the needs of SNCR. The main disadvantage of the SNCR method is the significantly lower (by about 30–40%) efficiency of denitrification of flue gas compared to SCR. In addition, there is a possibility of occurrence of certain amounts of ammonia in the exhaust and in fly ash and gypsum, which requires careful supervision of the process.

6. PURIFYING THE EXHAUST FUMES

The electrostatic precipitator is the most effective dust collectors used in the industry [Shah…2017]. New patents have been created on an ongoing basis, which aim to modernise the device and upgrade the methods of cleaning exhaust gases [United States Patent…2012]. The principle of electrostatic precipitators operation has not changed for decades, but their design develops in the direction of weight reduction and dimensions whilst improving the efficiency of dust removal (Figure 3).
Electrostatic precipitators (as the name suggests) used the influence of the electrostatic field on the solid particles, in the form of dust grains and drops of mist called aerosol, which are found in the exhaust fumes. The active space in the form of an electrostatic field is generated between corona discharge electrodes and collecting electrodes [Suleman…2012]. Corona discharge electrodes have a negative charge, whereas the collecting electrodes were grounded. The exhaust fumes were leaded by a transport channel, getting into the chamber of the electrostatic precipitator. Dust particles in the active space are charged by negative ions and finally particles obtain a negative potential.
In the next step, dust is deposited on the collecting electrodes, and then the particles are separated and removed from the collecting electrodes by introducing them into vibrations. Under the influence of gravity, dust is embedded in the lower part of the electrostatic precipitator (the material falls into dust collection hoppers). The device shall be protected against appearing of there-entrainment dust particles phenomenon to the electrostatic precipitator chamber.

The dust was removed from the electrostatic precipitator and collected in the dust collection hoppers; it's more than 80% PM 2,5 [Szczepańska…2018]. The de-dusting devices prevent the entry of harmful solid particles into the natural environment. Maintaining a high level of electrostatic precipitators' efficiency is important because of the role it fulfils in the entire exhaust fumes purification process [Tracz…2016].
The efficiency of the electrostatic precipitator is extremely important, because of the role that electrostatic precipitators play in the pollution purification process. The following factors have the most important influence on the efficiency of exhaust gas de-dusting: gas flow rate, dust concentration in gas, dust resistivity and supply voltage. The efficiency of the electrostatic precipitator depends mainly on the gas flow velocity through the collecting and discharge electrodes located in the object chamber. The dependence is such that as the amount of gas flowing through the electrostatic precipitator increases, its efficiency decreases, whereas when the amount of gas flowing decreases, the efficiency of the electrostatic precipitator increases.

6. METHODOLOGY OF DUST–GAS POLLUTION RESEARCH ON THE EXAMPLE OF THE ELECTROSTATIC PRECIPITATOR

Laboratories have their own list of offered parameters that can be used during the measurement processes, research of processes, systems and energy devices. This list of factors is also used during the modernisation or review of the energy devices as electrostatic precipitators to demonstrate the compliance with emission standards.
However, after the warranty period, the final selection of the measured quantities belongs to the person who orders the test. Taking into account the environmental aspect and maintaining the highest level of exhaust gas cleaning devices efficiency, it is important to carry out measurements that could determine the following parameters:

- concentration of ammonia in the exhaust dust;
- dust concentration before and after the electrostatic precipitator, otherwise an assessment of the electrostatic precipitator effectiveness;
- chemical composition of the emitted dust;
- exhaust volume flow;
- oxygen content in the exhaust;
- moisture content in the exhaust;
- exhaust temperature;
- sulphur dioxide emissions;
- carbon monoxide emissions.

During the test, after the modernisation or technical condition control of the electrostatic precipitator, it is necessary to take dust samples and determine

- dust particle size;
- content: cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), vanadium (V), copper (Cu), aluminium (Al.), arsenic (As), zinc (Zn), sulphuric acid (H_2SO_4), ammonia (NH_3), total organic carbon, total carbon, share of flammable and non-flammable parts.

For this purpose, appropriate methods could be used to determine the size of chemical compounds in the fumes. Measurements of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x) and oxygen (O_2) concentrations are carried out continuously by instrumental methods, using a multi-gas analyser, according to the following standards:

- NO_x – PN-EN 14792:2017-04;
- CO – PN-EN 15058:2017-04;
- CO_2 – ISO 12039:2001;
- O_2 – PN-EN 14789:2017-04.

Measurements of flue gas stream are implemented in accordance with PN-Z/04030-7: 1994. For this purpose, multi-point probing is used to determine the dynamic pressure of gases, using a micromanometer and an 'S' type stacking tube [PKN…1994].
Measurements of moisture content are carried out using the condensation and temperature method by measuring the moisture from the sucked in partial gas stream and measuring the saturation temperature. The amount of moisture captured is measured using a graduated cylinder [PKN…2017].
Determination of the content of trace elements in samples taken of emitted fly ash is performed on the emission spectrometer. The determination of trace elements in the samples taken is carried out in accordance with the standard PN EN 14385:2005. Special elements such as antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), nickel (Ni), thallium (Tl) and vanadium (V) are also measured. The method can also be used to determine mercury (Hg) when sampling from the side stream [PKN…2005]
However, the particle size distribution of dust emissions is tested by laser diffraction method in accordance to ISO 13320:2009. ISO 13320:2009 provides guidance on instrument qualification and size distribution measurement of particles in many two-phase systems (e.g. powders, sprays, aerosols, suspensions, emulsions and gas bubbles in liquids) through the analysis of their light-scattering properties. It does not address the specific requirements of particle size measurement of specific materials [ISO…2009].

7. CONCLUSIONS

A side effect of electricity generation from thermal power stations is dust–gas pollution. The exhaust fumes are purified, amongst others, from chemical compounds such as nitrogen oxides (NO_x), sulphur oxides (SO_x) and carbon oxides (CO_x). These chemical compounds are found in the flue gas in the form of solid and liquid aerosol components. Flue gas cleaning installations are built between the power boiler and the chimney to reduce dust emissions (the electrostatic precipitator), remove sulphur dioxide and denitrogenise combustion gases. The EU conditions that have already been satisfied by Polish Energy Sector are a long and extremely expensive process, which relate to reducing the pollutants' emission.

The choice of exhaust purification methods should be made based on the multi-variant analysis of technical possibilities in order to meet these standards of physical quantity characterising the pollutants emission. The economic analysis by taking into account the specificity of construction solutions boiler will allow for the development of an accurate modernisation concept.

Maintaining a high level of efficiency of these power installations is very important because they could be assigned to a group of critical machines, that is, to devices that do not have a reservation, and the investment cost incurred for their purchase is relatively high. The exploitation of critical machines significantly influences the achievement of an appropriate threshold of the economic result for a given enterprise. Reliability of critical objects is enforced by maintaining the continuity of energy production. The next step of the research will be the analysis of methods used for diagnosing the technical condition for critical machines. The assessment of the technical condition for critical machines should be carried out in order to maintain the full efficiency of the facility and not to allow for frequent failures leading to the device being taken out of service.

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