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Investigation of spraying lances used in low power boilers for non-catalytic reduction of nitrogen oxides (SNCR)

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Introduction

Starting from 1990 norms concerning emission from power plants become more and more restrictive. In case of coal burning the limitation concerns among others nitrogen oxides (both NO and NO_2 in equivalent of NO_2).

Present standards are defined by Regulation of the Minister of the Environment from 2014 [1]. For the power below 50 MW coming from heat sources the nitrogen oxides limit, after 2015, in equal to 400 mg/m^3_c, for range 50–100 MW – 300 mg/m^3_c and for the power above 100 MW – 200 mg/m^3_c. The power coming from heat sources is counted for all the boilers together if the exhaust gases are introduced to one emitter – chimney.

European Union is planning further restrictions concerning nitrogen oxides emission – new preliminary norms have been presented in Best Available Techniques (BAT) Reference Document for the Large Combustion Plants in 2013 [2]. For presently working 50–100 MW plants the proposed limit is equal to 270 mg/m^3_c and for 100–300 MW the limit is 180 mg/m^3_c. For new 50–300 MW plants the proposed limit is equal to 100 mg/m^3_c.

It is seen that especially the small installations consisting of few boilers (i.e. WR 25 boilers – 29 MW, or commonly used WR 10 boilers) will have to obey the most restrictive norms. It is evaluated that several hundred of such boilers work in Polish industry.

The traditional methods (mainly burning technologies) for nitrogen oxides reduction can be applied for emission below 300 mg/m^3_c that is why now it is a need for implementation of so-called secondary methods.

To the most known secondary methods used for reduction of nitrogen oxides emission belong ammonium radical methods. Ammonium radicals NH_2 react with nitrogen oxides giving N_2, water and CO_2. Ammonia or urea injected into exhaust gases is used as a radicals source in this reaction. The reaction takes place in the presence of catalyst or without the catalyst. In the second case we deal with selective non-catalytic reduction of nitrogen oxides (SNCR). This method is especially recommended for small energetic plants because of its simple implementation and low investment costs [3].

Efficiency of application of SNCR method depends on many parameters. It is important that the reduction component has a contact with the exhaust gases at appropriate temperature (urea: 900÷1150°C, ammonia: 870÷1100°C). Very important is also the proper reagent distribution in the exhaust gases. That is why the spraying lances, usually introducing water solution of urea into exhaust gases, are one of the most important elements of SNCR installation.

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Selection of spraying lances for SNCR system dedicated for low power boilers

The spraying lances used in SNCR have to fulfil the following requirements:

- have large range of efficiency regulation,
- generate drops with proper diameters,
- give the proper energy to the drops which enable them reaching of the expected distance,
- ensure resistance at 1200°C and for encroaching,
- ensure easy maintaining in boiler wall (without bending water pipes).

Spraying lances are produced as a one-phase (hydraulic) or two-fluid (pneumatic) devices. The one-phase lances are characterized by small regulation range, generate large drops and are sensitive for blocking. The pneumatic, second group of lances, have large regulation range, produce drop spray of defined shape and spray angle and enable formation of small drops [4]. That is why, the two-fluid (pneumatic) lances are used in SNCR low power boilers as the spraying devices.

The lances constructions can be distinguished from the mixing area point of view. There are two types of lances: with internal phases mixing and with external phases mixing. The internal phases mixing despite of certain regulation limit, enables uniform spraying density and leading out the spray, from the internal chamber, through one or few nozzles. That is why lances with internal mixing zone have been selected for our investigations.

An extra criterion, coming from low power boilers wall construction, was limit of an external lance diameter – it cannot by larger than 20 mm.

Experimental methodology

The special laboratory installation has been constructed for conduction of measurements concerning investigation of process parameter of spraying lances. It consisted of spray chamber (6 m of length), feed-measurement section for gas and liquid phase distribution as well as proper measuring devices.

The following parameters of the selected lances have been measured in the installation:

- spray angle,
- spray deviation from the horizontal axis,
- Sauter drop diameter – d_{32} (volume-surface diameter),
- output air velocity.

During the measurement the following parameters have been changed:

- lance construction (number and size of holes delivering external phase into the mixing chamber, length of the mixing chamber, spray nozzle diameter),
- water flow rate,
- air overpressure,
- feed configuration: LA (Liquid to Air) – central flux: air, external flux: water or AL (Air to Liquid).

The spraying angle and the spray deviation from horizontal axis have been measured by the use of a photographic method using the proper exposition time to compensate the spray fluctuation, sharpen the colors borders and enable to lay the tape measures on the background. Figure 1 shows such elaborated example picture.

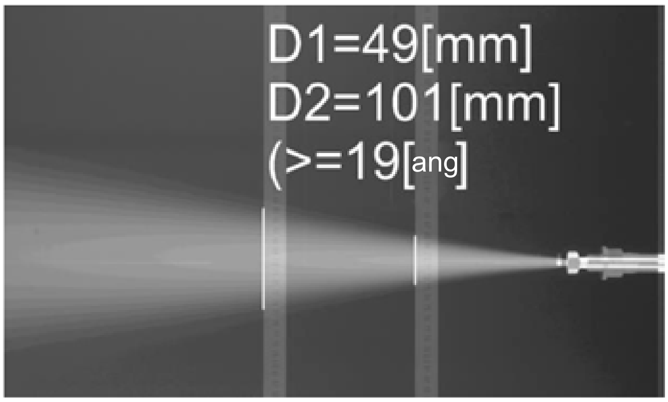

Fig. 1. Measurement of a spray angle

For the drop diameters determination the following two methods were used:

- the immersion liquid method MCI: drops catching on the microscopic glass covered by immersion liquid (silicon oil) introducing into core or lower part of the spray; taking of microscopic pictures in proper scale and their analysis by the use of Image-ProPlus or ImageJ program;
- laser diffraction – the use of Spraytec apparatus (Malvern Co.) enabling for automatic *in-situ* measurements of high concentrated aerosols.

Figure 2 shows a microscopic picture of drops obtained by the use of MCI method.

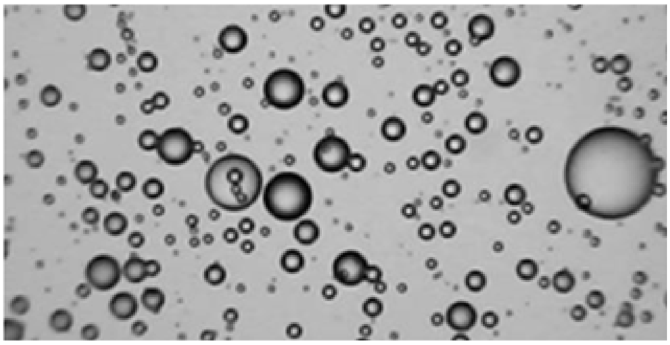

Fig. 2. Microscopic picture of drops – MCI method

Velocity of air leaving the lance (without water flow) was measured by the use of pressure gauge VOLTCRAFT VPT-100.

Selected results of the measurements

Preliminary investigations showed that LA feed configuration, contrary to AL configuration, does not cause the spray pulsation. That is why this configuration has been selected and used for further investigations.

Relationship between spray angle of one-nozzle lance and ratio of mass flow of two phases – ALR (Air to Liquid Ratio) kg/kg – is given in Figure 3.

It is seen that all the obtained spray angle of one-nozzle lances are located in the range 11 ÷ 33°. Increasing of the ALR values decreases the difference of spray angles for different lance constructions. Moreover, lances with internal mixing enable using of the multiple nozzle heads increasing the spray angle (i.e. three symmetrically located nozzles).

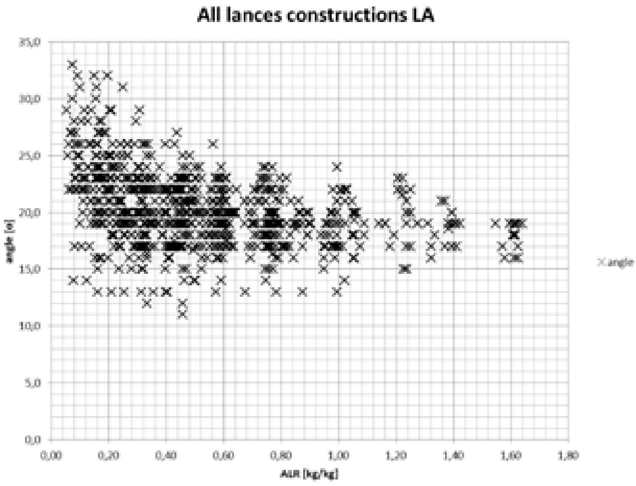

Fig. 3. Dependence of spray angle on ALR

Fig. 4 shows dependence of spray deviation from horizontal axis in a distance of 0.7 m and 1.7 m from the nozzle output – the positive values refer to down spray deviation.

The spray deviation, in the distance of 0.7 m from the nozzle output, is practically equal to zero and the maximum spray deviation obtained in the distance of 1.7 m is equal to 30 cm only. Moreover, the spray deviation decreases with the increasing of ALR value.

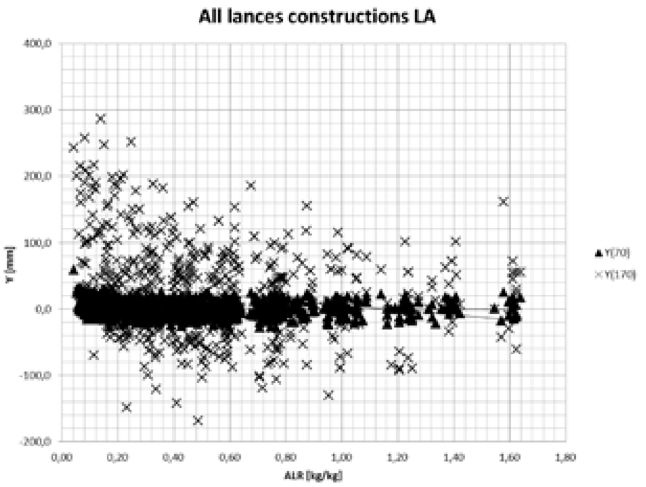

Fig. 4 shows dependence of spray deviation from horizontal axis in a distance of 0.7 m and 1.7 m from the nozzle output – the positive values refer to down spray deviation.

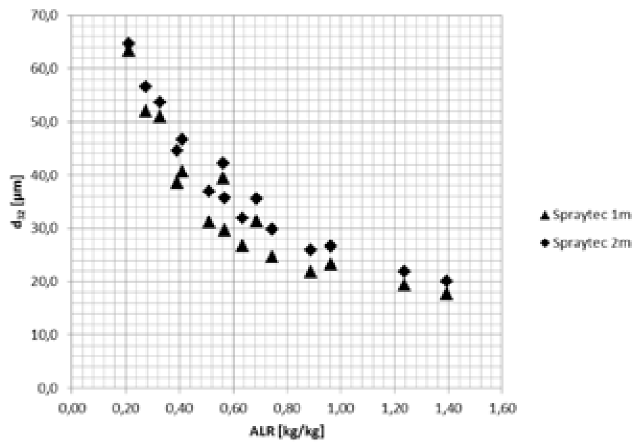

Fig. 5. Dependence of mean drops diameter d_{32} on the measurement point

Dependence of mean drop diameters on the measurement point for one of the investigated lances is shown in Fig. 5. The measurement has been done by the use of Spraytec device in the distance of 1 m and 2 m from the nozzle output.

The picture (Fig. 5) clearly shows that increasing distance from the nozzle output causes increasing of the mean diameter of drops but the differences between the diameters are small (few micrometers).

Comparison of the mean drop diameters measured by the immersion liquid method MCI and Spraytec apparatus for one of the lances used is given in Figure 6.

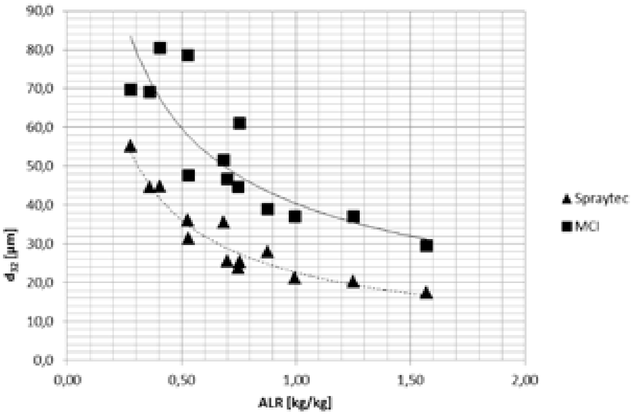

Fig. 6. Comparison of the methods used for determination of the mean drop diameters d_{32}

Diameters measured by the Spraytec device are smaller than those measured by the immersion liquid method (MCI). The differences can come from the fact that in case of the immersion liquid method the measurement was done by points in the spray core while in the case of the used of Spraytec device the measurement was done in the whole horizontal cross-section at the spray. It is obvious that the MCI method is less accurate (measurement of the drop trace) and more labor-intensive but has one advantage – it can be applied with the use of simple tools and without costly measuring devices.

Figure 7 shows dependence of air spray velocity at 2.5 m from the nozzle output as a function of a mass flow for a few different nozzle diameters.

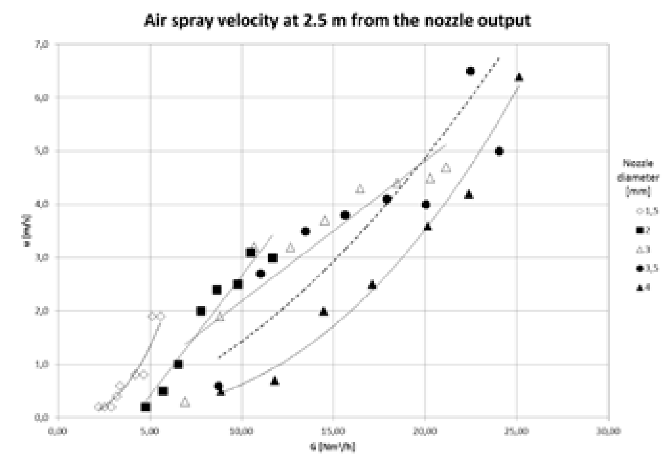

Fig. 7. Air spray velocity [m/s] as a function of a mass flow G [Nm^3/h]

The dependence of air spray velocities on the mass flows and the nozzle diameters are evident but it is important to notice that 2.5 m from the nozzle output air velocity is still significant.

Conclusions

The use of SNCR method for reduction of nitrogen oxides in low power installations is presently the best solution because of its simple application and low investment costs. However, diversity of boiler constructions and proper selection of spray nozzles (proper characteristic) cause that each particular installation needs its own approach.

Two-fluid lances (pneumatic) seem to be the most appropriate for introduction of a reductive component into purified exhaust gases.

The proper test stand and research methodology enable for determination of complete characteristic of the spraying lance.

The ratio of a mass flow of gas phase to a mass flow of liquid phase (ALR) is the basic parameter which influences the Sauter diameter of the formed drops (d_{32}).

Two-fluid lances guarantee appropriate kinetic energy of the drops enabling deep penetration into exhaust gases flux in a small burning chamber of low power boilers.

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