Part 1

AIR PROTECTION FROM POWER INDUSTRY EMISSIONS

1.3. Sulfur oxide emission reduction

1.3.2. Technologies of sulfur oxide emission reduction

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Brief description of desulfurization technologies and installations

More than 400 methods based on different chemical and physical principles are proposed to remove sulfur dioxide from flue gases:

- chemical binding with formation of the recoverable and unreclaimable wastes;
- selective sorption by solid substances (activated carbon, zeolites, resins) with the following regeneration of sorbents;
- selective liquid-phase sorption by specific organic liquids;
- conversion of sulfur dioxide to trioxide in the gas phase using catalysts or special electrical discharges;
- liquid-phase catalytic reduction of sulfur dioxide to elemental sulfur.

About 20 ways, ensuring SO_2 removal with acceptable technical and economical indicators, are applied in practice. Technologies using calcite and limestone are: wet limestone, wet lime, wet-dry limestone, dry limestone are most often applied in the world practice for desulfurization of flue gases.

Due to these technologies, installations at more than 400 industrial power boilers, mainly, of large capacity, are constructed despite of the large amount of desulfurization wastes formed.

Different classification of desulfurization technologies is possible. The following main classifications of desulfurization technologies are applied world-wide: by aggregative state of input reagents and wastes formed and by multiplicity of the reagents application, listed in Tabs. 1.16 and 1.17.

Table 1.16. **Classification of desulfurization technologies by aggregative state of input reagents and wastes formed**

Dry technologies	Wet-dry technologies	Wet technologies
Dry limestone Dry lime Dry soda	Simplified wet-dry (E-SOx technology) With hollow absorber-dryer With circulating inert mass	Ammonia-cyclical Magnesite cyclical technology With Venturi scrubbers Wet limestone Dry limestone Ammonium-sulfate (AST) Natrium sulfite-bisulfite (double alkaline)

Table 1.17. **Classification of desulphurization installations by multiplicity of reagent application**

Multiplicity of reagent usage	The effectiveness of desulfurization, %	Aggregative state of reagents and waste	Duration during the boiler operation	Combination with the boiler or other equipment of the boiler
Single (non regenerative technologies)	Low, less than 35	Dry (dry reagents and wastes)	Periodical (seasonal) operation	Combined with the boiler
Multiple (regenerative technologies)	Average, 35 ... 70	Wet-dry (liquid reagents, dry wastes)	Permanent operation	Combined with ash collectors
	High, 70	Wet (reagent and wastes in the form of suspension or solution)		Special apparatus

Dry desulfurization technologies. They are technologies, when dry reagents are loaded into the boiler furnace, convection pass of the boiler or into the gas flue of flue gases. In this case, the following reactions occur:

$$CaCO_3 \rightarrow CaO + CO_2;$$

$$CaO + SO_2 + {}^1/_2O_2 \rightarrow CaSO_4;$$

$$Na_2CO_3 + SO_2 + {}^1/_2O_2 \rightarrow Na_2SO_4 + CO_2.$$

Wet-dry desulfurization technologies. Desulfurization technology is called a wet-dry one, if the reagent is loaded into flue gases in a form of finely dispersed drops of the aqueous suspension or aqueous solution, evaporating in flue gases. It results in obtaining the reacted substance in a dry form at the absorber outlet. At that the following reaction occurs:

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 \cdot {}^1/_2H_2O + {}^1/_2H_2O.$$

Injection of the reagent in a liquid form accelerates the process of SO_2 sorption, since the reagent and sulfur dioxide are present in water as ions, which accelerates their interaction as compared to dry technologies, and reduces the reagent excess in relation to SO_2.

In wet-dry technology it is important to choose a size of drops of the aqueous suspension or aqueous solution of reagent, depending on the temperature of gases and required efficiency of desulfurization in order to provide the necessary binding of sulfur dioxide before the drops evaporation, when the sorption process practically stops.

Wet desulfurization technologies. In the wet desulfurization technologies flue gases are washed intensively with the aqueous suspension or aqueous solution, which ensures dissociation of the reagent on ions. In the process of gas washing, the collected sulfur dioxide dissolves in water and also transfers to the ionic form of SO_3^{2-}. It maximally accelerates its binding by the reagent. Regenerative and non-regenerative wet technologies are used. At that the following reactions occur:

$$SO_2 + H_2O = H_2SO_3;$$
$$SO_3 + H_2O = H_2SO_4;$$
$$CaCO_3 + CO_2 + H_2O = Ca(HCO_3)_2;$$
$$Ca(HCO_3)_2 + H_2SO_3 = CaSO_3 \cdot {}^1/_2H_2O + {}^3/_2H_2O + 2CO_2;$$
$$Ca(HCO_3)_2 + H_2SO_4 = CaSO_4 \cdot 2H_2O + 2CO_2;$$
$$CaO + H_2O = Ca(OH)_2;$$
$$Ca(OH)_2 + H_2SO_3 = CaSO_3 \cdot {}^1/_2H_2O + {}^3/_2H_2O;$$
$$Ca(OH)_2 + H_2SO_4 = CaSO_4 \cdot 2H_2O.$$

An amount of spraying water, containing the reagent, is usually large, so that using flue gas heat, less than 0,5% of water can be vaporized. At that flue gases are highly cooled up to the wet-bulb temperature (dew point of water vapor). This is the reason that in wet technologies the purified flue gases are always additionally heated to avoid corrosion of the following gas path, including smoke exhausters and chimney.

The main technical and economic indicators of desulfurization installations

Technical indicators of desulfurization installations are the following:

- flow rate of the purified flue gases (m^3/h, m^3/s);
- desulfurization efficiency, actual and achievable (%);
- specific emission of sulfur dioxide with the purified gases (g/MJ) [SO_2 concentration in the purified gases (g/m^3; mg/m^3; ppm)];
- reagent, its toxicity;
- excess of the reagent relative to the stoichiometric ratio of reagent/SO_2;
- hydraulic resistance of the installation gas path (Pa, kgs/m^2);
- specific rate of the reagent, referred to 1 m^3 of the purified gases under normal conditions: 0 °C, 760 Mmhg (kg/m^3 l/m^3);
- temperature of the purified flue gases (°C);
- temperature of the purified flue gases behind the installation and in front of the smoke exhauster (chimney) (°C);
- absolute and specific rates of the supplemental working environments - water, air, steam (kg/h, kg/s, kg/m^3 kg/1000 m^3);
- dust content of the purified flue gases (g/m^3, mg/m^3);
- a number of hours of the installation operation in a year;
- stable operation build-up time (h);
- possible operation at the boiler load change (a range of flow rate of the purified flue gases).

Economic indicators of desulfurization installations include:

- specific capital investments (rub/kW);
- specific operational costs (cop/(kW h));
- sulfur dioxide collection costs (rub/t);
- specific energy consumption (% of the power unit capacity or equivalent boiler capacity);
- specific costs of waste or commercial products of desulfurization (rub/t);
- specific area for mounting the equipment in a cell of the power unit or the boiler and on the general layout (m^2/kW).

Hereafter is a brief description of the key desulfurization technologies.