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INFLUENCE OF DROPLET SEPARATION EFFICIENCY FROM GAS AFTER CONTACT WITH LIQUID IN SPRAY SCRUBBERS ON GAS CLEANING EFFICIENCY

The paper presents the equation representing the dependence of such parameters as: gas cleaning efficiency in scrubber, a pollutant concentration in an inlet gas stream, an initial pollutant concentration in liquid being dosed to the scrubber, a pollutant concentration in a liquid flowing out from apparatus, a ratio of sprayed liquid volume stream to gas volume stream, and circulation number of sprayed liquid in apparatus on an actual gas cleaning efficiency in plant.

NOMENCLATURE

G – volumetric flow rate of gas, m^3/h,
C_{c1} – pollutant concentration in liquid at scrubber inlet, g/m^3,
C_{c2} – pollutant concentration in liquid at scrubber outlet, g/m^3,
C_{cp} – initial pollutant concentration in liquid being dosed to scrubber, g/dm^3,
C_{g1} – pollutant concentration in gas at scrubber inlet, g/m^3,
C_{g2} – pollutant concentration in gas at scrubber or droplet separator outlet, g/m^3,
C_{gt} – theoretical pollutant concentration in gas at scrubber outlet (if there is no liquid being flowing out from scrubber), g/m^3,
C_{guk} – pollutant concentration in liquid droplets carried by gas, g/m^3,
d_1 – humidity in gas at scrubber inlet, g/kg of dry gas,
d_2 – humidity in gas at scrubber outlet, g/kg of dry gas,
L – volume stream of liquid being dosed to scrubber, dm^3/h,
n – number of liquid circulations in plant,
U'_k – liquid concentration in gas before its entering a droplet separator, g/m^3,
U''_k – liquid concentration in gas after its leaving a droplet separator, g/m^3,
η – actual gas cleaning efficiency in plant,
η_n – actual gas cleaning efficiency after the *n*-th circulation of absorption liquid through plant,
η_t – gas cleaning efficiency of scrubber (without pollutant in liquid droplets leaving scrubber).

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1. INTRODUCTION

The liquid in the installations for flue gas dedusting and cleaning gaseous pollutants circulates in the following system: tank – pump – apparatus for cleaning post-process gases – tank. During multiple circulation liquid is enriched with solid particles contained in the gases subjected to dedusting, particles being the products of chemical reactions and the compounds absorbed in the particles of flue gases. Afterwards, the solid particles are removed from the liquid or it is neutralized in further stages. However, the properties of the liquid obtained differ from the properties of liquid before flue gas cleaning. Simultaneously with conducting the process, a stream of gases being cleaned entrains the droplets of process liquid from each wet deduster or absorber. The entrainment and the transport of liquid droplets can be responsible for numerous construction and exploitation problems. It can also have negative influence on the purity of atmospheric air, surface waters and soil. Droplet separators and demisters installed inside or outside scrubbers eliminate this disadvantageous phenomenon, which occurs in many apparata used in order to allow the gas–liquid contact. Their efficiency affects greatly the emission of pollutants into environment. Effect of flue gas cleaning in scrubber, which can be sufficient to preserve emission standards, may be destroyed by ineffectively working droplet separator and as a consequence the actual emission of pollutants into the atmospheric air will be greater than permissible one.

2. THE INFLUENCE OF DROPLETS SEPARATION IN SCRUBBER ON FLUE GAS CLEANING EFFICIENCY

The influence of blowing away the droplets of liquid from scrubber on the gas cleaning efficiency was investigated in the installation with vertical countercurrent spray scrubber (figure 1).

The equation representing the balance of pollutant being removed in scrubber for a single contact of liquid with gases being cleaned can be written as follows:

$$C_{g1} + (L/G)\, C_{c1} = C_{g2} + (L/G)\, C_{c2} \,. \tag{1}$$

The gas humidity at the inlet (d_1) and outlet (d_2) compared with that in the volume stream of liquid dosed to scrubber is small enough to be excluded from further considerations.

An efficiency of gas cleaning in the installation is described by the following equation:

$$\eta = \frac{C_{g1} - C_{g2}}{C_{g1}} = 1 - \frac{C_{g2}}{C_{g1}} \,. \tag{2}$$

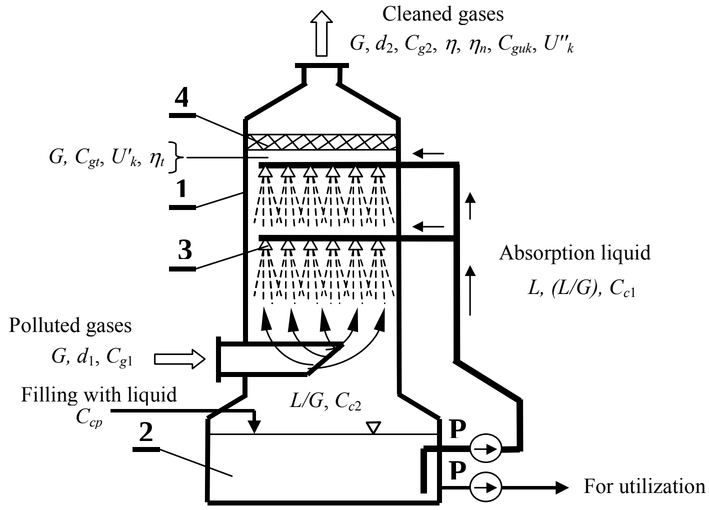

Fig. 1. The outline of absorption system and balance of pollutant being removed in installation with a circulation of absorption liquid: 1 – absorber, 2 – absorption liquid tank, 3 – spraying nozzle, 4 – inertial droplet separator, P – pump

A final concentration of the pollutant absorbed in gases at the outlet of scrubber (without droplet separator) or droplet separator is:

$$C_{g2} = C_{gt} + C_{guk} . \tag{3}$$

Based on equations (3) and (2) we arrive at:

$$\eta = 1 - \frac{C_{gt}}{C_{g1}} - \frac{C_{guk}}{C_{g1}} , \tag{4}$$

$$\eta_t = 1 - \frac{C_{gt}}{C_{g1}} . \tag{5}$$

Equation (5) describes a cleaning efficiency of flue gas in scrubber after the process of absorption conducted inside (without considering the droplet separation).

The concentration of pollutant separated on liquid droplets is proportional to the amount of liquid separated in the from of droplets, and the concentration of the pollutant absorbed by liquid reaches:

$$C_{guk} = U_k C_c . \tag{6}$$

The substitution of equations (5) and (6) for equation (4) gives:

$$\eta = \eta_t - \frac{U_k C_c}{C_{g1}}. \tag{7}$$

The concentration of pollutant C_{c1}, C_{c2} in droplets of liquid separated and actual process efficiency η are changing during the flue gas cleaning with every return of liquid to the scrubber (n), and the pollutant concentration in the liquid dosed to scrubber is equal to its concentration in liquid drained from scrubber after a previous contact with gases and return to scrubber. Therefore:

$$C_{c1(n)} = C_{c2(n-1)}. \tag{8}$$

Thus, equation (7) can be formulated as follows:

$$\eta_n = \eta_t - \frac{U_k C_{c2(n-1)}}{C_{g1}}. \tag{9}$$

Based on equations (1) and (2) it can be concluded that:

$$C_{c2(n)} = C_{c2(n-1)} + \frac{C_{g1}\eta_n}{U_k}. \tag{10}$$

After substitution of equation (10) for equation (9) we obtain:

$$C_{c2(n)} = \frac{C_{g1}\eta_t}{U_k} + C_{c2(n-1)}\left(1 - \frac{C_{guk}}{U_k}\right). \tag{11}$$

In order to simplify the notation, the constants in equations (7) and (11) were defined as follows:

$$\frac{C_{g1}\eta_t}{U_k} = A, \quad \left(1 - \frac{U_k}{\left(\frac{L}{G}\right)}\right) = B, \quad \frac{U_k C_{cp}}{C_{g1}} = D.$$

For consecutive circulations of liquid dosed to scrubber (n = 1, 2, ..., n) equation (9) can be reformulated:

$$\eta_1 = \eta_t - \frac{U_k C_{cp}}{C_{g1}}, \tag{12}$$

$$\eta_2 = \eta_t - U_k \frac{A}{C_{g1}} - DB, \tag{13}$$

$$\eta_n = \eta_t - U_k \frac{A}{C_{g1}}(1 + B + B^2 + B^3 + ... + B^{n-2}) - DB^{n-1}. \tag{14}$$

The expression enclosed in brackets in equation (14) is in the form of a decreasing geometric sequence with the multiplier *B* and the sum of terms equal to:

$$S_n = \frac{1 - B^{n-1}}{1 - B}.$$

In that case, equation (14) becomes:

$$\eta_n = \eta_t - \frac{U_k A}{C_{g1}} \cdot \frac{1 - B^{n-1}}{1 - B} - DB^{n-1}. \tag{15}$$

By inserting expressions *A*, *B* and *D* into equation (15) we obtain:

$$\eta_n = \left(\eta_t - \frac{U_k C_{cp}}{C_{g1}} \right) \left(1 - \frac{U_k}{L/G} \right)^{n-1}. \tag{16}$$

The dependence (16) obtained allows the actual flue gas cleaning efficiency to be determined (with taking into considerations the pollutant carrying away by liquid droplets) for any multiplicity of liquid circulation in scrubber. To calculate the efficiency of gas cleaning the concentration of pollutant at the scrubber inlet (C_{g1}), the concentration of liquid in the gas leaving the scrubber (U_k), the initial concentration of pollutant in liquid (C_{cp}), L/G ratio and the theoretical efficiency of pollutant removal in the scrubber (η_t) have to be known.

3. INFLUENCE OF DROPLET REMOVAL EFFICIENCY ON GAS CLEANING EFFICIENCY

The influence of the removal of liquid droplets absorbed on the actual flue gas cleaning efficiency is examplified by installation in which hydrogen fluoride is absorbed in water. The volume stream of flue gas at 22500 m^3/h flow rate is cleaned in countercurrent vertical spray scrubber of 2.0 m in diameter, to which water is dosed at the rate of 100 m^3/h (L/G = 4.44 dm^3/m^3). Hydrogen fluoride whose concentration in a gaseous phase at a scrubber inlet reached 1.5 g/m^3 is absorbed by a liquid (in absorber) with the efficiency of 98%. In the stream of cleaned gas that leaves a scrubber, the concentration of droplets is 3 g/m^3. The concentration of absorbed hydrogen fluoride increases as a result of water circulation in installation, therefore its concentration in droplets leaving the scrubber also increases.

If there is no droplet separator in the installation, the actual efficiency of hydrogen fluoride removal from flue gas will decrease by about 65% (from 95% to about 30%), as early as after the second circulation of liquid. When the sixth circulation of water is completed, the actual efficiency of hydrogen fluoride removal drops to zero, although it is still being removed in scrubber with 95% efficiency (figure 2).

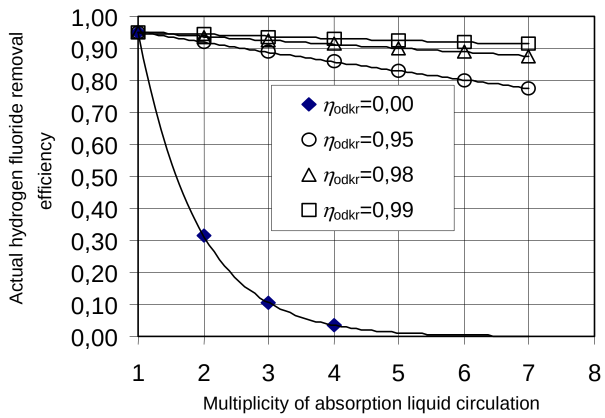

Fig. 2. The dependence of actual efficiency of hydrogen fluoride removal on the number of absorption liquid circulations and the efficiency of droplet removal from flue gases in installation

This results from the analysis of the variation in the efficiency of flue gas cleaning with a liquid circulation in the installation where the droplet separator has to be installed in the scrubber or outside the scrubber. The droplet collector installed should provide such an efficiency of droplet removal from the stream of cleaned air that hydrogen fluoride emission from installation (in gaseous phase and droplets) does not exceed the permissible value. A decrease in the efficiency of flue gas cleaning, in the absence of droplet separator or usage of an ineffective device for removing droplets from scrubber, is often observed in the industrial systems.

PIKOŃ [1] mentions the results of separating droplets by Michajlow in a horizontal countercurrent spray scrubber, in which liquid was sprayed by hydraulic atomizers under the pressure of 0.2–0.3 MPa. The spectrum of droplet diameters produced in such conditions shows the so-called heavy liquid spraying characterized by an average volume-surface droplet diameter greater than 350 μm. The influence of gaseous phase velocity on a liquid removal from the scrubber is presented in figure 3 (PIKOŃ [1]).

Figure 3 shows that gaseous phase velocities higher than 1.0 m/s in countercurrent spray scrubbers result in a high ratio of droplet separation. That is why a recommendation to not exceed such a velocity in spray scrubbers is given in many handbooks.

Fig. 3. Influence of gaseous phase velocity on liquid removed from scrubber

Nowadays, even a gaseous phase velocity of 6–8 m/s is applied because excellent constructions of inertial droplet separators are developed and practically used. The values of liquid separation in different types of absorbers and wet dust collectors can be calculated based on the equations given by RAMM [2].

4. CONCLUSIONS

During flue gas cleaning in countercurrent spray scrubbers, in which practically used gas velocities exceed nowadays 3.0 m/s, the removal of a liquid sprayed in scrubber is higher than 10%.

In the case of closed circulation of absorption liquid, the droplets leaving scrubbers may have very disadvantageous influence on the actual flue gas cleaning efficiency and may cause a significant loss of liquid circulating in scrubber, a secondary emission of pollutants included in droplets of liquid being removed into the atmosphere as well as a corrosion of installation elements located after the scrubber.

Droplet separators of high droplet removal efficiency (exceeding 98%) should be used to minimize the amount of liquid droplets leaving scrubber and entering the atmosphere, and other related phenomena.

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[2] RAMM W.M., *Absorbcija gazow*, Izd. Chimija, Moscow, 1976.

ZALEŻNOŚĆ SKUTECZNOŚCI OCZYSZCZANIA GAZÓW W INSTALACJI
OD SKUTECZNOŚCI ICH ODKRAPLANIA
PO KONTAKCIE Z CIECZĄ W APARATACH NATRYSKOWYCH

Podano równanie opisujące zależność rzeczywistej skuteczności oczyszczania gazów odlotowych w instalacji od skuteczności oczyszczania gazów w skruberze, stężenia usuwanego zanieczyszczenia w gazach na wlocie do skrubera, początkowego stężenia zanieczyszczenia w cieczy podawanej do skrubera, unosu kropel tej cieczy z aparatu natryskowego, stosunku strumienia objętości rozpylanej cieczy do strumienia objętości oczyszczanych gazów i krotności tej cyrkulacji w obiegu tego aparatu.