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INTENSIFICATION OF GAS PURIFICATION
IN IMPINGING-STREAM SCRUBBERS

The results of the model calculations of SO_2 absorption in spray absorber and in impinging-stream scrubber have been presented. The results of investigation have confirmed the assumption that intensification of the absorption occurs in impinging-stream scrubbers. A significant absorption activation was observed on an impinging-streams level, where droplet hold-up and mass transfer surface are greatest.

LIST OF SYMBOLS

a_k	– mass transfer surface	m^2/m^3,
$K_{g,j}$	– mass transfer coefficient in the layer j	$kmol/(m^2 \cdot s \cdot kPa)$,
$k_{g,j}$	– mass transfer coefficient on gas side in the layer j	$kmol/(m^2 \cdot s \cdot kPa)$,
P	– overall pressure	kPa,
$P_{SO_2,j}^{\bullet}$	– equilibrium partial pressure of SO_2 in the layer j	kPa,
$p_{SO_2,j}$	– partial pressure of SO_2 at the beginning of the layer j	kPa,
R	– constant	$kJ/(kmol \cdot K)$,
$R_{SO_2,j}$	– flux of SO_2 in the layer j	kmol/s,
T	– gas temperature	K,
u_g	– gas velocity in absorber	m/s,
$\dot{V}_g$	– gas flux	m^3/s,
Δz	– layer height	m,
ρ_m	– molar density	$kmol/m^3$.

1. INTRODUCTION

The intensification of mass transfer process in absorbers is one of the most important problems in designing and exploitation of those apparata.

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Absorption activation takes place during use of impinging-streams scrubbers. Due to high velocity of primary streams (before collision) both the droplet diameter and the mass transfer resistances decreased. High velocity of droplets after streams' collision effect increased the hold-up of droplets in the section of absorption and the surface of mass transfer. Flux of gas and liquid after collision of liquid streams is similar to the flux in crossed systems. In spray absorbers with counter-current flux, a high velocity at the nozzle outlet caused mass transfer resistances to decrease; on the other hand, the time of droplet hold-up in absorption section was shortened. The results of calculation have shown that for the same droplet diameter in both absorbers the effect of hold-up time is dominant, which results in a decrease in absorption rate at higher velocity at the nozzle outlet.

One of the most important problems which occur during absorption in slurry is generation of sufficiently small droplets and generation of a large mass transfer surface. A lot of desulphurization processes are based on absorption in slurry. The slurry contains particles whose size approaches tens μm. Because of such large particles also the orifices of the nozzles used have to be large and therefore, the size of the droplets generated is big. The nozzles used in flue gas desulphurization generate the droplets whose size ranges from 1200 to 1500 μm. These are only initial parameters of the nozzle operation. When the process takes place, the presence of particles in the slurry and conditions which are conducive to crystallization cause rather rapid deterioration of the characteristics of the droplets generated. When impinging-stream scrubbers are used, these problems virtually do not occur, because droplets are generated after collision of streams.

In an available literature, a lot of papers deal with generation of droplets and their flow after collision of streams [1], but only few articles discuss the usage of impinging-streams in absorption process.

2. THE MODEL OF SO₂ ABSORPTION IN THE DROPLETS OF LIMESTONE SLURRY

The model of SO_2 and HCl absorption in the droplets of slurry was presented by SZYMANOWSKI [2] and SZYMANOWSKI, WARYCH [3]. Basic assumptions of the process model are as follows:

1. In the case of SO_2, mass transfer resistance is observed in gaseous and liquid phases.

2. It is assumed that the overall mass transfer coefficient for chlorides depends on the mass transfer resistance on the gas side and $K_{g,j}^{HCl} = k_{g,j}^{HCl}$.

3. The shape of drop is spherical.

4. There are uniform conditions in every point inside a drop, which provides an

ideal mixing state.

5. Absorption zone was divided into layers. The concentrations of SO_2 and HCl in gases change with the height of absorption zone.

6. It is assumed that in spray absorber, the conditions inside the drops are the same in a given layer. Conditions in the subsequent layers change, depending on the compounds absorbed in higher layers.

7. Scrubber with impinging streams was divided into two parts: the first region – above the stream-collision level, and the second – below this level. Conditions inside the drops in the first region were calculated as mean conditions at the inflow to the region and at the outlet from the region. In the second region, the assumptions for calculation of conditions inside the drops of each layer are the same as the assumptions for spray absorber.

8. There is assumed a thermodynamic equilibrium in the drops of a sorptive solution which comprises the following ions: OH^-, HSO_4^-, SO_4^{2-}, HSO_3^-, SO_3^{2-}, HCO_3^-, CO_3^{2-}, Cl^-, Mg^{2+}, Ca^{2+}, H^+ and such dissolved gases as SO_2 and CO_2

The balance of SO_2 being absorbed in each layer is described by the following equation:

$$\frac{\Delta z \cdot P \cdot a_k}{u_g \cdot \rho_m} = \frac{\ln\left[\dfrac{(p_{SO_2,j+1} - \overset{\bullet}{p}_{SO_2,j})}{p_{SO_2,j} - \overset{\bullet}{p}_{SO_2,j}}\right]}{K_{g,j}}. \tag{1}$$

Simultaneously, the following equation is satisfied:

$$R_{SO_2,j} = \frac{\overset{\bullet}{V}_g (p_{SO_2,j+1} - p_{SO_2,j})}{R \cdot T}. \tag{2}$$

Balance equation for chlorides is the same as that for SO_2, but the coefficient of overall mass transfer resistance is equal to the coefficient of mass transfer resistance on the gas side.

Mass transfer coefficients k_l and k_g were calculated depending on local conditions in a given layer. In the scrubber with impinging streams, inside one layer there are drops whose trajectories of flight are different and therefore their velocities in relation to the stream of gas and the residence time in layer also differ.

In the paper, the model of droplet motion after streams impinging was used to calculate mean transfer coefficients in each layer and the surface of interfacial area.

Equation by HSU and SHIH [4] has been used in order to calculate k_l. The coefficient of mass transfer on the gas side has been calculated according to the Frossling equation.

Ion concentration inside drops has been calculated according to the equations of ther-

modynamic balance including constants of reactions and electroneutrality condition. The calculation of equilibrium ion concentration at interface was based on the stagnant-film theory, and diffusion coefficients were modified to approximate the surface-renewal theory. In order to solve the problem, the following boundary conditions were accepted:

1. No net flux of calcium, magnesium, sulphate; the flux of charge equal to zero.

2. SO_2 transport to the interface is the same as sulphite transport inside liquid.

3. The flux of HCl to the interface is equal to the flux of Cl^- ions entering drop, $N_{g,\text{HCl}} = N_{c,\text{Cl}^-}$.

3. ANALYSIS OF MODEL CALCULATION RESULTS

The results of model calculations have been presented as the changes in the flux of SO_2 absorbed and a partial pressure of SO_2 versus the height of absorption section.

In order to compare the processes taking place in both absorbers, calculations were made for similar conditions. We calculated the following parameters: the L/G ratio, 10 dm^3/m^3; pH 5.5; the drop diameter, 1500 μm; chloride and sulfite concentration in the slurry, 0.1 $kmol/m^3$ and $0.2 \cdot 10^{-3}$ $kmola/m^3$, respectively; inlet SO_2 concentration, 3000 mg/m_n^3 (m_n^3 means cubic meters under normal conditions); inlet HCl concentration, 200 mg/m_n^3. The height of absorber was 2.0 m and the streams impinged on the level of 0.4 m.

Under these conditions, the efficiency of SO_2 removal in the spray scrubber reached 60.2% and in the scrubber with impinging stream – 77.6%.
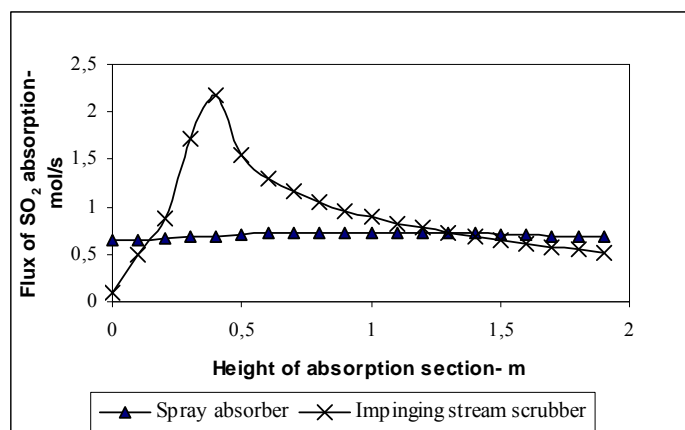

Fig. 1. The flux of SO_2 absorption in spray absorber and in impinging-stream scrubber versus the height of absorption section

The greatest differences in mass transfer rate in both absorbers appear near the impinging-streams level (figure 1). In impinging-stream scrubber, near this level, the greatest decrease in a partial pressure of SO_2 is also observed (figure 2). The reason for the absorption flux activation on this level is an increase in the droplet hold-up and an increase in the mass transfer surface. The profile of mass transfer surface in absorber is similar to the profile of absorption flux (figure 3).
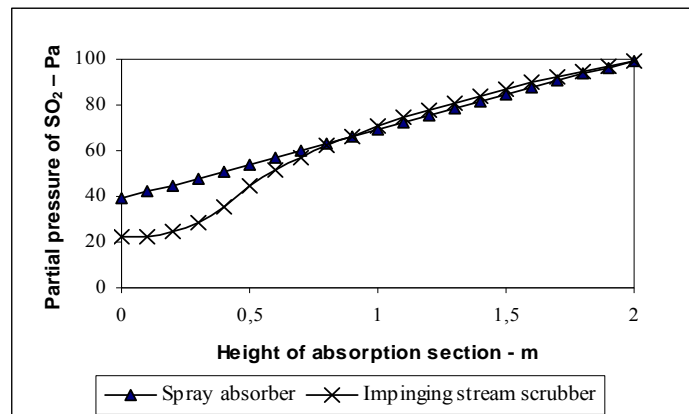

Fig. 2. Partial pressure of SO_2 in spray absorber and in impinging-stream scrubber versus the height of absorption section
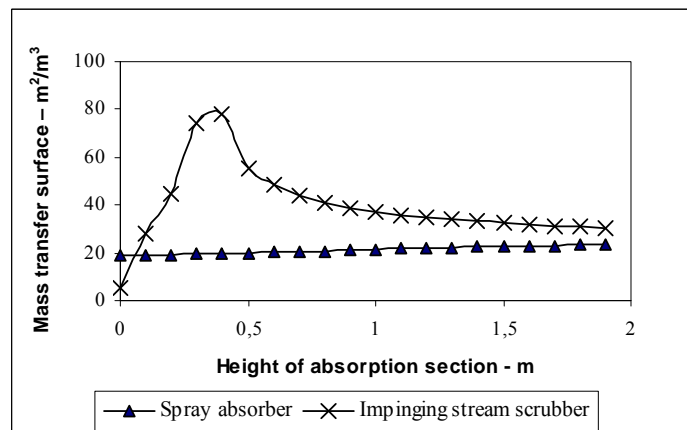

Fig. 3. Mass transfer surface in spray absorber and in impinging-stream scrubber versus the height of absorption section

Calculation for both absorbers was made at the same mean droplet diameter. In the scrubber with impinging streams, it is possible to obtain droplets smaller in size (as

described at the beginning of the article), which has even more positive impact on the absorption process.

4. CONCLUSIONS

The analyses show that it is possible to activate the absorption process in the impinging-stream reactor and simultaneously to reduce the size of absorber and to minimize cost investment. A very important advantage of such a reactor lies in eliminating the problems with spraying a slurry, clogging a nozzle and deteriorating its parameters.

The model offers a number of simplifications, especially in the parts which describe the movement of droplets after the collision of streams and mutual relationships between the drops from neighbouring nozzles. Because of these reason it is important to develop the model taking into account these phenomena.

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INTENSYFIKACJA OCZYSZCZANIA GAZÓW W SKRUBERACH ZDERZENIOWYCH

W pracy porównano wyniki obliczeń modelowych absorpcji SO_2 w absorberze natryskowym oraz absorberze ze zderzającymi się strugami cieczy (skruberze zderzeniowym). Uzyskane wyniki potwierdzają, że zastosowanie zderzających się strumieni cieczy intensyfikuje proces absorpcji. Istotne przyspieszenie tego procesu zaobserwowano w strefie zderzenia strug cieczy, gdzie zatrzymanie kropli i powierzchnia kontaktu międzyfazowego są największe.