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Comprehensive Study of Hydraulic and Mass-Transfer Characteristics Determination under Absorption Conditions Performed on Structured Packings Raschig Super-Pak

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This paper refers on the hydraulic and mass-transfer characteristics of several high capacity structured packings Raschig Super-Pak (RSP250Y, RSP350Y, RSP500Y) under absorption conditions. Measurements were performed in column with inner diameter 0.15 m. The comparison with data published in Rejl et al. (2015) for structured packing Raschig Super-Pak 250Y performed in column with inner diameter 0.29 m allows unique assessment of column diameter effect on hydraulic and mass-transfer characteristic of packings. Such study should provide an answer whether is it possible to acquire or under which experimental conditions obtain a reliable hydraulic and mass-transfer characteristics of packing on the columns, from industrial point of view, with small diameter. Obtained characteristics on packings with three different geometric areas enable the evaluation of geometric area effect on the hydraulic and mass-transfer characteristics.

1. Introduction

The standardization of the measuring method for the determination of packing separation efficiency should start with a full understanding of all the conditions that affect its measurements in order to maintain them at the identical level during the measurement of different packings with the aim of comparing or evaluating the effects of the geometric modification of newly developed/designed packings. The current state of the art is such that the scatter of mass-transfer characteristics measured by different teams on the same packing can hide the separation efficiency improvements of newly developed packings.
There are only a few studies in the literature that deal with the effects of the column diameter on pressure drop and on mass-transfer characteristics. Random packings in columns with a smaller diameter achieve lesser pressure drops. The packing density close to the column wall (the number of packing pieces per unit volume) is lower in comparison to the bulk which resulting in a lower local pressure drop. In small columns, there is a comparatively higher proportion of gas or vapor channels along the walls which results in a lower pressure drop in comparison to columns with a wider diameter (Valenz et al. 2013).
In Olujic (1999) is shown that in columns with a smaller diameter the Montz B1−250 structured packing has shown substantially higher pressure drops in comparison with the drops measured in columns of a larger diameter. There was recommended to use columns with a diameter of at least 0.4 m for obtaining reliable data which would make the equipment and its operation more expensive and might discriminate against academic research which is usually conducted in columns with smaller diameters.
This paper therefore focuses on column diameter effect on hydraulic and mass-transfer characteristic of modern high-capacity packing Raschig Super-Pak. The packing is fundamentally different to the well-known corrugated perforated or non-perforated, textured sheet metal structured packings. It consists of a systematic sequence of smooth sinusoidal waves above and below the plain of the metal sheet. As the both sides of the channel are formed by the single sheet of the metal which alternately forms its upper and lower side, the channels are 50 % open and thus the intense radial mixing of the phases can be anticipated.

2. Experimental

The experiments were carried out in the automatically controlled column with a 0.15 m inner diameter. The measurements were performed with different amount of packing elements from 1 to 6 in order to subtract the end effects and verify the experimental methodology. Influence of packing height and tracer concentration on the hydraulic and mass-transfer characteristics is shown and discussed. Liquid distribution over the cross-section of the column was carried out by the pipe type distributor with drip-point density of 1,405 dp/m^2. Gas entered the column through a large drum where the flow was calmed and preceded into the column through the grid which secured its uniform distribution.
Pressure drop of the packing has been measured with the air-water system. The pressure drop related to 1 m of the packing has been evaluated out of the relation Eq(1).

$$\frac{dp}{dh} = \frac{p^{in} - p^{out}}{H} \qquad (1)$$

Volumetric mass-transfer coefficient in the liquid phase, k_La, has been measured by oxygen striping from the water to the stream of the nitrogen. The system exhibits mass-transfer resistance solely in the liquid phase. k_La has been evaluated from the oxygen concentrations in the liquid phase under the assumption of the plug flow of the liquid phase out of the relation Eq(2). The oxygen concentration has been measured by optical oxygen probes.

$$k_La = \frac{u_L}{H} ln \frac{c^{in}_{O_2,L}}{c^{out}_{O_2,L}} \qquad (2)$$

Volumetric mass-transfer coefficient in the gas phase, k_Ga, has been measured by sulfur dioxide absorption from the air into the aqueous solution of the sodium hydroxide. Due to the instantaneous reaction at the interface the system exhibits mass-transfer resistance solely in the gas phase. k_Ga has been evaluated from the sulfur dioxide concentrations in the gas phase under the assumption of the plug flow of the gas out of the relation Eq(3). The sulfur dioxide concentration has been measured by infrared analyzer (ppm) and UV fluorescence analyzer (ppb).

$$k_Ga = \frac{u_G}{H} ln \frac{c^{in}_{SO_2,G}}{c^{out}_{SO_2,G}} \qquad (3)$$

Effective interfacial area has been measured by absorption of the diluted CO_2 from the air into the aqueous sodium hydroxide solution, which is the system, where the gas-phase relative mass-transfer resistance is low and the rapid reaction of CO_2 with OH^- consumes quantitatively CO_2 within the liquid film. In such case, the mass-transfer rate is determined by the reaction-transport phenomena in the liquid film and is determined solely by the physical quantities of the system. Effective interfacial area can be calculated by combination of the relation for the CO_2 local mass-transfer rate and its balance along the height of the packing Eq(4). The carbon dioxide concentration has been measured by infrared analyzer and NaOH concentration by titration.

$$a = \frac{(K_{OG}a)_{CO_2}}{He\sqrt{D_{L,CO_2} k_{OH} c_{OH,ave}}} = \frac{1}{He\sqrt{D_{L,CO_2} k_{OH} c_{OH,ave}}} \frac{u_G}{H} ln \frac{c^{in}_{CO_2,G}}{c^{out}_{CO_2,G}} \qquad (4)$$

Value of the reaction term $He\sqrt{D_{L,CO_2} k_{OH} c_{OH,ave}} = 2.24 \cdot 10^{-3}\ m/s$ (20 °C and 1 M NaOH solution) was determined by still level experiments (Linek et al. 1995) as this procedure circumvents the errors induced by application of different physical data of solubility and diffusivity by the authors.

3. Results and discussion

3.1 Pressure drop

The methodology of pressure drop measurements on column with inner diameter 150 mm was verified by measuring on several packed bed heights – from 2 to 6 packing elements. It was found that pressure drop is not dependent on the packed height within the tested range. The pressure drop data of Raschig Super-Pak 250Y measured on dry (see Figure 1a) and wet (see Figure 1b) packing is in perfect agreement (relative deviation less than 4% for all liquid loads, B) in comparison with data obtained in columns with two-times and approximately three-times bigger in diameter. On the other it was found that observed capacity (loading and mainly flooding point) is up to 25% underestimated when it is determined in the column with small diameter. Unpublished pressure drop data in dependence on the F factor and liquid load are shown in Figure 2a for Raschig Super-Pak 350Y and Figure 2b for Raschig Super-Pak 500Y.

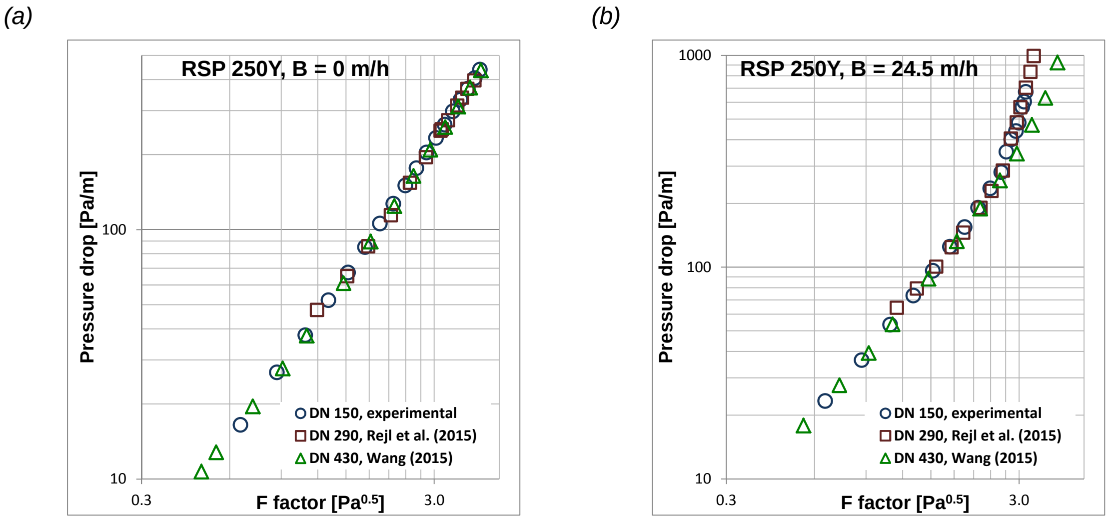

Figure 1: Assesment of the pressure drop dependance on the column diameter. Comparison of the Raschig Super-Pak 250Y pressure drop measured in three columns with different inner diameter (a) dry packing and (b) wet packing (B=24.5 m/h).

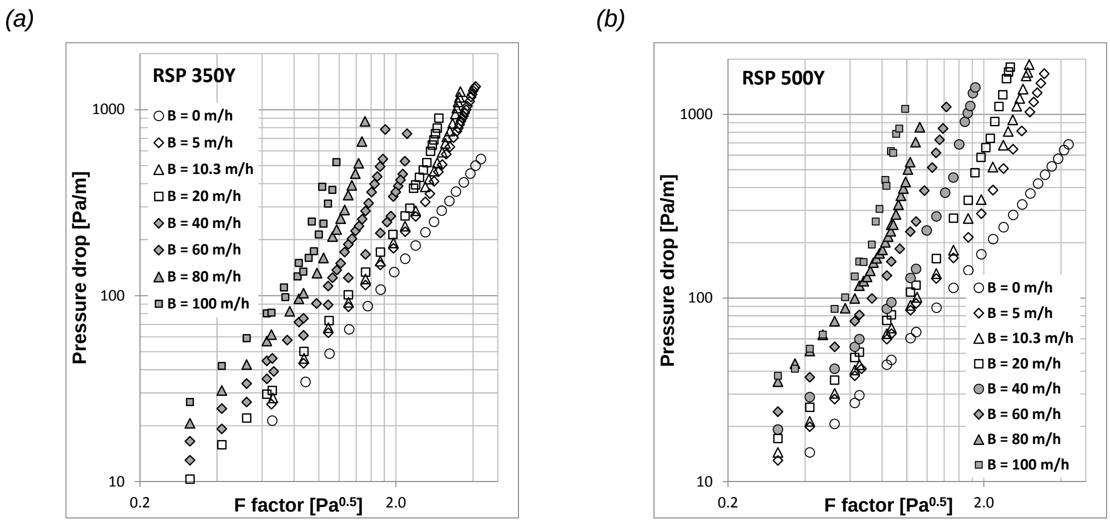

Figure 2: Pressure drop on dry and wet packing measured in column with inner diameter 150 mm (a) Raschig Super-Pak 350Y and (b) Raschig Super-Pak 500Y.

3.2 Volumetric mass-transfer coefficient in liquid phase

Experimental procedure and reliability of the measured k_La values was tested by measuring on four packed bed heights and with significantly different inlet concentration of oxygen. The values obtained on three different packed bed heights (one was use to subtract the end effects) together agree with average relative deviation 5%. The effect of inlet oxygen concentration on k_La values was studied by experiments with inlet water saturated by the air or the pure oxygen. It was found that the results do not differ by more than 5.5% (see Figure 3a). Net k_La values were compared with the ones obtained at the same working place and in the column with inner diameter of 290 mm (see Figure 3b). The worst relative deviation between k_La values measured in column with inner diameter 150 mm and 290 mm is 9 %. Therefore we can consider k_La values obtained in the column with inner diameter 150 mm transferable to industrial scale columns. Especially in columns with small diameter has to be payed attention on the packing wall wipers as was shown in Rejl et al. (2017).

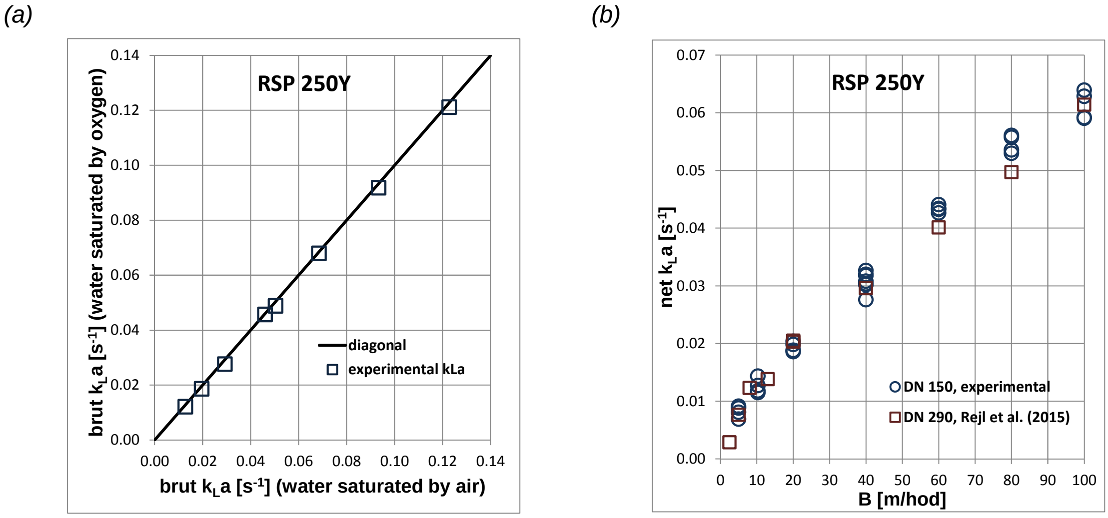

Figure 3: Comparison of the measured k_La values on Raschig Super-Pak 250Y (a) influence of inlet oxygen concentration and (b) column diameter effect.

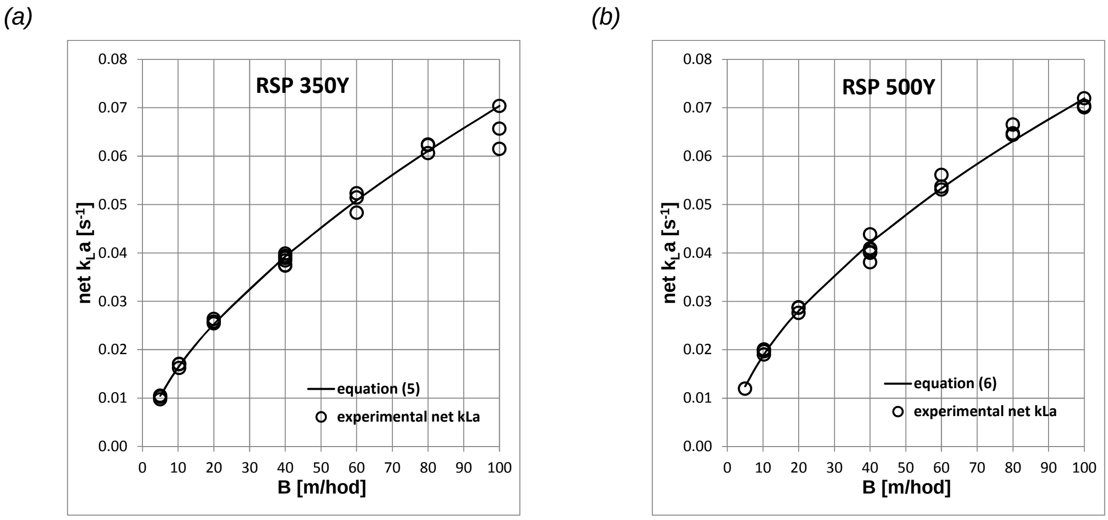

Figure 4: Values of k_La in dependence on the liquid load measured in column with inner diameter 150 mm (a) Raschig Super-Pak 350Y and (b) Raschig Super-Pak 500Y.

Evaluated values of k_La for high capacity structured packings Raschig Super-Pak 350Y and Raschig Super-Pak 500Y in dependence of liquid load are shown in Figure 4a and Figure 4b. The data were successfully correlated by power function (Equation 5 and 6) with average relative deviation of 3.1 % for both packings. Resulting powers of 0.64 and 0.59 coincide to the ones published for other structured packings. Net k_La values are highest for RSP 500Y and lowest for RSP 250Y but the increase does not correspond to the change of the geometric interfacial area.

$$k_L a_{RSP\ 350Y} = 0.00376 B^{0.636} \tag{5}$$

$$k_L a_{RSP\ 500Y} = 0.00486 B^{0.585} \tag{6}$$

3.3 Effective interfacial area

Measurements of effective interfacial area were performed on two packed bed heights and with significantly different inlet concentration of CO_2 in order to test experimental procedure and reliability of the methodology. The values obtained on two different packed bed heights together agree within the experimental data scatter.

It was observed that evaluated values of "*a*" depends on the inlet CO_2 concentration (see Figure 5a). Values increase with decreasing inlet concentration of CO_2 and limit to the values obtained in the column with inner diameter 290 mm. (see Figure 5b). Therefore it is recommended using as low as possible inlet CO_2 concentration for determination effective interfacial area in the columns with inner diameter 150 mm or lower.

(a) *(b)*

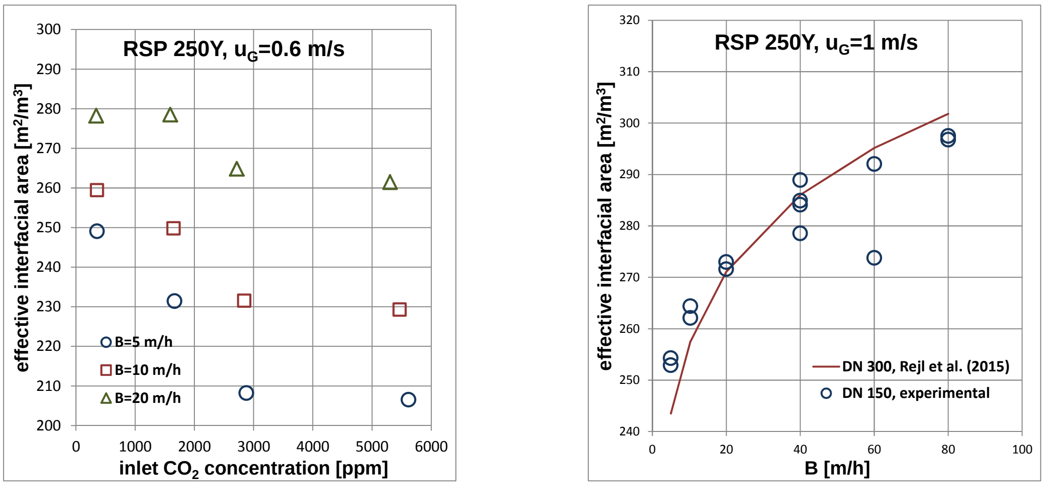

Figure 5: Comparison of the measured effective interfacial area values on Raschig Super-Pak 250Y (a) influence of inlet CO_2 concentration and (b) column diameter effect.

Evaluated values of "*a*" for high capacity structured packings Raschig Super-Pak 350Y and Raschig Super-Pak 500Y in dependence of liquid load and gas velocity are shown in Figure 6a and Figure 6b. The data were successfully correlated by power function (Equation 7 and 8) with average relative deviation of 1.5 % for both packings. Resulting powers shows slight dependence on the liquid load and almost negligible dependence on the gas velocity. Values of "*a*" are highest for RSP 500Y and lowest for RSP 250Y but the increase does not correspond to the change of the geometric interfacial area.

(a) *(b)*

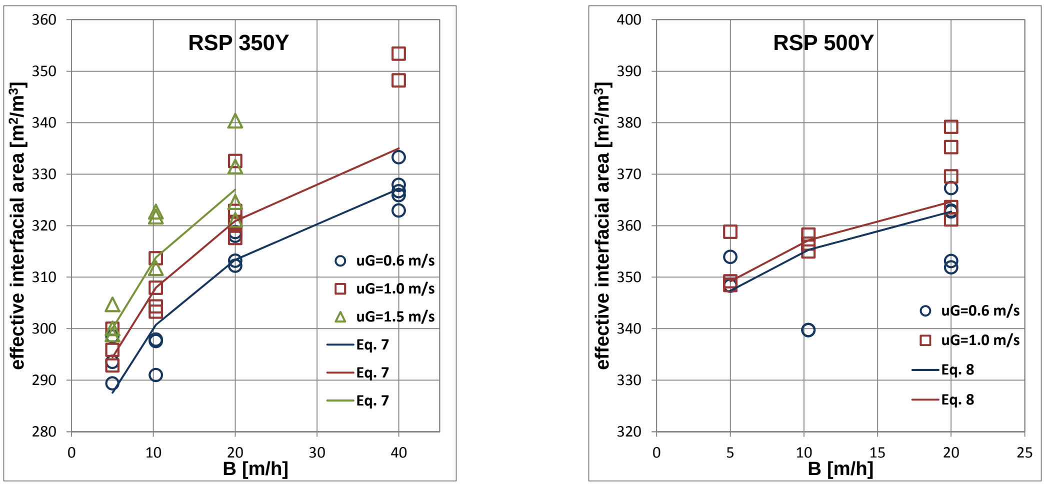

Figure 6: Values of effective interfacial area in dependence on the liquid load and gas velocity measured in column with inner diameter 150 mm (a) Raschig Super-Pak 350Y and (b) Raschig Super-Pak 500Y.

$$a_{RSP\ 350Y} = 266B^{0.062}u_G^{0.046} \quad (7)$$

$$a_{RSP\ 500Y} = 332B^{0.031}u_G^{0.010} \quad (8)$$

3.4 Volumetric mass-transfer coefficient in gas phase

During the measurements of k_Ga, strong dependence of k_Ga on the inlet SO_2 concentration was found (see Figure 7a). k_Ga values increase with decreasing inlet concentration of SO_2 and with six-fold change k_Ga values will increase by about 25%. This effect is independent on the packed bed height as it was found for the measurements on 2, 4 and 6 packing elements. The effect slightly decreases with increasing liquid flow rate. The data obtained for lowest inlet SO_2 concentration were compared with the ones published in Rejl et al. (2015) obtained in the column with inner diameter 290 mm (see Figure 7b). Despite all the experimental efforts, it has not been possible to achieve k_Ga values better than approximately 25% lower in comparison with data measured in column with 290 mm inner diameter.

(a) *(b)*

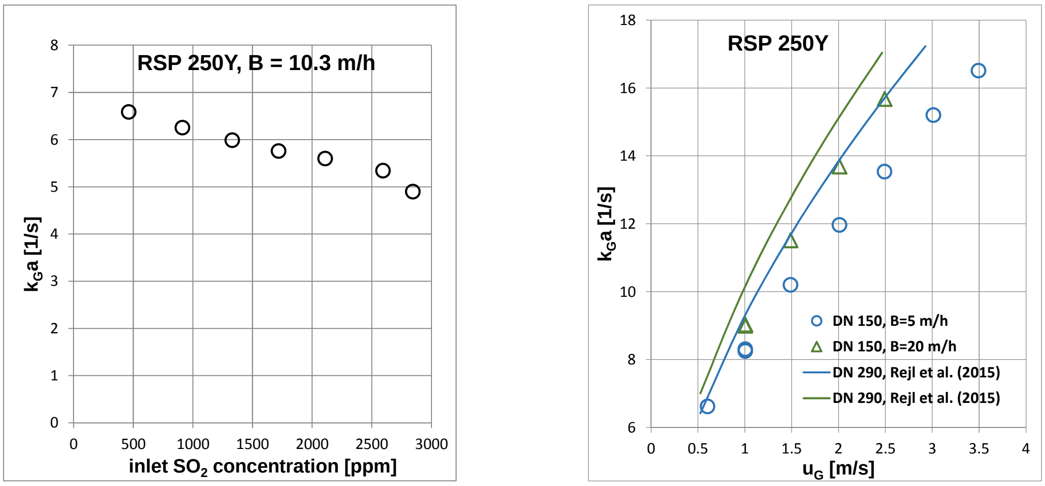

Figure 7: Comparison of the measured k_Ga values (obtained on 4 packing elements) on Raschig Super-Pak 250Y (a) influence of inlet SO_2 concentration and (b) column diameter effect.

4. Conclusions

The effect of the column diameter and the packing height on the mass-transfer characteristics and the pressure drop are evaluated on the basis of the data measured in columns with diameters of 0.15, 0.29 and 0.43 m packed with RSP 250Y. It was found that below the loading point, the difference between the pressure drops was within the experimental data scatter. On the other it was found that observed capacity (loading and mainly flooding point) is up to 25% underestimated when it is determined in the column with small diameter. Determination of k_La values is reliable and transferable to industrial scale column same as measurement of effective interfacial area with low inlet CO_2 concentration (up to 500 ppm). k_Ga measurement should be performed with as low as possible inlet SO_2 concentration but such obtained values are approximately 25% lower. This paper also presents measured and evaluated hydraulic and mass-transfer characteristics of RSP 350Y and RSP 500Y which has never been published.

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