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# THE EFFECTS OF OPERATING CONDITIONS ON THE PRESSURE VARIATION AT THE BOTTOM OF A 16.6 CM I.D. RECIPROCATING PLATE COLUMN

*The effects of the intensity of vibration, superficial gas velocity, content of solid particles and rheology of the liquid phase on the total and time–averaged pressure variation at the bottom of a 16.6 cm i.d. reciprocating plate column were studied. The total and time–averaged pressure variation at the column bottom were found to increase with increasing vibration intensity, liquid viscosity and content of solid particles, but to decrease with increasing superficial gas velocity. The pressure variation at the column bottom was greater in the column filled with CMC solutions than in the one with distilled water. The pressure variation at the column bottom was correlated with the vibration intensity and the liquid phase hold–up. The pressure variations at the bottom of columns of different diameter were also compared. The oriffice coefficient for plates of approximately the same free fraction area was found to decrease with increasing column diameter.*

*Key words: Reciprocating plate column, Pressure variation, Gas holdup, Carboxymethylcellulose.*

Multiphase (gas–liquid, gas–liquid–solid) reciprocating plate columns (RPC) have been widely used in recent decades, mostly for aerobic wastewater treatment and purification [1], the biosynthessis of extracellular pullulan polysaccharides [2,3] and the synthessis of dextrane [4], as well as for the production of antibiotics, citrc acid and ethanol [5]. This type of contact unit enables the uniform distribution of gas bubbles, a high gas content and large interfacial gas–liquid area in the column [6], which takes gas–liquid RPC into a class of a new generation of reactors or bioreactors [7].

The pressure variation at the bottom of the column (average and total) is one of the most important parameters for the design and selection of an appropriate gas compressor, the calculation of the mixing power and the design of a complete RPC and its geometry. Previous investigations were realized with Newtonian and non–Newtonian liquids in RPC of 2.54 and 9.2 cm, indicating that the pressure variation at the bottom of the column depended on: the vibration intensity (defined as the product of the amplitude and frequency of vibration), the superficial gas velocity, the rheological behaviour of the liquid phase, type and content of the solid phase present in the column as a charge and, finally, on the column geometry (diameter, number of plates, diameter of the holes on the plate and the free area of one plate). A review of the theoretical, as well as empirical correlations for the calculation of the total and average pressure variation at the bottom of RPC can be found elsewere [8,9].

Generaly, the variation of the pressure at the column bottom increases with increasing vibration intensity and does not depend on the column geometry and system used for the investigation (two–phase gas–liquid or three–phase, gas–liquid–solid system). By increasing the vibration intensity in the case of gas–liquid and gas–liquid–solid systems, the pressure variation at the bottom of a 2.54 i.d. RPC has a maximal value at the critical vibration intensity $(Af)_{cr}$, and then starts to decrease [10–15]. Such a phenomenon was not observed in the 9.2 cm i.d. RPC for the investigated range of vibration intensities [9,15]. For $Af < (Af)_{cr}$, the variation of the vibration intensity at the bottom of the column is proportional to the product of the vibration intensity to the exponent $n$ (ranging between 1 and 2) and the value of the liquid hold–up in the column [9,11]:

$$\Delta p^* \text{ or } \Delta p_{sr} = k \cdot (Af)^n \cdot (1 - \varepsilon_g) \tag{1}$$

where $\varepsilon_g = 0$ is for a liquid–solid system. When a turbulent liquid flow regime is obtained through the holes of plate (Re > 50), as in the case of water as the liquid phase, the pressure variation at the column bottom is approximately proportional to the square of the vibration intensity $(n = 2)$, independent of the internal column diameter [15,16]. In concordance with the "quasi–steady state" model of liquid flow, the pressure change at the column bottom is determined by friction losses [17,18]. For laminar flow through the holes of the plate (Re < 10), as in the case of glycerin and carboxymethylcelulose (CMC) solutions as the liquid phase, the pressure variation at the column bottom is linear with the vibration intensity $(n = 1)$ [15].

Regardless of the characteristics of the liquid phase and column diameter, the pressure variation at the column bottom decreases by increasing the superficial gas velocity. The effect is mainly caused by the smaller density of the gas–liquid dispersion and

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lower friction interactions between the liquid phase and the plates of the vibration set–up, i.e. the mixing device [10–12,14,19].

Under the same conditions of vibration intensity and superficial gas velocity, independent of the used system (two or three phase system), the pressure variation at the column bottom increases by increasing the viscosity and by decreasing the surface tension of the liquid phase [10,20,21]. Furthermore, by increasing the liquid viscosity, the pressure variation at the bottom of column also increase for CMC solutions of higher concentration (CMC solutions of higher concentration variations its rheology and being the pseudo–plastic one) regardless of the column diameter and type of multiphase system (two: gas–liquid, or three phase: gas–liquid–solid) in the RPC [8,22,23].

The presence of solid particles in the space between two plates of the vibration set–up increases the pressure variation at the bottom of the RPC, because there is higher frictional interaction between the liquid phase, vibration device and solid phase, regardless of the liquid characteristics and column diameter [8,15,16,22–25]. The pressure variation at the bottom of the RPC depends on the type and content of solid phase particles. At superficial gas velocities higher than 1 cm/s, the pressure variation at the bottom of the RPC is higher if Rashig rings are applied instead of spheres [8]. The pressure variation is higher at increased content of the solid phase due to the higher frictional interaction between the solid particles and the liquid phase [15].

The pressure variation at the bottom of the RPC increases by increasing the number of perforated plates [10] and by decreasing the free area of the plate [16], because there is larger resistance to liquid flow through the plate holes independent of the analyzed system (two phase: gas–liquid, or three–phase system: gas–liquid–solid) and rheological behaviour of the liquid phase.

The total and average variation of the pressure at the column bottom were investigated in the present study with a reciprocating plate column of 16.6 cm i.d. with Newtonian (water) and non–Newtonian (CMC solutions) liquids in the presence of solid particles (spheres, diameter 8.35 mm) placed in the space between the plates (the solid phase content was 3.8 and 6.6% by volume). The main goal of this investigation was the analysis of the influence of operating conditions (vibration intensity, superficial gas velocity and the presence of the solid phase in the column) on the pressure variation at the column bottom, and the definition of a simple correlation which might be used to link the pressure change at the column bottom with these parameters in two phase (gas–liquid) or three–phase systems in a RPC of different internal diameter.

## EXPERIMENTAL

A scheme of the experimental set–up of the RPC has been presented in recently published papers [19,24]. The geometry of the column as well as the range of operating parameters are given in Table 1. The RPC consisted of a glass tube of internal diameter 16.6 cm and a vibration set–up (vibration mixer). The mixing device in the column consisted of a rod (chemically passivated iron) on which 15 perforated plates were mounted (made from light metal) on equal distance. By using a 1.5 kW electromotor and an excenter, the mixing device (perforated plates) was reciprocatically moved in the column. The amplitude was constant 2.35 cm, in all the experiments, while the frequency of vibration was varied in the range from 0 to 6 Hz by a three–phase frequency regulator (Yaskawa, Model VS–606V7). The gas flow rate was controlled by using a needle valve and measured by a rothameter (Medingen, Dresden, Germany). The hydrostatic gas pressure at the inlet (column bottom) was measured by a digital manometer (Laser, Leskovac, Serbia).

Table 1. Geometric characteristics of the column and the operating conditions

| | |
|---|---|
| Column diameter (cm) | 16.6 |
| Column height (cm) | 153 |
| Dispersion height (cm) | 97 |
| Working column volume (dm$^3$) | 20.87 |
| Length of the tie–rod (cm) | 10.3 |
| Number of plates | 15 |
| Plate diameter (cm) | 16.25 |
| Hole diameter (cm) | 0.8 |
| Plate depth (cm) | 0.12 |
| Fraction of free area (%) | 46.6 |
| Spacing between the plates (cm) | 5.0 |
| Amplitude of vibration (cm) | 2.35 |
| Frequency of vibration (Hz) | 2–6 |
| Superficial gas velocity (cm/s) | 0.5–1.5 |

Air of room temperature was used as the gas phase, which was fed by a compressor and regulating valve (the average value of the pressure was 200 mbar) at the bottom of the column through four nozzles (nozzle diameter 1.5 mm). The superficial gas velocity was 0.5, 1.0 or 1.5 cm/s. Distilled water (Newtonian fluid) and aqueous solutions of carboxymethylcelulose of 0.5 and 1.0 wt.% concentration (CMC produced by PP 500, "Lucel", Lučani, Serbia) were the liquid phase used as the charge in the column. CMC solutions have pseudoplastic characteristics (non–Newtonian fluid). The rhelogical behaviour of the CMC solutions was determined with a rotational viscometer (Haake Rotovisko RV 100). The physical characteristics of the used liquids in this study are shown in Table 2. The solid phase, also used as a charge in the column, were

*Table 2. Physical properties of the liquid phase (20°C)*

| Liquid | Density kg/m³ | Flow index | Consistency coefficient Pa ·s" |
|---|---|---|---|
| Distilled water | 998.0 | 1 | 0.0010 |
| 0.5% CMC | 1002.7 | 0.88 | 0.0313 |
| 1.0% CMC | 1004.4 | 0.72 | 0.2253 |

polypropylene spheres (density 930 kg/m³) of diameter 8.35±0,05 mm. The determined number of spheres (190 or 321, which gave a content of the solid phase in the column of 3.8 or 6.6% vol.) were equally distributed between the plates of the vibrating mixer.

The pressure variation at the bottom of the column was measured by a pressure transducer in the range –50 to +50 kPa (Model TPr–100.05 IChTM, Belgrade, Serbia). The pressure transducer was operated through A/D converter and acquisition system connected to a PC. The average pressure variation at the bottom of the column was calculated by integration of the instanteneous value of the pressure at the column bottom for defined time intervals [9,15]:

$$\Delta p_{av} = \frac{1}{T} \cdot \int_0^t |\Delta p|\, dt \qquad (2)$$

The total pressure variation at the bottom of the column was obtained after summation of the maximal values of the pressure variations during the reciprocating movement of the mixing device to the highest (t) and the lowest (b) position in the column [9,15]:

$$\Delta p^* = \Delta p_b + \Delta p_t \qquad (3)$$

The stop–method was used to measure the gas hold–up in the column. At the same time the vibration of the mixing device, as well as the gas flow were stopped and the height of the liquid was measured. The gas hold–up was calculated according to the calibration diagram, which represents the relation between the height of the liquid phase in the column and the content of the gas phase present in the column. The gas hold–up was calculated as the ratio of the volume of the dispersed phase (gas) in the column and the total volume of the dispersion:

$$\varepsilon_g = \frac{V_g}{V_d} = \frac{V_d - V_L}{V_d} \qquad (4)$$

**RESULTS AND DISCUSSION**

The dependance of the total and average pressure variations at the bottom of the column on the vibration intensity in the case of a single phase system ("pure" liquid phase) is shown in Figure 1. An increase of the pressure variation appeared after an increase of the vibration intensity as a consequence of the higher
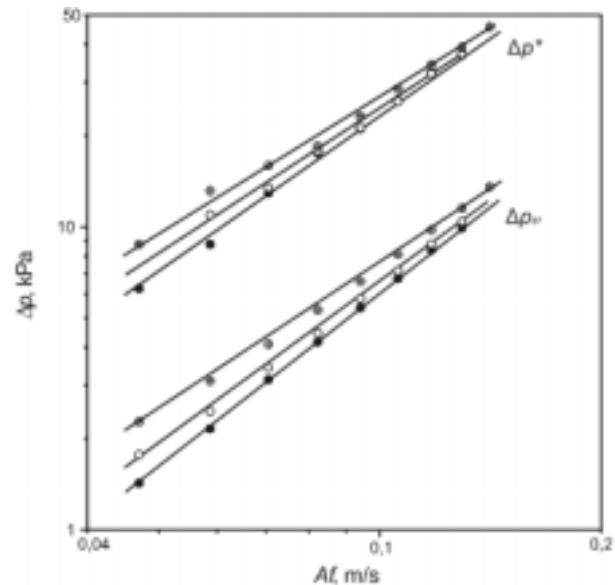


*Figure 1. Dependance of the time–averaged and total pressure variations at the column bottom on the vibration intensity for one phase systems (distilled water – black symbols; CMC 0.5% – open symbols; CMC 1.0% – + centered symbols)*

friction interaction between the perforated plates and liquid independent of the rheological behaviour of the liquid [17,28,29]. This is in concordance with the results of recent investigations performed in RPC of 2.54 and 9.2 cm internal diameter published elsewere [11,13–15,19]. The lowest pressure variations, in the investigated range of vibration intensity in this study, were detected when water was used as the liquid phase, and the highest if the most viscous CMC solution (1 wt.%) was the liquid phase in the column. This effect is also caused by more intensive friction between the liquid phase and the perforated plates of the mixing device in the case of the more viscous solution (Table 2). Furthermore, it may be seen from the data shown in Figure 1 that the slope of the linear dependance of the pressure variations at the bottom of the column and the vibration intensity decreases with increasing CMC concentration. The values of the slopes and the intercept of Equation (1), n and k, which are the two parameters of such a linear relationship, were calculated by applying the least squares method and the obtained data are shown in Table 3. In the case of water (Newtonian liquid) as the liquid phase, the flow regime is turbulent (Re = 750±2100) for the whole range of vibration intensity and, the pressure variations at the column bottom are approximately proportional to the square of the vibration intensity. This result is in concordance with earlier investigations performed in RPC of 2.54 and 9.2 cm i.d. [11,13–15]. When an aqueous solution of CMC was used as the liquid phase in the column (concentrations 0.5 and 1 wt.%, which are non–Newtonian liquids; the flow regime of such solutions corresponds to an inter–regime if Re = 40–110
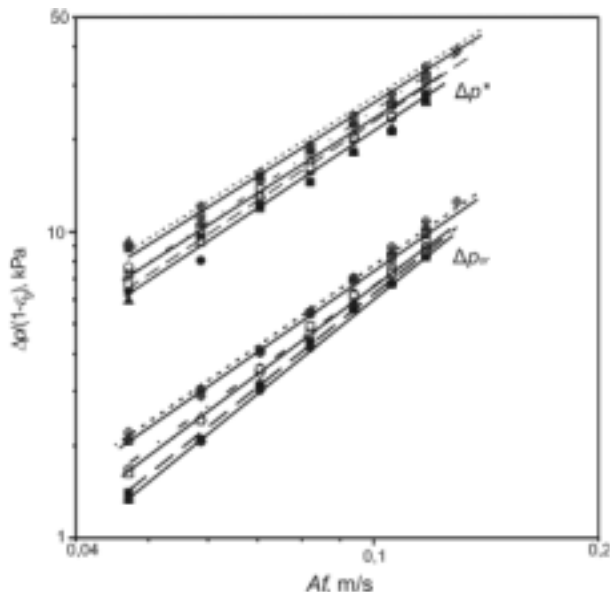
*Figure 2. Effects of the superficial gas velocity on the corrected time–averaged and total pressure variations at the column bottom for gas–liquid systems (ug, cm/s: 0.5 – circle; 1.0 – triangle; 1.5 – square; distilled water – black symbols; CMC 0.5% – open symbols; CMC 1.0% – + centered symbols; pure liquid: dashed line – distilled water; dash–dot–dash line – CMC 0.5%; dotted line – CMC 1.0%)*

or a laminar regime if Re = 2–8) the determined exponent *n* had a value less than 2.

The dependances of the total and average pressure variation at the bottom of column on the vibration intensity at superficial gas velocities of 0.5, 1.0 and 1.5 cm/s (gas–liquid system) are shown in Figure 2. These relations were corrected by multiplying the measured values of the pressure variations with the corresponding values of the liquid hold–up and compared to the values obtained in the case of "pure" liquids (single phase system: liquid or liquid–solid in a column). This figure shows that the corrected values of the pressure variations at the bottom of the column depend on the vibration intensity and liquid characteristics, but do not or only slightly depend on the

superficial gas velocity. As in the case of the "pure" liquid, the corrected value of the pressure variations at the bottom of the column increases with increasing vibration intensity and liquid viscosity as a result of the more intensive friction interaction between the plates of the vibration mixer and liquid. The pressure variations at the bottom of the column are higher, under the same operating conditions, when more viscous and non–Newtonian fluids are applied instead of water, which was also obtained in some earlier investigations [15]. The pressure variations at the bottom of the column slightly decrease or are constant, without any relation to the rheology behaviour of the liquid phase with increasing superficial gas velocity. Such an effect is caused by lower friction interaction in the system with a higher gas hold–up, i.e. a smaller density of the gas–liquid dispersion. Similar results were also obtained in earlier investigations performed in a RPC of smaller i.d. and are reported elsewere [8,10,11,19,20]. The presence of the gas phase in the RPC and the obtained value of the hold–up under certain operating conditions also influenced the pressure variations at the bottom of the column, which, were smaller in the case of the gas–liquid compared to the "pure" liquid system.

As in the case of the "pure" liquid, the dependance of the average and total variation of the pressure at the bottom of the column on the vibration intensity in the gas–liquid system, might be determined by Equation (1). As may be seen from the data shown in Table 3, the exponent for the average pressure variation at the bottom of the column is about 2 for water, and less than 2 for aqneous CMC solutions. The values for *n* in the case of a "pure" liquid and in the case of a gas–liquid system in a RPC are very similar. A correlation that could be used to predict the pressure variations at the bottom of the column were derived and shown in Table 3.

A comparison of the pressure variation at the bottom of columns with different i.d. is shown in Figure 3, which represents a relationship between the normalized and corrected average value of the pressure variations at the bottom of the column $\Delta p_{av}\varepsilon^2/n_p\rho_l(1-\varepsilon_g)(1-\varepsilon^2)$ and the vibration intensity for a "pure" liquid (distilled water) and a gas–liquid system at one value of

*Table 3. Parameters of equation (1) for one–, two– and three–phase systems (u$_g$ = 0.5–1.5 cm/s)*

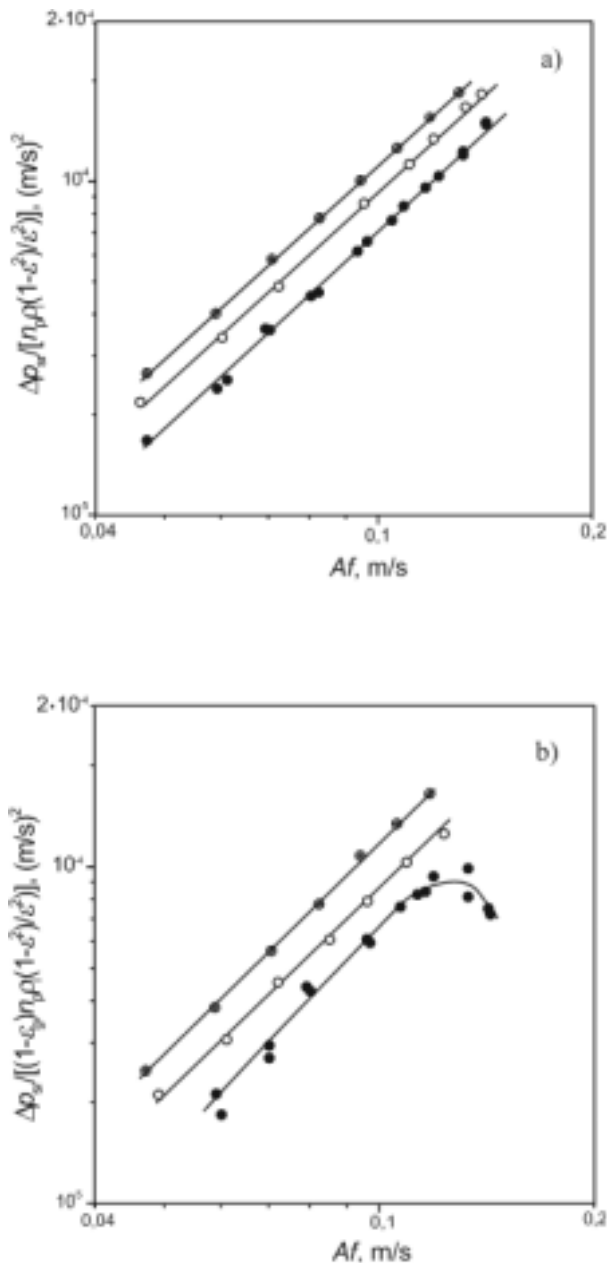| Liquid | System | $\Delta p_{sr}$ | | $\Delta p^*$ | |
|---|---|---|---|---|---|
| | | *n* | $k$ kPa·(m/s)$^{-n}$ | *n* | $k$ kPa·(m/s)$^{-n}$ |
| Distilled water | L, L–G | 2 | 615.6 | 1.617 | 899 |
| | L–S, G–L–S (3,8%) | 1.58 | 324.6 | 1.31 | 610.7 |
| | L–S, G–L–S (6,6%) | 1.29 | 265.4 | 0.97 | 425.5 |
| CMC solution (0.5%) | L, L–G | 1.85 | 473.4 | 1.57 | 862.3 |
| | L–S, G–L–S (3,8%) | 1.64 | 419.6 | 1.34 | 683.7 |
| | L–S, G–L–S (6,6%) | 1.09 | 187.2 | 0.91 | 416.9 |
| CMC solution (1%) | L, L–G | 1.71 | 390.9 | 1.46 | 740.6 |
| | L–S, G–L–S (3,8%) | 1.78 | 676.1 | 1.54 | 1276.4 |
| | L–S, G–L–S (3,8%) | 1.18 | 255 | 1.2 | 947 |

Figure 3. Dependance of the normalized corrected time–averaged pressure variations at the column bottom on the vibration intensity: a) pure liquid (distilled water) and b) system gas–liquid (u_g, cm/s: 0.5) (column diameter, cm: 2.54 – black symbols; 9.2 – open symbols [15]; i 16.6 – + centered symbols, this study)

Table 4. Values of the oriffice coefficient, calculated using the time–averaged power consumption for RPC of different diameter (distilled water)

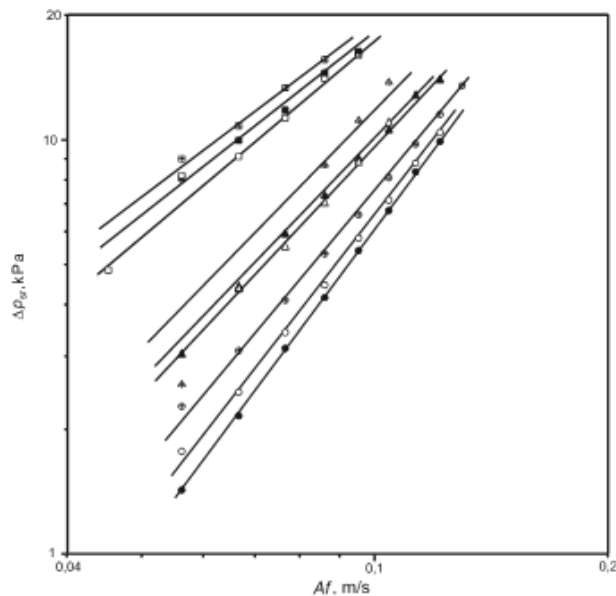| D_c, cm | d_o, cm | ε, % | C_o | Reference |
|---------|---------|------|------|-----------|
| 2.54 | 0.8 | 51 | 1.23 | [15] |
| 9.2 | 0.8 | 45.4 | 1.05 | [15] |
| 16.6 | 0.8 | 46.6 | 0.99 | This study |



Figure 4. Dependance of the normalized corrected time–averaged pressure variations at the column bottom on the vibration intensity for liquid–solid systems (distilled water – black symbols; CMC 0.5%– open symbols; CMC 1.0% – + centered symbols; pure liquid – circle; solids content, % v/v: 3.8 – triangle; 6.6 – square)

the superficial gas velocity (0.5 cm/s). The normalized and corrected average value of the pressure variations at the bottom of the column increase increasing the internal column diameter. Such an effect might be explained by the decrease of the value of the orifice coefficient in the case of the RPC with a larger internal diameter (Table 4).

The average pressure variations at the bottom of the column versus the vibration intensity are shown in Figure 4. A similar relation was also observed in the case of the dependence of the total pressure variations at the bottom of the column and the vibration intensity. Regardless of the solid phase content in the column, the pressure variation at the bottom of the column increases with increasing vibration intensity, which is a result of the more intensive friction between the liquid phase, solid phase (spheres) and perforated plates of the vibration mixer [14,15,24–26]. A higher pressure variation at the bottom of the column was obtained, for the same content of polypropylene spheres, if CMC solution was used as the liquid phase. The exponent in Equation (1), which might also be used for pressure variation calculations in a solid–liquid system, depends on the solid phase content in the column and has a value between 1.5 and 1.8 for a solid content of 3.8%, and, about 1 for a solid phase content of 6.6% (Table 3). A decrease of exponent n with increasing of solid content in the column obviously exists, which may be explained by the change of the liquid flow regime in the holes of the perforated plate and by the smaller effective free cross–sectional area of the column. Exponent n
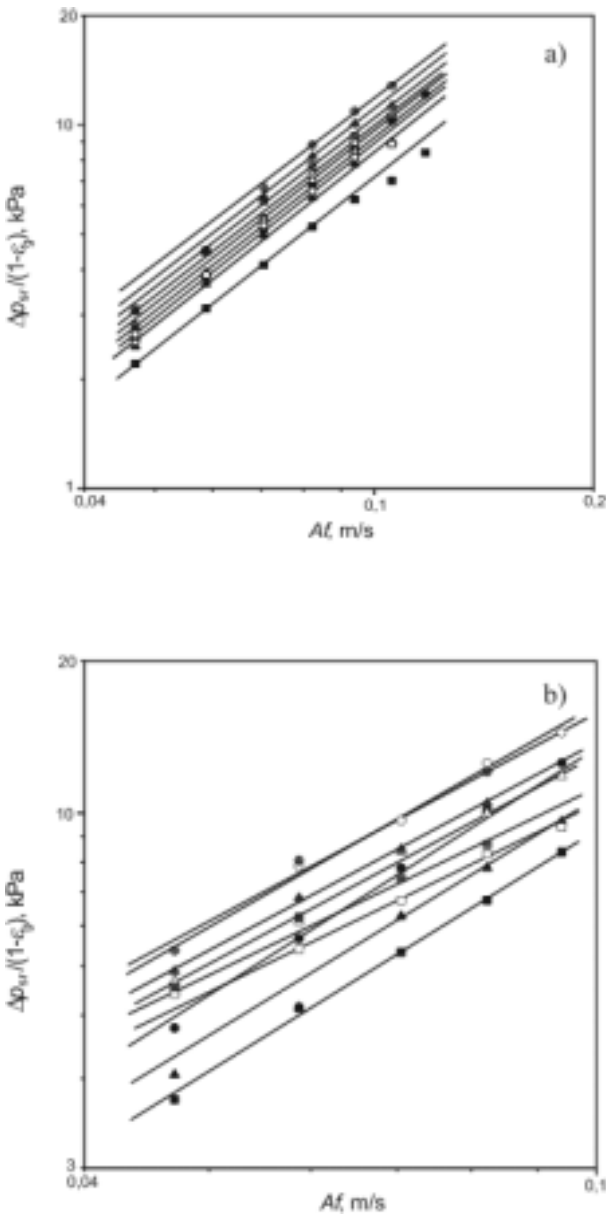
*Figure 5. Effects of the superifical gas velocity on the corrected time–averaged and total pressure variations at the column bottom for gas–liquid–solid systems: a) $\varepsilon_s$ = 3.8%; b) $\varepsilon_s$ = 6.6%; ($u_g$, cm/s: 0.5 – circle; 1.0 – triangle; 1.5 – square; distilled water – black symbols; CMC 0.5% – open symbols; CMC 1.0% – + centered symbols)*

decreases from a value of about 2, obtained in the case of liquid flow through the RPC without solid polypropylene spheres, to a value of about 1, when a larger amount of solid particles are used in the RPC. Such an effect was also reported in the case of a RPC filled with Rashig rings between the plates of the vibration mixer [8].

The dependence of the average pressure variations at the bottom of the RPC divided by the liquid hold–up (1–$\varepsilon_g$) and the vibration intensity at superficial gas velocities of 0.5, 1.0 and 1.5 cm/s is shown in Figure 5.
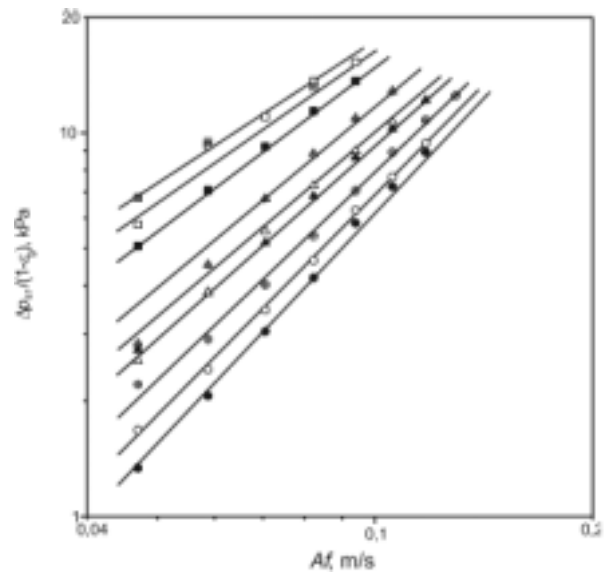


*Figure 6. Dependance of the normalized corrected time–averaged pressure variations at the column bottom on the vibration intensity for gas–liquid–solid systems ($u_g$ = 0.5 cm/s; distilled – black symbols; CMC 0.5% – open symbols; CMC 1.0% – + centered symbols; "pure" liquid – circle; solids content, % v/v: 3.8 – triangle; 6.6% – square)*

With increasing vibration intensity and liquid viscosity, such a corrected value of the average pressure variation at the bottom of the RPC decreases. The slope of such linear realationships in the case of gas–liquid systems has a value of about 1.5 for water and about 1.1 for 1 wt.% CMC solution (Table 3). A decrease of exponent $n$ is the result of liquid flow regime changes in the holes of the perforated plates caused by an increase of the liquid viscosity. Moreover, exponent $n$ decreases with increasing content of the solid phase in the RPC. The main reason for such an effect are flow regime changes in the holes of the perforated plate from an inter–regime to a laminar one. This effect is probably also caused by a decrease of the free section area for liquid flow if a larger number of polypropylene spheres are present in the space between the two plates [8]. Because a similar value of exponent $n$ was obtained for a liquid–solid system and a gas–liquid–solid system, a single correlation for both systems was derived for calculating the pressure variations at the bottom of a RPC (Table 3).

A comparison of the pressure variations at the bottom of a RPC in the case of multiphase systems and one single phase, i.e. "pure" liquid present in the column, is shown in Figure 6. Regardless of the liquid used in this study, the presence of the solid phase influences the friction force and its increase causes an increase of the pressure variations at the bottom of the RPC. Furthermore, for the same reason, under the same operating conditions, an increase of the solid phase content between two perforated plates influences the pressure variation and its increase at the bottom of a RPC.

## CONCLUSION

The influence of the vibration intensity, superficial gas velocity, content of the solid phase present as a charge in the column, as well as the rheology of the liquid phase on the total and average variation of the pressure at the bottom of a multiphase RPC with 16.6 cm i.d. was investigated. The average and total pressure variation increase with increasing vibration intensity, the viscosity of the liquid phase and the content of the solid phase in the column, and decrease with increasing superficial gas velocity. Under the same operating conditions, the pressure variation at the bottom of the RPC is higher if CMC solutions are used instead of water as the liquid phase in the column.

The parameters of an empirical correlation (equation 1), which correlate the pressure variation at the column bottom with the vibration intensity and gas hold–up were derived for the systems investigated in this study. In the case of a RPC with pure liquid, the exponent of the vibration intensity depends on the flow regime through the holes of the perforated plate. For water it is $n = 2$, while in the case of CMC solutions it is less than 2. The value of the exponent in the case of CMC solutions decreases with increasing solid content in the column. It was assumed that the changes of the flow regimes through the holes exist. A smaller value of exponent $n$ obviosly indicated that it changed from a turbulent, through an inter–regime to a laminar one, mainly as a result of the decrease of the effective free cross–sectional area of the plates.

On the basis of the corrected and normalized pressure variation at the bottom of RPC with different i.d. it was established that the column diameter influence of the oriffice coefficient. Namely, an increase of the RPC column diameter with approximately the same free area of plates decreases the oriffice coefficient.

## LIST OF SYMBOL

A     – amplitude of vibration, m

$A_f$     – intensity of vibration, m/s

f     – frequency, Hz

$n_p$     – number of perforated plates

p     – instanteneous pressure at the bottom of the column, kPa

$\Delta p$     – the variation of instanteneous pressure at the bottom of the column, kPa

$\Delta p_{av}$ – the average pressure variation at the bottom of the column, kPa

$\Delta p^*$ – the total pressure variation at the bottom of the column, kPa

t     – time, s

$u_g$     – superficial gas velocity, m/s

## GREEC LETERS

$\varepsilon$     – free area of the plate perforations

$\varepsilon_g$     – gas hold–up

$\varepsilon_s$     – content of the solid phase in the column

$\rho_l$     – density of the liquid phase, kg/m$^3$

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## IZVOD

UTICAJ OPERATIVNIH USLOVA NA PROMENU PRITISKA NA DNU KOLONE SA VIBRACIONOM MEŠALICOM PREČNIKA 16,6 cm

(Naučni rad)

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U radu je ispitivan uticaj intenziteta vibracije, prividne brzine strujanja gasa, udela čvrstih čestica i reoloških osobina tečnosti na ukupnu i srednju promenu pritiska na dnu kolone sa vibracionom mešalicom prečnika 16,6 cm. Srednja i ukupna promena pritiska na dnu kolone sa vibracionom mešalicom se povećavaju sa povećanjem intenziteta vibracije, viskoznosti tečnosti i udela čvrstih čestica, a smanjuje sa povećanjem prividne brzine strujanja gasa. Pri istim ostalim operativnim uslovima, promena pritiska na dnu kolone je veća kod rastvora karboksimetilceluloze nego kod vode. Izvedene su empirijske korelacije koje povezuju promenu pritiska na dnu kolone sa intenzitetom vibracije. Izvršeno je, takođe, poređenje promene pritiska na dnu kolona različitog prečnika. Sa povećanjem prečnika kolone kod KVM sa pločicama približno iste površine slobodnog preseka smanjuje se vrednost koeficijenta otvora.

Ključne reči: Kolona sa vibracionom mešalicom, Promena pritiska na dnu kolone, Sadržaj gasa, Karboksimetilceluloza.