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LIQUID FLOW STRUCTURE AND MASS TRANSFER IN HORIZONTAL AXIS ROTATING DISKS CONTACTORS. II* MASS TRANSFER KINETICS IN LIQUID AND GAS PHASES

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For countercurrent phases flow in a rotating disks contactor (RDC), in this second part of our research, a cellular model and a combined model plug flow-perfect mixed/plug flow were used to describe the liquid flow structure, while criterial relationships for the characterization of mass transfer kinetics in RDC was selected from several possibilities.

This second part is dedicated to presenting the results obtained in terms of the mass transfer kinetics for the liquid phase and the gas phase when they come into contact in the RDC. Air humidification was selected for determination of mass transfer coefficients referring to gaseous phase.

Keywords: mass transfer, rotating disks contactors, criterial relationships, partly mass transfer coefficient, experimental methods

1. Introduction

In order to minimize the mass transfer resistance, an effective method for gas-liquid contacting is to generate thin films of liquid that is exposed to gas flow. One of the liquid film generation techniques includes the procedure of forming liquid film on the surface of disks, partially immersed in liquid. The generation of the thin film of liquid takes place by rotating the contactor disks. The disks are partially immersed in the liquid, their upper part being in contact with the gas, which contains one or more components to be transferred to liquid. During the rotational movement, the liquid film formed on the surface of the discs is brought into contact with the gas phase. The width of the liquid film, and therefore the mass transfer surface, depends on the immersion depth of the disks. The main advantage of this design is that the gas-liquid interface is of constant size and known. In addition, the contact between the phases is generated by maintaining the liquid phase as a thin film and that minimizes the mass transfer resistance, compared to others gas-liquid

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*This is the second part of the same article, published in Issue 2/2023 of the same journal contacting procedures [1-3]. Areas of use of the rotating disks contactor (RDC) are found especially in bioengineering applications, where the RDC is used as a bioreactor for biological wastewater treatment, or for others aerobic bioengineering processes [4, 5] (citric acid by aerobic fermentation, specialized bacterial or fungal cultures, cell cultures, bio cellulose production etc.). The use of RDC in aerobic biochemical processes is based on the fact that a biofilm, containing the system of microorganisms that transforms the substrate (carbon source in the most cases), is formed on the disks surface; that is covered by a mobile film of liquid through which oxygen is transferred to biofilm [6, 7]. For the case of biofilm wastewater treatment Fig. 1 shows an enumeration of transfer and bioreaction processes when part of disc contactor surface is rotating in the air (moving from A to B) or rotating in the wastewater being processed (moving from B to C).

It is obvious that in the complexity of the processes mentioned by exemplification from Fig. 1, can intuit the importance of phases flow structure and of oxygen transfer in gaseous and liquid phase. The current paper focuses on these three aspects. It thus starts from the fact that there is too little information on these aspects, which be taken up in technological design or in simulation, in a concrete case, of an RDC device.

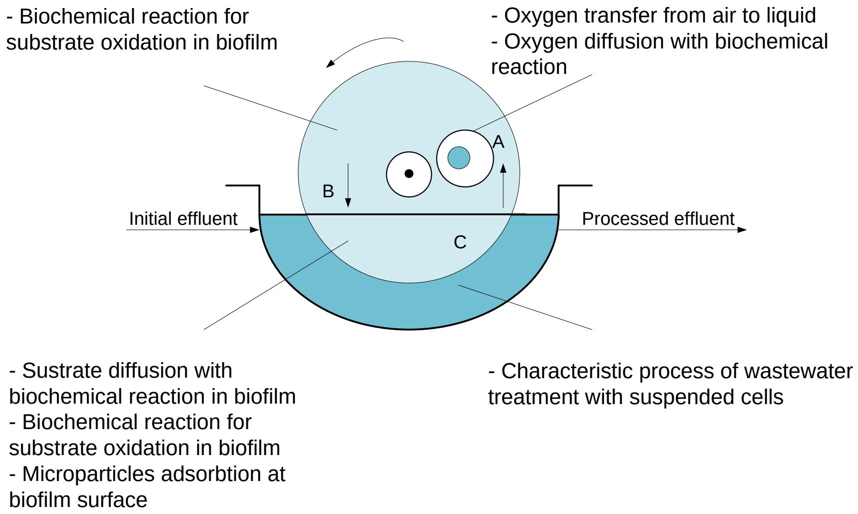

Fig. 1. Processes characterizing the aerobic wastewater treatment in RDC

We thus show that respect to phases flow structure in the RDC, no characteristic data can be found [8], even if from experimental measurements of mass transfer, in closed RDC, it can be deduced that the plug flow (PF) is accepted for both phases [8, 9]. For RDC open in the atmosphere for oxygenation (Fig. 1) it can formally consider that the gaseous phase has a PM flow. For liquid phase the DT flow could result through a series of PM cells, which are formed between disks, coupled with a PF flow at entry and exit of liquid in/from the RDC [10]. In this paper we accept the considerations regarding the gas flow structure of. With respect to liquid phase flow structure, we bring a concrete experimental investigation based on residence time distribution (RTD) measurements when an impulse tracer is applied at liquid input in RDC [10].

In the case of liquid phase mass transfer, the published data followed three directions: i) the application of the renewal theory to this case [7, 11-14], ii) the use of k_l determination method for falling film flow to this case [15], iii) the experimental investigation of process factors influences of on k_l [16, 17], for example by programming experiences. The first direction shows an important influence of the disks rotation speed and of liquid flow rate on liquid phase mass transfer coefficient, k_l, [13, 14]. The second direction also finds cases where the thickness of the liquid film is not really influenced by the usual speed of the disks and the liquid flow rate [18, 19] so that k_l is placed in an area where it has a constant value. The third direction correlates experimental data, and it is dependent on the method of them obtaining [11]. It is worth noting that most of the experimental data used to support the mentioned three directions is based on measuring the oxygenation of the liquid phase, without considering that the neglecting the oxygen transfer resistance in the gaseous phase is not very correct. In our work we use the carbon dioxide absorption from pure gas in RDC, as procedure for correctly determining the k_l and on it process factor influence. Relevant aspects on the modeling of mass transfer in liquid and gaseous phases in a RDC are presented. Mathematical modeling is a valuable tool in designing and optimizing the processes in chemical engineering, as well as in understanding their mechanisms [20-22].

The work has two parts. The first part showed the experimental development for both parts and the results regarding the structure of liquid phase flow in the RDC. This second part is dedicated to presenting the results obtained regarding the mass transfer kinetics for the liquid phase and the gas phase when they come into contact in the DRC. Therefore, the two parts have common elements and have the same references list.

For characterization of the mass transfer kinetics respect to gas phase, practically no data can be found in the literature. In this work the kinetics of air humidification was investigated work for the characterization of mass transfer in the gas phase in RDC phases contacting.

2. Experimental equipment, experimental procedures and methods

The description of the experimental investigation on the kinetics of mass transfer characteristic of gas and liquid phases contacting in the RDC was presented in the first part of the paper. We mention that at the contact phases in the RDC, the interphase transfer zone, depending on the depth of immersion of the discs in the liquid, can be accurately known. To characterize the mass transfer kinetics in the liquid phase, the working procedure used was the absorption of pure CO_2 in water, when the equilibrium of the process is known, and the measurement of the absorbed gas flow rate is simple and accurate. In the case of researching the kinetics of mass transfer in the gas phase, the working procedure consisted of humidifying the air, when the balance of the process is related to the saturation pressure of water vapor in the air, and when measuring the air parameters at the inlet and outlet from the DRC ensures the determination of the transferred species flow.

3. Results and discussions

We begin with the problem of mass transfer kinetics in the liquid phase, where the absorption of pure carbon dioxide in water was used for experimental investigations. As shown in the first part of the paper, the experimental design followed a factorial design with two levels and three factors (speed of the liquid (w_l), speed of the discs (n) and depth of immersion of the discs in the liquid (h)). With Table 6[3] we present the results regarding all the measured components of relation (3).

Table 6

Matrix of planned experimental results for k_l

Exp./ Name	Dimensionless process factors			Measured and computed responses			
	X_1	X_2	X_3	n_A [kmol/s]	A [m^2]	Δc_{Am} [kmol/m]	k_l [m/s]
1	+1	-1	-1	$2.286 \cdot 10^{-7}$	0.367	0.025	$2.499 \cdot 10^{-6}$
2	+1	-1	+1	$2.942 \cdot 10^{-7}$	0.420	0.022	$3.216 \cdot 10^{-6}$
3	+1	+1	-1	$2{,}781 \cdot 10^{-7}$	0.367	0.022	$3.041 \cdot 10^{-6}$
4	+1	+1	+1	$3.423 \cdot 10^{-7}$	0.420	0.019	$3.742 \cdot 10^{-6}$
5	-1	-1	-1	$5.274 \cdot 10^{-7}$	0.367	0.023	$5.767 \cdot 10^{-6}$
6	-1	-1	+1	$4.301 \cdot 10^{-7}$	0.420	0.025	$4.702 \cdot 10^{-6}$
7	-1	+1	-1	$6.650 \cdot 10^{-7}$	0.367	0.020	$7.271 \cdot 10^{-6}$
8	-1	+1	+1	$8.755 \cdot 10^{-7}$	0.420	0.012	$9.572 \cdot 10^{-6}$
9	0	0	0	$4.525 \cdot 10^{-7}$	0.399	0.021	$4.948 \cdot 10^{-6}$
10	0	0	0	$4.241 \cdot 10^{-7}$	0.399	0.022	$4.638 \cdot 10^{-6}$
11	0	0	0	$4.497 \cdot 10^{-7}$	0.299	0.021	$4.917 \cdot 10^{-6}$
Temperature 25 °C, Pressure 1 bar							

Table 6 is a form of Table 2 in which the dimensionless factors are indicated below (30). Here Gv_l is expressed in L/h.

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[3] One can see the first 5 Tables in the first part of the same article, published in Issue 2/2023 of the same journal.

As one can see, Table 6 also has data in the center of the factorial plan. These allow the calculation of reproducibility variance, which in the specific procedure for determining of β coefficients from general relationship (31) control the elimination of insignificant ones [28]

$$X_1 = \frac{w_l - 0.000662}{0.000221} = \frac{G_{vl} - 75}{25},\ \ \mathrm{X}_2 = \frac{n - 0.6}{0.2},\ X_3 = \frac{h/D - 0.375}{0.125} \tag{30}$$

$$k_l = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3 \tag{31}$$

Proceeding in this way the β coefficients identifying and the eliminating of the insignificant ones, the relation (32) was obtained. From Table 6 and from this relation we establish that the k_l values are in the field of those reported in the literature [5-7, 26-29]. Also, we see here that practically all three factors have an influence on k_l. The influences are complex because along with the linear positive influences of X_1 (dimensionless liquid flow velocity), X_2 (dimensionless rotation speed if disk) and X_3 (dimensionless depth of sinking disks) we also find the influence of the binary interaction X_1X_2 (over 11% around of mean value) and even that which expresses the interaction of the three factors $X_1X_2X_3$ (about 9% around of mean value).

$$k_l = 10^{-6}(4.965\,1 + 1.863\,1 X_1 + 0.941 X_2 + 0.321\,1 X_3 + 0.652\ X_1 X_2 + 0.412\ X_1 X_2 X_3) \tag{32}$$

The mentioned complex influence oriented the presentation of mass transfer kinetics results in liquid phase in the form of a criterial relationship. Thus, the dimensional analysis applied to this case identifies, along with the geometric simplex S_g, the Reynolds criterion for liquid flow (Re_l), the Reynolds criterion for disks rotating in liquid phase *(Re)*, and the Sherwood criterion for mass transfer in the liquid phase (Sh_l) (33)

$$S_g = \frac{h}{D},\ \mathrm{Re}_l = \frac{w_l D \rho}{\eta},\ \ \mathrm{Re} = \frac{n D^2 \rho}{\eta},\ \mathrm{Sh}_l = \frac{k_l D}{D_A} \tag{33}$$

It is recognized in the mentioned criteria expressions that the characteristic length is the disc diameter (D). The liquid phase has density ρ and viscosity η and D_A is the CO_2 diffusion coefficient in water, at the working temperature. Returning to the expression of liquid phase mass transfer kinetics with a criterial relation, we show that its form is given by the relation (34), with *c*, *m*, *n* and *p* as numerical constants.

$$\mathrm{Sh}_l = c\,\mathrm{Re}_l^m\,\mathrm{Re}^n\,S_g^p \tag{34}$$

Table 7 contains experimental data from Table 6 in the form requested by relation (34). The minimizing of mean square deviation (35), between logarithms of the experimental Sh_l number and those calculated based on the relation (34), brings the problem of c, m, n and p identifying with the solving of a four linear equations system (36).

Table 7

Experimental values of criterions from relation (35)

Exp	Re_l	Re	S_g	$Sh_{l;}$
1	98.2	$1.296 \cdot 10^4$	0.250	236.4
2	98.2	$1.296 \cdot 10^4$	0.500	304.7
3	98.2	$2.592 \cdot 10^4$	0.250	288.1
4	98.2	$2.592 \cdot 10^4$	0.500	354.5
5	196.5	$1.296 \cdot 10^4$	0.250	546.3
6	196.5	$1.296 \cdot 10^4$	0.500	445.4
7	196.5	$2.592 \cdot 10^4$	0.250	688.7
8	196.5	$2.592 \cdot 10^4$	0.500	906.8
9	135.4	$1.944 \cdot 10^4$	0.344	468.7
10	135.4	$1.944 \cdot 10^4$	0.344	439.4
11	135.4	$1.944 \cdot 10^4$	0.344	465.7

$$F(c,m,n,p) = \sum_{i=1}^{11}\left(\ln \mathrm{Sh}_{1i} - \ln c - m \ln \mathrm{Re}_{li} - n \ln \mathrm{Re}_i - p \ln S_{gi}\right)^2 \tag{35}$$

By solving of system (36) it finds the solution c = 0.031, m = 1.034, n = 0.479, p = 0.185 so that relation (34) takes the form (37). We note here the strong dependence of the Sh_l number on Re_l and Re. We insist on the fact that Sh_l depends on $Re^{0.479}$, that is, k_l depends on $n^{0.479}$, which agrees with many considerations and published data based on particularization of renewal theory to this mass transfer case [22-24]

$$\begin{gathered}
11\mathrm{C} + \mathrm{m}\sum_{i=1}^{11}\ln(\mathrm{Re}_{1i}) + \mathrm{n}\sum_{i=1}^{11}\ln(\mathrm{Re}_i) + p\sum_{i=1}^{11}\ln(S_{gi}) = \sum_{i=1}^{11}\ln(Sh_{li}) \\
\mathrm{C}\sum_{i=1}^{11}\ln(\mathrm{Re}_{1i}) + + \mathrm{m}\sum_{i=1}^{11}\left(\ln(\mathrm{Re}_{1i})\right)^2 + \mathrm{n}\sum_{i=1}^{11}\ln(\mathrm{Re}_i)\ln(\mathrm{Re}_{1i}) + p\sum_{i=1}^{11}\ln(S_{gi})\ln(\mathrm{Re}_{1i}) = \sum_{i=1}^{11}\ln(Sh_{li})\ln(\mathrm{Re}_{1i}) \\
\mathrm{C}\sum_{i=1}^{11}\ln(\mathrm{Re}_i) + \mathrm{m}\sum_{i=1}^{11}\ln(\mathrm{Re}_{1i})\ln(\mathrm{Re}_i) + \mathrm{n}\sum_{i=1}^{11}\left(\ln(\mathrm{Re}_i)\right)^2 + p\sum_{i=1}^{11}\ln(S_{gi})\ln(\mathrm{Re}_i) = \sum_{i=1}^{11}\ln(Sh_{li})\ln(\mathrm{Re}_i) \\
\mathrm{C}\sum_{i=1}^{11}\ln(S_{gi}) + \mathrm{m}\sum_{i=1}^{11}\ln(\mathrm{Re}_{1i})\ln(S_{gi}) + \mathrm{n}\sum_{i=1}^{11}\ln(\mathrm{Re}_i)\ln(S_{gi}) + p\sum_{i=1}^{11}\left(\ln(S_{gi})\right)^2 = \sum_{i=1}^{11}\ln(Sh_{li})\ln(S_{gi})
\end{gathered} \tag{36}$$

$$\mathrm{Sh}_l = 0.031\mathrm{Re}_l^{1.034}\,\mathrm{Re}^{0.479}\,S_g^{0.185} \tag{37}$$

$$\mathrm{Sh}_l = 0.00256\mathrm{Re}_l^{1.034}\,\mathrm{Re}^{0.479}\,Sc_l^{0.33}S_g^{0.185} \tag{38}$$

When the phase is an aqueous cells culture medium, our attempts to obtain bacterial cellulose on a rotating drum device indicate the correction of the relationship (37) to consider the influence of the Schmidt number (Sc_l), as it results from (38).
Fig. 10 shows how well relation (37) covers the experimental data obtained for the Sh_l number. It can be seen that this coverage is good enough, so this fact recommends relation (37) as one with application power.

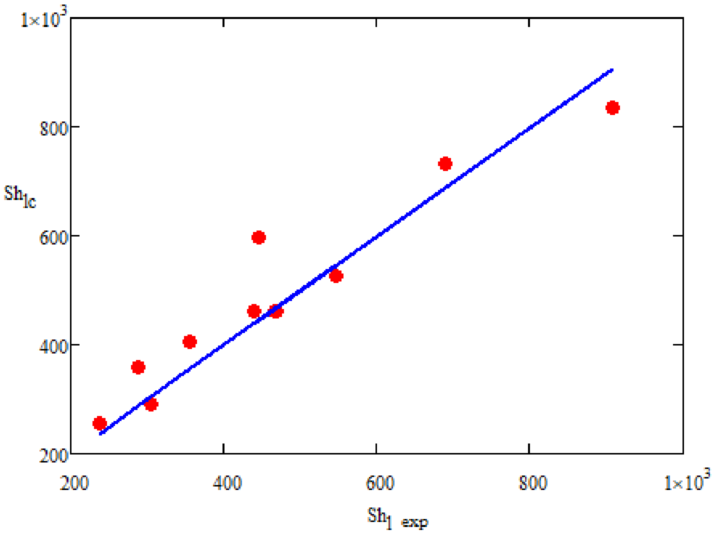

Fig. 10. Deviation of computed liquid phase *Sherwood number* values from experimental ones

We show that the expression of mass transfer kinetics in liquid phase at gas-liquid contacting in the RDC by criterial relations is also found in other works [28, 29].

The second part of this paragraph is dedicated to presentation of the results obtained when it investigates the mass transfer kinetics in the gas phase, when it contacts a liquid in the CDR. We have shown that there is not much published data on this problem. The reason consists in the fact that gas phase, when gas-liquid contacting occurs in a RDC does not offer a significant resistance to species transfer (oxygen in the cases of aerobic biochemical processes). That is especially sustained for cases of aerobic biochemical processes when the liquid phase transfer oxygen, as a low soluble species in water, can control the processes rate. The experimental part of paper showed that the air humidification in RDC was the procedure used to investigate the mass transfer kinetics in the gas phase was. It also showed that this process is determined by *4* factors (liquid velocity (liquid flow rate), gas velocity (gas flow rate), rotation speed of disks, immersion depth of disks in the liquid) so that the experimental organization followed a factorial plan 2^4.

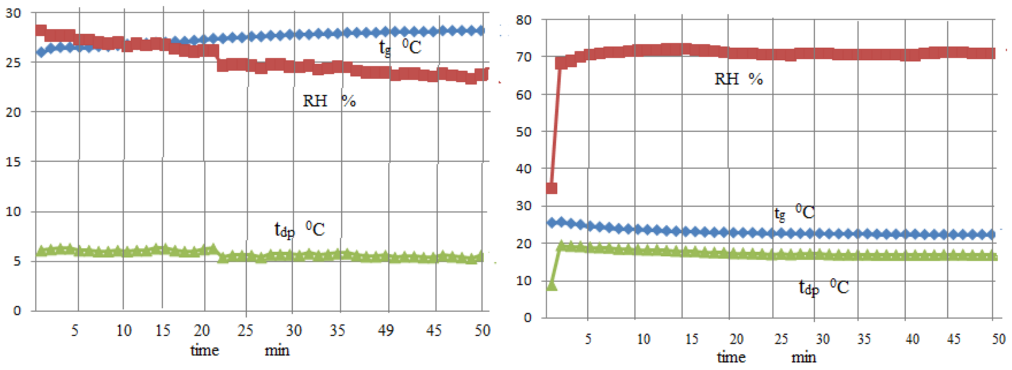

Fig. 11. State of the air parameters at RDC entrance (left)
and RDC exit for Gv_l=80 L/h, Gv_g=1200 L/h,
n = 0.8 s^{-1} and h = 0.09 m (Exp. 3 from Table 4)

Since the known air humidity at the RDC entrance and exit allows the determination of water transferred flow rat from water to air, Fig. 11 shows such measurement. We present the results as in the case of mass transfer in the liquid phase. So, we bring here the matrix of the experimental planning, given by Table 4, to which we make additions that express transferred flow rate (n_A), mean driving force (Δy_{Am}), mass transfer area (A) and, obviously, the partial transfer coefficient k_{cg} .

Table 8

Matrix of planned experimental results for k_{cg}

Exp.	X_1	X_2	X3	X_4	n_A [kmol/s]	Δy_{Am} [mol fr.]	A [m^2]	*kcg* [m/s]
1	+1	+1	-1	+1	$8.545 \cdot 10^{-8}$	$9.376 \cdot 10^{-3}$	0.420	$5.405 \cdot 10^{-4}$
2	+1	+1	-1	-1	$8.299 \cdot 10^{-8}$	$9.145 \cdot 10^{-3}$	0.386	$6.161 \cdot 10^{-4}$
3	+1	+1	+1	+1	$8.486 \cdot 10^{-8}$	$9.521 \cdot 10^{-3}$	0.420	$5.286 \cdot 10^{-4}$
4	+1	+1	+1	-1	$8.039 \cdot 10^{-8}$	$9.388 \cdot 10^{-3}$	0.386	$5.804 \cdot 10^{-4}$
5	+1	-1	-1	+1	$5.992 \cdot 10^{-8}$	$9.360 \cdot 10^{-3}$	0.420	$3.752 \cdot 10^{-4}$
6	+1	-1	-1	-1	$4.522 \cdot 10^{-8}$	$9.605 \cdot 10^{-3}$	0.386	$3.191 \cdot 10^{-4}$
7	+1	-1	+1	+1	$4.286 \cdot 10^{-8}$	$9.710 \cdot 10^{-3}$	0.420	$2.618 \cdot 10^{-4}$
8	+1	-1	+1	-1	$4.163 \cdot 10^{-8}$	$9.826 \cdot 10^{-3}$	0.386	$2.679 \cdot 10^{-4}$
9	-1	+1	-1	+1	$8.801 \cdot 10^{-8}$	$9.370 \cdot 10^{-3}$	0.420	$5.571 \cdot 10^{-4}$
10	-1	+1	-1	-1	$8.352 \cdot 10^{-8}$	$9.011 \cdot 10^{-3}$	0.386	$6.289 \cdot 10^{-4}$
11	-1	+1	+1	+1	$8.325 \cdot 10^{-8}$	$9.366 \cdot 10^{-3}$	0.420	$5.272 \cdot 10^{-4}$
12	-1	+1	+1	-1	$8.302 \cdot 10^{-8}$	$9.493 \cdot 10^{-3}$	0.386	$5.927 \cdot 10^{-4}$
13	-1	-1	-1	+1	$5.221 \cdot 10^{-8}$	$9.538 \cdot 10^{-3}$	0.420	$3.246 \cdot 10^{-4}$
14	-1	-1	-1	-1	$4.446 \cdot 10^{-8}$	$9.207 \cdot 10^{-3}$	0.386	$3.273 \cdot 10^{-4}$
15	-1	-1	+1	+1	$4.278 \cdot 10^{-8}$	$9.488 \cdot 10^{-3}$	0.420	$2.674 \cdot 10^{-4}$
16	-1	-1	+1	-1	$4.291 \cdot 10^{-8}$	$9.822 \cdot 10^{-3}$	0.386	$2.961 \cdot 10^{-4}$
17	0	0	0	0	$6.356 \cdot 10^{-8}$	$9.654 \cdot 10^{-3}$	0.399	$4.125 \cdot 10^{-4}$

18	0	0	0	0	$6.159 \cdot 10^{-8}$	$9.495 \cdot 10^{-3}$	0.399	$4.612 \cdot 10^{-4}$
19	0	0	0	0	$6.451 \cdot 10^{-8}$	$9.554 \cdot 10^{-3}$	0.399	$4.129 \cdot 10^{-4}$
20	0	0	0	0	$6.322 \cdot 10^{-8}$	$9.398 \cdot 10^{-3}$	0.399	$4.119 \cdot 10^{-4}$

$$X_1 = \frac{w_l - 0.000472}{0.000178} = \frac{G_{vl} - 60}{20}, \quad X_2 = \frac{w_g - 0.0077}{0.00157} = \frac{G_{vg} - 900}{300}, \quad X_3 = \frac{n - 0.6}{0.2} \quad X_4 = \frac{h/D - 0.375}{0.125} \tag{39}$$

The results are in Table 8 where X$_1$ - X$_4$ dimensionless factors are expressed with relation (39) The first analysis of Table 8 k_{cg} values found that: i) their order is slightly more than 10 times higher than k$_l$ values, ii) they have a narrow range of variability (between $2.674 \cdot 10^{-4}$ m/s and $6.289 \cdot 10^{-4}$ m/s) contrary to the variability quite high of process factors; iii) the air (gas phase) velocity (flow rate) has a noticeable positive influence on these values. The data from Table 10 together with the statistical procedure for their interpretation (25) allow the correlation of k_{cg} with process factors through a relationship like relationship (31), but with 16 β coefficients. Proceeding in this way to the β coefficients identifying and the eliminating of the insignificant ones, the relation (40) was obtained.

$$kcg = 4.487\ 10^{-4} + 1.426\ 10^{-4} X_2 - 2.299\ 10^{-5} X_3 \tag{40}$$

In (40) the influence of dimensionless disks rotation speed (X$_2$) is below 5% compared respect to mean value so it can be stated that only the flow of gas phase, expressed by its dimensionless gas velocity (X$_2$), influences k_{cg}. This quantitative result for k_{cg} was above qualitatively announced.

Table 9

Experimental values of criterions from relation (35)

Exp	Re	Re_g	Re_l	S_g	Sh_g
0	$1.296 \cdot 10^4$	424.672	314.38	0.50	9.728
1	$1.296 \cdot 10^4$	283.175	628.76	0.25	11.072
2	$2.592 \cdot 10^4$	424.672	314.38	0.50	9.515
3	$2.592 \cdot 10^4$	283.175	628.76	0.25	10.447
4	$1.296 \cdot 10^4$	212.381	314.38	0.50	6.753
5	$1.296 \cdot 10^4$	141.587	628.76	0.25	5.744
6	$2.592 \cdot 10^4$	212.381	314.38	0.50	4.713
7	$2.592 \cdot 10^4$	136.531	707.355	0.25	4.984
8	$1.296 \cdot 10^4$	424.672	196.488	0.50	10.026
9	$1.296 \cdot 10^4$	283.175	392.975	0.25	11.321
10	$2.592 \cdot 10^4$	424.672	196.488	0.50	9.489
11	$2.592 \cdot 10^4$	283.175	392.975	0.25	10.669
12	$1.296 \cdot 10^4$	212.381	196.488	0.50	5.843
13	$1.296 \cdot 10^4$	141.587	392.975	0.25	5.891
14	$2.592 \cdot 10^4$	212.381	196.488	0.50	4.813
15	$2.592 \cdot 10^4$	141.587	392.975	0.25	5.329

Showing criteria of our data, for gaseous phase mass transfer kinetics, to have a criterial relation, starts with dimensional analysis of problem, when we identify the Sh_g dependent criterion and the Re, Re_g, Re_l and simplex S_g as independent criterions. Then the general form of waited criterial relation is given by relation (41). Here Re, Re_l and S_g become from relation (33) and Sh_g and Re_g are expressed with relation (42) where D_{va} is the diffusion coefficient of water vapors in air and ρ_a and η_a are the air density respectively air dynamic viscosity

$$\mathrm{Sh}_g = c\,\mathrm{Re}^m\,\mathrm{Re}_g^n\,\mathrm{Re}_l^p\,S_g^q \tag{41}$$

$$\mathrm{Sh}_\mathrm{g} = \frac{k_{cg}D}{D_{va}}, \quad \mathrm{Re}_\mathrm{g} = \frac{w_g D\rho_a}{\eta_a} \tag{42}$$

Table 9 shows the transformation of Table 8 data, to highlight the dependence of the Sh_g criterion on the independent criteria Re, Re_g, Re_l and S_g. The minimizing of mean square deviation (43), between logarithms of the experimental Sh_g number and those calculated based on the relation (42), brings the problem of *c, m, n, p* and *q* identifying with using of *Matchad* procedure *Minimize* or by solving of the correspondent five linear equations system.

$$F(c,m,n,p,q) = \sum_{i=1}^{16}\left(\ln(Sh_{g\mathrm{i}} - \ln c - m\ln(\mathrm{Re}_i) - n\ln(\mathrm{Re}_{g\mathrm{i}}) - p\ln(\mathrm{Re}_{l\mathrm{i}} - q\ln(S_{g\mathrm{i}})\right)^2 \tag{43}$$

It is thus identified that $c = 1.766$, $n = -0.016$, $m= 0.331$, $p= -0.039$, $q= 0.066$ and consequently the relation (41) will have the particularization (44). The small values for *n*, *p* and *q* recommend the use of relation (44) in the form (45), which is in agreement with the general criterial relations for mass transfer in gases (31, 32).

$$\mathrm{Sh}_g = 1.766\,\mathrm{Re}^{-0.016}\,\mathrm{Re}_g^{0.331}\,\mathrm{Re}_l^{-0,039}\,S_g^{0.066} \tag{44}$$

$$\mathrm{Sh}_g = 0.95\,\mathrm{Re}_g^{0.351} \tag{45}$$

Fig. 12 shows that almost all computed values of Sh_g number are registered with deviations of +/- 25% compared to the experimentally obtained ones.

In relation to the accepted characterization of gas flow expressed by an apparent Reynolds number (Re_g) it should be considered that the gaseous phase flow between the RDC disks is more complicated. But this is another problem, which merits to be analyzed as a convective forced flow in a finite space.

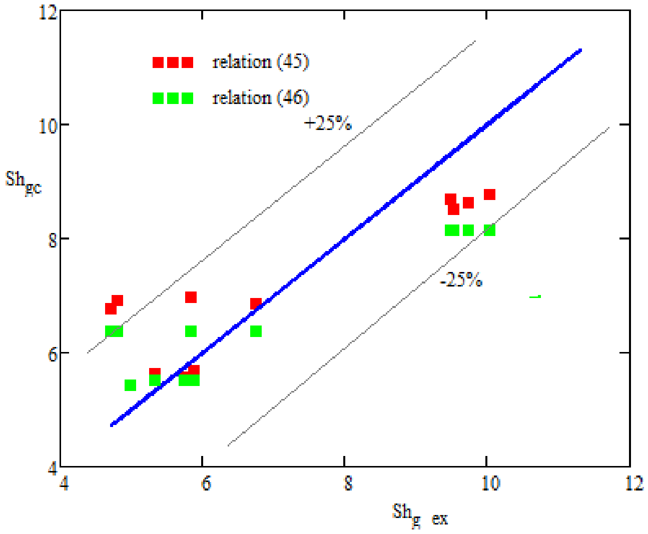

Fig. 12. Deviation of computed gas phase Sherwood number values from experimental ones

It is appreciated that the characterization of the mass transfer kinetics in RDC, as it is given by relations (44) and (45), can be successfully used, for cases of gas (air) washing for easily soluble components (SO_2, Cl_2, HCl, VOC), air humidification, and water (culture media) desorption of some species closely related to liquid phase.

4. Conclusions

Although the use of RDC is presented in many physical, chemical and biochemical applications (air conditioning, gas-liquid reactions, blood oxygenation, tissue culture, and biological wastewater treatment), there is a lack of a systematic approach to characterize the flow and mass transfer in a such equipment. Using experimental investigation and mathematical modeling, the current work pursued the characterization of liquid phase flow as well as the expression of the mass transfer kinetics in liquid and gaseous phases in RDC contacting. Respect to mass transfer problems, it is shown that:

- a pilot laboratory device was created and equipped in such a way as to allow; a) investigating of liquid phase flow structure by mean of tracer pulse method; b) characterization of the mass transfer kinetics in liquid phase through absorption of pure CO_2 by water; c) identification of the mass transfer kinetics for gaseous phase through air humidification.

- the experimental measurements for characterization of mass transfer kinetics for liquid phase showed that this kinetics is influenced by the three process factors that also determined the liquid phase flow structure; the organization of experimental investigation after a complete 2^3 factorial design allowed: a) the analytical highlighting of the complex link between k_l and the process factors; b) transformation and processing of k_l dependence upon process factors through a criterial relationship; c) highlighting the dependence of k_l on $n^{1/2}$ as provided by the renewal theory and as shown by many data from the literature.

- in the case of characterization of mass transfer kinetics for gaseous phase to the three factors determining the structure of liquid phase flow and mass transfer kinetics in the liquid phase must to be added the velocity (flow rate) of gaseous phase through RDC; the organization of the experimental investigation with a 2^4 factorial design led to the result that k_{cg} is strongly influenced by the gas flow, which is in agreement with the general considerations referring to mass transfer in gases.

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