Bioprocess Biosyst Eng (2003) 26: 75–82
DOI 10.1007/s00449-003-0333-1

ORIGINAL PAPER

I. Vinage · Ph. R. von Rohr

Biological waste gas treatment with a modified rotating biological contactor. II. Effect of operating parameters on process performance and mathematical modeling

Received: 28 May 2003 / Accepted: 4 July 2003 / Published online: 19 September 2003

Abstract In the first part of this paper, we introduced a modified rotating biological contactor (RBC) for the biological treatment of waste gas, and demonstrated its feasibility by applying the process to the biodegradation of toluene in a 91-liter reactor containing 20 biofilm support discs with a diameter of 40 cm [1]. We showed that the proposed system allows the unlimited growth of the biofilm to be suppressed, hence eliminating the risk of clogging associated with other biological waste gas treatment systems. Furthermore, we observed stationary long-term performance for more than one year under typical standard operating conditions. In this part of our work, we investigate experimentally the influence of the main process parameters, i.e., gas flow rate, inlet gas concentration, and rotational speed of the biofilm supports on process performance for the same system. Experimental results indicate that the modified RBC system is mass transfer limited for toluene loadings below 150 g/m^{3}h, whereas at higher inlet concentrations of the pollutant, it becomes limited by the biodegradation reaction inside the biofilm. Surprisingly, the disc rotational speed is found to have no major effect on process performance for the system under investigation. A time-independent mathematical model of the process is also presented, and predictions are compared with experimental degradation data. In the range of the investigation process parameters, good agreement between the experimental data and simulation results is obtained.

Keywords Rotating · Biological · Contactor · Biofilm · Toluene

I. Vinage · P. R. von Rohr (✉)
Institute of Process Engineering,
ETH Zurich, Sonneggstrasse 3,
8092 Zurich, Switzerland
E-mail: vonrohr@ivuk.mavt.ethz.ch
Tel.: +41-1-6322488
Fax: +41-1-631141

List of symbols

C	concentration in the gas phase, g/m^3
D	diffusion coefficient, m^2/s
D_{eff}	effective diffusion coefficient in the biofilm, m^2/s
EC	elimination capacity: amount of substrate degraded per unit reactor volume and time, g/m^{3}h
f_s	biofilm surface enlargement
J	diffusion flux, g/m^{2}s
K_L	gas–liquid mass transfer coefficient, m/s
K_m	Michaelis–Menten constant, g/m^3
m	gas–liquid distribution coefficient, g/g
r	radial position, m
$r_{\max}$	maximum degradation rate, g/m^{3}s
RE	removal efficiency, %
S	concentration in the liquid phase and in the biofilm, g/m^3
v	velocity, m/s
z	position perpendicular to the discs, m
δ_B	thickness of the biofilm, m
δ_G	thickness of the gas phase, m
δ_L	thickness of the liquid film, m

Introduction

In the first part of this study, we introduced a novel reactor system for the biological treatment of waste gas, i.e., the modified rotating biological contactor (RBC). This system is capable of exploiting the main advantages of the waste water RBC, which is widely used and generally considered a very robust process. These advantages are the imminent control of the biofilm growth through shear forces acting on the film due to the rotation of the discs, which allow stable long-term performance, as well as low maintenance requirements and an accurate control of the main process parameters, such as pH, temperature, and supply and concentration of nutrients. The principal operating parameters to be

Table 1 Variation ranges of the operating parameters for the characterization of the modified RBC

Operating parameter	Variation range
Gas flow rate	0.45–3.12 m^3/h
Gas inlet concentration	0.1–9.6 g/m^3
Disc's rotational speed	0–11 rpm

considered in the modified RBC system are the gas flow rate, the inlet gas concentration, and the rotational speed of the shaft on which the discs supporting the biofilm are mounted.

A modified bench scale RBC was set up and run under standard operating conditions for a period of more than one year. It was demonstrated that the modified RBC process is feasible for the biological treatment of waste gas [1]. Not only has it been possible to successfully suppress the unlimited growth of the biofilm, but it has also been proved that the system is able to match the industrial demand of stable long-term operation at minimum maintenance requirements. The standard operating conditions that were used throughout the first part of the study correspond to a rather high inlet concentration of the pollutant (3.1 g/m^3), hence indicating the robustness of the process under rugged operating conditions. We may therefore state that the modified RBC does not experience the problem of system clogging, as measurements of the biofilm thickness have revealed that the average thickness remains nearly constant at about 600 μm during the entire experimental investigation.

In this second part of our study, we further characterize the modified RBC system by assessing the effects of the main operating parameters, i.e., gas flow rate, inlet gas concentration, and rotational speed of the discs, on process performance. This is achieved by pursuing a combined experimental and theoretical approach, which is described below.

A detailed discussion of the experimental set-up adopted for the biological degradation of toluene in a modified RBC was provided in the first part of this study [1]. This set-up is again used in this part, and the main operating parameters were varied in the ranges stated in Table 1.

The mathematical model developed for the modified RBC process is presented first, followed by the main experimental results obtained in this study. Experimental data and model predictions are then compared, in order to verify the quality of the model. Moreover, we compare our experimental results with the literature data on the biodegradation of toluene in both biofilters and biotrickling filters, so as to compare the performance of the newly devised process with conventional methods.

Modeling

It is worth noting that the mathematical modeling of waste water RBC processes has mainly been limited to the development of empirical relationships based on available pilot plant data that were then used to design new apparatus. Models reported in the literature have attempted to describe qualitatively the influence of the process parameters such as liquid flow rate, disc rotational speed, and inlet substrate concentration on process performance [2, 3, 4].

A fundamental approach towards a sound understanding of the physical, chemical, and biological phenomena governing the RBC process for the treatment of waste water was undertaken by Hansford et al. [5]. In this study, we use a similar approach. In fact, the model for the removal of the substrate is derived by considering the volume elements on the discs for the liquid film, and the biofilm. In our application, we must also account for the gas phase, and the mass balances for the substrate are made for these volume elements.

The mass balances over the control volumes are based on the following assumptions. First, the degradation reaction only takes place in the particular part of the disc which is exposed to air. In fact, oxygen as well as the pollutant are absorbed from the gas phase into the liquid film, where the degradation reaction takes place. We assume that the degradation reaction inside the biofilm can be described by the Michaelis–Menten equation. Secondly, substrate transport in the gas phase occurs only by convection parallel to the disc surface, whereas transport in the liquid film and the biofilm occur by diffusion perpendicular to the disc surface. The influence of the rotation on mass transfer has been neglected here. Moreover, we assume that the biofilm has a constant thickness, and the activity of the biofilm is equally distributed. Additionally, there is no net biofilm accumulation, and no oxygen limitation occurs. Some of these assumptions, namely the zero net accumulation and the constant average thickness of the biofilm have already been justified experimentally [1]. The validity of the other assumptions is discussed below.

Under these assumptions, the mass balance for the volume elements can be written as:

1. Gas phase:

$$\frac{\partial c}{\partial t} = v(r)\frac{\partial c}{\partial r} - D\frac{\partial^2 c}{\partial z^2} \tag{1}$$

where c denotes the concentration of the pollutant in the gas phase, v the velocity of the gas phase, r the radial postion, D the diffusion coefficient of toluene in the liquid phase, and z the direction perpendicular to the discs.

2. Liquid film:

$$\frac{\partial S}{\partial t} = D\frac{\partial^2 S}{\partial z^2} \tag{2}$$

where S is the concentration of the pollutant in the liquid phase and in the biofilm.

3. Biofilm:

$$\frac{\partial S}{\partial t} = D_{\text{eff}}\frac{\partial^2 S}{\partial z^2} - r_{\max}\frac{S}{K_{\text{m}} + S} \tag{3}$$

where D_{eff} denotes the diffusion coefficient of the pollutant in the biofilm, r_{max} the maximum degradation rate, and K_m the Michaelis–Menten constant.

Using δ_G, δ_L, and δ_B, which represent the thickness of the gas, liquid, and biofilm phases, respectively, we can express the boundary conditions as follows.

The gas phase toluene concentration at $r = 0$, i.e., at the outlet of the shaft, equals the inlet concentration:

$$c_G = c_{in} \text{ at } r = 0 \tag{4}$$

We assume that at the interface, i.e., at $z = \delta_G$, the gas and liquid phases are in equilibrium:

$$S = \frac{c}{m} \text{ at } z = \delta_G \tag{5}$$

In Eq. (5), m denotes the distribution coefficient between the gas and the liquid phases.

Moreover, there is no net diffusion flux from the biofilm into the biofilm support material (substratum) at $z = \delta_L + \delta_B$:

$$J = -D_{eff}\frac{\partial S}{\partial z} = 0 \quad (z = \delta_L + \delta_B) \tag{6}$$

The above material balance equations were solved at steady state using a finite difference method.

According to the two-film theory, the mass transfer into the liquid film is described using the following expression for the mass transfer coefficient:

$$K_L = D/\delta_L \tag{7}$$

We have neglected the mass transfer resistance of the gas phase to estimate K_L.

The actual surface of the biofilm is an important parameter. It is obvious that the actual biofilm surface is larger than the surface of the substratum, and the enlargement factor describing this difference is expressed as f_s.

The sensitivity of the mathematical model with respect to the different model parameters was duly checked by varying the parameter values within physically meaningful ranges following recommendations taken from the literature. This is described in more detail in [6].

An example of the sensitivity of model parameters is shown in Fig. 1, where the influence of the maximum degradation rate and the effective diffusion coefficient are shown for a gas flow rate of 0.96 m^3/h and an inlet concentration of 5 g/m^3. The values of the other model parameters in this example are: $K_m = 0.1$ g/m^3, $K_L = 1.1e\text{-}4$ m/s, $\delta_B = 200$ μm, and $f_S = 2$.

It is readily observed that at low degradation rates, the process is controlled by r_{max} only, as shown in the lower part of the figure. As the degradation rate increases, the process becomes limited by transport inside the biofilm for small effective diffusion coefficients. If D_{eff} is increased, reaction limitation occurs. For high values of r_{max}, the process is only limited by transport in the biofilm, even if the diffusion coefficient is higher than in water. Increasing the inlet concentration increases the extent of the reaction limitation domain.

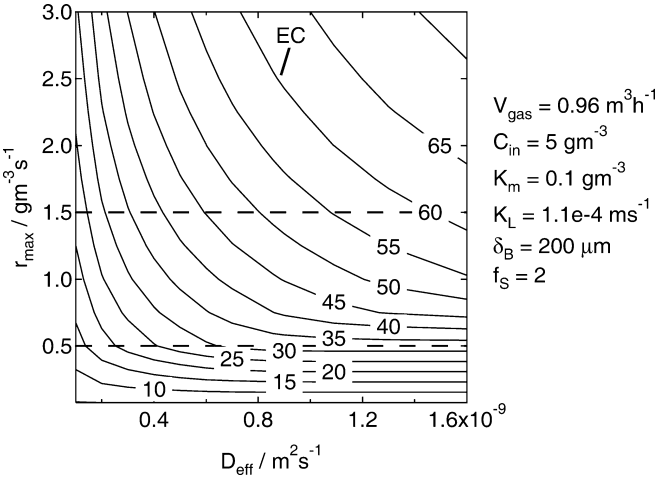

Fig. 1 Contour plot of the elimination capacity of toluene vs. the effective diffusion coefficient D_{eff} and the maximum degradation rate r_{max}, gas flow rate = 0.96 m^3/h, inlet concentration = 5 g/m^3

Ottengraf and coworkers have distinguished between two limiting cases for reaction in a biolayer, i.e., a reaction limited case and a transport limited case [7]. The transition from diffusion to reaction limitation with increasing diffusion coefficient in the biofilm is actually illustrated in the lower half of Fig. 2. The concentration profiles of toluene inside the biofilm were calculated at a radial position of 4 cm for a gas inlet concentration of 5 g/m^3 and a maximum degradation rate inside the biofilm of 0.5 g/m^3h, and varying the value of the diffusion coefficient. The curves shown in the lower half of Fig. 2 correspond to the lower dashed line in Fig. 1.

It can be observed in Fig. 2 that the process is transport limited for small diffusion coefficients, as the pollutant is completely degraded before penetrating the whole biofilm. In contrast, the entire thickness of

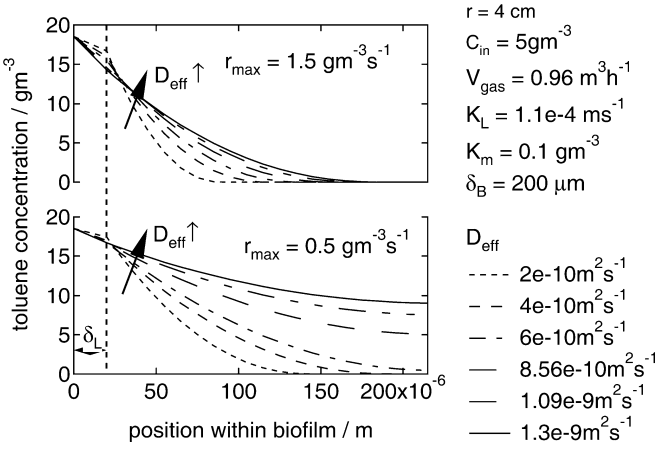

Fig. 2 Toluene concentration profile within the biofilm as a function of the effective diffusion coefficient D_{eff} for two different maximum degradation rates r_{max} and a radial position of 4 cm

the biofilm is needed if the value of the diffusion coefficient is increased, thus indicating reaction limitation.

The concentration profile of the pollutant for a maximum degradation rate of 1.5 g/m^{3}h is shown in the upper half of Fig. 2. The inlet concentration was again 5 g/m^3. In fact, this case corresponds to the upper dashed line in Fig. 1. In this case, the pollutant is completely degraded before penetrating the entire thickness of the biofilm, even if the diffusion coefficient is chosen higher than the diffusion coefficient of toluene in pure water. Hence, the process is exclusively controlled by transport in the biofilm.

Figure 3 illustrates the concentration profile of the pollutant in the gas phase for different values of the effective diffusion coefficient. The values of the model parameters correspond to the values in the upper and lower halves of Fig. 2, respectively, i.e., an inlet concentration of 5 g/m^3, a gas flow rate of 0.96 m^3/h, and maximum degradation rate of 0.5 and 1.5 g/m^{3}h.

We may conclude that the concentration of the pollutant in the gas phase remains constant up to a radius that approximately corresponds to the immersion depth of the discs. Moreover, the toluene concentration rapidly decreases with increasing disc radius. However, this is easily explained by the fact that the interfacial area between the liquid and gas phases increases with increasing radial position along the disc. Furthermore, the outlet concentration decreases with increasing diffusion coefficient and with increasing reaction rate as expected.

Experimental results

The influence of the main operating parameters, i.e., rotational speed of the biofilm support, gas concentration and gas flow rate, on process performance were investigated experimentally. All measurements reported were taken during well-established steady states. The standard operating conditions were always resumed between two experiments at other operating conditions. New experiments at conditions different from the standard operating conditions were only initiated after the reactor performance had returned to its expected steady-state values in standard conditions. These were a gas flow rate of 0.96 m^3/h, a toluene inlet concentration of 3.1 g/m^3 and a rotational speed of the discs of 6 rpm.

Influence of gas flow rate and concentration

The influence of the synthetic waste gas flow rate and the pollutant concentration on process performance were studied experimentally at four different air flow rates, 0.45 m^3/h, 0.96 m^3/h, 2.04 m^3/h, and 3.12 m^3/h, and inlet concentrations between 0.1 and 9.6 g/m^3. In these series of experiments, the rotational speed was always fixed at a value of 6 rpm.

Experimental results obtained in the bench scale modified RBC are illustrated in Fig. 4, where the toluene elimination capacity is plotted vs. the toluene inlet load for the four different gas flow rates investigated. It is worth noting that the unit is g toluene per m^3 reactor and hour for both parameters.

The increase of the toluene elimination capacity with increasing pollutant inlet load indicates that mass transfer limitations govern the process. However, it is not straightforward to attribute this mass transfer limitation to the gas–liquid mass transfer, the diffusion within the biofilm, or both phenomena. It is also observed that, for high inlet loads, i.e., above 150 g/m^{3}h, the elimination capacity flattens towards an asymptotic maximum value of approximately 55 g/m^{3}h. In this region, the elimination capacity remains independent of inlet load and of gas flow rate, hence indicating that the process is limited by the biodegradation reaction in this

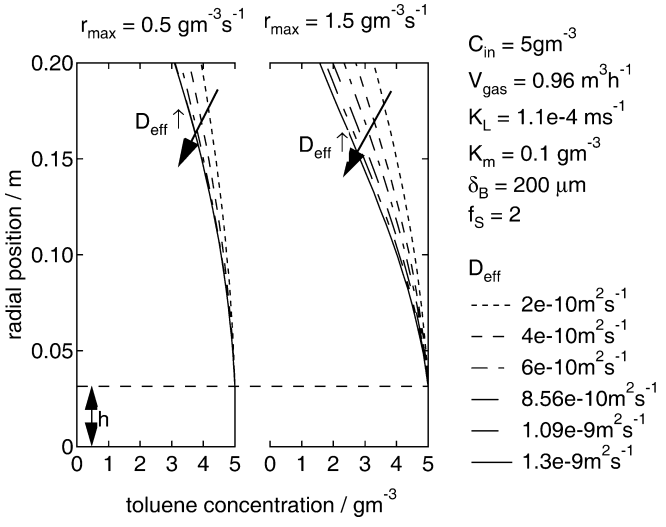

Fig. 3 Toluene concentration profile in the gas phase as function of the effective diffusion coefficient D_{eff} for two different maximum degradation rates $r_{\max}$

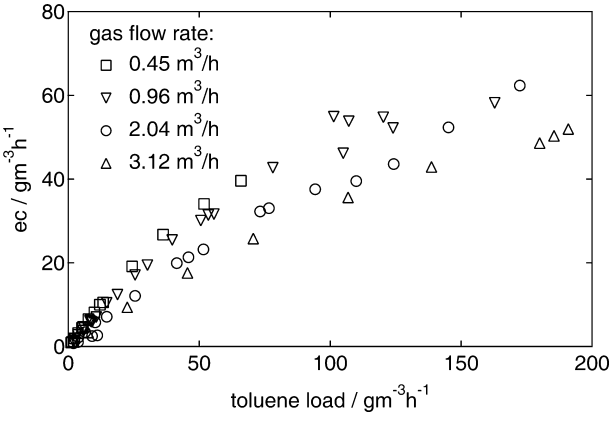

Fig. 4 Toluene elimination capacity vs. inlet load for different air flow rates: 0.45 m^3/h (*squares*), 0.96 m^3/h (*inverted triangles*), 2.04 m^3/h (*circles*), and 3.12 m^3/h (*triangles*)

domain. This result clearly demonstrates that oxygen limitation does not occur in the region where the process is not limited by the degradation reaction.

Similar behavior is observed when the elimination capacity is plotted against the inlet concentration. In fact, at low values of the inlet concentration, the elimination capacity increases nearly linearly with increasing concentration. Similarly, the elimination capacity tends to reach a constant value at higher concentrations, as illustrated in Fig. 5.

These results may also be expressed as percentages of toluene conversion vs. the inlet load, as shown in Fig. 6.

We observe that the removal efficiency decreases with increasing gas flow rate and with increasing inlet load. A maximal removal efficiency of 85% could be reached for a gas flow rate of 0.45 m^3/h and a corresponding inlet concentration of 0.47 g/m^3. In the region where the process is reaction limited, i.e., at inlet toluene loads above 150 g/m^3h, the removal efficiency becomes independent of the gas flow rate.

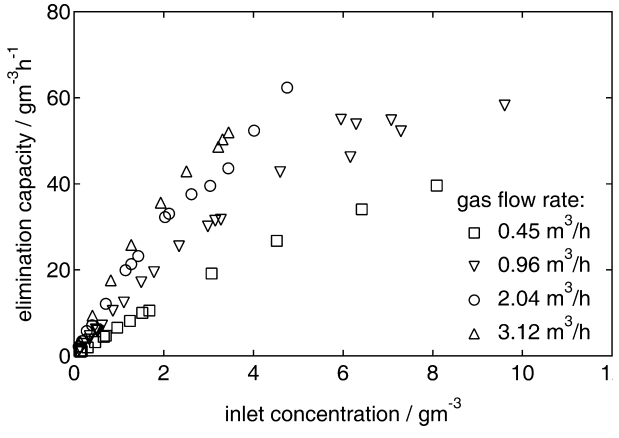

Fig. 5 Toluene elimination capacity vs. inlet concentration for different air flow rates: 0.45 m^3/h (*squares*), 0.96 m^3/h (*inverted triangles*), 2.04 m^3/h (*circles*), and 3.12 m^3/h (*triangles*)

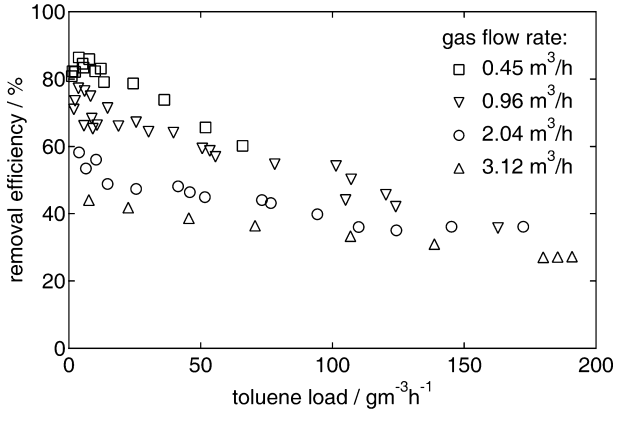

Fig. 6 Toluene removal efficiency vs. inlet load for different air flow rates: 0.45 m^3/h (*squares*), 0.96 m^3/h (*inverted triangles*), 2.04 m^3/h (*circles*), and 3.12 m^3/h (*triangles*)

It is worth mentioning that, for gas phase concentrations up to 1.3 g/m^3, no toluene could be detected in the liquid phase. For higher inlet concentrations in the gas phase, the concentration in the liquid phase increases with increasing inlet concentration, as expected. For all cases, the liquid phase concentration was far below the equilibrium concentration corresponding to the composition of the gas phase. This result may be used as proof that mass transfer from the gas into the liquid film is limiting.

Influence of rotational speed

The effect of the rotational speed was also investigated. It is clear that the long-term influence of the rotational speed on biofilm thickness and structure will be substantial, as the shear stress exerted on the biofilm increases with increasing rotational speed. Hence, for the experimental results presented in this section, we studied the effect of short-term variations in the rotational speed on process performance, i.e., an experimental run never exceeded a few hours, thus ensuring that the microorganisms were not irreversibly influenced. This was especially important in the case of experiments at 0 rpm, in order to avoid the biofilm running dry.

The toluene elimination capacity is plotted vs. the rotational speed in Fig. 7. The air flow rate was 0.96 m^3/h in this case, and the inlet concentration was varied between 0.12 and 6.66 g/m^3. The rotational speed was varied between 0 and 11 rpm.

It can be concluded from the results shown in Fig. 7 that the rotational speed does not exhibit a major effect on the elimination capacity. In fact, for all inlet concentrations investigated, the elimination capacity was independent of the rotational speed, even in the practically unfeasible case when the discs were not rotating. This result clearly indicates that only the part of the disc which is exposed to the gaseous phase takes part actively

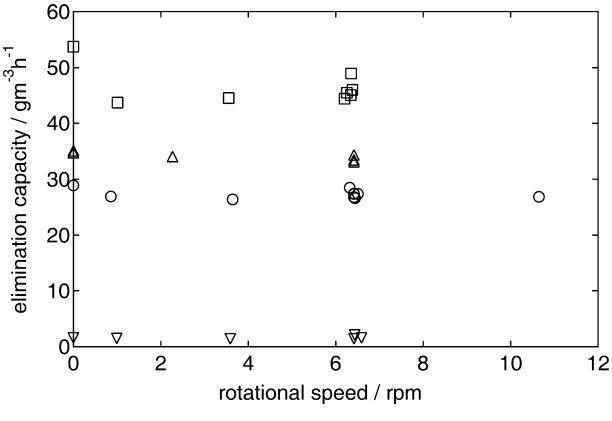

Fig. 7 Toluene elimination capacity vs. rotational speed for an air flow rate of 0.96 m^3/h and different gas inlet concentrations: 6.66 g/m^3 (*squares*), 3.19 g/m^3 (*triangles*), 2.84 m^3/h (*circles*), and 0.12 m^3/h (*inverted triangles*)

in the degradation process. This can easily be explained by considering that the most important absorption step takes place during the rotation through the gas phase, i.e., during this time, the pollutant and oxygen are absorbed into the liquid film carried along on the discs. Similar results were observed when experiments were carried out at higher air flow rates.

Similarly, the toluene concentration in the liquid phase is not affected by variations in the rotational speed. This behavior was observed at two different air flow rates, i.e., 0.96 and 3.12 m^3/h, as shown in Fig. 8.

Thus, summarizing the above experiments carried out in the modified RBC for waste gas treatment, short-term variations in the rotational speed do not adversely influence the gas–liquid transport of toluene, as the process performance is not altered. This result is quite surprising, as it had been observed in the literature that increasing the rotational speed increased the oxygen mass transfer in application to waste water treatment (e.g., [8, 9]). However, this conflicting discrepancy may easily be resolved by considering that the solubility of toluene in water is very low, and that mass transfer limitations may be of crucial importance in gas–liquid mass transfer in waste gas treatment RBCs.

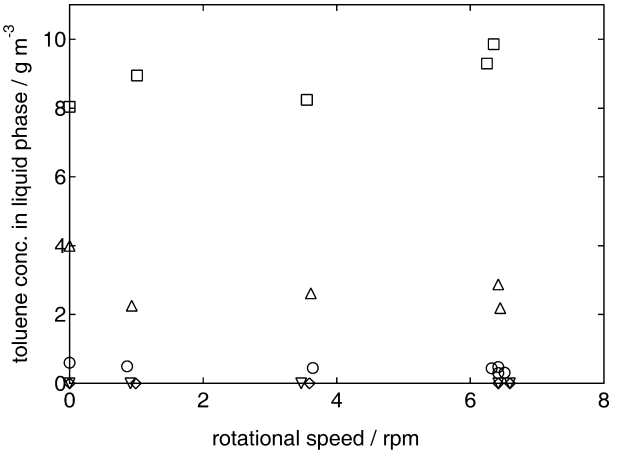

Fig. 8 Toluene concentration in the liquid phase for an air flow rate of 0.96 m^3/h and different inlet concentrations: 6.66 g/m^3 (*squares*), 2.84 g/m^3 (*circles*), 0.12 g/m^3 (*diamonds*), and for an air flow rate of 3.12 m^3/h and different gas inlet concentrations: 3.30 g/m^3 (*triangles*), and 0.14 g/m^3 (*inverted triangles*)

Comparison with literature data

In the next step, experimental degradation results obtained in the novel modified RBC for waste gas treatment were compared with the literature data on toluene degradation in biofilters and biotrickling filters. The experimental conditions in the different arrangements as well as the key results are summarized in Table 2.

These results may then be compared by plotting elimination capacity vs. inlet load for the modified RBC and the conventional biological waste gas treatment facilities, as shown in Fig. 9.

It is obvious from the diagram that the performance of the modified RBC is situated among the highest elimination capacities for toluene reported in the literature. However, these results were compared on a basis of mass of pollutant eliminated per hour and reactor volume. It is clear that a comparison on the basis of degradation per surface of the biofilm support would be favorable in our case. However, these values are hardly found in the literature, as results obtained in biofilters and biotrickling filters are most commonly reported on a volume basis. Nevertheless, the performance of the modified RBC is satisfactory, given the fact that the process may be operated continuously for long times without running the risk of compacting or clogging at minimum maintenance requirements.

Moreover, it is worth recalling that the thickness of the discs in the modified RBC is relatively high (0.5 cm) in our case. This was necessary to ensure sufficient stability of the discs, since the spacer sleeves that were used to fix the distance between two discs had to be placed near the shaft in order to be able to remove disc segments for biofilm analysis. For this reason, the surface of the biofilm support material per reactor volume is rather small. In a real case, the discs can be as thin as 1 mm, hence even improving process performance as compared with conventional processes.

Table 2 Experimental data for toluene removal in biofilters, biotrickling filters (BTF) and the modified RBC

Reference	Reactor	Max. load (g/m^3h)	Max. EC (g/m^3h)	Gas flow rate (m^3/h)	Gas velocity (m/h)	Gas residence time (s)
[10]	Biofilter	273	72	1.2	68	58
[11]	Biofilter	200	25	6.5	91	30.8
[12]	BTF	217	71	1.5	83	56.2
[12]	BTF	217	83	1.5	83	56.2
[13]	BTF	70	50	0.332	13	308.4
[14]	BTF	1316	123	0.75	103	36.7
[14]	BTF	1308	111	1.5	206	18.4
[14]	BTF	1297	85	3	412	9.2
[15]	BTF	89	57	7	99	36.4
[15]	BTF	87	31	7	99	36.4
Modified RBC	RBC	66	40	0.45	33–3	104
Modified RBC	RBC	163	58	0.96	70–7	48.7
Modified RBC	RBC	172	62	2.04	148–16	22.9
Modified RBC	RBC	191	52	3.12	226–24	15

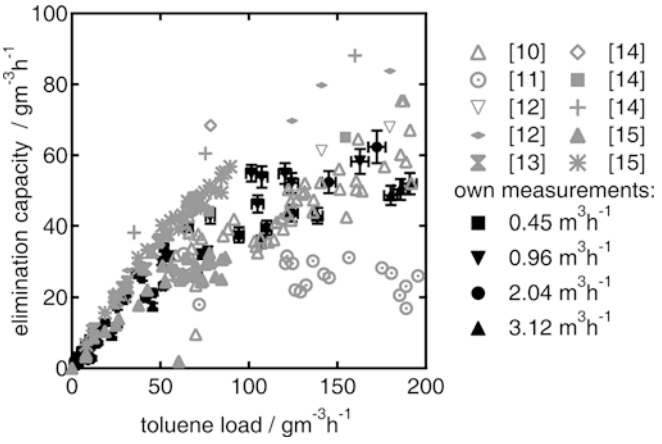

Fig. 9 Elimination capacity of the modified RBC compared with literature data for biofilters and biotrickling filters

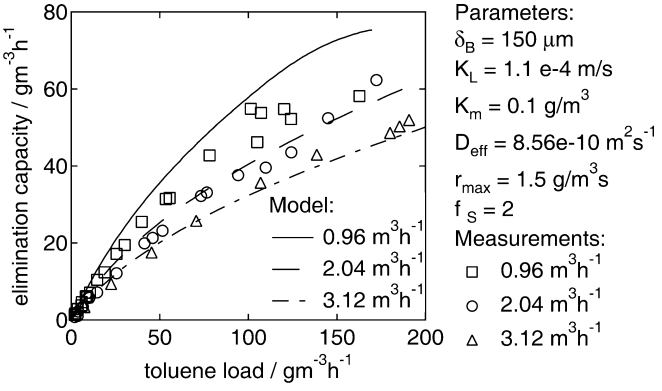

Fig. 10 Elimination capacity of the modified RBC: comparison between model and experimental results

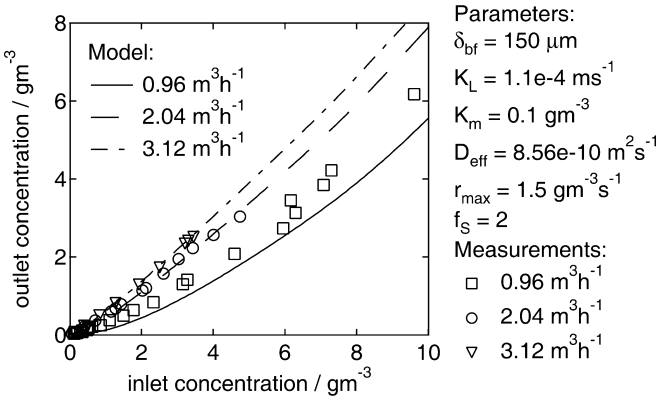

Fig. 11 Outlet concentration of the modified RBC vs. inlet concentration: comparison between model and experimental results

Table 3 Parameter values used in the simulations

δ_B	150	μm
K_L	1.1*e*−4	m/s
K_m	0.1	g/m^3
D_{eff}	8.56*e*−10	m^2/s
r_{max}	1.5	g/m^{3}h
f_S	2	–

Comparison between model and experiments

Finally, elimination capacities obtained from the model calculations are compared with the experimental results in Fig. 10, whereas calculated outlet concentrations are compared with the measured data in Fig. 11. The values of the model parameters used in the calculations and shown in Figs. 10 and 11 are listed in Table 3.

The agreement between the experimental results and the model predictions is fairly good for gas flow rates between 2.04 and 3.12 m^3/h, as readily observed in Fig. 10. For a rather low gas flow rate of 0.96 m^3/h, the predicted values are slightly higher than the measured data. The maximum difference between measured and predicted values is 19%, which may be considered as an acceptable error.

The agreement between the predicted outlet gas concentrations and the measured data illustrated in Fig. 11 is satisfactory also for gas flow rates between 2.04 and 3.12 m^3/h. Similarly to the case described above, the discrepancies between the experimental data and the model results are larger at low flow rates. In this case, the results differ by a maximum of 20%.

The large deviations observed at low gas flow rates may be explained by considering that the gas phase resistance should also be taken into account in gas–liquid mass transfer calculations under these conditions. Generally, the gas–liquid mass transfer coefficient is expected to decrease with decreasing gas flow rate. Hence, at a certain point, the resistance of the gas phase can no longer be neglected.

Conclusion

In this work, we developed and characterized a novel system for biological waste gas treatment: the modified RBC. One of the major advantages of this system is the control of biofilm growth through the shear stress acting on the biofilm due to the rotation in the water phase. The presence of a bulk liquid phase allows the process parameters to be controlled most efficiently when compared with conventional biological waste gas treatment processes. This system was shown to exhibit stationary long-term performance for a period of more than one year, hence indicating its feasibility for industrial application.

In this second part of our experimental study of toluene degradation in a modified RBC, we assessed the effect of the main operating parameters on the process. This was achieved by thoroughly studying the effect of gas flow rate, gas concentration, and rotational speed of the biofilm support on the performance, expressed as elimination capacity or pollutant removal efficiency.

We found that mass transfer phenomena govern the process for toluene loading below 150 g/m^{3}h. However,

the process becomes limited by the degradation reaction taking place inside the biofilm at higher gas loadings. Surprisingly, in the system investigated, the rotational speed of the discs did not show any effect on the degradation efficiency.

The degradation results of the newly devised process were compared with the degradation results of conventional waste gas treatment facilities. The performance of the modified RBC is satisfactory, especially if it is considered that the comparison is made on a volume basis, whereas a surface basis would be more suitable for the modified RBC process.

A mathematical model for the modified RBC process was developed and used to study the process performance theoretically. Model predictions are in good agreement with the experimental results obtained in the laboratory-scale facility. Agreement is especially good for gas flow rates between 2.04 and 3.12 m^3/h, but discrepancies are higher for a gas flow rate of 0.96 m^3/h. The deviation is attributed to the gas phase resistance in the gas–liquid mass transfer calculations, which cannot be neglected at lower gas flow rates.

The present investigation is extended to substrates with a high solubility in water in order to study the influence of the disc rotational speed on gas–liquid mass transfer.

References

1. Vinage I, Rudolf von Rohr P (2003) Biological waste gas treatment with a modified rotating biological contactor. I. Control of biofilm growth and long-term performance. Bioprocess Biosyst Eng in press
2. Banerjee G (1997) Hydraulics of bench-scale rotating biological contactor. Water Res 31:2500–2510
3. Delborghi M, Palazzi E, Parisi F, Ferraiolo G (1985) Influence of process variables on the modeling and design of a rotating biological surface. Water Res 19:573–580
4. Leduc R, Buchanan I (1993) Minimization of multistage RBC active disc area. J Environ Eng 119:271–286
5. Hansford GS, Andrews JF, Grieves CG, Carr AD (1978) A steady-state model for the rotating biological disc reactor. Water Res 12:855–868
6. Vinage I (2002) Biological waste gas treatment using a modified rotating biological contactor. Dissertation ETH No 14702, Zurich
7. Ottengraf SPP, Vandenoever AHC (1983) Kinetics of organic-compound removal from waste gases with a biological filter. Biotechnol Bioeng 25:3089–3102
8. Banerjee G (1997) Treatment of phenolic wastewater in RBC reactor. Water Res 31:705–714
9. Sassi G, Ruggeri B, Bosco F, Specchia V (1996) Relaxation time analysis of a rotating biological contactor. Chem Eng Sci 51:2853–2858
10. Bibeau L, Kiared K, Leroux A, Brzezinski R, Viel G, Heitz M (1997) Biological purification of exhaust air containing toluene vapor in a filter-bed reactor. Can J Chem Eng 75:921–929
11. Kiared K, Fundenberger B, Brzezinski R, Viel G, Heitz M (1997) Biofiltration of air polluted with toluene under steady-state conditions: experimental observations. Ind Eng Chem Res 36:4719–4725
12. Cox HHJ, Deshusses MA (1999) Biomass control in waste air biotrickling filters by protozoan predation. Biotechnol Bioeng 62:216–224
13. Pedersen AR, Arvin E (1997) Toluene removal in a biofilm reactor for waste gas treatment. Water Sci Technol 36:69–76
14. Sjöberg A (1999) Toluene removal from waste air by combined biological and non-thermal plasma techniques, Dissertation ETH No 13092, Zurich
15. Weber FJ, Hartmans S (1996) Prevention of clogging in a biological trickle-bed reactor removing toluene from contaminated air. Biotechnol Bioeng 50:91–97