THE TWO-PHASE BIOREACTOR WATER / SILICON - OIL : PROSPECTS IN THE OFF- GAS TREATMENT

Jean-Marc Aldric[(1)]*, Jacqueline Destain [(1)]and Philippe Thonart[(1,2)]

(1) Faculté Universitaire des Sciences Agronomiques de Gembloux,

Unité de Bioindustries, Centre Wallon de Biologie Industrielle.

Passage des déportés, 2, 5030 Gembloux, Belgium.

(2) Centre Wallon de Biologie Industrielle, Service de Technologie Microbienne, Université de Liège, Bd du Rectorat Bat. 40 B-4000 Liège, Belgium

* fax number : 003281 / 61 42 22 ; e-mail adress :aldric.jm@fsagx.ac.be

KEYWORDS: TWO-PHASE BIOREACTOR ; SILICON OIL; V.O.C.; OFF GAS TREATMENT

ABSTRACT: A research was carried out to develop a biphasic biological reactor able to clean the gas effluents polluted by volatile organic compounds (V.O.C). Initially, *Rhodococcus erythropolis* T 902.1 had been selected on the basis of its capacity to degrade isopropyl-benzene (IPB).

The effect of gas flow and IPB concentration on the biodegadation of IPB was evaluated.

The results show that the use of silicon-oil allows large quantities of IPB to be absorbed within the medium of biological abatement. On the other hand, the biodegradation rate is directly correlated to the inlet flow of IPB. Thus, the reactor presents interesting opportunities in the biological treatment of gas effluents.

1 INTRODUCTION

A research is carried out within the framework of gaseous treatment. It aims to develop a biphasic reactor "water / silicon- oil ". Silicon-oil is used to allow a better biological abatement of the aromatic organic compounds by improving their solubility within the two-phase bioreactor. Initially a bacterial strain (*Rhodococcus erythropolis T 902.1*) was selected on the basis of its good capacity to degrade isopropyl-benzene (IPB), a compound selected as a model for the family of benzene. Various research was performed in order to improve degradation of VOC in gas effluents, particularly by improving the mass transfer of VOC within the reactor. Yeom and Daugulis (2001) (1) recommend the use of a biphasic biological reactor whose organic phase (hexadecane) constitutes 1/3 of the reactional medium. Hexadecane presents the property to be slightly toxic for the micro-organisms. A similar process showed its effectiveness on the biodegradation of a mixture of organic pollutants (B.T.E.X.) by a *Pseudomonas sp*. strain (2a ; 2b).

Van Ede *et al.* (1995) (3) showed, by the theory called Film Variable Holdup (F.V.H.) model, an enhancement in the gas transfer thanks to the presence of a dispersed octene phase.

Moreover, it could be shown that the transfer rate and the biodegradation of apolar pollutants in biological waste gas treatment, as well as transfer rate of oxygen, can be enhanced by a dispersed organic solvent (FC40, 10 % V/V). Theoreticaly, it could be shown that the addition of solvent has a more significant effect on the enhancement of transfer rate in case of poorly water-soluble compounds compared to moderately water-soluble ones. (Teresa *et al.*, 1997) (4).

On the other hand, Nielsen *et al*.(2003) (5) showed an increase of the oxygen's solubility within the system by the addition of hexadecane. This increase provides a potential for enhancement of oxygen's mass transfer rate.

Dumont and Delmas (2001) (6) reviewed the general concept of oil-in-water systems. This was supposed to demonstrate the ability of an immiscible oil phase to influence the possible way for transfer from the gas phase to the aqueous phase.

An other way to enhance oxygen gas transfer rate is proposed by using soybean oil-in-water dispersion (7).

In this context, silicon oil can also be used to reproduce the effect of a solvent. Thus, Budwill and Coleman (1997) (8) developed a biofilter with silicon oil addition that improves hexane biodegradation. Moreover, Gardin *et al.*

64 improved the biodegradation of xylene and butyl acetate by using an aqueous-
65 silicon oil two-phase system.
66 Finally, Aldric (2001) (9) showed the value of the use of the silicon oil in a
67 proportion of 10 % in a two-phase bioreactor. Silicon oil allows an important
68 improvement of the gas retention into biphasic medium, i.e. the volume of gas
69 retained within a volume of reactional medium liquid. Furthermore,
70 coefficient of oxygen mass transfer is not decreased compared to an aqueous
71 medium. These aspects show the possibilities of application in the field of the
72 off-gas treatment. Indeed, the silicon oil allows a significant solubilisaton of
73 volatile organic compounds. The object of this study thus consists in
74 specifying the influence of silicon oil on the biodegradation of IPB, selected as
75 model for the B.T.E.X. compounds.

76 ## 2 MATERIALS AND METHODS

77 ### 2.1 *Strain and chemicals*
78

79 The *Rhodococcus erythropolis* strain was obtained from the collection of the
80 Walloon Center for Industrial Biology (C.W.B.I.; Belgium) (10 and 11).
81 All substrates and other chemicals were purchased from VWR internationnal
82 (Leuven, Belgium) or Aldrich (Bornem, Belgium).

83 ### 2.2 *Bioreactor and assembly*

84 The stirred bioreactor used for biodegradation (LSL Biolafitte BL06.1, Saint
85 Germain en Laye, France) was described by Aldric (2001). Its reactional

volume reaches 4.5l and the stirring speed was maintained at 600 rpm. The assembly is schematized in figure 1.

The IPB concentrated gas is generated by stripping within a thermostatized glas bottle. The gas flow is permanently controlled by a flow meter.

The concentration of IPB in the gas coming in the bioreactor is controlled by an adjustable mixture between polluted gas and air.

2.3 *Experimental design*

Doehlert design (12) was selected to evaluate the effect of two factors on the biodegradation: gas flow and IPB concentration of inlet gas. The values of concentration and flow corresponding to the experimental points are selected so that the pairs concentration-flow are located at the angles of a perfect hexagon in bidimensional space "Concentration / Flow". Nevertheless, the adjustment of the parameters to their fixed values is difficult because of the technical constraints. The statistical analysis of the results thus requires to take into account the real average values of the two studied parameters. The shifted points obtained in experiments are indicated on figure 9. The area defined by the Doehlert design is a circle in a two dimensional space. 5 levels were retained (mg/Nm^{3*}) for the "concentration" factor and 3 levels for factor "flow" (l/min).

The 10 performed experiments are included and characterized in table 1. Shaded experiments represent the repetitions of the central experiment.

---

* Nm^3 : m^3 under normal conditions of temperature and pressure (25°C – 101325 Pa)

Statistical analysis of the results was carried out with the software SAS ® .

The Doehlert design (12) permits to establish a second degree regression model with interactions of the second order

2.4 *Sampling and analytical methods*

Gas samples are regularly taken from each bubble of sampling as well as in the liquid reactional medium. IPB concentration was estimated thanks to a Perkin Elmer headspace sampler HS 40 XL (for liquid samples) and a gaz chromatograph Hewlett Packard 5890 equiped with a Alltech INC. Deerfield EC-WAX column and flame ionisation detector (for gas-samples). Temperatures of the injector, column and detector were respectively 153, 150 and 250 °C.

2.5 *Implementation of the biomass*

The culture of *Rhodococcus erythropolis* in 868 medium (glucose 20g/l.; casein peptone 20 g/l; yeast extract 10 g/l) is harvested after 64 hours (optical density 600 nm =1.4). The inoculum for the biological reactor is obtained by centrifugation of 2.25 L of this culture. The pellet obtained is washed twice and diluted in 200 ml saline water (6g/l NaCl). The inoculum is then introduced into the bioreactor where the medium for biodegradation is composed of silicon oil (10% V/V) and aqueous medium M284 (90 % V/V) whose composition is : Tris-HCl 6.06g/l ; NaCl 4.68g/l ; KCl 1.49g/l; NH_4Cl

1.07g/l ; Na_2SO_4 0.43g/l; $MgCl_2$. $6H_2O$ 0.20g/l ; Na_2HPO_4 $2H_2O$ 40mg/l ; $CaCl_2$. $2H_2O$ 30mg/l ; Fe(III)NH_4citrate 4.8mg/l. $ZnSO_4$.7 H_2O 0.144 mg/l ; $MnCl_2$.4 H_2O 0.1 mg/l ; H_3BO_3 0.062 mg/l ; $CoCl_2$.6 H_2O 0.19 mg/l; $CuCl_2$.2 H_2O 0.017 mg/l ; $NiCl_2$.6 H_2O 0.024 mg/l ; Na_2MoO_4.2 H_2O 0.036 mg/l; ethanol 1g/l.

2.6 *Determination of concentrations and flows*

Only the data corresponding to a stabilization of the IPB concentration within the liquid medium is retained. The following relation is indeed correct because IPB consumption by the biomass (term to the left) is equal to the transferred quantity (term to the right):

$$\left(Q_{in}-Q_{out}\right)=K_L a\left(C_L{}^0-C_L\right)$$

where $K_l a$ is the total coefficient of mass transfer for IPB (min^{-1}); Q_{in} and Q_{out} are respectively the inlet flow and outlet flow of IPB (mg IPB/min.l of reactional medium); C^0_L = saturating concentration of IPB in the biphasic liquid medium (mg/Nm^3) ; C_L= equilibrium concentration of IPB in the biphasic liquid medium (mg/l).

Inlet flow and outlet flow of IPB are given by the following equations:

149 $$Q_{IN} = \frac{Conc.IN_{mean} \times flow}{vol}$$

150

$$Q_{OUT} = \frac{Conc.OUT_{mean} \times flow}{vol}$$

$$Conc_{mean} = \sum_{i=1 \grave{a} n} \frac{Conc_i \times (t_i - t_{i-1})}{t_{tot}}$$

151

152 where $Conc._{mean}$ = weighted average of concentrations during an equilibrium
153 phase (mg/Nm^3).
154 $Conc_i$ = specific concentration (mg/Nm^3) measured by gas injection at time
155 t=i.; flow = flow of gas effluent loaded in IPB; t = time (h) and Vol= the
156 volume of the reactional medium.

157 2.7 *Determination of the biodegradation rate*
158

159 The biodegradation rate can be easily calculated by the following formula:
160 Biodegradation rate = 100 x (Q_{in} - Q_{out}) / Q_{in} where Q_{in} and Q_{out} are described
161 above.
162
163

3 RESULTS AND DISCUSSION

3.1 *Follow-up of the IPB biodegradation in a gas effluent*

Previously, *Rhodococcus erythropolis* T 902.1 showed good potential for biodegradation of aromatic compounds (benzene, toluene and xylene) in liquid medium. Moreover, this strain has very interesting properties to produce starter culturess, specifically due to drying procedure. The industrial applications are thus possible (10).

More specifically, this strain contains a catabolic plasmid conferring it the aptitude to degrade toluene and the other aromatic compounds such as the IPB, selected as model within the framework of this research (11).

In this research, this strain was implemented in a two-phase bioreactor which was developed to degrade IPB in gas effluents. The use of the silicon oil is the originality of the proposed two-phase reactor. This phase is used to improve the transfer and the biodegradation of the IPB from off-gas.

A laboratory scaled two-phase reactor was developed to study the influence of the IPB concentration and the flow of gas (fig.1).

The device permits generation of a polluted effluent with a flow and a specified IPB concentration. This device is followed by sample points within the reactional liquid medium, at the entry and the exit of the bioreactor (see description, fig. 1). The follow-up makes it possible to determine the rate of IPB biodegradation and the loading capacity of the bioreactor for the various values of the studied parameters (flow and IPB concentration). Moreover, in

187 order to follow the two studied parameters, Doelhert design was implemented
188 as explained previously (see paragraph 2.3). The experiments included in
189 Doelhert design were monitored during 3 days. As described previously, the
190 measurements taken into account to determine the parameters (biodegradation
191 rate and loading capacity) are those corresponding to a stability of the
192 concentration in the liquid medium (consumed quantity = transferred quantity)
193 The evolution of IPB concentration in inlet gas, outlet gas and within the
194 liquid medium is given, as example, in figures 2 and 3 for the two most
195 significant experiments corresponding respectively to a low flow and a high
196 flow of IPB (mg/min.l)
197 Figure 2 shows the evolution of the IPB concentration as described above. The
198 experiment presented at figure 2 corresponds to a 0.60 mg/min.l IPB flow of
199 reactional medium. Both concentration within the liquid and concentration in
200 outlet gas of bioreactor are very low, what represents a very good
201 biodegradation yield.
202 The experiment presented at figure 3 corresponds to the highest loading of IPB
203 (9.47 mg/min.L) and shows the evolution of the IPB concentration for this
204 experiment. It is obvious that the concentration in outlet gas is high (1727
205 mg/Nm^3 on average) but comparatively to concentration in inlet gas and to the
206 gas flow, the biodegradation yield remains very acceptable.
207 These two examples show that the IPB biodegradation by the selected strain is
208 important, including for high loads of IPB (more than 9 mg/min.l ; $540g/m^3.h$).

In order to define the potentialities of the proposed bioreactor, the biodegradation rate (% of IPB degraded by the biomass) and the loading capacity (mg/min.l) were given for each experiment.

3.2 *Biodegradation rate functions of flow and concentration*

The biodegradation rate is the relationship between the quantity of polluant degraded by the biomass (mg/min.l) and the flow of pollutant entering bioreactor (mg/min.l). It expresses the efficiency of the bioreactor for each pair (concentration - flow).

For each experiment of Doehlert design, the biodegradation rate of the IPB was calculated as indicated below:

$$\Gamma = \frac{100 \times Q_{in} - Q_{out}}{Q_{in}}$$

where τ is the biodegradation rate of IPB (%).

Q_{in} and Q_{out} are respectively the flows of IPB entering and outgoing from the bioreactor (mg/min.l). The biodegradation rate of IPB for each experiment and each day is shown in figure 4. The biodegradation rates are high in all experiments, except for experiments 5 and 7. In the implemented range of flow and concentration, the biodegradation rate is never lower than 53 % except for the first day of experiment 8. After comparing the biodegradation rate according to the days of experimentation, it is observed that the biodegradation rate is often the highest at the end of the experiment (third

day). This can be explained by an adaptation phase of the biomass to the presence of IPB.

As described previously, the objective of this research is to evaluate the effect of the gas flow and the IPB concentration on the effectiveness of the proposed bioreactor, i.e. on the biodegradation rate. It is why a statistical analysis of the results was carried out.

3.3 *Statistical analysis of the results*

The statistical analysis of the results, according to the response surface method, is carried out in order to establish a second degree regression model between the biodegradation rate and the two chosen parameters: gas flow (l/min.) and IPB concentration (mg/Nm^3).

Considering that the cells must be adapted, only the values of biodegadation rate corresponding to the third day are taken into account for the statistical analysis.

For this purpose, the values of biodegradation rate measured were transformed by the arcsinus square root transformation. This traditional transformation permits to observe the conditions for application for the analysis of the results according to Doelhert (12). On the basis of above mentioned considerations, a second degree regression model can be proposed:

$$\arcsin^{-1}\Gamma = 1.987 - 0.216Q - 1.4*10^{-4}Conc_{in} + 1.12*10^{-4}Q \times Conc_{in} + 9.97*10^{-3}Q^2 + 1.29*10^{-8}Conc_{in}^2$$

$R^2 = 0.9399$

253 Γ represents the IPB biodegradation rate (%)

254 Q is the inlet flow of gas (l/min) - first factor.

255 $Conc_{in}$ is the IPB concentration of inlet flow (mg/Nm^3) - second factor.

256 For each estimated coefficient, table 2 presents p value. As shown in table 2,
257 the first degree coefficient of the flow (0.0017) is highly significant. The
258 factor flow (Q) is thus most influential on the biodegradation rate. In addition,
259 figure 5 permits visualization of the combined effect of flow and concentration
260 of the effluent on the biodegradation of the IPB. The contours of second order
261 equation indicate the "concentration-flow" pairs for which the same
262 biodegradation rate is observed. By means of this diagram, it is possible to
263 estimate the biodegradation rate for a flow-concentration pair. The shape of
264 the diagram indicates that the variation of the flow induces a strong variation
265 of the biodegradation rate. On the other hand, for the same flow, the variation
266 of effluent concentration slightly influences the biodegradation rate.
267 These observations can be explained by the fact that the two-phase bioreactor
268 is able to transfer and absorb great quantities of pollutants only if the
269 superficial gas velocity, generated by a high flow, is not too high into the
270 bioreactor.

271 3.4 *Loading capacity for the experiments*

272
273 The biodegradation rate characterizes the efficiency of a process. However, it
274 is also important to determine the limits of the bioreactor. Therefore, the
275 loading capacity can be defined as the absolute quantity of IPB degraded by

276 the biomass per unit of time and unit of reactional volume: $Q_0 = Q_{in} - Q_{out}$
277 (mg/min.l). Figure 6 presents the described loading capacity. The loading
278 capacity is logically correlated with the flow of IPB from inlet gas (mg/min.l).
279 However, the limit seems to be reached in experiment 5 with a 7.5 mg/min.l.
280 loading capacity (450g/m^3.h). This limit can be explained by figure 7 which
281 shows the IPB concentration in the biphasic liquid medium. Experiments 5, 7
282 and 9 (fig. 7) show that the concentration in the liquid medium reaches
283 approximately 1200 mg/l. This concentration within the liquid medium (C_L)
284 seems to be a factor limiting the mass transfer of the IPB. Indeed, when the C_L
285 concentration increases, the potential of transfer (C^0_L–C_L) decreases.

286 3.5 *Evolution of cellular concentration in the bioreactor*

287 The initial cellular concentration within the bioreactor is standardized.
288 However, the evolution of the biomass is variable from one experiment to
289 another. It is thus important to discuss the influence of the cell multiplication
290 on the effectiveness of the biodegradation. The evolution of cellular
291 concentrations is presented in figures 8 (four repetitions of the central
292 experiment) and 9 (other individual experiments).
293 The variability of observed growth for a repetition of the central experiment
294 (fig.8) does not permit to highlight a relation between the quantity of brought
295 pollutant per unit of time and the cellular multiplication. However and
296 generally, an adaptation phase of microorganisms is observed at the beginning
297 of the experiment (24h). The cellular concentration increases then slightly

298 during experiments. This observation must be coordonated to the increase of
299 the degradation rate functions of time. It should be noted that the cell
300 multiplication is minimal for experiments corresponding to the lowest flows of
301 IPB (respectively 0.57 and 0.11 mg/min.l; exp. 2 and 8). For small quantities
302 of added carbon substrates, the cell multiplication is then very low. On the
303 other hand, growth is observed during the experiments with higher potential
304 carbon sources.
305 In addition, the quadruple repetition of the central experiment (fig.8) allows to
306 compare 4 identical experiments and to show that the most significant
307 biodegradation rate (82%; experiment 3) is obtained when the cell
308 multiplication was the highest. The cellular concentration thus plays a role in
309 the effectiveness of the bioreactor.

310 *3.6 Conclusions*

311 The obtained results show that the use of a two-phase bioreactor with silicon-
312 oil as second phase allows absorbtion of large quantities of IPB and its good
313 biological degradation with appropriate microorganism. The analysis of the
314 results shows that the biodegradation rate seems to be related mainly to the gas
315 flow (l/min.) comparatively to the IPB concentration (mg/Nm^3) in the gas
316 effluent.
317 A limit of concentration in the liquid medium can also be suggested, what
318 leads to a transfer limitation of the IPB from polluted gas towards the liquid
319 medium by a reduction in the potential of transfer ($C^0_L – C_L$). Otherwise, it was

shown that an increase in the cellular concentration during experiment improves the effectiveness of the bioreactor.

Thus, in the tested configuration, the two-phase bioreactor is able to degrade 7.5 mg/min.l of reactional media (450g/m^3.h).

It is also shown that an adaptation step of the biomass is necessary to reach substantial rates of abatement. However, the biomass is maintained and even increases during the experimentation.

The bioscrubbers usually used in the off-gas treatment are able to treat a polluted effluent concentrated with 1000 mg/Nm^3 at a flow of 1.5 l/min.l (90m^3/m^3.h). This corresponds to a flow of 1.5mg/min.l of bioscrubber (13).

The proposed reactor presents interesting opportunities in the biological treatment of gas effluents polluted by aromatic compounds in high concentration. The suggested process might be applied in the range of concentration and flow where thermal oxidation is too expensive (between 1 and 7 g/Nm3).

REFERENCES

1. Yeom S.H., Daugulis A.J. (2001). Development of a novel bioreactor system for treatment of gazeous benzene. Biotechnology and bioengineering. 72, 156 - 165.

339 2a. Collins L.D., Daugulis A.J. (1999). Simultaneous biodegradation of
340 benzene, toluene and p-xylene in a two-phase partioning bioreactor: concept
341 demonstration and pratical application. Biotechnology Progress. 15, 74-80.
342 2b. Collins L.D., Daugulis A.J. (1999).Benzene, toluene and p-xylene
343 degradation. Part II. Effect of substrate interaction and feeding strategies in
344 toluene/benzene and toluene/p-xylene fermentation in a partitioning
345 bioreactor. *Applied microbiology and Biotechnology*. 52, 360 - 365.
346 3. Van Ede C. J. , Van Houten R. and Beenackers. (1995). Enhancement of
347 gas to water mass transfer rates by a dispersed organic phase. *Chemical*
348 *Engineering Science*, 50 (18), 2911 - 2922.
349 4. Teresa M. , Beverloo W. A., Tramper J. and Beeftink H. (1997)
350 Enhancement of gas-liquid mass transfer rate of apolar polluttants in the
351 biological waste gas treatment by a dispersed organic solvent. *Enzyme and*
352 *Microbial Technology* 21, 578-588.
353 5. Nielsen D., Daugulis A., Mc. Lellan (2003) A Novel Method of simulating
354 oxygen mass transfer in two-phase partitioning bioreactors. Published online
355 23 june 2003 in Wiley Interscience (www.interscience.wiley.com).
356 6. E. Dumont and H. Delmas (2003) Mass transfer enhancement of gas
357 absorption in oil-in-water systems: a review**,** *Chemical Engineering and*
358 *Processing*, 42, 6, 419 - 438.
359 7. Rols J.L. and Goma G. (1991) Enhanced oxygen transfer rates in
360 fermentation using soybean oil-in-water dispersions. *Biotechnology letters.*
361 *13, 7-12.*

8. Budwill K., Coleman R.N. (1997). Effect of silicon oil on biofiltration of n-hexane vapours. *Med. Fac. Univ. Gent*. 62/4b, 1521-1528.

9. Aldric J.M. (2001). Contribution à la mise au point d'un réacteur biphasique destiné à la dégradation des composés organiques volatiles par voie biologique. Mémoire de fin d'études présenté en vue de l'obtention du diplôme d'études approfondies en sciences agronomiques et ingénierie biologique. Faculté Universitaire des Sciences Agronomiques de Gembloux.

10. Weekers F., Jaques P., Sprindael D., Mergeay M., Diels L. and Thonart P. Improving the catabolic functions of desiccation-tolerant soil bacteria. *Appl. Biochem. Biotech*., **77-79,** p251-266.

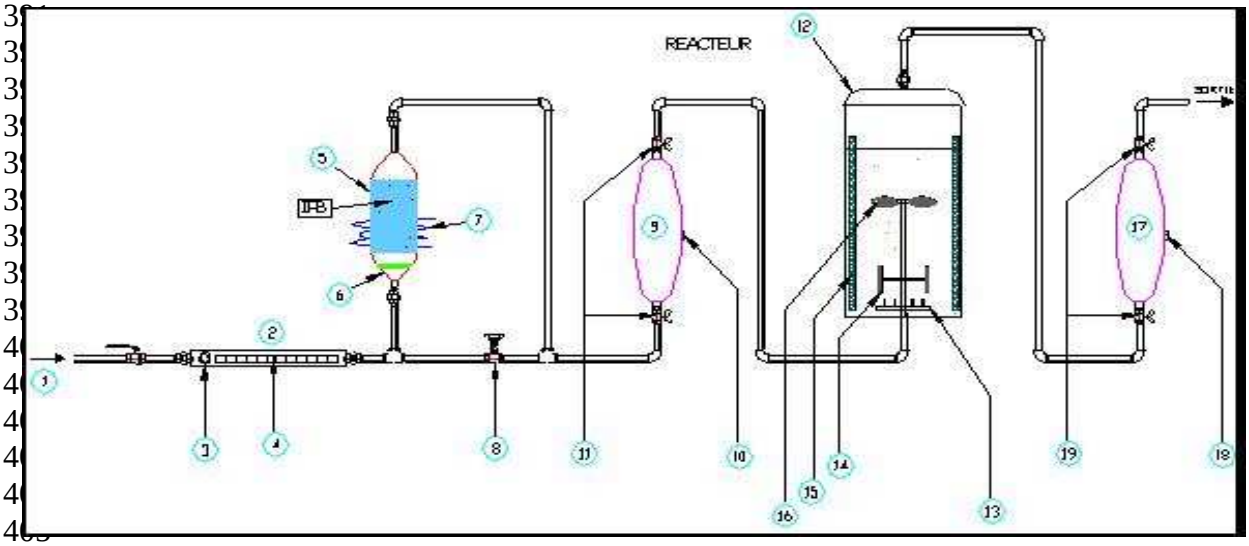
11. Weekers F., Rodriguez C., Jaques P., Mergeay M. And Thonart P. Dissemination of catabolic plasmids among dessiccation-tolerant bacteria in soil microcosms. *Appl. Biochem. Biotech*.**91-93,** 219-232.

12. Doehlert D. H., Klee V.L. Experimental designs through level reduction of the *d*-dimensional cuboctahedron, *Discrete Mathematics*, 2, July 1972, 309-334.

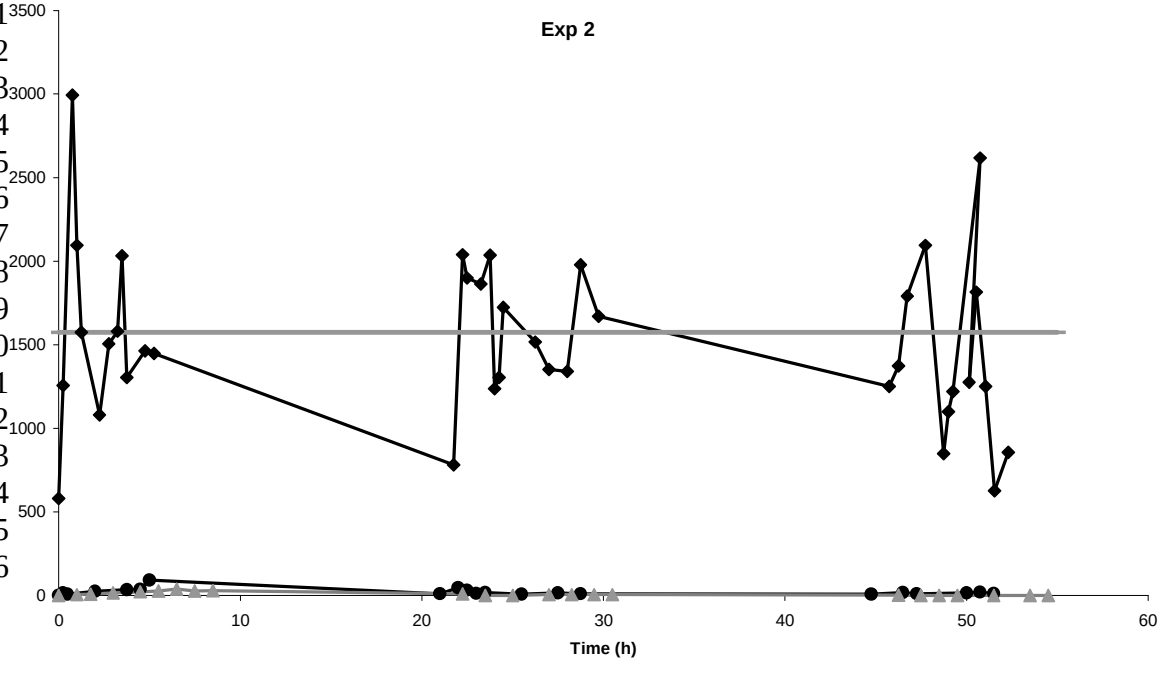
13**.** Solstys N. Technique de l'ingénieur, traité Génie des procédés J 3 928

Figures

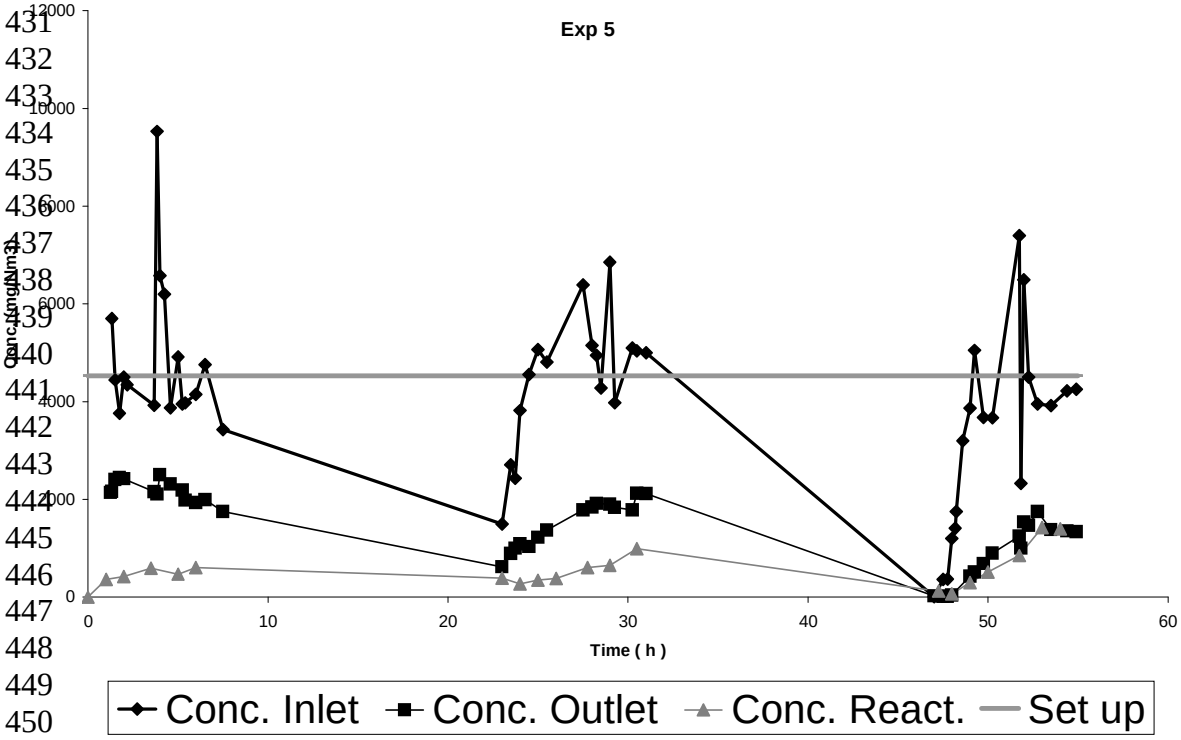
1.


REACTEUR
IPB

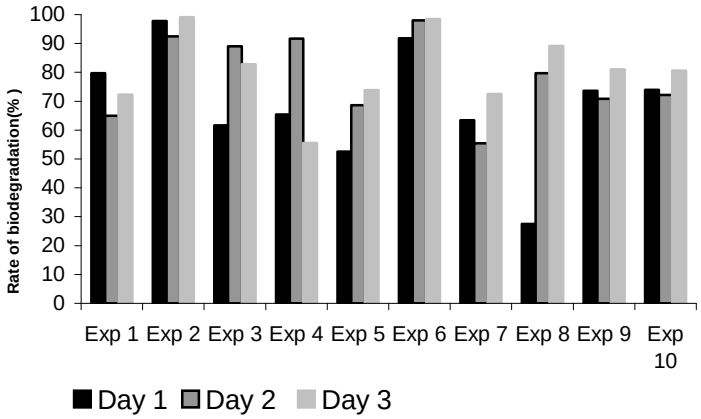
2


Exp 2
Concentration (g/m3)
Time (h)
Conc. inlet
Conc. outlet
Conc. React.
Set up

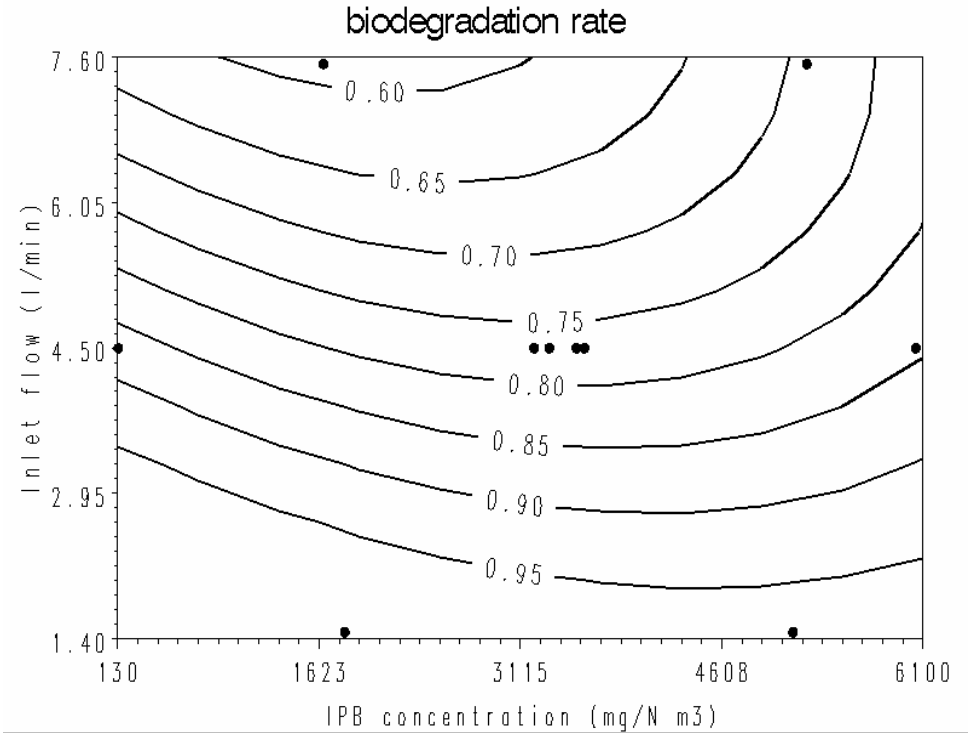
3


Exp 5
Conc.(mg/Nm3)
12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
Time (h)
Conc. Inlet
Conc. Outlet
Conc. React.
Set up

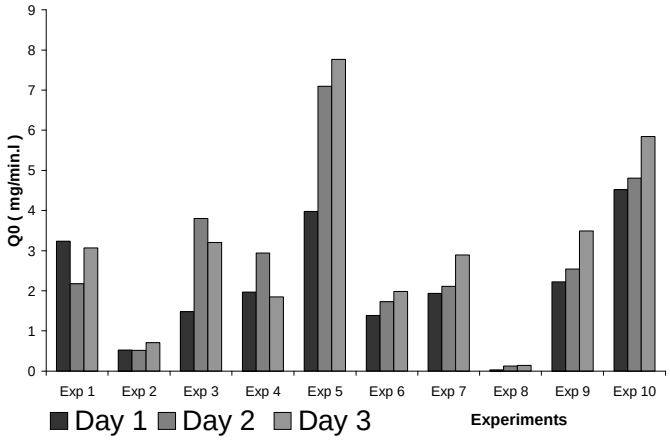
4.


Rate of biodegradation(%)
100
90
80
70
60
50
40
30
20
10
0
Exp 1
Exp 2
Exp 3
Exp 4
Exp 5
Exp 6
Exp 7
Exp 8
Exp 9
Exp 10
Day 1
Day 2
Day 3

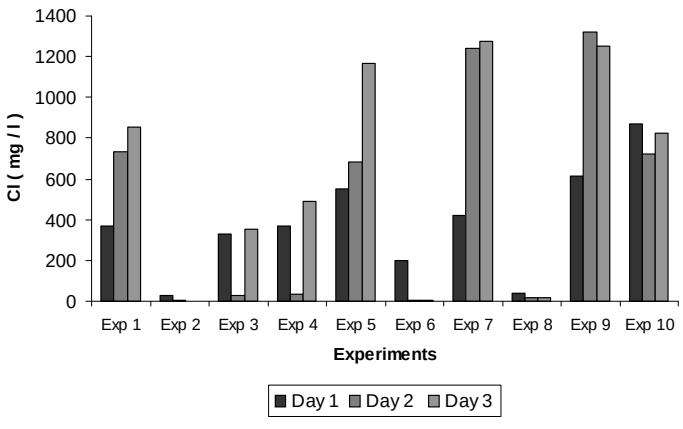
5.


biodegradation rate
7.60
6.05
4.50
2.95
1.40
Inlet flow (l/min)
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
130
1623
3115
4608
6100
IPB concentration (mg/N m3)

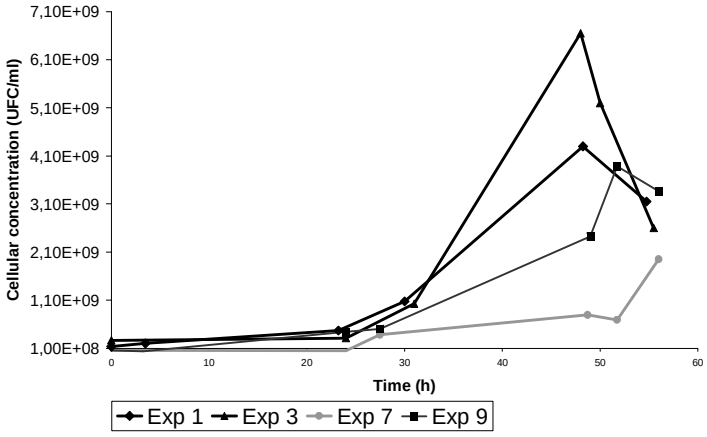
6


Q0 (mg/min.l)
0
1
2
3
4
5
6
7
8
9
Exp 1
Exp 2
Exp 3
Exp 4
Exp 5
Exp 6
Exp 7
Exp 8
Exp 9
Exp 10
Day 1
Day 2
Day 3
Experiments

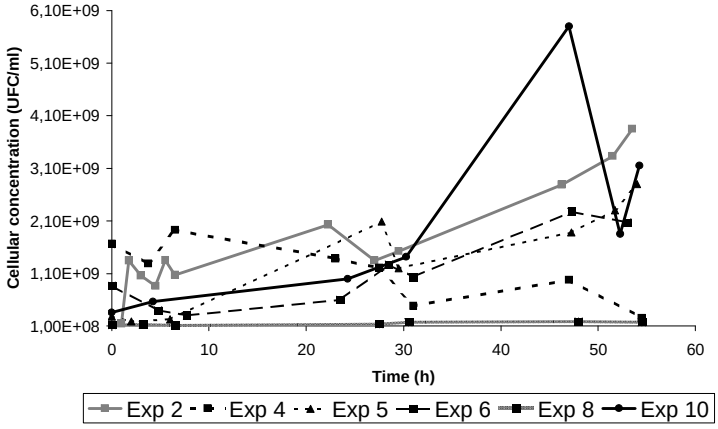
7.


Cl (mg / l)
0
200
400
600
800
1000
1200
1400
Exp 1
Exp 2
Exp 3
Exp 4
Exp 5
Exp 6
Exp 7
Exp 8
Exp 9
Exp 10
Experiments
Day 1
Day 2
Day 3

8.


7,10E+09
6,10E+09
5,10E+09
4,10E+09
3,10E+09
2,10E+09
1,10E+09
1,00E+08
Cellular concentration (UFC/ml)
0
10
20
30
40
50
60
Time (h)
Exp 1
Exp 3
Exp 7
Exp 9

9.


6,10E+09
5,10E+09
4,10E+09
3,10E+09
2,10E+09
1,10E+09
1,00E+08
Cellular concentration (UFC/ml)
0
10
20
30
40
50
60
Time (h)
Exp 2
Exp 4
Exp 5
Exp 6
Exp 8
Exp 10