

*Full Length Research Paper*

# **Study of oxygen transfer processes improvement for domestic wastewaters treatment**

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Received 14 September, 2018; Accepted 25 February, 2019

**In aerated processes, the oxygen transfer was limited by the presence of the suspended matter as colloid and the dissolved matter, which might decrease the biological degradation effectiveness. In this publication, three series of tests were conducted to study possibilities to reduce these matters: bacterial adaptation which was conducted in a biological aerated filter, adsorption/biosorption conducted on a biological aerated filter with a biofilm of adapted bacteria and percolation in a bioreactor with a packed plastic media. All the tests carried out gave convincing results concerning turbidity and chemical oxygen demand, as parameters limiting the oxygen transfer for a better biodegradation. The advanced adaptation improved their elimination. So, all these treatment techniques could be used as pretreatment processes; in addition, they required very little energy, particularly adsorption/biosorption and percolation.**

**Key words:** Pretreatment, purification, biological aerated filter, adsorption, biosorption, percolation, packed plastic media.

## **INTRODUCTION**

Domestic wastewaters posed a serious problem in arid and semi-arid regions of the Middle East and North Africa, including Morocco, on the environment and health, resulting in several negative impacts. Water quality degradation is quickly joining water scarcity in most countries of these regions (Chaoua et al., 2017). To deal

with this problem, the Biological Aerated Filters (BAF) representing the most economical upgrading technology, have been put in place.

BAF is a flexible reactor, which provides a small footprint process option at various stages of the wastewater treatment (Farabegoli et al., 2009). It

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contains a granular media with high surface area allowing bacteria to develop as a biofilm. This bioreactor was widely used in aerobic wastewater treatment and provided excellent purification performances (Chaudhary et al., 2003; Datta and Allen, 2005; Papadia et al., 2011; Pramanik et al., 2012).

Oxygen was the key element in the aerobic biological purification process. However, when it is limited, the kinetics of biological degradation decreased. This might be due to the presence of the colloidal and the dissolved matters present in the wastewater (Seo, 2011). Their prior elimination would improve the biological degradation process, by enhancing the oxygen transfer.

In the presence of the biofilm, colloidal matter can be eliminated by adsorption. Dissolved matter can be removed by a complex mechanism involving convection, diffusion, adsorption, hydrolysis and finally, the degradation reaction itself (Picard, 2011). Some pollutants like heavy metals, dyes and refractory organic matter could be removed by biosorption through absorption, adsorption, and ion exchange (Gadd, 2008). The role of the biofilm in purification was more accentuated when the bacteria were adapted, because their increasing population allowed them to further colonize the surface area (kumar et al., 2013; Roux and Ghigo, 2006; Vargas, 2013).

During wastewater percolation in a trickling filter, some dissolved gases could be removed by the physicochemical way, especially through spreading the wastewater over the packed plastic media in a thin film. This spreading also promoted a better contact between the biofilm formed on the packed plastic media and the dissolved matter and consequently increased the biodegradation of the organic matter and the retention of the colloidal matter (Metahri, 2012; Racault and Seguret, 2004).

The objectives of this study were to show the treatment capacity of BAF, purification performance on the elimination of organic pollution and suspended solids of domestic wastewaters that came from a suburban site located about 15 km from Casablanca.

## MATERIALS AND METHODS

### Presentation of the study area

The wastewater used in this study came from a suburban area not connected to a municipal network, 15 km located from the Casablanca city. This wastewater has been harvested from an open-air ditch, put in a can, and immediately transported to the laboratory for analysis and tests.

### Description of the experimental pilot

Tests of adaptation were performed in a PVC pilot as a biological aerated filter, operating in batch mode (Figure 1a). It consisted of a cylindrical column of height of 70 cm and a diameter of 10 cm. It

was fulfilled by a packing media P1 (Figure 1b), with characteristics shown in Table 1. It was aerated by an aerator made of rigid expanded polyurethane like a diffuser (length of 9 cm and width of 1 cm), placed at the bottom of the BAF, and giving an air flow rate of 0.5 L/s. The sludge detached from biofilm during the biological process was evacuated from the BAF by a purge valve located under the aerator. The sampling was made from a valve located at the top of the bioreactor. A grid was placed above to fix the packing media to prevent its flotation by the air bubbles coming from the diffuser.

Tests of adsorption/biosorption were made in the same reactor that was used for adaptation tests, but without aeration. For percolation, tests were performed in the same bioreactor and were operated in continuous mode. It was fulfilled of packing media P1, P2 and P3 (Figure 1b), with characteristics shown in Table 1. The characteristics of wastewaters used in different series of tests are shown in Tables 2, 3, and 4.

### Monitoring of parameters and used material

During different tests, the monitoring of the treatment performances was conducted with the following physicochemical parameters: chemical oxygen demand (COD), dissolved oxygen (DO), pH, turbidity and conductivity. The COD and turbidity were determined by the Palintest 7000 type photometer. The dissolved oxygen was measured by an oxygen probe connected to the oximeter (Hach 40d-HQ multi oximeter). The pH was measured by the same device. The conductivity was determined by using the conductimeter (Orion model 125).

The bioreactor performances could be expressed by the abatement rate and abatement, respectively by the following equations:

$$Y (\%) = (L_0 - L) / L_0 \quad (1)$$

$$\text{Abt} = L_0 - L \quad (2)$$

Where,  $L_0$ , is the initial value (Turbidity, COD),  $L$  is the initial value (turbidity, COD),  $Y$  is the abatement rate, and  $\text{Abt}$  is the abatement (Turbidity, COD).

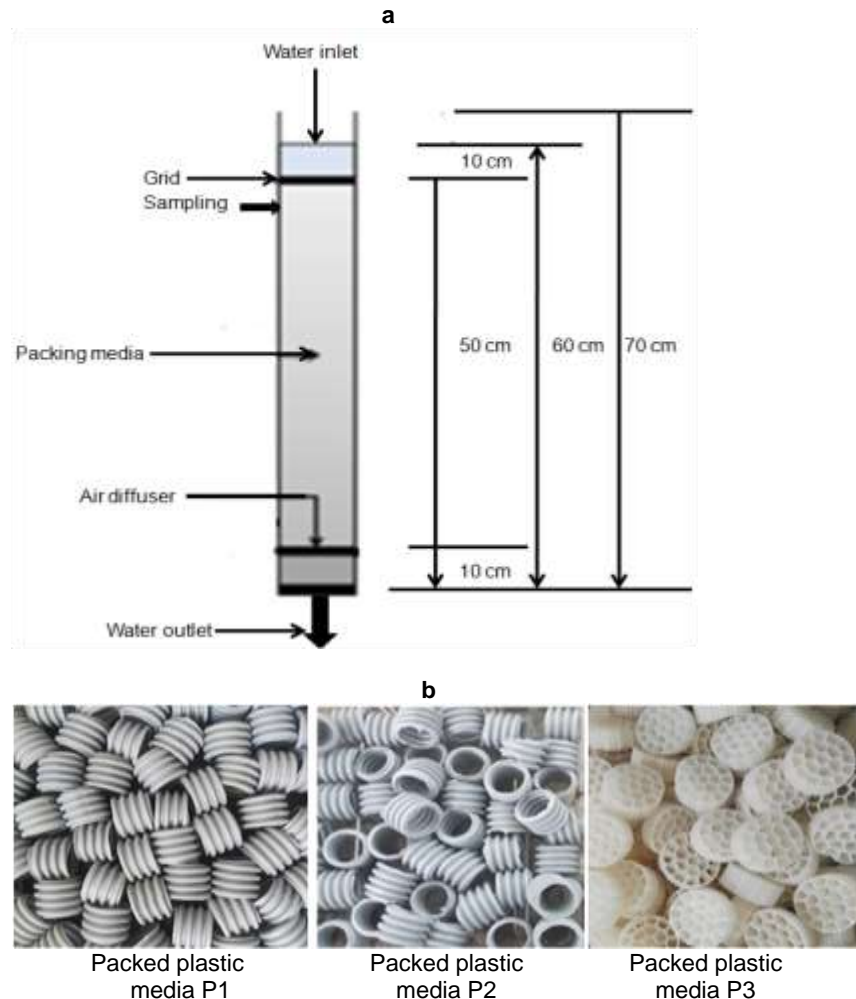
### Operating protocol

In the laboratory, three series of tests were done:

(1) Adaptation of the bacteria through seven tests, conducted in a biological aerated filter, fulfilled by a packing media operating in batch mode. After each test, when the COD reached maximum elimination, the residual reject was evacuated from the BAF and replaced by a new domestic wastewater solution more concentrated. This operation was repeated several times until it reached good bacteria acclimatization. The characteristics of the rejects used during different adaptation tests are shown in Table 2.

(2) Adsorption/Biosorption tests were conducted in a non-aerated BAF with packing media, colonized by adapted bacteria and operating in batch mode. Four tests were performed. For each one, when the adsorption/biosorption reached its maximum, the wastewater was removed from the bioreactor. It was then replaced by a new solution. Table 3 shows the characteristics of wastewaters used in the adsorption/biosorption tests.

(3) Percolation of wastewaters in a trickling filter. The tests were carried out on three clean non-colonized packing media, with three rates for each one: 0.106, 0.212 and 0.318 m/h. The characteristics of wastewaters are shown in Table 4.



**Figure 1.** (a) Experimental pilot. (b) Packing used in the reactor for the three experiments.

## RESULTS AND DISCUSSION

### Adaptation tests

The COD decreased during time and during the different adaptations essays (Figure 2a). The abatement rate of COD (Figure 2b), improved further when the bacteria responsible of the biodegradation reached a high degree of adaptation (Figure 2c).

The improvement of COD abatement was corroborated by some authors (Kherbeche et al., 2017; Lele and Watve, 2014; Pramanik et al., 2012; Amrouche et al., 2011). They have shown that the abatement rate improved with the increase of the initial concentration of the COD, in adaptation tests realized on synthetic solutions of glycerol as an organic substrate. Similarly, Kherbeche (2016) showed that, in comparative tests between two BAFs, one was fed by domestic wastewater and the other by domestic wastewater with increase in

COD; the kinetics of biodegradation improved more when COD is increased.

Concerning the turbidity, the wastewater presented variable initial values (Table 2). During the adaptation tests, it decreased (Figure 3a). Figure 3b shows the elimination rate; it is depended on the adaptation degree during the first hours, but then it reached about 97% after 96 h for the whole adaptation tests.

The elimination of the turbidity was due to the suspended matter retention in the bioreactor, which probably occurred because of (1) the physical interception phenomena by the packing media and/or (2) the biofloculation by extracellular polymeric substances (EPS) of the biofilm, increasing further when bacteria adaptation is improved (Lekhlif et al., 2015; Hongyuan and Wenchao, 2013; Boltz et al., 2006; Sheng et al., 2010).

The conductivity presented in Figure 4a varied according to the adaptation degree and gave values from

**Table 1.** Characteristics of the packing media.

Parameter	Packing media P1	Packing media P2	Packing media P3
Color	Grey	Grey	White
Diameter (mm)	19.5	15	25
Length (mm)	15	15	12
Specific surface (m <sup>2</sup> /m <sup>3</sup> )	~419	~869	~427
Porosity (%)	85	87	92,5

**Table 2.** Characteristics of wastewater during adaptation tests.

Parameter	Adapt 1	Adapt 2	Adapt 3	Adapt 4	Adapt 5	Adapt 6	Adapt 7
Dilution ratio	5	5	3	2	1	1	1
L <sub>0</sub> (mgO <sub>2</sub> /L)	560	590	1000	1750	2700	3000	3200
DO (mg/L)	7.07	0.42	0.47	0.29	0.29	0.49	0.33
Turbidity (NTU)	170	160	280	150	550	750	625
Cond (μS/cm)	2.06	2.39	4.35	3.11	5.91	6.17	6.12
pH	6.56	6.91	6.73	5.91	6.72	6.77	7.23
T°C	18.1	19.1	17.6	18.9	17.9	17.4	18.2

**Table 3.** Characteristics of wastewater during the adsorption/biosorption tests.

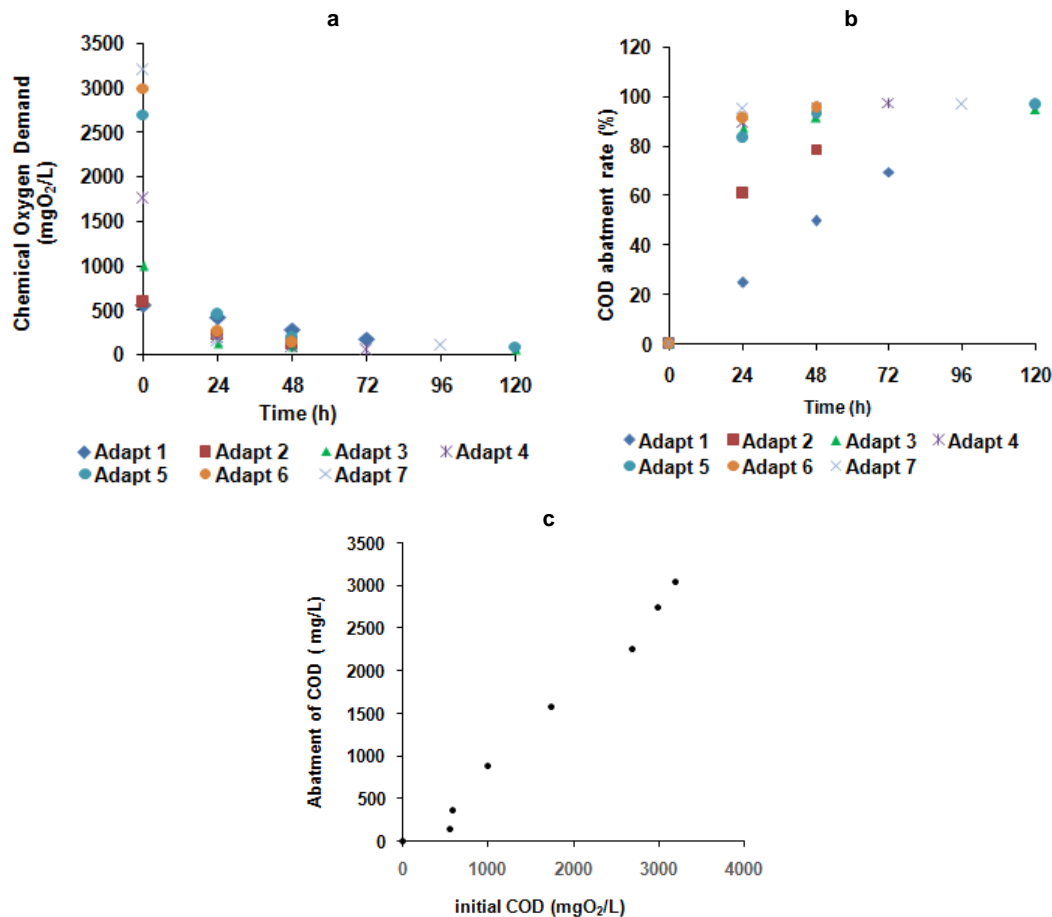
Parameter	Peripheral zone wastewater of Casablanca			
	Essay 1	Essay 2	Essay 3	Essay 4
L <sub>0</sub> (mgO <sub>2</sub> /L)	3000	2200	1800	1550
DO (mg/L)	0.3	0.31	0.31	0.27
Turbidity (NTU)	525	580	520	440
Cond (μS/cm)	6.01	5.99	6.02	6.09
pH	7.28	7.42	7.28	7.4
T°C	19.1	19.4	19.2	20.2

**Table 4.** Results of the different trickling filter tests on the packed plastic media at different Peripheral rate (m/h)

Parameter	P1			P2			P3		
	0.106	0.212	0.318	0.106	0.212	0.318	0.106	0.212	0.318
Peripheral speed (mL/min)	0.106	0.212	0.318	0.106	0.212	0.318	0.106	0.212	0.318
L <sub>0</sub>	2400	2700	2700	2400	2600	2600	2200	2200	2700
L	750	950	1400	1400	1500	1400	1250	1250	1050
COD yield	68.7	64.81	48.14	41.67	42.3	46.15	43.18	43.18	61.11
Initial turbidity	900	900	520	400	410	500	380	410	380
Final turbidity	420	440	380	210	170	160	120	170	140
Turbidity (Y %)	53.3	55.5	26.9	47.5	58.5	68	68.4	58.5	63.1
DO <sub>i</sub>	0.23	0.21	0.27	0.29	0.28	0.22	0.31	0.31	0.31
DO <sub>f</sub>	0.24	0.24	0.34	0.97	0,19	0.16	0.41	1.02	0.31
pH <sub>i</sub>	7.29	7.29	7.45	7.47	7.87	8.17	8.11	8	7.95
pH <sub>f</sub>	8.34	8.37	8.26	8.7	8.49	8.53	8.73	8.34	8.41

7.07 to 9.33 μS/cm for the first adaptation, and values varying between 2.26 and 6.17 μS/cm for the other

adaptations. The conductivity increase for the first adaptation could be explained by the hydrolysis of long-



**Figure 2.** (a) COD evolution during the different adaptations. (b) Evolution of the rate of reduction COD during the various adaptations. (c) Evolution of the rate of elimination of the COD as a function of the initial concentration after 24 h.

chain organic matter into little molecules which involved conductivity increase, and in the same time the absence of sufficient biomass that allowed the elimination of solution ions, including metal cation, by biosorption to colonize it. The conductivity decrease was probably due to some phenomena: biosorption of the organic matter by biofilm extracellular polymeric substances, reduction of the mineral fraction by biological reaction as trace elements, complexation of metals by the hydrolyzed organic matter and their biosorption on the biomass with formation of metal bridges and/or metals precipitation resulting from the pH increase (Figure 4c) (Prieto et al., 2002).

As shown in Table 2, it was noted that except for the 5 times diluted wastewater, with initial DO of 7.07 mg/L (adaptation 1), the DO for the other samples was low, it was between 0.29 and 0.47 mg/L. These low values were both due to the dissolved matter whose presence increased the viscosity of water (Chern et al., 2001; Jimenez et al., 2013) and to the suspended matter which affected negatively the gas-liquid oxygen transfer (Kuan, 2009). With time and the various adaptations, this

(Kherbeche, 2016). Indeed, during the first adaptation, characterized by slow biodegradation kinetics (Figure 2a and 2b), the packing plastic media were clean and the bacteria took some time to adapt their enzymes, and then concentration increased (Figure 4b). For a long time, it reached about 9 mg/L for all the tests, because of the reduction of suspended and dissolved matters.

The pH of the different solutions increased for all adaptations (Figure 4c). This behavior has been noted by other authors (Kherbeche et al., 2017; Pakanati et al., 2018). This could either be due to the elimination of CO<sub>2</sub> by aeration or to the denitrification that could be installed in the biofilm, especially when its thickness increased. ET-taleb et al. (2014) and Wicke et al., (2007) mentioned that the organic matter decomposition in anaerobic conditions led to the increase of pH. Otherwise, Oehmen et al., (2005) have shown that this increase could be explained by the consumption of nitrogen compounds during the reactor aeration. They have also shown an identical pH behavior after 2 h of aeration in a sequencing batch reactor. Jeong et al. (2008) noted the same observations.

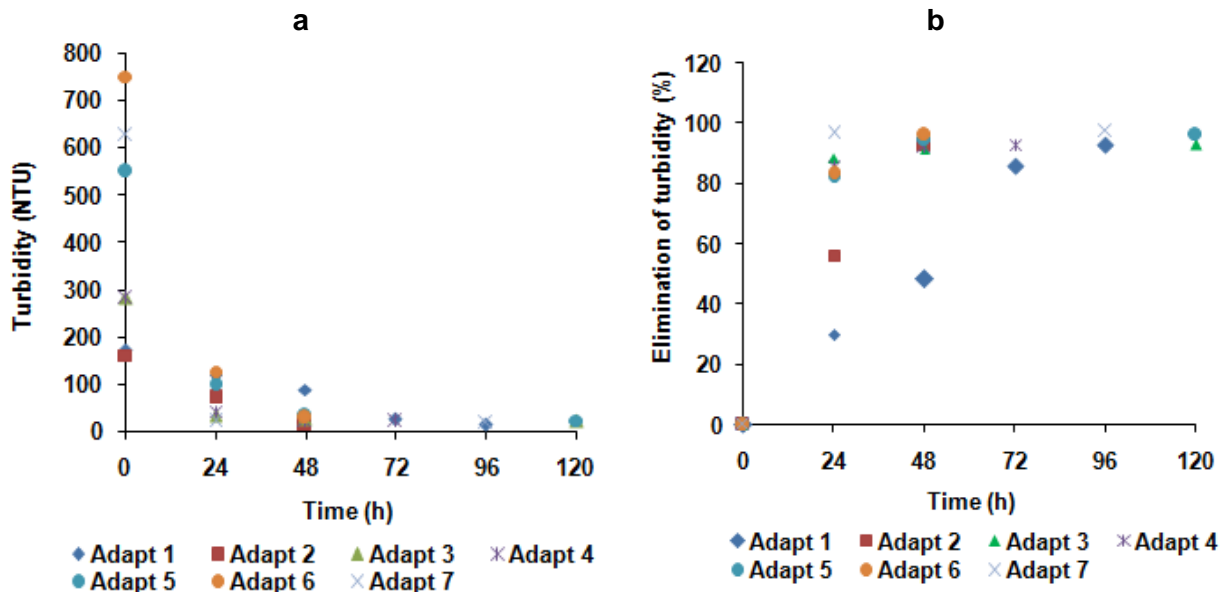


Figure 3. (a) Turbidity evolution. (b) Evolution of elimination rate of the turbidity.

### Adsorption/Biosorption tests

Figure 5a and 5b shows respectively both the evolution of the COD and its abatement rate for the four tests. The COD reduced probably because of the dissolved matter retention on biofilm by biosorption. It was better when the COD was high (Figure 5c). This could be probably explained by a better matter transfer by diffusion in the boundary layer, which was created (in the absence of agitation) between the liquid phase and the biofilm (Picard, 2011; Lé, 2008).

Figure 6a shows that turbidity was eliminated for all tests. Nevertheless, when its values increase, its abatement rate decreased (Figure 6b). This could probably be explained by the limited biofilm capacity to absorb efficiently the colloidal matter. The eliminations of colloidal and dissolved matters seemed not to be the same way. They occurred according to different mechanisms. Colloidal matter was eliminated by adsorption on the limited surface area of the biofilm, whereas dissolved matter was eliminated by biosorption on a high surface area including that of the internal porosity of the biofilm.

The conductivity varied very slightly for all the tests (Figure 7a), in a range between 10 and 80  $\mu\text{S}/\text{cm}$ . This small variation was probably the consequence of concomitant reactions which have contradictory effects: (1) the elimination of electrical entities was present in solution by several phenomena: biosorption of organic ionized molecules of metals (Lé, 2008; Jeong et al., 2008), metal complexes, and formation of metal bridges at the biofilm (Et-Taleb et al., 2014), and (2) endogenous respiration, which could release ions in solution following the destruction of microorganisms or the resolubilization

of some metal precipitates when the pH increased (Figure 7c).

Figure 7b shows that the concentration of dissolved oxygen varied between 0.26 and 0.63 mg/L. Its values remained more or less constant, particularly for the second and the third test. It improved in the fourth test after 2 h, probably because of the dissolved matter retention in the biofilm and the bioflocculation of the suspended matter.

For pH, there was at first an increase for all the tests and then stabilization around an average value of 7.7 (Figure 7c). This was the same observation noted in the previous adaptation tests. The increase in pH might be due to the denitrification process (Oehmen et al., 2005; Horan, 2003).

### Percolation tests

The percolation tests, giving the results presented in Table 5a, b and c, showed that COD and turbidity were substantially reduced. The removed COD corresponded probably to the gaseous compounds, such as  $\text{H}_2\text{S}$  and other volatile organic compounds dissolved in the wastewater. Turbidity decreased due to retention of the suspended matter on packing media P1, P2 and P3, probably by interception and decantation on its high surface area.

The removal rates depend on the percolation rate and the packing media type. It varied between 26.9 and 68.4% for turbidity and between 48.14 and 65.90% for COD.

Conductivity decreased slightly in all tests (Figure 8a). This could probably be justified by the volatile matter

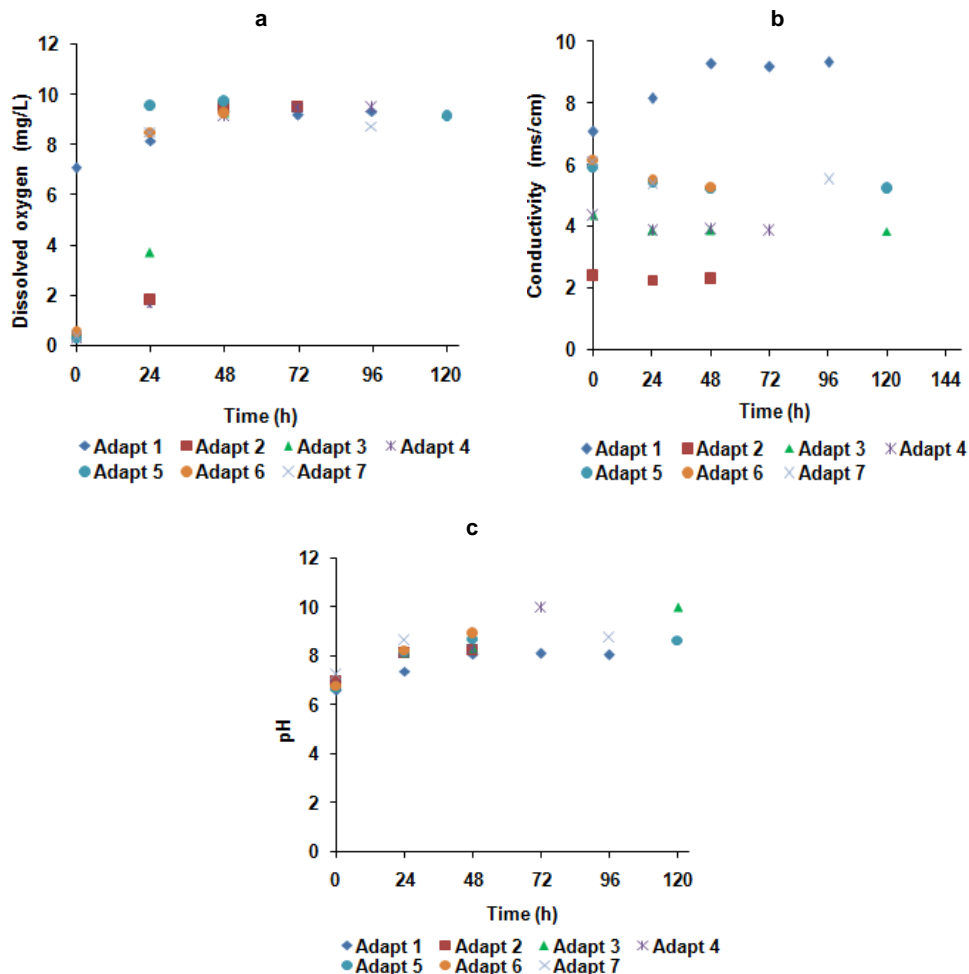


Figure 4. (a) Evolution of the dissolved oxygen. (b) Evolution of the conductivity dissolved oxygen. (c) Evolution of pH, according to the degree of adaptation.

elimination, in particular H<sub>2</sub>S which resulted in a shift of chemical equilibrium to hydrogen sulphide formation (Reactions 1 and 2).



This could be confirmed by the pH increase during the various tests (Figure 8b), resulting from the elimination of H<sub>2</sub>S.

### Conclusion

All the tests carried out in the three series gave convincing results concerning the limiting parameters of the oxygen transfer: the suspended and dissolved matters. The adaptation tests have shown that the elimination of these two parameters improved further with

the degree of adaptation. The biosorption and the percolation tests gave interesting elimination rates. So, they could be used as a pretreatment process. In addition, they required very little energy.

These tests, performed separately, showed more or less similar yields, but they were differentiated in terms of treatment time. The percolation performed on a clean packed plastic media seemed to have better treatment dispositions; under real operation, the clean packed plastic media would be colonized by adapted bacteria, so that they could further be involved high treatment performance. In addition to percolation, the phenomenon of biosorption would also occur. This could substantially improve the elimination rate of suspended and dissolved matter and make better the oxygen transfer.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

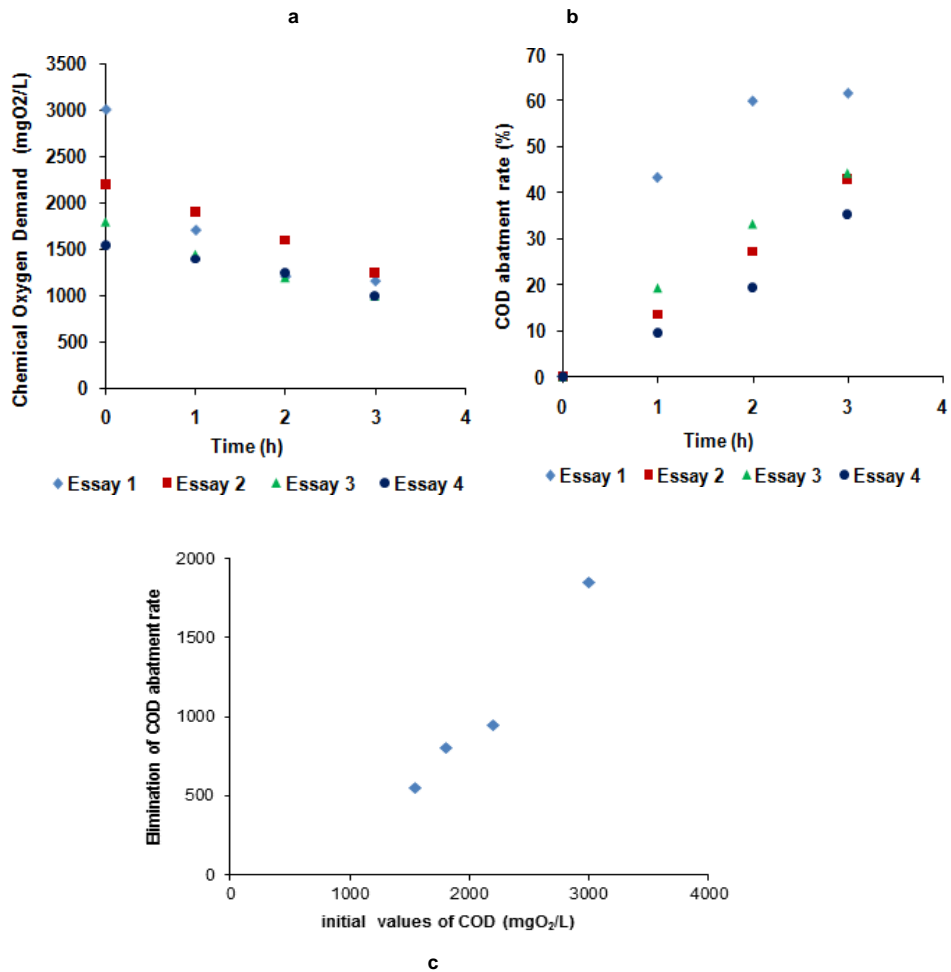


Figure 5. (a) Evolution of CO. (b) Evolution of the COD abatement rate. (c) Evolution of the COD abatement during, biosorption tests after 3 h.

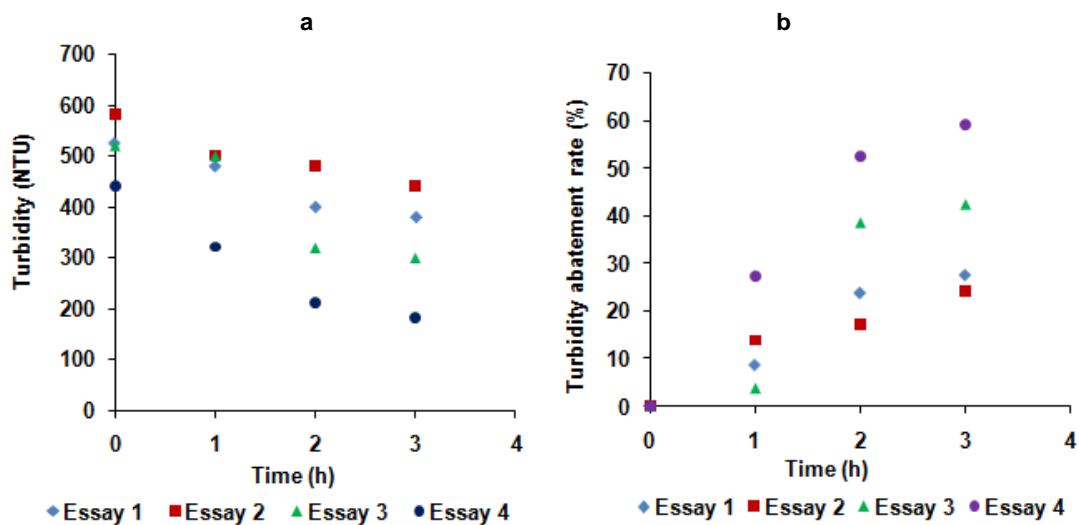


Figure 6. (a) Evolution of the turbidity. (b) Evolution of the abatement rate of the turbidity. (c) Evolution of the turbidity abatement, during biosorption tests after 3 h.



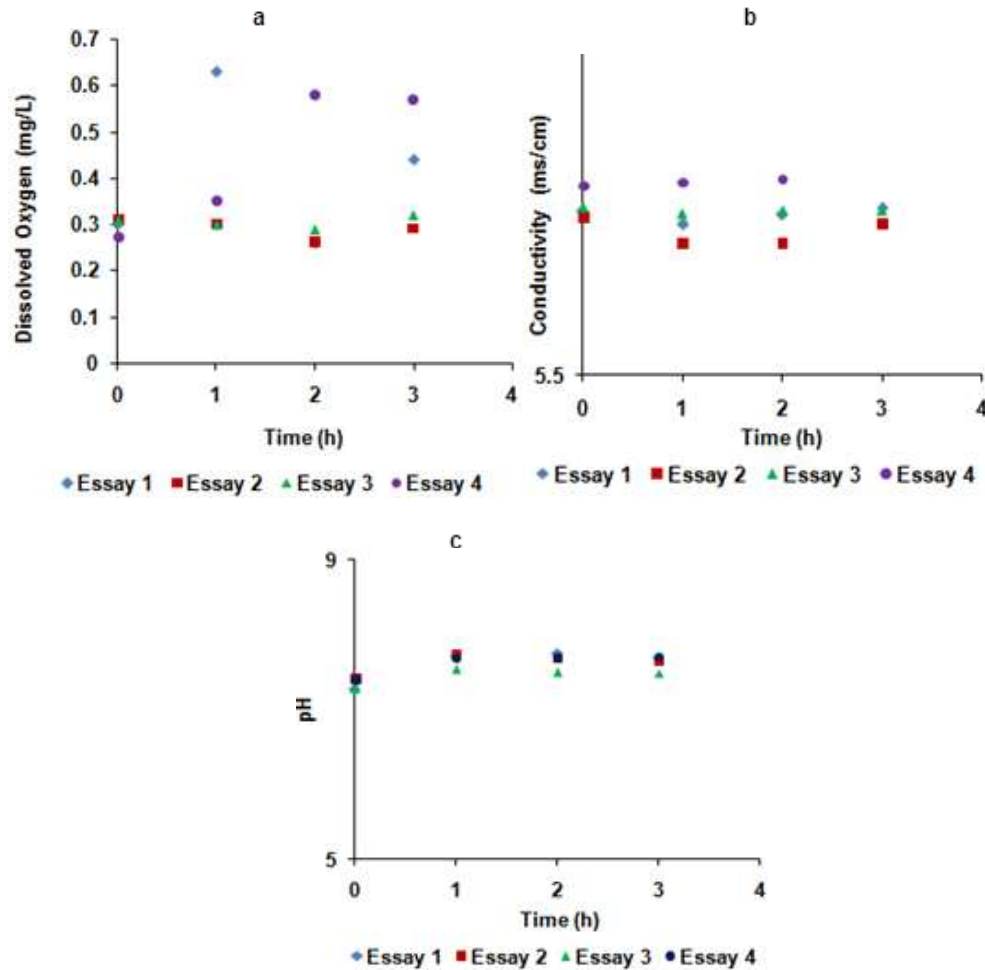


Figure 7. (a) Evolution of conductivity. (b) Evolution of dissolved oxygen. (c) pH Evolution.

## ACKNOWLEDGEMENTS

The authors acknowledged the Director of Hassania School of Public Works and the inhabitants of Hay Iraqui area who helped to realize this work.

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