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A NEW APPROACH TO THE EVALUATION OF BIOLOGICAL TREATABILITY OF INDUSTRIAL WASTEWATER FOR THE IMPLEMENTATION OF THE "WASTE DESIGN" CONCEPT

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ABSTRACT

An intrinsic characteristic of the Italian industrial production system is the presence of several industrial districts with a prevalent manufacturing typology, in which several small and medium enterprises dealing with the same or similar products are concentrated in a small territory. An important textile district is localized in Como area, north of Italy. In many cases, industrial districts are served by large treatment plants that receive the majority of the pollution loading from several small and medium enterprises that do not have internal treatment facilities. The treatment fee is determined by regional regulations; commonly, the single wastewater stream connected to the sewer is billed by the sewer manager to the source industry on the basis of the flow rate and of a complex formula that takes into account a series of parameters. This method is unable to properly evaluate the relationship between treatment fee and actual treatment costs, since conventional physical-chemical and biochemical parameters are not necessarily linked to wastewater treatability. New advanced respirometric methodologies could be used as wastewater characterization techniques, since they are particularly suited to represent the effect of a given wastewater on the final wastewater treatment plant. Hence, they could be better correlated to treatment costs. The instrument developed is composed of two parallel moving bed continuous flow completely mixed reactors of the working volume of about 5 l each, equipped with oxygen sensors connected to a computer that acts as a controller and as a data acquisition and processing unit. Some examples of experimental results obtained with synthetic waste and with real sewage are presented. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Biological treatability; oxygen uptake rate; respirometry; textile wastewater; treatment fee.

INTRODUCTION

The industrial water supply and wastewater treatment

In the industrial district of Como a large number of medium and small size textile factories, uniformly distributed in that area, consume large quantities of fresh water. Since 1989 the water is supplied mainly from an industrial aqueduct fed with water from the Como lake and distributing 35,000 m^3/day of water. Part of the industrial water supply still comes from local wells. The industrial processing wastewater is generally discharged into the public sewer system. The processing wastewater, mixed with 20% domestic sewage, is collected and treated by centralised treatment plants. The incoming wastewater composition of three plants, operated by the Company Lariana Depur SpA, is reported in Table 1. The prevalent manufacturing typology in the Como area is textile; the composition of the total industrial wastewater treated by Lariana Depur is shown in Table 2.

As is well known, the textile finishing industry uses large amounts of water, mainly because of washing operations. Therefore, processing wastewaters have high flow rates. The treated wastewater from the three plants is discharged into small streams without dilution capacity. The ratio between the stream flows and treated waters is often close to one. As a consequence, residual refractory compounds, particularly dyestuff and surfactants, give pollution and aesthetic problems (colour and foam). For these reasons, in the near future very strict standards for treated wastewater discharges will be required by local authorities to rise surface waters quality and preserve their uses.

Table 1. Wastewater composition

ALTO LURA PLANT Type of water	N° days discharge	Flow m^3 year 1995	%
domestic wastewater	*365*	*1'341'567*	*17*
*equalized industrial wastewater**	*322*	*3'543'467*	*46*
not equalized industrial wastewater	*230*	*383'819*	*5*
infiltration water + rain water	365	2'491'377	32
treated wastewater	**365**	**7'760'230**	**100**
ALTO SEVESO PLANT Type of water	**N° days discharge**	**Flow m^3 year 1995**	**%**
domestic wastewater	365	1'759'464	23
equalized industrial wastewater	322	1'163'584	15
not equalized industrial wastewater	230	3'071'988	40
infiltration water + rain water	365	1'672'414	22
treated wastewater	**365**	**7'667'450**	**100**
LIVESCIA PLANT Type of water	**N° days discharge**	**Flow m^3 year 1995**	**%**
domestic wastewater	365	269'120	18
equalized industrial wastewater	322	481'490	32
not equalized industrial wastewater	230	155'494	10
inflitration water + rain water	365	601'095	40
treated wastewater	**365**	**1'507'199**	**100**

*equalized industrial wastewater (24 hours/day - 7 days/week)

Table 2. Composition of industrial wastewater

Type	Alto Lura %	Alto Seveso %	Livescia %
From printing manufactures	*32*	*38*	*4*
From dyeing manufactures	*50*	*28*	*0*
From dyeing and printing manufactures	*10*	*31*	*79*
Total textile wastewater	**92**	**97**	**83**
Others (food, chemical, galvanic, ...)	**8**	**3**	**17**

Upgrading the water managing system

For five years Lariana Depur SpA, supported by CIDA Srl, has been carrying out an intensive programme to upgrade the water managing system. The programme includes:

upgrading of sewer systems and treatment plants;
treated water recycling in the industrial aqueduct;
minimisation, control and characterisation of industrial wastewater.

Researches were carried out to design the new treatment facilities. Biological treatment, including nitrification and denitrification, followed by chemical treatment, including coagulation-precipitation and ozonation, is the treatment sequence adopted to meet the stringent discharge standards. The new plants are partly constructed and partly under construction.

The effluent from the treatment plants can be polished and then reused for industry, feeding the industrial aqueduct. A research project was undertaken to investigate available post-treatment options, interactions between effluent quality and its performance in the industrial reuse, operational parameters and costs. Several European partners are involved with CIDA Srl in the project, financed with a contribution from the European Community. CIDA Srl was particularly involved in the minimisation, control and characterisation of textile wastewater. The major factories, discharging over 100 m^3/day, had to build equalisation tanks to reduce quality and quantity fluctuations, improving in this way the treatment capacity of the plants. To control the discharge of the single factory, control systems were installed consisting of a flowmeter and an automatic water sampler. Many audits were performed on textile factories in order to characterise the wastewater streams produced by every single phase of the manufacturing processes. It was possible to identify minimisation and internal treatment facilities options and feasibility studies were carried out.

Some factories have already adopted new operational procedures and minimisation in-plant technologies such as:

- internal wastewater treatment (biological + physico-chemical treatments) to reduce the pollutant charge and to recycle water;
- treatment of lightly polluted wastewaters (activated carbon adsorption, nanofiltration, reverse osmosis) to recycle water;
- treatment of highly polluted wastewaters (evaporation, microfiltration, ultrafiltration, anaerobic digestion) to reduce the pollutant charge;
- storage of lightly polluted wastewaters for secondary uses;
- separation of particular wastes before washing operations (printing paste) and their disposal as solid waste.

CIDA Srl verified that it is possible to reduce water consumption (5-10%) simply with new operational procedures and to recycle part of the wastewater (20-25%) separating low polluted and high polluted streams and introducing single stage treatments (sand filtration, activated carbon absorption, membrane filtration).

<u>Biological treatability evaluation of industrial wastewater</u>

In Italy the treatment fee is determined by regional regulations; commonly, the single wastewater stream connected to the sewer is billed by the sewer manager to the source industry on the basis of the flow rate and of a complex formula that takes into account a series of parameters. This method is unable to properly evaluate the relationship between treatment fee and actual treatment costs, since conventional physical-chemical and biochemical parameters are not necessarily linked to wastewater treatability.

New advanced respirometric methodologies could be used as wastewater characterization techniques, since they are particularly suited to represent the effect of a given wastewater on the final wastewater treatment plant. Hence, they could be better correlated to treatment costs. A new algorithm of fee calculation, based on these methodologies, will be implemented. Plant managers will apply the new algorithm of fee calculation, at first as a simulation to be compared to the traditional method. Results will be used by plant managers to support actions towards the most polluting industries, stimulating the introduction of less polluting manufacturing processes (clean technologies, source reduction of pollutants, etc.), less expensive for depollution. The fee lever is therefore used as a "peaceful" suggestion instrument for the introduction of eco-compatible (ecological and economical) processes.

A reliable methodology could represent the basis for the introduction of a "Code of Best Industrial Practices" and make the "Polluter Pays Principle" more effective. Moreover, the awareness of the environmental impact of the produced waste will be more immediate; this will contribute to resource minimization in terms of water consumption and necessary waste treatment and to better protection of receiving water bodies.

A new approach to industrial wastewater characterization

It is recognised that respirometry would be an excellent control parameter, since it represents a direct measure of viability and activity of biological organisms. Oxygen uptake rate (OUR) as well as nitrate uptake rate (NUR) can be measured directly on plant biomass. It also provides a good means to obtain kinetic parameters, stoichiometric coefficients and toxicity terms and to determine the biodegradable fractions of wastewater. Characterisation of wastewater in order to obtain an optimal waste composition is expensive, when using the techniques developed over the last ten years (Ekama *et al.*, 1986; Henze *et al.*, 1995; Spanjers and Vanrolleghem, 1995; Bortone *et al.*, 1993). Thus, the OUR offers a cheaper solution; the interpretation and the transformation of the OUR measurements to process and cost related wastewater components is possible.

Different types of respirographic biosensors have already been set up. Batch measurements are generally considered valuable for determination of wastewater and sludge characteristics, while continuous experiments are suitable for determination of stoichiometric coefficients and for control. In any case, in order to be used for consortial plant management, validation, simplification and standardisation of test methodologies is necessary. Furthermore, requirements for an appropriate fee design are: irreprehensible test protocol and quick response. Irreprehensible test protocol is needed to achieve an incontrovertible evaluation of potential biological process damages due to the discharge; while quick response is required for alerting, almost in real time, the sewer managers, when industrial toxic compound discharge happens.

The objective of the present research was the development of a sort of "respirometric biosensor" that can give results in correlation with the major or minor difficulty of treatment of the studied waste stream and could be used to assess the costs associated with its treatment, more objectively with respect to chemical analysis. Once the single wastewater streams connected to a centralised plant have been characterised for their treatability, the plant manager can be able to force, also through the fee lever, industries to apply cleaner technologies or pre-treatments in order to obtain a resulting wastewater more amenable for the final treatment. This can be the first step towards the application of the "waste design" concept.

MATERIALS AND METHODS

The instrument developed is composed of two parallel moving bed continuous flow completely mixed reactors of a working volume of about 5 l each, equipped with oxygen sensors connected to a computer that acts as a controller and as a data acquisition and processing unit (Fig. 1). The control programme was implemented on Lab View (National Instrument) by SEC-Modena. Air is provided to the reactors until oxygen concentration reaches a stated upper value. After air shut-off, oxygen concentration begins to decrease, and, from the slope of the curve, oxygen uptake rate (OUR) can be calculated. Calculation of OUR is made as soon as the curve is sufficiently linear or when oxygen concentration reaches a stated lower value (Randall *et al.*, 1991) (Fig. 2).

For the evaluation of the treatability of wastewaters of a treatment plant, the two reactors are first inoculated with sludge of the final treatment plant and acclimated to the composite waste that is found at the end of the sewer. Small cubes of polyurethane foam were used as moving support material for biomass growth. This simplifies the operation, avoiding secondary clarifiers and recycling pumps, and allows low HRTs, and therefore to obtain rapid responses in terms of OUR during tests.

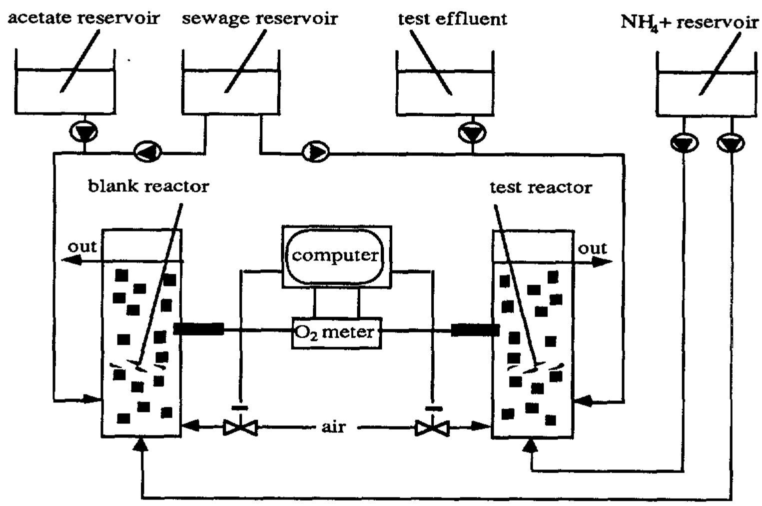

Figure 1. Scheme of the differential respirometer.

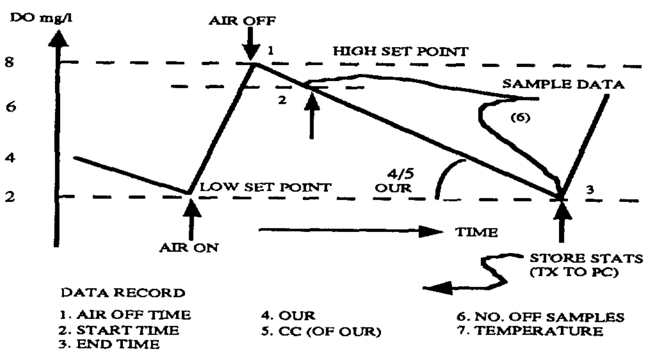

Figure 2. Example of data display and of OUR calculation procedure (Randall *et al.*, 1991).

The experimental scheme is very close to the one reported in the ISO Method 11733, but instead of measuring effluent COD from control and test reactors, information about biodegradability of the test stream is derived by OUR profiles, and IC 50 estimation can also be obtained. To evaluate the degree of treatability of a single stream, an equalised sample of it is analysed and then added with the composite waste to one of the two reactors, while the second is fed with the composite waste with the same amount of COD added - as acetate or as another easily biodegradable substrate - and ammonia of the test sample. At least three growing dosages are used. The test is completed with ammonia addition to both reactors (Fig. 3).

From the analysis of the differential responses, evaluation of percentage of biodegradable COD, inhibition to respiration, inhibition to nitrification and process kinetics can be obtained.

The first step shown in Fig. 3 allows the estimation of the amount of degradable COD in the test stream; increasing the dosage of COD in both reactors, it is possible to evaluate whether the growth of OUR is proportional (absence of respiration inhibition) or less than proportional (inhibition) with respect to the growth of OUR in the blank reactor. The same result can be obtained with increasing dosages of ammonia to detect nitrification inhibition. The respirometer was tested in the laboratory, at first using synthetic wastewater and later with real sewage. During this experimental phase, acetate and ammonia dosages were tested. In a second phase, the whole test procedure was carried out on textile wastewater. The latter experiments are still under progress. In this phase, steady state condition of the two reactors was reached at a composite textile wastewater flow rate of 0.7 l/h. Such flow rate has been drastically increased and reactors are nowadays working at 1.5 l/h, still showing enough capacity to significantly respond, in terms of OUR increase, to single industrial stream dosages. Average OUR increases have been statistically compared by means of variance ratio tests.

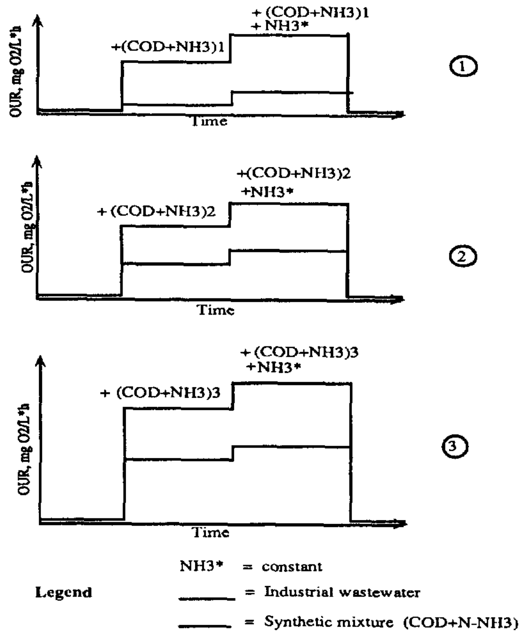

Figure 3. Graphic example of test procedure.

RESULTS AND DISCUSSION

In the following graphs, some examples of experimental results obtained with synthetic waste and with real sewage are presented. In Fig. 4, results of a test carried out on a synthetic waste composed of peptone and acetate are shown. The addition of sodium acetate at two dosages, first 200 mg/l COD and then 400 mg/l COD, resulted in almost a double increase of the oxygen uptake rate. OUR results are calculated as the averages during the addition period; the variation of OUR values is due to several noise problems depending on the probe, on mixing, etc., but do not affect the statistical significance of the test. In Fig. 5 an example of ammonia addition test with three increasing dosages is presented. It can be seen that the OUR does not grow linearly with ammonia concentration, probably because the concentration is close to saturation. This example shows also the possibility of obtaining kinetic data (at least μ_{max} and K_s) from respirometric data processing, once the yield coefficient is known.

Finally, the example reported in Fig. 6 presents results of a test where first only ammonia and then also COD were added; this test, in addition with the previous ones, can show evidence of inhibition to nitrification due to the tested waste. In Fig. 7, the increase of OUR corresponding to the first dosage (0.1 l h^{-1}) of the characterization procedure is reported. The average increase in OUR (7.71 mg O_2 l^{-1} h^{-1}) is only 65% of the corresponding OUR increase revealed in the control reactor, where the same concentration of COD and TKN of the single industrial stream was dosed as acetate and ammonium chloride. A known amount of ammonia was then added to both reactors during the first dosage. OUR increase in the test reactor was only 22% of the one recorded in the blank reactor. In all cases, differences resulted were highly significant (F>99%).

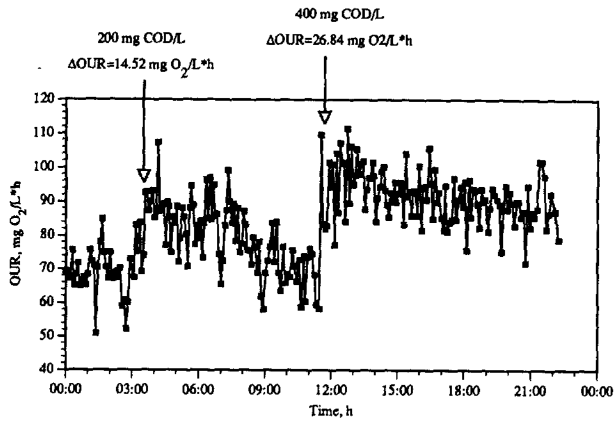

Figure 4. Results of a readily available COD addition test carried out on synthetic sewage.

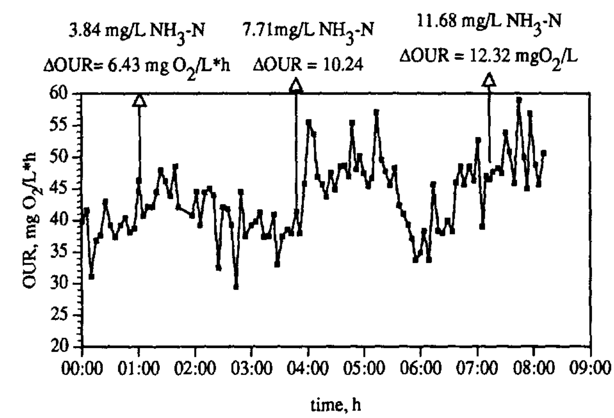

Figure 5. Example of results of an ammonia addition test.

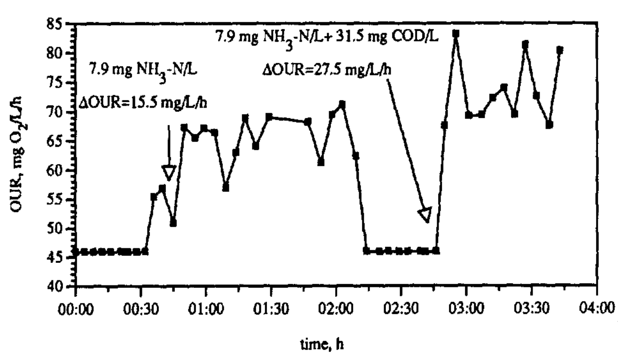

Figure 6. Example of test of addition of ammonia and of ammonia+COD.

In Fig. 8, results corresponding to the second dosage (0.2 l h^{-1}) are reported. The average increase in OUR (7.71 mg O_2 l^{-1} h^{-1}) is 35% of the corresponding OUR increase in the control-acetate reactor. An unexpected higher increase of OUR due to nitrification was recorded It has to be taken into account that the estimated inhibition of nitrification was still very high, around 75%. In Fig. 9, OUR courses, corresponding to the third single textile wastewater dosage (0.3 lh^{-1}), are reported. The average increase in OUR (7.71 mg $O_2 l^{-1} h^{-1}$) is 31% of the corresponding OUR increase in the control-acetate reactor. Considering the high inhibition effect towards nitrification, observed in the previous dosages, no extra dosage of ammonia was carried out in this run. With both second and third dosages OUR differences were highly significant (F>99%). A rough estimation of the dosage that inhibits heterotrophic and nitrification activity can be done by experimental results. On the basis of the results of the two ammonia dosages, it is possible to conclude that the tested textile wastewater stream exerts most of its inhibition capacity towards the nitrification activity.

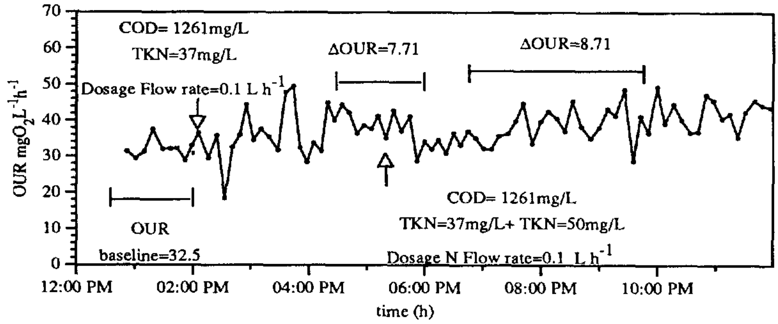

Figure 7. First dosage (0.1 l h^{-1}) of a single textile wastewater and ammonia nitrogen.

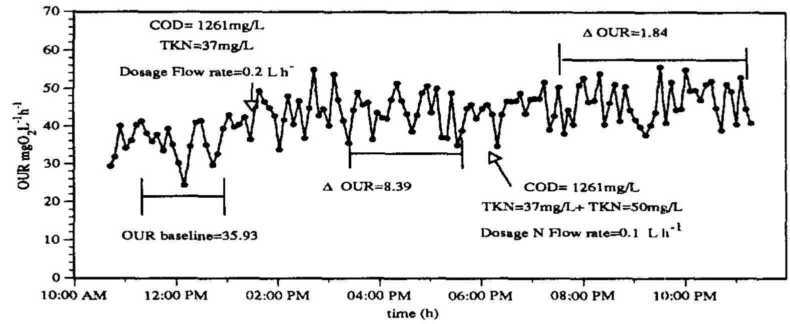

Figure 8. Second dosage (0.2 l h^{-1}) of a single textile wastewater and ammonia nitrogen.

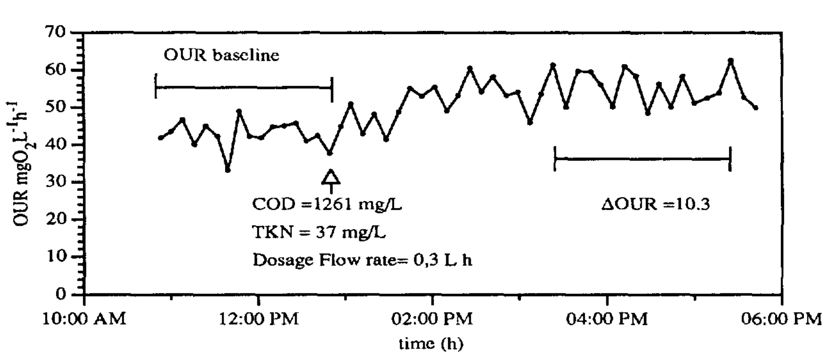

Figure 9. Third dosage (0.3 l h^{-1}) of a single textile wastewater and ammonia nitrogen.

Results obtained with the test methodology described above can then be used for the calculation of the treatment fee. This calculation is not based on a theoretical formula, but is calibrated on the degree of difference of the given stream with respect to optimal treatability, and related to the true treatment costs of the wastewater treatment plant.

WASTE DESIGN

The use of this characterisation method can allow plant managers to prevent treatment problems due, for example, to toxic discharges. These technical instruments, together with the fee lever, can also be used to "design" the correct wastewater that can be treated in a given treatment plant. But the concept of "waste design" should not be limited to an off-line procedure of characterisation and of request to industries of qualitative or quantitative changes to their discharges. In a broader application, this concept should be extended to an on-line management system, based on a network of sensors, actuators and facilities that can allow the plant manager to detect in the sewer (or before the discharge to the sewer) the presence of excess hydraulic loadings, of excess organic or nutrient loading and of toxicants and to put in operation measures - intermediate storage, equalisation, bypasses, etc. - that can allow to maintain an optimal treatment result and therefore protect the natural environment. On-line biosensors can be used for revealing toxicity.

CONCLUSIONS

The correct management of consortial industrial treatment plants needs improvements in the wastewater characterisation methods with respect to standard chemical analyses, in order to better evaluate the true treatability of the given wastewater stream into the final treatment plant.

Respirometry can be a powerful tool, but it needs to be standardised and simplified in order to be applicable as a screening and management procedure. The research work described led to the development of an automatic differential respirometric biosensor that can be used to detect not only the fraction of biodegradable organics, but also the degree of inhibition of heterotrophic respiration or of nitrification linked to the treatment of a given wastewater stream. Data can then be used for the calculation of the treatment fee, with a higher degree of correspondence to the true treatment costs associated to the given wastewater.

The application of this characterisation and fee calculation method can lead to the introduction of cleaner technologies when an industry, billed with high fees for the presence of inhibitory compounds in its wastewater, looks for the convenience of modifying its manufacturing cycle, or of substituting reagents or materials or of applying pre-treatment technologies.

The biosensor described, together with others, can be a new tool in the hand of plant managers to design the composition of the wastewater in relation with the available treatment technologies and to the sustainable management costs.

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