On the treatment of fish filleting waste water by means of rotating biological contactors

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Abstract

A simplified model for the removal of organic load from fish filleting waste water by means of rotating biological contactors (RBC) is presented. The model takes into account the surface area as representative of the active biomass. Information on the BOD-COD correlation for fisheries waste water is also presented. Finally, the evolution of the different forms of nitrogen during the biological treatment is discussed.

Introduction

The fish filleting industry in Mar del Plata is one of the main food processing industries. Some of the fisheries use only a simple settling tank as primary waste-water treatment. In view of increasing requirements of water pollution standards, a high interest exists in improving the removal of contaminants from waste water prior to its discharge to sewers. In this paper, I report on the biological treatment of fish filleting waste water by means of rotating biological contactors (RBC). These are fixed-film treatment systems which utilise corrugated plastic media. The media in turn rotate slowly while partially (usually 40 to 50%) immersed in the waste water.

Materials and methods

The waste water was collected from fish filleting plants located at the harbor of Mar del Plata. In the laboratory, it was kept refrigerated at 4°C in a plastic vessel, which served also as primary settler. The waste water was then pumped to the RBC system using a peristaltic pump, with the following flow rates (in ℓ/d): 31; 40.7; 49.5 and 125. The system was operated at room temperature, between 18° and 22°C.

The analyses performed were: biochemical oxygen demand (BOD_5); chemical oxygen demand (COD); nitrite-nitrogen; nitrate-nitrogen and total Kjeldahl nitrogen according to *Standard Methods* (1976). Ammonia-nitrogen was determined according to a method adapted in our laboratory (González, 1984).

The RBC unit was custom-built in plastic material (PVC). It consisted of three stages, each of which had ten disks attached to an axis that rotated supported by bearings at the end of each stage and driven by a variable-speed motor. During operation, 40% of the surface of the disks was immersed in the waste water. A scheme of a single stage is shown in Fig. 1.

Kinetic model of substrate consumption

For the correct sizing of a waste-water treatment system, proper knowledge of the kinetic parameters for the removal of the contaminants is needed. The following simple model provides such kinetic parameters, based on the following assumptions for its development: the liquid in each stage is completely mixed; the concentration of oxygen in the liquid is not limiting. These are conditions that were satisfied by operating the system at its maximum rotating speed. A third assumption is that the substrate (contaminant) is consumed exclusively by the biomass adhered to the surface of the disks, which is equivalent to neglecting the substrate consumption by the small amount of biomass suspended in the liquid phase. This is generally true, because the amount of attached biomass is much larger than the amount of suspended biomass. Finally, the model is obtained from a substrate balance:

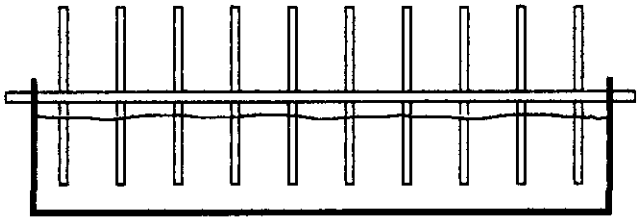

Figure 1
Schematics of a single stage of the RBC system

$$\left\{\begin{array}{c}\text{mass of substrate}\\ \text{that enters the}\\ \text{control volume}\end{array}\right\} = \left\{\begin{array}{c}\text{mass of substrate}\\ \text{that exits the}\\ \text{control volume}\end{array}\right\} + \left\{\begin{array}{c}\text{mass of substrate}\\ \text{that is consumed in}\\ \text{the control volume}\end{array}\right\}$$

that is:

$$\frac{F}{A} Si = \frac{F}{A} Se + \frac{dS}{A\,dt} \qquad (1)$$

where:

- F = flow rate (ℓ/d)
- Si = substrate concentration at the inlet of the stage (g/ℓ)
- Se = substrate concentration at the exit of the stage (g/ℓ)
- $\frac{dS}{A\,dt}$ = specific rate of substrate consumption (g/d·m²)
- A = area over which the biomass is attached (m²).

For the specific rate of substrate consumption several expressions have been proposed, most of which are modifications of the Monod expression for bacterial growth. The following fisheries waste-water treatment model is proposed:

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Received 6 December 1994; accepted in revised form 1 August 1995.

$$\frac{dS}{A\,dt} = \frac{Rm \dfrac{F\,S}{A}}{Cs + \dfrac{F\,S}{A}} \qquad (2)$$

where:

Rm = maximal specific rate of substrate removal
Cs = specific substrate load for which the rate of degradation is half of the maximal removal rate.

This is adapted from an expression proposed originally by Kincannon and Stover (1982), and has the advantage of considering the specific load imposed on an RBC treatment system. This is considered more appropriate for effluents which have variable flow rate and substrate concentration, like those from fish filleting factories in Mar del Plata. Substituting Eq. (2) into Eq. (1):

$$\frac{F}{A}Si = \frac{F}{A}Se + \frac{Rm \dfrac{F\,S}{A}}{Cs + \dfrac{F\,S}{A}} \qquad (3)$$

and rearranging:

$$\frac{F\,(Si - Se)}{A} = \frac{Rm \dfrac{F\,S}{A}}{Cs + \dfrac{F\,S}{A}} \qquad (4)$$

In a completely mixed system, the values of Se (substrate concentration at the exit of the system) and S (substrate concentration within the system) are the same.

These equations take into account the surface area covered by micro-organisms, instead of the amount of micro-organisms present. This simplification is made because in an actual decontamination system the amount of micro-organisms is not controllable and is also difficult to measure accurately, while the area covered with micro-organisms can be easily measured or specified in a design.

An expression for the area required can be obtained by inverting both sides of Eq. (4):

$$\frac{A}{F\,(Si - S)} = \frac{A\,Cs}{Rm\,F\,S} + \frac{1}{Rm} \qquad (5)$$

and rearranging:

$$A\left\{\frac{1}{F\,(Si - S)} - \frac{Cs}{Rm\,F\,S}\right\} = \frac{1}{Rm} \qquad (6)$$

Finally:

$$A = \frac{F}{Rm}\left\{\frac{1}{\left(\dfrac{1}{Si - S} - \dfrac{Cs}{Rm\,S}\right)}\right\} \qquad (7)$$

The kinetic parameters Rm and Cs can be evaluated from a Linewaver-Burk plot: from Eq. (6), if A/F (Si - S) is plotted in y axis vs. A / F S, a straight line of slope equal to Cs / Rm and intercept equal to 1/ Rm should be obtained. From these two

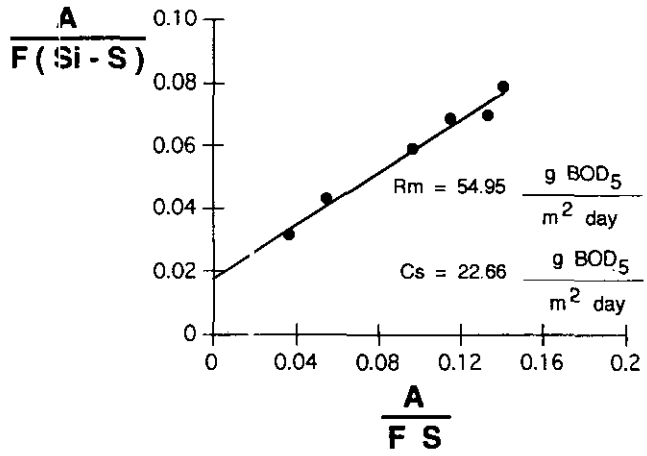

Figure 2
Linewaver-Burk plot for determination of parameters. Stage 1: Substrate as BOD_5

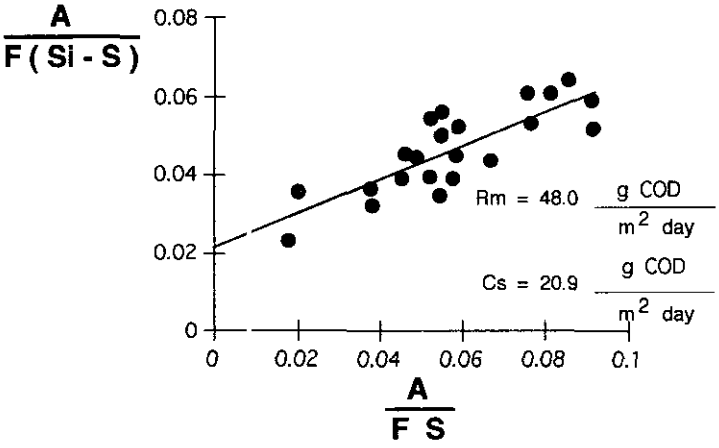

Figure 3
Linewaver-Burk plot for determination of parameters. Stage : : Substrate as COD

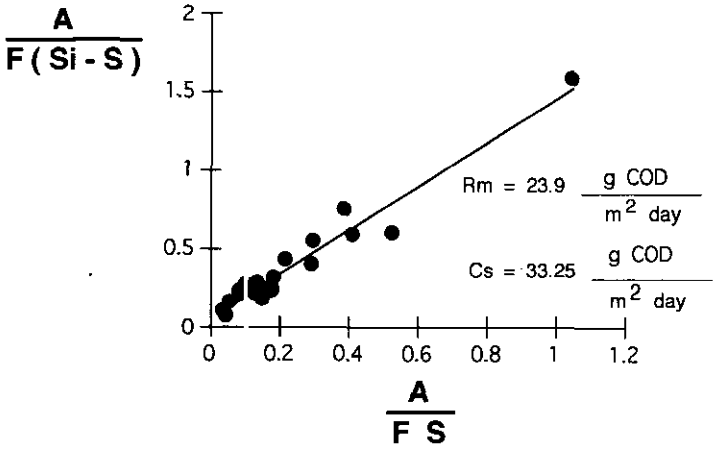

Figure 4
Linewaver-Burk plot for determination of parameters. Stages 2 and 3: Substrate as COD

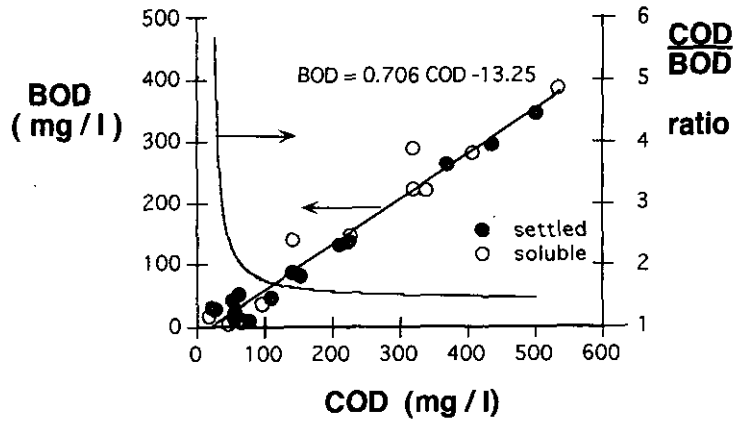

Figure 5
Correlation of BOD_5 vs. COD

values Cs and Rm can be obtained immediately.

Consequently the substrate expressed as BOD_5 in Stage 1 (Fig. 2), was plotted against the substrate expressed as COD in Stages 1, 2 and 3 (Figs. 3 and 4). The data of Stage 1 are presented separately from Stages 2 and 3 because of the much higher load imposed on the first stage. For the case of substrate measured as BOD_5, the Rm value was 54.95 g $BOD_5/m^2 \cdot d$, and Cs equalled 22.66 g $BOD_5/m^2 \cdot d$. When the substrate was measured as COD, in the first stage the Rm value was 48.0 g $BOD_5/m^2 \cdot d$, and Cs equalled 20.9 g $BOD_5/m^2 \cdot d$, while for the second and third stage the Rm value was 23.9 g $BOD_5/m^2 \cdot d$, and Cs equalled 33.25 g $BOD_5/m^2 \cdot d$.

It can be seen that the maximal rate of substrate removal is much lower in the later stages, while the Cs value increases. This is consistent with the change in characteristics of the waste water as it passes through a staged treatment system: in the first moments, the micro-organisms degrade those substances that are easier to assimilate, while those more difficult to metabolise pass to the following stages. This explains the reduction in the maximal removal rate in the second and third stages. The parameter Cs which can be interpreted as an inverse measure of the "affinity" of the bacterial population for the substrate (the larger Cs, the lower the "affinity"), increases in the later stages when the fraction of substrate difficult to degrade is higher.

BOD_5 - COD relationship

Formulating the correlation between BOD_5 and COD is of practical importance, since both are two of the most common measurements of the contaminant load present in a waste water. Since the oxygen demand results from micro-organism activity it is generally seen as more representative of a natural biodegradation process and the COD method is preferred because of its simplicity and because it requires much less time for completion (about 3 h for COD vs. BOD_5). The COD values are particularly useful for a routine control of the performance of a waste-water treatment system, where the residence time of the waste water is much less than the 5 d required by the BOD_5.

COD and BOD_5 were measured on whole waste water and on filtered waste water ($d_p < 0.45$ µm). The results of the correlation are shown in Fig. 5, where the full dots represent the oxygen demand of whole waste water and the empty dots correspond to filtered waste water. Both sets of data were grouped in a single correlation because the slopes of the lines for correlations calculated separately do not differ significantly ($p < 0.05$). This suggests that the variations in characteristics of the soluble and particulate fraction are similar along the treatment system. The correlation between COD and BOD_5 can be expressed as:

$$BOD_5 \text{ (mg } O_2/\ell) = 0.706 \text{ COD (mg } O_2/\ell) - 13.25$$

Also in Fig. 5 the COD/BOD_5 ratio is plotted as a function of the COD. The reason for the variation in the COD/ BOD_5 ratio is the same as for the variation in the values of the kinetic parameters: when an advanced degree of treatment has been reached (low oxygen demand values), the micro-organisms have degraded most of the contaminant load they are able to assimilate, while other refractory substances or metabolites remain. These refractory substances are equally degraded by the energy conditions of a COD test, therefore increasing the COD/BOD_5 ratio as treatment advances.

Even though this kind of correlation can be satisfactorily established for one kind of waste water and it certainly is of great help, it should be emphasised that it cannot be applied to different systems, neither can it be safely extrapolated for values beyond the range used when establishing the correlation.

Analysis of the generated biomass

As a consequence of the biological treatment of the waste water, biomass (cell mass) is generated, which may potentially be used later. One of the potential uses is that of supplement in animal feeds as single-cell protein (SCP). To have an initial estimate of the feasibility of using the generated biomass as feed supplement, the slurry from the stages was centrifuged at 13 500 g, then freeze-dried and analysed for its lipid, protein and ash content. The results are summarised in Table 1. The protein content is very similar to that obtained in an extract when fish offal and peat are composted (Martin and Chintalapati, 1989).

TABLE 1
CHARACTERISTICS OF THE SCP RECOVERED FROM RBC PROCESS

Parameter	Value (g %)
Total Kjeldahl nitrogen	9.84
Protein (Lowry method)	44.5
Lipids (Soxhlet extraction)	6.1
Ash (550°C)	6.7

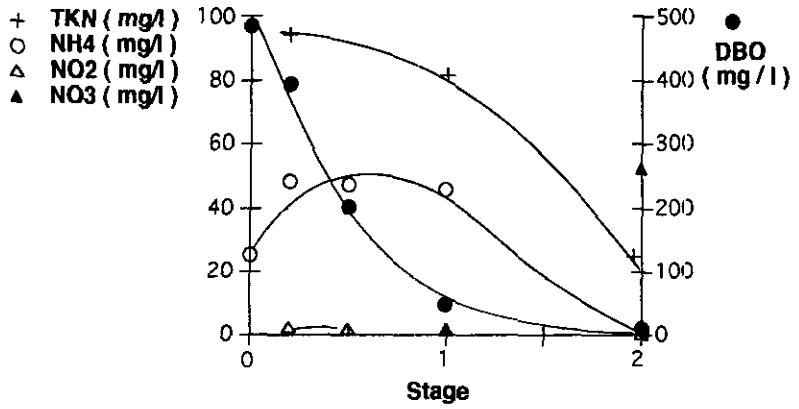

Figure 6
Evolution of BOD_5 and nitrogen forms at flow rate = 31 l/d

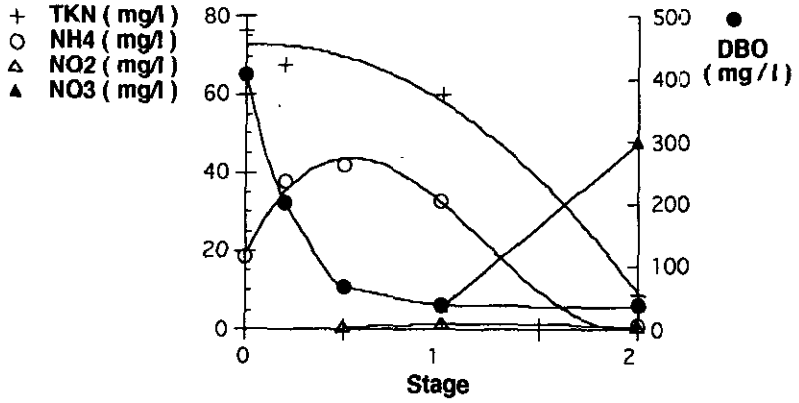

Figure 7
Evolution of BOD_5 and nitrogen forms at flow rate = 40.7 l/d

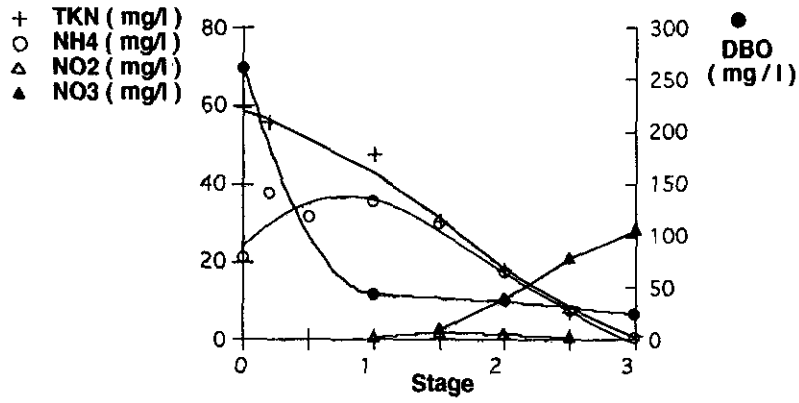

Figure 8
Evolution of BOD_5 and nitrogen forms at flow rate = 49 l/d

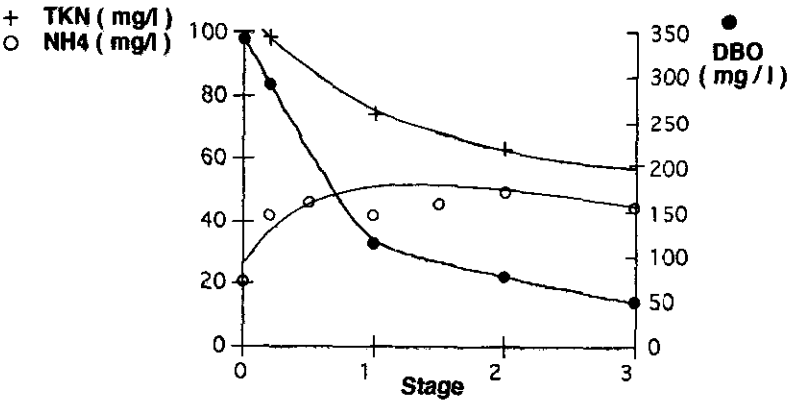

Figure 9
Evolution of BOD_5 and nitrogen forms at flow rate = 125 l/d

Evolution of the nitrogen forms

Fisheries waste waters contain ammonia and other nitrogenated compounds, such as proteins, amino acids and basic volatile amines, some of which are degraded to ammonia and then oxidised to nitrite and nitrate in the successive steps of a biological treatment, process called nitrification:

$$2NH_4^+ + 3\,O_2 \Rightarrow 2NO_2^- + 2H_2O + 4H^+$$

$$2NO_2^- + O_2 \Rightarrow 2NO_3^-$$

The bacteria that are responsible for the first stage of nitrification are mainly *Nitrosomonas* sp. while the *Nitrobacter* sp. oxidise nitrite to nitrate. Biological oxidation of nitrogenous compounds proceeds usually at a lower rate than the oxidation of the carbonaceous substrates. However, achievement of nitrification while the effluent is being treated is advantageous because if water were discharged with high ammonia content, this would be oxidised to nitrate in the receiving water body anyway, with the consequent oxygen demand.

The evolution of nitrogenous compounds in the RBC system was observed by measuring the total Kjeldahl nitrogen, and ammonia, nitrite and nitrate nitrogen. They are plotted in Figs. 6, 7, 8 and 9 for the different flow rates used. A plot of the BOD_5 is also included to show the evolution of the organic load.

It can be seen that the ammonia-nitrogen concentration increases in the first stages. This indicates that in the first stages other nitrogenous compounds such as amines, amino acids and peptides are degraded to ammonia. The nitrite-nitrogen does not appear significantly in any of the cases. This is consistent with the fact that the controlling (slower) step in the oxidation of ammonia is its conversion to nitrite (Eckenfelder, 1979). The nitrate-nitrogen reaches its maximum values in the later stages of the treatment, and after the BOD_5 has been reduced to 30 to 50 mg/ℓ. This is also consistent with other observations that indicate that nitrifying populations of micro-organisms predominate only after the BOD_5 has been reduced to about 30 mg/ℓ (Antonie, 1976).

Conclusions

It has been shown that the kinetics of organic substrate removal (either as BOD_5 or COD) by biological contactors, can be satisfactorily represented using simple models.

The nitrogen forms present in fisheries waste water can also be oxidised in such systems, from which SCP with about 44% protein can be recovered.

Acknowledgements

The author wants to acknowledge support from the Universidad Nacional de Mar del Plata, Argentina; the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) of Argentina and the International Foundation for Science (IFS)from Stockholm, Sweden.

References

ANTONIE, RL (1976) *Fixed Biological Surfaces of Wastewater Treatment - The Rotating Biological Contactor.* CRC Press, Cleveland, Ohio, USA.

ECKENFELDER, WW (Jr.) (1980) *Principles of Water Quality Management,* CBI. Publishing Co., Boston, Massachusetts, USA.

GONZÁLEZ, JF (1984) On the ammonia-nitrogen determination in fisheries wastewaters by means of the indophenol method. *Environ. Technol. Let.* **5** 345-348.

KINCANNON, DF and STOVER, EL (1982) 1st. International Conference on Fixed Film Biological Processes, King Island, Ohio, USA.

MARTIN, AM and CHINTALAPATI, SP (1989) *Biol. Wastes* **27** 281.

STANDARD METHODS (1976) *Standard Methods for the Examination of Water and Wastewater* (14 th edn.) APHA.