DISEÑO DE UN RBC UTILIZANDO UNA PLANTA PILOTO CON EFLUENTE INDUSTRIAL

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Traducción Parcial

1. Introducción.

Los Contactores Biológicos Rotativos (RBC) han sido utilizados vastamente en los últimos 30 años en Europa y los Estados Unidos para el tratamiento de efluentes domésticos e industriales que sean biodegradables. El RBC es un proceso de biofilm en el que múltiples discos rotan parcialmente sumergido en un tanque que contiene el efluente a ser tratado.
Pretratamiento consistente en rejas o decantación es normalmente utilizado como con otros procesos biológicos, y la biomasa generada en separada en un clarificador secundario.

Un estudio piloto de un año fue conducido en Paraguay por técnicos de la empresa Fabripar Ingeniería S.A. y la Ing. Joanne Barlow, quien participó como parte de un trabajo de cooperación con la Universidad de Cranfield, Inglaterra.

El trabajo tuvo como objetivo la evaluación tanto operacional como mecánica de un RBC diseñado y construído por Fabripar. Algunos de los parámetros analizados fueron la carga orgánica, carga hidraúlica, velocidad y número de etapas.

Table 1. RBC – Comparación de parámetros de diseño

OLR total	OLR total	OLR soluble	OLR soluble	HLR	HLR	Source of information
lbs BOD/1000ft2.d	g BOD/m2.d	lbs SBOD/1000 ft2.d	g BOD/m2.d	USgpd/ft2	m3/m2.d	
		3 to 4	15 to 20	1 to 3	0.04 to 0.12	Simplified Wastewater Treatment Plant Operations by Edward J Hall. Technomic Pubs, USA 1995. ISBN 1-56676-216-2
						Theory and Practice of Waster & Wastewater Treatment by Ronald L Droeste. John Wiley & Sons, USA 1997.
	5				0.017 to 0.05 (up to 0.12 for lower quality effluents)	Biological Filtration and Other Fixed Film Processes CIWEM 2000. ISBN 1-870752-44-9 (UK for 20:30 effluent. State HRT < 1hr gives poor effluent and no advantage >3hrs)
	5 (settled) or 7.5 (raw)					Manual of British Practice in Water Pollution Control: Unit Processes - Biological Filtration IWEM 1988
2 to 6	10 to 30					EPA Manual for small communities. 1977. Recommedation p8-13 by G Tchobanoglous, 1974

A one year pilot plant study was carried out in Paraguay on the process and mechanical performance of a unit by Fabripar S.A. Previous work by others (see reference) has shown several inadequacies in pilot plant results based on small scale units, which can produce misleading results. The most significant deficiency in using scaled down pilot plant has been reported to be the fact that the scaling down changes the rotational velocity: peripheral velocity ratio (see reference). Normal full scale plants operate with a rotational velocity of between 1 to 5 rpm and a disc/wheel diameter of 1.8 to 3m (see reference). This gives a peripheral velocity of 5.6 to 37.7 m/min. The combination of rotational and peripheral velocity influence the dissolved oxygen content in the water from the mixing effects as well as how easily the biomass sloughs off of the media. Where small scale pilot units are used either the rotational speed will have to be higher than the full scale unit resulting in greater mixing and dissolved oxygen content or the peripheral speed will have to be slower tending to allow the biofilm to develop more easily without sloughing off. Therefore it was decided to conduct a one year pilot trial of a full scale RBC to determine process and mechanical performance.

As part of the developmental stage pilot plant trials were planned using diluted industrial effluent as a synthetic medium strength domestic effluent. The initial trials were carried out at Fabripar's factory.

Contactor Biológico Rotativo en Fabripar Ingenieria S.A.

2. Materials and Methods.

2.1 Pilot Plant Arrangement
The pilot plant consisted of:

- A $4m^3$ transportable storage tank for the crude effluent;
- Two RBC feed tanks with a combined volume of $6m^3$ which allowed the crude effluent to be diluted;
- A tank providing flow control via a float valve to the RBC;
- RBC capable of treating $6m^3$/day combined with a flow equalisation chamber and bucket pumps as well as a discharge section with bucket pumps suppliying the clarifier, and
- a secondary clarifier with automatic pumped sludge removal controlled via an adjustable timer. The sludge was pumped to two sludge drying beds each 2m x 1m giving a total drying surface of $4m^2$.

The RBC was designed to treat $6m^3$/d of effluent with an average COD of 500 mg/l. This was chosen since a COD of 500 mg/l corresponds with a medium concentration untreated domestic wastewater as detailed by Metcalf & Eddy. The suspended solids of a medium strength wastewater are around 220 mg/l and BOD 220 mg/l. It was intended to achieve a minimum of 80% COD removal to comfortably meet the Paraguayan discharge consents, which are COD < 150 mg/l, BOD < 50 mg/l and Suspended Solids < 80 mg/l.

Trial periods were ran to test the difference in performance when using two or three stages of media. The diameter of the media packs was 1.8m and they were rotated at two different speeds 2.7rpm and 1.4rpm. The clarifier overflow rate at $6m^3$/d was 14.6m/d (360USgal/ft^2.d) which was slighty below the recommended range of 400 to 800 USgal/ft^2.d. This should however increase the performance of suspended solids removal (Antonie 1976).

The effluent used in for testing was taken from a nearby industry . This was selected for three reasons.

- The effluent was known to be biodegradable, since it is currently successfully treated using DAF and activated sludge.
- The effluent was readily available since the company was near to the factory and Fabripar had constructed the wastewater treatment plant at this company so there was a established relationship.
- The effluent from this industry was concentrated, with around 5000 mg/l COD, which meant we could dilute at the pilot plant reducing transport costs for bringing the waste to the pilot plant.

Previous work carried out using an RBC pilot plant for the treatment of industrial waste by Stover and Kincannon (Dupont and McKinney 1980) found that a maximum of 70% COD removal could be achieved up to a loading of 7lbs/1000ft^2.d (34.5 gCOD/m^2.d). It is purported that the reason for this relatively low COD removal was the large amounts of fats, oils and slowly degradable organic materials in this wastewater. Using the two stage RBC the intended organic loading rate was 17.2 gCOD/m^2.d and with three stages this dropped to 11.5 gCOD/m^2.d, indicating that we should be able to expect 70% COD removal if our results compared with Stover and Kincannon.

COD and suspended solids analysis were carried out in Fabripar's laboratory. COD values for total, filtered and supernatant after one or two hours sedimentation were taken. COD analysis was carried out in accordance with Standard Methods 18th Edition 5220D.

2.2 Phases of Operation

- **Phase 1**. 30 January to 19 April 2004. During this period of 81 days the unit was operated to establish the biofilm and steady operating conditions. The RBC was operated using two stages at 2.7 rpm.

- **Phase 2**. 20 April to 5 May 2004. We continued to operate with two stages at 2.7 rpm but changed the feed to effluent after treatment with DAF which had an average COD = 1130 mg/l and an average flow of $4.7m^3/d$, resulting in an OLR = 30.5 $gCOD/m^2.d$.
- **Phase 3**. 6 May to 6 August 2004. To try to combat the two problems of high suspended solids in the feed and the potential problems from polymer addition it was decided to take effluent before DAF treatment. This had a high COD > 5000 mg/l with relatively low suspended solids. This feed was diluted with well water to give a feed of 500 mg/l COD at $6m^3/d$. Data was collected over a 92 day period using the RBC in two stage mode rotating at 2.7rpm. On 13 May 2004 an automatic positive displacement gear pump with adjustable timer was installed to remove the sludge from the clarifier. Prior to this the sludge had been removed manually via a valve at the base of the tank and the 14 hour period during the night when manual sludge removal had not been possible had resulted in problems with anaerobic conditions causing floating sludge in the clarifier. Results shown below are from the period starting 21 May 2004, when the five part composite samples were introduced.
- **Phase 4**. 7 August to 6 September 2004. The speed of the RBC media wheels was reduced to 1.4rpm. During this period the RBC continued to be operated using two stages but the flow was reduced to an average of 2.9 m^3/d.
- **Phase 5**. 7 September to 19 October 2004. The RBC operation was changed to use three stages for treatment and the flow was increased back to 6 m^3/d. Rotational speed = 1.4rpm. Between 19 October and 4 November cleaning of the storage tanks was carried out to ensure no biomass had developed in the storage tank which would affect the performance of the RBC. This was due to the fact that numerous problems had been encountered trying to maintain the feed concentration at 500 mg/l of COD.
- **Phase 6**. 4 November to 1 December 2004. Continued in the same mode of operation as Phase 5 but used an automatic sampling unit (ISCO SAMPLER 6700) to take 150ml samples of the final effluent every 10 minutes which were then composited over a 24 hour period and analysed. This arrangement was put in place due to the difficulty in manually obtaining representative composite samples and the fact that we were having to remove floating sludge and solids which had collected in the clarifier outlet trough every day and therefore had concerns these may be artificially improving the results. The RBC did not receive continuous feed for the period from 8 November to 23 November and as a result no analysis was taking during this period and it has been excluded from the summary of Phase 6 in Figure 1.
- **Phase 7.** 2 December to 18 December 2004. On 1 December 2004 a bypass through the combined overflow was observed from Stage 1 to the final discharge section of the RBC before the clarifier. This bypass was blocked and the RBC operation changed back to two stage only but still using automatic sampling at 10 minute intervals. Using the unit as two, rather than three, stage also reduced the problems that had been experienced with the blockage of the hoses which connected stages 2 and 3 and the final outlet chamber.

3. Results and Discussion

3.1 Biofilm Development

The plan was to use the screened crude wastewater to build up the biofilm on the RBC media (average SS = 810 mg/l, COD = 3100 mg/l), then we would change the feed to effluent after the DAF treatment which had a COD of around 1500 mg/l and much lower suspended solids (average 270 mg/l).

Many literature sources indicate that visible biofilm development normally takes place within one to two weeks of starting the feed the effluent. Antonie (1976) states than normally after one week the biofilm has a thickness of 1 to 4 mm. Screened raw undiluted effluent started to be feed to the RBC. After 3 ½ weeks there was virtually no evidence of any biofilm. We found further information on RBC use at temperatures $>20^0C$ (see reference) which indicated that problems were encountered at these temperatures if the OLR was below 7 $gCOD/m^2.d$. Subsequently we increased the flow to $3.4m^3/d$ and a thick biofilm developed on stage 1 within one week and a much thinner biofilm on stage 2.

On April 19 the feed was changed to the post DAF effluent containing polymer. The purpose was to determine the RBC performance without the heavy suspended solids loading from the raw effluent.

This Phase 2 was continued for 17 days until May 5, 2004. During this time the average COD was 1130 mg/l and flow 4.7m^3/d giving an OLR of 30.5 gCOD/m^2.d . There was also a noticeable decrease in the biofilm thickness on both stages.

Following the change of the effluent at the start of Phase 3, the biofilm did not appear to build up again very quickly, but no further biofilm was lost from the media and slowly some additional biofilm developed.

The biofilm in stage 3 after the start of Phase 5 built up very slowly and after more than 2 months still appeared rather thin and patchy compared to stages 1 and 2. It would be expected that since Stage 3 had a lower organic loading the biofilm would not be so thick, but it had been anticipicated it would be thicker than it was.

<u>3.2 COD Removal Performance</u>

Initially the sampling was taken by manually taking five 200ml samples of both the feed to the RBC and treated effluent from the clarifier at regular intervals throughout the working day of 07:00 to 17:00. In Phase 4 the sampling regime was improved since all samples were taken using an automatic sampler (Model ISCO 6700) which took 150ml samples at 10 minutes intervals during the week and 20 minute interval at the weekend.

The kinetic constant, k, was calculated using Eckenfelder´s model:

$$S = S_0 (Q / (Q + kA))^n$$

Where S = Treated COD concentration (mg/l)

S_0 = COD of feed effluent (mg/l)

A = Surface area of media per stage (m^2)

Q = Flowrate (m^3/d)

n = Number of stages

Phase 1. Only two lots of samples for analysis were taken once the biofilm seemed to have stabilised. The first with a TCOD of 4995mg/l showed a 81% reduction in TCOD and an 83% reduction in SCOD at an OLR of 104gTCOD/m^2.d. The second three days later had an influent TCOD of 3200mg/l and a TCOD reduction of 65% and SCOD of 72% with an OLR of 67gCOD/m^2.d. This was deliberately being heavily overloaded.

Phase 2. Samples were taken on 8 of the 17 days, but for three of the days the results seem highly questionable. It is felt that this is due to not having used enough samples to make up a representative composite sample.

The summary of the results from Phases 2 to 6 is shown in Table 2.

Table 2. Results of RBC Trials.

	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7
No of days	17	78	31	43	12	17
No of samples taken	8	38	12	18	11	13
TCOD in (mg/l)	1132	488	519	423	610	418
SCOD in (mg/l)	482	138	128	85	171	139
SS in (mg/l)	451	198	259	187	265	148
TCOD out (mg/l)	621	106	90	88	185	126
SCOD out (mg/l)	355	55	59	55	144 [Note 1]	42
SS out (mg/l)	246	91	124	72	89	85
OLR overall ($gCOD/m^2.d$)	30.6	11.4	8.6	8.1	10.9	13.9
% TCOD removal	45	78	83	79	70	70
% SCOD removal	26	60	54	35	---	70
% SS removal	43	54	52	61	66	43
K (m/d)	0.0287	0.0633	0.0497	0.0436	0.0286	0.0402

Note 1 – This value is of the COD of the supernatant after one hour of settlement in the laboratory. It is not only soluble COD.

Total COD removal varied between 45 and 83%, whilst this shows some improvement on the maximum of 70% achieved by Stover and Kincannon. The percentage removal of soluble COD was lower at between 26 to 60%. However this may well be due to the relatively low level of SCOD/TCOD of 0.20 to 0.42.

Except for in Phase 2 the organic loading rates were maintained within the recommended levels. Having reviewed several literature sources (shown in Table 1) it was decided that the overall organic loading rate should be below 15 g $COD/m^2.d$.

The suspended solids removal was between 38 an 66%. Based on our data it is difficult to see any clear benefit in using three stages rather than two. Phases 5 and 6 were those operated with three stages of treatment. The percentage removal of suspended solids seems better when three stages are used, but there does not seem any improvement in the Total COD removal by adding the third stage and the removal of the soluble COD appears deteriorate when the third stage is used.

The average suspended solids on the inlet to the RBC was higher in all phases than that which would be expected from medium strength domestic wastewater. Whilst the average SS of untreated medium strength wastewater is given as 220 mg/l, the RBC would always be preceded by primary treatment. Metcalf and Eddy state that a well designed primary settlement tank will remove 50 to 70% of the incoming suspended solids. Assuming the more conservative figure of 50% removal the feed to the biological treatment stage should have an average of 110 mg/l of suspended solids. The average suspended solids in our trials on the RBC inlet varied from 129 to 451 mg/l, with an overall average of 226 mg/l. This, along with the nature of the solids, may account for our apparent difficulties in removing as much of the suspended solids as we had intended in the system.

The range of hydraulic loading rates recommended by Antonie for domestic effluent are 1 to 5 $USg/ft^2.d$ which in SI units convert to 0.0407 to 0.2035 $m^3/m^2.d$. The hydraulic loading rates that were used in our trials were below these values, which should not have had any negative effective on the process.

The kinetic constants of each phase varied between 0.0286 and 0.0633, with an average of 0.049 m/d. This is slightly lower than the k value of 0.0566m/d obtained from trials by Navarro et al (2004) in Argentina using a synthetic biodegradable effluent. This indicates good biodegradability of the effluent in our trials through the RBC process, but due to the fats, oils and grease content and the content of small fibres which pass through the pre-screening, it would be expected that the kinetic constant is not as high as a synthetically prepared soultion for testing in the laboratory.

It should be noted the method of suspended solids analysis was changed at the start of Phase 6 to improve its accuracy.

3.3 Solids Removal Performance

Table 3 shows the overall percentage removal of suspended solids during each phase. However in the process of biological treatment of the wastewater some of the organic matter comprising the COD is converted to solids. Therefore analysis was taken during the period 27 July to 20 October 2004 of the feed to the clarifier in order to try to establish the performance of the clarifier, separately from the RBC.

Table 3: Sludge Mass Balance through Clarifier 27 July to 20 October 2004.

Description	Mean of measurements	Number of samples
SS in clarifier feed	676 mg/l	35
Volume of sludge removed from clarifier	55 litres/day	86
% dry solids in sludge removed	1.5%	10
Average flow to RBC	3 m^3/d	83
Treated effluent SS	88 mg/l	37

Constructing a mass balance for the period from 27 July to 20 October shows:

Solids entering clarifier = 3 m^3/d x 676 g/m^3 = 2028 g/d

Solids removed in sludge = 55,000 g/d x 0.015 = 825 g/d

Solids in effluent = 88 g/m^3 x 3 m^3/d = 264 g/d.

There seems to be a shortfall of 939 g/d of solids between the inlet and outlet solids of the clarifier, which was not possible to be accounted for, although it is thought that some solids could have been lost through floating sludge in the clarifier.

3.4 Performance variation between each of the stages

During the period 20 July to 13 October samples were taken of the effluent directly from each stage to compare the performance throughout the unit. Each sample was taken manually and made up of 3 samples of about 200ml mixed together. The wheels in the RBC had to be stopped briefly to enable the sampler to be manually dipped into the section to take out a sample.

Table 4 shows the results of the COD taken from each stage. The samples were settled in the laboratory for one hour and then the supernatant was sampled for COD. This was to make an allowance for the effect of the clarifier. However as can be seen from the results, except on 8 September 2004, the performance of the settlement in the ideal conditions of the laboratory was more effective than the performance of the clarifier. In fact the data shows that the samples taken directly from stage 2 and then settled in the laboratory had consistently better results than the final treated values from the clarifier.

Table 4

RBC COD reduction according to stage

date	DQOi (mg/l)	DQO wheel 1 after 1 hour sed (mg/l)	% red rueda 1	DQO wheel 2 after 1 hour sed (mg/l)	% red rueda 2	DQO wheel 3 after 1 hour sed (mg/l)	% red wheel 3	DQOe (mg/l)	% red total
20-Jul-04	395	165	58	41	90	---	---	55	86
05-Ago-04	---	92	---	106	---	---	---	---	---
10-Ago-04	485	84	83	73	85	---	---	78	84
18-Ago-04	971	113	88	107	89	---	---	113	88
24-Ago-04	331	55	83	44	87	---	---	78	76
31-Ago-04	703	96	86	78	89	---	---	101	86
08-Sep-04	408	273	33	233	43	---	---	147	64
16-Sep-04	255	32	87	<32	>87	<32	>87	38	85
21-Sep-04	323	32	90	<32	>90	<32	>90	55	83
01-Oct-04	387	44	87	<32	>92	<32	>92	61	84
06-Oct-04	476	96	80	84	82	101	79	107	78
12-Oct-04		55		55		26			
13-Oct-04	285	62	78	55	81	70	75	114	60
Average			78		83		85		79

Note: The poor performance on 08-sep-04 is most likely due to the system still being in recovery after it was shut down for 8 hours on 06-sep-04 to allow the new RBC unit to be connected.

Also the results indicate that there is not a significant advantage in using the second and third stage for this effluent at the conditions tested. On 12 and 13 October samples were taken of each stage and sent to two different external laboratories to verify our own results. In the external laboratories BOD as well as COD was analysed. The average BOD:COD ratio was 0.42:1. The comparisons are shown in Figure 1 and 2.

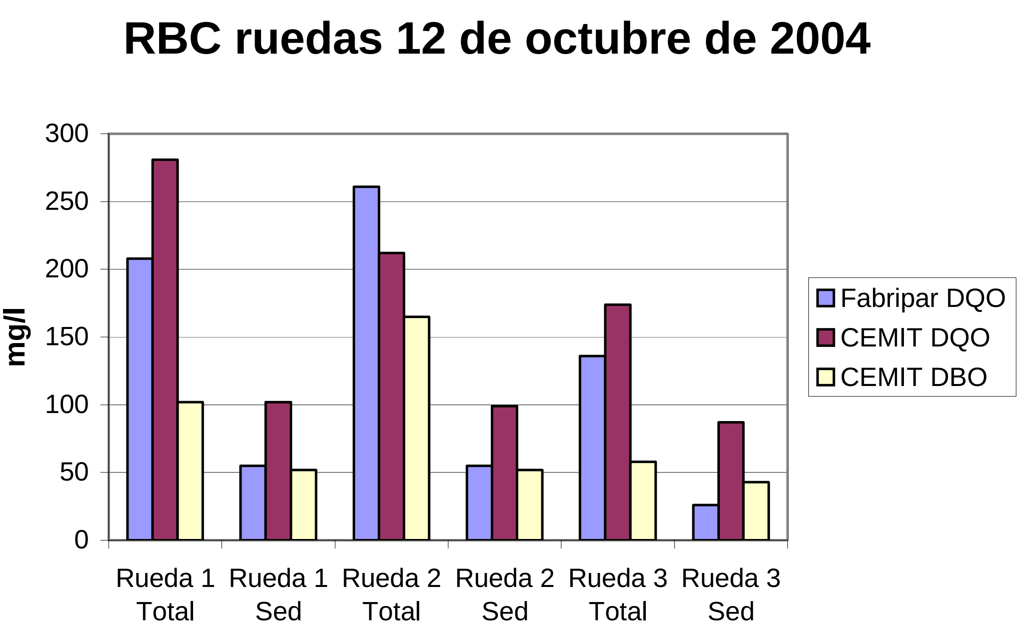

Figure 1

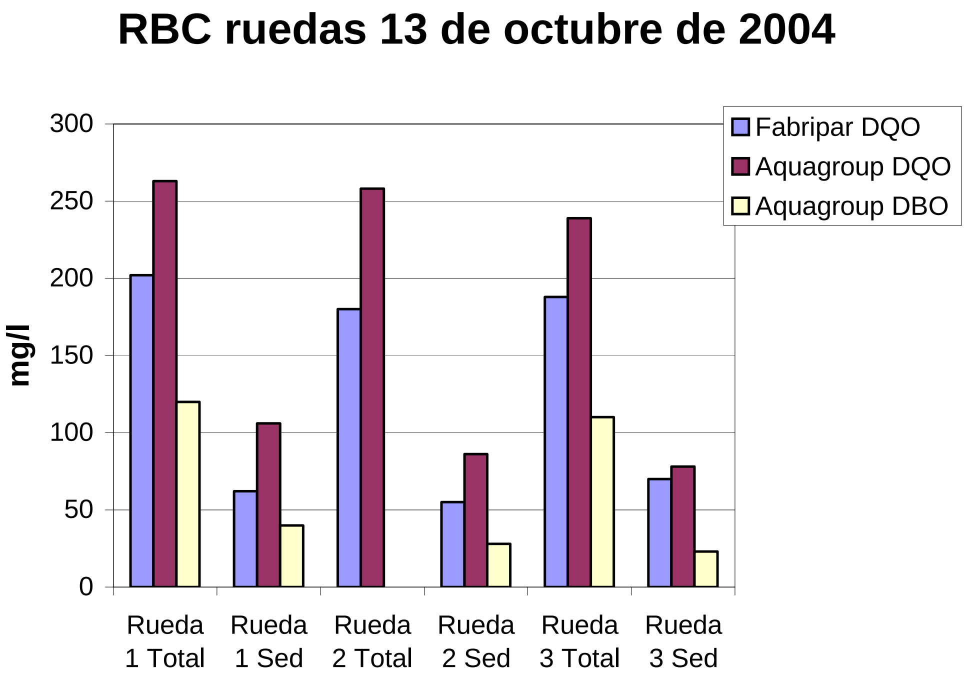
RBC ruedas 13 de octubre de 2004
mg/l
300
250
200
150
100
50
0
Rueda 1 Total
Rueda 1 Sed
Rueda 2 Total
Rueda 2 Sed
Rueda 3 Total
Rueda 3 Sed
Fabripar DQO
Aquagroup DQO
Aquagroup DBO

Figure 2

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