Design of a carrier for wastewater treatment using moving bed bioreactor

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Abstract: - A new carrier has been designed in order to maximize substrate removal when is used in moving bed bioreactors. Initially, six different biofilm carriers were designed which differ from commercially available products. They were designed according to carrier surface properties such as specific surface area or shape. Two of these models were chosen for a deep study carried out on laboratory scale using one reactor fed with wastewater from a Spanish water-treatment plant. The reactor was divided in two vessels to test the behavior of the chosen models (models B and F) as compared with that of commercial ones. Over the course of seven months, tests of hydrodynamic behavior, total suspended solids (TSS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were done. The results showed that the model B is not a good model, while the model F gets very similar efficiency to that of the commercial carrier in BOD and 12% superior in COD.

Key-Words: Carrier, Wastewater treatment, Moving bed bioreactor, Surface properties, Production cost, Chemical oxygen demand

1. Introduction

Environment conservation requires wastewater purification. This purification consists of a series of stages, one of which is the biological phase. It is usually carried out by retaining the fluid in a biological reactor, thus allowing the bacteria-fluid reaction to take place [1], [2].

The length of time during which the fluid must be retained and the enormous size of the vessels required in the biological phase have led to a search for new techniques which require less time and space. Moving bed technology is based on the natural purifying activity of the bacteria. The microorganisms which decompose the contaminating elements grow attached to a support, thus forming an organic biological film. This biological film is kept in suspension and in continual movement within a tank or reactor which contains the water to be treated [3], [4].

Carriers such as sand or gravel have the advantage of their low or zero cost, but also they have a series of considerable disadvantages [5]. The most important one is that the finer types may escape from the reactor, contaminating the water, which will require constant topping up. Besides, their density is in general superior to that of the water, and the friction caused by the collisions of the particles splits up the biofilm.

It is for all these reasons that artificial supports are being developed: elements which are specifically designed to maximize the bacteria-fluid interface using minimum energy [6]. These carriers are elements with similar densities to that of water (between 0.90 and 1.20 kg/dm3), in order to make them float more easily.

This paper describe how new carriers were designed and tested. The objective is to get a carrier with the best geometric characteristics in relation to the existing commercial carriers, low production costs and at least similar efficiency to that the commercial carriers [7].

2. Previous study.

Commercial carriers can be separated into two large groups: those which are derived from cylindrical shapes and those with more complex shapes. The main difference between these two groups lies in the fact that the carriers based on more complex forms need to be larger in size in order to be competitive from an economic point of view and must be made of harder materials. This makes them heavier and

consequently they require a greater pumping work [8]. On the other hand, cylindrical shapes have better hydrodynamic behavior and suffer fewer mechanical losses as a result of collision.
The internal and external walls and the separating walls are covered by the biofilm of bacteria. They are divided up by internal walls with a view to increasing the surface area but at the same time avoiding making the openings so small as to lead to their becoming clogged [7]. The most common divisions are those in which the internal walls form a cross or an alveolar structure.
The external wall may be covered in fins or ribs, so as to assure minimum friction against other carriers or against the reactor during the process. Thus, it preserves the biofilm of the external wall of the carrier and guarantees a good hydrodynamic behavior and a major resistance to be deformed [8].
In relation to the geometric properties of the carriers, three parameters have been studied:

- Area-volume ratio or relation between the size of the surface area to which the microorganisms can attach and the volume.
- Percentage cavities or size of the specific surface effectively used.
- Passage diameter or diameter of the smallest interior cavity.

These values should be as high as possible to get a great surface on which the bacteria stick and in the case of the passage diameter avoid blocking the carrier by particles present in the water [9].
Other parameters analyzed are:

- Resistance to clustering. The appearance of deposits on the media reduces the biological contact surface area.
- Percentage of occupation. The space occupied by the carriers within the medium in relation to the total volume.

In order to avoid the clustering, it is necessary to maintain the carriers continually in motion. Consequently, their design should facilitate such movement but it also should have enough structural resistance so as not to become misshapen. Also a percentage of occupation between 60 or 70% [10, 11] facilitates the constant motion and let the optimum aeration of all surfaces.
Another key aspect in the design of carriers is the material with they are made and the production process.
Because of the need to obtain complex elements of very small dimensions and thicknesses, the production process should be the injection moulding that has the lowest costs and fastest production times [6]. For this type of manufacture, it is the plastic polymers and more specifically poliethylene, polypropylene or polystyrene that offer the best physical, mechanical and chemical properties [16].
However, the density of polystyrene is higher than that of water, so it does not float, and it has less thermal stability and less resistance to chemical products than the other materials so it was rejected for the new designs.
There are different varieties of polyethylene according to its density (low, medium, high and ultra-high). Both high and ultra-high have similar densities to that of water, but the second one is more expensive and more difficult to process due its rigidness.
On the other hand the high density polyethylene is extremely resistant to corrosion but polypropylene, despite having a lower density, is the most rigid of the polyolefinic polymers and maintains the shape of the carrier with temperatures over 100ºC so it should be the material chosen.
One of the requisites established when setting out to design new carriers is the production cost. This parameter depends, amongst other factors, on:

- The model complexity. A complex design complicates the manufacturing process and therefore raises the production costs.
- The number of elements/m3 that determines the production cost in €/m3.
- The filling ratio or the space that the carries can occupy.

A high value in the number of elements/m3 means high production cost, while a major value of the filling ratio represents a major number of carriers in the same volume and then a major treatment capacity [7].

3. Development of new designs

According to the previous study, the new designs should have simple shapes, good hydrodynamic properties and they should preferably be manufactured using injection molding although the extrusion manufacturing can be observed. The main properties are shown in the table 1. These values are the result of the analysis of commercial carriers with the best hydrodynamic properties [12, 13].
At the end of the development process, six models have been obtained which fulfill the conditions established (Table 1).

Property	Value
Density	≈ water
Area-volume ratio	> 700 m2/m3
Percentage of cavities	> 70%
Passage diameter	> 2.5 mm
Elements/m3	High
Filling ratio	High
Material	Polypropylene

Table 1. Values to achieve with the new designs.

In the process we define a cylindrical shape with an parametric thick wall, then added the fins and inner walls. The parameters of design that define to each new model (Table 2) were optimized using the *SolidWorks* software.

Model	Dimensions (mm)	Elements/m3	Filling ratio
A	h = 8.0 r = 4.5 x = 1.0	1075.00	83.20
B	h = 4.2 r = 4.0	942.80	57.10
C	h = 9.0 r = 6.6	1177.49	74.00
D	h = 9.0 r = 7.5 r’ = 4.0	495.50	85.00
E	h = 9.0 r = 1.7	967.03	89.00
F	r = 1.5 r’ = 4.0	1998.00	98.80

Table 2. Design parameters and values of the geometric properties over the six initial models.

In all of them the nomenclature followed is:

e = thickness of the external walls in mm. Default value: 0.50 mm.
e’ = thickness of the internal walls in mm. Default value: 0.30 mm.
r = radii in mm.
r’ = radii in mm.
h = height of the model in mm.
x = longitudinal distance in mm.

Model A (Figure 1). It is a cylinder in which the centres of the circumference arcs are displaced along the radii of the quadrants by the distance x. It has four central fins that increase the treatment surface.

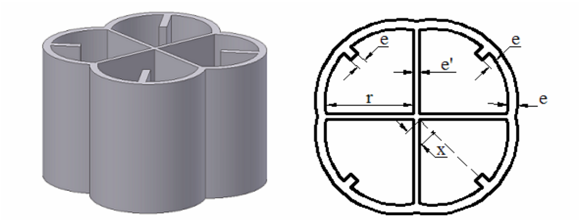

Figure 1

Model B (Figure 2). The cylinder has a horizontal dividing plaque of 0.5 mm with a view to obtaining a larger surface on which the microorganisms can be fixed. The idea is to create “recipients” full of bacteria, where maximum use is made of the surface area of the cylinder and interpenetration of the elements is avoided. It is important to point out that in this model the height of the cylinder cannot be too great to avoid blocking the recipients (Table 2).

Finally, the model has a wedge-shaped elevation on its central fins to prevent the elements from possibly becoming packed together.

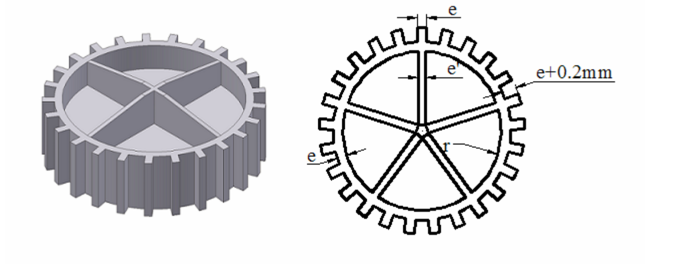

Figure 2.

Model C (Figure 3). In this case the cylinder has a triangular prism inside it.

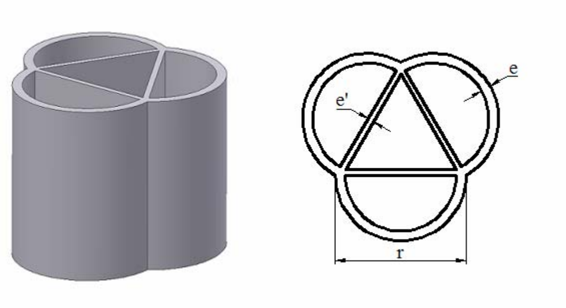

Figure 3.

Model D (Figure 4). It is made up of two concentric cylinders joined together by means of fins.

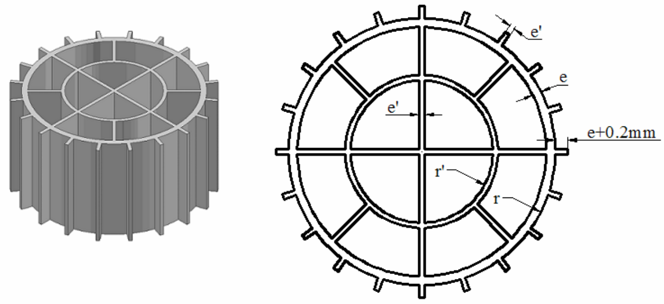

Figure 4

Model E (Figure 5). It has an internal cylinder enclosed with six cylinders with the same radii, r. Internal fins have been coupled in an attempt to increase the internal surface area.

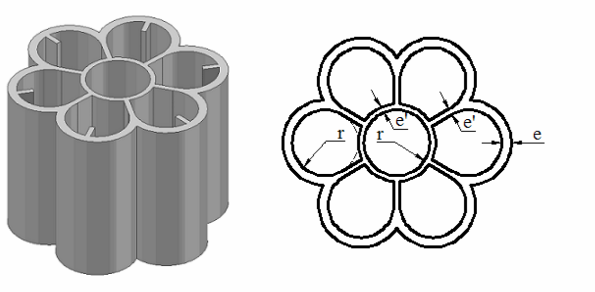

Figure 5

Model F (Figure 6). It is an internal cylinder with three helixes 120º out of phase with respect to each other. This model is the most novel alternative with the only drawback that the elements may interpenetrate, but this problem can be easily solved by varying the pitch of the elements. In this case, the manufacturing process would be by extrusion.

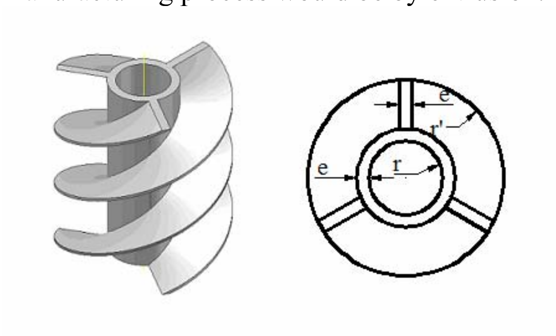

Figure 6

Model	A/V Ratio (m2/m3)	Passage diameter (mm)	% Cavities (%)
A	834.84	2.65	73.00
B	942.87	4.79	70.03
C	842.36	2.65	70.00
D	928.80	2.70	76.45
E	845.75	3.40	71.22
F	947.37	2.60	88.17

Table 3

The results obtained are showed in the table 3. There, it can be seen that the greatest A/V ratio is found in models B, D and F whilst the greatest percentage of cavities is found in models A, D and F. In relation to the passage diameter, there are two models with values far above: model B with 4.79 mm and model E with 3.4 mm, but this one has not good results in the rest of the parameters and produces accumulations of material along the intersections between the arcs which cannot be detached by contact with other elements. So from a geometric point of view, the models which could be manufactured are F, D and B, which have a greater passage diameter than A.

On the other hand the model D with eight central walls, four of which do not cross the whole cylinder, has a very complicated production. That increases the costs to levels far above those of other models. In this case, two models B and F offer the best characteristics for manufacture and use, although the comparison of the elements/m3 of the selected model, shows that model B has a lower production cost than F, but a minor filling ratio.

With the end of choosing the best carrier between these two models B and F, they were tested in a little reactor built for the project. The main elements of the reactor are:

- A methacrylate tank divided into two parts with a view to carrying out comparative tests in identical conditions on the designed carrier and a commercial carrier [14]. The tests are carried out with the vessels 40% full and the total volume of each vessel is 29 l (Figure 7).

Figure 7

- Two pipes connected to the tank collect the purified water and take it to a tank.
- A 0.5 CV pneumatic pump supplies the oxygen needed by the microorganisms injecting air in the form of bubbles from the bottom of the reactor.
- A water tank with a capacity of 1000 l contains the wastewater which proceeds from the biological treatment inlet of a water-treatment plant in Asturias (Spain), and is propelled with the aid of a peristaltic pump at 15 rpm in order to guarantee that the water will remain in the reactor for 8 hours (Figure 8).

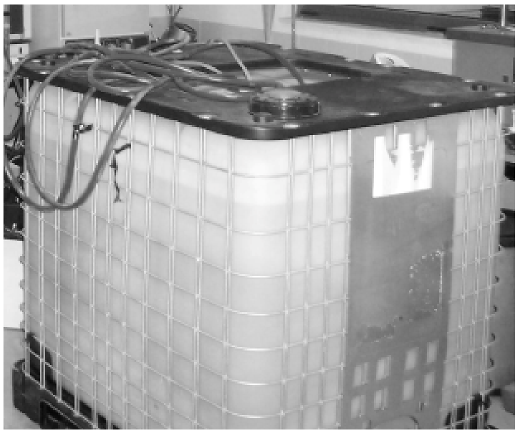

Figure 8

It was necessary to control several parameters that affect the growth of microorganism. These parameters are:

- The biofilm incubation time. About three days on laboratory.
- The system plugging.
- The high concentration of dissolved oxygen.
- The removal of the mud. In this case there was not much mud produced.

In any case, a good movement of the fluid and a high concentration of dissolved oxygen delay the plugging

of the system and increase the growth of the microorganisms.
The tests were carried out for seven months [15]. Each month the wastewater was collected in the water-treatment plant and carried to the laboratory. The tests were carried out during the first twenty days of the month, due to the fact that in the last ten days there were not significant differences in the results. The parameters analyzed are:

- Hydrodynamic behavior
- Total Suspended Solids
- Biochemical Oxygen Demand
- Chemical Oxygen Demand

Hydrodynamic behavior. Both carriers (model B and F) had the same behavior at the beginning of the tests. Once the new wastewater arrived at the laboratory and the methacrylate tank was filled, the carriers drew together in the upper part of the reactor. After 24 hours the carrier F began to move in an adequately way, whilst carrier B needed 96 hours.
To study this factor, samples of the carriers were taken from the tank every day and weighted. It was noticed that the density of the carriers changed with time due to the adherence of the biofilm to the surface of the carriers. In the model F, the change of the density was faster than over B, speeding up the movement of the carriers.
Total Suspended Solids (TSS). This value reflects the amount of solids maintained in suspension in the water. This test was done daily with two filters of microfiber glass according to the standard UNE-EN 872 [16]. However the wastewater had not enough suspended solids to draw conclusions.
Biochemical Oxygen Demand (BOD). This value refers to the amount of oxygen used by the respiratory activity of the microorganisms. In this case a major decrease in this value respect to the initial one in the wastewater means a minor activity of the microorganisms, that is the water is cleaner.
The test was made twice daily, with a portable oxymeter and the results of each month are transformed into a percentage of efficiency [20]. The two carriers have an average of efficiency superior than the commercial carrier, 8% and 12% for the carrier B and the carrier F respectively.
Although the two carriers have a good behavior, the carrier B needs a longer period of adaptation, because the first week of the test the efficiency is lower than the commercial carrier and then this one increases, leading to an average of higher efficiency than the commercial carrier gets.
Chemical Oxygen Demand (COD) refers the quantity of oxygen necessary to oxidize all the oxidizable material, both organic and mineral. In this case, a major value of COD means dirtier water. This test was made daily with a molecular absorption photometer according to the standard ISO 15705 [17] and the values were written and represented on graphs as the figure 9 and 10 that represent the results obtained in the fourth month.

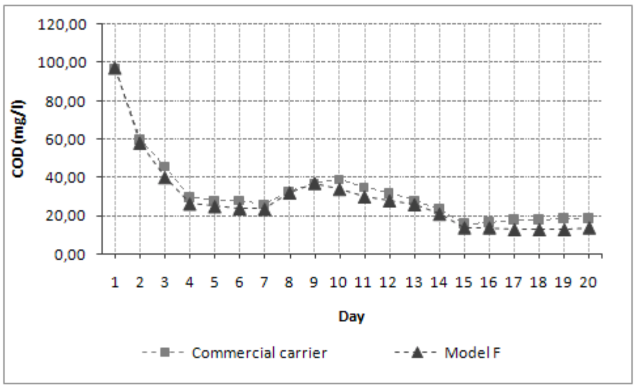

Figure 9

In the figure 9 the two carries, the commercial one and the carrier F, have identical behavior. There is an adaptation period with a strong decrease in the value of the COD and then a stability period followed by a light increase of the COD and a very soft decrease which is maintained in time, so in the figures only sixteen days have been drawn. Although they have the same behavior, the commercial carrier has always higher values in COD than the carrier F, and the wastewater has the highest values. So the carrier F has a better capacity of cleaning than the commercial carrier.
On the other hand, the carrier B has not good results for the COD, because of after four days, its behavior is worse than that of the commercial carrier (Figure 10).

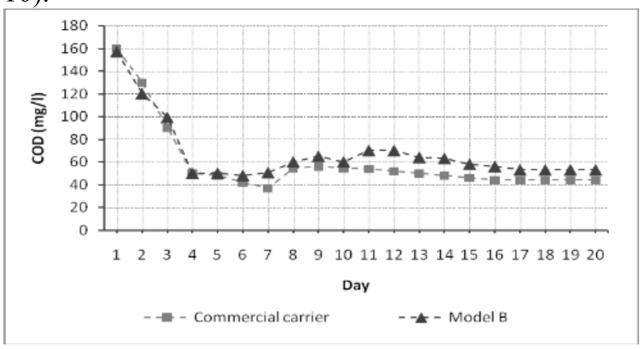

Figure 10

When the results are transformed into a percentage of efficiency, carrier F shows values of between 30 and 50%, which are very similar to the results shown by the reference carrier. On the other hand, model B shows values 15% lower than the commercial model, so carrier B is not a viable model according to this parameter.
The results of the test shows that model F is a carrier with good geometric properties, not very high production costs and a slightly superior efficiency than the commercial carriers. Besides the carrier F

represents a new and completely diverse family of plastic elements for the adherence of bacteria, with nothing at all in common with existing models. It is totally innovative.

Conclusions

In the carrier design process, we follow a standard methodology. Initially, a product design specification (PDS) was been established with the client requirements, and with the result of the study of the state of art. The selection of the possible geometric body was made in benchmarking meetings with Technical Drawing and Mathematic university lecturers. We use a·3D parametric CAD to evaluate the characteristics of proposed geometrics. Six geometrics were selected and studied their characteristics. Two models were then selected in terms of manufacturing difficulty and their mobility within the tank. These models were later manufactured and went into operation in a prototype plant, with slightly higher results than that of existing commercial models, and the addition of a lower production cost..

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