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Use of Dehydrated Peeled Fruit of *Luffa Cyllindrica* as Support Medium in Trickling Filters: Analysis of Its Performance Regarding the Reduction of the Organic Content and Microbiologic Considerations

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Use of Dehydrated Peeled Fruit of *Luffa Cyllindrica* as Support Medium in Trickling Filters: Analysis of Its Performance Regarding the Reduction of the Organic Content and Microbiologic Considerations

Marcos R. Vianna[α], Gilberto C. B. De Melo[σ] & Márcio R. V. Neto[ρ]

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Keywords: trickling filters; microbiology of trickling filters; luffa cyllindrica; biofilms; alternative support media; wastewater treatment.

I. Introduction

A trickling filter, whose typical configuration is shown in figure 1, is an aerobic process for wastewater treatment that is simple to build and to operate. It is used for the treatment of domestic and industrial effluents. Its operation consists in passing the liquid effluent through a support media. A biologic film develops over the surface of the medium. The biologic activity developed on this film will be responsible for the stabilization of the organic content of the effluent. It is distributed by means of a rotative arm, over the support media. The bio film remains part of the time in contact with the effluent and part of the time exposed to the atmosphere and, in this way, to the oxygen of the air.

According to Matasci et al (1988), this treatment process was largely used in the United States, but has declined because of the increasing legal exigencies in that country regarding the organic content in the treated effluent. In Brazil as in many other developing countries, in which the lack of domestic wastewater treatment plants is still a problem, trickling filters can be an adequate solution, especially for small communities.

The degree of stabilization achieved depends on many factors, such as: volumetric and organic loading, kind of support medium, temperature, ventilation, among others, but it hardly achieves values beyond 85% in terms of $BOD_{5,20}$ removal, according to WEF & ASCE (1992). The higher the desired removal efficiency, the higher will be the necessary sophistication and complexity of the facility.

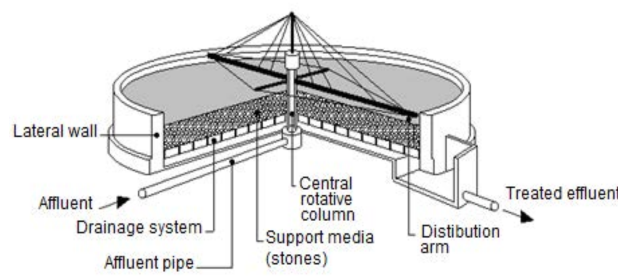

Figure 1: Typical trickling filter. Figure adapted from Jordão and Pessoa (2009).

Regaring the support medium, the greater the offered specific surface, the greater will be its efficiency. With this purpose, pieces of coking coal, which presents a porous nature, are used in some installations, as well as plastic media especially developed for this purpose.

The use of of *Luffa cyllindrica* was the poposed innovation of this study. This plant – see figure 2 – can be found all over the Brazilian territory. Its dehydrated peeled fruit is commonly used as natural sponge for bathing and cleansing, for handicraft activities, in pharmacology and in some industries. It is characterized by a very fibrous structure, which offers a great surface for biological film fixation, with very small specific gravity, and when dehydrated it degrades very slowly, because of its natural function of keeping the seeds for plant propagation. For that reason, it was

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devised that it could be used to perform this extra function as a medium in trickling filters.

(a) Plant and flower

(b) Dehydrated peeled fruit

Figure 2 : *Luffa cyllindrica* (a) plant and flower; (b) traditional dehydratedPeeled fruit, according to<http://cucurbitaceae. livejournal.com/7702.html?Thread =19222 > (accessed in 16/04/2014).

Studies concerning the use of *Luffa cyllindrica* for wastewater treatment are few, and specifically as biofilm supporting medium in trickling filters are unknown. In Brazil, Agra (2009) studied its use as substrate in continuous submerged attached growth pilot bioreactors. The results obtained showed that these reactors were efficient for carbonaceous matter stabilization and in the nitrification process. Sousa *et al.* (2008) studied its use for the immobilization of nitrifying bacteria in a laboratory-scale submerged attached growth bioreactor for polishing the effluent of an UASB reactor treating domestic wastewater. In Mexico, Ruiz-Marin *et al.* (2009) compared results obtained in semi-continuous reactors using *Luffa cyllindrica* and PVC support medium. Artificial wastewater was used in the study, and higher percent phosphorus removals were obtained in *Luffa cyllindrica* reactors. The use of the plant for the treatment of nondomestic effluents is also reported. In Brazil, Oliveira (2007) studied its use for metallic ions and dyes removal in textile industries effluents. In Algeria, Laidani *et al.* (2010) studied copper adsorption by *Luffa cyllindrica* fibers. In Nigeria, Oboh *et al.* (2011) studied the use of this material as a biosorbent for removal of divalent metals from aqueous solutions.

When considering the microbioloby of the trickling filters, the studies are insuficient. Regading to trickling filters in which *Luffa cyllindrica* is used as support medium, these studies do not exist.

Branco (1978) describes the composition of the biologically active film which covers each one of the stones in the upper layer of a trickling filter as follows, see figure 3.

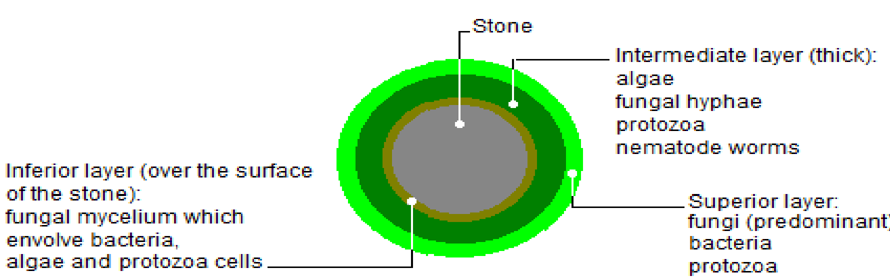

Figure 3 : Composition of the biofilm on a trickling filter support medium, as described by Branco, 1976.

- ✓ *Superior layer:* predominance of fungii; bacteria; protozoa;
- ✓ *Intermediate layer (thick):* algae, filamentous or not (only in the stones hit by sunlight); fungal hyphae; protozoa; nematode worms;
- ✓ *Inferior layer (over the surface of the stone):* fungal mycelium which envolve bactéria, algae and protozoa cells.

The main objective of this experimental work was to assess the behaviour and capability of the peeled dehydrated fruit of *Luffa cyllindrica* to act as a bio film support medium in trickling filters, for stabilization of the organic matter of domestic sewage. For this purpose, traditionally used parameters in the evaluation of sewage treatment were measured - Biochemical Oxygen Demand ($BOD_{5,20}$), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Settle able Solids (Set S) – in the affluent and effluent of trickling columns filled with this material, and the results were compared to others obtained from a similar trickling column filled with stones. Besides, taking into account that studies concerning the microbiology of these filters could not be found, it has tried to determine, in a preliminary and rough way, the main biologic composition of the bio films developed over the *Luffa cyllinrica* and rocks medium.

II. Experimental Work

The experimental work was conducted in a pilot scale treatment plant constructed according to the description that follows (Fig. 4). Raw sewage stream was taken from a domestic sewage sewer of the city of Belo Horizonte, and continually pumped to an inlet chamber which functioned as a grit chamber. Within this unit the effluent was also screened and, after that, homogenized in the chamber by means of a mechanical mixer.

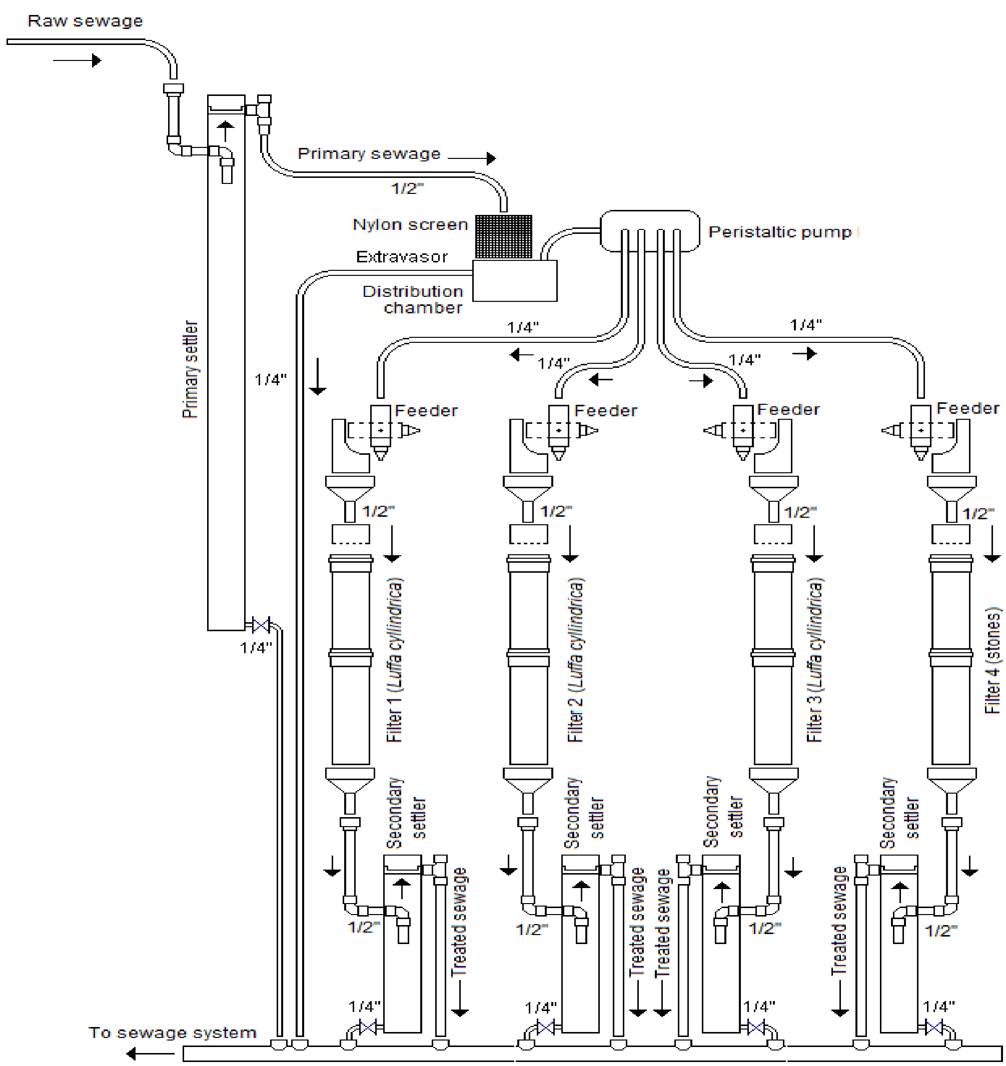

Figure 4 : General arrangement of the pilot plant, consisting of a primary settler, and four parallel and identical secondary biologic systems, three of them operating with *Luffa cyllindrica* as biofilm support medium (F1, F2, F3), and the last one using stones (filter 4).

The experimental treatment process commences after this tank. Free from grit and coarse material previously screened, sewage was conducted to the primary settler through a plastic flexible hosepipe. A fine screen made of nylon (similar to those used in windows to stop mosquitoes) was placed before the hose inlet to avoid clogging.

After primary settling, sewage (now primary sewage) was conducted to a distributing chamber, where another nylon screen was installed. This chamber was fed with a flow that was greater than the distributed outflow, therefore its excess was discharged. From this chamber, sewage was distributed and sent to each parallel filter through peristaltic pumps, responsible for the maintenance of a constant flow.

Before reaching the filter, the flow passed through a feeder which converted the continuous flow in pulse hydraulic charges, to simulate what occurs in real trickling filters, which are fed by rotary arms. The hydraulic charge was distributed over the filter surface through a perforated plate installed 20 cm over it.

Each pilot plant was constituted by a 200 mm plastic PVC sewer type pipe. Its interior was filled initially with the supporting medium: peeled and dehydrated Luffa cyllindrica fruits in three of them and 25 mm diameter stones in the fourth. The fruits were initially installed in vertical position. Along the experiment they were cut in sizes that allowed their random disposition inside the columns. No effect was observed because of this change.

The treated sewage after each filter was conducted to secondary settlers and, after that, to the drainage of the laboratory. Considering the average flow sent to each trickling column, equals to 2 mL/s, the hydraulic loading rate was 5,5 $m^3.m^{-2}.day^{-1}$. According to WEF & ASCE (1992), this value can be classified as intermediate rate, which ranges from 0,935 $m^3.m^{-2}.day^{-1}$1 to 37, 41 $m^3.m^{-2}.day^{-1}$. Raw and treated sewage samples were collected regularly and analysed in the laboratory of the Environmental and Sanitary Engineering Department of the School of Engineering of UFMG (Table 1).

III. Results

a) Raw sewage charactheristics

Figure 5 represents graphically the obtained results for BOD, COD and TSS, expressed in mg/L. SetS results are expressed in mL/L, so they are not represented in the graphic. Results obtained for these four parameters will be detailed in the following items.

Table 1: Physical, physicochemical and chemical analyses, procedures used and frequency. All analyses were performed as stated by the Standard Methods for the Examination of Water and Wastewater - APHA, AWWA, WEF (1995)

Analysis	Methodology	Frequency
Total suspended solids (TSS)	Gravimetric method	Twice a week
Settleable solids (SetS)	Imhoff cone method	Twice a week
Chemical Oxygen Demand (COD)	Closed flux –Titulometric method	Twice a week
Biochemical Oxygen Demand(BOD5,20)	Iodometric method	Once a week

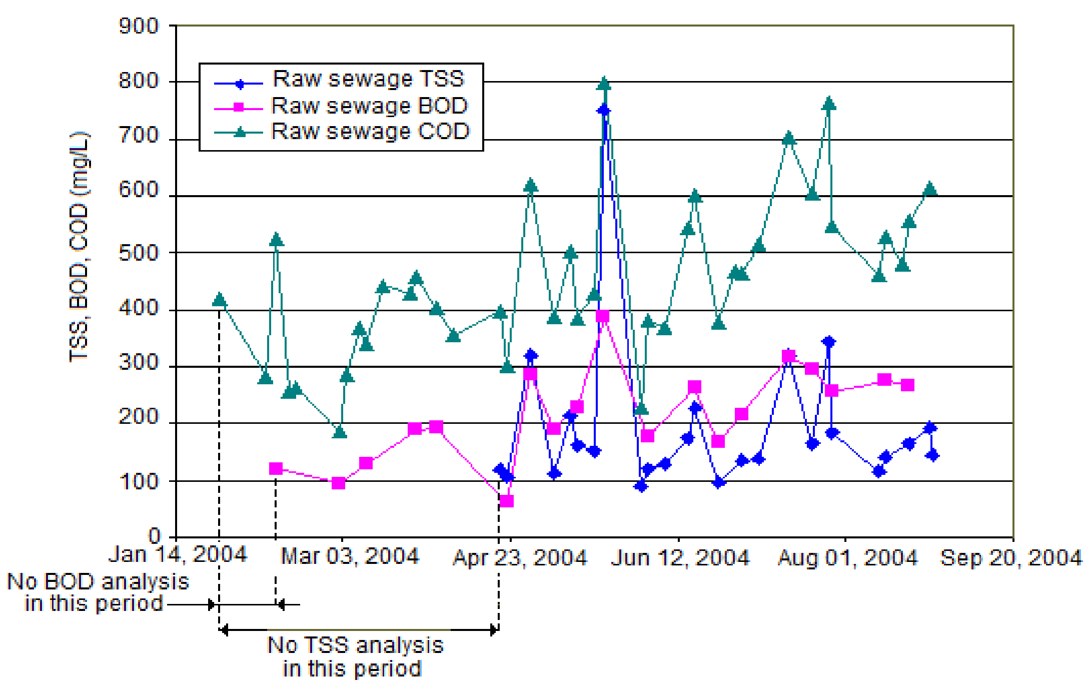

Figure 5 : Temporal series of BOD, COD e TSS contents of the raw sewage.

b) Biochemical oxygen demand ($BOD_{5,20}$)

Varied between 61 and 387 mg.L^{-1}. The average was 216 mg.L^{-1}. After the primary settler it has shown values varying between 61 and 282 mg. L^{-1}. The average for all values was 177 mg. L^{-1}. Percent removal in the primary settler was 18%.

c) Chemical oxygen demand (COD)

Varied between 185 and 601 mg.L^{-1}. The average was 451 mg. L^{-1}. After the primary settler it has shown values varying between 168 and 598 mg. L^{-1}. The average for all values was 390 mg. L^{-1}. Percent removal in the primary settler was 14%.

d) Total suspended solids (TSS)

Results were obtained between April 20 2004 and August 27, 2004 and varied between 90 and 752 mg. L^{-1}. The average was 193 mg. L^{-1}. After the primary Settler it was 141 mg. L^{-1}.

e) Settable solids (SetS)

Varied between 0, 10 and 11 mg.L^{-1}. The average was 2, 22 mg. L^{-1}. After the primary settler it was 0, 80 mg. L^{-1}.

IV. Performance of the Filters with Respect to Organic Load Reduction

Although the following items contemplate only the $BOD_{5,\ 20}$ and COD reduction obtained in he experimental work, the variations in the concentrations of total suspended solids and settleable solids were also determined. Also, the $BOD_{5,\ 20}$ removal efficiency was compared to the efficiencies predicted by some classic formulas used for trickling filters design. These additional data can be found in Vianna (2012).

a) $BOD_{5,20}$ removal

Results obtained upstream the secondary settler are shown in Figure 6 and Figure 7 shows the statistical analysis and the corresponding box-whisker graphics. The average value downstream the *Luffa cyllindrica* filters was 58 mg.L^{-1}, while the average value downstream the filter filled with stones was 79 mg.L^{-1}.

Results obtained downstream the secondary settler are shown in Figure 8 and Figure 9 shows the statistical analysis and the corresponding box-whisker graphics. The average value downstream the secondary settlers after the *Luffa cyllindrica* filters was 43 mg/L, while the average value downstream the secondary settlers after the filter filled with stones was 57 mg.L^{-1}.

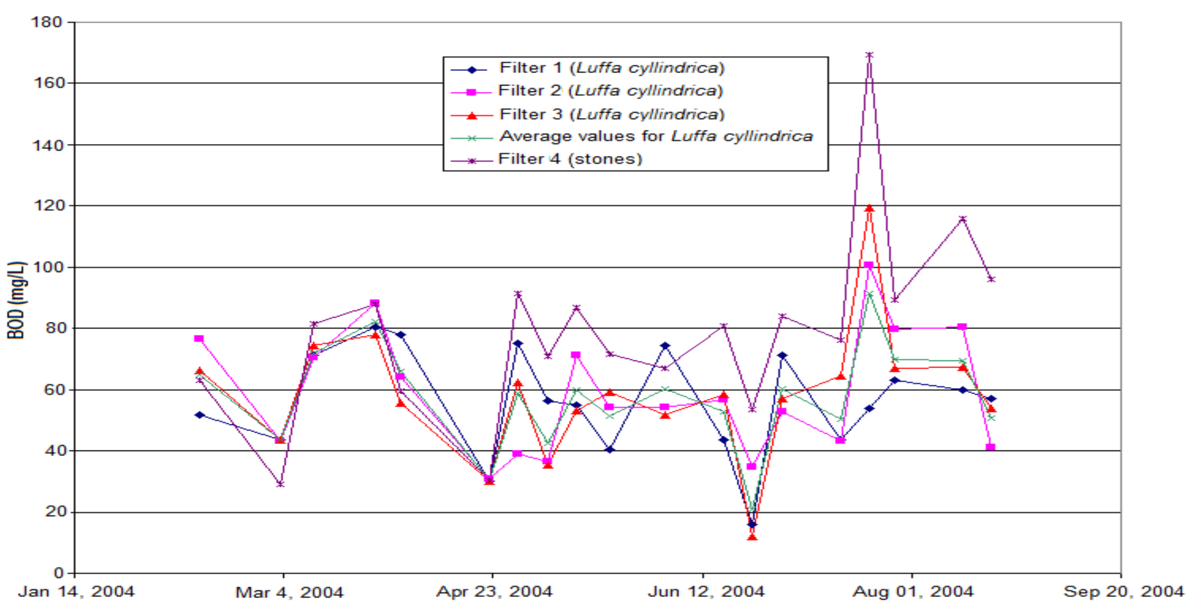

Figure 6 : Biochemical oxygen demand ($BOD_{5,\ 20}$) downstream the trickling filters filled with *Luffa cyllindrica* (F1, F2, F3 and average value) and downstream the filter filled with stones (upstream the secondary settlers): temporal series.

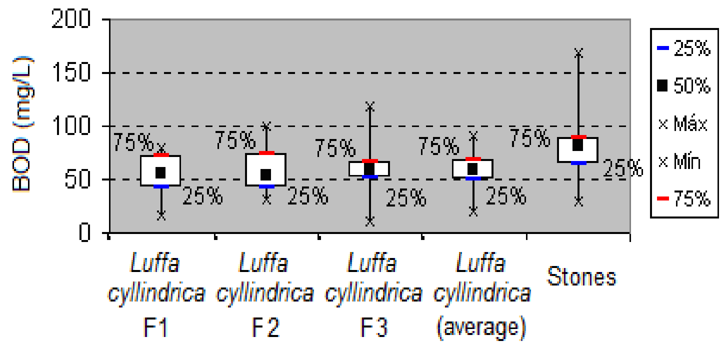

Figure 7 : Box-whisker graphics for biochemical oxygen demand ($BOD_{5,20}$) downstream the filters filled with *Luffa cyllindrica* (F1, F2, F3 and average value) and downstream the filter filled with stones (upstream the secondary settlers).

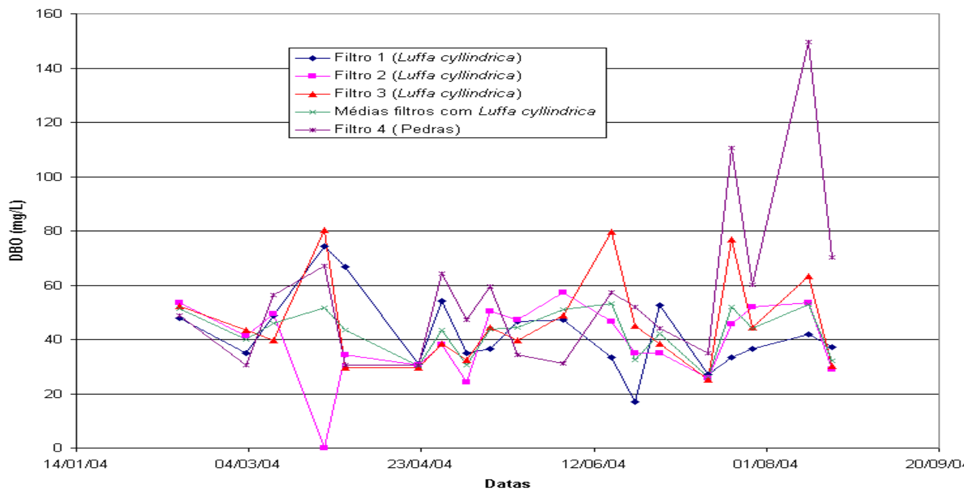

Figure 8 : Biochemical oxygen demand ($BOD_{5,20}$) downstream the trickling filters filled with *Luffa cyllindrica* (F1, F2, F3 and average value) and downstream the filter filled with stones (downstream the secondary settlers): temporal series.

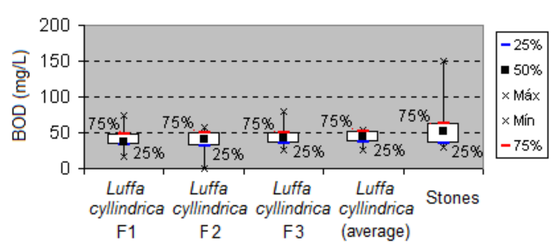

Figure 9 : Box-whisker graphics for biochemical oxygen demand ($BOD_{5,20}$) downstream the filters filled with *Luffa cyllindrica* (F1, F2, F3 and average value) and downstream the filter filled with stones (downstream the secondary) settlers

b) COD remotion

Results are shown in Figure 10 and Figure 11 shows the statistical analysis and the corresponding box-whisker graphics. The average value downstream the *Luffa cyllindrica* filters was 183 mg/L, while the average value downstream the filter filled with stones was 209 mg/L.

Results obtained downstream the secondary settler are shown in Figure 12 and Figure 13 shows the statistical analysis and the corresponding box-whisker graphics. The average value downstream the secondary settlers after the *Luffa cyllindrica* filters was 154 mg/L, while the average value downstream the secondary settlers after the filter filled with stones was 166 mg/L.

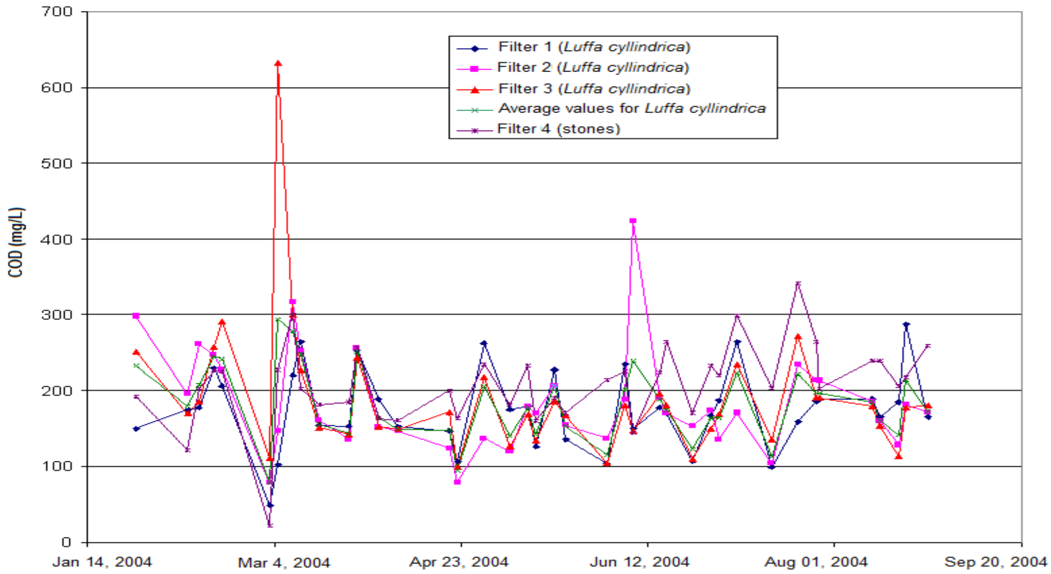

Figure 8 : Chemical oxygen demand (COD) downstream the trickling filters filled with *Luffa cyllindrica* and downstream the filter filled with stones (upstream the secondary settlers): temporal series.

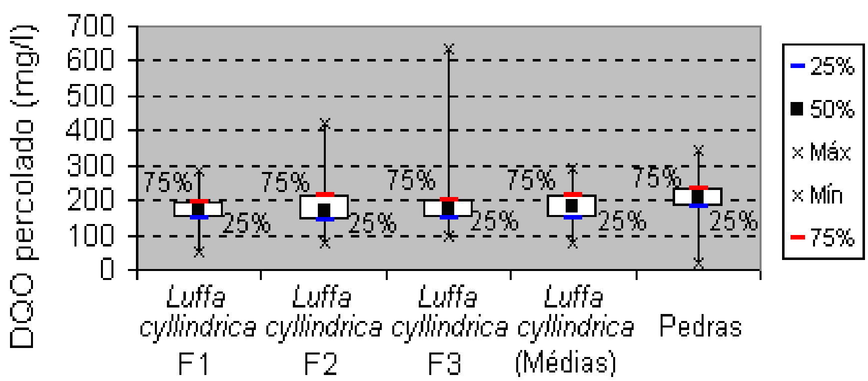

Figure 9 : Box-whisker graphics for chemical oxygen demand (COD) downstream the filters filled with *Luffa cyllindrica* (F1, F2, F3 and average value) and downstream the filter filled with stones (upstream the secondary settlers).

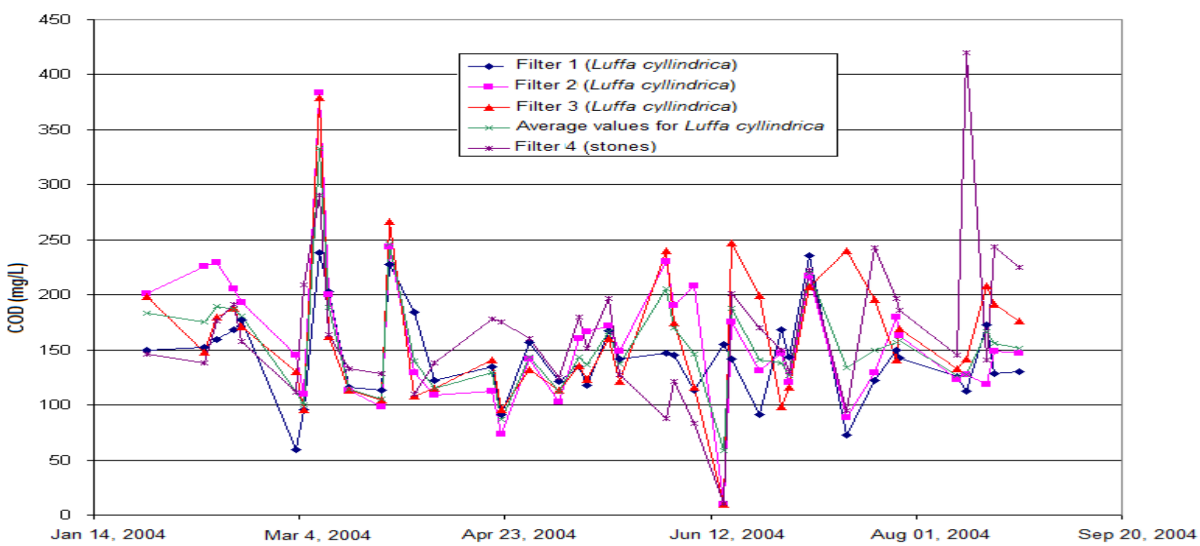

Figure 10 : Chemical oxygen demand (COD) downstream the trickling filters filled with *Luffa cyllindrica* and downstream the filter filled with stones (downstream the secondary settlers): temporal series.

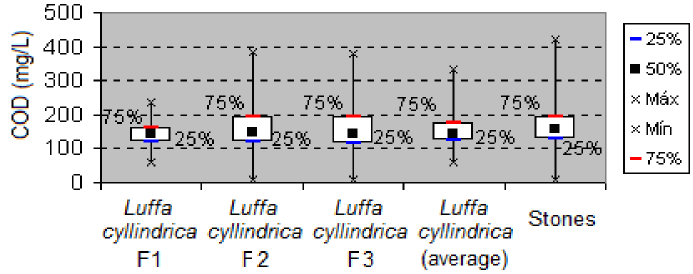

Figure 11 : Box-whisker graphics for chemical oxygen demand (COD) downstream the filters filled with Luffa cyllindrica (F1, F2, F3 and average value) and downstream the filter filled with stones (upstream the secondary settlers).

V. Microbiological Aspects of the Support Medium

Samples of the biomass laying inside the *Luffa cyllindrica* and stone filters were collected and submited to microscopic analysis. Only the first 5 cm depth of the medium surface were investigated. The samples were sent to the hidrobiology laboratory and examined in their qualitative aspects.

a) Luffa cyllindrica support medium

There were found bacteria (figure 12), fungi (figure 13), stalked ciliates (figure 14) and free-living nematodes (figure 15).

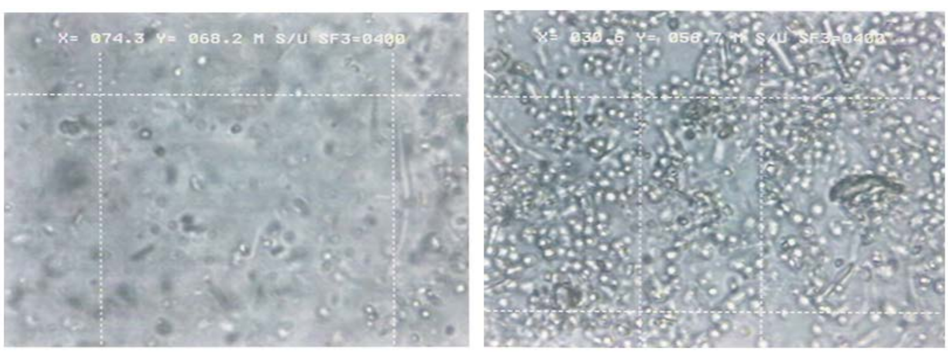

Figure 12 : Biomass found in *Luffa cyllindrica* biomass: bacteria.

Figure 13 : Biomass found in *Luffa cyllindrica* biomass: fungi of the genus Geotrichum

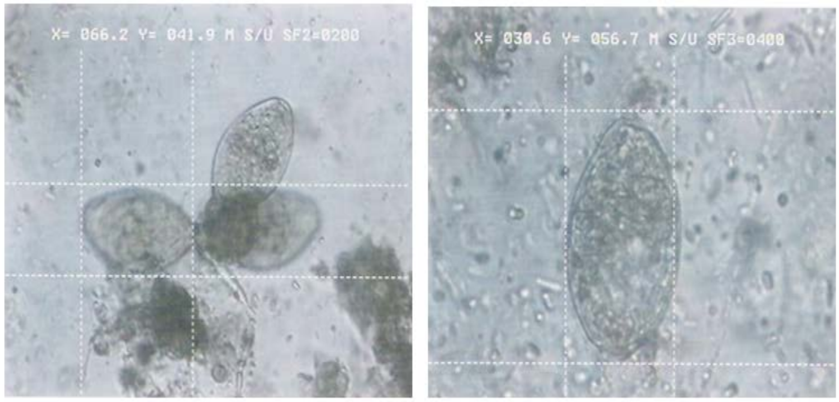

Figure 14 : Biomass found in *Luffa cyllindrica* media: fixed or stalked ciliates (left) and stalked without stalk (right).

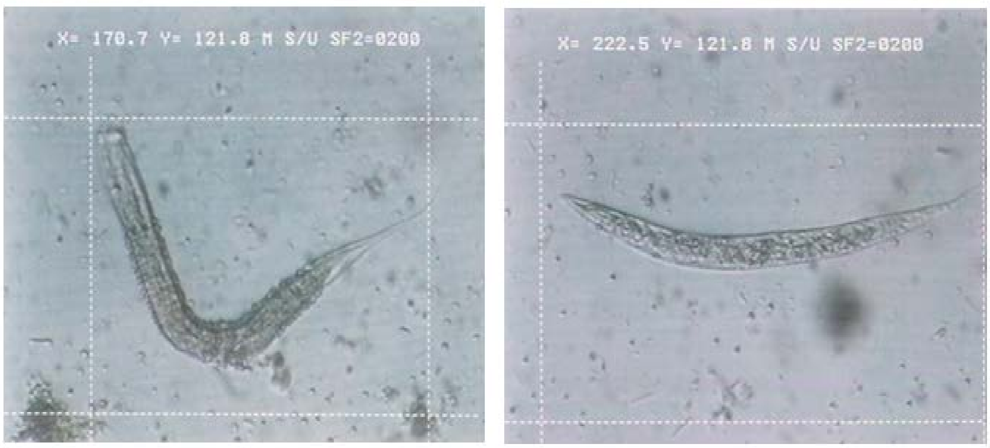

Figure 15 : Biomass found in *Luffa cyllindrica* media: nematode

b) Stones support media

In this support media only bacteria (figure 19) and fungi (figure 20) were found.

Figure 19 : Biomass found in stones media: bacteria *Sphaerotilus natans*.

Figure 20 : Biomass found in stones media: fungos *(Leptomitus)*

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VI. Discussion

a) Raw sewage characteristics

From the exposed before and considering the average results, the raw sewage concentration could be classified as medium, see table 2.

Table 2 : Typical composition of domestic sewages, according to Metcalf & Eddy (2003), compared to values obtained in the experimental results

Parameter	Values of literature			Results from the experiment
	Strong	Medium	Weak	
Total suspended solids – TSS ($mg.L^{-1}$)	350	200	100	193
Settleable solids– SetS ($mL.L^{-1}$)	20	10	5	2.22
Biochemical oxygen demand – $BOD_{5,20}$ ($mg.L^{-1}$)	300	200	100	216
Chemical oxygen demand – COD ($mg.L^{-1}$)	1000	500	250	451
: Note: The following relationships can be obtained from values above:				
COD/BOD ratio	3,3	2,5	2,5	2,1
Relação TSS/BOD ratio	1,17	1	1	0.9

Lower values obtained for BOD, COD and TSS occurred in the rainy period of the year, while higher values occurred in the dry period, thus reflecting the infiltration of storm water in the sanitary sewers.

On the other hand, lower values obtained for SetS occurred in the dry period of the year, while higher values occurred in the rainy period. It is interesting to observe the inverse tendency of this parameter when compared to the others. Settleable solids were higher when sewage was diluted, probably because of the entrance of inert material brought by storm water that entered into the sewer system, whereas the other parameters representing the organic

b) Performance of the filters with respect to solids and organic load reduction

It is important to note that during the essays it was observed that the fibrous structure of the dehydrated fruits lost volume continuously, and the height of the filter medium decreased steadily, and it was necessary to restore the filter medium every month by adding fresh peeled fruits in the upper part of the reactor, to restore the original height. In spite of the thickening of the structure, no loss of efficiency of the process was observed.

c) Biochemical oxygen demand ($BOD_{5,20}$)

The average percentage removal efficiencies of the filters relative to the primary sewer obtained along the whole observation period were:

$$\text{Filters filled with } \textit{Luffa cyllindrica}: \left(100\frac{177-58}{177}\right)\% = 67\%$$

$$\text{Filter filled with stones: } \left(100\frac{177-79}{177}\right)\% = 55\%$$

When the results downstream the secondary settlers are considered, the average removal efficiencies relative to the primary sewer along the whole observation period were:

$$\text{Filters filled with } \textit{Luffa cyllindrica} \text{ followed by secondary settlers: } \left(100\frac{177-43}{177}\right)\% = 76\%$$

$$\text{Filter filled with stones followed by secondary settlers: } \left(100\frac{177-57}{177}\right)\% = 68\%$$

When the whole system is considered, from the raw sewage until the exit of the secondary settler, the average removal efficiencies along the observation period were:

$$\text{Filters filled with } \textit{Luffa cyllindrica} \text{ followed by secondary settlers: } \left(100\frac{216-43}{216}\right)\% = 80\%$$

$$\text{Filter filled with stones followed by secondary settlers: } \left(100\frac{216-57}{216}\right)\% = 74\%$$

d) Chemical oxygen demand (COD)

The average of chemical oxygen demand (COD) percentage removal efficiencies of the filters relative to primary sewer along the whole observation period were:

$$\text{Filters filled with } \textit{Luffa cyllindrica}: \left(100\frac{390-183}{390}\right)\% = 53\%$$

$$\text{Filter filled with stones: } \left(100\frac{390-209}{390}\right)\% = 46\%$$

When the results downstream the secondary settlers are considered, the average removal efficiencies relative to primary sewer obtained along the whole observation period were:

$$\text{Filters filled with } \textit{Luffa cyllindrica} \text{ followed by secondary settlers: } \left(100\frac{390-154}{390}\right)\% = 61\%$$

$$\text{Filters filled with stones followed by secondary settlers: } \left(100\frac{390-166}{390}\right)\% = 57\%$$

When the whole system is considered, from the raw sewage until the exit of the secondary settler, the average removal efficiencies along the observation period were:

$$\text{Filters filled with } \textit{Luffa cyllindrica} \text{ followed by secondary settlers: } \left(100\frac{451-154}{451}\right)\% = 66\%$$

$$\text{Filter filled with stones followed by secondary settlers: } \left(100\frac{451-166}{451}\right)\% = 63\%$$

VII. Microbiologic Considerations

a) Luffa cyllindrica support medium

There were found more species in *Luffa cyllindrica* than in stones media, which can be indicative that the degree of stabilization of the organic matter in more evoluted in the first one. As described, not only bactéria and fungi were found: also stalked ciliates and free-living nematodes were present. The presence of these representatives of the animal kingdom, not presente in the samples collected in the biomass encountered in the stones media, seems to show that there is a greater complexity of the food chain and, thus, a more advanced stage. This can probably explain the greater degree of the organic content stabilization obtained in this support media.

Bacteria population, which species were not identified in this work (exception for *Sphaerotilus natans*), are obligatory presence in media where organic stabilization occours. The same is valid for fungi, noting that the genus gênero *Geotrichum* can be found both in soils and sewage (ROSE & HARRISON, 1987). Regarding to the stalk ciliates, whih genus was not identified, their presence was expected n the superficial layers of the trickling filters, as afirmed by Branco (1978). This auhor also states that the presence of worms, such as nematodes, would be expected, as confirmed in this work.

b) Stones support media

In opposition to what eas described above, in this support media there was not found great diversity of species. As described, oly bacteria and fungi were observed, which can indicate lower complexity of the food chain and therefore a less evoluted stage when compared to what happened in *Luffa cyllindrica* media. The less elevated degree of stabilization of the organic content observed in the stones media seems t comprove this hypothesis.

VIII. Conclusion

The study showed that, for specific conditions, the peeled dehydrated fruit of *Luffa cyllindrica* can be used as support medium in trickling filters.

A comparison between the results obtained for the studied parameters and the values allowed by COPAM – the environmental agency of Minas Gerais State, Brazil (MINAS GERAIS, 2008) is presented below. It shows that trickling filters that use *Luffa cyllindrica* as support media can be a suitable and sustainable alternative for domestic sewage treatment in this state.

- ✓ The average value allowable for biochemichal oxygen demand ($BOD_{5,\ 20)}$) in liquid effluents is 60 mg/L. The average value in the treated sewage downstream the *Luffa cyllindrica* systems was 43 mg. L^{-1}. It is also lower than the value obtained downstream the stone system, which was 57 mg.L^{-1}.
- ✓ The average value allowable for chemichal oxygen demand (COD) in liquid effluents is 180 mg. L^{-1}. The average value in the treated sewage downstream the Luffa cyllindrica systems was 154 mg. L^{-1}. It is also lower than the value obtained downstream the stone system, which was 166 mg. L^{-1}.

When considreing anyone of the two parameters above, the performance of the filters containing *luffa cyllindrica* was superior to the filter containing stones.

Although it was not a specific purpose of this study, it was observed that the biofilm formed in the filters containing *Luffa cyllindrica* presented greater diversity of genus and and superior evolutive stage to those found in the filter containing stones.

IX. Recommendations

The experiments here described were conducted in pilot filters of small dimensions inside a laboratory facility. They have been protected along the whole experimental period against many external conditions that could interfere in the process, such as: direct exposition to sunlight, greater variations of temperature, exposition to rain, among others. Thus, a similar experimental work in open field and using larger filters would be the natural next step for further investigations.

The internal dimensions of the reactors did not allow the conduction of a study on efficiency versus height of the medium. So, this is also an important experimental work to be done.

Another investigation to be recommended is the assessment of the physical stability of the peeled dehydrated fruit during time it remains in activity, when the biofilm is installed over their fibrous structure and some liquid is retained inside its void spaces. In order to lower the cost of the installation of trickling filters, it would be desirable that the filling medium could be self-sustainable, so the walls of the filter could be of no structural nature.

An investigation on efficiency as a function of the hydraulic loading rate is also recommended, besides the treatment capacity as a function of the organic loading rate, and possible effects of recirculation.

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