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# WASTEWATER TREATMENT IN TRICKLING FILTERS USING *LUFFA CYLLINDRICA* AS BIOFILM SUPPORTING MEDIUM

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**Abstract:** Domestic sewage treatment experiments were conducted in trickling filters in laboratory pilot plants in which the peeled dehydrated fruits of *Luffa cyllindrica* were used as a support medium for microbiological growth, in order to verify its capacity to remove organic matter, measured in terms of Biochemical Oxygen Demand ($BOD_{5,20}$) and Chemical Oxygen Demand (COD). Other parameters such as suspended and settleable solids were also measured. The results obtained, when compared to results from similar pilot plant using stones as supporting medium, and with the removals predicted by classic formulas used for trickling filters design, indicated that this support medium may substitute with advantages, under specific conditions, the traditional support media. Further studies are recommended.

**Keywords:** Trickling filters; *Luffa cyllindrica*; biofilms; alternative support media; wastewater treatment.



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## INTRODUCTION

A trickling filter, whose typical configuration is shown in **Fig. 1**, is an aerobic wastewater treatment process simple to be built and operated. It is commonly used for industrial effluents and domestic sewage treatment. Its operation consists on passing the effluent to be treated over a fixed bed of support medium. A biological film grows on the surface of the medium. The biological activity of the film will be able to stabilize the organic constituents of the effluent. The biofilm is part of the time in contact with the flowing wastewater, and part of the time exposed to the air for oxygen uptake.

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.

According to Matasci *et al*. (1988), these filters experienced a widespread and declined use in the United States, and this use diminished due to the increasing exigencies for higher efficiency of organic matter removal in wastewater treatment facilities. In Brazil and in most developing countries, where the discharge of untreated wastewater streams is still a common practice, including domestic sewage, trickling filters may turn into a convenient solution, especially for small urban communities, without significant investments on building and operation.

The use of peeled and dry fruits of *Luffa cyllindrica* as a support medium instead of the stones traditionally used for this purpose was the proposed innovation in this research. This fruit (see **Fig. 2)** is commonly found all over the Brazilian territory and 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 devised that the dry fruits could be used to perform this extra function as a medium in trickling filters. Other common uses of *Luffa cyllindrica* in Brazil are handicraft activities, some industrial applications and pharmacology.

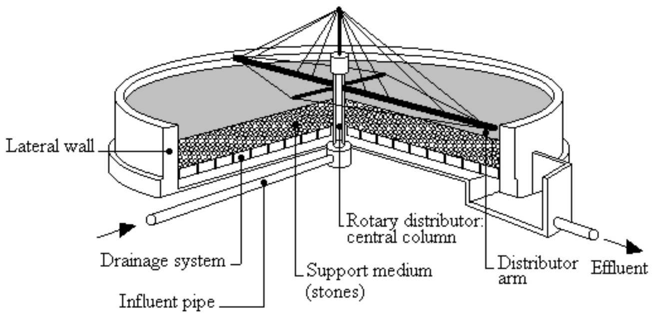


**Fig. 1** Typical configuration and main parts of a classic trickling filter. Figure adapted from Jordão and Pessoa (2009).

**Fig. 2** *Luffa cyllindrica* (a) plant and flower; (b) traditional dried peeled fruit, according to <http://luffas.com.br/produtos.php> (accessed in 10/05/2012).

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 media. Artificial wastewater was used in the study, and higher percentual phosphorus removals were obtained in *Luffa cyllindrica* reactors. The use of the plant for the treatment of non-domestic 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.

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 biofilm 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), Settleable Solids (SetS) – 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. The results of $BOD_{5,20}$ removals were compared to the percent removals predicted by classic formulas used for trickling filters design, and a comparison was done between the results achieved for the conventional and alternative support materials.

## EXPERIMENTAL METHODS

The experimental work was conducted in a pilot scale treatment plant constructed in the Pilot Installations Laboratory of the Environmental and Sanitary Engineering Department of the School of Engineering of UFMG, according to the description that follows (**Fig. 3**). 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.

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.

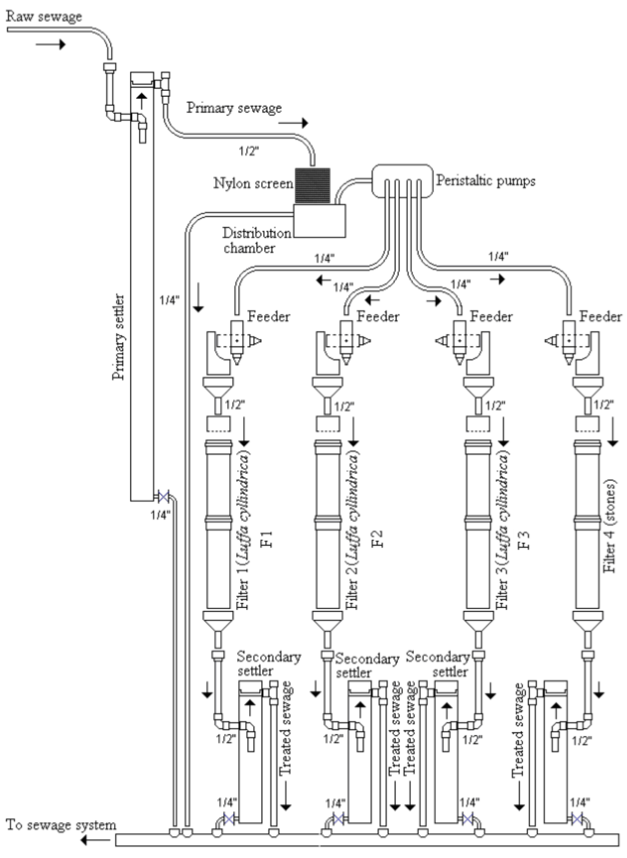


**Fig. 3** General arrangement of the pilot plant, consisting of a primary settler, and four parallel and identical secondary biologic systems, three of them operating with *Luffa cyllindrica* as biofilm support medium (F1, F2, F3), and the last one using stones (filter 4).

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:

$$\frac{Q}{A} = 5.5 \text{ m}^3 \text{ m}^{-2} \text{ day}^{-1}$$

According to WEF & ASCE (1992), this value can be classified as intermediate rate, which ranges from 0.935 $m^3$ $m^{-2}$ $day^{-1}$ 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)**.

**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 |
|---|---|---|
| Suspended solids (SS) | 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 ($BOD_{5,20}$) | Iodometric method | Once a week |

## RESULTS

The results presented below were obtained in the period between January 27th and August 26th, 2004, in which reactors were operating in stationary state conditions.

### Raw sewage characteristics

**Figure 4** 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.

About Biochemical oxygen demand ($BOD_{5,20}$), the results varied between 61 and 387 mg/L. The average of all observations was 216 mg/L.

After the primary settler, $BOD_{5,20}$ showed values varying between 61 and 282 mg/L. The average value for all observations was 177 mg/L. The average percent removal for this parameter in the primary settler was therefore:

$$\left(\frac{216-177}{216}100\right)\% = 18\%$$

### Chemical oxygen demand (COD)

Results ranged from 185 to 801 mg/L. The average of all observations was 451 mg/L. After the primary settler, COD presented values that varied between 168 and 598 mg/L. The average value for all observations was 390 mg/L. The average percent removal for this parameter in the primary settler was therefore:

$$\left(\frac{451-390}{451}100\right)\% = 14\%$$

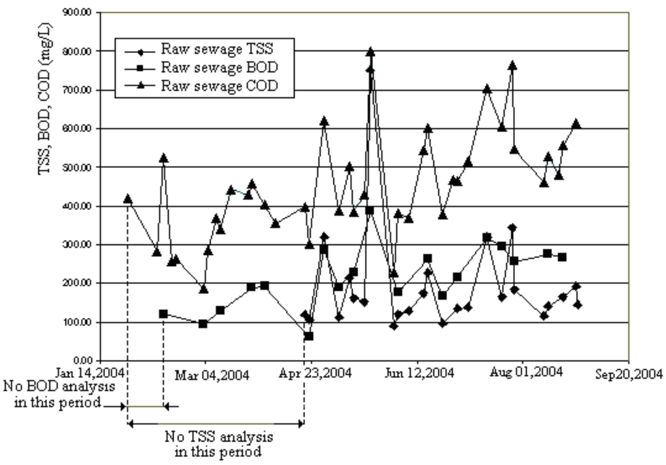


**Fig. 4** Temporal series of BOD, COD e TSS contents of the raw sewage.

The results of total suspended solids (TSS) were obtained between April 20th and August 27th, 2004. They varied from 90 to 752 mg/L. The average of all observations was 193 mg/L. After primary settling this value dropped to 141 mg/L.

The results settleable solids (SetS) varied from 0.10 to 11 mL/L. The average of all observations was 2.22 mL/L. After primary settling this value dropped to 0.80 mL/L.

### Performance of the Filters with Respect to Solids and Organic Load Reduction

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

Results are shown in **Figs 5** and **6** show the statistical analysis and the corresponding box-whisker graphics. The average value downstream the *Luffa cyllindrica* filters was 58 mg/L, while the average value downstream the filter filled with stones was 79 mg/L. 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.

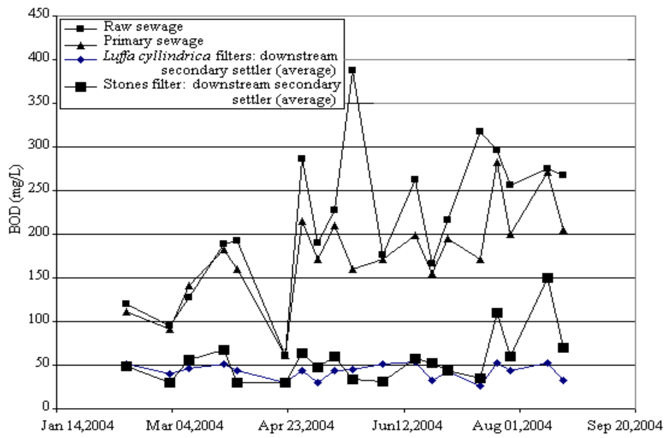


**Fig. 5** Biochemical oxygen demand (BOD5,20) in raw and primary sewage, downstream the trickling filters filled with Luffa cyllindrica and downstream the filter filled with stones: temporal series.

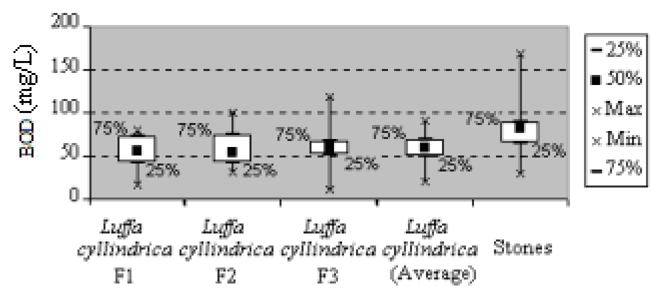


**Fig. 6** Box-whisker graphics for biochemical oxygen demand (BOD5,20) downstream the filters filled with Luffa cyllindrica (F1, F2, F3 and average value) and downstream the filter filled with stones (upstream the secondary settlers).

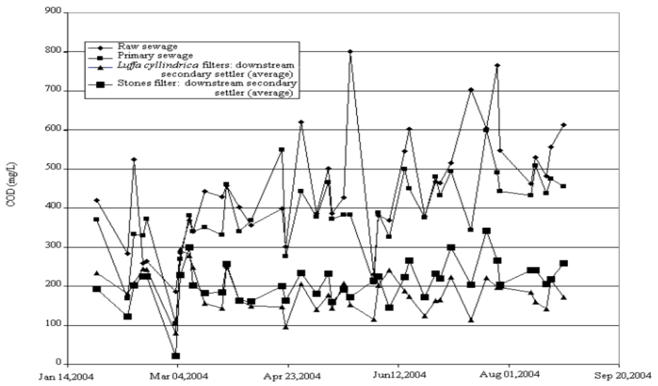


**Fig. 7** Chemical oxygen demand (COD) in raw and primary sewage, downstream the filters filled with *Luffa cyllindrica* and downstream the filter filled with stones: temporal series.

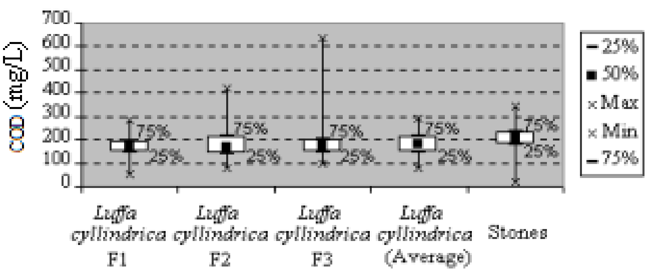


**Fig. 8** Box-whisker graphics for chemical oxygen demand (COD) downstream the filters filled with *Luffa cyllindrica* (F1, F2, F3 and average value) and downstream the filter filled with stones (upstream the secondary settlers).

The results of chemical oxygen demand (COD) are shown in **Figs 7** and **8** show 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. 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.

Results of total suspended solids (TSS) are shown in **Figs 9** and **10** show the statistical analysis and the corresponding box-whisker graphics. The average value downstream the *Luffa cyllindrica* filters was 66 mg/L, while the average value downstream the filter filled with stones was 101 mg/L. The average value downstream the secondary settlers after the *Luffa cyllindrica* filters was 45 mg/L, while the average value downstream the secondary settlers after the filter filled with stones was 72 mg/L.

Results of settleable solids (SetS) are shown in **Figs 11** and **12** show the statistical analysis and the corresponding box-whisker graphics. The average value downstream the *Luffa cyllindrica* filters was 0.95 mL/L, while the average value downstream the filter filled with stones was 1.36 mL/L. The average value downstream the secondary settlers after the *Luffa cyllindrica* filters was 0.81 mL/L, while the average value downstream the secondary settlers after the filter filled with stones was 1.06 mL/L.

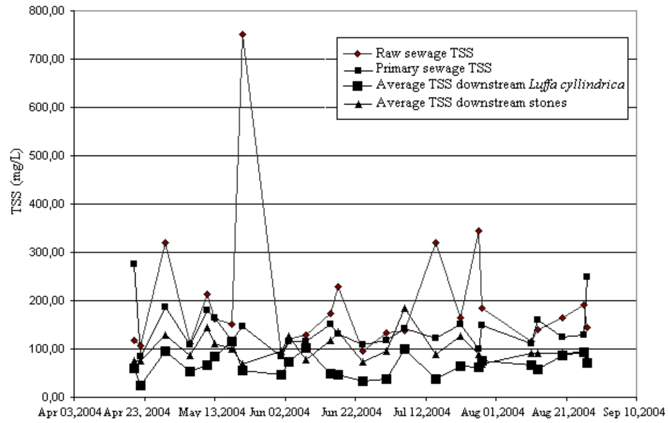


**Fig. 9** Total suspended solids (TSS) in raw and primary sewage, downstream the filters filled with *Luffa cyllindrica* and downstream the filter filled with stones (upstream the secondary settlers): temporal series.

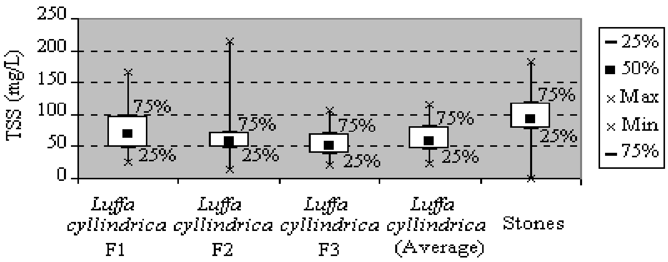


**Fig. 10** Box-whisker graphics for total suspended solids (TSS) downstream the filters filled with *Luffa cyllindrica* (F1, F2, F3 and average value) and downstream the filter filled with stones (upstream the secondary settlers).

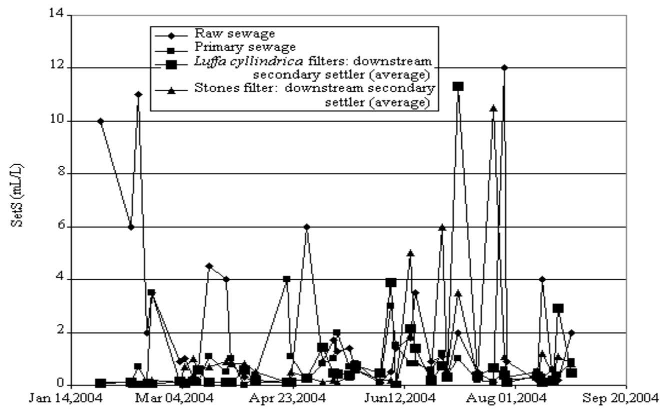


**Fig. 11** Settleable solids (SetS) in raw and primary sewage, downstream the trickling filters filled with *Luffa cyllindrica* and downstream the filter filled with stones: temporal series.

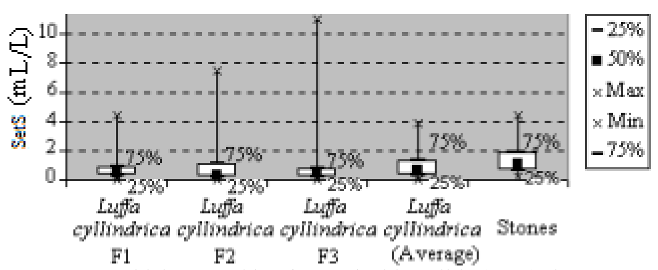


**Fig.12** Box-whisker graphics for settleable solids (SetS) downstream the filters filled with *Luffa cyllindrica* (F1, F2, F3 and average value) and downstream the filter filled with stones (upstream the secondary settlers).

**Classic formula predictions for BOD**

In order to compare the efficiencies of $BOD_{5,20}$ removal obtained in the experiment to the removal predicted by some classic formulas used for trickling filters design, the following items are presented.

**NRC formula** $E_1 = \dfrac{100}{1 + 0,443\left(\dfrac{W_1}{VF}\right)^{0,5}}$

where $E_1$ is the efficiency of the filter and $F$ is a factor obtained by the following expression:

$$F = \frac{\left(1 + \frac{R}{Q}\right)}{\left[1 + \left((1-P)\frac{R}{Q}\right)\right]^2}$$

The input data are $W_1$ = daily organic load = 0.03059 kg $DBO_{5,20}$ /day; $V$ = filter medium volume = 0.0314m$^3$; $P$ = pondering factor = 0.9; $R/Q$ = recirculation rate = 0, thus: $F = 1$, and the efficiency will be: $E_1 = 70\%$

**British formula** $\dfrac{L_e}{L_o} = \dfrac{1}{1 + k\Theta_B^{t-15}\dfrac{A_s^m}{Q_B^n}}$

where $L_e$ and $L_o$ are filter effluent and affluent organic loads, respectively.

The input data are $k$ = first order rate coefficient = 0.0204; $\Theta_B$ = temperature coefficient = 1.111; $t$ = sewage temperature = 20º C; $A_s$ = superficial area of the medium = 62 m$^2$/m$^3$ (recommended for stones ranging from 1” to 3” - WEF & ASCE, 1991); $m$ = recommended coefficient = 1.407, $Q_B$ = volumetric hydraulic rate = 5.5 m$^3$ m$^{-3}$ day$^{-1}$; $n$ = recommended coefficient = 1.249; $L_o$ = affluent $BOD_{5,20}$; $L_e$ = effluent $BOD_5$, thus: $\dfrac{L_e}{L_o}$=0.4227 and the efficiency will be: $E = 58\%$.

**Galler and Gotaas formula**

$$L_e = \frac{0,1577K(QL_o + RL_e)^{1.19}}{(Q+R)^{0.78}\left(1 + \frac{D}{0,3048}\right)^{0.67} a^{0.25}}$$

where $L_e$ = filter effluent organic load ($DBO_{5,20}$) and $K$ is a coefficient obtained by the following expression:

$$K = \frac{4,619}{Q^{0,28}t^{0,15}}$$

The input data are: $Q$ = affluent flow to the filter = 2×10$^{-3}$ L/s; $L_o$ = filter affluent organic load ($DBO_{5,20}$) = 177 mg/L; $R$ = recirculation flow, 0; $D$ = filter medium depth = 1m; $a$ = filter radius, 0.100 m; $t$ = sewage temperature, 20ºC, thus: $K = 16,79$, $L_e = 65,81$ and the efficiency will be: $E = 63\%$.

**Velz formula** $\dfrac{L_D}{L_o} = 10^{\frac{-K_1 D}{0,3048}}$

where $L_D$ and $L_o$ are filter effluent (before the secondary settler) and affluent organic loads, respectively, and $K_t$ is a coefficient obtained by the following expression:

$$K_t = K_{20}\Theta_V^{t-20}$$

The input data are: $D$ = filter depth = 1 m; $\Theta_V$ = coefficient = 1.047; $K_{20}$ is 20º C constant rate = 0.1505, thus: $K_t$=0.1505, $\left(\dfrac{L_D}{L_o}\right)$=0.3208, and the efficiency will be: $E = 68\%$.

## DISCUSSION

**Raw sewage characteristics**

According to Metcalf & Eddy (2003) and considering the average results, raw sewage could be classified as medium concentration sewage, see **Table 2.** 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 load of domestic origin were diluted by this water.

**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.

### 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:

Filters filled with *Luffa cyllindrica*:

$$\left(100\frac{177-58}{177}\right)\% = 67\%$$

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:

Filters filled with *Luffa cyllindrica* followed by secondary settlers:

$$\left(100\frac{177-43}{177}\right)\% = 76\%$$

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:

Filters filled with *Luffa cyllindrica* followed by secondary settlers:

$$\left(100\frac{216-43}{216}\right)\% = 80\%$$

**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) | 350 | 200 | 100 | 193 |
| Settleable solids - SetS (mL/L) | 20 | 10 | 5 | 2.22 |
| Biochemical oxygen demand ($BOD_{5,20}$) | 300 | 200 | 100 | 216 |
| Chemical oxygen demand (COD) | 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 |
| TSS/BOD ratio | 1.17 | 1 | 1 | 0.9 |

Filter filled with stones followed by secondary settlers:

$$\left(100\frac{216-57}{216}\right)\% = 74\%$$

**Table 3** shows the experimental results obtained for $BOD_{5,20}$ removal efficiency and those predicted by the classic formula.

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

Filters filled with *Luffa cyllindrica*:

$$\left(100\frac{390-183}{390}\right)\% = 53\%$$

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:

**Table 3.** $BOD_{5,20}$ removal efficiencies as obtained in the experiments and as predicted by classic formula, compared

| Classic formula | Reduction of $BOD_{5,20}$ (%) | | |
|---|---|---|---|
| | Predicted by the formula | Obtained in *Luffa cyllindrica* media | Obtained in stone medium |
| NRC | 70 (1) | 76(1) | 68(1) |
| British | 58 (1) | | |
| Galler and Gotaas | 63 (1) | | |
| Velz | 68 (2) | 67(2) | 55(2) |

[1] Downstream the secondary settler; [2] Downstream the trickling filter

Filters filled with *Luffa cyllindrica* followed by secondary settlers:

$$\left(100\frac{390-154}{390}\right)\% = 61\%$$

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:

Filters filled with *Luffa cyllindrica* followed by secondary settlers:

$$\left(100\frac{451-154}{451}\right)\% = 66\%$$

Filter filled with stones followed by secondary settlers:

$$\left(100\frac{451-166}{451}\right)\% = 63\%$$

The average percentage of total suspended solids (TSS) values for the removal efficiency of the filters relative to primary sewer obtained along the whole observation period were:

Filters filled with *Luffa cyllindrica*:

$$\left(100\frac{141-66}{141}\right)\% = 53\%$$

Filter filled with stones:

$$\left(100\frac{141-101}{141}\right)\% = 28\%$$

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

Filters filled with *Luffa cyllindrica* followed by secondary settlers:

$$\left(100\frac{141-45}{141}\right)\% = 68\%$$

Filter filled with stones followed by secondary settlers:

$$\left(100\frac{141-72}{141}\right)\% = 49\%$$

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

Filters filled with *Luffa cyllindrica*:

$$\left(100\frac{193-45}{193}\right)\% = 77\%$$

Filter filled with stones:

$$\left(100\frac{193-72}{193}\right)\% = 63\%$$

In general, settleable solids values downstream the filters were higher than the values found for the primary sewage, probably due to the presence of filters biomass carried out from these units (this is actually the desired situation: that the biomass leaving the reactor is settleable, to be retained into the secondary settler and thus removed from the sewage).

The average percentage increases in the filters, relative to the primary sewer, along the whole observation period, were:

Filters filled with *Luffa cyllindrica*:

$$\left(100\frac{0.95-0.80}{0.80}\right)\% = 19\% \text{ (increase)}$$

Filter filled with stones:

$$\left(100\frac{1.36-0,80}{0.80}\right)\% = 70\% \text{ (increase)}$$

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

Filters filled with *Luffa cyllindrica* followed by secondary settlers:

$$\left(100\frac{0.81-0.80}{0.80}\right)\% = 1.3\% \text{ (increase)}$$

Filter filled with stones followed by secondary settlers:

$$\left(100\frac{1.06-0.80}{0.80}\right)\% = 33\% \text{ (increase)}$$

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

Filters filled with *Luffa cyllindrica* followed by secondary settlers:

$$\left(100\frac{2.22-0.81}{2.22}\right)\% = 64\% \text{ (decrease)}$$

Filter filled with stones followed by secondary settlers:

$$\left(100\frac{2.22-1.06}{2.22}\right)\% = 52\% \text{ (decrease)}$$

## CONCLUSIONS

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 medium can be a suitable and sustainable alternative for domestic sewage treatment in this state.

- The average value allowable for total suspended solids (TSS) in liquid effluents is 100 mg/L. The average value in the treated sewage downstream the *Luffa cyllindrica* systems was 45 mg/L. It is also lower than the value obtained downstream the stone system, which was 72 mg/L.
- The average value allowable for settleable solids (SetS) in liquid effluents is 1.00 mL/L. The average value in the treated sewage downstream the *Luffa cyllindrica* systems was 0.81 mL/L. It is also lower than the value obtained downstream the stone system, which was 1.06 mL/L.
- 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. It is also lower than the value obtained downstream the stone system, which was 57 mg/L.
- The average value allowable for chemichal oxygen demand (COD) in liquid effluents is 180 mg/L. The average value in the treated sewage downstream the *Luffa cyllindrica* systems was 154 mg/L. It is also lower than the value obtained downstream the stone system, which was 166 mg/L.

The results obtained for $BOD_{5,20}$ analysis showed that the average reduction of the organic content offered by *Luffa cyllindrica* filters was higher than the calculated with formulas traditionally used in the projects of biologic trickling filters, such as NRC, British, Velz and Galler & Gotaas.

## 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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