PRELIMINARY ANALYSES OF THE EFFICIENCY OF SUSTAINABLE FILTERS AND HYDROELECTRIC POTENTIAL FOR A CLEAN ENERGY GENERATION AND WATER DEPOLLUTION SYSTEM

ANÁLISES PRELIMINARES DA EFICIÊNCIA DE FILTROS SUSTENTÁVEIS E POTENCIAL HIDROELÉTRICO PARA UM SISTEMA DE GERAÇÃO DE ENERGIA LIMPA E DE DESPOLUIÇÃO DE ÁGUA

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Abstract: In last decades, water pollution has become more pronounced on all rivers in Latin America, Africa and Asia. Thus, it is estimated that the deterioration of water quality will extend further over the coming decades, increasing threats to human health, environment and sustainable development. Simultaneously, it has been observed a depletion of non-renewable energetic sources and its increasing replacement by renewable sources. Therefore, the United Nations (UN) has been setting goals regarding sustainable development for the countries. Thus, the present study aimed to create and design a mechanism that integrates clean energy generation and water depollution from small and medium-sized streams by using agro-industrial waste. For this, it was necessary to survey the theoretical framework besides the hydrological study of Pinhalzinho II watershed, which was chosen for the simulation. Thus, it was started the design of the hydroelectric microcentral coupled to a sustainable water purification system using the softwares: AutoCAD© and SketchUp 3D©. In addition, the stream flow was determined and its energy potential was calculated in order to estimate the amount of energy that could be generated by the system. Then, laboratory scale filters were constructed from sugarcane bagasse and cassava peel for efficiency analyses. Finally, the upstream (raw water) and downstream (after filtering) water samples were analyzed and their parameter values determined. After data treatment, it was found that the results were not satisfactory; conversely, they showed a reduction in raw water quality, achieving efficiency only for the thermotolerant coliforms parameter. Nevertheless, regarding the hydroelectric microcentral project and the hydroenergetic potential of the stream, the results were promising.

Keywords: Microcentral hydroelectric. Agro-industrial byproducts filters. Sanitation. Sustainability. SDG.

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Resumo: Nas últimas décadas, a poluição hídrica se acentuou praticamente em todos os rios da América Latina, da África e da Ásia. Assim, estima-se que a deterioração da qualidade da água se estenderá ainda mais durante as próximas décadas aumentando as ameaças à saúde humana, ao meio ambiente e ao desenvolvimento sustentável. Ao mesmo tempo, observa-se um esgotamento de fontes energéticas não renováveis e uma crescente substituição destas por fontes renováveis. Devido a esses e outros motivos a Organização das Nações Unidas (ONU) vem determinando metas aos países em relação ao desenvolvimento sustentável. O presente trabalho teve como objetivo criar e projetar um mecanismo que integre geração de energia limpa e a despoluição da água de córregos de pequeno e médio porte, a partir de resíduos agroindustriais. Para tanto, foi necessário o levantamento de referencial teórico, além de realizar o estudo hidrológico da bacia hidrográfica do Córrego Pinhalzinho II, escolhido para simulação. Dessa maneira, iniciou o processo de elaboração do projeto da microcentral hidrelétrica acoplada a um sistema de despoluição sustentável de água, onde utilizaram-se os softwares AutoCAD® e SketchUp 3D®. Ainda, determinou-se a vazão do córrego e calculou-se seu potencial energético, a fim de quantificar energia que poderá ser gerada pela microcentral. Em seguida, construíram-se filtros a partir do bagaço de cana-de-açúcar e da casca de mandioca em escala laboratorial para a verificação e análise de eficiência. Por fim, analisaram-se as amostras de água a montante (água bruta) e a jusante (após filtragem), determinando-se os valores de seus parâmetros. Nesse sentido, com o tratamento dos dados obtidos, constatou-se que os resultados não foram satisfatórios, pelo contrário, mostraram que houve redução da qualidade da água bruta, verificando-se eficiência apenas para o parâmetro coliformes termotolerantes. Apesar disso, em relação ao projeto da microcentral hidrelétrica e ao potencial hidroenergético do córrego os resultados foram promissores.

Palavras-chave: Microcentral hidrelétrica. Filtros de subprodutos agroindustriais. Saneamento. Sustentabilidade. ODS.
1 INTRODUCTION

All human practices depend, directly or indirectly, on the use of water. In addition to biological survival through direct consumption, sectors linked to the supply of products and services, such as industry, commerce and agriculture, depend on water to maintain their activities (JACOBI; GRANDISOLI, 2017).

Since the 1980s, the demand for water has increased worldwide at a rate of approximately 1% per year due to factors such as: population growth, socioeconomic development and changes in consumption patterns. In addition, this worldwide demand is expected to continue increasing at a similar rate until 2050, which will result in an increase of 20% to 30% in relation to the current demand (WWAP, 2019).

It was observed that in the last few decades water pollution has increased in almost all rivers in Latin America, Africa and Asia. It is estimated that the deterioration in water quality will continue even further over the next few decades, increasing threats to human health, the environment and sustainable development (WWAP, 2018).

In this sense, according to the United Nations World Report on the Development of Water Resources (WWAP, 2017), more than 80% of the planet's wastewater returns to the environment without treatment, contributing to the continuous widespread of water associated diseases, such as cholera and schistosomiasis, in many developing countries.

Concerning energy supply, water is also one of the few sources of renewable energy and does not contribute to global warming, the main environmental problem nowadays (ANEEL, 2005). However, one in five people in the world does not have access to modern electricity; three billion people depend on wood, coal, charcoal or animal waste, that are non-renewable sources of energy which contribute to climate change, accounting for approximately 60% of the total global greenhouse gas emissions (PNUD, 2015). Yet, according to this source, renewable energy currently represents only 15% of the global energy mix.
Thinking about this, the generation by micro hydroelectric plants located in open channels, water distribution networks, irrigation networks or discharge of treated sewage can be used as an alternative source of energy generation and it has been a solution for cities aiming a clever use of the available water resources (SOSNOSKI, 2015). Currently, there are numerous techniques and processes for the treatment and depollution of rivers and lakes. Considered one of the main water treatment technologies for public supply, filtration has been used efficiently in several countries (DI BERNARDO; DANTAS, 2005). The authors define filtration types, quick or slow, due to the water flow speed through the filter media: filtration rates between 3 and 12 m³.m⁻².d⁻¹ are considered slow, whereas those ranging from 120 to 600 m³.m⁻².d⁻¹ are considered quick.

Because of these and other reasons, the United Nations (UN), since 2000, has been setting goals for countries in relation to sustainable development (PNUD, 2015). The United Nations Millennium Declaration, released in 2000, established the basic commitments to the development of human dignity worldwide and drew up eight Millennium Development Goals (MDGs) all by the target date of 2015. In 2015, the MDGs were revised and expanded to seventeen Sustainable Development Goals (SDGs), present in the 2030 Agenda for sustainable development, to be met by 2030 (PEREIRA; SILVA; MASSAMBANI, 2018). According to PNUD (2015), this Global Goals are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. Therefore, all of them are integrated.

Thereby, the objectives of this project are directly related to some SDGs of 2030 Agenda, mainly to ensure the availability and sustainable management of water and sanitation for all (SDG 6); to ensure reliable, sustainable, modern and affordable access energy for all (SDG 7); and make cities and human settlements inclusive, safe, resilient and sustainable (SDG 11).

Thus, the present study aimed to create and design a system that integrates clean energy generation and water depollution of small and medium-sized streams,
built from agro-industrial byproducts, aiming at the recovery of degraded ecosystems.

2 DEVELOPMENT

2.1 Methods

Considering the simulations that were carried out in the laboratory and using softwares, the Pinhalzinho II stream hydrographic basin (Figure 1) was chosen as a cutout for the realization and simulation of the project, where it was necessary to study the water area of the stream, which is destined for the release of treated sewage from the municipality of Umuarama, in south region of Brazil. This basin is located on the Caiuá rocky substrate (FRANÇA JUNIOR; SOUZA, 2010).

**Figure 1**- Hydrographic basin of the Pinhalzinho II stream

Source: FRANÇA JUNIOR; SOUZA (2010).

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This hydrographic basin has approximately 182 km$^2$ of area, with an average altitude of 430 meters. The length of the Pinhalzinho II stream is 27.8 km (SILVA, 2019 FRANÇA JUNIOR; SOUZA, 2010). According to Paraná (1991) this brook is classified in the Class II of fresh waters provided in CONAMA Resolution 357/2005 (BRASIL, 2005).

After this initial characterization, the process of project elaboration of the hydroelectric microcentral coupled to a water treatment system that uses plant residues (agro-industrial byproducts) for filtration (Figure 2) began. For the design of the clean energy generation and water decontamination system, the following softwares were used: AutoCAD®, from Autodesk, and SketchUp 3D®, from Google.

The project basically consists of a system fixed to the edge of the stream composed of an entrance that has a protection grid with small holes, which will divert part of the water from the river course to the system, retaining materials and animals. In the course of the system, the water will pass through a turbine that will rotate and convert the water's potential energy into kinetic energy. When rotating, the turbine will drive an electric energy generator, which will transform the kinetic energy into electricity. After, the water will enter a treatment tank where it will be filtered through a grid system that will contain vegetable waste products, such as sugarcane bagasse and / or cassava peel (which is most often discarded by brazilian agro-industries) interspersed with gravel and sand type boulders. At the end of the journey through the system, the water will return to its natural course by a channel connecting the outlet of the filtration system to the water body.
Subsequently, in order to choose the material with the highest filtration efficiency to compose the projected water treatment system, four filters (Figure 3) containing agro-industrial byproducts were built on a laboratory scale: Filter 1 - sugarcane bagasse, interspersed with gravel and sand; Filter 2 - cassava peel, interspersed with gravel and sand; Filter 3 - sugarcane bagasse and cassava peel (in layers), interspersed with gravel and sand-type gravel; Filter 4 - sugarcane bagasse and cassava peel (mixture), interspersed with gravel and sand-type gravel. In the micro hydroelectric plant coupled with a filtration system, the filter materials will be retained individually within a stainless steel grid, whereby the water will pass and undergo the filtration process.
After the construction of the filters, water samples were analyzed downstream (after filtration), their Water Quality Index (WQI) parameters were determined and compared with the WQI parameters of the upstream sample (raw water).

Since this study is a preliminar analysis, it was not determined the filters lifetime as well as the change period of filter bed. The refinement of this work will demand other project phases. Then, the samplings were performed according to NBR 9898 - Preservation and sampling techniques of liquid effluents and receiving bodies (ABNT, 1987a), after carrying out sampling planning as determined by NBR 9897 (ABNT, 1987b). All samples were analyzed according to the parameters determined by the methodologies of the Associação Brasileira de Normas Técnicas (ABNT). All parameters were determined in duplicate, respecting the recommendations of the official methods (APHA, 2005).

During the collection, the pH (with potentiometer), temperature (with thermometer) and dissolved oxygen (with oximeter) were determined, all coupled in an Aquaread® Model AP-700 & AP-800 multiparameter probe (Broadstairs, United Kingdom), according to the manufacturer’s recommendations. Afterwards, the data for the calculation of stream flow were acquired. The turbidity was determined using a Policontrol® Model AP2000 turbidimeter (Diadema, Brazil). To quantify the
biochemical oxygen demand, the DBO$_{5,20}$ method was used, according to NBR 12614 (ABNT, 1992a). The total phosphorus quantification was performed according to NBR 12772 (ABNT, 1992b). The total residue was obtained by the gravimetric method, according to NBR 10664 (ABNT, 1989). The quantification of thermotolerant coliforms was determined by the filter membrane technique: Determination of Escherichia coli, CETESB L5.230 (CETESB, 2012).

Furthermore, using the data collected in loco, the flow of the stream (Q) was obtained through Equation 1:

$$Q = \frac{(0.8 \times L \times A)}{t} \text{ [m}^3\text{s}^{-1}]$$  \hspace{1cm} (1)

where:

L = length between the 2 strings, [m];

A = cross-sectional area of the river, [m$^2$];

$t$ = time measured, [s].

The area of the river cross section (A) was obtained from the expression (Equation 2):

$$A = W \times (h_1 + h_2 + h_3 + hN / N) \text{ [m}^2\text{]}$$  \hspace{1cm} (2)

where:

W = river width, [m];

$h$ = depth of each measurement, [m];

N = number of depth measurements.

Thus, the flow velocity, or filtration rate, was obtained by dividing the flow of the stream by the cross section, in m.s$^{-1}$.

Then, the hydroelectric potential for the micro hydroelectric plant was determined. The hydroelectric potential ($P_e$) (Equation 3) of a Central Hydroelectric Generator is the capacity to use energy for the transformation, being determined by variables of measurement of water drop and flow, considering also yield and losses of pipes and generators.
\[
Pe = g \times Q \times H_b \times \eta_t \times \eta_g \quad [\text{KW}]
\] (3)

where:
- \( g \) = gravitational acceleration, [9.81 m.s\(^{-2}\)];
- \( Q \) = stipulated permanent flow, [m\(^3\).s\(^{-1}\)];
- \( H_b \) = geometric height, [m];
- \( \eta_t \) = hydraulic efficiency of the turbine, [%];
- \( \eta_g \) = generator's performance, [%].

Thus, according to ELETROBRÁS (1985), which “assumes machines with a yield of approximately 77% for the turbine and 95% for the generator, and uses the following power formula to be installed in a small plant”, as well, the Equation 4 becomes a simplification of Equation 3 because it considers the head losses in the turbine pipes and the efficiency of the generating unit, simplifying the adjustment of the power (P) to be calculated.

\[
P = 7.16 \times Q \times H_b \quad [\text{KW}]
\] (4)

where:
- \( Q \) = stipulated permanent flow, [m\(^3\).s\(^{-1}\)];
- \( H_b \) = geometric height, [m].

### 2.2 Results and discussion

#### 2.2.1 Water quality parameters

The flow characterization data was obtained through the mentioned equations. The stream flow was estimated in 3.017 m\(^3\).s\(^{-1}\) and the flow cross-sectional area was calculated to be 15.475 m\(^2\). Therefore, it was obtained the flow velocity value (filtration rate) of 0.195 m\(^3\).m\(^{-2}\).s\(^{-1}\), which means the filtration rate can be characterized as quick.

The data obtained from \textit{in loco} analyses as well as those from WQI parameters are shown in Table 1.
Table 1 – Results of water quality parameters

| Sample  | T (°C) | pH   | TU (NTU) | TR (mg·L⁻¹) | DO (%) | BOD (mg·L⁻¹) | P_total (mg·L⁻¹) | TC (MPN.100mL⁻¹) |
|---------|--------|------|----------|-------------|--------|--------------|-----------------|-----------------|
| River   | 23.3   | 7.79 | 0.98     | 105         | 127.0  | 6.9          | 0.091           | 750             |
| Filter 1| 33.4   | 4.13 | 1.80     | 18175       | 0      | 0            | 3.703           | 0               |
| Filter 2| 27.5   | 7.08 | 12.65    | 293         | 97.1   | 0            | 0.107           | 0               |
| Filter 3| 28.6   | 4.47 | 10.75    | 5477        | 79.6   | 5.9          | 2.357           | 0               |
| Filter 4| 28.3   | 4.48 | 8.60     | 5011        | 82.6   | 6.4          | 2.263           | 0               |

Source: Authors, 2020.

Legend: T – temperature, TU – turbidity, TR – total residue, DO – dissolved oxygen, BOD – biochemical oxygen demand, P_total – total phosphorus, TC – thermotolerant coliforms. Units: °C – degrees Celsius, NTU – nephelometric turbidity units, MPN – most probable number.

From these preliminary results presented, it can be seen that, with respect to the parameters temperature, turbidity, total residue, dissolved oxygen, biochemical oxygen demand and total phosphorus, all filters were not efficient. Conversely, they contributed to the decrease the water quality of the samples. It is noteworthy that filter 2 exhibited the best results among all tested, however it was inefficient for turbidity reduction.

In relation to pH, it was observed that there was a decrease in the parameter value in filters 1, 3 and 4, thus making the samples acidic. These filters contain untreated sugarcane bagasse, and due to the absence of treatment, they acidify the water (OLIVEIRA et al., 2017).

As the filters contained organic materials layers (sugarcane bagasse and / or cassava peel) it was observed that mineral layers (sand and gravel) were insufficient for filtration mechanisms, like transport and adherence. The study developed by Justen (2019) also discarded the use of rice peel as filtrating material although many others organic materials have been efficient, such as the vegetable sponge and Pinus elliottii pine cone.

Alves et al. (2014) also reported slight acidification in wastewaters treated with cassava peel, as well as an increase of total solids after treatment.

Such undesirable effects may occur due to the turbulence in filter fluid and
the formation of preferential channels (DIOGO, 2010).

In addition, it was noted that all filters showed 100% efficiency in respect to thermotolerant coliforms parameter, eliminating all bacteria present in water samples. Nakamura, Tonetti and Coraucci Filho (2006) also obtained high removal rates of coliforms from wastewaters by using mix filters of bamboo and sand. According to Di Bernardo, Brandão and Heller (1999), the coliforms removal by sand filters increases with its biological maturity. This means that the higher amount of biological materials in filter, the better is its efficiency in removal total coliforms.

Regarding water quality legislation, the data obtained demonstrated that the stream does not fit only in the BOD parameter. After filtration process, other parameters were non-conform, as pH and total phosphorus.

In spite of these results, it is possible to note that this study aids to reach the goal 6.3 of SDG 6, since it presents an option to reduce the pollution levels in water bodies. Organic filters are an alternative to improve water quality, and after its useful lifetime they can be compostable, as Magalhães et al. (2006) showed.

Due its characteristics, the present study also collaborates with goal 11.c of SDG 11 because it utilizes local materials to the confection of sustainable filters.

2.2.2 Hydroelectric microcentral coupled to water removal system

2.2.2.1 AutoCAD® Project

The hydroelectric microcentral project coupled to the sustainable water decontamination system in AutoCAD® can be seen in Figure 4.
Figure 4 - Hydroelectric microcentral project connected to the sustainable water decontamination system in AutoCAD©

(a) Floor plan; (b) Layout; (c) Section A; (d) Section B.

Source: Authors, 2020.
2.2.2.2 SketchUp 3D® Project

The design of the hydroelectric microcentral plant coupled with a sustainable water depollution system in SketchUp 3D® is showed in Figure 5.

Figure 5 - Project of hydroelectric microcentral connected to a sustainable water decontamination system in SketchUp 3D®

(a) Input; (b) Layout; (c) Machine house; (d) Output.

Source: Authors, 2020.

2.3 Hydroelectric potential

The hydroelectric potential was calculated in 464.4 KWh daily. This amount of energy could be used to serve needy communities, to illuminate parks and squares, among other purposes.
This finding contributes to the clean energy technologies research, including the renewable ones, recommended by goal 7.3a of SDG 7.

3 FINAL CONSIDERATIONS

Thus, the preliminary analyses proposed in this study suggest that the filters produced from sugarcane bagasse and cassava peel are inefficient for their purpose. However, changes will be made, other materials will be tested (as treated sugarcane bagasse and rice peel) and a new set of analyzes will be performed. In addition, the prominence of the hydroelectric microcentral was verified, both in the generation of electric energy and in the depollution of river water, in prospects for a sustainable future.

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