EXPERIMENTAL ANALYSIS OF THE KINETICS OF TRANSFER AND DECOMPOSITION PROCESSES FOR MODELLING OF FILLING OF RESERVOIRS

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Abstract. *The objective of this work is to develop models for the kinetics of transfer and decomposition processes during the filling of reservoirs, based on a laboratory experimental investigation. This is achieved observing the mass variations and concentration variations of C, N and P in samples of vegetable origin studied during their decomposition. The samples are dried in vacuum, weighed and then submerged in a constant flow of water. The initial concentrations of C, N and P are determined in the samples after the drying and before the submersion. As the samples are destroyed in the analysis, several replicas are necessary. A flume was designed and built to conduct this controlled experiment. This apparatus consists of a channel 3.21 m long, 0.35 m wide, and 0.335 m deep with glass walls and floor mounted on a metal frame. The results of this experiment, expressed in mass loss and variations in the concentrations of C, N and P as functions of the time and of the number of Reynolds, will be used to adjust the kinetic models of the processes. Regarding the mass loss, very significant results were obtained and they will be incorporated using a simple model equation. Regarding the other concentrations the process is more complex and requires further investigation.*

Keywords*: kinetics, stream decomposition, mass transfer, mineralization.*

1. Introduction

Nowadays the growth of the world population, the innovation need and the growing concern with the environment are doing with that industries use new sources of energy and stimulate the interest in the best use of natural reserves and the development of new technologies. In Brazil, there is a great incidence of reservoirs with the native vegetation submerged. In general, in the creation of a reservoir, the submersion of the native vegetation restricts the exploration of the lumber potential of the area and can significantly alter the characteristics of the water (Bianchini Jr., 1998).

The numeric simulation of the filling of hydroelectric's reservoirs is an important tool in the creation planning of reservoirs. A detailed simulation demands the knowledge in the kinetics of transport and decomposition processes involved. The necessary parameters for simulations can be determined through laboratory experiments, obtained in controlled conditions.

The decomposition process of an organism in the nature can be divided in three distinct processes, which happen at the same time: fragmentation, leaching and real decomposition. The fragmentation is the division of an organism in smaller parts that are loaded for another part of the ecosystem and then decompound. The leaching is the liberation by osmosis of soluble chemical compounds due to the organism death. Again, these compounds will be decompound in another part of the ecosystem.

These two processes are not included in the real decomposition, but as it is impossible to separate them in field experiments, they are treated as "decomposition", in other words, mass loss. The real decomposition is the transformation of complex chemical compounds in simple and, therefore, accessible to the biomass producing organisms - plants, algae and bacteria. This decomposition is divided in two processes: immobilization and mineralization. The first process is the transformation of difficult digestion compounds, mainly cellulose and lignin, in organic compounds of great molecular weight and complexity denominated humic compounds. This material is metabolized only by specialized organisms and produces sensitive effects in the coloration of the water - the coke ponds, common throughout Brazil, are ambient with high concentration of these compounds. The mineralization is the transformation of organic compounds in minerals compounds that are accessible to producers, as several forms of N (nitrite, nitrate, ammonia) and phosphates, that are essential to support the foodchain. The excess of these compounds are the cause of the eutrophy in aquatic environments.

The microbial community has a fundamental role in the mineralization process, and it is known that any submerged organic material is covered in little time for a biofilm of organisms that metabolize this material (called perifíton). The dissolved compounds, evidently, are metabolized by the microbial community of water (the plankton community), but the particulate phase is almost entirely under the action of perifíton. The particulate vegetable biomass is of difficult digestion - the sugars are leached quickly and the one that remains has very high C:N and C:P ratios, what is a difficulty for animals to digest. The microbial biomass, on the other hand, has much lower C:N and C:P ratios, and because of this it is more palatable. Almost all aquatic detritivore animals, actually, feed of the perifíton associated to the detritus, and not of the detritus. The transformation of vegetable biomass in microbial biomass through the metabolization of the died material by the microbial community results in a compound of detritus + perifíton of difficult separation, so that in our experiments we will treat them as a unit. This can result in odd situations, as an increase of the nitrogen concentration along the decomposition - that just reflects the transformation of vegetable biomass in microbial.

One of the objectives of this work is to present in detail the parameters adopted in the project of an experimental apparatus (flume) capable to simulate at laboratory the dynamics of the aquatic phase during the filling of a reservoir, particularly the kinetics of decomposition of vegetable origin samples. An experimental apparatus, developed at the Transport Phenomena Laboratory of Engineering Course of UERJ, was projected with the purpose of accompanying the mass variations and C, N and P concentrations of the sample studied along its decomposition.

The present work is organized in the following way: Section (2) describes the equations that govern the kinetics of the decomposition of organic material submerged in a continuous flow of water; Section (3) describes the details of the experimental apparatus that was projected and built specifically to simulate the process in subject, together with the project criteria and the execution procedures; the Section (4) describes the instrumentation of the apparatus; Section (5) supplies the employed experimental procedures; Section (6) presents the experimental results; and Section (7) presents the conclusions of the work.

2. Equations of the kinetics of transport and decomposition processes

2.1. Decomposition kinetics equations

Decomposition kinetics models proposed in the literature (Barros, 1999) describe the decline of two fractions, with different rates (k). Barros et al. proposes the use of the following expression to describe the loss of organic matter:

$$M(t) = LPOM\ exp\ (-\ K_1\ t) + RPMO\ exp\ (-\ K^2\ t) \tag{1}$$

where:
LPOM: Initial Labile Particulate Organic Matter
RPMO: Initial Refractory Particulate Organic Matter
K_1: Constant of exponential decay of MOPL
K_2: Constant of exponential decay of MOPR

This model type describes the weight loss process very well. The adaptation of the data to the model used by Barros (1999) was always above 95%. Some representative results are condensed in Tab. 1 and in Fig. 1. Table 1 shows the values of the parameters obtained in the experiments. The considered species were *Eleocharis*, which is a margin plant of the reservoirs (a small rush), *Potamogeton*, which is a submerged plant with wide leaves, and *Nymphaea*, which is a submerged plant with floating leaves (as a small water lily).

Figure 1. *Eleocharis*, *Potamogeton* and *Nymphaea* species, used in the experiments.

Table 1. Experimental results for the decay properties of the species: *Eleocharis*, *Potamogeton* and *Nymphaea*. Medium values obtained in 20 experiments.

	LPOM	K_1	RPMO	K_2	half life
Eleocharis	17.3	1.5	82.7	0.0047	147
Potamogeton	20.77	1.5	79.23	0.024	29
Nymphaea	27.2	1.5	72.8	0.1122	6

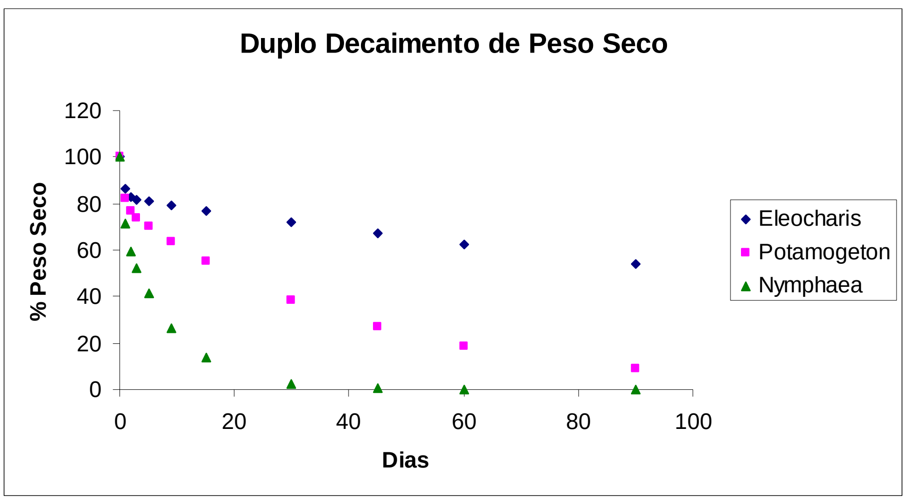

Figure 2. Dual decay of dry weight of the *Eleocharis*, *Potamogeton* and *Nymphaea* species, in agreement with the outcome predict by Eq. (1).

The results above refer to experiments accomplished in a static environment. The next section describes the experimental apparatus developed to study the transport effect in the decomposition kinetics. This effect is realized as a dependence of the decay parameters, K1 and K2, in function of the transport parameters.

3. Experimental apparatus

To observe the phenomenon of stream decomposition process an experimental apparatus, denominated flume, was designed and built. This apparatus maintains a flow with controlled physical, chemistries and biological conditions. This section describes in detail the initial project parameters that was adopted and brings a brief description of the used experimental procedures.

3.1. Design of the experimental apparatus

Geometry and dimensions of the whole apparatus were determined in order to make possible the observation of the most interesting situations during the experiments.

The flume, showed in Fig. 3, consists in a channel 3.21 m long, 0.35 m wide, and 0.335 m deep with glass walls and floor mounted on a metal frame. This metallic frame was constructed with steel structural tubes with squared and rectangular sections and has received a galvanization treatment to avoid the oxidation process. Figure 3 shows the sketch of the apparatus in 3 views. The drawings were carried out in SolidiWorks 3D modeling software.

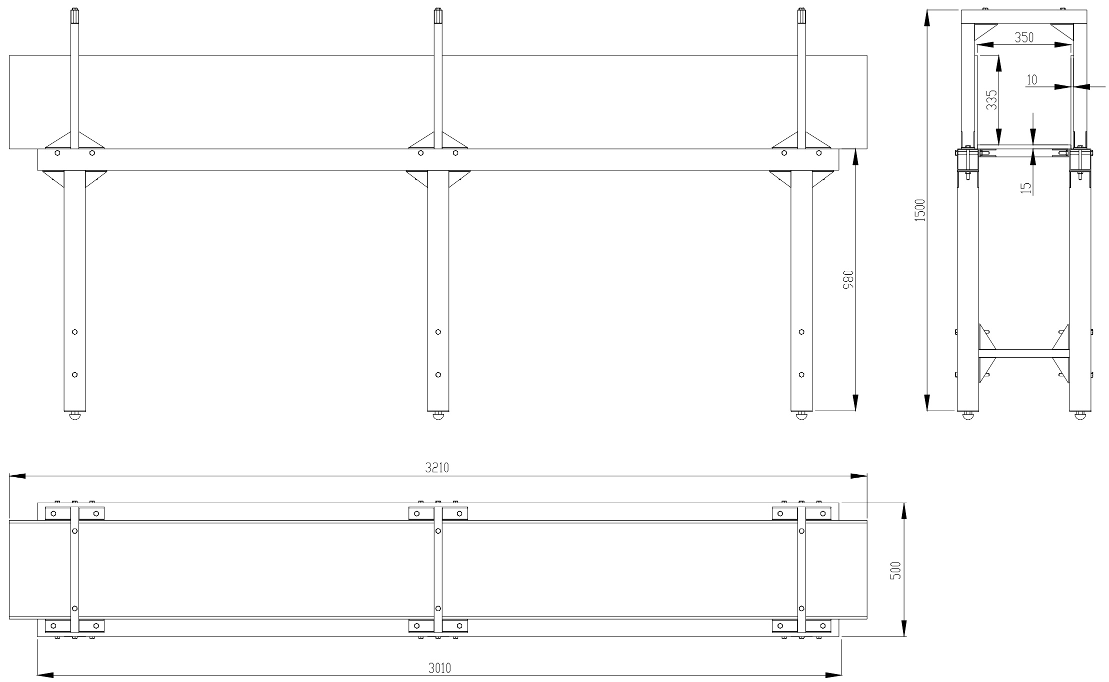

Figure 3. Flume, 3 orthographic views, measures in mm

The fluid of the circuit flows by gravity from a superior reservoir to the flume. In the first part of the flume there is a beehive that softens the turbulence caused by the change of flow direction. Cages, where the samples are conditioned during the experiment, are disposed in the medium third of the flume. These cages have a mesh that is big enough to not introduce perturbations in the flow, although small enough to guarantee that the physical losses (fragmentation) are minimized. After passing along flume, the fluid is stored in an inferior reservoir, and so can be analyzed, discarded or led to the superior reservoir to circulate again throughout the circuit.

3.2. Experimental apparatus construction

The flume channel was constructed with 10 and 15 mm thickness glass plates, mounted on a frame made of steel structural tubes with squared and rectangular sections. To assemble the structure, brims were made of steel plate and then welded to specific parts of the structure. After the construction, the metallic structure parts have received a galvanization treatment to avoid the oxidation process. The assembly of the structure was made joining the brims, that were welded to some of the structural tubes, to the others structural tubes by screws. This construction type creates a rigid structure, that can be dismounted, if necessary, without committing their components. The metallic structure has feet with height adjustment, allowing the leveling of the channel. The glass was used for the construction of the channel to allow visualizations of the experiment under several angles. Figure 4 shows the 3D isometric view of the flume.

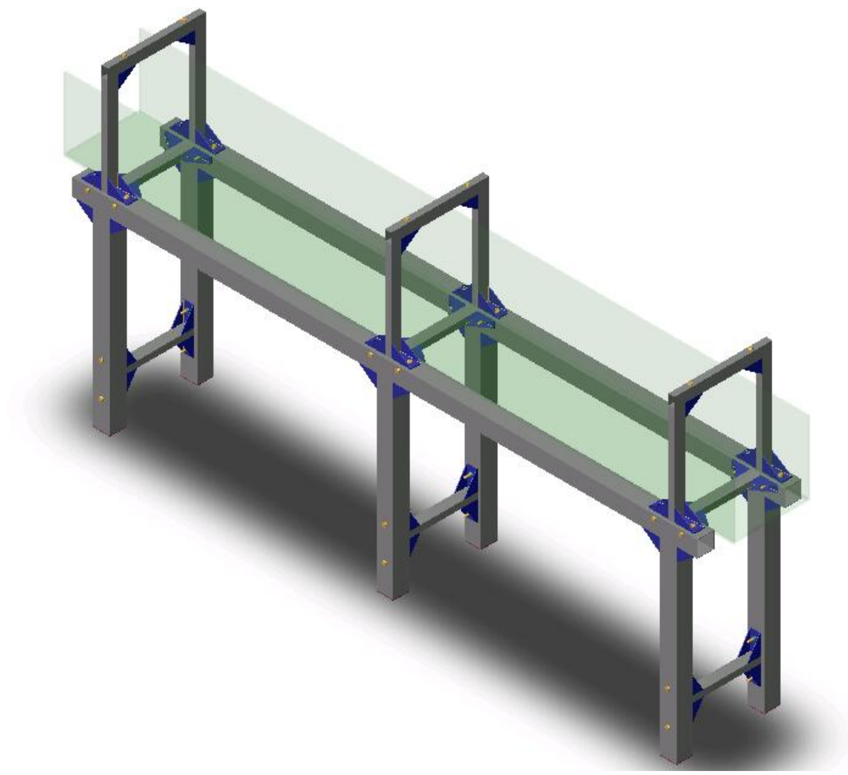

Figure 4. Flume, 3D isometric view.

4. Instrumentation

The instrumentation is responsible for the control of the velocity of the flow, the positioning system for the sensors and the data acquisition. While some measurements were performed by reading instruments and writing down the values by hand, we had implemented automatized data acquisition and control in the most demanding tasks. With this purpose, a PC-based data acquisition and control system was implemented using specific hardware and software.

1. Velocity measurements: average velocity measurements were obtained using a 2 mm Pitot tube, connected to an inclined water column micro-manometer, allowing accurate velocity measurements down to 0.1 m/s.

2. Temperature measurements: temperature measurements were obtained using thermocouple thermometers connected to a data acquisition system, or others thermometers.

3. Sensors positioning system: the traveler gear is a 2 DOF positioning system constituted by a screw system that allows precision of 0,25 mm in the positioning. The mechanical system is ready to be driven by step-motors, and to be integrated into the automatic system.

4. Pressure measurements: differential pressure measurements were mostly performed using U-type micro-manometers, and the readings were currently performed manually. Pressure transducers may eventually substitute these personal micro-manometers and provide continuous logging of experimental pressure data.

5. Mass measurements: mass measurements were obtained using a precise balance that is four decimal digits accurate.

5. Experiments

The stream decomposition experiments were accomplished using the litter bags method (Swift et al., 1979). Samples of Eleocharis, Potamogeton and Nymphaea were put in the decomposition bags. Such species were used in this experiment to allow a subsequent comparison with results obtained in the static experiment, since, in general, the leaching potential and the dissolution and mineralization speeds depend on the chemical characteristics of the resources (Aprile, 1999).

The samples were dried in vacuum and their initial C, N and P concentrations were measured. After weighting, the samples were put in the decomposition bags. Each bag has received 50g of each species. A water flow was established in the channel of the flume. The velocity of the flow was measured and when it turned constant, the bags were submerged in the flow, being disposed in the medium third of the channel. As the sample was destroyed in the analysis, several replicas were necessary.

Every sampling day (days: 1, 2, 3, 5, 9, 15, 30, 45, 60, 90), a set of bags was removed of the flume. The temperature of the water was measured daily or with 1 or 2 days intervals. After they have been removed of the water, the samples was dried in vacuum, weighed and theirs C, N and P concentration was measured.

The flow parameters used in this experiment were: velocity of 0,01 m/s and Reynolds number based on the width of approximately 3500. The weight of the samples, the drying temperature and the velocity of the flow were established after the accomplishment of preliminary tests to adjust and optimize those procedures.

6. Results

The experimental results obtained in this work are summarized in Tab. 2 and Fig. 5.

Table 2. Experimental results for the stream decay properties of the species Eleocharis, Potamogeton and Nymphaea.

Days	*Eleocharis*			*Potamogeton*			*Nymphaea*		
	LPOM	RPMO	M	LPOM	RPMO	M	LPOM	RPMO	M
0	17,3	82,7	100	20,77	79,23	100	27,2	72,8	100
1	3,8602	82,3122	86,1724	4,6344	77,3511	81,9855	6,0691	65,0734	71,1426
2	0,8613	81,9263	82,7876	1,0341	75,5168	76,5509	1,3542	58,1669	59,5211
3	0,1922	81,5421	81,7343	0,2307	73,7260	73,9567	0,3022	51,9934	52,2955
5	0,0096	80,7792	80,7888	0,0115	70,2707	70,2822	0,0150	41,5425	41,5575
9	2,4E-05	79,2747	79,2748	2,8E-05	63,8384	63,8384	3,7E-05	26,5204	26,5205
15	2,9E-09	77,0704	77,0704	3,5E-09	55,2769	55,2769	4,6E-09	13,5274	13,5273
30	4,9E-19	71,8241	71,8241	5,9E-19	38,5654	38,5654	7,8E-19	2,5136	2,5136
45	8,4E-29	66,9348	66,9348	1,0E-28	26,9062	26,9062	1,3E-28	0,4671	0,4671
60	1,4E-38	62,3784	62,3784	1,7E-38	18,7718	18,7718	2,2E-38	0,0868	0,0868
90	4,0E-58	54,1750	54,1750	4,9E-58	9,1372	9,1372	6,4E-58	0,0030	0,0030

The adjustment of the kinetic constants provides the values presented in Tab. 3.

Table 3. Experimental results for the stream decay properties of the Eleocharis, Potamogeton and Nymphaea species.

	LPOM	K_1	RPMO	K_2	half life
Eleocharis	17.3	3.0	82.7	0.018	63,91
Potamogeton	20.77	3.0	79.23	0.096	10,74
Nymphaea	27.2	3.0	72.8	0.420	3

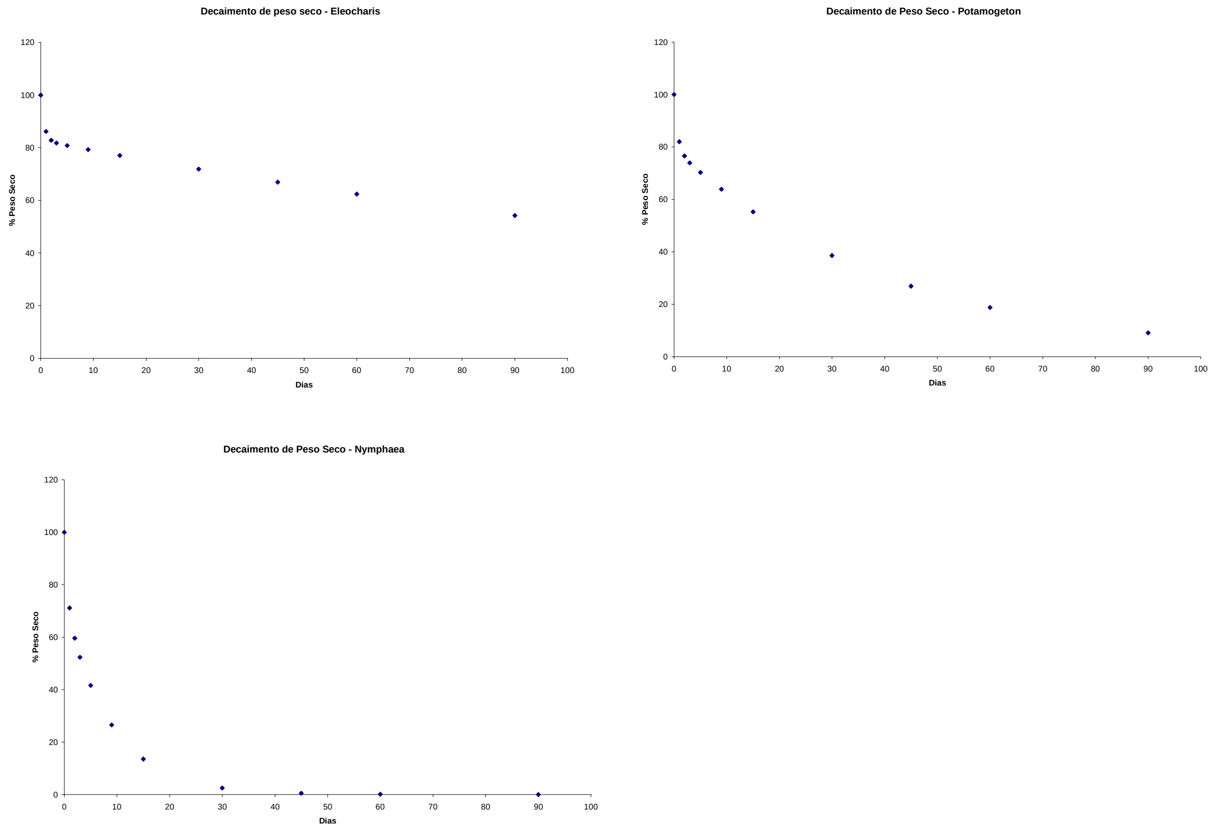

Figure 5. Stream dual decay of dry weight of the Eleocharis, Potamogeton and Nymphaea species, in agreement with the outcome predict by Eq. (1).

7. Conclusions

The preliminary results indicate that the kinetic constants are considerably influenced by the flow conditions. Typically, there is an increase of order 100% on the values of the decay constants K_1 and K_2, for the flow conditions considered. The continuation of the experiments will extende the results to other interesting flow conditions, as well as provide information about the behavior of the C, N and P concentrations along the decay process.

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10. Responsibility notice

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