Wat. Sci. Tech. Vol. 25, No. 7, pp. 179–191, 1992.

0273–1223/92 $15·00

TREATMENT OF WASTEWATER WITH A LOW CONCENTRATION OF ORGANICS USING AN ANAEROBIC FLUIDIZED BED REACTOR

A. L. F. C. Maragno* and J. R. Campos**

**Department of Civil Engineering, Federal University of Uberlândia, Av. dos Universitários, 155, Campus Stª. Mônica, Uberlândia, Minas Gerais, Brazil*
***Department of Hydraulic and Sanitary Engineering, University of São Paulo, São Carlos Engineering School, Av. Dr. Carlos Botelho, 1465 São Carlos, São Paulo, Brazil*

ABSTRACT

In this work performed in the Laboratory of Sanitation of São Carlos Engineering School- University of São Paulo, the results obtained from the operation of a laboratory scale anaerobic fluidized bed reactor are presented for the treatment of a synthetic wastewater with a mean COD of 557 and 700 mg/l during the two phases in which the reactor was studied. In the first phase (Phase A) the mean hydraulic residence time ($\bar{t}$) was maintained at 1.0 h and in the second phase (Phase B), 1.5 h. The duration of each phase, counted from the initial startup period, was 197 days and 108 days, respectively. The reactor was constructed using an acrylic tube of 1.50 m height and a total volume of 10.5 l. The support material consisted of sand with the grains retained between sieves with openings of 0.210 mm and 0.149 mm. The total height of the fluidized bed was maintained at 1.40 m throughout the experiment. The reactor was operated at ambient temperature (13^0C to 31^0C), and was fed with synthetic wastewater composed mainly of bovine liver extract, glucose, sodium bicarbonate and ammonium acetate. The results of physical and chemical analyses: pH, alkalinity, temperature, volatile acids, COD, nitrogen and phosphorus are presented. An evaluation was also made during the experiment of the thickness of the biofilm gathered on the sand grains collected over the whole height of the reactor. The mean efficiency of COD removal attained was 62% for the first phase and 71% for the second phase.

KEYWORDS

Anaerobic treatment; synthetic wastewater; fluidized bed reactor; biofilm; wastewater treatment; diluted wastewater; anaerobic treatment.

INTRODUCTION

Until the sixties the anaerobic digestion process was used basically for the stabilization of sludge from wastewater treatment plants. The control of anaerobic processes was generally precarious and the reactors were operated like sludge reservoirs. Because of these aspects, the reactor's volume became too big and the hydraulic residence time was frequently greater than 30 days.

Greater understanding of the biological process and the possibility of increasing the solids retention time independent of the hydraulic residence time increased the range of using the anaerobic digestion process.

As a result, discoveries of new kinds of reactors were made, among which the anaerobic filter (Young and McCarty, 1969; Foresti et al., 1978),the upflow anaerobic sludge blanket reactor (Lettinga et al., 1980 ; Christensen et al., 1984; Lettinga et al., 1984; Zeeuw, 1984), the anaerobic baffled reactor (Bachmann et al., 1982, 1985) and the anaerobic fluidized bed reactor (Jeris et al., 1974, 1977; Jeris and Owens, 1975,; Cooper and Wheeldon, 1980; Hickey and Owens, 1981; Jewell et al., 1981; Boening and Larsen, 1982; Andrews and Trapasso, 1985; Ademoroti, 1986) stand out.

Simultaneously much other work was performed concerning kinetics, toxicity, microbiology and biochemistry, all referring to the anaerobic biological process (Toerien and Hattingh, 1969; Clark and Speece, 1970; Lawrence and McCarty, 1970; Mosey et al., 1971; Hayes and Theis, 1978; Mosey, 1982; Peres, 1982; Parkin et al., 1983; Speece, 1983; Novaes, 1986; Speece et al., 1986).

Nowadays many systems involving these kinds of reactors can already be found built and operating. Thus, the information obtained in the field already exists as an important source of data for the better evaluation of the results that were obtained in laboratory research.

The first experiences with these new reactors were usually performed using wastewater with Chemical Oxygen Demand (COD) greater than 1000 mg/l, however, more recently the adaptation of these reactors has been investigated for wastewater with a much smaller COD, also including, in this case, domestic wastewater.

Among the new list of anaerobic reactors, the anaerobic fluidized bed reactor apparently stands out as an interesting solution, with a potential for the treatment of wastewater having a relatively low concentration of organic material.

The present work is based on the principal results derived from the operation of an anaerobic fluidized bed reactor at laboratory scale. It was fed with synthetic wastewater composed mainly of bovine liver extract, glucose, sodium bicarbonate and ammonium acetate. The mean COD of the influent was maintained at 557 mg/l during the first phase, and 700 mg/l during the second phase of operation.

The purpose of this research was to evaluate the performance of an anaerobic fluidized bed reactor when fed with influent containing a relatively low concentration of organic material.

The fact stands out that these results served as a base for the performing of consecutive work, at the School of Engineering of São Carlos of the University of São Paulo, with anaerobic fluidized bed reactors and influent with even lower values of COD.

The results of this later research will be the subject of future publications and will also positively reinforce the possibility of the use of this kind of reactor in the treatment of dilute substrates.

METHODOLOGY

Description of the Experimental Apparatus

The system used in this research consisted essentially of a substrate reservoir, substrate pumping, fluidized bed reactor, decanting and security accessory units, recirculation pump and damping chamber.

Two storage tanks were used for the synthetic wastewater preparation. This was pumped from one of these tanks to the entry of the reactor, while the other tank remained clean, ready for use the next day. Even so acidogenesis was observed.

The fluidized bed reactor, shown in Figure 1, was constructed in acrylic, with a height of 1.50 m and 0.096 m diameter and a volume of 10.5 litres. The support material consisted of sand with the grains held between sieves with openings of 0.210 mm and 0.149 mm. The total height of the fluidized bed was maintained at 1.40 m.

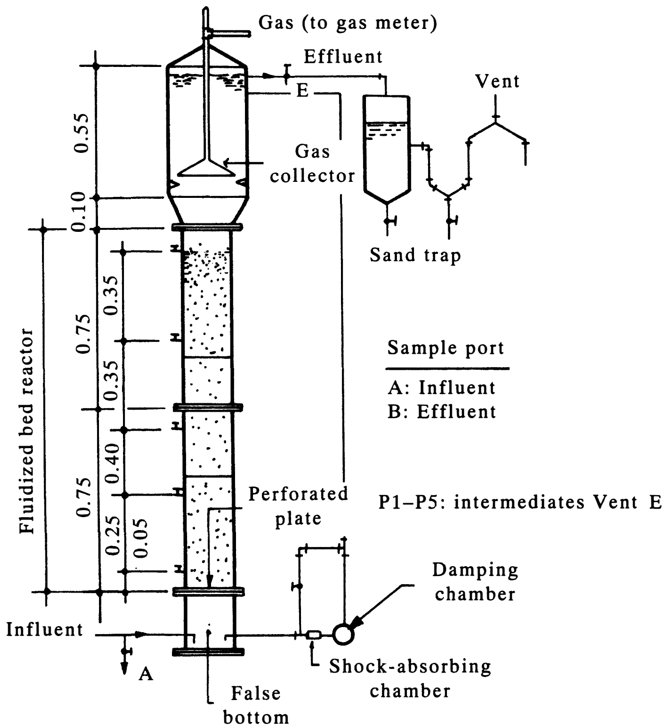

Fig.1 Schematic diagram of anaerobic fluidized bed reactor

Above the fluidized bed reactor, an accessory decanting unit was installed, made of steel sheet with an inner diameter of 0.20 m and 0.64 m height and with an inside funnel for gas collection.

Five sample ports were located along the height for sample collection as shown in Fig. 1.

An accessory security unit was installed to avoid the loss of supporting material.

Characterization of the Synthetic Wastewater

The synthetic wastewater was prepared daily in one of the tanks provided for that purpose, using basically bovine liver extract, sodium bicarbonate, glucose and ammonium acetate. The liver extract (1 kg of liver + 1250 ml of water) was prepared beforehand in the laboratory and stored in small volumes in a freezer.

The mean characteristics of the composition of the substract are shown in Table 1.

Table 1 Characteristics of the Synthetic Wastewater

Component	Day of Examination		
	1^{st} to 40^{th}	41^{st} to 65^{th}	66^{th} to 305^{th}
Liver Extract (ml/l)	1.7	0.7	0.7
Sodium Bicarbonate (mg/l)	850	1500	1050
Glucose (mg/l)	850	210	210
Ammonium Acetate (mg/l)	53	850	1050
Potassium Phosphate (mg/l)	-	4	4
Manganese Sulphate (mg/l)	-	-	15

Although an effort was made to achieve the best control of these characteristics and of the composition of the substrate, there were large variations in the values of the measured parameters due to the addition of liver extract, which, naturally, showed outstanding variations in concentration. This material was used, keeping in mind its low cost and the large diversity of its component products.

The Reactor's Operation

This research began after finishing an earlier work, based on the operation of this reactor, that was performed for a period of 9 months. In that prior research, decreasing hydraulic residence times were used from 5.5 hours to 1.0 hour.

In order to calculate the residence time, the mean outflow and the empty volume of the reactor were considered, using the height occupied by the fluidized bed.

For the present research the reactor was operated in two phases. Phase A was performed during 197 days and Phase B, during 108 days (total: 305 days). Mean hydraulic residence time was maintained at 1.0 h and 1.5 h in Phase A and Phase B, respectively.

The daily routine involved the determination of the temperature and the pH of samples collected at points A and E (Fig. 1).

The parameters analysed for the influent and effluent of the reactor, and the frequency of the analyses, are shown in Table 2.

For the determination of COD, raw and centrifuged samples were used.

The samples for the determination of pH, total alkalinity and volatile acids were centrifuged previously for 10 minutes, at 10,000 g. This procedure was used as standard for all the centrifuged samples.

Table 2 Frequencies of the Principal Analyses Performed on the Influent (A) and Effluent (E)

Parameters	Point of Sampling Influent(A) Effluent(E)	Method
pH, Temperature (^0C)	Daily	Potentiometric (pH)
Total Alkalinity (mg $CaCO_3$/l)	Twice a week	Potentiometric (up to pH 4.3)
Volatile Acids (mg HAc/l)	Twice a week	Direct Titration
COD (mg/l, raw and centrifuged samples)	Twice a week	Reflux with dicromate

All the parameters indicated in Table 2 were determined following the procedure established in the 14th edition of Standard Methods for the Examination of Water and Wastewater (1976), except for the analyses of volatile acids, for which the method of direct titration developed by Di Lallo and Albertson (1961) was used.

Besides the routine collection, samples of bulk liquid and bioparticles along the reactor height were also studied for a better knowledge of the vertical profile of the unit.

To determine the thickness of the biofilm gathered on the support particles, a special projection apparatus (Mitutoyo PV 150) was employed, producing profiles that were used to measure the projected area. In each test a hundred bioparticles were used. Initially the area of projection of the particles with biofilm was determined, and then, after the removal of this biofilm, the procedure was repeated. With these data it was possible to estimate the mean thickness of the biofilm.

As mentioned earlier, the height of the bed was fixed at 1.40 m, therefore all the excess bioparticles were removed when the height of the bed exceeded this value. This procedure was performed aproximately once a month. Collection of samples in the intermediary points of the reactor was effected. The samples removed were composed of two different phases: the sand with gathered solids and the bulk liquid.

The samples were left in a quiescent condition and the supernatant was collected. The sand with volatile solids was beaten with distilled water in a commercial liquifier. The following analyses with the supernatant and the beaten sand were performed: COD, total nitrogen, phosphorus, suspended solids and total solids. One part of the sand removed from the intermediate sample ports was used in the above mentioned analyses, and the rest was washed and returned to the reactor.

RESULTS

In Figures 2, 3 and 4, results of the determinations of pH, temperature, alkalinity and volatile acids and COD concerning Phases A and B are presented.

The mean COD removal efficiency (E) corresponding to each phase of operation was, respectively, 57% and 68% considering all the collected data. Since the adaptation of the system occurred during the initial period of each phase (see Figure 2), the efficiency during this stage was lower than that of the second half of the corresponding period of each phase. Calculating the mean COD removal efficiency (E) with the exclusion of data corresponding to the period of adaptation, the following results were obtained: (raw samples): Phase A: 62%; Phase B: 71%.

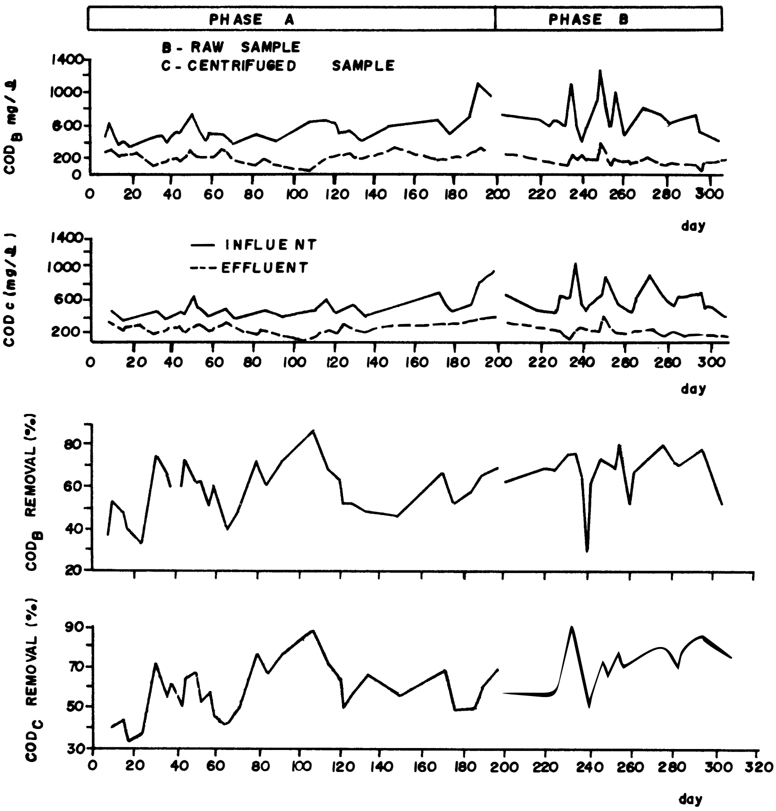

Fig. 2 Variation of COD and reactor efficiency during Phases A and B

Note in Figure 2, showing curves related to the COD removal, that in Phase B there was always a gradual efficiency increasing of the reactor, until values above 80% were attained in the last days of operation. This fact demonstrates that a gradual adaptation of the system occurred with the evolution of the process, indicating greater potential of the reactor under study.

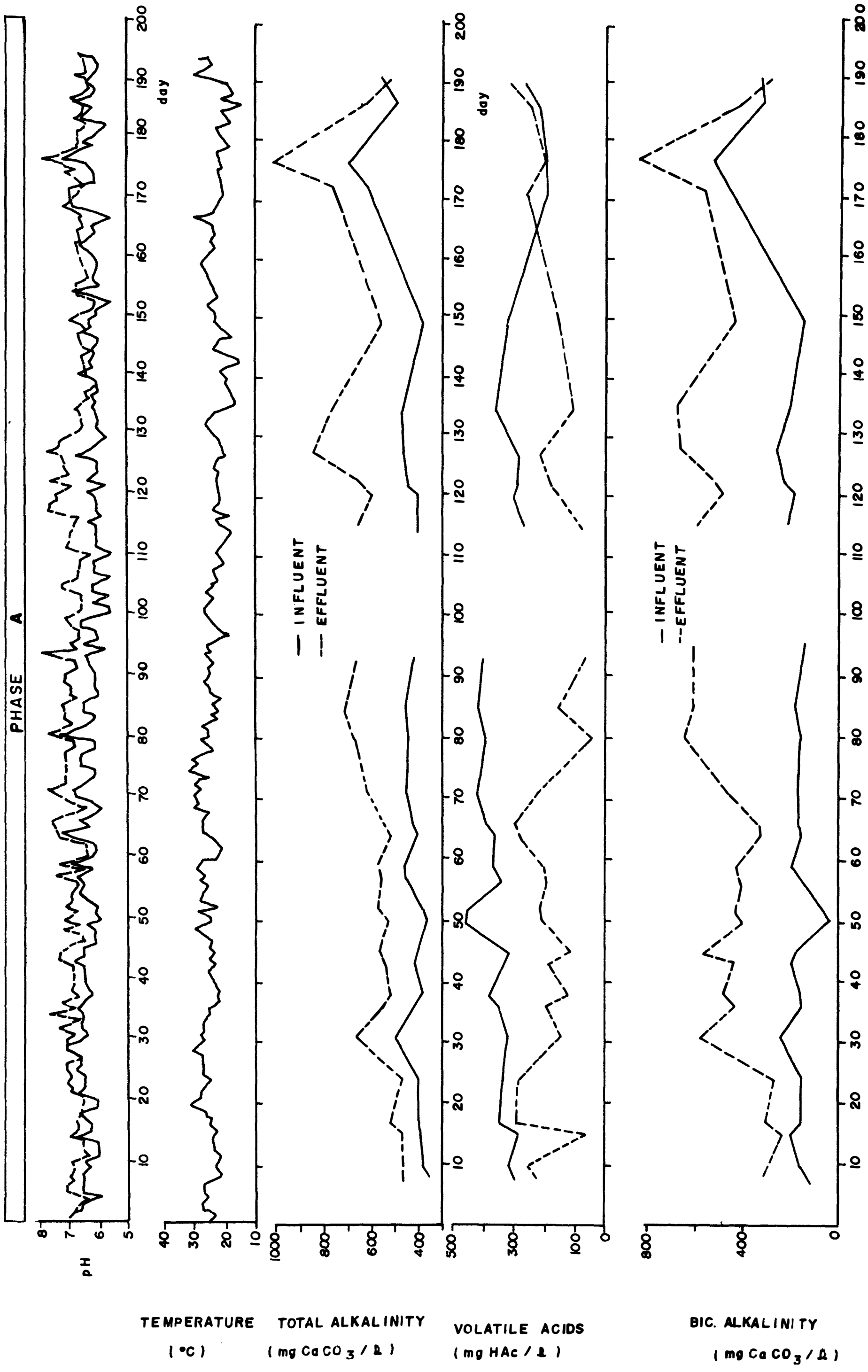

Fig.3. Variation of pH, temperature, alkalinity and volatile acids during Phase A

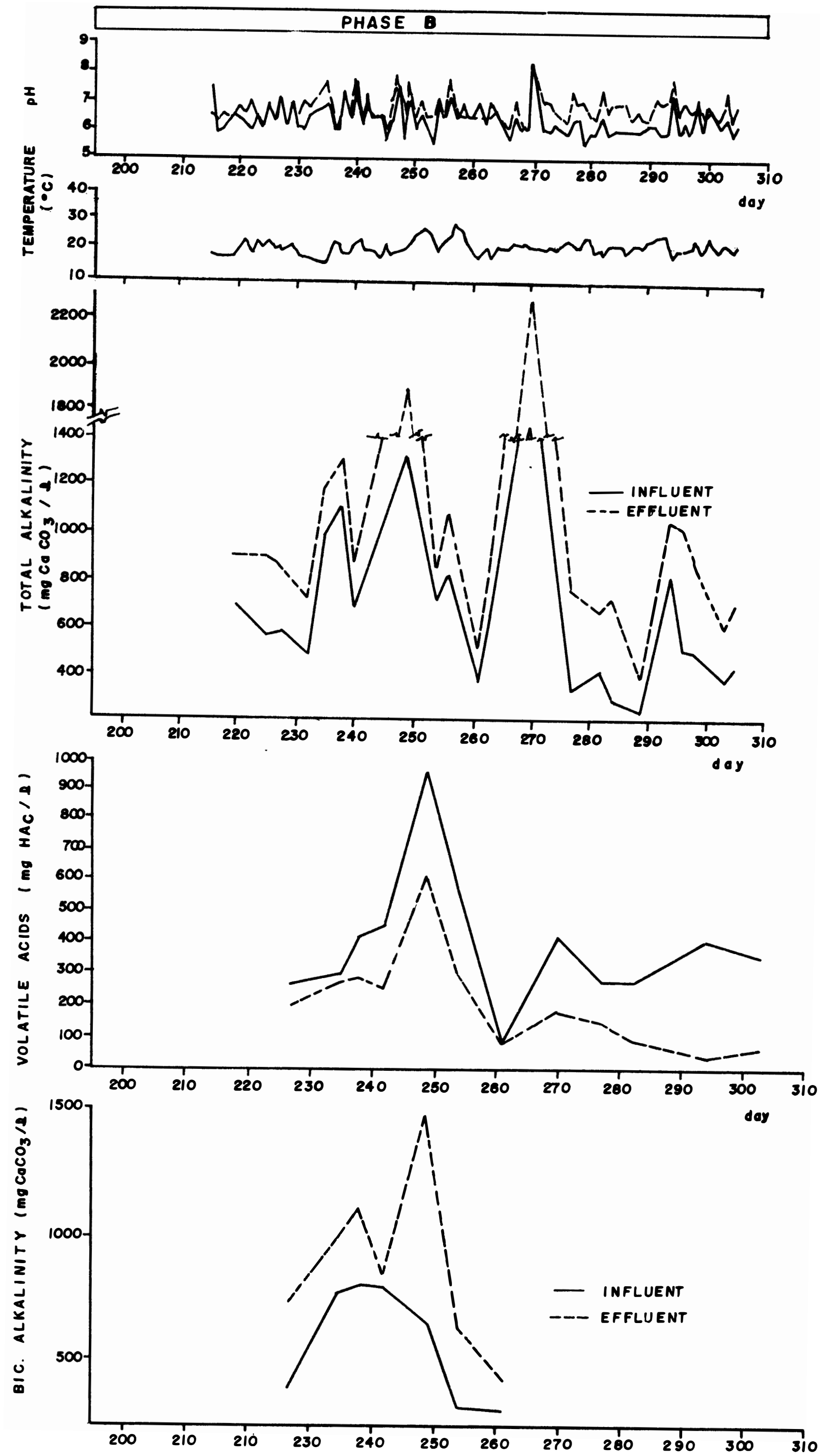

Fig. 4 Variation of pH, temperature, alkalinity and volatile acids during Phase B

In Figures 5, 6 and 7 results are presented concerning samples (bulk liquid and bioparticle) collected along the height of the reactor. The following parameters were considered: COD, total nitrogen, phosphorus and volatile solids (VS). It is interesting to mention that it is very difficult to remove perfect samples, taking into account that damage to the biofilm may occur during the passage of the sample through the sample port. Despite this, generally the results obtained consist of interesting complementary information for the understanding of the behavior of the reactor.

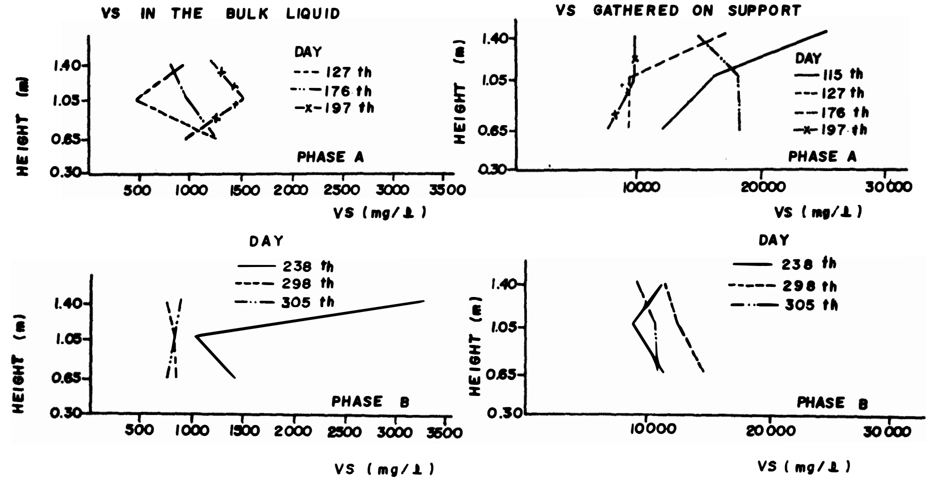

Fig. 5. Variation of volatile solids along reactor height during Phases A and B.

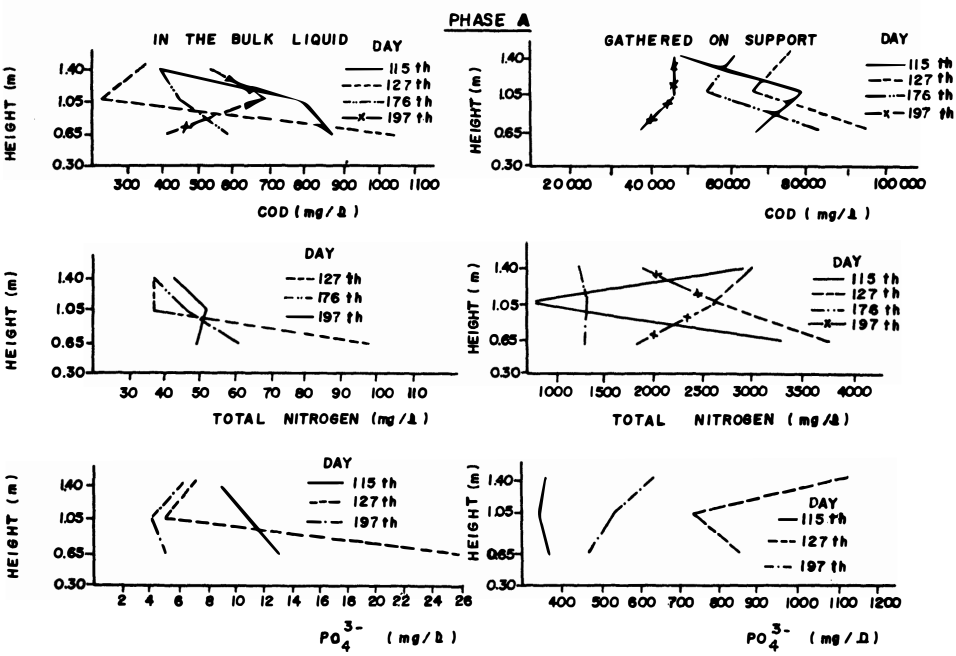

Fig. 6. Variation of COD, total nitrogen and phosphorus along reactor height during Phase A

PHASE B

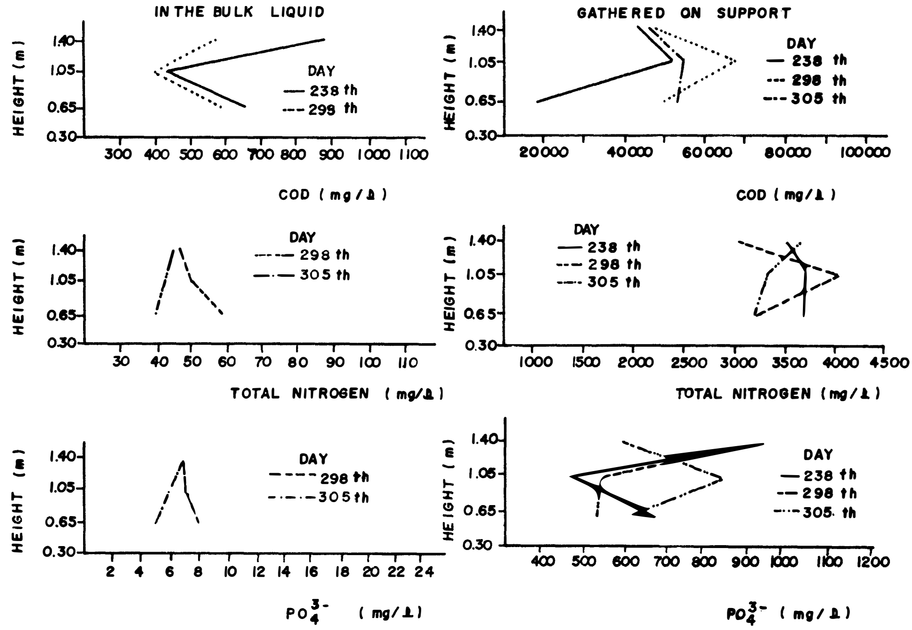

Fig. 7. Variation of COD, total nitrogen and phosphorus along reactor height during Phase B.

From the data in Figure 5 it can be observed that a greater quantity of volatile solids was attached to the surface of the supporting material. In the bulk liquid the concentration of VS varied predominantly between 500 and 1,500 mg/l, while within the biofilm this concentration was between 8,000 and 27,000 mg/l. In Phase B, the gathered VS distribution was relatively uniform along the height, although during Phase A an increase in the concentration of VS within the upper layers of the bed is evident.

The curves presented in Figures 6 and 7, although showing a relatively high dispersion of the results, allow the observation of strips which indicate the range of concentration of total nitrogen, of phosphorus and also of COD, related to the effect of the bulk liquid and of the material gathered on the grains of sand. COD/Total Nitrogen ratio varied in the range of 8:1 to 13:1 for bulk liquid and 10:1 to 50:1 for the attached material. In this last case, however, ratios between 15:1 and 20:1 were prevalent.

In general, in the two operating phases the mean thickness of the biofilm increased along the height of the reactor. The largest measured biofilm thickness during the research was 76 µm .

Although the thickness control of the biofilm and the existence of a complementary accessory to retain solids of the reactor effluent, the carryover of volatile suspended solids (VSS) in the final effluent reached mean values of 66 mg/l in Phase A and 86 mg/l in Phase B.

In addtion to the description of the main research some considerations about the solids retention time are presented. This parameter was estimated for the two phases and resulted in being relatively small, varying preponderantly within the range of ten to fifteen days.

FINAL REMARKS

The principal results of this research were presented in the previous item and some general conclusions can be made from this experience. Although a study about a model involving the kinetics of the process has not been presented, some specific observations about the work accomplished are interesting.

The first observation refers to the applicability of the fluidized bed reactor using sand as a support material and relatively small concentrations of influent COD (average smaller than 700 mg/l). In this sense it is worth emphasizing that later research of the same work group confirmed the applicability of this reactor for even smaller values of COD.

The methodology of periodic removal of bioparticles and the return of clean sand to the reactor was apropriate for the control of the size of the bioparticles.

The increase of the mean biofilm thickness along the reactor height was verified. The following mean thicknesses were obtained for the two phases of the operation: 0.043 mm, 0.045 mm and 0.048 mm for the points situated, respectively at 0.70 m, 1.05 m and 1.40 m above the bottom of the reactor.

The bed stratification was clearly established, in order that the larger grains of sand predominated in the lower part of the reactor; besides this, there were large variations in the concentrations of nitrogen, phosphorus, solids and COD of the solids along the height of the reactor.

The stratification led to a situation in which a greater concentration of the substrate associated to smaller concentrations of volatile solids attached to the sand at the bottom of the reactor. On the other hand, at the top of the reactor, just the opposite occurred.

ACKNOWLEDGEMENT

The authors thank the administration of the Hydraulic and Sanitary Engineering Department of the Federal University of Uberlândia, also CAPES (Coordenação do Aperfeiçoamento do Pessoal de Nível Superior), FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo), CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for the support offered for the realization of this work and the Dept. of Hydraulic and Sanitary Engineering, São Carlos Engineering School - University of São Paulo, where the research was performed.

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