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EXPERIMENTS ON BIOMASS TRANSPORT INSIDE UPFLOW SLUDGE BLANKET REACTORS INTERMITTENTLY FED

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ABSTRACT

This work describes the experimental activities developed to study the biomass transport phenomena occurring in upflow anaerobic reactor influencing the biomass washout. The experimental investigations have been carried out on pilot UASB fed with the aim to determine the height to which washout is affected by: daily flow distribution; upflow velocity; concentration and sedimentation properties of the biomass. The experiments had shown a considerable influence on the biomass behavior of the time interval between two successive feeds of the reactor. It was found that, if this period is more than 1 hr larger losses of the biomass into the effluent were obtained, independent of the upflow velocity. Shorter time periods give rise to a regular sludge expansion of the interface even with very high upflow velocities (up to 4 m/hr), and accordingly exhibit limited sludge washout.

KEYWORDS
UASB, sludge washout, solids transport, upflow velocity, intermittently fed.

الخلاصة

يصف البحث الفعاليات المختبرية لدراسة ظاهرة انتقال الكتلة الحية التي تحدث في مفاعل الجريان الصاعد الاهوائي للحمأة وتأثير سرعة الجريان الصاعد على عملية انجراف الكتلة الحية خارج المفاعل، الشيء الذي يودي بدوره الى انخفاض كفاءة المفاعل بسبب هذه الظاهرة. تمت هذه التجارب باستخدام منظومة الجريان الصاعد الاهوائي للحمأة بعد تقليمها بحمأة حبيبية من نفس موقع الدراسة لغرض إيجاد الارتفاع الحرج الذي يؤثر على عملية جرف الكتلة الحية من خلال تغير كل من: كمية الجريان الداخل الى المفاعل، سرعة الجريان الصاعد، إضافة الى تركيز وكثافة الكتلة الحية الداخلة الى المفاعل. وخلال البحث تبين بصورة واضحة تأثر سلوك الكتلة الحية بالمدة الزمنية الفاصلة بين كل دورة تغذية بمياه الفضلات، وفي الحقيقة إذا كانت هذه الفترة أكثر من ساعة واحدة فان عملية جرف الكتلة الحية خارج المفاعل سيكون كبيرا وبشكل مستقل عن تأثير سرعة الجريان الصاعد. بينما خلال الفترات الزمنية الأقل من ساعة واحدة سببت تمدد منتظم للحمأة حتى في حالة زيادة سرعة الجريان الصاعد الى (4 متر/ ساعة) مما سبب في تقليل ظاهرة انجراف الكتلة الحية خارج المفاعل.

INTRODUCTION

The anaerobic biological sludge blanket systems proposed over recent years have been considerable interest because of their good removal efficiencies of organic substrates, their relatively of simple layout and the low capital and operating costs. The most successful systems include the upflow anaerobic sludge blanket (UASB - Lettinga et al., 1980). UASB is consisting of a tank fed from below in which the wastewater to be treated flows vertically upwards: the biomass forms a thick layer of sludge on the bottom under a suspension composed of biologically formed granules (blanket). The granule washout into the final effluent of UASB is obviously a critical feature in the operation of these systems (Barber and Stuckey, 1999). If this were to happen, system performance would drop because of the presence of organic solids in the effluent (Lettinga and Hulshoff Pol, 1991) and the reduction of the biomass in the system (Nachaiyasit and Stuckey, 1997). However, continuously fed systems have shown small washout even with high average upflow velocities, in the order of 1 to 1.5 m/hr (Barber and Stuckey, 1999), a result that is essentially attributable to the good sedimentation properties of anaerobic sludge. There is essentially no information available on the washout in systems intermittently fed, which is convivially exist in the wastewater treatment plants of small communities (Garuti et al., 1992).
This work describes the problem of washout in intermittently fed anaerobic systems by referring to experimental tests carried out in a variety of working conditions. These were made possible by using the pilot UASB located at the Al-Mansour company wastewater treatment plant (WWTP) (Baghdad, Iraq). The tests are purposed to determine the extent to which treatment performance is affected by factors such as: daily flow distribution; upflow velocity; concentration and sedimentation properties of biomass.
The work was organised in two phases. **Phase 1** analyses of the wastewater characteristic in the anaerobic sections of the Al-Mansour WWTP by monitoring the sludge concentration under different flow conditions.
Phase 2 of the work was carried out in the laboratory using a glass pilot plant UASB inoculated with the sludge from the Al-Mansour WWTP. UASB was fed with a flow having the same organic matter concentration to reproduce operating conditions close to those of the actual system and physically observe sludge dynamics in the system. Repeated measurements of the total suspended solids (TSS) and soluble chemical oxygen demined (COD) content of the effluent made it possible to determine washout and removal efficiencies according to the way the blanket expanding.

MATERIALS AND METHODS

The experimental activities were carried out at the Al-Mansour WWTP, which consist of an activated sludge biological system with an aeration tank, a settling tank, a thickening tank, a digester for the excess sludge at the end of the treatment processes for an overall volume of 70 m^3.
The organic substrate content of influent wastewater is partially degraded by the biomass in anaerobic conditions.
The UASB pilot plant was made from a glass tube with a diameter of 0.1 m and a height of 2.5 m, the wastewater enters the reactor from the bottom across distribution system to allow equal contact between granular bacteria and wastewater. The total volume of the reactor is 0.0196 m^3. The active volume is 0.0094 m^3 (Fig.1). Wastewater is pumped up by a pipeline system, flow meters and valves controlled by a timer system. The system was designed to control discharge and upflow velocity.

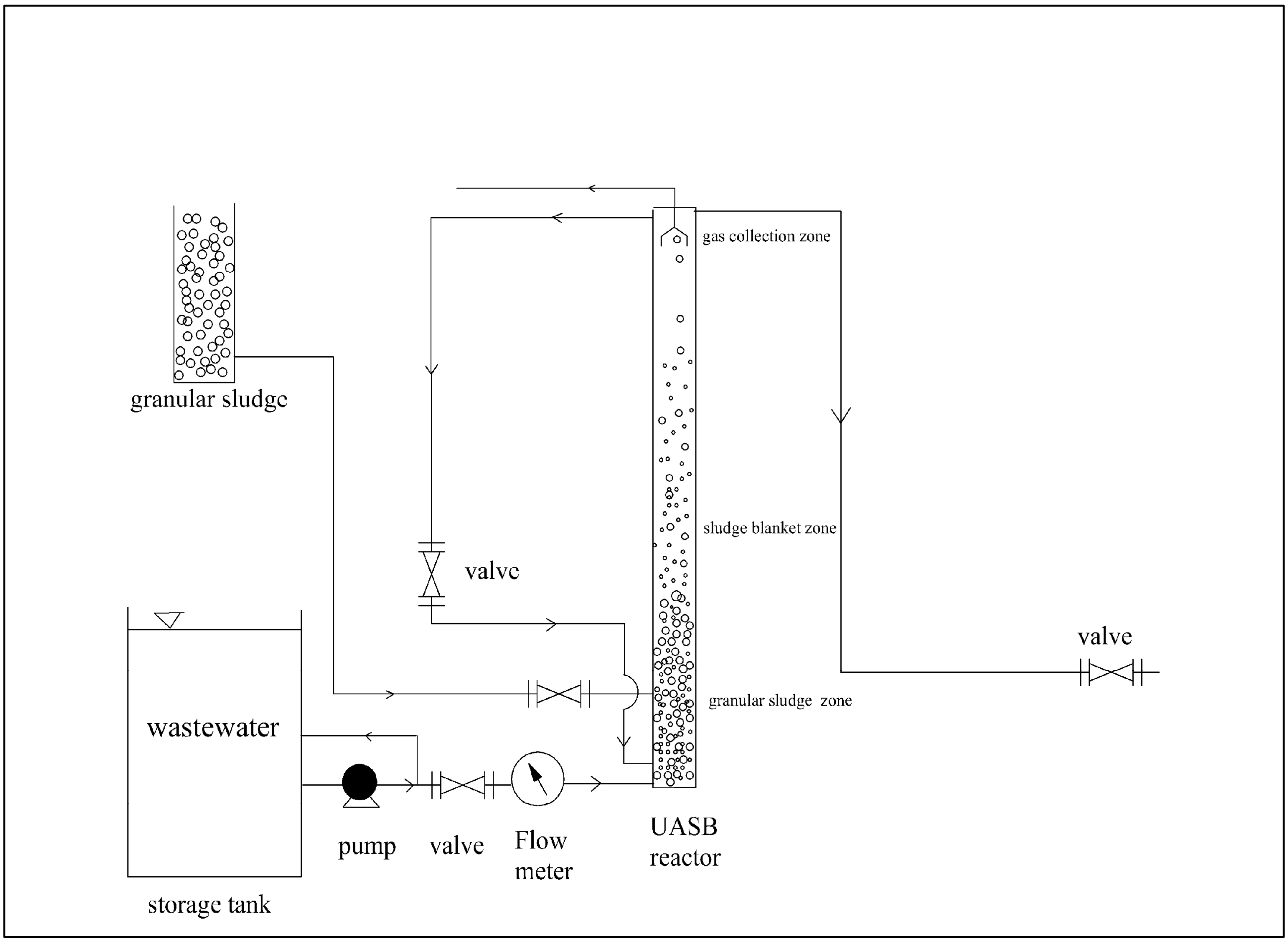
The TSS concentration was measured for all sludge samples in compliance with the Standard Methods (1989). The pilot plant was filled up to a height of 1.20 m with 0.0094 m^3 of sludge and $7.30 \cdot 10^{-3} \cdot m^3$ of wastewater from the Al-Mansour WWTP. During the tests, the system was fed generally with a mixture of tap water and glucose having a total COD of 230 g/m^3 (equal to the mean value measured in the influent flow at the Al-Mansour WWTP). In order to check the experimental results, some tests were repeated using wastewater from the Al-Mansour WWTP and these gave acceptable results. In all cases, the temperature and pH of the flow fed to the pilot plant were maintained at almost constant values of 25° C and 6.9, respectively. Experimentation consisted of 10 different tests (Table 1, Figure 1 Schematic representation of the UASB reactor).

TESTS CARRIED OUT ON THE UASB PILOT PLANT

The results of tests were conducted using the glass pilot UASB set up in the laboratory and varying the duration of the feed interruption phases (D_i), the upflow velocity of the flow being treated (*u*), the duration of the feed phases (D_f), the duration of the cycle (D_c), which is given by the sum of the above two times . The main advantage of this series of experiments consists in observing the expansion of the sludge blanket. Ten tests were carried out with different values of D_i: for the first five tests it was less than or equal to 1 hr; for the others it was > 1 hr. The results of the first five tests (Table 1, Columns 7 and 8) show that the sludge blanket almost expanded regularly, regardless of the upflow velocity (some contractor were observed only for *u* close to 4 m/hr or higher). Under these conditions, a clear interface in the sludge blanket was seen to form, a maximum expansion, small TSS concentrations were always measured (Fig.2, for Test 1). Increases in D_i (Tests 6 to 10) showed a significantly thickened sludge blanket on the bottom during the feed interruption phases; the formation of many channels in the sludge blanket when the feed started; most of the wastewater flow passing at high speed (much higher than *u*) through these channels during the feed phases, with a for impotence ‘short circuiting’ of the sludge blanket, the formation of an irregular interface which disappeared for D_i greater than 3 hr and high TSS concentrations in the effluent. Moreover, increases in D_i led to a greater volume of biogas trapped in the sludge blanket, which was obviously released in the form of large bubbles at the start of feeding and further contributed to the irregular expansion of the sludge blanket in the form of explosion. The influence of upflow velocity on sludge blanket expansion was assessed on the considerations made above, by referring to regular expansion conditions. In particular, the results of Test 1 were used. These results were obtained with D_i equal to 10 min and relative to nine different values of u, the determination over time of the height of the sludge blanket interface during four cycles is reported in Figure 3 as can be seen periodic steady–state conditions were reached in all cases after just two cycles. Obviously, the interface reached gradually higher levels as u increased. The height increase was particularly significant when the upflow velocity passed from 2.30 m/hr to 3.00 m/hr. All the curves show a rapid rise in the sludge at constant speed immediately following the start of feeding and as it continues, the curves show indicating the fall in the interface rising speed after the gradual dispersion of the granular, which were less subject to wastewater flow transport effects. The influence of upflow velocity on washout was proved by means of the measurements of suspended solids in the plant effluent (Fig. 2).

As these measurements are held to be coincident with the mean value of TSS concentration in the effluent during five minutes intervals around the moment of maximum sludge blanket expansion. It was possible to calculate sludge mass escaping into the effluent during this interval. This value was held to be significant index of the measurement of overall system washout (M_w column 2, Table 2) as it constituted the high percentage of the washout and was generally increasing as *u* increased.

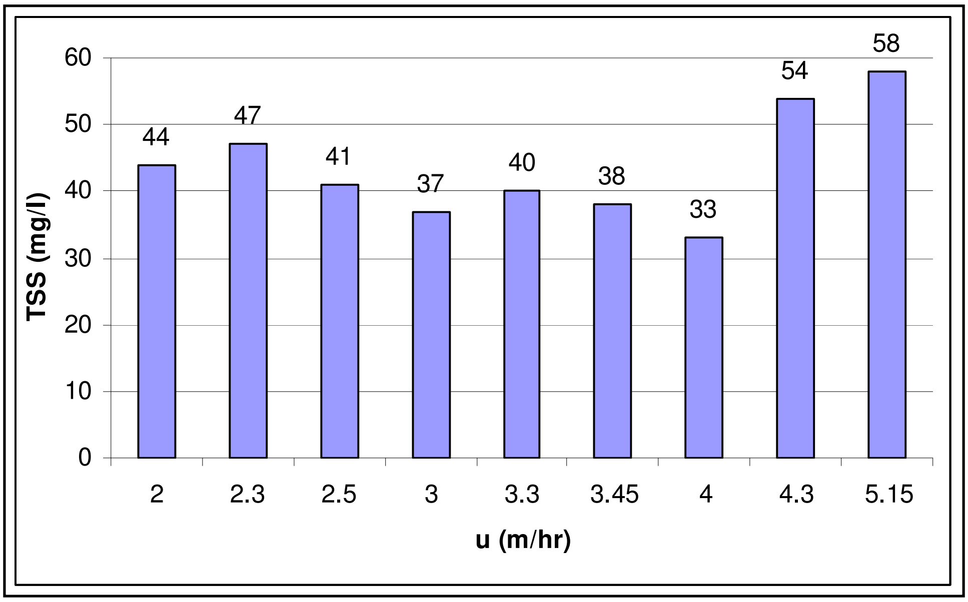
Column 3 of Table 2 reports the values indicated with m_w and obtained by the ratio of M_w with the



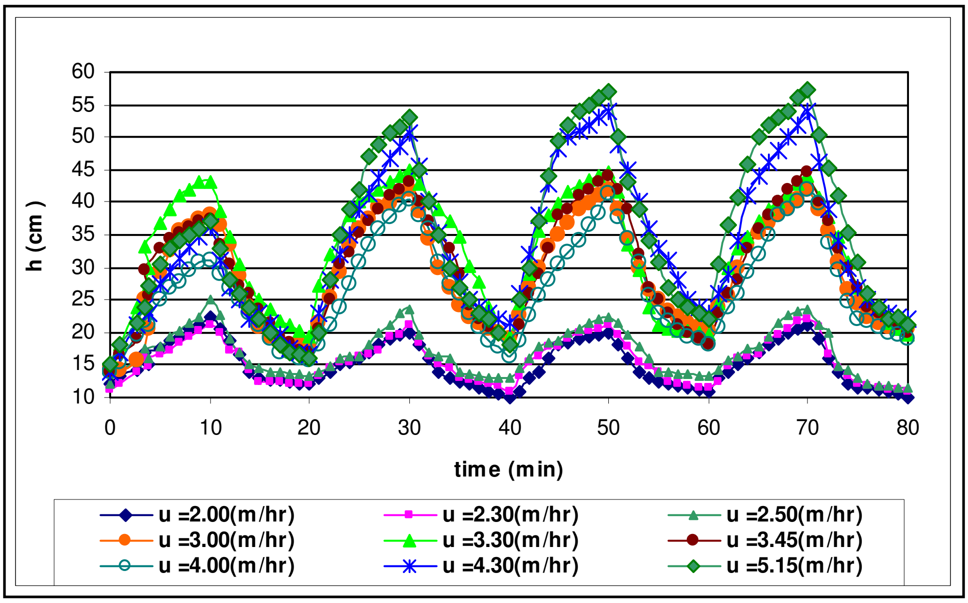
Fig(1).: Schematic Diagram of the UASB Pilot Plant

Table (1) Operating conditions and results of tests on the UASB pilot plant.

Test No.	**Df (min)**	**Di (min)**	**Dc (min)**	**u (m/hr)**	**Number of Investigations**	**Investigations with blanket regular expansion**	**Investigations With blanket Regular expansion (%)**
1	**3**	**4**	**2**	**5**	**6**	**7**	**8**
	10	10	20	2.00	20	20	100
	10	10	20	2.30	20	20	100
	10	10	20	2.50	20	20	100
	10	10	20	3.00	20	20	100
1	10	10	20	3.30	20	20	100
	10	10	20	3.45	20	19	95
	10	10	20	4.00	20	19	95
	10	10	20	4.30	20	18	90
	10	10	20	5.15	20	18	90
	10	20	30	2.00	10	10	100
2	10	20	30	2.30	10	10	100
	10	20	30	4.00	10	10	100
	10	20	30	5.15	10	9	90
	10	30	40	2.30	10	10	100
3	10	30	40	4.00	10	10	100
	10	30	40	5.15	10	10	100
	10	40	50	2.30	10	10	100
4	10	40	50	4.00	10	9	90
	10	40	50	4.30	10	9	90
	10	40	50	5.15	10	9	90
	10	06	70	2.00	10	9	90
	10	60	70	2.30	10	10	100
5	10	60	70	3.30	10	9	90
	10	60	70	3.45	10	9	90
	10	60	70	5.15	10	8	80
	10	90	100	2.30	10	7	70
6	10	90	100	4.00	10	4	40
	10	90	100	4.30	10	2	20
	10	90	100	5.15	10	0	0
	10	180	190	2.30	6	3	50
7	10	180	190	4.00	6	2	33
	5	180	185	4.30	6	1	17
	5	180	185	5.15	6	0	0
	10	480	490	2.30	3	0	0
8	5	480	485	4.00	3	0	0
	5	480	485	4.30	3	0	0
	5	480	485	5.15	3	0	0
9	5	1440	1445	2.00	3	0	0
	5	1440	1445	2.30	3	0	0
	5	1440	1445	4.00	3	0	0
	5	4320	4325	2.15	3	0	0
10	5	4320	4325	2.34	3	0	0
	5	4320	4325	3.70	3	0	0



Fig(2). Mean TSS concentrations detected in the effluent of the pilot UASB during Test 1 at the moment of maximum sludge blanket height



Fig(3). The sludge blanket interface height detected in the pilot UASB during Test No. 1

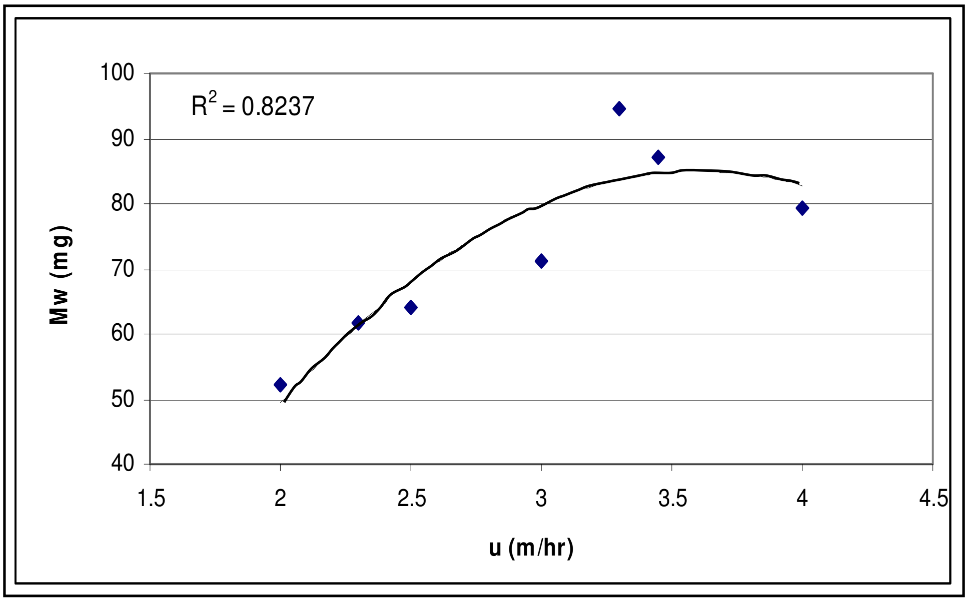
sludge mass present in the plant at the beginning of the test. The value of m_w was seen to range between 0.17 and 0.25 % when *u* was less than 4.00 m/hr. Moreover, in these conditions the correlation between upflow velocity and washout was second order law (Fig. 4). With values of *u* higher than 4.00 m/hr, m_w exceeded 0.3 % even with regular sludge blanket expansion. This determination was caused by turbulence, which increases separation of the sludge blanket interface. During each investigation in Test 1 the COD of effluent from the pilot plant was determination. The mean values corresponding to each upflow velocity and relative removal efficiencies are reported in Table 2 (column 4 and 5 respectively). Efficiencies are shown in the diagram in (Fig. 5) with a second degree polynomial fitting of the experimental data. It is seen that the best results quadrate to values of *u* between 3.00 and 4.00 m/hr with removal efficiencies values above 60 % with lower values of *u*, the removal efficiencies decrease because of the formation of small channels for the wastewater being treated in the sludge blanket, and although this dose not give rise to the washout that results in the incomplete degradation of organic substrate.

The following observations were obtained:

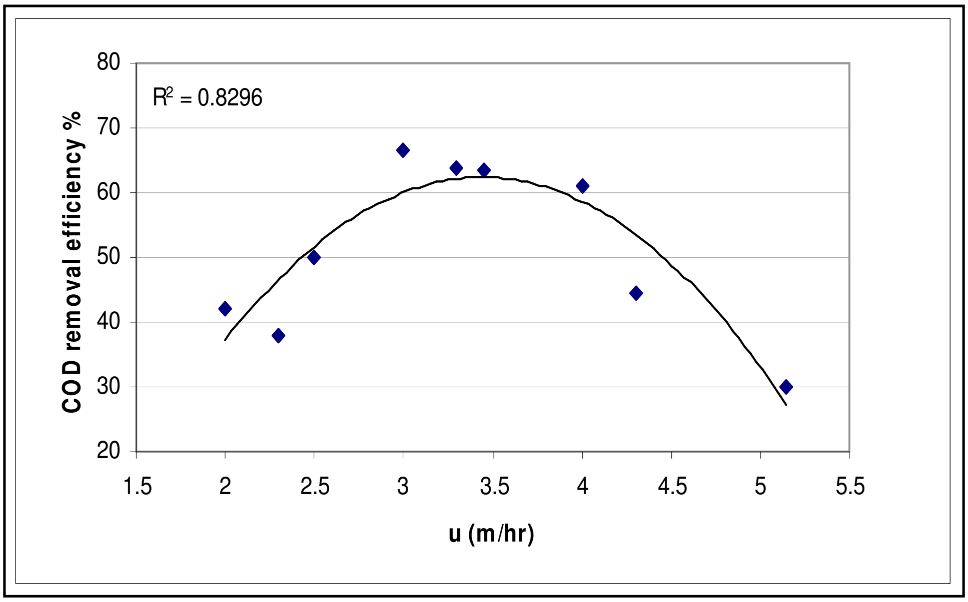
_If velocity between 3 and 4 m/hr then will be not effect on the washout and assures very high removal efficiencies.
_For velocity values below, 3 m/hr a negligible blanket expansion will aims, but at the same time results in a channeling phenomenon, which lowers treatment efficiency.
_If velocity is higher than 4 m/hr, an increase in the washout and reducing in performance in organic substrate removal will be obtained.

Table (2). Washout flows and filtered COD values in the effluent during Test No. 1

u **(m/hr)**	**M_w (mg)**	**m_w (%)**	**Filtered COD (mg/l)**	**COD Removal efficiency**
1	**2**	**3**	**4**	**5**
2.00	52.20	0.172	129.4	41.90
2.30	61.67	0.177	148.3	38.10
2.50	64.00	0.184	120.8	50.00
3.00	71.08	0.204	76.60	66.67
3.30	94.50	0.272	83.00	63.89
3.45	87.17	0.205	83.00	63.60
4.00	79.40	0.205	76.60	61.10
4.30	126.30	0.364	127.5	44.58
5.15	122.50	0.358	161.0	30.00



Fig(4). Variation of washout with upflow velocity ($R^2 = 0.8237$)



Fig(5). Removal efficiency for filtered COD for different upflow velocity ($R^2 = 0.8296$)

CONCLUTIONS

The study shows that, when velocity between 3 and 4 m/hr the effect on the washout decreased and assures very high removal efficiencies.

The results illustrate that, for velocity values below, 3 m/hr a negligible blanket expansion will aims, but at the same time results in a channeling phenomenon, which lowers treatment efficiency.

It seen that, if velocity is higher than 4 m/hr, an increase in the washout and reducing in performance in organic substrate removal will be obtained.

The results illustrate that the when the feed flow is interrupted for long periods (above 1 h) considerable losses of biomass into the effluent will be obtained.

From the results it seen that, with shorter periods blanket expansion takes place on a regular basis even with very high upflow velocities (up to 4 m/hr), giving rise to limited washout and high removal efficiencies, especially with velocities ranging between 3 and 4 m/hr.

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