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Influence Of Organic Loading Rate (OLR) And Hydraulic Retention Time (HRT) On The Performance Of Huasb And Uasb Reactors For Treating Tapioca-Based Starch Industrial Waste Stream: A Comparison

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ABSTRACT

In this paper, the influence of Organic Loading Rate (OLR) and Hydraulic Retention Times (HRT) on the performance of UASB and HUASB reactors for treating tapioca-based starch industrial waste stream has been investigated under six influent COD concentrations (ranging from about 1700-5800 mg/l) and five hydraulic retention times (ranging from 8 to 24 hrs). The influence of the above parameters (i.e., OLRs and HRTs) on the COD removal (%) and bio-gas yield has been discussed in detail. It is concluded that the influence of OLRs and HRTs on the performance of the above two reactors are found to be similar. However HUASB reactor has higher COD removal efficiency and higher gas yield under identical conditions and can also handle higher biomass concentration, than UASB reactor.

Keywords: *HUASB and UASB reactors; Tapioca-based starch industrial stream; Organic Loading Rate; Hydraulic Retention Time; COD removal (%) and Bio-gas yield.*

1. INTRODUCTION

In recent years, HUASB (Hybrid Upflow Anaerobic Sludge Blanket) reactors are used for treating a variety of waste streams, than UASB reactors, due to proven advantages of the former over the latter. However, critical review of literature on HUASB and UASB reactors for treating a variety of effluents, have revealed that studies on HUASB is rather few, when compared to reported studies on UASB and Hybrid Anaerobic Reactors (HAR). Further reported studies on starch-based waste stream (like cassava, tapioca) using HUASB reactor are rather rare [Govindaradjane, 2006]. Hence, there is a necessity and also there exists ample scope for investigating tapioca-based starch effluent under identical laboratory conditions and evaluating the performance of UASB and HUASB reactors. The organic loading rates (OLRs) and Hydraulic Retention Time (HRTs) affect the COD removal (%) efficiency and bio-gas yield in any anaerobic treatment process and therefore it is necessary to understand the influence of OLR and HRT on the performance of the reactors treating an industrial waste stream. Hence in this paper, the influence of various OLR and HRT on the performance of HUASB and UASB reactors evaluated in terms of COD removal (%) and bio-gas yield has been investigated under identical conditions of operations to understand their relative performance.

2. MATERIALS USED

2.1. Effluent: Source, Sampling and Characteristics

The effluent was collected from a starch industry located near Pondicherry, South India, and was stored at 4°C under controlled conditions. The frequency of collection of effluent was once in three months so as to determine variations, if any, in the characteristics of the effluent over a period of 12 months. The salient physico-chemical characteristics of the starch effluent samples were determined based on standard methods for examination of water and waste water, (APHA, 2005) and are given in Table 1. The effluent is found to be acidic and found to have a very high initial concentration of COD. Based on BOD/ COD ratio of 0.61, it is assessed that the chosen effluent is amenable for anaerobic digestion.

2.2. Support Media

In the case of anaerobic reactors, support media made from synthetic material, especially using polymers have been used predominately. For example, plastic pall rings, polyurethane rings, polypropylene pall rings, polyethylene cascade rings, nylon fibres have been used. Natural materials (including materials) like blast furnace slag, volcanic rocks, ceramic rasching rings have also been used, but scarcely. In the present study, commercially available PVC based support media comprising of numerous windings (or) S-shaped portions, was used. The specific surface area of the above media is ten times more than the conventional media. Salient characteristics of the chosen support media (as furnished by the manufacturer), is given in Table 2.

3. EXPERIMENTAL INVESTIGATIONS

3.1. *Experimental Set-up*

The experimental set-up for continuous mode of operations consisted of UASB and HUASB reactors, made of perspex (acrylic) material with a cylindrical column of 100 mm internal diameter; 1600 mm height; total volume of 11.0 litres; effective volume of 9.7 litres and a gas liquid solid separator (GLSS) installed at the top of the reactor. The selected support media was located at the top one-third of the reactor, i.e., for 30 cm height. But for the support media, all other dimensions in HUASB reactor and UASB reactor are identical. The reactors were fed from the influent tank through silicon tube by means of a peristaltic pump of (Make : Miclin; Model : PP.20). A distributor was attached to the inlet pipe so as to facilitate uniform influent distribution. A space of 2.5 cms height was left between the distributor and the reactor base. The influent to the reactor is through its bottom and the reactants move from the bottom to the gas liquid solid separator (GLSS) at the top, where the gas gets separated and collected, which is measured by a wet gas meter assembly (working on the principle of water displacement). A brass check valve of 25 mm size was fixed at the bottom of the reactor to facilitate the sludge withdrawal. Five sampling ports were installed along the height of the reactor at different zones viz., sludge bed zone, sludge blanket zone and settling zone. The influent tank was provided with an agitator to ensure proper mixing of waste water. The treated effluent from the top of reactor is obtained by overflow through the GLSS at the top of the reactor. In the head space, an outlet for flow of gas was provided at the top most conical part of the reactor. This outlet was connected through a silicon tube to a wet gas meter. A photograph of both the reactors is shown in Fig.1.

3.2. *Acclimatization and Start-up*

As the starch waste water was found deficient in nitrogen and phosperous, the same was amended with calculated quantities of nitrogen and phosperous, the ratio of COD: Nitrogen: Phosperous was maintained at 100: 5: 1 [Sharma et al (1994)]. The values of COD and bio-gas yield were monitored till attainment of steady state. Thus, the acclimatization of tapioca-based starch effluent in anaerobic batch reactor was completed in 65 days.

The UASB and HUASB reactors were seeded from acclimatized seed sludge got from the batch-mode operation. Initially about 30-50% of the reactor volume was filled up with active sludge having VSS concentration of about 30,000 mg/l which will be equal to the VSS concentration of about 15,000 mg/l, considering the entire reactor. The raw waste water was diluted to a COD concentration having an average value of 1500 mg/l and then, the influent rate was limited to 0.0097 m^3/day (i.e., VLR of 1.50 kg.COD/m^3day at a HRT of 24 hrs). The reactors were then operated continuously for 90 days under identical conditions and the effluent characteristics were monitored frequently at about 4-7 days interval, until the attainment of steady state. Further the OLR adopted in this study and the monitoring frequency adopted were same as the suggestions of earlier investigators [Selvamurugan et.al, (2011); Coskun et.al, (2012); Lettinga et.al (1991); Lettinga et.al, (1991); Jayantha & Ramanujam (1995) and Shivayoginath & Ramanujam (1991)]. It is found that the start-up process of both the reactors has been completed at the end of 90th day and the steady state condition obtained on the 82nd day and 68th day respectively for UASB and HUASB reactors.

3.3. Continuous Mode of Operation

After the attainment of steady state, the experiment was continued with two different combinations of operating parameters namely: (1) influent COD concentration (six concentrations, namely, 1746.70; 2488.60; 3493.30; 4548.10; 5229.75 and 5862.00 mg/l) and (2) rate of flow (five flow rates, namely, 404, 540, 606, 808 and 1212.50 ml/hr. which corresponds to 24,18,16,12 and 8 hours of hydraulic retention time - HRT). For each influent COD concentration, the experiments were carried out for five HRTs. Thus there were 30 combinations for the entire experimental work, for each type of reactor. During the entire experimental investigations, the VLRs and OLRs were in the range of 1.76 to 17.62 kg.COD/m^3.day and 0.088 to 0.635 kg.COD/ kg.VSS.day for UASB reactor; 0.076 to 0.629 kg.COD/ kg.VSS.day for HUASB reactor. VLRs were maintained the same for both the reactors. For each combination of experimental work, various effluent parameters, namely pH, alkalinity, VFA, VSS (in the sludge blanket and in the effluent), biochemical oxygen demand (BOD), chemical oxygen demand (COD), were determined during the entire experimental investigations, based on standard methods (APHA, 2005). The gas produced was measured using the wet gas flow meter and recorded on the basis of COD removed (i.e., m^3/kg.COD removal). The above parameters were obtained for both the reactors, under identical conditions of operations and the results were critically assessed to draw inferences and salient conclusions.

4. RESULTS AND DISCUSSION

4.1. Status at Steady State Condition

It is found that during the start-up process HUASB reactor attained the steady state condition 14 days ahead of the UASB reactor and that the maximum COD removal (i.e., 78.32%), under identical conditions and HRT.

4.2. Effect of OLR on COD Removal (%)

For both the reactors, at a particular HRT, as the OLR increases, the COD removal (%) also increases and the above trend is found to be the same for all influent COD concentrations considered. Similarly as the HRT decreases, COD removal (%) also decreases and it is found to be independent of the influent COD concentration considered. [Fig: 2 and 3].

The COD removal (%) and OLR values are in the range of 78.60 to 58.9% and 0.088 to 0.633 (kg.COD/kg.VSS.day) for UASB reactor and in the range of 83.10% to 72.10% and 0.076 to 0.629 (kg.COD/kg.VSS.day) for HUASB reactor, considering the entire range of influent concentrations. The maximum COD removal is 78.32 % for UASB reactor, whereas, it is 83.10% for HUASB reactor, under identical conditions of operation. The maximum COD removal achieved in UASB reactor is comparable to the reported values by various investigators for the treatment of starch-based waste streams by UASB reactors [Annachhatve and Amtya (2000); Karthikeyan and Sabarathinam (2002); Yi Jing Chan et.al, (2009); Coskun et.al, (2012); Shahrul Shafendy Bin Ibrahim et.al, (2012)].

4.3. Effect of VLR and HRT on COD Removal

For both the reactors, at a HRT of 24 hours, as the VLR increases from 1.76 to 4.56 (kg.COD/m^3.day the COD removal (%) also increases. However, further increase in VLR (i.e., for 5.26 and 5.91 kg.COD/m^3.day) leads to reduction in COD removal (Fig. 4 and 5). The above trend is similar to the trend (between VLR and COD removal) reported by Gonzalez (2001). It can also be seen that as the HRT decreases (i.e., from 24 hours to 8 hours), VLR increases and the corresponding COD removal (%) decreases. The above trend is found to be independent of the influent COD concentrations considered (Fig. 6 and 7) and it is in agreement with the reported trends by Routh (2000) for various HRTs. The reduction in COD removal with increase in VLR may be attributed to the resulting building up of VFA in the reactor thereby imposing considerable stress on the bio-mass in the reactor. Similar observations have been made by Augoustinos et al. (1969) and Carpos and Anderson (1992), Yi Jing Chan (2009).

The maximum COD removal efficiency attained in this study (i.e., 78.32% for UASB and 83.10% for HUASB) is comparable to the maximum COD removal efficiency reported by, Jayantha and Ramanujam (1995), Pavel et al. (1994) for UASB reactor and by Fang and Kwang (1994) and Kamaraj (2003), Yi Jing Chan (2009), Coskun et.al, (2012), Shahrul Shafendy Bin Ibrahim et.al, (2012) for a starch waste stream.

4.4. Gas Conversion

In general, it is found that the trend between biogas yield and COD removal efficiency (%) and between biogas yield and OLR are found to be the same both for UASB and HUASB reactors (Figs. 8 - 9 and 10 - 11). Similarly trends between HRT and biogas yield for all influent COD concentrations are found to be the same for both the reactors. It is found that the biogas yield gradually increases initially with increase in COD removal (%), OLR, VLR and HRT (i.e., from 0.25 to 0.29 m^3/kg.CODremoval for UASB reactors and from 0.27 to 0.30 m^3/kg.COD removal for HUASB reactor) and thereafter the yield decreases with decrease in COD removal (%) (i.e., from 0.27 to 0.18 m^3/kg.COD removal for UASB reactor and from 0.28 m^3 to 0.24 m^3/kg.COD removal for HUASB reactor) (Figs. 12 - 13 and 14 - 15). Similar trend in biogas yield were reported by Nandy and Kaul (2001) and Silva et.al (1999).

The salient composition of biogas collected from the two reactors is given in Table 3. It is seen that the increase in methane content with increase in influent COD concentration is only marginal in the UASB reactor. The same trend is seen in HUASB reactor, with the only difference that the actual methane content (%) in the HUASB reactor is marginally higher than UASB reactor.

4.5. Effect of Biomass Concentration on COD Removal

Biomass concentration has increased steadily from 20.10 to 30.11 g.VSS/l for UASB reactor and 23.21 to 32.06 g.VSS/l for HUASB reactor under identical range of VLRs (Fig. 16 and 17). The maximum biomass concentration achieved in HUASB reactor may be due to the support media provided at about one-third the height of the above reactor. The above trend is similar to the trends reported by Kennedy et al. (1989) and Soto et al. (1992).

4.6. Effect of VLR/ HRT on OLR

As the VLR (which is a function of HRT) increases, OLR also increases for all influent COD concentrations a trend similar in both the reactors (Figs. 18 - 19 and 20 – 21). OLR values range from 0.088 to 0.633 kg.COD/kg.VSS.day and from 0.076 to 0.629 kg.COD/m^3.day for UASB and HUASB reactors, respectively for identical range of VLRs. OLRs realized in this study (i.e. in the UASB reactor) are comparable to the reported values of OLR by Manjunath (1987), Selvamurugan (2011) and Coskun et.al, (2012).

5. CONCLUSIONS

Following are the salient conclusions of this study:

(1) HUASB reactor has an early start-up (i.e., it attains the steady state condition 14 days ahead of UASB reactor), which is advantageous from the operation of the treatment process. It is also to be noted that the early start-up has not affected the performance of the reactor, especially, COD removal efficiency.

(2) The trend between OLR and COD removal (%) and OLR and COD removal (%) found to be same in both the UASB and HUASB reactors, for the experimental ranges of HRTs and influent COD concentrations, considered.

(3) However, the maximum COD removal in HUASB reactor is 83.10%, which is higher than maximum COD removal (i.e., 78.32%) in UASB reactor, but, at identical influent COD and HRT.

(4) The trend between bio-gas yield and COD removal (%) in both the reactors is found to be the same. But, the maximum gas yield is slightly better in HUASB reactor and equal to 0.30 m^3/kg.COD removal, at identical HRT and VLR, but at an OLR of 0.155 kg.COD/kg.VSS.day. However, the methane content in the biogas generated in both the reactors are almost the same and is in the range of 54 – 56%.

(5) HUASB reactor can support higher biomass concentration i.e., 23.21 to 32.06 g.VSS/l than 20.1 to 30.11 g.VSS/l in UASB reactor, which may be attributed to the presence of support media provided at the top of the HUASB reactor, which facilitate additional microbial growth. Thus, the HUASB reactor contemplated in the present study is presumed to be capable of handling still higher influent COD concentrations, than the experimental range of values of the present study.

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Table: 1 Characteristics of Tapioca-based Specialty Starch Effluent

Sl. No.	Parameters	Value / Description
1.	Colour	Very light brownish
2.	Odour	Alcoholic
3.	pH	5.69
4.	Alkalinity	2630
5.	Volatile Fatty Acids (VFA)	1625
6.	Total Suspended Solids (TSS)	720
7.	Total Dissolved Solids (TDS)	2200
8.	Total Volatile Solids (TVS)	1510
9.	Total fixed solids (TFS)	690
10.	Total solids (TS)	2920
11.	Biochemical Oxygen Demand (BOD)	3500
12.	Chemical Oxygen Demand (COD)	5750
13.	Total Khejdhal Nitrogen (TKN)	280
14.	Phosphorous (P)	25 – 48

Note: (i) All values except pH, are in mg/l, (ii) All values are average of four samples characterized over the period of investigation.

Table: 2 Characteristics of support media

Size Mm	Surface Area m^2/m^3	Void ratio %	Density gm/l
26	500	87	140
55	350	92	110

Table: 3 Salient Composition of biogas produced in the reactors

Sl No	Influent COD concentration mg/l	Methane content		Carbon di-oxide	
		UASBR	HUASBR	UASBR	HUASBR
1	1768.60	54.8 %	57.9 %	35.0 %	32.0 %
2	4563.20	56.1 %	59.4 %	32.0 %	30.0 %

Note: (i) The above influent concentrations were at HRT of 24 hours. (ii) Values of other gases, etc. are not indicated.

Fig: 1 Experimental view of UASB and HUASB Reactors

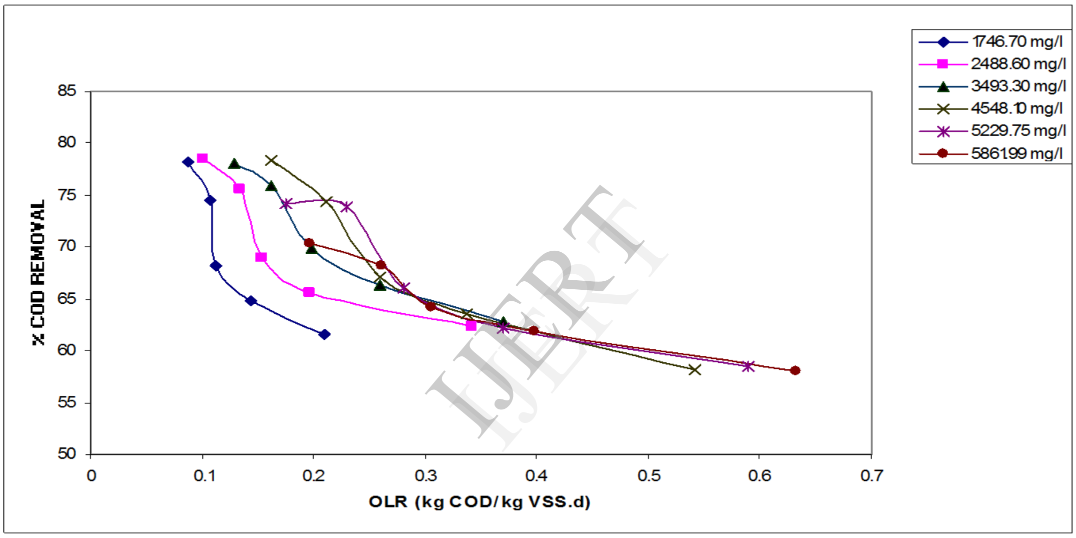

Fig 2: OLR Vs COD removal (%) for various influent COD concentrations and HRTs for UASB reactor

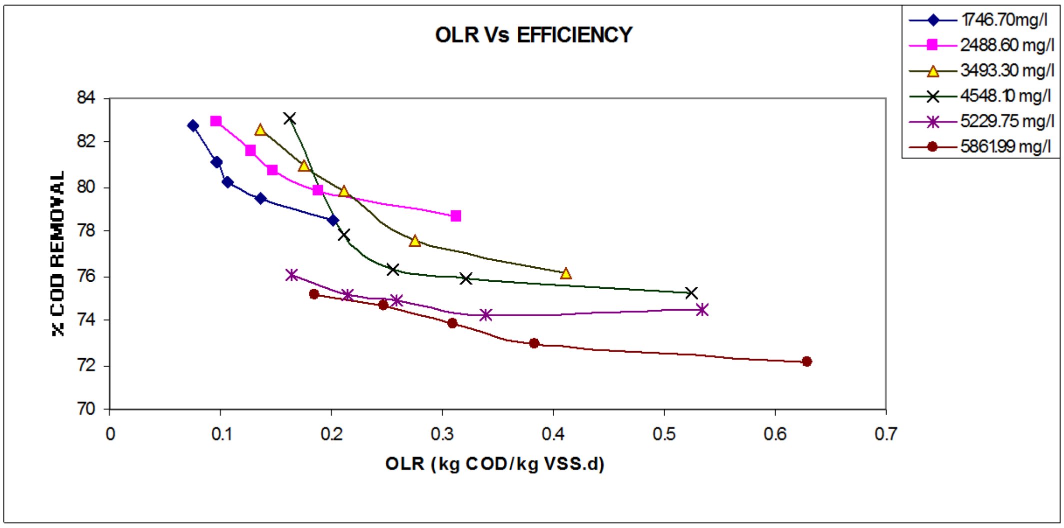

Fig 3: OLR Vs COD removal (%) for various influent COD concentrations and HRTs for HUASB reactor

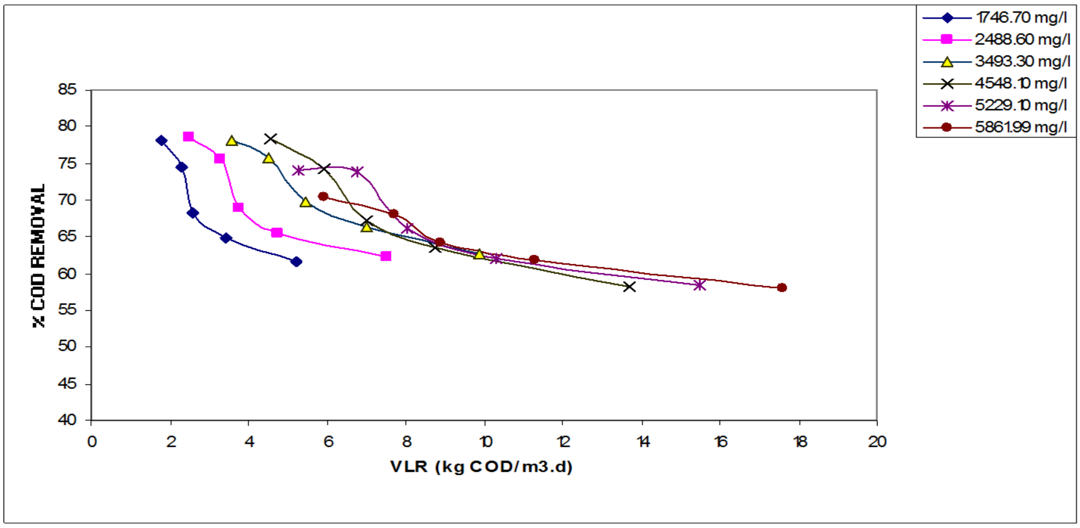

Fig 4: VLR Vs COD removal (%) for various influent COD concentrations and HRTs for UASB reactor

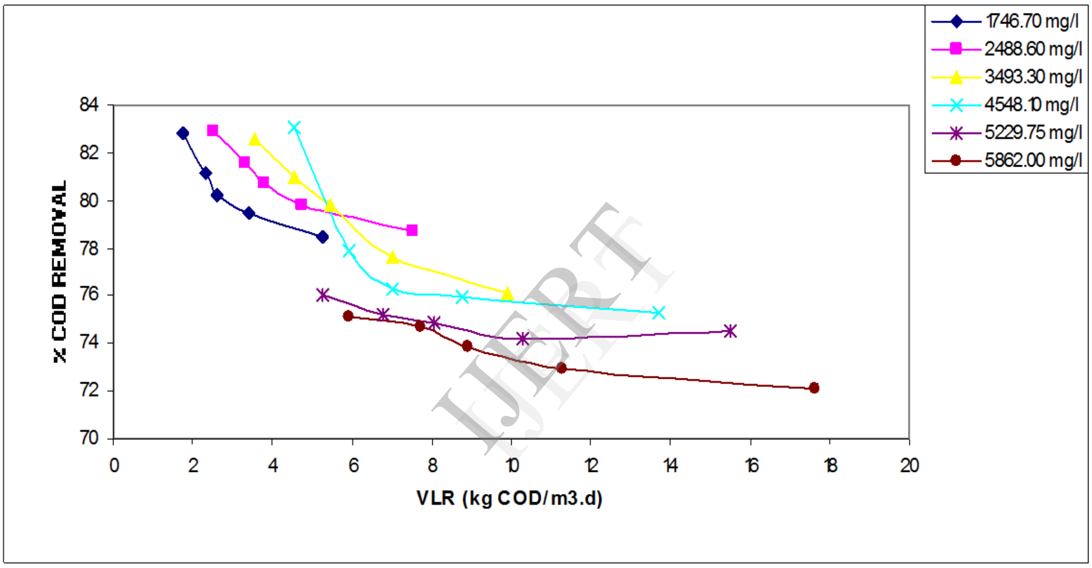

Fig 5: VLR Vs COD removal (%) for various influent COD concentrations and HRTs for HUASB reactor

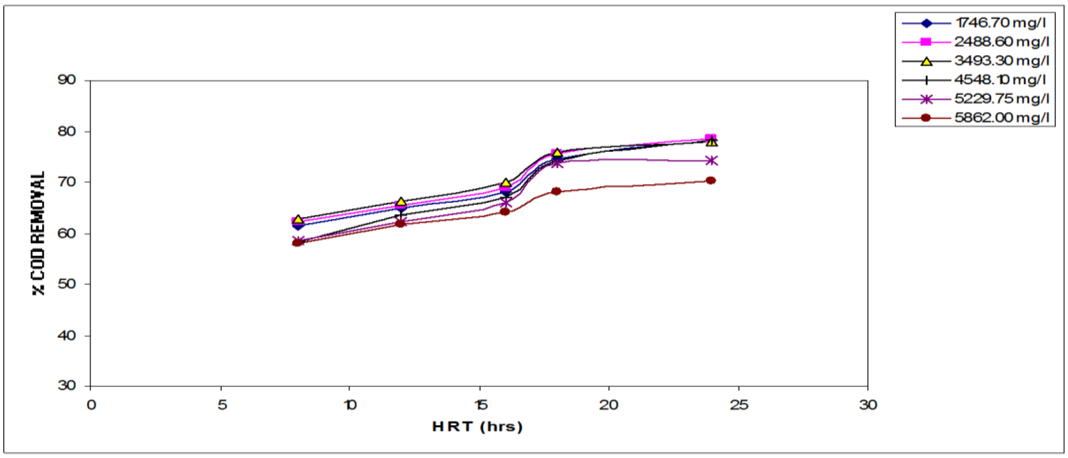

Fig 6: HRT Vs COD removal (%) for various influent COD concentrations and HRTs for UASBreactor

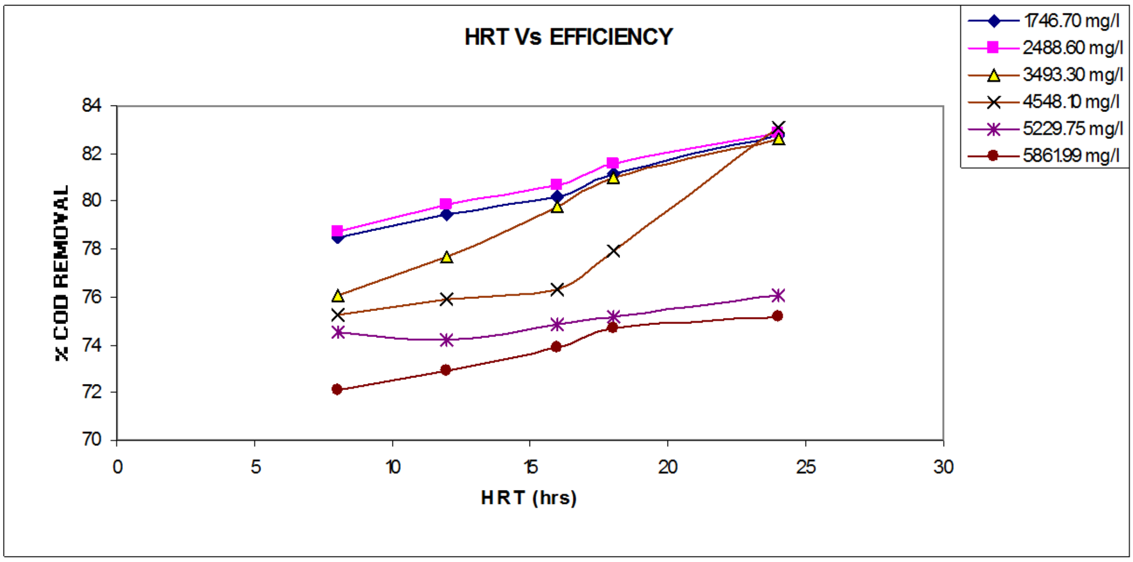

Fig 7: HRT Vs COD removal (%) for various influent COD concentrations and HRTs for HUASBreactor

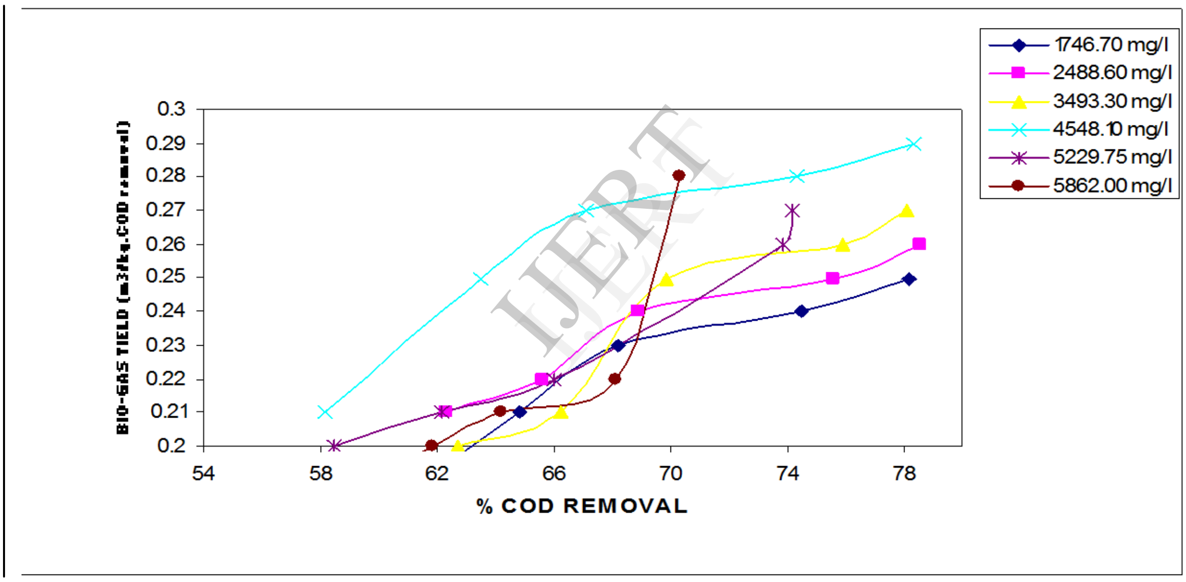

Fig 8: COD removal (%) Vs bio – gas yield for various influent COD concentrations and HRTs for UASB reactor

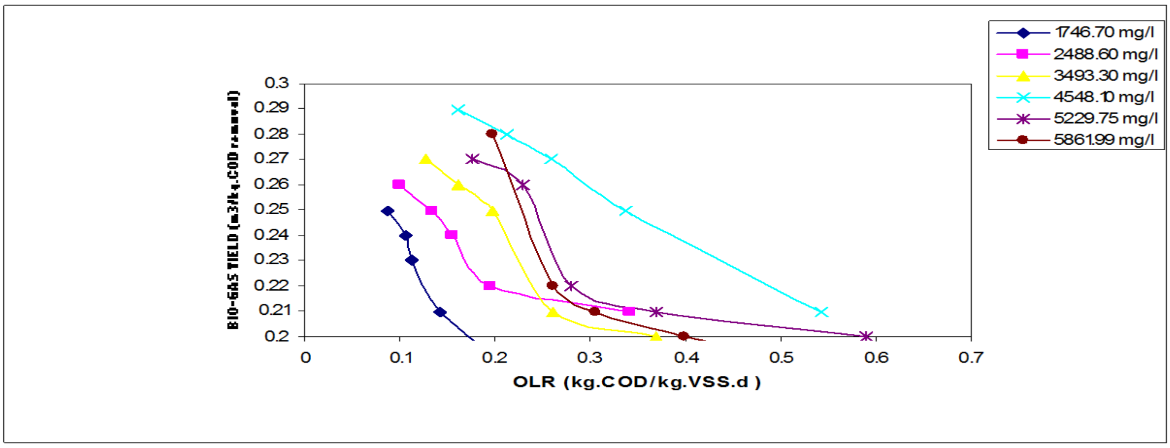

Fig 9: OLR Vs bio–gas yield for various influent COD concentrations and HRTs for UASB reactor

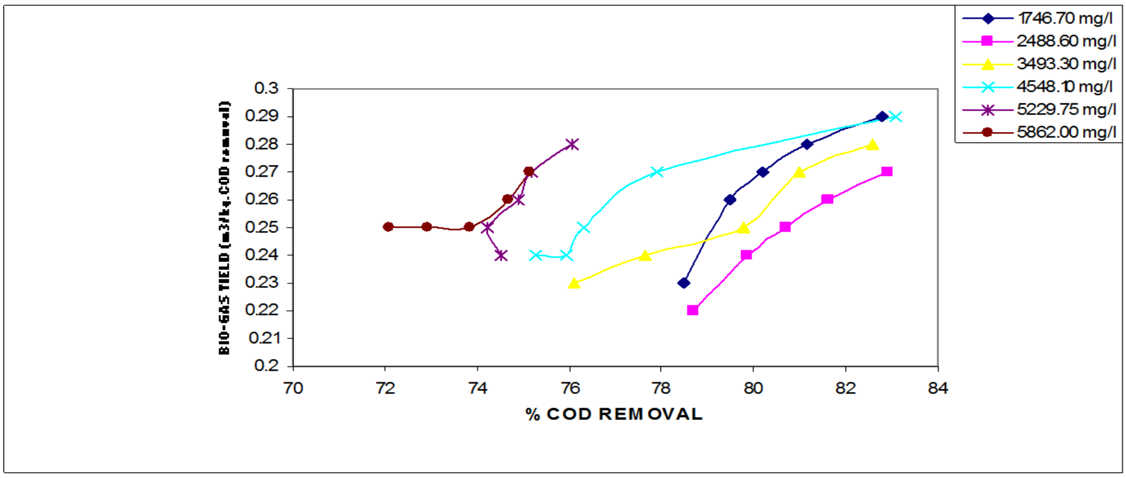

Fig 10: COD removal (%) Vs Bio-gas yield for various influent COD Concentrations and HRTs for HUASB reactor

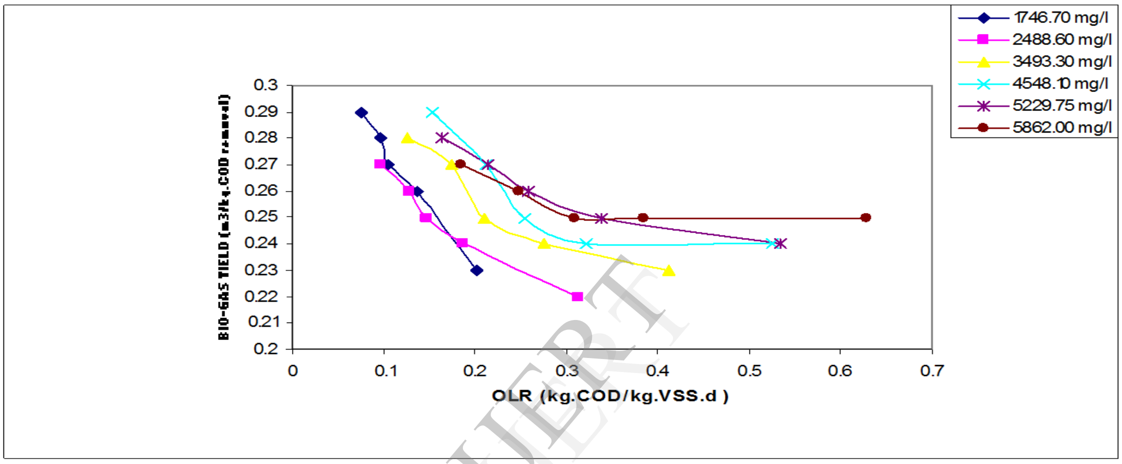

Fig 11: OLR Vs Bio-gas yield for various influent COD Concentrations and HRTs for HUASB reactor

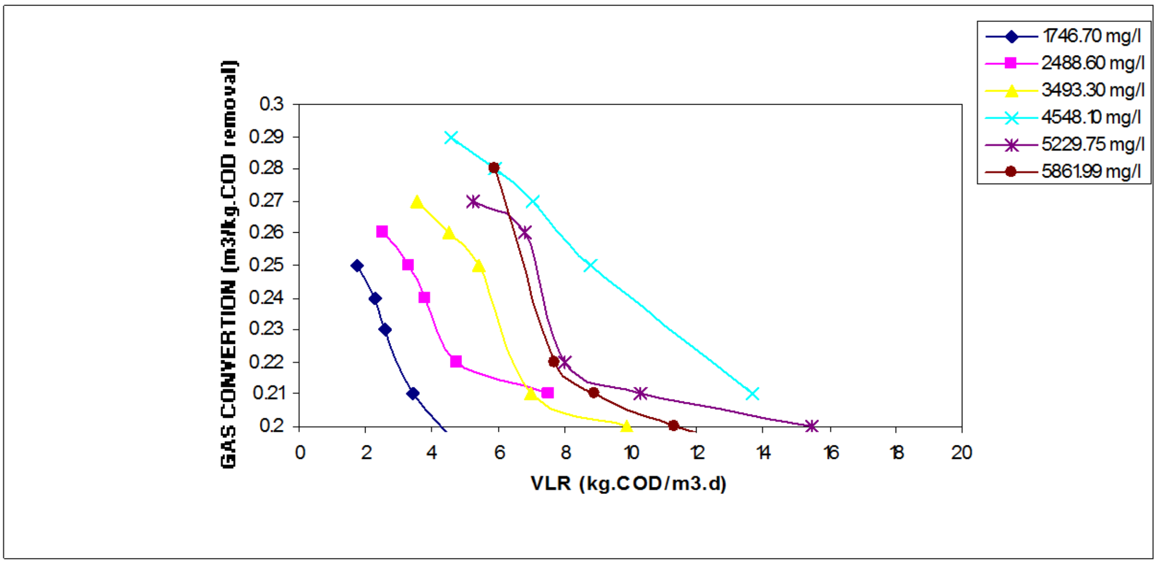

Fig 12: VLR Vs bio–gas yield for various influent COD concentrations and HRTs for UASB reactor

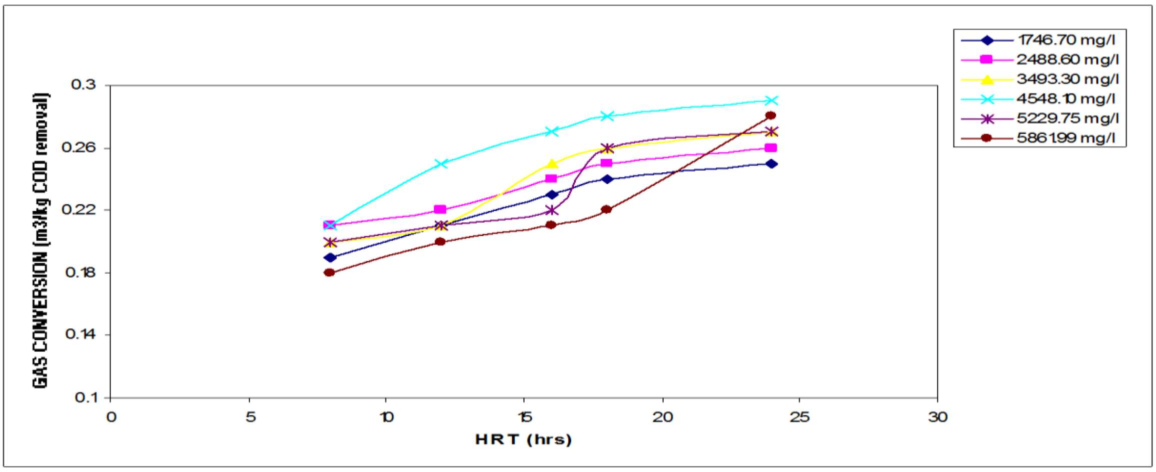

Fig 13: HRT Vs bio–gas yield for various influent COD concentrations and HRTs for UASB reactor

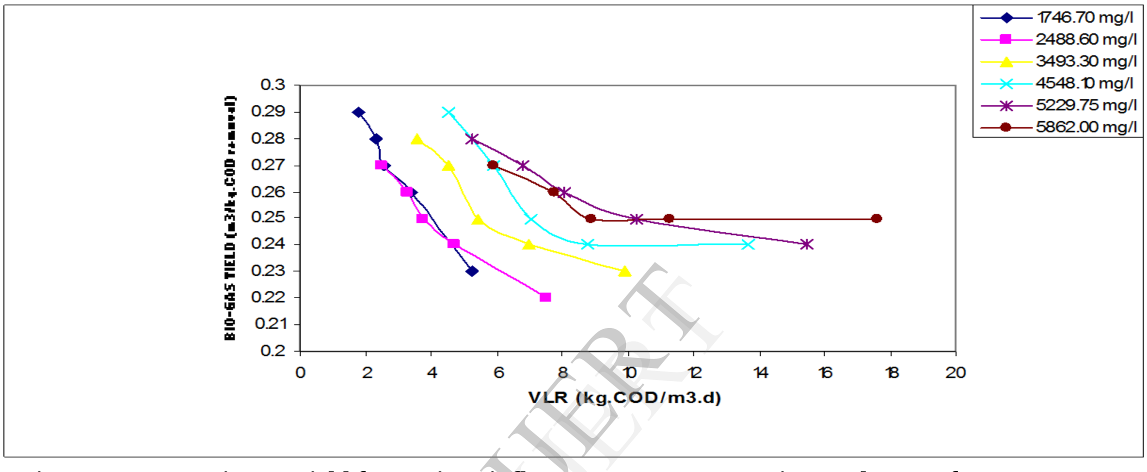

Fig14: VLR Vs Bio-gas yield for various influent COD Concentrationsand HRTs for HUASB reactor

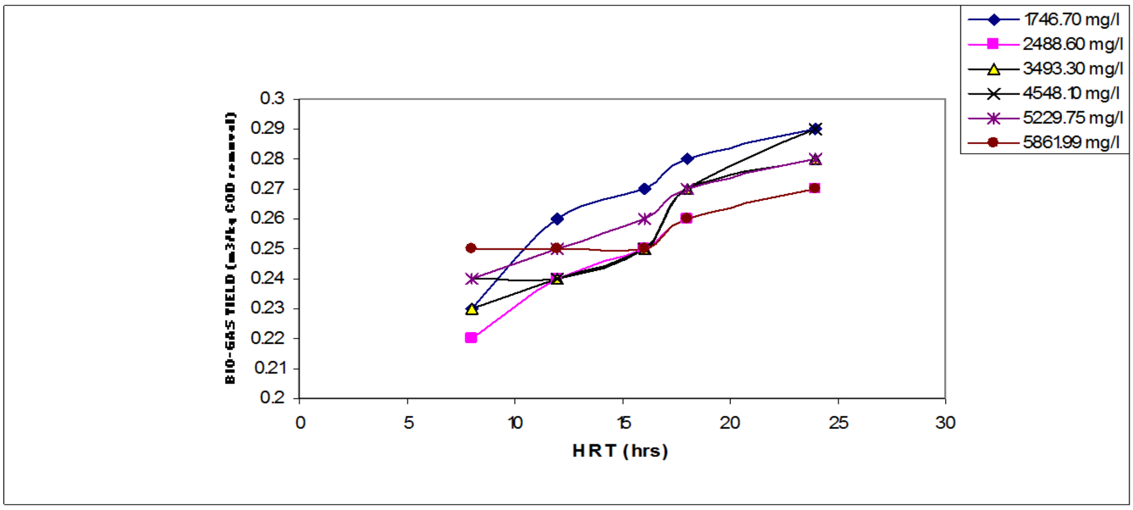

Fig 15: HRT Vs Bio-gas yield for various influent COD Concentrations and HRTs for HUASB reactor

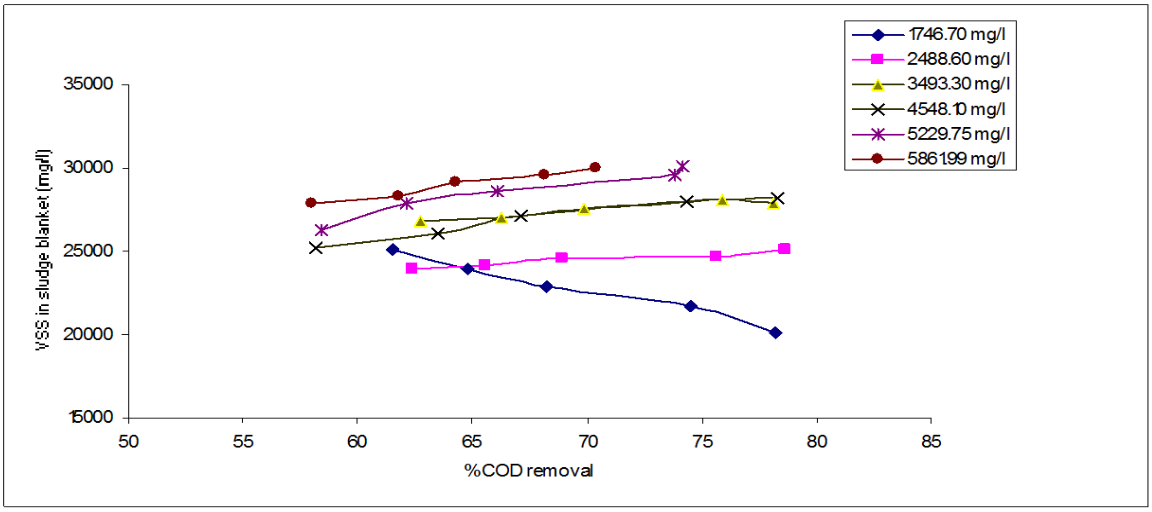

Fig 16: COD removal (%) Vs VSS for various influent COD concentrations and HRTs for UASB reactor

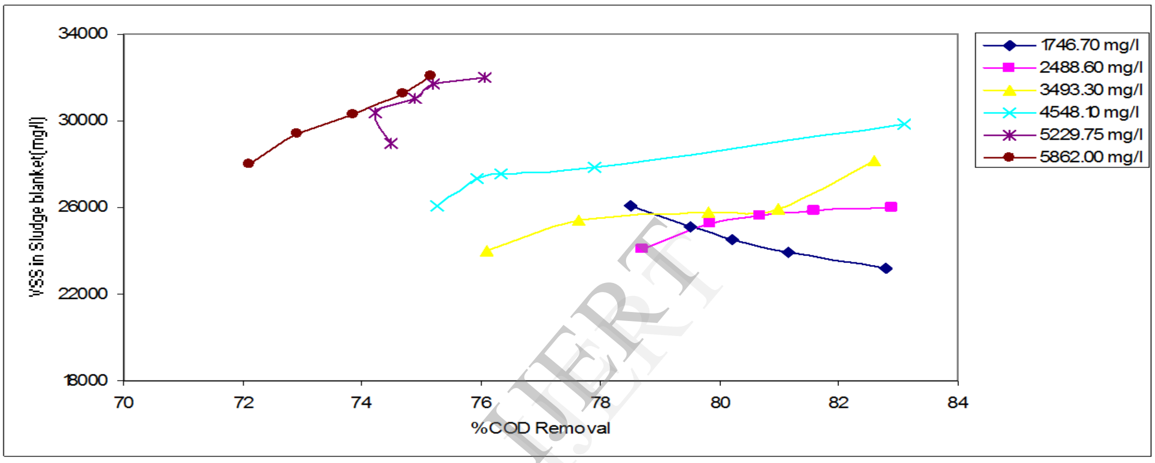

Fig 17: COD removal (%) Vs VSS for various influent COD Concentrations and HRTs for HUASB reactor

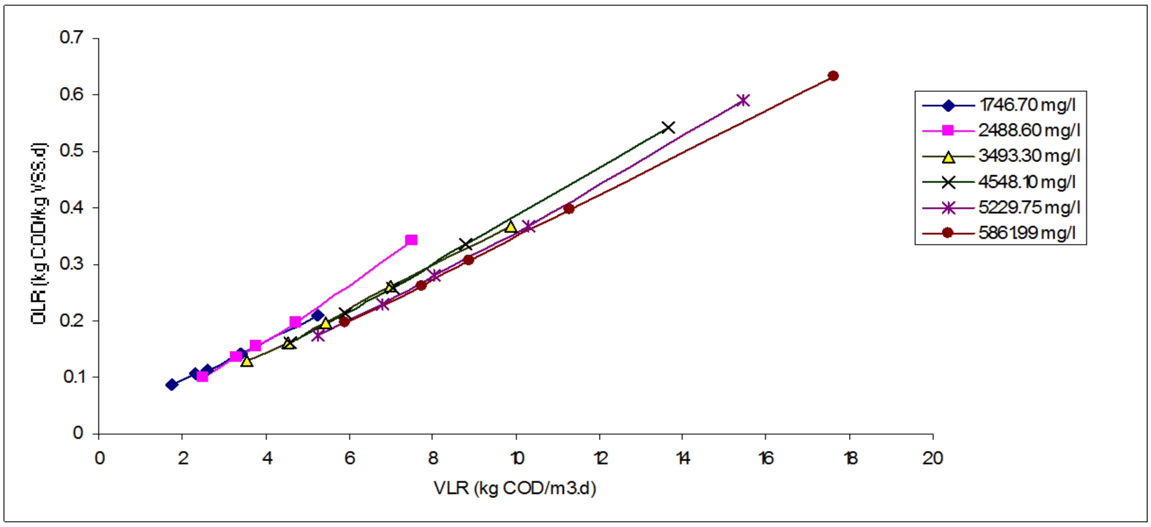

Fig 18: VLR Vs OLR for various influent COD concentrations and HRTs for UASB reactor

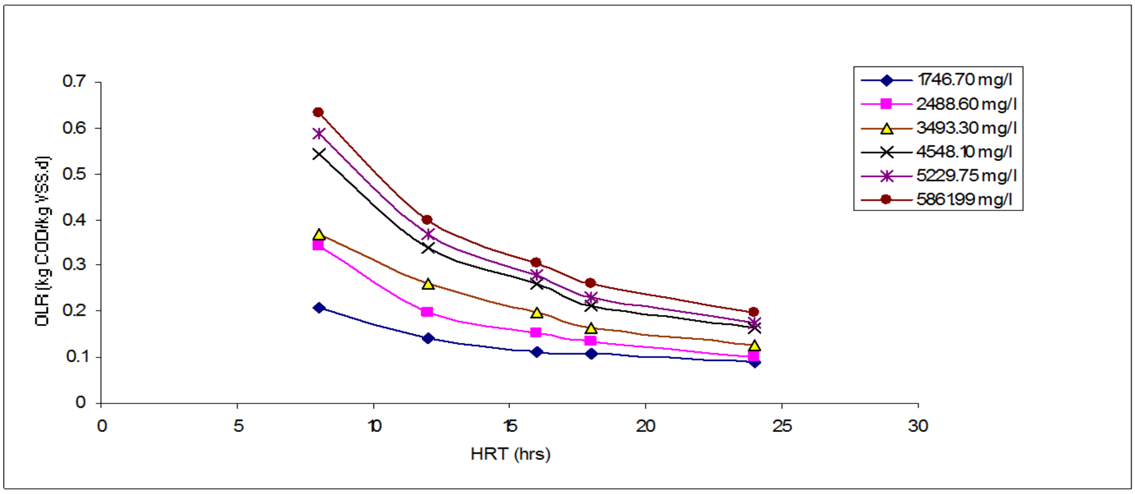

Fig 19: HRT Vs OLR for various influent COD concentrations and HRTs for UASB reactor

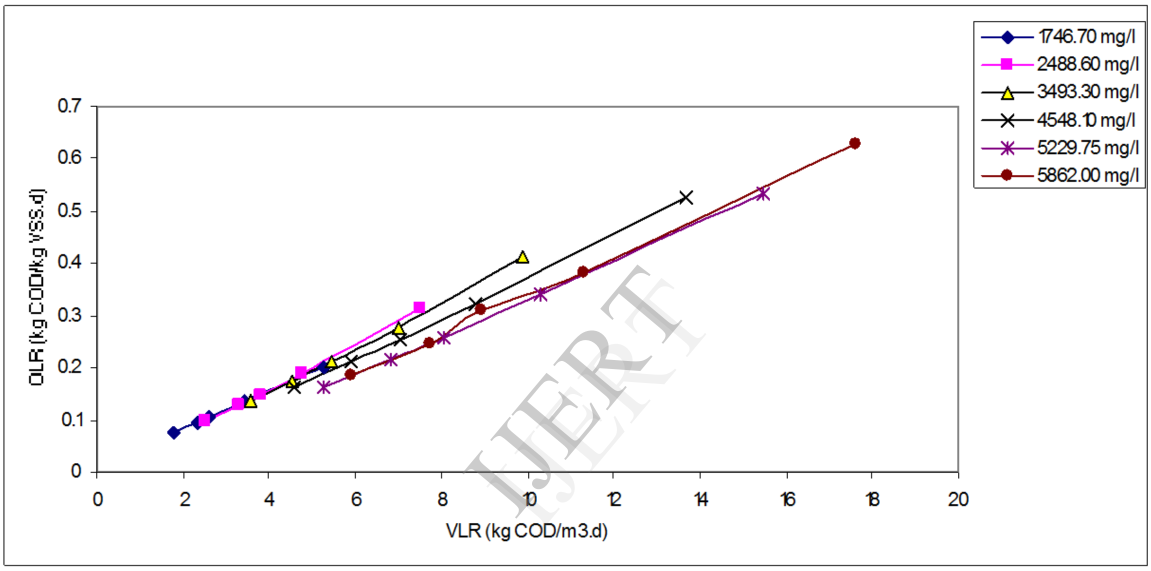

Fig 20: VLR Vs OLR for various influent COD Concentrationsand HRTs for HUASB reactor

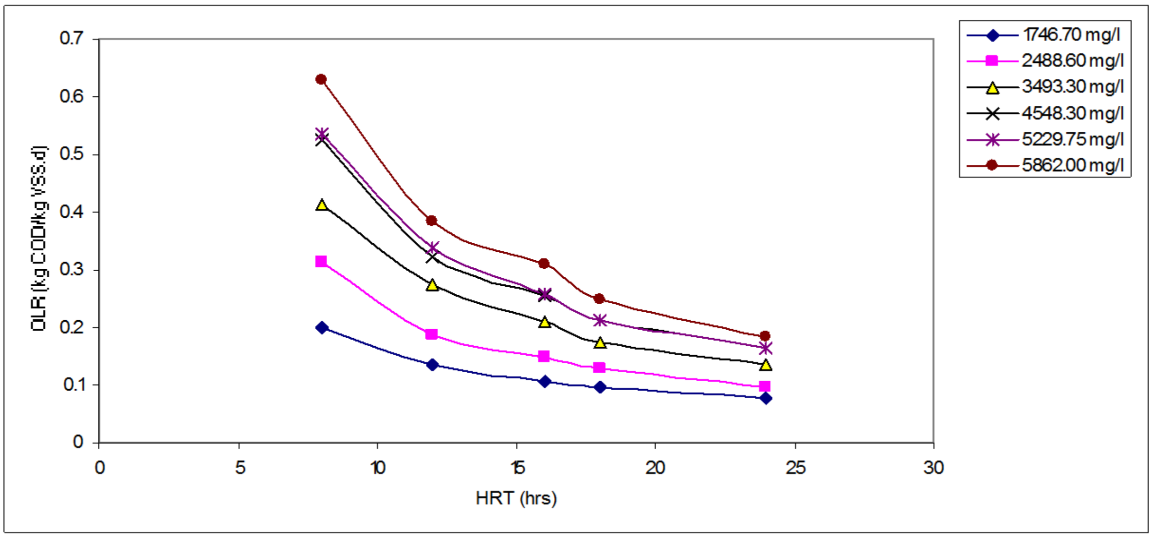

Fig 21: HRT Vs OLR for various influent COD Concentration and HRTs for HUASB reactor