V EXPERIMENT RESULT & DISCUSSION

5.1 Wastewater Characteristics

The characteristics of the wastewater generated from this slaughterhouse from the analysis were not typical. They were not as high in COD concentration as initially expected. This is probably because the pollution load was reduced by holding back in the manufacturing substances, i.e. from offal processing and blood collecting. Furthermore, the wastewater was more diluted by excessive water consumption. Infiltration also affected the quality of wastewater. Consequently, mixed streams of wastewaters showed significantly reduced concentrations. Even so, some activities, e.g. killing and rendering still produced quite a high organic load.

The feed wastewaters were passed through the air flotation unit for suspended particles and grease removal. After which, dispersed particles larger than 1 mm. were removed by the drum screen. Average values of wastewater after passing the floatation unit were shown in Table 5.1.

The pH of the wastewater was always slightly higher than neutral, which presented no problem for anaerobic treatment and no chemicals were necessary for neutralizing.

The climatic temperature range of 29°C to 31°C was also in the proper range for treatment by anaerobic process, and it was possible therefore to treat wastewater at ambient temperature. McInerney and Bryant (1979) illustrated that the organisms were divided into two main temperature groups ; the thermophilic group which was active between 45°C - 70°C and the mesophilic group from 20°C -40°C. As for pH, the optimum was about 7.0, the range being 5-8. Souza (1986) stated that anaerobic process occured at an acceptable rate between 15 and 35^{o}C and at a relatively high rate between 30 and 40^{o}C.

Table 5.1 Wastewater Characteristics After Floatation Unit

Parameter	Range	n	max/min	x	n-1
pH	7.2 - 7.9	9	1.1	7.6	0.2
Temperature (^{o}C)	29.4 - 31.5	9	1.1	30.3	0.9
BOD_5 (mg/1)	107 - 538	9	5.0	239	131
COD (T) (mg/1)	206 - 1027	9	5.0	484	261
COD (F) (mg/1)	98 - 492	9	5.0	218	119
Alkalinity (mg/1 as $CaCO_3$)	130 - 284	9	2.2	209	52
Suspended Solids (mg/1)	95 - 286	9	3.0	160	80
Volatile Suspended Solids (mg/1)	37 - 79	9	2.1	47	23
VSS/SS	0.3 - 0.4	9	1.3	0.4	0.05
Total Kjeldhal Nitrogen (mg/1 as N)	76 - 195	9	2.6	127	44
Ammonia Nitrogen (mg/1 as N)	32 - 44	9	1.4	37	3.7
Total Phosphorus (mg/1 as P)	7.9 - 11.9	9	1.5	9.4	1.3
Ortho Phosphate (mg/1 as P)	5.2 - 9.1	9	1.8	6.7	1.1
Grease and Oil (mg/1)	65 - 104	8	1.6	82	18

Note : These characteristics were monthly random of raw wastewater after passed flotation unit during 9 months of experiment study but the wastewater being used in the experiment was more processed by screening and regularly sampling 3 times a week.

BOD_5 and COD showed the ratio of 0.5 which means the wastewater was highly biodegradable and suitable for treatment by biological process.

Suspended solids seem to be rather high. Nevertheless, considering the high volatile suspended solids, the wastewater still had high opportunity to be treated biologically due to its high degradability. The average ratio of VSS to SS was approximately 0.4. Sayed et al. (1984) successfully treated slaugterhouse waste which contained high suspended solids without preliminary sedimentation.

Nitrogen and phosphorus were undoubtedly high in the protein enriched wastewater. It was rich in macronutrients needed for anaerobic treatment, for this slaughterhouse the ratio of COD : N : P was approximately 100 : 10 : 1.

Iza et.al. (1991) summarized the characteristics of the anaerobic process at the workshop held in Valladolid, Spain stating that for nutrients, the wastewater must be characterized with respect to its macronutrient content. Ideally, the C : N : P ratio should be in the range 100 : 1-10 : 1-5. Souza (1986) described that the nutrients N and P should be provided in the ratio of COD : N < 70 and COD/P < 350, otherwise treatment in the reactor was not impeded.

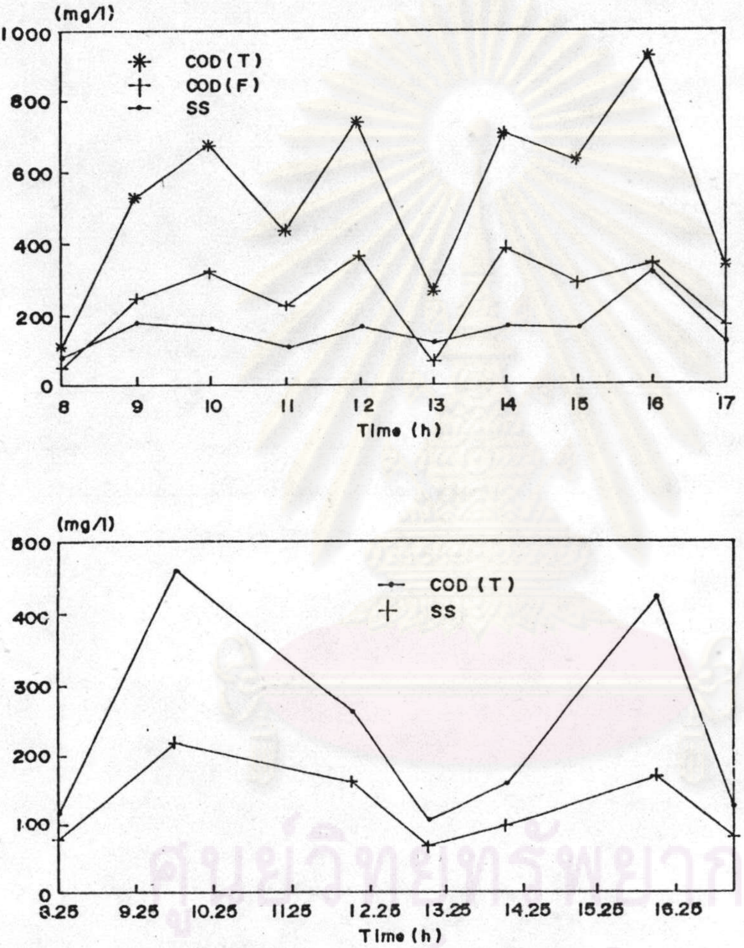
Grease and oil also showed high values but not seriously so.

5.2 Fluctuation of Wastewater Concentration

Fluctuation in organic concentration due to a variety of processes during the day made it difficult to identify the water quality, and also to verify the treatment process efficiency. To cope with this problem, it is important to note that all samples have been taken by composite samples, except on site measuring for physical and variable values like pH and temperature.

Nevertheless, the number of animals slaughtered still caused the problem of high fluctuation from day to day. Hogs killing was a regular event but no exact amount was attainable. Together with cattle killing, which took place once a week and on Buddha day which might be also once a week, there were 3 different catagories of wastewater characteristics; high, moderate and low concentrations, based on both cattles and hogs killing, hogs killing only and no killing respectively.

Results obtained from grab sampling of wastewater during working hours are shown in Fig. 5.1. It is evident that the COD of wastewater during working hours varied. Two peaks were found, one in the morning around 9.00 to 9.30 a.m. and another in late afternoon between 3.00 to 4.00 p.m. The difference between COD on cattle killing day and hogs killing day is also shown.



Condition :
hogs and cattles
being processed

Condition :
only hogs being
processed

Figure 5.1 Wastewater Concentration During Working Hours.

The equalization tank could not be a solution to this problem due to its vulnerability to septicity. After being tested by pumping the wastewater into a 12 m^3 tank (used as an equalizing tank) for one day, it was found that the outcoming wastewater COD concentration was reduced. The pre-acidification which was unfavourable was likely to occur. Pre-acidification would be benificial in case specific toxic or obnoxious compounds were present in the wastewater, i.e., sulfite or compounds that would promote sludge flotation and foaming (Lettinga and Pol, 1986).

Lettinga and Pol (1991) reported that apart from the need to equalize the high variations in the flow and/or the pollution strength of the wastewater, an additional reason for installing an equalization tank in an anaerobic wastewater treatment scheme was to achieve the desirable extent (i.e. 10-20%) of pre-acidification. The installation of such a device might become particularly beneficial for higher strength wastewaters, e.g., COD values exceeding approximately 10 g/l. Hickey et al. (1991) stated that at least partial acidification occurs in the influent storage or equalization tank prior to the anaerobic reactor without any encouragement, or attention to foster this occuring.

Moreover, the shortage of hogs production in Thailand since September, 1991 affected the whole experimental data. The amount of hogs slaughtered decreased from 400 heads at the start of this research to 150 during the middle stage of the investigation. By the end of the study, slaughtering days had decreased from 6 days to 3-4 days a week.

5.3 Influent Distribution

Organic loads fluctuated with respect to the 3 catagories; both hogs and cattles killing, hogs killing and no killing. As a result, the concentration of wastewater could be classified as high, medium and low, respectively.For this study, high concentration ranged between 600-900 mg/l COD, medium 300-600 mg/l and low with lower than 300 mg/l. The COD distribution curve of the whole influent samples which collected after screening during experiment period is shown in Fig.5.2.

It was found that most of the samples were of the medium to low range (or about 200-400 mg/l.) which conformed to the operation function of this slaughterhouse, since medium range was hogs slaughtering which took place at least four times a week whereas others were only once a week. The interesting feature was the data range of 200-400 mg/l where COD occupied 50% of the whole data,which means that this kind of wastewater had as low a concentration as domestic wastewater which is said to be 200-300 mg/l COD.

When the probability of influent result was calculated, it was found that the 50% and 90% probabilities of the influent COD were 300 and 600 mg/l, respectively. The probability of the influent was shown in Fig.5.3.

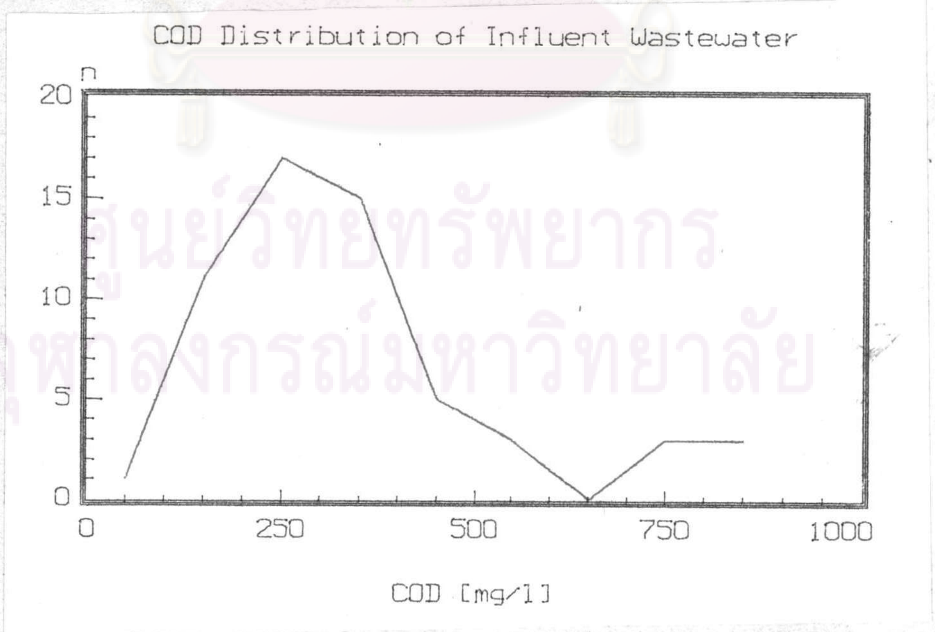


Figure 5.2 Distribution of Influent Wastewater

Note : 63 samples of wastewater were taken during study period

5.4 Process Start-up

Both processes were started-up in June, 1990. Sludge, brought from Burirum distillery plant where the pilot plant was previously located, was used as seeding. The amount of seeding sludge was approximately 11% and 16% for fixed-bed and RAUS respectively.

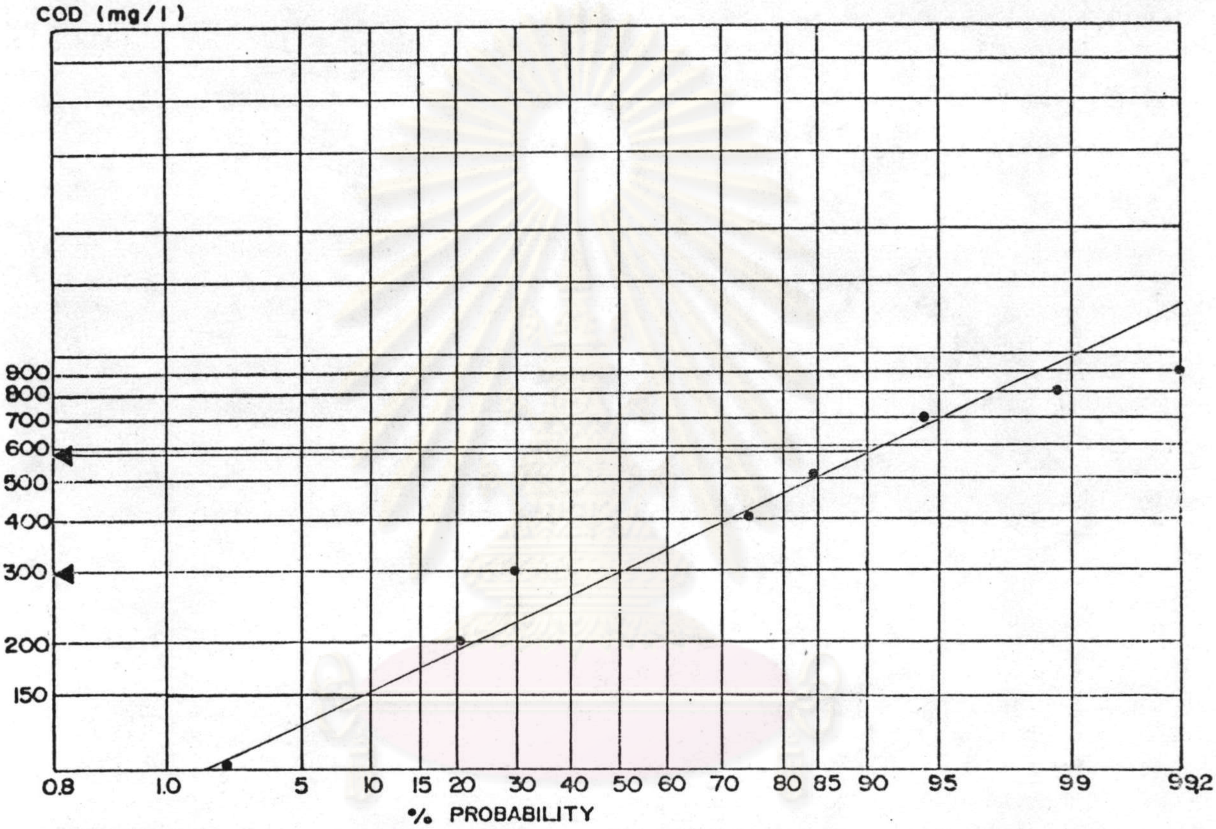


Figure 5.3 Probability of COD in Influent Wastewater

Souza (1986) reported that a quantity of granular sludge which occupied 10% to 15% of the total reactor volume was enough to guarantee the success of the start-up.

5.4.1 Anaerobic Fixed-bed Reactor

The anaerobic fixed-bed reactor had been started with the flow rate of 0.14 m^3/h at Burirum by others (GTZ, 1991). The hydraulic retention time which was calculated from the ratio of effective volume of the reactor (3.4 m^3) to the flow rate was 24 h. The volumetric organic loading rate was 0.6 kg/(m^3.d). After 3 weeks, acclimatization was gained. The COD removal efficiency showed high performance as seen in Table 5.2.

Young & Dahab (1982) stated that during a period of maturing, microorganisms responsible for waste decomposition and methane formation became attached to the media surfaces or accumulated in the interstitial void spaces by the combined action of flocculation and settling. Tests have shown that this period ranged from 3 to 10 weeks depending on method of seeding.

After success with microorganisms growth, the flow rate was gradually increased as shown in Fig.5.4. When this study was commenced, the process had been already in operation for 1 year with a last flow of 0.85 m^3/h.

5.4.2 Reversing Anaerobic Upflow System

RAUS was started by others with a flow rate of 0.2 m^3/h (GTZ, 1991). The hydraulic retention time of this case was also calculated from the ratio of effective volume to the flow rate. The effective volume used was the the volume of both reactors added together ($3.4\ m^3 + 2.9\ m^3 = 6.3\ m^3$). The volumetric organic loading rate was 0.3 kg/(m^3.d) with HRT of 32 h. It was more difficult to start RAUS than fixed bed reactor, since the configuration of RAUS contained two reactors which alternated as both reactor and sedimentation tank at certain intervals of time. Obviously, it was necessary to raise the number of active cells in both reactors. The process started with 8 working hours a day. Two hours feeding in the first direction, stop for 1 hour for sedimentation and, finally, 2 hours reversing feed direction, this procedure was repeated 4 times a day when the experiment started. The start-up flow pattern and the effluent quality are shown in Fig 5.4 and Table 5.2, respectively.

Wieland and Rozzi (1991) discussed that the duration of start-up depended on numerous biological, chemical and physical parameters. The start-up was influenced by the wastewater composition and strength, the volume, activity and adaptaion of the inoculum, environmental parameters like temperature, pH, nutrient and trace elements content, operation parameters like loading rate, retention time and liquid mixing and, finally, on reactor configuration geometry and size.

Table 5.2 Water Quality During Start-up

TIME FROM	HRT (h)		INFLUENT COD	EFFLUENT COD		EFF^{cy} (%)	
STARTED	AnFB	RAUS	(mg/l)	AnFB	RAUS	AnFB	RAUS
1 week	24	32	611	427	605	30	1
3 weeks	24	32	1142	458	743	60	35
1 month	16	32	755	255	494	66	34
2 months	8	32	783	296	386	62	51
3 months	8	32	609	234	256	62	58
4 months	8	20	368	170	157	54	57
5 months	7	8	594	224	278	62	53
6 months	7	8	612	238	246	61	60
9 months	7	8	798	301	312	62	62

Source : GTZ Project (1991)

<u>Note</u> : Start-up was already succeeded by staffs of GTZ project before experiment study took place

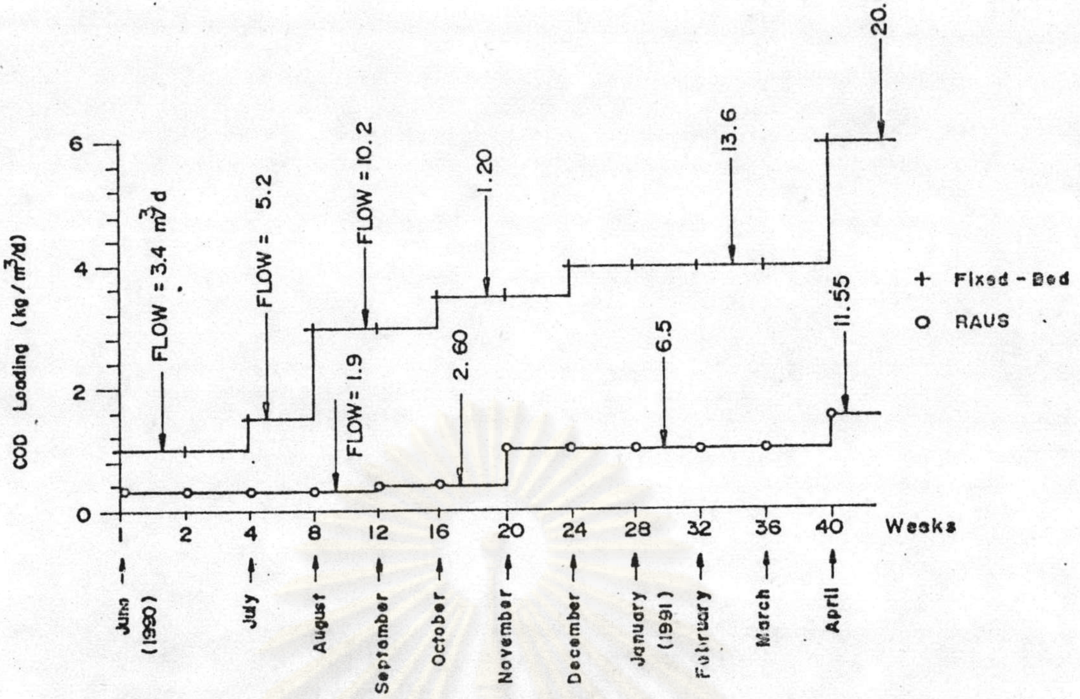


Figure 5.4 Flow pattern during start-up

Source : GTZ Project

Lettinga and Pol (1991) found that when granular seed sludge was used for UASB, the presence of suspended solids in the influent may slow down the growth in the amount of granular sludge.From experiments conducted with slaughterhouse wastewater, it was found that the coarser suspended particles did not exert a serious detrimental effect on the strength of granular seed sludge. On the other hand, the experiments with slaughterhouse wastewater revealed that the presence of colloidal matter might lead to a serious drop in the specific activity of the granular sludge when prolonged higher sludge loading rates were being imposed.

5.5 Process Treatability

5.5.1 COD Treatability

Both processes reacted similarly with fluctuating wastewaters. The effluent COD closely related to the influent COD. On the other hand, high influent COD could induce high effluent COD.Therefore, constant effluent quality could not be seen even at steady state. The influent and effluent COD concentration of the whole experiment are presented in Fig.5.5.1 for fixed-bed reactor and Fig.5.5.2 for RAUS reactors. For easily comparison, the average value of the influent and effluent COD concentration of fixed-bed reactor and RAUS reactors are also shown in Fig.5.5.3 and Fig.5.5.4, respectively.

Owing to a closely related COD influent and effluent, the trend of change could be compared. As such, parallel lines following the same pattern could be seen. The influent COD fluctuated throughout the study period. The value depended on number of animals killed at the time the sample was taken. The difference between total COD and filtered COD is a fraction of insoluble COD in solid form that varied in accordance with wastewater composition.

The effluent COD fluctuated less, especially the filter effluent which always showed the least value and was quite stable. High COD concentration of influent had a greater effect on the effluent quality at high hydraulic loading rate than at low hydraulic loading rate.

COD effluent was sometimes higher than COD influent due to the wash out of biomass, i.e., when 1 m^3/h was applied to fixed- bed reactor.

In Fig. 5.5.1 and Fig 5.5.2, if influent and effluent COD were taken into consideration, it was found that the difference between them, or the removed COD, gradually decreased with increasing flow rate.Thus, the efficiency decreased when higher flow rate or higher hydraulic loading rate was applied.

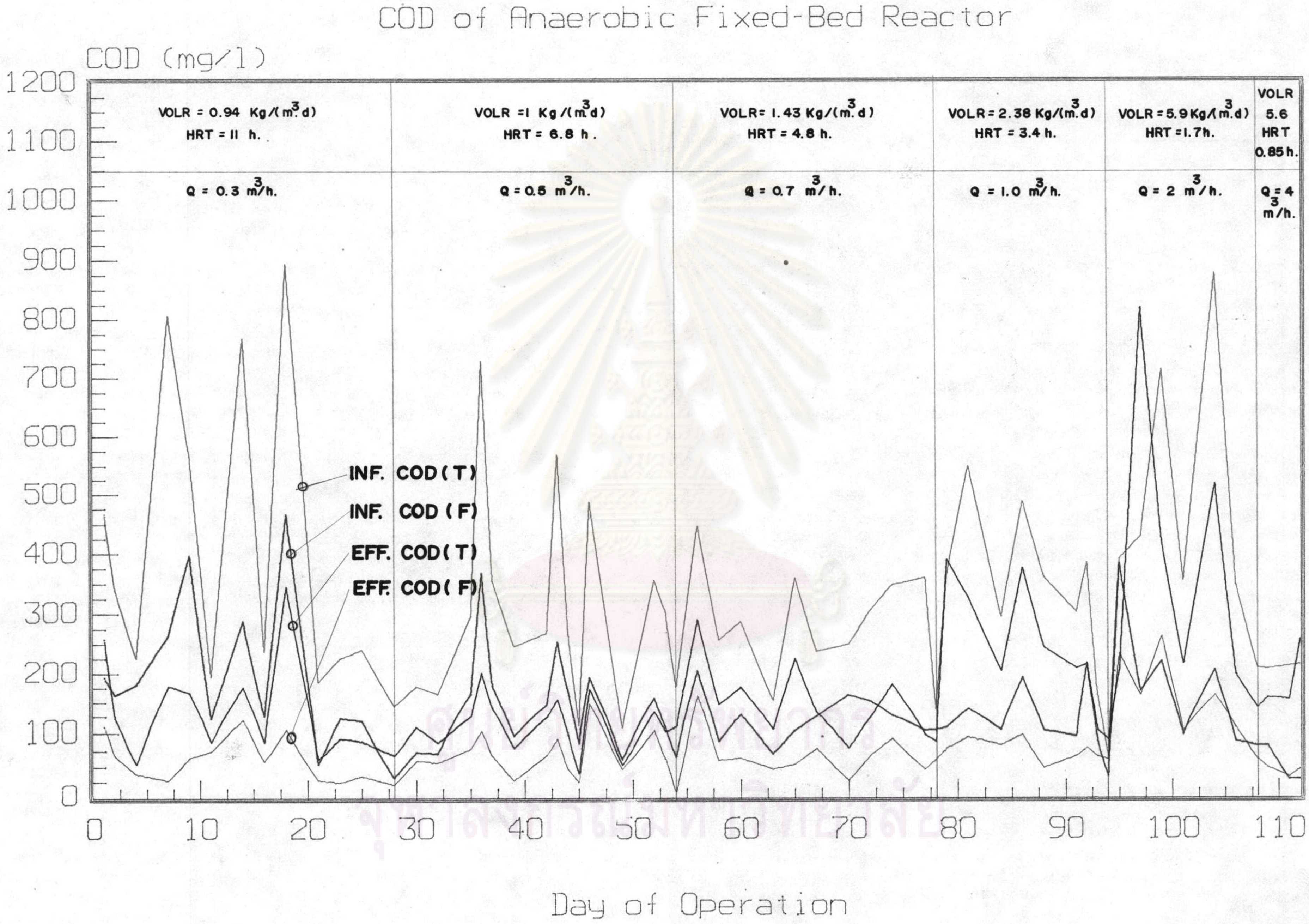


Figure 5.5.1 Influent and Effluent COD of Fixed-bed Reactor

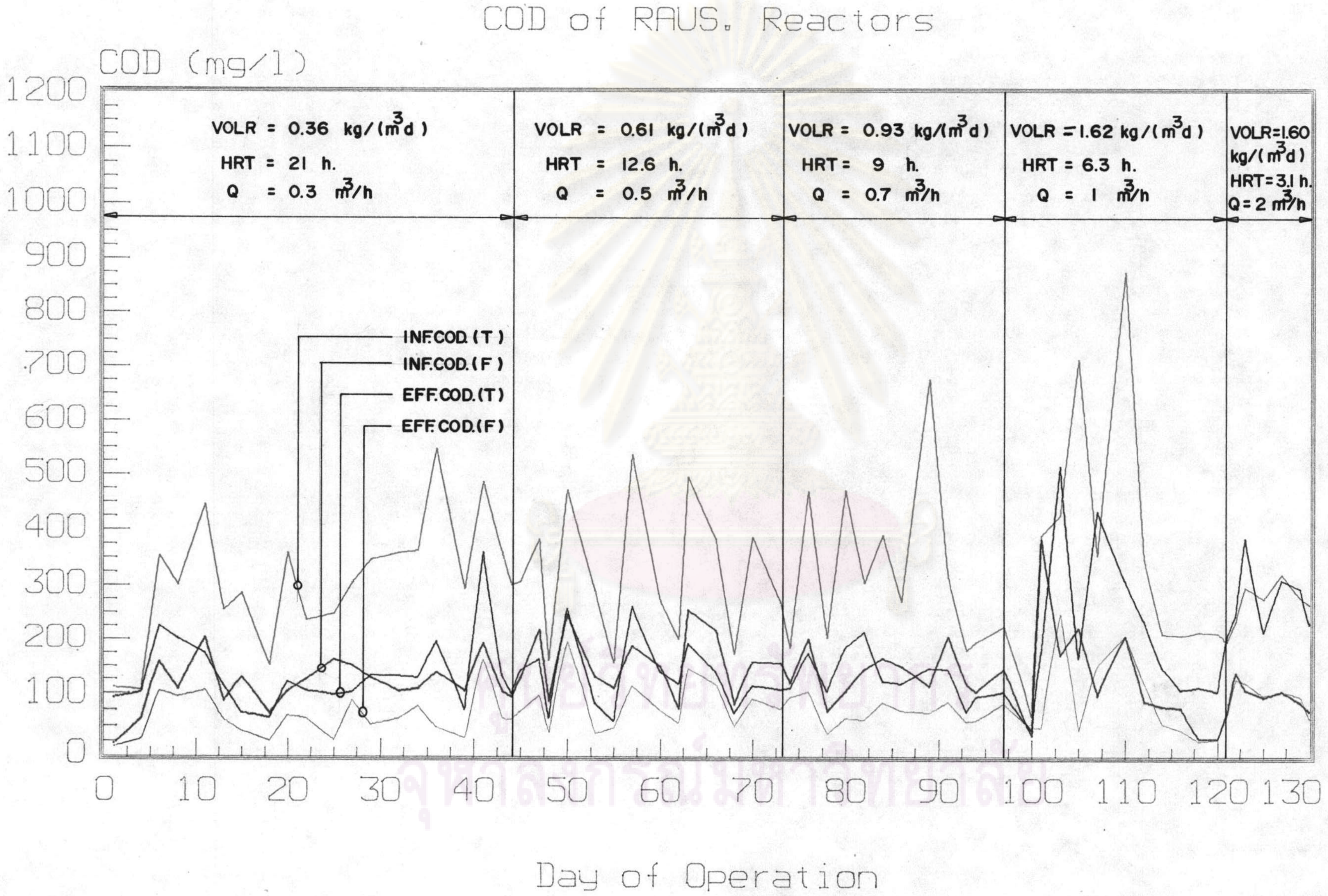


Fig 5.5.2 Influent and Effluent COD. of RAUS

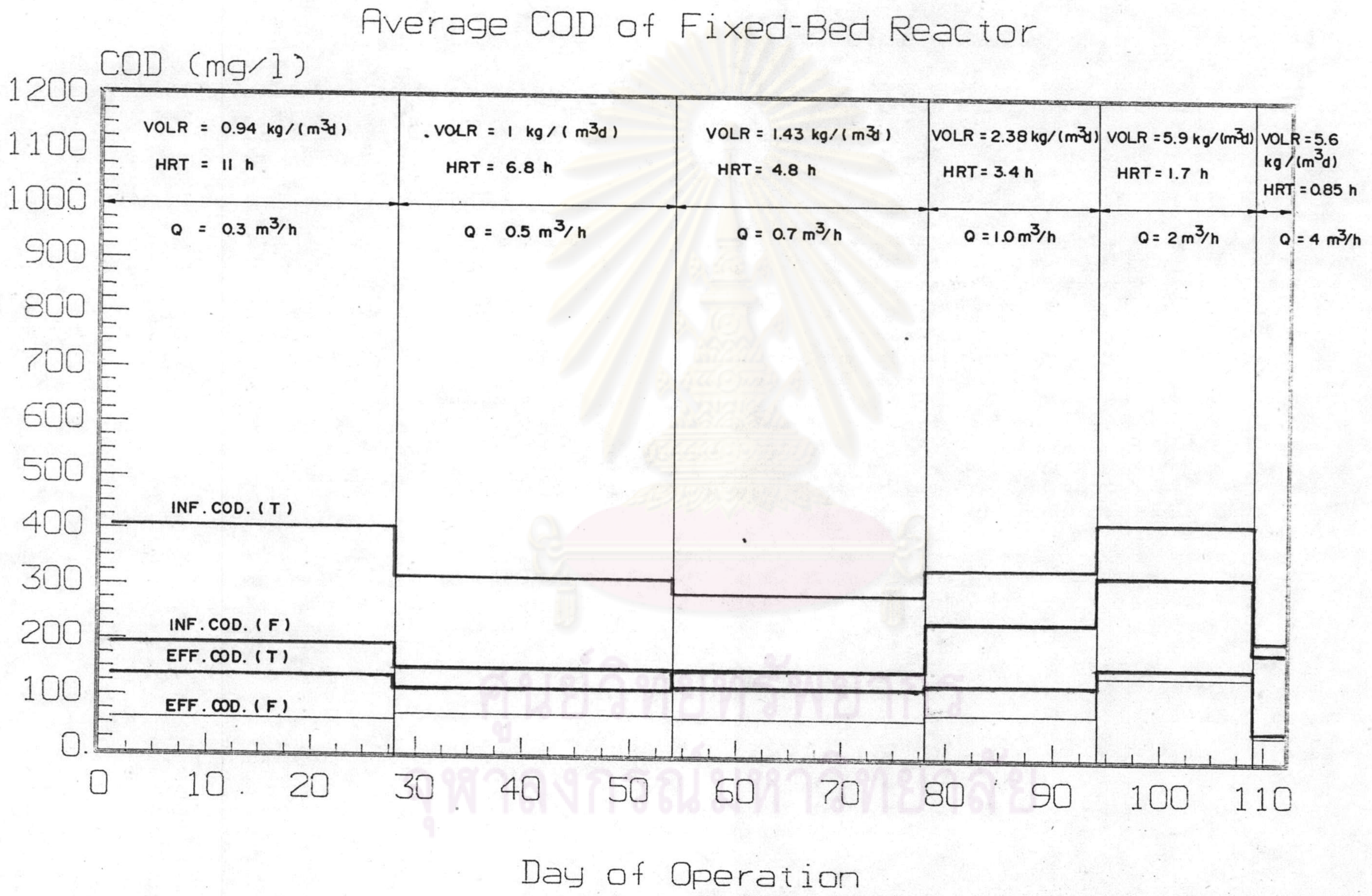


FIGURE 5.5.3 AVERAGE COD. INFLUENT AND EFFLUENT OF FIXED-BED REACTOR

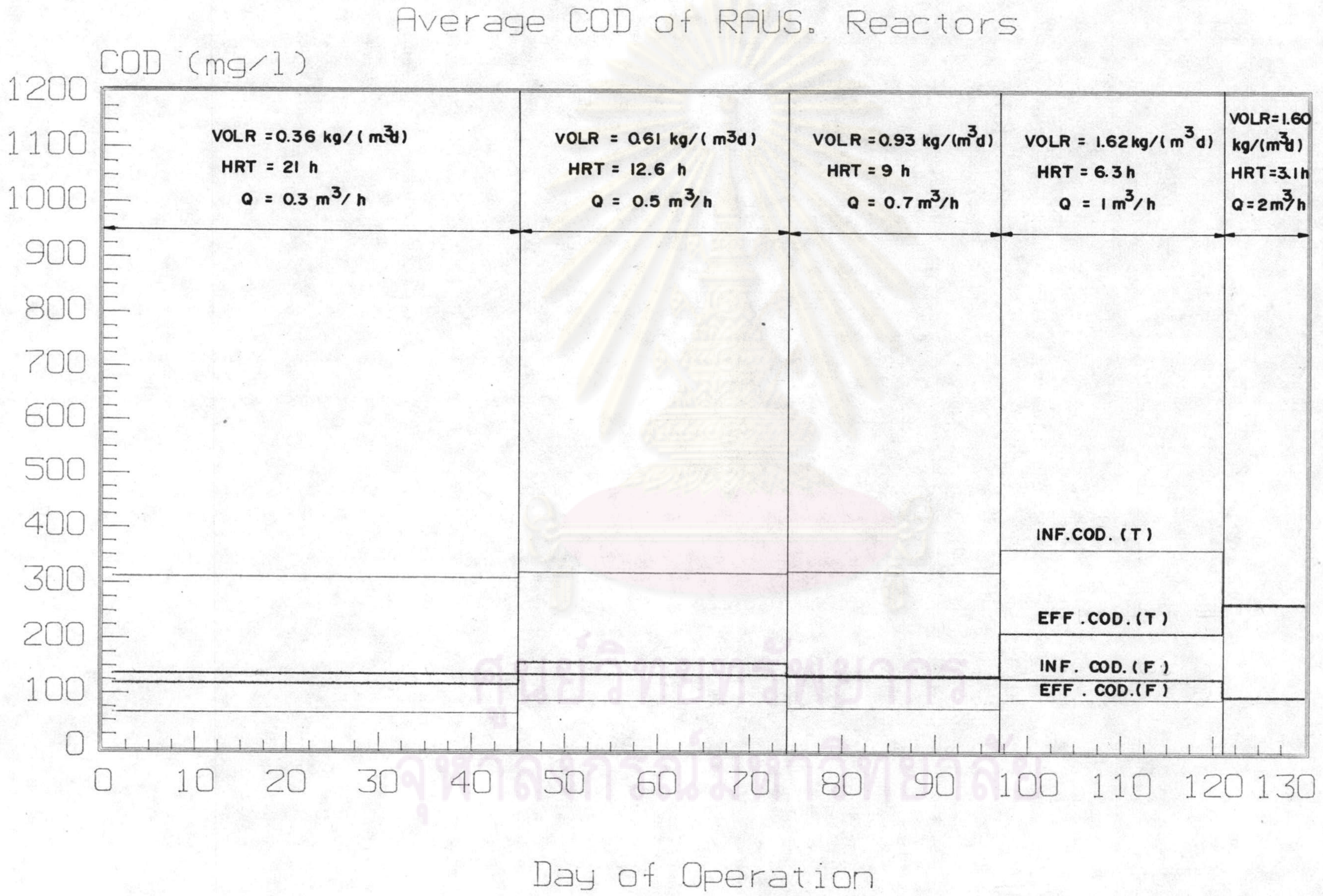


FIGURE 5.5.4 , AVERAGE INFLUENT AND EFFLUENT COD. OF RAUS

Young & Dahab (1982) stated that COD removal efficiency of anaerobic packed bed of a given height and design was inversely related to the hydraulic retention time (HRT) in the void volume within the reactor.

The removal efficiency percentage, which is widely used for presenting process treatability, was not an effective representation for this research. For both processes, the percentage of removal efficiency showed no sign of being constant, as the consistency of both processes would never occur. Fig. 5.5.5 and Fig. 5.5.6 show the percentage of removal efficiency for each process.

In fact, the effluent quality, which was almost stable (except when incoming wastewater was extremely high), could guarantee the stability and consistency of both processes. Nevertheless, average removal efficiency in each HRT can better illustrate the whole feature of research study as seen in Fig. 5.5.7 and Fig.5.5.8.

From Fig. 5.5.7 and Fig. 5.5.8 it should be clearly seen that COD removal efficiency decreased when the hydraulic loading rate was increased. On the other hand, the COD removal efficiency decreased when the hydraulic detention time decreased.

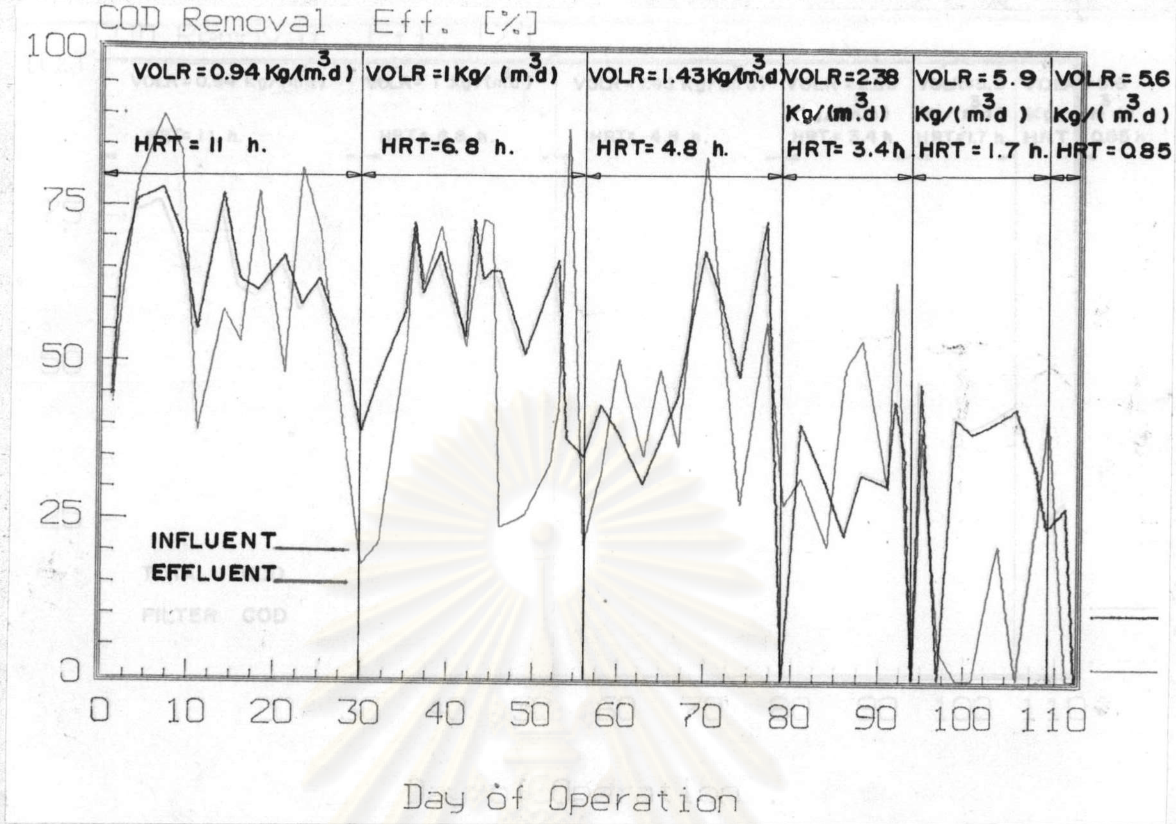


Fig. 5.5.5 Percent Removal Efficiency of Fixed Bed Reactor

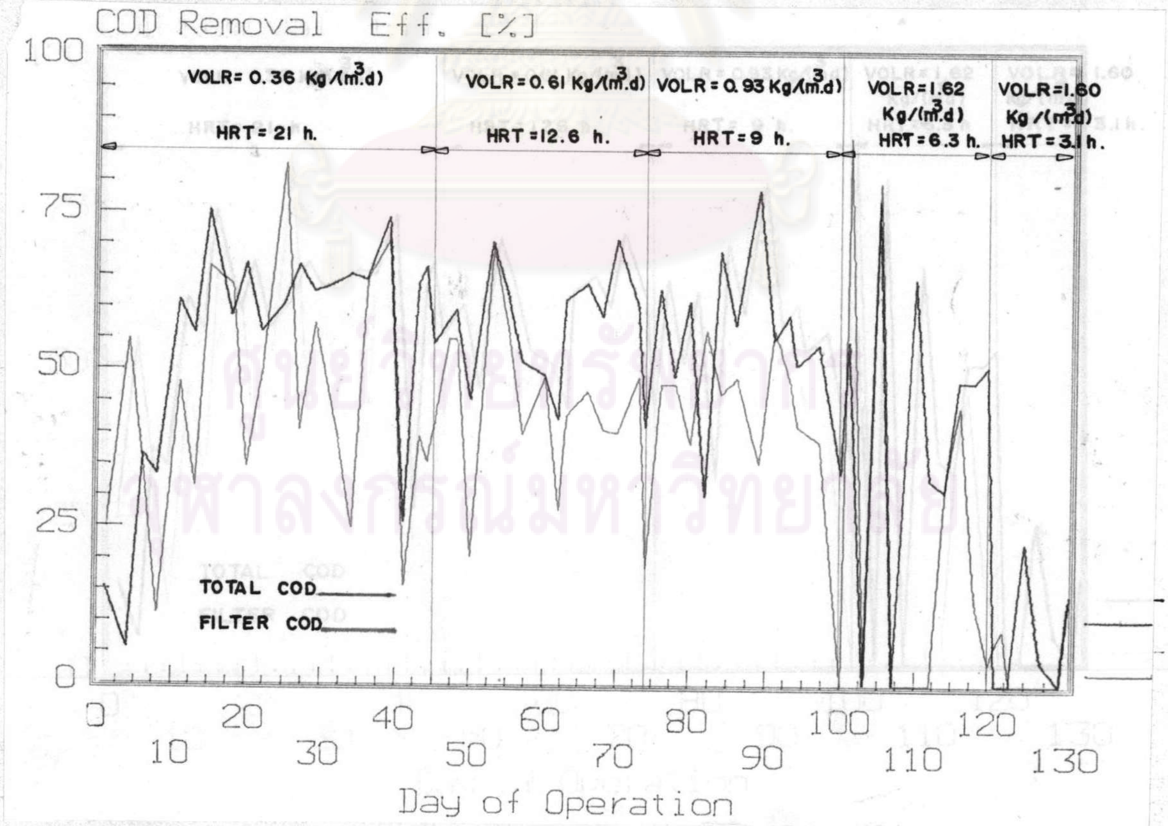


Fig. 5.5.6 Percent Removal Efficiency of RAUS

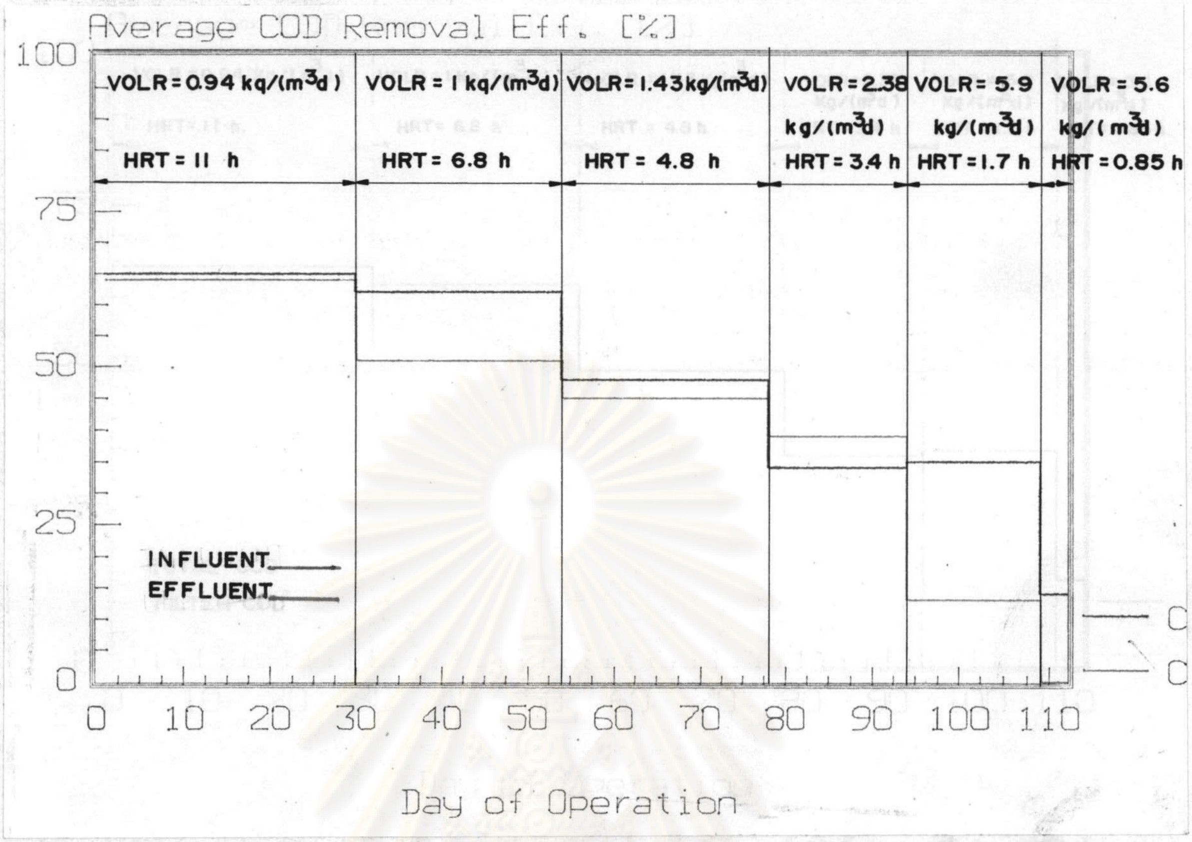


Fig.5.5.7 Percent Average Removal Efficiency of Fixed-bed Reactor

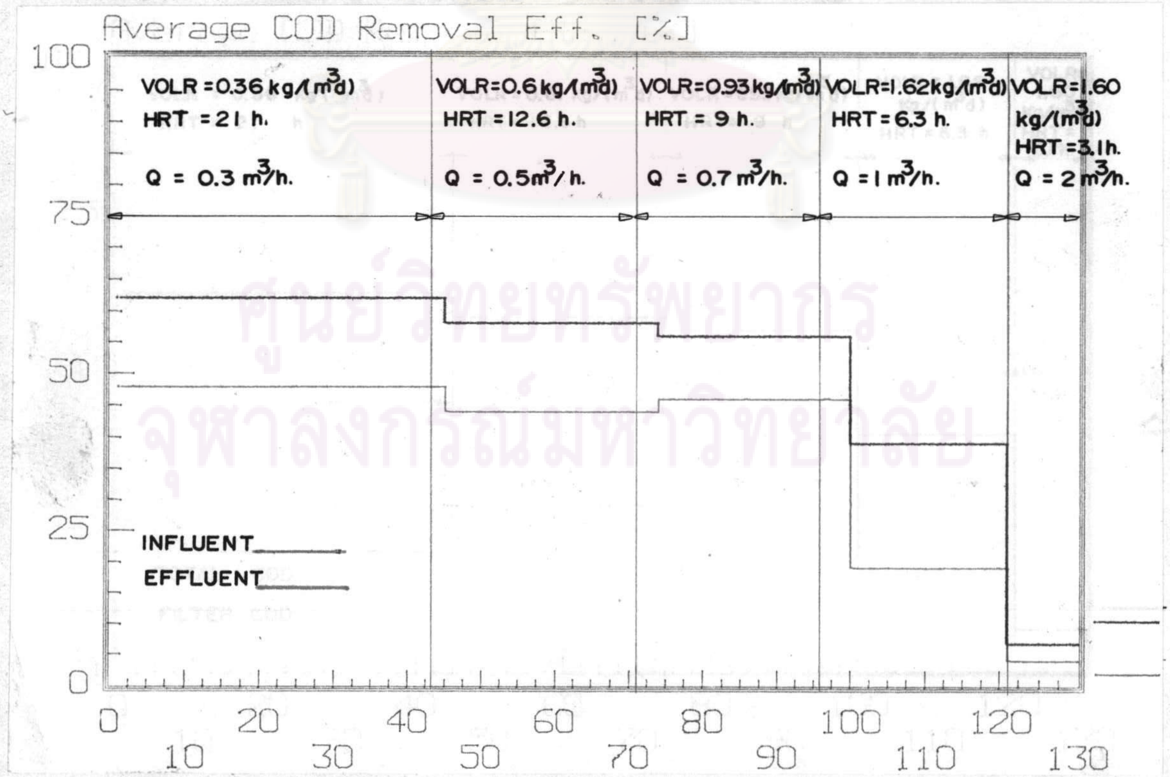


Fig. 5.5.8 Percent Average Removal Efficiency of RAUS Reactors

5.5.2 Solids

Suspended solids in the wastewater were normally in the range of 60-300 mg/l but sometimes oscillated with irregular events.

Souza (1986) described that the smaller the concentration of suspended solids in the wastewater, the less problematical the treatment would be. The maximum acceptable suspended solids depended on the total concentration of organic material in the wastewater. In the case of a low-concentration waste (typical COD 500 mg/l) and which proved to have been successfully treated, the suspended solids concentration reaches low absolute values (approximately 250 mg/l), but high relative values (0.5 g SS/g COD).

For fixed-bed reactor the average concentrations of suspended solids, at different HRT, are illustrated in Table 5.3. Suspended solids in influent and effluent are also shown in Fig. 5.5.9 with an average influent and effluent suspended solids in Fig.5.5.10.

Table 5.3 Average Influent and Effluent Suspended Solids of Fixed-bed reactor

Flow rate (m^3/h)	HRT (h)	VOLR $kg/(m^3/d)$	SS Influent				SS Effluent				%EFF
			min	max	x	n-1	min	max	x	n-1	
0.3	11.0	0.94	60	245	125	56	8	72	38	24	70
0.5	6.8	1.00	52	247	140	63	8	92	49	21	60
0.7	4.8	1.43	79	219	136	49	46	140	82	30	36
1.0	3.4	2.38	26	311	150	79	64	283	162	74	0
2.0	1.7	5.90	60	1868	727	571	96	244	184	43	70
4.0	0.9	5.60	208	868	434	307	64	360	205	121	47

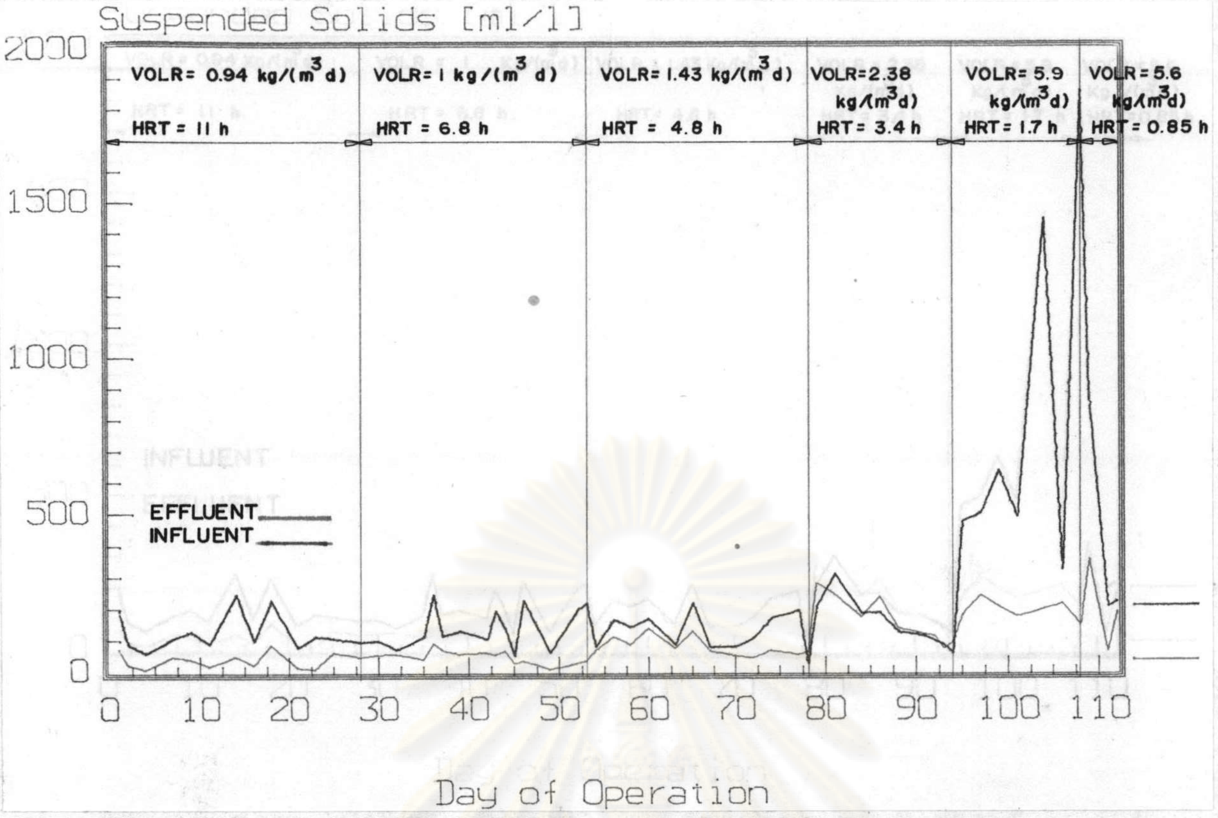


Figure 5.5.9 Suspended Solids of Fixed Bed Reactor

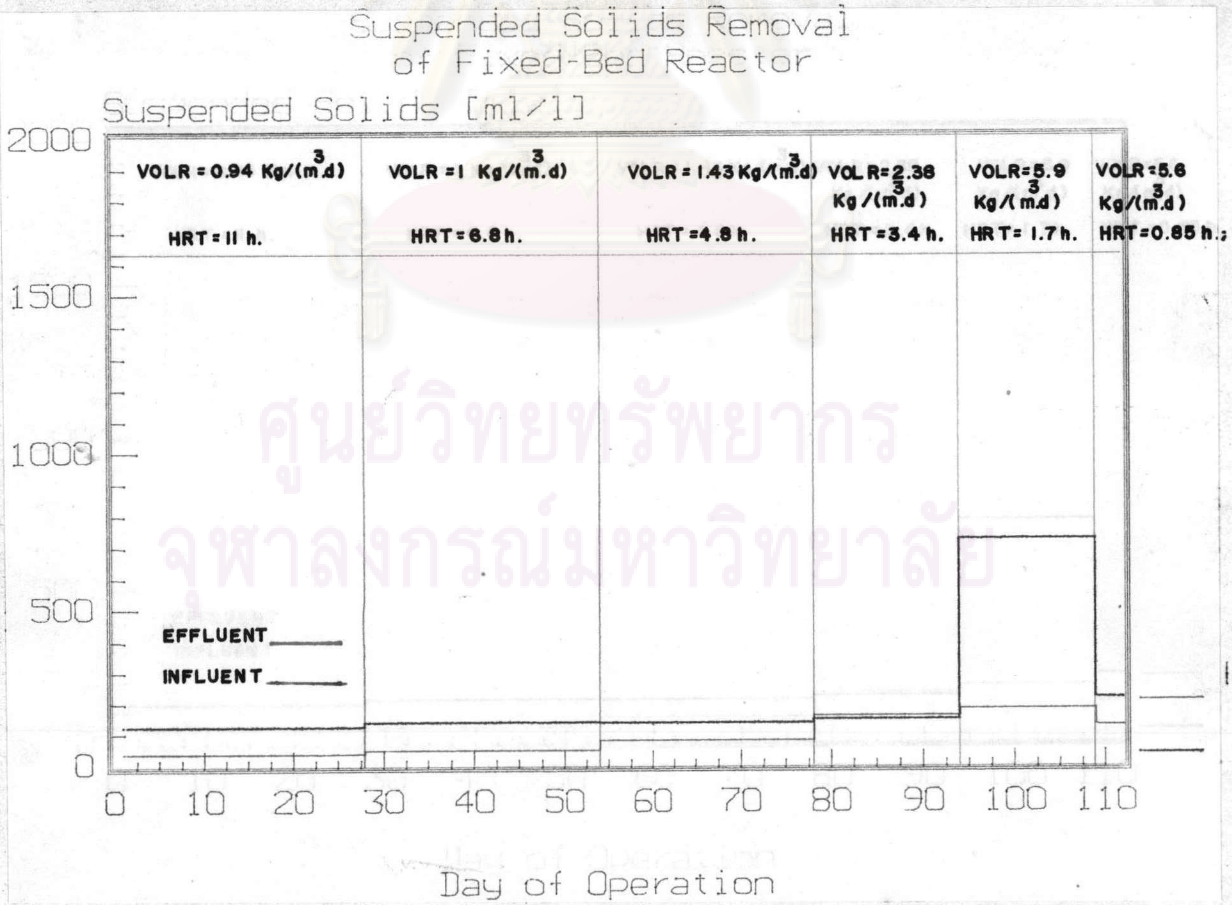


Figure 5.5.10 Average Suspended Solids of Fixed Bed Reactor

From Table 5.3 and Fig.5.5.9, it can be seen that the suspended solids in influent from HRT 11 h. to 3.4 h or a day of operation from 0 to 93, had a range from 26-311 mg/l. This value was in the typical range of this slaughterhouse wastewater. When the influent COD was taken into consideration with SS, the ratio of SS/COD was undoubtedly less than 0.5 g SS/g COD which is supposed to be an acceptable level for treatment by anaerobic process (Souza, 1986).

Fig.5.5.9 shows that the effluent of suspended solids was very low at the begining of the experimental work and higher from time to time. It demonstrated that the reactor worked properly with a high removal efficiency of suspended solids at a long hydraulic retention time and gradually decreased with a shorter hydraulic retention time. Especially at HRT of 3.4 h, the effluent suspended solids seem to be higher than the influent suspended solids. Supported by settleable solids from wastewater effluent in Fig.5.5.11, significantly increasing settleable solids could also be detected at 3.4 h. HRT. It should be concluded that at 3.4 h. hydraulic retention time, biomass washout occured. Thus, automatically affecting the effluent quality. Viewing back to the COD value in Fig.5.5.1, it could be seen that at this washout HRT the effluent total COD also apparently increased, while the effluent filtered COD which was solids free, was normally low.

From the day of operation 94 to 112, the influent suspended solids significantly increased. This phenomenon was caused by less wastewater from the slaugterhouse process, so that backwater from the nearby anaerobic pond connected to the influent sump occured. Consequently, these high suspended solids were not typical for this wastewater. The process could however, still remove these relatively high suspended solids, calculated to be 70% for HRT 1.7 h. and 47% for HRT 0.85 h.

For RAUS reactors, the average influent and effluent suspended solids is shown in Table 5.4.

Table 5.4 Average Influent and Effluent Suspended Solids of RAUS

Flow rate (m^3/h)	HRT (h)	VOLR $kg/(m^3/d)$	SS Influent				SS Effluent				%EFF
			min	max	x	n-1	min	max	x	n-1	
0.3	21.0	0.36	52	311	154	64	20	72	44	16	66
0.5	12.6	0.61	54	368	137	91	23	128	57	27	54
0.7	9.0	0.93	69	543	246	167	28	193	90	52	58
1.0	6.3	1.62	60	1868	646	529	29	403	216	113	57
2.0	3.1	1.60	137	809	561	203	77	487	270	121	52

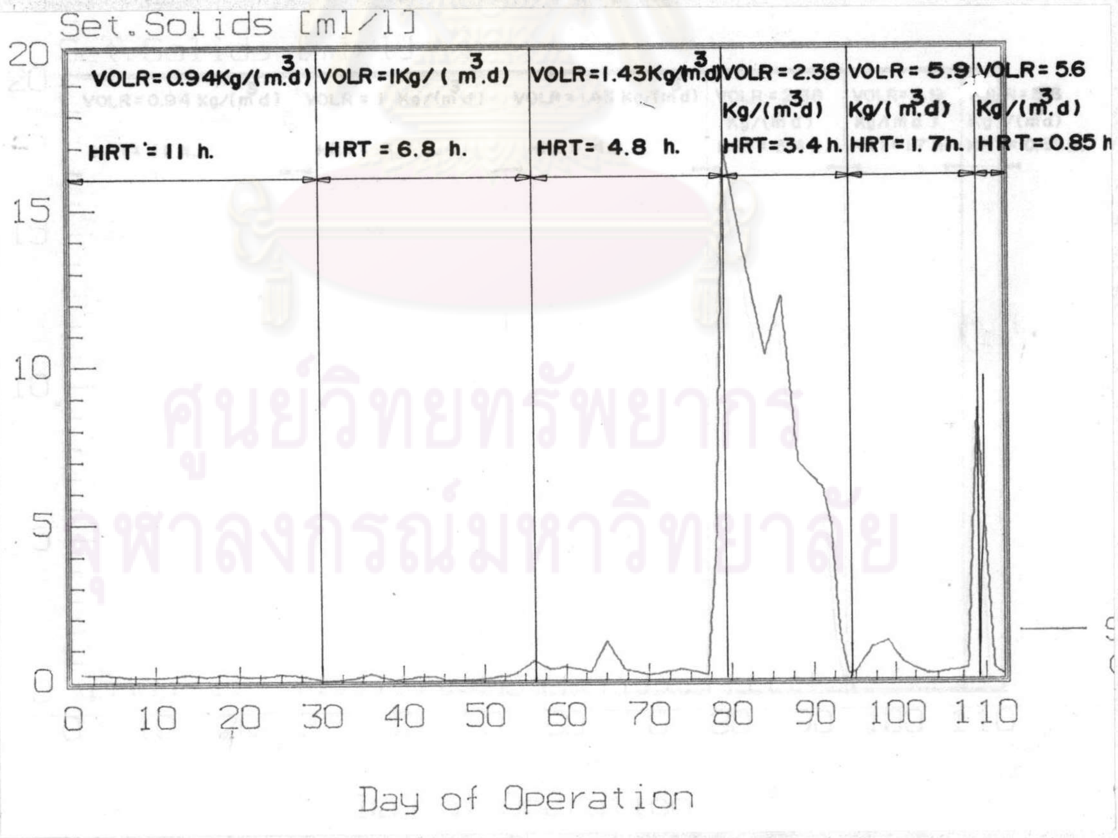


Figure 5.5.11 Settleable Solids of Fixed-Bed Reactor

Souza (1986) stated that there were two criteria which, if occuring simultaneously (SS < 1 g/l and SS/COD < 0.5), would not impede the treatment of the wastewater in a suspended growth anaerobic reactor.

In this case, if the suspended solids in the HRT of 6.3 h. were neglected (the same reason of backwater from anaerobic pond), the influent suspended solids would never reach 1 g/l. The SS/COD ratios which are always less than 0.5 ensure the possibility of treating this amount of suspended solids in the wastewater with RAUS. The results in Table 5.4 can support the above assumption, that the suspended solids removal efficiency of treating this wastewater by RAUS could maintain the range of 52-66% even if the hydraulic retention time was as short as 3.1 h.

The influent and effluent suspended solids together with an average value are shown in Fig.5.5.12 and Fig.5.5.13 and settleable solids in Fig.5.5.14 respectively.

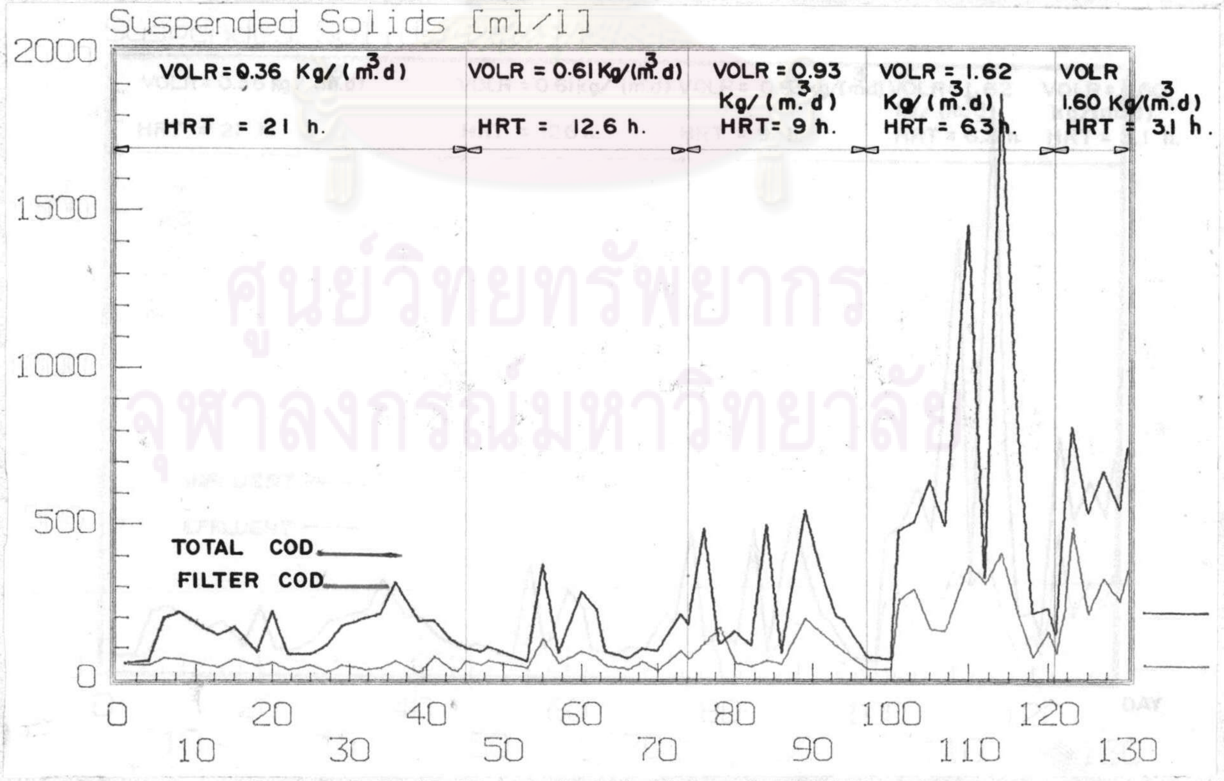


Figure 5.5.12 Suspended Solids of RAUS Reactors

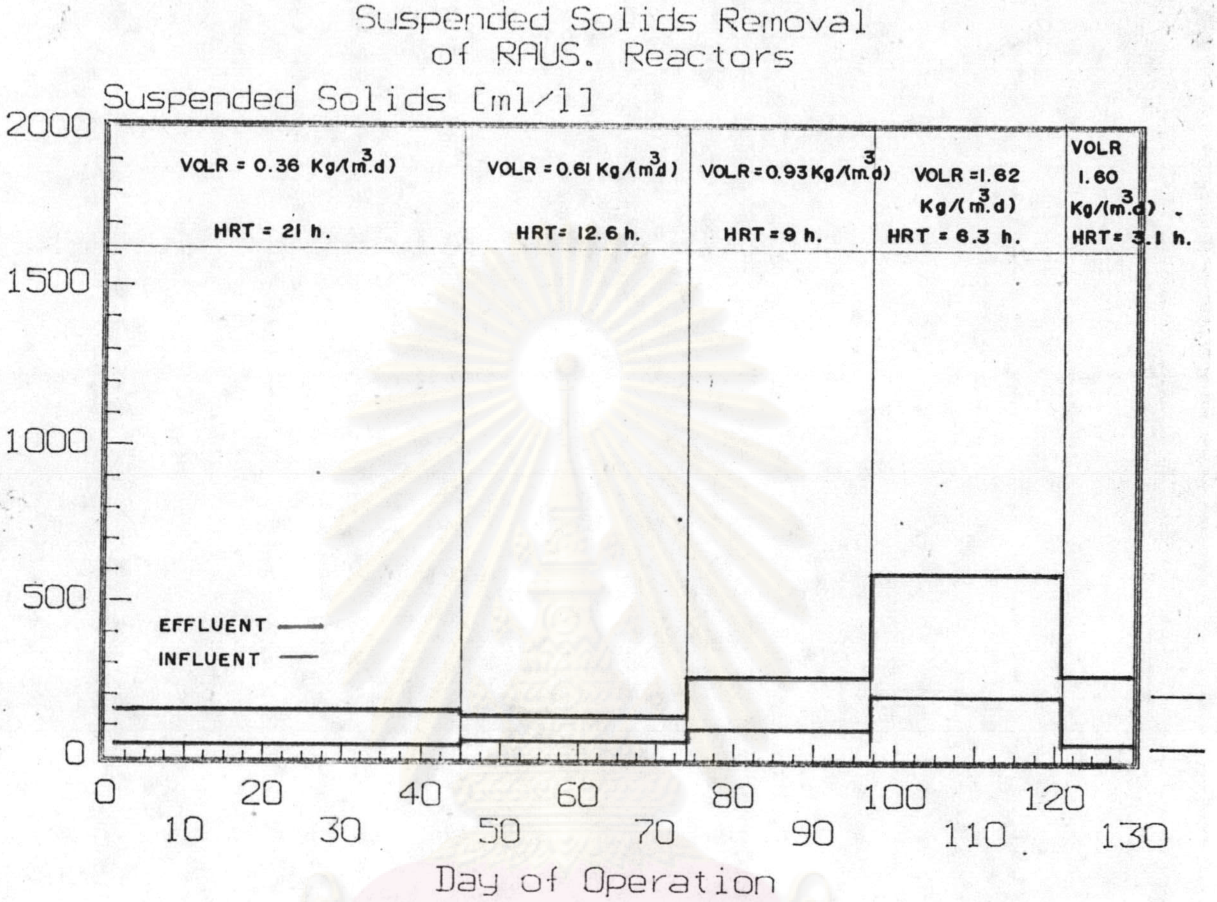


Figure 5.5.13 Average Suspended Solids of RAUS Reactors

From Fig. 5.5.12, it can be seen that effluent suspended solids were very low and quite stable at the longest HRT of 21 h. Although sometimes high influent suspended solids were fed, there seems to be no change in the performance. The standard deviation of the effluent which is approximately 3 times less than the deviation of the influent illustrates the stability of SS removal. Fig. 5.5.14 shows that there is sometimes biomass washout in the effluent but not as serious as in the fixed-bed reactor as seen in the average value of RAUS settleable solids in Fig.5.5.15. Since there were both flocculent and granular sludges in RAUS reactors, the flocculent sludge was more likely to washout than the granular.

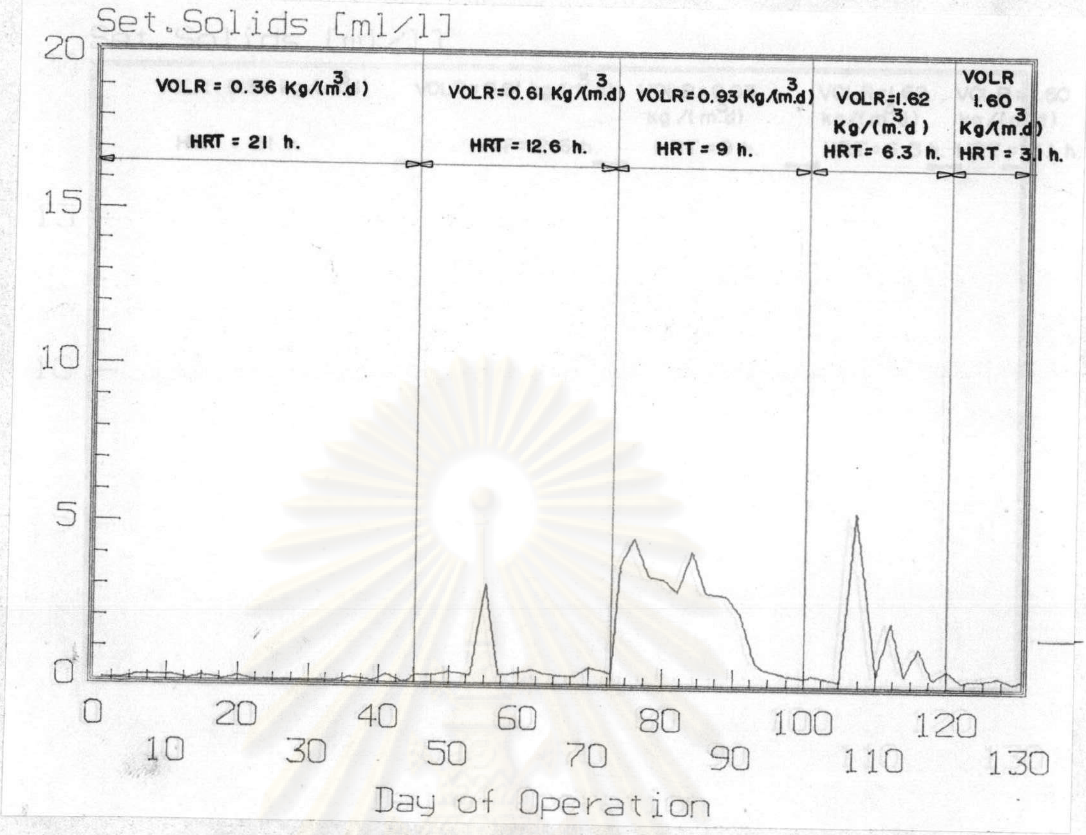


Figure 5.5.14 Settleable Solids of RAUS Reactors

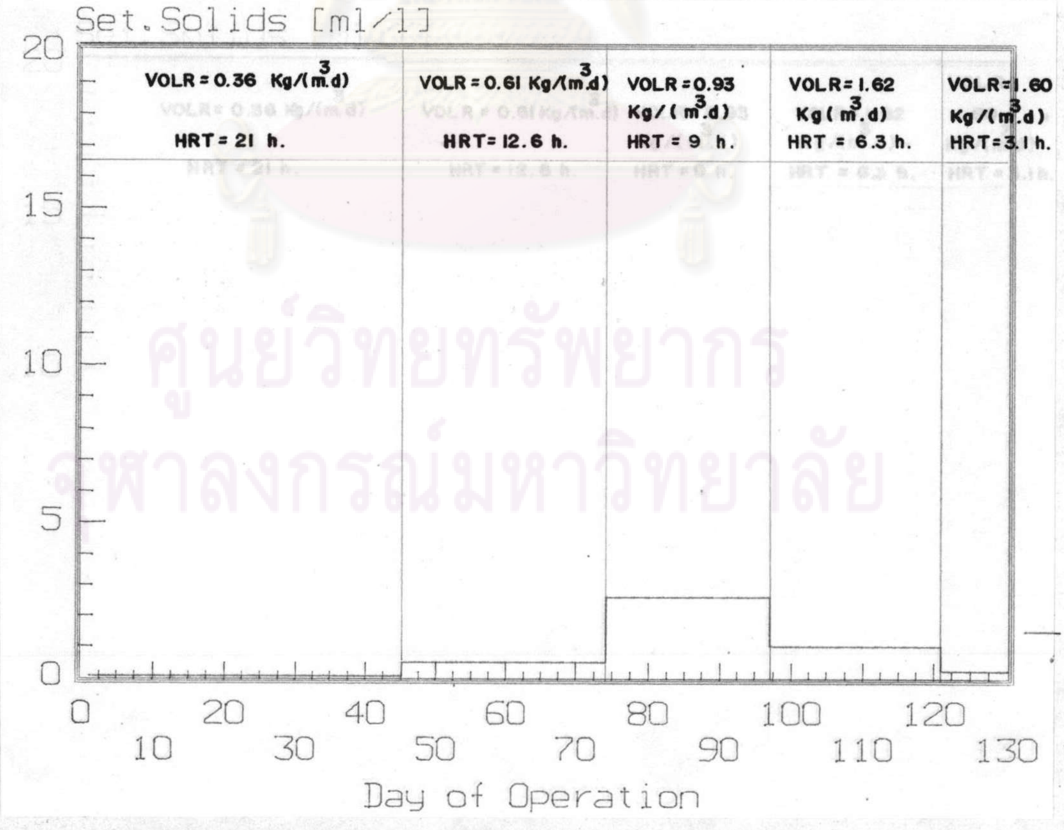


Figure 5.5.15 Average Settleable Solids of RAUS Reactors

5.5.3 Temperature

The temperature of the influent wastewater was in the range of 29.4-31.2°C. After being treated, the effluent wastewater temperature was around 29.8-30.0°C. Effluent temperatures were always quite constant even if sometimes the influent was lower than its average temperature as shown in Fig 5.5.16 and Fig. 5.5.17.

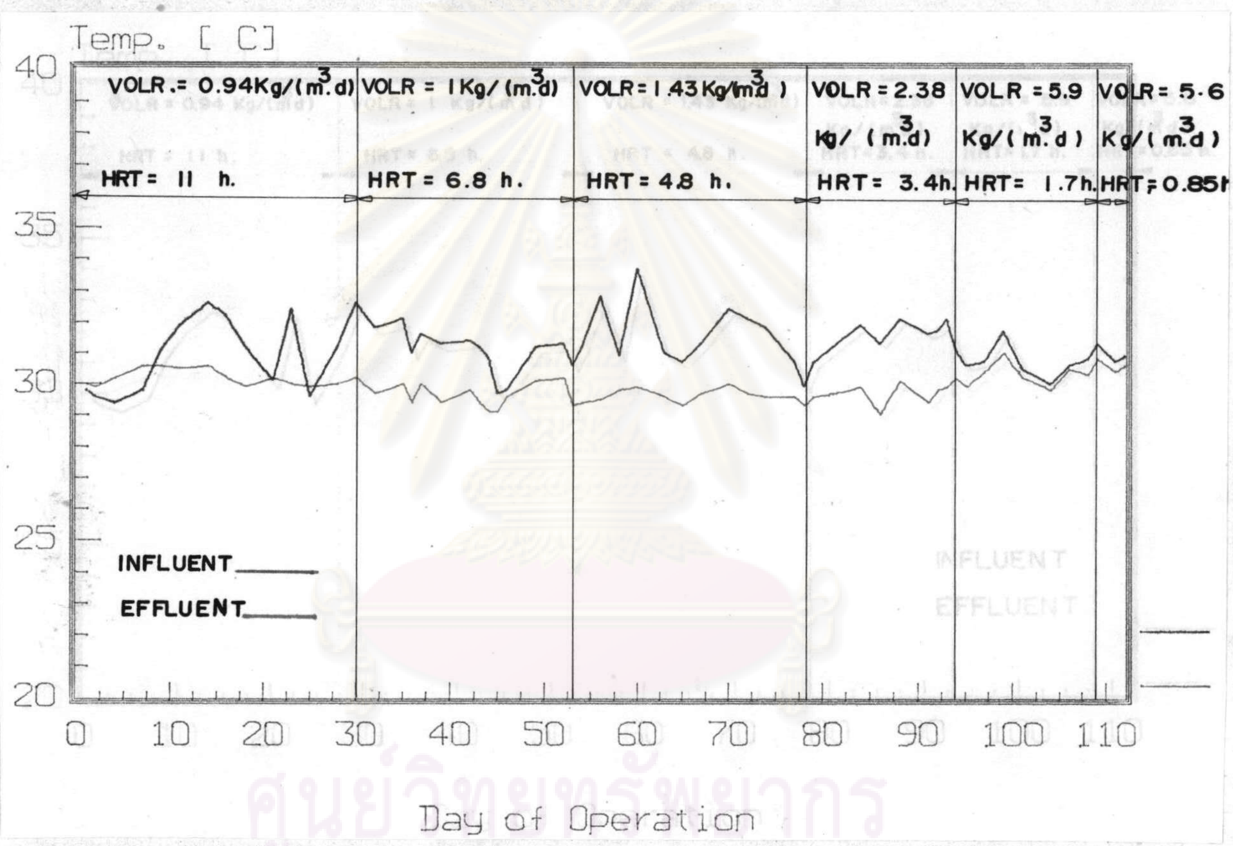


Figure 5.5.16 Influent and Effluent Temperature of Fixed Bed Reactor

Both Fig.5.5.16 and Fig.5.5.17 illustrated that the temperature was in the proper range for anaerobic treatment. No effect could be detected from oscilation in temperature. Nevertheless, during the research, the standard deviation of temperature was only 0.9. Supported by Fig.5.5.18 and Fig.5.5.19

which are the average value of influent and effluent Temperative of fixed-bed and RAUS reactors only slightly chages were observed In the past anaerobic packed beds have been operated successfully at temperatures ranging from 20-35°C (Young & Dahab 1982). The previous reserarchers also reported the same results of no effect from temperature when treating slaughterhouse wastewater. Bull et al. (1983) studied effects of temperature on fluidized bed reactor by using synthetic meat extract wastewater. He found that 10°C temperature increase or decrease had little effect on effluent quality.

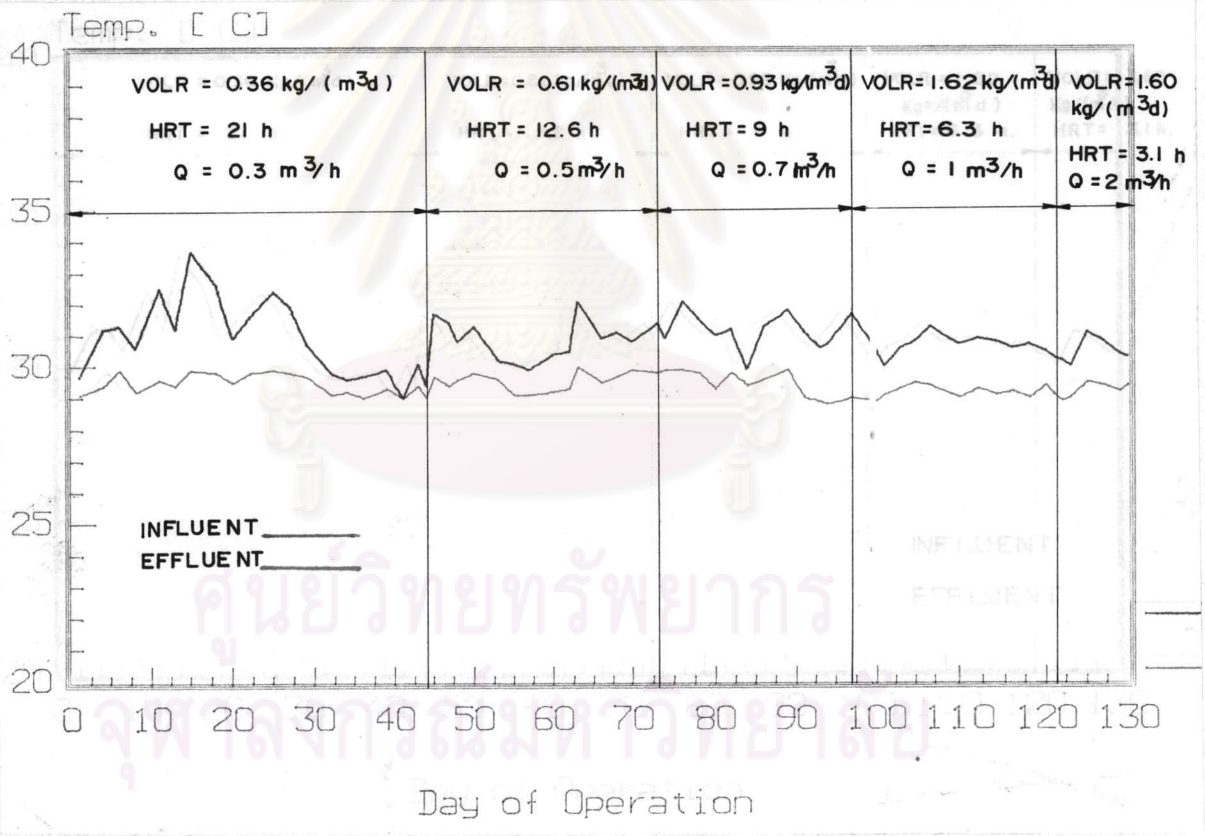


Figure 5.5.17 Influent and Effluent Temperature of RAUS

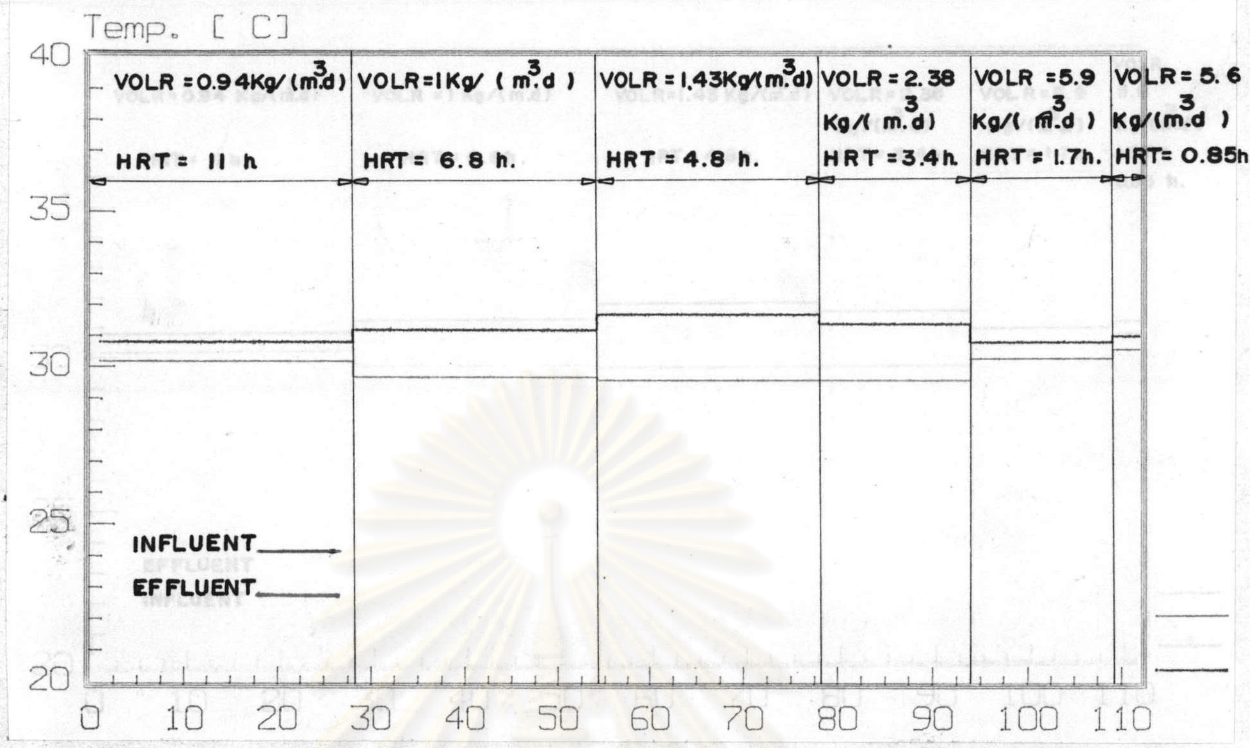


Figure 5.5.18 Average Influent and Effluent Temperature of Fixed Bed Reactor

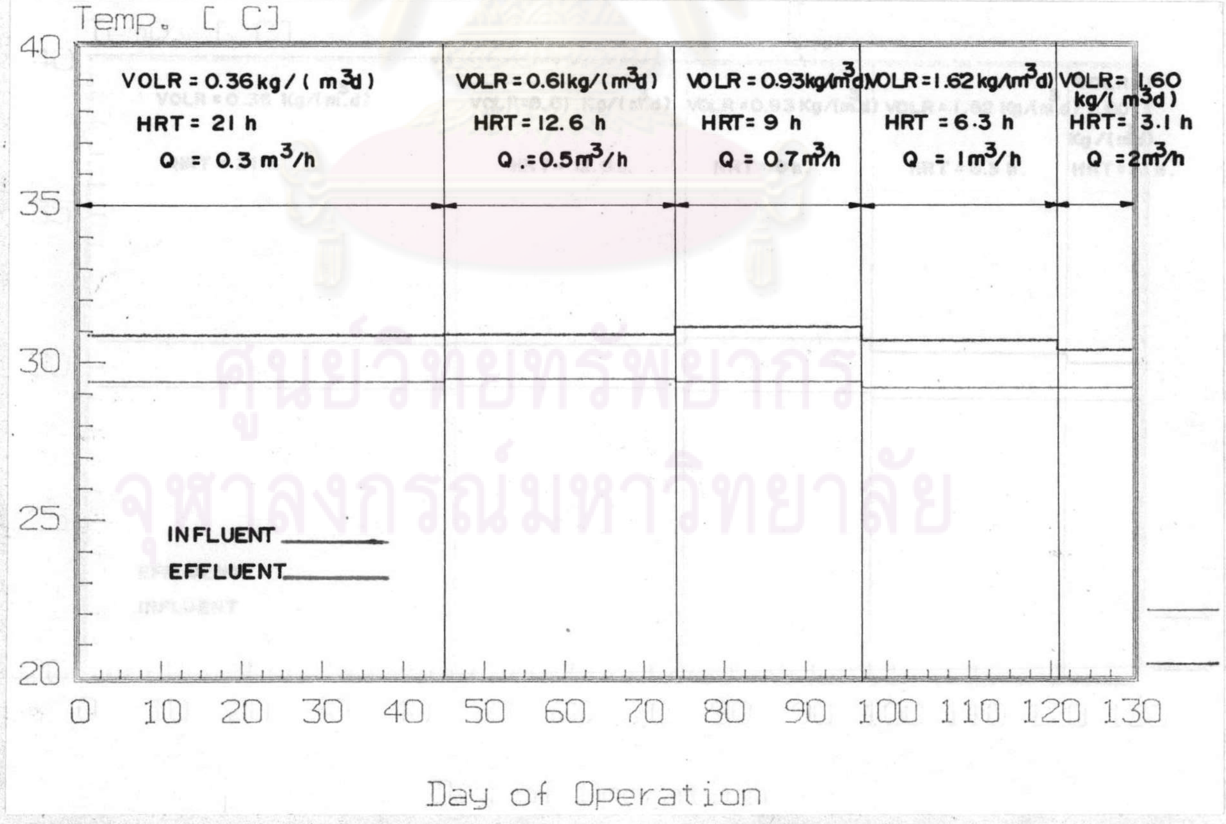


Figure 5.5.19 Average Influent and Effluent Temperature of RAUS

Steiner et al. (1985) experimented on an anaerobic digestion system with a 2 litres fermenter. The wastewater contained 2.9% to 10.5% volatile solids. The experiments were carried out at 35°C and 55°C. The result showed that the reduction efficiency on COD and volatile solids were identical at both temperatures.

Toldra et al. (1986) experimented with a fluidized bed reactor on treating hog slaughterhouse, dairy and brewery wastewaters and found that the removal efficiency of dairy and brewery waste decreased with decreasing in temperature but no detrimental effect was observed when treating slaughterhouse waste.

5.5.4 pH

For pH, both fixed bed and RAUS could bring about neutral pH from the influent which was always around 7.5-8.0. No adverse effect from pH was detected during the experimental work as seen in Fig 5.5.20 and 5.5.21. More clearly illustrates with an average value of pH of fixed-bed and RAUS reactors in Fig 5.5.22 and Fig.5.5.23 which always show the straight line of equal pH. There was also no report about the detrimental effect on anaerobic treatment from wastewater pH range equal to this wastewater. Only a low pH for long term operation was not recommended (Young & Dahab 1982, Bull et al. 1983). Souza (1986) found that the optimum pH for anaerobic process was around 7.0. pH values below 6.5 or above 7.5 might be harmful to the bacteria, mainly to the methanogens.

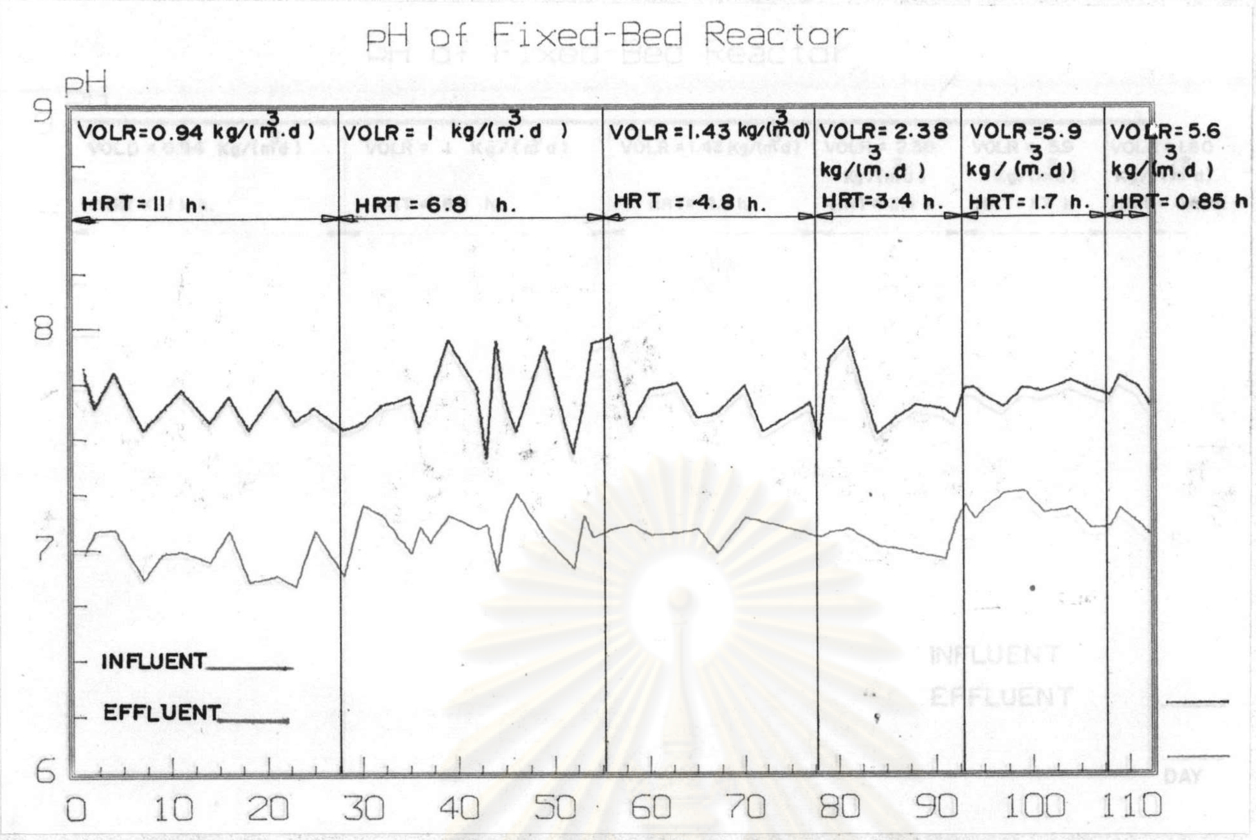


Figure 5.5.20 pH of Fixed Bed Reactor

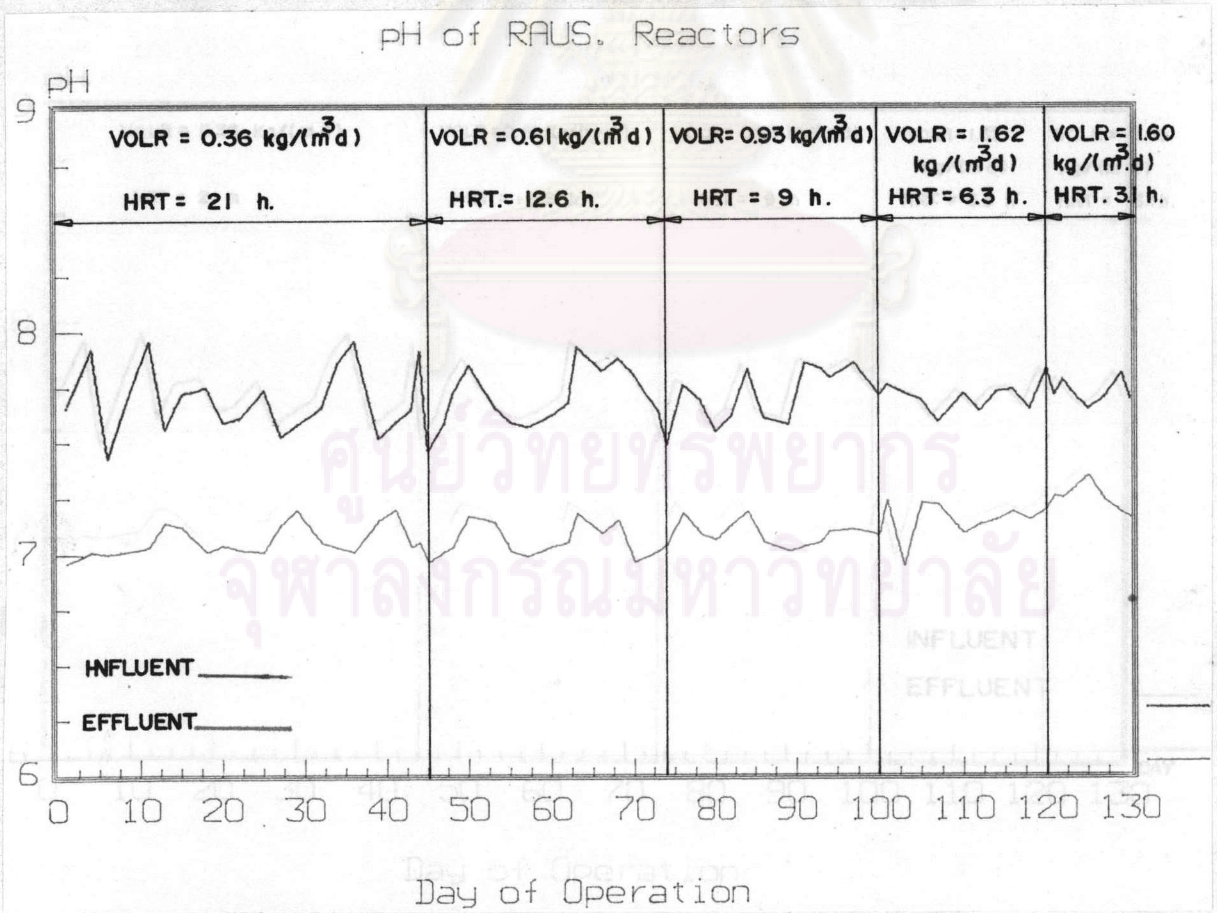


Figure 5.5.21 pH of RAUS

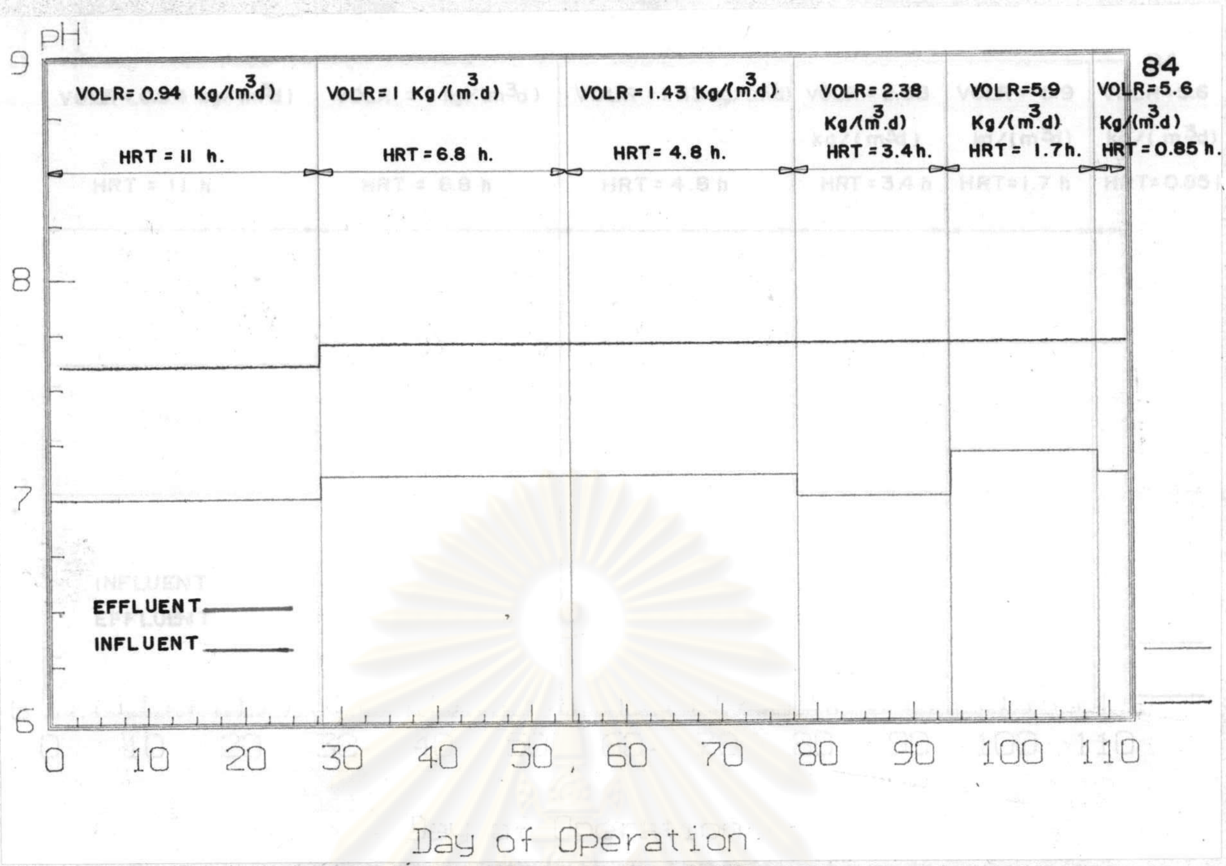


Figure 5.5.22 Average pH of Fixed Bed Reactor

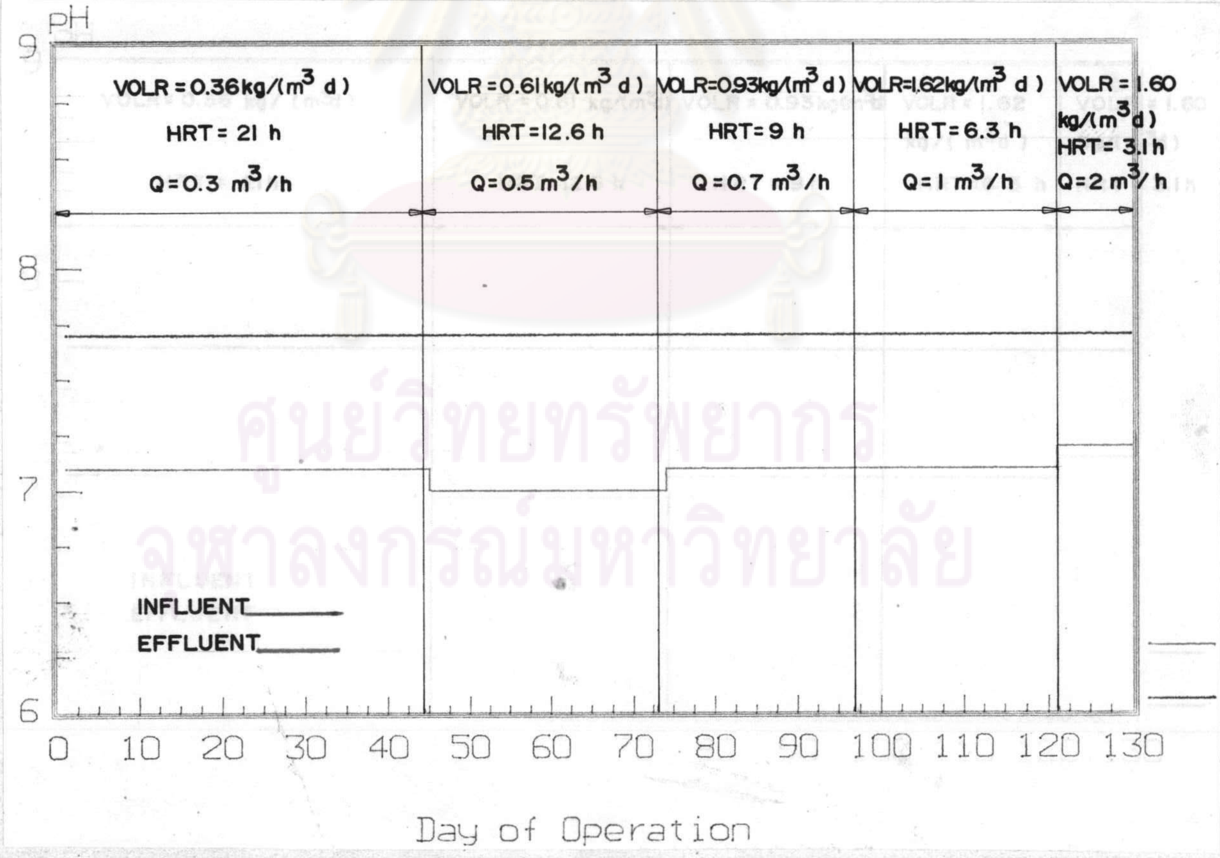


Figure 5.5.23 Average pH of RAUS

5.5.5 Alkalinity

One of the most important control parameters in anaerobic treatment is alkalinity and its associated alkalinity ratio parameter. This value is strongly related to the pH control strategy. For this kind of wastewater alkalinity needed as a buffer for both processes was sufficient. Influent pH always showed figures above 7.0 and alkanity was also present. Throughout the research, pH never dropped below 6.8, hence, inhibition from acidic condition never took place.

It could be concluded that alkalinity presented no problem for slaughterhouse wastewater. Fig. 5.5.24 illustrates alkalinity for both processes, the effluent alkalinity was always higher than the influent alkalinity, due to bicarbonate produced during anaerobic degradation. See equation 5.1 to 5.3.

$$\text{Org N} \dashrightarrow NH_3\text{-}N \quad (5.1)$$

$$\text{Org C} \dashrightarrow CO_2 \dashrightarrow H_2CO_3 \quad (5.2)$$

$$NH_3 + H_2CO_3 \dashrightarrow NH_4HCO_3 \quad (5.3)$$

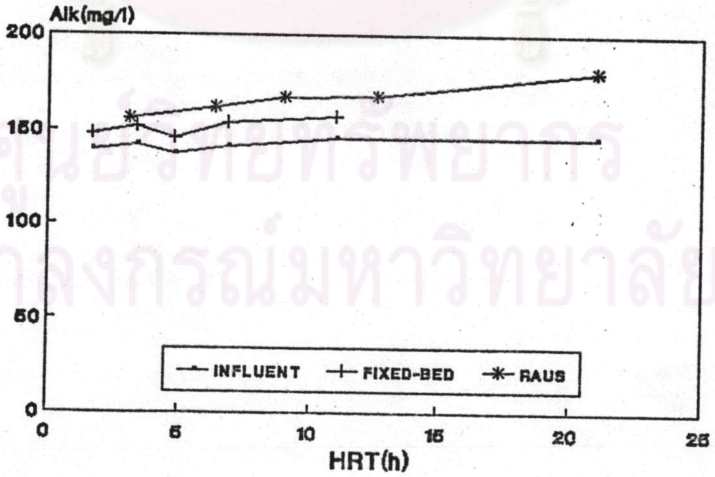


Figure 5.5.24 Average alkalinity of Fixed-bed and RAUS at different HRT

5.5.6 VFA

Volatile fatty acids were detected in very low quantity. Not more than 25 mg/l was found. Acetic acid occupied a larger percentage of 80-100%. Propionic acid was sometimes found as seen in Table 5.5.

Table 5.5 Volatile Fatty Acid in reactors

Flow rate	HRT (h)		INF		AnFB		RAUS	
(m^3/h)	AnFB	RAUS	Acet.	Prop.	Acet.	Prop.	Acet.	Prop.
0.3	11	21	14	-	7	-	4	-
0.5	6.8	12.6	12	-	5	-	6	-
0.7	4.8	9.0	18	2	7	-	6	-
1.0	3.4	6.3	16	-	11	-	9	-
2.0	1.7	3.1	20	5	17	3	20	-

80

From Table 5.5, VFA present in the influent showed that partial acidification took place in the influent stream. Low VFA in the effluent indicated that methanogenic bacteria in the reactor could use the volatile fatty acid produced during acidification. **Fig. 5.5.25** illustrates the amount of VFA of both processes.

Sayed and de Zeeuw, (1988) conducted the experiment with a one-stage flocculent sludge UASB reactor. By feeding slaughterhouse wastewater at 30°C to the 10.5 litres reactor, VFA of 50 mg/l could be detected for 1,925 mg/l COD wastewater. With different concentrations of 2695, 6056 and 11,118 mg/l COD, the result of VFA detected were 65, 420 and 600 mg/l respectively.

The result conformed to Sayed & de Zeeuw, therefore, slaughterhouse wastewater could detect small amount of VFA. It could be because of the volatile acid produced from hydrolysis was immediately used by various kinds of methanogenic bacteria (as seen by scanning electron microscope in Topic 5.9).

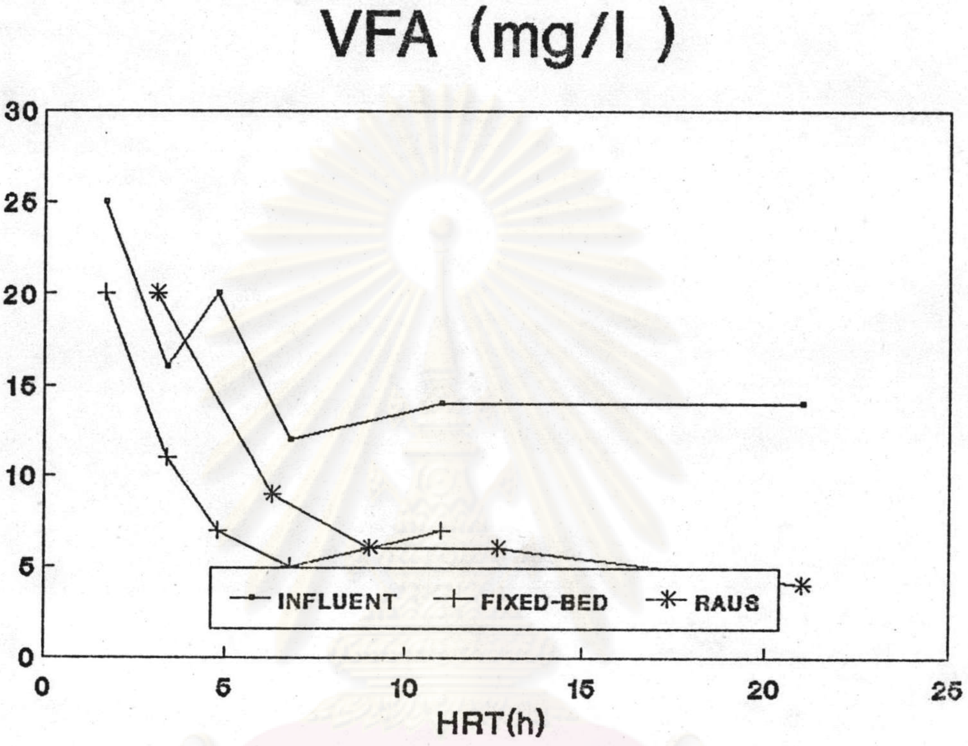


Figure 5.5.25 Average VFA of fixed-bed and RAUS at different HRT

5.6 Gas Production

Gas production was measured by gas measuring instruments available in the pilot plant. A gas pipe was connected to a bottle which was linked to a pressure sensor. The sensor would automatically switch on the pressure pump to pump out excess pressure accumulated by gas production. The procedure was controlled by computer.

The gas production, which was recorded by computer, is still being questioned. Only a small amount was detected over a short period of two weeks, after which, no more was detected.

The problem could be leakage of gas along the pathway to the measuring instrument. Attention was paid to sealing joints and holes. It was however found not worth solving this problem. Production volume still showed the same value. Gas condensed to water could be one reason as condensate water was seen in the gas pipe during piping investigation.

Nevertheless, the highest value observed when the measuring instrument functioned properly was only 0.4 m^3/d with an average of 0.2 m^3/d at 1.5 kg/(m^3.d) volumetric loading rate.This figure shows that the gas production was as low as 0.1 m^3/kg COD applied. McCarty (1964) showed that the theoretical methane production from the complete stabilization of 1 kg BOD_L or 1 kg COD was 0.348 m^3 at standard temperature and pressure. Sayed, et.al (1984) conducted a 30 m^3 UASB pilot - scale experiment with slaughterhouse waste. COD was reported to be 1,500-2,000 mg/l. At an average loading of 1.6 kg COD/m^3.d, 6.5 m^3/d gas production could be obtained. The methane yield amounted to 0.28 m^3/kg of COD removed, the methane content of the biogas from the wastewater varied between 65 and 75%.

Soluble COD was an interesting point of low gas production since all data showed that only 40-50% of COD was soluble. Nevertheless, the soluble COD removal efficiency still showed the same range of removal efficiency as total COD did. If so, the gas production should be the same.

It was suspected that sulphate reduction occured in the reactors but sulphate reduction should not be the main problem for low sulphate wastewater. This suspicion was confirmed by sulphide analysis for influent and effluent from fixed bed and RAUS. The results of 36, 48 and 28 mg/l sulphide contents in influent, effluent from fixed-bed and RAUS reactors respectively, show that the sulphate reduction took place in the influent stream before being fed to the reactor and increased a little in the fixed-bed reactor.

Ammonification also occured in the reactor. The NH_3-N analysis for influent, effluent from fixed - bed and RAUS reactors show values of 38, 34 and 32 mg/l respectively. Souza (1986) said that the N and P removal in an anaerobic reactor was practically nil, with the transformation of the organic N into ammonium N.

5.7 Sludge Inside the Reactors.

The main concept of a high-rate anaerobic reactor is retaining as high a concentration of biomass as possible. Unless such a high biomass affects the effluent quality from washout, the proper amount has to be released. Hickey et.al, (1991) stated that one common feature offered by all the high-rate processes was the ability to effectively seperate hydraulic and solids retention times. In anaerobic filters,this is accomplished by development of biofilms on support surfaces.In suspended growth system i.e. UASB, this is accomplished by the development of granules or flocs that have extremely good settling properties.

The type of biomass production in terms of sludge is dependent on wastewater characteristics, some are flocculent while some are granular. Hickey et.al, (1991) also described that granulation did not occur in all cases. No granulation occured in a reactor fed with a mixture containing high ammonium concentrations (1,000 mg NH_4-mg/l). For some wastewaters such as cheese whey, granular sludge did not develop using non-granular materials, but if granular sludge was inoculated, the granules could be maintained. In any case, it was possible to operate UASB reactor without formation of granules i.e.slaughterhouse wastewater (Sayed et al., 1984). Nevertheless, granular sludge was not formed in a reactor fed with slaughterhouse wastewater directly, while granulation was observed when the suspended solids were removed.

5.7.1 Sludge Concentration

For Slaughterhouse wastewater which was treated by fixed- bed and RAUS processes, granular sludge could be obtained. After start-up of one year, both processes contained a high concentration of sludge at the bottom of the reactors, estimated to be 0.3-1.0 m.depth with concentration of 50 g/l for fixed-bed and 90 g/l for RAUS. The sludge was a very dense blackish liquid, and granular could not be seen from the draw-off sludge unless rinsed 2-3 times with water. The biggest pellet of granular was about 3 mm. Sludge from RAUS was more flocculent than Fixed bed while higher in concentration. Fig.5.7.1 showed the concentration of biomass of both reactors.

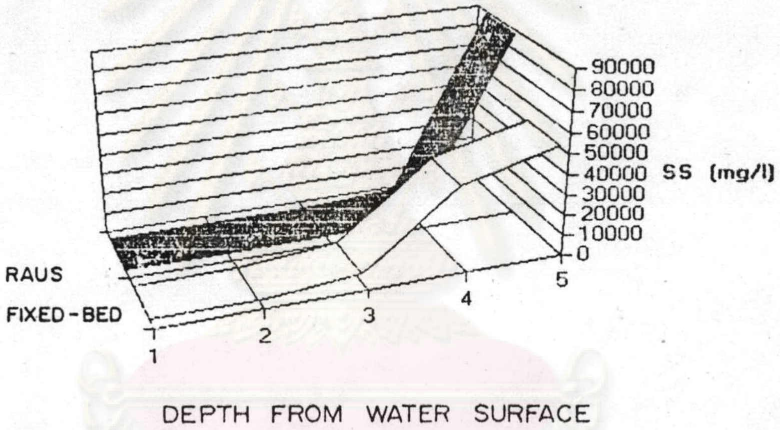


Figure 5.7.1 Biomass concentration in fixed-bed and RAUS reactors

From Fig 5.7.1, suspended biomass concentration along the depth from the water surface area shows that effective biomass population significantly increased in the bottom part of both reactors, especially at a depth of more than 4 metres.

5.7.2 Biomass of Fixed-Bed Reactor

Besides suspended biomass through out the reactor space and granular sludge in the bottom, it is important to note that there was also fixed film biomass that took part in the treatment activity of the fixed-bed reactor. Fixed-film that attached the filter media, accompanied by granular sludge that entrapped the matrix space and suspended biomass ensured the treatment efficiency of fixed-bed reactor. Hickey et.al, (1991) said that much of the biomass is present as suspended and/or entrapped biomass in the interstitial pore volume of the support media.

Young and Dahab (1982) illustrated that a major part of the suspended solids in anaerobic packed bed are held loosely within the interstitial spaces of the media matrix. Only about one-quarter to one-half of the total mass was held by attachment to the media surfaces. He also said that the unit surface area of the media was not as important as other media characteristics such as shape and void size for establishing satisfactory treatment performance. The most important media characteristic seems to be the ability to hold a high concentration of biological solids in the media matrix, either attached to the media surfaces or held loosely within the interstitial void spaces.

Hickey et al. (1991) stated that biofilms, formed on various plastic and wood supports, reached a thickness of about 1 to3 mm.for fixed-bed reactors.

Filter inspection revealed about 3 mm. of attached biofilm as found by Hickey. Surprisingly, clumps of biomass thicker than 5 mm. were found entrapped in the Y-shaped filter core, inside which was the filter ring to strengthen the ring structure. It could be concluded that this type of filter material also aided in the settling of suspended solids in the wastewater. Young (1991) said that the growth on media surfaces and the settling of biological solids provides some COD removal. Fig. 5.7.2 showed the filter media of fixed-bed reactor.

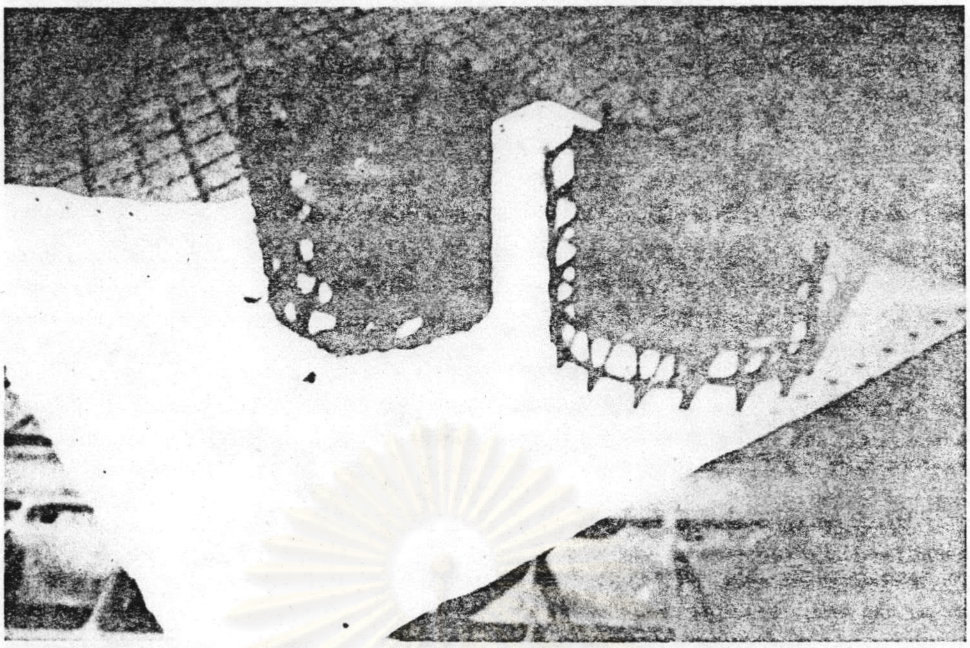


Figure 5.7.2 Fixed-Bed reactor filter media

5.7.3 Biomass in RAUS

The RAUS biomass concept includes suspended biomass as a contact digester but no mixer. Mixing of RAUS was due to the production and rising of gas bubbles. Moreover, RAUS had a big advantage of high granular concentration and could entrap organic particles as well as normal suspended biomass.

5.7.3.1 sludge profile during sedimentation step

Fig 5.7.3 shows the sludge profile of both reactors during the sedimentation period. It illustrates that the volume of sludge in U-shape and V-shape reactors were significantly detected after 4.0 m. and 4.5 m. depth from water surface respectively. These profiles supported information about the settling ability of the sludge during the feeding pauses. The SVI of the sludge was approximately 20 ml/g. Vieira and Souza (1986) studied the treatment efficiency of UASB with low strength wastes (domestic sewage). They reported that granular sludge with good activity and settling characteristics was observed within 8 months of operation. The average diameter of the pellet was 4 mm. with a SVI of 25 ml/g.

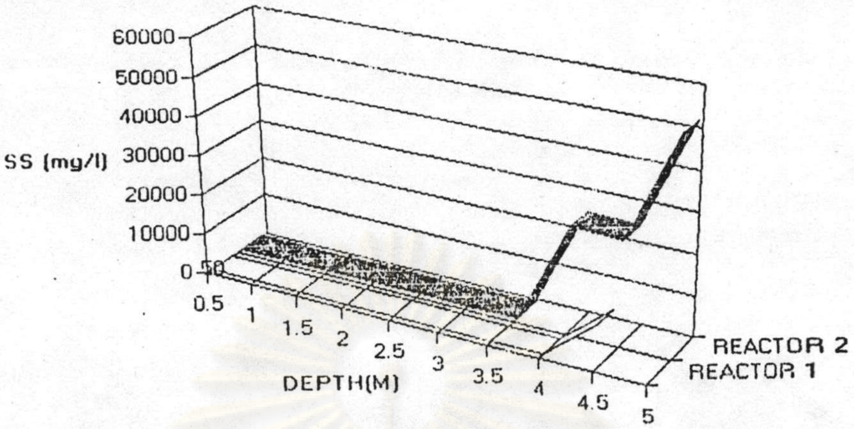
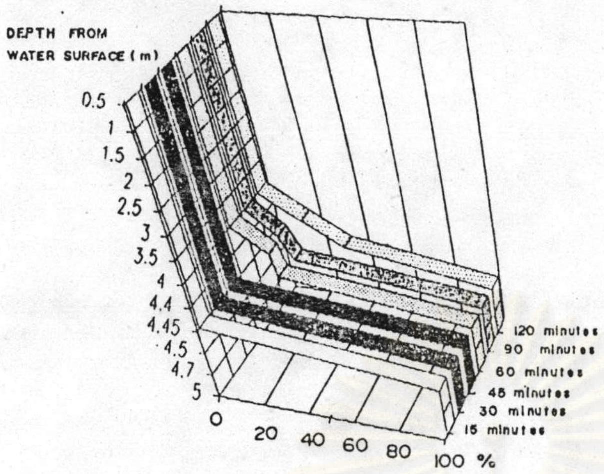


Figure 5.7.3 Sludge profile-during sedimentation period

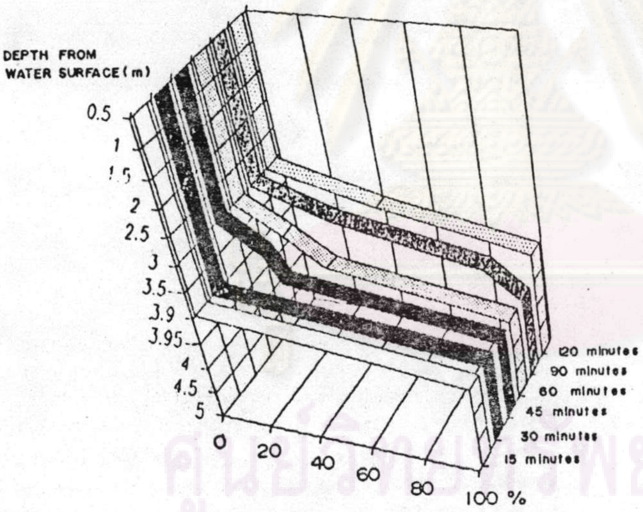
5.7.3.2 Sludge profile during feeding step

The sludge profiles in both reactors were made during two hours feeding. Measuring was done every 15 minutes for the first hour and every half an hour in the second hour. Hence, the measuring times were 15, 30, 45, 60, 90 and 120 minutes after feeding. The distance of the measuring points was 0.5 m. along the reactor height so there were about 120 samples for two reactors within 2 hours. It was therefore not practical to analyse suspended solids by gravimetric method. An instrument was selected and used to show the expansion of the sludge layer. This instrument could however not show suspended solids value since there was no instrument available for measuring suspended solids ranging from 0 to 100 g/1. The results show only a relative value of sludge concentration in percentage but cannot relate to suspended solids. Fig.5.7.4 and Fig.5.7.5 show the sludge profile (in precentage of detection limit) during feeding step.



CONDITION : sedimentation
tank
HRT = 12.6 h
v = 0.3 m/h

Figure 5.7.4 Sludge profile in sedimentation : step of RAUS (Reactor 1; U-shape)



CONDITION : reactor
HRT = 12.6 h
v = 0.3 m/h

Figure 5.7.5 sludge profile in reactor stage of RAUS (Reactor 2; V-shape)

Fig. 5.7.4 and Fig. 5.7.5 show the sludge profiles of both reactors of RAUS when the hydraulic retention time was 12.6 h. and the upflow velocity was 0.3 m/h. The V-shape reactor acted as a reactor while the U-shape acted as a sedimentation tank (feeding direction was from V-shape reactor to U-shape reactor).

The V-shape vessel which acted as a reactor in this measurement started with sludge detected at the depth of 4.0 m. from the surface water after feeding for 15 and 30 minutes. This sludge depth is similar to the depth of the sludge during the sedimentation period of this reactor as seen in Fig.5.7.3. The sludge was expanded to a depth of 3.9 m. after the feeding had started for 45 and 60 minutes. In the same way the U-shape started with sludge detected at 4.5 m, after 60 and 90 minutes,sludge in U-shape expanded to the depth of 4.4 m. from the water surface.It was concluded that the sludge expansion in both reactors was very low. At HRT 12.6 h. or upflow velocity of 0.3 m/h, the expansion of sludge in the reactor to which the wastewater was fed (V-shape in this case) was only 0.1 m. after feeding for 45 minutes. The expansion in the sedemention tank (U-shape) was also only 0.1 m. but it could only be detected after, a longer period of measurement or after feeding for 60 minutes, that is to say 15 minutes after the reactor expansion.

5.7.3.3 pH and Temperature Profile

pH and Temperature profile from the surface water along the reactors height were made. Both reactors gave the same results with low pH at the bottom.

The low pH at the lower part can be explained by the activity of acidogenesis bacteria which produced volatile acids. High concentration of biomass at this part could entrap organic particles, so liquefaction taking place promoted low pH as seen in Fig.5.7.6.

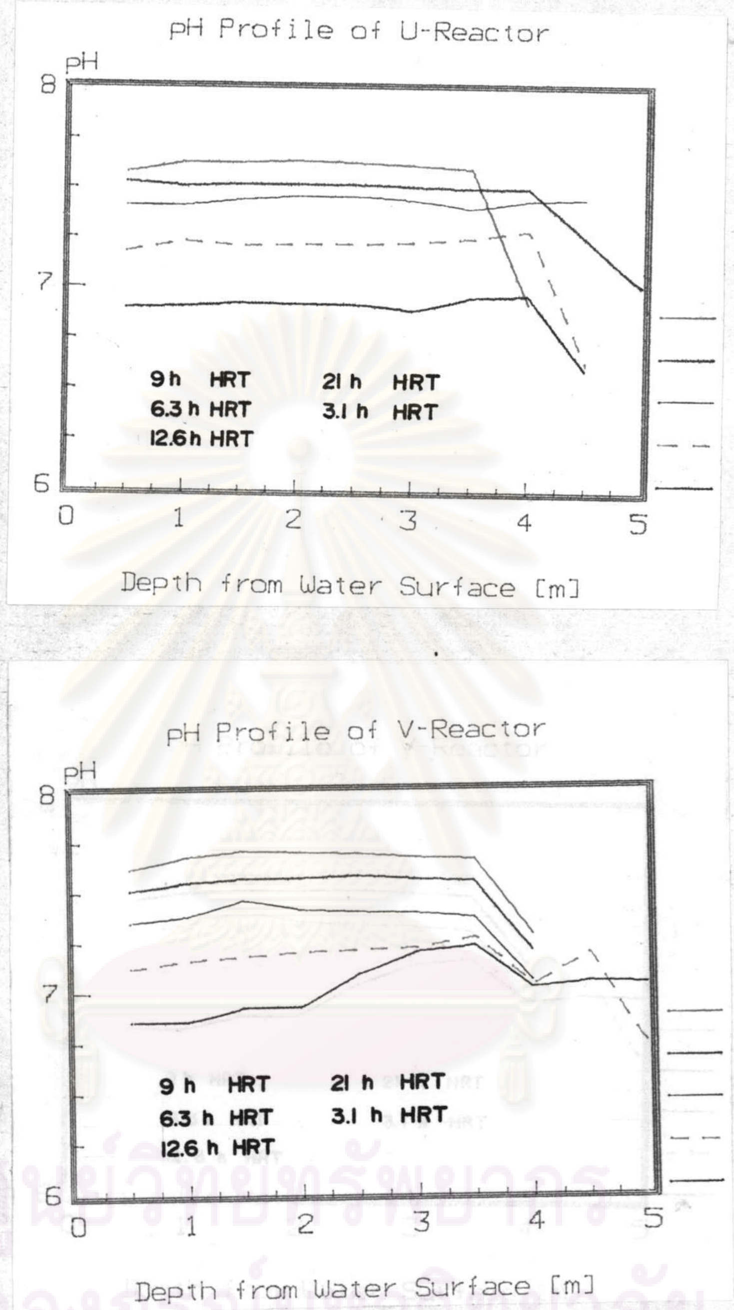


Figure 5.7.6 pH profiles

The difference between pH at each HRT depends on the environmental factor of the measuring day, i.e, the influent pH. However the results was not much different. The range was between 7.2 to 7.7 except at the failure HRT that presented apparently low pH.

Temperature profiles of each hydraulic retention time seem to be the same. High temperature at the top due to sunlight exposure and lower at the lower part as seen in Fig. 5.7.7.

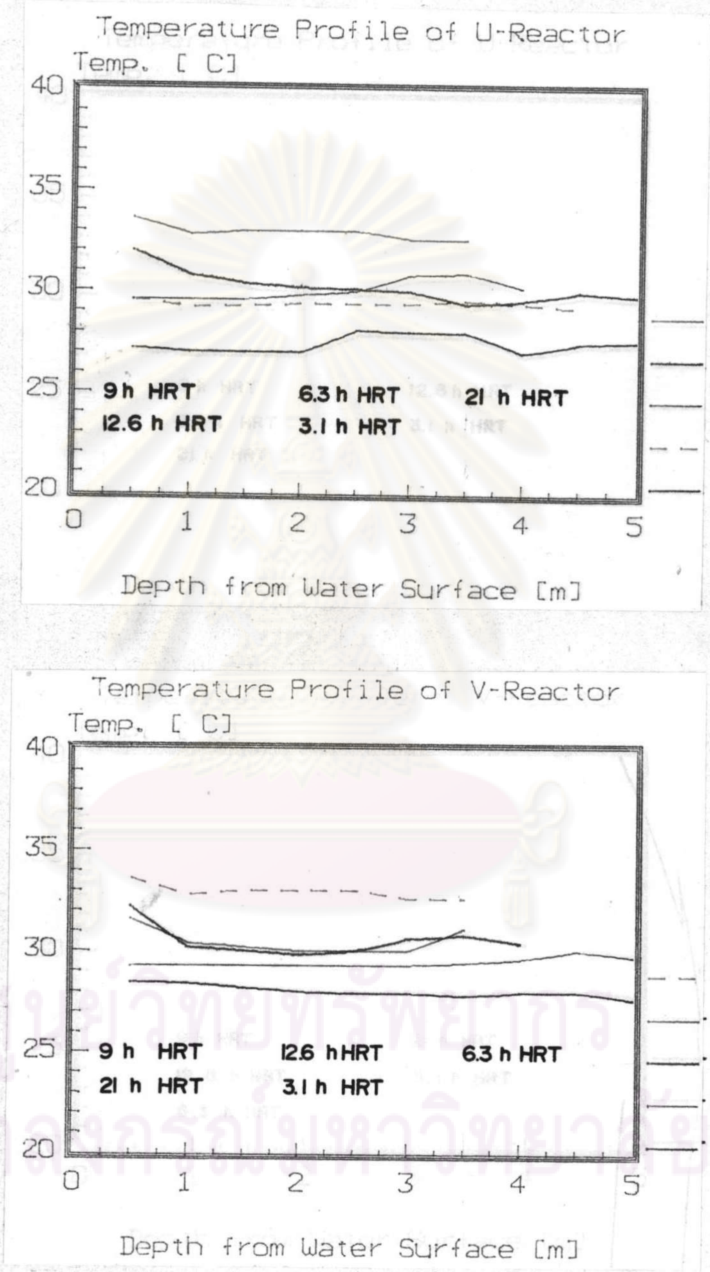


Figure 5.7.7. Temperature profiles

5.8 Process Failure/Ultimate loading

5.8.1 Fixed bed Reactor

The fixed-bed reactor was unable to work properly after 1 m^3/h flow rate was applied. Severe biomass washout was observed. An average removal of COD and suspended solids of fixed-bed reactor were shown in Fig 5.8.1.

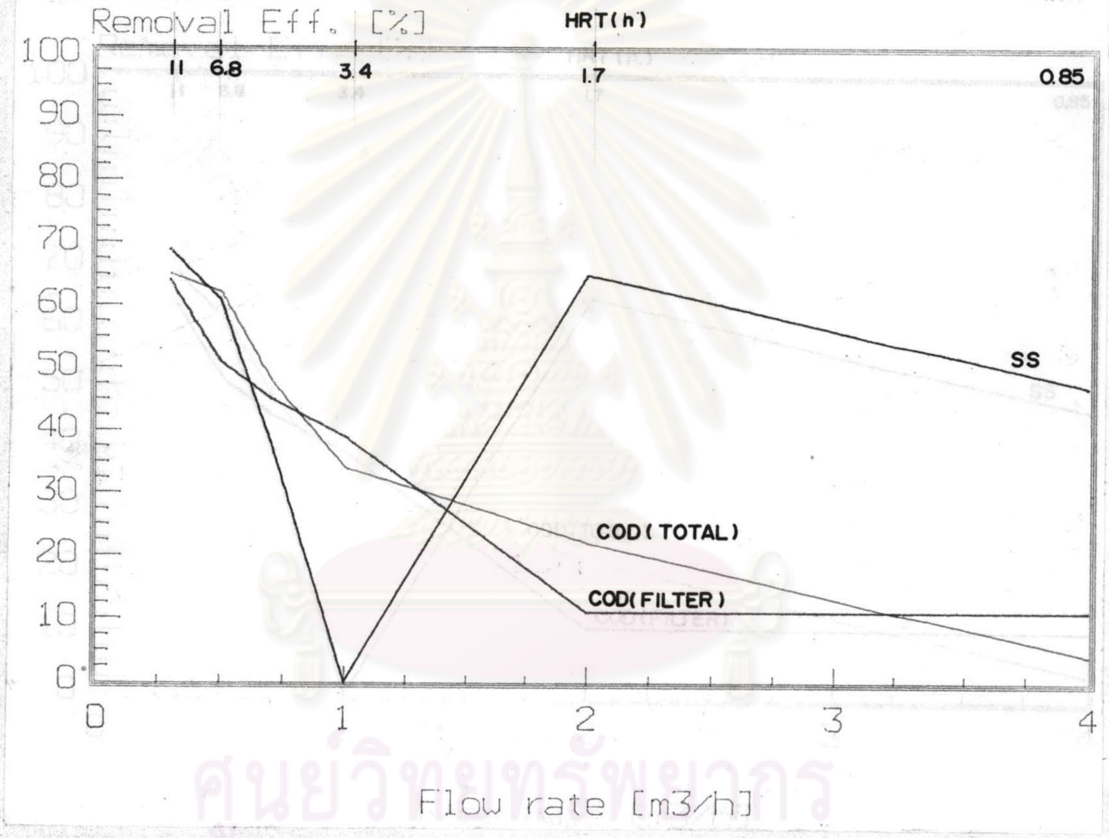


Figure 5.8.1 Average Removal of fixed bed reactor

From Fig 5.8.1 the process failure in terms of suspended solids occured at 3.4 h HRT. The removal efficiency of suspended solids dropped drastically from 60% at 6.8 h. HRT to zero at 3.4 h HRT. This failure was due to the washout of biomass which was evident form higher solids in the effluent. 30% average COD removal was, however, still achieved. After the failure, the SS removal efficiency seems to be higher while the COD removal efficiency gradually dropped. The higher SS removal efficiency at 1.7 h HRT was achieved due to the fact that no biomass washout was no longer experienced. The explanation for this happenning may be that small biological solids were already washed out of the reactor at the failure HRT. The remaining granular and biofilm that retained in the reactor could however function again. Moreover, at 1.7 h HRT the suspended solids in the influent was significantly high due to the backwater from a nearby pond. These high SS were entrapped in the interstitial void and settled within the space matrix so that the effluent presented better quality than at failure HRT. The COD removal could be better illustrated that the reactor had low treatability. At this failure hydraulic retention time, the volumetric organic loading rate was 2.38 kg/(m^3.d) with the upflow velocity of 1.2 m/h.

5.8.2 RAUS

RAUS removal efficiency can be illustrated in Fig 5.8.2

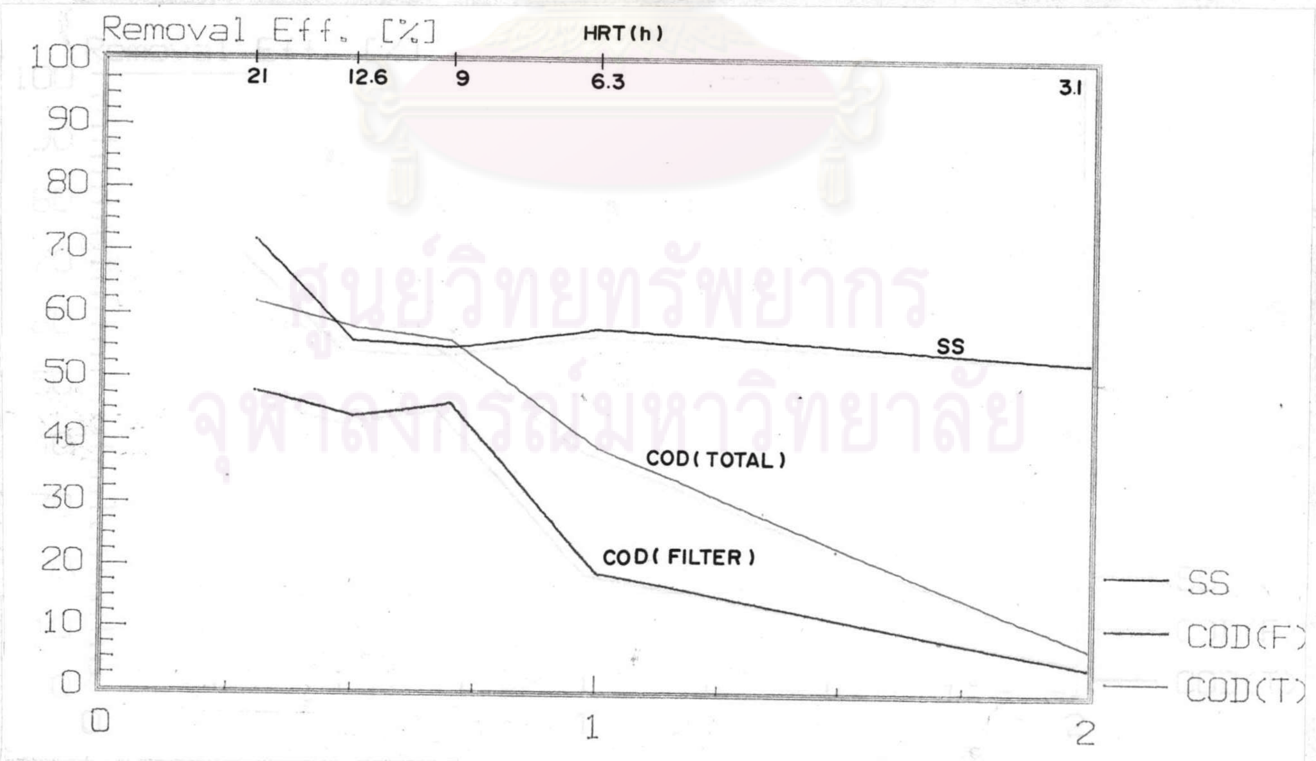


Figure 5.8.2 Average Removal of RAUS

The absolute failure of RAUS could be seen when the COD removal efficiency approached zero at 3.1 h HRT while the SS removal efficiency seemed to be no changed. It could be concluded that RAUS could retain high suspended solids by granular sludge inside the sedimentation unit. At this failure hydraulic retention time, RAUS was operated with 1.3 m/h upflow velocity and the volumetric organic loading rate achieved was 1.6 kg/(m^3.d). Flocculent biomass washout could be seen due to high superficial velocity.

There were some reports that the more dilute the waste, the higher would be the upflow superficial liquid velocity at a specified organic loading rate and reactor height. The type of sludge present in the reactor restricted the maximum permissible superficial velocity, together with the organic space loading rate applied. For floculant sludge reactors maximum superficial velocities of 0.5 m/h can be tolerated, sometimes even up to 1.5 m/h. For granular sludge reactors, superficial velocity can be set at approximately 3 m/h average over a day for soluble wastewaters and at 1-1.25 m/h or partially soluble wastewaters. Temporarily, for a few hours per day, superficial velocities up to 6 m/h and 2 m/h can be tolerated for soluble and partially soluble wastewaters, respectively. Under these conditions most of the granular sludge will be retained in the reactor.. The high superficial velocities may result in the washout of poorly settleable (smaller) granular sludge particles (Lettinga and Pol 1986, Lettinga and Pol 1991, Wieland and Rozzy 1991).

5.9 Optimum Condition

From the experimental result with this wastewater, the fixed-bed could be optimally operated at the hydraulic retention time of 6 h whereas RAUS at 9 h. At the HRT, both fixed-bed and RAUS could achieve the volumetric organic loading rate around 1 kg/(m^3.d) with 50% COD removal efficiency. The upflow velocity at the optimum HRT for fixed-bed reactor was 0.5 m/h while RAUS was 0.4 m/h.

5.10 Microorganisms Observation

5.10.1 Granular Size

Granular sludge was observed by scanning electron microscope (SEM). The sample were prepared by Chulalongkorn Science and Environmental Research Institute. Average size of granulars was found to be 400 to 600 micron as shown in Fig. 5.10.1 and Fig. 5.10.2.

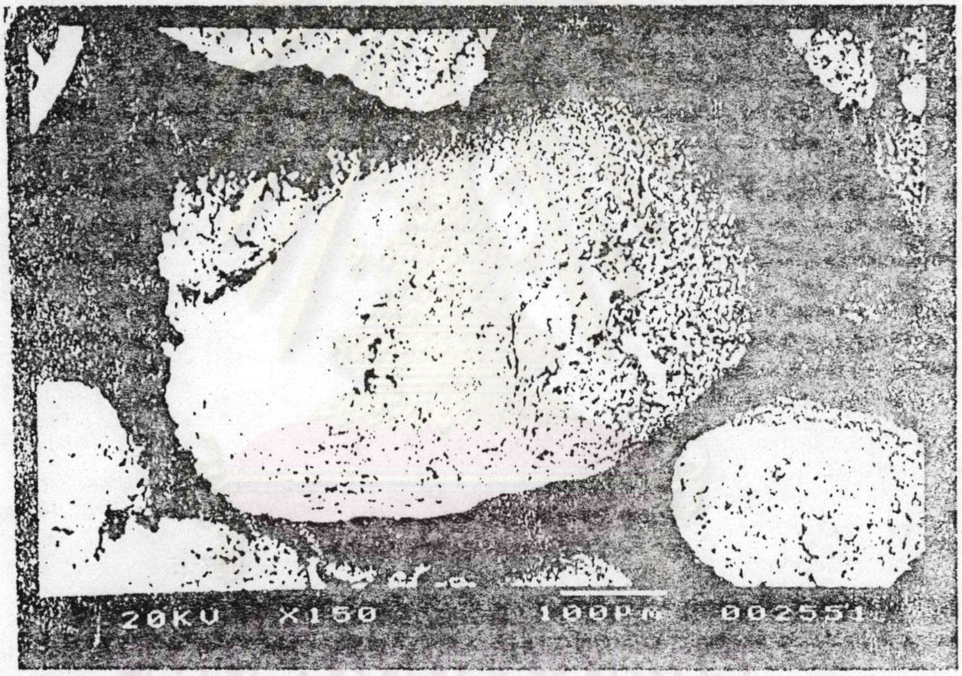


Figure 5.10.1 Granular sludge from Anaerobic Fixed Bed Reactor

Figure 5.10.2 Granular sludge from RAUS reactors

5.10.2 Microorganisms on granular surface

When high magnification of 5,000 - 10,000 was used to observe microorganisms on granular sludge surface. One could easily find plenty of coccus, rod and filamentous bacteria bridging over surface area as shown in Fig.5.10.3, 5.10.4, 5.10.5 and 5.10.6.

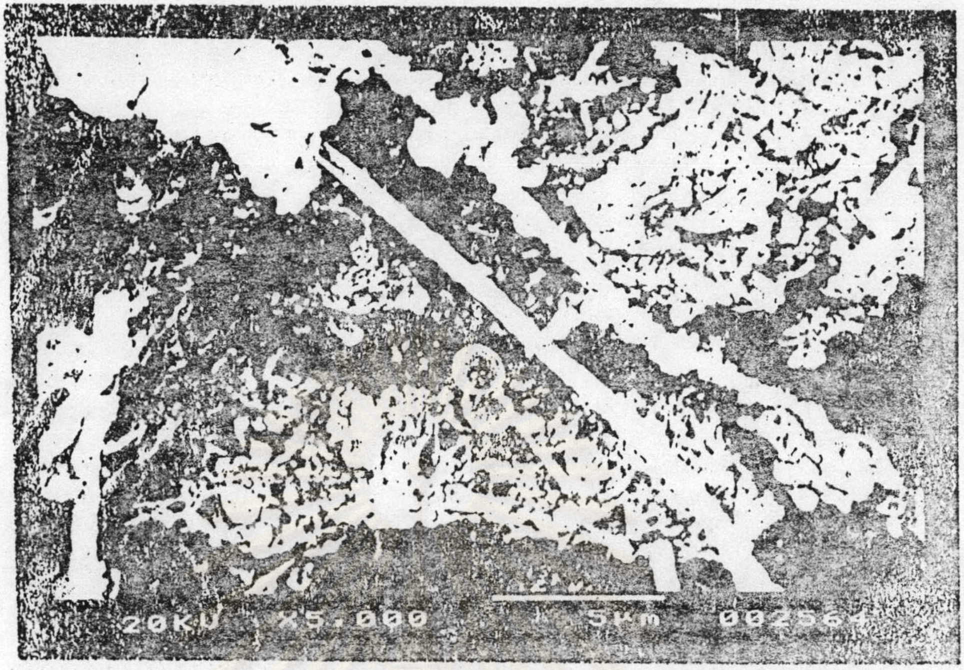


Figure 5.10.3 Filamentous bacteria on Fixed Bed Granular Surface

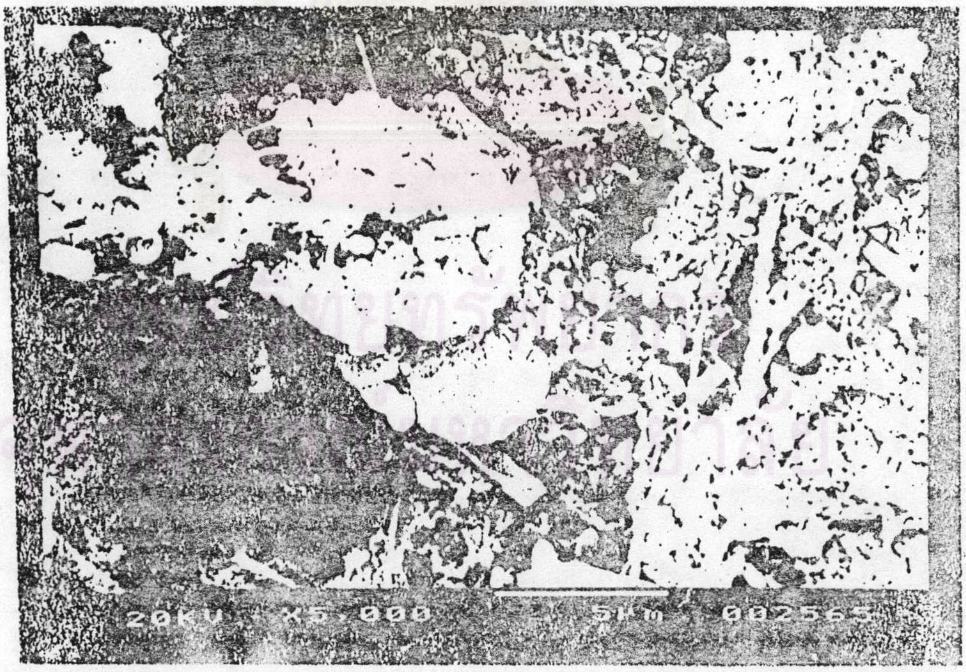


Figure 5.10.4 Coccus and Rod Bacteria on Fixed Bed Granular Surface

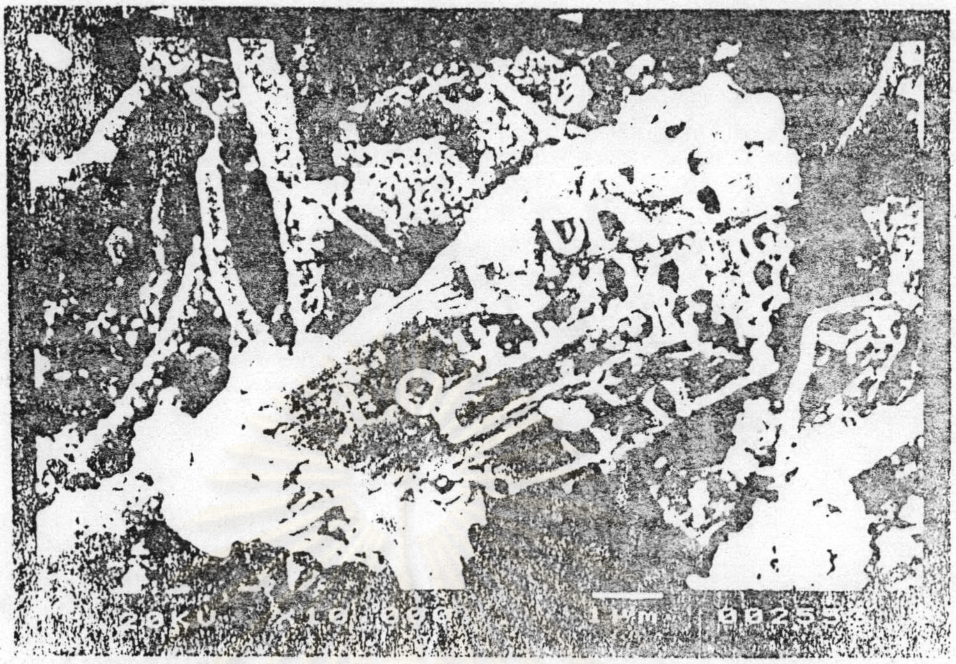


Figure 5.10.5 Filament bacteria on RAUS granular surface

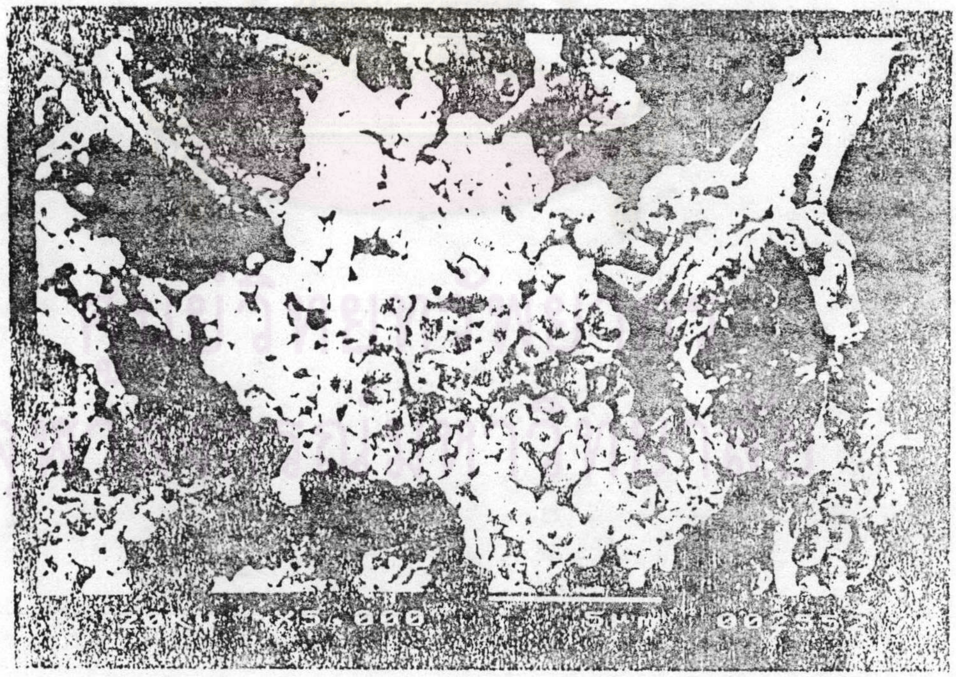


Figure 5.10.6 Coccus and Rod Bacteria on RAUS granular surface

5.10.3 Microorganisms inside granular sludge

When granular sludge was cut to observe inside structure, the same kinds of bacteria that covered outside surface also occupied area inside as shown in Fig. 5.10.7 and Fig. 5.10.8

Figure 5.10.7 Filaments bacteria inside Fixed-Bed Granular

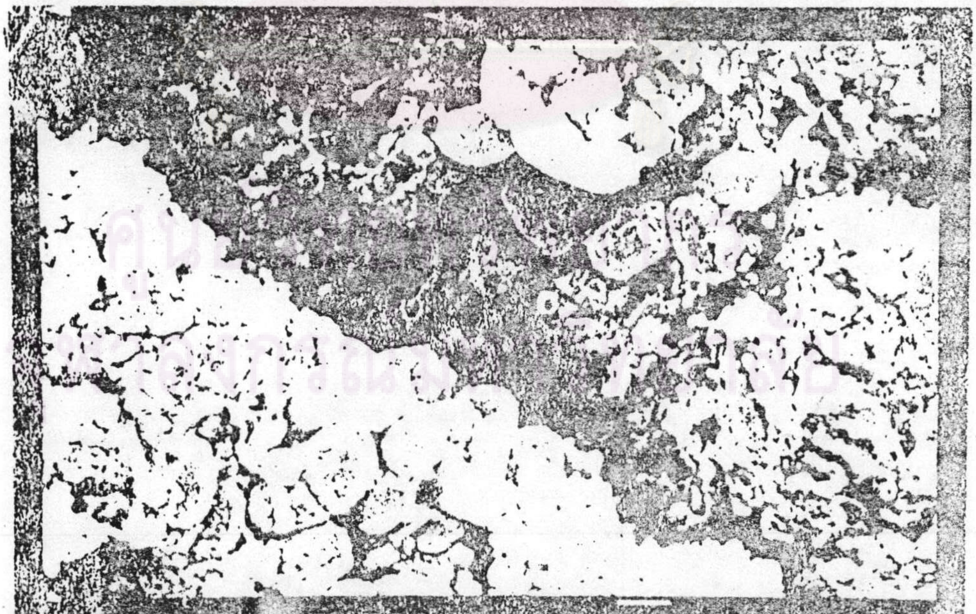


Figure 5.10.8 Coccus and Rod bacteria inside Fixed Bed Granular

Figure 5.10.9 Filaments bacteria inside RAUS granular

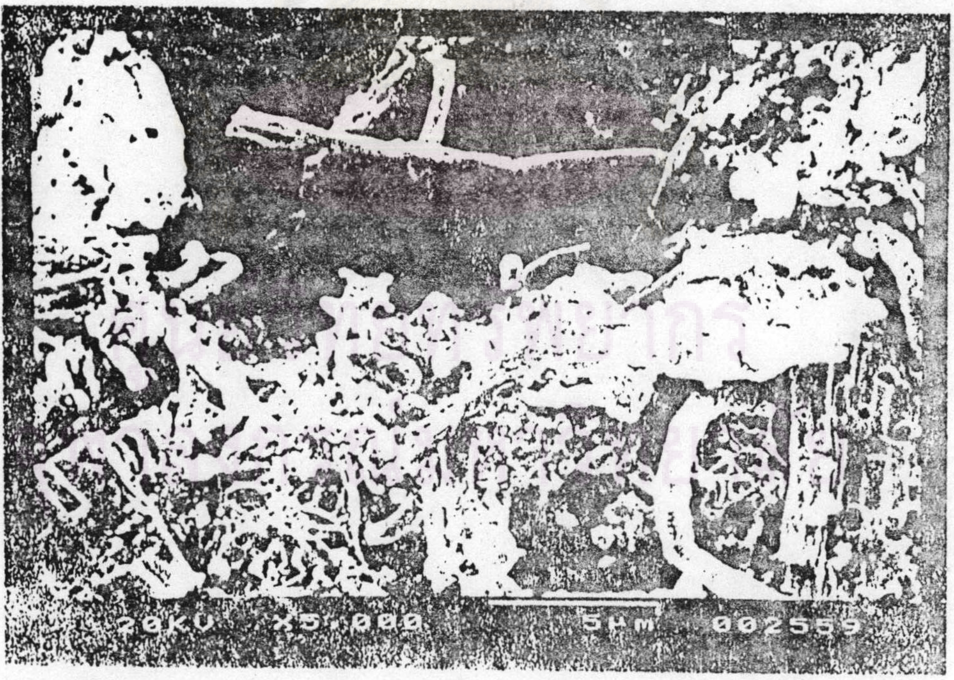


Figure 5.10.10 Bacteria inside RAUS granular Coccus and Rod

From Fig 5.10.3 - Fig 5.10.10 Various kinds of bacteria, i.e. Coccus, short curved rods, rods, and filaments were found both covering the granular surface and throughout the granular space. Filamentous cells were covered by colonies of cocci or rods and form microflocs of 10-50 micron. In some area, bundles of filamentous bacteria were clearly visible as seen in Fig. 5.10.5 Short curved rods were also easily found as seen in Fig.5.10.8. Somtimes clumps of cocci were also found as seen in Fig. 5.10.6.

From the summary of characteristics of methanogenic bacteria by William et al. (1987), it could be concluded that the rods and cocci bacterias on the granular sludge were the species in methanobacterium family.

The summary of characteristics of methanogenic bacteria by William et al. (1987) is shown in Appendix D.