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BIOLOGICAL CONVERSION OF BIOMASS TO METHANE

QUARTERLY PROGRESS REPORT
for Period June 1, 1977 - September 30, 1977

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DISCLAIMER

Introduction

During the past quarter, work has continued on the use of beef feed lot manure for the production of methane. Additional data were collected on the operation of the fermentors at thermophilic temperatures. Data was also collected at the mesophilic temperature. A considerable effort has been expended on characterizing the reactor effluent and evaluating the dewatering characteristics of the reactor slurry.

Evaluation of the type of reactor on methane yields have continued. Data have been collected on these systems operating at a total retention time of 10 days. Response of the system and reaction rates have been determined.

Manure Fermentation

Beef feed lot residue obtained from the College of Agriculture's beef farm was used in these studies. The manure was collected and processed in the same manner as previously reported. During this period, Reactor 1 was used as a control. The temperature, retention time and loading rate were maintained relatively constant. The temperature was maintained at 60°C. The retention time was set at 10 days with a feed solids concentration of approximately 5 percent. The data collected during this period are shown in Table 1. The run was initiated on June 26, 1977. The data presented are the average values for the week.

At the beginning of week 1 and 2, the temperature control system malfunctioned. Due to the high temperatures, the thermal overload on the water heater was activated with a resultant loss of heating capacity. Since this occurred on a weekend, the temperature decreased to 50°C before

Table 1. Summary of Data for Reactor 1. Control at 60°C

Week	θ days	Gas lph	CH_4 %	CH_4 lpH	V.S. Fed kg/d	CH_4 Prod. m^3/kgV.S.	CH_4 Prod. m^3/m^3-d	Loading Kg V.S./m^3-d
1	8.65	53.0	62.0	32.86	5.23	0.151	1.05	6.75
2	9.12	36.8	61.3	22.56	4.08	0.133	0.72	5.26
3	9.32	56.4	62.7	35.36	4.69	0.181	1.13	6.05
4	9.27	55.8	62.2	34.71	4.96	0.168	1.11	6.40
5	9.15	50.9	61.2	31.15	4.77	0.157	1.00	6.15
6	10.89	48.2	56.9	27.42	4.81	0.137	0.88	6.21
7	9.11	43.1	61.1	26.33	4.84	0.131	0.84	6.25
8	8.98	47.9	66.1	31.66	5.57	0.136	1.01	7.19
9	8.75	49.9	63.8	31.84	5.63	0.136	1.02	7.26
10	8.71	37.3	63.0	23.50	5.22	0.108	0.75	6.74
11	8.77	14.1	56.9	8.02	4.21	0.046	0.26	5.43
12	8.79	13.3	53.1	7.06	3.94	0.024	0.23	5.08

the problem was corrected. This temperature drop resulted in somewhat lower gas production, especially during week 2.

The gas production during week 3 through 9 show the gradual decrease in the biodegradability of the manure due to storage. The manure was stock piled in a moist condition. Biological stabilization occurred during the storage period. During week 10, the ammonia-nitrogen increased to the 700 to 800 mg/l range with a pH of 8.0. At this high pH and 60°C temperature the free ammonia (NH_3) was 200 mg/l. The gas production decreased due to the higher volatile acids. Unfortunately, the gas seals

Table 2. Summary of Data for Reactor 2.

Week	Temp °C	θ days	Gas lph	CH_4 %	CH_4 lph	V.S. Fed kg/d	CH_4 Prod. m^3/kgV.S.	CH_4 Prod. m^3/m^3-d	Loading Kg V.S./m^3-d
1	60	3.04	109	62.0	67.58	12.90	0.125	2.09	16.65
2	60	3.76	59.5	55.0	37.73	12.97	0.070	1.17	16.74
3	60	7.38	17.9	53.1	9.5	3.92	0.058	0.29	5.06
4	60	11.10	54.8	61.3	33.59	4.46	0.180	1.05	5.75
5	60	8.91	47.3	60.0	28.38	4.47	0.152	0.88	5.77
6	60	9.16	43.1	60.2	25.95	4.75	0.131	0.80	6.13
7	TR	7.58	41.5	60.7	25.19	6.52	0.093	0.78	8.41
8	40	4.97	36.8	62.4	22.96	9.18	0.050	0.71	11.85
9	40	8.65	29.2	62.2	18.16	4.57	0.095	0.56	5.90
10	40	4.92	37.5	61.2	22.95	8.85	0.062	0.71	11.42

on the mixer shaft started to leak. This leak appears to be the reason for the sharp drop in gas production.

After completion of the runs at different retention times as reported in the last report, the loading was significantly increased. This was an attempt to evaluate the response of the process to high loading rates. The data presented in Table 2 show that loadings of greater than 16 kg of volatile solids per m^3 per day at a retention time of less than 4 days were achieved. A more detailed presentation of data for weeks one through three is shown in Figure 1. Time 0 corresponds to the first day of week 1. The loading was increased to approximately 15 kg V.S./Day-m^3 (0.93 lb V.S./Day-c.f.). With a three day residence time, the response was

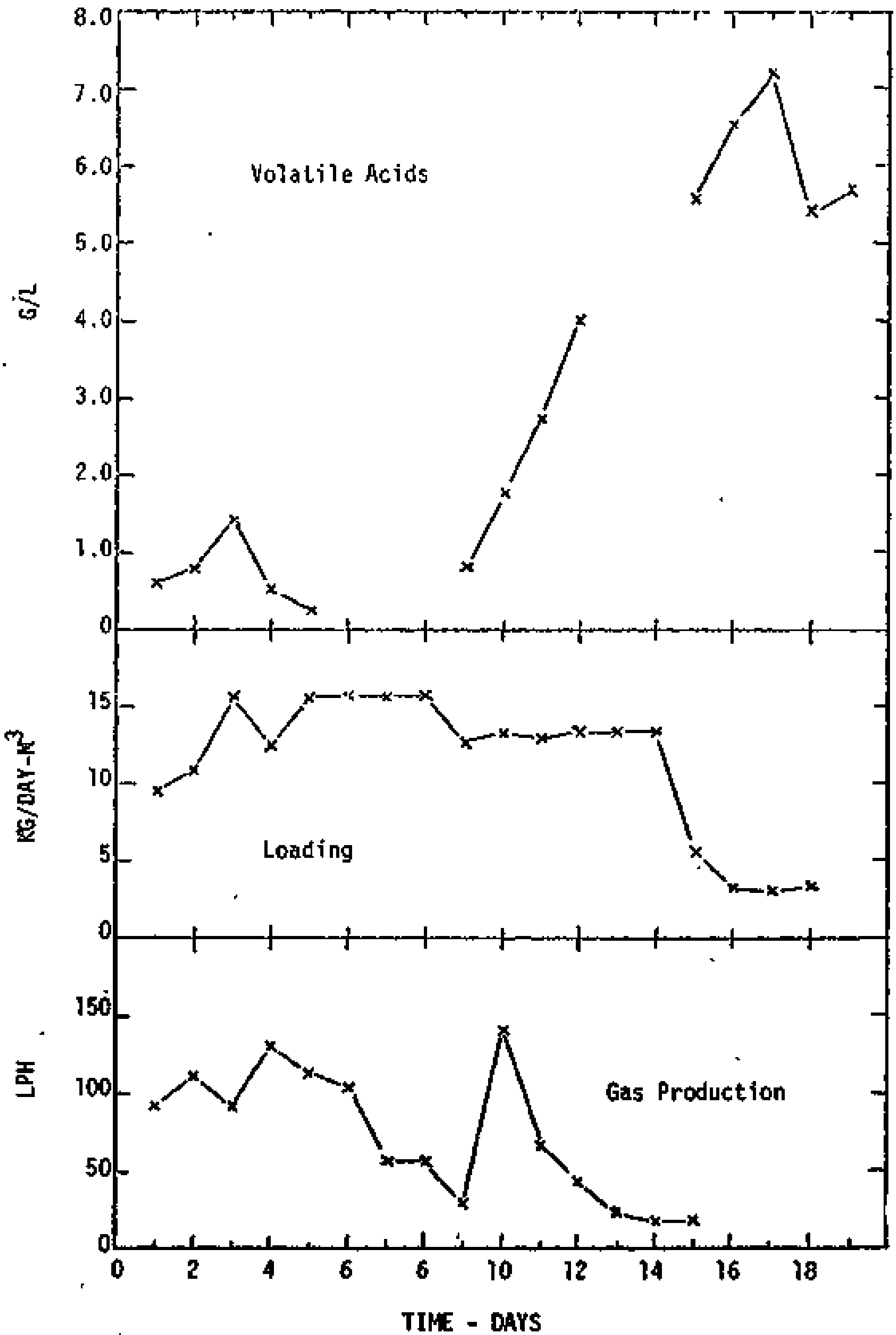


Figure 1. Reactor Response to High Loading at Short Residence Time.

very favorable. The volatile acids increased to 1400 mg/l, but were quickly reduced to less than 500 mg/l. Unfortunately, on Day 7, the temperature dropped to 50°C. This temperature problem was repeated on Day 8. The gas production dropped significantly. The temperature shock was sufficient to disrupt the microbial balance. The volatile acids increased and were at about 4000 mg/l by the end of the second week. A marked reduction in loading did not allow the system to recover. The volatile acids continued to increase while the pH dropped to 6.2. Failure resulted with the gas production decreasing to less than 10 liters per hour.

During week 3, reactor 2 was reseeded with the effluent from reactor 1. Recovery was rapid and complete within one week. During week 7, the temperature was lowered to 40°C and the retention time reduced to 5 days. The data for week 8 are the averages of Sunday through Wednesday. On Thursday, the temperature reached 71°C due to a failure of the temperature controller. The system was essentially sterile. The gas production was 0 lph. Reseeding with effluent from reactor 3 brought the unit back in operation. By week 10, the retention time was again at 5 days. Additional data are being collected at the 5 day retention time.

The loading on reactor 3 was increased by increasing the feed solids to approximately 10 percent. With the initial retention time of 6 to 7 days, the loading was approximately 13 kg V.S./Day-m^3. The volatile acids increased to 5000 mg/l during week 1. Excessive foaming developed and the gas handling system was frequently filled with foam. Gas production data during this period are not valid. In fact, the foam problem was so severe during week 4 that it was not possible to obtain any gas readings.

Table 3. Summary Data for Reactor 3.

Week	Temp °C	θ days	Gas lph	CH_4 %	CH_4 lph	V.S. Fed Kg/d	CH_4 Prod. m^3/kgV.S.	CH_4 Prod. m^3/m^3-d	Loading Kg V.S./m^3-d
1	60	6.53	70.5	55.0	38.78	10.49	0.089	1.20	13.5
2	60	7.46	63.1	58.9	37.17	9.35	0.095	1.15	12.1
3	60	4.87	99.3	61.9	61.47	14.58	0.101	1.90	18.8
4	60	4.85	-	59.2	-	14.94	-	-	19.3
5	60	5.86	71.6	55.6	39.81	11.46	0.083	1.23	14.8
6	60	6.12	80.2	55.7	44.67	11.37	0.094	1.38	14.7
7	TR	9.02	62.1	60.4	37.51	6.67	0.135	1.16	8.6
8	40	9.37	35.0	63.2	22.13	5.05	0.105	0.68	6.5
9	40	8.93	37.0	62.6	23.16	5.21	0.106	0.72	6.7
10	40	8.79	42.6	64.0	27.26	5.91	0.110	0.84	7.6
11	40	9.16	48.4	64.0	30.98	6.48	0.114	0.96	8.4
12	40+	9.26	57.3	54.1	31.10	5.49	0.136	0.96	7.1

During week 2, the ammonia nitrogen was in the 600 to 700 mg/l range. With a pH of 7.8 to 7.9, ammonia inhibition may have been part of the cause for the high volatile acids.

During week 7, the temperature was reduced to 40°C. With a retention time of 8 to 9 days, the methane production was 0.105 to 0.115 m^3/kg V.S. fed to the system. The higher gas production during week 12 resulted from evaluated temperatures. Temperature controller problems resulted in 50 to 60°C temperatures during the last three days of this

Table 4. Summary Data for Reactor 4.

Week	Temp °C	θ days	Gas lph	CH_4 %	CH_4 lph	V.S. Fed kg/d	CH_4 Prod. m^3/kgV.S.	CH_4 Prod. m^3/m^3-d	Loading kg V.S./m^3-d
1	60	5.92	79.7	61.0	48.62	11.56	0.101	1.50	14.9
2	60	8.18	34.1	60.7	20.7	7.58	0.066	0.64	9.78
3	60	5.08	100.7	61.2	61.63	13.73	0.108	1.91	17.7
4	60	4.79	95.0	58.7	55.77	14.05	0.095	1.73	18.1
5	60	4.53	123.7	58.8	72.74	15.59	0.112	2.25	20.1
6	60	5.35	78.8	57.6	45.39	12.34	0.088	1.41	15.9
7	TR	11.9	48.6	63.8	31.00	6.27	0.119	0.96	8.1
8	40	14.0	31.6	64.7	20.45	3.44	0.143	0.63	4.4
9	40	14.58	30.9	63.3	19.56	3.29	0.143	0.61	4.2
10	40	14.07	20.1	61.1	12.28	3.77	0.076	0.38	4.9
11	40	14.27	14.1	61.4	8.66	4.34	0.048	0.27	5.6
12	40	13.98	16.0	55.3	8.85	3.39	0.063	0.27	4.4
13	40	13.02	17.7	57.7	10.21	3.21	0.076	0.32	4.1

week. Additional runs at this retention time are presently underway to verify the data obtained to date.

The loading on reactor 4 was also increased by increasing the feed solids to a concentration of approximately 10 percent. Excessive foaming was also encountered. The ammonia nitrogen increased to 600 to 700 mg/l while the pH was 7.9 to 8.0. During week 2, the volatile acids increased to 3000 mg/l. By reducing the loading during week 2, the volatile acids decreased to less than 1000 mg/l. It was possible to load the system at 20 kg V.S./Day-m^3 (1.25-lb/Day-c.f.) and maintain operation. Because of the inadequacies of the gas handling system, gas production data are suspect. During week 5, the gas handling problems were minimal. The gas production rate of 0.112 m^3 of methane per kg V.S. fed compares favorably with the control reactor rate of 0.157 m^3/kg V.S. fed. In general, these high loads resulted in an excessive amount of foaming. This problem may need consideration in the design of a full scale system if high loading rates are expected.

During week 7, the temperature was reduced to 40°C and the feed solids concentration to approximately 5 percent. The high gas production during week 8 and 9 resulted from a low rate of solids fed and a relatively high gas production due to the solids remaining in the reactor from the 10 percent feed. The gas production continued to decrease, resulting in unexpectedly low gas production rates. At a 15 $\pm$ day retention time, the m^3 of methane per kg V.S. fed should have been much higher. The reason for this low gas production is not known. Additional data are being collected at this temperature and loading.

The nitrogen levels in the reactors and the feed slurry tanks are given in Table 5. As would be expected, the total Kjeldahl nitrogen in the mix tank was a function of the solids concentration. The data shown are the average and standard deviation. The extreme variability is due to some variation in solids concentration, but more importantly, to the sample error. When using the micro-Kjeldahl and a concentrated slurry, only 1 ml of sample is used. The difficulty in obtaining a representation sample is the major cause of this variation. The average ammonia concentrations are more consistant. These determinations were

Table 5. Summary of Average Nitrogens

Week	Feed Solids %	Tank	Total Kjeldahl mg/l as N	Ammonia mg/l as N
1 thru 6	5	M-2	1303 ± 741	342 ± 86
	5	D-1	2963 ± 515	578 ± 171
	5	D-2	2859 ± 710	518 ± 194
	10	D-3	2732 ± 983	832 ± 420
	10	D-4	2355 ± 978	765 ± 325
	10	M-1	2495 ± 891	494 ± 114
7 thru 12	5	M-2	1446 ± 663	191 ± 85
	5	D-1	2799 ± 661	572 ± 127
	5	D-2	2414 ± 475	486 ± 209
	5	D-3	2980 ± 575	530 ± 157
	5	D-4	3022 ± 448	561 ± 141
	5	M-1	1831 ± 726	262 ± 91

M = feed mixing tank D = digester

made using the specific ion electrode technique. The variability is due to both analytical variation and variations in ammonia content. The ammonia present in the raw manure depends upon the ammonia loss during storage. At times, movement of the manure produced intense ammonia odors, indicating a significant loss of ammonia.

Because of the extreme variations in the total Kjeldahl nitrogen, this analysis has been discontinued as a routine test. Analysis of the nitrogen content of the residue will continue.

Particle Size Distribution

Wet sieve analyses of the raw manure slurry and of the slurry from the reactors have been conducted to determine the particle size distribution and the composition of the different size fractions. Table 6 shows the results of this analysis of the manure feed slurry and the reactor effluents. For the manure feed slurry, approximately, 60 percent of the total solids are retained by the 200 mesh screen. The volatile total solids follow a similar trend.

By considering that the solids retained by the 200 mesh screen are suspended solids that can be removed without chemical treatment, one can determine how efficient a removal system will be required to capture the solids. In the feed slurry, 95 percent of these solids are larger than 100 mesh (145 μm).

The solids in reactor 1 were considerably smaller than the solids in the feed slurry. Less than 50 percent of the total solids were retained on the 200 mesh screen. For the suspended solids, only 85 percent were retained on the 100 mesh screen. In the feed slurry, approximately 60 percent of these solids were retained on the 9 mesh screen. In the effluent from reactor 1, this figure was only 25.4 percent. It would appear that a high degree of stabilization was occurring. This resulted in a substantial reduction in the particle size of the solids remaining in the reactor effluents.

Reactor 2, 3 and 4 enhibited a significantly different particle size distribution. The 200 mesh screen retained between 50 to 60 percent of the total solids. Approximately 40 percent of the total solids were retained on the 9 mesh screen. Because of the high loadings and short

Table 6. Slurry Particle Size Distribution

Sieve Size	Percent of Solids Retained			
	Total Solids	Volatile Tot. Solids	Suspended Solids	Volatile Sus. Solids
	Raw Manure Slurry (7-27-77)			
9	34.0	28.4	59.6	49.8
20	38.7	32.8	67.9	57.5
50	49.6	41.8	87.0	73.7
100	53.8	45.6	94.4	80.0
200	57.0	48.2	100	85.6
Pan	100	80.0	-	-
	Reactor #1 Effluent (6-29-77)			
9	12.1	8.8	25.4	18.5
20	21.9	15.9	46.0	33.4
50	35.0	24.7	73.5	52.3
100	40.6	27.1	85.3	56.9
200	47.6	29.9	100	62.3
Pan	100	59.7	-	-
	Reactor #2 Effluent (7-1-77)			
9	36.3	27.4	65.9	49.7
20	39.0	29.7	70.8	53.9
50	46.6	34.6	84.6	62.8
100	51.1	36.5	92.7	66.2
200	55.1	38.4	100.	69.7
Pan	100	66.5	-	-
	Reactor #3 Effluent (7-8-77)			
9	40.8	30.8	77.1	58.2
20	44.5	33.1	84.4	62.6
50	46.1	33.8	87.1	63.9
100	49.2	35.1	93.0	66.4
200	52.9	36.9	100.	69.8
Pan	100	65.9	-	-
	Reactor #4 Effluent (7-14-77)			
9	41.2	32.3	68.7	53.8
20	43.8	34.4	73.0	57.3
50	51.5	39.2	85.8	65.3
100	55.4	40.3	92.3	67.2
200	60.0	42.9	100	71.5
Pan	100	68.8	-	-

retention times employed for these reactors, the solids breakdown was not as complete. The volatile suspended solids in these three reactors are larger size particles. In all three reactors, over 90 percent of the volatile suspended solids are retained on the 50 mesh screen (297 μm). A high volatile suspended solids capture is possible with a system design to remove relatively large particles.

The nitrogen, phosphorus and potassium content of the various size fractions are shown in Table 7. There are no pronounced trends due to the variation in the data. It does appear that the larger solids may have a higher organic nitrogen content. The data also tend to show that the phosphorus content of the smaller particles may be higher.

Based on the particle size distribution and the composition of these size fractions, it would appear that most of the earily recovered organic nitrogen will be associated with particle sizes in excess of 0.3 mm. There will be a significant nitrogen loss with the smaller particles and, of course, the ammonia that is solution will not be recovered with a solids recovery system.

Table 8 shows the results of the fiber analysis. There is no significant difference in the cellulose and lignin content of the larger size particles. An attempt to conduct this analysis on the smaller particles was unsuccessful due to the presence of acid soluble inorganics, i.e. limestone. There is a quantity of crushed limestone in this manure that is pulverized in the chopping process. The larger particles settle so rapidly that they are removed in the process of feed slurry preparation. The fine particles pass through the system. The sample is treated with acid for cellulose hydrolysis. This material is dissolved, causing errors

Table 7. Composition of Different Size Fractions

Sieve #	% T.S. Retained	Nitrogen as % T.S.	Phosphorus as % T.S.	Potassium as % T.S.
Reactor #1, θ = 9.7 days, 58°C, Feed Solids = 5.24%				
9	12.1	1.41	0.39	0.10
20	21.9	1.46	0.43	0.12
50	35.0	1.10	0.47	0.18
100	40.6	0.33	0.45	0.14
200	47.6	0.74	0.43	0.13
Reactor #2, θ = 2.6 days, 58°C, Feed Solids = 5.30%				
9	36.3	1.10	0.46	0.21
20	39.0	1.06	0.51	0.28
50	46.6	1.10	0.64	0.46
100	51.1	0.59	0.43	0.29
200	55.1	1.25	0.65	0.45
Reactor #3, θ = 6.5 days, 58°C, Feed Solids = 9.18%				
9	40.8	0.54	0.40	0.17
20	44.5	1.41	0.39	0.21
50	46.1	0.34	0.33	0.24
100	49.2	0.36	0.47	0.24
200	52.9	1.25	0.65	0.25
Reactor #4, θ = 4.8 days, 58°C, Feed Solids = 9.11%				
9	41.2	1.82	0.52	0.25
20	43.8	1.00	0.46	0.22
50	51.5	0.77	0.57	0.32
100	55.4	0.51	0.78	0.27
200	60.0	0.36	1.20	0.34

Table 8. Fiber Analysis

Reactor	Sieve Size	Cellulose %	Lignin %	Protein %	Fixed Solids %
1	9	59.4	4.9	8.8	26.9
	20	56.4	4.9	9.1	28.6
	50	55.0	5.5	6.9	32.6
2	9	56.9	11.7	6.9	24.5
	20	57.3	-	6.6	-
	50	55.4	1.8	6.9	35.9
3	9	56.7	15.4	3.4	24.5
	20	55.3	-	8.8	-
	50	42.8	2.1	2.1	52.1
4	9	56.5	8.8	11.4	21.5
	20	57.8	11.3	6.2	22.3
	50	51.8	3.5	4.8	37.3

in the test. The lignin content then becomes negative for the smaller size fractions.

Centrifuge Dewatering Study

A Sharples Mark III solid-bowl basket centrifuge with a variable speed drive was used to evaluate the effect of centrifugal force on the solids capture and cake moisture. The results of tests on each of the reactors are shown in Figures 2 and 3. Operation of the centrifuge at 3000 rpm (1700 x g) yield cake solids in the 28 to 30 percent range. Tests were not conducted at higher speeds, but from the shape of the curve, it would appear that higher speeds will yield only marginal increases in the cake solids.

The slurry was pumped directly from the effluent storage tank to the centrifuge. No chemicals were added to the slurry. The flow rate to the centrifuge was 8.0 liters per minute. This flow rate is recommended for this machine.

Figure 4 shows the solids capture obtained at different centrifuge speeds. The feed to reactor 1 was approximately 5 percent solids. For reactor 4, the feed was approximately 10 percent. These curves show that the solid capture in reactor 1 reached the maximum at approximately 2300 rpm. The centrate contained about 10 g/l of dissolved solids and 8 g/l of suspended solids. The solids remaining were the fine suspended solids that would require chemical coagulation before they could be removed.

The effluent from reactor 4 had a much higher solids content. The dissolved solids were approximately double those in reactor 1. The solids capture continued to improve with increasing centrifuge speed.

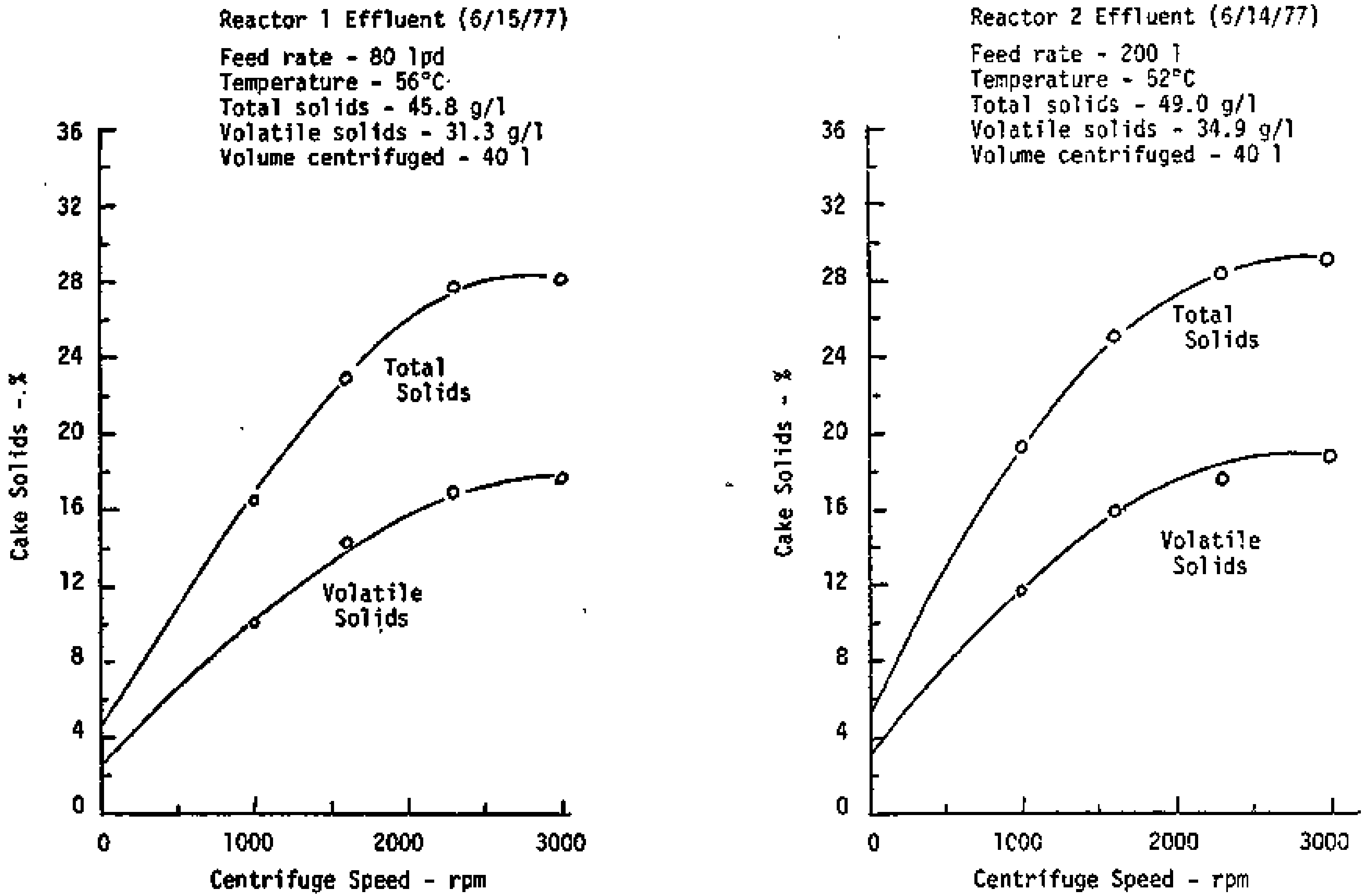


Figure 2. Reactor Slurry Dewatering by Centrifuge - Reactor 1 and 2

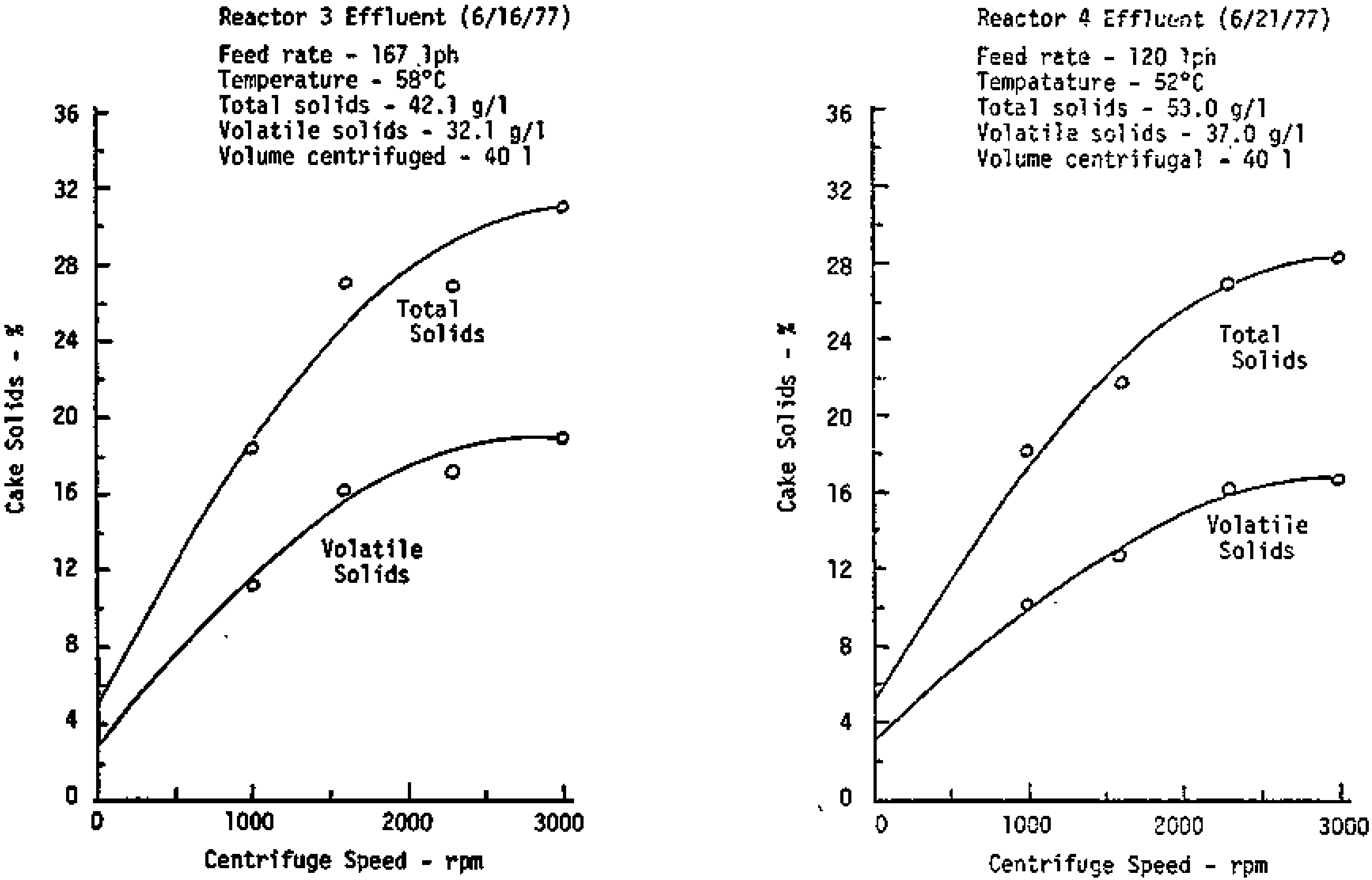
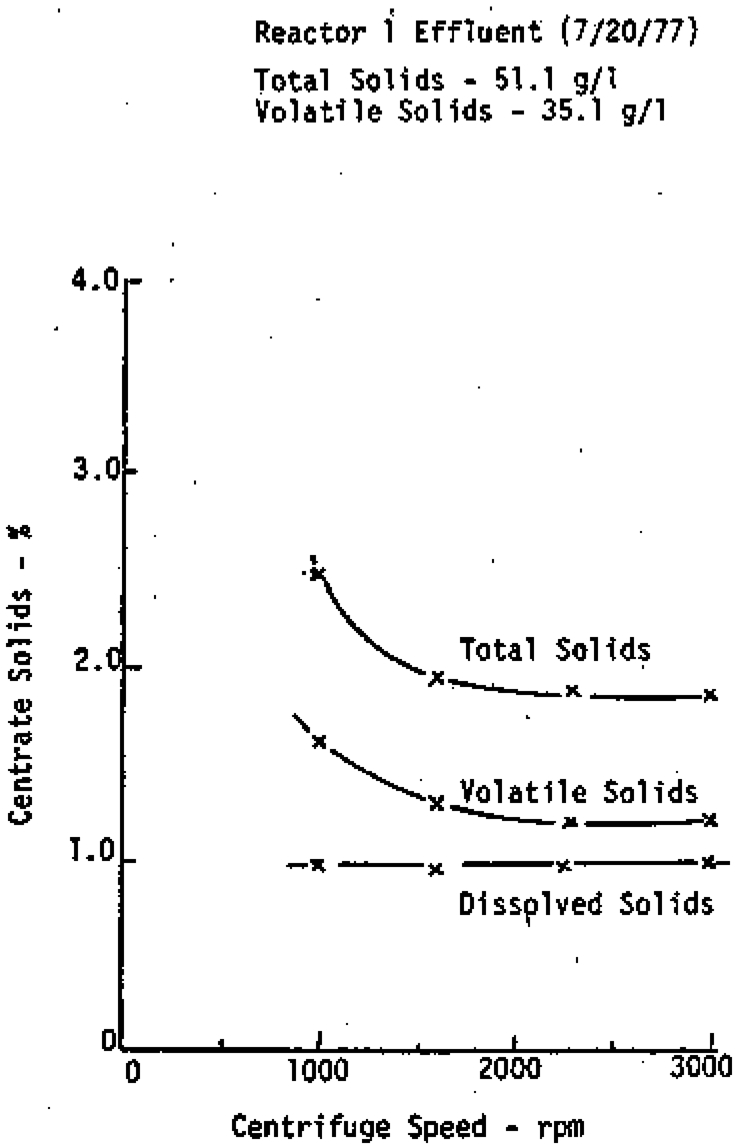
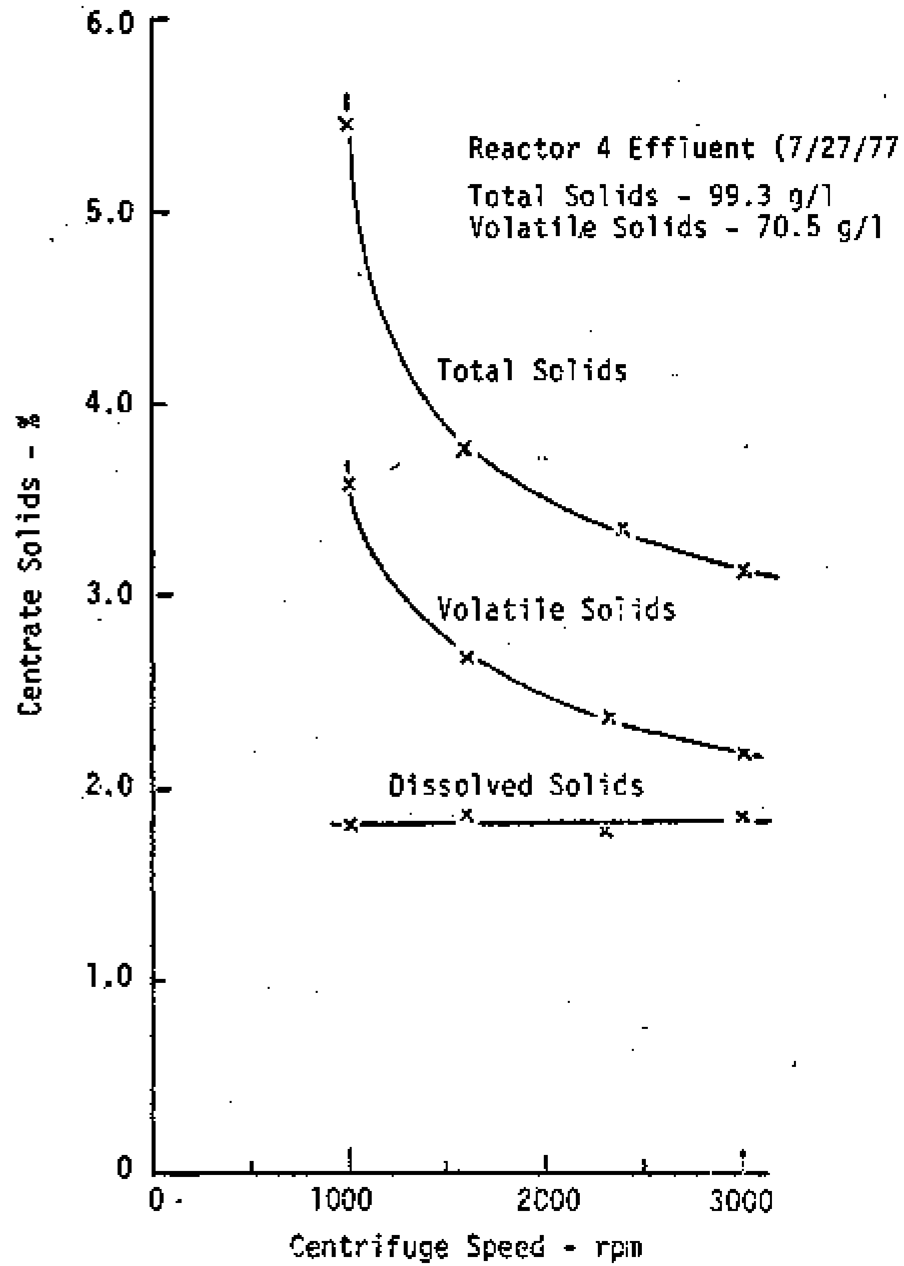


Figure 3. Reactor Slurry Dewatering by Centrifugation - Reactor 3 and 4


Reactor 1 Effluent (7/20/77)
Total Solids - 51.1 g/l
Volatile Solids - 35.1 g/l
Centrate Solids - %
4.0
3.0
2.0
1.0
0
0
1000
2000
3000
Centrifuge Speed - rpm
Total Solids
Volatile Solids
Dissolved Solids


Reactor 4 Effluent (7/27/77)
Total Solids - 99.3 g/l
Volatile Solids - 70.5 g/l
Centrate Solids - %
6.0
5.0
4.0
3.0
2.0
1.0
0
0
1000
2000
3000
Centrifuge Speed - rpm
Total Solids
Volatile Solids
Dissolved Solids

It would appear that the optimum speed has not been reached. The suspended solids in the centrate were approximately 15 g/l when the centrifuge was operated at 3000 rpm.

Complete-mix vs Staged Reactor Design

Studies on the effect of reactor design on the fermentation kinetics have continued. The systems were operating at a total retention time of 10 days. The feed slurry, shown in Table 9, was prepared daily. In order to ease the shock of adding substrate to reactor C, the feed volume was halved and added at 12 hour intervals. Also, in order to avoid temperature shock, the feed slurry was heated to 60°C prior to addition to the reactors.

Table 9. Feed Slurry Composition

Constituent	g/l
Shredded paper	38.5
Beef manure	12.0
CaO	3.5
NaOH	0.5
Nitrogen	1.0
Phosphorus	0.2

In general, the systems responded well to the reduced retention time. The daily gas production, shown in Figure 5, was reasonably constant during the first 15 days. A steady decrease in the gas produced by reactor A was observed. The pH and volatile acids (Figure 6 and 7) did not change significantly during this period. There was not ready explanation for

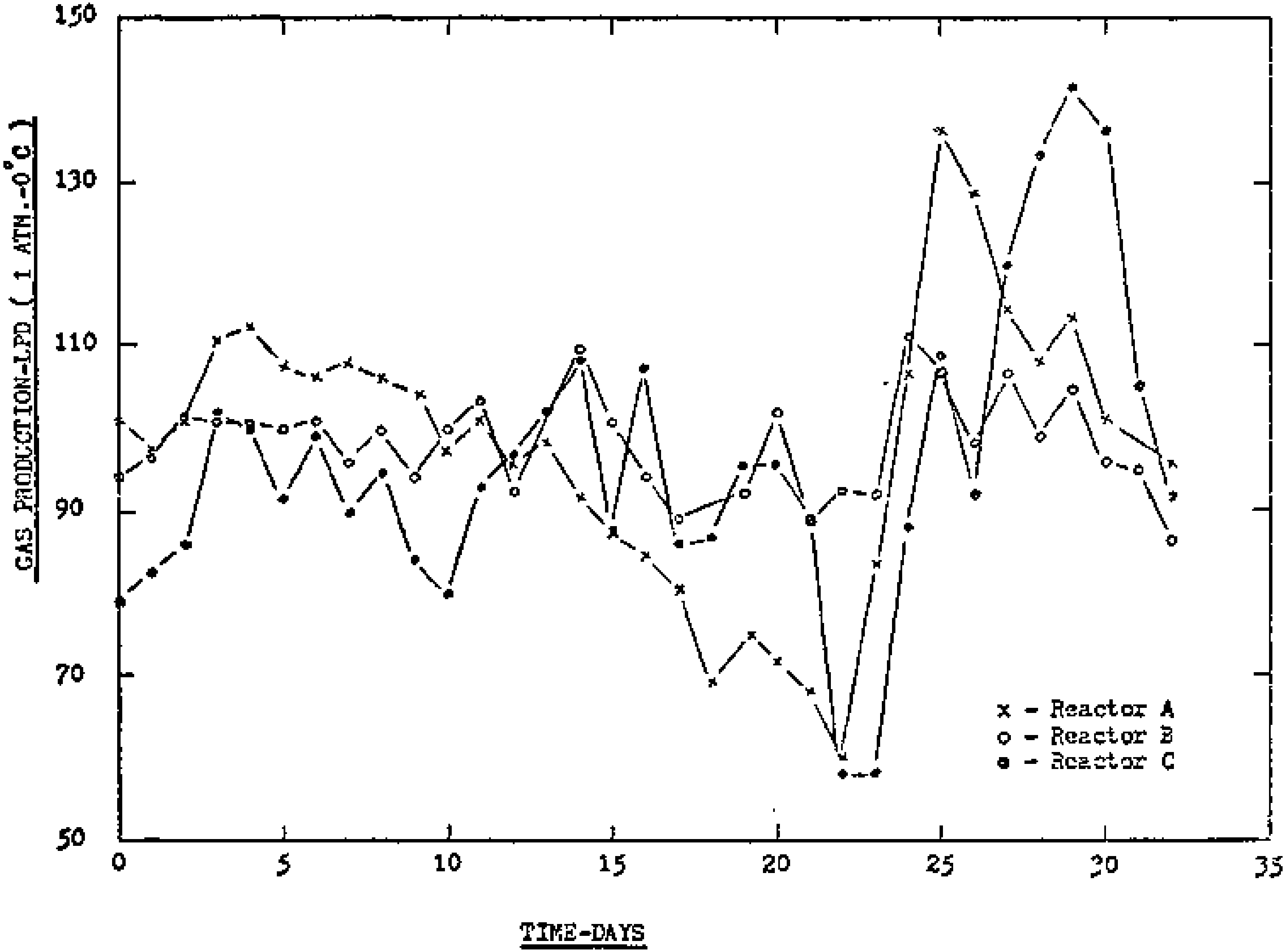


Figure 5. Gas Production from Complete Mix, Two-Stage and Plus Flow Reactors.

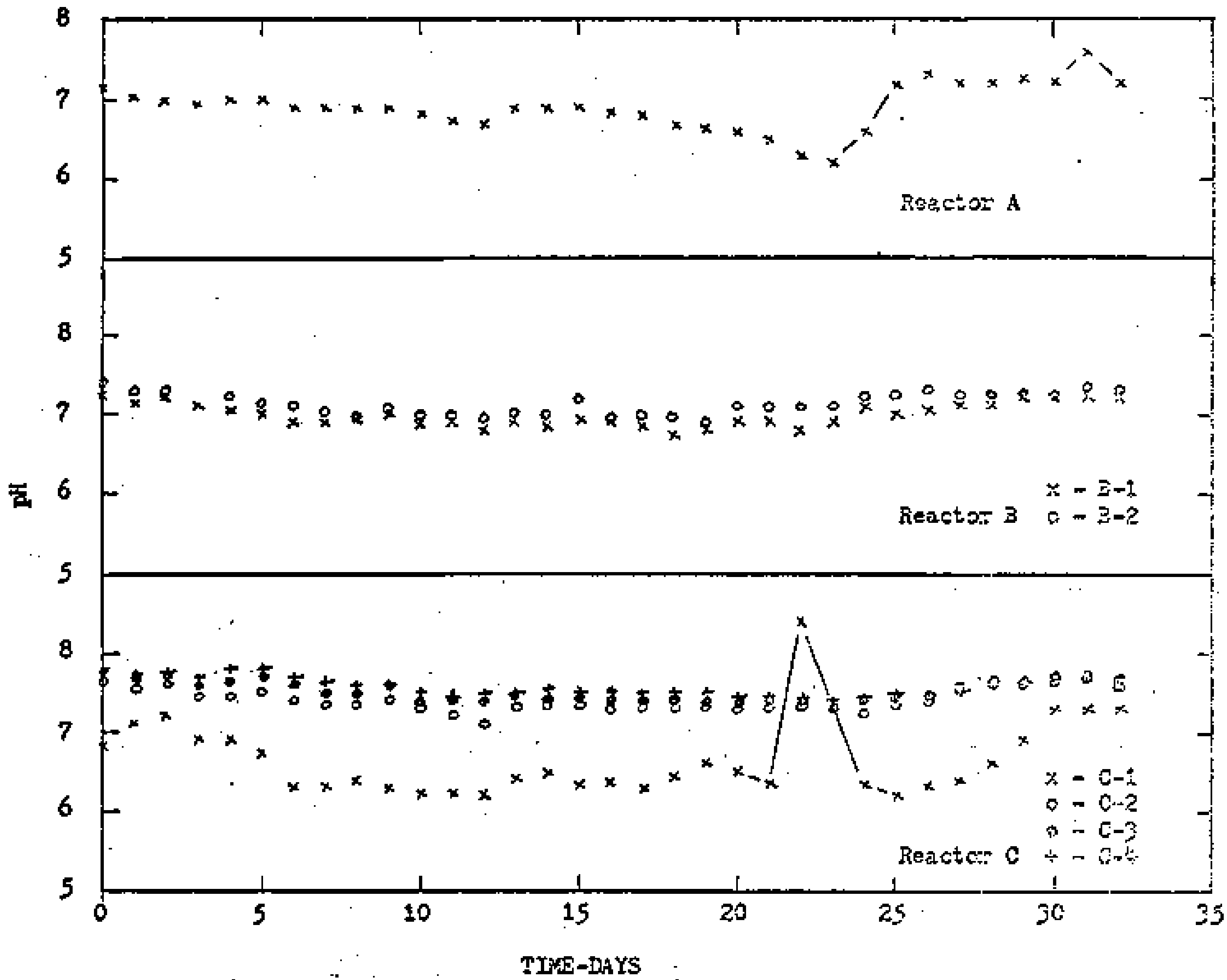


Figure 6. pH Values for Complete Mix and All Stages of the Two Stage and Plug Flow Reactors

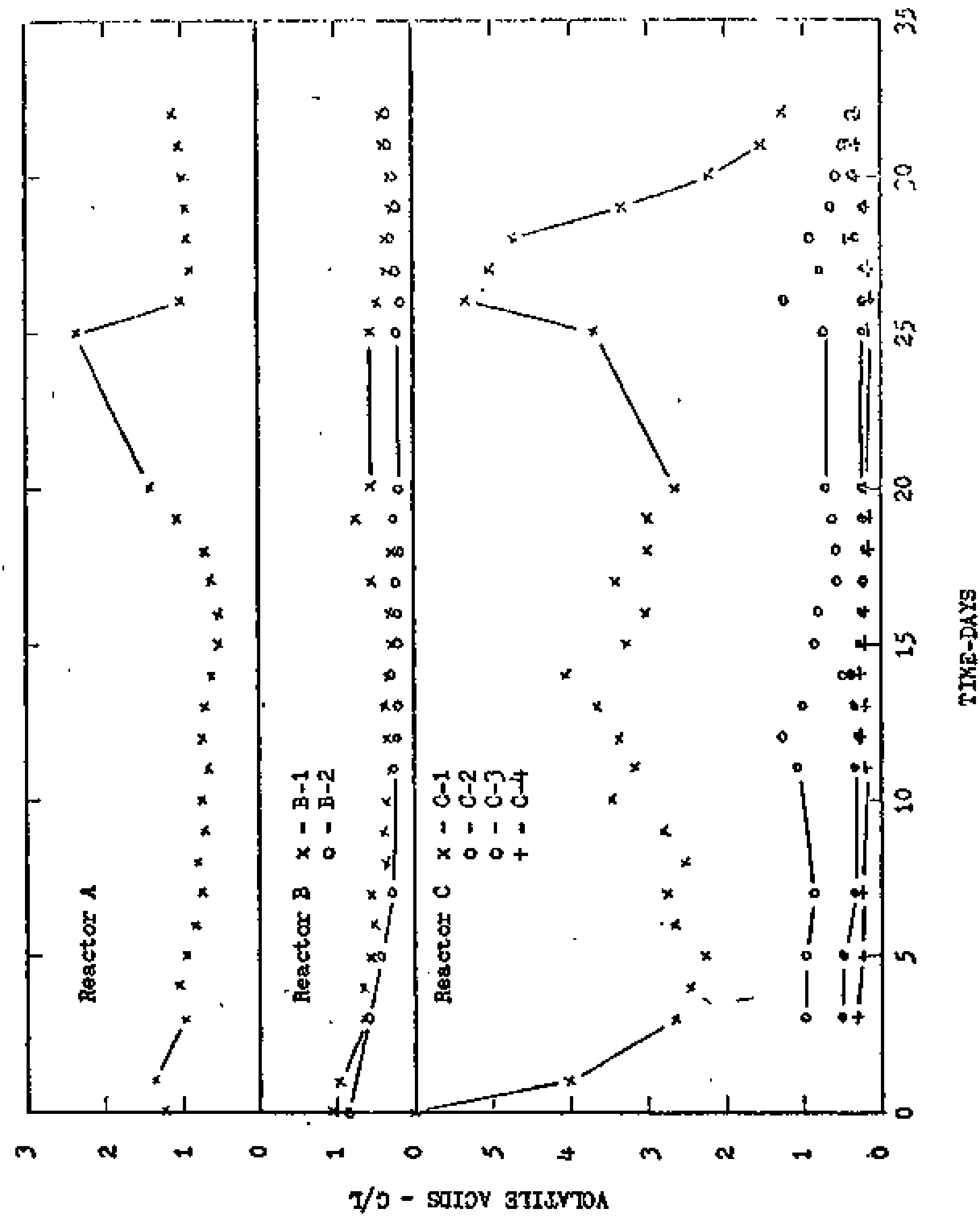


Figure 7. Volatile Acids for Complete Mix and All Stages of the Two Stage and Plug Flow Reactors

this decrease in gas production. A check of the nitrogen and phosphorus level in the reactors proved interesting. Phosphorus was found to be adequate in all reactors. However, the ammonia nitrogen in reactor A was zero. In reactor B and C, the ammonia nitrogen was less than 100 mg/l.

The cause of this low nitrogen was traced to the manner in which the feed was handled. The lime and sodium hydroxide added to the unbuffered feed raised the pH to approximately 10.5. Storage of the feed in the hot room for 12 hours prior to adding to the ractors allows a significant portion of the ammonia to volatilize. This loss was sufficient to cause a nitrogen deficiency in reactor A. This deficiency was not apparent in reactors B and C. Correction of this problem resulted in an immediate improvement in the gas production from reactor A.

On Day 21, reactor C received the entire feed volume in a single feeding. The pH increased to over 8.0, resulting in an inhibition of the microbes. This caused a marked increase in volatile acids. Resumption of the normal feed procedure with increased nitrogen substantially improved the operation of all three reactors. During the period of Day 25 to Day 33, the gas production increased significantly in all reactors. The volatile acid dropped to 1000 mg/l or lower in all reactors except C-1. Here these acids remained slightly above 1000 mg/l. It did appear that ammonia nitrogen was deficient.

The alkalinity is shown in Figure 8. This parameter closely correlated with the volatile acid concentration. Higher acids resulted in lower alkalinities as would be expected.

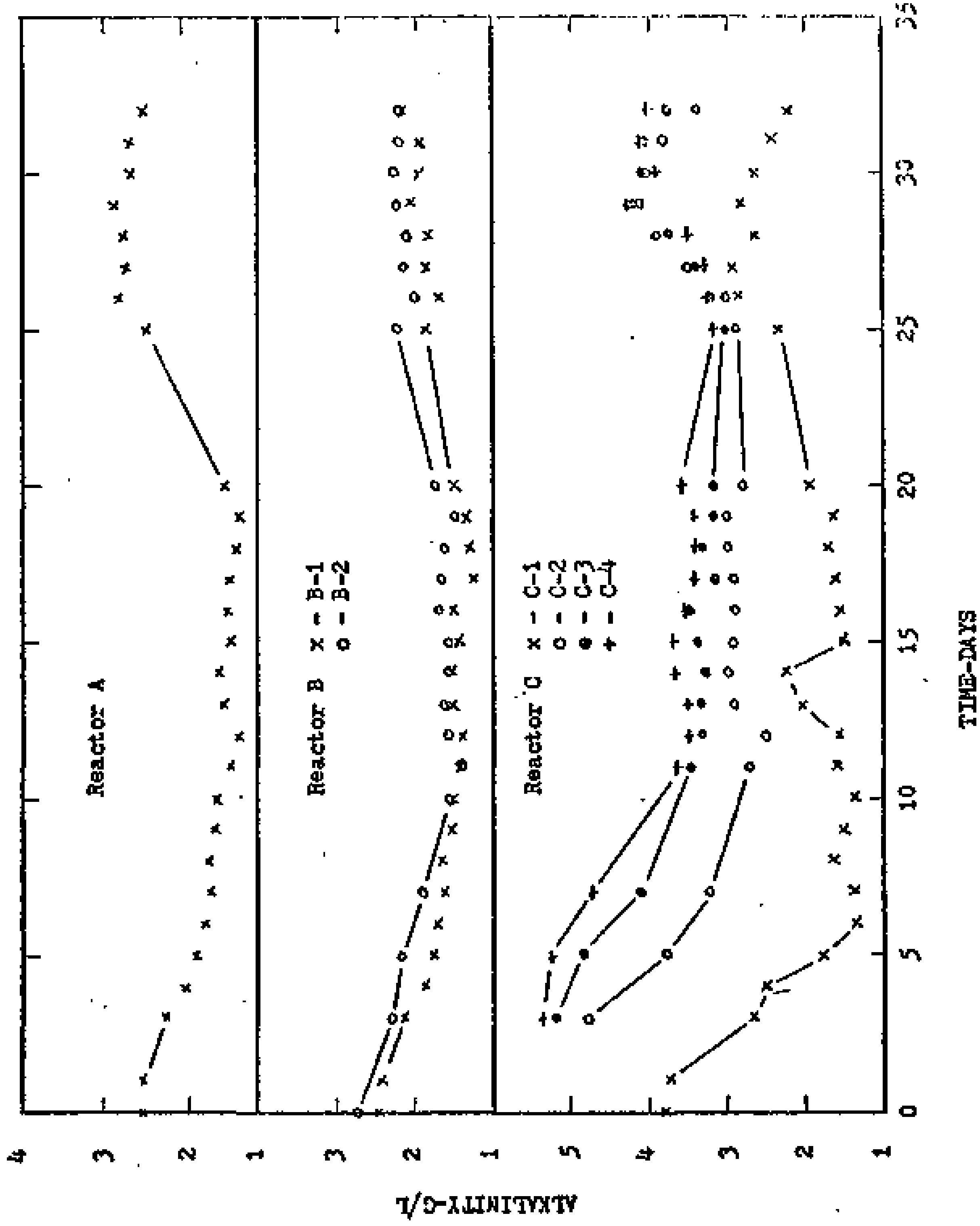


Figure 8. Alkalinity Levels in the Stages of the Complete Mix, Two Stage and Plug Flow Reactors

Table 10. COD and Volatile Solids Reduction[1]

Reactor	θ days	Vol. Solids-g/l		COD-g/l		K^2-day^{-1}	
		S_o	S_e	S_o	S_e	Vol. Solids	COD
A	10	38.0	13.7	53.0	17.0	0.177	0.212
B-1	5	38.0	11.5	53.0	16.5	0.461	0.442
B-2	5	11.5	10.9	16.5	15.6	0.011	0.012
C-1	2.5	38.0	22.5	53.0	31.4	0.276	0.275
C-2	2.5	22.5	9.7	31.4	14.9	0.528	0.443
C-3	2.5	9.7	9.6	14.9	13.6	0.004	0.038
C-4	2.5	9.6	9.6	13.6	13.1	0	0.015

[1]Average of 10 days of data

[2]K is calculated from $S_e/S_o = 1/(1+K\theta)$

The conversion efficiency of the reactors was evaluated on the basis of COD and volatile solids reduction. These data are shown in Table 10. Data collected during Day 15 to 25 were not included in these averages due to the nitrogen deficiency problem. A rate constant, K, was calculated using the COD data and the volatile solids data. Reactor C-2, followed by B-1, had the highest rate constant. In the previous study, where the total retention time was 14.63 days, reactor C-1 had a higher rate constant than C-2. This data suggests that 2.5 days may be too short a time for efficient substrate utilization. The limitation was not with the methogenic bacteria since the volatile acids did not increase to high levels. It would appear that it was hydrolysis of the solids that limited the conversion.

The most interesting results are the COD and volatile solids level from reactors A, B-1 and C-2. With a retention time of 2.5 days in each stage, the two stage system produced lower effluent COD and volatile solids than obtained from B-1, a complete mix system with a 5 day retention time. The effluent from both B-1 and C-2 was superior to A, a complete mix reactor with a 10-day retention time.

The gas production is given in Table 11 and 12. Reactor C exhibited a higher gas yield per unit of volatile solids added. The gas production per unit of volatile solids destroyed was lower for reactor C. There appears to be an error in the gas measurement. This is shown in Table 12 where the measured methane production is compared with the methane production based on COD reduction. These data show that the measured gas production for reactor C was about 8 percent low. Reactor A was 3.5 persent low and Reactor B was 1.6 percent low.

Based on the results of these studies to date, two stage digestion will produce the maximum gas per unit of substrate added. The data also show that a residence time of 2.5 days begins to inhibit the conversion of organic material. It would appear the optimum retention time in the first stage is between 2.5 and 3.6 days.

When the first stage rate is not inhibited due to a short retention time, the additional waste stabilization occurring in the subsequent stages is minimal. Therefore, the maximum gas production per unit volume of reactor can be obtained with a single stage reactor operating near the minimum retention time.

Table 11. Total Gas Production

Reactor	m^3/m^3-day	m^3/kg V.S. Fed	m^3/kg V.S. Dest.
A	2.18	0.576	0.89
B	2.38	0.602	0.85
C	2.31	0.609	0.82

Table 12. Methane Production-lpd

Reactor	Measured	Theor. (COD Red.)
A	52.3	54.2
B	55.4	56.3
C	55.4	60.0

*U.S. GOVERNMENT PRINTING OFFICE: 1978-740-306/294. Region 4.