

工學碩士 學位論文

**The Effective Stabilization of Sewage Sludge Using
T.P.A.D(Temperature- Phased Anaerobic Digestion)**

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2.1.2 3

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Abstract

The conventional single-stage anaerobic digestion system employed in Korea has been limited in an effective stabilization and sewage sludge. This indicates relatively higher management cost for the sewage sludge treatment. Temperature-phased anaerobic bioreactor system could be an alternative technology to circumvent these problems. This system includes a thermophilic (55 °C) reactor and a mesophilic (35 °C) reactor in sequence. The temperature-phased system employs a thermophilic process where consumption of organics at higher concentration can be performed. This system can be remove pathogen more efficiently and cause little scumming or foaming that has been typical in the conventional sludge treatment system.

The purpose of this study was to compare the performance of the temperature-phased (thermophilic/mesophilic) sludge treatment system with the conventional single-stage system in treating mixtures of primary sludge and waste activated sludge in terms of sludge stabilization methane production and hydraulic retention time.

For this study, TPAD system comprised a two-stage reactor system which was composed of a thermophilic anaerobic digestion system (12.6L) and a mesophilic reactor (34.8L) in sequential order while the conventional single-stage system had a working volume of 51L. Both reactor systems were run in various range of hydraulic retention time to comparatively analyze an optimal retention time for

each system.

The experimental results were summarized as follows. Little foaming was observed in TPAD system after 18 days of operation while the foaming was significant in the conventional system from the beginning. In terms of volatile solids (VS) removal the TPAD system showed a maximum rate at the HRT of 10 days. However, the conventional system gave a similar effect as in TPAD system after 28 days, indicating TPAD system was almost 3 times as effective as the conventional system in terms of treatment time.

COD, VS removal efficiency in the thermophilic reactor of TPAD system was inversely proportional to HRT but this was compensated in the mesophilic reactor in the system. The conventional system, however, needed longer HRT to reach the equivalent removal efficiency. pH and VFA/alkalinity ratio in both systems were generally maintained in a stable range regardless of HRT.

From the above results, it was generally concluded that the TPAD system was more efficient in stabilization of sludge, organics reduction, methane production, and decreased HRT, hence reduced volume in sludge digester.

This study showed contribute to an understanding of TPAD system in view of sludge treatment compared with the conventional system and to development of a TPAD system applicable to a field situation.

•

1997 56.6%
93 ,
1,239 가 .4)

가 1- 2%
, , ,
1,308 .1)

가
. 1997 가 13.5%
가
/
.1)

.3), 4)
가
,
,

.29)

, 가

.

,

가

가 .

,

TPAD

VS, COD

.

.

•

2.1.

2.1.1.

가 . 가
1960 가
가
가 가
가 가
. 1997 가
, , , , , , ,
, . . .1)

2.1.2.

가 ,

가
가

.2)

2.1.3.

Table 2.1. Generation of domestic sewage sludge and it's treatment status in Taegu and Kyungnam province

	(m ³ /)	(m ³ /)	(/)	1m ³ (kg/ m ³)	
	286.0	281.6	45.5	0.16	
	330.8	274.9	155.3	0.56	
	616.0	556.5	200.8	0.36	
	350.0	360.0	68.5	0.19	
	400.0	399.8	143.8	0.36	
	750.0	759.8	212.3	0.28	
	280.0	178.6	15.8	0.09	
	250.0	73.6	1.4	0.02	
	32.0	28.5	9.6	0.34	
	110.0	88.2	29.4	0.33	
	20.0	13.1	1.6	0.12	
	13.0	5.7	0.9	0.16	
	10.5	11.0	7.2	0.65	
	715.5	398.7	65.9	0.17	
	1,706.4	1,337.8	428.1	0.32	

Table 2.1

2.1.4.

가 , 65%

.3) ,

가

가 7000m3 ,

가 .

.3) ,

가

가 .

3000m³

2000m³

.3) , 가
가 .

가

.35)

가

가

20

50%

.29) ,

가

가

가

가

가

가

.35)

/

가

(Draft tube

type)

.3) ,

가

2/3

.31)

(egg type)

,

,

가

가

가

가

가

가

.4)

,

,

Salmonella

.14)

Class A biosolid

CRF Part 503

가

가

1mg 1000

class A

Class A

.14)

.4)

가

가

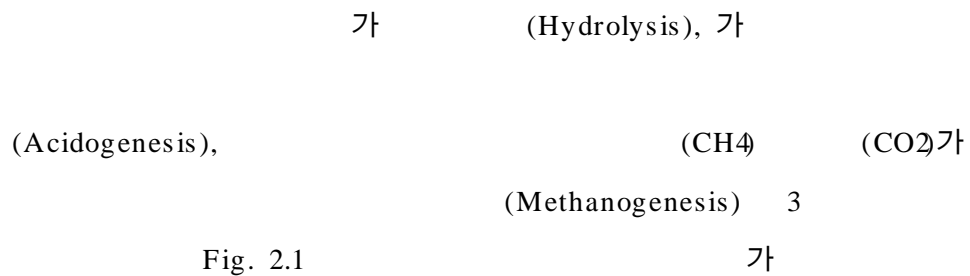
2.2.

가

가 가

가

Fig. 2.1. Procedures of methanogenesis in anaerobic digestion



가 .40)
Toerien 1 2

(nonmethanogenic) , 3
(methanogenic) .36)
(*Methanobacterium*, *methanobailus*) (*Methanococcus*,
Methanosarcina) .

2.2.1. 가 (Hydrolysis)

가 , (,
) , ,
(extracellular enzyme) , ,
가 가 .
가 pH,
가
.10)

2.2.2. (Acidogenesis)

(ethanol),
(acetic acid), (propionic acid), (lactic acid),
(butyric acid) .5) ,
pH 가 . pH 4
pH가 6.8- 7.4 pH
H2 . H2
가 가
pH 가 가

(propionate), (butyrate), (lactate), (butanol)
 "acetogenesis"

2.2.3. (Methanogenesis)

Methanobacterium, *Methanobanobacillus*, *Methanococcus*, *Methanosarcina* 4
 .19) Methane bacteria
 a 가 .33)
 가 . Fig. 2.2
 .2)
 (acetotrophic acetoclastic)
 (hydrogenotrophic) .4)

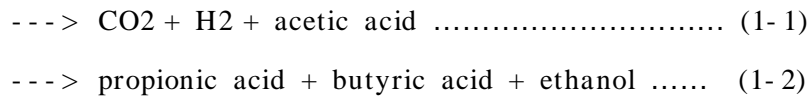
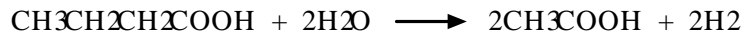
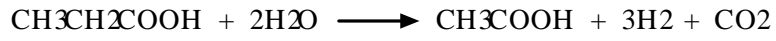


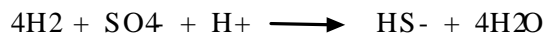
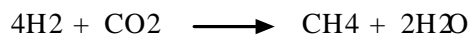
Fig. 2.2. Schematic for methane fermentation of complex wastes

(1-2)

.6)



가



formate, methanol, lactate, glucose,
, amino acid, $\text{H}_2 + \text{CO}_2$, $\text{CO} + \text{H}_2\text{O}$

.1)

72%가 ,

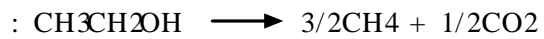
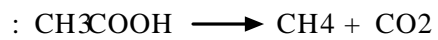
가

가 가

, Formic Acid, Acetic Acid, Propionic Acid, Bulyric Acid, Valeric Acid, Caproic Acid
Acetic Acid Propionic Acid가

H2, CO2, HCOOH,

Ethanol, Acetic Acid (38, 4)



가 .

가

10- 100

.2)

, 가 가 가

2.3.

1875 Damon Feires 가 ,
(waste activated sludge)
가 가
가

2.3.1.

가 factor 가 ,
Heukelekian 50 55 - 60 60
.18) 가
52 - 55 , 63 가 46

upset .13) Shamskhorzani 50 - 70
 가 60 - 65
 70 .32)
 53 - 55 가
 Class A pathogen .

2.3.2.

가 ,
 , shock
 .25), 30) ,
 .13)
 가
 heating system
 .

2.3.3.

Fair Moore 50 9 .12) Pfeffer
 20 30 가 , 가
 gas yield 10 가
 .28) , Rimkus 14 7 가
 가 .30)
 2 3
 HRT 2 3 가 .

, 5 7 .

2.3.4. Mixing

mixing 3가 .
scum foam .
grit .

가 . 가 mixing HRT
mixing
가 mixing
HRT .

2.4. 2

가 , ,
vessel
upset .
.16)

Fig. 2.3 2

Fig. 2.3. Single-stage and divided two-phase

가 .

first- second- phase

.9) 가

가

COD VS 가 .

, 2 .8)

Cohen 1% 2

.7) 가

가 .

100% 가 가 , 20 43%

가 ,

pH

phase Chemical-phased System Temperature-phased System

2.4.1. Chemical-phased System:

(가, ,)가 . 가 . , .

2.4.2. Temperature- Phased Anaerobic System:

Sung Nelson
TPAD (Temperature- Phased) 2
.27), 34)
2
10 가
.14), 20)

, Roberts

HRT

가

.31)

pH

Class A sludge

VS

가

Nocardia

scum

foaming

2

가

가

가

가

pH

가

2

가

가

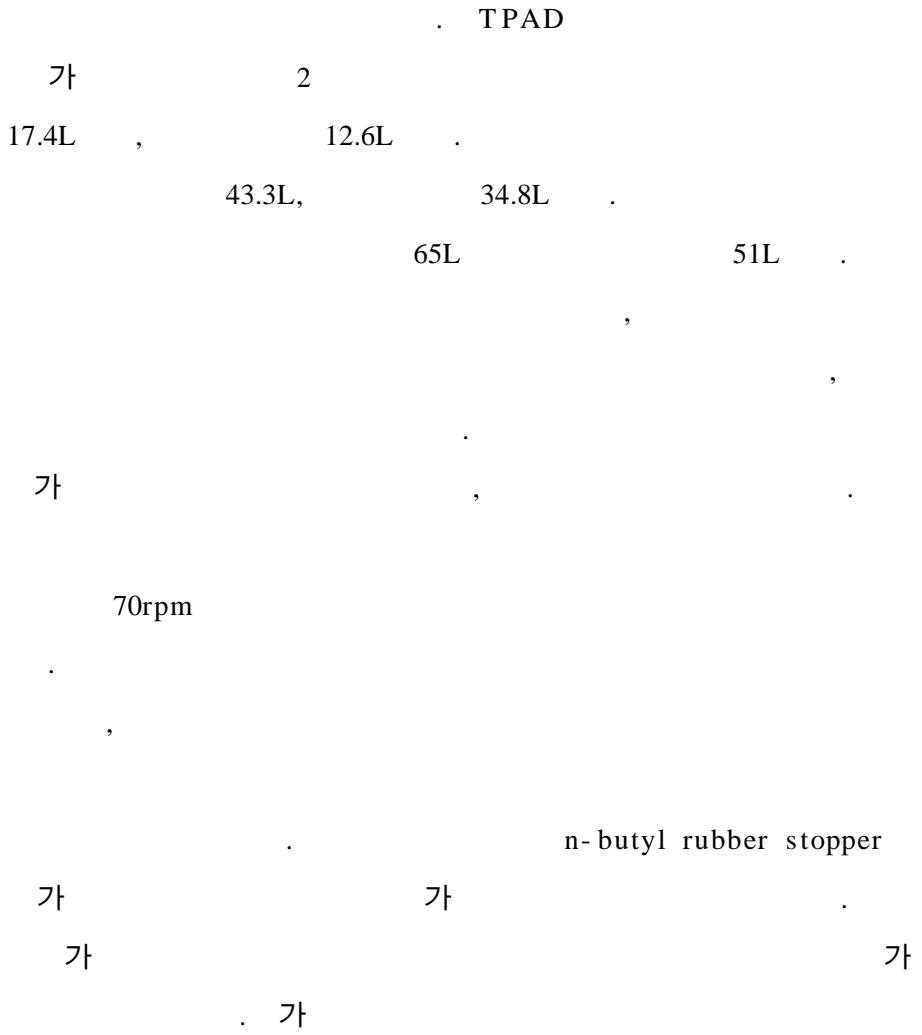
가 . start- up .

•

3.1

Fig. 3.1

TPAD (Temperature Phased Anaerobic Digestion)



TPAD System

Conventional System

A: First-stage digester	J: Digester contents sampling valve
B: Second-stage digester	K: Gas Collector
C: Conventional digester	L: Effluent
D: Influent line from feed pump	M: Thermostat
E: Effluent overflow first to second stage	N: Feed Tank
F: Gas exit port	O: Feed Pump
G: Sludge level	P: Timer
H: Stirring paddle	Q: Thermic rays
I: Mixer moter	

Figure. 3.1. Schematic diagrams of conventional and TPAD processes

가
4

55 ± 2 , 35 ± 2

30L

1 12

3.2.

S 2

4

12

, 4mm

Table 3.1

VS

15,000mg/L

, pH

7.52

3,600mg/L

as CaCO₃ .

Table 3.1.Characteristics of seeding sludge for the study

Content	Concentration(mg/L)
pH	7.52
Total Solids(mg/L)	32,541
Volatile Solids(mg/L)	14,970
COD(mg/L)	25,153
Alkalinity(as CaCO ₃ mg/L)	3,625

S
가
1
4.0mm , 4 2
Table 3.2
20,000mg VS/L, 30,500mg COD/L pH
7.1 .

Table 3.2. Characteristics of influent sludge for the study

Content	Concentration(mg/L)
pH	7.1
Total Solids(mg/L)	39,169
Volatile Solids(mg/L)	20,010
COD(mg/L)	30,542
Alkalinity(as CaCO ₃ mg/L)	1,340

3.3

Table 3.3

TS, VS				
pH	pH meter(Orion 330)			COD Standard
methods(1995)	closed reflux method			가
	가			가
	가	가		(XP- 331)
	TCD		가	GC(Model:
SHIMADZU GC- 8A)				(total
VFA) Anderson & Yang				50mL
	pH	0.1N H ₂ SO ₄		pH
5.1	3.5			mL
Anderson & Yang				
	.17)			

Table 3.3. Analytical methods and instruments.

Parameter	Analytical methods and instruments
pH	Orion 330 pH meter
Biogas volume	Displacement method of Water acidified and saturated with salt
Total Solids(mg/ L)	Dry oven(110)
Volatile Solids(mg/ L)	Electric Muffle Furnace(550)
Alkalinity(as CaCO ₃ mg/ L)	Titration Method Orion 330 pH meter
COD(mg/ L)	Closed Reflux, Titrimetric Method
Total VFA(mg/ L as HAC)	Titration Method by Anderson & Yang
Methane content	Combustible Gas Detector XP- 331 type

3.4

40%

12 /

TPAD 20

가

TPAD

Table 3.4

가

20

15 , 10 5

TPAD

가

20

가

20

24 , 28

32

가

가

(Table 3.4).

Table 3.4 Actual operational parameter during each period

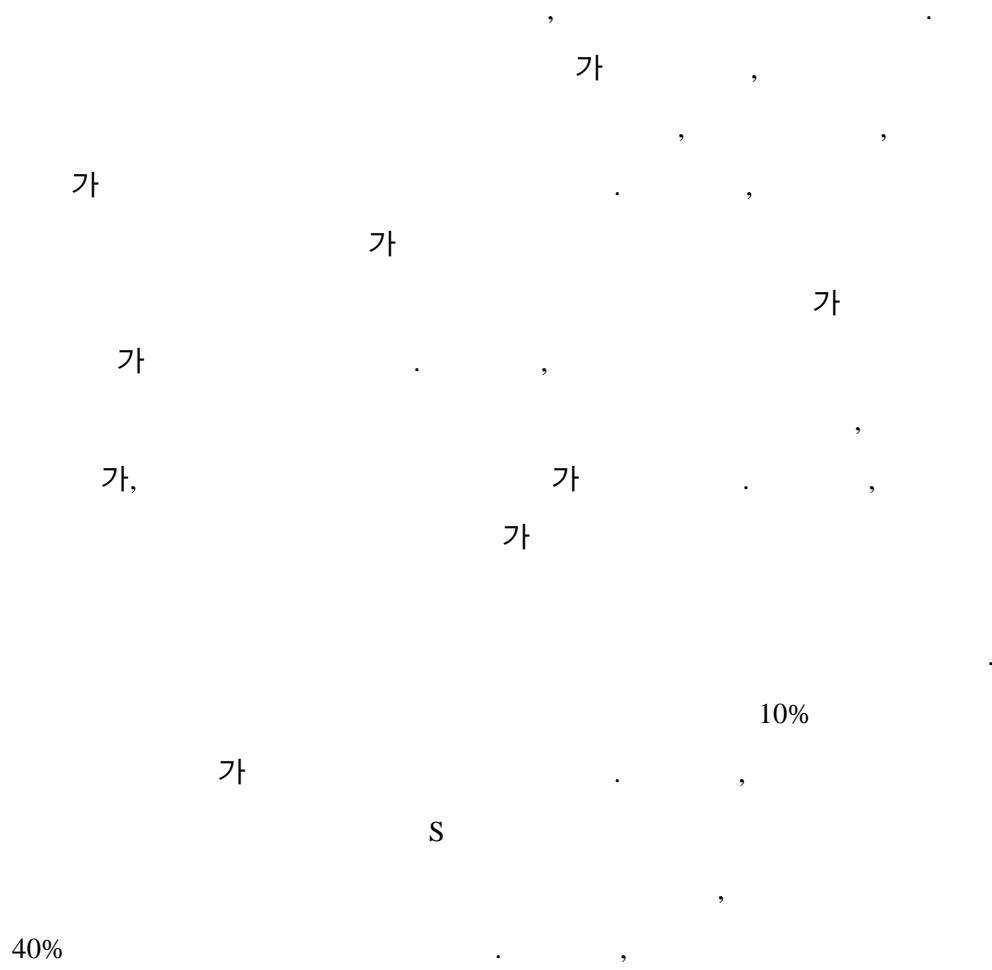
Period	Temperature()			Loading(kgVS/ m3)				HRT(d)			
	Conv	TPAD		Conv	TPAD			Conv	TPAD		
		Thermo	Meso		Thermo	Meso	Total		Thermo	Meso	Total
	35	55	35	0.64	2.87	0.82	0.76	20	5.3	14.7	20
	35	55	35	0.48	4.47	1.02	1.18	24	3.97	11.03	15
	35	55	35	0.32	5.74	1.23	1.52	28	2.65	7.35	10
	35	55	35	0.29	12.93	2.97	3.41	32	1.32	3.68	5

•

4.1

TPAD

가 - 200mV



가 TPAD

가

가 , Nocardia

.39)

28

가 , TPAD

가 15

. TPAD

.16)

4.2

Fig. 4.1

TPAD VS TPAD

TPAD VS

20 , VS
 TPAD VS
 VS
 가
 VS
 가 ,
 가 . Table 4.1
 TPAD VS

Table 4.1 VS removal efficiency for TPAD and conventional mesophilic anaerobic digester at various HRTs

Period	VS removal efficiency(%)			
TPAD(total)	40	44	50	45
Thermo	24	20	14	12.8
Meso	21	37	39	36
Conventional	36	48	50	52

TPAD VS
 5.3 1.32 24% 20% , 14%
 12.8% ,
 14.7 7.35 VS
 21% 39% 가 TPAD VS

HRT 10 50% . TPAD

가 가

가 가 .

가 VS 가

가 ,

5 10 . ,

VS VS 45%

가

I-IV 20 32 가

VS 36%, 48%, 50%, 52% 가

가

50%

TPAD 10

28

TPAD 3

Fig.4.1 Comparison of volatile solids removal with various HRT
between conventional and TPAD digesters

4.3 COD

Fig. 4.2 TPAD

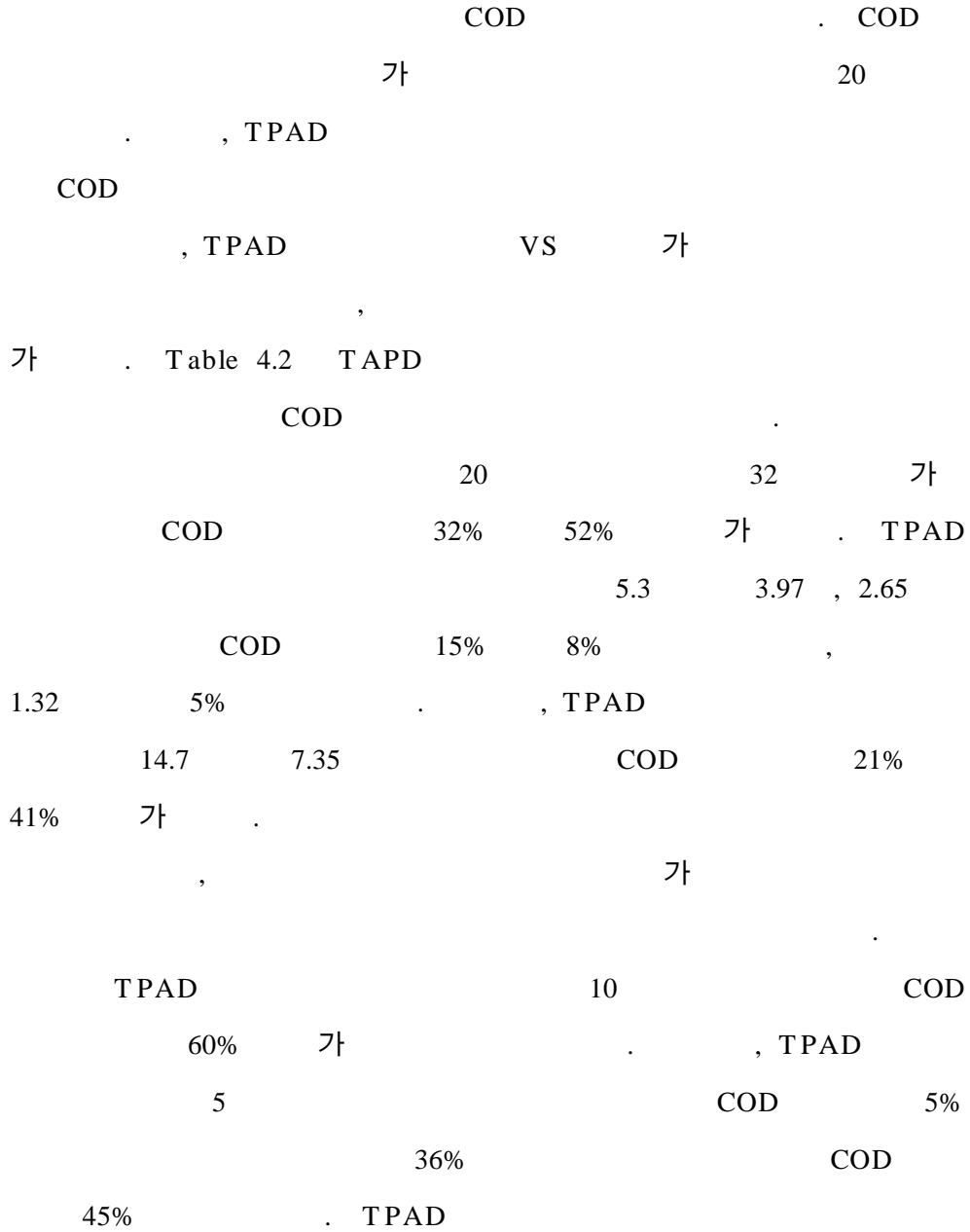
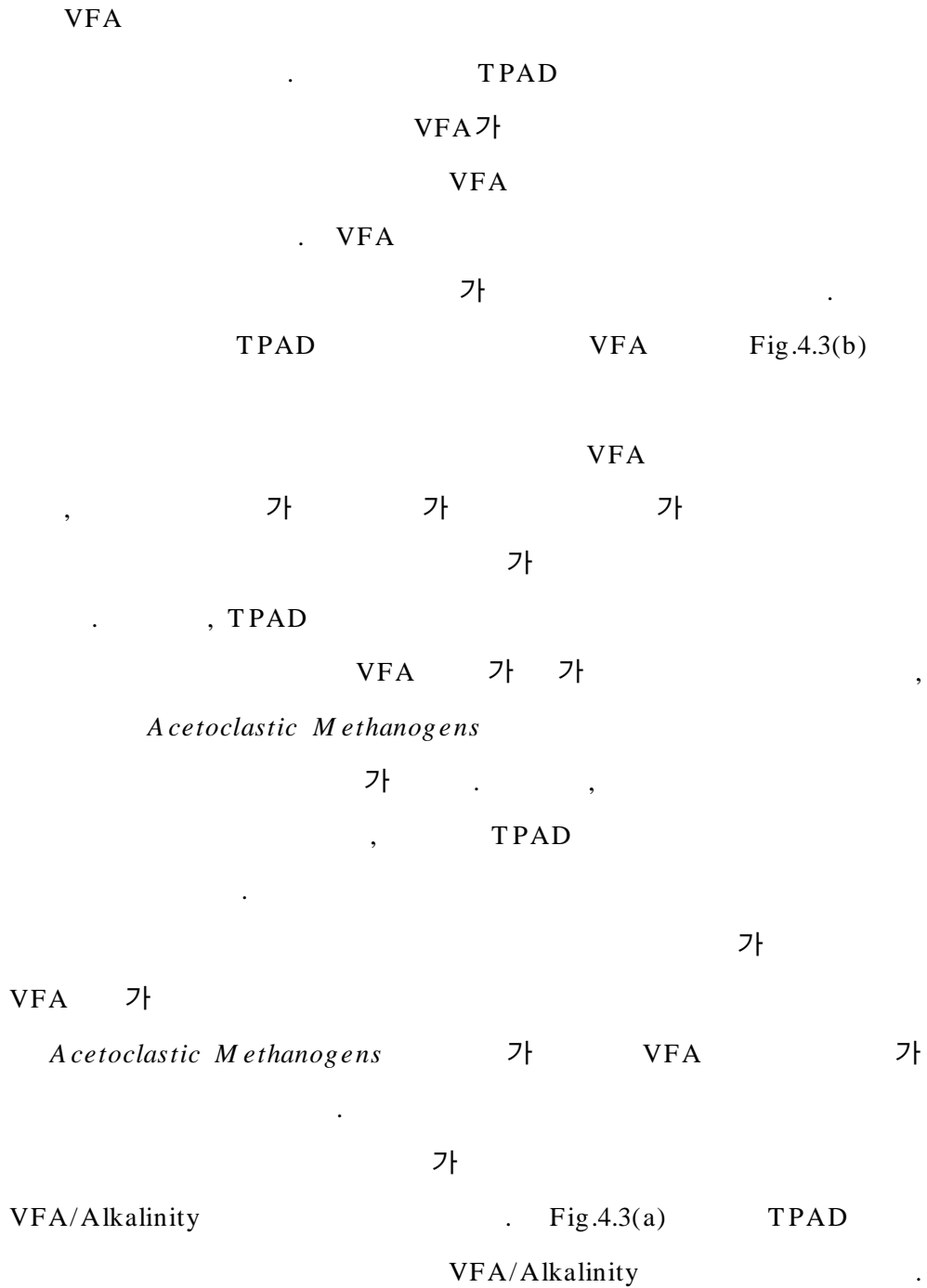


Fig. 4.2 Removal of COD according to the HRT at the conventional and TPAD digesters

4.4 VFA



TPAD		가		VFA/Alkalinity	
1.75	2.82	가	0.37		
	.				
	0.26	0.33			
가 0.5		가	0.8		
			.39)		

Fig.4.3 VFA and VFA/Aklinity ratio during periods I through IV

4.5 pH

가 . , pH, ,

pH 가

pH 가

가

pH가 가

가

Hydrogenotrophic Methanogens

가

Acetoclastic Methanogens

pH가 .

TPAD

VFA 가 Fig.4.4 pH 6.72

7.00 . 7.23 7.29

pH 7.26 7.38

가

pH

CO₂

H₂CO₃ 가

pH

TPAD

I 2,511mg/L as CaCO₃ IV

1,563mg/L as CaCO₃

3,000mg/L as

CaCO₃ 3,000mg/L as

CaCO₃ 2,000mg/L-

3,000mg/L as CaCO₃ 가 . Table 4.3

TPAD pH

Table 4.3 Average values of pH and alkalinity during periods I through IV

Period	Average pH				Average Alkalinity, mg/ l			
feed	7.06	7.05	7.09	7.11	1364	1343	1267	1298
Conventional	7.26	7.38	7.33	7.26	3192	3408	3337	3390
TPAD								
Thermo	6.72	6.89	6.89	7.00	2511	1981	1797	1563
Meso	7.23	7.29	7.25	7.23	3335	3298	3236	3089

Fig. 4.4. Variation of pH and alkalinity during periods I through IV

Roberts

pH

.3)

TPAD

pH

Table 4.3

Fig. 4.4

4.6 가

TPAD COD VS

(L CH₄/L/d) Table 4.4

Table 4.4 Methane production rate according to various HRTs in conventional and TPAD digesters

Period	Methane production Rate(L CH ₄ L/ days)			
TPAD(total)	0.072	0.118	0.091	0.059
Thermo	0.032	0.016	0.008	0.0003
Meso	0.086	0.155	0.121	0.080
Conventional	0.073	0.067	0.051	0.053

TPAD

5.3

1.32

VS COD

가

가

. , 가
 TPAD 가 . , TPAD
 가 가
 VS g
 가 가
 가
 가 가
 가 가
 Table 4.5
 TPAD 80
 mL CH₄/g VS

Table 4.5 Specific methane productions in conventional and TPAD digester

Period	mL CH ₄ /g VS feed			
	TPAD(total)	72	80	52
Thermo	8	4	3	1
Meso	63	77	50	22
Conventional	72	73	81	86

•

- 2 (TPAD)

,

.

1.

, TPAD

가

18

.

2. TPAD

VS

VS

10

.

VS

가

가

, 28

TPAD 10

.

3. COD

TPAD

VS

,

COD

가

COD

10

60%

,

20 32 가 COD 가

4. TPAD

pH

7.2- 7.4

VFA/Alkalinity

TPAD

1.75

2.82

가

0.37

0.30

가

5. 가

COD VS

TPAD

가

6.

TPAD

가

(HRT) 3

3

가

1. , “ ”, , 6(7), 10- 17, (1998).
2. , “ C/N ”, , (1996).
3. , “ ”, , (1998).
4. , “97 ”, (1998)
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