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Valuable Organic Liquid Fertilizer Manufacturing through TAO™ Process for Swine Manure Treatment

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Summary

TAO™ System is an auto-heated thermophilic aerated digestion process using a proprietary microbe called as a Phototropic Bacteria (PTB). High metabolic activity results in heat generation, which enables to produce a pathogen-free and digested liquid fertilizer at short retention times. TAO™ system has been developed to reduce a manure volume and convert into the liquid fertilizer using swine manure since 1992. About 100 units have been installed and operated in Korean swine farms so far.

TAO™ system consists of a reactor vessel and ejector-type aeration pumps and foam removers. The swine slurry manure enters into vessel with PTB and is mixed and aerated. The process is operated at detention times from 2 to 4 days and temperature of 55 to 65℃. Foams are occurred and broken down by foam removers to evaporate water contents. Generally, at least 30% of water content is evaporated, 99% of volatile fatty acids caused an odor are removed and pathogen destruction is excellent with fecal coliform, rotavirus and salmonella below detection limits.

The effluent from TAO™ system, called as the "TAO EFFLUX", is screened and has superb properties as a fertilizer. Normally N-P-K contents of screened TAO EFFLUX are 4.7 g/L, 0.375 g/L and 2.8 g/L respectively. The fertilizer effect of TAO EFFLUX compared to chemical fertilizer has been demonstrated and studied with various crops such as rice, potato, cabbage, pumpkin, green pepper, parsley, cucumber and apple. Generally it has better fertilizer effects and excellent soil fertility improvement effects.

Moreover, the TAO EFFLUX is concentrated through membrane technology without fouling problems for a cost saving of long distance transportation and a commercialization (crop nutrient commodity) to a gardening market, for example.

(**Key words** : TAO, Auto thermal aerobic digestion, Swine manure, Organic fertilizer, Plant growth, Fertilizer effect, Concentration, Membranes.

Introduction

TAO™ System, Thermophilic Aerated Oxidation System, converts swine manure into higher quality liquid fertilizer than a lagoon liquid. It makes no odor, pathogen free and digested liquid fertilizer providing better fertility than a chemical fertilizer. TAO system uses a

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proprietary microbe to enhance an odor control and a higher temperature operation with less power requirement and retention time than previous ATAD technologies. Moreover, the effluent of TAO system can be concentrated by membrane technology for a commercialization (crop nutrient commodity). This technology will be able to contribute to solve livestock environmental issues.

〈 TAO System 〉

Swine manure

This study used swine manure from a slurry type swine facility as shown in Table 1.

TAO Reactor

TAO reactor has a cylinder type with 2.0 meter height and 1.53 meter diameter as shown in Fig. 1. The inside volume of reactor is 2.45 cubic meter except foam removers and insulations.

Reaction Temperature Variations with Operation Modes

The reaction temperature variation was experimented depending on operation modes.

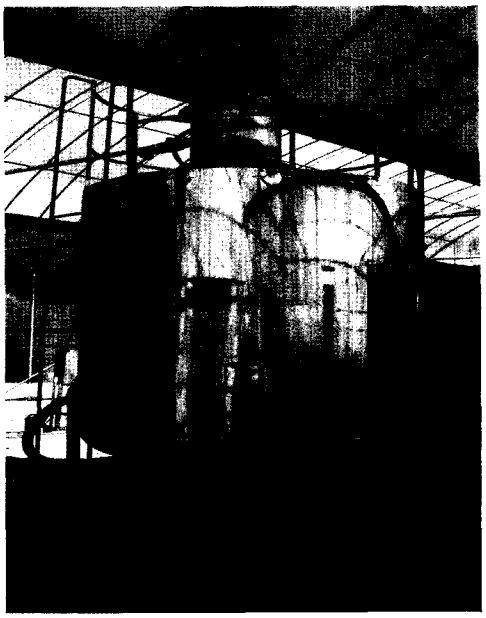

Fig. 1. TAO System.

Reaction temperature changes slightly whenever raw manure inputs in batch modes, RUN-4 (6 inputs per 4 hours) and RUN-6 (4 inputs per 6 hours). However, it keeps uniformly in the continuous mode, RUN-24, shown in Fig. 2.

Operation Factors

It is essential to keep the reaction temperature above 55℃ in the thermophilic digestion for pathogens destruction. In various operation factors, we found that the organic content was the one of key factor. We studied

Table 1. The Characteristics of Swine Manure

Items	Average	Items	Average	Items	Average
pH	7.63	T−N (mg/L)	4,818	COD (mg/L)	94,527
TS (%)	4.45	NH_4^+ (mg/L)	1,736	SCOD (mg/L)	41,785
VS (%)	2.90	T−P (mg/L)	1,737	*Escherichia coli*	$1.0\times10^4-4.0\times10^4$
VFAs (mg/L)	10,489	PO_4^{--}	940	*Salmonella spp.*	$N.D-4.4\times10^4$

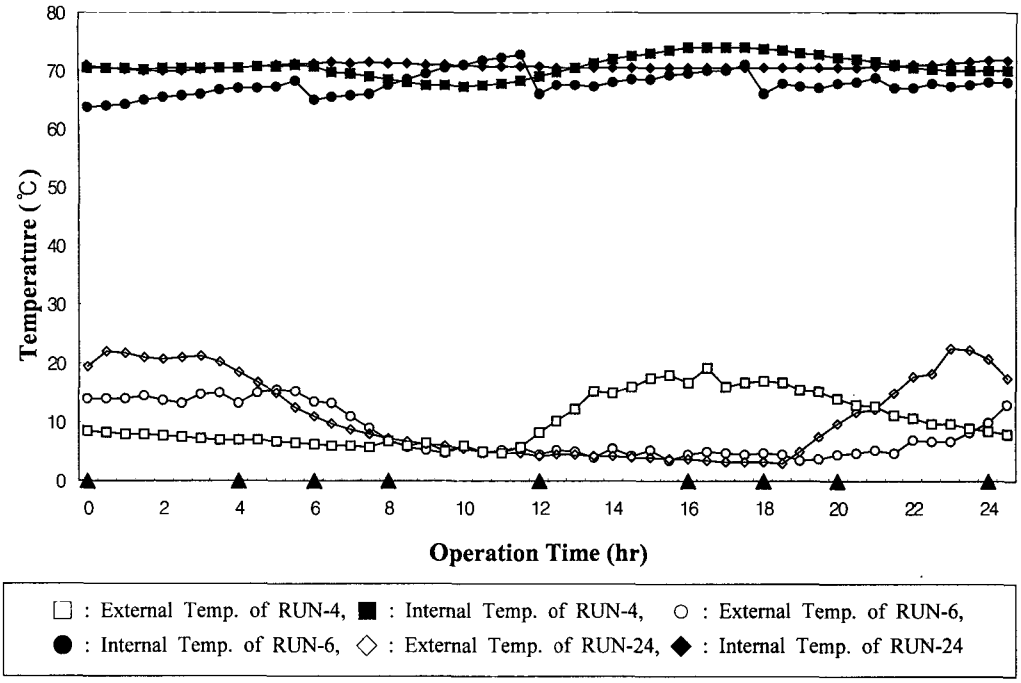

Fig. 2. Temperature Variations depending on operation modes.

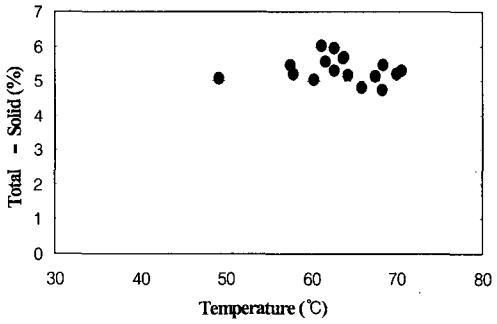

Fig. 3. Reaction Temp. with T-Solid.

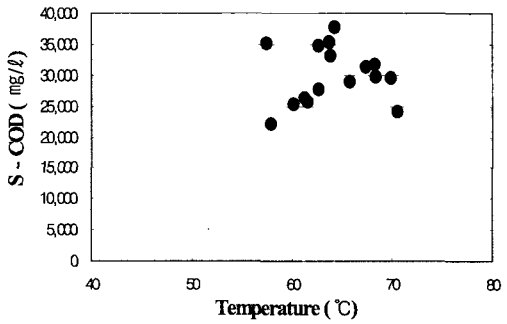

Fig. 5. Reaction Temp. with SCOD.

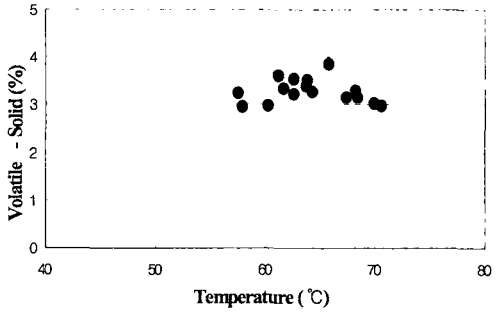

Fig. 4. Reaction Temp. with Volatile Solids.

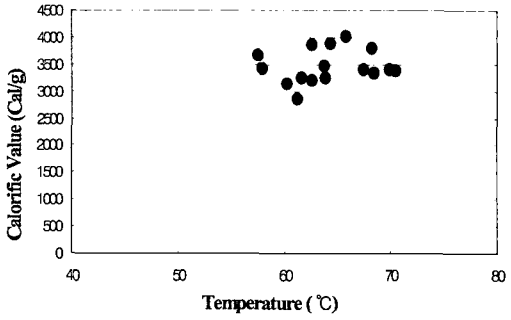

Fig. 6. Reaction Temp. with Calorific value

several indicators expressing the organic content, such as TS, VS, COD, SCOD and Calorific value to find a relationship with the reaction temperature. Comparing the maximum temperature with each indicator shown in Fig. 3~6, the proper range of TS is 5~7% for batch mode and 3~6% for continuous mode. 2.8~3.9% of VS, 20,000~40,000 mg/L of SCOD and 2,800~4,100 Cal/g of Calorific value were proper ranges.

Pathogens Destruction Effect

We studied the Rotavirus destruction effect in TAO reactor.

Method

The culture solution of 106 Rotavirus was diluted with ratio of 1:3,500 and it was input to storage tank and TAO reactor. The samples obtained per hour were diluted with $\times 10$, $\times 100$ and $\times 1{,}000$ and the CPE (Cytopathic effect) was examined after inoculating to MA 104 cell.

Result and Discusion

TS and VS of sample at zero time were 2.997% and 69.895%, respectively shown as Table 2. CPE of samples obtained per hour are shown in Fig. 7.

Table 2. Dry and Organic Matter Contents in Swine Manure

	Mean (%)	Standard deviation
Total solid	2.997	0.006
Volatile solid	69.895	0.082

Rotavirus of 3.5×10^6 lived in the storage tank during 24 hours and it was not detected in the TAO system after 12 hours reaction.

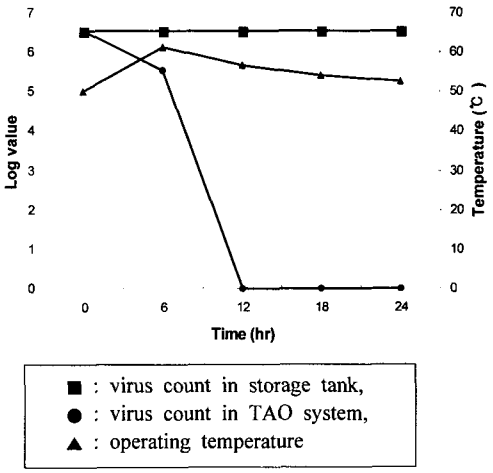

Fig. 7. Inactivation Effect of Rotavirus in TAO system.

Ammonia Emission

Gases emitted from TAO reactor were analyzed after condensation. It was mostly ammonia with 77% and 93% of total nitrogen as shown in Table 3. It shows that it can be another nitrogen source for fertilizer.

Table 3. Gases emitted from TAO system (unit: mg/L)

Items	PH	T-N	NO_2-N	NO_3-N	NH_4-N	T-P	F^-
Concentration	>8.6	2,535	1.5	4.23	2,337	117	8.3
Items	SO_4^{2}	Br	Cl	Na^+	Mg_2^+	Ca_2^+	K^+
Concentration	47.5	–	30.7	38.9	–	24.1	412.6

〈 Concentration of TAO effluent 〉

We studied the feasibility of concentration by membranes of TAO effluent (called as TAO Efflux) for making a highly concentrated liquid fertilizer.

Apparatus

Solids in the TAO Efflux was separated by Micro-filtration first and the permeate was concentrated by RO (Reverse Osmosis) finally with apparatus shown in Fig. 8. We examined the concentrated and permeated liquids' characteristics. Table 4 shows the RO membrane's specifications and this apparatus was operated with the external operation mode. The membrane was washed by alkaline cleaning method for organic removal and acidic cleaning method for inorganic removal.

Method

We measured TMP(trans-membrane pressure) and flux. The concentrated and the permeated characteristics were analyzed such as pH,

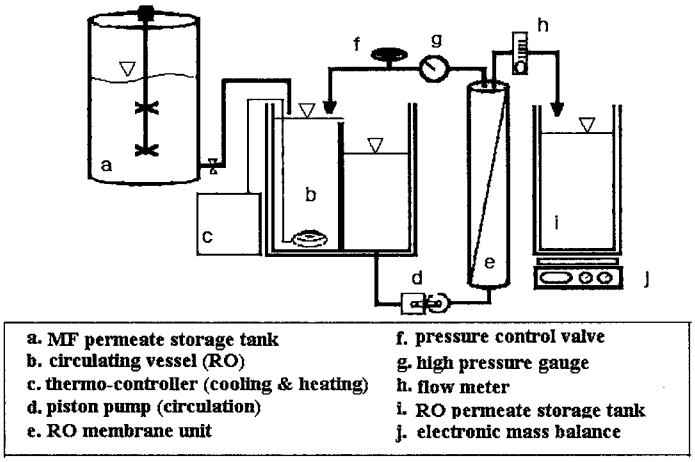

Fig. 8. Schematic diagram of RO reactor.

Table 4. Specifications of RO membrane used in Pilot experiment

Parameters	Specification
Types	Spiral wound
Material	Polyamide
Membrane	SW30-4040 (Sea water)
Effective area (m^2)	7.4
General Salt elimination rate (%)	99.4
Maximum operating Temperature (℃)	45
Maximum operating pressure (bar)	69
pH Range, Continuous Operation	2 - 11
Salt rejection based on test condition (NaCl, mg/L)	32,000

Electronic conductivity, TS, VS, COD, TKN, NH_4^+-N, NO_2^--N, NO_3^--N, SO_2^{-4}, Cl^-, Mg, Ca, Na, K and heavy metals of As, Cd, Cr, Cu, Ni, Pb, Zn.

Results and Discussion

Test results with operating pressure of micro filtered TAO Efflux are shown in Fig. 9 and 10. We found that the flux decreased rapidly at 40 bars pressure as shown in Fig. 9. The final permeate ratio with operating pressures decreased by 28.11% at 10 bars, 12.65% at 20 bars, 8.84% at 30 bars and 17.04% at 40 bars.

COD variations with operating pressure are shown in Fig. 10. COD of concentrate increased sharply as pressure went up and COD reduction ratio of the permeate was 99%. In 30 bars operating pressure, COD of permeate increased rapidly after 60 minutes up to 300 mg/L from 20 mg/L. This was assumed that the permeate concentration increased due to the concentrated higher concentration of solvent as the concentration polarization effect increased rapidly. As shown in Fig. 11, TKN was concentrated up to double as time passed. Chloride ion and TP were eliminated with 99% in the permeate as shown in Fig. 12 and

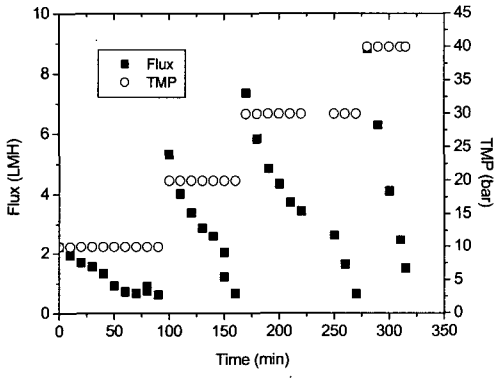

Fig. 9. Flux Variation by Pressure.

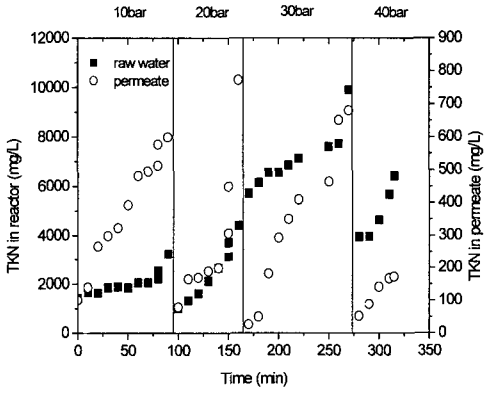

Fig. 11. TKN Variation with Time.

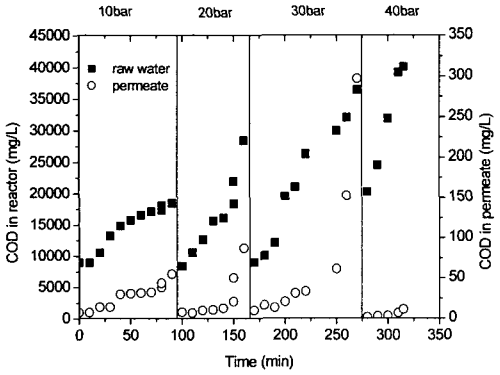

Fig. 10. COD Variation with Time.

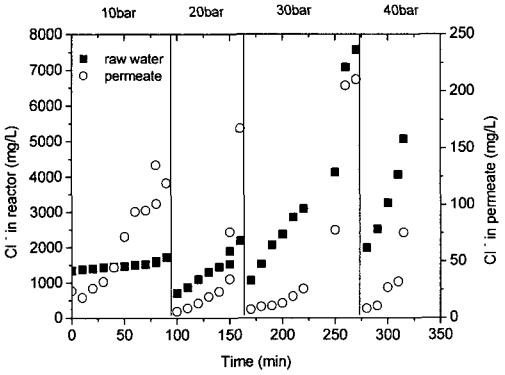

Fig. 12. Chloride Ion Variation with Time.

13. The conductivity influencing RO operation increased up to 43 mS from 20 mS in the concentrate, and increased up to 5 mS from 0.5 mS in the permeate.

Regarding to COD variation of the concentrate, TAO Efflux was concentrated 2 or 3 times by membranes with using of Micro Filtration and Reverse Osmosis. The other hands, COD of the permeate showed that it could be reusable. Besides, fertilizer sources such as nitrogen and phosphorus could be concentrated with high ratio at 40 bars.

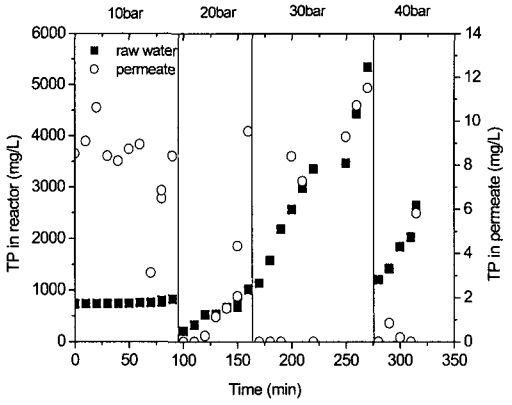

Fig. 13. TP Variation with Time.

Table 5. Overall Performance of TAO Efflux, MF and RO concentrated and permeated liquids

	TAO treated		MF Concentrate		MF Permeate	RO Concentrate	RO Permeate		
	Total	soluble	total	soluble			20bar	30bar	40bar
CODcr (mg/L)	34,260	28,490	82,600	55,310	9,848	29,500~40,248	45-314 (126.0)	25-195 (67.71)	20-60 (28)
Protein (mg/L)	10,194	4,762	23,677	7,628	1,849	4,957~ 6,004	i.g.		
Polysaccharide (mg/L)	4,617	2,414	9,114	3,762	1,099	2,849~ 3,424	i.g.		
TS (mg/L)	42,160		66,080		14,700	43,540	N.D.		
VS (mg/L)	20,480		35,870		9,750	27,090	N.D.		
PH	8.72		8.75		8.68	8.7~8.9	8.4~8.7	8.3~8.6	8.0~8.2
EC (mS)	21.4		22.0		20.4	44.1~53.4	0.5~55.2 (2.0)	0.2~3.8 (1.5)	0.3~1.3 (0.7)
TP (mg/L)	940.7		986.4		994.7	2,217~2,746	3.7~76.4 (29.1)	0.3~13.6 (7.8)	0~5.8 (1.4)
Cl (mg/L)	1,013		1,139		1,094	3,856~5,017	28~224 (84.6)	17.3~180 (69.7)	9.7~49.2 (28.4)
TKN (mg/L)	4,867	3,996	5,594	4,272	2,644	3,107~3,820	60.7~501 (319.6)	30.4~361 (218.6)	20.4~89 (41.4)
NH_4^+-N (mg/L)	1,647		1,684		1,629	2,829~3,337	43.3~424 (269)	18.2~269 (132)	7.5~64.1 (30.2)
NO_2 -N (mg/L)	19.88		20.42		20.03	i.g.			
NO_3 -N (mg/L)	27.15		27.49		26.94	i.g.			
T-N (mg/L)	4,914	4,043	5,642	4,319	2690.97	3,107~3,820	60.7-501 (319.6)	30.4-361 (218.6)	20.4-89.8 (41.4)
VFA (mg/L)	N.D.								

( ) : average of experimental data, N.D. : not detected, i.g. : ignorable (< 1mg/L)

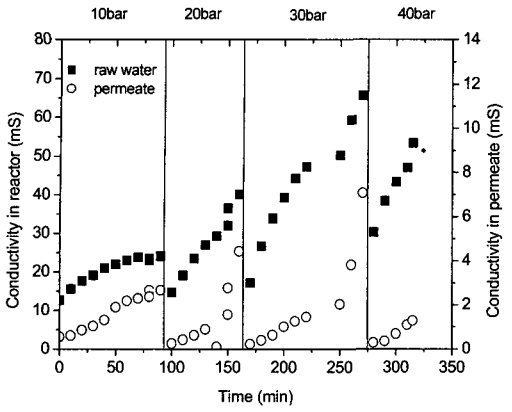

Fig. 14. Conductivity Variation with Time.

〈 Fertilizer Effect of TAO solids 〉

We demonstrated the fertilizer effect of TAO solids and Efflux (liquids). Especially, TAO solids were mixed with various sub-materials such as sawdust, rice bran and beans and demonstrated as a culture soil. TAO solids and Efflux have fertilizer sources as Table 6. Remarkably phosphorus of TAO Efflux (liquid) decreased after screening. Thus, TAO Efflux was developed as an organic liquid fertilizer and TAO solid was developed as the culture soil after mixing with various sub-materials, natural materials of sawdust, rice bran, leaf and artificial materials of bermuculite, zeolite, perlite with ratio of 2:8 or 3:7 adding some viscous materials of beans and molasses. Fig. 15 shows the developed solid fertilizer shapes with TAO solids.

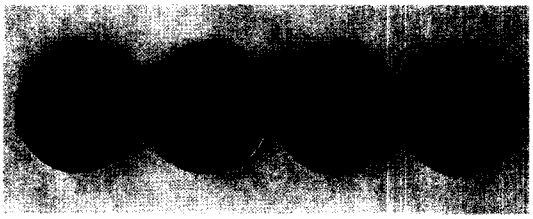

Fig. 15. Various Shapes of TAO Solids Fertilizer.

〈 Fertilizer Effect of TAO Efflux 〉

Table 7 shows the comparison between raw swine manure and various TAO Efflux. It

Table 6. Fertilizer sources of TAO Solids

Description	N (%)	P (%)	K (%)
TAO Solids (5%)	2.54	15.35	0.55
TAO Screened Solids (200 mesh)	0.40	0.04	0.26
TAO Efflux	0.48	0.12	0.27

Table 7. Comparison of fertilizer sources between swine manure and various TAO Efflux

	pH	TS (%)	Nitrogen (mg/L)		Phosphorus (mg/L)		K (mg/L)	Ca (mg/L)	Mg (mg/L)
			T-N	NH_4^+-N	T-P	PO_4^--P			
Swine manure	6.9	5.1	4,893	1,923	838.2	779.1	2,846	897.1	298.8
TAO Efflux screened	8.6	3.6	4,751	1,763	375.2	310.1	2,755	470.1	58.8
TAO Efflux micro-filtrated	8.8	1.2	3,132	1,468	81.4	51.1	2,637	35.1	1.7

shows that 1 ton of TAO Efflux is equivalent to 20 kg of 21-17-17 inorganic composite fertilizer.

Table 8 shows the plant growth effect of various combination of TAO Efflux. The highest existence ratio was shown in TAO Efflux 100% and the chemical fertilizer, but raw swine manure showed the worst ratio. Those results were same in the growth effect. TAO Efflux and chemical fertilizer were soluble to uptake by plants immediately, however, raw swine manure might be stabilized not to damage plants.

Regarding to the fertilizing effect study with tomato, the initial growth with chemical fertilizer was better than TAO Efflux in the initial length, the leaf width and chloropyl shown in Table 9. This phenomenon continued until the middle time of growth. It was assumed because TAO Efflux's nitrogen form was ammonia and chemical fertilizer's nitrogen form was nitrate.

On the other hands, the sweetness and the total quantity of tomato were better in TAO Efflux than chemical fertilizer shown in Table 10.

Table 8. Plant Growth of Cabbage depending on Various Combination of TAO Efflux

	Plant Growth (after 50 days)				
	Existence ratio (%)	Stem length (cm)	Stem width (cm)	No. of leaves (pcs)	Leaf color (1-5 dark)
TAO Efflux 100%	94	30.8	22.7	40.5	5
TAO Efflux M/F 100%	94	26.9	19.8	37.9	4
TAO Efflux 70% + M/F 30%	92	29.4	21.8	38.7	5
Raw swine manure	81	24.2	18.2	36.4	4
Chemical fertilizer	96	29.5	21.3	40.3	4
No fertilizer	90	20.2	15.5	34.3	2

Table 9. Tomato Growth Effect of TAO Efflux

	Initial Length (cm)	No. of Leaves (pcs)	Leaf length (cm)	Leaf width (cm)	Chloropyl (SPAD)
TAO Efflux screened	10.2	15.1	9.1	5.1	51.8
Chemical fertilizer	10.4	15.1	9.3	5.1	53.5

Table 10. Tomato Quantity and Productivity Improvement Effect of TAO Efflux

	Sweetness (Bx)	Hardness	No. of fruits (no./plant)	Total quantity (kg/10a)
TAO Efflux screened	5.9	1.2	20.3	10,140
Chemical fertilizer	5.6	1.4	19.4	9,930

TAO Efflux as an Organic Liquid Fertilizer supplemented with Chemical Fertilizer

We have demonstrated the fertilizer effect of TAO Efflux supplemented with chemical fertilizer to make a valuable fertilizer product. This demonstration results are shown in Table 11. In general, TAO Efflux contained fertilizer had better effect than chemical fertilizer in growth and quantity. The best supplement ration between TAO Efflux and chemical fertilizer was 30% : 70% in cabbage farming. Table 12 shows an economical benefit analysis, and farmers might make more profit by 13% when he used the organic fertilizer of TAO Efflux supplemented with chemical fertilizer.

Table 11. Growth and Product Quantity of Cabbage with various supplement ratio

N base mix ratio (TAO Efflux+Inorganics)	No. of Leaves (pcs/stem)	Height (cm)	Width (cm)	Dry matter Ratio (%)	Product Quantity	
					kg/10a	Index
0% + 100%	55.5	25.9	15.7	5.80	7,252	100.0
30% + 70%	57.3	27.1	16.8	4.72	8,152	112.4
50% + 50%	56.1	26.8	16.1	4.77	7,694	106.1
70% + 30%	55.6	25.8	16.0	4.78	7,387	101.9
100% + 0%	56.4	26.0	16.1	4.79	7,366	101.6
No fertilizer	45.0	19.4	11.5	6.94	3,007	41.5

Table 12. Economical benefit (unit: 1$/10are)

	Q'ty (kg/10a)	Income	Cost	Profit	Index
Control (Urea 100%)	7.252	2.034	0.470	1.564	100
TAO Efflux 30% +Urea 70%	8.152	2.287	0.518	1.769	113

Note) Cabbage price: $0.321/kg.

Table 13. Soil Microbes Change during planting period

	Soil Microbes after 15 days (CFU/mL)			Soil Microbes after a yield (CFU/mL)		
	Bacteria	Actinomyces bovis	Filamentous fungi	Bacteria	Actinomyces bovis	Filamentous fungi
TAO Efflux 100%	8.5×10(7)	8.0×10(4)	6.0×10(2)	8.2×10(7)	5.2×10(5)	3.2×10(2)
TAO M/F 100%	7.5×10(7)	5.0×10(4)	5.0×10(2)	6.3×10(7)	8.2×10(4)	2.3×10(2)
TAO Efflux 70% + M/F 30%	6.3×10(7)	7.0×10(4)	1.0×10(2)	7.3×10(7)	4.2×10(5)	4.5×10(1)
Raw swine manure	3.4×10(7)	8.0×10(4)	6.0×10(2)	6.5×10(6)	5.8×10(4)	7.3×10(2)
Chemical Fertilizer	2.5×10(7)	1.2×10(5)	ND	2.2×10(7)	6.2×10(4)	2.5×10(2)
No fertilizer	4.0×10(7)	8.0×10(4)	ND	3.0×10(7)	4.0×10(4)	1.5×10(2)

Note) $8.5\times10(7) = 8.5\times10^7$ ND: not detected.

〈 Change of Soil Microbes 〉

The soil microbes were examined after 15 days of cabbage planting and a yield as shown in Table 13. Bacteria in soil used TAO Efflux lived more than soil used chemical fertilizer in both of 15 days after and a yield. However, it decreased a lot in soil used raw manure after a yield. As actinomyces bovis increased in soil used TAO Efflux, but it decreased in soil used chemical fertilizer. Filamentous fungi decreased double in soil used TAO Efflux, but it increased rapidly in soil used chemical fertilizer after a yield.

Conclusion

Swine manure may convert to a valuable organic fertilizer. This study shows that swine manure could be a well stabilized, odorless and pathogens free liquid fertilizer with using TAO system. Moreover, it is proven that TAO Efflux could be concentrated by membrane technology without fouling problems and be a advanced commercial fertilizer with mixing of inorganic to supplement fertilizer sources.

Acknowledgements

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