New Night Soil Treatment Process with High Ratio of Septic Sludge

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NKK recently developed the "JAX process," a new night soil treatment process that allows mixture ratios of septic sludge to total night soil exceeding 50%. This paper describes some characteristics of the new process that were obtained in the pilot plant test, which ran from December 1997 to October 1998.

1. Introduction

Recently, there have been drastic changes in the conditions surrounding night soil treatment technology in Japan. One change is the movement led by the Ministry of Health and Welfare towards organizing "Sludge reclamation treatment centers". The policy seeks the establishment of technology to effectively use organic waste generated at individual regional sites through the acceptance of kitchen garbage by regional night soil treatment plants. Kitchen garbage is mixed with dehydrated sludge to augment methane fermentation and composting. Another change arises from the increased annual rate of introduction of flush toilet systems in agricultural, mountain, and fishing village areas. This requires technology that can accommodate the increased rate of septic sludge from household septic tanks charged into night soil treatment facilities. The paper describes technology that responds to this increased mixing rate of septic sludge.

Relatively new night soil treatment facilities mainly use the membrane separation type of heavy load denitrification treatment process. This process, however, does not necessarily accommodate increased ratios of mixed septic sludge. Since the septic sludge results in larger variations of properties than those of night soil and provides lower organic concentrations in the liquid phase after separating solid matter, technology is still needed for facilities that must process high mixing ratios to adequately respond to the wide variations of loads.

To address this problem, NKK conducted a series of pilot plant tests in a joint project of five companies (NKK, TAKUMA Co., Ltd. Toray Engineering Co, Ltd., Mitsui Engineering & Shipbuilding Co., Ltd., and Mitsui Engineering Co., Ltd.) to develop the "Night soil treatment process for treating septic sludge". Tests were performed on the basic process of "Night soil treatment facilities using ultrafiltration membrane separation type heavy load treatment process" (trade name: ASMEX process). This is Evaluation technology No. 22 of the Japan Cities Cleaning Congress Association. The pilot plant test was conducted for about 11 months during the period from December 1997 to October 1998.

An outline of the pilot plant test is described below.

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2. Experimental method

2.1 Pilot plant facilities and flowchart

The pilot plant was installed in the Utsumi Numakuma Wide Area Administration Association Clean Center (Utsumi Cho, Numakuma Gun, Hiroshima Prefecture). The pilot plant was operated with a throughput ranging from 1.0 to 1.5 kl/d and mixing percentages of septic sludge from 50 to 100%. **Fig. 1** shows an outline of the target process of the pilot plant test and of the basic process, which is the conventional membrane separation type, heavy load denitrification treatment process. The major differences between these two processes are listed below.

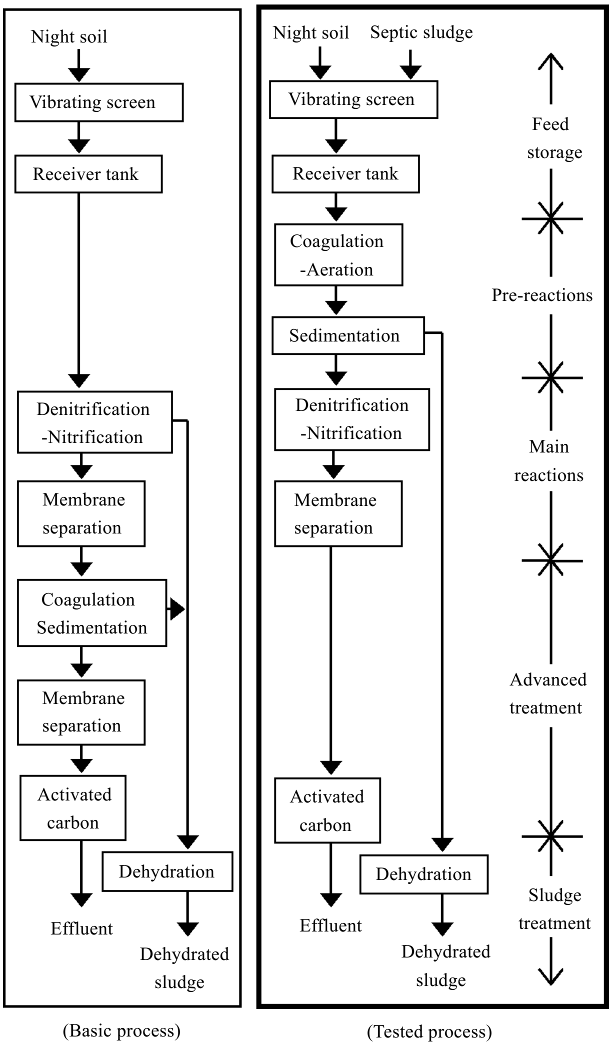

Fig. 1 Schematic flow diagram of basic and tested processes

(1) In contrast to the basic process, this process uses a pre-reaction stage. The pre-reaction stage includes coagulation dephosphorus treatment and sedimentation separation treatment to the night soil after relatively large solid matter is removed and to the septic sludge.

(2) The influent coming into the main treatment stage is switched from night soil after relatively large solid matter is removed for the basic process to treated water after the pre-reaction stage for this process.

(3) In the basic process, sludge is withdrawn at two points: the biological treatment tank and the coagulation sedimentation tank. In this process, however, sludge is withdrawn only at the sedimentation separation tank in the pre-reaction stage by recycling the excess activated sludge from the main treatment stage to the pre-reaction stage.

(4) For the advanced treatment stage, the basic process uses a coagulation treatment unit, the membrane separation unit, and an activated carbon adsorption treatment unit. This process, however, uses only the activated carbon adsorption treatment unit.

The individual treatment stages of the pilot plant facilities is outlined below.

(1) Feed storage stage

The feed storage stage comprises storage tanks for night soil and septic sludge. The night soil is charged into the storage tank after the relatively large solid matter is removed at the commercial Clean Center facilities.

(2) Pre-reaction stage

The pre-reaction stage comprises a coagulation tank, a coagulant charge unit, a pre-reactor, a degassing tank, and a sedimentation separation tank. At this stage, dephosphorus treatment is conducted by adding an iron-base coagulant (poly-iron) and a silica-base coagulant, and the biological treatment reaction is enhanced by applying strong aeration. These treatments provide good solid-liquid separation.

(3) Main treatment stage

The configuration of the main treatment stage is basically the same as that of the basic process. The steps are a primary anoxic tank, an oxic tank, a secondary anoxic tank, a secondary oxic tank, and a membrane separation unit. A recycling type membrane filtration unit, with UF flat membranes and MF hollow fiber membranes are used, as shown in **Table 1**. The UF and MF membranes were operated in parallel for comparison.

Table 1 Specifications of UF and MF membranes tested

	UF membrane	MF membrane
Material	Polyacrylonitrile	Polyacrylonitrile
Type	Flat sheet	Hollow fiber
Separation size	20000 dalton	0.01 μ m
Total area	2.1 m^2	4.2 m^2
Module type	Incased	Submerged in a tank

(4) Advanced treatment stage

Since dephosphorus treatment and denitrification treatment are conducted in the pre-reaction and main treatment stages, the advanced treatment stage consists only of the activated carbon adsorption treatment unit.

(5) Sludge treatment stage

The sludge treatment stage comprises a sludge storage tank, a sludge centrifugal separator, and a separated liquid storage tank. The sludge withdrawn from the sedimentation separation tank in the pre-reaction stage is introduced to the sludge storage tank, and the sludge is dewatered about three times a week. The resulting centrate is recycled into the primary anoxic tank of the main treatment stage.

2.2 Experimental conditions

Table 2 lists the conditions for the pilot plant test period. A continuous operation test for about 1 month was performed for each of the different seasonal conditions and septic sludge mixing percentages. A total of 8 conditions were tested.

Table 2 Operational conditions of the pilot plant

No.	Season	MRS*)	Feed	Flux $m^3/m^2/d$	
		%	kl/d	UF	MF
1	Winter	100	1.0	0.87	_
2	Winter	100	1.5	1.01	0.35
3	Winter	60	1.0	0.82	0.31
4	Spring	60	1.0	0.85	0.34
5	Spring	100	1.5	1.14	0.31
6	Summer	100	1.5	1.70	0.31
7	Summer	60	1.2	1.46	0.28
8	Autumn	50	1.0	1.42	0.29

*) Mixed ratio of septic sludge

2.3 Analysis and determination

The analytical samples were as follows: feed, supernatant of sedimentation separation tank, sludge withdrawn from the sedimentation separation tank, treated water from the oxic tank, excess activated sludge, membrane filtrate, activated carbon treated water, and centrate. The analytical items for those samples were: pH, BOD, COD_{Mn}, SS, n-hexane extract, total phosphorus, total nitrogen, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, kjeldahl nitrogen, MLSS, MLVSS, number of coliform group, color, and water content. For each condition, the analysis and determination were performed at a frequency of 3–4 in conformance to the sewer test method and other standards.

3. Result and discussion

3.1 Feed properties

Table 3 shows the properties of night soil used for the pilot plant test after removing relatively large solid matter through a fine, 1 mm opening sieve, along with the properties of the septic sludge. Variations in septic sludge properties have been reported, particularly in the SS concentration[1]. The septic sludge tested in the pilot plant also showed this feature distinctively. As seen in **Table 3**, the standard deviation of SS concentration in the septic sludge was more significant than that in the night soil. Accordingly, the septic sludge tested in the pilot plant was recognized as being representative in having this distinctive feature.

3.2 Pre-reaction stage

3.2.1 Biological treatment reaction in the pre-reactor

(1) Batch nitrification test

Since the pre-reactor continuously recycles excess activated sludge and provides strong aeration, the biological treatment reactions occurred in this stage in addition to coagulation and sedimentation. Thus, this stage is expected to contribute to reducing the load to the succeeding main treatment stage. A batch test was conducted in the pre-reactor to acquire supporting data to verify this effect. The result is described below.

Fig. 2 shows changes in the pH and ORP with time during the batch test in the pre-reactor. As shown in the figure, the pH showed a sudden drop, and the ORP increased 24 hours after the start of the test. By 48 hours, very little change was observed for both pH and ORP.

Table 3 Qualities of night soil and septic sludge introduced to the pilot plant

	Night soil (N=15)				Septic sludge (N=26)			
	Max.	Min.	Av.	S.D.	Max.	Min.	Av.	S.D.
BOD mg/ l	11000	4600	7310	1900	6480	1400	3480	1420
COD mg/ l	5500	2700	4010	940	6760	2200	3650	1280
SS mg/ l	6700	1500	4180	1670	17000	2900	6720	3550
T-N mg/ l	3200	1700	2270	410	1300	620	839	185
T-P mg/ l	390	200	259	57	300	89	152	46

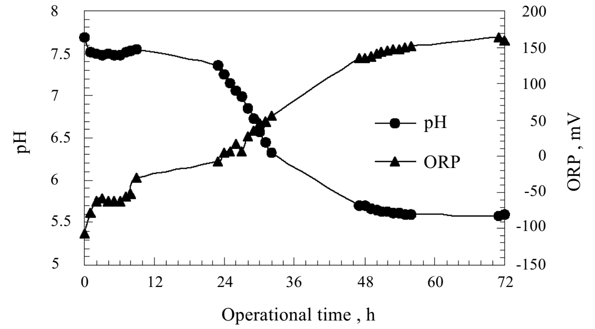

Fig. 2 Changes in pH and ORP during a batch test in the pre-reactor

Fig. 3 shows the changes in concentration of inorganic nitrogen (NO_3^--N, NO_2^--N, NH_4^+-N) and COD with time during the batch test. The figure shows that, at 24 hours after the start of the test, NH_4^+-N decreased and NO_3^--N increased. However, after 48 hours, the concentration and composition of inorganic nitrogen showed very little change. On the other hand, the COD gradually decreased from the start of the test until 48 hours. These findings clearly show that the pre-reactor provides COD removal and nitrification reaction.

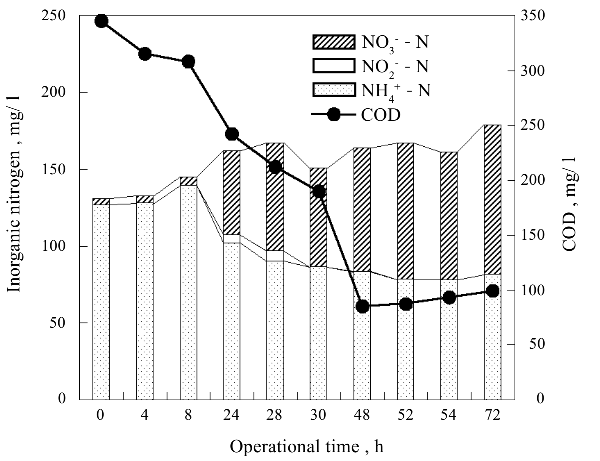

Fig. 3 Changes in concentration of inorganic nitrogens and COD during a batch test in the pre-reactor

(2) Operating status viewed from biota

Photo 1 shows protozoa in the sludge from the pre-reactor. The presence of both *Epistylis*, which normally appears in an activated sludge in good condition, and *Vorticella* can be seen in **Photo 1**. This phenomenon proves that the pre-reactor provides relatively good biological treatment reactions.

3.2.2 Changes of MLSS concentration with time

Fig. 4 shows changes of the MLSS concentration with time observed in the pre-reactor and the primary anoxic tanks. As shown in the figure, the MLSS concentration in the pre-reactor showed significant

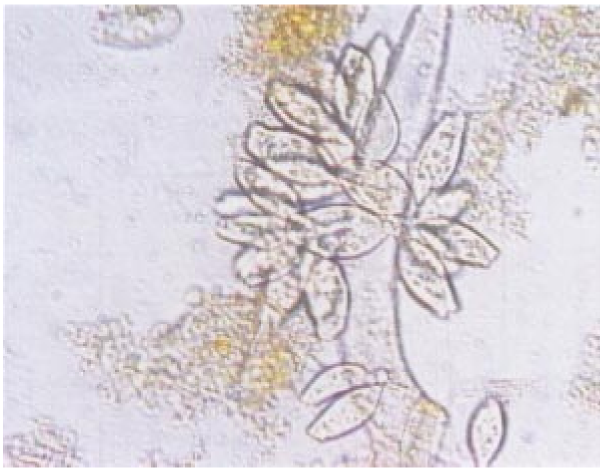

Photo 1 Protozoa seen in the pre-reactor

changes. This phenomenon probably arises from the changes in the properties of septic sludge, particularly changes in the SS concentration. On the other hand, the changes in MLSS concentration in the primary anoxic tank was less than that in the pre-reactor, making the MLSS concentration relatively stable. The SS concentration in the treated water from the reaction stage of this process is at a stable, low level, in a range of 620–1200 mg/l. Thus, the pre-reaction stage should also facilitate operational control of the main treatment stage, making control of the sludge particularly easy.

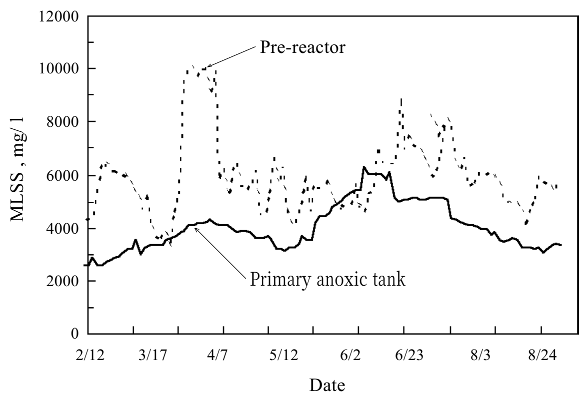

Fig. 4 Changes in concentration of MLSS in the pre-reactor and the primary anoxic tank

3.2.3 Removal treatment performance

Fig. 5 shows the rate of pollutant removal in the pre-reaction stage during the continuous feed test. As the figure shows, every case with a septic sludge mixing ratio greater than 50% had a pollutant removal rate of 80% or more except for total nitrogen. This clearly shows that the pre-reaction stage reduces the load to the succeeding main treatment stage. This stage also appears to help stabilize the main treatment stage.

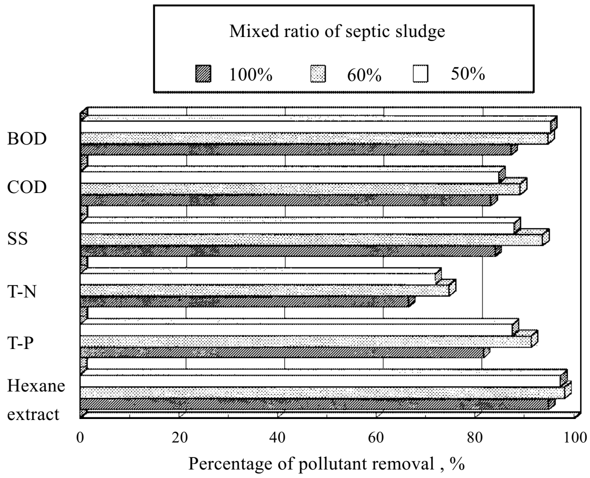

Fig. 5 Removal ratio of pollutant in the pre-reaction stage

3.3 Main treatment stage

3.3.1 Biological treatment reactions

(1) Denitrification treatment

Table 4 compares the inorganic nitrogen concentration in the main treatment stage for this process to that for the basic process. The amount of inorganic nitrogen, particularly NH_4^+-N, in the incoming water to the main treatment stage was one third or less that of the basic process. Thus, the load of NH_4^+-N to the biological treatment reaction tank was very light. This finding suggests that the addition of the pre-reaction stage stabilizes treatment in the main treatment stage, even when a large quantity of septic sludge with significant variations in properties is processed, and that the denitrification target is readily achieved.

Table 4 Changes in concentration of inorganic nitrogen in the main reactor

	Process	Inorganic nitrogen		mg/l
		NH_4^+ - N	NO_2^- - N	NO_3^- - N
Influent to the primary anoxic tank	Tested	204	3.5	32.3
	Basic	709	0.1	0.4
Primary anoxic tank	Tested	27.9	0.4	13.6
	Basic	53.2	0.4	18.7
Oxic tank	Tested	12.8	3.0	18.9
	Basic	14.0	0.4	55.1

(2) Operating stage viewed from biota

Photo 2 shows metazoa resembling *Rotaria* that was observed in the sludge of the main treatment stage oxic tank. *Metazoa* are said to contribute to reduction of the sludge[2]. The occurrence of *metazoa* that were not found in the pre-reactor suggests that the condition of activated sludge in the main treatment stage is better than that in the pre-reactor.

Photo 2 Metazoa seen in the oxic tank

3.3.2 Membrane filtration

Table 5 shows the quality and composition of membrane filtrate from the pilot plant test for the UF and MF membranes. There is no significant difference in water quality between the two kinds of membrane filtrate. Accordingly, either method should provide similar quality of treated water.

Table 5 Average qualities of filtrates

		By UF (N=26)	By MF (N=22)
BOD	mg/l	1.4	1.4
COD	mg/l	38.0	41.7
SS	mg/l	0.0	0.5
T-N	mg/l	8.6	7.6
T-P	mg/l	0.5	0.7
Color	mg/l	173	148

3.4 Advanced treatment stage

Table 6 shows a comparison between the average quality of water treated by activated carbon adsorption unit and the target quality of effluent for septic sludge mixing ratios of 100%, 60%, and 50%. The water quality treated by activated carbon adsorption satisfied all requirements for the effluent. The difference between the maximum and minimum values for each water quality criterion was small, indicating that the treatment is consistent. In particular, the average value of total nitrogen in water treated by activated carbon never exceeded 10 mg/l, regardless of differences in the septic sludge mixing ratio; i.e., the biological denitrification reaction in the main treatment stage was favorably maintained.

3.5 Sludge treatment stage

3.5.1 Properties of centrate

For a 50% septic sludge mixing ratio, **Fig. 6** shows a comparison of the sludge loads between the centrate obtained from dehydrating the withdrawn sludge and

Table 6 Qualities of effluent from activated carbon tower

			Mixed ratio of septic sludge			Targeted
			100 %	60 %	50 %	value
pH	–	Average	7.9	7.5	7.2	
		Min./Max.	7.6/8.2	7.3/7.8	6.8/7.6	5.8 ～ 8.6
BOD	mg/l	Average	0.8	0.9	1.2	
		Min./Max.	0.5/1.3	0.7/1.1	0.7/2.7	<10
COD	mg/l	Average	5.4	6.0	3.5	
		Min./Max.	3.3/7.6	3.5/7.8	2.8/4.2	<10
SS	mg/l	Average	0.0	0.0	0.0	
		Min./Max.	0.0/0.0	0.0/0.0	0.0/0.0	<5
T-N	mg/l	Average	3.0	3.7	5.6	
		Min./Max.	1.4/4.8	1.6/6.1	1.6/11.3	<10
T-P	mg/l	Average	0.5	0.2	0.4	
		Min./Max.	0.2/1.0	0.1/0.2	0.0/0.9	<1
Color	mg/l	Average	4	9	3	
		Min./Max.	1/11	6/12	1/6	<30
Number of		Average	0	0	0	
coliform groups	CFU/ml	Min./Max.	0/0	0/0	0/0	<3000

the supernatant from the pre-reaction stage sedimentation separation tank. As seen in the figure, pollutant loads from the centrate were lighter than those coming from the supernatant in the sedimentation separation tank, and the centrate was relatively clean. Therefore, introduction of the centrate should stabilize the load of the main treatment stage at a light loading level.

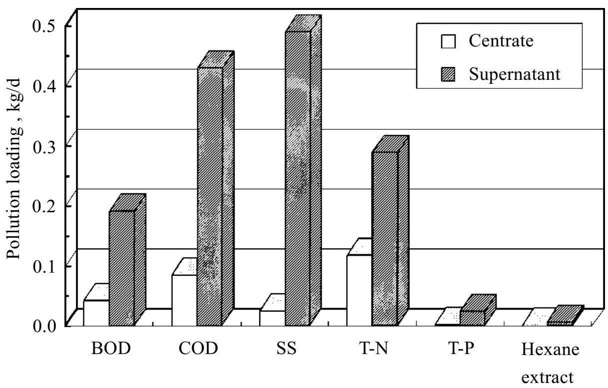

Fig. 6 Comparison of water quality treated by centrifugation and by sedimentation after coagulation-aeration

3.6 Removal treatment performance at each stage

Fig. 7 shows the pollutant removal rate at each stage for the case of a 50% septic sludge mixing ratio. The figure shows that 80% or more of all pollutants except total nitrogen was removed in the pre-reaction stage. Consequently, the pre-reaction stage of this process is expected to reduce the loads to the main and advanced treatment stages, and to achieve stable advanced treatment in the main treatment stage, as well as in the advanced treatment stage. A similar result was also observed in the 100% and 60% septic sludge mixing ratio cases.

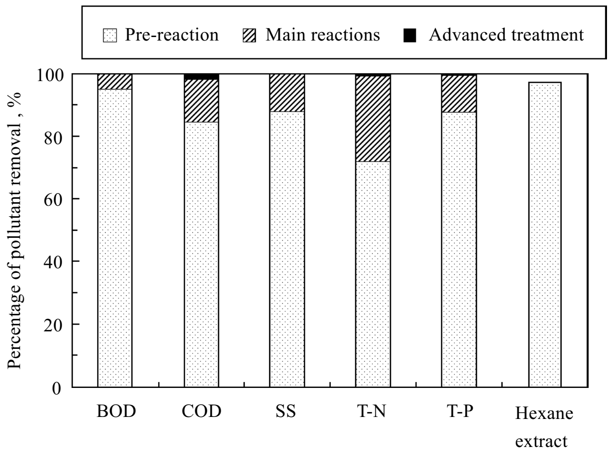

Fig. 7 Percentage of pollutant removal at each stage of the tested process

4. Conclusion

This study was a joint project conducted by five companies under a technology development support project of the Waste Research Foundation. Findings from the pilot plant test are described below.

(1) The removal rate of BOD, COD, SS, and total phosphorus in the pre-reaction stage was as high as 80% or more. Thus, the pilot plant tests demonstrated that the load to the succeeding main treatment stage is reduced and that the biological treatment reaction for nitrogen removal and other functions are performed at a high, stable level.

(2) Also, good quality treated water was attained for phosphorus removal. Accordingly, it was proved that this process consistently provides effluent that fully satisfies the target water quality.

(3) The pilot plant was operated for nearly one year with this simple process using a single stage membrane separation unit. The results demonstrated that this process readily achieves the treatment targets such as the

removal of nitrogen and phosphorus, even when a large amount of septic sludge, which results in significant variations in properties, is introduced. Moreover, this process reduced the load to subsequent operations.

On the basis of these pilot plant test results, the Waste Research Foundation approved this process under the 15th evaluation technology, “The technology of membrane separation for heavy load biological denitrification treatment for night soil with a high septic sludge mixing ratio: A method applying the pre-reaction separation phosphorus removal,” in August 1999. This approval was used to introduce the process to the market under the trade name “JAX Process” as a night soil treatment process offering excellent treatment performance, maintainability, and economy, in response to the expected increase of septic sludge due to social demand.

We would like to express our appreciation to the staff of the Clean Center of Utsumi Numakuma Wide Area Administration Association of Numakuma Gun, Hiroshima Prefecture for their cooperation and suggestions, including the offer of the test plant site.

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