REPORT BY THE TECHNICAL STUDY COMMITTEE CONCERNING AN ADVANCED TREATMENT OF FOOD INDUSTRY WASTEWATER

1984

JAPAN ENVIRONMENT CORPORATION

CONTENTS

1.Introduction

Recently the progress of eutrophication caused by nitrogen and phosphorus in the closed water area, such as inner bays, inner sea and lakes, becomes a serious social problem.

To cope with the eutrophication problem, the more stringent effluent standards of nitrogen and phosphorus are applied to the closed sea area, such as Lake Biwa and Lake Kasumigaura.

And as the nitrogen and phosphorus removal technologies of the food industry wastewater treatment, there are many cases to introduce the biological nitrification-denitrification method for nitrogen removal and the chemical coagulation-sedimentation method for phosphorus removal.

However, the present treatment processes need a large treatment facility, which requires a large area and complicated operation control, and cause various problems, such as the generation of a large amount of sludge and high initial and operation costs, so that it is a big finacial burden for middle-sized food enterprises.

In this research, as an alternative of existing methods, the controlled aeration activated sludge method, the advanced treatment process which can be applied generally to the food indstry wastewater treatment, was studied by the experiments in a bench-scale indoor plant and then based on the result by the operation experiment in a pilot plant to clarify its treatment effect and the economical effeciency.

2.Progress of the study by the technical study committee

The following are the outline of the progress of the study by the technical sudy committee.

2-1. The 1st study committee (Nov. 28, 1983)

The study plan concerning the advanced treatment of the food industry wastewater' was submitted to the Pollution Control Service Corporation.

The detail of the study plan is described in the following chapter.

2-2. The 2nd study committee (Feb. 1, 1984)

This committee studied the result of the intermediate experiment which had implemented based on the study plan submitted to the Pollution Control Service Corporation in the 1st committee and submitted 'the intermediate report - the study on the advanced treatment of the food industry wastewater' to the Pollution Control Service Corporation.

2-3. The 3rd study committee (Mar. 30, 1984)

This committee received the study report (see Supplement) from the Environment Engineering Co., an organization that the study was entrusted, and studied the report plan of the committee.

3. Outline of the study plan

3-1. Advanced treatment methods for food industry wastewater

The activated sludge method is widely applied in the treatment of various kinds of organic wastewater from the food industry.

However, most food enterprises are small to middle-sized and their wastewater has the following characteristics.

(1) Since the products and amounts differ according to the season, the quality and quantity of wastewater greatly fluctuates.

(2) The quality and quantity of wastewater greatly differ according to the time of day.

(3) Compared to wastewater volume, the pollution load is very high, usually about 1000mg/ ℓ of BOD.

(4) Wastewater is generated mainly in the daytime.

(5) It is difficult to acquire personnel who are devoted to the maintenance of treatment facilities.

These are the reasons why a bulking sludge occurs and the wastewater cannot be sufficiently treated by the present facilities with the activated sludge method.

In this research, a batch type controlled aeration activated sludge method was studied as a treatment method for food industry wastewater from small to middle-sized enterprises to clarify its superior bulking control function and stable treatment characteristics for removal of organic substances such as BOD and COD.

In addition, to apply this method as an advanced treatment process for food industry wastewater, the study was conducted to clarify the removal efficiency of nitrogen and phosphorus, which have come under regulation.

The controlled aeration activated sludge method was developed by the Fermentation Research Institute of the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry, aimed at easy, effective and advanced treatment of small to medium sized quantities of organic wastewater.

In principle, it is a batch type activated sludge method, in which wastewater is treated in one aeration tank (used for regulating and settling). It has the following characteristics in the aeration phase; aeration starts after finishing untreated water inflow but no aeration at the inflow so that bulking sludge, the biggest problem of this method, can be completely controlled by forming a clear substrate concentration gradient in the aeration tank, allowing stable treatment.

This method is already being applied in wastewater treatment of some industries such as lunch service centers and pharmaceutical plants, and this is shedding light on its efficiency.

In addition, utilizing, aerobic and anaerobic conditions, controlled by aeration, nitrogen and phosphorus concentrations in the wastewater can be reduced and this is it attracting attention as a low-cost removal method for these pollutants.

3-2. Outline of the Experiment Plan

(1) Wastewater for the experiment

Using 4 different kinds of wastewater from chicken, noodle, tofu (bean curd) and the soy sauce industries, research and experimentation ware conducted.

At the implementation of the experiment, when the contaminant ratio was not suitable for biological treatment, urea and potassium phophate were added to obtain the following:~ BOD : N : P = 100 : 5 : 1.

(2) Experiment equipment

In the experiment, 8 tanks (effective aeration tank volume of 10 ℓ) and 4 tanks (efffective aeration tank volume of 20 ℓ) made of transparent acrylic resin were used. The 10 ℓ aeration tanks were set in a transparent water tank in which the wastewater temperature was held at 20℃ and the 20 ℓ aeration tanks were at room temperature.

Temperature, pH, ORP and DO were continuously measured and recordered.

Wastewater inflow, aeration, sludge settling and drawing of treated water were controlled by timer and the specific time schedule was repeated automatically.

(3)Study method

To treat food industry wastewater by the controlled aeration activated sludge method, the following three pollutants were targeted;

① Organic compounds; ex. BOD, COD, etc.
② Nitrogen compounds; ex. K-N, NO_2-N, NO_3-N, etc.
③ Phousphorus compounds; ex. PO_4-P, P_2, O_5-P, etc.

For individual or simultaneous treatment of the sustances, the experiment was conducted using bench-scale indoor equipment to study basic conditions such as the optimum time schedule, load and the removal limits.

3.3 The pilot plant

Based on the results, of item 3-2 above, a continous operation pilot study using the controlled aeration activated sludge method was implemented in a food plant to confirm the method and to study its stability.

The following table shows the main equipment.

The treatment capacity was $2m^3$/d.

(Planned area of the pilot plant)
1700, Oh-hori, Futsu City, Chiba Prefecture
Kagisa Soy Sauce Co. Ltd.

Table Marin dimensions pilot plant

Name		Type	Note
Tanks	Untreated water tank	tank $2m^3$	
	Aeration tank	tank $5m^3$	Effective volume $4m^3$
Machines	Untreated water transfer pump	Submerged pump	
	Untreated water supply pump	Submerged pump	
	Aeration blower	BSS-25	$0.25Nm^3$/min×2 units
	Treated water pump	Self suction vertical pump	
	Mixing pump	Submerged pump	
Instrumentation	pH meter	Immersion glass electrode	To be connected to the caustic soda feeding pump
	ORP meter	Immersion platinum electrode	
	DO meter	Immersion galvanic electrode	
	Recorder	Dotted recording meter	

4. Abstract of the study result

4-1. Food factory research

(1) Research was conducted in 4 different kinds of food plant, soy sauce, chicken processing, tofu and noodle manufacturing plants, so as to understand wastewater properties, water quality and quantity and effluent patterns, and to collect basic data on the different industries for use in the indoor and pilot plant experiments.
In the soy sauce manufacturing plant, the main wastewater consists of various kinds of water from washing discharged during each manufacturing process and thus there are daily or weekly fluctuations according to the work process.
In the chicken processing plant, drain and various kinds of washing wasterwater from the chicken cutting process are generated and thus the water quality and quantity are relatively stable.
In the tofu manufacturing plant, since the main product is deep-fried tofu, the main wastewater is from immersion and compression. The water quantity and concentration are lower and higher respectively compared to ordinary tofu manufacturing plants.
In the noodle manufacturing plant, the main pollution source is wastewater from the boiling vessel. The noodle washing & cooling wastewater and various washing source make up about 85 % of the wastewater volume.

(2) Water quality analysis was conducted on the existing wastewater treatment facilities of the 4 food plants above to collect basic data so as to understand the function and the treatment efficiency of the existing facilities and to allow comparison with the controlled-aeration activated sludge method.
In the soy sauce manufacturing plant, the average untreated water quality was 1400mg/ ℓ of BOD, 133mg/ ℓ of nitrogen and 17.4mg/ ℓ of phosphorus and the water quality after being treated by the trickling method was 295mg/ ℓ of BOD, 42mg/ ℓ of nitrogen and 5.9mg/ ℓ of phosphorus because of exfloitation of the media sludge during the low winter temparature.
In the chicken processing plant, the average untreated water quality was 900mg/ ℓ of BOD, 163mg/ ℓ of nitrogen and 17.3mg/ ℓ of phosphorus and the water quality after being treated by the fixed bed activated sludge method was 49mg/ ℓ of BOD, 32mg/ ℓ of nitrogen and 6.8mg/ ℓ of phosphorus.
In the tofu, manufacturing plant, the average untreated water quality was 3420mg/ ℓ of BOD, 136mg/ ℓ of nitrogen and 15.6mg/ ℓ of phosphorus and the water quality after being treated by the contact aeration method was 20mg/ ℓ of BOD, 45mg/ ℓ of nitrogen and 4.8mg/ ℓ of phosphorus.
In the noodle manufacturing plant, the average untreated water quality was 1450mg/ ℓ of BOD, 22.9mg/ ℓ of nitrogen and 4.2mg/ ℓ ofphosphorus and the water quality after being treated by the batch type activated sludge method was 4mg/ ℓ of BOD, 2mg/ ℓ of nitrogen and 1mg/ ℓ of phosphorus.
Investifation found that the existing facilities had a common problem which was maintenance trouble due to bulking and in many cases the efficiency of the treatment facilities were impaired.

4-2. Indoor experiment using the controlled aeration activated sludge method

(1) Using actual wastewater from the soy sauce, chicken, tofu and manufacturing plants, basic experimental conditions for BOD, nitrogen and phosphorus removal by the controlled aeration activated sludge method were studied using a bench-scale plant (capacity of 10 ℓ).
In the study, the basic knowledge was obtained on bulking control when using the controlled aeration activated sludge method.
In the soy sauce manufacturing plant, all organic substances could be sufficiently removed. As for the sludge property, SVI of the controlled aeration method was 100, but that of the non-controlled aeration method was 300 ~ 400, falling within the bulking range.
In the chicken processing plant, the COD value was increased by addition of nitrous acid due to nitrification of nitrogen compounds. As for the sludge property, SVI of the controlled aeration method was about 100 and that of the non-controlled aeration method was about 200.
In the tofu manufacturing plant, one of the wastewater substrates quickly leads to bulking, and in a short

period, about one week, bulking occured; SVI of the controlled aeration method was about 200 and that of the non-controlled aeration method was 300 ~ 400, within the bulking range.
In the noodle manufacturing plant, the sludge property was stable, SVI of the controlled aeration method was 120, but that of the non-controlled aeration method was 300 and filamentous bacteria were observed.

(2) Research was conducted to study nitrogen and phosphorus removal using the controlled aeration activated sludge method and to clarify the efficienties of different time schedules under both aerobic and anaerobic conditions.
In addition, the effect on nitrogen and phosphorus removal efficiency under different experimental conditions was studied and knowledge on nitrification and dinitrification speeds and phosphorus uptake and release was obtained.
In the controlled aeration activated sludge method, nitrogen could be biologically removed by a combination of nitrification and dinitrification utilizing aeration and anaerobic mixing conditions. In addition, phosphorus release and uptake of the activated sludge could be obtained in aerobic and anaerobic conditions created by untreated water inflow and aeration.
The controlled aeration activated sludge method's removal efficiency for BOD, nitrogen and phosphorus was compared in the following studies; the nitrogen removal system, phosphorus removal system and nitrogen & phosphorus removal system.
BOD removal efficiency was high in every system, more than 99 %.
Nitrogen removal efficiency of 90 % was found to be the case in the treatment system with nifrification and denitrification.
Phosphorus removal efficiency of 70 % can be expected only with the nitrogen removal process but with no phosphorus release process. Because phosphorus is released and uptaken in aerobic and anaerobic conditions created by raw water inflow and aeration.
The reaction rate in the nitrification and denitrification processes of the nitrogen removal system was slower than ordinary; the nitrification rate (at 20℃) was 0.02 kg/kg·d and the denitrification rate (at 20℃) was 0.06 kg/kg·d.
This was probably due to the difference in bacterial growth caused by the wastewater composition, BOD/N = 8 ~ 9 (high), and bacterial utilization methanol, which was added as a hydrogen donor in the experiment.

(3) Using actual wastewater from the soy sauce manufacturing plant, nitrogen and phosphorus removal using the controlled-aeration activated sludge method was studied utilizing an indoor bench-scale plant (capacity of 20 ℓ).
Based on this study, the optimum time schedule and the treatment characteristics for nitrification, denitrification and phosphorus removal using the controlled-aeration activated sludege method could be found.
Knowledge on BOD, nitrogen and phosphorus removal was obtained from 4 experimental conditions; the non-controlled aeration method, the controlled aeration method, the controlled aeration method with the anaerobic mixing process and the controlled aeration method with methanol addition in the anaerobic mixing process.
In the experiment, the average concentrations of influent nitrogen and phosphorus were excessivly high; 650 mg/ ℓ was BOD, 64 mg/ ℓ was nitrogen, 7.8mg/ ℓ was phosphorus and BOD : N : P = 100 : 9.8 : 1.2.
The treatment load conditions were BOD space loading of 0.50 - 0.14 kg/m^3· d (average 0.29 kg/m^3· d) and nitrogen loading of 0.04 - 0.02 kg/m^3· d (average 0.03 kg/m^3· d).
Regardless of the treatment method, the removal efficiencies of organic substances - TOC, COD and BOD - were good.
Although there was a big fluctuation in influent BOD from 300 to 1000 mg/ ℓ , the treatment performance was stable; treated BOD was 10 mg/ ℓ or less and removal efficiency was 98 % or more.
Both TOC and COD of the treated water were stable, 30 mg/ ℓ or less, but the removal efficiency was 90 %, a little lower than that of BOD.
Although there was a big difference in aeration time according to the treatment time schedule, from 12 to 20

hours, the nitrification ratios of influent organic nitrogen and ammonia nitrogen were 95 % or more.

Nitrogen removal efficiency varied greatly according to the treatment method; 58.7 % in the non-controlled aeration method, 73.9 % in the controlled aeration method, 81.3 % in the controlled aeration with the anaerobic mixing process and 94.4 % in the controlled aeration method with methanol addition in the anaerobic mixing process. The efficiency of controlled aeration with methanol addition in the anaerobic mixing process was stable; NO_3-N of the treated water was 1 mg/ ℓ or less and 5mg/ ℓ of T-N or less.

There was no difference in the nitrification rates calculated from K-N decrease quantity and from NOx -N inrease quantity, 1.45 - 1.88 mg/N/g - MLSS/hr.

The denitrification rate increased 6 times on addition of a hydrogen donor; 0.40 mg-N/g-MLSS · Hr with no additiion of a hydrogen donor and 2.39 mg-N/g-MLSS · Hr on addition. In the controlled aeration method, the denitrification rate on inflow of untreated water was 2.56 - 2.89 mg-N/g-MLSS · Hr, and thus the method of untreated water feeding as a hydrogen donor should be studied.

Phosphorus removal was not made clear by the experiment because there were various factors affecting phosphorus removal, not only the time schedule but BOD loading, and sludge age as well. However, there was a tendency of P-201 < P-202, P-203 < P-204 and the removal efficiencies of the controlled aeration method (P-202, P-203 and P-204) were higher than that of the non-controlled aeration method (P-201); 86 % in P-204.

4-3 The pilot plant

In Feb. 1984, a pilot plant of the controlled aeration activated sludge method with a capacity of $2m^3/d$ was installed in the soy sauce manufacturing plant area and operational experimentation was conducted.

Based on the results from the indoor bench-scale apperatus, experimentation on continous operation was conducted with treatment conditions being confirmed and data on the outcome was obtained.

(1) A pilot plant with a capacity of $2\ m^3/d$ was installed in the soy sauce manufacturing plant area and operational experimentation was conducted.

The wastewater was pumped up from the existing untreated water adjusting tank to the untreated water adjusting tank of the pilot plant and after equalization of the water quality by storage in the tank, it was sent to the aeration tank. Air was injected into the aeration tank with diffusers and anaerobic mixing was conducted with a mixing pump. The treated water was drawn by pump and the treated water level was adjusted with a level meter. The facility was automatically operated by timer so that continous experimentation was easy.

(2) The efficiency of a screen, which is the simplest method, was studied for the following reasons; influent concentration and pollutant load due to SS was high, SS made up 50 % of BOD, and in a batch type controlled aeration activated sludge method, the efficiency greatly depends on SS removal.

As a result, the mean value of the non-excess probability of SS in the wastewater was 760 mg/ ℓ before installation of a screen but it became 320 mg/ ℓ after installation, which clarified the high efficiency of SS removal of by a conveyor type screen.

(3) The acclimation of the pilot plant was conducted during a low water temperature period, 12 - 15℃, in winter, but by adjusting the seeding sludge volume at MLSS of 4000 mg/ ℓ , the acclimation could be completed in two weeks for BOD removal and one month for the nitrification reaction system.

After finishing the acclimation of the pilot plant, the conventional controlled aeration method's removal efficiency of BOD was 98 %, but that of TOC was 91 % and COD 90 %, which implied an organic polluted compornent which was attributed to the presence of non-biodegradable organic substances in the soy sauce manufacturing wastewater.

Since the nitrogen and phosphorus ratio in the wastewater was approximately BOD : N : P = 100 : 10 : 1, the excess nitrogen was oxidized to nitrite and nitrate by nitrification. Nitrification caused nitrite to be converted to nitrate as the acclimation proceeded.

Since phosphorus was uptaken by the sludge, in the treated water there was almost no residual phosphorus. The average removal efficiencies were 82 % for nitrogen and 97 % for phosphorus during this treatment

period.
In the experiment, the nitrification ratio was 94 % and this nitrogen removal efficiency was probably due to denitrification of the added nitric acid at the inflow of untreated water. This result was very similar to that of the indoor bench-scale apperatus.

(5) After acclimation, the hourly changes of the pilot plant were studied.
The untreated water carried on the research days, March 6th and 7th, a BOD loading of 0.15 kg/m^3 · d, about half of the ordinary value, and 4060 mg/ ℓ of MLSS but the ratios of BOD : N : P = 100 : 11.6 : 1.3m, which was ordinary.
By the formation of a particular substrate concentration gradient brought about by the controlled aeration method, TOC, BOD and organic substaces reached equilibrium after 6 hours of aeration.
Nitrogen was oxidized to nitrous acid and nitric acid at a water temperature of 15℃ and the nitrification rate constant was 0.014 kg/kg · d, which was lower than that of the indoor bench-scale apperatus. This is probably due to a slow down in nitrifying bacterial growth at low water temperature.

(5) In the controlled aeration activated sludge method pilot plant installed in the soy sauce manufacturing plant, nitrogen and phosphorus removal which was clarified by the indoor bench-scale opperatus was confirmed by comparing the appropriate time schedules for nitrification, denitrification and phosphorus removal.
In the controlled aeration activated sludge method, bulking can be controlled by the substrate concentration gradient formed in the aeration tank. Nitrification, denitrification and phosphorus removal are possible through maximum utilization of the physiological function of the activated sludge by creating aerobic and anaerobic conditions in the aeration tank. Consequently, as a treatment process suitable for food industry wastewater, a batch type compact system with easy maintenance and low cost for nitrogen and phosphorus removal was established.

4-4 Economic evaluation of the advanced treatment process for the food industry wastewater

Based on the above study, it was found that the controlled aeration activated sludge method is efficient in achieving a stable reactive system through control of bulking, and simultanous removal of nitrogen and phosphorus is possible by selecting the suitable time schedule for nitrification, denitrification and phosphorus removal.
This advanced treatment process for nitrogen and phosphorus removal was designed for food industries with a wastewater discharge of 50 m^3/d, 400 m^3/d and 800 m^3/d.
This was compared with the advanced process based on the continous activated sludge method for nitrification and denitrification and a chemical coagulation process for phosphorus removal.
The advanced treatment process utilizing the controlled aeration activated sludge method for nitrogen and phosphorus removal was designed and then compared with the ordinary method and it was found that its structure is simpler leading to easier maintenance and a 43~46% reduction in operation cost. The cost is very low, ¥ 119/ m^3 for the 50m^3/d set up and ¥ 70/m^3 for the 400m^3/d or more set up. This shows that it is an economical treatment process which includes tertiary treatment.
The controlled aeration activated sludge method can also reduce the facility area by 22 ~ 25 % compared to ordinary facilities.

5. Conclusion

This study was conducted using the controlled aeration activated sludge method aiming at an advanced wastewater treatment system for the food industry and the result was evaluated from technical and economic view points. The study clarified the following points; in the controlled aeration activated sludge method, bulking could be controlled by the substrate concentration gradient which formed in the aeration tank; nitrification, denitrification and phosphorus removal were possible through maximum utilization of the physiological function of the activated sludge by creating aerobic and anaerobic conditions in the aeration tank. Consequently, as a treatment process suitable for food industry wastewater, a batch type compact treatment method with easy maintenance and low cost system for nitrogen and phosphorus removal was established.

Supplement

Report on
"the study on the the advanced treatment of the food industry"

March, 1984

Environment Engineering Co., Ltd.

CONTENTS

Ⅰ. Entrusted study items

This is the report of 'the study on the advanced treatment of the food industry wastewater'.

Ⅱ. Outline of contents and items of the study

1. Study on food industry wastewater properties

This report explains the result of a study done on the actual condition of wastewater from four different kinds of food manufacturing plants (soy sauce, chicken, tofu and noodle) and the associated wasewater properties. The result of this study into the existing treatment facilities is also explained in this report.

2. Study on basic treatment conditions of the actual wastewater

Basic treatment conditions of the controlled aeration activated sludge method were studied using indoor bench-scale apperatus (10 ℓ , 20 ℓ), using actual wastewater from the four food plants and the result is explained in this report.
The controlled aeration method was compared to the noncontrolled aeration method from the viewpoint of bulking control.
Treatment efficiency was also compared between the controlled aeration activated sludge method and the ordinary activated sludge method of the existing faclities.

3. Study on bulking control

Conditions that generated bulking when processing food industry wastewater were studied using an indoor bench-scale apperatus.
Operation parameters were clarified by studying the efficiency of the controlled aeration activated sludge method using the tofu manufacturing plant wastewater.

4. Study on nitrogen and phosphorus removal using the controlled aeration activated sludge method

Using the indoor bench-scale apperatus, nitrogen and phosphorus removal efficiency of the controlled aeration activated sludge method was studied using actual manufacturing plant wastewater.
In the experiment, the optimum time schedules for nitrification, denitrification and phosphorus removal were selected and the treatment characteristics were clarified.

5. Pilot plant on-site experiment

The continous operation experiment was conducted using a pilot plant with a capacity of 2 m^3/d set-up in the soy sauce manufacturing plant.
For the establishment of a general advanced treatment utilizing the controlled aeration activated sludge method for nitrogen and phosphorus removal, basic treatment conditions were confirmed and the efficiency was studied.

6. Study on advanced treatment of COD

Aiming at advanced treatment of COD and coloration of treated water from soy sauce manufacturing using the controlled aeration activated sludge method, the A-Hipo method was studied.

Basic treatment conditions were studied under laboraroty conditions.

Ⅲ. Report on the study into advanced treatment of food industry wastewater

1. Introduction

The activated sludge method, which is highly efficient, is widely used in the treatment of various organic wastewater generated by food plants.

However, almost all food plants are small to medium sized and have the following characteristics;

(1) Since the products and production amount differ according to the season, the quality and quantity of wastewater greatly fluctuates.

(2) The quality and quantity of wastewater greatly differs according to the time of day.

(3) Compared to the wastewater volume, the pollution load is very high, usually about 1000mg/ ℓ of BOD.

(4) Wastewater is generated mainly in the daytime.

(5) It is difficult to acquire personnel devoted to the maintenence of the treatment facility.

For the above reasons in activated sludge facilities bulking sludge occurs and wastewater cannot be sufficiently treated.

This research was conducted so as to study a batch type controlled aeration activated sludge method as a treatment for food industry wastewater from small to medium sized enterprises and for clarification of its superior bulking control and stabiling in treating organic substances, such as BOD and COD.

In addition, as an advanced treatment process of food industry wastewater, study was conducted on nitrogen and phosphorus removal, regulated pollutants, through enhancment of the method.

At first, an indoor bench-scale experiment was conducted to study basic treatment conditions related to BOD, nitrogen and phosphorus removal from wastewater from various food industries.

Through general evaluation including evaluation of the efficiency of this method based on the bench scale result and study on the efficiency of existing treatment facilities, an on-sight pilot-plant experiment was conducted.

Consequently, this study aims at the application of the controlled aeration activated sludge method as an advanced treatment process for the food industry which can easily and effectively treat not only organic pollutants but nitrogen and phosphorus as well.

2. Study on the actual food industry wastewater condition

Research was conducted in four different kinds of food plant (soy sauce, chicken, tofu and noodle), to understand wastewater properties, quality, quanity and effluent patterns, and to collect basic data for validation test by the indoor experiment and the pilot plant experiment.

2-1. Soy sauce manufacturing plant wastewater (Research from Nov. 9th, 1983)

Since almost all factories employing brewing, including soy sauce ones, are small to medium sized, the operation and maintenance cost of wastewater treatment plant, places a great burden on them.

However, public concern on environmental preservation is very high and there have been many articles and papers on basic research on the design and operation of wastewater treatment facilities even in industry magazines.

(1) Soy sauce manufacturing plant processes and wastewater

Various kinds of brewed soy sauce are manufactured in different compound ratios of protein, starch, salt, water, etc. The manufacturing process of the typical strong soy sauce is shown in Fig. 2-1.

At first, water is sprayed on degreased soy beans in a ratio greater than 6 : 5, water : soy beans and then it is steamed for about 4 hours. After steaming, it is rapidly cooled down.

Wheat, the raw material of starch, is crushed after roasting and 'koji' is manufactured from the steamed beans, roasted wheat and bran. Adjusted salt water Be 19℃) is added to the koji.

On the day of preparation above and the next, the blew is throughly mixed but following this it is only slightly agitated once every 4 days. After comencement of fermentation it is mixed once every 3 days, after gushing subsides once every 10 days, and in the maturation period twice a month. After 4 - 8 months, unrefined soy sauce is produced.

The unrefined soy sauce itself, or after adding salt water, sediment or other things is compressed by machine. After compression and filtration, raw soy sauce is separated from oil by specific gravity and left as it is quietly for 5 - 10 days. Finally after removing scum and sediment, it is sterilized by boiling.

Various kinds of washing wastewater are generated as shown in Fig. 2-1.

Wastewater comes from washing of the steammers, koji room, press filters, unrefined soy sauce tanks, filters, bottles, floors, etc. Among them the main sources are bottle washing and miscellaneous wastewater and generally they occupy 70 - 90 % of all wastewater.

(2) Wastewater volume and effluent pattern

The relationship between the work process, wastewater volume and effluent pattern is shown in Fig. 2-2.

In the morning, the main wastewater was from bag and bottle washing and in the afternoon, mainly from steammer washing.

The effluent volume on the research day was about 35 m^3 but water quality and quantity can fluctuate greatly according to the day of the week due to the feilt the work process varies according to the day.

Similarly hourly changes in the wastewater quality and quantity varied greatly probably because the duartion of wastewater discharge from each process was short, and the times at which washing occured, producing high concentrated wastewater, varied.

The ratios of nitrogen and phosphorus were high in the commonly found wastewater, BOD : N: P = 100 : 8 : 1.6.

(3) Hourly changes of wastewater quality

During wastewater inflow (8:00 - 16:00), hourly water quality analysis was conducted.

Samples were taken at the inlet of the existing adjusting tank and a composit sample was prepared by combining the hourly samples.

The results from the analysis are shown in Table 2-1, and hourly changes of work process and wastewater quality are shown in Fig. 2-3.

In the morning, as wastewater mainly came from bag washing, the wastewater volume was constant but BOD concentration was relatively high.

In the afternoon, the BOD concentration peak was at 14:00 due to steamers washing; after 15:00 the concentration was low but there was a peak in wastewater volume due to various washing processes.

(4) Analysis result of the wastewater from each process

Table 2-2 shows the analysis result of each process wastewater.

Looking at the wastewater quality from each process, BOD concentration was 2000 - 4000 mg/ ℓ from steaming and steamer cleaning wastewater, 1000 - 2000 mg/ ℓ from koji room floor washing, bag washing, compressor washing, etc., these ware the main pollution sources.

As there was almost no separation of wastewater in the soy sauce manufacturing plant, polluted wastewater was diluted with large amounts of other wastewater such as from bottle washing, and other processes before discharge. Consequently the final concentration of the wastewater was not so high.

SS concentration was high in the soy bean steaming wastewater.

Although due to work on the research day, the koji room washing wastewater could not be sampled, result from another sample showed BOD of 100 mg/ ℓ or less, very low compared with the general research result, BOD of 1000 - 4000 mg/ ℓ .

(5) Characteristics of the wastewater

Problematic is the big fluctuation in the wastewater quality and pollutant load due to the daily change in the manufacturing process at the soy sauce plant. Great attention should be paid especially when these flucuations are accompanied by a high chlorine ion concentration because proper treatment can be impaired. The overall quality of the wastewater depends on the presence or absence of wastewater from dialy steamers washing, filter washing and koji room washing, and the largest volume being from bottle washing, and it has been found that there are differences in BOD concentration from 500 to 1800 mg/ ℓ and the wastewater volume varying from one to two times.

The correlation between BOD and COD in the wastewater is shown in Fig. 2-4.

Since BOD and COD in SS are high, selection of an appropriate screen might be effective to decrease the load.

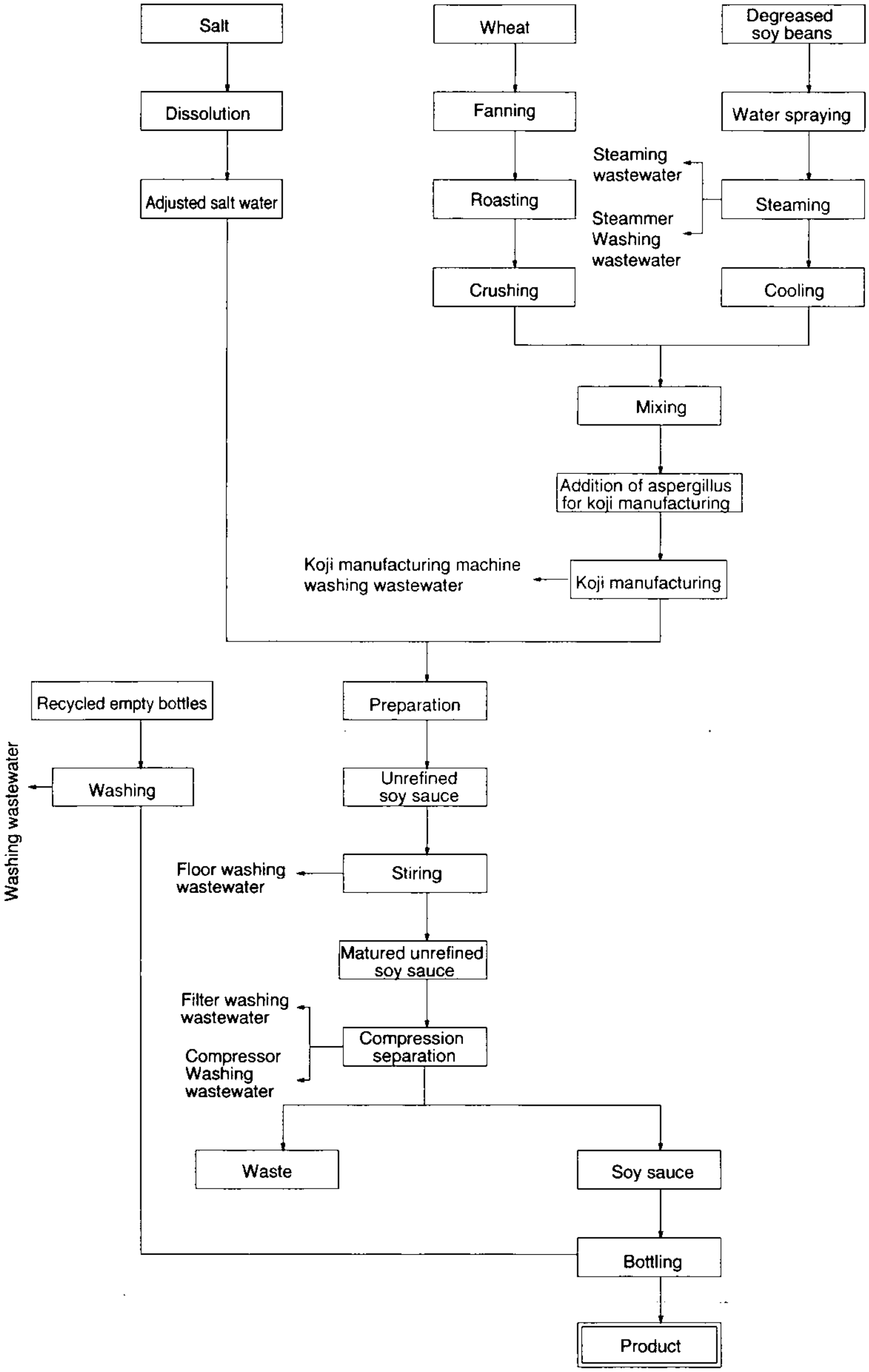


Fig 2-1 Soy sauce manufacturing process and kinds of wastewater

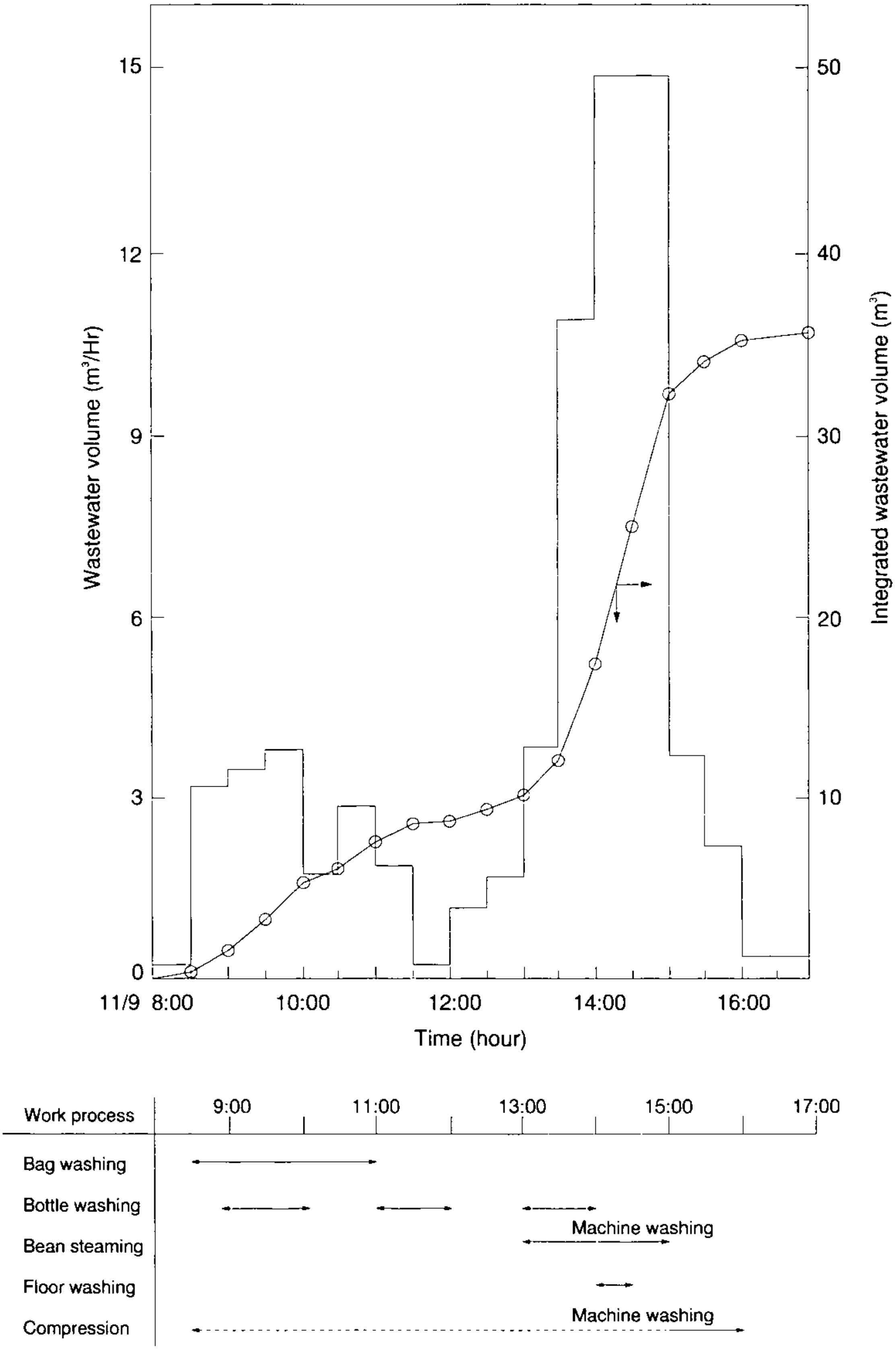


Fig 2-2 Soy sauce manufacturing plant: Wastewater volume and effluent pattern

Table 2-1 General wastewater analysis results (Adjusting tank inlet)

Items Samples	Wastewater volume (m^3)	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	Color (degree)	$Cℓ^-$ (mg/ℓ)	K–N (mg/ℓ)	T–P (mg/ℓ)	n-hexane (mg/ℓ)
8:00		6.4	440	(420)	410 (210)	1190 (790)	190	750			
9:00	1.7	7.0	430	(260)	440 (200)	880 (530)	250	240			
10:00	3.6	6.8	660	(430)	760 (390)	1550 (690)	290	340			
11:00	2.3	7.0	100	(210)	220 (130)	360 (290)	180	300			
12:00	1.1	7.1	110	(290)	310 (190)	540 (330)	260	280			
13:00	1.4	7.0	78	(150)	140 (93)	240 (180)	160	240			
14:00	7.3	6.5	800	(480)	720 (450)	1400 (870)	280	310			
15:00	14.8	7.9	270	(120)	180 (83)	230 (90)	140	150			
16:00	3.3	6.8	180	(310)	270 (210)	470 (310)	210	450			
Composite	35.5	6.7	390	(250)	360 (210)	770 (540)	190	270	60	12	65

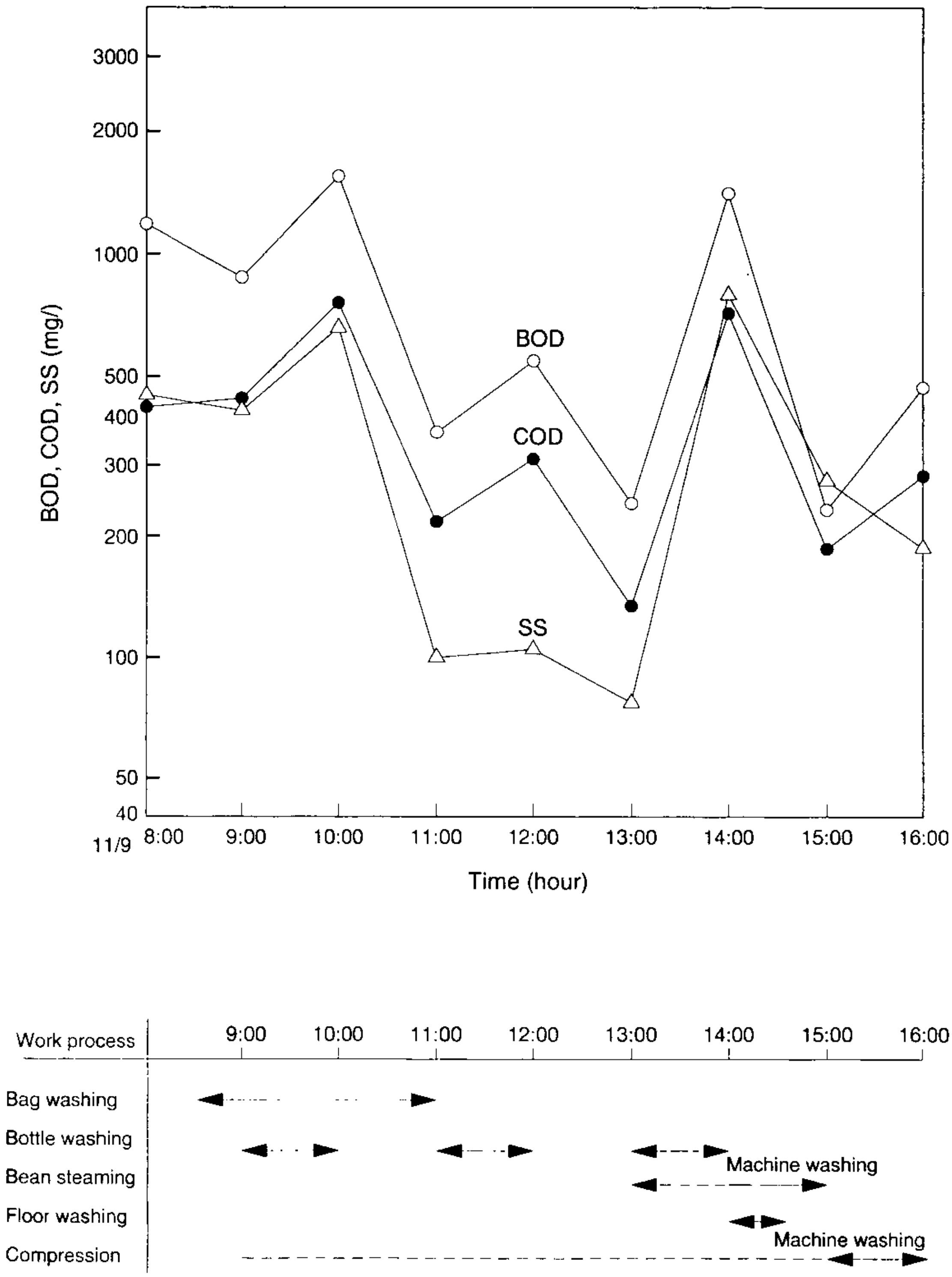


Fig 2-3 Soy sauce manufacturing plant: Hourly changes in wastewater quality

Table 2-2 Analysis results of wastewater from each process

Items Samples	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	Color (degree)	$C\ell^-$ (mg/ℓ)	K–N (mg/ℓ)	T–P (mg/ℓ)
11/9 10:45 Bag washing wastewater	7.1	780	(450)	960 (430)	1500 (850)	330	300	120	7.7
11:40 Bottle washing wastewater	9.7	330	(87)	100 (94)	170 (150)	140	88	7.4	8.4
13:30 Bean steaming wastewater	6.5	1800	(1960)	2150 (1950)	4220 (3110)	100	81	160	18.0
13:30 Bean steaming and conveyor washing wastewater	6.8	490	(590)	1220 (870)	1190 (940)	77	74	59	7.1
14:00 Steaming machine washing wastewater	6.5	980	(870)	1870 (1280)	2270 (1490)	98	74	70	9.9
14:00 Koji room floor washing wastewater	6.1	310	(1040)	840 (650)	1830 (1360)	430	1440	210	23.0
14:30 Compressor washing wastewater	6.1	470	(680)	690 (500)	1400 (1080)	460	880	165	20.0
11/10 Sauce boiling vessel washing wastewater	7.4	180	(86)	230 (99)	220 (120)	46	61	52	1.2
11/11 Koji manufacturing room washing wastewater	8.1	36	(24)	138 (139)	32 (5)	29	54	6.9	1.8

Treated water of the existing facility 11:50	7.5	87	(39)	74 (38)	60 (13)	120	240	28	3.7
16:00	7.3	140	(69)	110 (56)	100 (32)	140	270	31	5.4

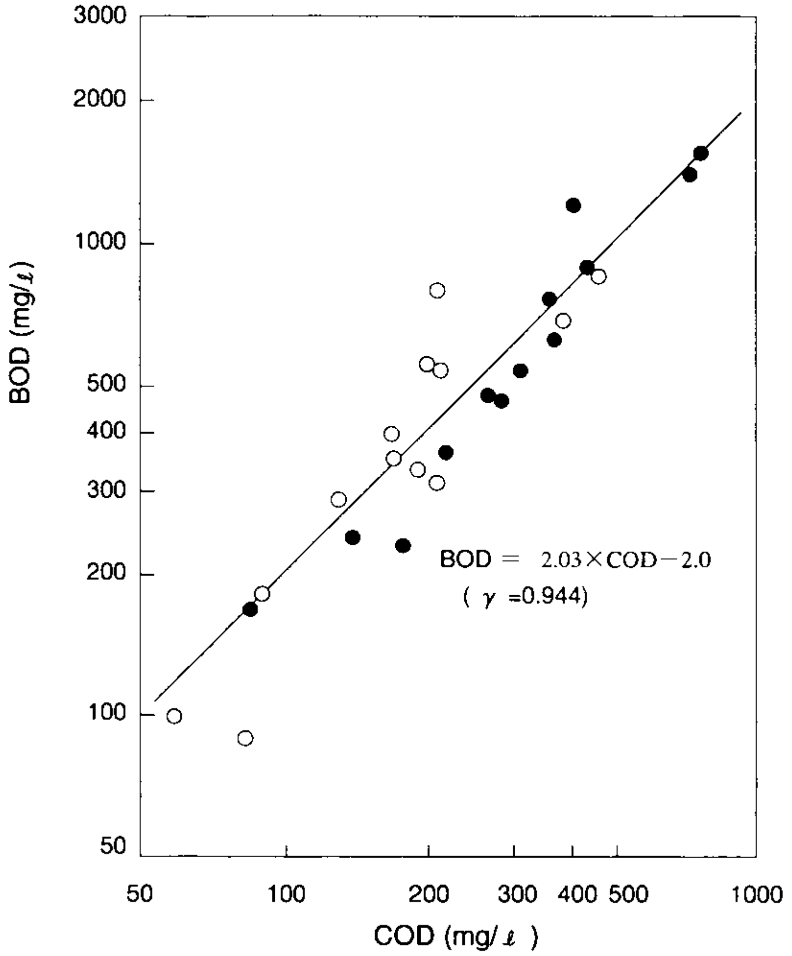


Fig 2-4 Soy sauce manufacturing plant: BOD-COD correlation

2-2 Chicken processing plant wastewater (Research conducted on Nov. 9th, 1983)

Processing includes blood letting, plucking and cutting in the chicken processing plant, and the main pollution sources are blood and body fluid.
It has been found that there is a close relationship between the number of treated chikens and pollution load.

(1) Chicken treatment process and kinds of wastewater

The chicken treatment process and kinds of wastewater are shown in Fig. 2-5.
Following is the outline of the process and wastewater characteristics.

(i) Receiving platform

Live chickens in baskets are transferred from trucks to a platform and they are hung on a conveyor and passed through to the blood letting room.
The wastewater generated in this process is from platform washing and it is discharged along with chicken excreta and feathers in the morning.

(ii) Blood letting process

This process involves removing blood from the chickens, and once in the afternoon wastewater is generated through washing the blood letting room. Almost all of the chicken blood quickly coagulates if it is left and this blood is transferred and disposed of separately.

(iii) Hot water immersion process

To remove feathers easily, the chickens are immersed in hot water. In this process, wastewater is from overflowing and draining of the hot water immersion tank.
Wastewater is generated only in the morning.

(iv) Plucking process

Feathers are plucked by machine. A large number of feathers in the wastewater are caught by a screen and transferred for separate disposal. Wastewater is generated only in the morning.

(v) Final plucking

Plucking and washing are a manual process. Washing wastewater is generated only in the morning.

(vi) Cooling and disinfection process

After plucking, the chickens are immersed in a water tank with disinfectant (sodium hypochlorite) for cooling and disinfection. After finishing all the work, the liquid is discharged in the evening.

(vii) Cutting process

For shipment, the chickens are cut. Floor washing wastewater is generated mainly in the afternoon.

(viii) Basket washing process

Since live chickens are transferred in baskets, the baskets must be washed and disinfected. The wastewater is generated on draining in the afternoon, and contains the disinfectant whose main compound is o-dichlorobenzene.

(2) Wastewater volume and effluent pattern

The relationship among the work process, the wastewater volume and the effluent pattern is shown in Fig. 2-6.

The blood removal and plucking processes are carried out from 5:30 to 12:00 and the cutting and basket washing processes are from 8:00 to 15:00. As a result, the wastewater volume is almost constant through out the day.

The wastewater volume on the research day was about 140 m^3 and the number of treated chikens was about 7000.

(3) Hourly changes in wastewater quality

The influent was analyzed every hour during the wastewater inflow time (5:30 - 17:00).

Samples were taken at the inlet of the existing adjusting tank and a composite sample was prepared by combination of samples.

Results from analysis are shown in Table 2-3, and hourly changes in the wastewater quality are shown in Fig. 2-7. Although there were concentration peaks in the wastewater in the morning and afternoon, the pollutent load was steady except at each processes drain time, because the the main wastewater was from washing.

(4) Analysis result of wastewater from each process

Table 2-4 shows the analysis results of wastewater from each process.

The wastewater discharged from the hot water immersion process contained chicken blood and thus the concentration of organic substances was very high.

Water in the cooling water tank during the disinfection process became more and more contaminated as the work proceeded, and at drain time in the evening, it was estimated to reach a BOD level of 200 - 300 mg/ ℓ .

Due to disinfection, sodium hypochlorite in the cooling water tank and o-dichlorobenzene, cresol, etc., in the basket washing tank, it was necessary to study the effect of such chemicals on the biological treatment.

Nitrogen and phosphorus concentrations were high in the final wastewater; BOD : N : P = 100 : 20 : 2.3, and the wastewater from the cutting process contained a high concentration of n-hexane extracts because of chicken fat.

(5) Chracteristics of the wastewater

The main pollutants in the wastewater were blood and body fluids generated from blood letting plucking, and cutting.

Consequently the concentration of nitrogen and phosphorus was high.

The main wastewater was from washing, and daily changes were small with concentration fluctuations limited to the short period of draining.

Fig. 2-8 shows the correlation between BOD and COD.

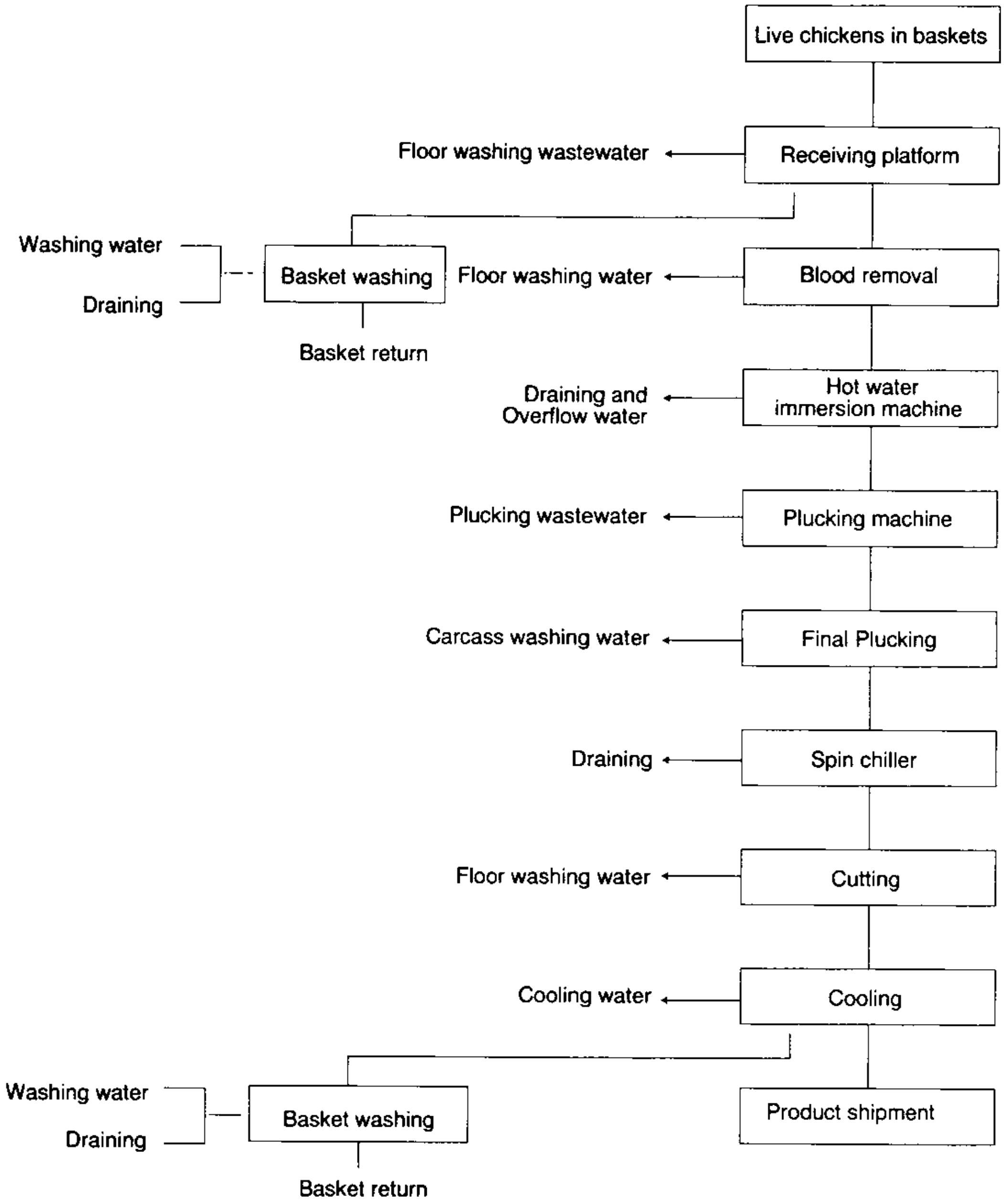


Fig 2-5 Chicken treatment process and kinds of wastewater

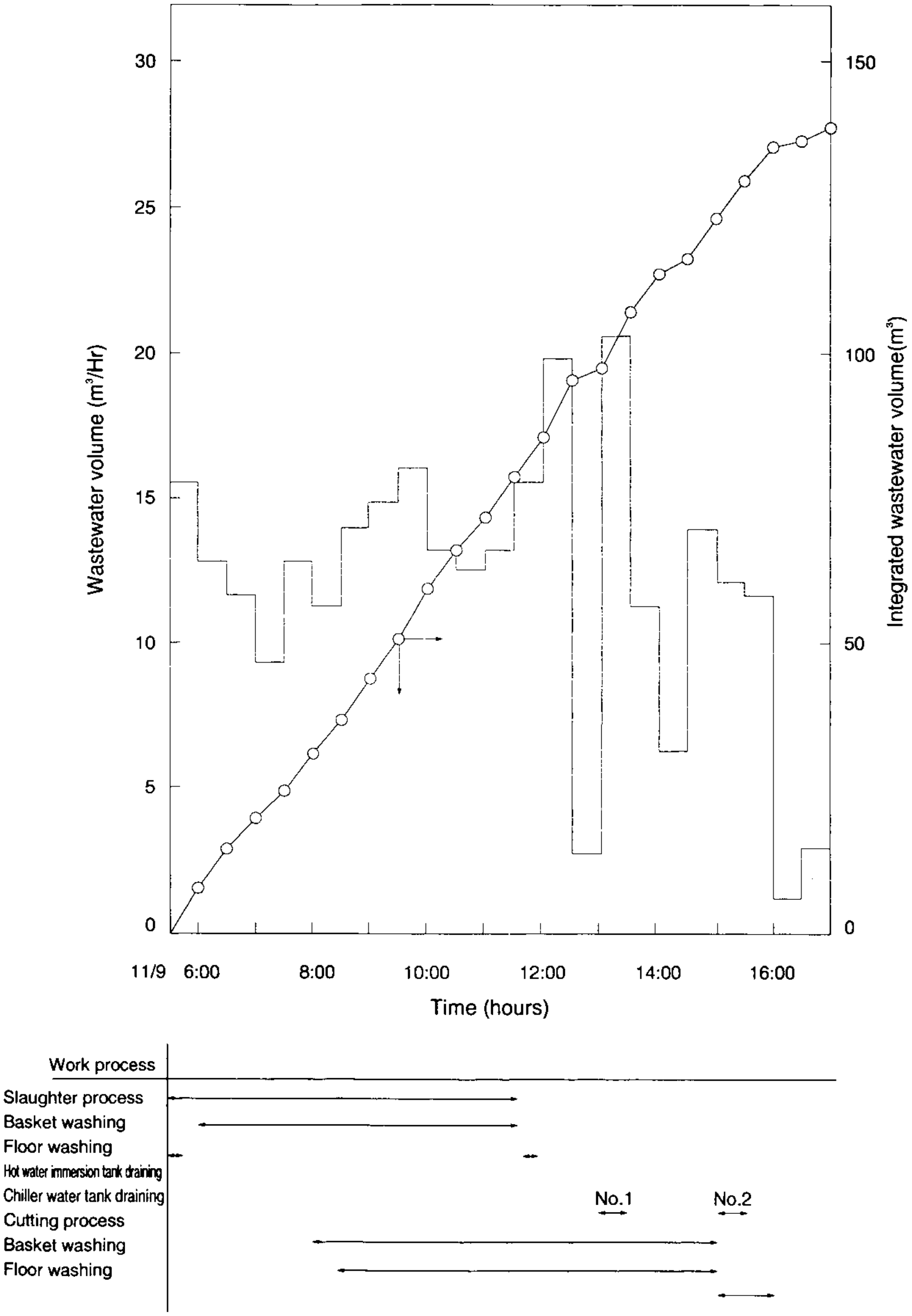


Fig 2-6 Chicken processing plant:: Wastewater volume and effluent pattern

Table 2-3 General wastewater analysis results

Items / Samples	Wastewater volume (m^3)	Water temperature (℃)	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	Color (degree)
General wastewater 5:35	–	13.0	6.8	170	(89)	150 (69)	320 (76)	230
6:00	7.8	13.5	6.9	140	(92)	120 (65)	220 (120)	190
7:00	12.4	16.0	6.8	410	(320)	420 (200)	630 (410)	320
8:00	11.2	16.5	6.9	570	(390)	490 (210)	800 (450)	330
9:00	12.7	16.5	6.9	470	(250)	350 (140)	500 (270)	270
10:00	15.4	15.5	6.9	340	(260)	320 (140)	510 (270)	270
11:00	13.0	17.0	6.7	350	(320)	370 (220)	650 (350)	320
12:00	14.5	16.0	6.8	400	(450)	440 (310)	760 (350)	370
13:00	11.4	18.0	6.9	420	(480)	510 (340)	870 (610)	450
14:15	16.1	13.0	6.5	280	(240)	270 (170)	590 (330)	230
15:00	10.1	10.5	6.6	210	(200)	230 (130)	430 (220)	150
16:00	12.0	14.0	6.6	230	(170)	200 (120)	390 (260)	150
17:00	2.6	15.0	6.7	210	(140)	170 (96)	380 (200)	132
Composite	139.2	–	6.8	320	(260)	300 (200)	580 (350)	210

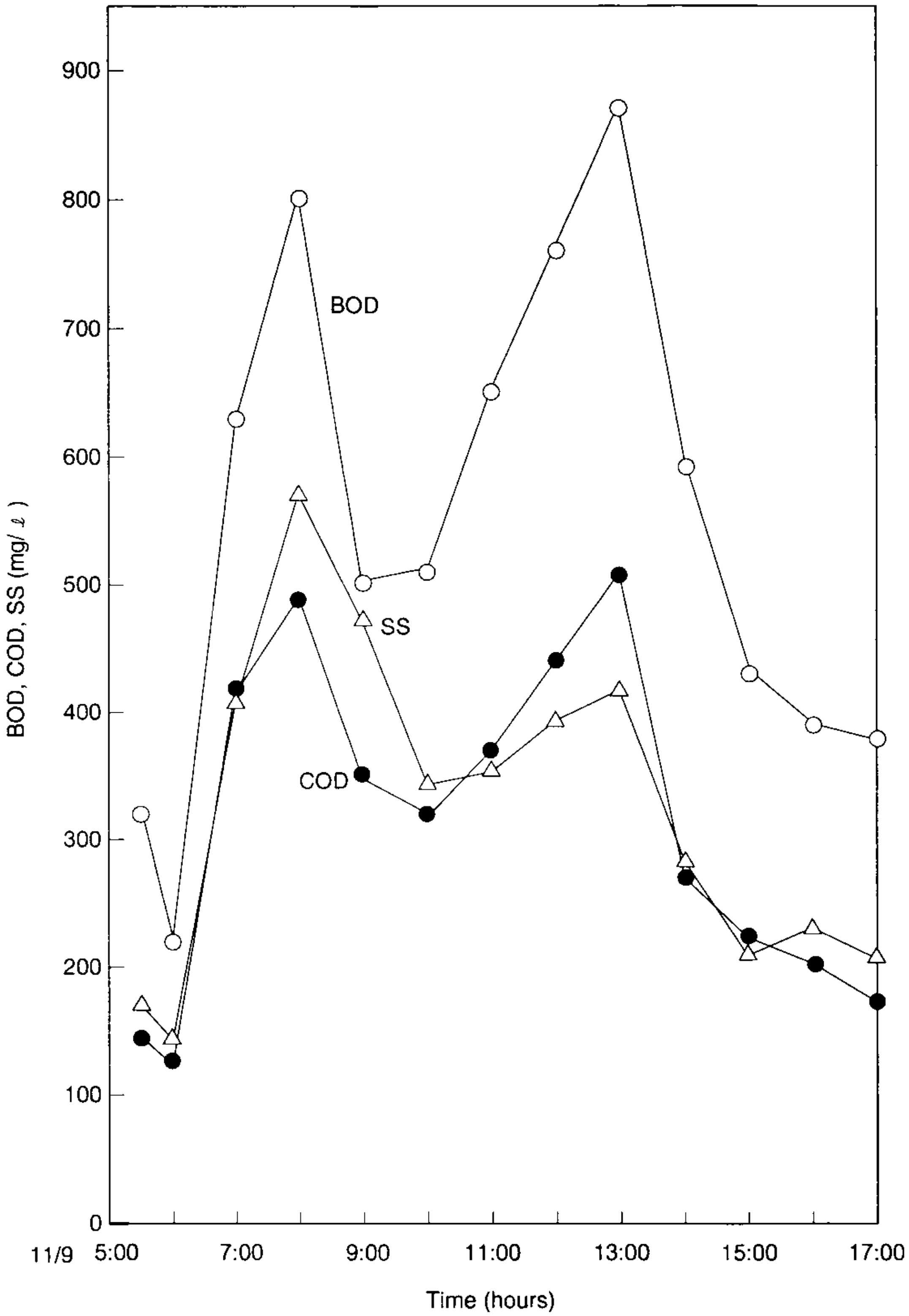


Fig 2-7 Chicken processing plant: Hourly changes in wastewater quality (General wastewater)

Table 2-4 Analysis results of wastewater from each process

Items Samples	pH (−)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	Color (degree)	K–N (mg/ℓ)	T–P (mg/ℓ)	n-hexane extracts (mg/ℓ)
General wastewater composite	6.8	320	(260)	300 (200)	580 (350)	210	115	13.3	34.0
Slaugher factory wastewater composite	7.1	350	(250)	290 (190)	380 (140)	260	122	16.5	52.0
Cutting factory wastewater composite	5.9	350	(99)	200 (78)	540 (140)	160	31	5.3	640
Hot water immersion drain	7.4	380	(1160)	1150 (1040)	1080 (840)	640	620	44.6	6.6
No.1 chiller water tank drain	6.8	88	(160)	140 (110)	230 (150)	–	49	11.4	12.0
No.2 chiller water tank drain	6.8	57	(120)	110 (80)	140 (100)	–	40	9.8	22.0
Basket washing wastewater 1	7.1	120	(56)	40 (17)	80 (30)	–	19	3.0	27.0
Basket washing wastewater 2	7.1	6	(16)	32 (12)	85 (10)	–	15	2.7	–

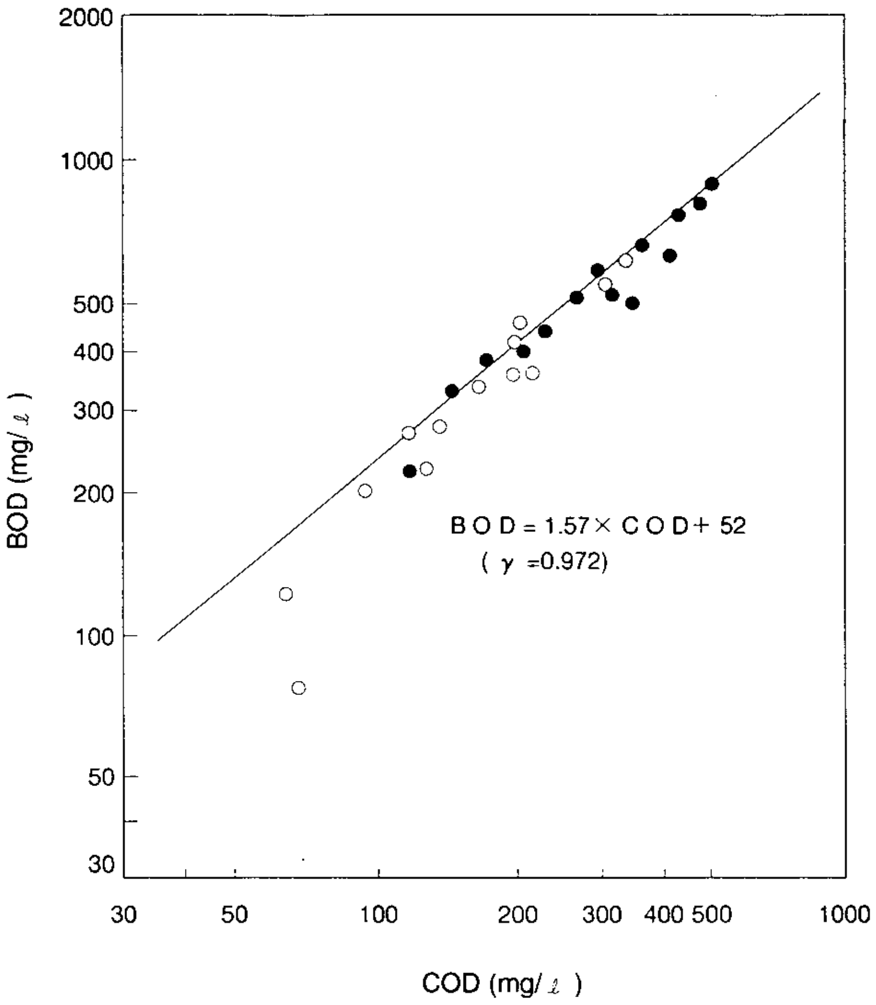


Fig 2-8 Chicken processing plant: BOD-COD correlation

2-3 Tofu manufacturing plant wastewater (Research conduted on Nov. 16th, 1983)

Tofu is one of the many soy bean products, such as miso (fermented soy bean paste), soy sauce, natto (fermented soy beans), boiled beans, etc.
In general, tofu manufacturing plants are small; about 90 % of the plants are privatly managed and the typical raw material volume is 200 - 500 bales (one bale is 60 kg).
Wastewater is generated from various processes such as water immesion, squeezing, water cooling, and cooling (including machine cooling). Usually, tofu manufacturing plant wastewater is slightly whitish and putrescible and has a special odor like soy milk.

(1) Bean curd manufacturing process and kinds of wastewater

Tofu is manufactured by extraction of soluble compounds with hot water and solidification of its protein with oil.
Tofu products include deep-fried tofu, fried tofu with vegetables and thick sliced fried tofu and dried soy bean casein is made from soy milk, an intermediate product of tofu.
To manufacture deep-fried tofu, it is sliced then dewatered and finally fried in oil. The manufacturing of this tofu is slightly different from other kinds of tofu.
Fig. 2-9 shows the manufacturing process and kinds of wastewater.
The plant at which research was conducted produces only deep fried tofu.
The raw material, soy beans, are weighed and waste, sand, gravel, straw, etc. are removed. Then after air washing, the beans are placed in the immersion tank. The immersion time differs according to the season; usually 8 - 10 hours in summer and 18 - 20 hours in winter. During this process, wastewater is discharged intermittently. The soaked beans are ground and pulverized during which a small amount of water is added; this farms a slurry. The ground soy beans are called 'go' and the finer the 'go' particles are, the more soy milk compounds can be extracted. Water is added and the 'go' is heated. In the case of manufacturing momen (cotton) tofu, the total added water volume is 10 - 11 times that of the raw material (soy beans). The heated 'go' is then filtered to separate the bean curd lees and soy milk. During filtration and separation, washing wastewater is discharged intermittently due to separator washing.
For solidification, the soy milk is held at the constant temperature of 70℃, and it is agitated while the solidification agent is added. The solidified bean curd is cut and after removing the supernatant it is transferred to a box. There are holes in the bottom and four sides of the box. A cloth is set inside and the whole thing is dewatered through compression. The wastewater discharged during compression contains a very high BOD concentration. Wastewater from the cloth and box washing is also generated.
The tofu is then sliced and fried in oil and packed for shipment, but there is almost no discharge of wastewater during this process.

(2) Wastewater volume and effluent pattern

Fig. 2-10 shows the wastewater volume and the effluent pattern of the tofu manufacturing plant.
There was a peak in the wastewater volume after 16:00 because a large volume of waster was used for floor and machine washing. In the deep-fried tofu manufacturing process, since wastewater mainly comes from compression, cloth washing and vessle washing, the wastewater volume was almost constant.
The wastewater volume on the research day was about 60 m^3.

(3) Hourly changes in wastewater quality

The wastewater quality differed according to the manufacturing process and in most cases there was a correlation between the wastewater concentration and wastewater volume.
Table 2-5 shows the hourly wastewater quality analysis results .
PH increased between 7:00 - 7:30 and 17:00 - 17:30 due to alkali discharge from caustic soda washing.
The soy bean immersion wastewater was discharged between 6:30 - 6:45 and 10:55 - 11:10.
Fig. 2-11 shows the hourly change in the quality of the wastewater from the tofu manufacturing plant.
There were organic substance peaks, BOD and COD, at 6:30 and 11:00 and they were probably due to the

immersion wastewater.
The color of the wastewater was usually light yellow probably because of the compression wastewater, and consequently the organic pollutant concentration was usually high.
A composite sample was prepared by combining the hourly samples. The analysis result shows both nitrogen and phosphorus were slightly in lack for the biological treatment; BOD : N : P = 100 : 3.5 : 0.5.

(4) Analysis result of the wastewater from each process

Table 2-6 shows the analysis result of the wastewater from each process.

(i) Immersion wastewater

For easy grinding of soy beans and extraction of soy milk compoundss, soy beans are soaked in water. The concentration of the immersion wastewater differed according to the length of immersion. In this research, the concentration of the immersion wastewater was relatively high, BOD of 5000 - 9000 mg/ ℓ .

(ii) Dewatering wastewater

Wastewater generated from the dewatering process (squeezing) had the following characteristics; low water volume was, yellowish, high viscosity, a high volume of soluble soy milk substances and high pollutant concentration. The average water quality was pH of 5-6, 9,000 - 11,000mg/ ℓ of BOD and 1,000 - 2,000 mg/ ℓ of SS. From this we could infer that the pollutant concentration was relatively high in the wastewater from the dewatering process.

(iii) Water cooling wastewater

After dewatering, the tofu was put into a water tank with running water for cooling and calcium hydroxide removal. The wastewater volume was large but the pollutant concentration was low. When manufacturing packed tofu, since the cooling water doesn't directly contact the tofu, the cooling water concentration was very low compared to momen tofu cooling wastewater.

(iv) Cleaning wastewater

After the manufacturing process, a large amount of water was used for machine and floor washing to sanitize the manufacturing facilities and factory. Tofu waste and package scraps on the floors and machines were discharged with the wastewater.

(5) Characteristics of the wastewater

In general, a large quantity of soy bean fat and protein was in the tofu manufacturing plant wastewater. We found the average BOD was high, about 4000 mg/ ℓ , and n-hexane extracts were 11 mg/ ℓ due to the high pollutant load of the dewatering wastewater.
The nutrition for BOD was in lack, BOD : N : P = 100 : 3.5 : 0.5.
Fig. 2-12 shows the correlation between BOD and COD of the tofu manufacturing plant wastewater.

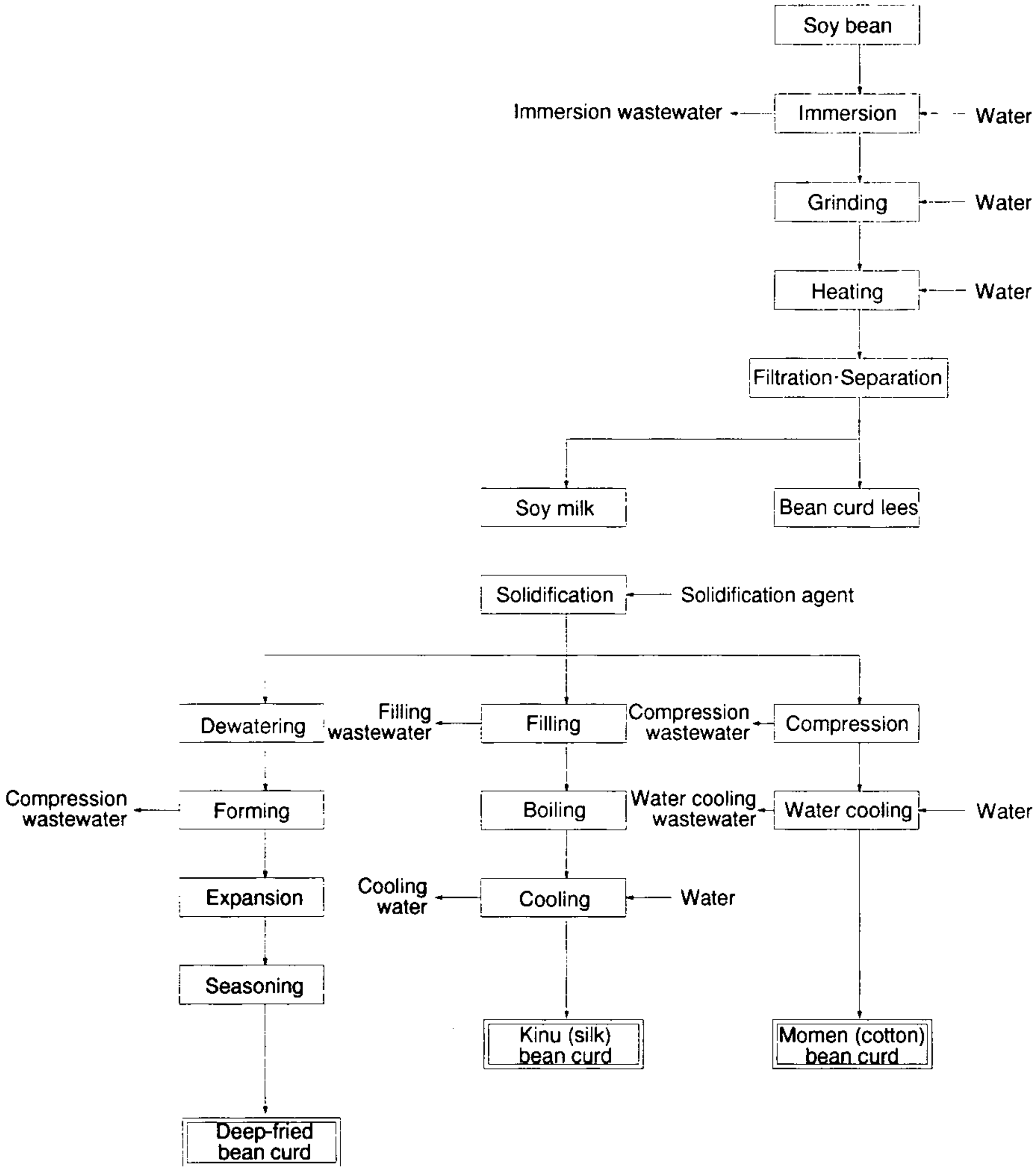


Fig 2-9 Bean curd manufacturing process and kinds of wastewater

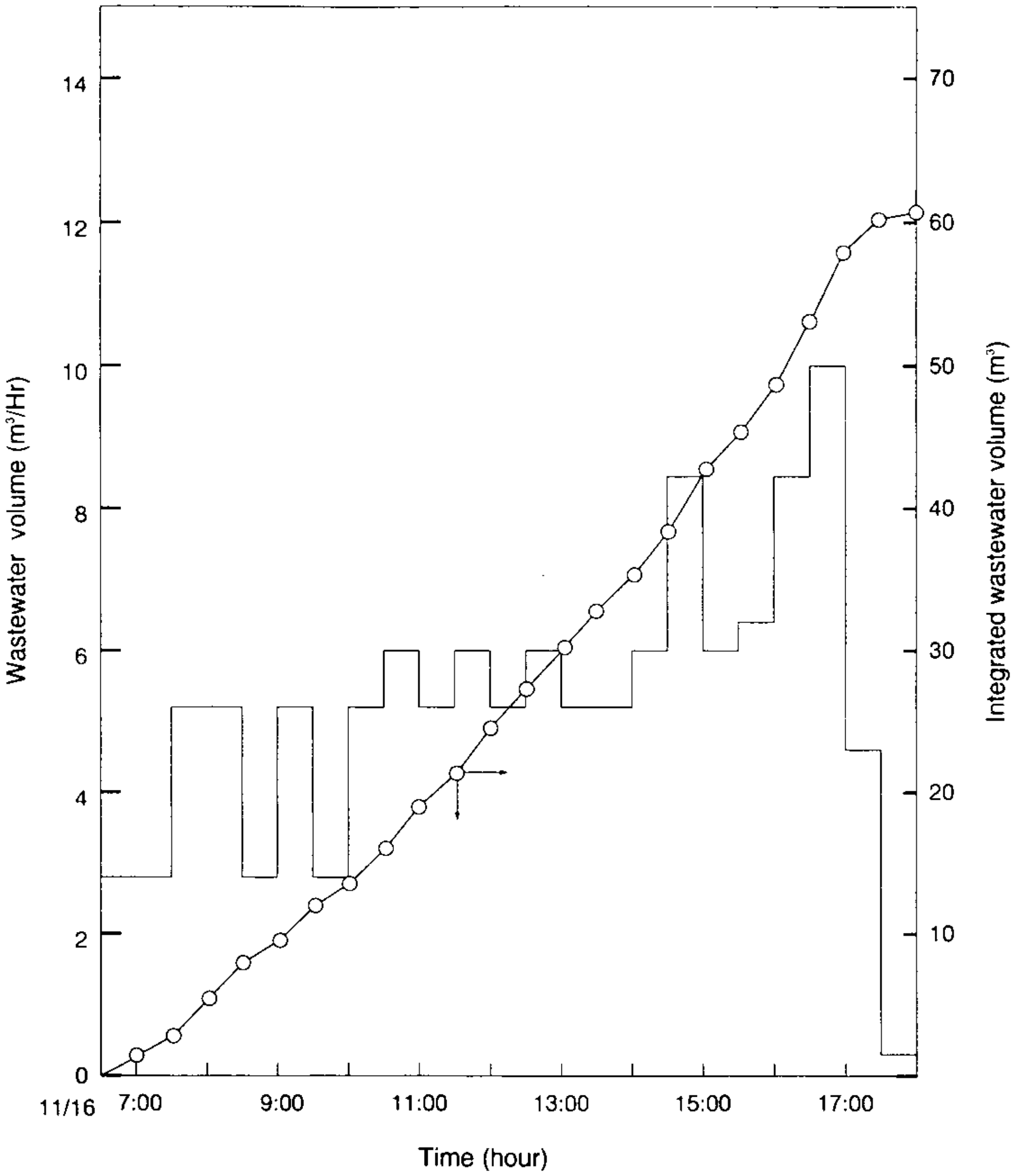


Fig 2-10 Bean curd manufacturing plant: Wastewater volume and effluent pattern

Table 2-5 General wastewater analysis results

Items Samples	Wastewater volume (m³)	pH (−)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K–N (mg/ℓ)	T–P (mg/ℓ)	n-hexane extracts (mg/ℓ)
General wastewater 6:30		4.6	610	(2240)	2710 (2440)	5620 (4630)			
7:00	1.4	11.8	540	(580)	790 (670)	1330 (1140)			
7:30	1.4	11.5	230	(410)	500 (370)	930 (720)			
8:00	2.6	4.5	530	(1450)	1910 (1710)	3110 (2650)			
9:00	4.0	4.3	860	(2030)	2750 (2460)	3640 (3350)			
10:00	4.0	4.3	610	(2010)	2710 (2360)	4380 (3240)			
11:00	5.6	4.6	180	(4480)	5170 (4880)	9170 (7830)			
12:00	5.6	4.3	550	(1900)	2510 (2210)	3850 (3070)			
13:00	5.6	4.3	500	(1980)	2700 (2380)	4200 (3180)			
14:00	5.2	4.2	490	(1550)	1990 (1730)	3040 (2440)			
15:00	7.2	4.5	410	(1340)	1670 (1500)	3120 (2210)			
16:00	6.2	9.2	420	(1690)	2260 (1990)	2950 (2560)			
17:00	9.2	11.2	370	(180)	280 (160)	500 (300)			
17:30	2.3	12.1	680	(390)	390 (280)	690 (630)			
Composite	60.3	4.6	430	(1640)	2130 (1880)	3950 (2230)	140	183	11.0

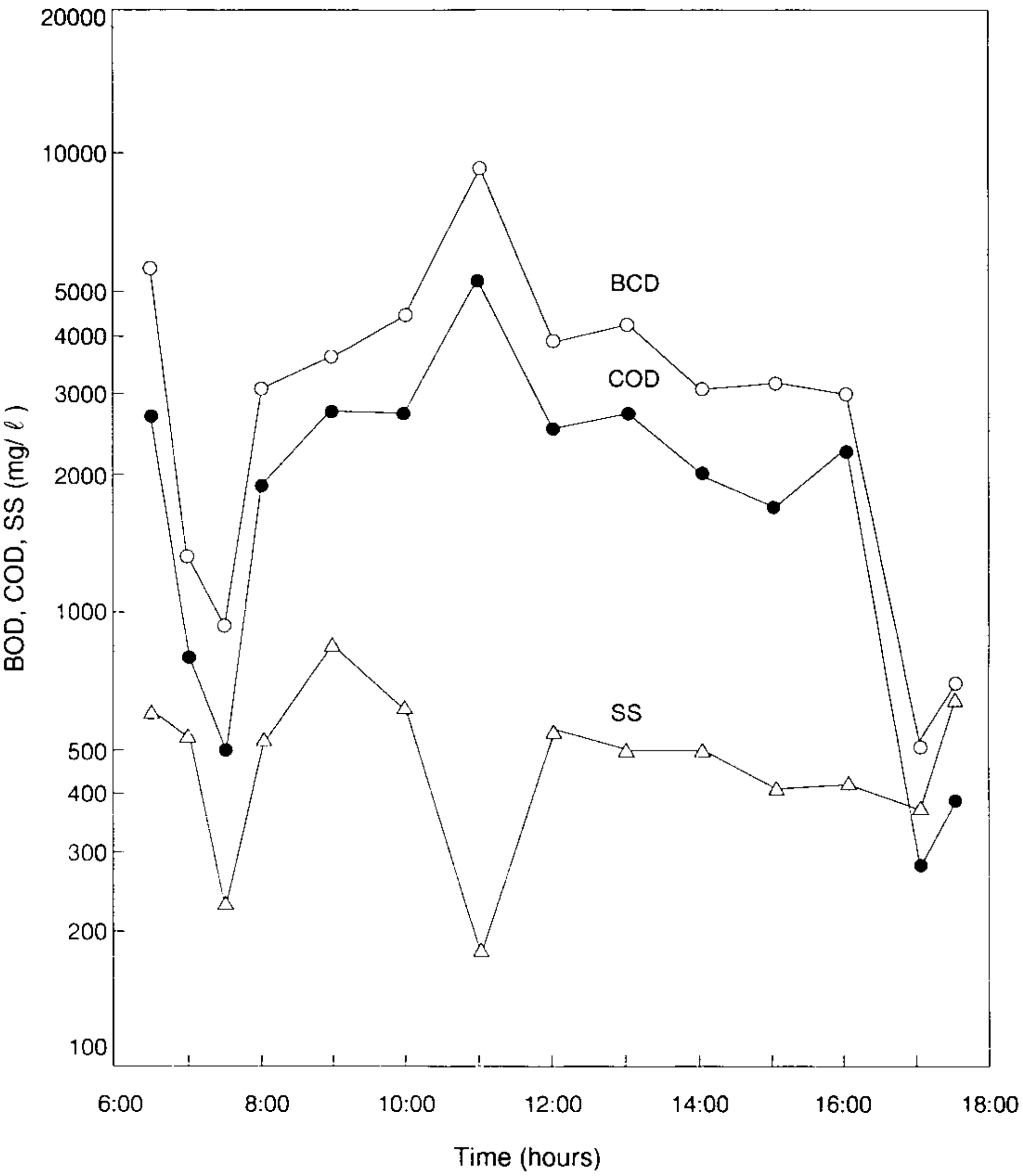


Fig 2-11 Bean curd manufacturing plant: Hourly changes in the general wastewater

Table 2-6 Wastewater analysis results of each process

Items / Samples		pH (−)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K−N (mg/ℓ)	T−P (mg/ℓ)	n-hexane extracts (mg/ℓ)
General wastewater composite		4.6	430	(1640)	2130 (1880)	3950 (2230)	140	18.3	11.0
No.1 Soy bean immersion wastewater	6:30	5.2	1020	(8980)	12300 (10700)	20300 (19500)	510	150	1.0
No.2 Soy bean immersion wastewater	11:00	5.1	830	(8860)	11200 (10300)	18400 (16500)	460	150	3.2
NaOH water tank wastewater	7:15	12.7	200	(1940)	1790 (1690)	2910 (2600)	210	13.2	14.4
Filter washing water	7:15	11.4	110	(100)	160 (120)	350 (140)	22.0	1.2	9.8
Dewatering wastewater	11:00	4.7	1650	(2240)	5760 (4740)	7500 (5630)	250	33.0	7.6
Forming machine overflow water	11:00	5.2	1010	(2250)	5670 (4940)	3270 (5790)	320	19.6	4.2
Vessel and filter washing water	16:15	7.6	69	(170)	280 (240)	310 (240)	18	1.9	4.0

Treated water of the existing facility	16:00	8.1	10	(60)	68.0 (63.0)	13 (9)	25.0	3.4	1.8

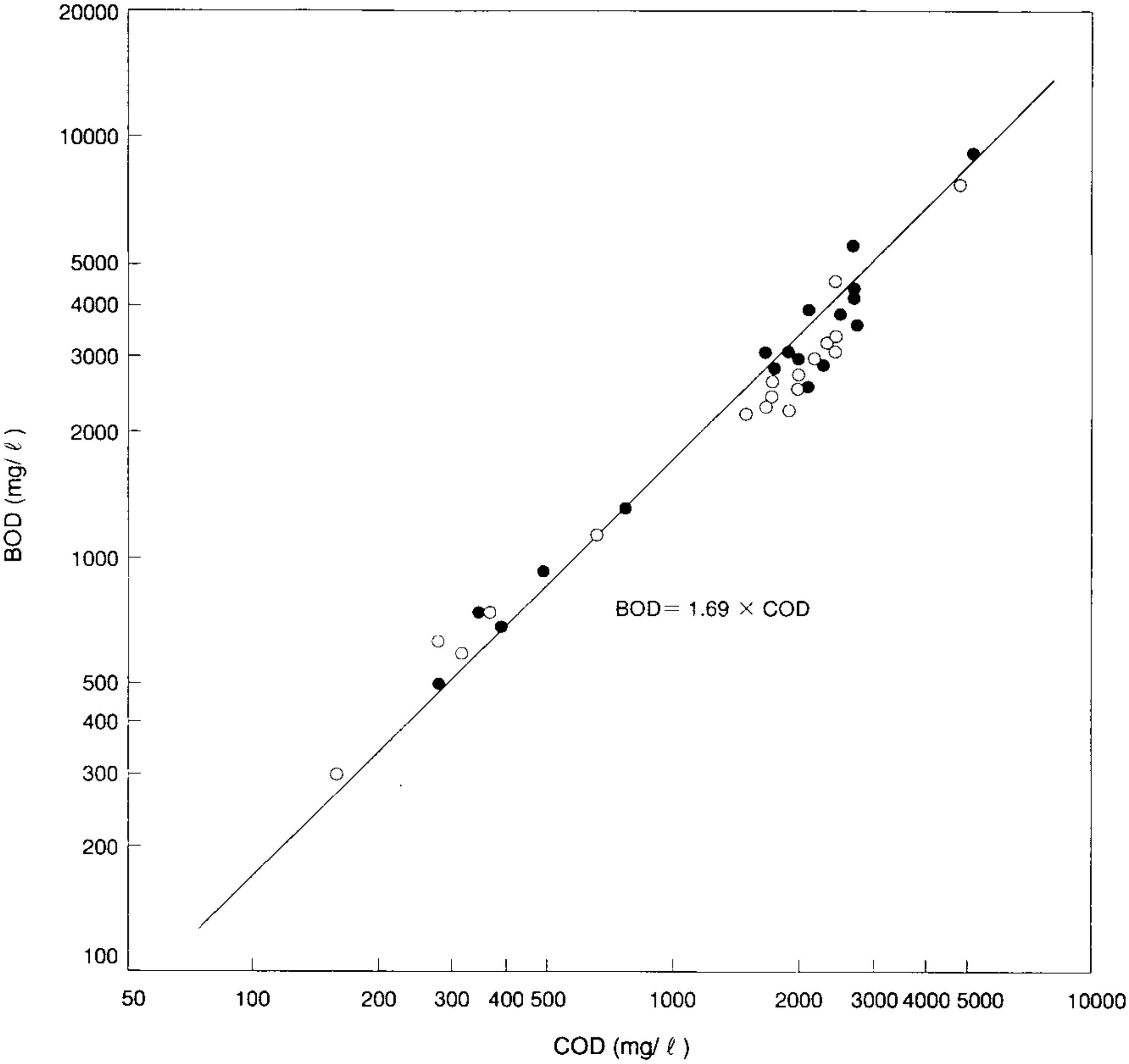


Fig 2-12 Bean curd manufacturing plant: BOD-COD correlation

2 -4 Noodle manufacturing plant wastewater (Research conducted on Nov. 16th, 1983)

There are more than 7000 noodle manufacturing enterprises and almost all are small-sized factories located in urban areas.

Since most noodle manufacturing industries are cottage industry size, no attention has been paid to the wastewater problem. However, recently large size factories such as instant noodle manufacturing plants are being established, and wastewater treatment has become necessary.

In general, the quantitiy of the wastewater discharged from noodle manufacturing plants is low but because of its high pollution load, the industry is apt to cause water contamination of rivers, lakes, etc.

(1) Noodle manufacturing process and kinds of wastewater

Fig. 2-13 shows the manufacturing process of various noodles. /Regardless of the type of the noodle manufacturing facility, the process could be classified into two stages; the first was kneading the raw materials with water and rolling; the second was drying the noodles under the appropriate conditions of temperature and humidity.

At first, salt was added to the raw material wheat flour and then water followed by sufficient kneading to increase elasticity and cohesiveness. The dough was rolled to form a noddle belt. Attension was paid to the rolling pressure, rolling time, etc.

Following that the noodle belt was cut into noodles which were boiled in a boiling vessel.

The boiled noodle was cooled down with water and packed for shipment.

The main wastewater of noodle manufacturing came from boiling, noodle washing & cooling and other washing processes. The boiling wastewater discharged after noodle boiling was the most polluted from the entire process.

Noodle washing & cooling wastewater was generated after boiling and during removal of starchy substances, and since it is generated continously, the quantity of the wastewater was large.

After finishing production, machine and factory cleaning wastewater was generated.

(2) Wastewater volume and effluent pattern

Fig. 2-14 shows the wastewater volume and the effluent pattern in the noodle manufacturing plant.

At 10:00 in the morning, there was a peak in the pollutant load of the wastewter due to boiler draining and machine washing.

At 15:00 in the afternoon, there was another peak due to floor and machine washing after finishing noodle production but the pollutant concentration was low.

The wastewater volume on the research day was about 73 m^3 but the volume increased during the cold period of winter because of an increase in noodle manufacturing.

(3) Hourly changes in wastewater quality

Table 2-7 shows the result of the hourly water quality analysis.

Noodle manufacturing starts early in the morning and usually finishes in the morning except on special occasions. The wastewater is therefore mainly generated in the morning and in general 85 % is from noodle washing & cooling and the rest 15 % is from boiling vessel washing etc.

On the research day, noodle manufacturing was finished in the morning as usual.

There was a peak in organic pollutants due to boiler vessel draining between 9:40 and 10:30.

Fig. 2-15 shows the hourly changes in the general wastewater from the noodle manufacturing plant. The wastewater was slightly acidic during the discharge of the boiler due to the pH of the hot water.

A composite sample was prepared by combining the hourly samples and was analyzed as general wastewater. The result shows that the ratio of nitrogen and phosphorus are sufficient, BOD : N : P = 100 : 4.3 : 0.5, but in lack in the boiling wastewater which is the main polluntion source.

(4) Analysis result of the wastewater from each process

Table 2-8 shows the analysis results of the wastewater from each process.

(i) Boiler wastewater

The quantity of wastewater generated from the noodle boiling process, was law but it was the most polluted.

Buckets containing noodles were immersed in hot water and boiled while being strongly vibrated and thus wheat compounds were dissolved into the wastewater, causing a high pollution load. /The water quality of the process is shown in Table 2-8, (water temperature of 90℃).

(ii) Noodle washing & cooling wastewater

A large quantity of water was used for cooling the boiled noodles and for removing starchy compounds on the surface of the noodle. The lower the water temperature, the better the quality and preservation. The pollutant concentration of the wastewater was very low compared to that from the boilier but it contained a great quantity of solids.

(5) Characteristics of the wastewater

In general, 85 % of the wastewater was from noodle washing but the pollutatn load was highest from the boiler, which accounted for 60 % of the total. Wastewater from the boiler was discharged at high temperature and high pollutant concentration simultanously with noodle washing wastewater at low temperature and low concentration. The main pollutant in the wastewater was starch.

Fig. 2-16 shows the correlation between BOD and COD of the noodle manufacturing plant wastewater.

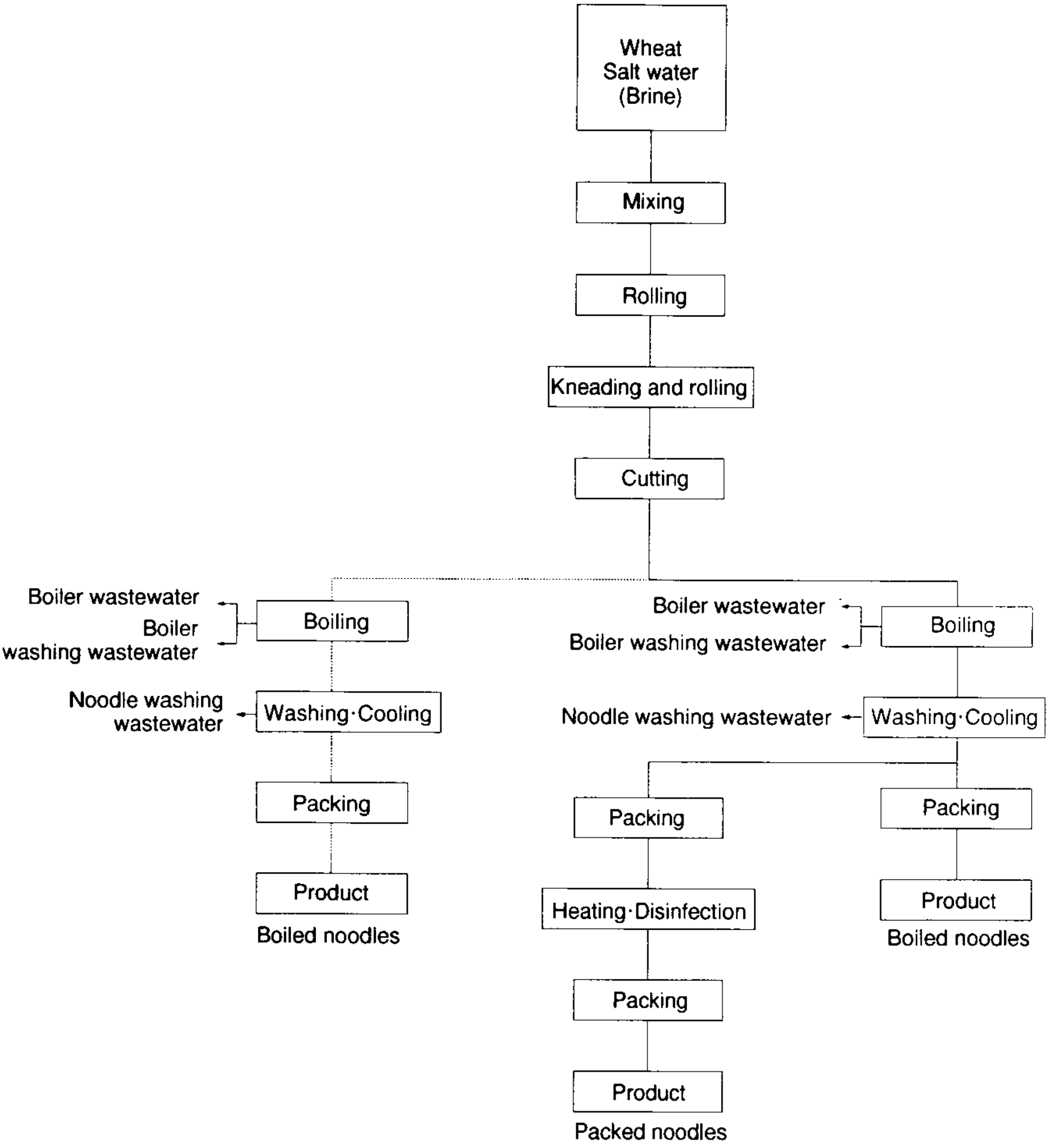


Fig 2-13 Noodle manufacturing process and kinds of wastewater

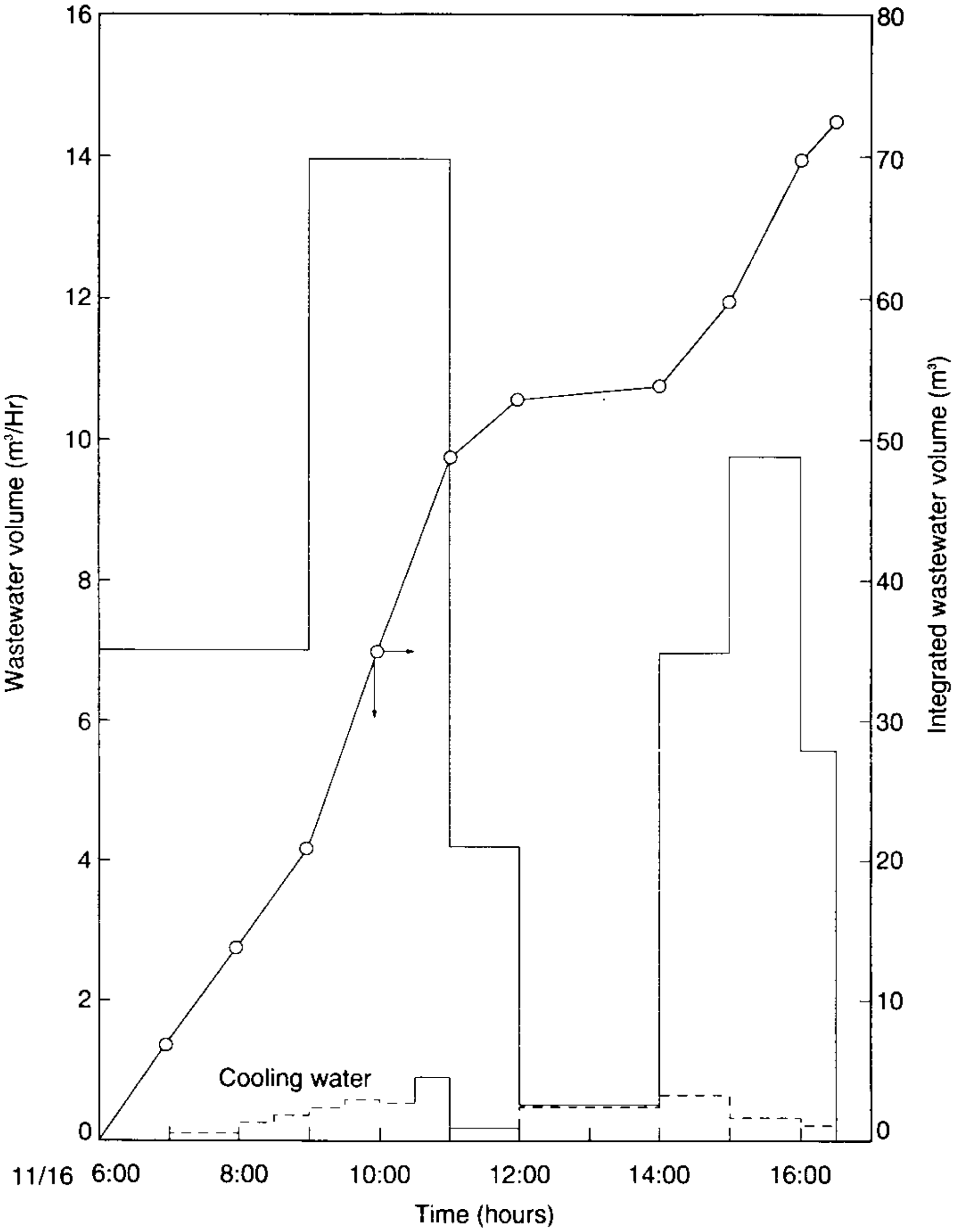


Fig 2-14 Noodle manufacturing plant: Wastewater volume and effluent pattern

Table 2-7 General wastewater analysis result

Items / Samples	Wastewater volume (m³)	pH (-)	SS (mg/ ℓ)	TOC (mg/ ℓ)	COD (mg/ ℓ)	BOD (mg/ ℓ)	K–N (mg/ ℓ)	T–P (mg/ ℓ)	n-hexane extracts (mg/ ℓ)
General wastewater 6:10		7.4	41	(27)	28 (18)	31 (26)			
7:00	7.0	7.3	46	(26)	29 (16)	33 (23)			
8:00	7.0	7.0	440	(51)	120 (30)	210 (73)			
9:00	7.0	7.9	56	(73)	140 (100)	150 (120)			
9:40	14.0	5.9	190	(330)	560 (450)	690 (590)			
10:00		5.1	230	(610)	1050 (860)	1200 (950)			
10:30	14.0	5.4	210	(590)	980 (900)	1130 (980)			
11:00		6.9	68	(130)	240 (180)	280 (210)			
11:45	4.2	7.7	56	(30)	45 (24)	72 (35)			
14:00	7.0	8.4	135	(120)	270 (190)	310 (200)			
14:30		6.9	86	(72)	75 (67)	160 (130)			
15:00		6.7	98	(70)	96 (59)	170 (130)			
16:00	9.8	7.1	38	(45)	63 (44)	80 (69)			
16:30	2.8	7.7	29	(38)	58 (40)	76 (63)			
Composite	72.8	6.4	130	(190)	270 (230)	360 (320)	15.6	1.9	3.4

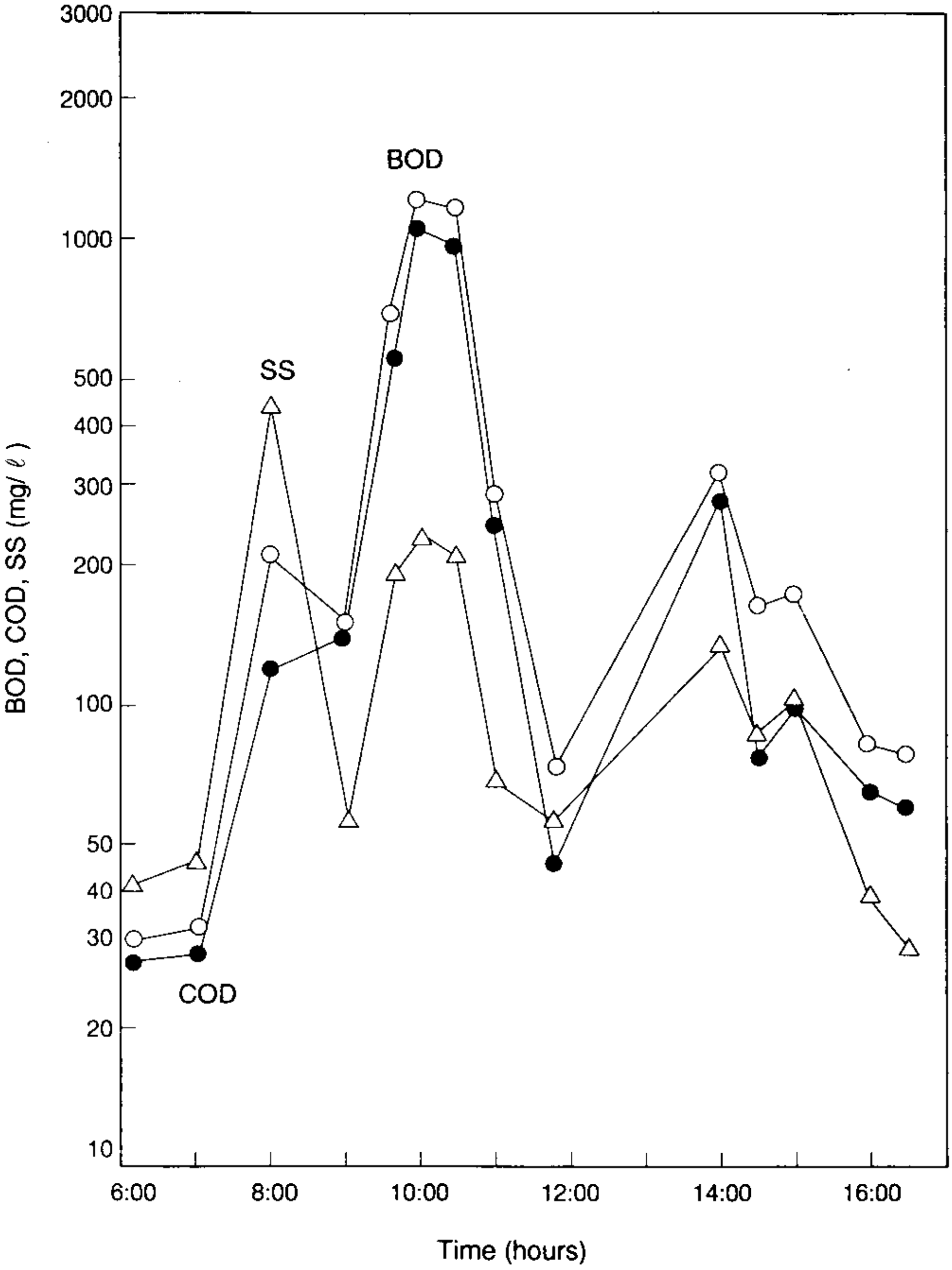


Fig 2-15 Noodle manufacturing plant: Hourly change in general wastewater

Table 2-8 Wastewater analysis results of each process

Items Samples	pH (−)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K−N (mg/ℓ)	T−P (mg/ℓ)	n-hexane extracts (mg/ℓ)
General wastewater composite	6.4	130	(190)	270 (230)	360 (320)	15.6	1.9	3.4
Wheat noodle boiler drain (upper)	5.9	1680	(2160)	3940 (3270)	4100 (3630)	64.0	2.4	0.4
Wheat noodle boilier drain (lower)	5.4	500	(920)	1590 (1320)	1700 (1400)	30.0	4.7	−
Buckwheat noodle boiler drain (upper)	5.0	1480	(1320)	2280 (1790)	2560 (2100)	65.5	20.0	0.3
Buckwheat noodle boiler drain (lower)	5.0	910	(890)	1910 (1100)	2060 (1400)	59.0	17.2	−
Chinese noodle steam condensed water	9.0	310	(280)	450 (420)	600 (470)	13.0	1.6	0.8
Chinese noodle washing water	8.5	150	(120)	250 (160)	270 (150)	8.9	1.5	−

Biologically treated water of the existing facility	7.6	4	(13)	7 (6)	3 (1)	1.5	1.2	0.3
Filtration treated water of the existing facility	7.7	4	(12)	6 (5)	2 (1)	1.5	0.9	0.2

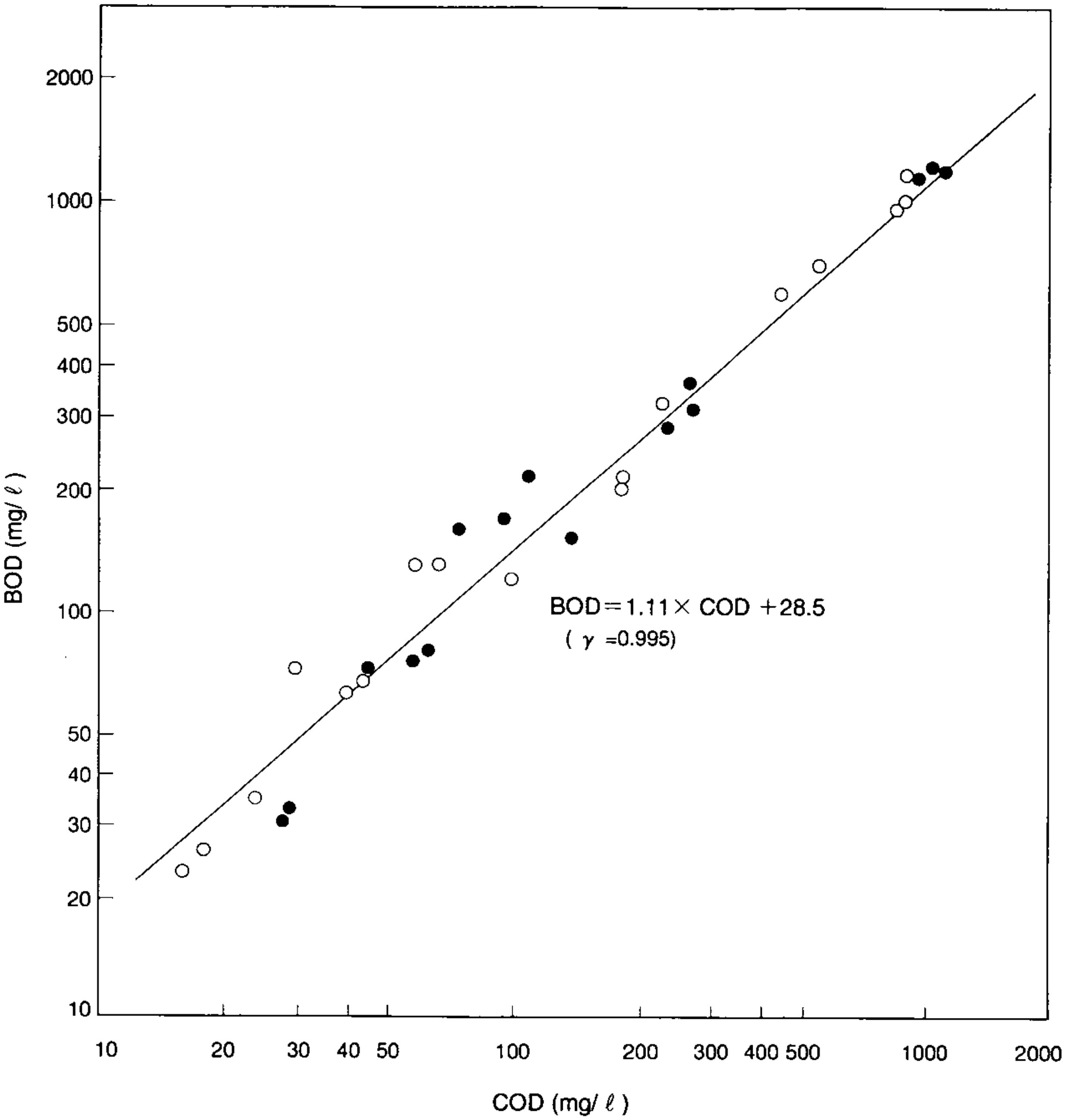


Fig 2-16 Noodle manufacturing plant: BOD-COD correlation

2-5 Conclusion

Research was conducted to study quantity and quality of wastewater from four food plants (soy sauce, chicken processing, tofu and noodle).
Following is the summary of the results.

(1) The main wastewater from the soy sauce manufacturing plant came from various kinds of washing during the manufacturing process (research conducted on Nov. 9th, 1983). Since the work process varied daily or even weekly, the quality and quantity of the wastewater also varied.
The wastewater quantity on the research day was 35 m^3 and BOD concentration in the general wastewater was 770 mg/ ℓ .
Nitrogen and phosphorus ratios in the wastewater were excessive; BOD : N : P = 100 : 8 : 1.6.

(2) The chicken processing plant wastewater came from various kinds of washing and draining arising from blood letting, plucking and cutting. The main contaminants were blood and body fluid.
The daily work schedule was relatively unvaring and the water quality and quantity were stable.
The wastewater volume on the research day was 140 m^3 and BOD concentration in the general wastewater was 580 mg/ ℓ . Nitrogen and phosphorus ratios in the wastewater were relatively high; BOD : N : P = 100 : 20 : 2.3, (Nov. 9th, 1983).

(3) Since deep-fried bean curd was the main product at the researched bean curd manufacturing plant, the main wastewaters were from soaking, dewatering (squeezing) and various kinds of washing.
The daily work schedule was fixed and there were peaks in quantity due to floor and machine washing and a peak in quality due to the water used for soaking.
The wastewater volume on the research day (Nov. 16th, 1983) was 60 m^3 and the pollutant load was high, 3950 mg/ ℓ of BOD.
Nitrogen and phosphorus ratios in the wastewater were in lack; BOD : N : P = 100 : 3.5 : 0.5.

(4) The main wastewater from the noodle manufacturing plant came from boiling, noodle washing & cooling and washing. The main pollutant source was the boiler wastewater.
Most of work was conducted in the morning and there was a peak in the water quantity and quality caused by draining the boiler.
The wastewater volume on the research day (Nov. 16th, 1983) was 73 m^3 and BOD concentration in the general wastewater was 360 mg/ ℓ .
Nitrogen and phosphorus ratios of the wastewater were higher than other researched data; BOD : N : P = 100 : 4.3 : 0.5.

3. Study on existing wastewater treatment facilities

The quality of the water from the existing wastewater treatment plants of the four food plants (soy sauce, chicken processing, rofu and noodle) was analyzed to understand the function and treatment efficiency of the existing facilities and to collect basic data for comparison with the controlled aeration activated sludge method.

3-1 Soy sauce manufacturing plant

It was clear, from the study of the manufacturing process, the main wastewater was from washing. The quantity of highly polluted wastewater was small and the general wastewater contained organic substances in low concetration.

The main treatment method was biological such as activated sludge , oxidation pond, rotating biological contactor, and trickling filter. Simple methods, for example the coagulation sedimentation method, could also have been applied.

(1) Outline of the existing wastewater treatment facility

The wastewater of the plant was treated using the trickling filter method.

The wastewater was collected in an untreated water tank and sent to an adjusting tank after solids were removed by vibrating filter.

A regulated amount of wastewater stored in the adjusting tank was then sent to a circulating water tank and then treated biologically using a trickling filter for removal of organic substances such as BOD and COD.

The trickling filter media of this plant was plastic, consequently high treatment efficiency was expected.

Next the biologically treated water was sent to a dissolved-air flotation tank for removal of SS including exfoliated sludge and finally discharged after disinfection with sodium hypochlorite.

Fig. 3-1 shows the flow diagram of the treatment facility.

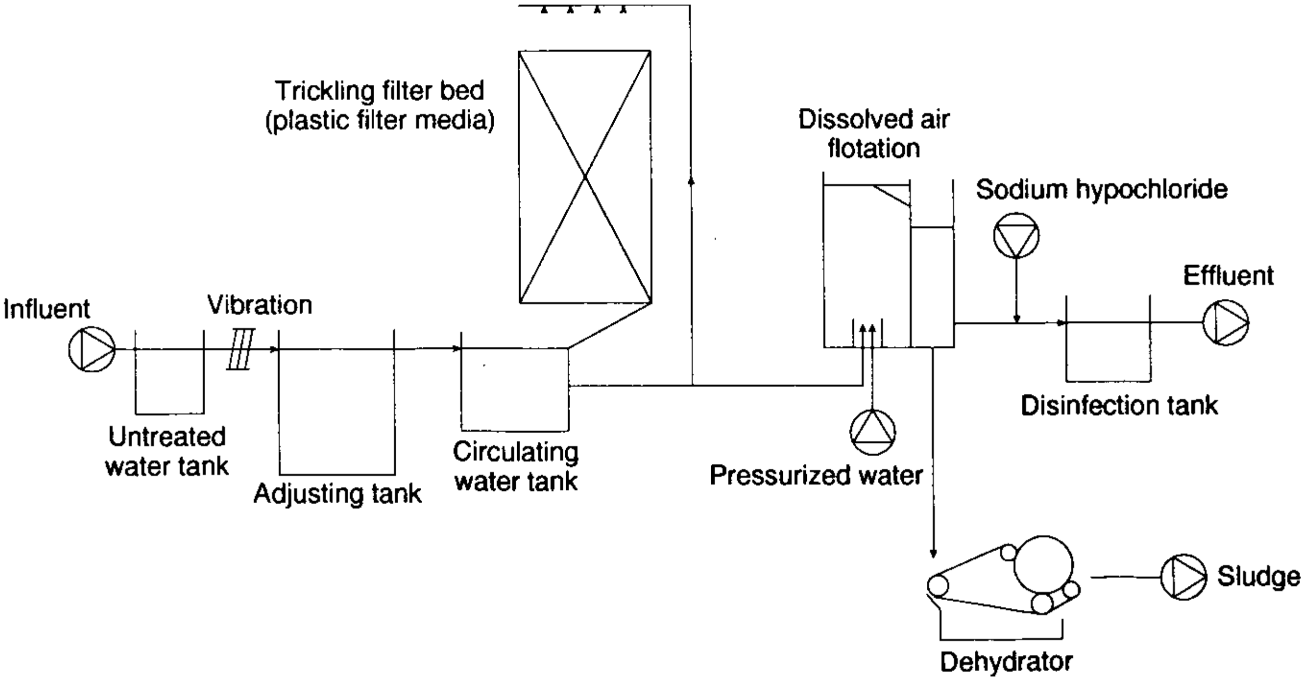


Fig 3-1 Flow diagram of the existing wastewater treatment facility of the soy sauce manufacturing plant

(2) Untreated water properties and treated water quality

The untreated and treated water of the existing wastewater treatment facility of the soy sauce manufacturing plant were analyzed to understand their properties.

In principle, at 3:00 in the afternoon, untreated water samples were taken at the outlet of the adjusting tank and treated water samples from the outlet of the dissolved-air flotation tank.

The water quality was analyzed according to the JIS K 0102 industrial effluent test and sewage testing methods as shown in Table 3-1.

However, color was analyzed by absorption spectrophotometry following the platinum cobalt standard solution method used for testing drinking water. A wave length of 370 nm using 20 mm cells was used and a calibration curve was prepared using platinum cobalt color standard solutions.

Analytical methods are shown in table 3.1.

Table 3.1 Analytical methods

Measurement items	Measurement methods
pH	Glass electrade
SS	Glass fiber filter
COD	Acid 100℃ $KMnO_4$
TOC	Combution CO_2
BOD	General dilution
Color	Platinum cobalt standard solution
T-N	Integration of nitrogens
Organic N	Kjeldahl
NH_4^+ − N	Distillation titration
NO_2^- − N	Naphthylethylene-diamine
NO_3^- − N	Brucine/sulfanilic acid
T-P	Acid decomposition molybdenum blue
Cl	Silver nitrate titration
M-alkalinity	Titration method pH5

Table 3-2 shows the untreated water quality analysis results and Table 3-3 shows the treated water quality analysis result.

The untreated water differed according to the manufacturing process on the sampling day.

On the days when the boiler was discharged, for example the 16th and 23rd of Dec., BOD concentration was high and chlorine low.

When soy sauce was in the wastewater due to washing of the unrefined tank etc. for example on Jan. 13th, BOD, choline ions and color were all high.

Average water quality from Dec. 12th to Jan. 31st was 400 mg/ ℓ of BOD, 133 mg/ ℓ of nitrogen, 17.4 mg/ ℓ of phoshporus, BOD : N : P = 100 : 9.5 : 1.2. This was higher than the ordinary daily average.

The treated water quality of the existing facility worsened because of the low winter temperature causing sludge exfoliation influencing the treatment efficiency.

The efficiency of BOD removal was about 80 % and this corresponded to the efficincy of TOC removal.

Although the average efficiency of nitrogen removal was about 70 %, about 40 mg/ ℓ of nitrogen compounds remained in the treated water.

About 70 % of the phosphorus could be removed but about 6 mg/ ℓ of phosphorus compounds remained in the treated water.

The nitrogen and phosphorus removal efficiencies per unit of removed BOD from the average treated water were BOD : N : P = 100 : 8.2 : 1.0. The nitrogen removal ratio was slightly high but this was not due to nitrification and denitrification.

(3) Problems

Maintenance of the trickling filter is relatively easy but if the sludge is exfoliated from the filter media at low winter temperatures like on the research days, it requires time for recovery, which means the treatment efficiency of the facility is drastically lowered.

Although SS load in the wastewater was high, the vibrating screen could catch coarse solids but not fine solids, and thus it was not effective in decreasing the BOD load. /About a 36 % decrease in BOD load can be expected through the appropriate selection of screen.

Table 3-2 Untreated water quality of the soy sauce manufacturing plant wastewater

Date	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	T-P (mg/ℓ)	$C\ell^-$ (mg/ℓ)	Color (degree)
Dec.12	6.69	460	250	303 (131)	870 (530)	66.4	10.6	213	194
14	6.50	410	283	409 (249)	1070 (640)	67.9	10.8	169	
16	6.19	1010	540	1540 (667)	2710 (1150)	115	16.1	110	
19	6.75	580	879	1110 (903)	1830 (1580)	166	21.9	946	
21	6.89	140	273	299 (190)	520 (350)	56.6	10.3	221	
23	6.68	840	863	1480 (990)	2080 (1470)	185	22.7	118	
26	5.98	2430	2070	3390 (2360)		417	68.0	1470	
Jan.9	6.90	940	610	1170 (750)	2780 (1640)	162	16.2	810	171
11	7.55	135	162	210 (162)	460 (370)	37.9	5.3	335	103
13	6.32	2830	1580	370 (1640)	3220 (2790)	377	41.7	1780	679
17	6.90	320	190	356 (199)	620 (410)	46.0	5.5	169	86.5
20	6.95	435	490	714 (500)	1330 (1080)	113	11.8	541	229
24	6.68	380	305	518 (336)	820 (520)	72.5	6.3	177	142
27	6.81	230	137	258 (173)	400 (240)	27.1	1.4		90.0
31	6.75	310	415	514 (385)	850 (640)	80.1	12.3	221	148
n	15	15	15	15	14	15	15	14	9
$\bar{x}$	6.70	760	600	980 (640)	1400 (960)	133	17.4	520	205
σ_{n-1}	0.37	810	550	910 (630)	960 (710)	118	17.4	540	184

Table 3-3 Treated water quality of the existing treatment facility of the soy sauce manufacturing plant

Date	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	NO_2-N (mg/ℓ)	NO_3-N (mg/ℓ)	T-P (mg/ℓ)	$C\ell^-$ (mg/ℓ)	Color (degree)
Dec.12	7.21	252	62	151 (529)	225 (54.0)	41.8	<0.01	0.05	6.8	154	181
14	7.49	130	84.4	139 (82.4)	260 (120)	38.1	<0.01	0.09	6.2	280	
16	7.40	122	100	129 (79.6)	144 (77)	35.1	0.01	0.07	5.5	213	
19	7.38	126	126	142 (101)	220 (85)	40.5	0.01	0.02	6.0	195	
21	7.32	100	86.5	100 (66.9)	120 (56)	19.6	0.01	0.03	4.7	121	
23	7.32	222	123	174 (88.2)	370 (135)	56.4	0.01	0.04	10.6	243	
26	7.55	106	60.1	92.7 (54.1)			0.02	0.04		99.4	
Jan.9	7.45	129	71	122 (67.7)	250 (150)	32.0	0.02	0.03	3.4	155	174
11	7.40	174	190	242 (144)	570 (350)	70.3	0.02	0.03	7.8	769	215
13	7.42	174	115	159 (99.6)	220 (150)	35.3	0.02	0.03	5.5	162	197
17	7.70	116	71	116 (71.5)	193 (115)	36.3	0.04	0.07	5.4	202	100
20	7.50	128	215	260 (198)	460 (370)	57.2	0.02	0.03	6.2	316	181
24	7.47	138	88	156 (110)	200 (120)	39.1	0.03	0.04	3.2	265	265
27											
31	7.82	830	72	277 (82.0)	600 (81)		0.01	0.02		261	
n	14	14	14	14	13	12	14	14	12	14	8
$\bar{x}$	7.46	196	105	161 (92.7)	295 (143)	41.8	0.02	0.04	5.9	245	195
σ_{n-1}	0.16	188	47	58 (38.6)	156 (101)	13.4	0.01	0.02	2.0	163	50

3-2 Chicken processing plant

The wastewater from the chicken processing plant was reddish due to blood letting, etc.
Due to an upgrading in the effluent standards, the activated sludge method, effective in removeing blood coloration, was the main treatment method.

(1) Outline of the existing wastewater treatment facility

Basic wastewater treatment was with the activated sludge method at this plant.
Wastewater collected in an untreated water tank was sent to a vertical bar screen by pump and stored in an adjusting tank after removal of solids such as feathers and meat.
A regulated amount of wastewater flowed to the activated sludge treatment facility, and air was blown into the aeration tank by blower.
The facility at the plant was a fixed bed activated sludge method which included a small amount of filter media set in the aeration tank.
The supernatant from the settling tank was disinfected with chlorine and the treated water discharged.
The settled activated sludge was returned to the aeration tank by air lift pump.
Fig. 3-2 shows the flow diagram of the treatement facility.

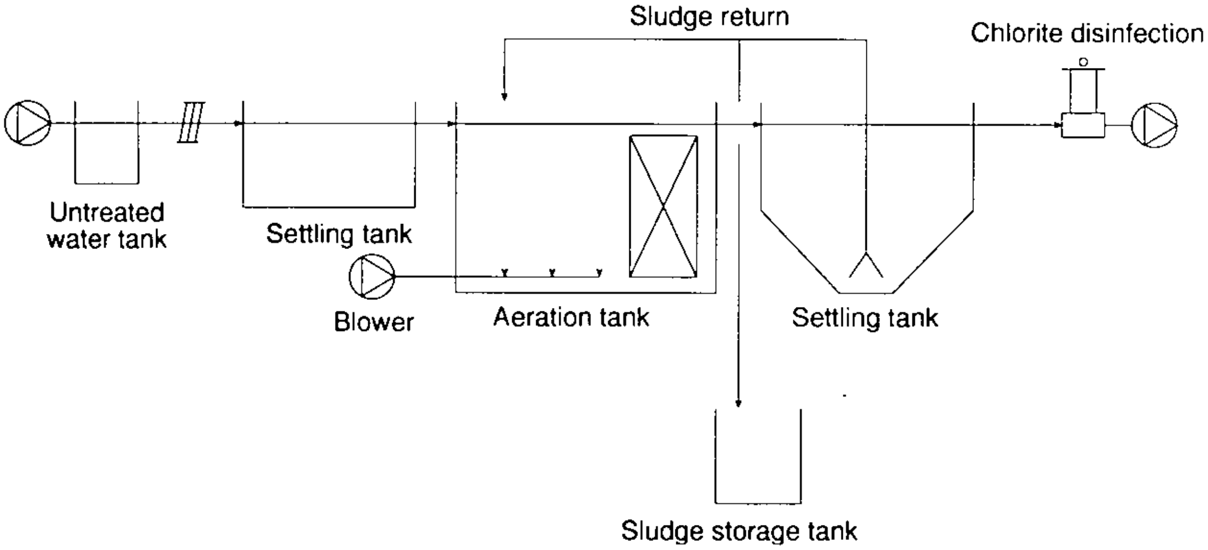


Fig 3-2 Flow diagram of the existing wastewater treatment facility of the chicken processing plant

(2) Untreated water properties and treated water quality

The quality of the untreated and treated water of the existing falicity at the chicken processing plant was analyzed to understand the properties of the untreated and treated water.

In principle, untreated water samples were taken at the outlet of the adjusting tank and treated water samples were at the overflow of the settling tank around 12:00 when the slaughtering process (blood letting) finished.

The water quality analysis methods are shown in Table 3-1.

Table 3-4 shows the untreated water quality analysis result and Table 3-5 shows the treated water quality analysis result.

The quality of the influent was stable since the manufacturing process followed a schedule.

Average water quality from Dec. 12th to Jan. 31st was 900 mg/ ℓ of BOD, 163 mg/ ℓ of nitrogen, 17.3 mg/ ℓ of phosphorus, BOD : N : P = 100 : 18 : 1.9.

Attention needed to be paid to the behavior of nitrogen and phosphorus in the treated water because nitrogen and phosphorus concentrations were relatively high in this treatment facility which utilized the activated sludge method.

Looking at the treated water quality of the existing treatment facility shown in Table 3-5, the reaction proceeded to the nitrification stage due to the excessive nitrogen compounds. When ATU was added to control nitrification, BOD was higher with respect to COD and TOC (figures in < > on 24th and 31st of Jan.), than on no addition.

About 50 % of the nitrogen compounds in the treated water was oxidized to nitrite and nitrate.

On average, 80 % of nitrogen and 60 % of phosphorus compounds in the treated water were removed and compared to the removal ratio of BOD, the high efficiency of nitrogen removal was well worth noting; BOD : N : P = 100 : 15 : 1.2.

This was due to the operation of the treatment facility; since wastewater inflow was only from 5:30 to 17:00 and the adjusting tank was not fully utilized, there was no influent to the aeration tank at night causing the nitrification reaction to proceed under batch conditions.

On the other hand, in the morning wastewater with relatively high concentration was sent to the treatment facility so that DO in the aeration tank decreased and as a result denitrification proceeded in some portions.

The retention time in the aeration tank of more than one day also probably lead to a high nitrogen removal efficiency.

However the abnormal operation condition caused problems such as sludge flotation and chronic bulking due to denitrification in the settling tank.

(3) Problems

Significant water contamination problems were frequent bulking in the aeration tank in which filter media was set as the fixed bed activated sludge method and carry over of sludge to the settling tank.

Since nitrogen and phosphorus were excessive in the wastewater, the activated sludge method was not sufficient for solving the problems, such as floating sludge due to denitrification in the settling tank after nitrification and carry over of untreated phosphorus compounds.

Table 3-4 Untreated water quality of the chicken processing plant wastewater

Date	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	T-P (mg/ℓ)	$\mathrm{C}\ell^{-}$ (mg/ℓ)	Color (degree)
Dec.12	6.79	170	384	368 (220)	990 (700)	148	14.9		296
14	6.91	396	435	460 (312)	1500 (940)	185	18.9		
16	6.81	240	282	297 (224)	730 (420)	118	15.3		
19	6.92	476	354	420 (274)	770 (540)	173	20.7		
21	6.89	408	387	425 (286)	680 (500)	159	21.6		
23	6.73	392	309	363 (230)	810 (550)	142	20.8		
26	6.70	886	394	475 (318)		175	16.6		
Jan.9	6.85	330	278	332 (209)	1080 (667)	141	13.5		265
11	6.82	376	291	345 (245)	950 (580)	151	17.7		306
13	6.94	368	320	365 (254)	600 (450)	169	13.8		235
17	7.08	292	440	451 (369)	1030 (860)	176	17.3		310
20	7.10	300	403	438 (341)	930 (810)	180	18.6		541
24	6.91	400	397	454 (330)	850 (640)	181	14.8		347
27	6.86	412	394	461 (323)	890 (660)	165	17.3		285
31	6.93	384	490	489 (351)	850 (600)	178	17.3		337
n	15	15	15	15	14	15	15		9
$\bar{x}$	6.88	389	371	410 (286)	900 (640)	163	17.3		325
σ_{n-1}	0.11	157	63	59 (53)	220 (150)	19	2.5		88

Table 3-5 Treated water quality of the existing wastewater treatment facility of the chicken processing plant

Date	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	NO_2-N (mg/ℓ)	NO_3-N (mg/ℓ)	T-P (mg/ℓ)	$C\ell^-$ (mg/ℓ)	Color (degree)
Dec.12	5.98	29.0	24	38.5	52.0	12.4	1.62	2.14	9.22		57
14	6.78	6	20.6	24.9	35	13.2	1.43	20.9	7.47		
16	6.38	5	19.9	24.6	14	6.8	1.05	22.3	7.31		
19	6.00	35	21.4	30.7	28	6.4	0.74	24.1	10.8		
21	6.51	12	15.5	20.0	20	6.7	2.08	22.3	6.71		
23	7.29	6	27.0	20.5	53	29.8	0.64	2.55	6.74		
26	7.15	13	17.6	22.8			2.47	10.2			
Jan.9	4.92	27	13	25.6	48	8.9	2.06	29.7	6.8		28
11	7.19	13	11	19.7	52	21.6	3.40	3.82	6.3		26
13	7.31	11	17	20.6	55	28.3	2.04	1.78	4.3		30
17	5.91	64	19	36.6	62.9	11.9	9.96	9.94	6.1		33
20	7.12	10	18	33.6	104	32.8	10.9	3.18	5.1		36
24	7.00	18	17	39.7	83 〈12〉	23.7	12.8	2.18	4.8		30
27											
31	7.01	16	24	41.8	24 〈12〉		7.55	0.46			34
n	14	14	14	14	13	12	14	1.4	12		8
$\bar{x}$	6.61	19	19	28.5	49	16.9	4.2	11.1	6.8		34
σ_{n-1}	0.70	16	4	8.1	25	9.8	4.2	10.4	1.8		10

3-3 Tofu manufacturing plant

In general, a large amount of soy bean oil and protein was in the wastewater of the tofu manufacturing plant and relatively high BOD, SS and oil were a problem; the average wastewater quality was 1000mg/ ℓ of BOD, 800 mg/ ℓ of SS and 100 - 200 mg/ ℓ of n-hexane extracts. The pollutant load of the dewatering wastewater from the compression process was high, and the quantity of wastewater from water cooling was large.

Biological treatment is effective for treatment of wastewater which contains a large volume of soluble organic substances. However, almost all tofu manufacturing plants are small, consequently when installing treatment facilities, consideration is necessary from the view point of control technology such as flow equalization. Coagulation treatment is an option for small-sized factories in which wastewater quantity is low but there are problems of facility maintenance and disposal of a large volumes of sludge that are generated.

(1) Outline of the existing wastewater treatment facility

The wastewater treatment in the plant consisted of an activated sludge method utilizing contact aeration. Wastewater collected in an untreated water tank was pumped up to a vibrating screen for removal of SS such as tofu waste.

The wastewater was then stored in an adjusting tank and a regulated amount of water was sent to a contact aeration tank.

Filter media were installed in the contact aeration tank and air was blown by blower. A portion of mixed liquor was circulated by pump. The mixed liquor was treated in a settling tank and the supernatant was further treated by sand filter and activated carbon adsorption.

Settled activated sludge was returned to the contact aeration tank and one portion was disposed of as excess sludge.

The treated water was discharged after disinfection with chlorine.

Fig. 3-3 shows the flow diagram of the treatment facility.

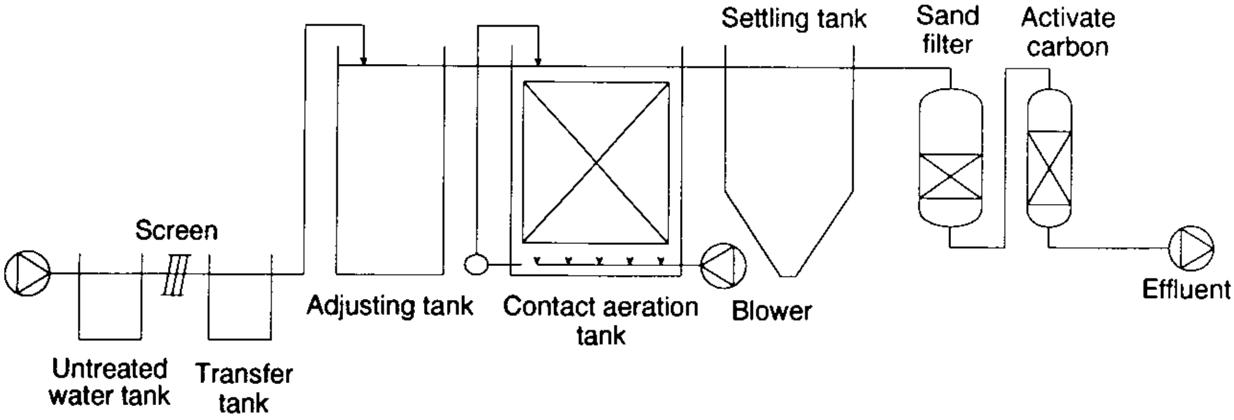


Fig 3-3 Flow diagram of the existing wastewater treatment facility at the tofu manufacturing plant

(2) Untreated water properties and treated water quantity

The quality of the untreated and treated water of the existing wastewater treatment facility of the bean curd manufacturing plant was analyzed.

Untreated water samples were taken at the inlet of the adjusting tank after screening and treated water samples after filtration and activated carbon adsorption around 12:00 after draining of the soy bean immersion tank.

Water quality analytical methods are shown in Table 3-1.

Tables 3-6 and 3-7 show the result of water quality analysis of the untreated and treated water, respectively.

The untreated water quality was relatively unvarying and the concentration of organic substances was high; the average water quality from Dec. 12th to Jan. 31st was 3420 mg/ ℓ BOD of and 2720 mg/ ℓ of COD.

The concentration of soluble organic substances was high after elimination of SS, 3100 mg/ ℓ of soluble BOD of and 2590 mg/ ℓ of COD.

Nitrogen in the untreated water was 136 mg/ ℓ and phosphorus was 15.6 mg/ ℓ. For biological treatment, nitrogen was lacking and the ratio of phosphorus was very low; BOD : N : P = 100 : 4.0 : 0.5.

PH of the wastewater was a slightly acidic and the pollutant load was high. This was probably due to the dewatering wastewater.

In the treated water, TOC and COD but not BOD compounds remained, which showed that rather non-biodegradable substances remained. This was probably because, although the wastewater pollutant load was high, due to the application of the fixed-bed contact aeration method, keeping a relatively old sludge caused the generation of biological waste.

Although the nitrogen and phosphorus ratios were low, average T-N and T-P were 44.5 mg/ ℓ and 4.8 mg/ ℓ in the treated water, respectively. This was probably due to the excess supply of nutients, nitrogen and phosphorus, for the biological treatment.

(3) Problems

This was a contact aeration method but the basic principle was the activated sludge method. Sludge control was therefore very important for maintenance.

There were several problems such as COD and TOC removal from the treated water, and maintaining the adequate balance of nitrogen and phosphorus.

On bulking of the activated sludge, clogging occured frequently in the filter tank installed as on advanced treatment method after biological treatment and it required a complicated operation to maintain water quality control.

Table 3-6 Untreated water quality of the tofu manufacturing plant wastewater

Date	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	T-P (mg/ℓ)	$C\ell^{-}$ (mg/ℓ)	Color (degree)
Dec.12	4.71	244	1430	1750 (1650)	2840 (2490)	66.4	9.2		183
14	4.41	376	1790	2630 (2500)	3740 (3630)	87.7	12.6		
16	4.91	212	1690	2490 (2390)	3490 (3030)	141	14.1		
19	7.12	60	1970	2690 (2490)	3050 (2970)	147	15.8		
21	4.85	238	2070	2760 (2620)	3450 (2880)	139	25.8		
23	4.80	232	1640	2310 (2210)	2970 (2730)	137	17.4		
26	5.05	466	3260	4340 (4180)		185	32.6		
Jan.9	7.49	258	1720	2370 (2190)	3600 (3450)	137	9.5		297
11	5.19	166	1060	1590 (1550)	1990 (1910)	89.0	8.2		174
13	4.50	340	2150	3020 (2920)	3290 (3060)	149	14.3		301
17	4.19	116	1820	2750 (2620)	3630 (3480)	150	11.8		175
20	6.41	526	2330	3510 (3330)	4930 (4380)	187	22.5		433
24	4.47	312	1880	2860 (2800)	3340 (2840)	151	9.6		309
27	4.11	314	1910	2910 (2800)	3690 (3080)				205
31	4.68	462	2050	2850 (2630)	3860 (3490)				205
n	15	15	15	15	14	13	13		9
$\bar{x}$	5.13	288	1920	2720	3420 (3030)	136	15.6		254
σ_{n-1}	1.04	131	480	650	650 (590)	36	7.3		88

Table 3-7 Treated water quality of the existing wastewater treatment facility of the bean curd manufacturing plant

Date	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	NO_2-N (mg/ℓ)	NO_3-N (mg/ℓ)	T-P (mg/ℓ)	$C\ell^-$ (mg/ℓ)	Color (degree)
Dec.12	8.00	8	67	53.1	9	41.4	1.16	1.90	5.7		72
14	7.80	9	71.9	57.7	27	41.8	0.50	0.64	6.1		
16	7.92	4	89.3	61.7	18	56.4	0.29	0.37	7.3		
19	10.95	47	45.4	29.7	37	6.1	0.01	0.34	2.0		
21	7.61	2	55.2	35.8	5	7.3	1.71	30.1	6.1		
23	7.91	3	65	43.2	17	13.7	0.65	11.2	6.8		
26	7.98	4	46.4	40.6			0.62	0.38			
Jan.9	8.05	5	27	31.8	3	35.0	0.38	4.27	2.4		42
11	8.25	8	29	36.6	20	39.1	0.35	1.80	2.9		47
13	8.10	7	49	50.5	33	52.7	0.30	0.42	5.5		110
17	8.10	7	51	48.5	28	67.1	0.40	0.28	5.4		68
20	8.15	10	29	48.1	17	65.6	0.47	0.90	5.2		71
24	8.25	4	36	46.5	10	52.9	0.47	5.03	2.1		44
27											
31	8.11	16	82	85.7	39		0.18	0.10			101
n	14	14	14	14	13	12	14	14	12		8
$\bar{x}$	8.22	10	53	47.8	20	39.9	0.54	4.12	4.8		69
σ_{n-1}	0.80	11	20	14.4	12	21.2	0.43	8.07	1.9		26

3-4 Noodle manufacturing plant

In the noodle manufacturing plant, noodle washing wastewater made up 85 % of the total and boiler wastewater discharged after finishing was the most polluted comprising, 60 % of the total pollution load.

The main pollutant was from elusion of the raw material wheat flour during the noodle boiling process etc., (noodles were broken into pieces by boiling and solids were exfoliated by washing) and since in general the elusion loss of flour was more than 10 %, the increase in yield was desirable from the view point of the effective utilization of raw materials and company profit.

Based on a study on the relationship between raw noodle thickness, boiling time, boiling temperature and elusion volume, it was found that the boiling time should not be longer than necessary.

The main pollutant of the wastewater was starch and there was a problem that bulking was easily generated due to an unbalance in the pollutants. /Effective facilities are necessary because in many cases noodle manufacturing plants are constructed on a small site near urban areas; consequently there are often restrictions with respect to space on constructing wastewater treatment facilities.

(1) Outline of the existing wastewater treatment facility

In this plant, the wastewater was being treated with a batch type activated sludge method.

The wastewater was collected in an untreated water tank and then sent to an adjusting tank.

The wastewater stored in the adjusting tank flowed to an aeration tank after passing through a vibrating screen.

Wastewater inflow into the aeration tank occured simultanously with aeration and mixing by aerator.

The aeration stopped a few hours before drawing the wastewater so that the activated sludge could settle down.

Before another inflow of wastewater, the supernatant was sent to a treated water tank and then SS was removed in a filter tank. Finally it was disinfected and discharged.

In this plant for decreasing the pollution load of the activated sludge, the aeration tank volume was larger so that excess sludge generation could be lowered via the lagoon treatment method.

Fig. 3-4 shows the flow diagram of the treatment falicity.

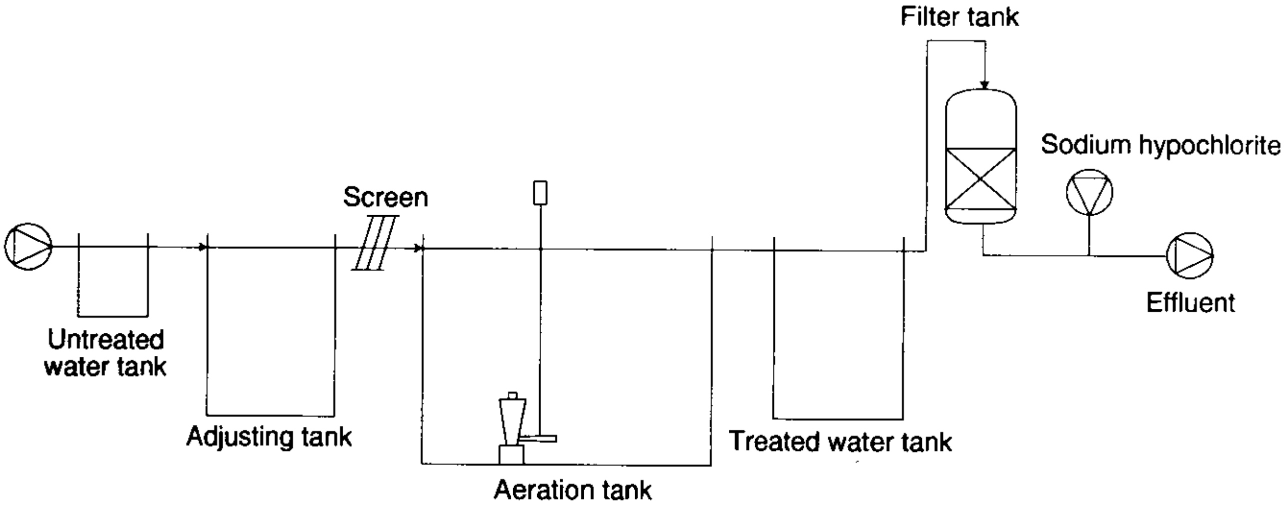


Fig 3-4 Flow diagram of the existing wastewater treatment facility of the noodle manufacturing plant

(2) Untreated water properties and treated water quality

The quality of the untreated and treated water of the existing wastewater treatment facility of the noodle manufacturing plant were analyzed.

In principle, untreated water samples were taken at the inlet of the adjusting tank and treated water samples at the outlet of the filter tank from 10:00 to 12:00 furing draining of the boiler.

Water quality analysis methods are shown in Table 3-1.

The unreated water quality depended on the quality of the boiler wastewater and there was a tendancy that on days with a low temperature and large production amount, the pollutant load and BOD concentration of the untreated water were high.

Tables 3-8 and 3-9 show the result of untreated and treated water quality analysis, respectively. Average untreated water from Dec. 12th to Jan. 31st had high organic pollutant concentration; 1450 mg/ ℓ of BOD, 1150 mg/ ℓ of COD and 653 mg/ ℓ of TOC.

Nitrogen was 22.9 mg/ ℓ and phosphorus was 4.2 mg/ ℓ . Nutrition in the wastewater was lacking for biological treatment; BOD : N : P = 100 : 1.6 : 0.3.

In most cases, the pH of the wastewater was slightly acidic due to boiler wastewater. Organic substances, BOD and TOC, were completely removed because of low BOD loading and thus COD was a little high only when the settling characteristics of the sludge were bad and SS in the treated water was high.

The average concentrations of nitrogen and phosphorus were very low, 2 mg/ ℓ and 1 mg/ ℓ , respectively, and the activated sludge property showed a lack of nutrient supply.

In the aeration tank, because of increased DO and less frequency of sludge withdrawal, the sludge was always unflocked and the settling characteristics worsened.

(3) Problems

Since this was a lagoon type batch activated sludge method, the operation was always performed under a low load condition and it caused unflocked activated sludge. Since there were many cases that the supernatent remained turbid and the sludge setttling ability worsened, the sludge has been withdrawing more frequently than a few years ago.

The lagoon type requires a large installation area, a larger volume of activated sludge and relatively more electrical power for aeration and mixing.

Table 3-8 Untreated water quality of the noodle manufacturing plant wastewater

Date	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	T-P (mg/ℓ)	$C\ell^-$ (mg/ℓ)	Color (degree)
Dec.12	4.81	328	995	1590 (1330)	1880 (1670)		6.5		32
14	6.90	146	436	796 (657)	970 (840)	18.8	4.5	132	
16	4.89	236	675	1280 (1060)	1590 (1240)	26.2	4.4	191	
19	5.61	280	840	1460 (1240)	1680 (1410)	29.2	4.4	247	
21	5.49	304	763	1290 (1100)	1420 (1110)	22.3	5.2	199	
23	5.58	146	444	826 (659)	1000 (880)	15.6	5.4	147	
26	5.61	146	419	758 (671)		16.4	4.1	129	
Jan.9	7.38	450	600	1250 (1000)	1590 (1100)	28.3	1.8	166	83
11	6.70	178	481	886 (735)	1200 (880)	17.6	2.5	147	36
13	6.55	106	225	443 (335)	500 (400)	14.9	2.8	66.2	24
17	6.08	196	650	1190 (1130)	1470 (1260)	25.4	4.2	191	23
20	7.15	212	710	1590 (1410)	1630 (1320)	24.8	4.3	191	149
24	5.72	324	935	1300 (1130)	1930 (1660)	35.7	4.1	258	68
27	5.07	176	485	892 (723)	980 (860)				25
31	4.33	434	1130	1730 (1500)	2460 (2100)			239	34
n	15	15	15	15	14	12	13	13	9
$\bar{x}$	5.86	244	653	1150 (970)	1450 (1200)	22.9	4.2	177	53
σ_{n-1}	0.91	106	248	369 (330)	495 (430)	6.5	1.2	54	42

Table 3-9 Treated water quality of the existing wastewater treatment facility of the noodle manufacturing plant

Date	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	O_2-N (mg/ℓ)	O_3-N (mg/ℓ)	T-P (mg/ℓ)	$C\ell^-$ (mg/ℓ)	Color (degree)
Dec.12	7.41	5.2	11	4.0	2		< 0.01	0.04	1.57		8
14	7.51	19	14.7	10.9	4	16.4	< 0.01	0.02	0.60		81
16	7.25	2	15.2	5.6	3	0.74	0.01	0.08	0.99	69.9	
19	7.42	3	17.3	4.8	1	0.30	< 0.01	0.03	2.14	69.9	
21	7.42	19	23.4	10.6	3	2.5	0.01	0.09	1.75	69.9	
23	7.51	4	18	6.5	3	2.2	< 0.01	0.04	2.90	77.3	
26	7.55	5	13.4	5.8			< 0.01	< 0.01		77.3	
Jan.9	7.32	12	12	17	5	1.6	< 0.01	0.02	0.03	99.4	22
11	7.81	24	11	21.9	7	4.9	0.02	0.06	0.01	88.4	19
13	7.50	16	18	25.0	5	1.4	0.01	< 0.01	1.10	81.0	20
17	7.72	54	15	32.0	9	4.3	0.01	0.01	0.60	69.9	10
20	7.60	12	7	13.3	3	1.4	< 0.01	< 0.01	0.90	73.6	10
24	7.81	7	7	10.3	2	1.4	< 0.01	< 0.01	0.01	73.6	7
27											
31	7.59	12	7	9.5	4		< 0.01	< 0.01		77.3	6
n	14	14	14	14	13	11	14	14	12	12	9
$\bar{x}$	7.53	14	14	12.7	4	2.0	< 0.01	0.03	1.05	77.3	20
σ_{n-1}	0.17	13	5	8.4	2	1.4	0	0.03	0.90	8.9	24

3-5 Conclusion

The wastewater quality of the existing wastewater treatment facilities of the four food plants (soy sauce, chicken processing, tofu and noodle) were studied and the the quality of the untreated and treated water was analyzed. As a reslut, knowledge on the treatment efficiency of the existing treatment facilities was obtained.
Results are as follows.

(1) The existing treatment facility of the soy sauce manufacturing plant utilized the trickling filter method.
The characteristics of the untreated water varied according to the production process and on average nitrogen and phosphorus were slightly excessive; 1400 mg/ ℓ of BOD, 133 mg/ ℓ of nitrogen, 17.4 mg/ ℓ of phosphorus; BOD : N : P = 100 : 9.5 : 1.2.
Due to exfolitation of the sludge from the filter media during low winter temperuature, the removal efficiency decreased and the average treated water quality was 295 mg/ ℓ of BOD, 42 mg/ ℓ of T-N and 5.9 mg/ ℓ of phosphorus.

(2) The existing treatment facility of the chicken processing plant utilized the fixed-bed activated sludge method.
The untreated water characteristic was stable and on average nitrogen and phosphorus were excessive; 900 mg/ ℓ of BOD, 163 mg/ ℓ of nitrogen, and 17.3 mg/ ℓ of phosphorus; BOD : N : P = 100 : 18 : 1.9.
Due to nitrification caused by irregular operation of the existing treatment facility, the average water quality of the treated water was 49 mg/ ℓ of BOD, 32 mg/ ℓ of T-N, 6.8 mg/ ℓ of phosphorus.
BOD of the treated water was a little high due to nitrifictaion.
Since denitrification was promoted by operation conditions of the existing treatment facility, nitrogen removal was efficient.

(3) The existing treatment facility of the tofu manufacturing plant utilized the contact aeration method and the filtration and activated carbon adsorption method as an advanced treatment.
The concentration of organic substances was very high in the untreated water and on average nitrogen and phosphorus were lacking; 3420 mg/ ℓ of BOD, 136 mg/ ℓ of nitrogen, and 15.6 mg/ ℓ of phosphorus; BOD : N : P = 100 : 4.0 : 0.5.
The average treated water quality had 20 mg/ ℓ of BOD, 44.6 mg/ ℓ of T-N and 4.8 mg/ ℓ of phosphorus.
Compared to BOD, TOC and COD concentrations were high; 53 mg/ ℓ of TOC and 47.8 mg/ ℓ of COD.

(4) The existing treatment facility of the noodle manufacturing plant utilized the batch-type activated sludge method.
The characteristic of the untreated water varied acoording to the production amount and on average nutrition was biologically in lack; 1450 mg/ ℓ of BOD, 22.9 mg/ ℓ of nitrogen, and 4.2 mg/ ℓ of phosphorus; BOD : N : P = 100 : 1.6 : 0.3.
Since the pollutant load was low for treatment by the lagoon method, the average water quality was very good - 4 mg/ ℓ of BOD, 2 mg/ ℓ of T-N and 1 mg/ ℓ of phosphorus - but the activated sludge was slightly unflocked.

(5) Based on the research of the existing treatment facilities of the four food plants, it was found that the common problem was maintenance.
Since the substrate composition of the wastewater could be easily treated biologically, the activated sludge method was the main treatment method. However, many troubles occurred due to bulking causing inefficient operation of the treatment facilities.
One of the solutions is the modified activated sludge method, for example filling filter media, but it is not the fundamental solution for the maintenance problem.
For wastewater which contains a lot of nitrogen and phosphorus, application of some advanced treatment remains as a problem to be solved.

4. Study on basic treatment conditions of the controlled aeration acitivated sludge method in the indoor experiment plant

Using the actual wastewater of four food plants (soy sauce, chicken processing, tofu and noodle), basic treatment conditions for BOD, nitrogen and phosphorus removal via the controlled aeration activated sludge method were studied using an indoor bench-scale apperatus (capacity of 10 ℓ)

This study using actual wastewater allowed us to gain basic knowledge on bulking control when using the controlled aeration activated sludge method.

4-1. Wastewater treatment at the soy sauce manufacturing plant

The main wastewater at the soy sauce manufacturing plant was from various kinds of washing and thus BOD was high and nitrogen and phosphorus were slightly excessive, BOD : N : P = 100 : 9.5 : 1.2.

The concetration of SS was also high and bulking frequently occurred when utilizing the activated sludge method.

This research compared the treatment efficiency of controlled aeration and the non-controlled aeration methods in a batch type activated sludge system.

(1) Experimental conditions

- Wastewater for the experiment -

Samples of the actual soy sauce manufacturing plant wastewater were taken at the same frequency as in 3-1 (2).

Consequently the properties of the wastewater were the same as in Table 3-2 and the ratios of nitrogen and phosphorus were a little high.

Figs. 4-1, 4-2 and 4-3 show the non-excess probability of BOD, nitrogen and phosphorus of the sampled wastewater.

- Activated sludge -

In this experiment, activated sewage treatment plant sludge was used for seeding. Since many filamentous bacteria were in the sludge and the water tended to be of a bulking type, for one month from the beginning of the experiment to Jan. 16th, all experiments were conducted under the same conditions with the controlled aeration activated sludge method for completion of acclimation.

- Experiment equipment -

In this experiment, aeration tanks made of transparant acrylic resin plate with a capacity of 10 ℓ were installed in thermostaticlly controlled water tanks.

A regulated amount of untreated water was supplied by pump. In the controlled aeration method, aeration started after inflow of the untreated water and in the non-controlled aeration method, aeration started when the untreated water began to flow into the tank.

Aeration volume was adjusted so that DO began to increase just after starting aeration.

Photo 4-1 shows the experimental equipment.

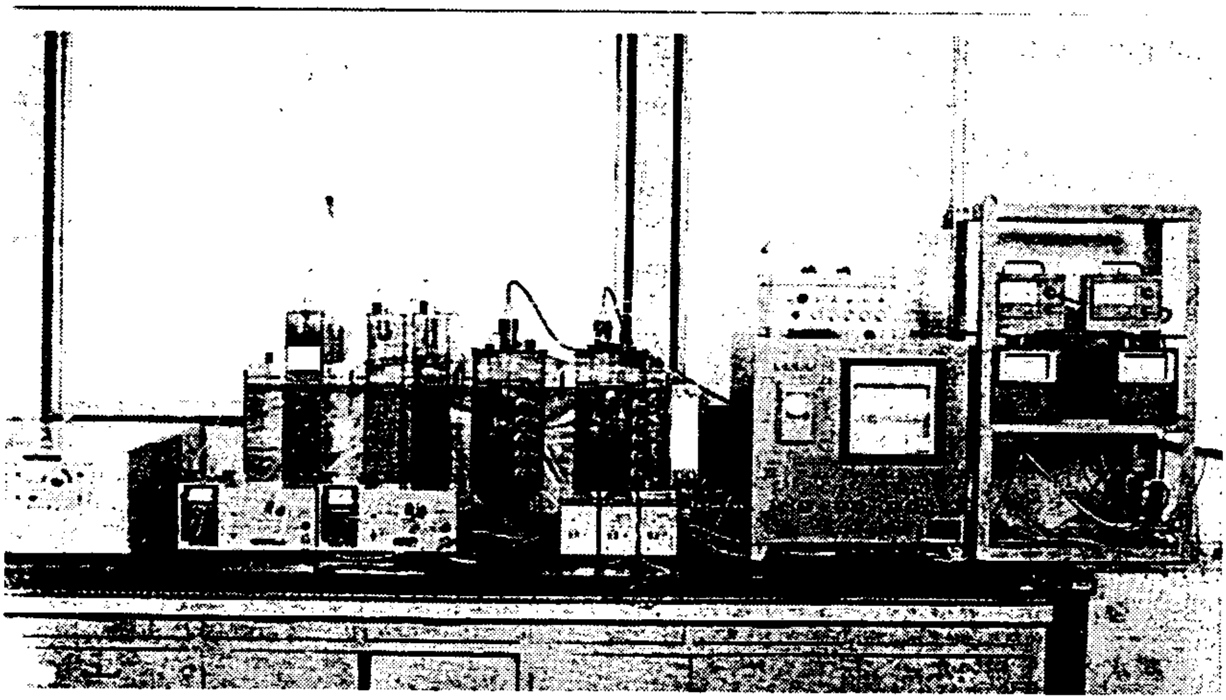


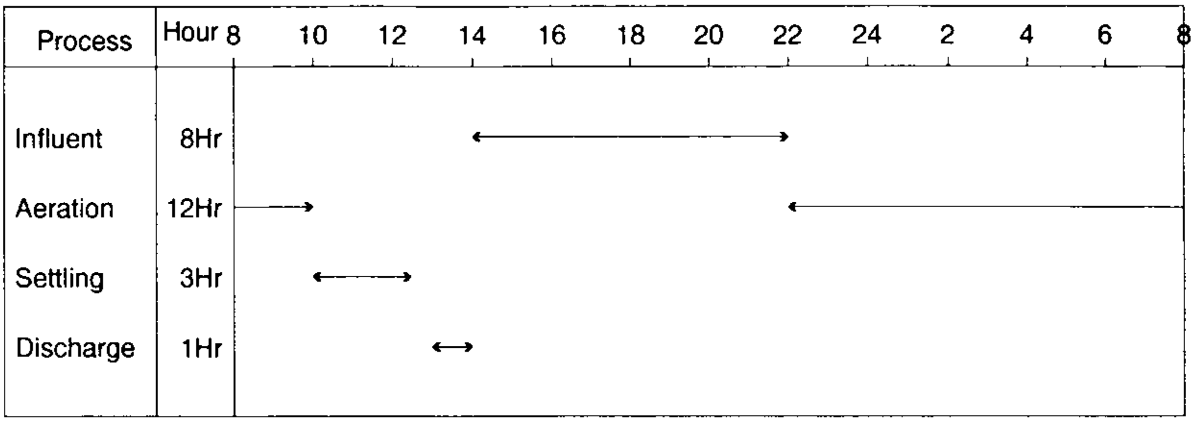
Photo 4-1 Indoor experimental equipment

The experiment equipment was automatically controlled by timer.

- Experimental conditions -

The controlled and non-controlled aeration methods were compared under the same pollutant load conditions and the aeration tanks were held at 20℃.
In addition, to study the effect of water temperature two controlled experiments were conducted one at 20, and the other at the winter temperature of 10 - 15℃.
At first, sludge acclimation was performed on the controlled aeration systems and then the three different experiments started on Jan. 17th.
During the acclimation period, filamentous bacteria were not removed from the winter temperature controlled aeration system due to the low temperature.
Since drawing of the treated water was half of the aeration tank volume, BOD space loadings were common, half of raw water BOD concentration.
In principle, activated sludge concentration in the aeration tank (MLSS) was held at 2000 mg/ ℓ by controlling withdraw of sludge.
The aeration time was 12 hours in both the controlled and non-controlled aeration methods and supernatant was analyzed as treated water, 3 hours after finishing aeration.
Fig. 4-4 shows the time schedule.

Controlled aerationt time schedule (Sam eas acclimation period)



Non-controlled aeration time schedule (after Jan. 17th)

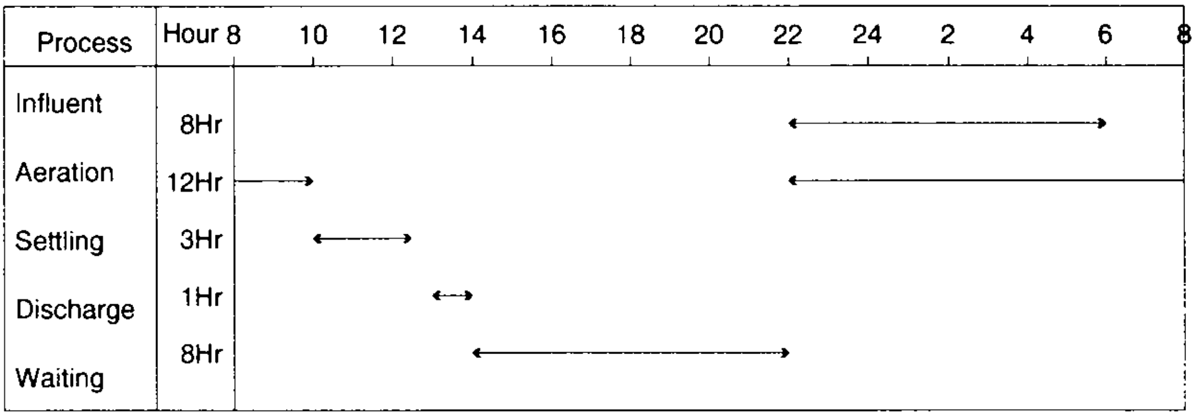


Fig 4-4 Treatment time schedule

(2) Treatment result

The treatment result using the soy sauce manufacturing plant wastewater in the indoor bench-scale apperatus is shown in figs. 4-5 and 4-6.

The treatment efficiencies of organic substances - TOC, COD and BOD - were high except at the beginning of the acclimation period.

After Jan. 17th when the experimental conditions were switched to controlled and non-controlled aeration, the treated water quality remained stable at 20 mg/ ℓ of BOD or less, although there was a fluctuation in the untreated water quality, 460 to 1360 mg/ ℓ of BOD.

Both TOC and COD were also stable, less than 40 mg/ ℓ and 60 mg/ ℓ respectively, but they were a little higher than the concentration of BOD due to non-biodigradable substances in the soy sauce manufacturing plant wastewater.

In the controlled aeration method at the low winter temperature, BOD and COD tended to be a little higher because of SS in the treated water.

Table 4-1 shows the analysis result of the sampled wastewater and tables 4-2, 4-3, 4-4 show the analysis result of the treated water quality of the controlled aeration (20 ℃), non-controlled aeration (20 ℃), and controlled aeration (10 - 15℃) experiments, respectively.

Since nitrogen and phosphorus are excessive in the untreated water, they remained in the treated water.

In both controlled aeration (20 ℃) and non-controlled aeration (20 ℃), nitrogen compounds, such as nitrite and nitrate were detected due to nitrification.

The comparison of concentrations of nitrous and nitric acid was such that, in the non-controlled aeration method, average nitrogen compounds which were converted to nitrite and nitrate were a little higher, 16.3 mg/ ℓ, than that of the controlled aeration method, 11.2 mg/ ℓ.

This was probably due to dinitrification on inflow of untreated water in the controlled aeration method and thus the nitrogen concentration of the treated water was slightly lower.

Nitrification also occurred in the low temperature (10 - 15℃) controlled aeration method and 11.6 mg/ ℓ of nitrified nitrogen compounds were found, which was almost the same as the controlled aeration method at 20℃. This showed that nitrification proceeded in the controlled aeration method even at low winter water temperatures.

The phosphorus removal efficiency was not clear in the final result because of the lower frequency of analysis, but the removal efficiency of the controlled aeration method was better, 1.5 mg/ ℓ, than the non-controlled aeration method, 2.2 mg/ ℓ. However, the phosphorus ratio in the activated sludge in this period was about 1.7 - 1.8 % both in the controlled and non-controlled aeration methods and there was no difference due to the aeration method.

(3) Comparison of activated sludge properties between the controlled and non-controlled aeration methods

The most significant characteristic of the controlled aeration activated sludge method is that bulking can be completely controlled making maintenance easy, and this method is widely applicable as a batch type activated sludge facility with various advantages.

This experiment clarified the basic characteristics of the activated sludge.

Fig. 4-7 shows the treatment result of BOD loading and the sludge properties when using the soy sauce manufacturing plant wastewater.

SVI, an index of the settling characteristics of the sludge, remained stable at around 100 in the controlled aeration activated sludge method (20℃) after Jan. 17th when treatment conditions were changed.

In the non-controlled aeration activated sludge method, SVI increased due to the generation of filamentous bacteria after about a week and bulking conditions were reached, SVI of 300 - 400. Microscope photos of the activated sludge from the controlled and non-controlled aeration methods are shown in Photos 4-2 and 4-3, respectively.

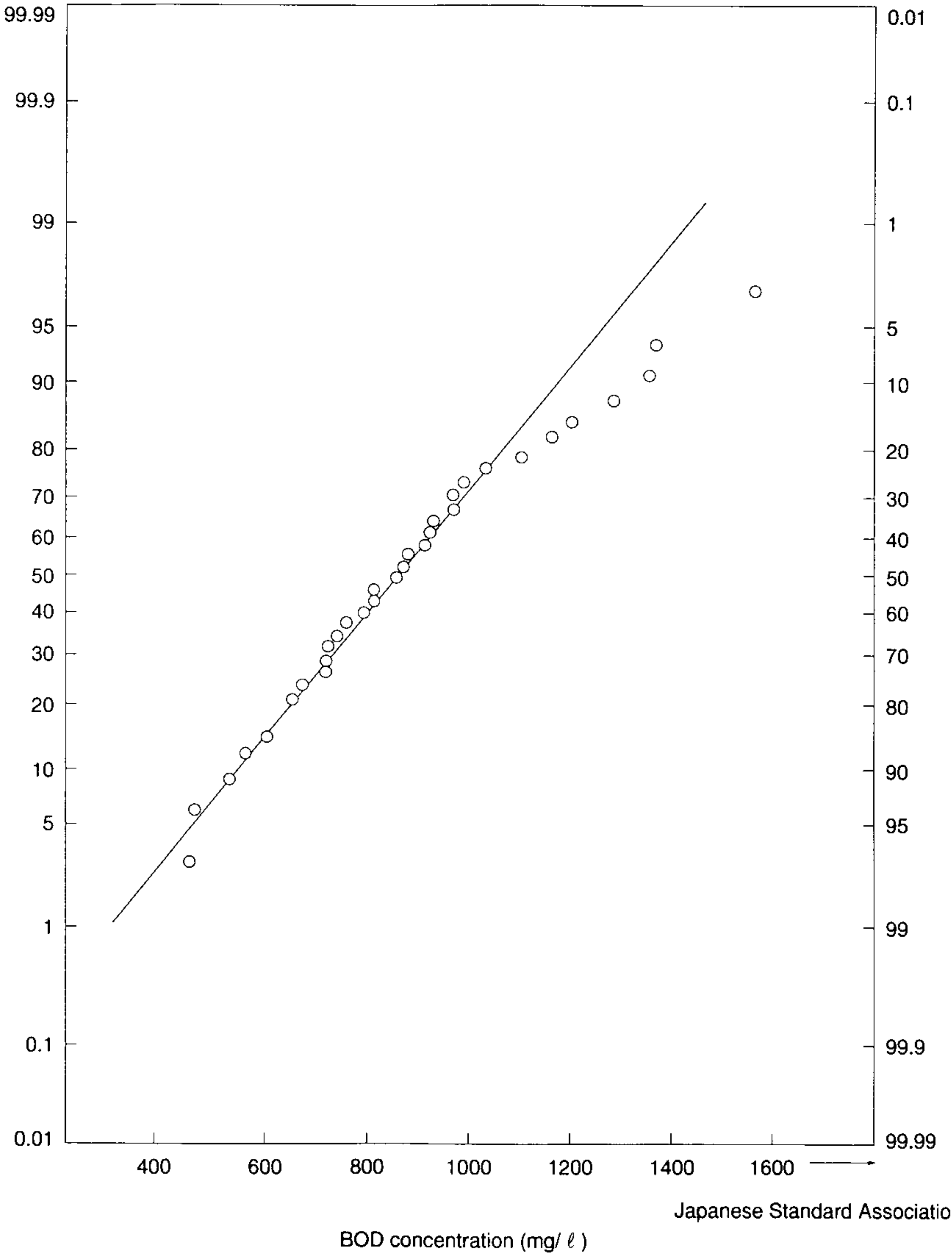
In the non-controlled aeration method, finamentous bacteria were clearly observed, 11 days after the start of treatment.

In the controlled aeration method, the bacteria were stable.

Literature tended to indicate that properties differed according to the substrate concentration gradient formed by different aeration methods in the aeration tank and this experiment found an excellent bulking control method.

In the low winter temperature (10 - 15℃) controlled aeration experiment, because of an increase in BOD loading from Jan. 21st to 24th, the settling characteristics of the sludge were poor after Jan. 24th. It was clear from an increase in MLSS, also due to no withdrawal of sludge, that sludge control was important in low water temperature conditions.

On inflow of untreated water, the respiration rate was 49.3 mg- O_2/g - MLSS · Hr in the controlled aeration experiment, and 8.21 mg- O_2/g - MLSS · Hr in the non-controlled aeration experiment, and after treatment the endogenous respiration speed was 4.41 and 4.83 mg- O_2/g - MLSS · Hr, respectively.



Japanese Standard Association

Fig 4-1 BOD Concentration non-excess probability of sampled water
(Soy sauce manufacturing plant wastewater)

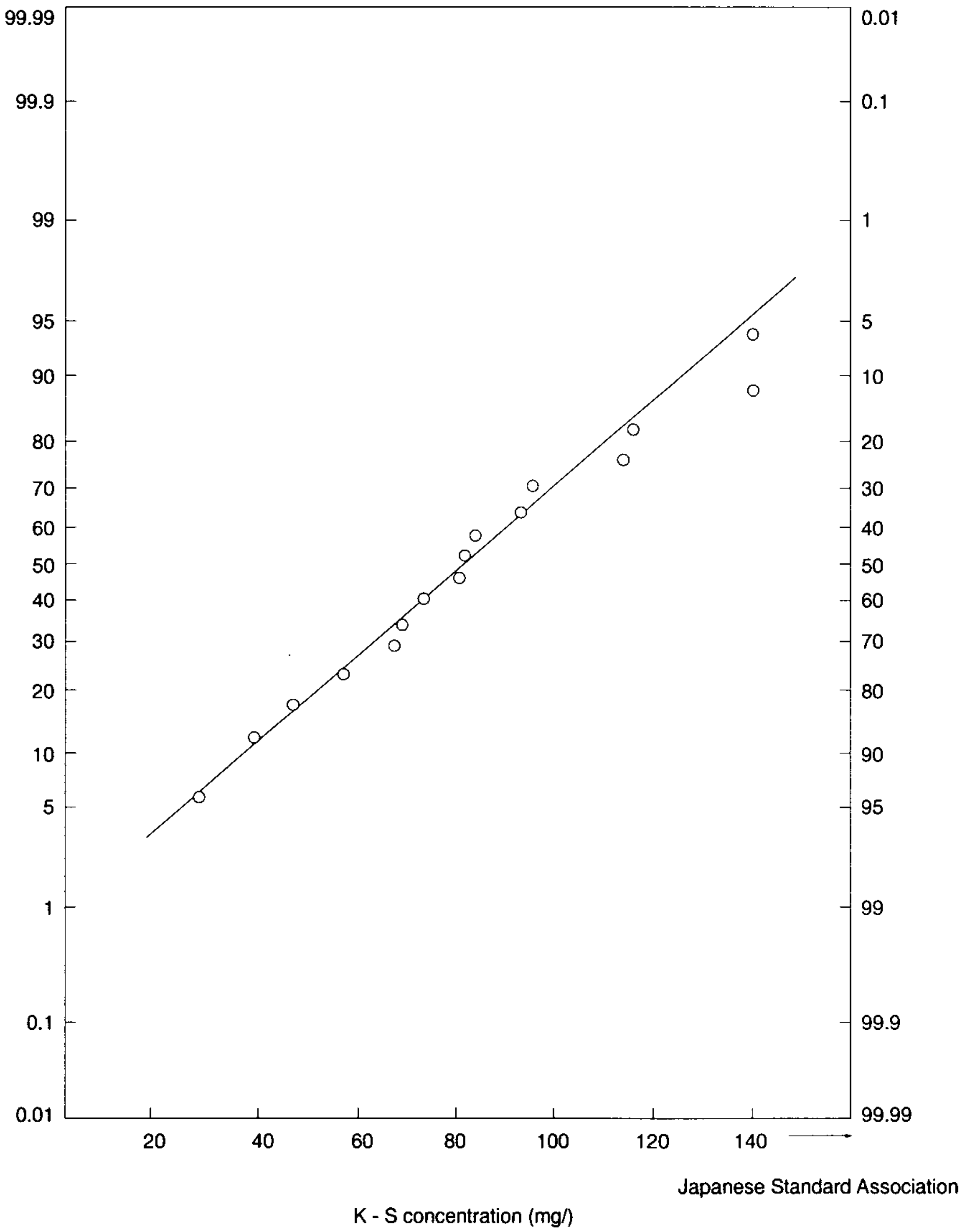


Fig 4-2 K-N concentration non-excess probability of sampled water
(Soy sauce manufacturing plant wastewater)

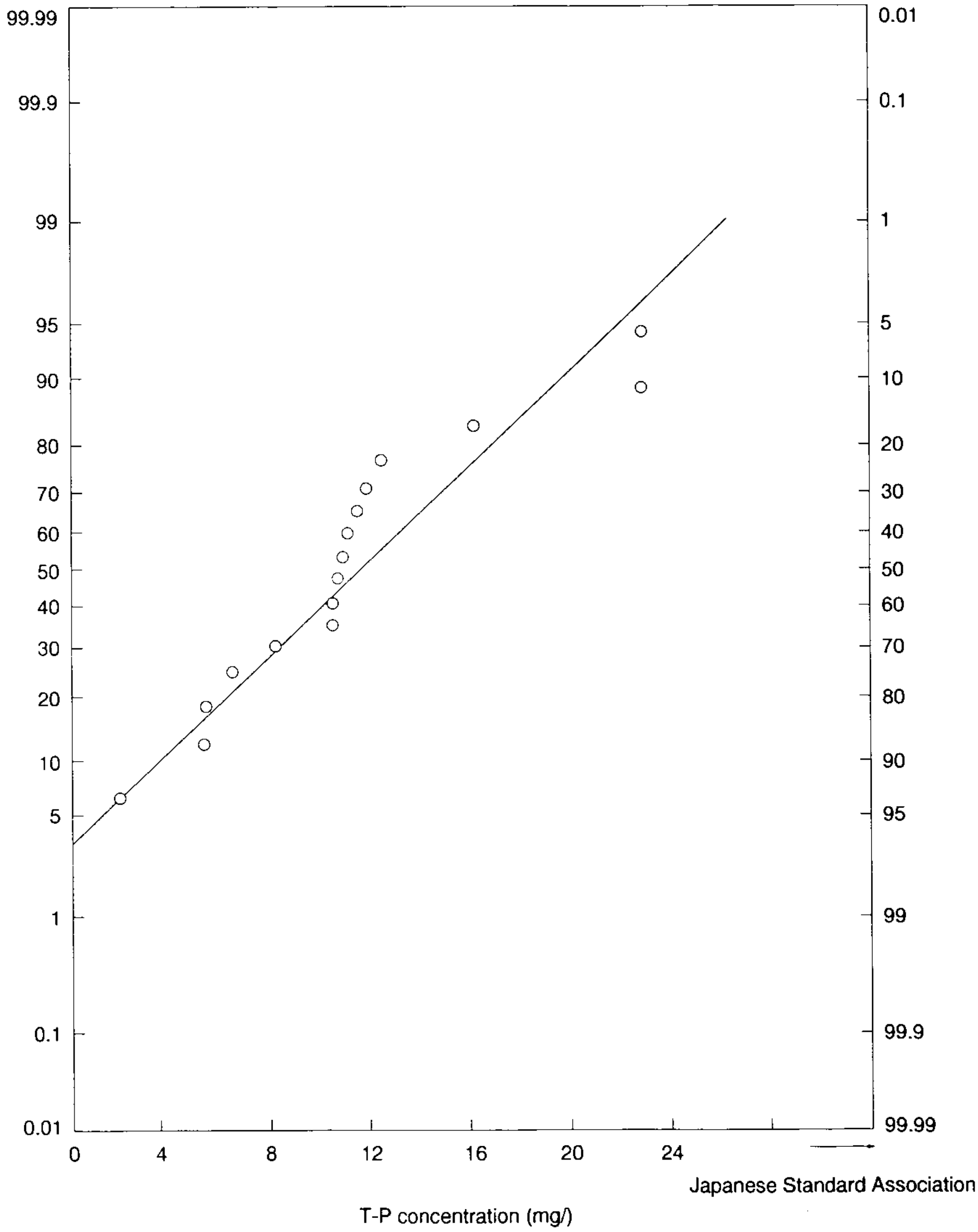


Fig 4-3 T-P concentration non-excess probability of sampled water
(Soy sauce manufacturing plant wastewater)

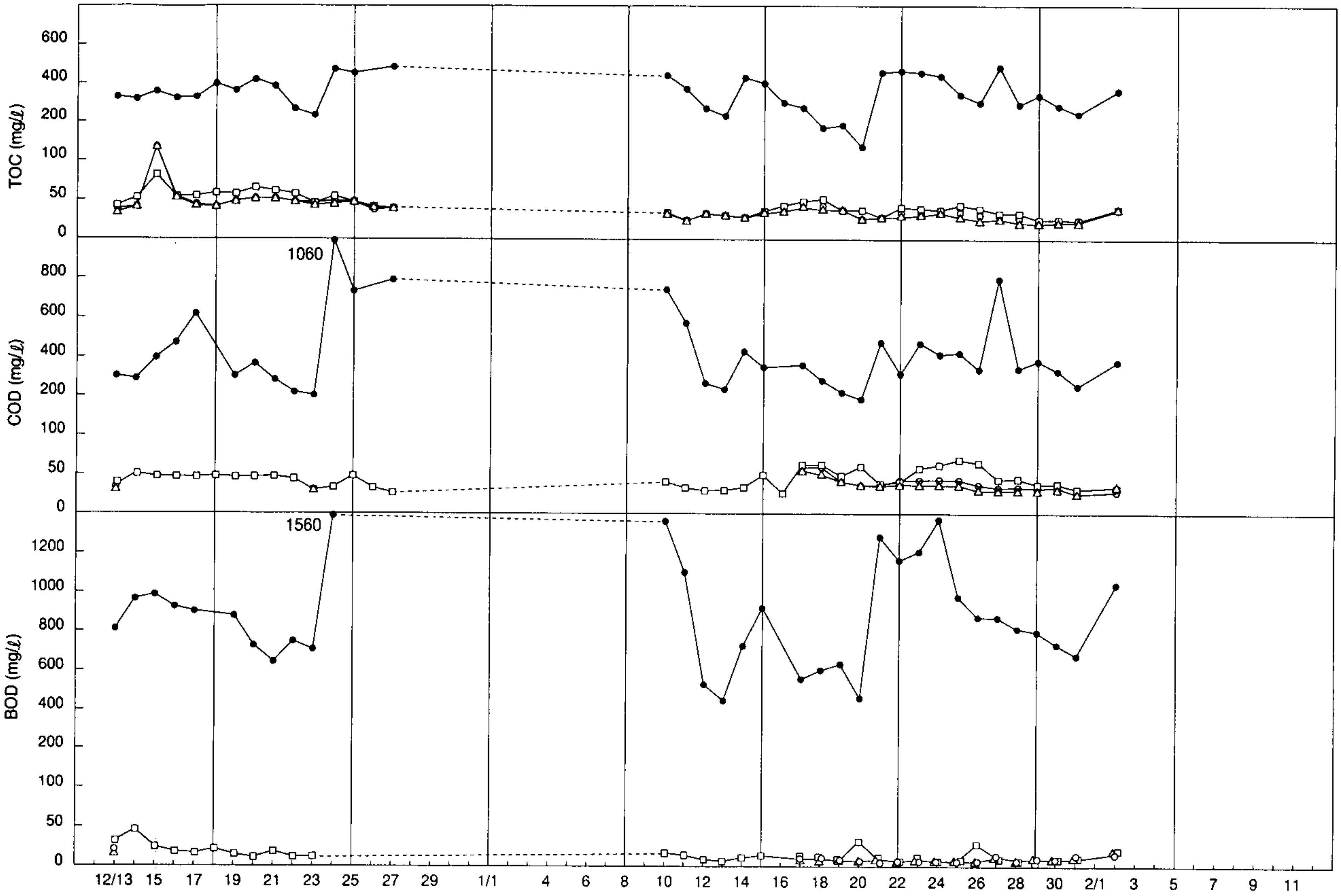


Fig 4-5 Treatment results from the soy sauce manufacturing plant
(Daily changes in TOC, COD and BOD)

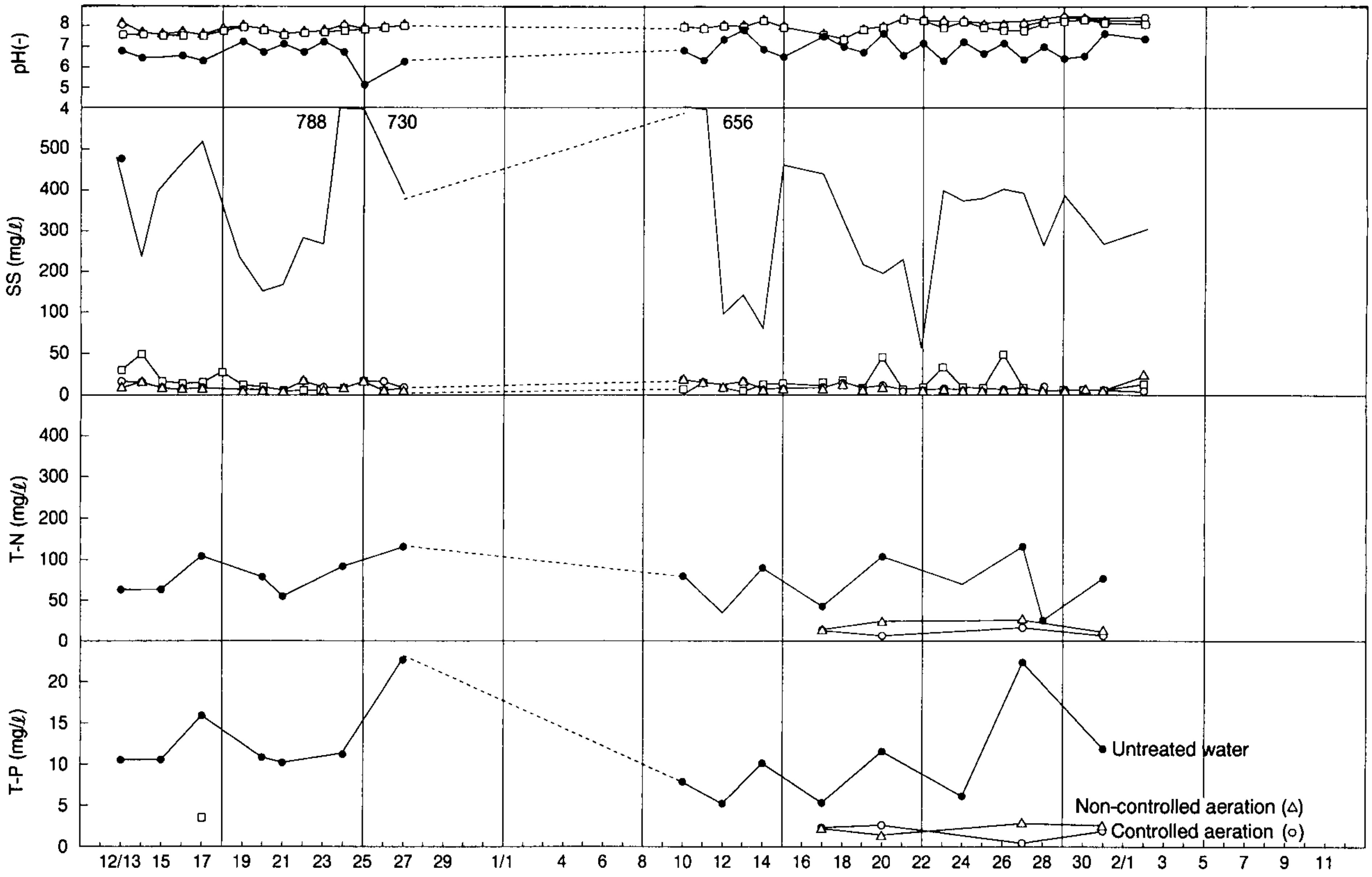


Fig 4-6 Treatment results from the soy sauce manufacturing plant
(Daily changes in pH, SS, T-N and T-P)

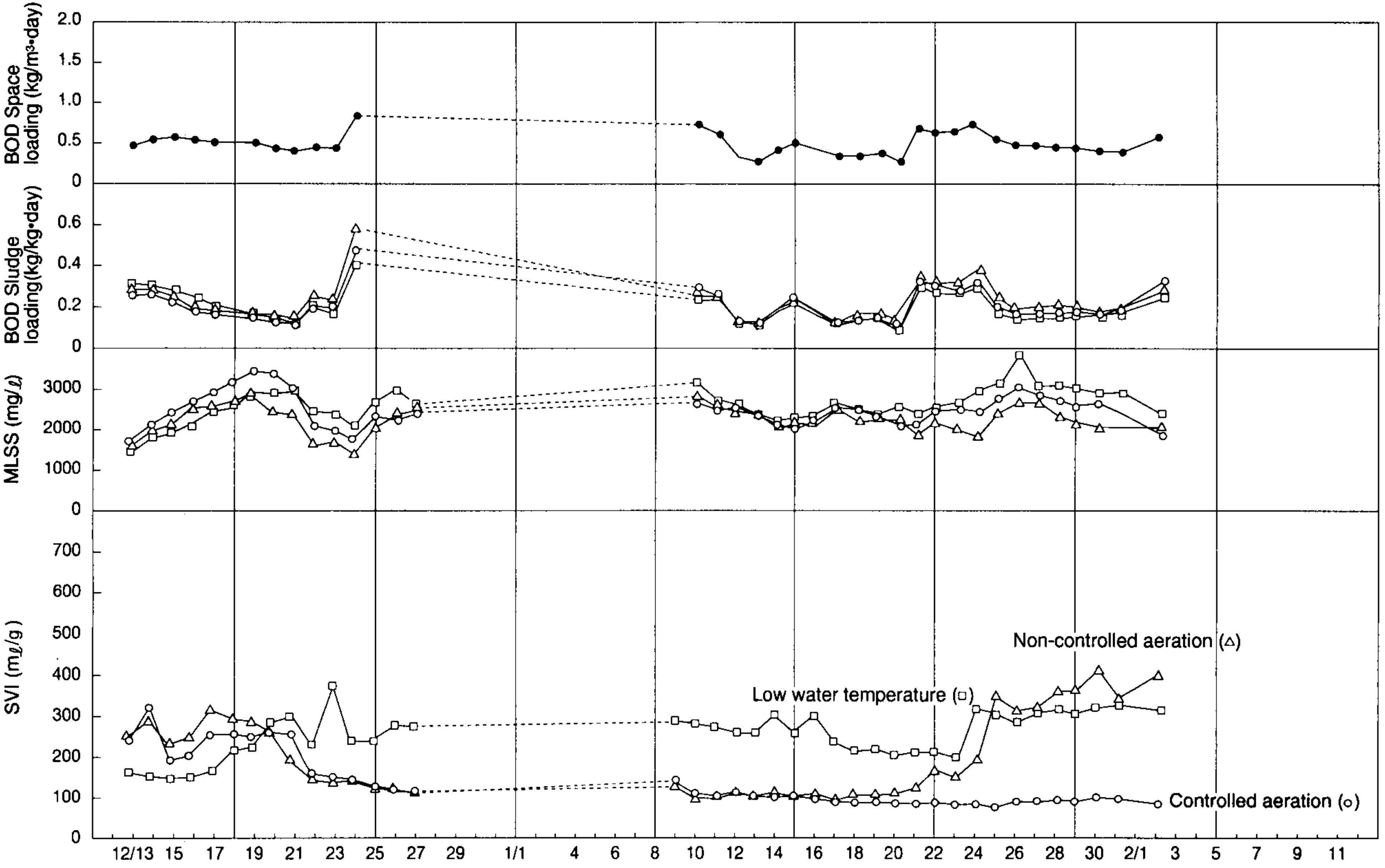


Fig 4-7 Treatment results from the soy sauce manufacturing plant
(BOD lodaing, MLSS, SVI)

Table 4-1 Water quality analysis results of the sampled wastewater put through the indoor bench apperatus (Soy sauce manufacturing plant wastewater)

Date	pH (-)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K-N (mg/)	T-P (mg/)	C^- (mg/)	Color (degree)
Jan.17	7.32	430	235	347 (181)	560 (442)	46.0	5.5	427	269
18	7.00	306	165	267 (130)	600 (340)			166	
19	6.70	220	177	201 (99)	630 (400)			166	13.5
20	7.71	194	120	183 (100)	460 (330)	113	11.8	166	156
21	6.60	224	419	447 (346)	1280 (1090)			548	
22	7.08	50	430	297 (270)	1160 (1080)			556	276
23	6.29	396	423	448 (257)	1200 (1020)			530	265
24	7.29	374	406	393 (214)	1360 (910)	72.5	6.3	534	273
25	6.60	378	309	398 (223)	970 (590)	–	–	166	152
26	7.11	394	271	335 (169)	860 (480)	–	–	177	183
27	6.21	388	449	776 (584)	870 (650)	139	22.7	390	117
28	6.89	254	265	332 (218)	810 (560)	27.1	1.41	–	107
29	6.41	390	312	371 (218)	790 (540)	–	–	70	133
30	6.62	322	247	323 (178)	720 (480)	–	–	69.9	147
31	7.51	260	215	240 (123)	670 (330)	80.1	12.3	77.3	149
Feb.1	6.69	286						228	156
2	7.42	304	336	365 (197)	1030 (670)	–	–	221	226
n	17	17	16	16	16	6	6	16	15
$\bar{x}$	6.91	304	299	358	873	79.6	10.0	781	175
σ_{n-1}	0.44	98	104	136	271	41.4	7.5	184	75

Table 4-2 Analysis of the treated water from the controlled aeration experiment (20℃)

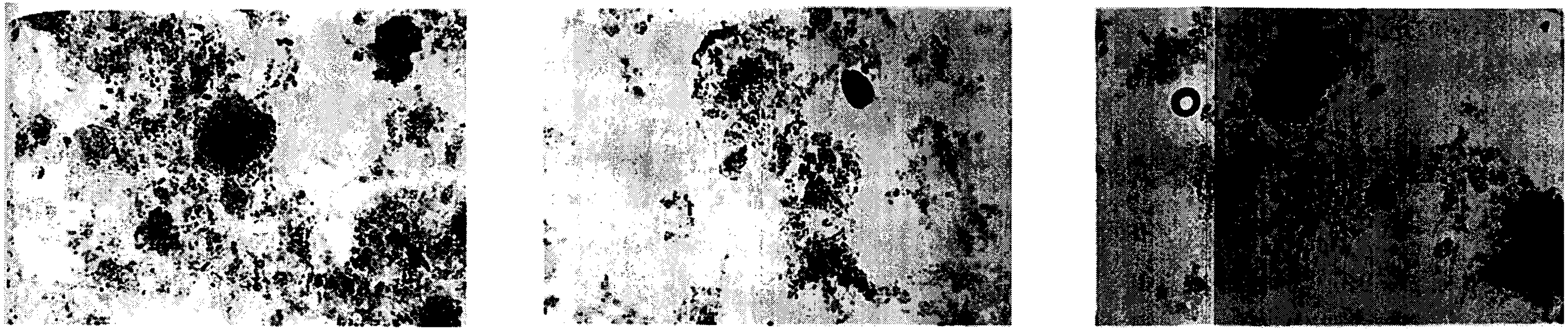
Date	pH (−)	SS (mg/l)	TOC (mg/l)	COD (mg/l)	BOD (mg/l)	K–N (mg/l)	NO_2–N (mg/l)	NO_3–N (mg/l)	T–P (mg/l)	Color (degree)
Jan.17	7.50	10	36	55.0		5.7	7.72	5.48	2.3	93.7
18	7.50	6	37	56.5	13		8.29	4.71		98.6
19	7.90	8	30	39.0	10		0.37	4.97		71.1
20	8.10	2	18	30.6	10	3.4	0.34	5.45	2.8	69.5
21	8.25	7	19	30.6	10		0.25	6.60		50.9
22	8.26	9	27	40.8	4		6.29	9.27		70.2
23	8.25	9	29	43.2	9 (5)	4.5	3.94	13.1	0.18	77.7
24	8.29	8	27	41.3	9 (4)		2.57	13.2		76.3
25	8.19	8	28	42.2	8 (4)	–	1.83	16.7	–	74.7
26	8.19	0	23	33.7	7 (5)	–	0.32	9.49	–	58.2
27	8.10	5	20	29.1	15 (4)	3.5	7.47	10.6	0.34	21.7
28	8.27	10	19.4	30.3	9 (6)	–	0.47	8.15		60
29	8.39	8	17	26.7	5 (3)	–	0.37	6.24	–	47.8
30	8.40	0	17	26.9	9 (4)	–	0.41	8.08	–	45.8
31	8.42	5	19	22.3	9 (5)	2.8	0.45	6.68	2.0	43.1
Feb.1										
2	8.29	6	27	24.0	8 (4)	–	2.21	7.41	–	43
n	16	16	16	16	15	5	16	16	5	16
$\overline{x}$	8.14	6	25	35.8	9	4.0	2.71	8.51	1.5	65
σ_{n-1}	0.28	3	6.5	10.2	3	1.1	3.03	3.42	1.2	17

Table 4-3 Analysis results of the treated water from the non-controlled aeration experiment (20℃)

Date	pH (-)	SS (mg/l)	TOC (mg/l)	COD (mg/l)	BOD (mg/l)	K-N (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	T-P (mg/l)	Color (degree)
Jan.17	7.42	3	33	51.0	6	5.7	5.86	8.66	2.3	92.6
18	7.59	11	34	47.7	9		0.47	14.4		93.2
19	7.89	7	29	38.6	10		0.37	11.5		64.7
20	8.05	11	20	33.6	7	4.2	0.28	16.4	1.6	64.6
21	8.32	5	19	29.7	8		0.14	10.8		46.8
22	8.40	5	24	33.0	7		0.14	18.3		62.9
23	8.30	5	25	35.9	6 (4)	4.7	0.15	20.7	0.21	70.9
24	8.22	4	25	34.6	7 (2)		0.17	17.7		70.5
25	8.19	5	24	34.6	6 (2)	-	0.17	22.4	-	68.6
26	8.15	7	20	29.6	6 (2)	-	0.32	9.49	-	53.9
27	8.29	8	17	26.6	13 (9)	3.5	9.34	17.6	3.11	47.2
28	8.30	13	17.8	28.0	11 (6)	-	0.19	13.6	-	46.4
29	8.40	7	16	25.1	9 (5)	-	0.26	14.1	-	46.3
30	8.31	3	18	26.3	10 (6)	-	0.34	13.8	-	50.3
31	8.29	5	22	26.3	12 (8)	3.5	0.31	13.5	3.6	56
Feb.1										
2	8.21	23	33	29.3	16 (10)	-	0.26	19.9	-	70.5
n	16	16	16	16	16	5	16	16	5	16
$\bar{x}$	8.15	8	24	33.1	9	4.3	1.17	15.2	2.2	62.8
σ_{n-1}	0.28	5	6	7.5	3	0.9	2.59	4.0	1.3	15.0

Table 4-4 Analysis results of the treated water from the controlled aeration experiment (10-15℃)

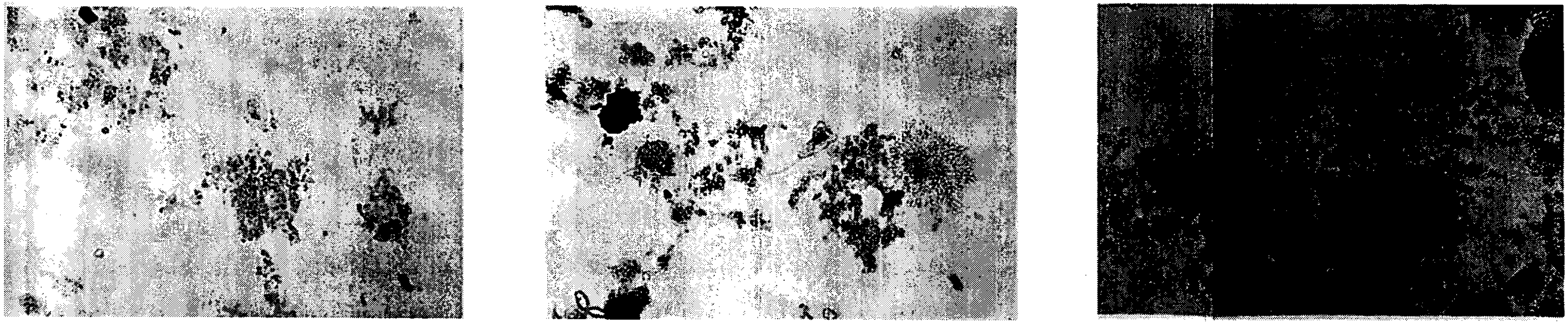
Date	pH (-)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	NO_2-N (mg/)	NO_3-N (mg/)	C^- (mg/)	Color (degree)
Jan.17	7.65	14	42	57.6	16	6.99	2.42	434	108.2
18	7.53	13	43	58.3	13	13.0	3.31	434	107.2
19	7.80	3	31	47.7	7	9.51	4.46	302	72.2
20	7.95	48	27	53.1	30	△66	2.96	228	76.0
21	8.18	3	19	35.5	5	3.36	3.83	199	49.6
22	8.29	5	31	42.4	8	9.32	3.73	379	73
23	8.02	34	32	52.1	16 (10)	8.48	3.41	467	90.7
24			31	59	8 (4)	16.2	5.19	504	
25	7.99	4	33	64.1	9 (3)	18.3	6.42	526	85.3
26	7.96	49	30	60.8	27 (22)	4.47	4.61	350	76.1
27	7.91	4	24	41.3	7 (6)	4.29	7.77	-	60.3
28	8.02	7	24.1	40.1	9 (5)	5.73	4.84	209	58.7
29	8.10	6	22	31.4	8 (5)	051	7.52	140	54.1
30	8.21	3	22	29.2	7 (5)	0.42	6.31	118	15
31	8.15	1	22	26.3	10 (6)	0.47	4.82	103	52.3
Feb.1									
2	8.21	11	30	29.4	12 (9)	1.20	7.31	92.0	55.9
n	15	15	16	16	16	16	16	15	15
$\overline{x}$	8.00	14	29	45.5	12	6.68	4.93	299	69.0
σ_{n-1}	0.21	16	7	12.7	7	5.52	1.69	153	24.0



1st day (SVI : 94)

4th day (SVI : 87)

7th day (SVI : 85)

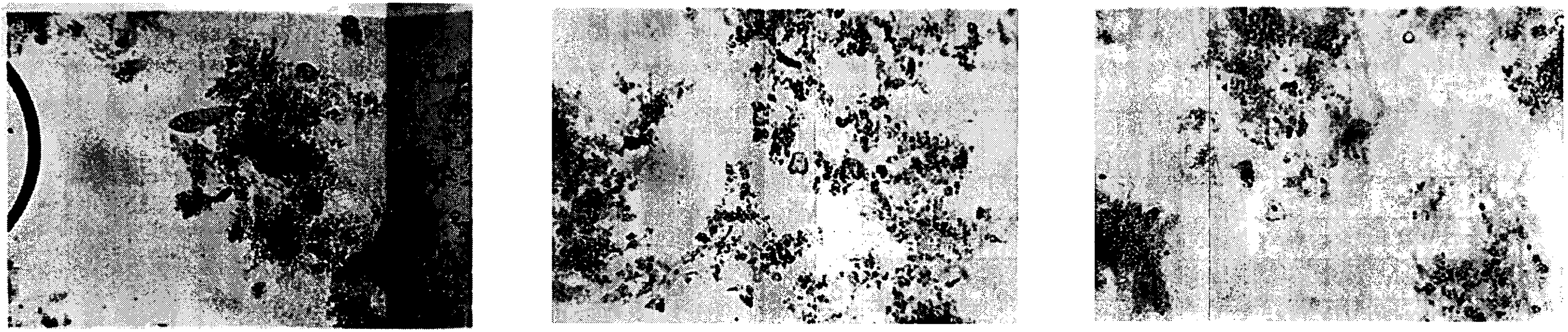


9th day (SVI : 92)

11th day (SVI : 97)

15th day (SVI : 100)

Photo 4-2 Microscope photos of activated sludge (Activated sludge from the controlled aeration experiment on the soy sauce manufacturing plant wastewater)



1st day (SVI : 93)

4th day (SVI : 107)

7th day (SVI : 157)

9th day (SVI : 345)

11th day (SVI : 324)

15th day (SVI : 395)

Photo 4-3 Microscope photos of activated sludge (Activated sludge from the non-controlled aeration experiment on the soy sauce manufacturing plant wastewater)

4-2 Wastewater treatment at the chicken processing plant

Due to blood letting, the BOD concentration was high and phosphorus and nitrogen concentrations were excessive in the chicken processing plant wastewater; BOD : N : P = 100 : 18 : 1.9. And as nitrification proceeded, a sludge flotation problem occurred during denitrification in the settling tank.
This research compared the treatment efficiencies of the controlled and non-controlled aeration methods with a batch type activated sludge system.

(1) Experimental conditions

- Wastewater for the experiment -

Samples of the actual wastewater of the chicken processing plant were taken at the same frequency as in 3-2 (2).
Figs. 4-8, 4-9 and 4-10 show the non-excess probilitity of BOD, nitrogen and phosphorus of sampled wastewater.

- Activated sludge -

In this experiment, activated sludge from a sewage treatment plant with a tendency of bulking due to winter was used for seeding.
About one month was necessary for acclimation of the sludge.

- Experimental equipment -

The indoor bench-scale experimental equipment (capacity of 10 ℓ) is shown in Photo 4-1.

- Experimental conditions -

Experiments were performed under three different conditions, controlled aertion (20℃) , non-controlled aertion (20℃) and controlled aeration at a lower water temperature (10 - 15 ℃).
The treatment time schedule is shown in Fig. 4-4.

(2) Treatment result

The treatment result from the chicken processing plant wastetwater put through the indoor bench-scale apperatus is shown in Figs. 4-11 and 4-12.
As acclimation proceeded, TOC compounds stabilized at around 30 mg/ ℓ but COD increased.
This was found to be from remaining nitrite in the treated water due to nitrification, not because of an increase in organic pollutant.
In many cases, fluctuation in BOD was due to SS compounds in the treated water.
In the latter half of the experiment nitrification occurred, and the pH of the treated water decreased to around 6.5.
Consequently nitrification was restricted by the low pH and stopped around K-N 30 mg/ ℓ .
At the beginning of the acclimation period, SS fluctuated greatly due to sludge flotation caused by denitrification. But later in the experiment, the problem could be solved by discharging the treated water before the start of sludge flotation.
Table 4-5 shows the analysis result of the sampled wastewater and Tables 4-6, 4-7 and 4-8 show the water quality analysis of the treated water from the controlled aeration (20℃), non-controlled aeration (20℃) and controlled aeration experiments (10 - 15℃), respectively.
Nitrification stopped at the nitrite forming condition because of the decrease in pH due to a lack of alkali in the wastewater, and to adjustment in the sludge age to a sludge concentration a found 2000 mg/ ℓ .
In the experiment, nitrogen concentration of the controlled aeration method was a little lower than that of the non-controlled aeration method due to denitrification on inflow of untreated water.
In the controlled aeration method (10 - 15℃) as well, nitrification proceeded. However in the experiment, nitrification ratio in the treated water was a little lower than the controlled aeration method at 20 ℃ because the nitrogen load was high and there was a lower rate of nitrification at low water temperature.
The removal efficiency of phosphorus was about 10 % better in the controlled aeration method than in the

non-controlled aeration method, but there was no clear difference according to the aeration method in this experiment because the removal efficiency of phosphorus itself was low and the phosphorus ratio in the sludge was only about 1.7 %.

(3) Comparison of activated sludge properties between the controlled and non-controlled aeration methods

Fig. 4-13 shows the treatment result of BOD loading and sludge properties when using the chicken processing plant wastewater.

SVI, an index of the settlling characteristics of the activated sludge, changed gradually after Jan. 17th when treatment conditions were changed and after 2 weeks SVI reached about 100 in the controlled aeration method and 200 in the non-controlled aeration method.

Microscope photos of the activated sludge from the controlled and non-controlled aeration methods are shown in Photos 4-4 and 4-5, respectively.

There was no clear difference in sludge properties under microscope observation, and thus SVI difference was probably due to the sludge coagulation property and flock shapes.

Filamentous bactiria were not observed even in the non-controlled aeration method since the BOD loading was stable at the optimum conditions, space loading of 0.5 $kg/m^3 \cdot d$ and sludge loading of 0.2 $kg/kg \cdot d$, and the substrate of the wastewater was not a strong factor in causing bulking.

In the low water temperature (10 - 15℃) controlled aeration experiment, SVI increased because of insufficient sludge withdrawal after Jan. 17th.

On untreated water inflow, the repiration rate was 32.0 mg - O_2/g - MLSS · Hr in the controlled aeration experiment and 12.1 mg - O_2/g - MLSS · Hr and after the treatment the endogenous respiration rate was 5.05 and 3.00 mg - O_2/g - MLSS · Hr, respectively.

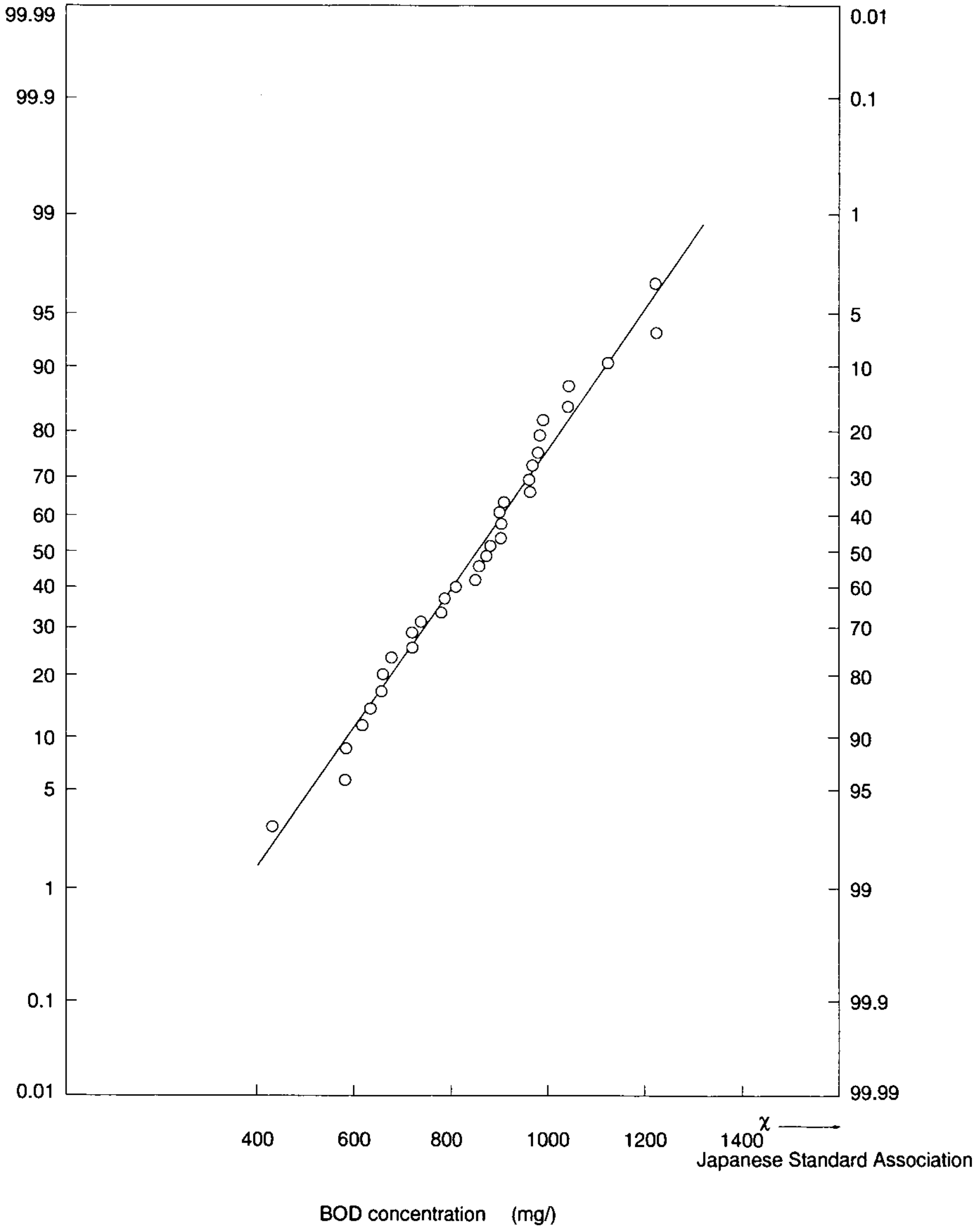


Fig 4-8 BOD concentration non-excess probability of sampled water
(Chicken processing wastewater)

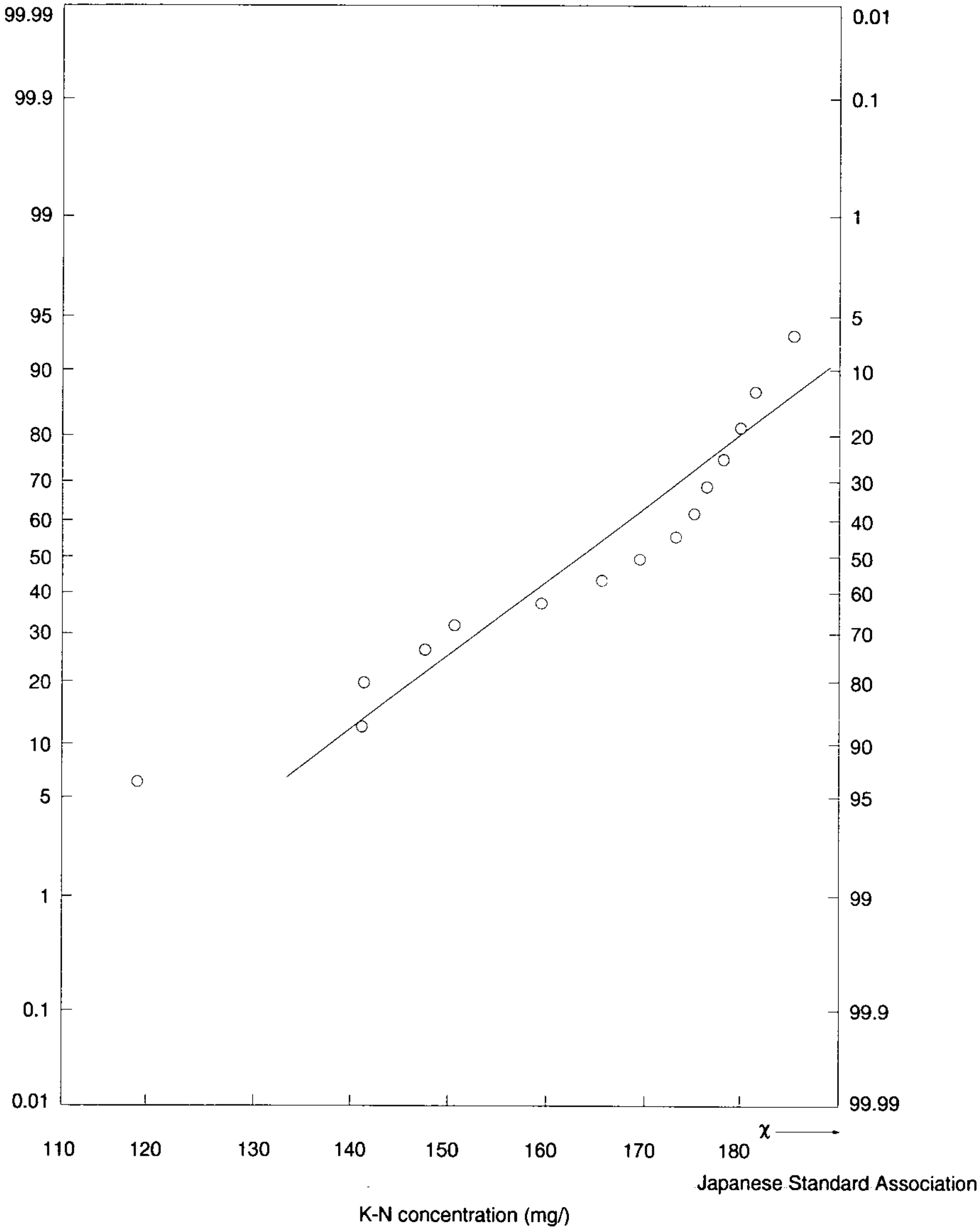
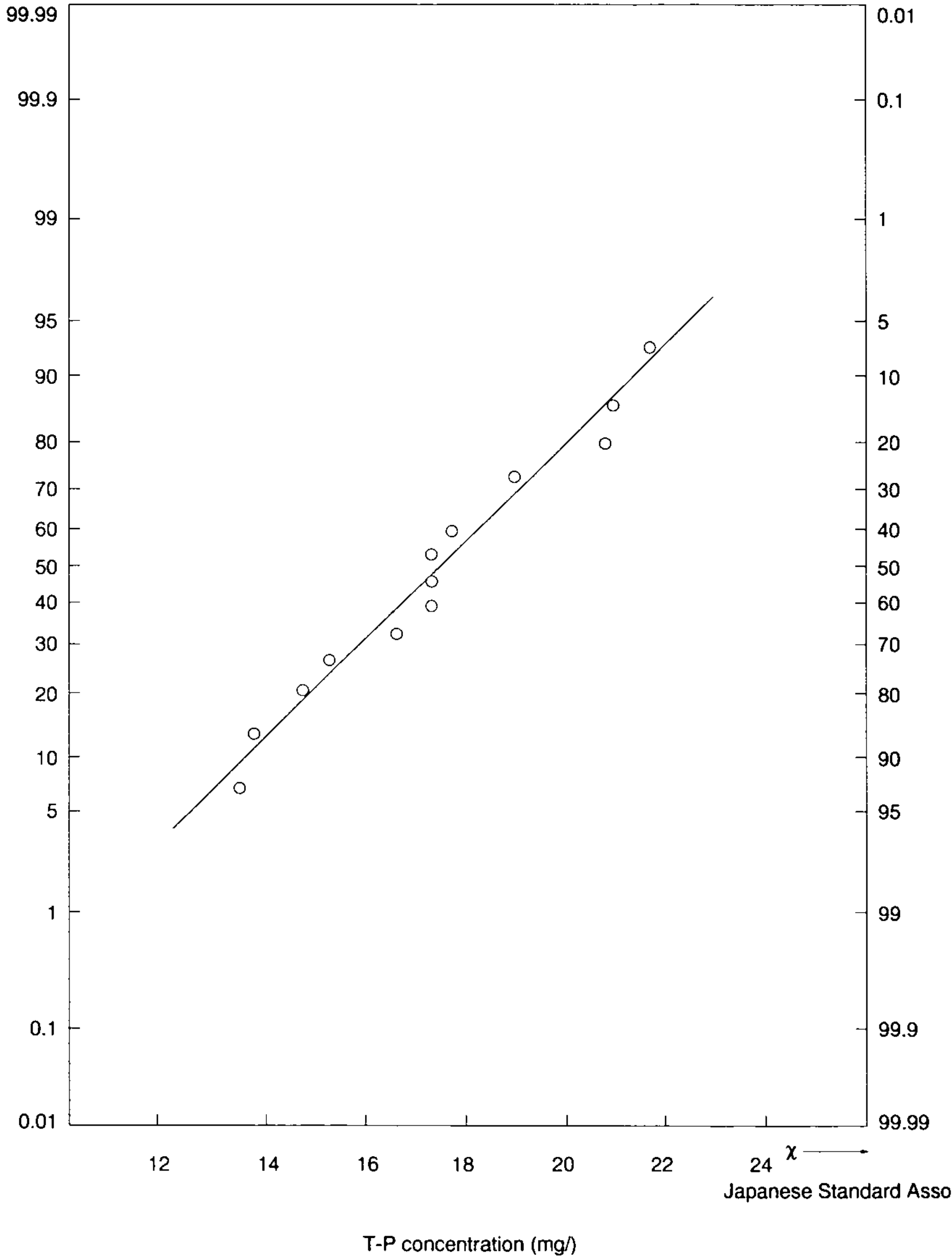


Fig 4-9 K-N concentration non-excess probability of sampled water
(Chicken processing wastewater)



Japanese Standard Association

Fig 4-10 T-P concentration non-excess probability of sampled water
(Chicken processing wastewater)

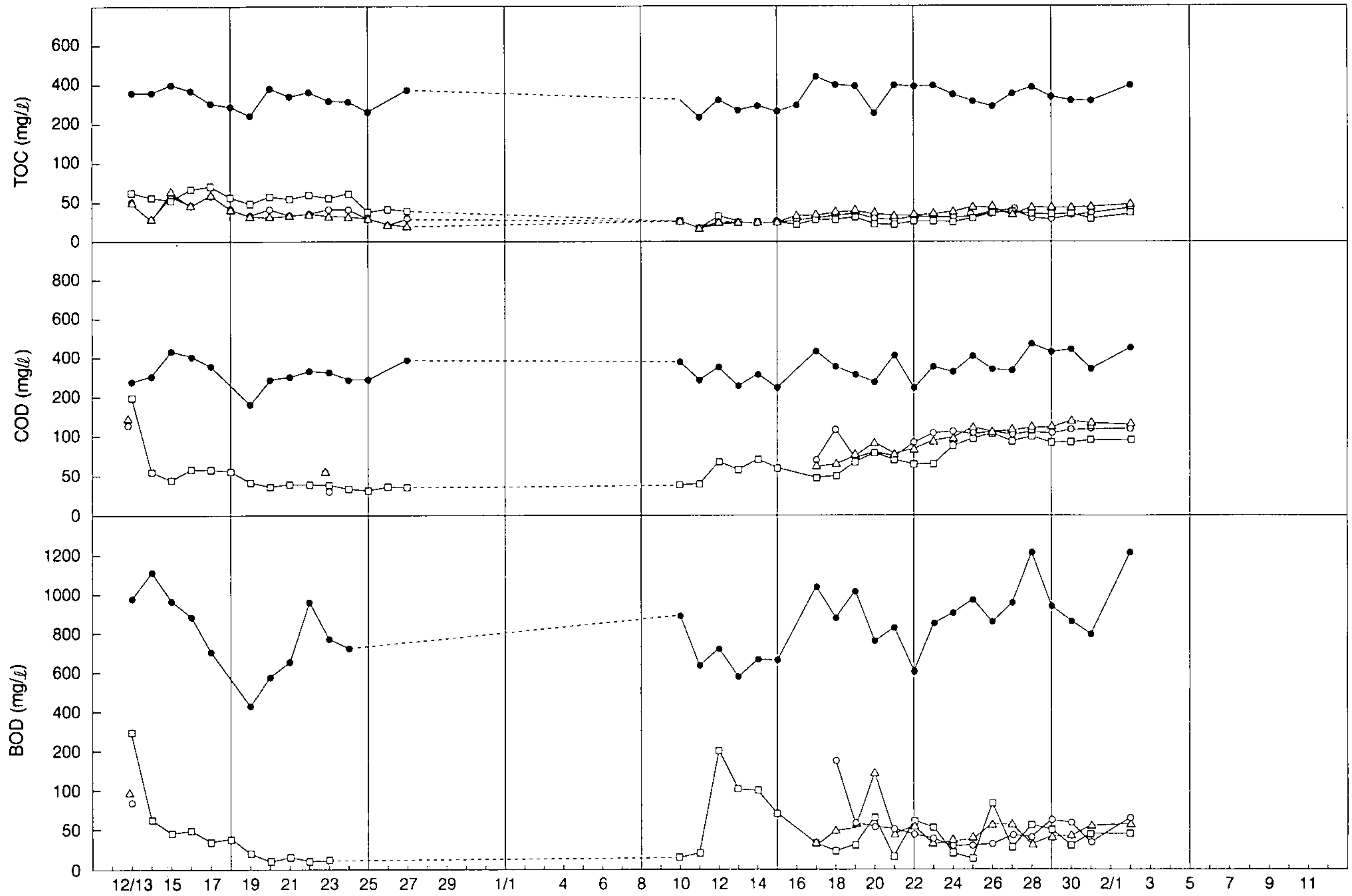


Fig 4-11 Treatment results from the chicken processing plant
(Daily changes in TOC, COD and BOD)

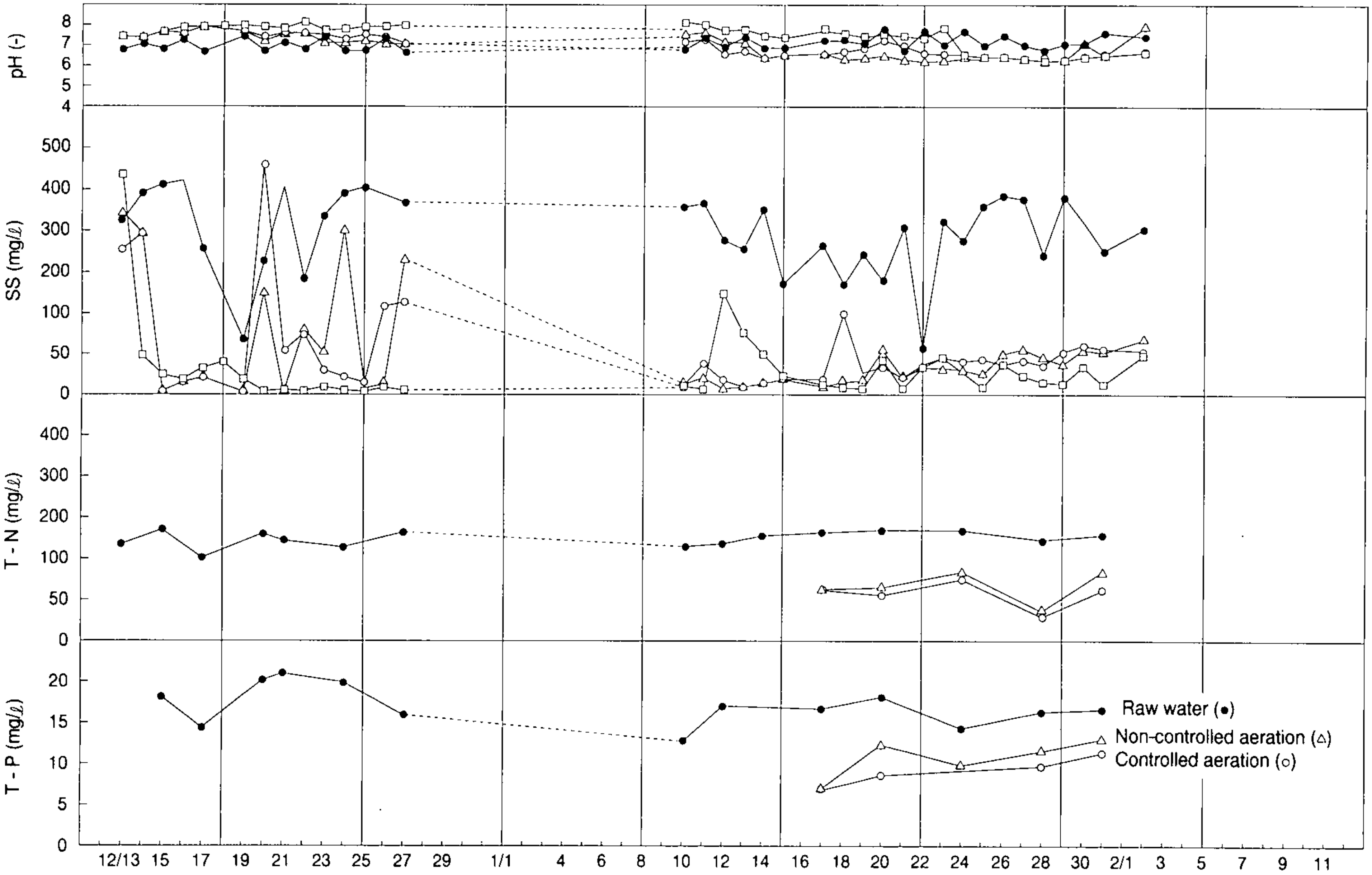


Fig 4-12 Treatment results from the chicken processing plant
(Daily changes in pH, SS, T-N and T-P)

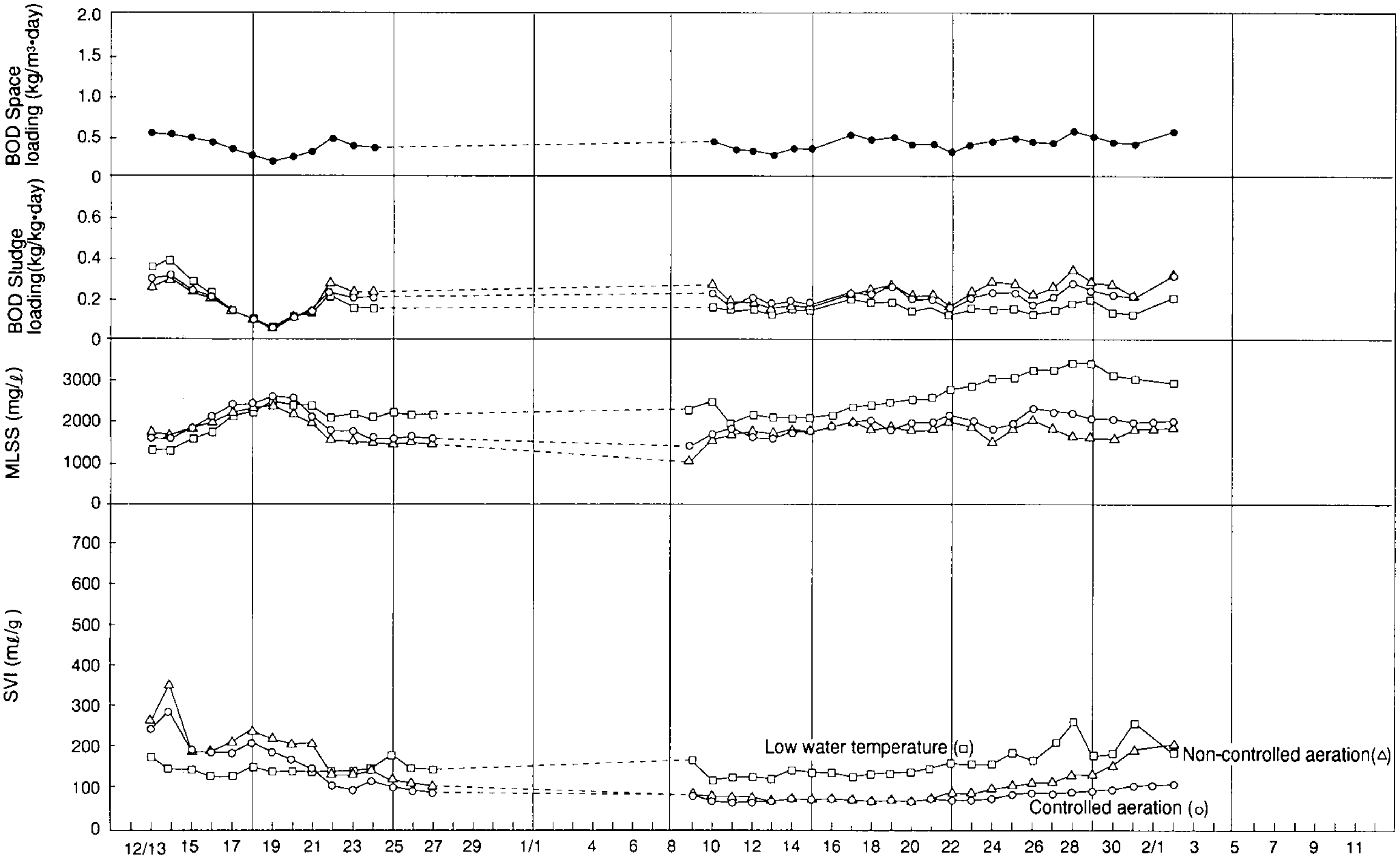


Fig 4-13 Treatment results from the chicken processing plant
(BOD loading, MLSS, SVI)

Table 4-5 Water quality analysis results of the sampled wastewater put through the indoor bench apperatus (Chicken processing plant wastewater)

Date	pH (-)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K-N (mg/)	T-P (mg/)	Color (degree)
Jan.17	7.31	271	409	408 (290)	1034 (769)	176	17.3	416
18	7.25	180	376	349 (272)	890 (670)			
19	7.18	252	374	305 (231)	1030 (730)			262
20	7.82	200	244	273 (200)	770 (580)	180	18.6	226
21	6.83	320	375	406 (290)	840 (660)			
22	7.80	62.5	372	235 (203)	610 (520)			333
23	7.10	312	370	329 (214)	850 (570)			279
24	7.78	292	333	307 (204)	900 (590)	181	14.8	264
25	6.92	378	309	398 (223)	970 (590)	-	-	152
26	7.46	420	271	335 (169)	860 (480)	-	-	183
27	7.09	220	330	317 (203)	950 (660)	-	-	216
28	6.81	427	362	455 (291)	1210 (790)	165	17.3	355
29	7.15	283	330	407 (259)	950 (600)	-	-	254
30	7.12	288	304	425 (257)	870 (570)	-	-	251
31	7.78	260	303	317 (195)	800 (470)	178	17.3	223
Feb.1	6.92	372						346
2	7.59	404	382	423 (268)	1210 (790)	-	-	354
n	17	17	16	16	16	5	5	15
$\overline{x}$	7.29	291	340	356	922	176	17.1	274
σ_{n-1}	0.35	95	45	63	153	6	1.4	73

Table 4-6 Analysis results of the treated water from the controlled aeration experiment (20℃)

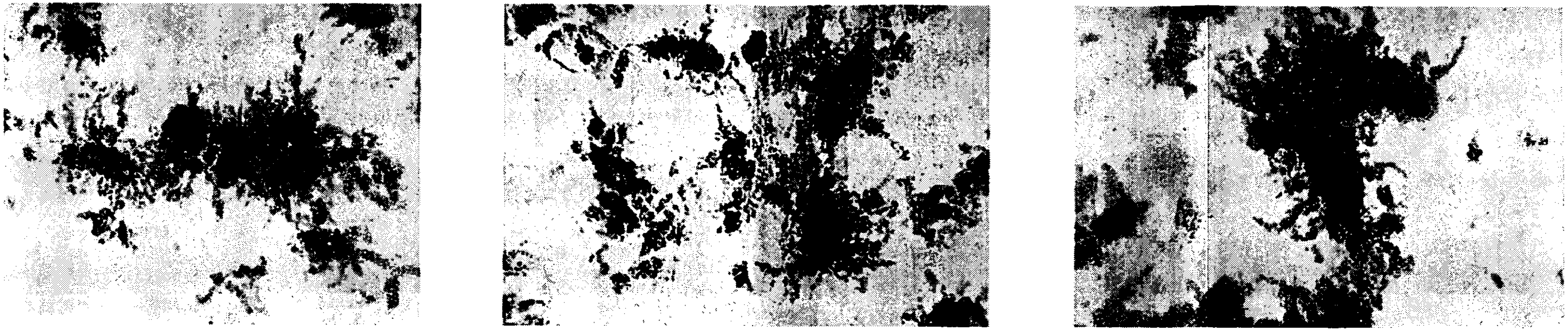
Date	pH (−)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K–N (mg/ℓ)	NO_2–N (mg/ℓ)	NO_3–N (mg/ℓ)	T–P (mg/ℓ)	Color (degree)
Jan.17	6.60	25	24	66.0		31.0	35.0	3.57	7.8	75.6
18	6.79	99	27	112 (64.0)	138 (16)		34.2	4.46		84.5
19	7.03	30	26	79.0	54		33.5	2.68		86.5
20	7.30	41	20	83.2	54	28.6	32.7	3.08	9.3	89.6
21	6.78	26	23	84.7	53		38.6	3.47		80.9
22	6.52	37	32	87.7	45		43.0	6.57		92.2
23	6.49	48	29	100	40 (23)	32.8	41.8	7.06	9.85	98.3
24	6.51	44	26	99.0	31 (20)		42.5	5.89		98.2
25	6.65	49	28	104	32 (19)	−	42.5	5.58	−	103
26	6.62	41	31	98.8	32 (22)	−	39.8	6.57	−	108
27	6.49	48	34	107	43 (26)	(27.9)	3.82	5.57	10.7	115
28	6.71	42	30.8	110	39 (16)	−	38.1	2.88	−	116
29	6.62	56	29	113	62 (19)	−	35.3	3.52	−	129
30	6.61	64	30	121	56 (22)	−	37.7	5.45	−	136
31	6.70	58	33	119	31 (27)	26.9	37.9	3.80	12.4	135
Feb.1										
2	6.78	51	38	112	66 (39)	−	30.4	1.43	−	181.4
n	16	16	16	16	15	5	16	16	5	16
$\overline{x}$	6.70	47	29	100	52	29.4	35.4	4.47	10.0	107
σ_{n-1}	0.21	18	4.5	16	27	2.4	9.3	1.65	1.7	28

Table 4-7 Analysis results of the treated water from the non-controlled aeration experiment (20℃)

Date	pH (－)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K-N (mg/)	NO_2-N (mg/)	NO_3-N (mg/)	T-P (mg/)	Color (degree)
Jan.17	6.61	17	25	60.0	31	17.2	31.6	5.10	7.8	60.2
18	6.35	23	29	64.4	50		25.1	10.6		72.3
19	6.40	24	32	69.1	53		24.3	12.1		70.1
20	6.50	60	31	90.2	125	25.1	28.2	16.8	13.0	83.5
21	6.21	25	28	78.7	50		29.5	10.8		70.8
22	6.28	33	27	81.5	53		35.3	12.4		81.1
23	6.28	37	32	94.0	32 (20)	37.8	40.3	14.0	10.4	90.6
24	6.25	33	31	103	32 (24)		45.2	8.79		103.3
25	6.40	30	41	112	35 (30)	–	49.6	9.43	–	117
26	6.42	58	42	116	59 (33)	–	49.0	9.49	–	123
27	6.41	60	36	126	58 (25)	(37.0)	2.42	5.73	12.4	130
28	6.71	51	38.1	128	36 (25)	–	46.7	3.12	–	116
29	6.60	42	33	118	43 (23)	–	45.7	3.18	–	117
30	6.59	57	33	133	43 (27)	–	49.1	6.19	–	96.4
31	6.53	53	36	127	54 (31)	37.0	48.8	4.48	14.1	96
Feb.1										
2	8.10	75	38	118	62 (39)	–	40.4	2.29	–	112.4
n	16	16	16	16	16	5	16	16	5	16
$\overline{x}$	6.54	42	33	101	51	30.8	37.0	8.41	11.5	96.2
σ_{n-1}	0.44	17	5	25	22	9.3	12.9	4.28	2.5	21.7

Table 4-8 Analysis results of the treated water from the controlled aeration experiment (10-15℃)

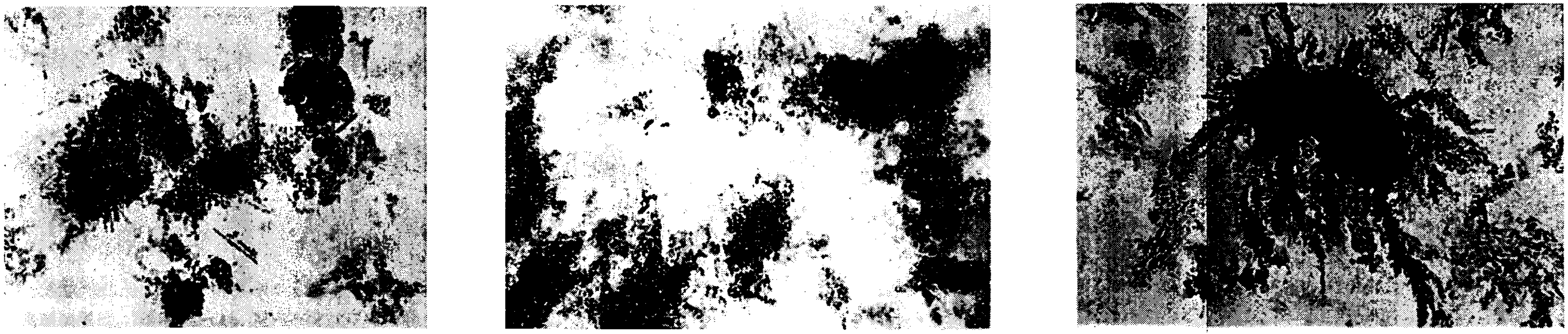
Date	pH (-)	SS (mg/l)	TOC (mg/l)	COD (mg/l)	BOD (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	Color (degree)
Jan.17	7.69	16	23	46.5	32	19.7	2.04	51
18	7.58	15	25	48.1	23	25.8	3.06	60.9
19	7.38	13	26	65.0	31	35.0	3.69	75.6
20	7.62	43	26	75.6	63	24.1	1.68	101
21	7.40	11	20	67.5	15	33.6	6.31	73.9
22	7.79	30	24	60.0	63	25.9	5.15	74.3
23	7.88	45	23	63.5	51 (22)	17.4	1.94	75.4
24			23	8.4	24 (15)	45.4	6.56	
25	6.68	17	26	86.0	17 (11)	43.4	5.35	90.2
26	6.89	43	33	102	81 (37)	35.2	3.03	122
27	6.35	23	29	87.0	31 (21)	37.5	4.15	103
28	6.51	19	31.1	92.0	53 (19)	37.1	1.96	92
29	6.50	21	29	85.4	33 (20)	35.9	2.80	104
30	7.31	39	30	87.2	48 (28)	26.7	2.34	102
31	6.72	14	29	90.6	47 (23)	40.5	10.5	91.4
Feb.1								
2	6.89	46	34	95.8	42 (34)	31.9	2.10	115.2
n	15	15	16	16	16	16	16	15
$\overline{x}$	7.15	26	27	77.3	41	32.2	3.92	89.0
σ_{n-1}	0.52	13	4	16.9	18	8.2	2.37	20.0



1st day (SVI : 75)

4th day (SVI : 70)

7th day (SVI : 79)

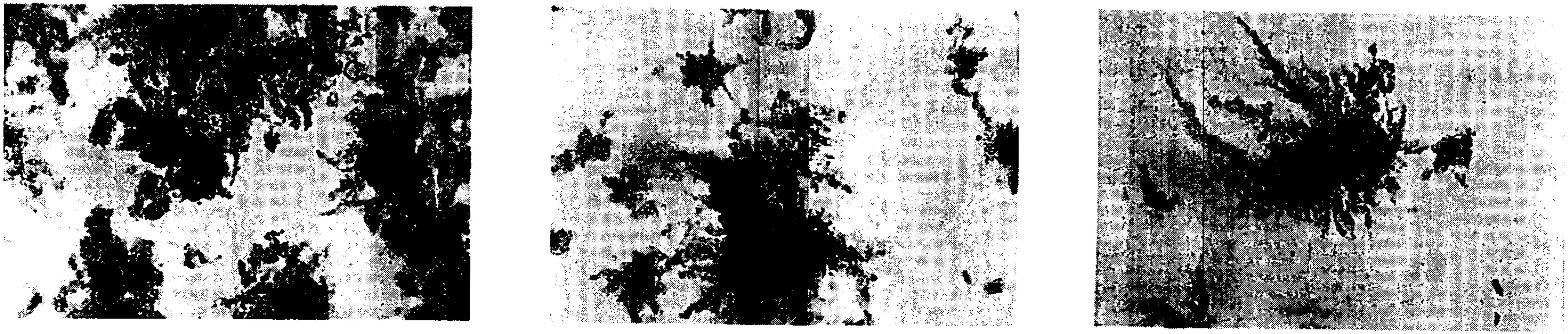


9thday (SVI : 98)

11th day (SVI : 92)

15th day (SVI : 114)

Photo 4-4 Microscope photos of activated sludge (Activated sludge from the controlled aeration experiment on the chicken processing plant wastewater)



1st day (SVI : 76)

4th day (SVI : 78)

7th day (SVI : 95)

9th day (SVI : 113)

11th day (SVI : 116)

15th day (SVI : 199)

Photo 4-5 Microscope photos of activated sludge (Activated sludge from the non-controlled aeration experiment on the chicken processing wastewater)

4-3 Wastewater treatment at the tofu manufacturing plant

At the tofu manufacturing plant, the organic substance load was high, 3420 mg/ ℓ of BOD, and 136mg/ ℓ of nitrogen due to the dewatering (squeezed) wastewater, and nitrogen and phosphorus concentrations were slightly lacking; BOD : N : P = 100 : 4.0 : 0.5.

As for the substrate in the wastewater, as it contained much sugar, it was easy to be biologically treated but filamentous bacteria were also easily generated.

This research compared the treatment efficiencies of controlled and non-controlled aeration in a batch type activated sludge system.

(1) Experimental conditions

- Wastewater for the experiment -

Samples of the actual wastewater from the tofu manufacturing plant were taken at the same frequency as in 3-3 (2).

Figs. 4-14, 4-15 and 4-16 show the non-excess probability of BOD, nitrogen and phosphorus of the sampled wastewater.

In this experiment, the wastewater was adjusted so that the raio of BOD : N : P was 100 : 5 : 1 by additon of urea and monopotassium phosphate.

Since the pollutant load of this wastewater was higher than that of other food industry wastewater, the sampled wastewater was diluted to adjust the BOD concentration to 1000 mg/ ℓ .

- Activated sludge -

In the experiment, activated sludge from a sewage treatment plant with a tendency of winter bulking was used for seeding.

About one month was necessary for the acclimation of sludge.

- Experimental equipment -

Photo 4-1 shows the indoor bench-scale experimental apperatus (capacity of 10 ℓ).

- Experimental conditions -

Experiments were performed under three different conditions, controlled aeration (20℃), non-controlled aeration (20℃) and controlled aeration at a lower water temperature (10 - 15℃).

Fig. 4-4 shows the treatment time schedule.

(2) Treatment result

The treatment result from the tofu manufacturing plant wastewater put through the indoor bench-scale apperatus is shown in Figs. 4-17 and 4-18.

In the controlled aeration experiment (20℃) as acclimation proceeded, organic substances - TOC, COD and BOD - could be removed well.

On the other hand, in the non-controlled aeration experiment (20℃) and the controlled aeration experiment (10 - 15℃), about one week after Jan. 17th, a large amount of sludge remained in the treated water due to poor settling characteristics of the sludge and it lead to an increase in COD and BOD.

PH of the wastwater was acidic, 4-5, due to generation of organic acid by rancidity, but it increased to 7 - 8 in the biologically treated water so that neutralization was not necessary before biological treatment.

Since the nitrogen and phosphorus ratios in the wastewater were low, almost no nitrogen and phosphorus remained in the treated water.

The ratio of phosphorus in the activated sludge was about 1.8 - 1.9 % in both the controlled and non-controlled aeration experiments and there was no difference in the sludge ratio according to the aeration method.

(3) Comparison of activated sludge properties between the controlled and non-controlled aeration methods

Fig. 4-19 shows the treatment result of BOD loading and sludge propreties when using the tofu manufacturing plant wastewater.

SVI, an index of the settling characteristics of the activated sludge, changed rastically shortly after Jan. 17th when treatment conditions were changed in the controlled and non-controlled aeration experiment. In the non-controlled aeration experiment (20℃), after only one week filamentous bacteria conditions, appeared SVI 300 - 400.

Even in the controlled aeration experiment (20 ℃), SVI increased for 10 days after Jan. 17th.

This was because filamentous bacteria were not decomposed due to insufficient withdrawal of sludge volume, and SVI decreased gradually after Jan. 25th when the sludge withdrawal volume was increased.

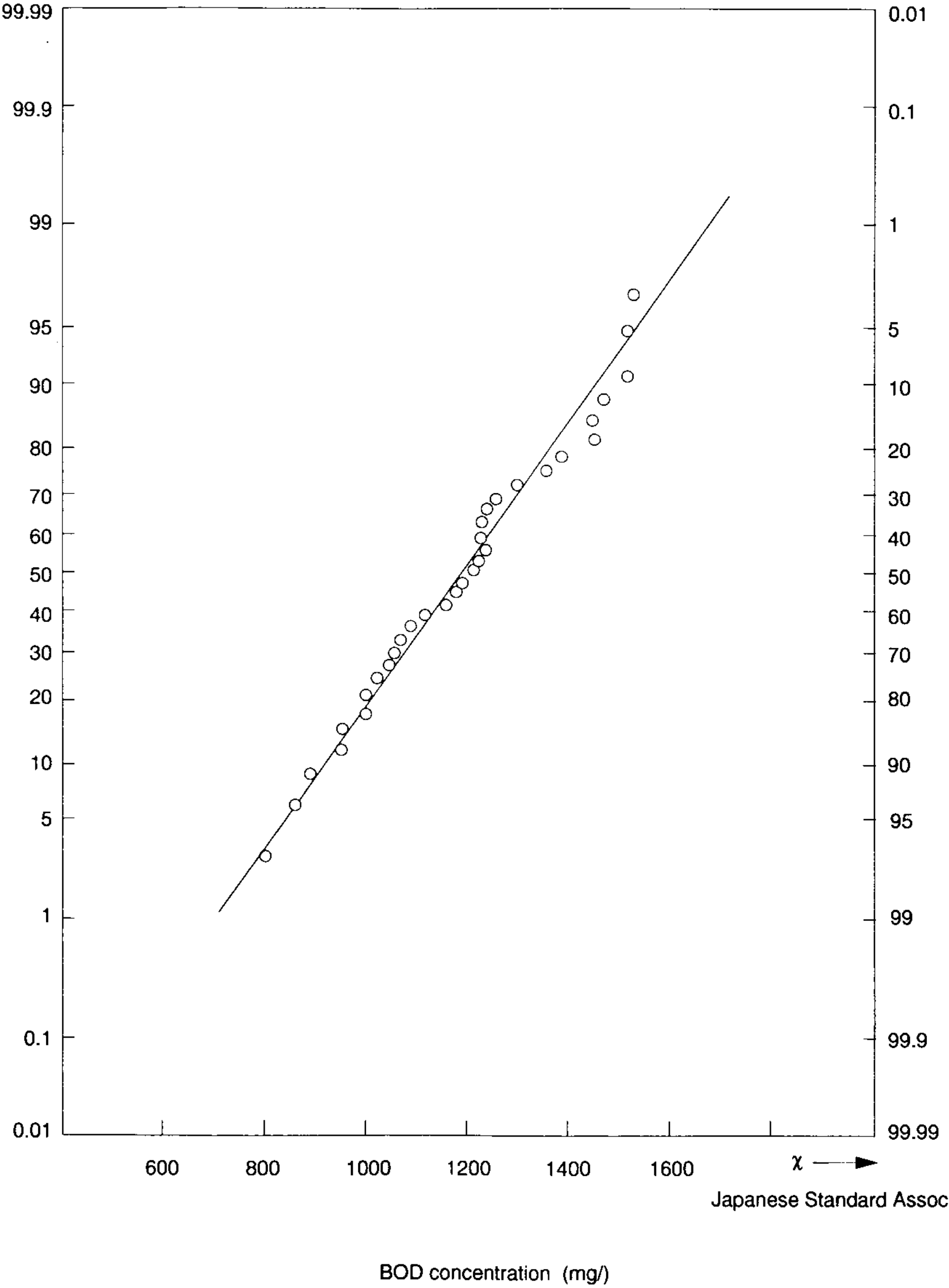
Microscope photos of the activated sludge from the controlled and non-controlled aeration experiments are shown in Photos. 4-6 and 4-7, respectively.

Through a microscope, filamentous bacteria were observed even in the controlled aeration experiment, which implied that the wastewater substrate had a strong tendency to cause bulking.

In the non-controlled aeration experiment, many filamentous bacteria were generated and a parfectly bulked sludge was observed.

In the low water temperature (10 - 15℃) controlled aeration experiment, filamentous bacteria which were included in the seeding sludge were not sufficiently decomposed and it caused poor settling characteristics during the experiment.

On inflow of untreated water, the respiration rate was 72.6 mg - O_2/g - MLSS・Hr in the controlled aeration experiment and 8.65 mg - O_2/g - MLSS ・Hr in the non-controlled aeration experiment and after treatment the endogenous respiration rate was 4.21 and 2.43 mg - O_2/g - MLSS ・Hr, respectively.



Japanese Standard Association

Fig 4-14 BOD concentration non-excess probability of sampled water
(Tofu manufacturing plant wastewater)

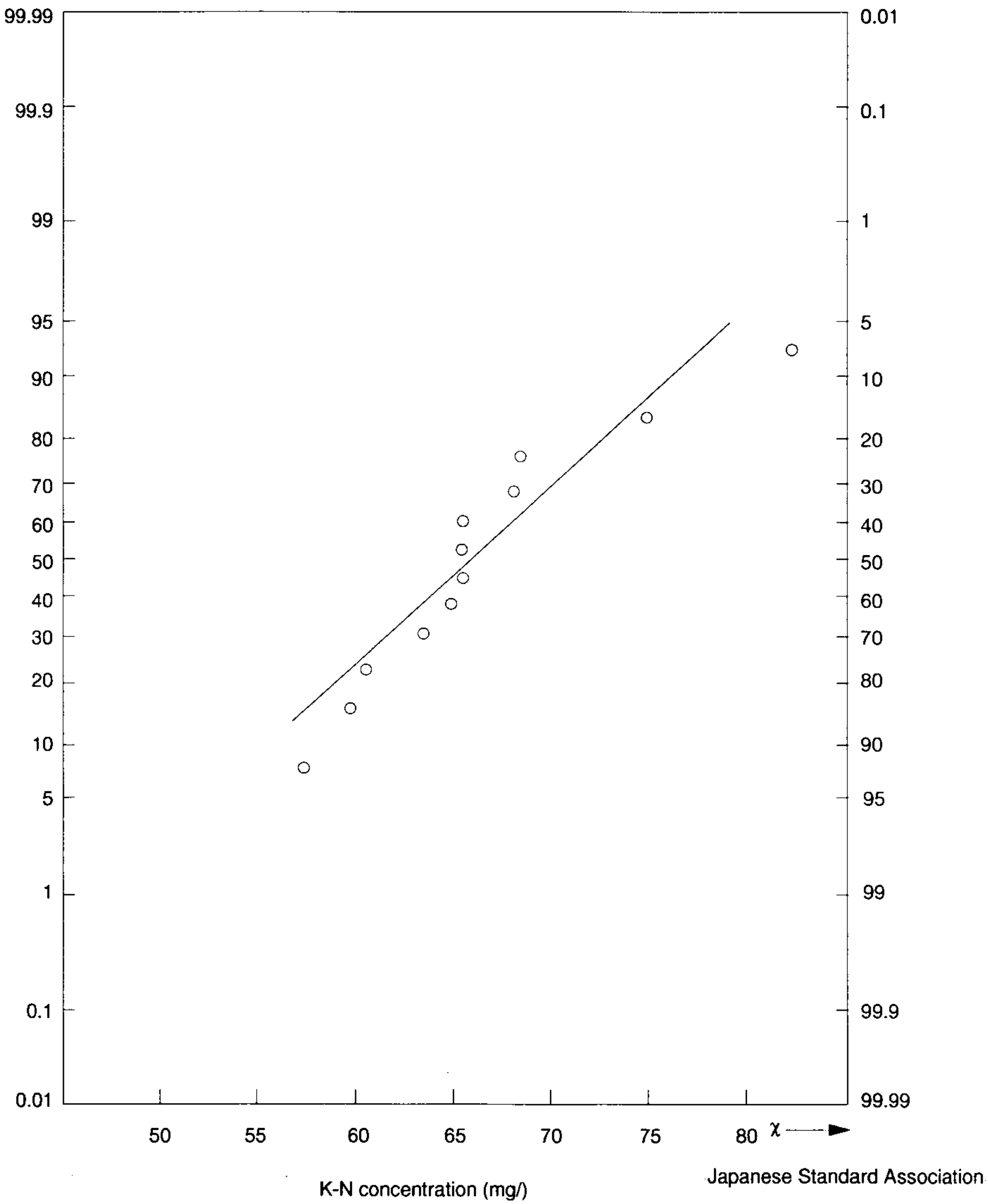


Fig 4-15 K-N concentration non-excess probability of sampled water
(Tofu manufacturing plant wastewater)

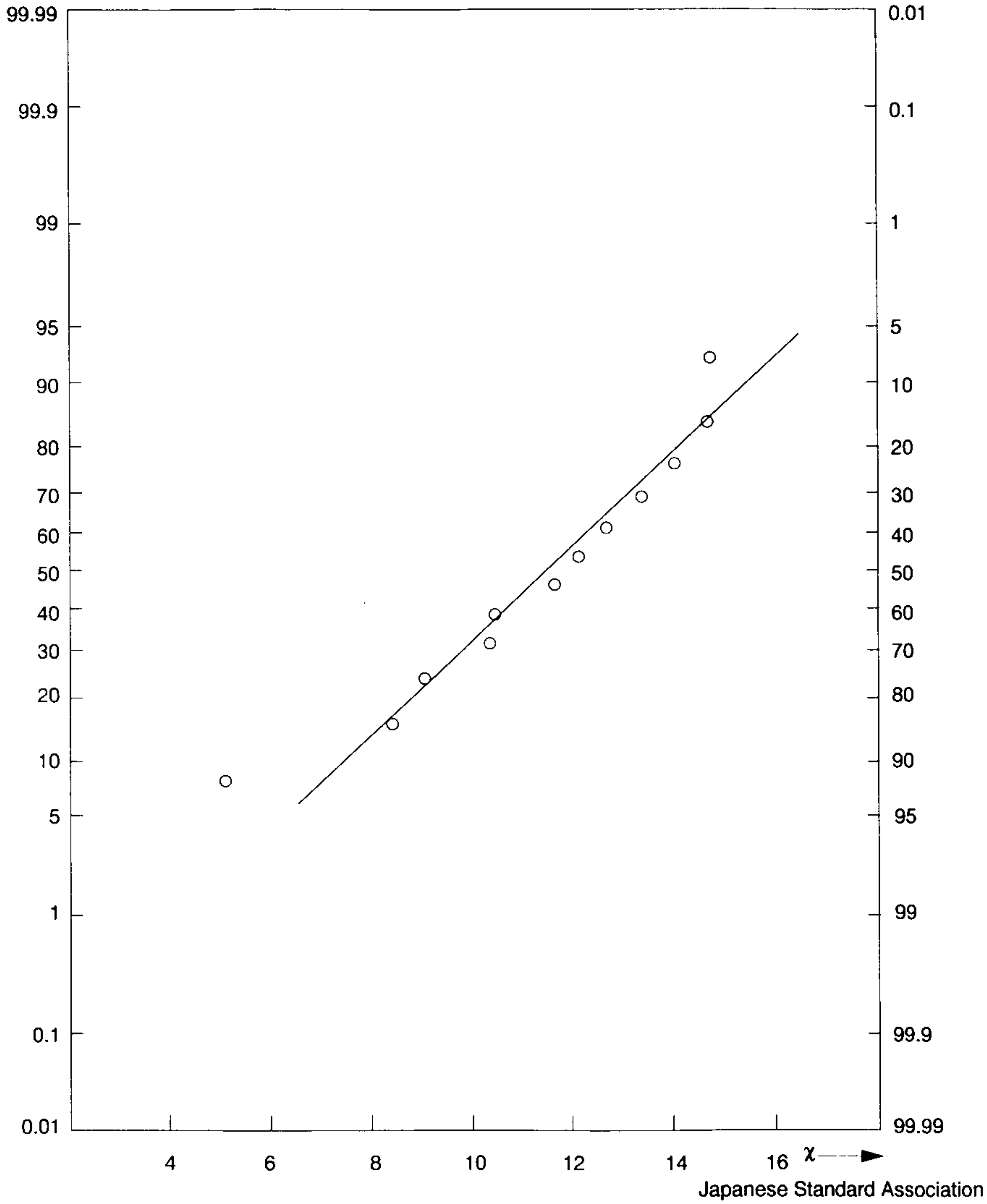


Fig 4-16 T-P concentration non-excess probability of sampled water (Tofu manufacturing plant wastewater)

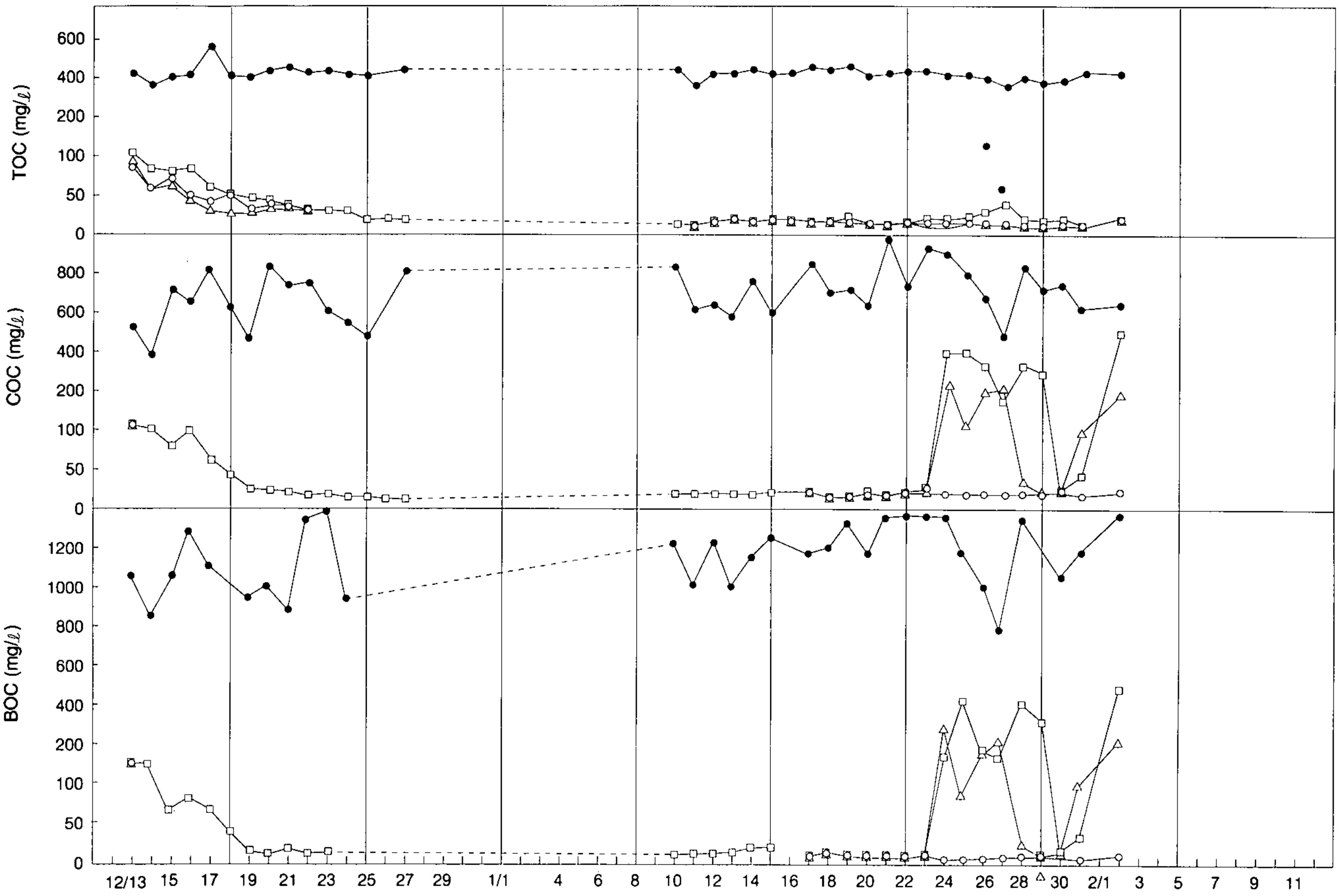


Fig 4-17 Treatment results from the tofu manufacturing plant
(Daily changes in TOC, COD and BOD)

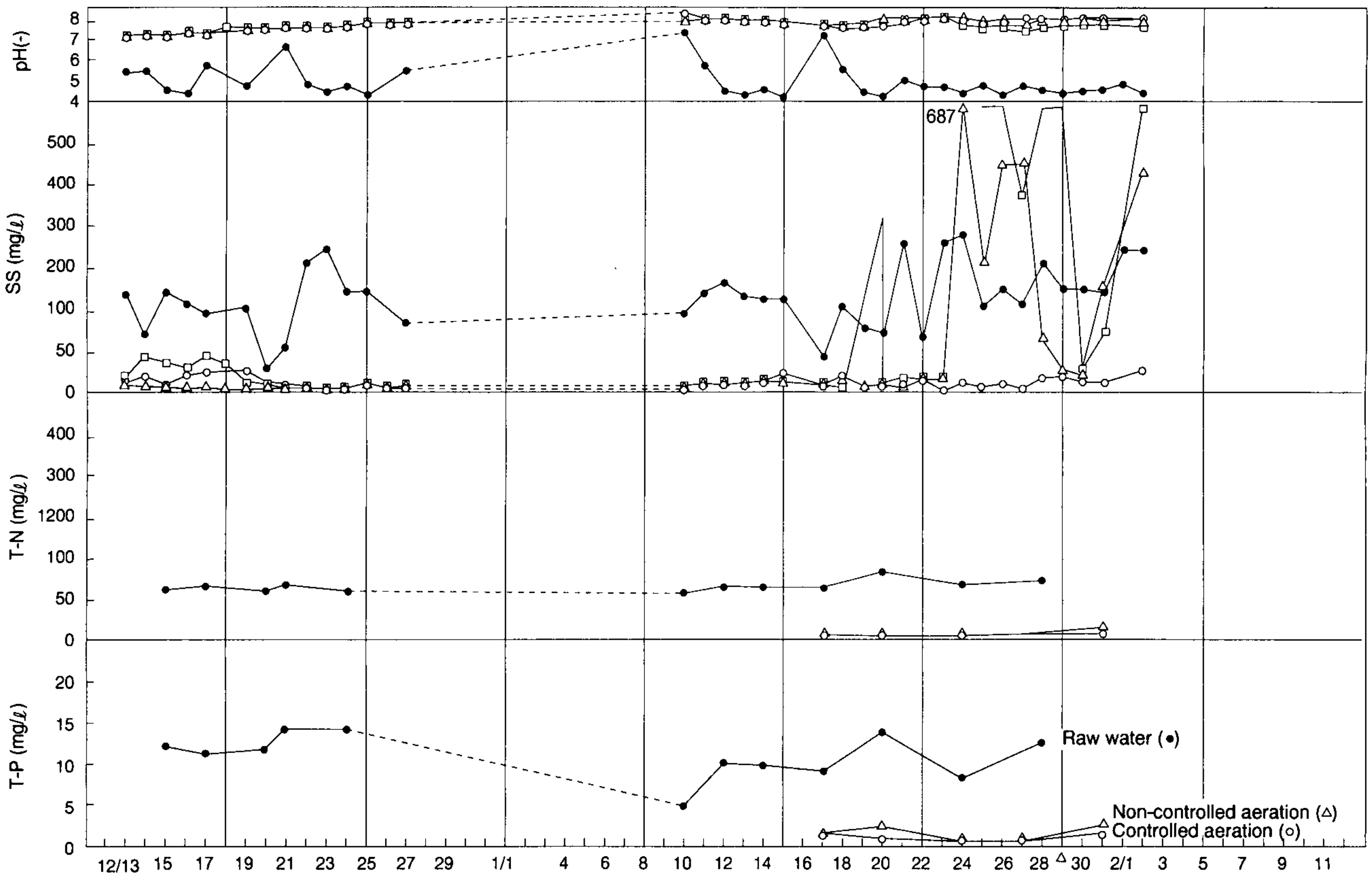


Fig 4-18 Treatment results from the tofu manufacturing plant
(Daily changes in pH, SS, T-N and T-P)

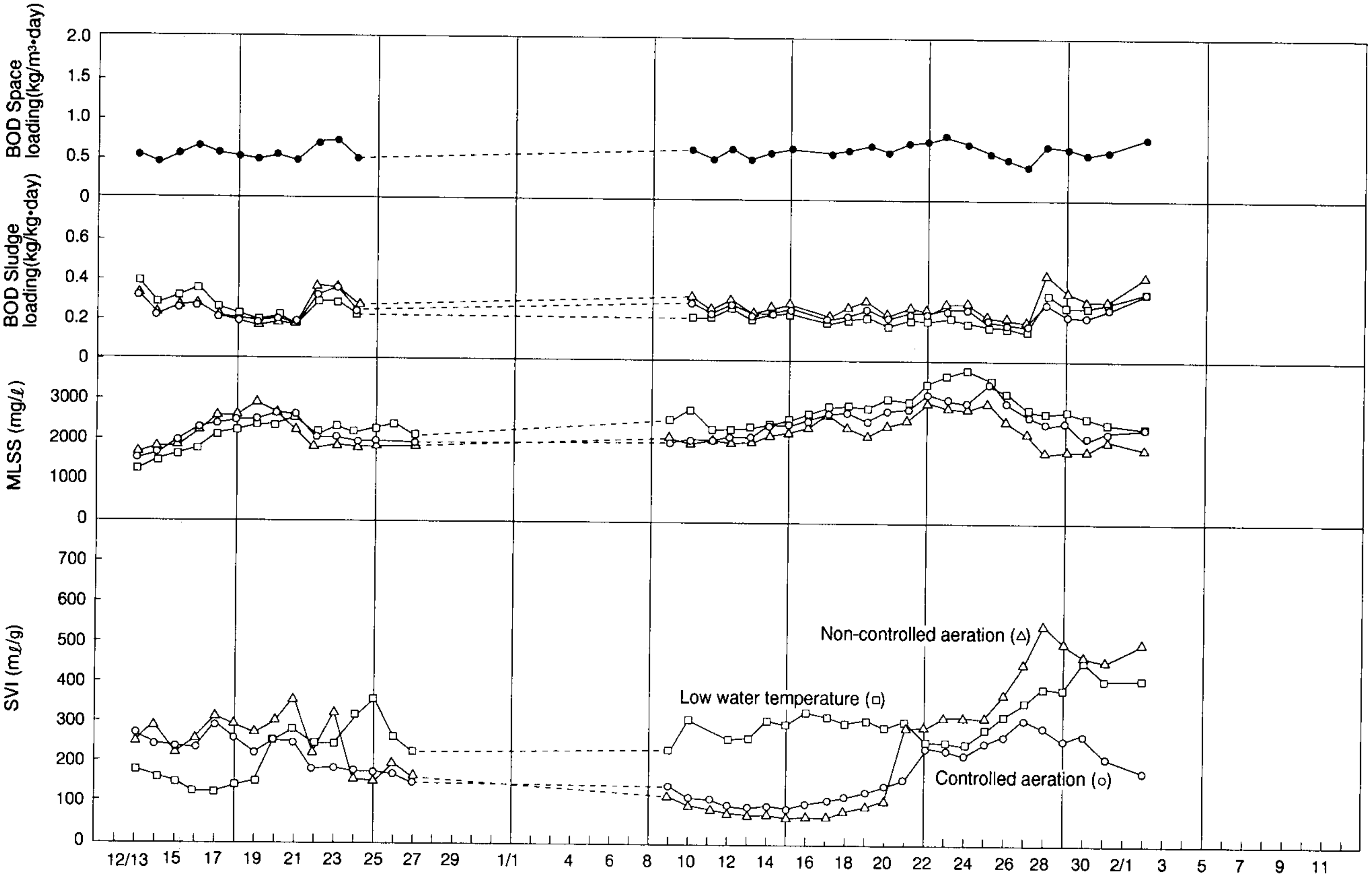


Fig 4-19 Treatment results from the tofu manufacturing plant
(BOD loading, MLSS, SVI)

Table 4-9 Water quality analysis results of the sampled wastewater put through the indoor bench apperatus (Tofu manufacturing plant)

Date	pH (−)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K-N (mg/)	T-P (mg/)	Color (degree)
Jan.17	7.15	41	463	867 (850)	1180 (1110)	65.6	9.1	73
18	5.61	104	448	713 (693)	1230 (1110)			
19	4.49	78	459	733 (693)	1360 (1310)			150
20	4.31	70	416	646 (574)	1190 (1070)	82.3	14.0	150.3
21	5.08	252	422	988 (888)	1390 (1110)			
22	4.69	60	439	720 (670)	1450 (1270)			216
23	4.65	258	430	950 (780)	1520 (1260)			121
24	4.51	276	422	900 (740)	1450 (1310)	68.2	8.3	128
25	4.79	106	412	806 (762)	1210 (1110)	–	–	135
26	4.31	144	410	680 (623)	1060 (940)	–	–	148
27	4.65	106	363	471 (420)	800 (730)	–		73
28	4.55	204	417	854 (780)	1520 (1280)	75.0	13.3	115
29	4.37	134	393	722 (658)	1230 (1130)	–	–	160
30	4.42	138	392	750 (608)	1090 (1000)		–	140
31	4.48	132	440	631 (509)	1220 (1110)			
Feb.1	4.69	236						131
2	4.32	238	429	646 (508)	1530 (1100)	–	–	140.5
n	17	17	16	16	16	4	4	14
$\bar{x}$	4.77	152	422	755	1277	72.8	11.2	134
σ_{n-1}	0.69	77	26	134	200	7.5	2.9	35

Table 4-10 Anaylsis results of the treated water from the controlled aeration experiment (20℃)

Date	pH (−)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K−N (mg/)	NO_2−N (mg/)	NO_3−N (mg/)	T−P (mg/)	Color (degree)
Jan.17	7.85	8	19	20.0		6.0	0.26	<0.01	1.7	25.1
18	7.70	17	18	20.8	12		0.06	0.08		22.4
19	7.73	7	20	19.8	9		0.70	0.22		25.8
20	7.95	8	14	17.6	9	2.2	0.29	0.11	0.9	29.5
21	8.09	14	16	21.1	13		0.88	0.21		24.5
22	8.16	15	17	19.9	13		0.38	0.13		25.5
23	8.22	2	15	20.4	9	3.1	0.21	0.12	0.03	27.6
24	8.10	10	15	20.7	5		0.06	0.03		27.3
25	7.89	6	16	20.7	5	−	0.03	0.04	−	27.5
26	8.11	9	14	18.4	7	−	0.19	0.05	−	22.4
27	8.18	7	14	20.5	12	7.8	0.30	0.12	0.47	25
28	8.20	17	13.5	20.6	15	−	0.86	0.10	−	26.6
29	8.15	19	13	21.4	16	−	0.87	0.13	−	26.6
30	8.12	11	14	19.2	9	−	0.81	0.14	−	24.4
31	8.11	12	14	18.8	11	5.9	0.99	0.11	1.9	24.4
Feb.1										
2	8.09	25	22	22.8	15	−	1.01	0.10	−	25.7
n	16	16	16	16	15	5	16	16	5	16
$\overline{x}$	8.04	12	16	20.2	11	5.0	0.49	0.11	1.0	25.6
σ_{n-1}	0.16	5.8	2.6	1.3	4	2.3	0.36	0.06	0.8	1.9

Table 4-11 Anaylsis results of the treated water from the non- controlled aeration experiment (20℃)

Date	pH (-)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K-N (mg/)	NO_2-N (mg/)	NO_3-N (mg/)	T-P (mg/)	Color (degree)
Jan.17	7.99	9	18	19.0	6	2.1	0.28	<0.01	1.7	23.7
18	8.00	15	16	14.8	7		0.04	0.04		12.3
19	8.10	6	17	16.6	7		0.33	0.14		16.7
20	8.10	10	14	17.2	9	6.3	0.29	0.13	2.3	14.2
21	8.20	8	12	17.8	8		0.32	0.14		11.9
22	8.10	23	15	18.0	9		0.35	0.11		17.8
23	8.12	13	14	17.4	7	4.7	0.03	0.04	<0.01	27.6
24	7.79	687	14	256 (17.3)	290 (6)		<0.01	0.01		31.4
25	7.88	197	15	103 (17.5)	89 (7)	-	0.04	0.04	-	28.3
26	7.88	443	14	201 (16.8)	190 (7)	-	0.04	0.02	-	23.1
27	7.92	447	13	202 (16.1)	230 (7)	(8.6)	0.02	0.04	0.08	22
28	8.15	61	11.9	35.0	26	-	0.34	0.11	-	17.4
29	8.15	23	12	22.8	13	-	0.44	0.16	-	17.4
30	8.15	18	13	18.6	8	-	0.24	0.12	-	18.5
31	8.05	156	15	102 (15.4)	100 (10)	(11.6)	0.19	0.04	2.9	21.1
Feb.1										
2	8.18	430	22	204 (14.2)	223 (6)	-	0.88	0.18	-	16.1
n	16	16	16	16	16	5	16	16	5	16
$\overline{x}$	8.05	159	15	79.1	76	6.7	0.24	0.08	1.4	20.0
σ_{n-1}	0.12	219	3	87.0	100	3.6	0.23	0.06	1.3	5.7

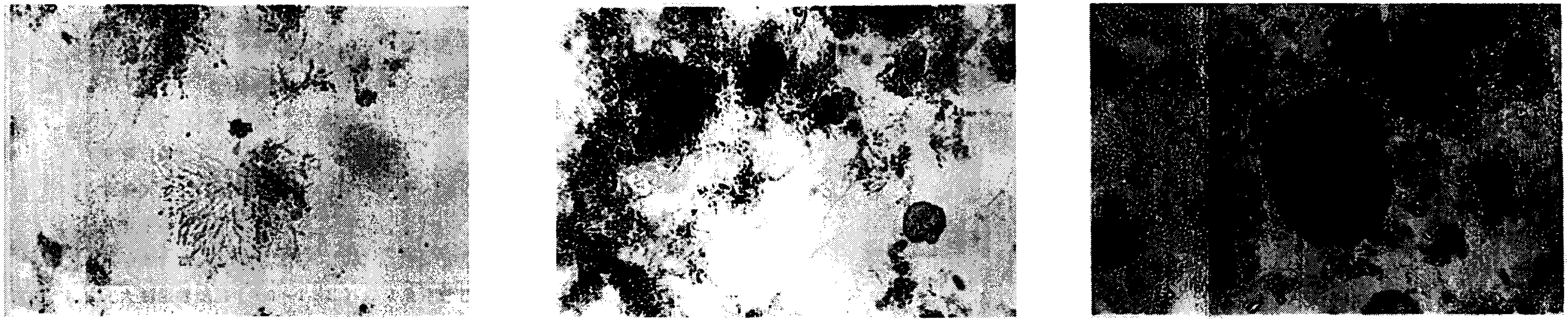
Table 4-12 Anaylsis results of the treated water from the controlled aeration experiment (10-15℃)

Date	pH (－)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	NO_2-N (mg/)	NO_3-N (mg/)	Color (degree)
Jan.17	7.80	11	23	24.3	13	0.03	<0.01	39.2
18	7.72	7	18	16.3	7	0.05	0.01	24.7
19	7.80	6	20	19.2	10	0.04	0.02	31.2
20	7.79	311	-	25.4	14	0.04	0.02	62.2
21	7.90	5	14	20.2	10	0.04	0.03	27.7
22	8.16	10	19	19.6	12	0.05	0.04	39.3
23	7.90	19	23	26.5	17	0.07	0.05	53.3
24	7.65	1300	22	407 (24.7)	182 (24)	0.02	0.03	
25	7.71	940	22	404 (27.7)	450 (13)	0.02	0.04	50.6
26	7.70	675	31	340 (29.0)	194 (16)	0.04	0.04	60
27	7.50	381	37	174 (19.8)	178 (11)	0.04	0.03	41.4
28	7.62	1060	16.6	347 (20.2)	450 (11)	0.02	0.02	40.4
29	7.69	778	15	300 (17.6)	340 (7)	0.03	0.02	36.6
30	7.89	21	17	26.6	17	0.04	0.05	45
31	7.79	74	16	44.7	39	0.05	0.03	35.1
Feb.1								
2	7.78	1305	23	512 (16.8)	500 (8)	0.07	0.03	33.2
n	16	16	15	16	16	16	16	15
$\overline{x}$	7.78	431	21	169	152	0.04	0.03	41.3
σ_{n-1}	0.15	499	6	182	184	0.02	0.01	11.1

1st day (SVI : 113)

4th day (SVI : 151)

7th day (SVI : 243)

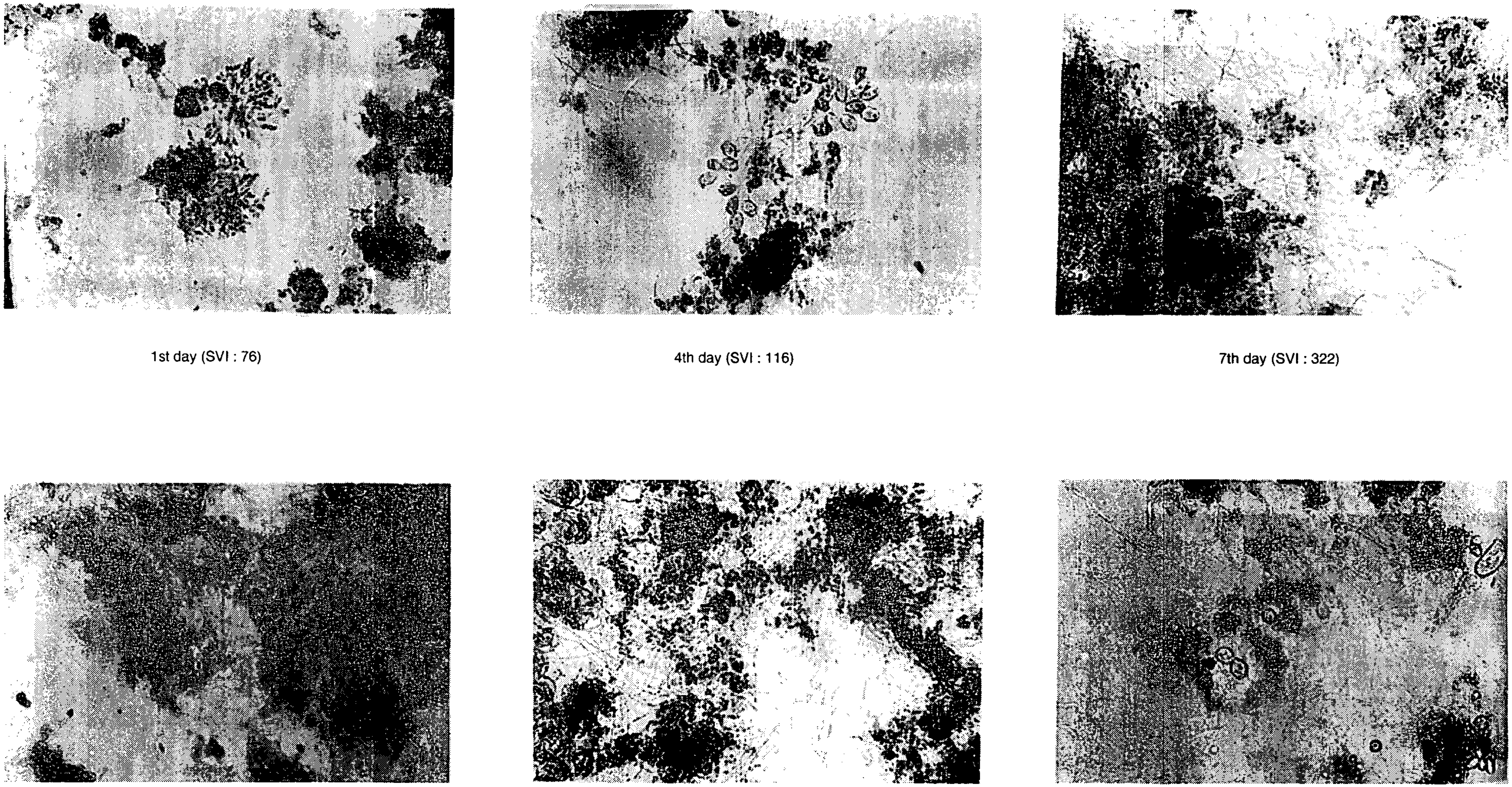


9th day (SVI : 256)

11th day (SVI : 317)

15th day (SVI : 229)

Photo 4-6 Microscope photos of activated sludge (Activated sludge from the controlled aeration experiment on the bean curd manufacturing wastewater)



1st day (SVI : 76)

4th day (SVI : 116)

7th day (SVI : 322)

9th day (SVI : 311)

11th day (SVI : 447)

15th day (SVI : 465)

Photo 4-7 Microscope photos of activated sludge (Activated sludge from the non-controlled aeration experiment on the bean curd manufacturing plant wastewater)

4-4 Wastewater treatment at the noodle manufacturing plant

In the noodle manufacturing plant, the pollutaion load of the wastewater was high due to wastewater from the boiler. On draining the BOD concentration was high and bulking occurred easily because the nutrition was unbalanced; BOD : N : P = 100 : 1.6 : 0.3.

This research compared the treatment efficiencies of controlled and non-controlled aeration using a batch type activated sludge method.

(1) Experimental conditions

- Wastewater for the experiment -

Samples of the actual wastewater from the noodle manufacturing plant were taken at the same frequency as in 3-4 (2).

Figs. 4-20, 4-21 and 4-22 show the non-excess probability of BOD, nitrogen and phosphorus of the sampled wastewater.

In this experiment, since nitrogen was lacking, urine and ammonium sulfate at a nitrogen ratio of 3 : 7 were added and phosphorus was adjusted through addition of monopotassium phosphate in the ratio, BOD : N : P = 100 : 5 : 1.

- Activated sludge -

In this experiment, activated sludge from a sewage treatment plant with a tendency of winter bulking was used for seeding.

About one month was necessary for acclimation.

- Experiment equipment -

Photo 4-1 shows the indoor bench-scale experimental apperatus (capacity of 10 ℓ).

- Experiment conditions -

Experiments were performed under three different conditions, controlled aeration (20 ℃), non-controlled aeration (20℃) and controlled aeration with a lower water temperature (10 - 15℃).

Fig. 4-4 shows the treatment time schedule.

(2) Treatment result

Figs. 4-23 and 4-24 shows the treatment result from the noodle manufacturing plant wastewater put through the indoor bench-scale apperatus.

The wastewater pullutant was mainly one substrate, starch, due to elution of the raw material wheat flour, and for the treatment of organic pollutants about two weeks were necessary for acclimation, which was different compared to the other food industy wastewater.

After Jan. 17th when acclimation finished, the removal efficiency of organic pollutants - TOC, COD and BOD - was good in the controlled aeration experiment (20℃) and non-controlled aeration experiment (20 ℃).

In the controlled aeration experiment (10 - 15℃), even after finishing acclimation, due to SS in the treated water, COD and BOD sometimes increased but it was not common.

Since the nutrients, nitrogen and phosphorus, were added to increase their ratios, a smale amount remained in the treated water.

The phosphorus ratio in the activated sludge was about 1.9 - 2.0 % and there was no difference in the uptake ratio between the controlled and non-controlled aeration experiments.

On the other hand, phosphorus in the treated water was high in the controlled aeration experiment compared to the non-controlled one.

(3) Comparison of activated sludge properties between the controlled and non-controlled aeration methods

Fig. 4-25 shows the treatment result of BOD loading and sludge properties when using the noodle manufacturing plant wastewater.

As in the experiment using the tofu manufacturing plant wastewater, a change in SVI, an index of the settling characteristics of the activated sludge, appeared relatively soon after Jan. 17th when treatment conditions were changed in the controlled and non-controlled aeration experiments.

In the controlled aeration esperiment (20℃), SVI was stable at around 120 but in the non-controlled aeration experiment (20℃), after about one week SVI rose to more than 300 and filamentous bacteria were observed.

Following that by increasing the sludge withdrawal volume, SVI decreased to around 200 even in the non-controlled aeration experiment (20℃) and the settling characteristics improved.

Microscope photos of the activated sludge from the controlled and non-controlled aeration experiments are shown in Photos 4-8 and 4-9, respectively.

Through a microscope, filamentous bacteria in the activated sludge were observed 4 days after starting the non-controlled aeration experiment (20℃).

At low temperature a bulking sludge was caused by filamentous bacteria because the mechanism of bacterial decomposition by the substrate concentration gradient could not be fully utilized due to insufficient withdrawal of sludge.

On inflow of untreated water, the respiration rate was 78.7 mg - O_2/g - MLSS · Hr in the controlled aeration experiment and 8.72 mg - O_2/g - MLSS · Hr in the non-controlled aeration experiment and after treatment the respiration rate was 2.19 and 1.95 mg - O_2/g - MLSS · Hr, respectively.

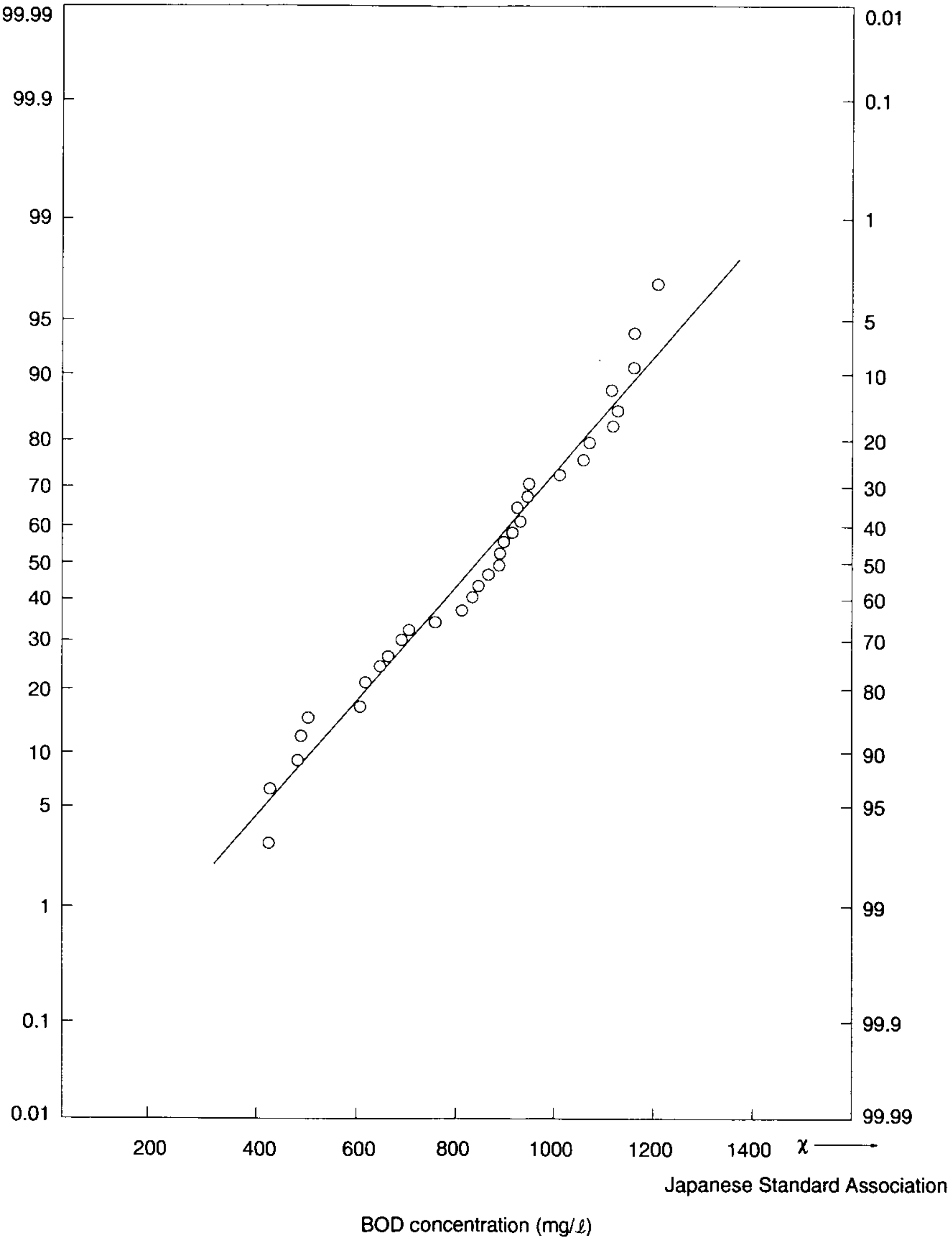


Fig 4-20 BOD concentration non-excess probability of sampled water
(Noodle manufacturing plant)

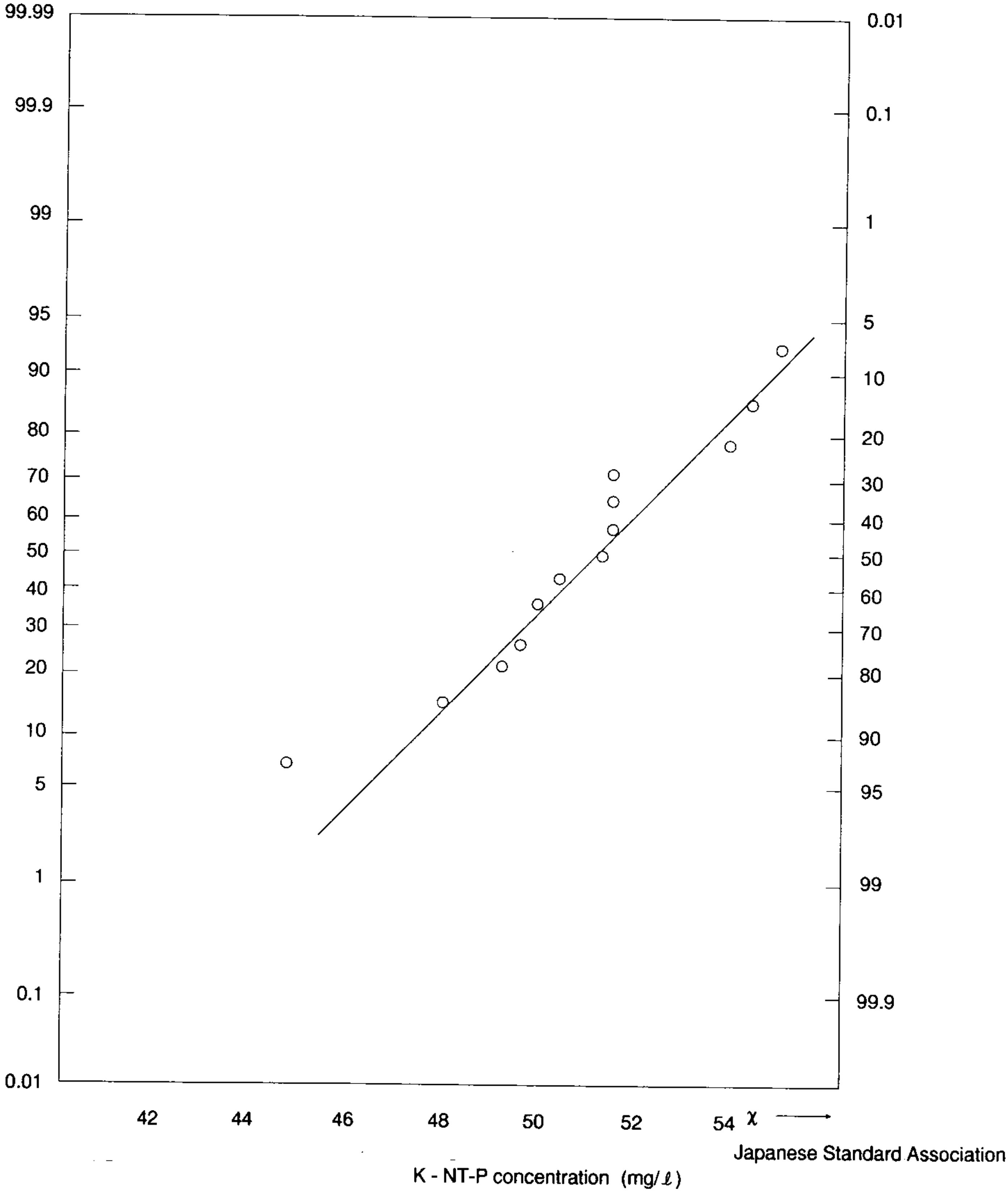


Fig 4-21 K-N concentration non-excess probability of sampled water
(Noodle manufacturing plant)

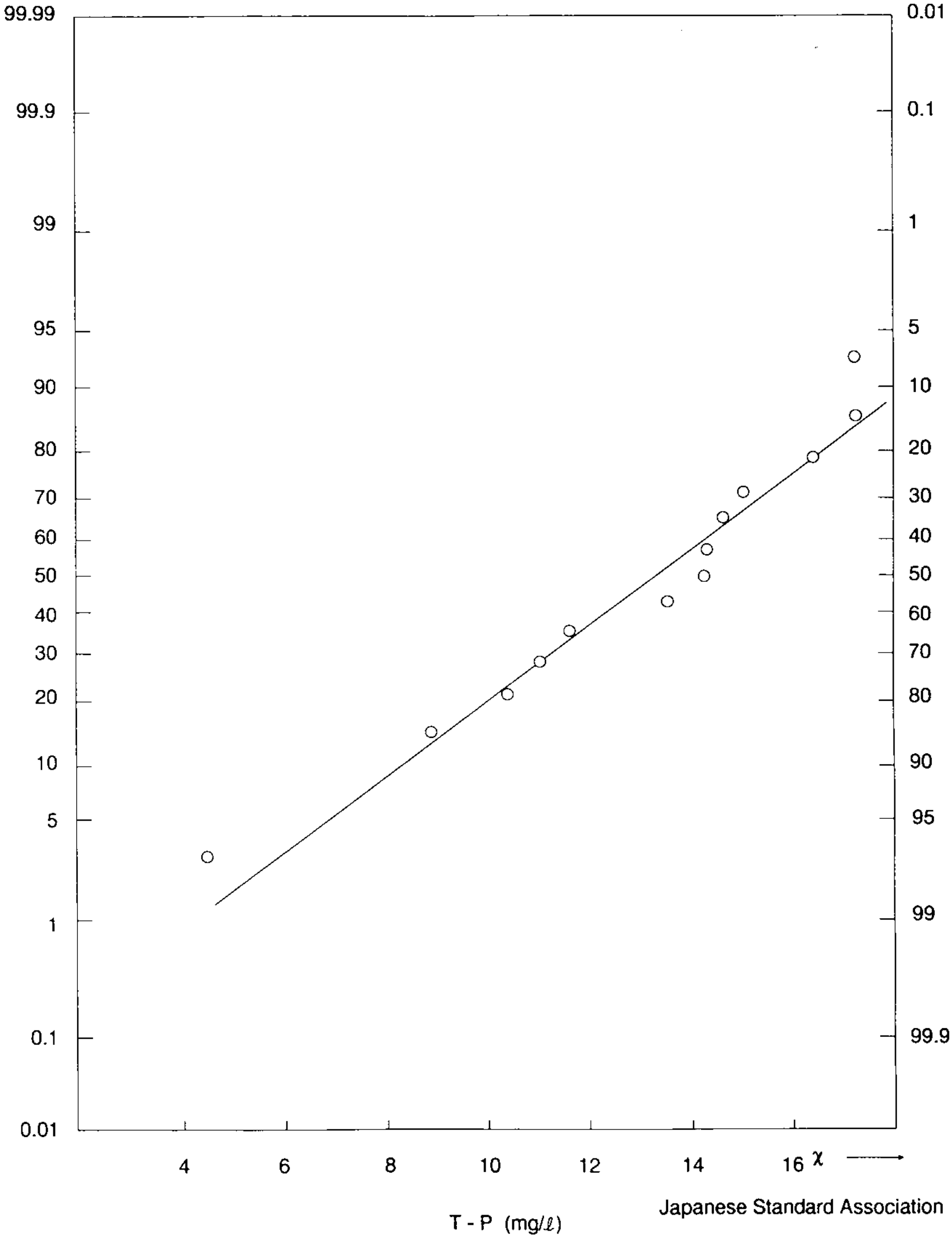


Fig 4-22 T-P concentration non-excess probability of sampled water
(Noodle manufacturing plant)

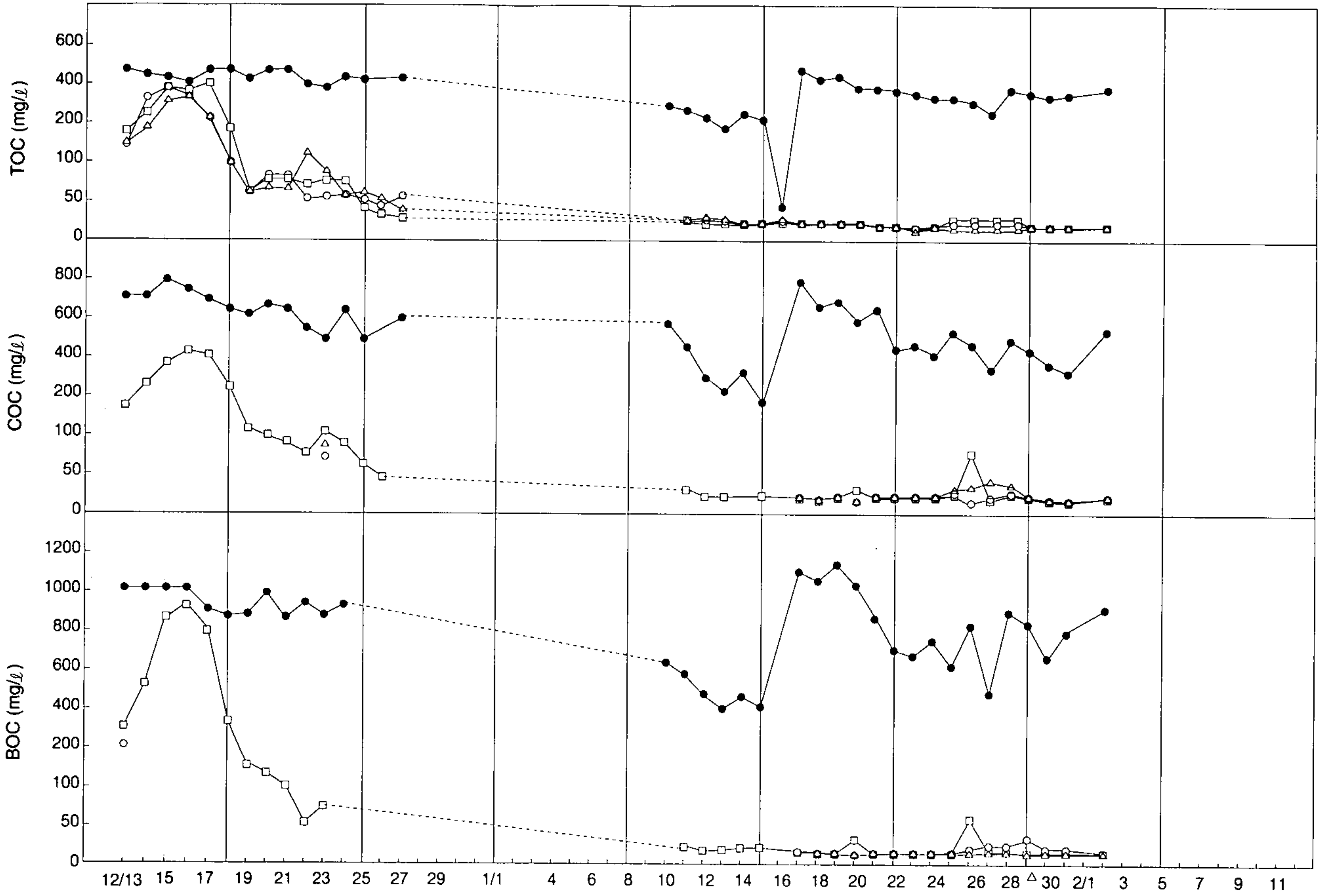


Fig 4-23 Treatment results from the noodle manufacturing plant
(Daily changes in TOC, COD and BOD)

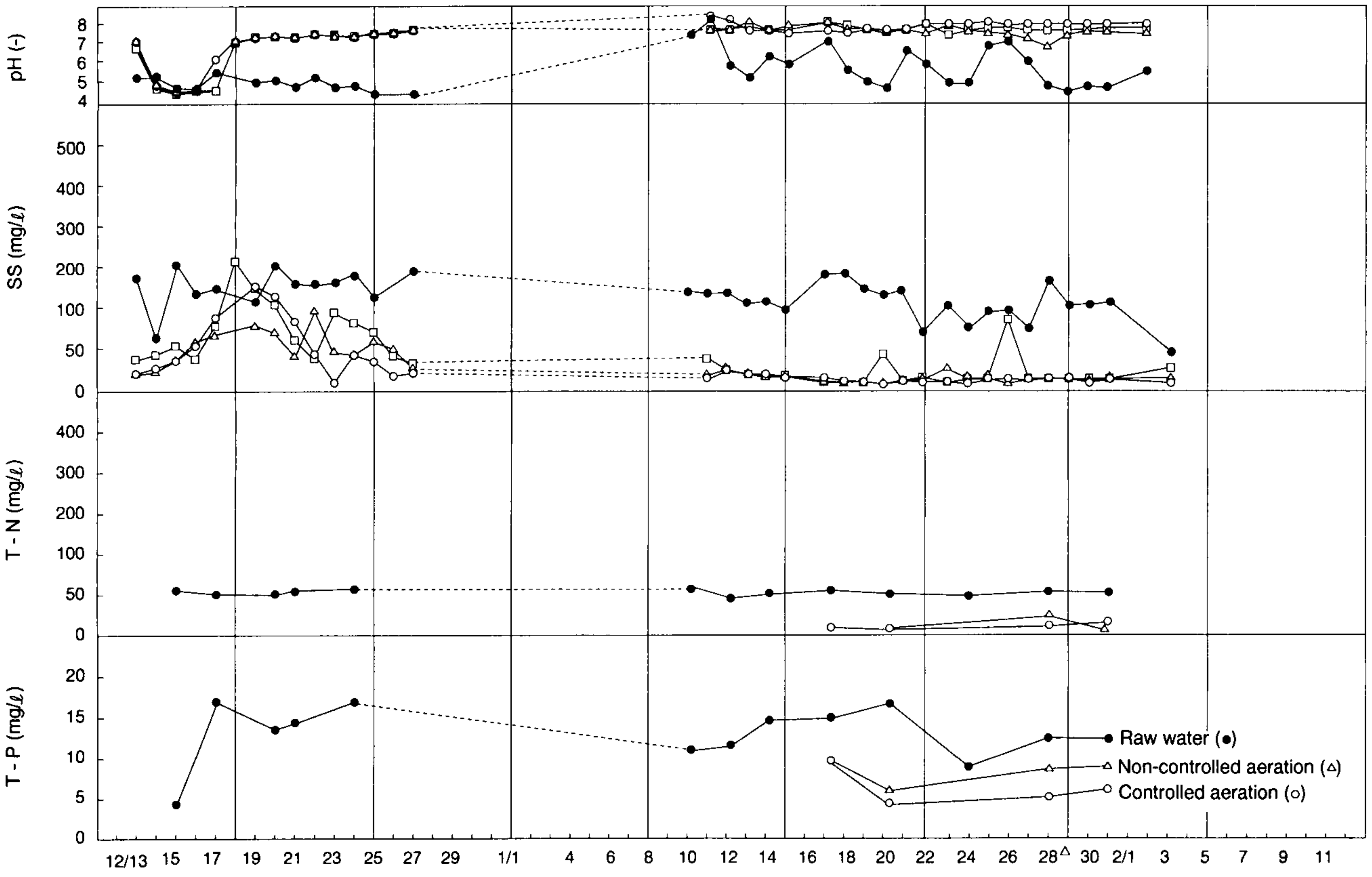


Fig 4-24 Treatment results from the noodle manufacturing plant
(Daily changes in pH, SS, T-N and T-P)

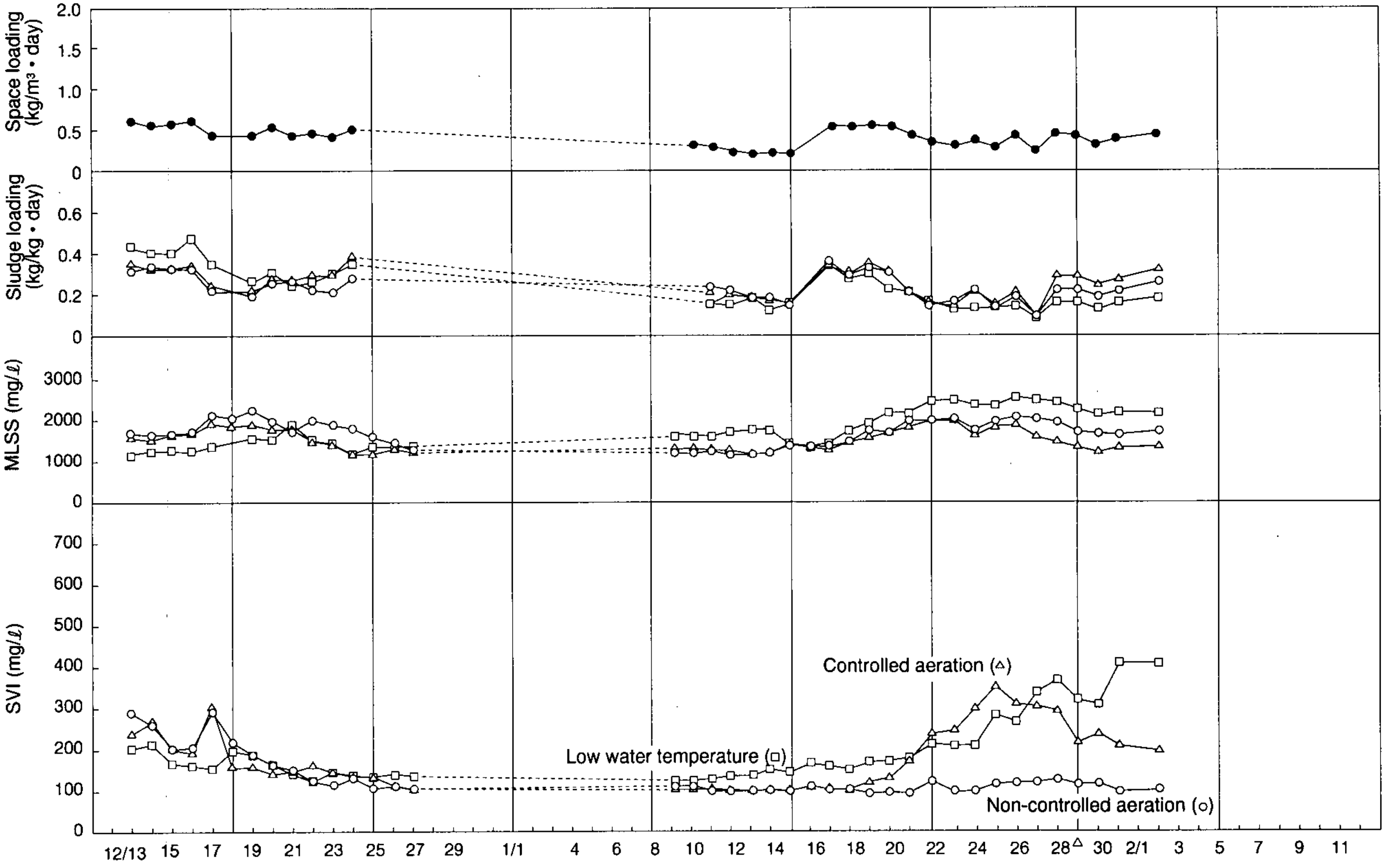


Fig 4-25 Treatment results from the noodle manufacturing plant
(BOD loading, MLSS, SVI)

Table 4-13 Water quality analysis results of the sampled wastewater put through the indoor bench apperatus (Noodle manufacturing plant)

Date	pH (–)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K–N (mg/)	T–P (mg/)	C^- (mg/)	Color (degree)
Jan.17	7.08	176	448	775 (688)	1100 (910)	54.1	15.0	147	50.3
18	5.50	178	417	635 (560)	1050 (840)		1	151	
19	5.00	142	430	677 (581)	1140 (920)			147	34.6
20	4.70	134	359	570 (500)	1040 (830)	49.8	6.4	147	68.5
21	6.53	142	360	633 (535)	850 (620)			110	
22	5.77	64	360	430 (380)	700 (560)			110	79.1
23	4.92	100	349	446 (380)	680 (560)			107	35.4
24	4.89	78	326	390 (310)	740 (600)	47.8	8.9	107	76.7
25	6.79	90	320	514 (429)	610 (560)	–	–	107	42.2
26	7.01	90	286	461 (387)	830 (480)	–	–	103	45
27	5.98	66	238	338 (294)	490 (460)	–	–	–	31
28	4.88	158	360	491 (421)	900 (750)	51.1	10.4	–	29
29	4.55	92	339	421 (375)	820 (700)	–	–	95.6	68
30	4.68	106	315	365 (295)	660 (600)	–	–	91.9	58.4
31	4.71	106	337	306 (237)	800 (290)	51.3	14.2	99.4	71
Feb.1	5.35	78							42.4
2	5.43	38	372	524 (424)	910 (780)	–	–	100	70.7
n	14	17	16	16	16	5	5	14	15
$\overline{x}$	5.52	108	351	498	832	50.8	13.0	117	53.5
σ_{n-1}	0.83	41	52	131	185	2.3	3.2	21	17.7

Table 4-14 Analysis results of the treated water from the controlled aeration experiment (20℃)

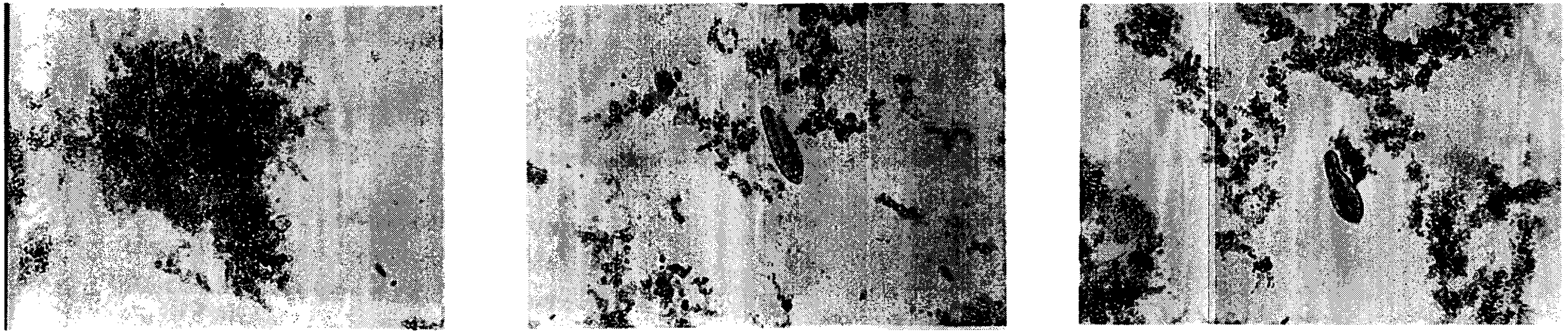
Date	pH (−)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K-N (mg/)	NO_2-N (mg/)	NO_3-N (mg/)	T-P (mg/)	Color (degree)
Jan.17	8.32	7	15	17.3		6.8	0.34	<0.01	9.5	
18	7.95	10	14	13.8	5		0.24	0.15		
19	7.88	5	15	16.4	7		0.30	0.09		
20	7.75	6	16	15.3	6	1.4	0.15	0.08	4.4	21.6
21	7.89	7	14	18.8	10		0.15	0.06		
22	8.03	12	13	15.2	10		0.41	0.12		
23	8.10	11	13	17.7	12	12.8	0.28	0.21	4.13	
24	8.09	7	13	17.8	15		0.64	0.12		31.1
25	8.02	7	13	17.8	12	–	0.94	0.13	–	32.1
26	7.91	13	13	18.6	19	–	1.26	0.19	–	34.2
27	7.99	11	13	19.7	20	16.0	1.42	0.17	5.30	35
28	7.99	12	11.4	18.9	20	–	1.78	0.12	–	28.4
29	8.17	–	12	23.6	27	–	2.17	0.18	–	31.1
30	8.01	11	12	20.0	13	–	2.96	0.47	–	36.4
31	8.09	10	10	15.8	11	12.6	3.02	0.31	6.1	16
Feb.1										
2	8.11	8	15	16.2	6	–	2.58	0.20	–	12.9
n	16	15	16	16	15	5	16	16	5	10
$\bar{x}$	8.02	9	13	17.7	13	9.8	1.20	0.16	5.9	27.9
σ_{n-1}	0.13	3	2	2.3	6	5.9	1.02	0.11	2.2	8.2

Table 4-15 Analysis results of the treated water from the non-controlled aeration experiment (20℃)

Date	pH (–)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K–N (mg/)	NO_2–N (mg/)	NO_3–N (mg/)	T–P (mg/)	Color (degree)
Jan.17	8.39	8	16	15.7	6	27.2	0.53	<0.01	9.5	
18	7.82	6	13	13.3	6		1.18	0.34		
19	7.72	4	14	16.2	9		0.65	0.18		
20	7.75	5	13	16.6	9	2.1	0.40	0.11	6.0	30.6
21	7.89	1	14	19.9	12		0.62	0.11		
22	7.79	5	14	16.8	9		2.35	0.65		
23	7.90	23	10	17.6	7	11.9	3.75	1.17	5.80	
24	7.75	9	9	20.0	12		6.10	1.16		19.2
25	7.58	16	10	24.9	7	–	9.18	1.77	–	19.2
26	7.25	9	11	30.3	10	–	13.8	4.01	–	23
27	7.08	11	10	33.4	8	5.9	15.1	2.40	8.52	25
28	6.72	14	10.3	35.1	11	–	16.9	1.30	–	24.8
29	7.59	13	9	24.5	13	–	8.76	2.14	–	20.5
30	7.68	11	10	19.6	7	–	5.59	1.61	–	24.6
31	7.78	7	9	18.7	7	4.9	6.85	1.59	8.3	12.6
Feb.1										
2	7.78	9	11	23.2	7 (4)	–	11.5	1.43	–	14.2
n	16	16	16	16	16	5	16	16	5	10
$\overline{x}$	7.65	9	11	21.6	9	10.4	6.45	1.25	7.6	21.4
σ_{n-1}	0.38	5	2	6.5	2	10.0	5.59	1.06	1.6	5.4

Table 4-16 Analysis results of the treated water from the non-controlled aeration experiment (10-15℃)

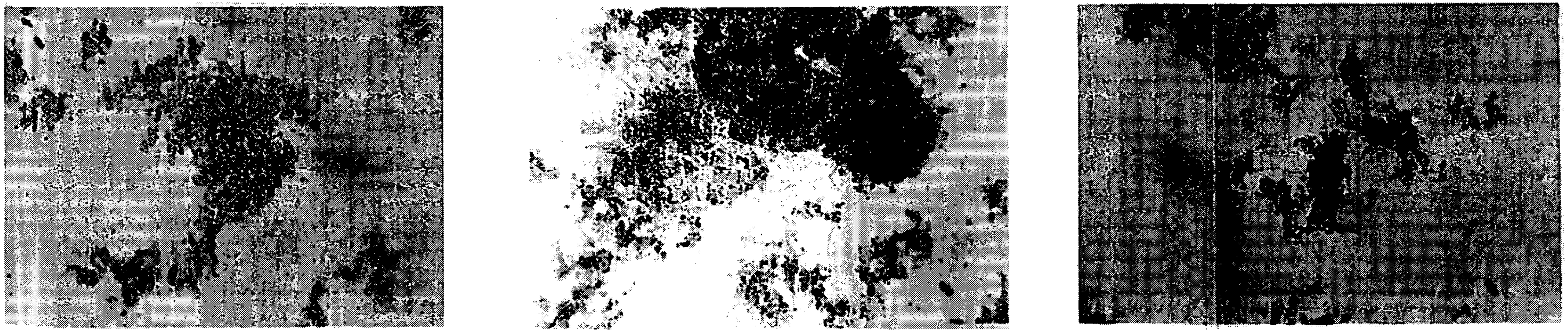
Date	pH (−)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	NO_2–N (mg/)	NO_3–N (mg/)	C^- (mg/)	Color (degree)
Jan.17	7.98	14	17	20.5	12	0.09	<0.01	77.3	
18	7.70	6	16	17.3	9	0.11	0.06	107	
19	7.60	4	16	18.6	8	0.13	0.03	125	
20	7.45	40	16	28.6	30	0.01	<0.01	140	27.1
21	7.71	5	11	15.4	6	0.01	0.02	147	
22	7.89	7	12	13.4	6	0.09	0.05	129	
23	7.58	8	14	17.2	9	0.08	0.05	121	
24	7.72	11	16	20.4	9	0.16	0.07	114	26.0
25	7.85	6	15	19.0	5	0.21	0.08	114	23.3
26	7.50	94	20	72.0	58	0.03	0.02	107	34.3
27	7.78	6	23	18.1	7	0.33	0.13	84.6	22.2
28	7.89	11	17.0	22.3	15	0.38	0.07	88.2	29
29	7.85	12	13	18.3	9	0.41	0.11	99.3	24.1
30	7.88	6	11	16.0	7	0.27	0.09	107	19.5
31	7.89	8	12	13.7	9	0.45	0.08	103	20
Feb.1								114	
2	8.00	25	18	21.3	14	0.69	0.09	107	25.5
n	16	16	16	16	16	16	16	17	10
$\overline{x}$	7.77	16	15	22.0	13	0.22	0.06	111	25.1
σ_{n-1}	0.17	23	3	14.0	13	0.19	0.04	18.4	4.4



1st day (SVI : 112)

4th day (SVI : 97)

7th day (SVI : 105)

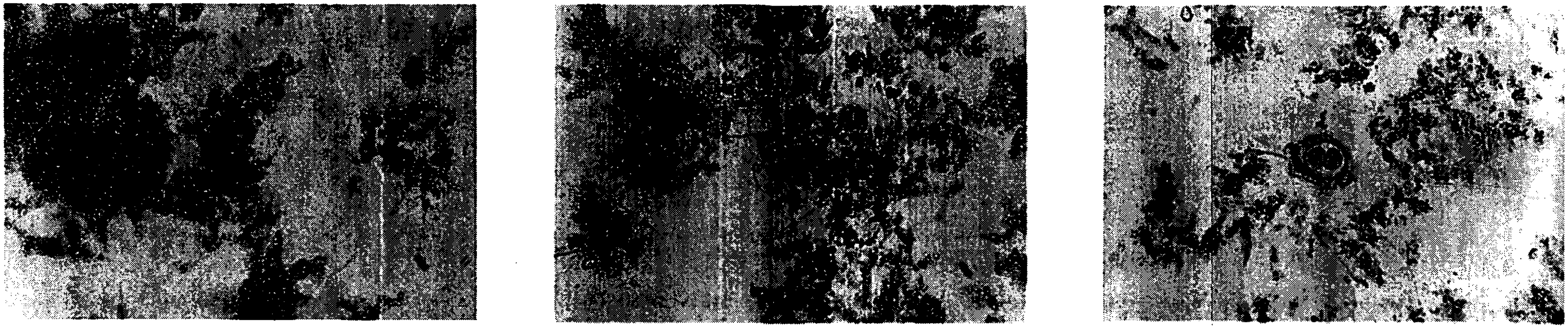


9th day (SVI : 122)

11th day (SVI : 126)

15th day (SVI : 107)

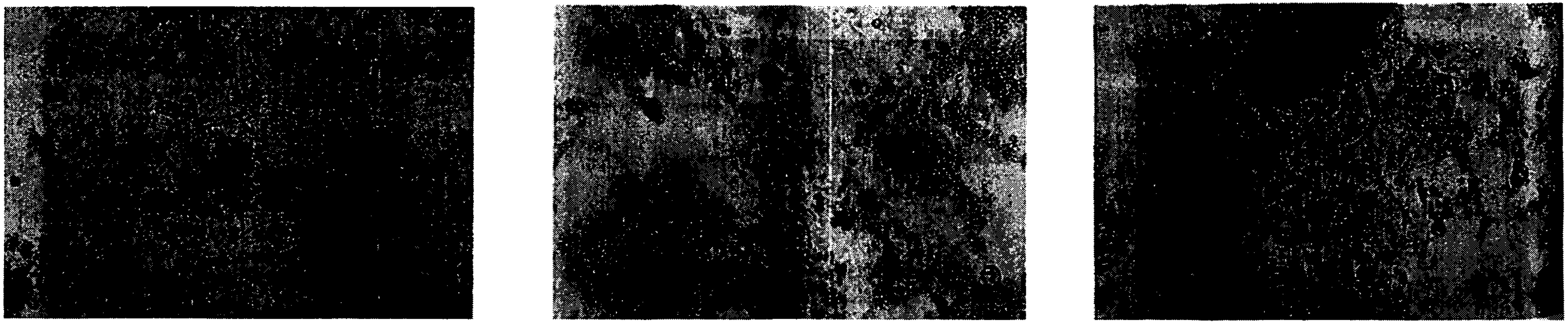
Photo 4-8 Microscope photos of activated sludge (Activated sludge from the controlled aeration experiment on the noodle manufacturing plant wastewater)



1st day (SVI : 107)

4th day (SVI : 134)

7th day (SVI : 256)



9th day (SVI : 363)

11th day (SVI : 318)

15th day (SVI : 210)

Photo 4-9 Microscope photos of activated sludge (Activated sludge from the non-controlled aeration experiment on the noodle manufacturing plant wastewater)

4-5 Conclusion

The effiency of the controlled aeration activated sludge method was clarified through comparison with the non-controlled aeration method using the actual wastewater of four food factories (soy sauce, chicken processing, tofu and noodle).
The efficiency of the controlled aeration method at low water temperatures was also studied.
The following is a summary of the results.

(1) In the following experiment, controlled aeration (20℃), non-controlled aeration (20℃) and controlled aeration (10 - 15℃), using indoor bench-scale apperatus (capacity of 10 ℓ) on the soy sauce manufacturing plant wastewater, the removal efficiencies of all organic substances were good.
In the controlled aeration method (20℃), SVI was stable at around 100 but in the non-controlled aeration method (20℃), it was 300 - 400 and bulking occured due to filamentous bacteria.
As a result, bulking control through the formation of a substrate concentration gradient under controlled aeration was confirmed.
In the controlled aeration activated sludge experiment at low water temperature, the importance of sludge control was clarified.
As for the behavior of excess nitrogen, nitrification proceeded both in the controlled and non-controlled aeration experiments and part of the wastewater was denitrificated on inflow of untreated water in the controlled aeration experiment.
As for excess phosphorus, the removal efficiency of controlled aeration was a little better than that of non-controlled aeration but the sampling frequency was in sufficient. /Further detailed study is necessary on this.

(2) In the chicken processing plant wastewater, nitrite was generated through nitrification due to on excess of nitrogen and this caused an increase in COD.
Due to comsumption of alkali by nitrification, the pH was lowered and it restricted nitrification so that all the nitrogen compounds were not completely nitrified.
In neither controlled aeration (20℃) or non-controlled aeration (20℃), were filamentous bacteria observed, but there was a difference in SVI; 100 in controlled aeration and 200 in non-controlled.

(3) Comparison of the controlled aeration (20℃) and non-controlled aeration (20℃) experiments on the tofu manufacturing plant wastewater found that, the wastewater substrate quickly led bulking due to filamentous bacteria, under non-controlled aeration (20℃) after one week SVI became 300 - 400, a bulking condition.
Even under controlled aeration, regular withdrawal of sludge was necessary for filamentous bacteria decomposition by the substrate concentration gradient.

(4) Comparion of the sludge properties in the controlled aeration (20℃) and non-controlled aeration (20℃) experiments on the noodle manufacturing plant wastewater found that, under controlled aeration (20℃) SVI was stable at around 120 but under non-controlled aeration (20℃) SVI exceeded 300 after about a week and filamentous bacteria were observed.

(5) Comparing the differences in both aeration methods, controlled and non-controlled, utilizing a batch type activated sludge method, under controlled aeration good settling characteristics of the activated sludge can be maintained along with bulking control through formation of a substrate concentration gradient.
The implication is that controlled aeration is effective for reducing maintenance of plants that treat food industry wastewater which frequently causes bulking.
Even when using controlled aeration, proper maintenance of the activated sludge is essential for utilization of the filamentous bacteria decomposition mechanism.

5. Characteristics of the controlled aeration activated sludge method an wastewater from the noodle manufacturing plant with respect to substrate removal speed

The Bikoken (Fermentation Research Institute) Type controlled aeration activated sludge method is an application of basic technology developed by the Fermentation Research Institute of the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry. The equipment stems from a highly simplified version of the existing continous activated sluge method, which can treat highly polluted wastewater with a large fluctuation in volume effectively in one aeration tank. And through application of recent microbiology research, it has become a highly usable wastewater treatment facility with complete control of settling, poor settling of sludge leads to bulking a major problem in the activated sludge method, achieving the required stablity.

Using actual wastewater from a noodle manufacturing plant, an experiment was conducted to clarify the characteristics of the controlled aeration activated sludge method with respect to substrate removal which is closely related to bulking contro. Comparison was made with the existing lagoon non-controlled batch-type activated sludge aeration facility.

5-1. Study on the substrate removal rate of the existing activated sludge facility the noodle manufacturing plant

By measuring the substrate removal rate in the existing batch-type activated sludge wastewater treatment facility at the noodle manufacturing plant and by collecting basic data on the existing treatment method, the activated sludge characteristics of the non-controlled aeration method were studied.

(1) Experiment

Boiler wastewater from the noodle manufacturing plant was used for the experiment and when the concentration was high, it was diluted to adjust it to a fixed concentration.

For measurement of the substrate removal rate, activated sludge was taken from the existing wastewater treatment facility and adjusted to a fixed concentration for the experiment.

For uniformity of the activated sludge, it was aerated before the experiment to eliminate any residual substrate.

The indoor bench-scale apperatus (capacity of 10 ℓ) for the experiment is shown in 4-1 (1), photo 4-1.

To eliminate experimental conditions that would lead to substrate removal being the the rate-determing factor of oxygen supply, the aeration volume was adjusted to increase, Do any time.

TOC and COD were measured as the substrate of the noodle manufacturing plant wastewater.

(2) Measurement of the substrate removal rate constant of TOC and COD

Using the activated sludge of the existing falicity, hourly changes in TOC and COD during batch treatment were measured.

Fig. 5-1 shows the study result on wastewater treatment in the existing lagoon.

The experiment was conducted at the acivated sludge concentration (MLSS) of 1200 mg/ ℓ and a water temperature of 15℃.

The initial concentration was adjusted to around 200 mg/ ℓ of TOC and 270 mg/ ℓ of COD.

After six hours of aeration, about 50 % of TOC and COD were removed.

As biochemical purification reaction formulas for wastewater, there is the one-phase theory put forward by Hinshelwood, Herbert, et al. and the two-phase theory by Garret & Sawyer, and Mc Cabe & Eckenfelder, etc.

Garret & Sawyer and Mc Cabe & Eckenfelder put forward the two-phase theory based on the fact that when substrate concentration is low, there is a first-order reaction between microorganism growth rate and substrate concentration, and when substrate concentration is high, micororganisms grow regardless of the substrate concentration. However, considering the above-mentioned result, the only difference between the one-phase theory and the two-phase is continous or discontinous function, and in principle they are the same.

Due to the fact that in general there are many kinds of substrates in industrial wastewater and the composition is not stable, μ m and K values as in the Monod formula are not fixed. Consequently,the average K value is considered as the general value and the substrate removal rate is represented in the first-order reaction, the pseudo first-order reaction or the pseudo second-order reaction.

In the experiment, study was conducted based on the assumption that the substrate removal rate of the wastewater was proportional to the residual concentration and represented in the first-order reaction.

$$-\frac{dc}{dt} = KSaC$$

$$\ln \frac{C}{Co} = -KSat$$

$$\text{therefore } \frac{C}{Co} = e^{-K \cdot Sat}$$

where Co = substrate concentration before treatment (mg/ ℓ)

C = substrate concentration in treated water (mg/ ℓ)

K = removal rate constant (ℓ /mg · Eh)

Sa = MLSS (mg/ ℓ)

t = aeration time (hours)

From the experimental result, C/Co and Sat were calculated and plotted to obtain K in the gradient.

Figs. 5-2 and 5-3 show the removal rate of TOC and COD, respectively.

As there was a single substrate in the wastewater, the substrate removal rate corresponded well with the first-order reaction. In the experiment, the substrate removal constants for TOC and COD were both about 0.1 and it was concluded that a relatively long time would be required for substrate removal.

(3) Initial substrate concentration effect

By changing the initial concentration of the wastewater, the effect on the substrate removal rate was studied.

Figs. 5-4 and 5-5 show the relationship between the aeration time and the residual substrate concentration of TOC and COD, respectively.

The experiment was conducted at 1300 mg/ ℓ of MLSS and a water temperature of 16 - 17℃.

Fig. 5-6 shows the relationship between the initial substrate concentration and the calculated substrate removal rate constant based on the result.

For both TOC and COD, there was a tendency that the higher the initial substrate concentration was, the lower the removal rate constant was.

Within the range of the initial substrate COD concentration, from 100 to 300 mg/ ℓ , and the initial substrate TOC concentration, from 50 to 250 mg/ ℓ , there was a linear relation between substrate concentration and removal rate and when substrate concentration rose by 100 mg/ ℓ , the substrate removal rate decreased by 0.1. When the substrate concentration was considered as sludge loading, a decrease in the substrate sludge loading of about 0.08 was needed to increase the substrate removal rate by 0.1.

(4) Water temperature effect

The effect on the substrate removal rate due to water temperature was studied at a constant initial substrate concentration.

Figs. 5-7 and 5-8 show the relationship between the aeration time and the residual substrate concentrations of TOC and COD, respectively.

Experimental conditions were 1000 mg/ ℓ of MLSS, TOC initial concentration of 250 mg/ ℓ , COD initial concentraion of 300 mg/ ℓ , and the water temparature was varied from 10 to 30℃.

Fig. 5-9 shows the relationship between the water temperature and the calculated substrate removal rate based on the result.

As the water temperature rose, the removal rate increased with a consequent speeding up of the treatment process. This corresponded to the general concept of substrate removal.

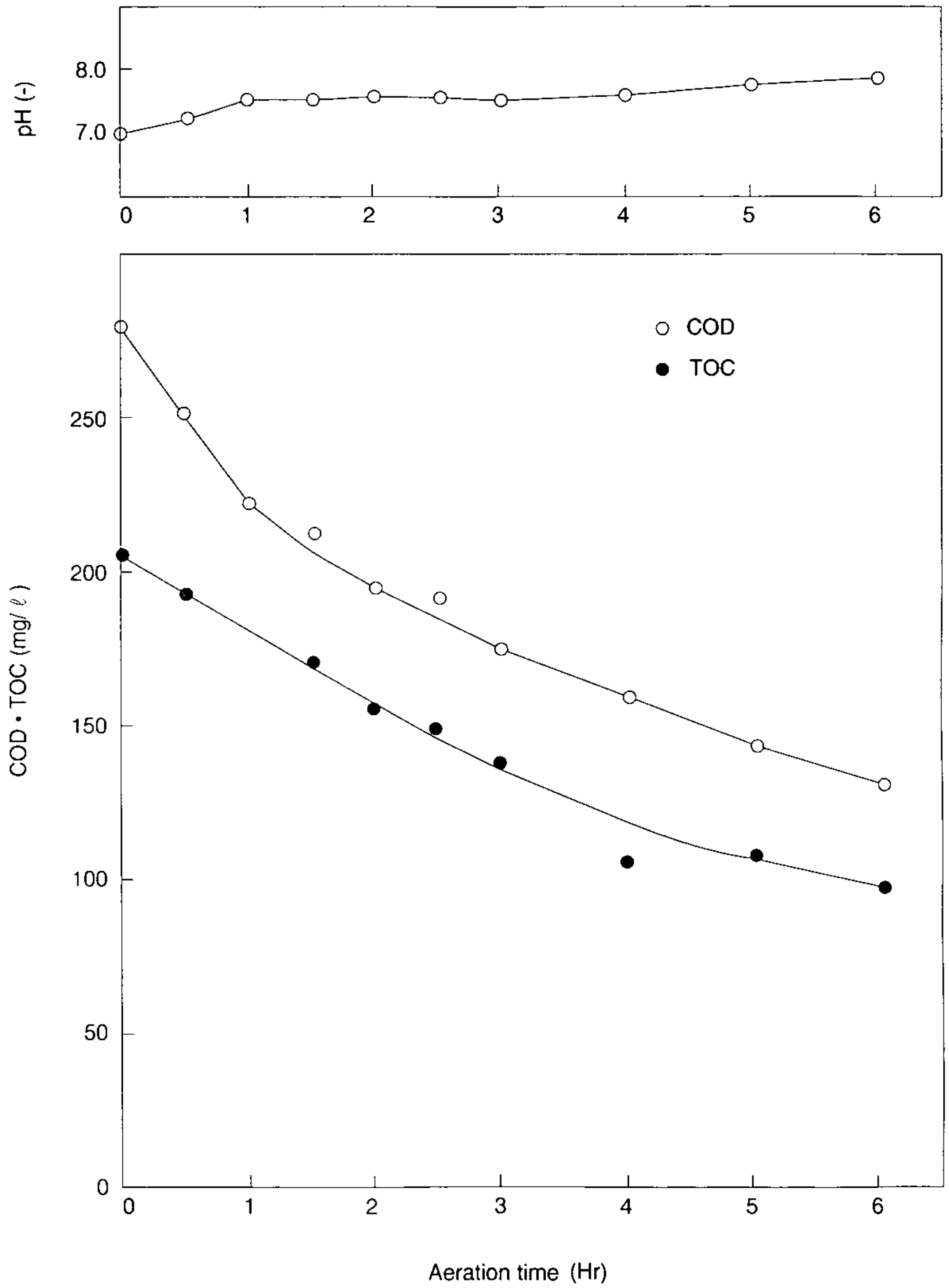


Fig 5-1 Results from the study on the efficiency of the sludge from the existing lagoon using wastewater from the noodle boiler (Water temperature 15℃, MLSS 1200mg/ℓ)

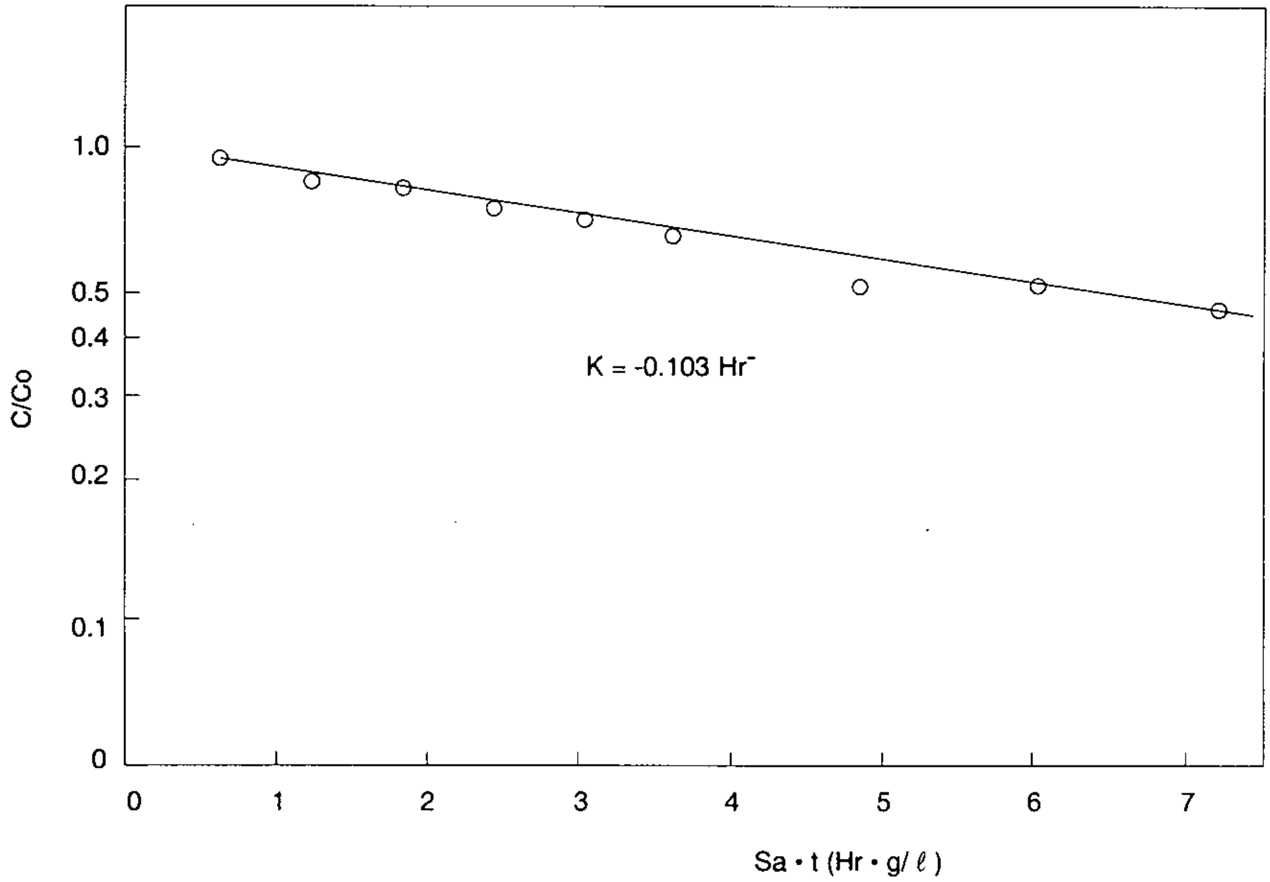


Fig 5-2 Results from the study on the rate of removal of TOD from noodle boiler wastewater using sludge from the existing lagoon
(MLSS 1200mg/ ℓ ,initial TOC 200mg/ ℓ , water temperature 15℃)

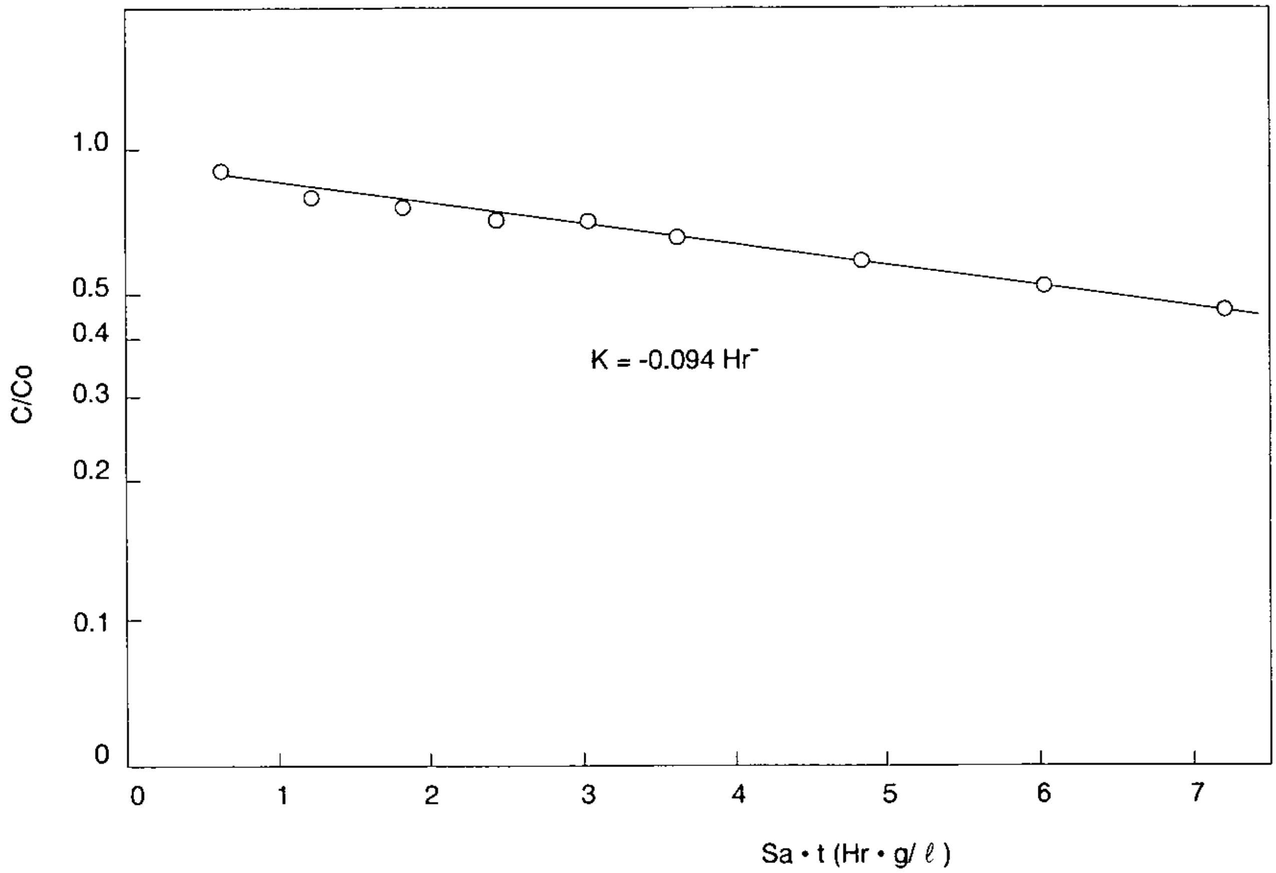


Fig 5-3 Results from the study on the rate of removal of COD from noodle boiler wastewater using sludge from the existing lagoon (MLSS 1200mg/ ℓ ,COD 270mg/ ℓ ,water temperature 15℃)

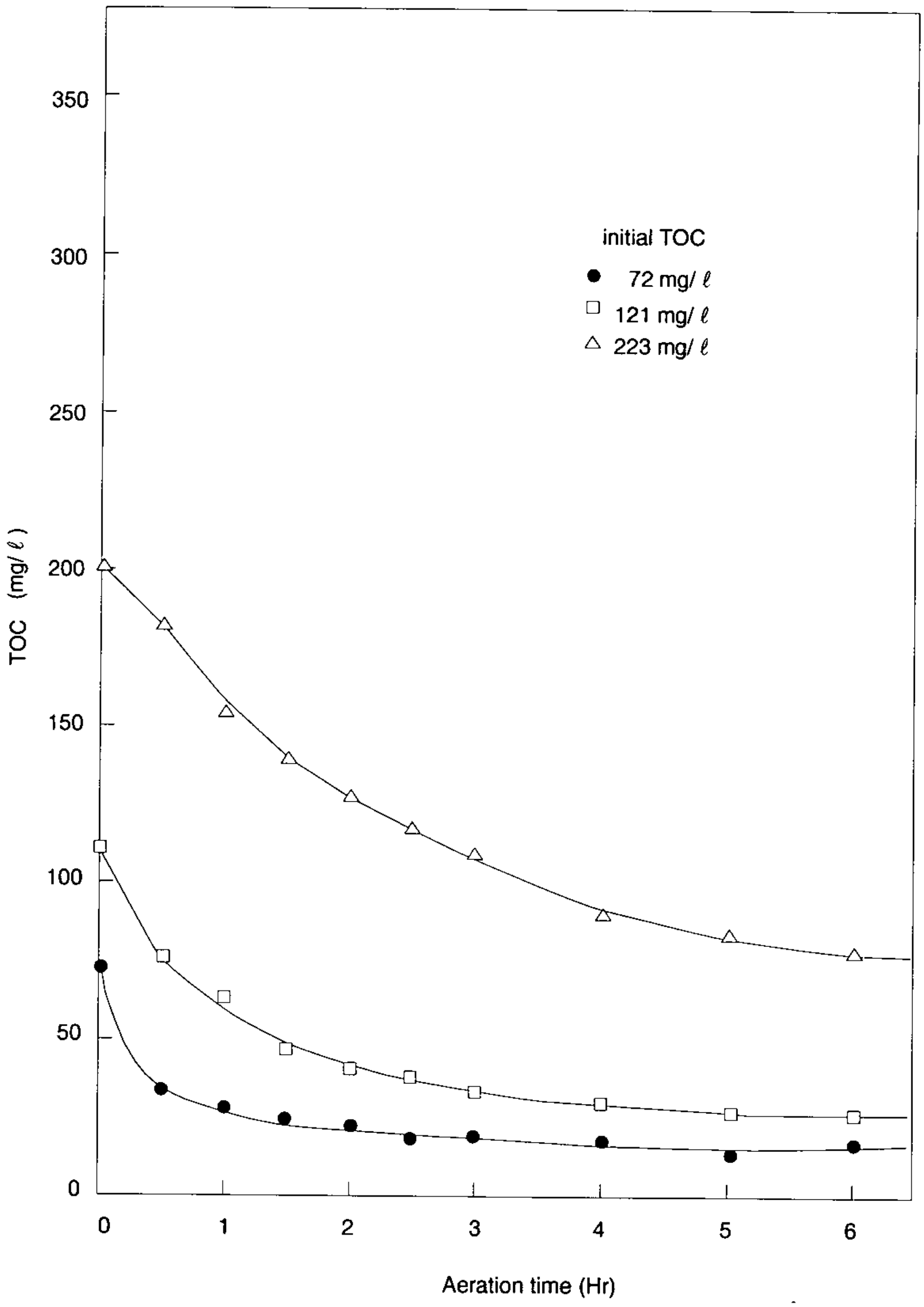


Fig 5-4 TOC compound removal using sludge from the existing lagoon
(Effect due to initial TOC concentration)
(Water temperature16.0~17.0℃ , MLSS 1300mg/ℓ)

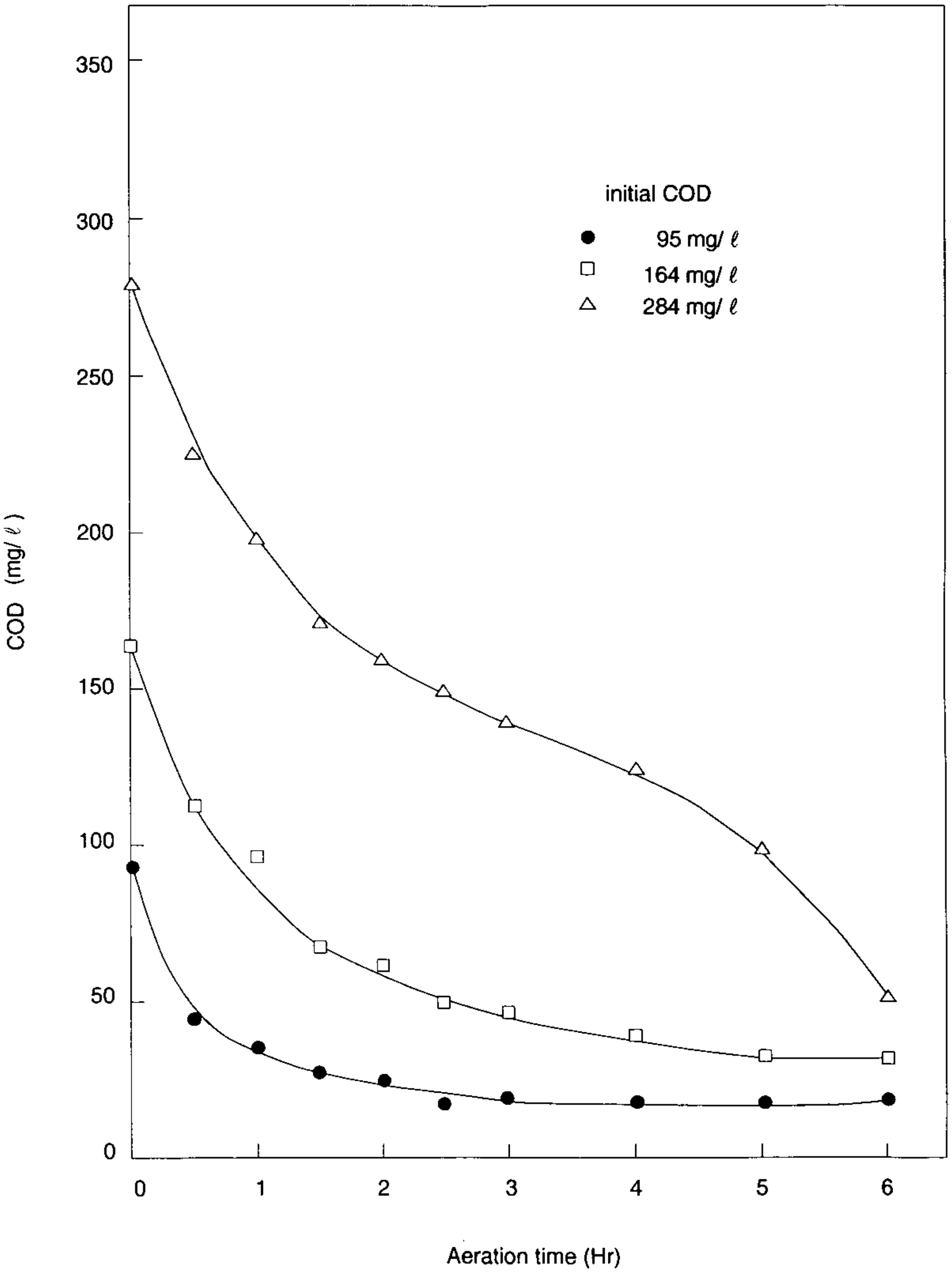


Fig 5-5 COD compound removal using sludge from the existing lagoon
(Effect due to initial COD concentration)
(Water temperature16.0~17.0℃ , MLSS 1300mg/ ℓ)

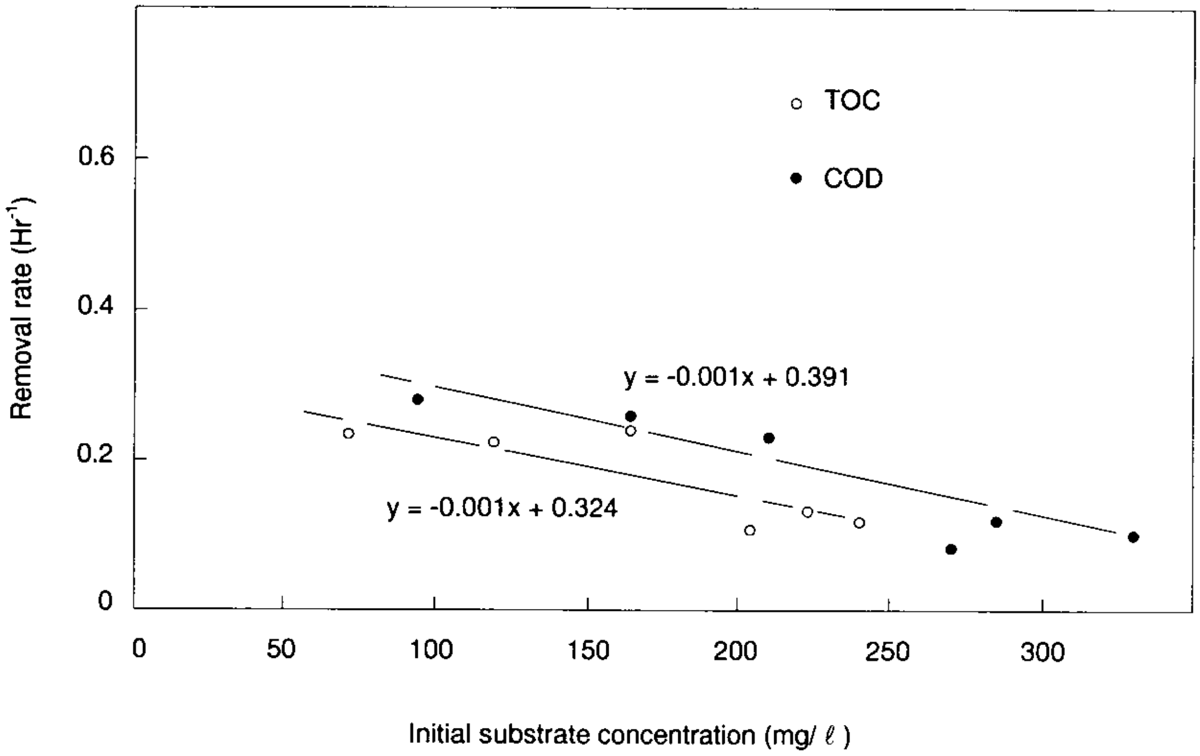


Fig 5-6 The relationship between the removal rate and the initial substrate concentration using sludge from the existing lagoon

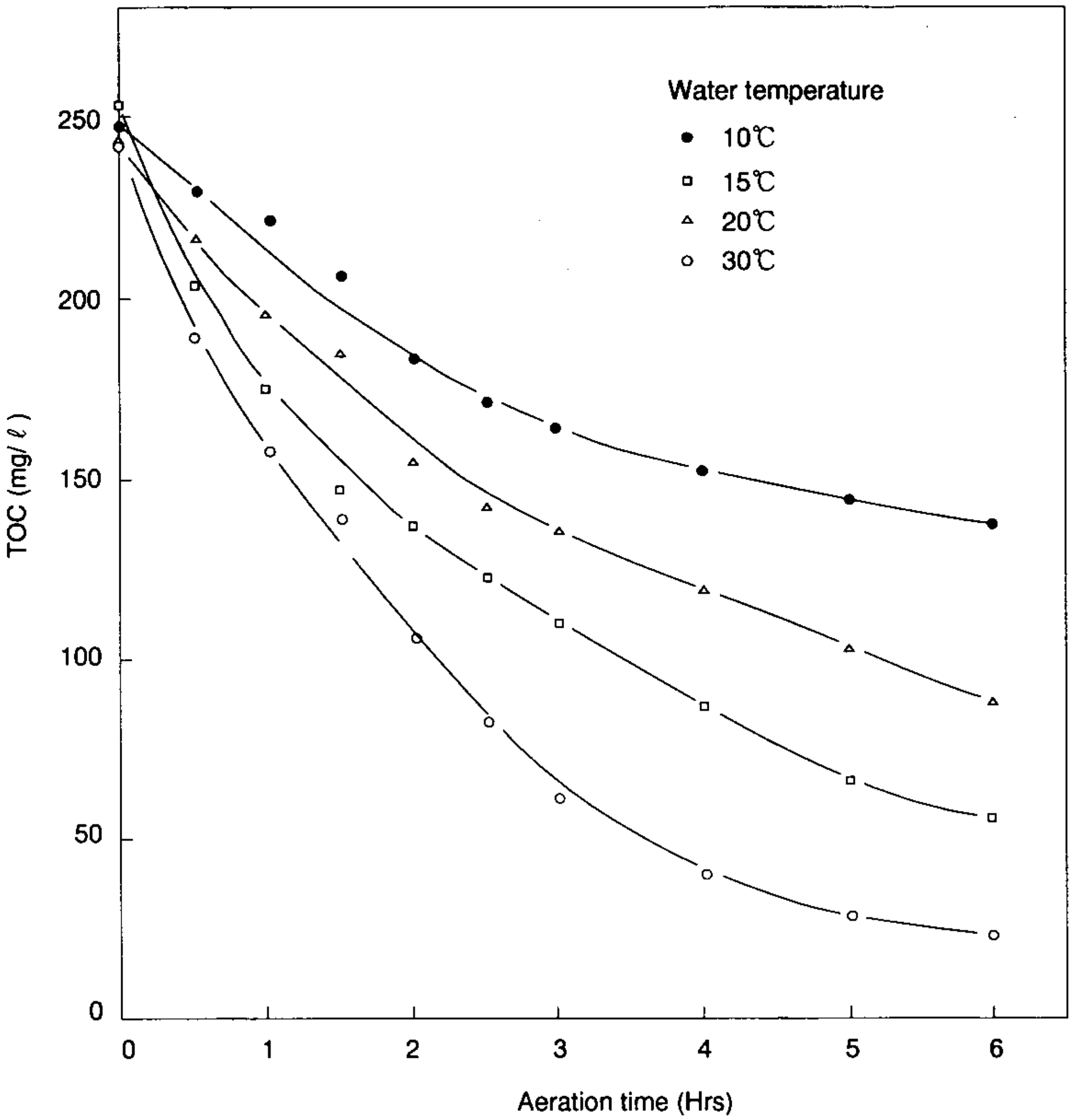


Fig 5-7 TOC compound removal using sludge from the existing lagoon
(Effect due to water temperature) (MLSS 1000mg/ ℓ)

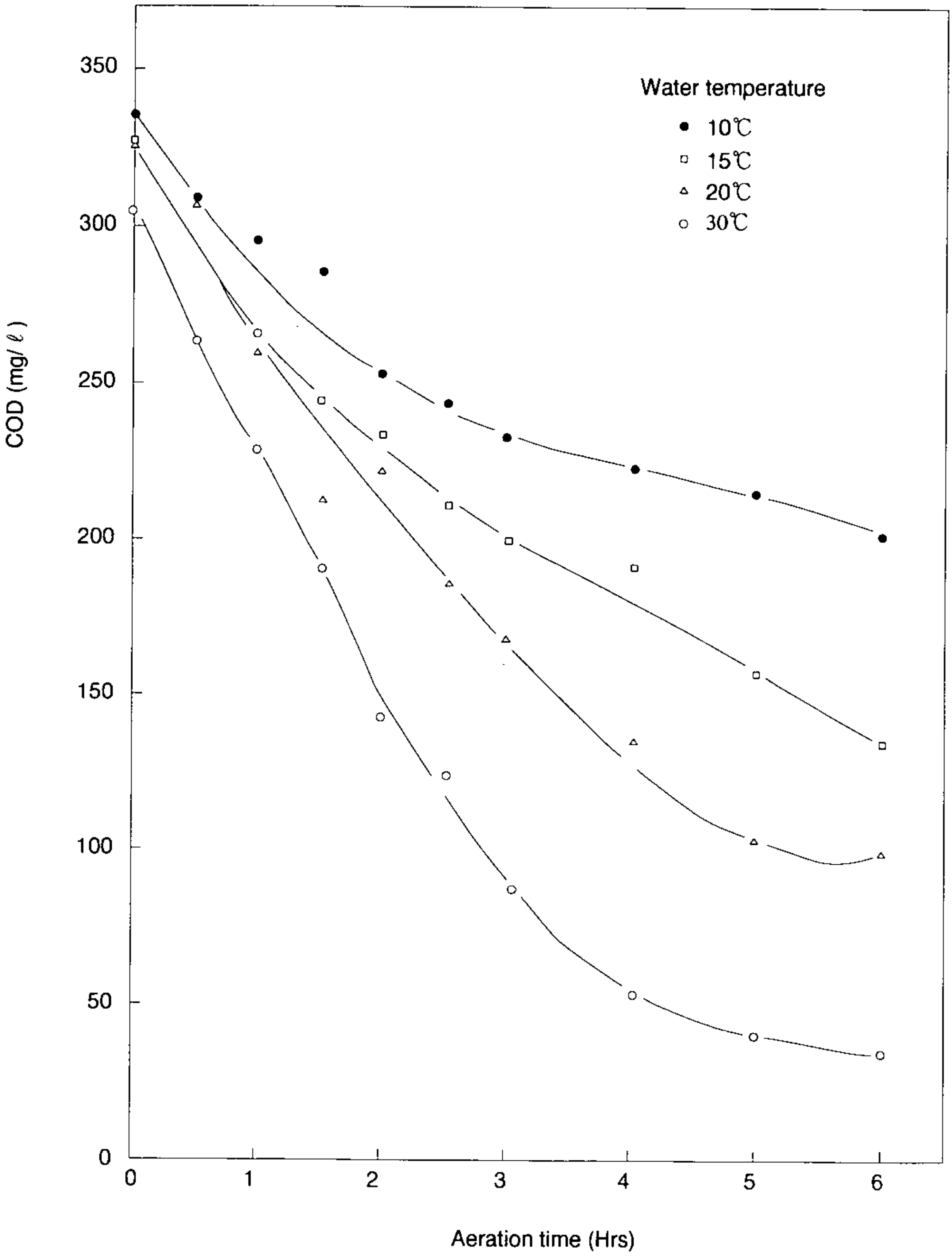


Fig 5-8 COD compound removal using sludge from the existing lagoon
(Effect due to water temperature) (MLSS 1000mg/ℓ)

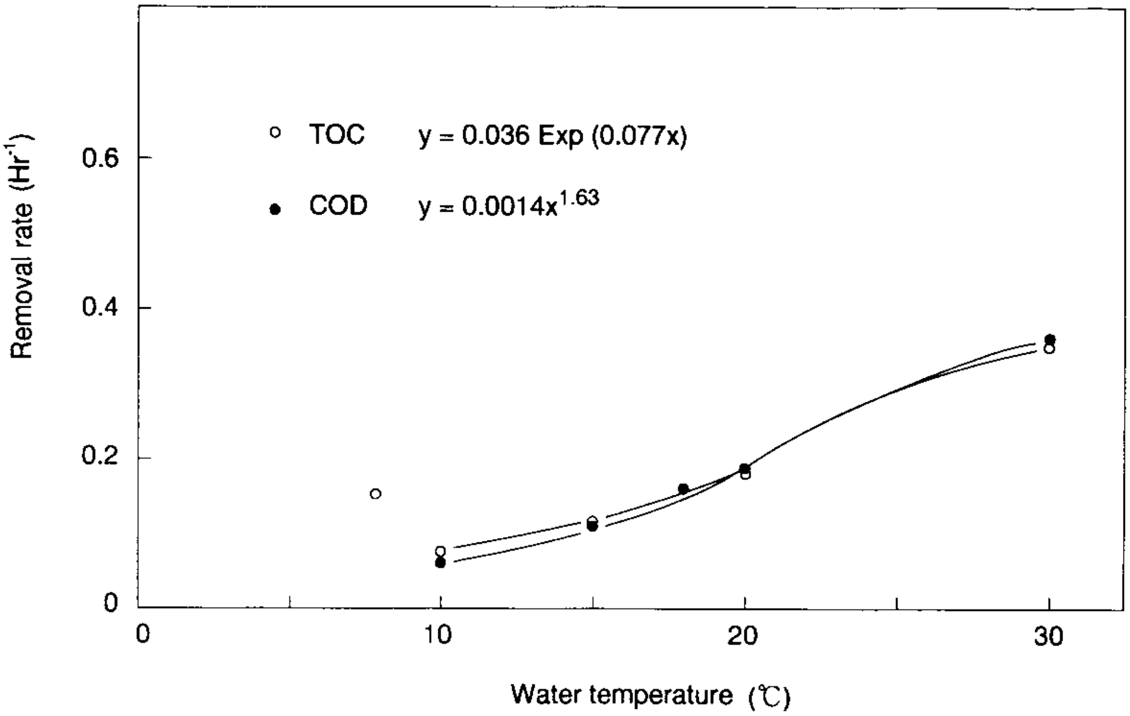


Fig 5-9 The relationship between the water temperature and the removal rate using sludge from the existing lagoon

5-2 Study on the substrate removal rate of the indoor controlled aeration activatied sludge on the noodle manufacturing plant wastewater

Basic data on the controlled aeration activated sludge method were collected through measurement of the substrate removal rate of the controlled aeration method using noodle manufacturing plant wastewater put through an indoor scale opperatus.

(1) Experiment

The activated sludge used for measurement of substrate removal rate was aerated in the indoor bench-scale opperatus before the experiment so as to bring about uniform conditions in the sludge.

(2) Initial substrate concentration effect

By changing the wastewater concentration, the effect of initial substrate concentration on the substrate removal rate was studied.

Figs. 5-10 and 5-11 show the results based on the aeration time and residual substrate concentration of TOC and COD, respectively.

The experiment was conducted at 1000 mg/ ℓ of MLSS and a water temperature of 16 - 17℃.

The results with respect to the initial substrate concentration and substrate removal rate of TOD and COD are shown in Figs. 5-12 and 5-13, respectively.

There is a linear relations hip between substrate concentration and the removal rate in the initial COD range between 100 and 350 mg/ ℓ , and the initial TOC range between 100 and 250 mg/ ℓ .

This result was the same as the relationship between substrate concentration and removal rate of the activated sludge using the non-controlled aeration method in the existing treatment facility.

In the controlled aeration activated sludge experiment, when the substrate concentration rose by 100 mg/ ℓ , the substrate removal rate decreased by 0.38.

This was equivalent to a substrate sludge loading decrease of about 0.03 with a subsiquent substrate removal rate increase of about 0.1.

(3) Water temperature effect

The effect of water temperature on the substrate removal rate was studied.

Figs. 5- 13 and 5-14 show the results on the aeration time and residual substrate concentration of TOC and COD, respectively.

The experiment was conducted at 800 mg/ ℓ of MLSS, a initial TOC concentration of 160 - 220 mg/ ℓ , initial COD concentration of 120 - 280 mg/ ℓ and a water temperature of 10 - 30℃.

Figs. 5-15 and 5-16 show the relationship between the water temperature and the substrate removal rate of TOC and COD compounds, respectively.

The substrate removal rate of TOC and COD compounds varied depending on the water temperature and initial substrate concentration.

Studying the relationship between water temperature and removal rate at the initial TOC substrate concentration of 160 mg/ ℓ , fig. 5-15 shows that there is an almost linear relationship and water temperature, the removal rate becomes bigger.

A similar relationship could be considered in the case of COD, but there was a big fluctuation in the initial substrate concentration in this experiment.

(4) Change in the respiration rate due to the controlled aeration activated sludge

The rate change in sludge respiration in the controlled aeration activated sludge experiment was measured. This experiment was conducted simultaneously with the experiment outlined in 5-2(3). The hourly change in sludge respiration was obtained from the measurement of oxygen consumption by sludge through the use of a DO meter. Fig. 5-17 shows the time and change in the sludge respiration rate at different water temperatures.

At a water temperature of 30℃ where the removal was high, although the substrate concentration decreased after 20 hours of aeration, the sludge respiration rate changed for 5 hours during aeration and then came to the endogenous respiration phase as shown in Figs. 5-13 and 5-14.

At a water temperature after 20℃ and 15 ℃, the respiration rate didn't proceed to the endogenous phase even after 6 hours of aeration.

This is related to the basic treatment system of the activated sludge method, and the results show that even if the substrate seems to be removed from the treated water by adsorption and oxidation, perfect treatment is not reached unless the assimilation reaction finishes.

Therefore treatment under appropriate load conditions is essential and if this is neglected, the physiological function of the activated sludge will be drastically hindered due to overloading.

In the experiment done at 10℃, the efficiency of the activated sludge with respect to respiration worsened in accordance with a worsening of substrate removal.

For proper activated sludge use, attention should be paid not only to substrate removal but also to the physiological function of the activated sludge.

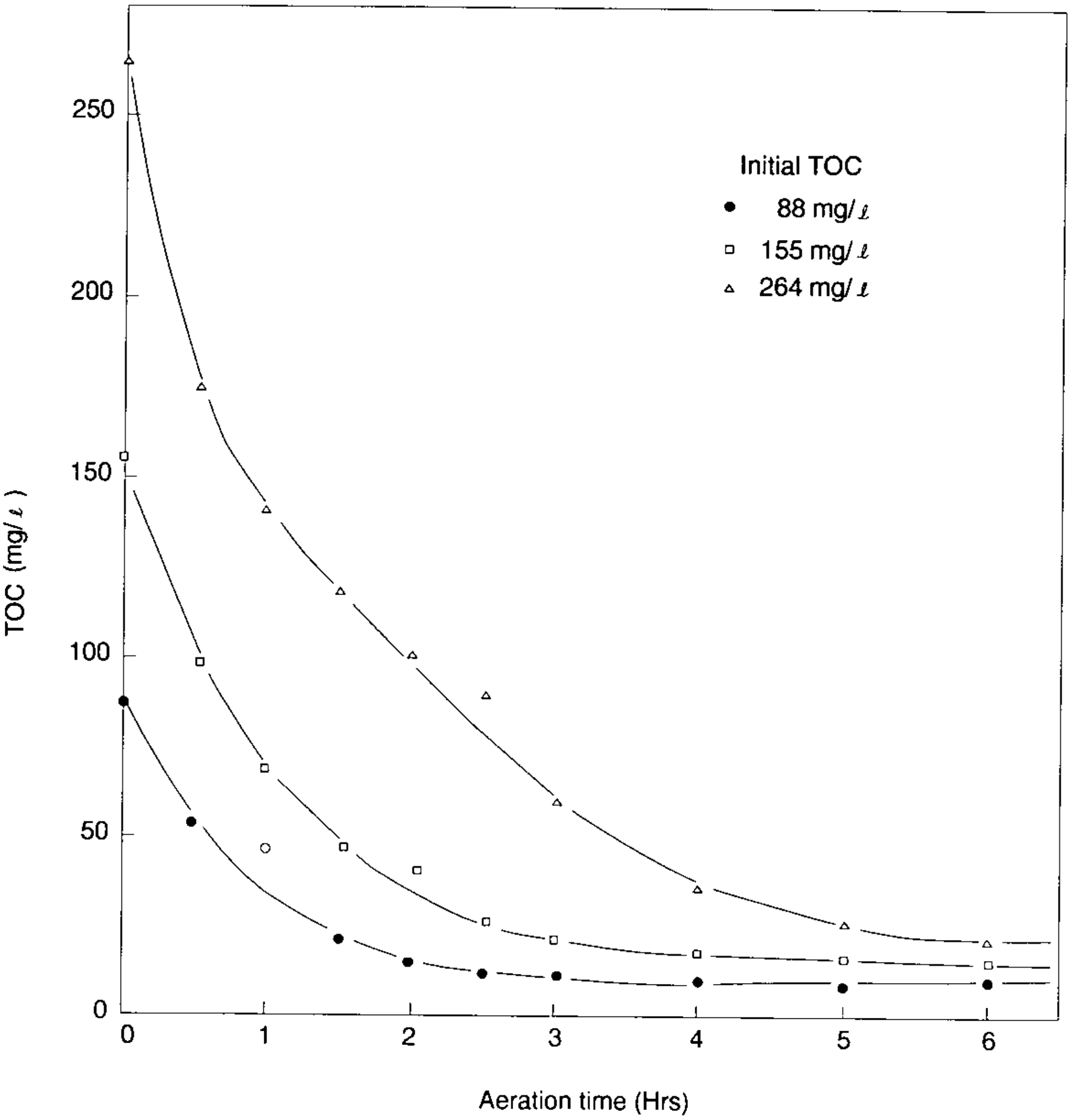


Fig 5-10 Sludge removal of TOC compounds in the indoor controlled aeration experiment
(Initial TOC concentration effect)
(Water temperature16.0~17.0℃ , MLSS 1000mg/ ℓ)

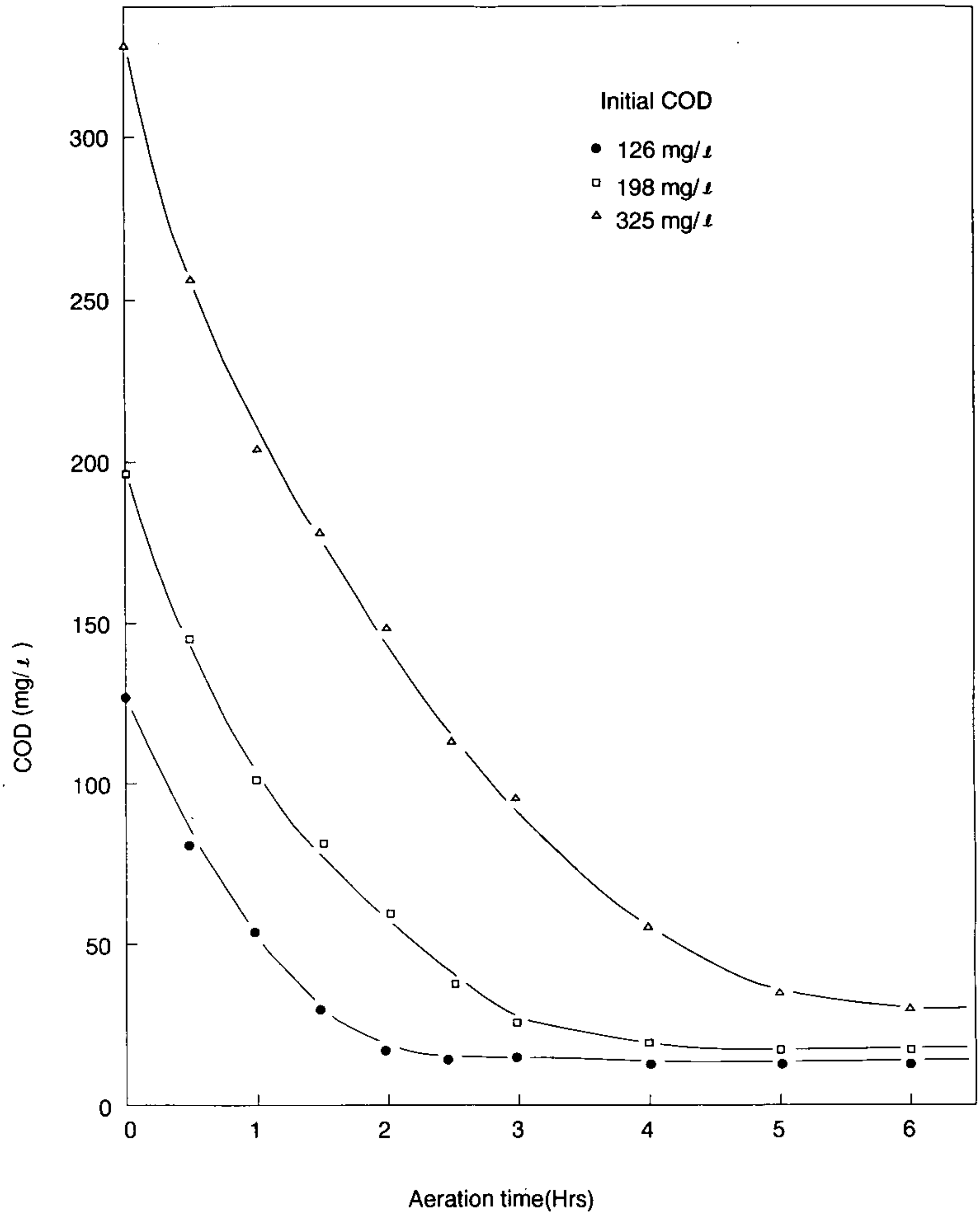


Fig 5-11 Sludge removal of COD compounds in the indoor controlled aeration experiment
(Initial COD concentration effect)
(Water temperature16.0~17.0℃ , MLSS 1000mg/ ℓ)

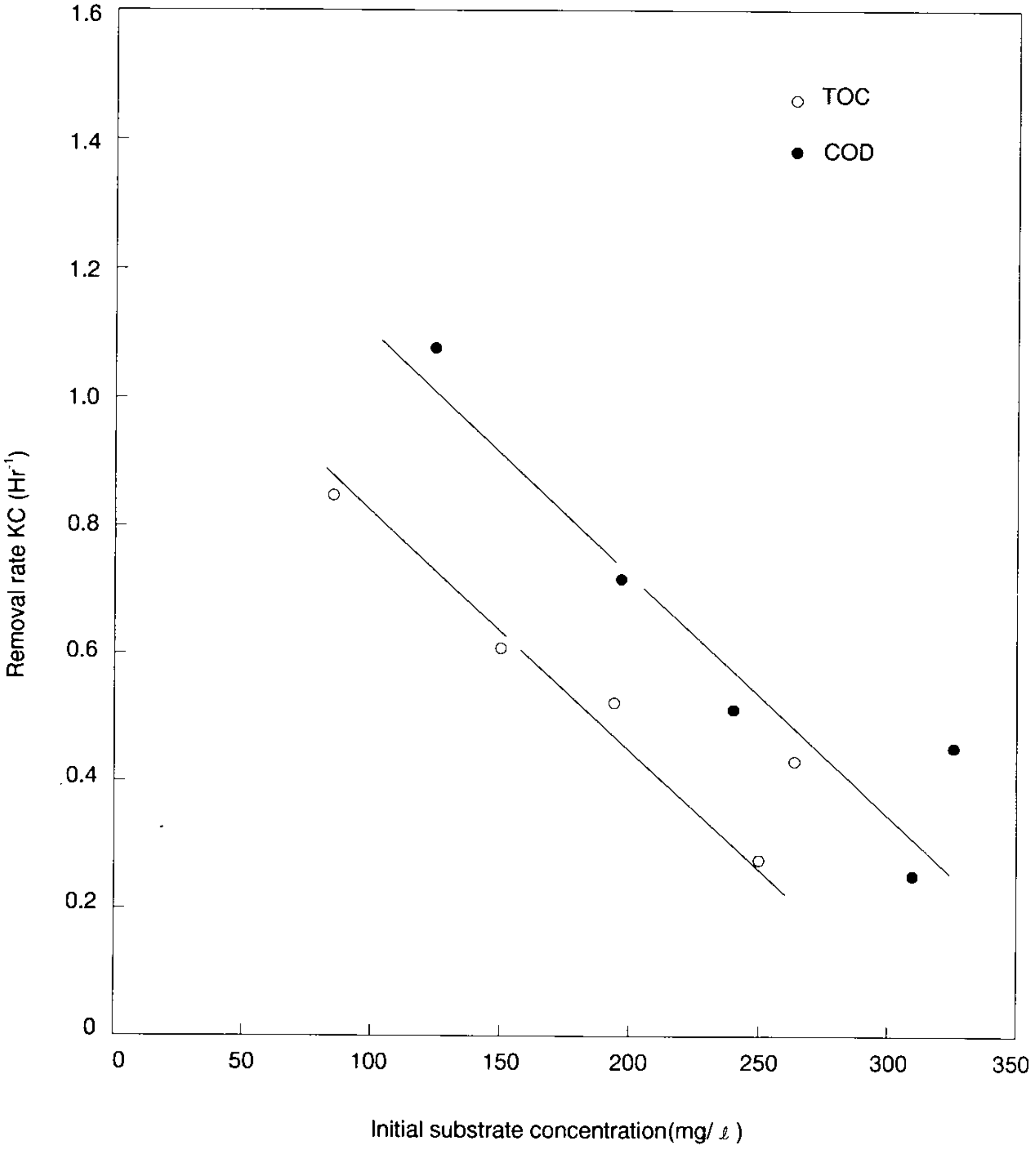


Fig 5-12 The relationship between the initial substrate concentration and the removal rate of the sludge in the indoor controlled aeration experiment (15℃)

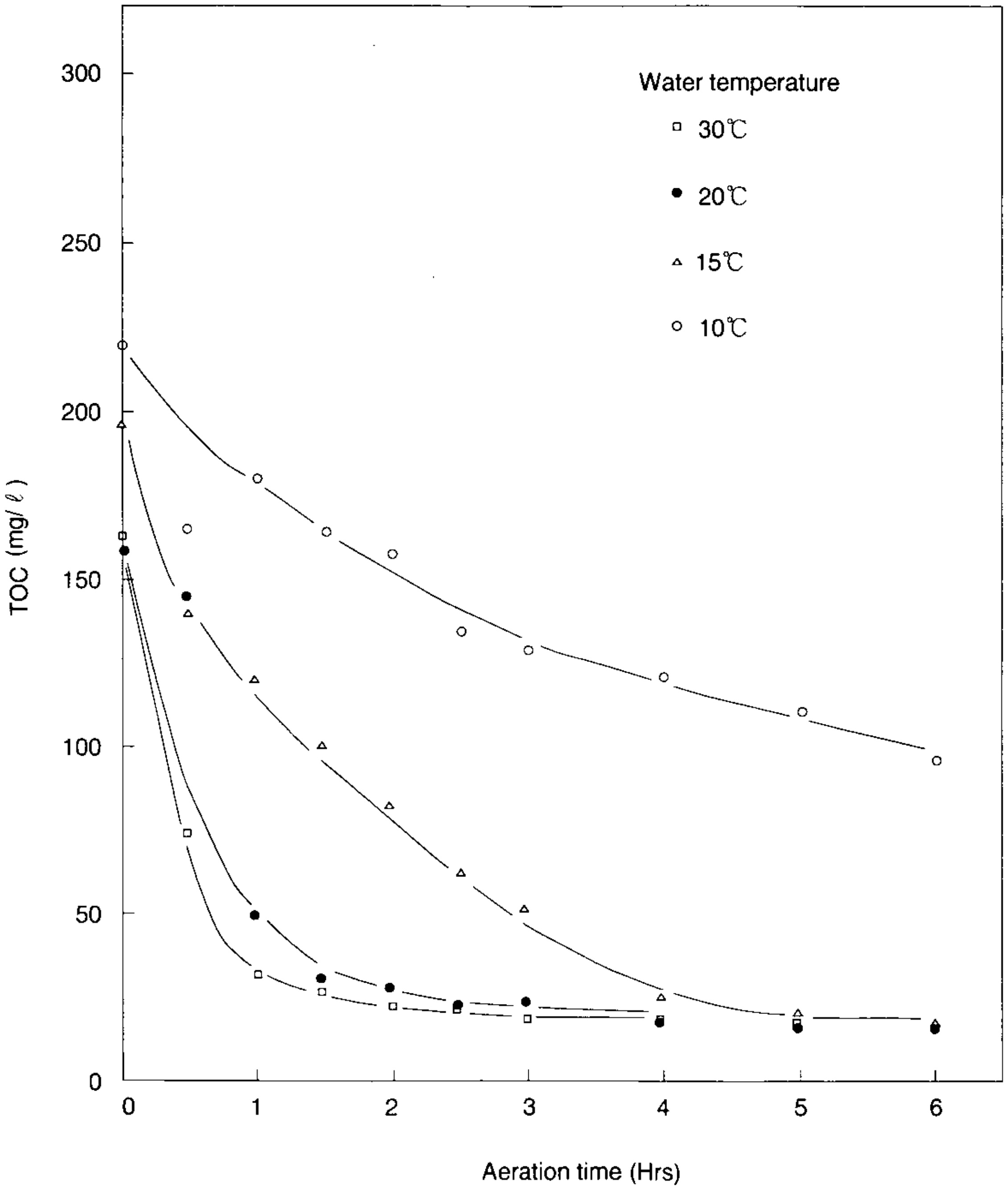


Fig 5-13 Sludge removal efficiency of TOC compounds in the indoor controlled aeration experiment (Water temperature effect) (MLSS 800mg/ℓ)

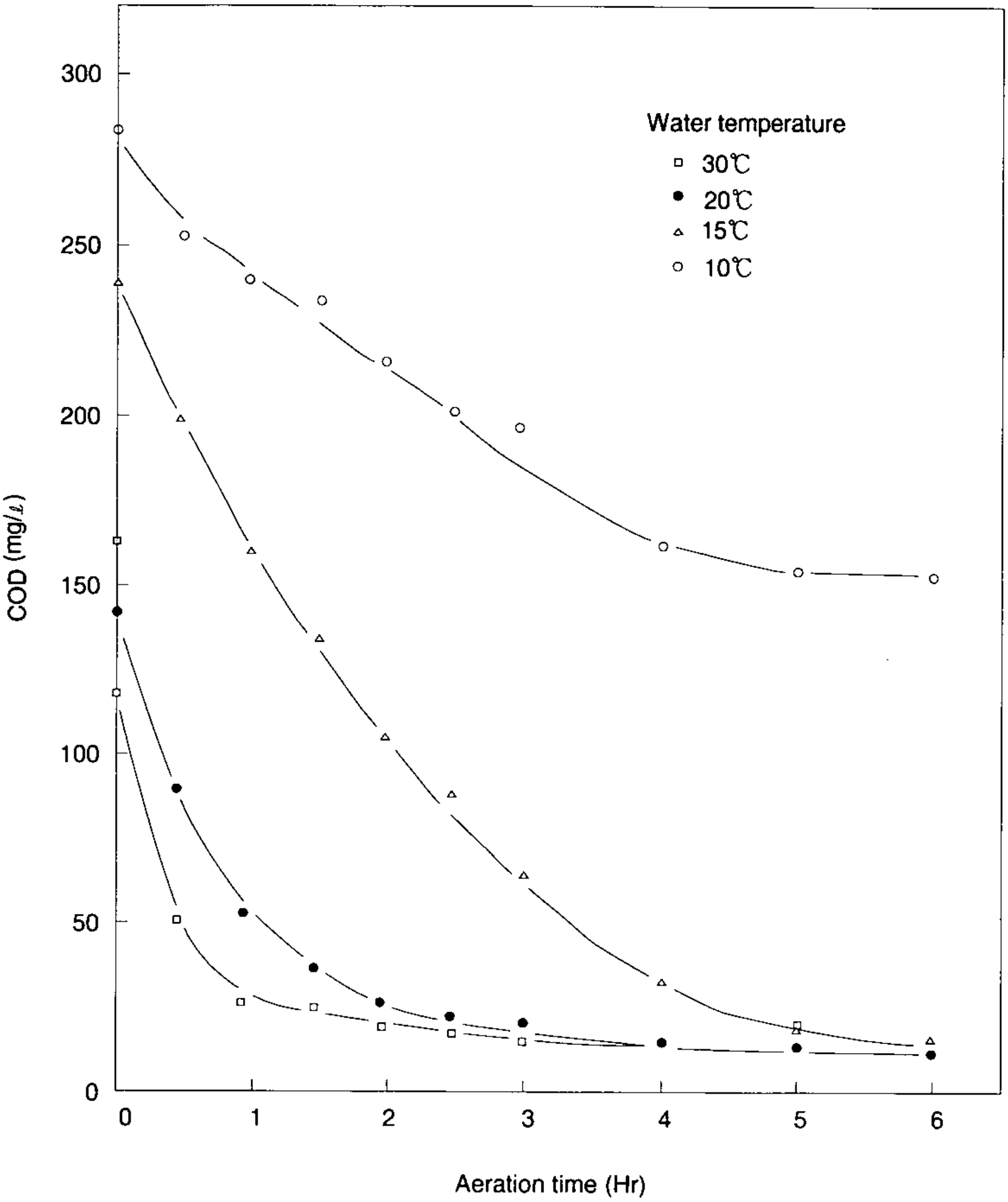


Fig 5-14 Sludge removal efficiency of COD compounds in the indoor controlled aeration experiment (Water temperature effect) (MLSS 800mg/ ℓ)

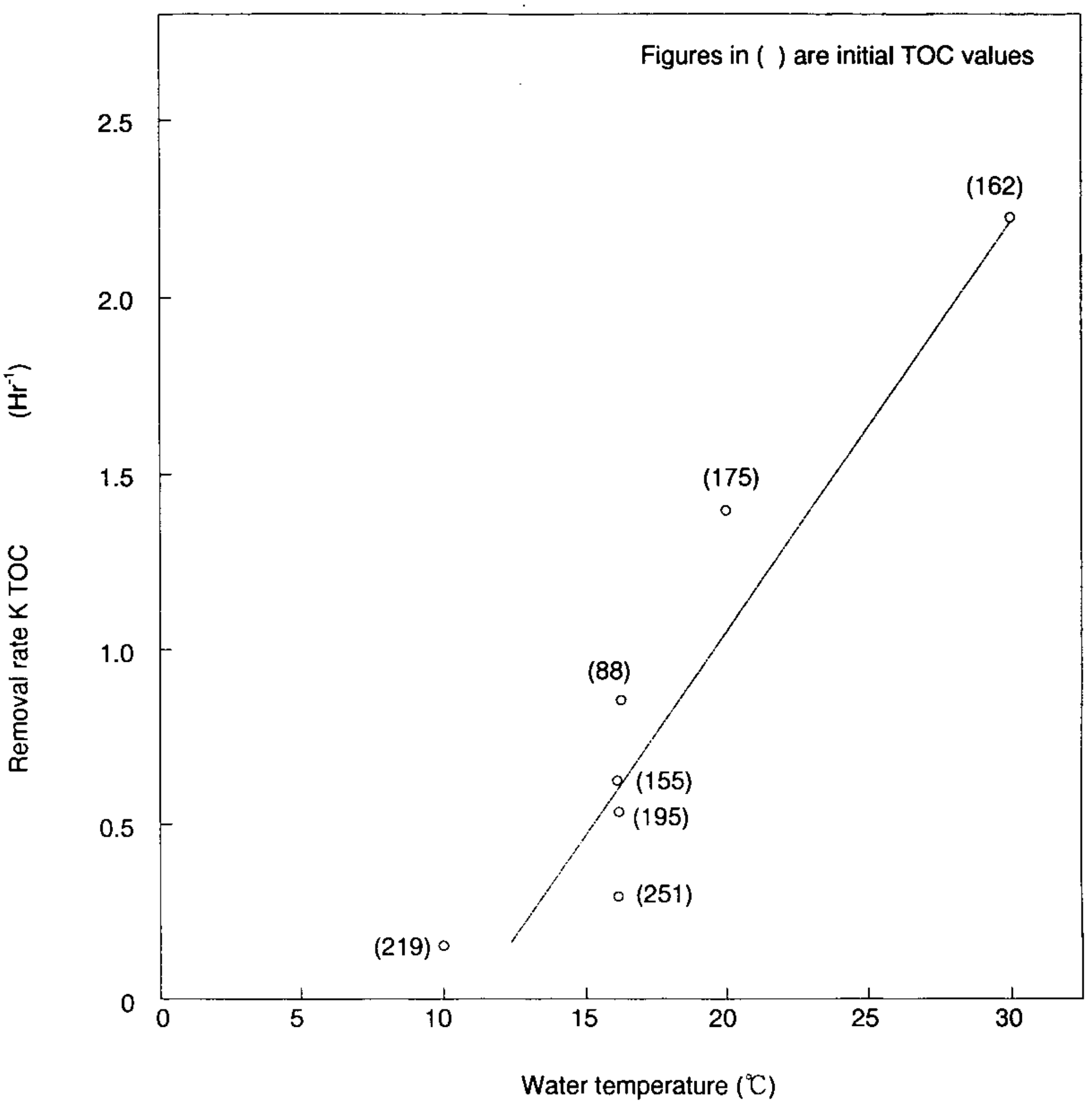


Fig 5-15 The relationship between water temperature and removal rate of the sludge in the indoor controlled aeration experiment (TOC)

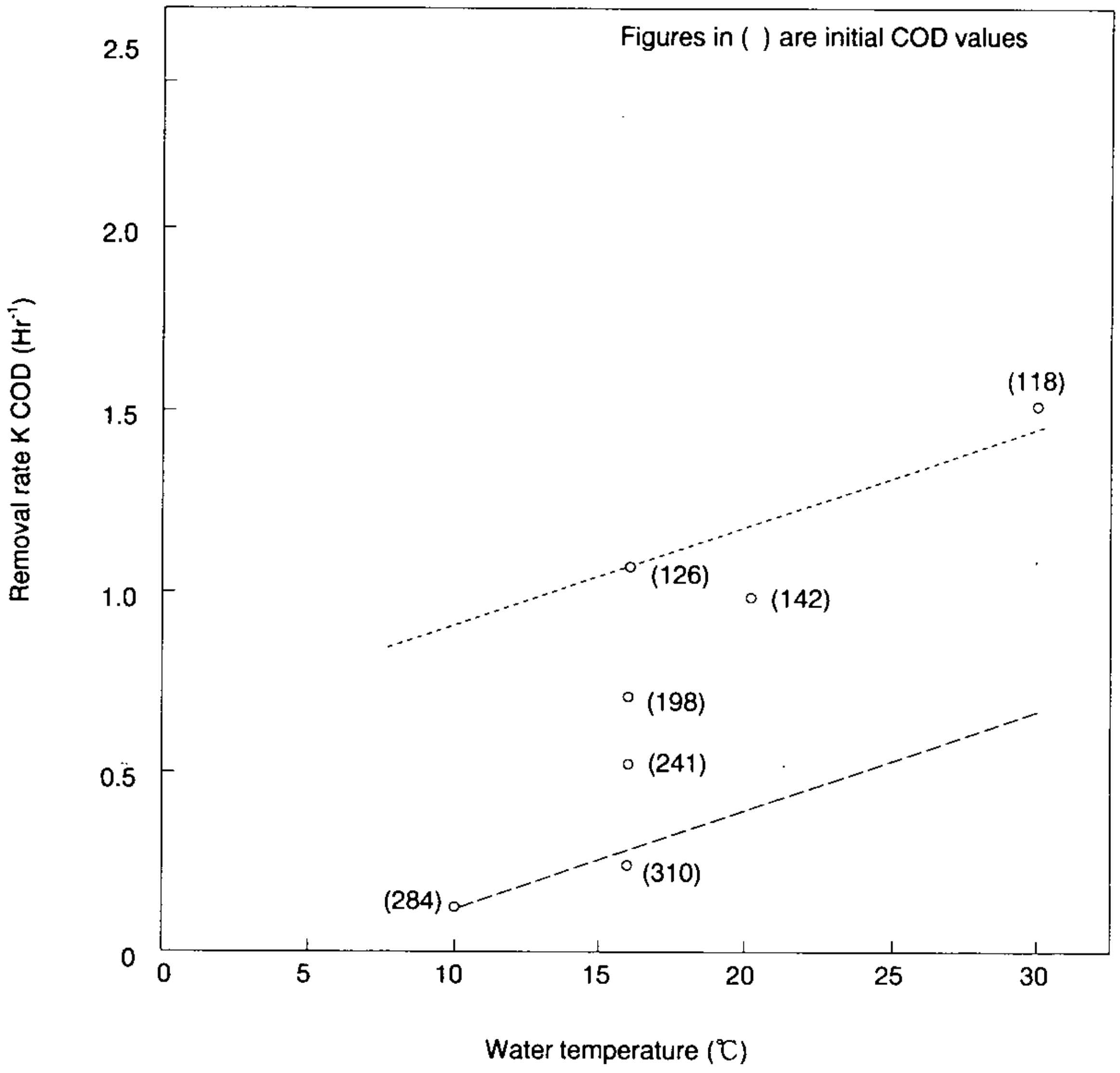


Fig 5-16 The relationship between the water temperature and the removal rate of the sludge in the indoor controlled aeration experiment (COD)

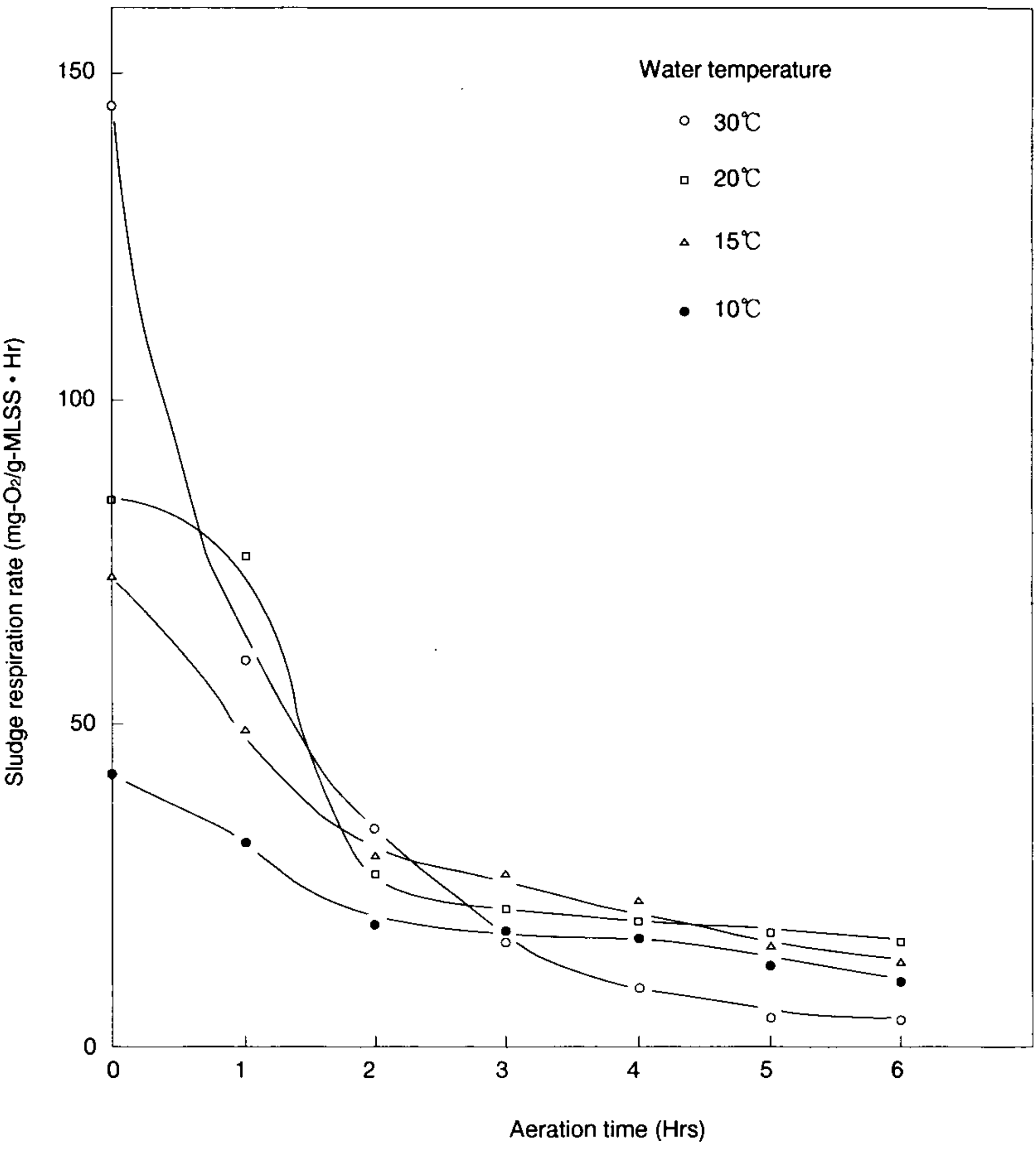


Fig 5-17 Comparison of sludge respiration rate and water temperature in the indoor controlled aeration experiment

5.3 Comparison of the existing activated sludge facility and the controlled aeration activated sludge

The characteristics of the non-controlled and controlled aeration methods were clarified from the viewpoint of the substrate removal rate by comparing the properties of the activated sludge in the existing treatment facility and the indoor bench-scale apperatus.

(1) Comparison of substrate removal rate

Using activated sludge from the existing noodle manufacturing plant wastewater treatment facility and from the indoor bench-scale apperatus, the substrate removal rates were compared in a batch test.

Figs. 5-18 and 5-19 show the comparison of the removal rates of TOC and COD, respectively. The experiment was conducted at MLSS of 1000 mg/ ℓ , water temperatuer of 16 - 17℃, an initial TOC concentration of 150 mg/ ℓ and initial COD concentration of 200 mg/ ℓ .

Comparing the activated sludge of the existing non-controlled aeration method, the removal speed constants of both TOC and COD of the activated sludge in the indoor bench-scale plant with the non-controlled aeration method were bigger, which signifies the sludge acitivity is high.

(2) Comparison of sludge respiration rates

The activated sludge properties were compared from the viewpoint of the rate of respiration.

Fig. 5-20 shows the comparison of the sludge respiration rate in experiment 5-3(1) above. Although the initial respiration rate of the sludge from the existing treatment plant utilizing the non-controlled aeration method was high, 30 mg-O_2/g-MLSS · hr, it was very inactive activated sludge compared to the respiration rate of the controlled aeration method, 115 mg-O_2/g-MLSS · hr.

In comparison of the change in the declining respiration rate as treatment proceeded to the endogenous phase after substrate removal, in the controlled aeration experiment although the initial respiration rate was high, it rapidly lowered and reached endogenous respiration after 4 hours of aeration.

This result showed that the sludge property of the controlled aeration method was good also with respect to the physiological function because the substrate removal rate and acitivity were high.

On the other hand, the shift to endogenous respiration was not clear in the non-controlled aeration experiment and there was no clear relationship between the decline in the respiration rate and substrate removal.

This difference was not only due to the activity of the sludge but also due to its physiological function caused by the paticular aeration system used in the controlled aeration experiment, in which the anaerobic condition on inflow of the untreated water and the aerobic condition at the end of the aeration were altered.

(3) Initial substrate concentration effect

The relationships between the initial substrate concentration and the removal rate in the non-controlled and controlled aeration experiments were compared.

Figs. 5-21 and 5-22 show the relationship between the initial substrate concentration and the removal rate of TOC and COD, respectively.

The relationship clarified that for an increase in the substrate removal rate of 0.1, the substrate sludge loading should have decreased by 0.08 in the existing facility utilizing the non-controlled aeration method, but in the controlled aeration method it was possible by lowering the substrate sludge loading by just 0.03.

We concluded that the controlled aeration activated sluge method was more stable against wastewater concentration fluctuations than the non-controlled aeration method.

(4) Water temperature effect

The relationships between the water temperature and the substrate removal rate in the non-controlled and controlled aeration experiments were compared.

Figs. 5-23 and 5-24 show the relationship between the water temperature and the removal rate of TOC and COD, respectively.

As there was an effect due to the initial substrate concentration, it was necessary to compare the non-controlled and controlled aeration methods under the same initial substrate concentrations.
Compared to the existing non-controlled aeration method, in controlled aeration, the substrate removal rate dramatically increased when the water temperature rose and the acitivity was high.

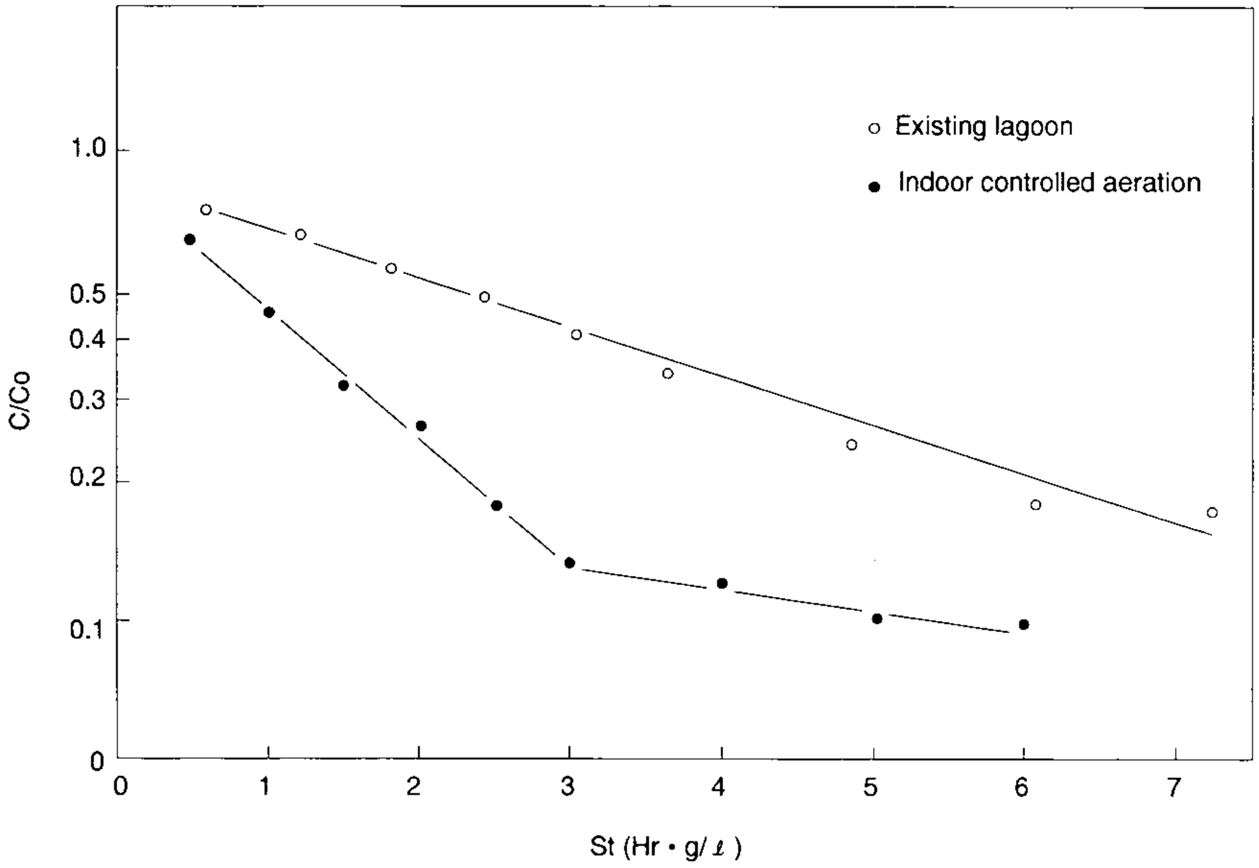


Fig 5-18 Sludge property comparison between the existing lagoon and indoor controlled aeration based on the rate of removal
(Water temperature16.0~17.0℃ , initial TOC value 150mg/ ℓ)

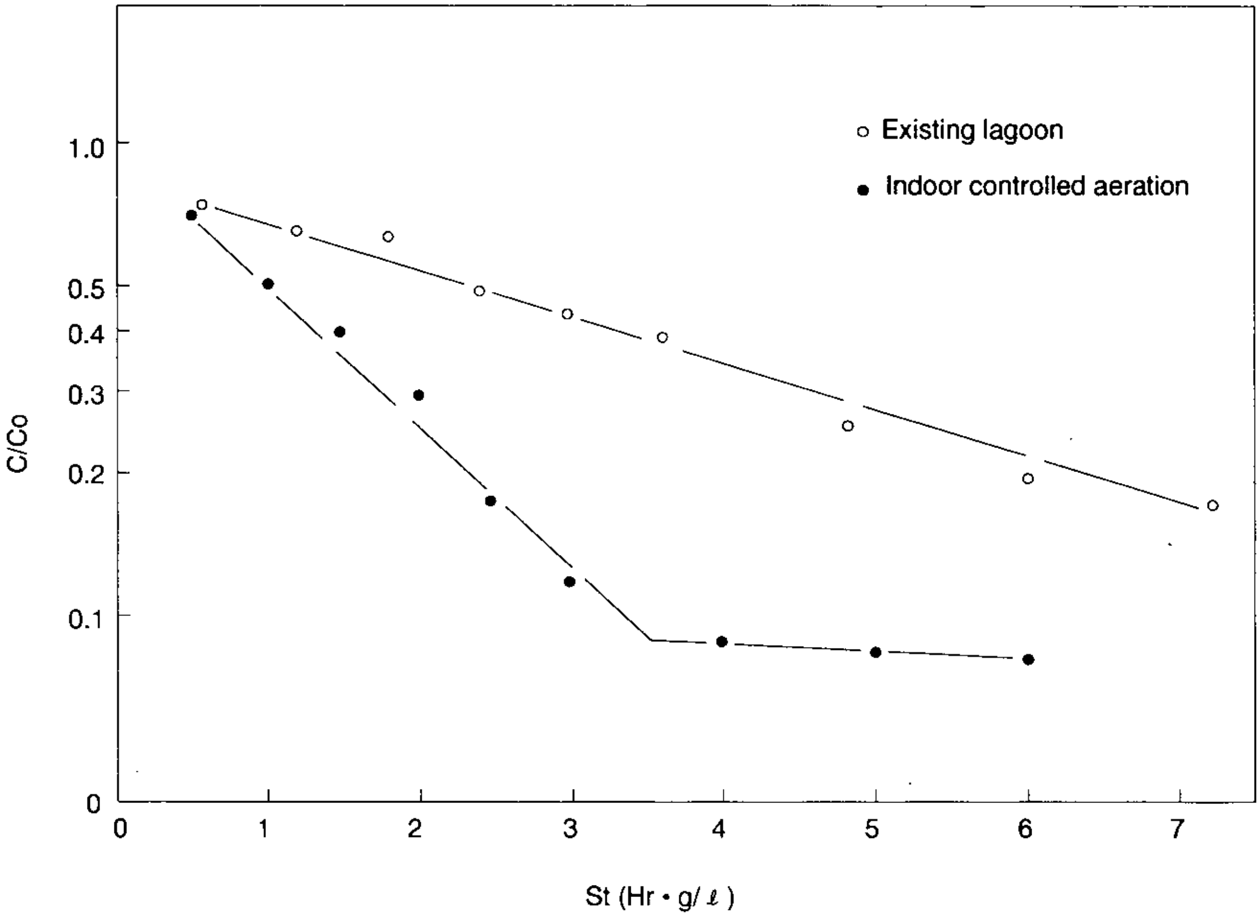


Fig 5-19 Sludge property comparison between the existing lagoon and the indoor controlled aeration based on the rate of removal
(Water temperature16.0~17.0℃, MLSS 1000mg/ ℓ , initial COD value 200mg/ ℓ)

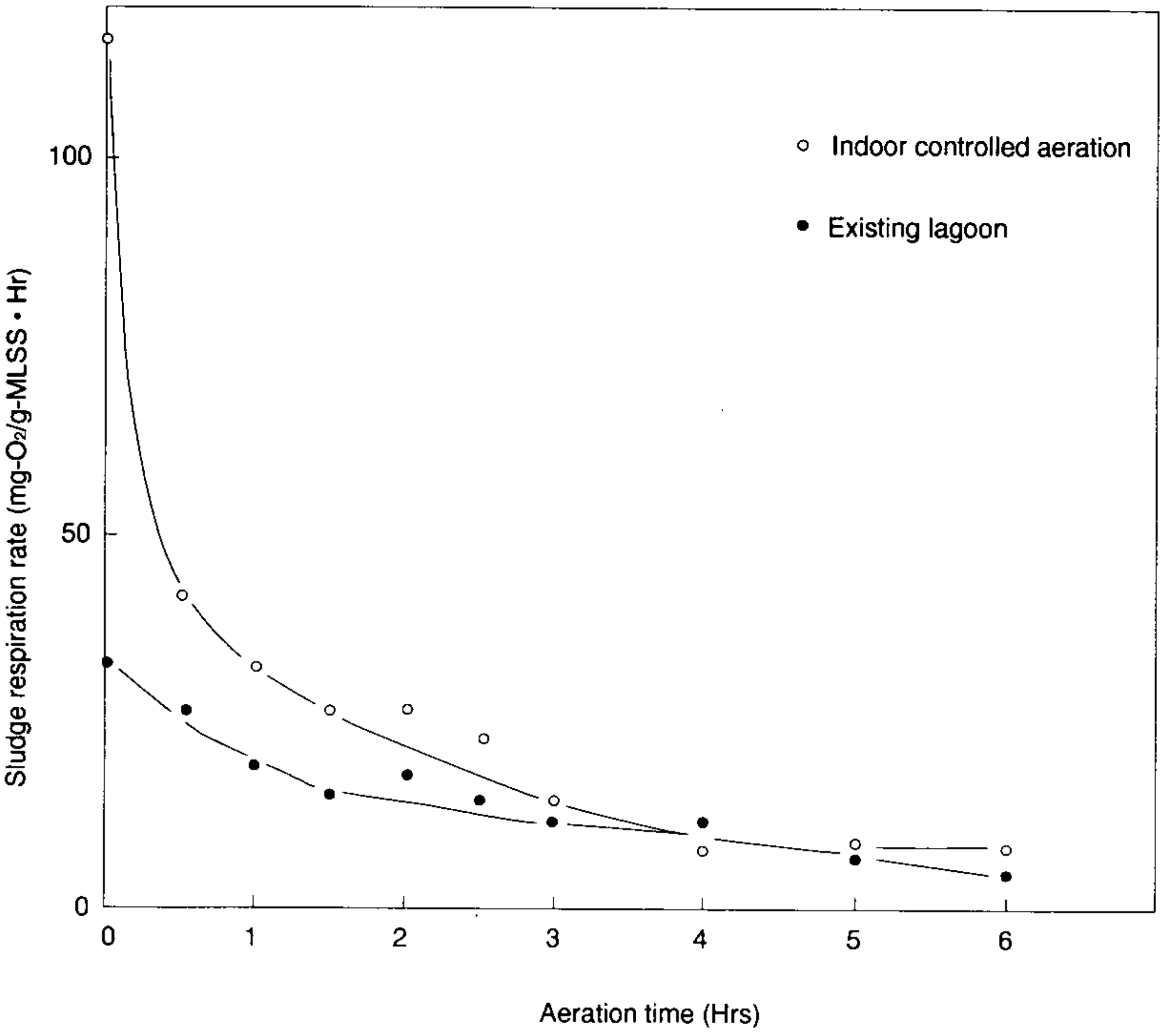


Fig 5-20 Sludge respiration rate change comparison between the existing lagoon and indoor controlled aeration

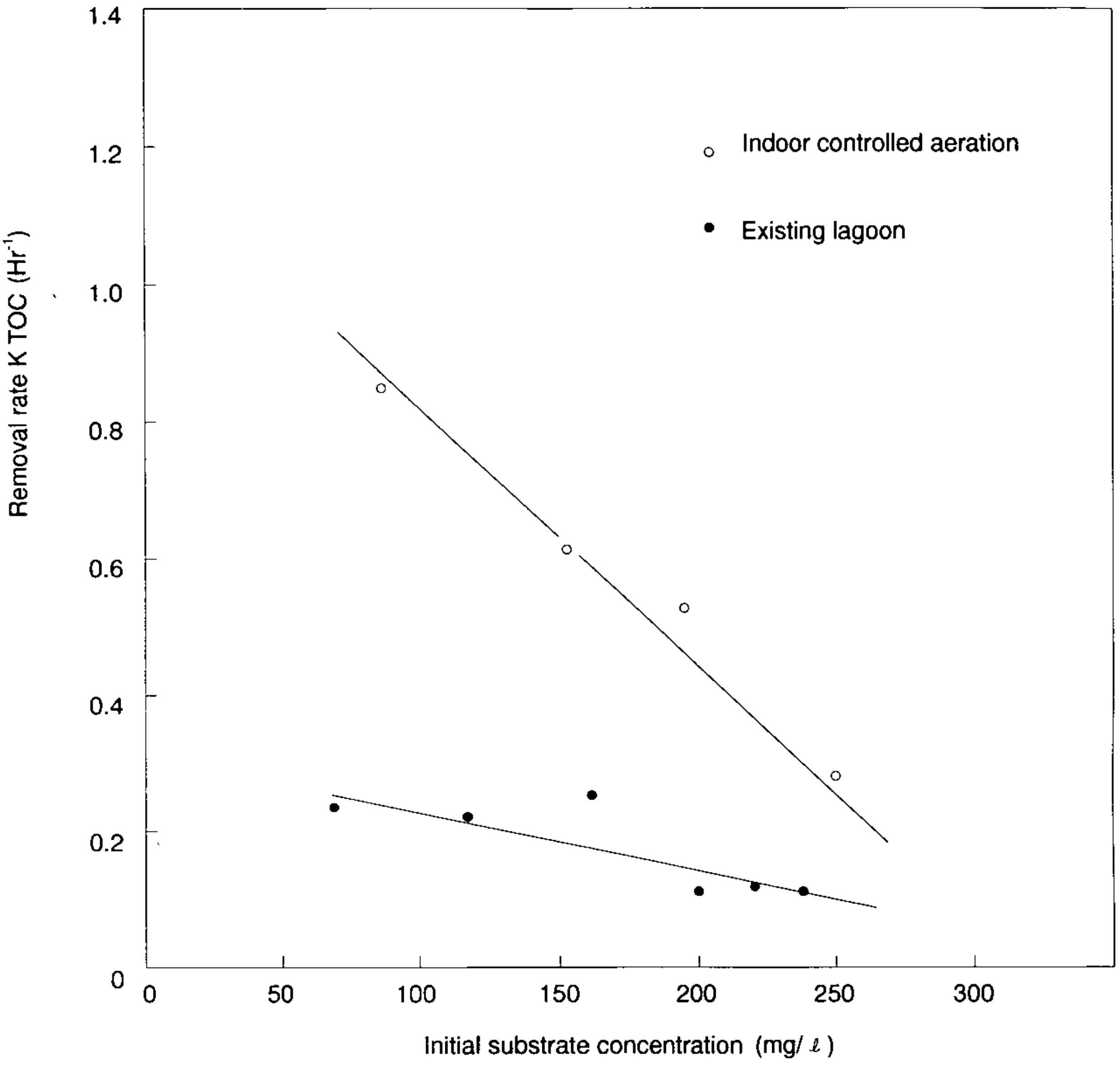


Fig 5-21 Sludge property comparison based on the substrate removal rate (TOC)
Initial substrate concentration effect

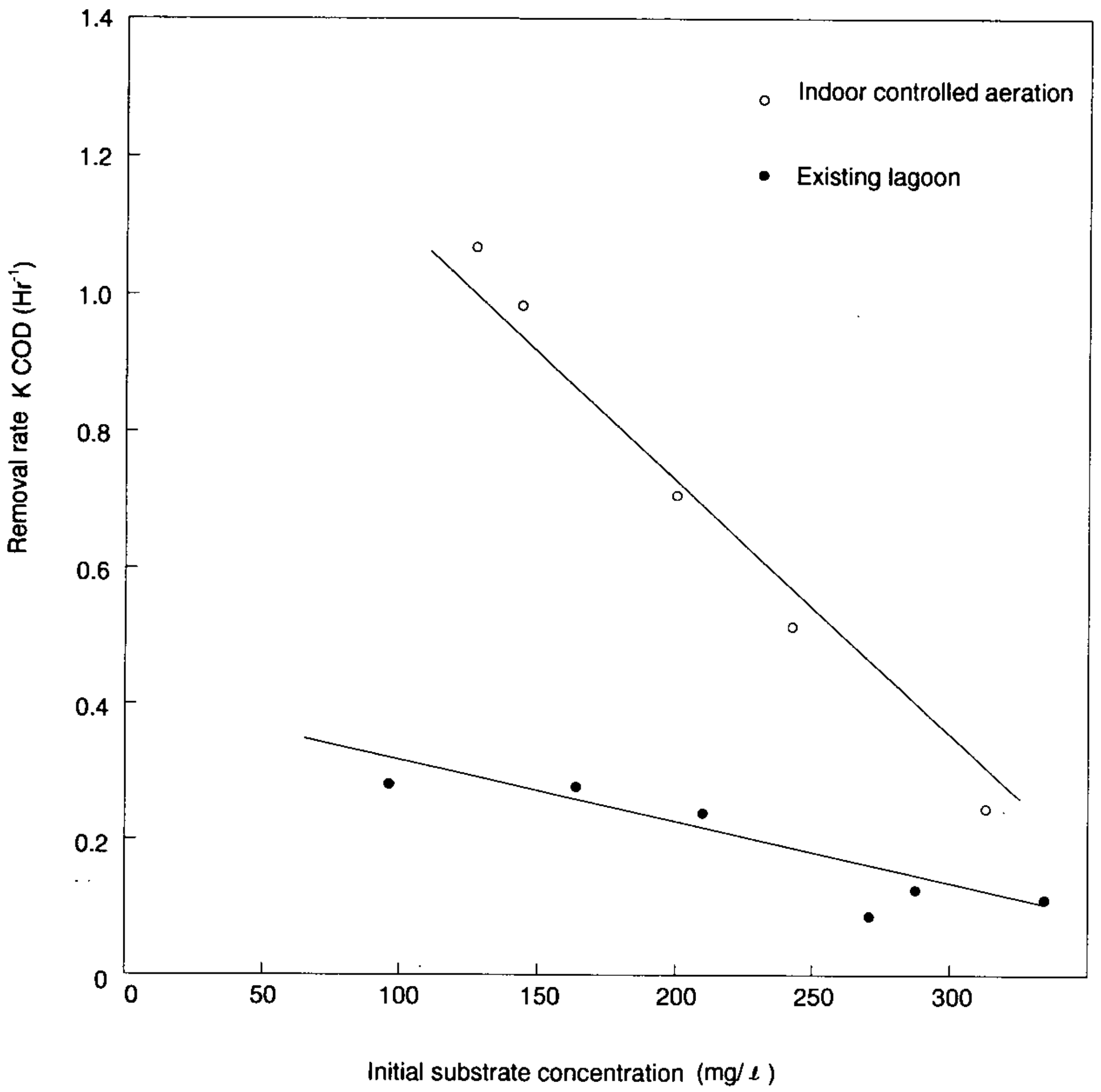


Fig 5-22 Sludge property comparison based on the substrate removal rate (COD) Initial substrate concentration effect

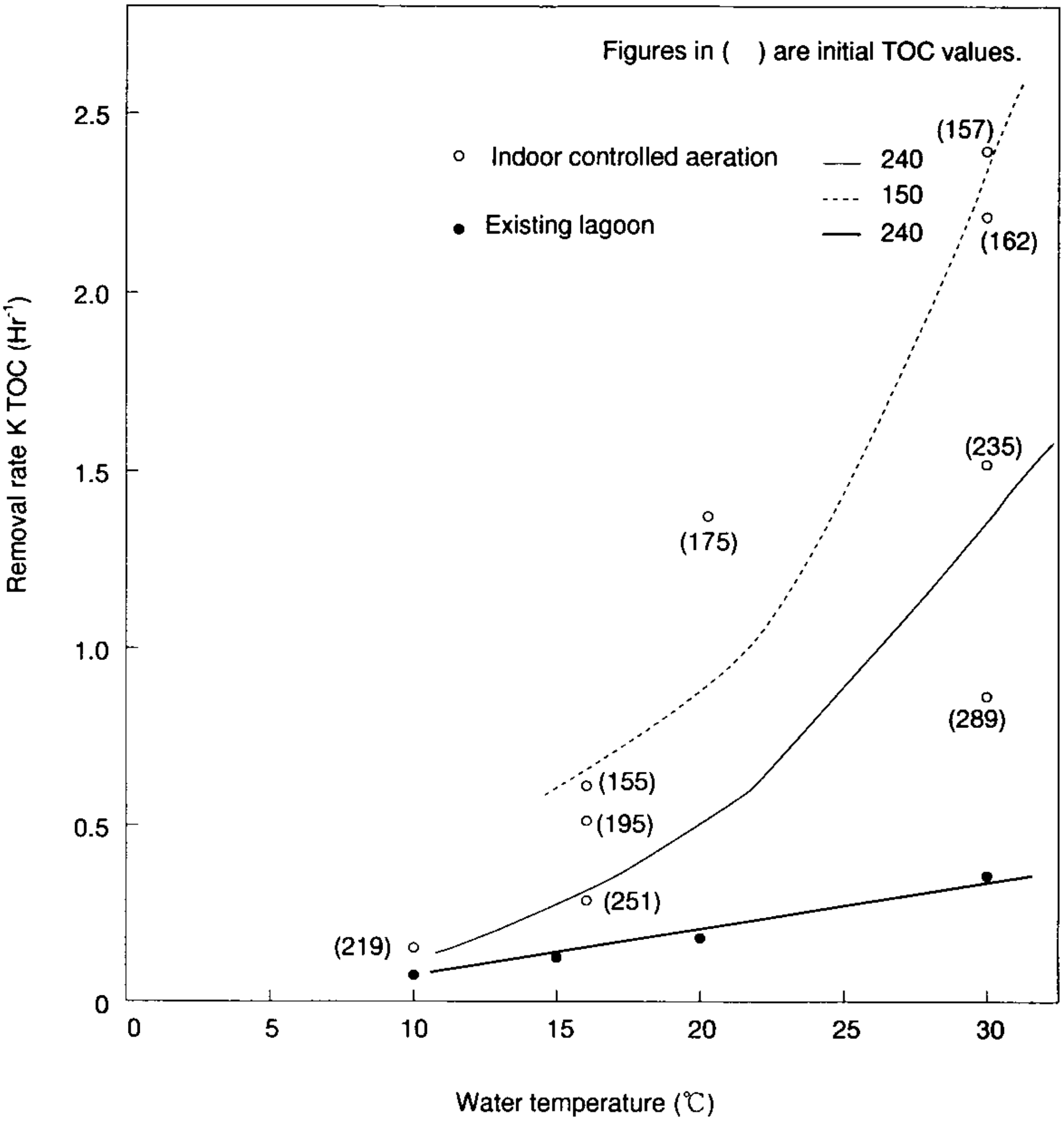


Fig 5-23 Sludge property comparison based on the substrate removal rate (TOC)
Water temperature effect

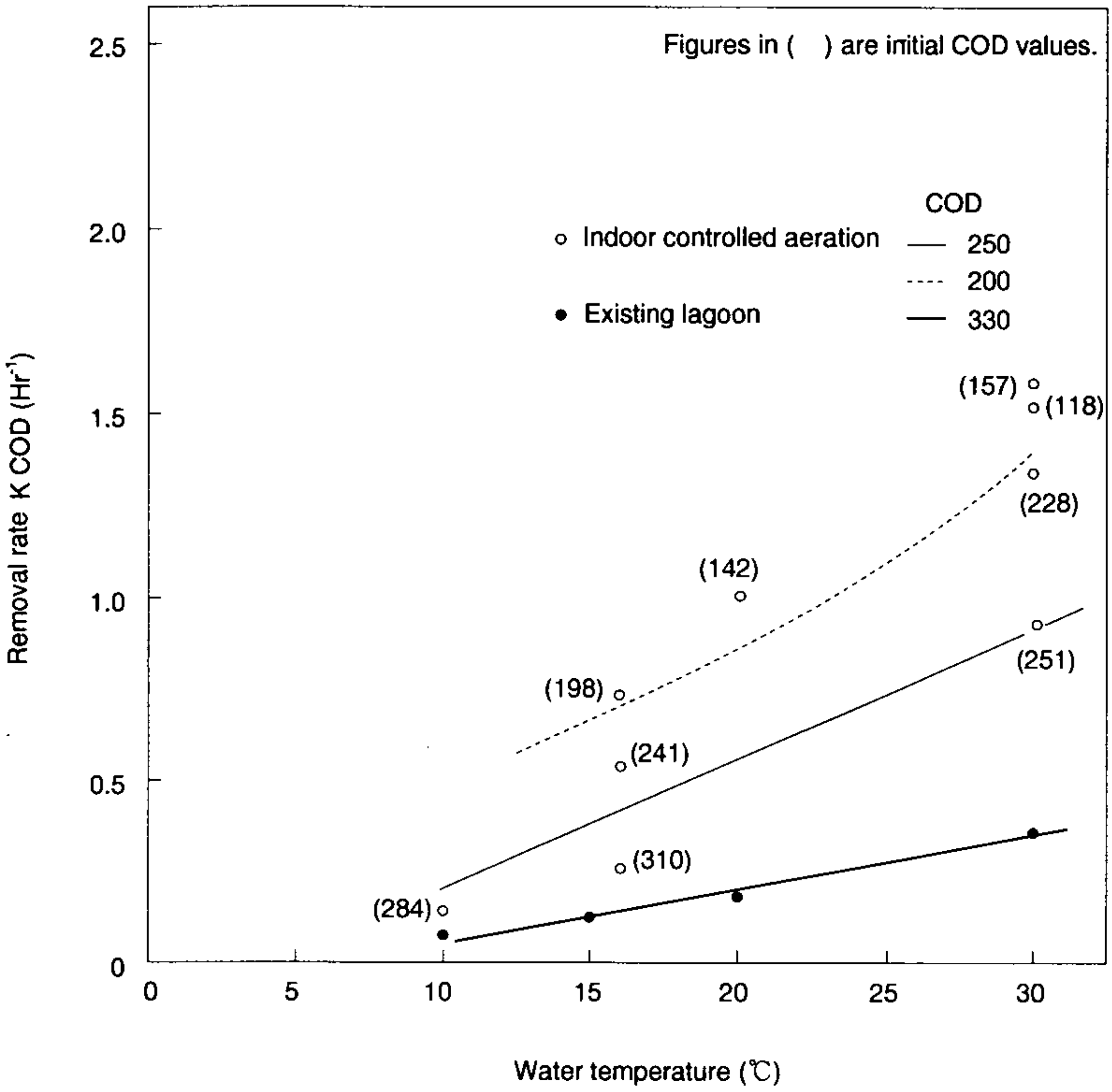


Fig 5-24 Sludge property comparison based on the substrate removal rate (COD)
Water temperature effect

5-4 Evaluation of the substrate removal rate in the indoor controlled aeration apperatus

The characteristics of the controlled aeration method were studied by evaluating the substrate removal rate with respect to the initial substrate concentration and water temperature.

(1) Initial substrate concentration effect

The relationship between the initial substrate concentration and the removal rate was evaluated with respect to water temperature.

Figs. 5-25 and 5-26 show the change in the substrate removal rate for TOC and of COD, respectively.

There was a tendency that when the water temperature decreased and the initial substrate concentration increased, the substrate removal rate dropped.

(2) Water temeparature effect

The relationship between the water temperature and the removal rate was evaluated with respect to the initial substrate concentration.

Figs. 5-27 and 5-28 show the change in the substrate removal rate for TOC and of COD, respectively.

There was a tendency that when the initial substrate concentration decreased and the water temparature increased, the substrate removal rate rose.

(3) Relationship between the initial substrate concentration and water temparature

It was found that the substrate removal rate was affected by the relationship between the initial substrate concetration and water temperature.

If the substrate removal rate can be estimated from the relationship between the initial substrate concentration and the water temperature, the efficiency of the controlled aeration treatment facility can be found to some extent.

Fig. 5-29 shows the relationship between the TOC initial substrate concentration, water temparature and substrate removal rate.

The result was that the efficiency was enhanced with a rise in temperature, for example, at the initial TOC concentration of 200 mg/ ℓ, the rate was 0.5 Hr^{-1} at a water temperature of 15 ℃, 1.0 Hr^{-1} at 20℃ and 1.5 Hr^{-1} at 25℃.

Fig. 5-30 shows the correlation between TOC and d-BOD & d-COD in the wastewater.

In the wastewater of the experiment, 200 mg/ ℓ of TOC was almost equivalent to a BOD loading of 350 mg/ ℓ and it was considered that in the influent of the controlled aeration experiment to be equivalent to double, 700 mg/ ℓ, or more.

Fig. 5-31 shows the relationship between the initial COD concentration, water temperature and substrate removal rate.

From the relationship between wastewater concentration and water temperature, the optimum aeration time when utilizing the controlled aeration activated sludge method can be estimated to maximize the treatment function through adjustment of the aeration time according to change in the wastewater concentration and seasonal water temperature.

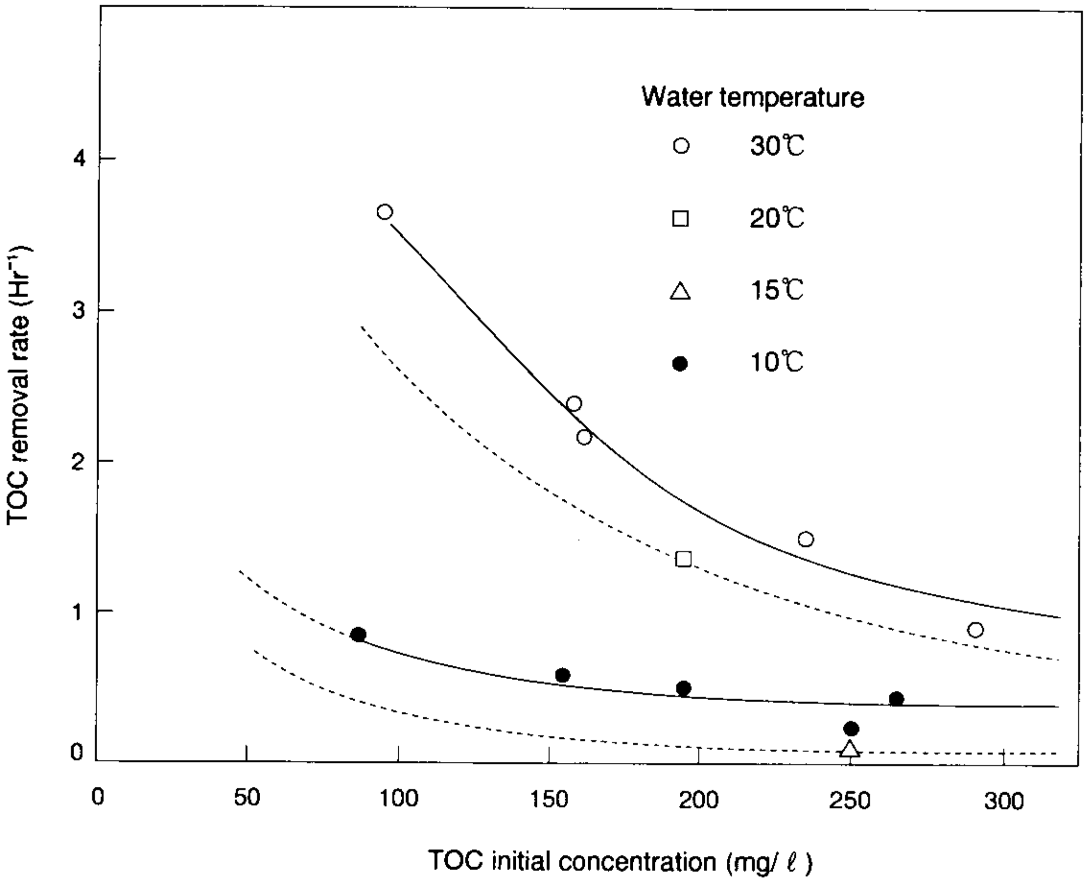


Fig 5-25 Relationship between the initial substrate concentration and the removal rate when using noodle boiler wastewater sludge in the indoor controlled aeration experiment

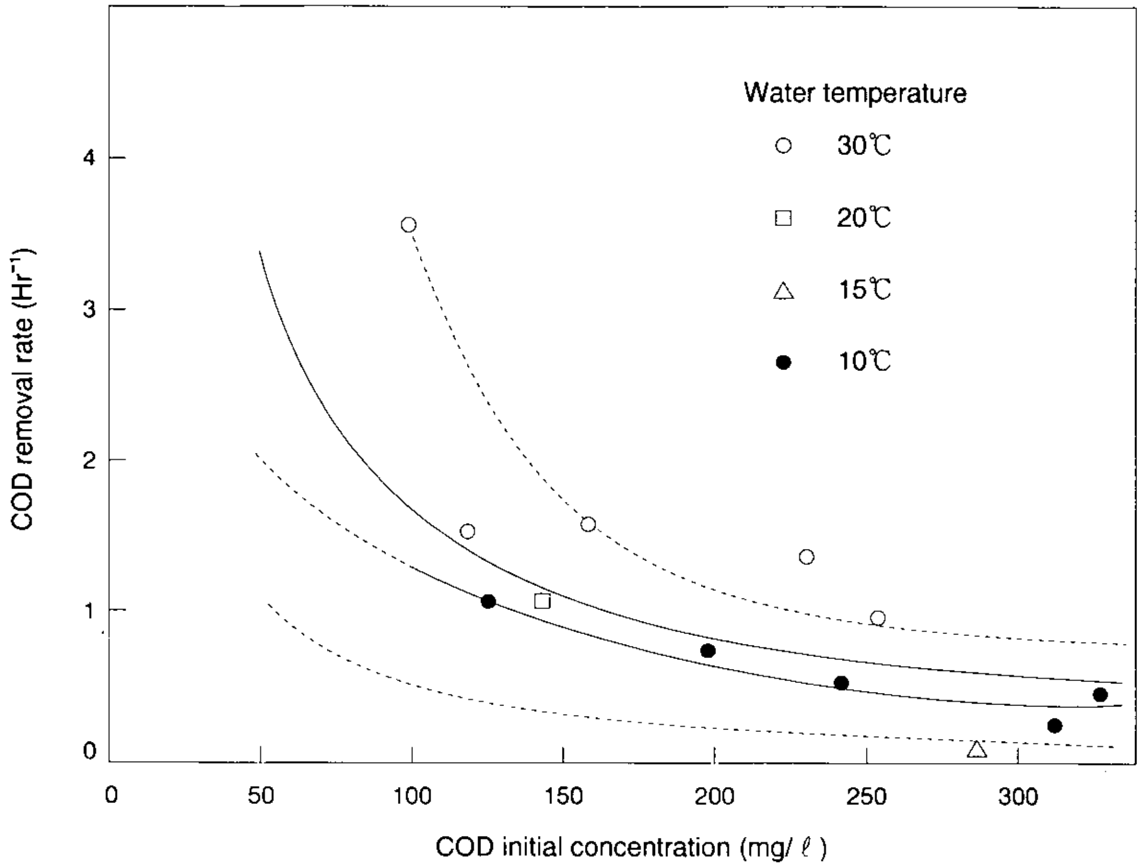


Fig 5-26 Relationship between the initial substrate concentration and the removal rate when using noodle boiler wastewater sludge in the indoor controlled aeration experiment

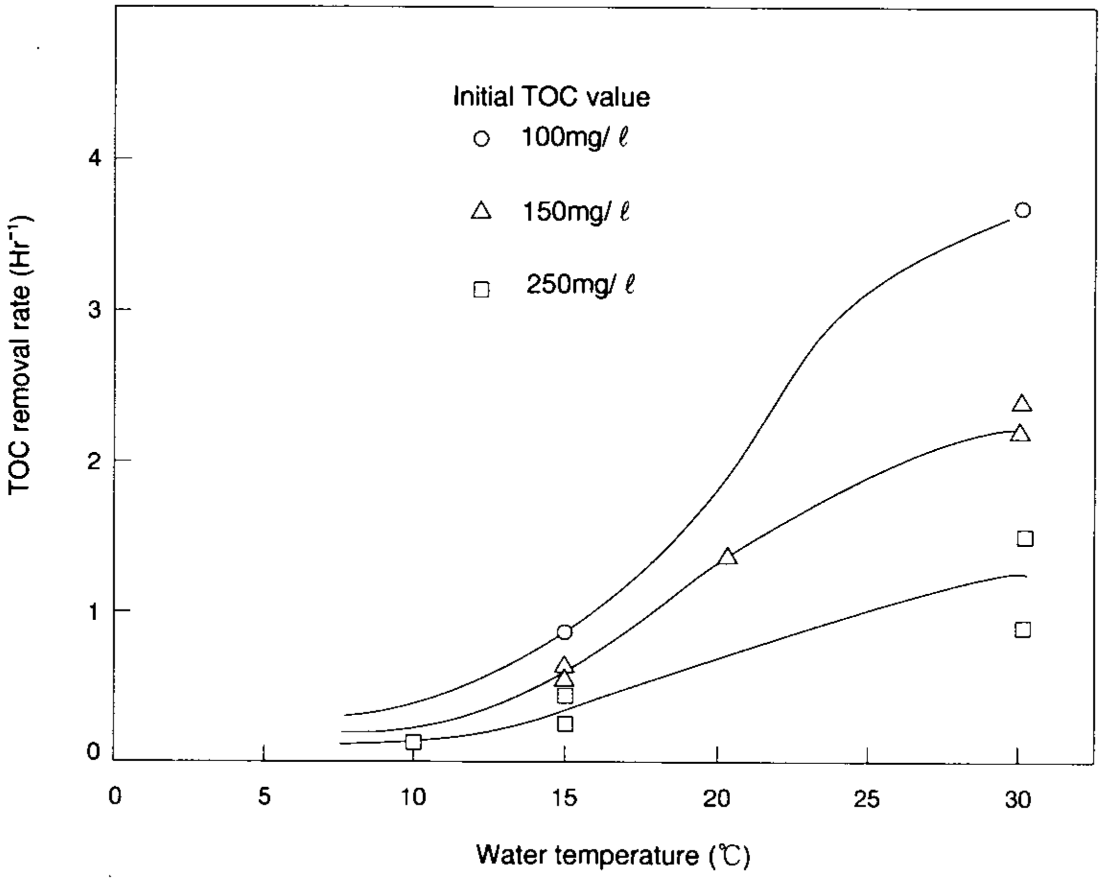


Fig 5-27 Relationship between water temperature and the removal rate when using noodle boiler wastewater sludge in the indoor controlled aeration experiment

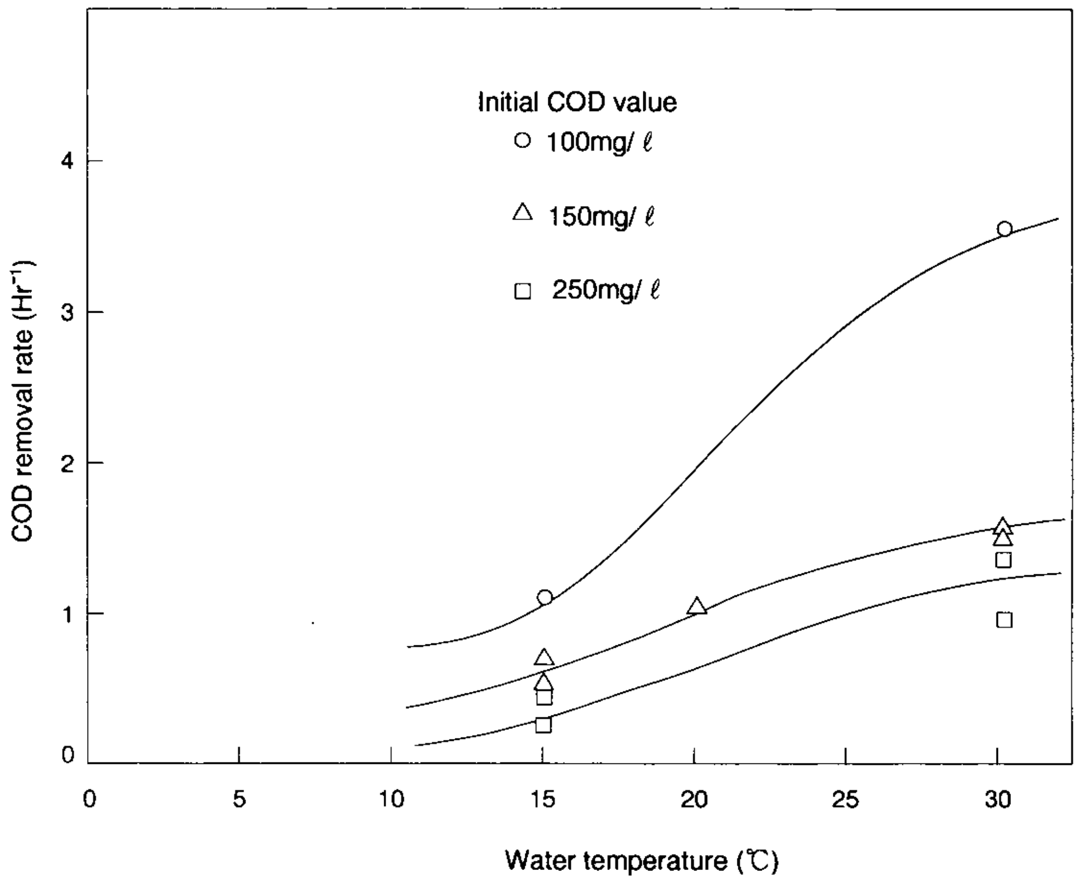


Fig 5-28 Relationship between water temperature and the removal rate when using noodle boiler wastewater sludge in the indoor controlled aeration experiment

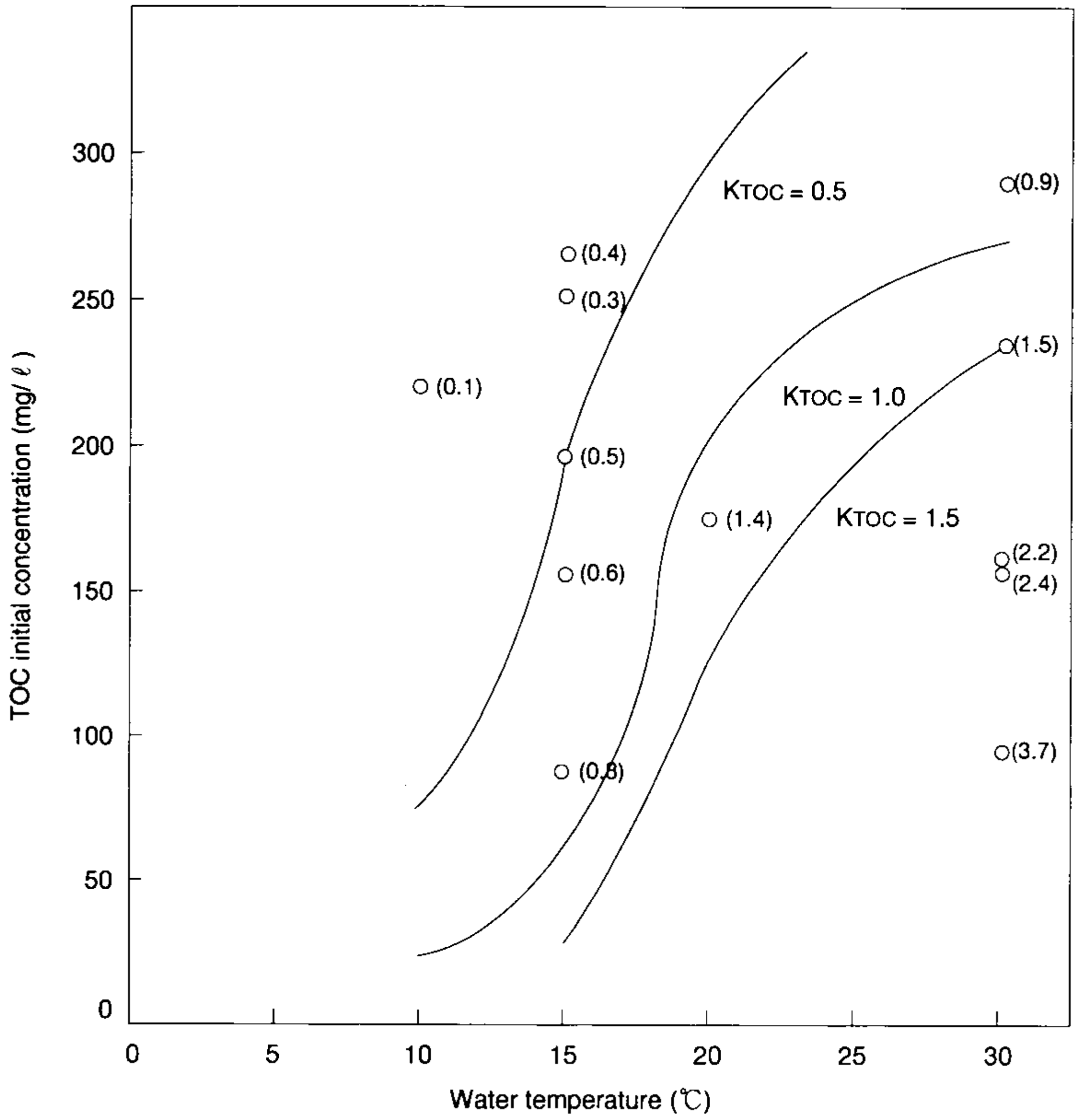


Fig 5-29 Change in the substrate removal rate due to the initial concentration and water temperature of noodle boiler wastewater in the controlled aeration experiment

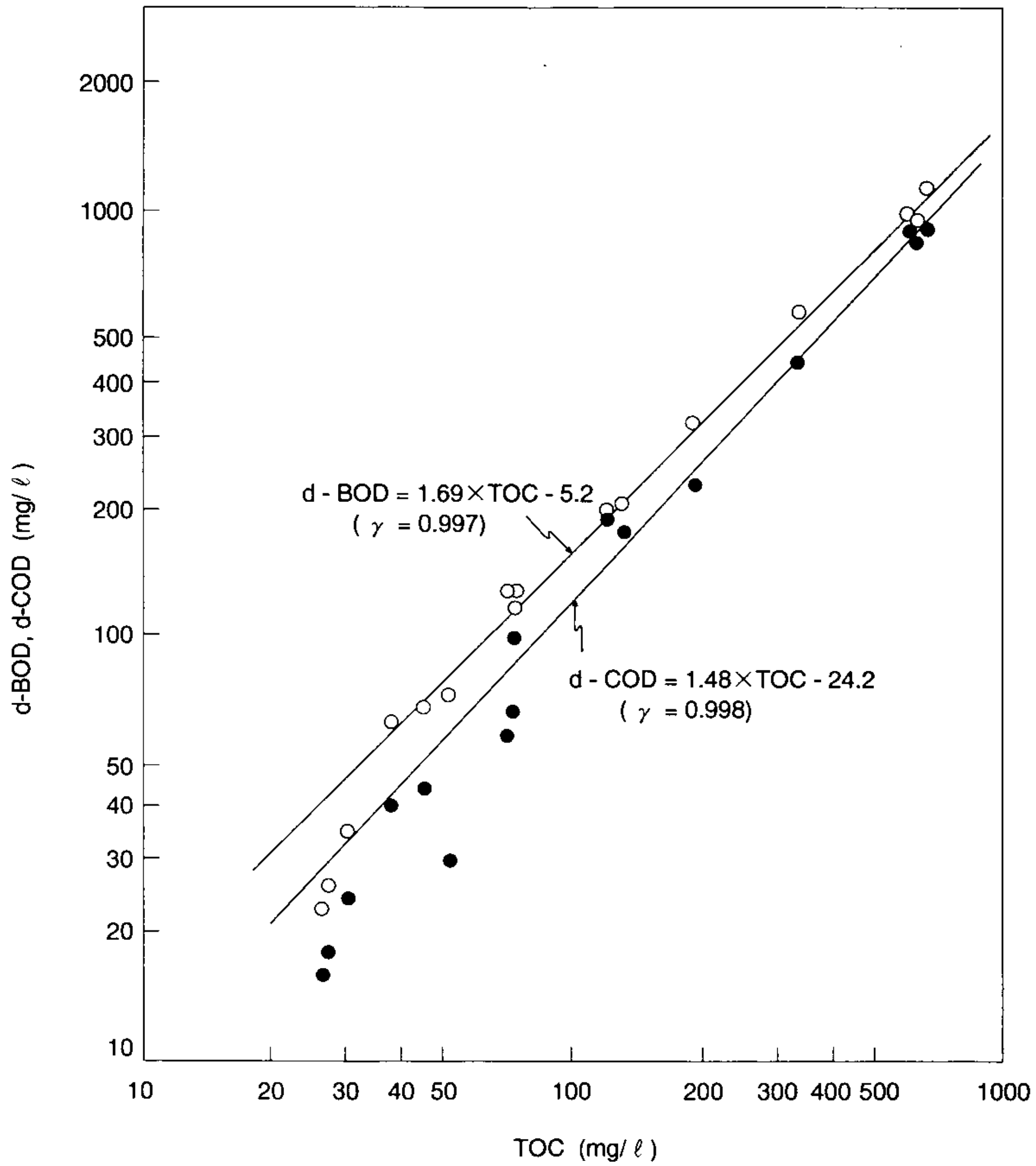


Fig 5-30 Correlation between TOC and d-BOD, d-COD in noodle manufacturing plant wastewater

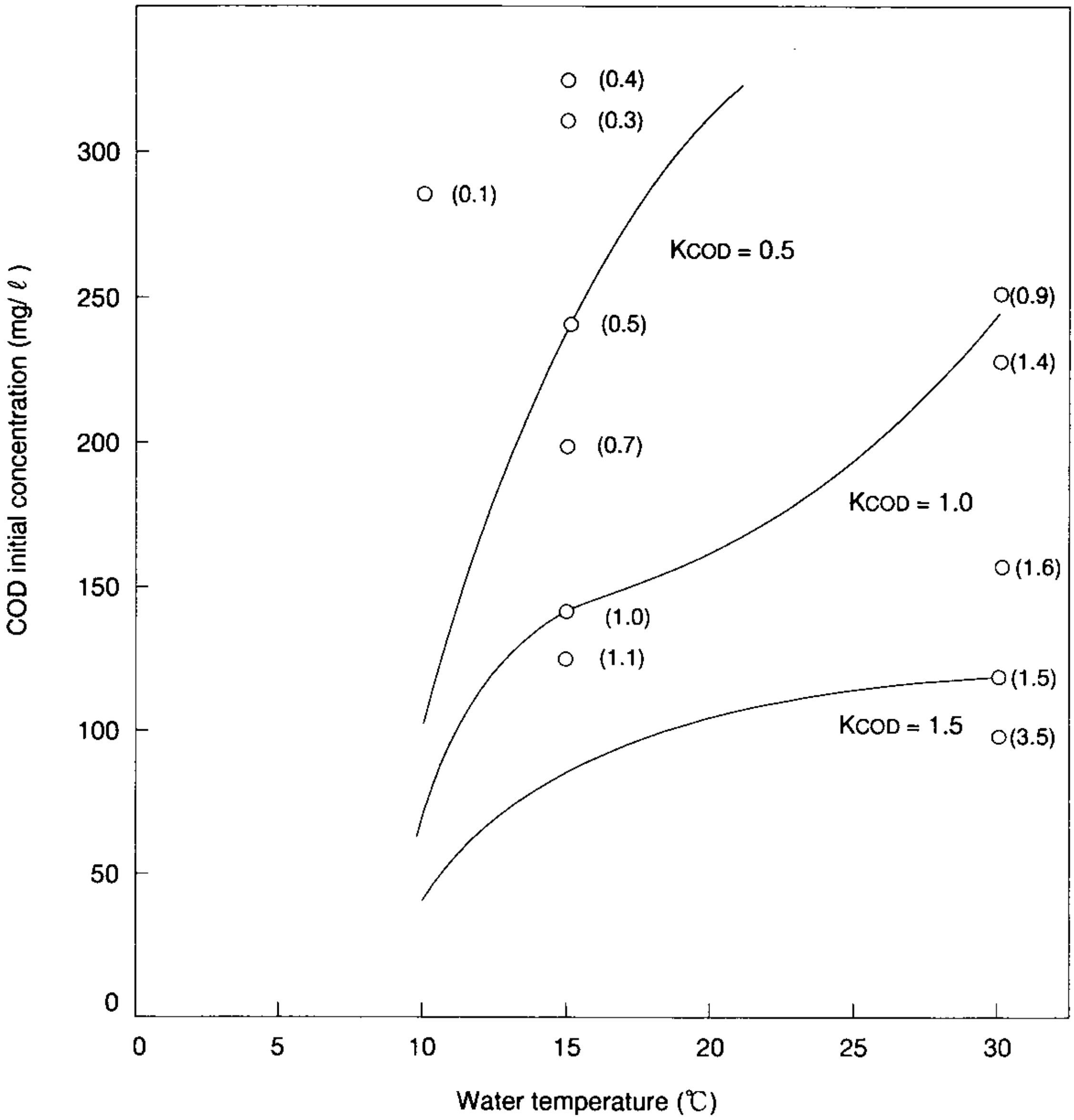


Fig 5-31 Change in substrate removal rate due to the initial concentration and water temperature of noodle boiler wastewater in the controlled aeration experiment

5-5 Conclusion

The characteristics of the controlled aeration activated sludge method were studied from the viewpoint of the substrate removal rate, and this method was compared with the existing wastewater treatment facility of a noodle manufacturing plant.
The following is a summary of the results.

(1) In the existing wastewater treatment facility of the noodle manufacturing plant (using a batch-type non-controlled aeration activated sludge method), the substrate removal rate was affected by the initial substrate concentration and water temperature.
The higher the initial substrate concentration, the lawer the substrate removal rate and, to increase the substrate removal rate by 0.1, the substrate sludge loading had to be decreased by 0.08.
The substrate removal rate increased along with a rise in water temperature.

(2) In the controlled aeration activated sludge method of the indoor bench-scale apperatus, the sludge substrate removal was higher than that of the activated sludge of the existing non-controlled aeration facility and it was also affected by the initial substrate concentration and water temperature.
The higher the initial substrate concentration, the lower the substrate removal rate and to decrease the substrate removal rate by 0.1, the substrate sludge loading had to be decreased by 0.03.
The substrate removal rate increased along with a rise in water temperature, but through sludge respiration rate measurement it was found that even if the substrate concentration of the treated water decreased, it didin't reach the endogenous respiration phase straight away. This point needed to be included in the consideration of substrate removal for the proper physiological function of the activated sludge.

(3) In comparison of the controlled aeration method and the existing non-controlled aeration method from the view of the substrate removal rate, it was found that the sludge substrate removal rate was higher and the acitivity greater in the controlled aeration method.
In the controlled aeration activated sludge experiment, the initial respiration rate of the activated sludge was higher and reached the endogenous respiration phase in a shorter time. This was probably due to the special physiological function of the controlled aeration method, repeated aerobic and anaerobic conditions.
From the relationship between the initial substrate concentration and the substrate removal rate, the controlled aeration method was more stable when there were loading fluctuations due to changes in the wastewater concentration compared to the non-controlled aeration method.

(4) The substrate removal rate was affected by the initial substrate concentration and the water temperature and it increased with a decrease in the initial substrate concentration and a rise in the water temperature.
This shows that the aeration time when using the controlled aeration activated sludge method can be estimated from the substrate removal rate, wastewater substrate concentration and water temperature, allowing proper adjustment of the treatment facility.

6. Study on the efficiency of the controlled aeration activated sludge method using tofu manufacturing plant wastewater

In the activated sludge method, there are two basic processes; the encapsulation process in which organic substances in wastewater are converted to microorganism cells and the separation process in which flocculated microorganisms are separated from the treated water through natural settling. For maximum utilization of the activated sludge method, proper maintenance of the different two processes is necessary.

In the experiment, using tofu manufacturing plant wastewater, knowledge was obtained concerning the basic function of the controlled aeration activated sludge method mainly on factors related to bulking control, such as nutrients, sludge age and water temperature.

6-1. Effect of nutrients

For proper metabolism of organic substances by activated sludge microorganisms when using the controlled aeration activated sludge method, a small amount of inorganic elements, nitrogen and phosphorus is necessary. Other inorganic elements are usually in sufficient quantity in the wastewater, but in many cases nitrogen and phosphorus are lacking.

The two elements are major constituents of cell nuclei and enzymes in microorganisms. If these nutrients are not supplied continuously, organic substance decomposition causes because the proliferation of microorganisms, and enzymes, grinds to a halt.

(1) Treatment result

Based on the experiment result as in 2-3 (5), in the tofu manufacturing plant, the ratios of nitrogen and phosphorus to BOD were lacking; BOD : N : P = 100 : 3.5 : 0.5 compared to those needed for activated sludge treatment, BOD : N : P = 100 : 5 : 1. /In wastewater treatment, nutrition balance is usually controlled through addition of nutrients, but there are many cases in which excess nitrogen and phosphorus remain in the treated water. An adequate balance of nutrients is desirable, also from the viewpoint of lowering the cost and eutrophication prevention.

The experiment was conducted using an indoor bench-scale apperatus (capacity of 10 ℓ) according to the experimental conditions of the controlled aeration method as in 4-3 (1). However the aeration time was 16 hours in this experiment.

For the experiment, the concentration of the tofu manufacturing plant wastewater was adjusted to a set value and urea and phosphoric acid were used for nitrogen and phosphorus addition.

Table 6-1 shows the water quality analysis result of the sampled wastewater.

The activated sludge used in the experiment was acclimated using the sampled wastewater for about one-month.

The treatment result is shown in Fig. 6-1.

The average nutrient ratio for BOD concentration in the sampled wastewater are as follows.

Apperatus No.	BOD	Nitrogen	Phosphorus
NP – 00	100	4.2	0.4
NP – 10	100	8.7	0.4
NP – 01	100	4.2	1.2
NP – 11	100	8.6	1.3

Phosphorus was lacking in NP-00 and NP-10 and nitrogen was excessive in NP-10 and NP-11.
The removal efficiency of TOC was very good in every apperatus; the average was 95 % or more.
COD removal efficiency was 97 % or more.
Similarly, this result shows that the addition of nitrogen and phosphorus had no effect on substrate removal from this wastewater.

(2) Sludge property effect

MLSS concentration varied according to BOD loading and excess sludge volume but in the experiment MLSS was adjusted to 2500 - 3200 mg/ℓ since SRT was 8 days in simple BOD space loading of 0.5 - 0.9 kg/m^3· d.
SVI, an index of the settling characteristics of the sludge, was good, 50 - 80, in NP-00 and NP-01 for the entire experimental period. In these experiments, there was no excessive nitrogen addition and it implied that the sludge settling characteristics were related to the nitrogen compound ratio.
Microscope observation found that the change in SVI was not caused by filamentous bacteria.
It is known that there are other factors which greatly affect the settling characteristics of the sludge, unfortunatly this experiment could not clarify them.

Table 6-1 Water quality analysis results of the sampled wastewater

Apperatus No.	Items Period	pH (-)	SS (mg/)	TOC (mg/)	COD (mg/)	BOD (mg/)	K-N (mg/)	T-P (mg/)
NP-00	Mar.5 ~11	4.91	196	407	1380	1700	69.4	8.2
	Mar.12~18	4.40	360	468	1450	1870	69.7	7.4
	Mar.19~25	4.40	360	435	913	1050	53.5	3.0
	Mar.26~31	6.72	73	435	905	1090	47.3	3.0
NP-10	Mar.5~11	5.48	204	407	1380	1700	128	8.2
	Mar.12~18	4.60	380	465	1450	1940	135	7.7
	Mar.19~25	4.60	380	435	945	1090	117	1.4
	Mar.26~31	6.88	59	434	890	1030	118	3.7
NP-01	Mar.5~11	5.12	174	407	1380	1700	62.7	17.0
	Mar.12~18	4.42	320	456	1450	1820	69.4	19.0
	Mar.19~25	4.42	320	435	938	1100	53.8	16.8
	Mar.26~31	7.22	57	434	930	1030	48.7	17.6
NP-11	Mar.5~11	5.99	190	407	1380	1700	129	20.9
	Mar.12~18	4.80	328	463	1450	1840	132	19.4
	Mar.19~25	4.80	328	433	993	1090	116	14.9
	Mar.26~31	7.10	73	438	943	1020	111	18.3

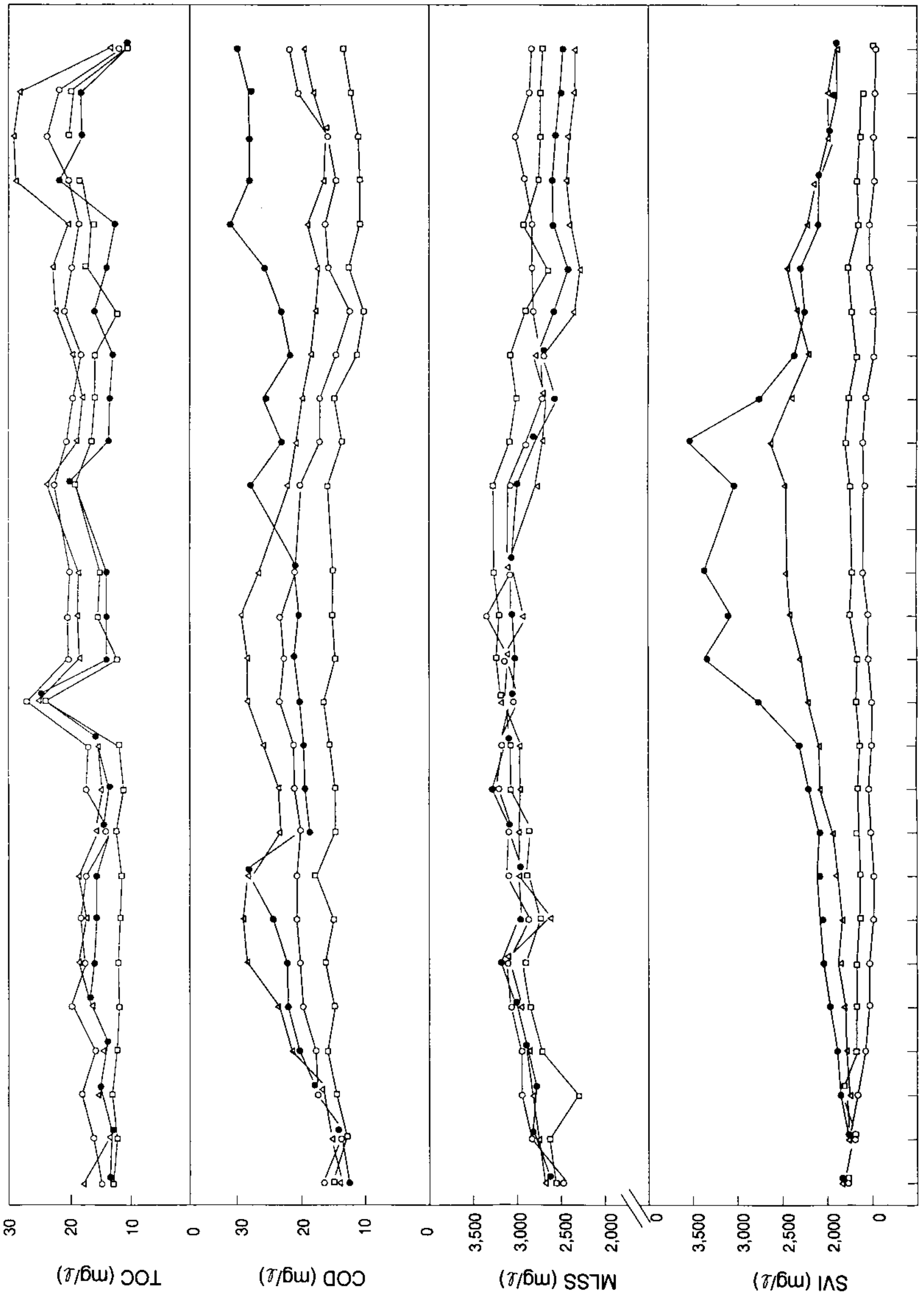


Fig 6-1 Effect of nutrients in tofu manufacturing plant wastewater
(Treatment results of TOC, COD, MLSS and SVI)

6-2 Effect of sludge age

The experiment was conducted a basic study on the change in SRT and treatment characteristics of the controlled aeration activated sludge method.
Knowledge on control of activated sludge volume due to BOD loading and SRT in the aeration tanks was obtained.

(1) Treatment result

Sludge age represents the average retention time of activated sludge in aeration tanks and it has been used as an important control factor in sewage treatment plants.
Sludge age is usually represented by the following formula:

$$As = VSa / QSf$$

where As = sludge age (day)
V = aeration tank volume (m^3)
Sa = MLSS concentration (kg/m^3)
Q = influent wastewater flowrate (m^3/d)
Sf = concentration of suspended solids in influent (kg/m^3)

The problem is that sludge in the settling tank and sludge growth in the aeration tank are not considered.
In the experiment therefore, the sludge age was represented as sludge retention time (SRT).
SRT is represented by the following formula:

$$SRT = (S' + Sx) / (Ss + Se)$$

where SRT = sludge retention time (day)
S' = suspended solid volume in the aeration tank (kg)
Sx = sludge volume in the settling tank, return sludge pipe, etc. (kg)
Ss = excess sludge volume (kg/day)
Se = suspended solid volume in treated water (kg/day)

The experimental method and conditions are the same as in 6-1 (1) but in this experiment, to adjust the retention time in the aeration tank (SRT), a fixed amount of sludge was withdrawn from the aeration tank just before the end of aeration.
Since the sludge withdrawal volume was 1/4, 1/8, 1/16, 1/32 and 1/64 of the aeration tank volume, SRT was 4, 8, 16, 32 and 64 days, respectively.
The sampled wastewater was the same as NP-11 in Table 6-1 and the average sampled wastewater quality was BOD : N : P = 100 : 8.6 : 1.3.
The treatment result is shown in Fig. 6-2.
TOC concentration in the treated water was low, 15 mg/ ℓ or less, except the experiment with SRT on value of 4 days.
COD concentration in the treated water was also low, 20 mg/ ℓ or less, except the experiments with SRT values of 4 and 8 days.
This was due to the relation that the lower SRT was, the lower the activated sludge concentration in the aeration tank was.

(2) Relationship between BOD loading and sludge generation volume

In the controlled aeration activated sludge experiment, sludge volume increased when BOD was removed by microorganisms in the aeration tanks. This was because energy generated from oxidation of organic substances by microorganisms was utilized for growth which caused an accumulation of sludge. The increse in sludge was different during each stage but estimation on excess sludge volume was very important for controlling sludge in the aeration tank and deciding the capacity of the sludge treatment facilities. The excess sludge volume was the sum of sludge from SS adsorption in the wastewater and sludge from biological growth yielded from removal of dissolved BOD. Since the yield coefficient of sludge varied according to the differing substrates and nutrition balance, attention needed to be paid to this point before experiments and planning.

In aeration tanks, activated sludge microorganisms grow via biochemical reactions of oxidation and assimilation using organic substances in the wastewater as nutrients and at the same time the wastewater is treated by oxidative decomposition. The reaction rate is affected by the aeration time, activated sludge microorganism volume and organic nutrient volume, but in the activated sludge method, these influences are generally represented by the ratio of organic nutrients to activated sludge microorganisms. Organic nutrients and activated sludge microorganism volume in the aeration tank are practically represented as BOD and MLSS, respectively, and BOD-SS loading (sludge loading) is used as an index of design and operation management.

BOD loading is not only the sludge loading but BOD space loading as well and the relationship between them is defined as follows:

① Sludge loading Ls (kg-BODs/kg-MLSS · d)

$$\frac{QCo}{VX}$$

② Space loading L (kg-BODs/m^3 · Ed)

$$\frac{QCo}{V}$$

For example, in the schedule in which untreated water with half the volume of the aeration tank inflows and treated water of the same volume is discharged once a day, using controlled aeration activated sludge like this experiment, BOD loading can be represented as simple loading calculated from the daily loading or the actual loading calculated from the aeration time.

For example, at 1000 mg/ ℓ of BOD, aeration time of 16 hours and 2000 mg/ ℓ of MLSS, the simple BOD space loading is 0.5 kg/m^3 · d and the simple BOD sludge loading is 0.25 kg/kg·d.

On the other hand, if it is represented as the actual BOD loading with consideration to the aeration time, the actual BOD loading is 0.5 kg/m^3 · d × 24/16 = 0.75kg/m^3 · d and the actual BOD sludge loading is 0.375 kg/kg·d.

Fig. 6-2 shows that MLSS concentration can be controlled by SRT when the BOD space loading is constant. This means that MLSS in the tank can be controlled by adjusting the sludge withdraw volume according to the generated sludge volume.

Fig. 6-3 shows the relationship between BOD loading and SRT.

In the experiment, BOD sludge loading was obtained from the relationship between SRT and MLSS concentration when BOD space loading was constant.

TOC and COD in Fig. 6-2 show that when the sludge withdraw volume is large and SRT is low, MLSS concentration is low and the sludge loading therefore is high, which affects the treatment efficiency.

On the other hand, although when the sludge withdraw volume is low and SRT is large, MLSS concentraion is high and sludge loading is low, the treated water is sometimes turbid because of unflocked sludge, etc. It is therefore necessary to achieve effective treatment by proper control of the sludge withdrawal volume and SRT.

(3) Effect on sludge properties

MLSS concentrations were 1200 - 1800 mg/ ℓ in the experiment with on SRT value of 4 days, 2600 - 3100 mg/ ℓ (8 days), 4400 - 4600 mg/ ℓ (16 days), 5400 - 6300 mg/ ℓ (32 days) and 6500 - 8200 mg/ ℓ (64 days).

Filamentous bacteria were not observed in the experiment as the controlled aeration treatment method was being used but the settling characteristic of the sludge varied slightly with SRT.

As shown in Fig. 6-2, at the sludge property control by SRT 4 days, the condition had been good, SVI of 60 - 150, for the entire experiment period. Except SRT 4 days, it fluctuated by other factors.

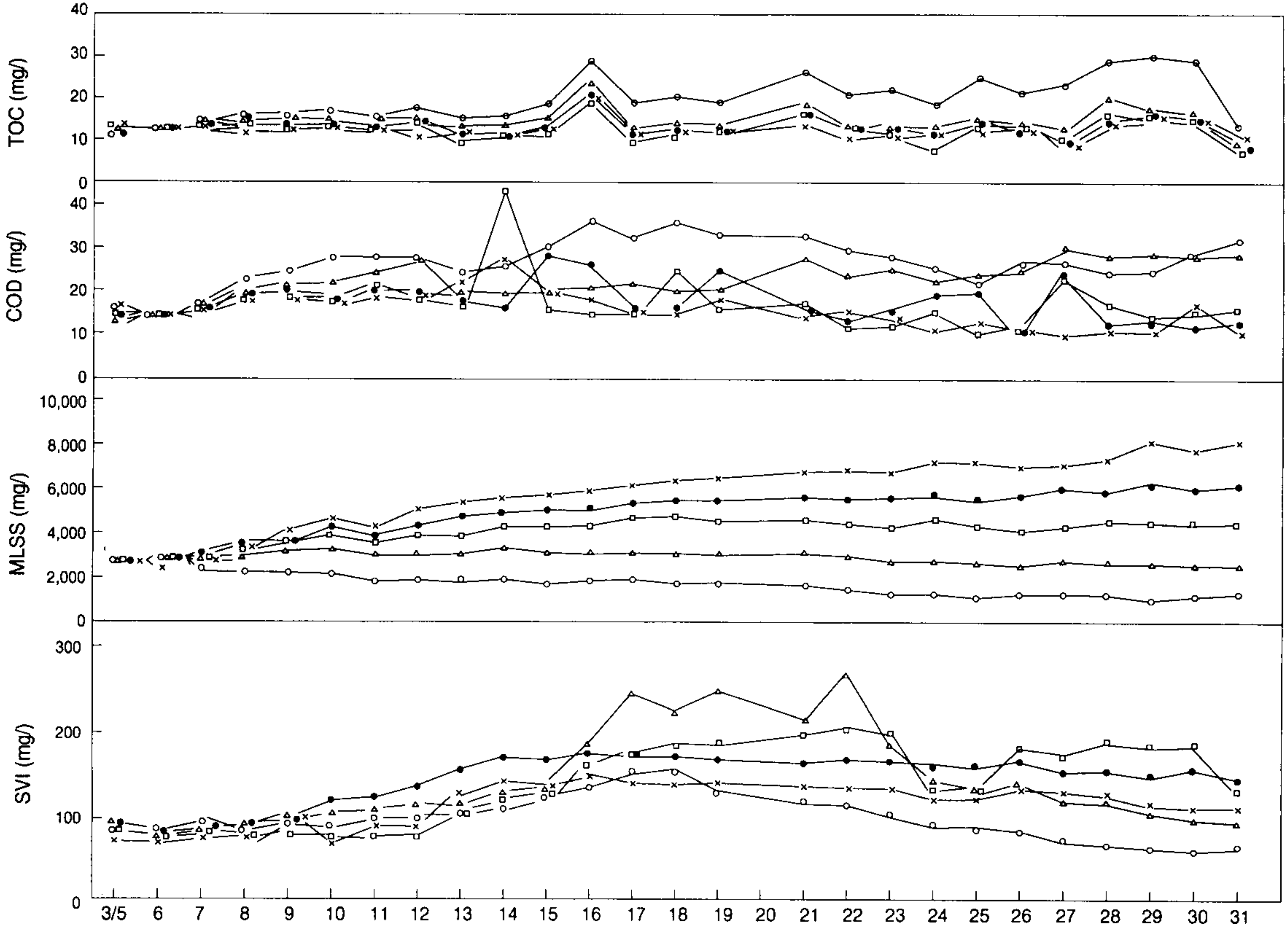


Fig 6-2 Effect of sludge age when using tofu manufacturing plant wastewater
(Treatment result of TOC, COD, MLSS and SVI)

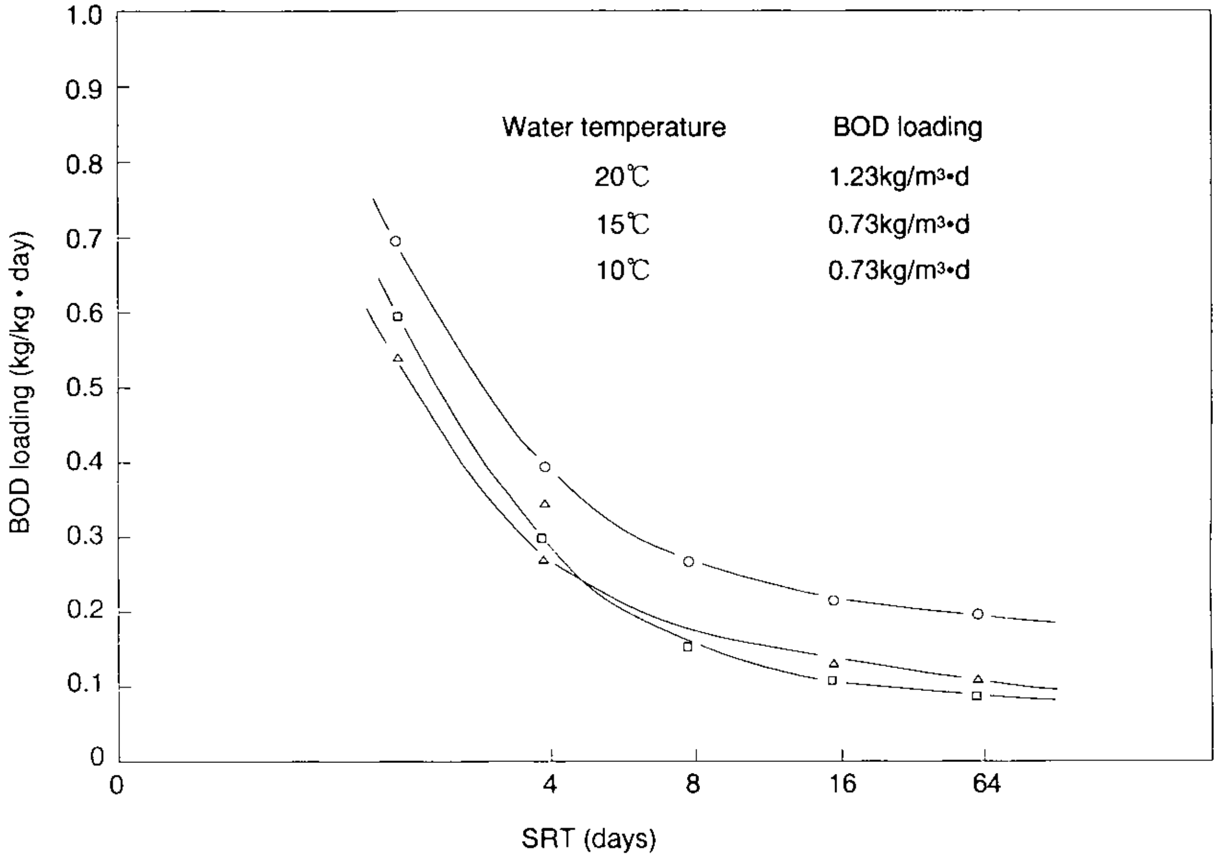


Fig 6-3 Relationship between BOD loading and sludge age when using the controlled aeration activated sludge method

6-3 Water temperature effect

Temperature influences the reaction rate of both chemical and biological reactions. Many formulas on the effect of water temperature in biolocial oxidation processes have been obtained through experimentation.
In general, the reaction rate is low at low water temperatures. However biological treatment is a combination of various related reactions (oxygen transfer, adsorption, oxidation, etc.,) and temperature is a rate-determining factor for oxidation.
For example, when the temperature is high, oxygen transfer is a rate-determining factor but on the other hand at low temperature the respiration is the rate-determining factor.
In this experiment, nutrient balance, SRT and water temperature were studied.

(1) Treatment result

Fig. 6-1 shows the result on the nutrient balance and treatment properties and fig. 6-2 shows the result on SRT and treatment properties.
The effect of water temperature was studied, at 20℃, 15℃, and 10℃.
Tables 6-2 and 6-3 show the effect of nutrients and SRT, respectively. Due to the short experimental period, 20℃ from March 5th to 20th, 15℃ from March 21st to 26th and 10℃ from March 27th to 31st, the effect of water temperature on treatment was not made clear with respect to the effect of nutrients.
This was probably also due to the load during the experiment; as shown in fig. 6-3, BOD sludge loading was 0.3 - 0.4 kg/kg · d and there was no great deviation from the appropriate load.
As for the effect on treatment due to water temperature and SRT, when SRT was 4 days because of low MLSS concentration and relatively high BOD sludge loading, 0.5 - 0.7 kg/kg · d, and the water temperature was low, TOC compounds in the treated water were slightly elevated.
However, except for 4 days, the effect of water temperature on treatment was not clear.

(2) Effect on sludge properties

Fig. 6-4 shows the result on water temperature and sludge generation volume.
In real world wastewater treatment, it is rare that the substrate in the wastewater consists of a single pure substance, and in the aeration tank, sludge growth by external respiration proceeds simultanously with autooxidation of cells through internal respiration. Consequently, the net biological growth of sludge is represented as the difference:

$$\Delta X = aLr - bX$$

where ΔX = excess sludge volume (kg/d)
Lr = quantity of removed BOD (kg/d)
X = acitivated sludge volume in mixed liquor (kg)
a = gross yield coefficient of sludge of removed BOD
b = autolysis coefficient by internal respiration (day^{-1})

The value varied according to the kind of substrate and it has been found that it is also varies according to the concentration of the substrate, presence or absence of other organic and inorganic substances, aeration time and water temperature.
Downing states that in general it can be considered that the excess sludge volume is low at low water temperatures in winter, but in actuality the volume is larger because the value b is very small at low water temperatures.
In the experiment, a (gross yield coefficient of sludge of removed BOD) was constant, a = 0.47, regardless of the water remperature.
On the other hand, b (autolysis coefficient by internal respiration) varied according to the water temperature, b = 0.07 at 20℃, b = 0.03 at 15℃ and b = 0.02 at 10℃, which corresponded to the theory of Downing.
Fig. 6-5 shows the relationship between water temperature and the autolysis coefficient, b.
When the BOD space loading and the quantity of removed BOD are constant, the gross yield coefficient of

sludge of removed BOD is also constant, and thus the excess sludge volume is larger at low water temperatures in winter when the autolysis coefficient of sludge is low.

In the study on water temparature and the settling characteristics of sludge concerning the effect of nutrients, at low water temperature, SVI of the wastewater with high phosphorus concentration tended to be lower than that lacking phosphorus.

As for the effect of SRT, it was clear that at low water temperatures, a lawer SRT led to better sludge settling characteristics. It was considered that sludge generation volume was related to the dependence of the autolysis coefficient on temperature.

Based on the above result, it was found that for sludge management of the controlled aeration activated sludge method at low water temperatures in winter, the settling characteristics of the sludge could be improved by increasing the excess sludge volume and keeping a lower SRT value than in summer.

In addition, attention should be paid to SRT control, because operation at low sludge loading is sometimes necessary since the substrate removal rate is lower at low water temperatures.

Table 6-2 Water temperature and treatment properties (Effect of nutrients)

Item Apperatus No.	Water tempurature(℃)	TOC (mg/ℓ)	COD (mg/ℓ)	MLSS (mg/ℓ)	SVI (mℓ/g)
NP-00	20	17	22	3230	59
	15	17	15	2530	56
	10	17	18	2720	53
NP-10	20	16	28	3120	146
	15	20	18	2530	139
	10	22	18	2520	100
NP-01	20	13	16	3290	73
	15	14	12	2940	76
	10	16	13	2800	59
NP-11	20	13	21	3130	236
	15	14	24	2650	138
	10	14	29	2610	97

Table 6-3 Water temperature and treatment properties (Effect of SRT)

Item SRT	Water tempurature(℃)	TOC (mg/ℓ)	COD (mg/ℓ)	MLSS (mg/ℓ)	SVI (mℓ/g)
4 days	20	19	34	1800	145
	15	22	25	1230	88
	10	24	28	1210	65
8 days	20	13	21	3130	236
	15	14	24	2650	138
	10	14	29	2610	97
16 days	20	11	19	4600	177
	15	12	13	4370	148
	10	13	15	4510	166
32 days	20	12	19	5430	171
	15	13	17	5750	160
	10	13	13	6260	147
64 days	20	11	16	6520	141
	15	12	12	7380	128
	10	13	13	8200	115

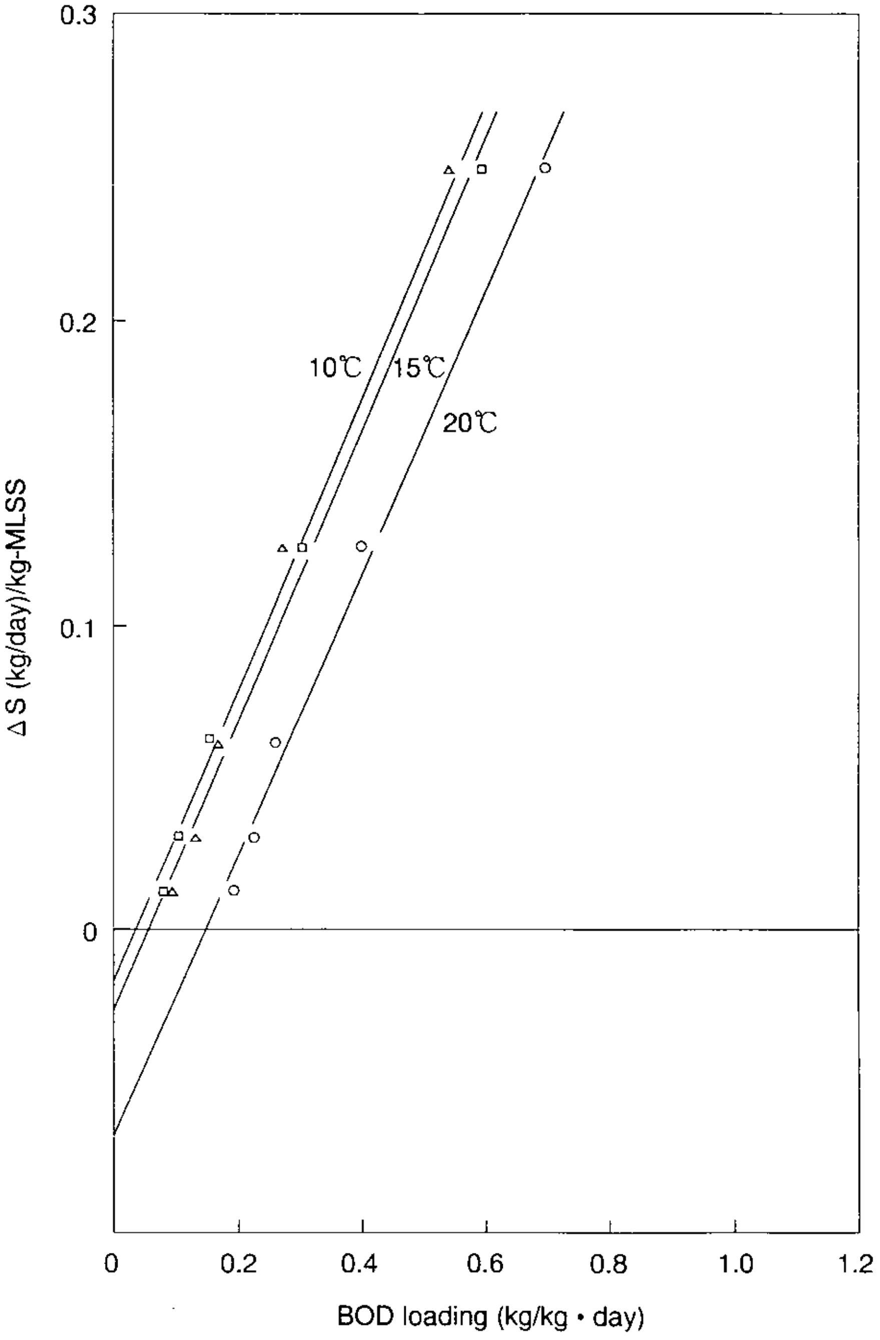


Fig 6-4 Study on sludge generation volume at the tofu manufacturing plant

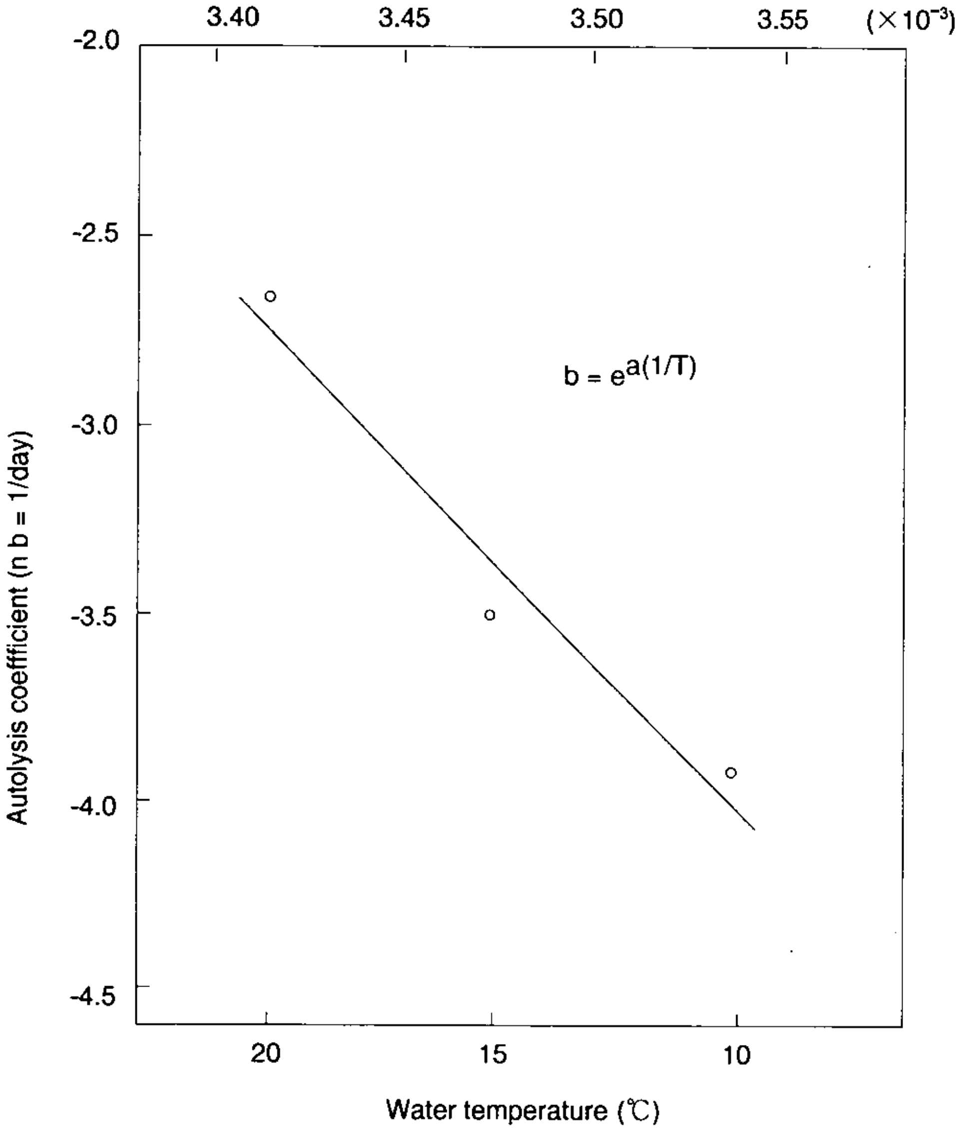


Fig 6-5 Relationship between water temperature and autolysis coefficient

6-4 Behavior of phosphorus and nitrogen

It is known that nitrogen compounds in wastewater are assimilated by microorganisms. For effective treatment activated sludge, there is a minimum with regard to nitrogen, phosphorus and minerals for microorganism growth that is required. When the composition of microorganisms is $C_5H_7NO_2$, the percentage of nitrogen is about 12.4 %. In general, the percentage of nitrogen compounds in the activated sludge is 6-15 % of dry sludge weight, although it varies according to the kind of sludge and the quantity of volatile substances. The necessary phosphorus quantity is 1/5 that of nitrogen. In the activated sludge method it is necessary to balance the ratios of nitrogen and phosphorus and it is desirable to control the ratios of the influent to around BOD : N : P = 100 : 5 : 1. Forms of nitrogen which can be utilized for assimilation by microorganisms are organic nitrogen compounds such as, amino acids, urea, NH_3, NO_2^-, etc.

Basic knowledge on the behavior of phosphorus and nitrogen compounds in the controlled aeration activated sludge experiment was obtained.

(1) Nitrification reaction

The nitrogen removal due to nitrification and denitrification via the controlled aeration activated sludge method will be described in detail later. Here is an explanation on the behavior of nitrogen remaining in the treated water from the experiment.

Fig. 6-6 shows the result on the temperature dependence of the relationship between SRT and nitrification ratio of nitrogen compounds remaining in the treated water.

As shown in Fig. 6-3, when SRT was more than 8 days, and the actual BOD sludge loading was 0.3 - 0.4 kg/kg · d and BOD/N ratio was 10 - 14, the nitrification ratio was about 95 % regardless of the water temperature. When SRT was 4 days, the actual BOD sludge loading was 0.5 - 0.7 kg/kg · d and the nitrification ratio varied greatly according to the water temperature.

Fig. 6-7 shows the result on the nitric acid conversion ratio. It was found that when SRT was 16 days or less, nitrification stopped at the nitrous acid stage because of a water temperature effect, hence to achieve completion through to the nitric acid stage, on SRT of 32 days or more was necessary.

Based on the above result, it was found that in the controlled aeration activated sludge experiment, nitrogen compounds remained in the treated water were reacted by nitrificiation in SRT 8 days or more and the reaction of conversion to nitrous acid was accomplished in SRT 32 days or more.

(2) Uptake of phosphorus

The phosphorus removal mechanism of the activated sludge via uptake and release of phosphorus utilizing aerobic and anaerobic processes will be described later, but here is a breif explanation of the behavoir of phosphorus when utilizing the controlled aeration activated sludge method.

Table 6-4 shows the phosphorus behavior with respect to the effect of nutrients.

Table 6-4 Phosphorus concentration in the treated water and phosphorus in sludge (Effect of nutrients)

Apperatus No. Item	NP－00		NP－10		NP－01		NP－11	
Water temperature (℃)	10	20	10	20	10	20	10	20
Phosphorus concentration in the treated water (mg/)	1.15	0.29	1.15	0.05	5.12	2.35	2.93	1.83
Phosphorus in sludge (%)	0.6	1.0	0.7	1.1	1.6	1.7	1.8	2.1

The result shows a tendency that the phosphorus concentration in the treated water was affected by water temperature and phosphorus concentration in the wastewater. The percentage of phosphorus in the sludge was affected by phosphorus concentration in the wastewater and it was also slightly affected by the change in water temperature.

The rate of uptake and release of phosphorus was probably affected by water temperature. However, this experiment was not sufficient to clarify the direct effect of water temperature on uptake and release of phoshporus necessitating more study.

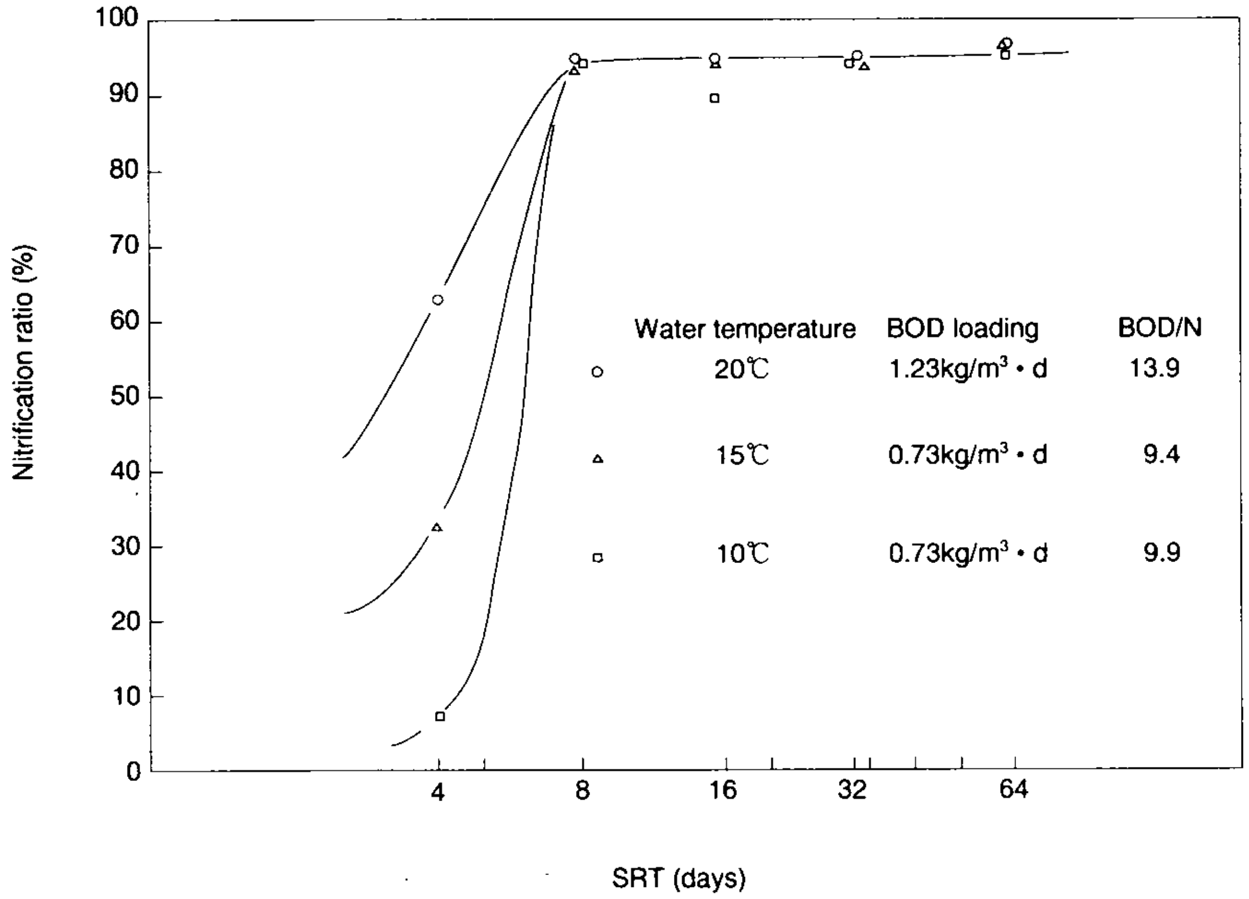


Fig 6-6 Relationship between nitrification ratio and sludge age in the controlled aeration activated sludge experiment

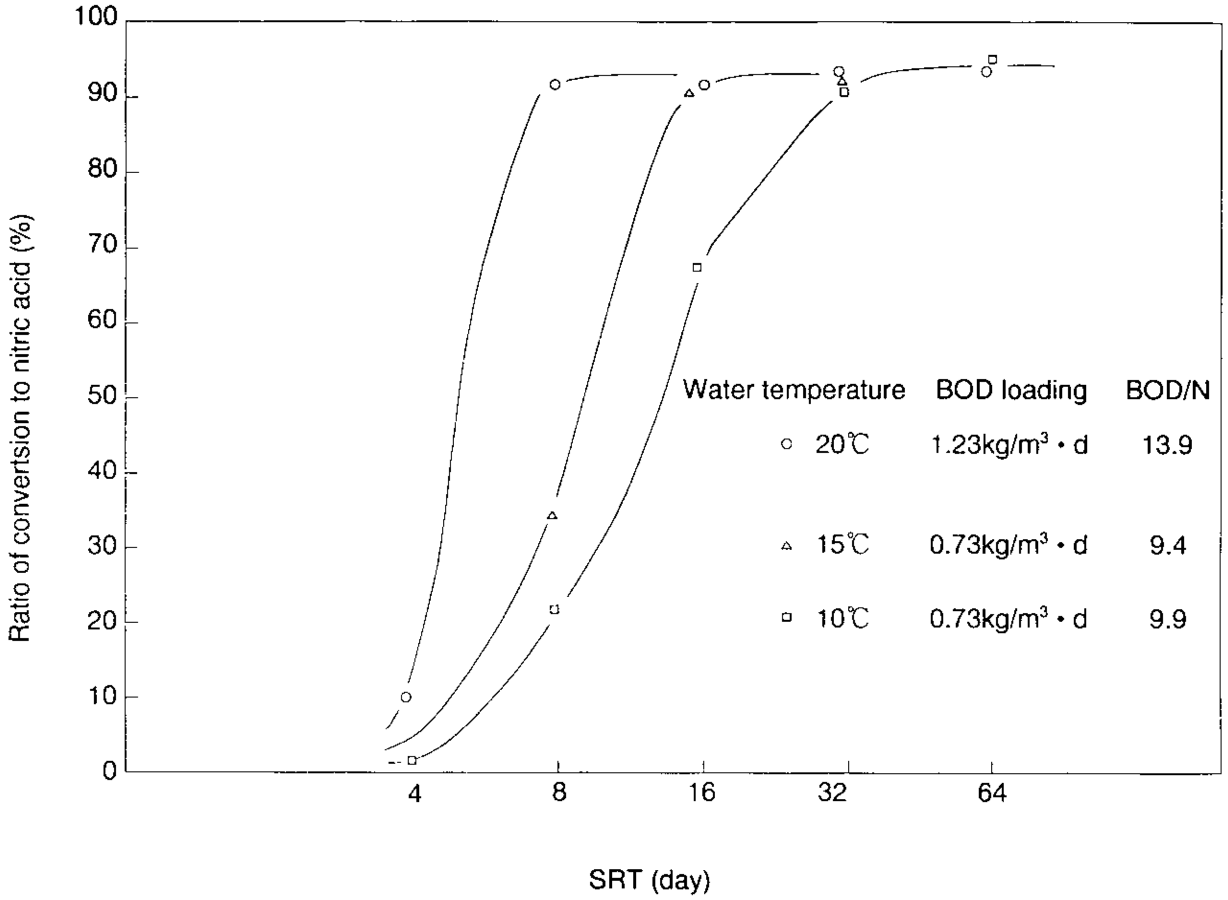


Fig 6-7 Relationship between ratio of nitric acid and sludge age in the controlled aeration activated sludge experiment

6-5 Conclusion

In the experiment, the basic treatment function of the controlled aeration activated sludge method was studied using tofu manufacturing plant wastewater.
The following is a summary of the knowledge obtained from the experiment.

(1) It was found that the balance of nutrients, nitrogen and phosphorus in the wastewater under the load conditions of the experiment had no effect on treated water quality, but excessive nitrogen in the wastewater affected the settling characteristics of the sludge although filamentous bacteria were not observed.

(2) Under treatment conditions woth SRT ranging from 4 - 64 days, the experiment was conducted with a fixed BOD space loading because MLSS concentration in the aeration tank fluctuated. At on SRT value of 4 days when the sludge loading was high, the treated water quality slightly worsened.
The effect of SRT on the settling characteristics of sludge in the controlled aeration activated sludge experiment was not clear since almost no filamentous bacteria were observed, but when SRT was 4 days the water quality was good for the entire experimental period.

(3) The effects of water temperature on the treatment properties concerning SRT, and nutrient balance in the wastewater were studied.
There was no clear difference relating to nutrient balance because the load was within the appropriate treatment range.
At low water temperatures, the treated water quality was worse when SRT was low cousing the sludge loading to be higher.
As for the effect of water temperature on sludge generation, a (gross yield coeffecient of sludge of removed BOD) was constant, 0.47, but b (autolysis ratio by internal respiration) varied according to the water temperature, 0.02 - 0.07 at 10℃ - 20℃; which indicated that at low water temperature, the autolysis ratio was small and the excess sludge volume large.

(4) Excess added nitrogen compounds remained in the treated water as nitrite and nitrate.
The nitfrification ratio of the controlled aeration activated sludge experiment was affected by water temperature and SRT and it was found that at on SRT value of 8 days or more, the nitfrification ratio could be expected to be about 95 % regardless of the water temperature.
There was a tendency that the percentage of phosphorus in the sludge was affected by the phosphorus concentration in the wastewater, and the phoshporus concentration in the treated water was affected by the water temperature. Probably because the rate of uptake and release of phosphorus was affected by water temperature.

7. Basic study on nitrogen and phosphorus removal using the controlled aeration activated sludge method

Recently eutrification due to nitrogen and phosphorus in closed water areas such as inner bays, inner seas, lakes, etc., is a big problem.

In some closed water areas, more stringent effluent standards with regard to nitrogen and phosphorus have been introduced to control eutrofication.

On the other hand, the nutrient removal efficiency using the conventional activated sludge method is low; only 40 - 60 % for nitrogen and 30 - 50 % for phosphorus.

The following experiment was conducted for basic study into nitrification and denitrification utilizing aerobic and anaerobic conditions through use of the controlled aeration activated sludge method, and knowledge on nitrogen and phosphorus removal via the controlled aeration activated sludge method was obtained.

7-1 Study on the efficiency of nitrogen and phosphorus removal using the controlled aeration activated sludge method

A study on nitrogen and phosphorus removal efficiency using the controlled aeration activated sludge method was conducted by comparing differing time schedules under a combination of aerobic and anaerobic conditions. Knowledge on nitrification, denitrification, phosphorus uptake and release speeds was also obtained.

(1) Experiment using indoor bench-scale apperatus

The efficiency of the controlled aeration activated sludge method was studied using made-up wastewater with a substrate composition similar to soy sauce manufacturing plant wastewater.

- Wastewater for the experiment -

As shown in Table 7-1 below, wastewater with a composition made up of 3 different substates was prepared.

Table 7-1 Water quality analysis and nutrition balance of the wastewater

Items / Treatment method	TOC (mg/ ℓ)	BOD (mg/ ℓ)	T-N (mg/ ℓ)	T-P (mg/ ℓ)	BOD : N : P
Nitrogen removal	369	670	72.4	5.4	100 : 10.8 : 0.8
Phosphorus removal	304	590	26.7	16.8	100 : 4.5 : 2.8
Nitrogen & phosphorus removal	318	560	65.0	15.1	100 : 11.6 : 2.7

- Activated sludge -

In the experiment, activated sludge from a sewage treatment plant was used for seeding.

In the experiment, after about a 2 month acclimation period, the hourly changes were studied under different treatment conditions.

Sludge withdrawal volume was due to adjust the average sludge concentration to 5000 mg/ ℓ .

Since methanol was added as a hydrogen donor for denitrification in the experiment, sufficient time was given for acclimation of the activated sludge.

- Experiment equipment -

Aeration tanks made of transparent acrylic resin with an effective volume of 80 ℓ were used for the experiment and the water temperature was controlled by thermostatic water tanks.

A regulated amount of untreated water was sent by continuous flow pump and aeration started after the inflow. The aeration volume was adjusted with a flow meter so that DO was 2-3 mg/ ℓ one hour after aeration gegan, because nitrification was necessary after BOD oxidation in the experiment.

For denitrification, a regulated amount of methanol was added as a hydrogen donor by continuous flow pump and anaerobic mixing was performed by a mixer with turbine blades.

Photo 7-1 shows the experimental equipment.

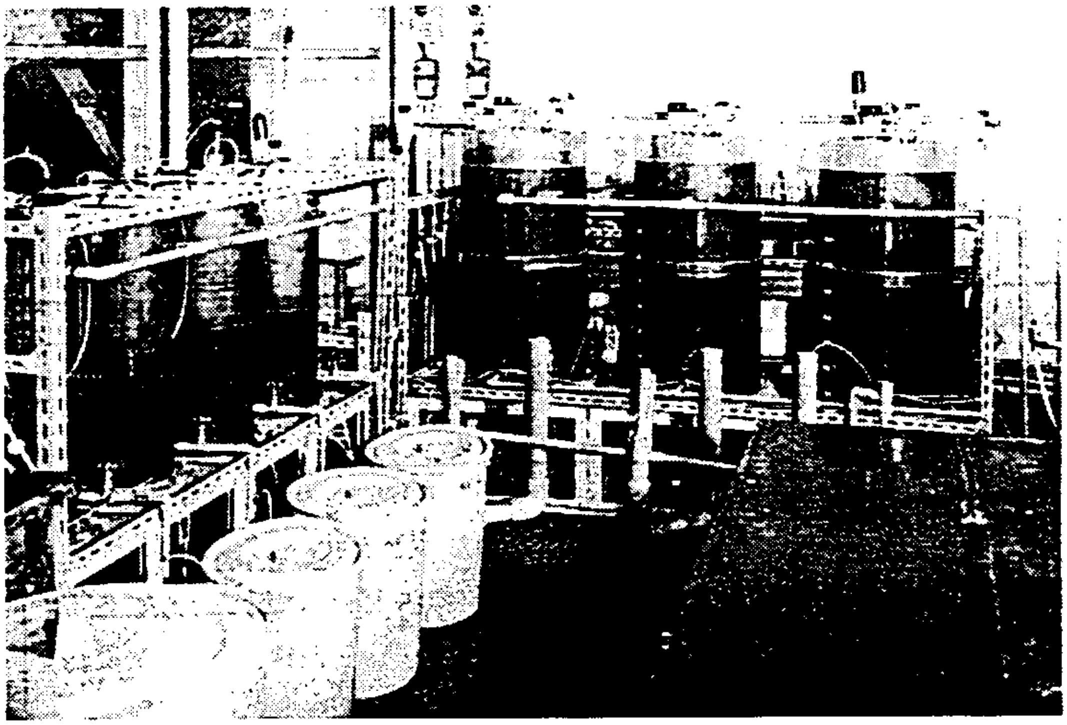


Photo 7-1 Indoor bench apperatus (capacity of 80 ℓ)

The experimental equipment was automatically controlled by timer.

- Experimental conditions -

Three different time schedules for nitrogen, phosphorus, and nitrogen & phophorus removal were compared. Table 7- 1 shows the treatment time schedules.

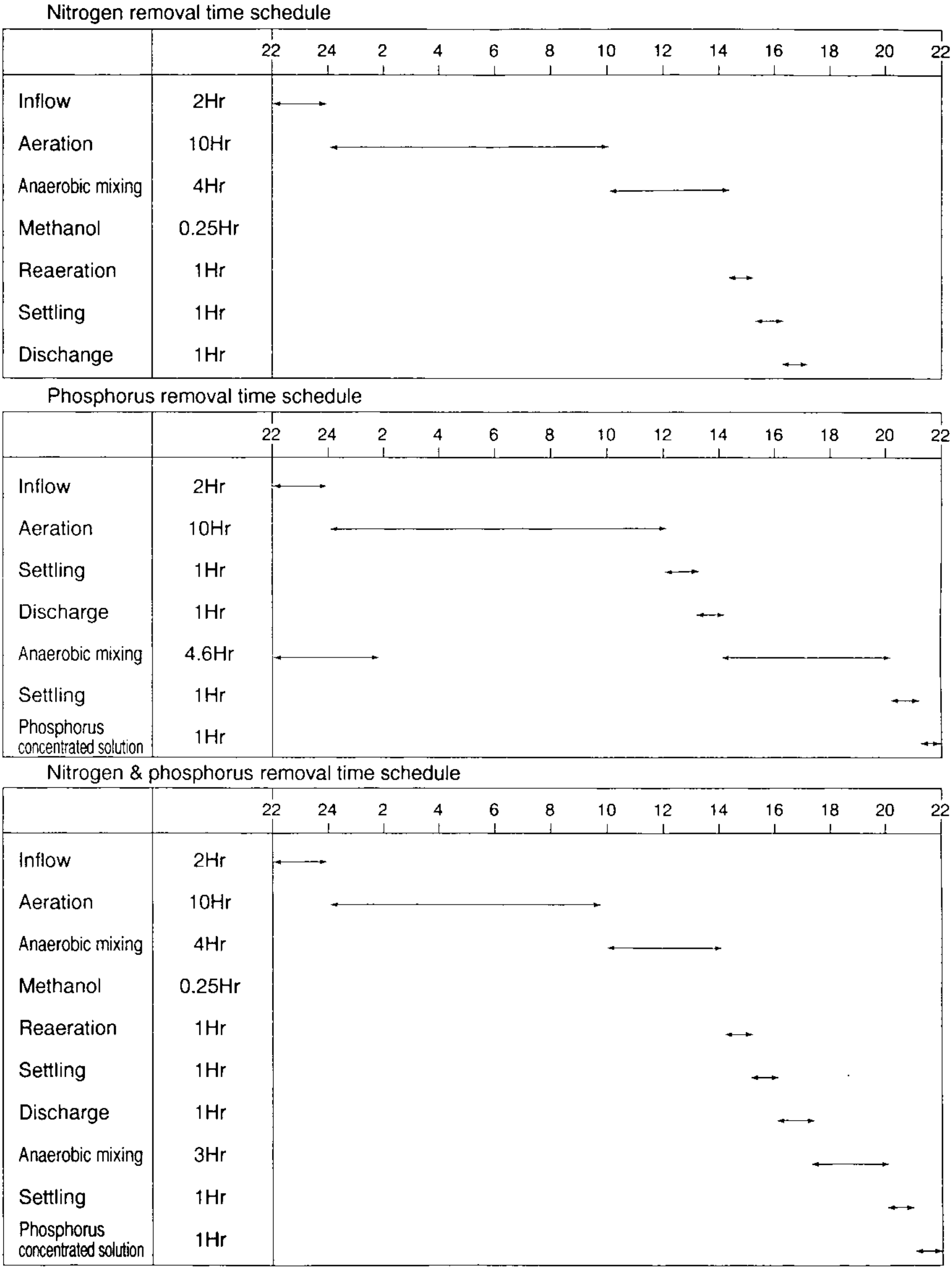


Fig 7-1 Treatment time schedules

In the nitrogen removal experiment, 40 ℓ of wastewater with a nutrition balance of BOD : N : P = 100 : 12 : 1 inflowed and the simple BOD space loading was 0.5 kg/m^3· d.

Since MLSS concentration was 5000 mg/ ℓ , after 10 hours of aeration for BOD oxidation & nitrification, the actual BOD sludge loading was 0.24 kg/kg · d.

After aeration, methanol was added as a hydrogen donor. Denitrification by anaerobic mixing lasted 4 hours, and the processes of reaeration, settling and discharge, one hour each. The remaing 5 hours was waiting time.

In the phosphosrus removal experiment, 40 ℓ of wastewater with a nutrition balance of BOD : N : P = 100 : 5 : 3 inflowed and the simple BOD space loading was 0.5 kg/m^3· d like the nitrogen removal system. Phosphorus was released from the sludge by 4 hours of anaerobic mixing which started on wastewater inflow and then was uptaken by the sludge again by 10 hours of aeration.

Then after 1 hour of settling, 30 ℓ of water was discharged over one hour.

Phosphorus did not remain in the treated water because it was uptaken into the sludge. Following that, for phosphorus removal, the wastewater in the tank was treated by 6 hours of anaerobic mixing, and after settling the wastewater, 10 ℓ , was discharged. It was treated separately as phosphorus concentrated water.

For nitrogen & phosphorus removal, 40 ℓ of wastewater with a nutrition balance of BOD : N : P = 100 : 12 : 3 inflowed and the treatment time schedule was the same as the nitrogen removal system, i.e., aeration, methanol addition, anaerobic mixing, reaeration, settling and discharge of 30 ℓ of treated water. After nitrogen removal finished, instead of the waiting time as in the nitrogen removal system, the phosphors removal process commenced; 3 hours of anaerobic mixing, settling and discharge of 10 ℓ of phosphorus concentrated water.

After more than 2 months of acclimation, the hourly change of the indoor bench-scale apperatus utilizing the controlled aeration activated sludge method was studied using these three different time schedules.

(2) Treatment result

Fig. 7-2 shows the experimental result of the nitrogen removal system. In the BOD oxidation & nitrification stage utilizing aeration, BOD was oxidized very rapidly and nitrification proceeded at around a pH of 7. Nitrification reached the perfect nitric acid type and ORP which had dropped to less than -200 m V at inflow was shifted to around +100 m V and DO concentration reached 3 mg/ ℓ or more after 3 hours of aeration. Nitrate was 35.9 mg/ ℓ at the end of aeration and the nitrification ratio obtained through the equation, (nitrogen quantity of influent - residual nitrogen quantity) / nitrogen quantity of influent, was 86 %.

In this experiment, as the amount of soy sauce in the wastewater was high, and 5 - 10 mg/ ℓ of organic nitrogen, difficult to be biologically utilized, was present, the nitrification ratio was worse than the general nitrification ratio throughout the experiment.

In the denitrification stage, anaerobic mixing with methanol addition as a hydrogen donor, the pH rose due to an increase in alkali and ORP dropped to -200 m V during the anaerobic stage. At the same time, nitrate was removed as nitrogen gas. As for phosphorus behavior under anaerobic conditions, phosphorus release was observed on inflow of wastewater but not during denitrification in the experiment.

This was probably due to phosphorus release control factors caused by nitrogen forms and difference in anaerobic levels, represented as ORP. Fig. 7-3 shows the result of the quantitative balance between BOD, nitrogen and phosphorus compounds during the nitrogen removal phase of the experiment.

About 80 % of BOD compounds were uptaken by the sludge during the initial adsorption on inflow and then 99 % was removed by aeration.

The initial adsorption ratio of nitrogen compounds onto the sludge was about 10 %, which was very low compared to that of BOD compounds.

Nitrification consumed 99 % of the nitrogen in the influent but the nitrification ratio obtained from residual nitrogen compounds was 86 %, which was due to the wastewater substrate composition mentioned earlier.

The denitrification ratio was 99 % or more and it was considered that 15 % was due to biological utilization, and 85 % through removal as nitrogen gas. The nitrogen removal efficiency was therefore decided by loading condition, and nitrification and denitrification rate.

The nitrogen removal efficiency ratio obtained by comparing the nitrogen quantity of the influent and the nitrogen quantity discharged in the treated water was about 92 %.

Phosphorus was released and uptaken by the sludge under aerobic and anaerobic conditions but a clear change was not observed in the study of the phosphorus ratio in the sludge.

In the nitrogen removal schedule, as phosphorus was discharged along with the sludge, the phosphorus removal efficiency was decided by the uptake ratio of phosphorus by the sludge and the quantity of sludge withdrawal.

In the experiment, the phosphorus removal efficiency was about 70 %.

Fig. 7-4 shows the experimental result of the phosphorus removal system. Although BOD was oxidized smoothly by aeration, in the experiment due to lack of nitrogen compounds in the wastewater, nitrification didn't occur.

And thus a pH decrease was not observed during aeration. ORP which had decreased to -300 m V on inflow rose to +100 m V by the end of aeration and down to - 300 m V again during anaerobic mixing.

Phosphorus release and uptake were observed synchronously with the increase and decrease of ORP. Fig. 7-5 shows the result of the quantitative balance between BOD, nitrogen and phosphorus in the phosphorus removal system.

About 80 % of BOD compounds were uptaken by the sludge during the initial adsorption on inflow, and then 99 % were removed by aeration, which was the same as the nitrogen removal system.

The quantity of nitrogen compound addition was small and the removal efficiency around 75 %. However, the residual nitrogen coumpounds consisted of nitrogen difficult to be utilized biologically.

Due to phosphorus release by the sludge on inflow of wastewater, the phosphorus level was about 1.25 times that of the influent.

Phosphorus uptake during aeration was about 45 %, and on discharge of 30 ℓ of treated water, the phosphorus removal efficiency was about 52 %. Following that, phosphorus was released again by anaerobic mixing and about 25 % of the phosphorus was present in the phosphorus concentrated wastewater.

The low phosphorus removal efficiency of the experiment was due to the low phosphorus uptake ratio during aeration.

Fig. 7-6 shows the experimental result of the nitrogen & phosphorus removal system.

In the BOD oxidation & nitrification via aeration stage, BOD was oxidized very rapidly and nitrification proceeded at around a pH of 7, which was the same as the nitrogen removal system. Nitrification reached a perfect nitric acid type.

The nitric acid concentration was 35.5 mg/ ℓ at the end of aeration and the nitrification ratio was 80 %.

Through anaerobic mixing in the denitrification stage with methanol addition, ORP dropped to around -200 m V.

Denitrification proceeded relatively slowly and the denitrification ratio was expected to be 99 % or more.

On the other hand, because of anaerobic and aerobic conditions, represented as ORP, phosphorus release and uptake occured, and at around an ORP of -300 m V on inflow of wastewater, much phosphorus was released.

Under aerobic conditions during aeration, the ORP level was about +100 m V and phosphorus uptake occured.

The decrease in ORP on methanol addition in the denitrification stage was relatively greater, -200 m V, than that on inflow, and as a result phosphorus release was small.

In the experiment, for making phosphorus concentrated wastewater, reaeration was done after discharge of treated water and because the ORP level was -300 m V, phosphorus was released. Fig. 7-7 shows the result of the quatitative balance between BOD, nitrogen and phosphorus in the nitrogen & phosphorus removal system.

About 85 % of BOD compounds were adsorbed onto the sludge and 99 % were removed by aeration.

With a nitrification ratio of 80 %, in the denitrification stage 99 % of the nitrogen could be denitrified. The nitrogen removal efficiency in the nitrification and denitrification stages depended on the nitrification ratio and a removal effeciency of about 80 % could be expected.

On the other hand, the nitrogen removal efficiency with respect to the nitrogen quantity in the influent and the nitrogen quantity discharged in the treated water including reaeration, discharge and withdrawal of phosphorus concentrated wastewater was 90 %.

Phosphorus was repeatedly released and uptaken in the aerobic and anaerobic processes. A level of phosphorus 2.3 times more than that in the influent was released on inflow of wastewater, and 77 % of the phosphorus released during aeration was uptaken.

About 20 % of the total quantity of released phosphorus was released during denitrification, and this phosphorus was uptaken during reaeration.

In the second anaerobic mixing, phosphorus was released and about 25 % of the influent phosphorus was included in the phosphorus concentrated wastewater, which was treated separately. We concluded that phosphorus uptaken by the sludge was about 50 % and phosphorus uptake ratio was high, 70 %, in the nitrogen removal system.

Fig. 7-8 shows the change in phosphorus concentration in the wastewater and the phosphorus ratio in the sludge in the different treatment systems. Comparing the change in the phosphorus concentraion in the wastewater of the aerobic & anaerobic processes, shown with dotted lines, the phosphorus ratio in the sludge did not change so much.

The phosphorus ratio in the sludge was the highest in the nitrogen & phosphorus removal system; max. 2.25 % and min. 1.98 %.

The phosphorus ratio in the sludge was low; 1.42 - 1.59 % in the nitrogen removal system; 1.65 - 1.76 % in the phosphorus removal system.

Table 7-2 shows the experimental result.

Table 7-2 Comparison of the treatment of the different time schedules

Items Time schedule	BOD removal efficiency (%)	Nitrification ratio (%)	Denitrification ratio (%)	Nitrogen removal efficiency (%)	Phosphorus removal efficiency (%)	Phosphorus ratio in sludge (%)
Nitrogen removal system	99.4	85.9	99.7	91.7	68.5	1.42~1.59
Phosphorus removal system	99.4	52.6	-	76.8	26.9 (52.2)	1.65~1.76
Nitrogen & phosphorus removal system	99.0	80.3	99.6	90.0 (89.9)	47.4 (71.7)	1.98~2.25

Figures in ( ) in the phosphorus removal efficiency coloumn were the case in which phosphorus concentrated water was treated separately.

From the results, there was no big difference in BOD removal according to the treatment system and 90 % of the nitrogen could be removed in the system with nitritication and denitrification processes.

Phosphorus removal efficiency was good, about 70 %, in the nitrogen removal system.

In the nitrogen & phosphorus removal system, a 60 % phosphorus removal efficiency could be expected at the end of the nitrogen treatment.

In the controlled aeration activated sludge method, therefore, BOD, nitrogen and phosphorus could be removed by utilizing aerobic and unaerobic conditions for BOD oxidation, nitrification and denitrification in the nitrogen removal time schedule.

(3) Nitrogen removal via nitrification and denitrification

Since nitrification and denitrification are performed in a single tank when using the batch type controlled aeration activated sludge method, an adequate time schedule should be selected according to the nitrification and denitrification rates.

Table 7-3 shows the calculated nitrification and denitrification rates.

Teble 7-3 Nitrification / denitrification rate constants of the infoor bench apperatus using the controlled aeration activated sludge method

Generated nitric acid

Items Treatment system	Nitrification rate constant(kg/kg·d)		Denitrification rate (kg/kg·d)
	Removed nitrogen	Removed nitrogen	
Nitrogen removal system (Water temperature 20℃)	0.018	0.020	0.055
Nitrogen & phosphorus removal system (Water temperature 20℃)	0.023	0.019	0.060

Nitrification / denitrification rate constants were generally obtained at a water temperature of 20℃
They are lower than (the nitrification rate constant, 0.07kg/kg·d
the denitrification rate constant, 0.126(kg/kg·d).

In the experiment, the nitrification rate constant was high, BOD / N = 8 - 9, and it was considered that because the ratio of nitrifying bacteria was less than that of BOD oxidizing bacteria, the nitrification rate was low.

On the other hand, denitrifying bacteria were facultative anaerobic bacteria and although methanol was used as a hydrogen donor, the denitrification rate was low in the experiment probably because BOD/N was high and the generation of methanol utilizing bacteria was not high.

(4) Phosphorus release and uptake under aerobic and anaerobic conditions

In the biological phosphorus removal system, utilizing the phosphorus metabolic function of the activated sludge, which consisted of phosphorus release under anaerobic conditions and excessive phosphorus uptake under aerobic conditions, the phosphorus removal efficiency depended on the growth of bacteria which accumulated polyphosphoric acid granules.

This fact clearly explained the experiment result. It meant that, phosphorus was released on inflow of untreated water and uptaken on aeration, as shown in Fig. 7-6.

Due to the presence of NOx during the denitrification stage under anaerobic conditions, phosphorus was not released but under anaerobic conditions with no NOx, it was released.

Comparing the rate of phosphorus release on inflow of untreated water, 0.035 kg/kg · d, the rate on no inflow was lower, 0.005 kg/kg · d. This was probably due to the above-mentioned metabolic function.

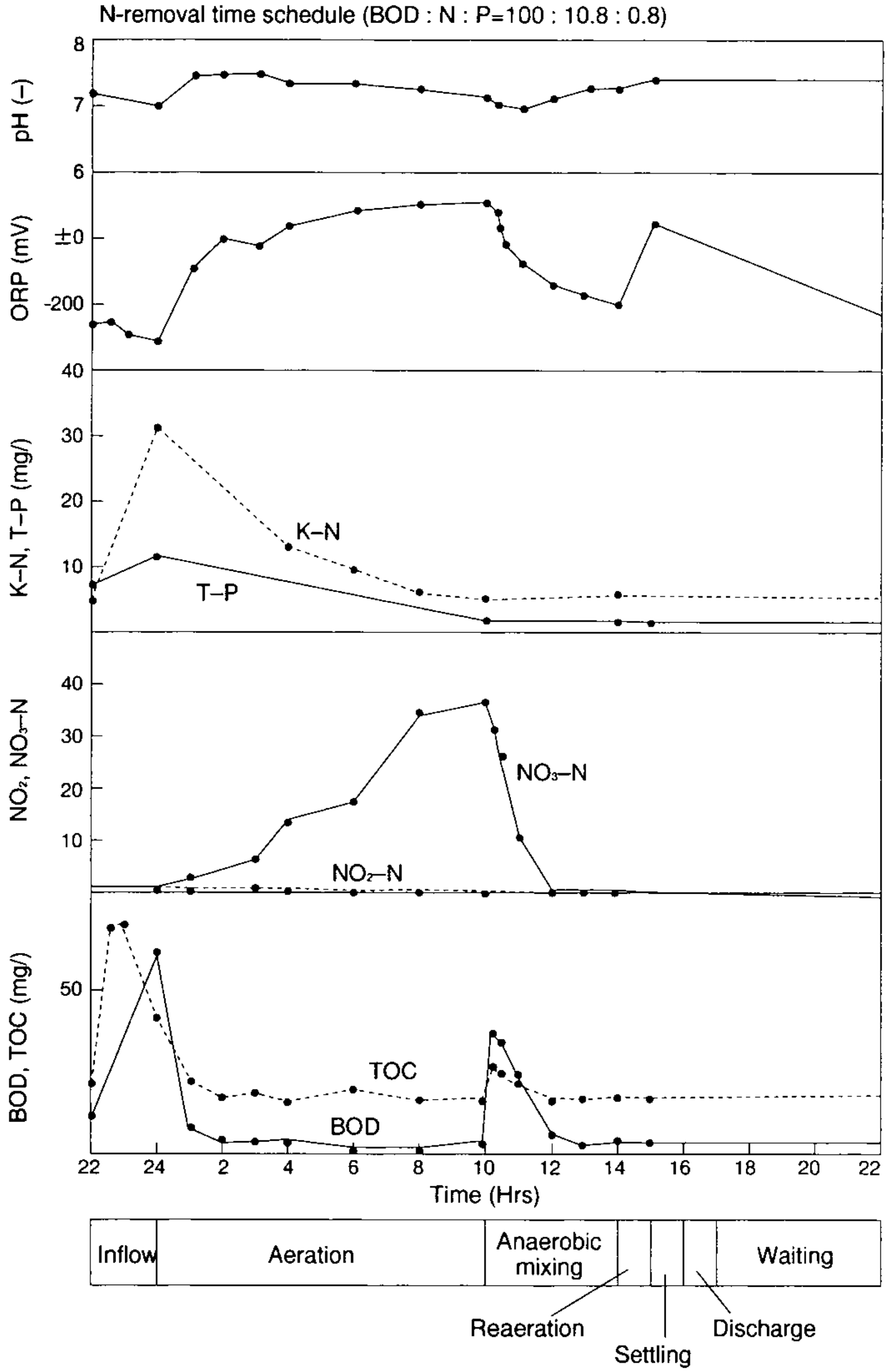


Fig 7-2 Hourly changes in the treated water quality using the controlled aeration activated sludge method

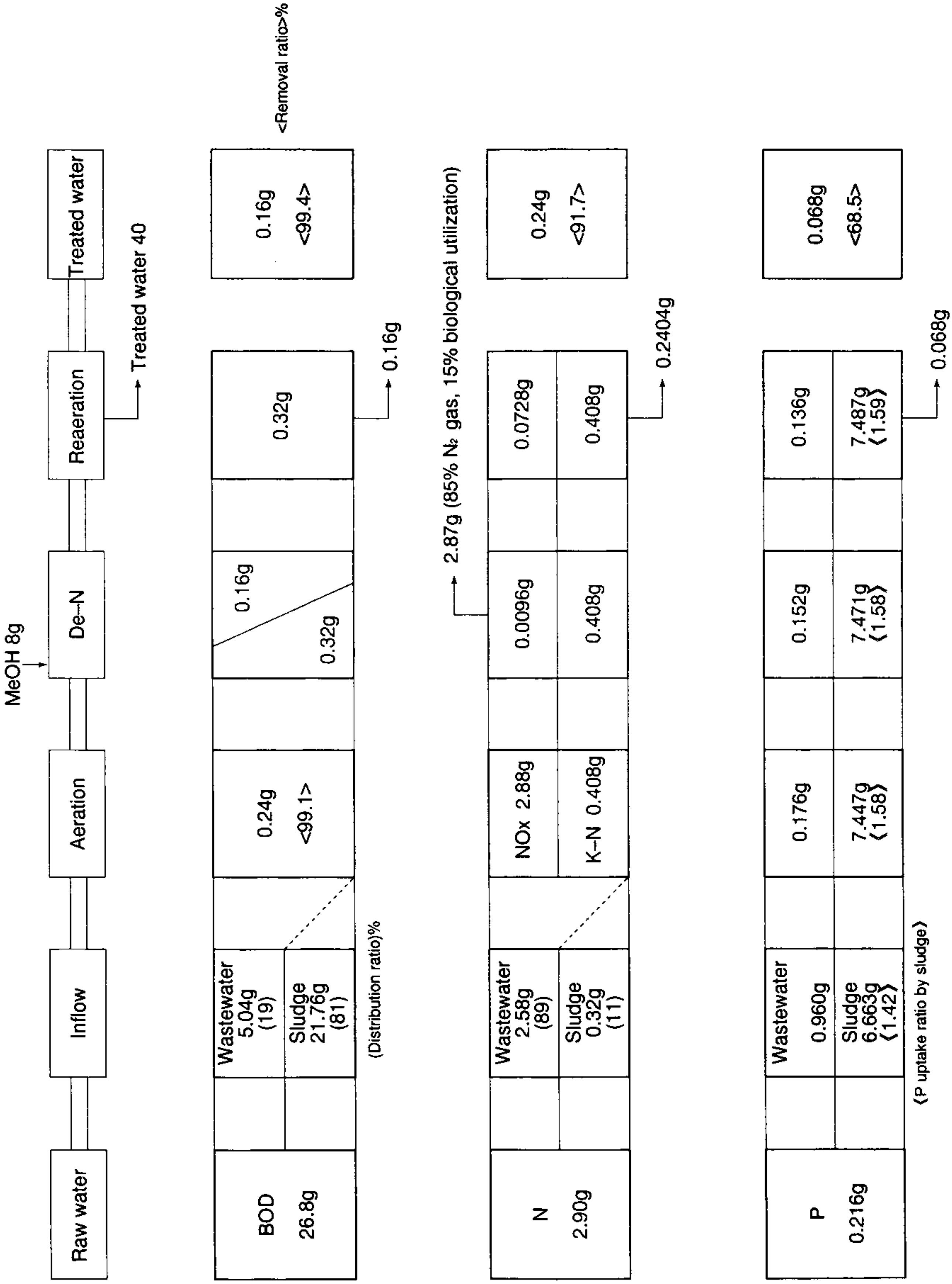


Fig 7-3 Quantitative Balance of BOD, N and P when using the controlled aeration activated sludge method (N-removal)

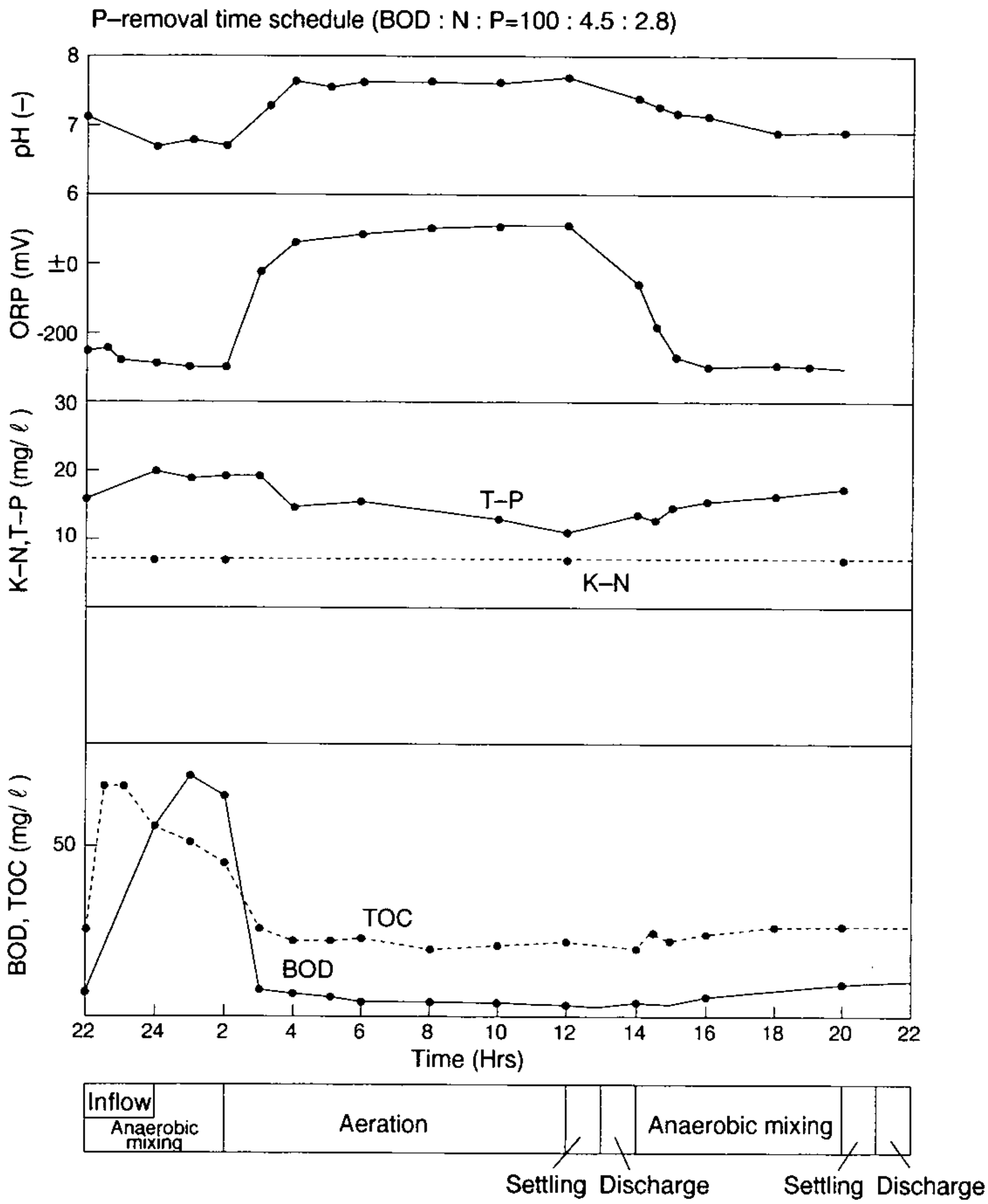


Fig 7-4 Hourly changes in the treated water quality using the controlled aeration activated sludge method

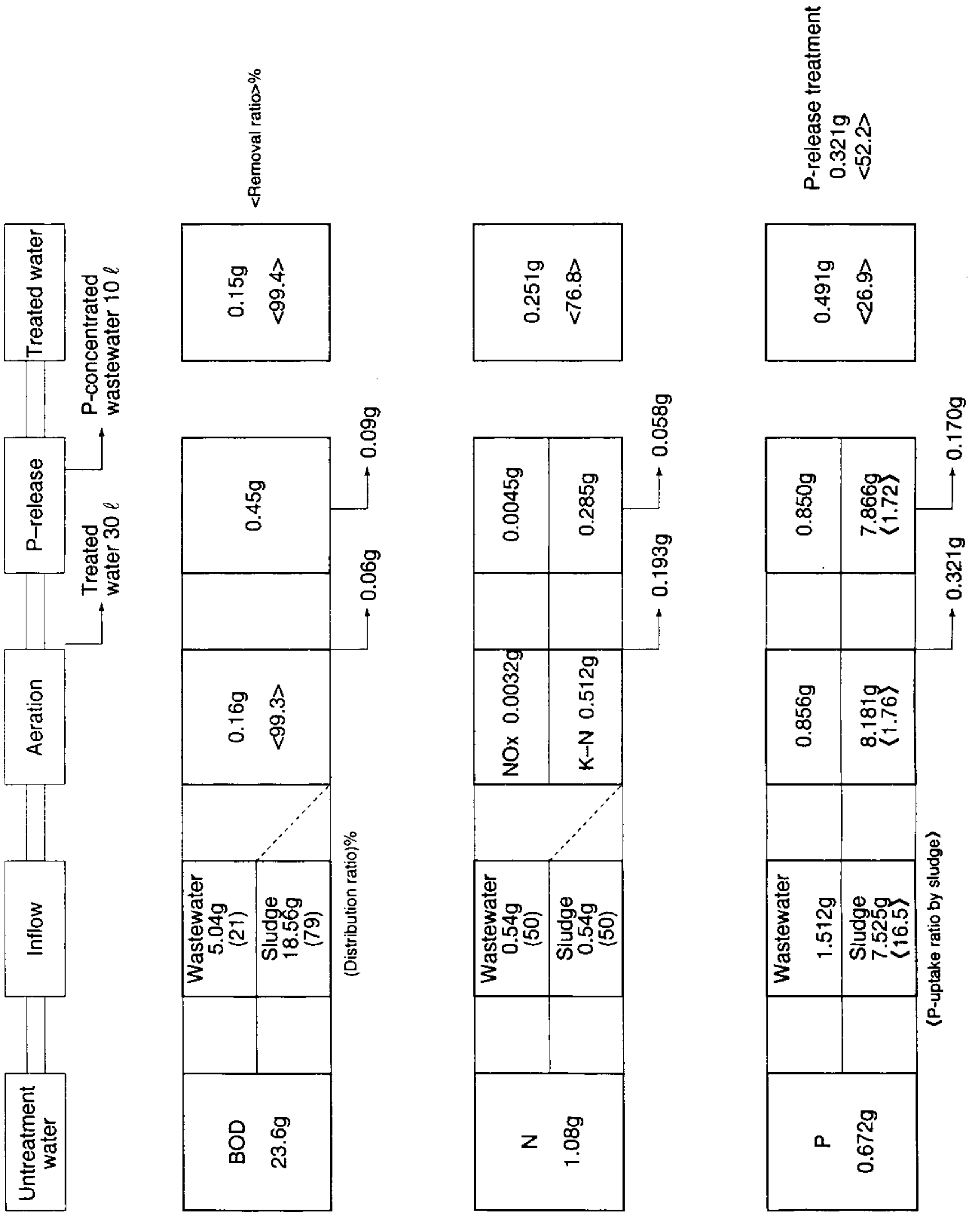


Fig 7-5 Quantitative Balance of BOD, N and P when using the controlled aeration activated sludge method (P-removal)

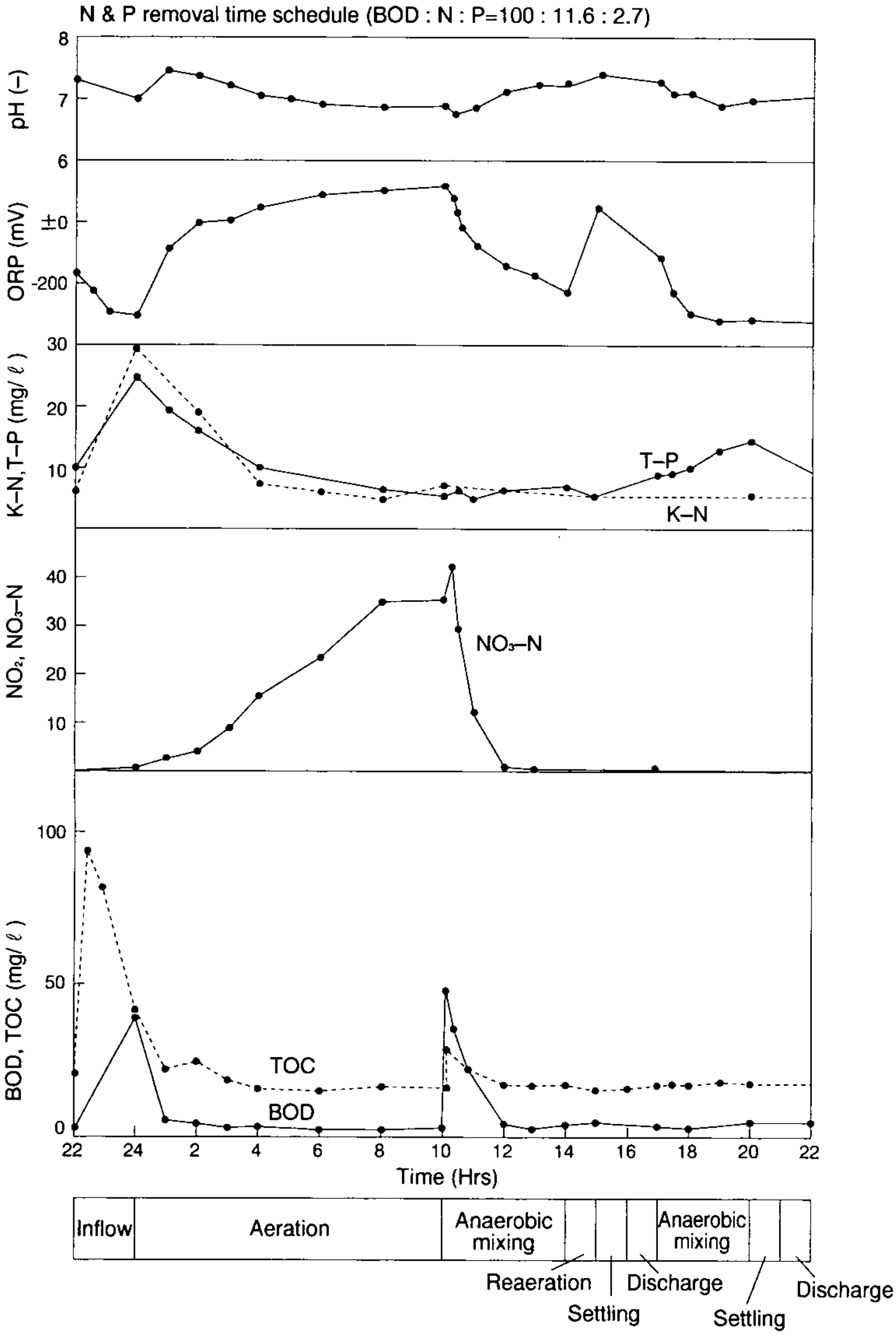


Fig 7-6 Hourly changes in the treated water quality using the controlled aeration activated sludge method

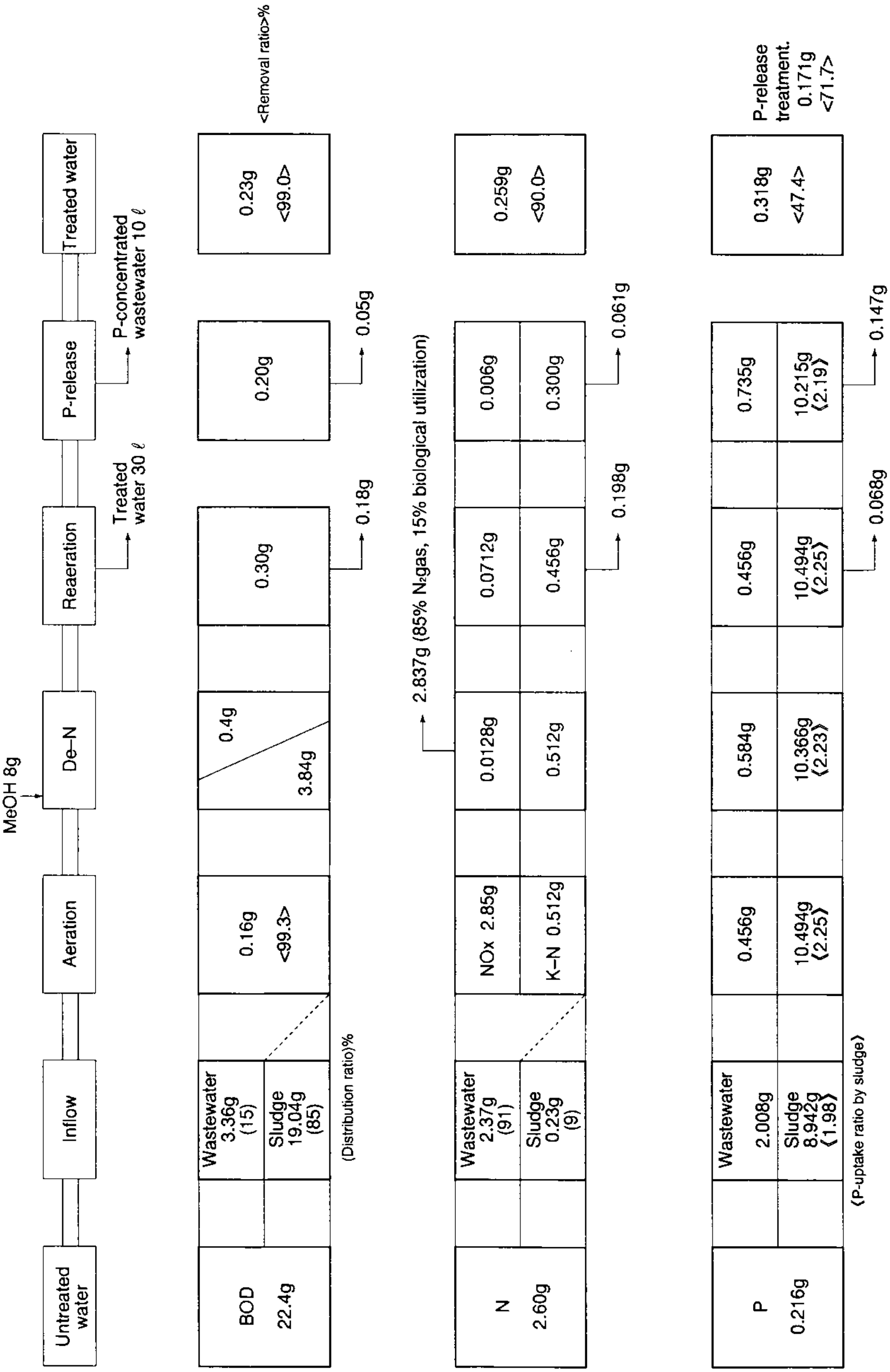


Fig 7-7 Quantitative Balance of BOD, N and P when using the controlled aeration activated sludge method (N & P removal)

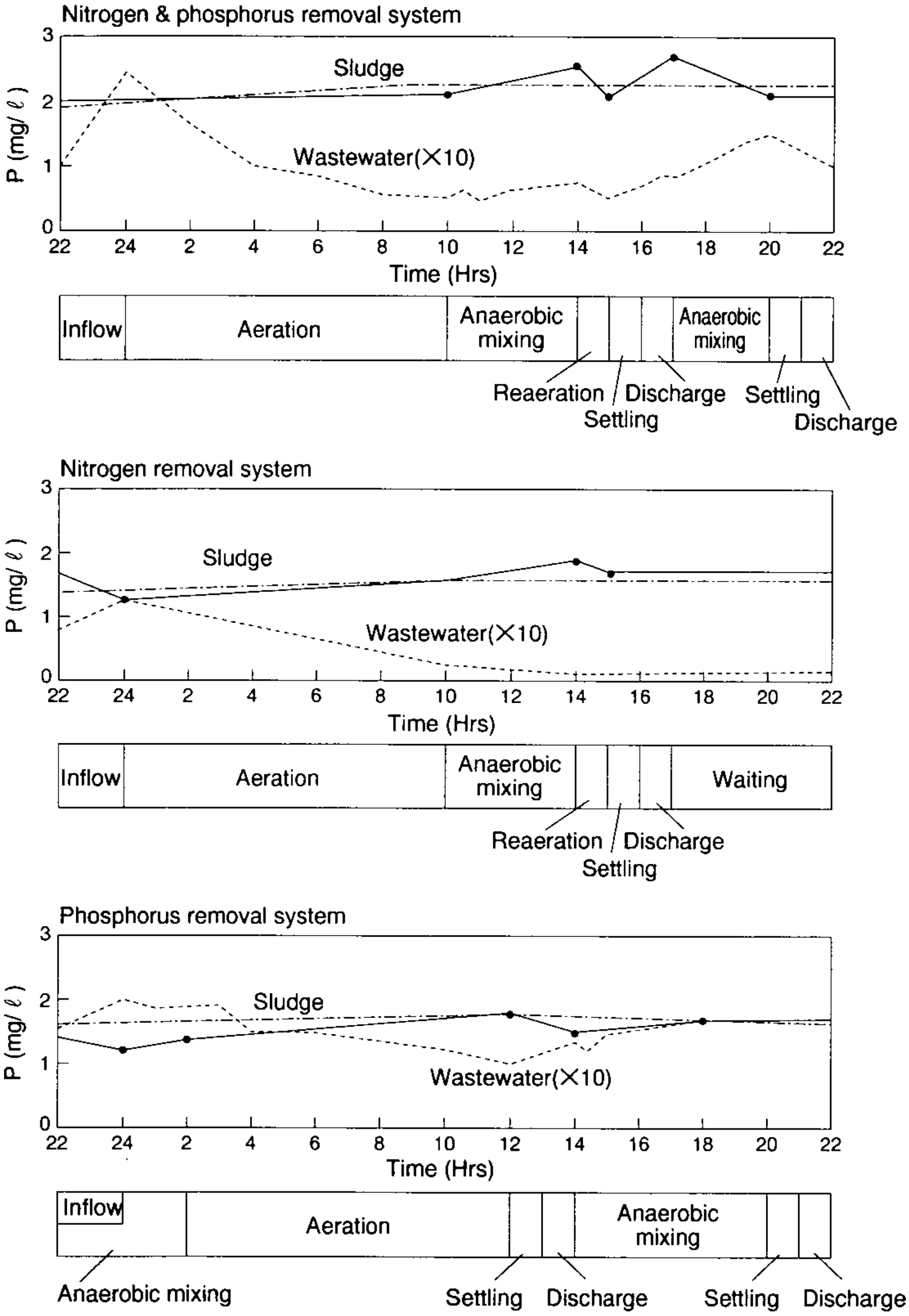


Fig 7-8 Hourly changes in phosphorus in sludge using the controlled aeration activated sludge method

7-2 Conclusion

Basic study on nitrogen and phosphorus removal using the controlled aeration activated sludge method was conducted and knowledge on the nitrogen and phosphorus removal mechanisms was obtained.
The following is a summery of the experiment.

(1) The controlled aeration activated sludge method is a batch type activated sludge method whose most attractive characteristic is complete control over bulking through the effect of the substrate concentration gradient that forms on no aeration on inflow of untreated water with commenement of aeration after finishing the inflow.

(2) In the controlled aeration activated sludge method, nitrogen can be biologically removed through a combination of nitrification and denitrification via aeration and anaerobic mixing, and phosphorus can also be biologically removed by utilizing the phosphorus release and uptake function of the activated sludge via a combination of anaerobic and aerobic conditions generated on untreated raw water inflow and aeration.

(3) BOD, nitrogen and phosphorus removal efficiencies were compared in the nitrogen removal system, the phosphorus removal system and the nitrogen & phosphorus removal system of the controlled aeration activated sludge method. BOD removal efficiency was high, 99 % or more, in all systems.
Nitrogen removal efficiency is expected to be 90 % in the treatment system with nitrification and denitrification processes.
The phosphorus removal efficiency can be expected to be about 70% when utilizing just the nitrogen removal system, and thus no special phosphorus release process is necessary because phosphorus can be released and uptaken under aerobic and anaerobic conditions arising on untreated water inflow and aeration.

(4) The reaction rate constents during nitrification and denitrification of the nitrogen removal system were slower than the ordinary constants; nitrification rate constant of 0.02 kg/kg · d and denitrification rate constant of 0.06 at 20℃.
This was probably due to the difference in bacterial growth due to high wastewater concentration, BOD / N = 8 - 9, and bacterial utilization of methanol, which was added as a hydrogen donor in the experiment.

8. Study on nitrogen removal from soy sauce manufacturing plant wastewater using the controlled aeration activated sludge method

The nitrogen and phosphorus removal efficiencies using the controlled aeration activated sludge method were studied using an indoor bench-scale apperaturs (capacity of 20 ℓ) using the actual wastewater of a soy sauce manufacturing plant.

The experiment clarified the treatment time schedule and the treatment conditions most suited for nitrification, denitrification and phosphorus removal.

8-1 Experiment using an indoor bench-scale apperatus

Although the main wastewater from the soy sauce manufacturing plant come from various kinds of washing, the BOD concentraion was relatively high, about 650 mg/ ℓ , and both phosphorus and nitrogen were excessive; BOD : N : P = 100 : 10 : 1.2. It was therefore necessary to treat not only organic substances, such as BOD compounds, but also nitrogen and phosphorus compounds.

In the experiment, the removal characteristics of nitrogen and phosphorus were studied by changing the treatment time schedule using a batch-type activated sludge method.

(1) Experimental conditions

- Wastewater for the experiment -

Actual soy sauce manufacturing wastewater was taken from the pilot plant installed in the manufacturing plant area, and after a portion of SS was removed with an 0.5 m/m screen it was used for the experiment. Table 8-1 shows the water quality analysis results of the sampled wastewater.

Table 8-1 Water quality analysis results of the sampled wastewater

	pH (-)	SS (mg/ ℓ)	TOC (mg/ ℓ)	COD (mg/ ℓ)	BOD (mg/ ℓ)	K-N (mg/ ℓ)	T-P (mg/ ℓ)	Cl^- (mg/ ℓ)	Color (degree)
$\bar{x}$	7.04	340	230	250	650	64	7.8	199	175
σ_{n-1}	0.26	230	75	83	220	23	3.2	48	57

The average water quality of the untreated water for the experiment was 650 mg/ ℓ of BOD , 64 mg/ ℓ of nitrogen , 7.8 mg/ ℓ of phosphorus in the ratio ; BOD : N : P = 100 : 9.8 : 1.2. Nitrogen and phosphorus were excessive in the wastewater.

This was similar to the average water quality under ordinary conditions. (See Table 2-1)

- Activated sludge -

The activated sludge of the indoor bench-scale apperatus (capacity of 80 ℓ) in 7-2(1) was used for seeding. The supplied seeding sludge had been used in nitrification and denitrification experiments using the made-up wastewater that included soy sauce, and thus the acclimation period was very short, about 15 days.

- Experimental equipment -

Aeration tanks made of transparent acryl resin with an effective capacity of 20 ℓ were used for the experiment. A regulated amount of untreated water was introduced and a regulated amount of treated water was withdrawn by continous flow pump. In the controlled aeration activated sludge method, aeration started after the inflow of untreated water and in the non-controlled aeration activated sludge method, aeration was performed at the sametime the inflow of untreated water. A regulated amount of methanol was added during the denitrification stage by continuous flow pump, and during the anaerobic mixing stage the water in the tank was mixed with a circulation pump. Operation of pumps and blowers were controlled automatically by timer.

Photo 8-1 shows the experimental equipment.

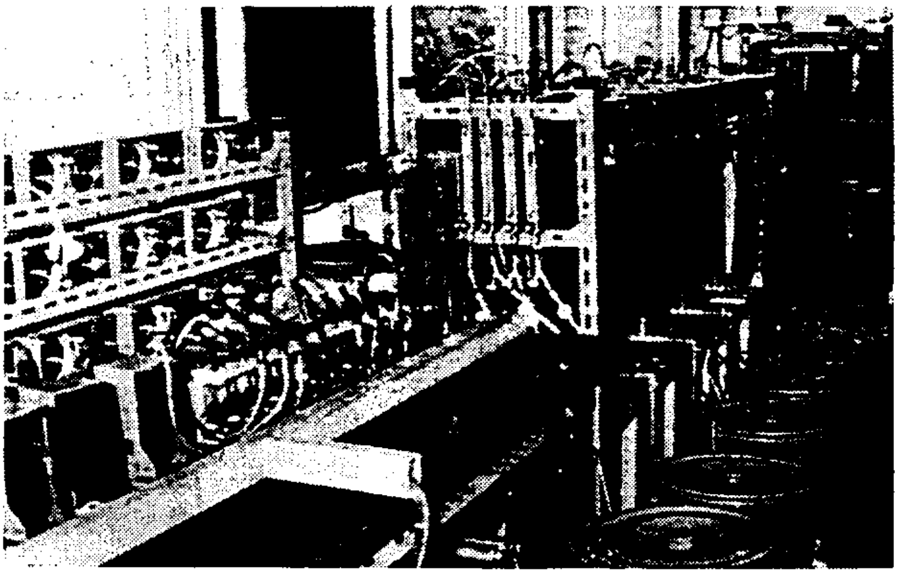


Photo 8-1 Indoor bench-scale apperatus (capacity of 20 ℓ)

- Experimental conditions -

There were four conditions for the experiment - the controlled aeration method and the non-controlled aeration method under the same loading condition, the controlled aeration method incorporating denitrification and the controlled aeration method with hydrogen donor addition on denitrification. The treatment characteristics of BOD, nitrogen and phosphorus were compared.

The water quality analysis methods for the treated water are shown in Table 3-1.

Table 8-2 shows the experimental conditions.

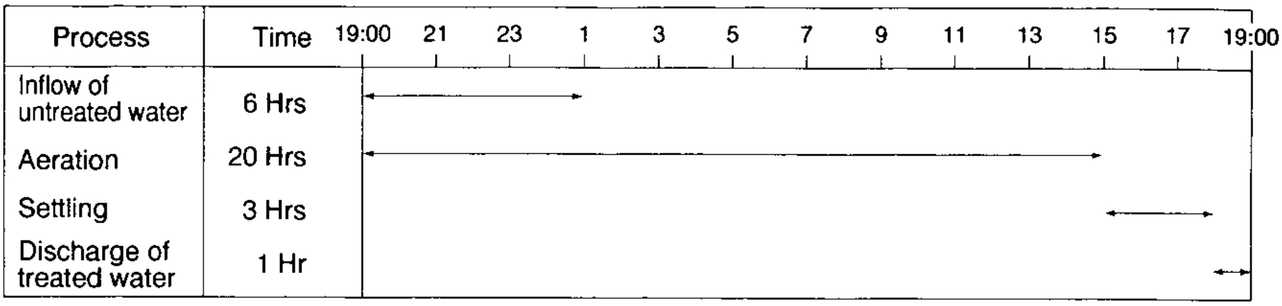
Table 8-2 Experimental conditions

Apperatus No.	P-201	P-202	P-203	P-204
Aeration method	Non-controlled aeration	Controlled aeration	Controlled aeration	Controlled aeration
Denitrification process	×	×	○	○
Methanol addition	×	×	×	○ (2g-MeOH/d)
Treated water quantity	10 ℓ /d (1/2 for the aeration tank volume)			
Aeration volume	8 ℓ /min			
Quantity of sludge withdrawal	1 ℓ /d (SRT=20days)			
Treated water temperature	Room temperature (20 ~ 25℃)			

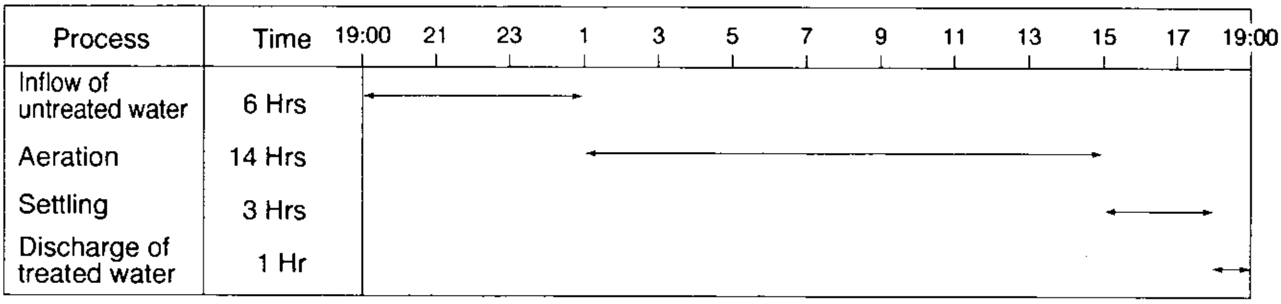
(2) Time shedule

Fig. 8-1 shows the treatment time schedule for each tank in the experiment. The aeration time was slightly different according to the aeration method and the presence or absence of denitrification. The sludge was withdrawn just before finishing aeration or reaeration.

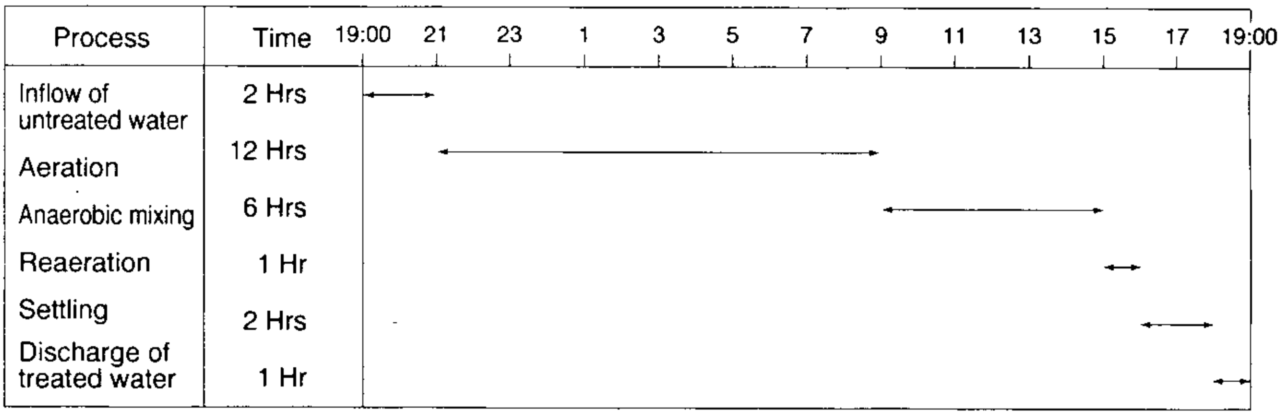
P–201 (Non-controlled aeration)



P–202 (Controlled aeration)



P–203 (Controlled aeration + anaerobic mixing)



P–204 (Controlled aeration + anaerobic mixing [methanol addition])

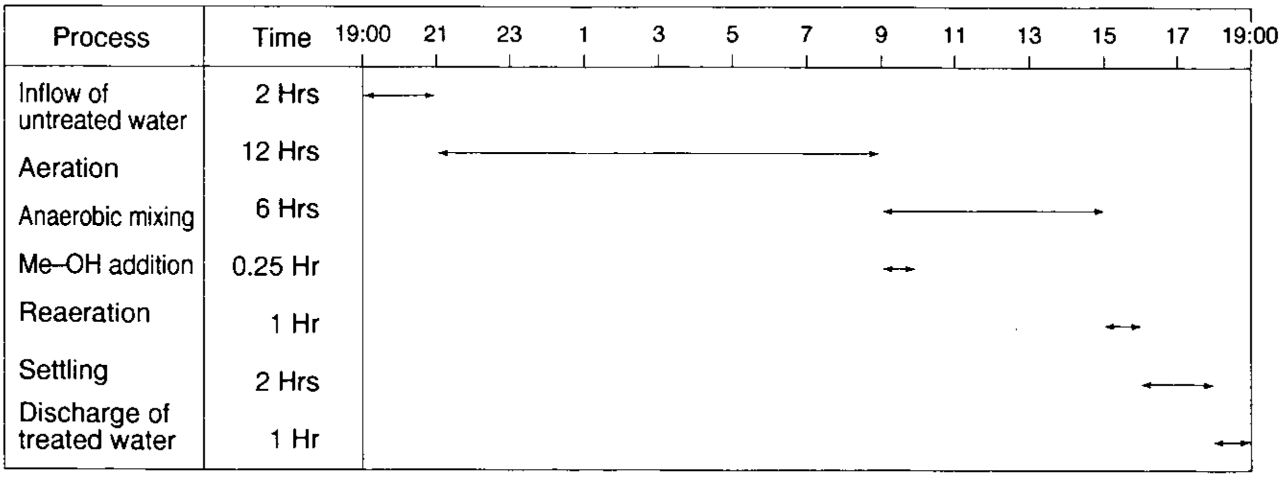


Fig 8-1 Treatment time schedule

8-2 Continous operation experiment

Based on the continous operation experiment using actual soy sauce manufacturing plant wastewater, the most appropriate treatment time schedule for nitrification, denitrification and phosphorus removal were selected through evaluation.

(1) Experimental conditions and result

The daily changes in the load during the experiment are shown in Fig. 8-2.

The aration time was different according to the time schedule for each tank but the BOD and nitrogen loads were calculated by simple loading without consideration to the aeration time. After Feb. 28th when sludge acclimation was completed, the BOD space and nitrogen loads were 0.50 - 0.14 kg/m^3 · d (average 0.29 kg/m^3 · d) and 0.04 - 0.02 kg/m^3 · d (average 0.03 kg/m^3 · d), respectively, and the BOD load fluctuated greatly compared to the nitrogen load. During continous operation, in which the same volume of sludge was withdrawn (1 ℓ / d) from each tank, the MLSS concentration was P-201 < P-202 < P-203 < P-204, and the maximum difference was 1000 mg/ ℓ .

This was probably due to sludge being withdrawn along with the treated water because of sludge flotation during the settling period, and different sludge autolysis volumes due to different aeration times. This will be explained in detail later.

Figs. 8-3, 8-4 and 8-5 show the daily change in the treatment performance of the experiment. Since the main wastewater of the soy sauce manufacturing plant came from washing, the pH of the sampled wastewater was about 7, neutral.

In P-202, P-203 and P-204, the pH of the treated water was 8.3 but in P-201 the pH was slightly lower, about 8.0. This was probably because organic nitrogen compounds in the sampled wastewater were converted to nitric acid by microbial oxidizative decomposition or the pH was lowered by H^+ release at that time. In the experiment, since alkalinity was relatively high, the pH decrease due to nitrification was not so great and an effect on nitrification due to pH lowering was not observed. Because a portion of SS compounds was removed with on 0.5 m/m screen, the concenteration was stable at 300 - 400 mg/ ℓ . Even after Feb. 28th when acclimation finished, a large quantity of SS was observed frequently in the treated water from P-201 and somtimes from P-202, P-203 and P-204. The reason was as follows; after aeration there was a settling period for separating activated sludge from the supernatant but if it was too long, DO in the tank was consumed by activated sludge and at it finally reach an anaerobic condition, DO = 0. In this condition, part of the activated sludge started respiration utilizing oxygen bonded to NO_2 and NO_3 in the wastewater and nitrogen began to be released as nitrogen gas. The released nitrogen gas attached to the settled activated sludge and as a result the sludge floated. Finally when the treated water was discharged in this condition, sludge discharged along with it and this led to the increase in SS in the treated water. This was greatly affected by nitric or nitrous acid concentration at the beginning of the settling period.

Cl^- concentration in the sampled wastewater was relatively low, about 200 mg/ ℓ , in the experiment and poisoning of the activated sludge was not observed during the BOD oxidation, nitrification and denitrification.

The color removal efficiency was relatively low, about 75 %; about 200 degrees in the sampled wastewater and about 50 degrees in the treated water from all expriments. This was probably due to non-biodegradable substances contained in the soy sauce manufacturing wastewater.

The removal efficiency of organic substances - TOC, COD and BOD - of all tanks was equal and high except regard to discharged SS compounds. Although the BOD concentration in the sampled wastewater greatly fluctuated from 300 to 1000 mg/ ℓ , the BOD concentration in the treated water was 10 mg/ ℓ or less in most cases, which meant the removal efficiency was stable, 98 %.

The concentrations of TOC and COD were also good, 30 mg/ ℓ of TOC or less and 30 mg/ ℓ of COD, but the removal efficiencies of TOC and COD were 90 %, a little lower than that of BOD. As described for color, this was probably due to non-biodegradable substances in the soy sauce.

There were several factors for phosphorus removal, such as treatment time schedule, BOD loading, sludge age and phosphorus ratio, and the experiment could not clarify these removal characteristics. However there was the tendency, P-201 < P-202, P-203 < P-204, and the phosphorus removal efficiency of the controlled aeration method (P-202, P-203 and P-204) was better than that of the non-controlled aeration method.

Among the controlled aeration experiments, the removal efficiency of P-204, in which aerobic and anaerobic conditions were more frequently altered because of the addition of the denitrification stage, was the best, 86 %.

Before Feb. 28th when the sludge acclimation was not sufficient, nitrogen compounds were converted to nitrite, and after Feb. 28th, when the acclimation was completed, they were converted to nitrate. In general, about one or one and half months are usually necessary for nitrification and denitrification. However in our experiment, acclimation completed in a short period, two weeks, after starting treatment, and this was probably due to the usage of the excess sludge from the made up wastewater which included soy sauce for which nitrification and denitrification had already finished, for seeding.

The nitrogen removal efficiency will be explained in detail later, but in brief after acclimation, organic nitrogen in the sample wastewater was oxidized and decomposed to nitric acid by microorganisms. Residual organic nitrogen was 2 - 3 mg/ ℓ in every tank. However the nitrate concentration in the treated water varied greatly according to the treatment time schedule, average T-N concentration of 27 mg/ ℓ in P-201, 17 mg/ ℓ in P-202, 12 mg/ ℓ in P-203 and 3.6 mg/ ℓ in P-204, and we found that nitrogen could be completely removed through introduction of a denitrification stage in the treatment time schedule of the controlled aeration method and by adding a hydrogen donor, such as methanol.

(2) Nitrogen removal and treatment process

Table 8-3 shows the mean values of the analysis results on each nitrogen form in the treated water after acclimation and the nitrogen removal efficiency.

Table 8-3 Analysis result of nitrogen compounds in the treated water

Apperatus No. Items	P-201	P-202	P-203	P-204
K-N (mg/ ℓ)	2.5	3.1	3.1	2.6
NO2-N (mg/ ℓ)	0.29	0.15	0.57	0.06
NO3-N (mg/ ℓ)	23.7	13.4	8.28	0.94
T-N (mg/ ℓ)	26.5	16.7	12.0	3.6
Nitrification ratio (%)	96.1	95.2	95.2	95.9
Nitrogen removal efficiency (%)	58.7	73.9	81.3	94.4

There was a big difference in the length aeration according to the time schedule ranging from 12 to 20 hours, but in every apperatus the nitrification ratio of organic nitrogen to nitrite and nitrate was 95 % or more. This was due to very low nitrogen loading, 0.025 kg/kg · d, of P-201 ~ P-204, comparied to the general nitrogen loading, 0.075 kg/kg · d (20℃), which represented a nitrification ratio of 95 % because there was a difference in MLSS concentration calculated from the actual loading with consideration to aeration time.

Comparing P-201 and P-202 which had no denitrification stage, the nitrogen removal efficiency was higher in the controlled aeration method than the non-controlled one; 58.7 % in P-201, non-controlled, and 73.9 % in P-202, controlled. This was because in the non-controlled aeration method, nitrogen removal only through microorganism uptake along with BOD removal. /On the contrary, the controlled aeration method dose not impliment aeration during untreated water inflow, the tank is anaerobic on inflow. / In addtition, almost all residual nitrates in the mixed liquor were denitrified on antreated water inflow because the necessary hydrogen donors for denitrification were introduced on inflow by replacing a half volume of water and consequently the nitrate nitrogen concentration in the treated water is half compared to the non-controlled aeration.

Comparing the three controlled aeration methods, P-202 (simple controlled aeration), P-203 (with anaerobic mixing stage) and p-204 (denitrification is promoted by carbon source feeding in the anaerobic mixing stage), the nitrogen removal efficiencies were very different, 73.9 % in P-202, 81.3 % in P-203 and 94.4 % in P-204, and the treatment performance of P-204 was stable; 1 mg/ ℓ of NO_3-N or less and 5 mg/ ℓ of T-N or less.

This result clarifies that for obtaining high nitrogen removal efficiency in a limited time period when using a batch type treatment method, use of anaerobic mixing is not sufficient for denitrification, and hydrogen donor addition is indispensable in anaerobic mixing stage.

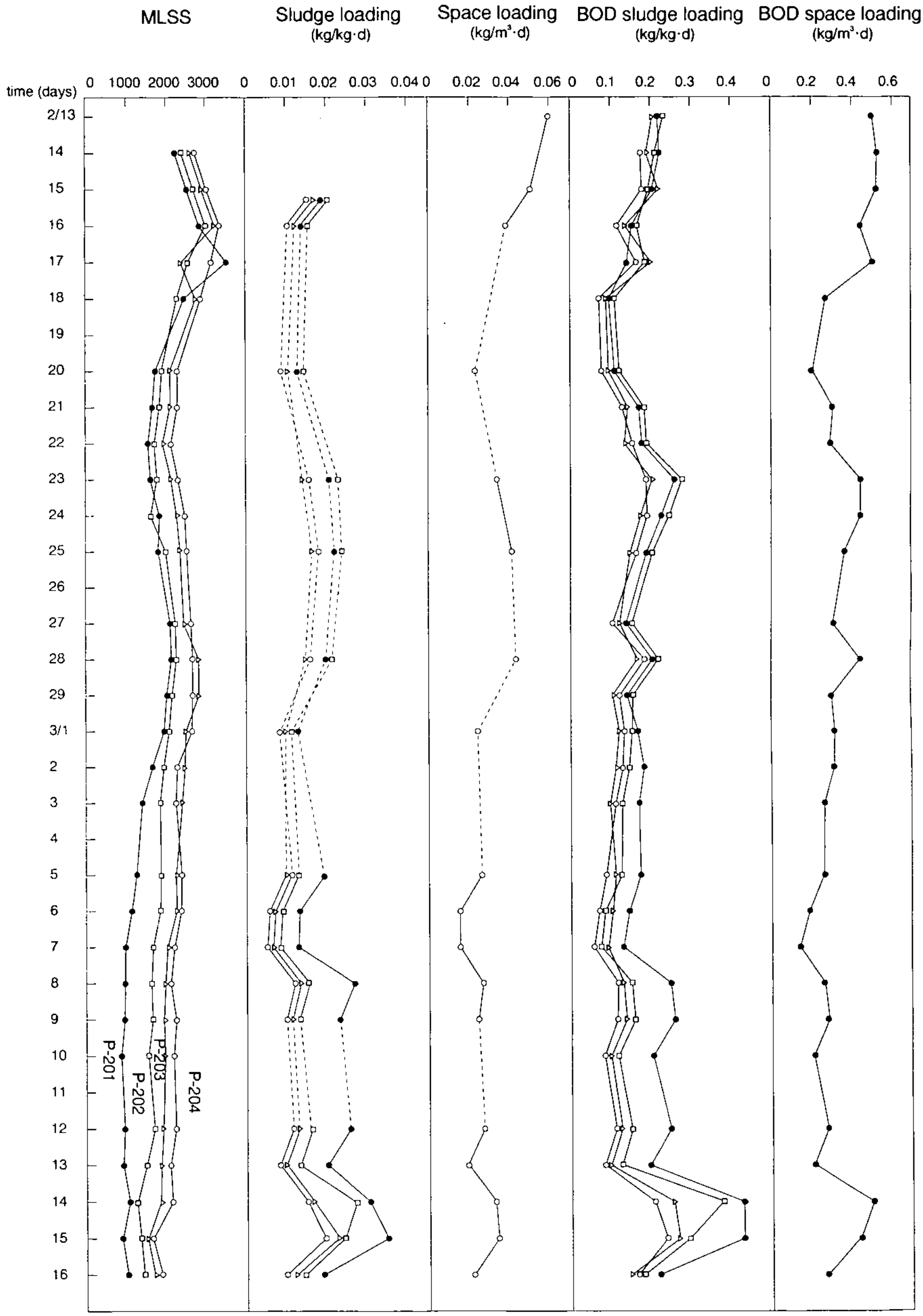


Fig 8-2 Treatment results from the indoor bench apperatus (20 ℓ) (BOD loading, nitrogen loading, MLSS)

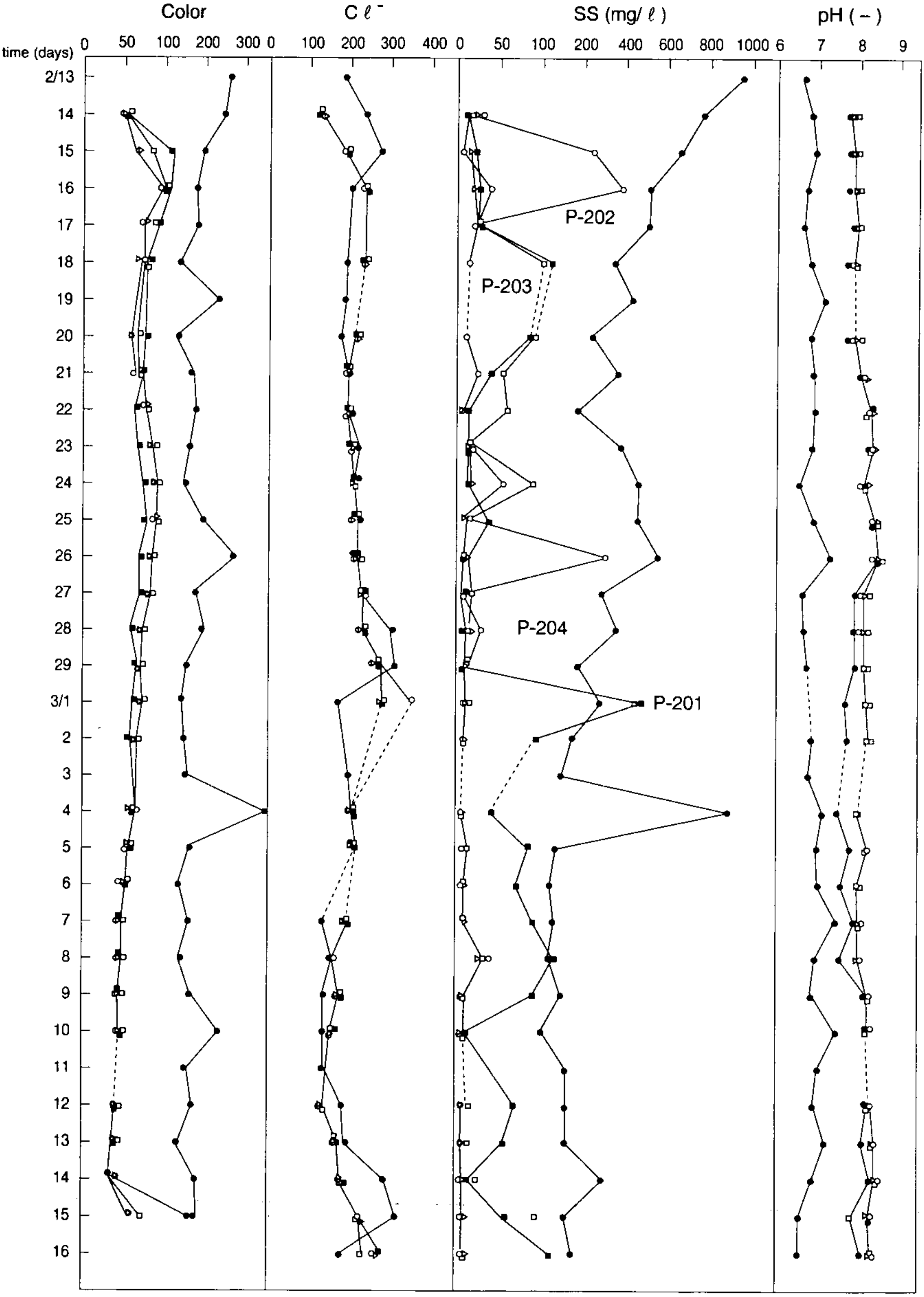


Fig 8-3 Treatment results from the indoor bench apperatus (20 ℓ) (pH, SS, Cl, color)

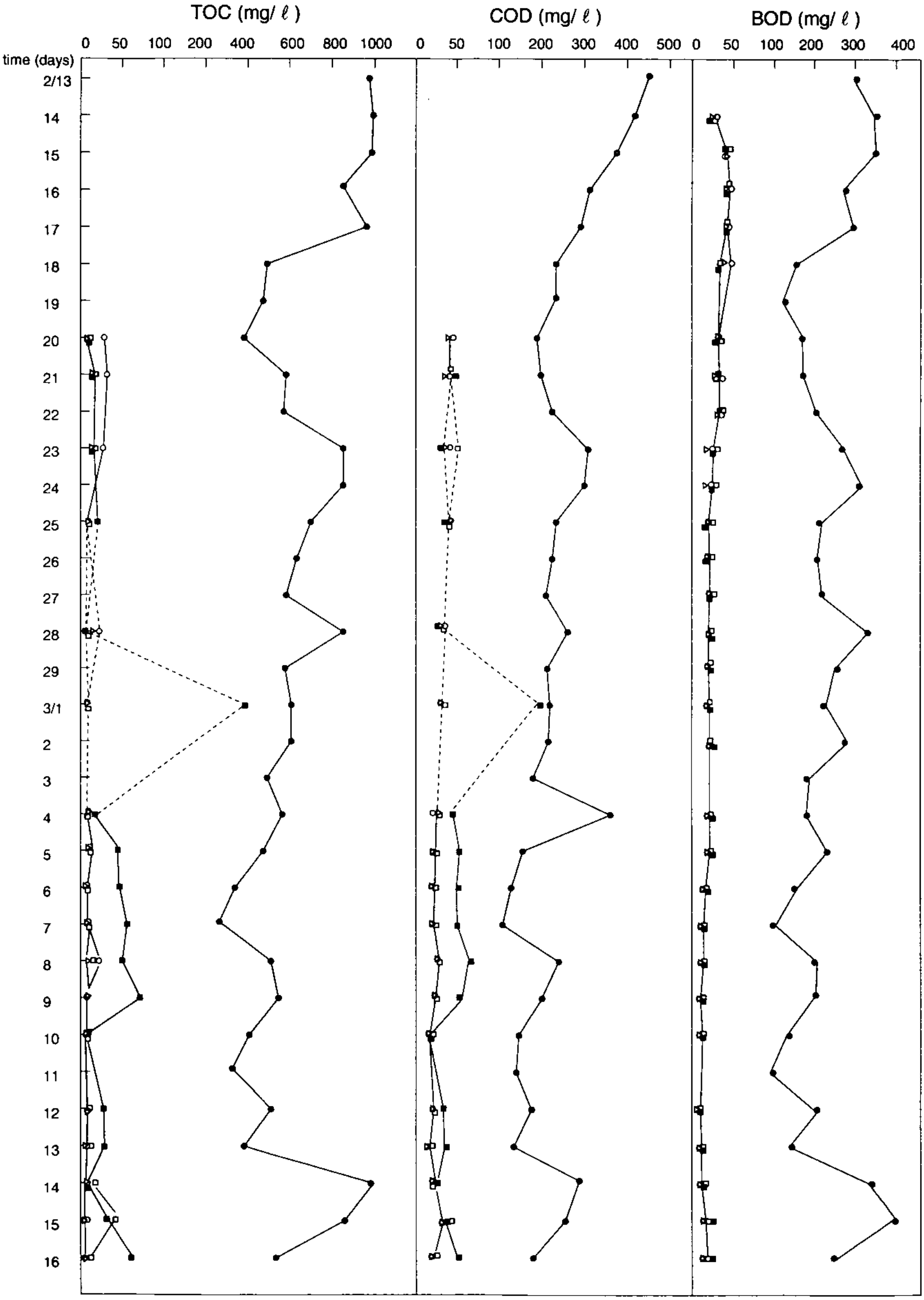


Fig 8-4 Treatment results from the indoor bench apperatus (20 ℓ) (TOC, COD, BOD)

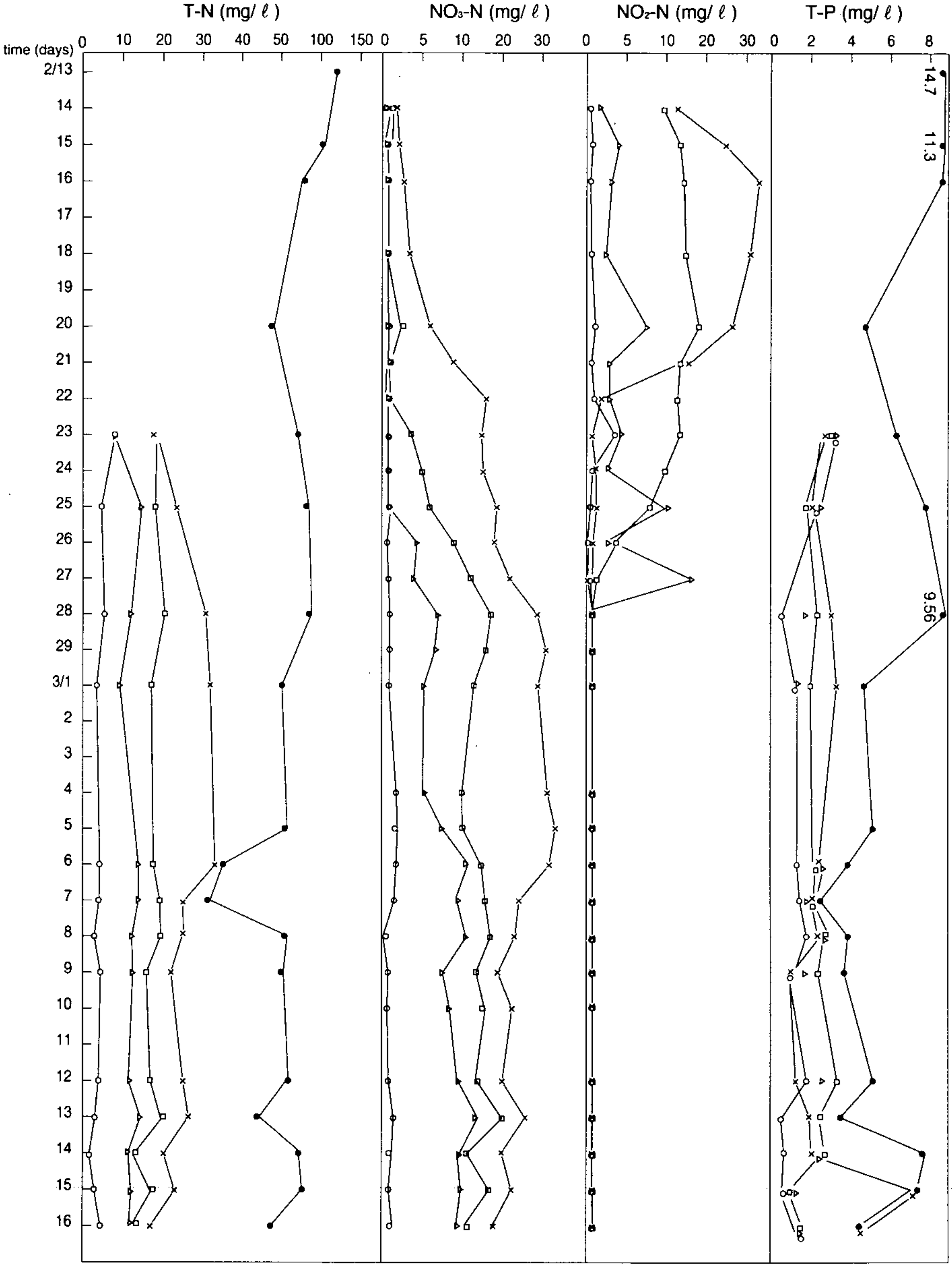


Fig 8-5 Treatment results from the indoor bench apperatus (20 ℓ) (T-P,NO₂-N, NO₃-N, T-N)

8-3 Study on hourly changes in the treatment characteristics

Based on the hourly changes in the indoor bench-scale apperatus using actual wastewater of a soy sauce manufacturing plant, BOD, nitrogen and phosphorus removal characteristics were studied using different treatment time schedules.

(1) Treatment conditions and result

Pesearch was conducted from the 13th to 14th of March. The untreated water characteristics are shown in Table 8-4.

Table 8-4 Characteristics of the raw water

pH (-)	SS (mg/ ℓ)	TOC (mg/ ℓ)	COD (mg/ ℓ)	BOD (mg/ ℓ)	K-N (mg/ ℓ)	T-P (mg/ ℓ)	Cl^- (mg/ ℓ)	Color (degrees)
7.10	320	340	300	1000	70.3	7.68	276	170

The condition of the untreated water on the research days was 1000 mg/ ℓ of BOD, about 1.5 times higher than the average value of the experiment, 650 mg/ ℓ of BOD, and the nitrogen and phosphorus ratios were slightly lower, BOD : N : P = 100 : 7 : 0.8.

BOD loading was 0.5 kg/m^3 · d and that for nitrogen, 0.035 kg/m^3 · d at simple loading. The result of each treatment time schedule is shown in Tables 8-6 ~ 8-9.

The treatment patterns of organic substance - TOC and BOD - removal were different according to the treatment method, controlled aeration or non-controlled aeration, but in both cases the treated water quality was good; 10 mg/ ℓ of BOD or less and 20 mg/ ℓ of TOC or less. Comparison of the treatment patterns of the controlled aeration and non-controlled aeration methods, influent TOC and BOD were quickly removed in P-201 due to aeration during untreated water inflow, and TOC and BOD concentrations in the tank were usually the same as those in the treated water.

On the other hand, in P-202, P-203 and P-204, since there was no aeration during inflow, TOC and BOD concentrations in the tank increased along with the inflow and reached a maximum at the end of inflow. Then, after starting aeration, they dropped rapidly and reached the same level as the treated water after 2 or 3 hours of aeration. And then along with the passage of time, the substrate concentration gradients of BOD and TOC ranging from plus to minus were formed in the aeration tank. /The biggest advantage of controlled aeration is control over bulking, which is the greatest problem of the activated sludge method, through formation of substrate concentration gradients, TOC and BOD. This treatment pattern was clear in the hourly changes of the research.

The removal characteristics of nitrogen and phosphorus will be described in detail later. However, in brief, the treatment performance was almost the same as the average result from the continous operation experiment.

(2) Nitrification and denitrification processes

As for the influent nitrogen behavior, in P-201, the non-controlled aeration method, influent K-N was quickly utilized by microorganism through oxidation of BOD compounds or oxidized to nitric acid that remained in the tank, consequently K-N, NO_2-N and NO_3-N concentrations in the treated water were almost constant, similar to the behavior of BOD compounds.

On the other hand, in the controlled aeration method, K-N in the tank increased along with the inflow of untreated water and decreased rapidly with the decrease in BOD compouds after aeration, and the excess nitrogen compounds were oxidized to nitric acid, and nitric acid concentration in the tank increased.

In both P-203 and P-204, which had an anaerobic mixing stage, DO in the tank dropped to 0 mg/ ℓ immediatly after aeration stopped. In P-203, which had no methanol addition, NO_3-N concentration decreased slowly and in P-204, which had methanol addition in the anaerobic mixing stage, the NO_3-N concentration decreased relatively rapidly.

In P-202 and P-203, in which residual NO_3-N was present in the treated water due to insufficient denitrification, as the tank became anaerobic due to stopping aeration on inflow of untreated water and there was hydrogen donor addition, denitrification occured and NO_3-N in the tank became almost 0 mg/ ℓ . This explained why, even in simple controlled aeration, the nitrogen removal efficiency was better than that of the non-controlled aeration method.

As described before, biological nitrification and denitrification proceed at the 0-order reaction. Table 8-5 shows the result for the rates of nitrification and denitrification in each tank calculated based on the experimental result.

The nitrification rate when utilizing the controlled aeration method was calculated on the assumption that for influent K-N, 5 % of the volume of influent BOD was consumed by microorganisms through BOD oxidation and the rest was oxidized to nitric acid on the inflow of untreated water.

The nitrification rate when using the controlled aeration method was calculated in two ways, from the decreased in K-N, and from the increase in nitric and nitrous acid concentrations.

Table 8-5 Nitrification and definitrification rates (Water temperature of 21℃)

Apperatus No. Item		P-201	P-202	P-203	P-204
Nitrification rate (mg-N/g · MLSS · Hr)	K-N	1.45	1.57	1.88	1.79
	NOx-N	-	1.77	1.67	1.68
Denitrification rate	(mg-N/g · MLSS · Hr)	-	-	0.40	2.39

In both of the nitrification rates calculated from the decrease in K-N and from the increase in NOx-N, there was no difference according to the treatment method and they were almost the same, 1.45 - 1.88 mg-N/g-MLSS · Hr (21℃), which was very low, about 50 - 60 % of the ordinary nitification rate at 20℃, 3.13 mg-N/g-MLSS · Hr.

This was probably due to the following reasons; nitrogen loading in the experiment after acclimation was very low, average 0.025 kg/kg · d, and sludge activity was lowered because of the relatively old sludge, 20 days, even on low loading.

Comparing the dinitrification rate of 0.4 mg-N/g-MLSS · Hr in P-203 which did not have hydrogen donor addition on anaerobic mixing, it was about 6 times lower than that in P-204, 2.39 mg-N/g-MLSS · Hr, which had hydrogen donor addition.

In the controlled aeration activated sludge method which should be finished within a fixed time limit because it is a batch type method, it is indespensable to increase the denitrification speed through hydrogen donor addition.

As for the nitrification rate, the measured denitrification rate with methanol addition was less than 50 % that of the general value, 5.25 mg-N/g-MLSS · Hr, and this was probably due to the above-mentioned reasons and an insufficient anaerobic condition due to the uncovered tank top. The denitrification rates on untreatment water inflow for P-202 and P-203 were 2.56 mg-N/g-MLSS · Hr and 2.89 mg-N/g-MLSS · Hr, respectively, which were the same or more than that of P-204, with methanol addition. This indicates that further study on the treatment process of untreatment water feeding as a hydrogen donor is necessary.

(3) Release and uptake of phosphorus

The removal of phosphorus by utilizing biological reactions via the activated sludge method is known as a biological phosphorus removal method, in which phosphorus released under anaerobic conditions is readily uptaken by microorganisms under aerobic conditions.

A paticular treatment time schedule is adopted for implimentation of the controlled aeration activated sludge method, and even in the conventional treatment schedule, aerobic and anaerobic conditions are varied until the end of the treatment.

However, since there were various factors influening phosphorus removal, such as aerobic and anaerobic conditions, BOD loading and sludge age, the treatment conditions of the experiment were not completely adequate but the process of phosphorus removal was fully shown in the hourly changes of P-204. Due to a shift to anaerobic conditions in the tank inflow of untreated water and release of some phosphorus, the T-P value became about 1 mg/ ℓ higher than that of P-203, in which the same amount of wastewater inflowed; phosphorus in the tank was then uptaken rapidly through aeration. In addition, through anaerobic mixing with methanol addition, the phosphorus concentration of the mixed liquor rose to 1.5 mg/ ℓ and through reaeration decreased to 1 mg/ ℓ or less due to sludge uptake.

As a result, the quantity of released and uptaken phosphorus was very small in the experiment because the sludge phosphorus ratio under conditions of excessive uptake was about 1.3 %. Consequently, more study on other factors including BOD loading and sludge age is necessary.

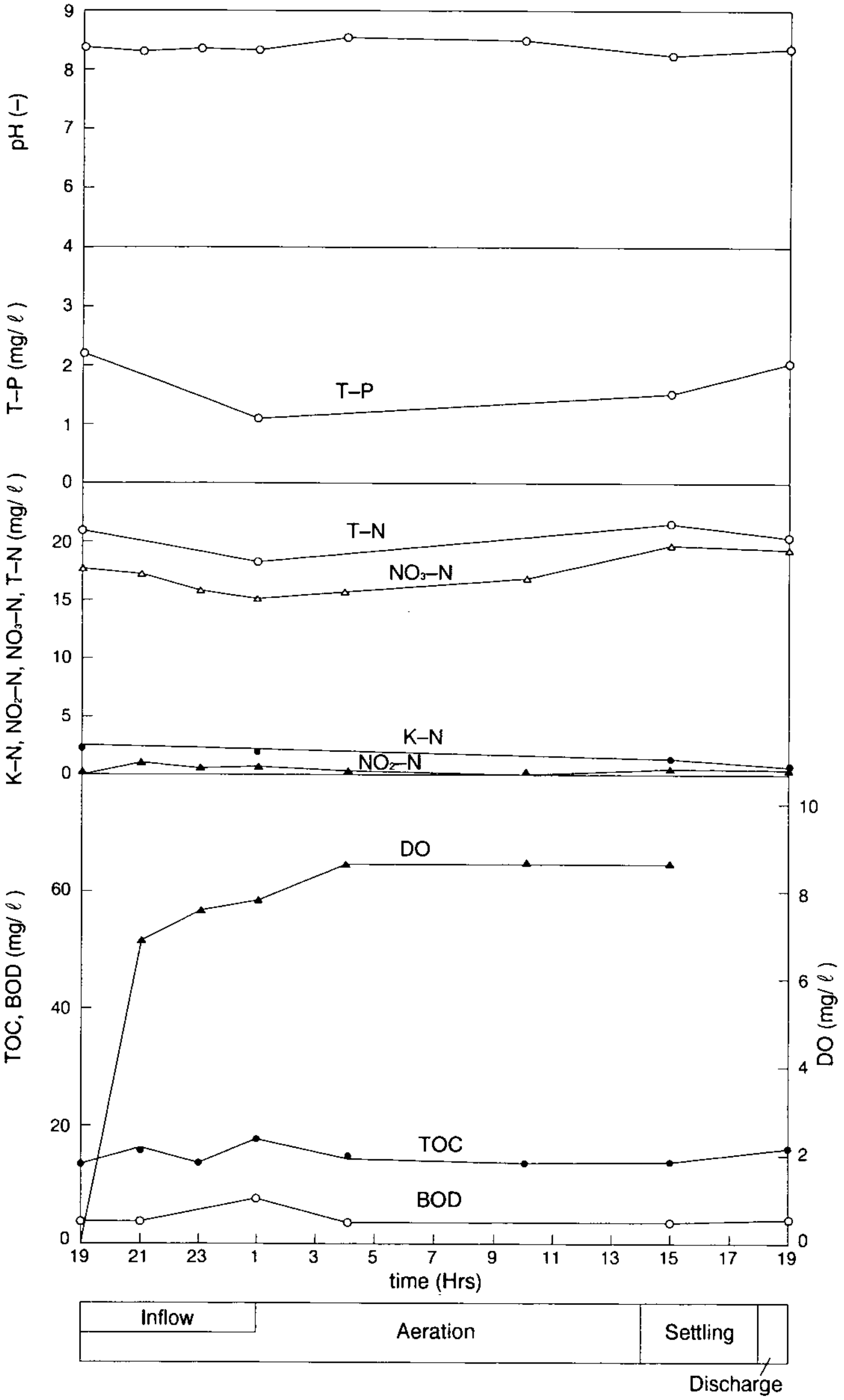


Fig 8-6 Hourly changes of the indoor bench apperatus (P-201)

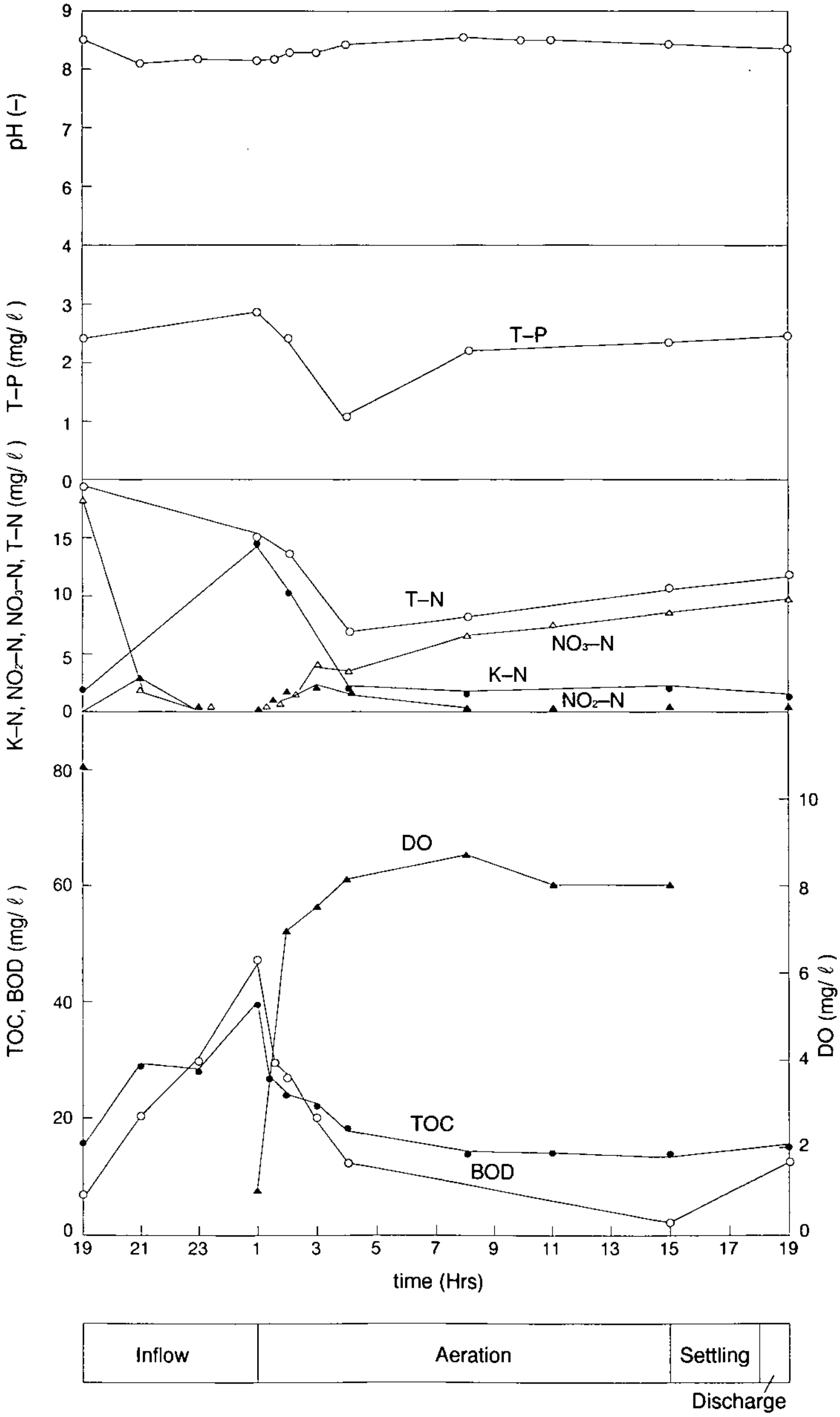


Fig 8-7 Hourly changes of the indoor bench apperatus (P-202)

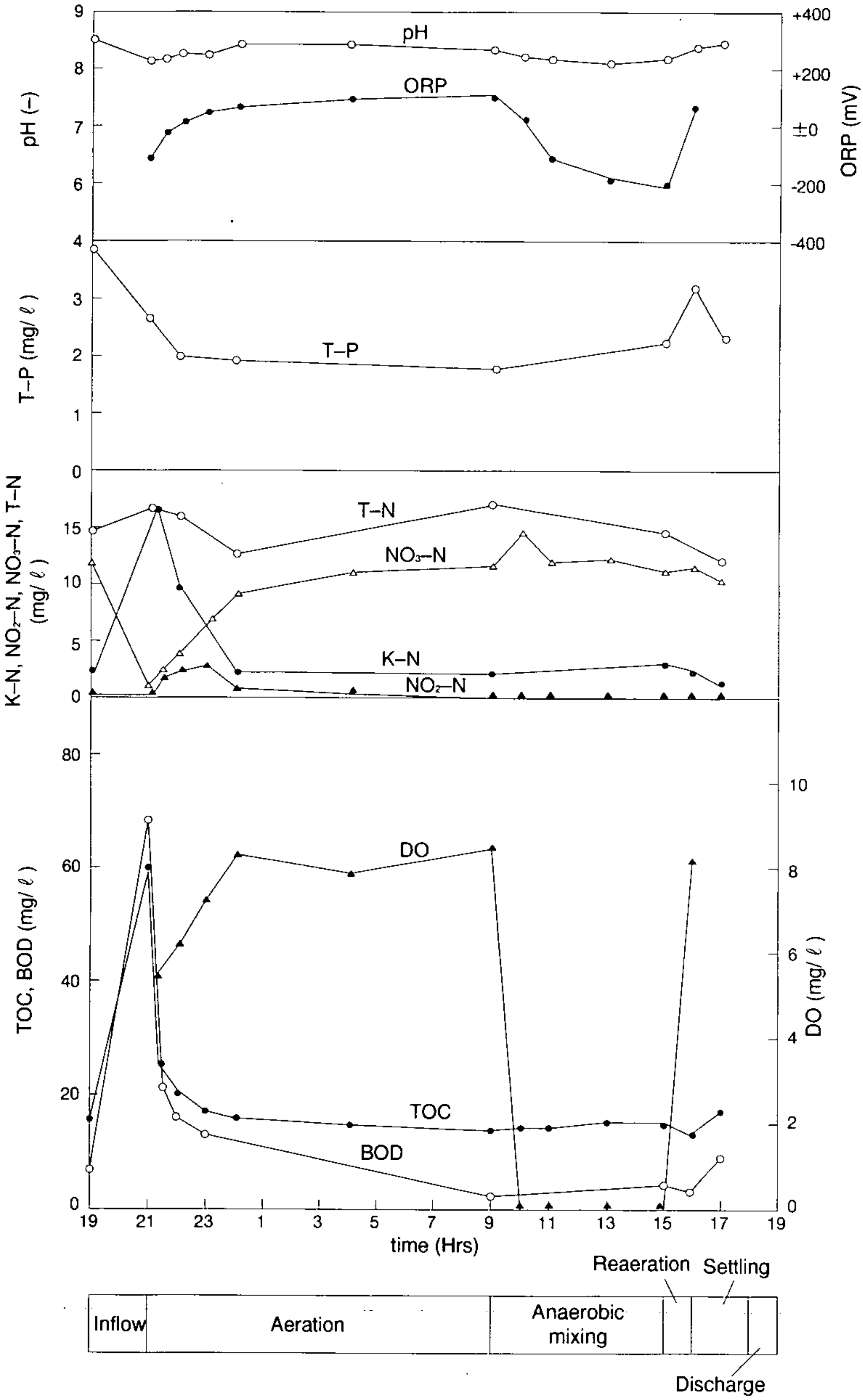


Fig 8-8 Hourly changes of the indoor bench apperatus (P-203)

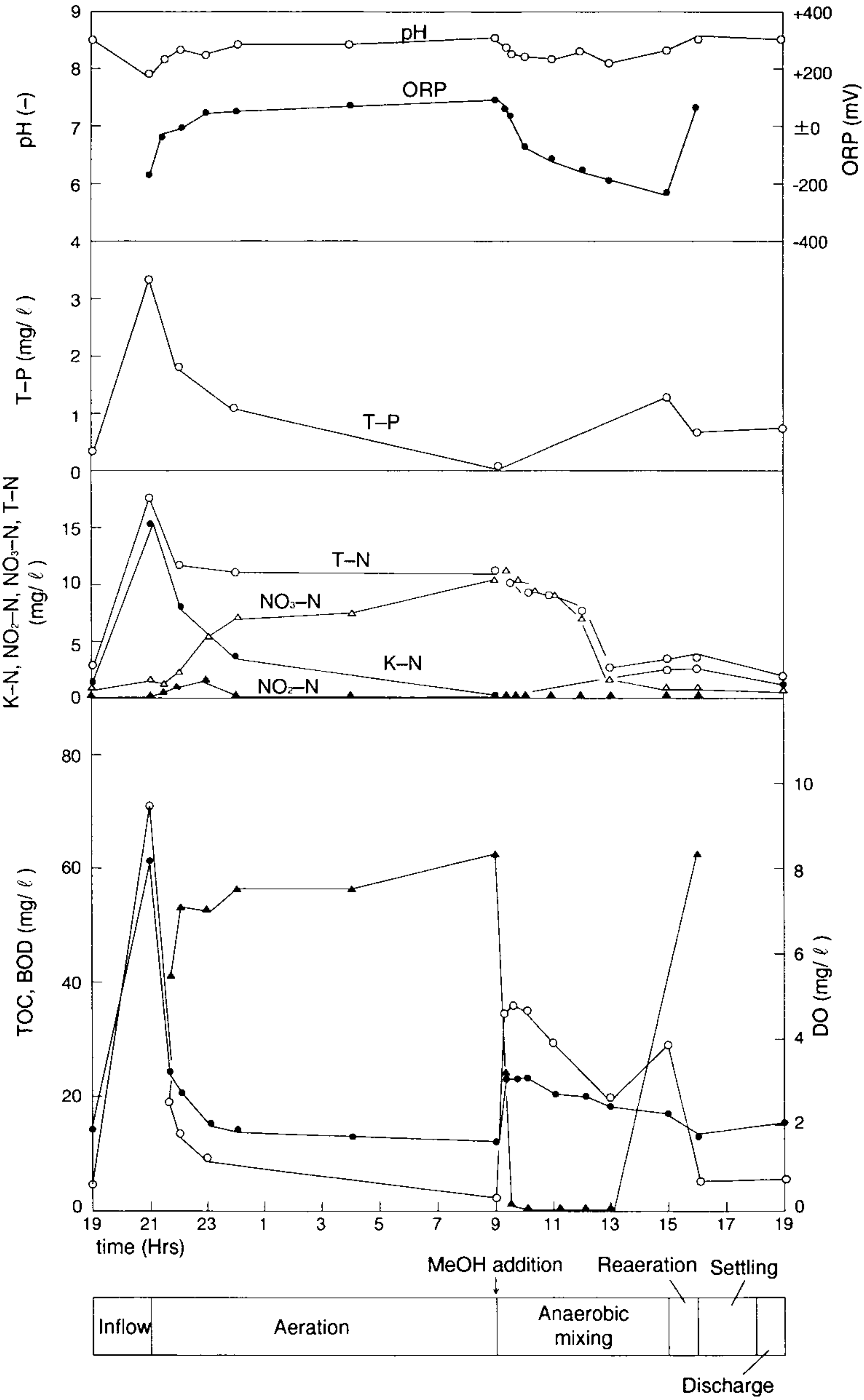


Fig 8-9 Hourly changes of the indoor bench apperatus (P-204)

8-4 Conclusion

Using actual wastewater from a soy sauce manufacturing plant, four cases were studied - non-controlled aeration, controlled aeration, controlled aeration with an anaerobic mixing stage and controlled aeration method with methanol addition in the anaerobic mixing stage - and knowledge on BOD, nitrogen and phosphorus removal was obtained.
The following are the results.

(1) The average untreated water quality for the experiment was 650 mg/ ℓ of BOD, 64 mg/ ℓ of nitrogen and 7.8 mg/ ℓ of phosphorus and nitrogen and phosphorus were excessive; BOD : N : P = 100 : 9.8 : 1.2.
The experimental loading was; BOD space loading of 0.50 - 0.14 kg/m^3 · d (average 0.29 kg/m^3 · d) and nitrogen loading of 0.04 - 0.02 kg/m^3 · d.(average 0.03 kg/m^3 · d)

(2) Removal efficiencies of organic substances - TOC, COD and BOD - were high regardless of the treatment method.
Although BOD in the untreated water fluctuated greatly from 300 to 1000 mg/ ℓ , treatment performance was stable; BOD in the treated water was about 10 mg/ ℓ , and the removal efficiency was 98 % or more.
The treatment performance for both TOC and COD were stable, 30 mg/ ℓ or less, but the removal efficiency was a little lower than that of BOD, 90 %.
SS carry over into the treated water was caused by sludge flotation because of denitrification at settling and the frequency was higher when NO_3-N concentration in the treated water was high; P-201 > P-202, P-203 > P-204.

(3) The nitrification ratio of organic nitrogen in the influent was 95 % or more in all experiments although there was a big difference in the length of aeration, from 12 to 20 hours according to the treatment time schedule.
The nitrogen removal ratio was differenct according to the treatment method, 58.7 % in non-controlled aeration, 73.9 % in controlled aeration, 81.3 % in controlled aeration & anaerobic mixing and 94.4 % in controlled aeration & anaerobic mixing with methanol addition, and the treatment performance of controlled aeration & anaerobic mixing with methanol addition was stable, 1 mg ℓ of NO_3-N or less and 5 mg/ ℓ of T-N in the treated water.

(4) There was no difference according to the treatment method in the rate of nitrification calclulated from the decrease in K-N and from the increase in NOx-N, 1.45 - 1.88 mg-N/g-MLSS · Hr.
The denitrification rate increased 6 times on hydrogen donor addition; 0.40 mg-N/g-MLSS · Hr with no addition of hydrogen donor and 2.39 mg-N/g-MLSS · Hr with addition. In the controlled aeration experiment, the denitrification rate on inflow of untreated water was 2.56 - 2.89 mg-N/g-MLSS · Hr. Consequently the process of untreated water feeding as a hydrogen donor should be studied.

(5) Phosphorus removal was not clear in the experiment because there were various factors affecting phosphorus removal, not only the treatment time schedule but BOD loading, and sludge age as well. However, there was the tendency, P-201 < P-202, P-203 < P-204, and the removal efficiencies of the controlled aeration experiments (P-202, P-203 and P-204) were higher than that of the non-controlled aeration experiments (P-201); 86 % in P-204.

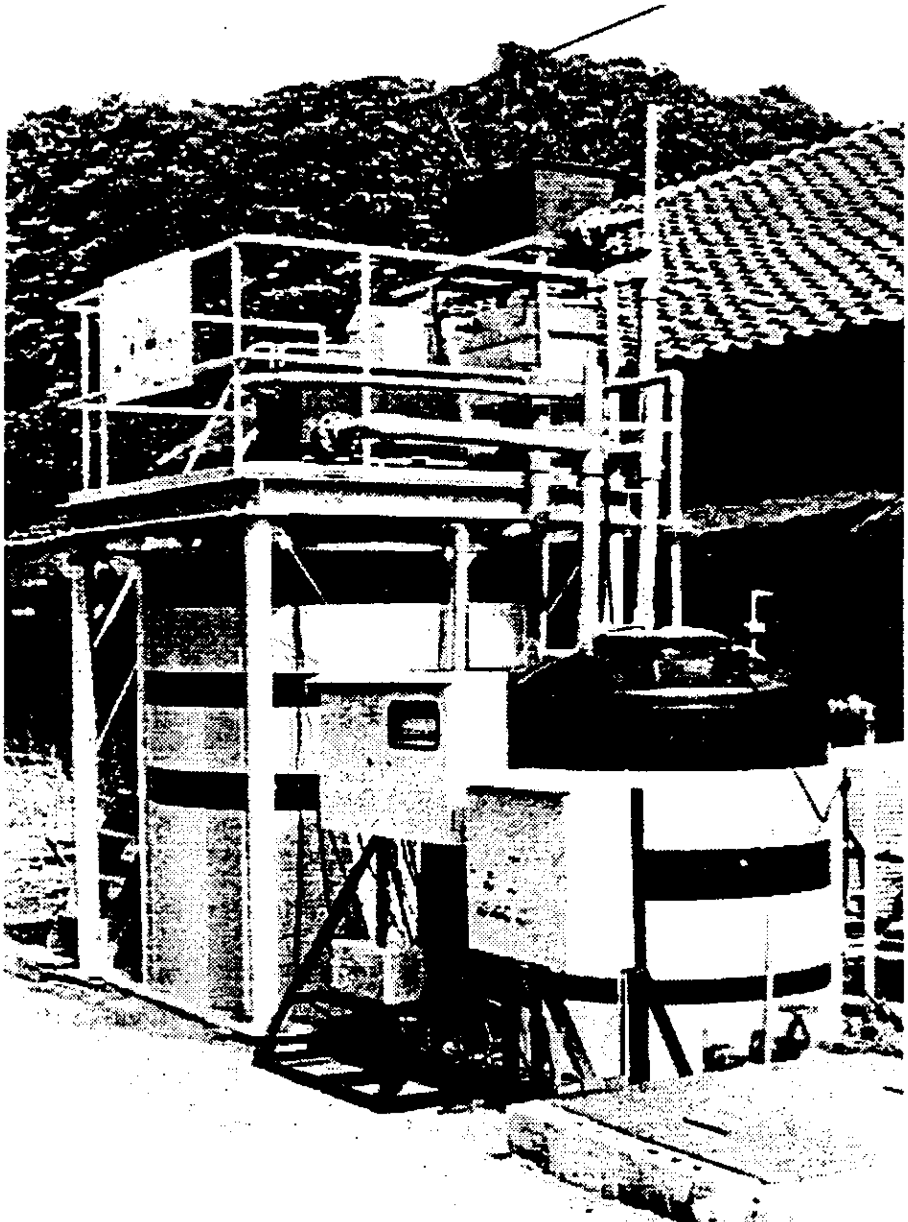


Photo 9-1 The pilot plant (aeration tank: 4m^3, untreated water equalization tank: 2m^3)

9. On site pilot plant experiment

The controlled aeration activated sludge method was developed by the Fermentation Research Institute of the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry for aiming at an easy, effective, and advanced treatment for small to medium quantities of organic wastewater.

In principle, it is a batch type activated sludge method, in which wastewater is treated in one aeration tank which has regulating and settling functions, and the following aeration characteristics; aeration starts after finishing untreated water inflow; no aeration occurs on inflow so that bulking of sludge, the biggest problem in the activated sludge method, can be completely controlled by forming a clear substrate concentration gradient in the aeration tank allowing stable treatment.

In addition, utilizing aerobic and anaerobic conditions, formed through controlled aeration, nitrogen and phosphorus concentrations in the wastewater can be reduced and thus it is attractive as a low-cost nitrogen and phosphorus removal method.

9-1 Experiment

In a pilot plant with a treatment capacity of 2 m^3/d, a continous operation experiment was conducted using soy sauce manufacturing plant wastewater.

With the aim of establishing on advanced treatment process utilizing the controlled aeration activated sludge method, basic treatment conditions were confirmed and the operatability was studied.

(1) Experiment site

A pilot plant was established in the soy sauce manufacturing plant area of 'Kagisa Soy Sauce Co., Ltd.' (1700, Oh-hori, Futsu City, Chiba Prefecture), and based on the result of the indoor bench-scale plant, the continous operation experiment was conducted for confirmation of treatment conditions and study on treatment stability.

(2) Experimental equipment

Photo 9-1 shows the pilot plant.

The treatment capacity was 2 m^3/d.

Operation could be controlled automatically by timer so that the continous operation experiment was easily conducted.

Fig. 9-1 shows the flow diagram of the pilot plant.

Wastewater was pumped from the existing untreated water adjusting tank to the untreated water adjusting tank of the pilot plant, and after equalization of the untreated water characteristics by storage in the tank, it was sent to the aeration tank. Since many SS compounds were in the influent, a screen was installed between the existing adjusting tank and the adjusting tank of the pilot plant to decrease and control SRT. The treatment capacity of the screen will be described in detail later.

The untreated water flowed into the aeration tank over one hour, but when necessary the flow was adjusted by the flow equalization tank.

Air was injected in to the aeration tank through a diffuser and anaerobic mixing was conducted with a mixing pump. There were two blowers with a capacity of 0.25 Nm^3/min each. For ordinary BOD oxidation, one blower was used and for the operation including nitrification, both blowers were used.

To increase alkalinity in the nitrification stage, a pump for feeding caustic soda was connected to a pH meter in the aeration tank, but there was no time that alkalinity was lacking during nitrification so it was not used during the experiment.

For addition of isopropyl alcohol as a hydrogen donor in the denitrification stage, a pump for feeding isopropyl alcohol was installed.

The treated water was drawn by pump and the quantity of the treated water was adjusted with a level meter.

Table 9-1 shows the main equipment of the pilot plant.

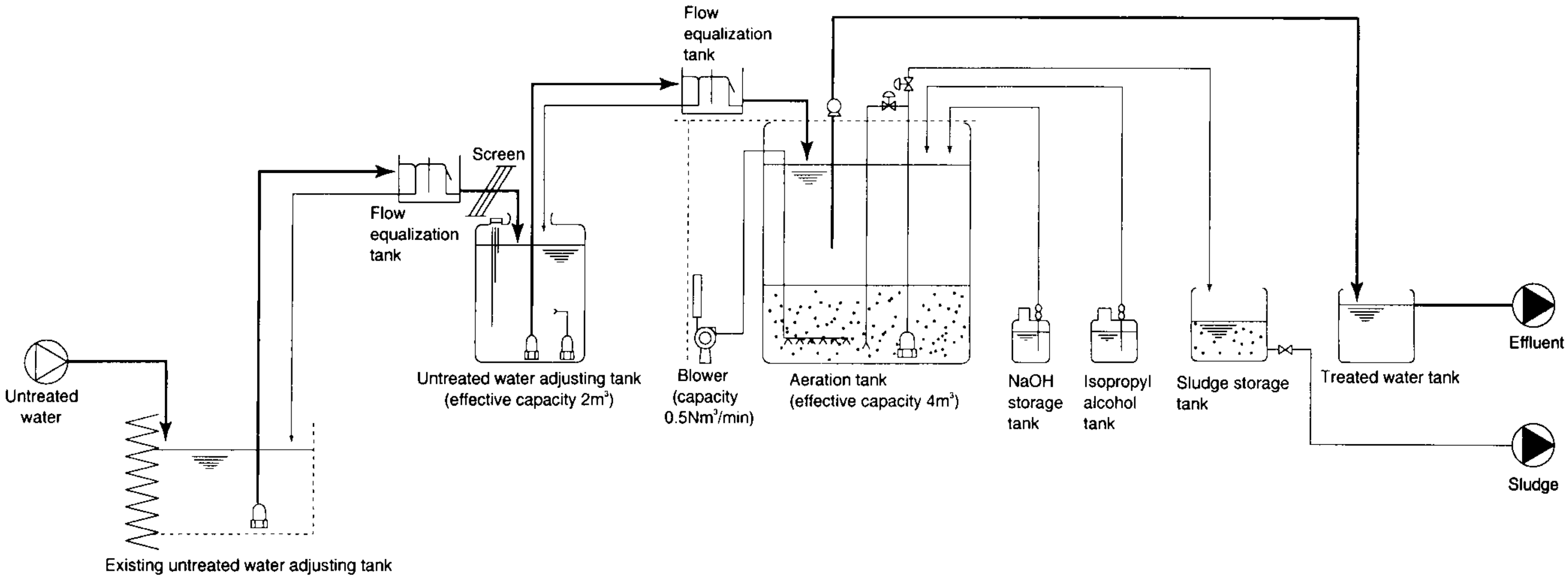


Fig 9-1 Flow diagram of the pilot plant (treatment capacity: $2m^3/d$)

Table 9-1 Main equipment of the pilot plant

Equipment		Type	Note
Tanks	Untreated water tank	Tank $2\ m^3$	
	Aeration tank	Tank $5\ m^3$	Effective volume $4\ m^3$
Machines	Untreated water transfer pump	Submerged pump 0.4 kw	
	Untreated water supply pump	Submerged pump 0.25 kw	$0.25\ Nm^3/min$ × 2units
	Aeration water pump	BSS-25 0.4 kw	
	Treated water pump	Self contained vertical pump 0.4 kw	
	Mixing pump	Submerged pump 0.25 kw	
Instrumentation	pH meter	Dipping glass electrode	To be connected to the caustic soda feeding pump
	ORP meter	Dipping platinum electrode	
	DO meter	Dipping galvanic electrode	
	Recorder	Chopper bar type recorder	

(3) Experimental conditions

- Wastewater for the experiment -

As mentioned in 3-1(2), the BOD concentration of the soy sauce manufacturing plant wastewater was relatively high and nitrogen and phosphorus ratios were slightly excessive compared to the normal nutrition balance. The main wastewater was washing wastewater from various processes and SS concentration in the influent was high.

Table 9-2 shows the untreated water quality of the experiment.

Table 9-2 Results of the sampled wastewater quality analysis

Items	pH	SS	TOC	COD	BOD	K-N	T-P	Cl^-	Color
	(-)	(mg/ ℓ)	(mg/ ℓ)	(mg/ ℓ)	(mg/ ℓ)	(mg/ ℓ)	(mg/ ℓ)	(mg/ ℓ)	(degrees)
n	40	40	40	40	40	19	19	37	37
$\bar{x}$	6.85	450	232	290	730	74.5	7.51	200	155
σ n-1	0.18	318	71	122	258	27.9	3.07	56	29

Phosphorus fluctuation was small compared to the fluctuation in BOD and nitrogen concentraions and the average quality of the sampled wastewater was BOD : N : P = 100 : 10.3 : 1.0.

The low phosphorus ratio in the experiment was probably due to the high ratio of BOD compound in SS.

- Activated sludge -

Excess sludge from a sewage treatment plant was used for seeding. The sludge volume was $0.5\ m^3$ and MLSS was kept relatively high, 4000 - 6000 mg/ ℓ , in the aeration tank during acclimation. Since the experiment was performed in low winter temperatures, we aimed to shorten the acclimation period of the wastewater substrate by decreasing the sludge loading.

- Treatment time schedule -

The experiment was conducted according to a treatment time schedule with the aim of BOD removal and acclimation in winter, for food industry wastewater utilizing the controlled aeration activated sludge method. Fig. 9-2 shows the treatment time schedule.

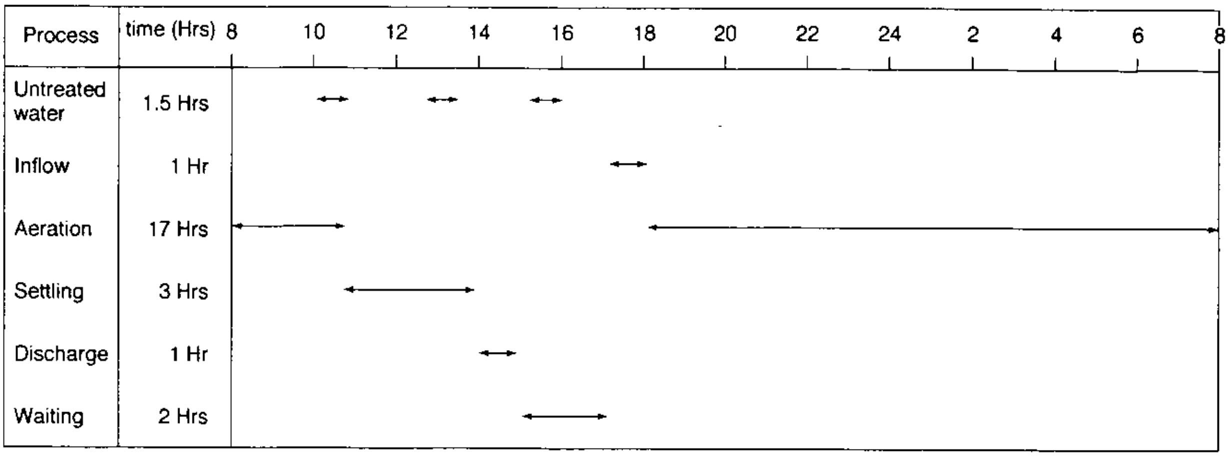


Fig 9-2 Treatment time schedule

The sampled wastewater was sent from the adjusting tank of the existing treatment plant to the untreated water adjusting tank three times in a day for equalizing the wastewater quality.

Once a day, 2 m^3 of the untreated water was sent from the adjusting tank to the aeration tank over a period of one hour, and it was then aerated for 17 hours.

After aeration, it was settle allowerd to for 3 hours and the supernatant was then discharged.

9-2 Characteristics of the sample wastewater

The wastewater contained various size waste, suspended solids, sand, etc. Removing them in advance decreased the load and eliminated equipment trouble such that the wastewater could be treated smoothly. In principle, therefore, at the inlet of the wastewater treatment facility, equipment for removal of solids and sedimentation should be installed.

In the experiment, the characteristics of the sampled wastewater were studied to select an appropriate screen.

(1) Removal of influent SS and the characteristics of the wastewater

As in Table 9-2, the ratios between TOC (dissolved organic pollutants), and total BOD and total COD (total organic pollutants), were BOD/TOC = 3.13 and COD/TOC = 1.25.

Fig. 9-3 shows the relationship between TOC and dissolved BOD and COD.

The dissolved compounds were d-BOD/TOC = 1.87 and d-COD/TOC = 0.82, and the effect of pollutants by SS coumpounds is 40 % in BOD and 35 % in COD.

Fig. 9-4 shows the relationship between SS concentration of the sampled wastewater and BOC in SS. The result clarifies 50 % of SS inflows as BOD loading to the treatment facility.

When using the batch type controlled aeration activated sludge method, inflow of SS compounds as BOD loading leads to an increase in sludge volume due to sludge generation, and a sludge volume increase due to SS compounds and a lowering of SRT by more frequent sludge withdrawal. It is not only confined to the problem of an increase in excess sludge volume, but causes other problems which affect the basic treatment characteristics.

(2) Research on screen performance

The removal efficiency of SS compounds from the wastewater was studied according to the pore size of the screen. Table 9-3 shows the result ot the sampled wastewater quality analysis.

Table 9-3 Result of water quality analysis

Items	pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	T-P (mg/ℓ)	Cl^- (mg/ℓ)	Color (degrees)
16th Feb	6.63	808	(276)	373 (125)	950 (480)	93.1 (41.4)	9.56 (3.55)	202	(5)

Figures in ( ) are analysis values of dissolved compounds.

SS of the sampled wastewater was high, 808 mg/ ℓ , and BOD in SS was 50 % and COD in SS 70 %, which meant there was a big SS influence on the pollution load.

Fig. 9-5 shows the relationship between the pore size and SS removal efficiency.

The SS removal efficiency was 20 - 25 % at a pore size of 0.25 m/m or more, but 35 - 60 % at a pore size of 0.125 m/m or less. Based on the SS removal efficiency, the removal effect for BOD, COD, nitrogen and phosphorus was studied, as in Fig. 9-6.

The removal efficiency of BOD compounds was worse than that of SS and in the case of an SS removal of 60 %, BOD removal was only 17 %, which implied BOD compounds in SS were very fine particles.

COD removal depends more on SS removal than BOD and a maximum removal efficiency of 34 % can be expected.

Based on the study on nitrogen and phosphorus compounds, it was considered that their characteristics were almost the same, although the ratio of phosphorus in SS was a little higher; the dissolved compounds ratio was 37 % for phosphorus , and 44 % for nitrogen. The removal efficiency according to the pore size of the screen was almost the same, a maximum 30 % for nitrogen and phosphorus .

There were various methods to remove SS from the wastewater, such as removal by screening, gravity settling, flotation due to density difference, filtration, centrifugal separation, etc. We studied screens, which were easily installed and easily maintained.

Screens were installed for effective operation of the treatment facility by removing relatively coarse suspended solids and wastes in the wastewater and for preventing damage and clogging of machines, for example, pumps, valves, pipes, etc. Kinds of screen for wastewater treatment were bar screen, net screen, drum screen, comminutor, vibrating sieve, etc.

A conveyor type screen manufactured by I company was seleted for the experiment to study the removal efficiency.

Fig. 9-7 shows the structure of the conveyor type screen.

After untreated water was sent to the tank by pump, SS compounds in the wastewater were precoated to the filter of the conveyor type screen and by precoating, more SS compounds were caught on the filter. Through blockage of the filter the water level rose and a float switch was activated. The filter cloth then moved so that a new filter area appeared. SS caught on the filter was removed with aninstalled hammering device cleaning the filter.

This procedure was repeated automatically by the conveyor type screen.

Fig. 9-8 shows the non-excess probability of SS concentration of the sampled wastewater before and after installation of the screen.

Before installation, the mean value of SS compounds in the wastewater was 760 mg/ ℓ but after installation, the SS removal efficiency became high; the mean value was 230 mg/ ℓ and the 90 % probability was 330 mg/ ℓ .

Fig. 9-9 shows the non-excess probability of BOD compounds in the sample wastewater before and after installation of the screen.

Before installation, the mean value of BOD compounds in the wastewater was 920 mg/ ℓ but after installation, the mean value became 480 mg/ ℓ and the 90 % probability was very high, 650 mg/ ℓ .
It was not so meaningful to compare the SS removal efficiency of screens because the properties of the wastewater before and after the installation of the screen were not the same. However, the result confirmed that the SS removal efficienty of the conveyor type screen selected for the experiment was suitable for SS removal of food industry wastewater with a similar wastewater property to that of the experiment.

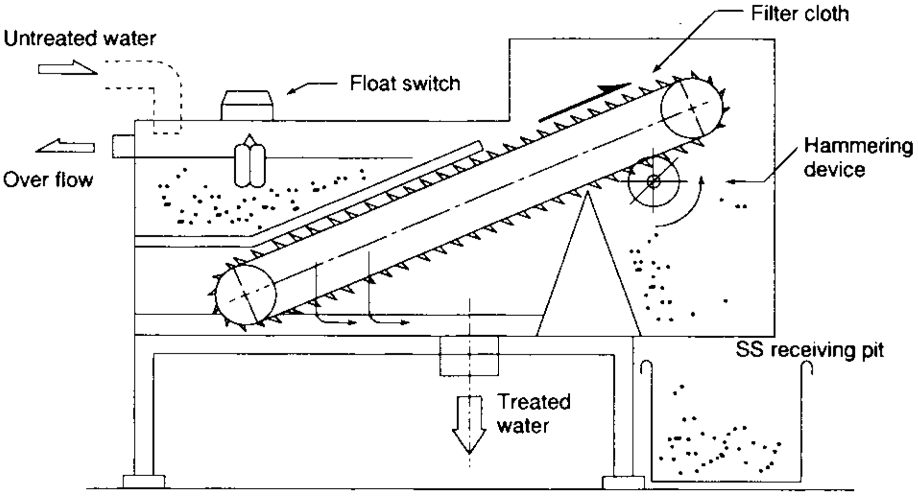
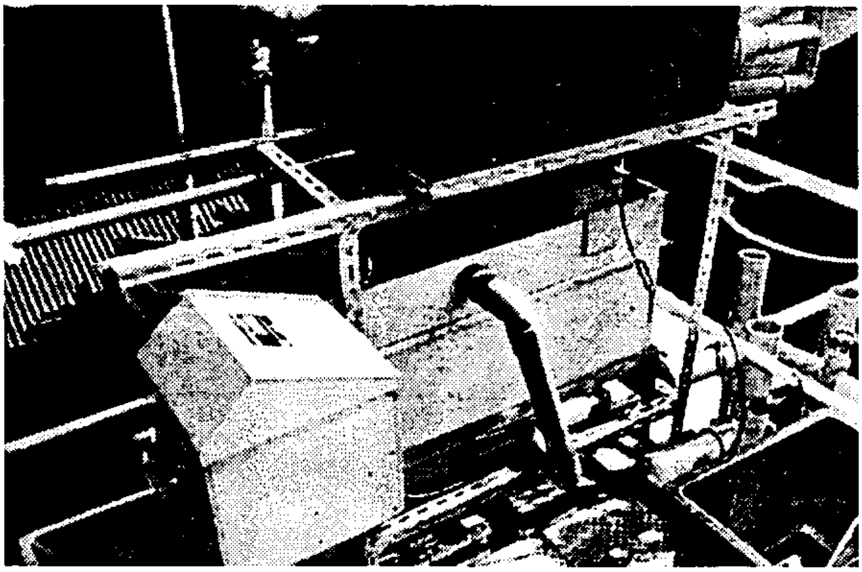


Fig 9-7 Structure of the conveyor type screen



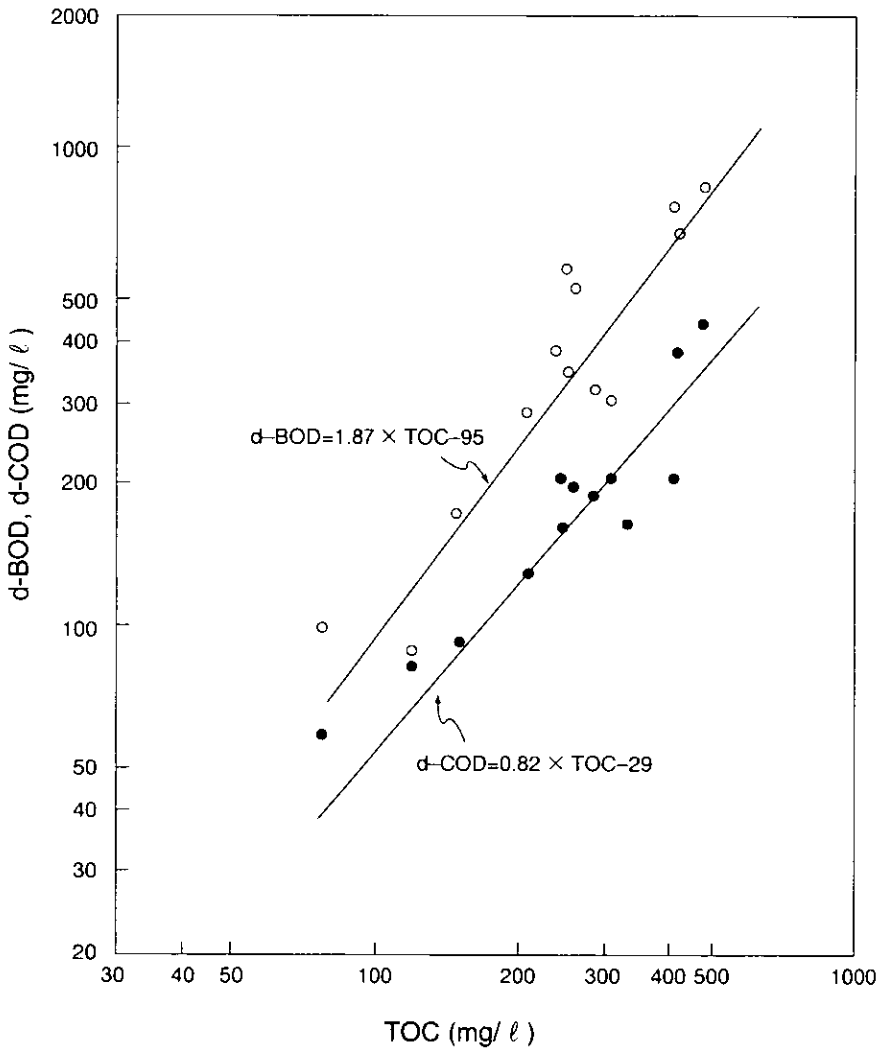


Fig 9-3 Correlation between TOC and d-BOD, d-COD of Kagisa soy sauce wastewater

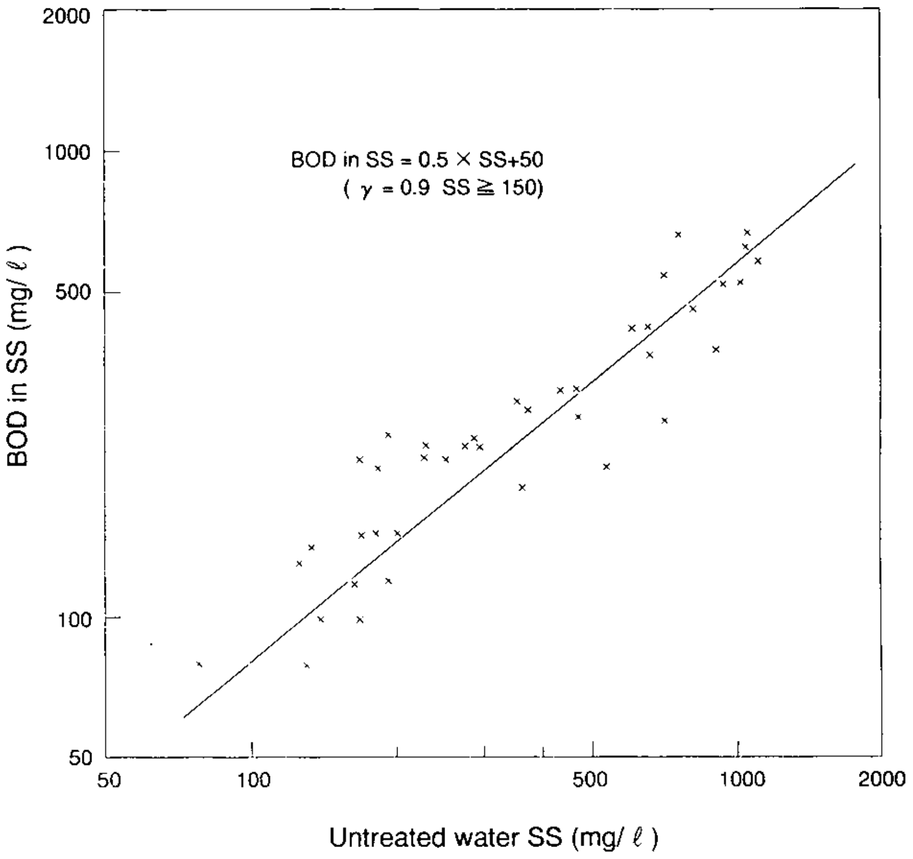


Fig 9-4 Relationship between SS in the untreated water and, BOD in SS

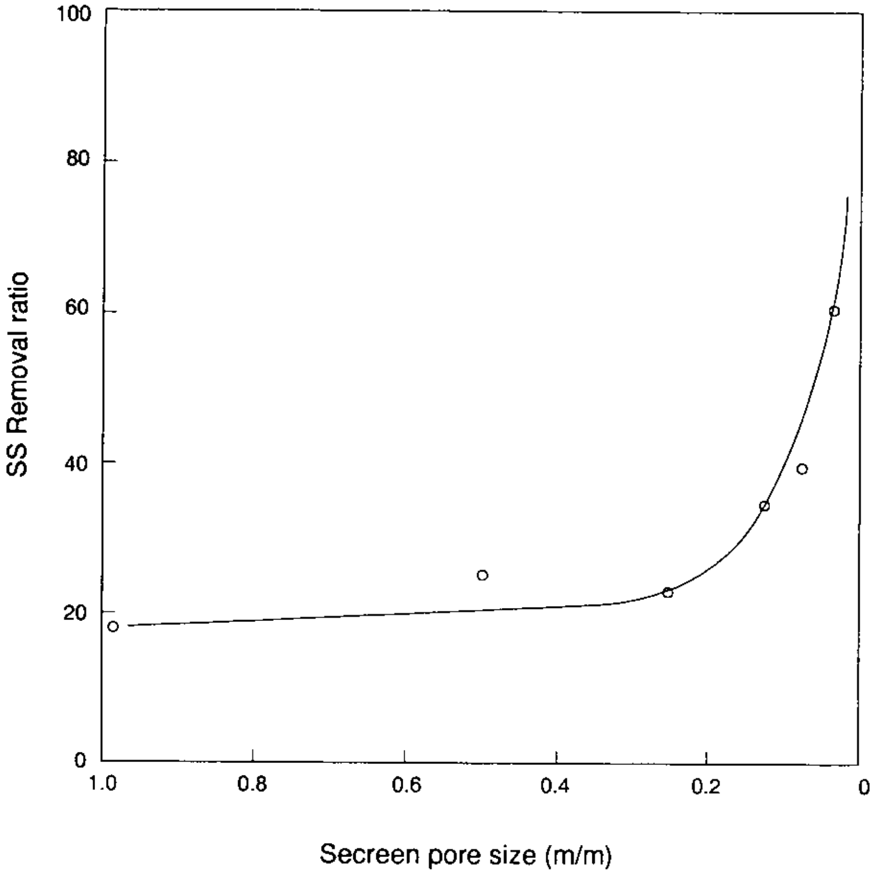


Fig 9-5 Relationship between the screen pore size and SS removal ratio

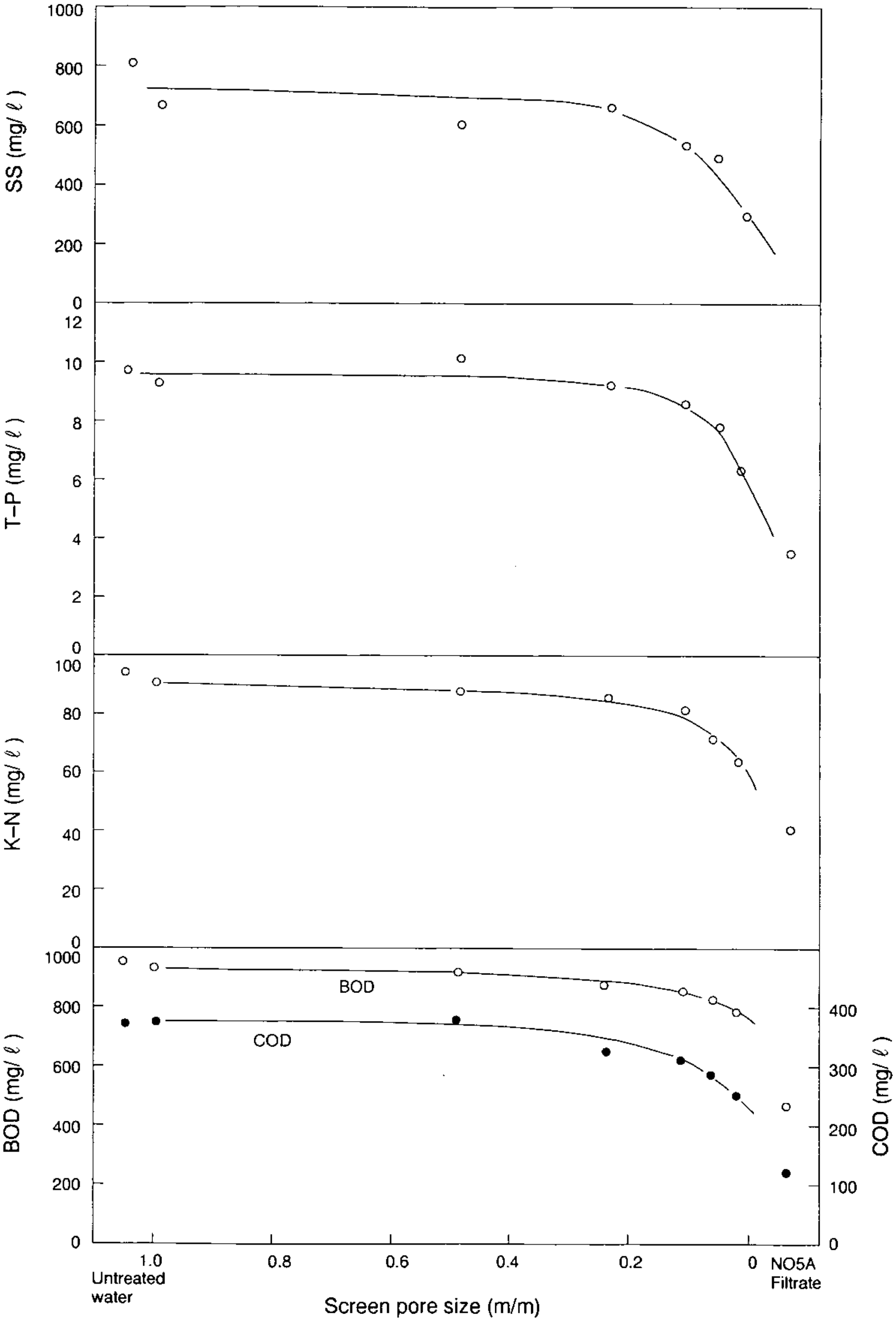


Fig 9-6 Water quality after screening

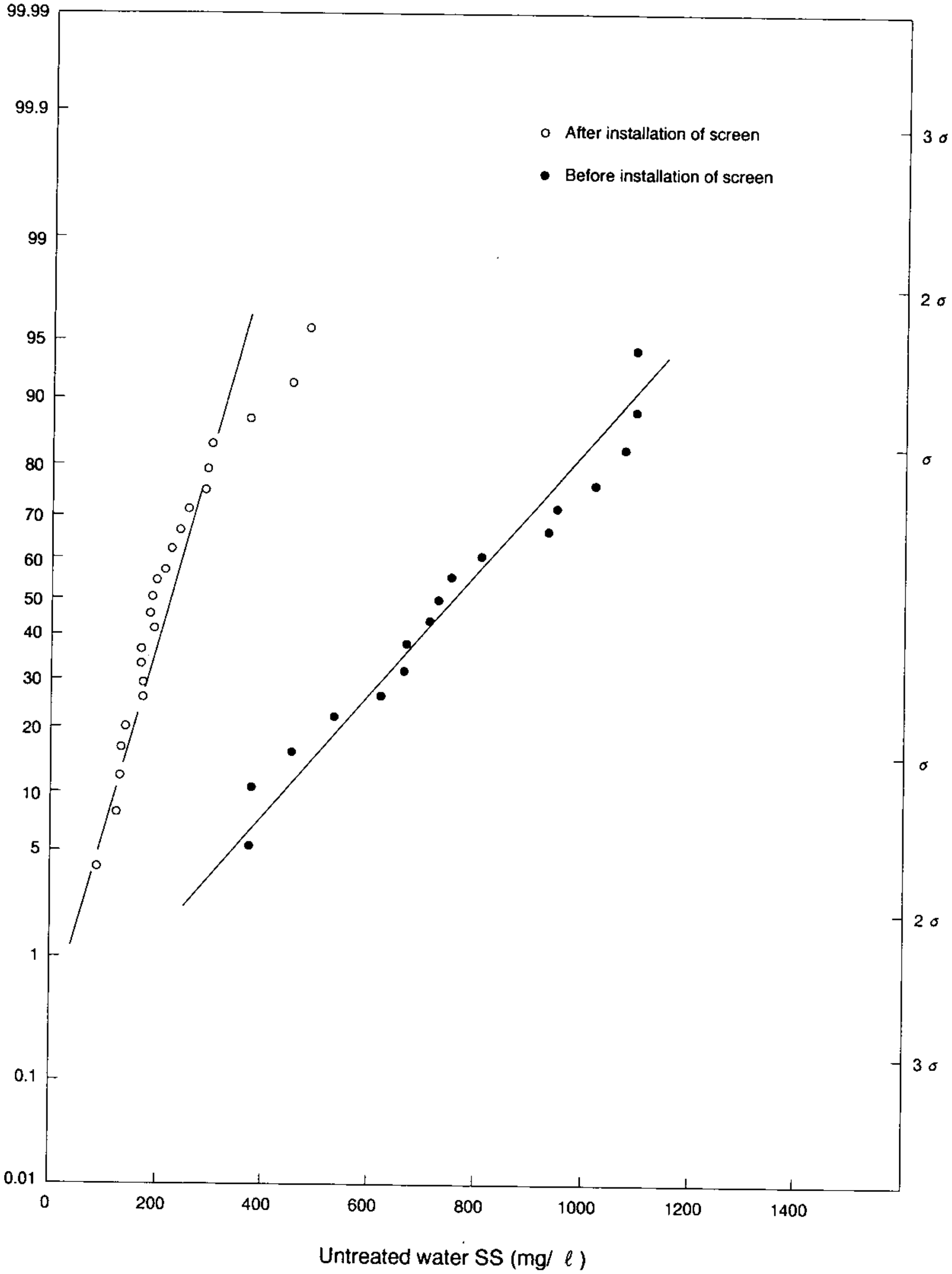


Fig 9-8 Treatment effect of screen (SS)

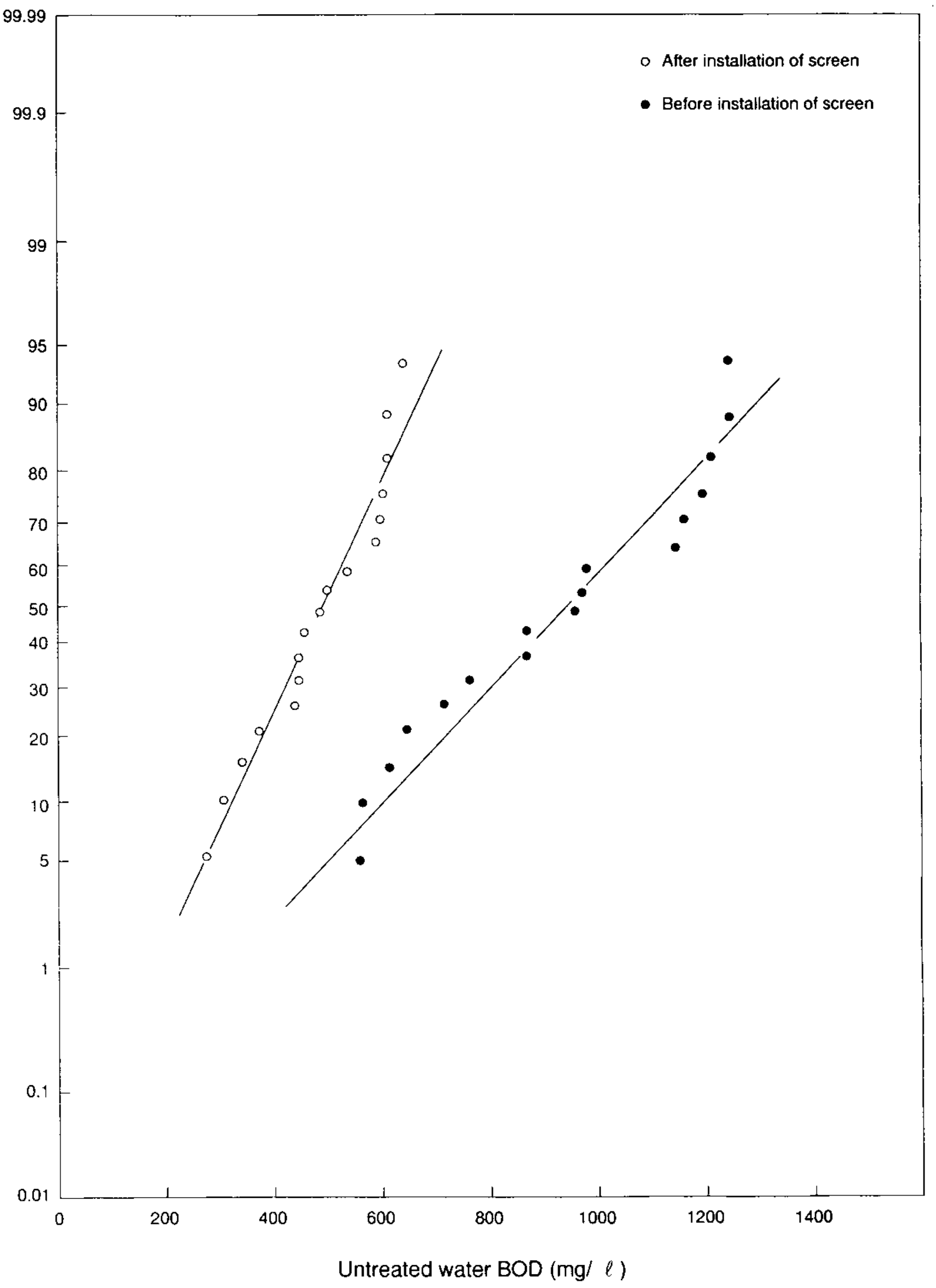


Fig 9-9 Treatment effect of screen (BOD)

9-3 Acclimation operation and treatment efficiency

Knowledge on sludge acclimation and wastewater treatment at low water temperature utilizing a batch type controlled aeration activated sludge method was obtained.

(1) Conditions for acclimation

In an ordinary acclimation operation, since MLSS concentraion in the aeration tank is low and the substrate concentration of the wastewater in the tank is high, aeration is done with no addition of wastewater until the BOD concentration in the supernatant becomes 40 - 50 mg/ ℓ or less. It is necessary to remember that after the sludge is seeded, even if conditions are good, in many cases sludge does not grow so rapidly and the water condition remains unchanged is for several days. The ideal acclimation of the controlled aeration activated sludge method is that when BOD of the supernatant reaches 40 - 50 mg/ ℓ or less, new wastewater is supplied to the aeration tank to replace the portion drawn as treated water, and it is aerated again. This procedure is repeated and when MLSS concentration in the aeration tank reaches 1,000 mg/ ℓ , continous operation can begin.

In the experiment, to aim at a short sludge acclimation period at low water temperature from the beginning of the operation, regular procedure was conducted; a large volume of seeding sludge was supplied and half the wastewater replaced. The treatment time schedule is shown in Fig. 9-2, water temperature 12 - 15℃.

(2) Acclimation period

It is totally understandable that the acclimation period differs according to the treatment system; BOD removal which requires only BOD oxidation, nitrogen removal which requires nitrification and denitrification processes, and phosphorus removal which utilizes aerobic and anaerobic conditions.

In the experiment, for BOD removal about two weeks were necessary for acclimation from the view of treated water quality and generated sludge volume, and for nitrogen removal about one month was necessary for stabilization of nitrification.

The period for phosphorus removal could not be clarified by the experiment because the phosphorus ratio was small. However, after about one month, phosphorus release from the sludge was observed and consequently, it seemed that biological phosphorus removal was possible.

9-4 Efficiency of the controlled aeration activated sludge method

The treatment effect of the controlled aeration activated sludge method in the conventional treatment time schedule was confirmed and behaviors of nitrogen and phosphorus were studied.

(1) Treatment conditions and efficiency

Fig. 9-10 shows the daily changes in the operation load condition of the experiment. BOD loading was calculated as a simple loading with no consideration to aeration. After Feb. 27th, when the sludge acclimation had completed, the sludge withdraw volume was adjusted to 3 - 4000mg/ ℓ of MLSS.

There was a big fluctuation in the quality of the influent, and the BOD space loading was 0.17 - 0.53 kg/m^3 · d (average 0.31 kg/m^3 · d). The sludge loading was 0.04 - 0.17 kg/kg · d (average 0.09 kg/kg · d).

SVI, an index of the settling characteristics of the sludge, was slightly high, 200 - 300. This was probably due to filamentous bacteria in the seeding sludge and the absence of the denitrification stage for nitrate.

Figs. 9-11 and 9-12 show the daily changes in the efficiency of the experiment. Since the main wastewater from the soy sauce manufacturing plant was washing wastewater, the pH was usually neutral, about 7.

The pH of the treated water was slightly high, about 8.

As described in 9-2 (2), after March 1st when a screen was installed, SS compounds in the wastewater decreased by 30 %, to an average of 230 mg/ ℓ .

SS in the treated water was relatively stable and after March 1st it stablized to at 20 mg/ ℓ or less.

The average color degree was 155 for the untreated water and about 50 for the treated water with a removal efficiency of about 70 %, which was almost the same as that of the indoor bench-scale apperatus.

Chlorine ion concentration was about 200 mg/ ℓ in the experiment and there was no effect on the activated sludge. However, attention should be paid to corrosion of the treatment facility.

As for organic substances, the TOC and COD compound removal efficiencies of were worse, 91 % and 90 % respectively, than that of BOD, 98 %, due to TOC and COD non-biodegradable substances included in the soy sauce manufacturing wastewater. However, this was not a big problem because the treated water quality was very stable, 21 mg/ ℓ of TOC, 29 mg/ ℓ of COD and 12 mg/ ℓ of BOD. The result was very similar to that of the indoor bench-scale apperatus.

(2) Removal of nitrogen and phosphorus

The nitrogen and phosphorus removal efficiencies from the experiment are shown in Fig. 9-13.

Kjeldal nitrogen (NH_4-N + organic-N) in the wastewater fluctuated from 33 to 131 mg/ ℓ and the average was 75 mg/ ℓ , the wastewater composition was BOD/N = 10. After Feb. 27th, the water quality was good at 2 - 6 mg/ ℓ , but due to excessive nitrogen in the wastewater, nitrites and nitrates were generated.

Nitrite began to increase from Feb. 19th and reached a maximum, 9.6 mg/ ℓ on Feb. 28th and then decreased becoming 0.1 mg/ ℓ after March 9th.

On the other hand, nitrate in the treated water began to increase a little later than nitrite and reached 6 - 9 mg/ ℓ after March 9th.

The result was that the acclimation for nitrification had almost completed by Feb. 27th and after March 9th nitrite type nitrification shifted to nitrate type nitrification. After the completion of nitrification, average total nitrogen was 13.5 mg/ ℓ and the nitrogen removal efficiency was about 80 %, which was much higher than that of the conventional activated sludge method, 50 - 60 %.

This was due to denitrification which occured on replacement of half of the wastewater, and the result was very similar to that of the indoor bench-scale apperatus.

Although the nitrification ratio in the experiment was 93 %, the pH of the treated water didn't drop even during nitrate type nitrification so that addition of alkaline was not necessary.

Due to the wastewater composition of BOD/P = 100, the phosphorus removal efficiency was very good, 97 %, and the phosphorus concentration in the treated water was 1 mg/ ℓ or less except for 1.2 mg/ ℓ on Feb. 29th.

The ratio of MLVSS in the pilot plant was about 80 %, which was a little lower than that of the indoor bench-scale apperatus, 85 - 90 %.

The phosphorus ratio of the sludge was 1.1 % on March 6th.

Table 9-4 shows the results of treatment after acclimation.

Table 9-4 Treatment results after acclimation

	pH (-)	SS (mg/ ℓ)	TOC (mg/ ℓ)	COD (mg/ ℓ)	BOD (mg/ ℓ)	K-N (mg/ ℓ)	NO_2-N (mg/ ℓ)	NO_3-N (mg/ ℓ)	T-N (mg/ ℓ)	T-P (mg/ ℓ)	Cl^- (mg/ ℓ)	Color (degrees)
n	25	22	25	25	25	11	15	15	11	12	23	22
$\bar{x}$	7.72	13	22	32	12	4.7	0.12	7.3	13.5	0.26	202	51
σ n-1	0.17	2.9	4.6	9.5	6.5	1.6	0.18	1.5	2.6	0.34	39	11
Removal efficiency(%)	-	97	91	89	98	94	-	-	82	97	-	67

(3) Study on hourly changes in the treatment characteristics

A study was conducted on the hourly changes in the pilot plant utilizing the controlled aeration activated sludge method after acclimation.

The research was performed from March 6th to 7th.

Table 9-5 shows the influent quality on the research day.

Table 9-5 Water quality analysis results of the influent

pH (-)	SS (mg/ℓ)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	K-N (mg/ℓ)	T-P (mg/ℓ)	Cl^- (mg/ℓ)	Color (degrees)
6.85	126	164	114 (77.5)	370 (240)	42.8 (30.7)	4.70 (1.99)	138	13.1

The influent quality on the research day was 370 mg/ℓ of BOD, which was about half the average pollution load of the experiment, 730 mg/ℓ. The nutrition ratio in the wastewater was balanced, BOD : N : P - 100 : 11.6 : 1.3, although the phosphorus concentration was slightly high.

The time schedule on the research days is shown in Table 9-2. /Untreated water inflowed between 17:00 - 18:00 on March 6th and aeration lasted 17 hours from 18:00 on the 6th to 11:00 on the 7th.

Treated water was discharged between 14:00 - 15:00 on March 7th.

The operation condition of the pilot plant on the research day is shown in Table 9-6.

Table 9-6 Operation condition of the pilot plant (March 7th)

Water volume (m^3/d)	Aeration time (Hrs)	Aeration volume (Nm^3/Hr)	Temperature (℃)	Water Temperature (℃)	DO (mg/ℓ)	pH (-)	MLSS (mg/ℓ)	BOD loading	
								(kg/m^3·d)	(kg/kg·d)
1.75	17	12	0.0 ~6.5	14.8 ~15.5	6.0	7.5 ~7.6	4060	0.15	0.04

Table 9-14 shows the hourly changes in pH, TOC, BOD and DO.

Due to the inflow of untreated water, a substrate concentration gradient of about 50 mg/ℓ of TOC and 110 mg/ℓ of BOD formed, and after 6 hours of aeration, TOC and BOD concentrations fell sufficienty reaching equilibrium.

DO started to increase after 3 hours of aeration and reached an equilibrium of 5 - 6 mg/ℓ. /If organic acid in the water is biologically decomposed, pH increases slightly and if nitrate is generated by nitrification, pH decreases. However the change was small.

Fig. 9-15 shows the hourly changes in ORP, nitrogen and phosphorus.

It was confirmed that after 2 hours of aeration, nitrification occured and nitrite and nitrate were generated. The nitrification rate constant was very low, 0.014 kg/kg · d, at a water temperature of 15℃, which signifies that nitrifying bacterial growth was slower than that in the indoor bench-scale apperatus, due to the low water temperature.

There was no big fluctuation in the hourly changes in phosphorus but T-P of the supernatant on inflow of untreated water, 1.5 mg/ℓ, decreased to 0.2 mg/ℓ after 3 hours of aeration via uptake by the sludge.

ORP changed from - 100 m V on untreated water inflow to + 100 m V due to aeration.

In the experiment, the water in the aeration tank of the pilot plant was continously measured with sensors for water temperature, pH, ORP and DO, and all were recorded. A pH sensor and a DO sensor can be connected an alkali feeding pump and an aeration blower, respectively.

Fig. 9-16 shows the record from the research days.

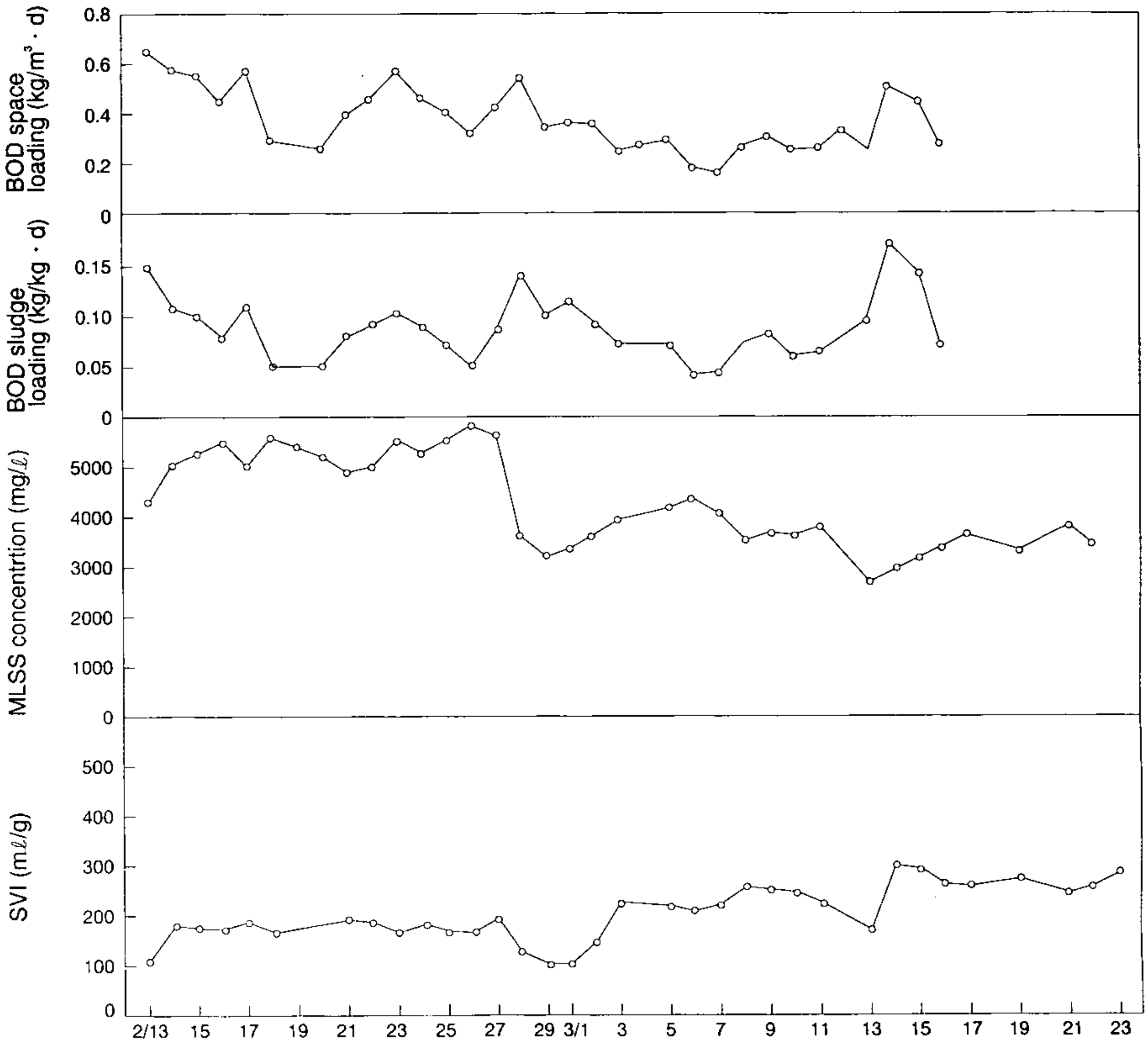


Fig 9-10 Treatment results from the pilot plant (BOD loading, MLSS, SVI)

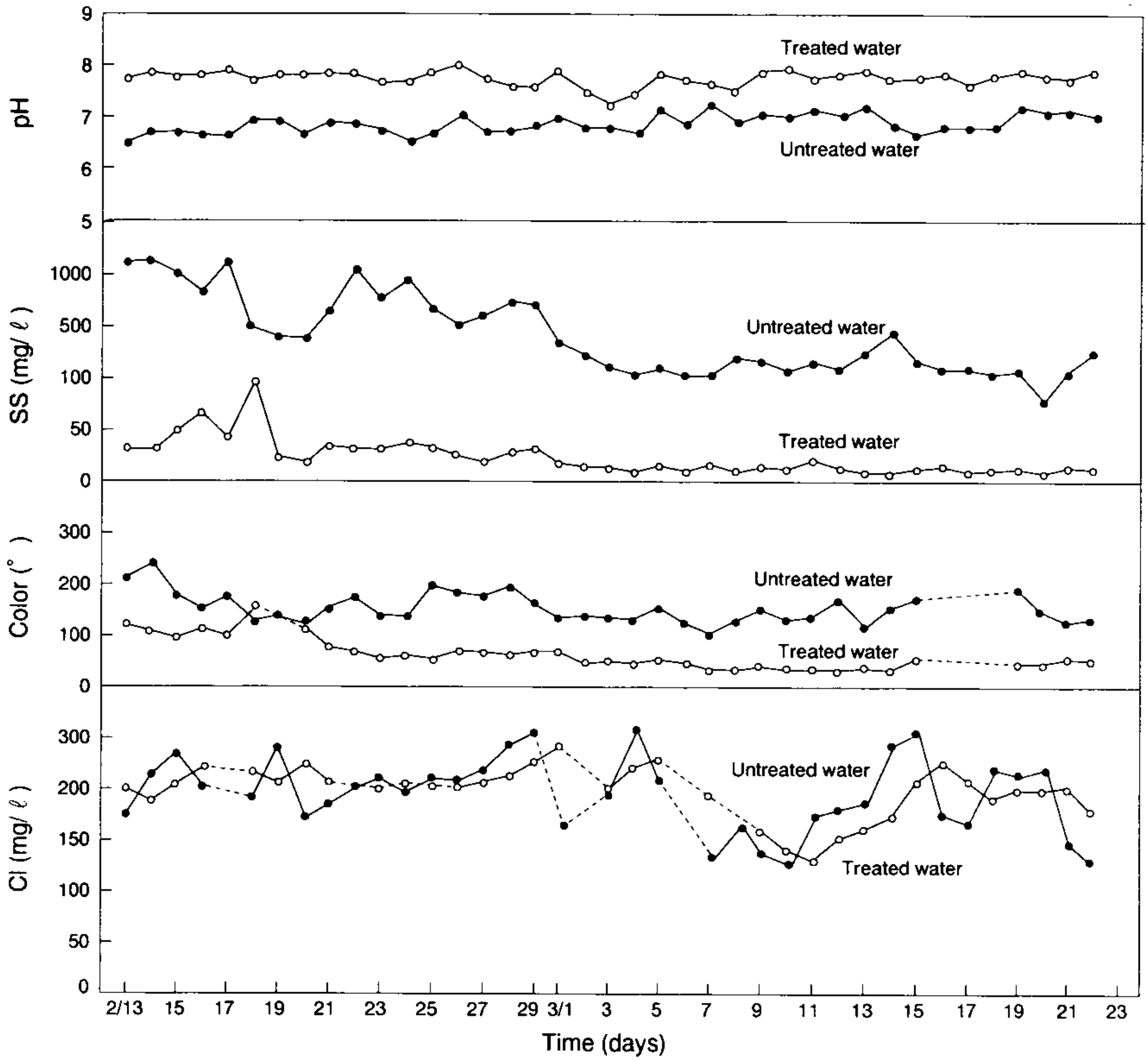


Fig 9-11 Treatment results from the pilot plant (pH, SS, color, Cl)

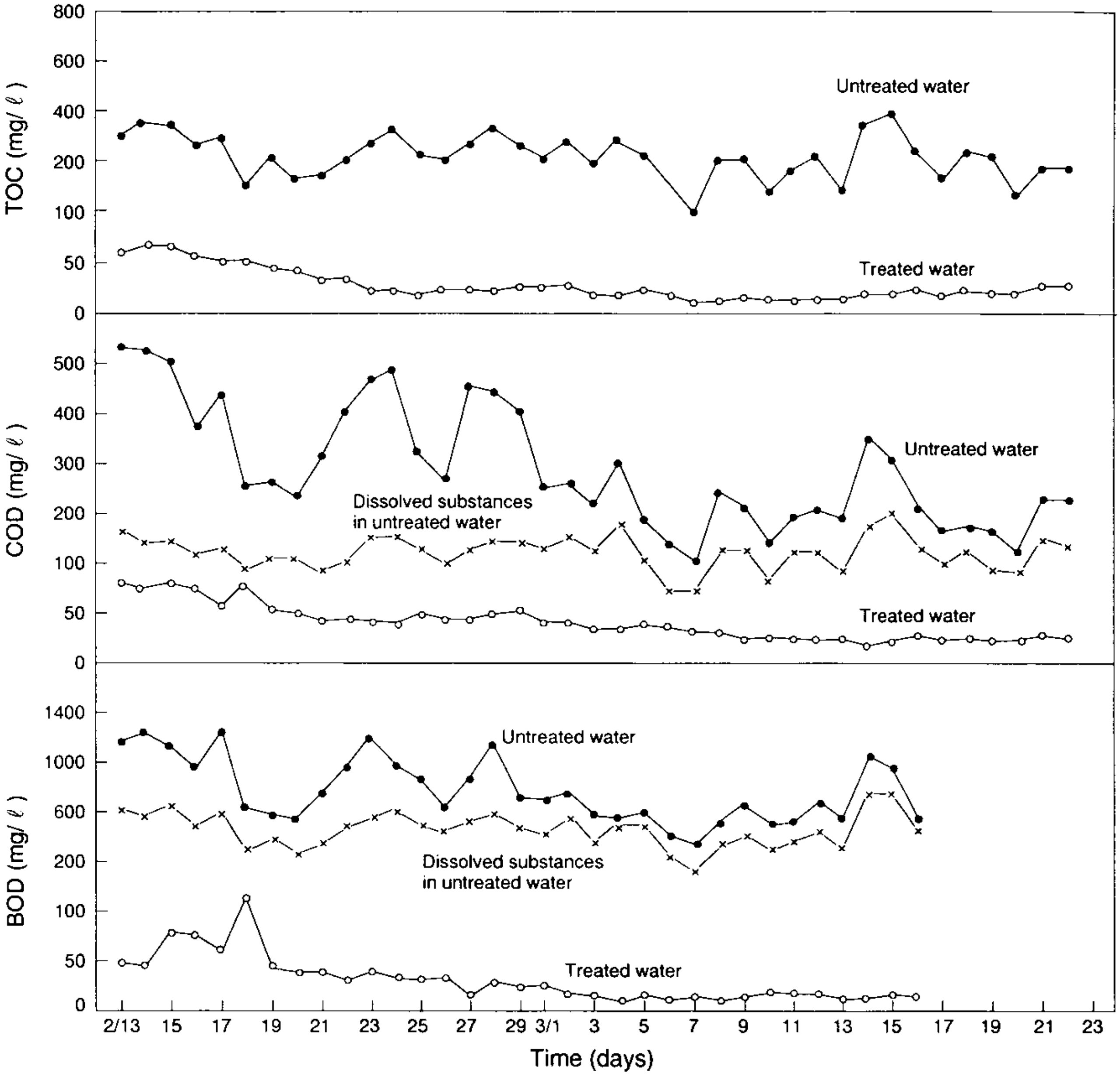


Fig 9-12 Treatment results from the pilot plant (TOC, COD, BOD)

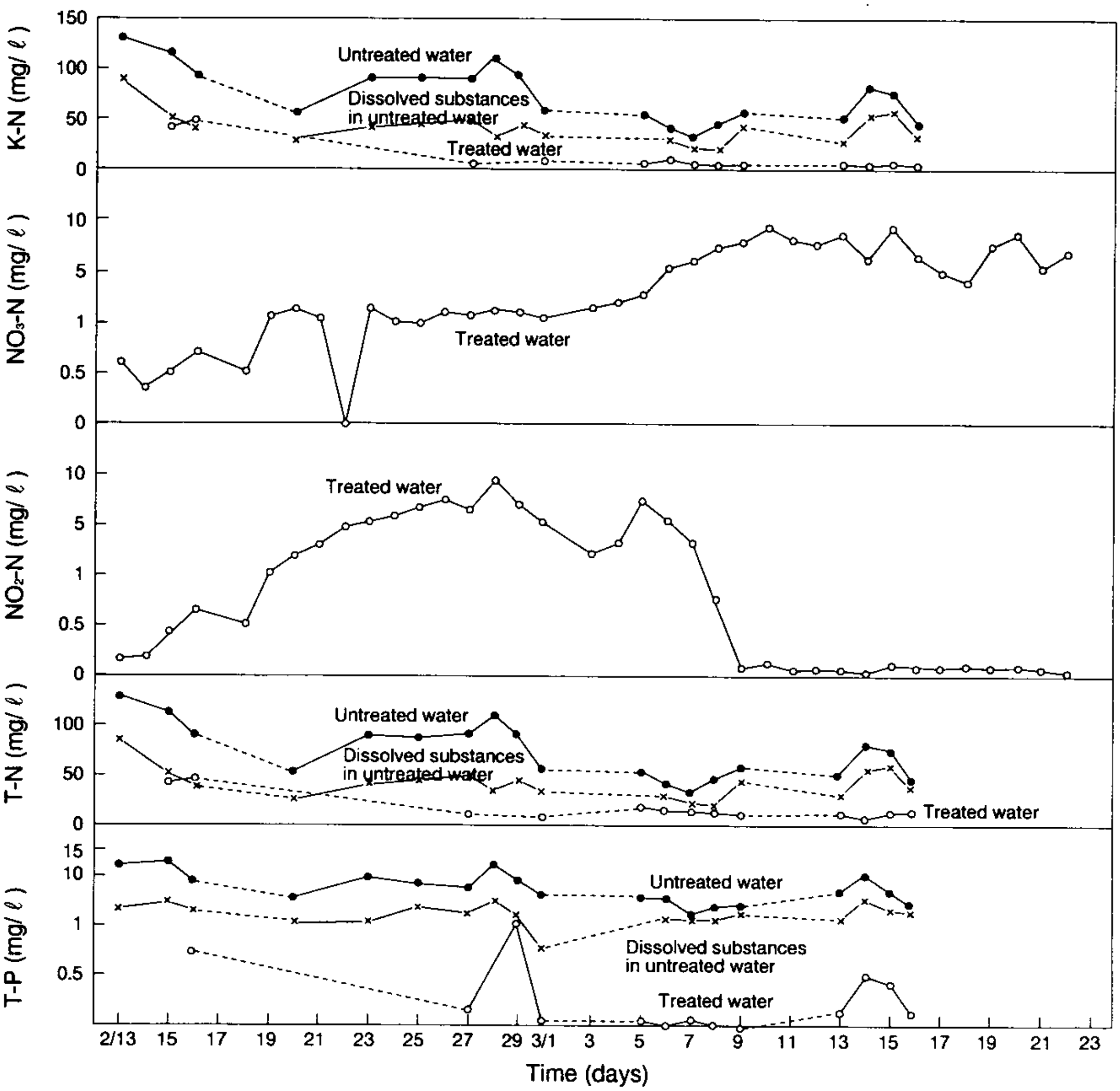


Fig 9-13 Treatment results from the pilot plant (K-N, NO_3-N, NO_2-N, T-N, T-P)

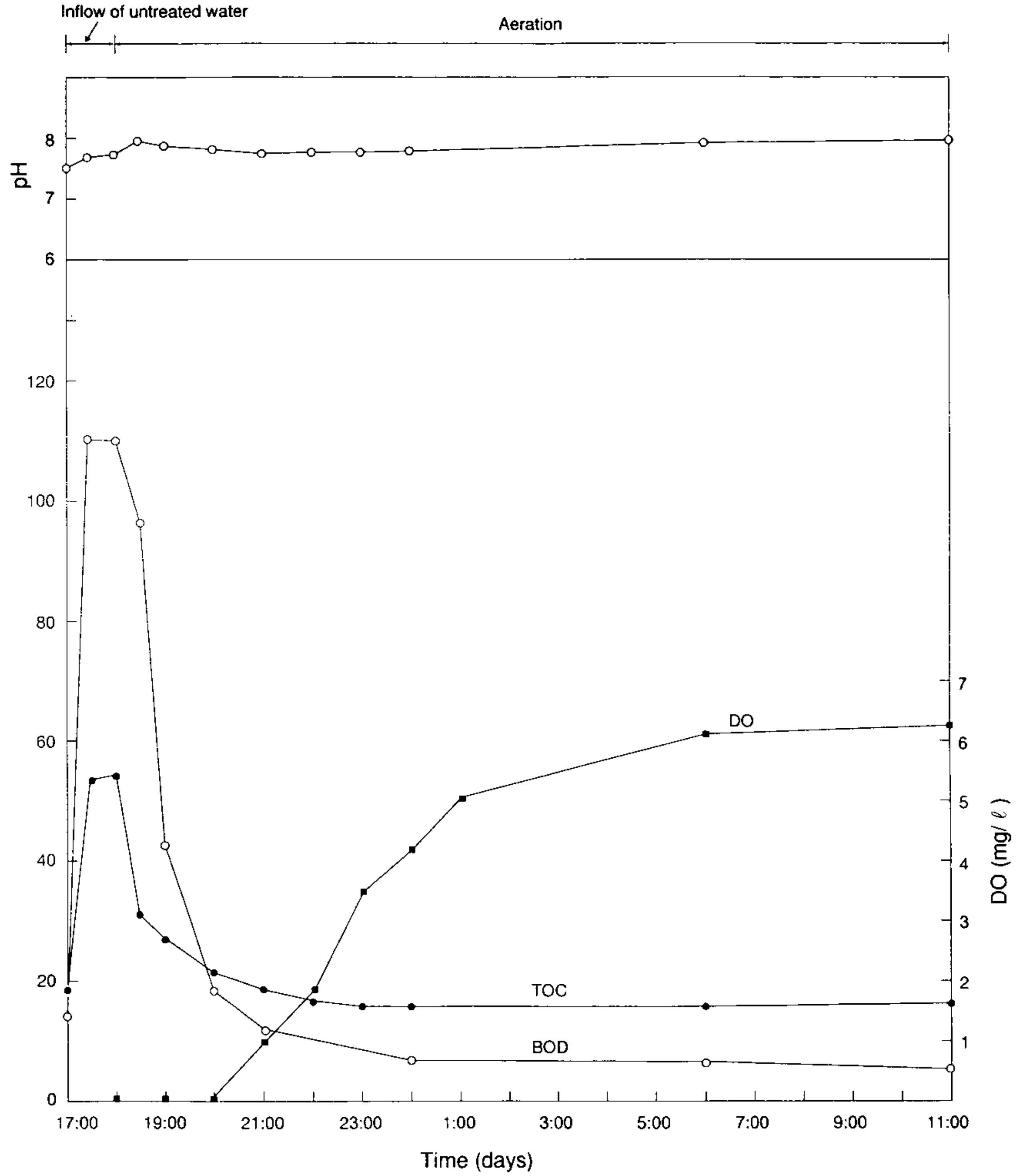


Fig 9-14 Hourly changes in the pilot plant (pH, TOC, BOD, DO)
(March 7th)

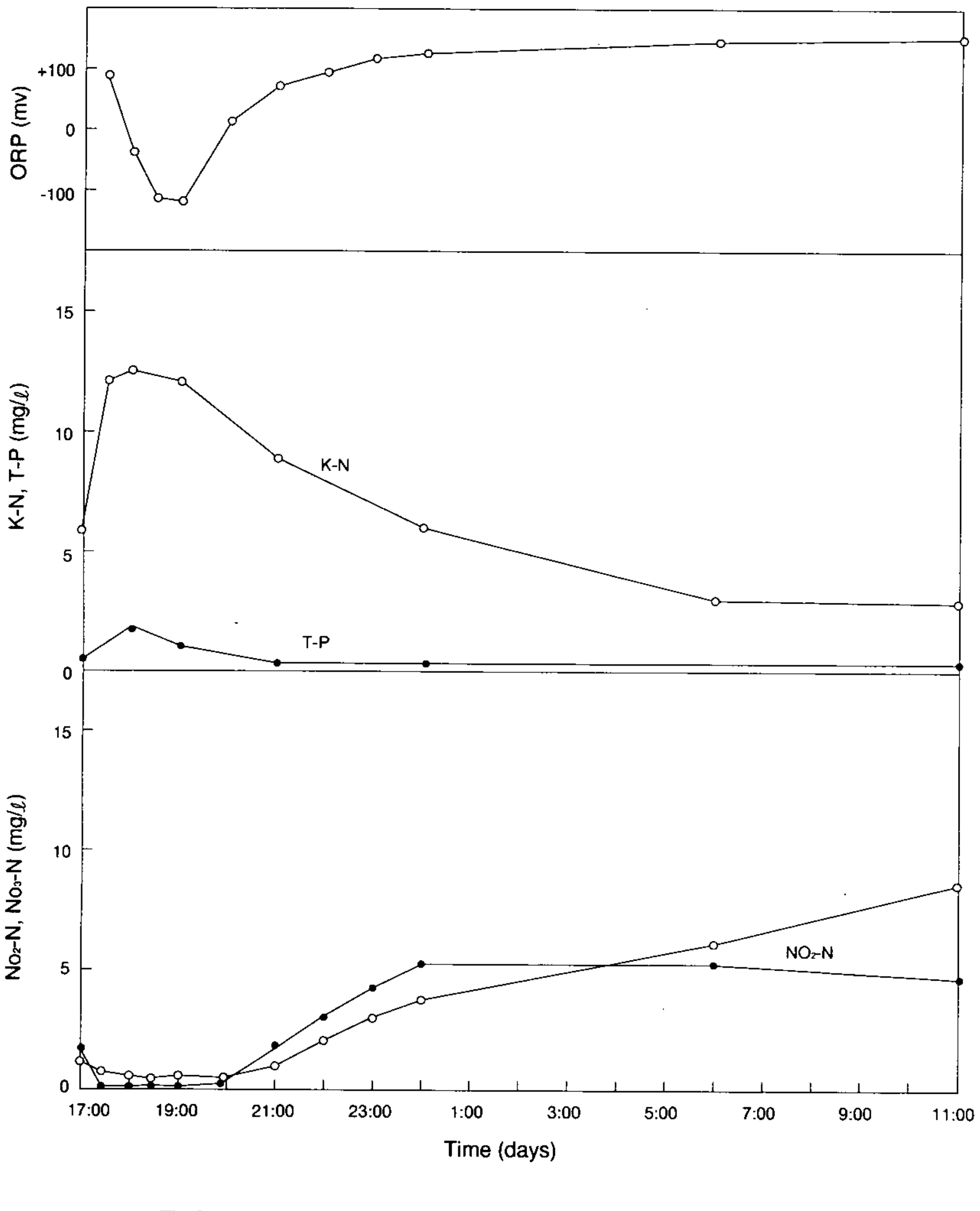


Fig 9-15 Hourly changes in the pilot plant (ORP, nitrogen, phosphorus)
(March 7th)

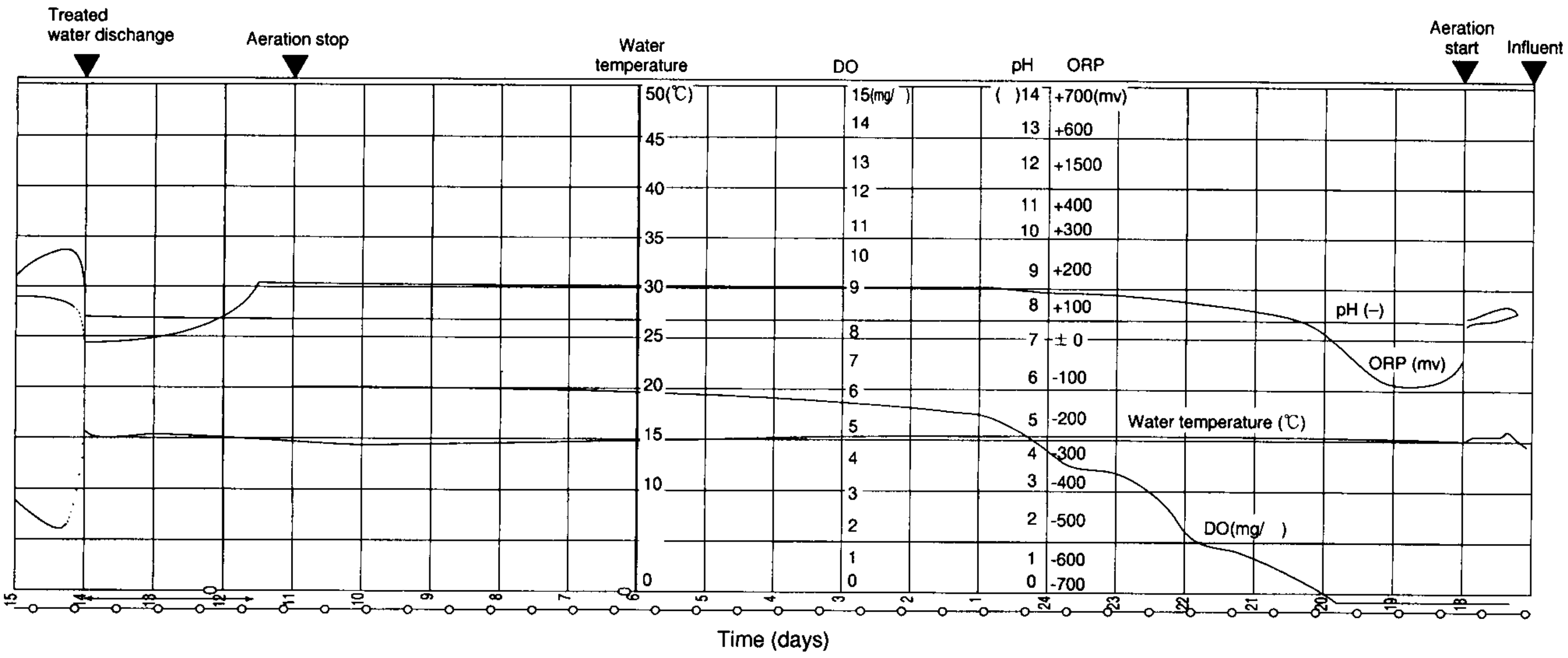
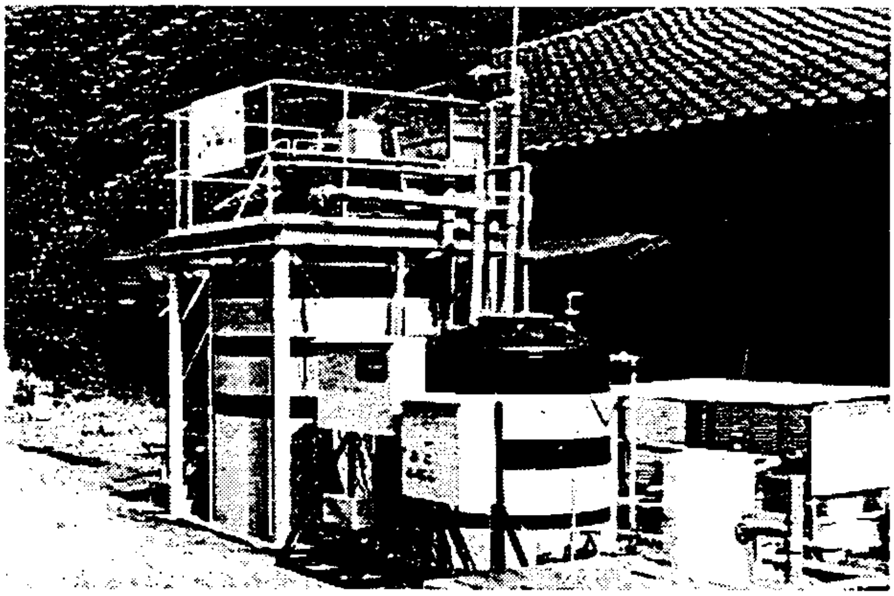


Fig 9-16 Hourly changes in the aeration tank condition of the pilot plant (pH, ORP, DO, water temperature) (March 7th)

9-5 Conclusion

In Feb. 1984, a pilot plant implimenting the controlled aeration activated sludge method with a capacity of 2m^3/d was installed in a soy sauce manufacturing plant area and experimentation was conducted.
Based on the result of the indoor bench-scale apperatus, a continous operation experiment was conducted and as a result, the treatment conditions were confirmed and knowledge on the treatment effect was obtained.
The results are as follows;

(1) A pilot plant with a capacity of 2 m^3/d was installed in the soy sauce manufacturing plant area and experimentation was conducted.



Wastewater was pumped from the existing untreated water adjusting tank to the untreated water adjusting tank of the pilot plant and, after equalization of the water quality by storage in the tank, it was sent to the aeration tank. Air was injected in to the aeration tank through diffusers and anaerobic mixing was conducted with mixing a pump. The treated water was drawn by pump and the treated water level was adjusted with a level meter. The facility was automatically operated by timer so that continous experimentation was easy.

(2) The treatment performance of the screen, the simplest method, was studied for the following reasons; influent SS concentration was high, the pollutant load due to SS was also high, BOD in SS of 50 %, and when utilizing a batch type controlled aeration activated sludge method, the treatment efficiency greatly depends on SS removal.
As a result, the mean value of the non-excess probability of SS in the wastewater was 760 mg/ ℓ before installation of the screen, but it dropped to 320 mg/ ℓ after installation. This clarified the effectiveness of SS removal using a conveyor type screen.

(3) The acclimation of the pilot plant was conducted during a low water temperature period, 12 - 15℃, in winter, but by adjusting the seeding sludge volume to 4000 mg/ ℓ of MLSS, the acclimation could be completed in two weeks for BOD removal and one month for the nitrification system.

(4) After finishing the acclimation of the pilot plant, through implimentation of the conventional controlled aeration method time schedule, the removal efficiency of BOD was 98 %, but that of TOC was 91 % and COD 90 %, which implied the presence of non-biodegradable organic substances in the soy sauce manufacturing wastewater.

(5) Since the nitrogen and phosphorus ratio in the wastewater was approximately BOD : N : P = 100 : 10 : 1, the excess nitrogen was oxidized to nitrite and nitrate through nitrification. In nitrification, nitrite was converted to nitrate as the acclimation proceeded.
As phosphorus was uptaken by the sludge, in the treated water there was almost no residual phosphorus.
The average removal efficiencies were 82 % for nitrogen and 97 % for phosphorus.
In the experiment, the nitrification ratio was 94 % and the above nitrogen removal efficiency was probably due to denitrificaiton of a small amount of nitric acid on untreated water inflow.
The treatment result was very similar to that of the indoor bench-scale apperatus.

(6) After acclimation, hourly changes in the pilot plant were studied.
The water quality on the research days, March 6th and 7th, was a BOD loading of 0.15 kg/m^3·d, about half of the ordinary value, and 4060 mg/ ℓ of MLSS, but the nutrition balance was in an ordinary condition; BOD : N : P = 100 : 11.6 : 1.3.
Through the formation of a substrate concentration gradient through implimentation of the controlled aeration method, organic substances, TOC and BOD, reached equilibrium after 6 hours of aeration.
Nitrogen was oxidized to nitrous and nitric acid at a water temperature of 15℃ and the nitrification rate constant was 0.014 kg/kg · d, which was lower than that of the indoor bench-scale apperatus. This was probably due to the inhibition of nitrifying bacterial growth at low water temperature.

(7) In the pilot plant, nitrogen and phosphorus behaviour with respect to the controlled aeration activated sludge method, clarified in the indoor bench-scale apperatus, was confirmed by comparing the appropriate time schedules for nitrification, denitrification and phosphorus removal.
Bulking could be controlled by the substrate concentration gradient which formed in the aeration tank, and nitrification, denitrification and phosphorus removal were possible through maximum utilization of the physiological function of the activated sludge by creating aerobic and anaerobic conditions in the aeration tank. Consequently, as a treatment process suitable for food industry wastewater, a compact batch type treatment method with easy maintenance and low cost for the advanced treatment of nitrogen and phosphorus could be established.

10 Study on advanced treatment of COD and color utilizing the A-Hipo method

Based on study on biological treatment of soy sauce manufacturing plant wastewater, it was clarified that BOD, nitrogen and phosphorus in the wastewater could be sufficiently removed through utilization of the controlled aeration activated sludge method. However, due to non-biodegradable substances probably from soy sauce, the removal of COD and color substances in the wastewater was not sufficient when only implimenting a biological treatment method.

As an advanced treatment method for COD and color substances in the biologically treated water from the soy sauce manufacturing plant, the A-Hipo method developed by our company was studied.

Fig. 10-1 shows the basic flow diagram of the A-Hipo system. It consists of two main processes; the first stage is an acid coagulation process in which the wastewater is treated with coagulation sedimentation under weak acid conditions at a pH of 4 - 5 using ferric salt as the coagulant; the second stage is a hydrogen peroxide & Fe catalyst oxidation process in which organic substances in the wastewater are chemically oxidized and decomposed through use of hydrogen peroxide and ferrous salt.

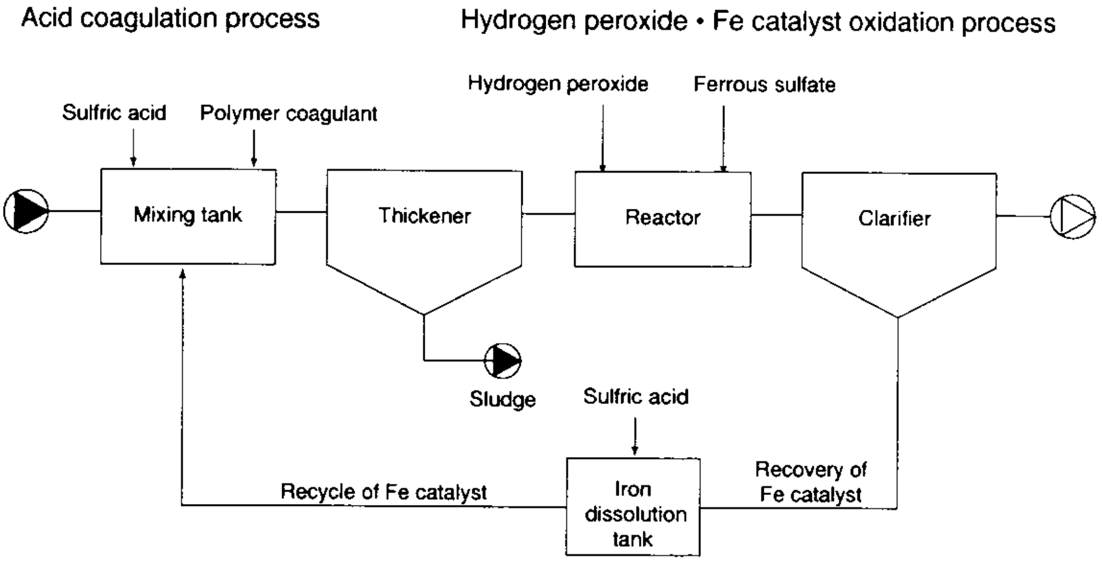


Fig 10-1 A-Hipo treatment system

10-1 Experiment

Taking samples of the biologically treated soy sauce manufactuirng plant wastewater, the acid cogulation and hydrogen peroxide & Fe catalyst oxidation processes were examined in beakers in a batch type experiment aimed at studying basic treatment conditions of the A-Hipo method.
In the acid coagulation process, Al(PAC) in place of Fe salt was also studied.

(1) Wastewater for the experiment

The sampled wastewater was the soy sauce manufacturing wastewater which had been biologically treated in the indoor bench-scale apperatus (20 ℓ) utilizing the controlled aeration activated sludge method.
Table 10 - 1 shows the result of the sampled wastewater quality analysis.

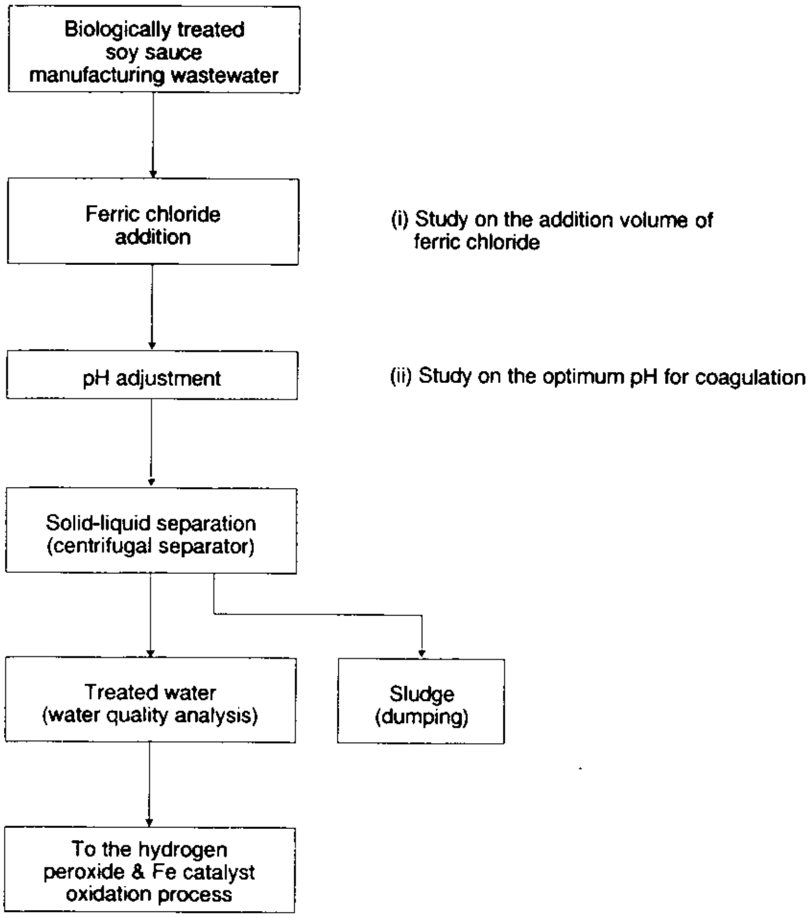
Table 10-1 Sample wastewater property

pH (-)	TOC (mg/ℓ)	COD (mg/ℓ)	BOD (mg/ℓ)	T-N (mg/ ℓ)	T-P (mg/ ℓ)	Color (degrees)
8.21	27	35.5	6	5.3	1.1	75.5

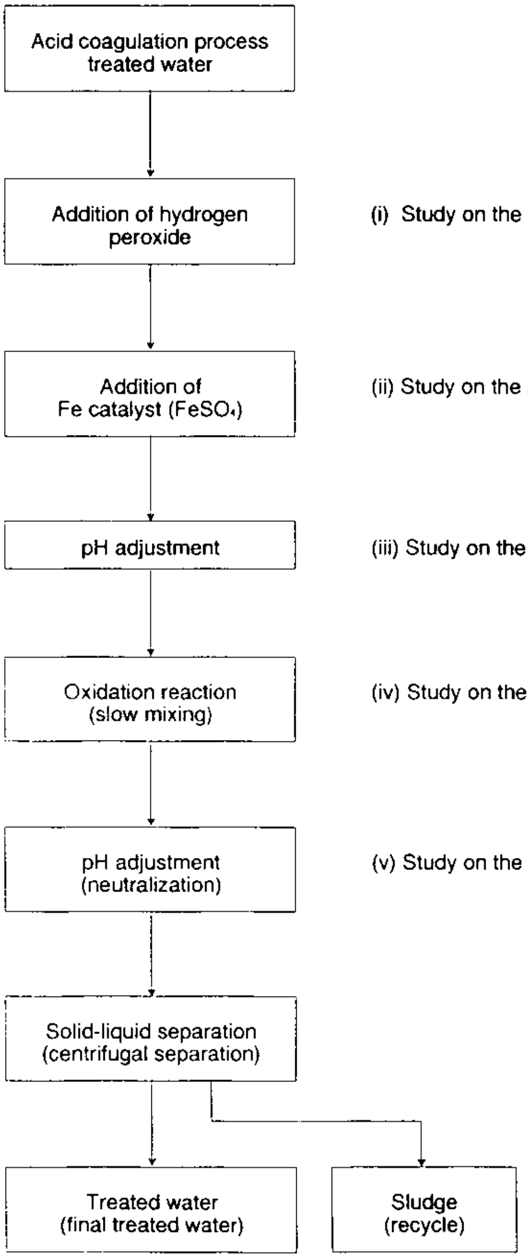
(2) Experimental method

The experiment was conducted on a beaker scale.
The sampled water in a beaker was mixed by magnetic stirrer and the pH was adjusted using a pH meter with a glass electrode. With consideration on the response characteristics, sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH) were used as pH adjusting agents.
In the experiment, acid coagulation treatment, a fixed amount of Fe salt, usually ferric chloride ($FeCl_3$), was added and after pH adjustment, it was stirred typically for 15 minutes. As a coagulant aid, anion polymer coagulant was used.
In the experiment, hydrogen peroxide & Fe catalyst oxidation, a fixed amount of Fe^{2+} salt and hydrogen peroxide (H_2O_2)were added and after pH adjustment, it was allowed to react for a fixed period under magnetic stirring. Then Fe catalyst was deposited and separated by pH adjustment. For Fe catalyst separation, anion polymer coagulant was used.
After coagulation or oxidation, solid-liquid separation was performed through use of a centrifugal separator (3000 rpm, 5 minutes) and the supernatant was taken as the treated water sample.
The following are the experiment procedure and study items of each treatment process.

(1) Acid coagulation treatment process



(2) Hydrogen peroxide & Fe catalyst oxidation process



(i) Study on the addition volume of hydrogen peroxide

(ii) Study on the addition volume of Fe catalyst

(iii) Study on the optimum pH for reaction

(iv) Study on the reaction time

(v) Study on the optimum pH for coagulation

10-2 Study on the coagulation treatment efficiency

Almost all biologically treated wastewater, such as night soil, leachate from industrial waste land fill, and color compounds and COD_{Mn} compounds of soy sauce, beer, etc. are substances which are difficult to be biologically treated and in principle their structures are the same as the macromolecular organic compounds of brown water leached from peat soil, such as humic acid, fulvic acid and polyhydric phenol, which are the final structures of organic substances from decomposition processes of the natural world.

Mucopolysaccharides contain glycoprotein structures and are intermediate substances generated in the metabolism of microorganic cell substrate. They are macromolecular organic compounds whose molecular weights are some thousands or several tens of thousands of daltons and all of them have functional groups and are color compounds.

These macromolecular organic compounds consist of stable protective colloids under neutral conditions like protein, and under the acid conditions, they are unstable and the colloid particles tend to coagulated although not in a generally uniform way.

(1) Effect of pH on coagulation

Figs. 10-2 and 10-3 show the relationship between pH for coagulation and COD and color, respectively, when ferric chloride or PAC were added to the sampled wastewater.

The addition volume was 200 mg/ ℓ of ferric chloride or PAC based on the conversed value of Fe or Al.

As a result, the removal efficiencies of COD and color were high at a pH of 5 for Fe and pH of 6 for Al, which implied the coagulation effect was very high under acidic conditions.

(2) Addition volume of metal salt and treated water quality

Figs. 10-4 and 10-5 show the relationship between the addition volume of Fe and Al, at the optimum pH for coagulation and COD and color of the treated water, respectively.

As a result, for both COD and color, when the addition volume of coagulant was 20 mg/ ℓ or less, the coagulation effect of Al was high, and when the addition volume was 20 mg/ ℓ or more, the coagulation effect of Fe salt was high. At on Fe salt addition of 200 mg/ ℓ or more, the treated water quality was 10 mg/ ℓ of COD or less and color was 12 degrees or less.

10-3 Study on the efficiency of the A-Hipo method

It is known that there are various specific reactions of hydrogen peroxide when it coexists with a metal salt. And reactions with metal ions, such as Fe^{2+}, Cu^{+} Cu^{2+} are performed mainly by the OH* radical.

It is considered that the hydrogen peroxide & Fe catalyst oxidation reaction is mainly orchistrated by the OH* radical. R* radical is probably generated by oxidation of organic substances in the wastewater and the active R* · radical triggers chain reactions. The lives of the OH* radical and R* radical in this reaction are estimated to be very short compared to that of the ordinary organic radical reactions because the radical concentration is very low.

Organic substances generated from this oxidation are highly adsorbed by Fe flocks and consequently they are removed by Fe catalyst effectively in the Fe catalyst removal process. From this organic substances which cannot be removed by Fe salt in the coagulation treatment process can be effectively removed by hydrogen perxoide & Fe catalyst oxidation treatment.

Decoloring brought about by direct attack of the chromophore of the color substance can be expected during oxidation through the activity of the by OH* radical.

It was clarified that the oxidation coagulation treatment at a pH of 5 was effective for the removal of COD and color substances in the soy sauce manufacturing plant wastewater. The treatment characteristics and condition of the A-Hipo method were studied for reducing the running cost.

(1) pH for the reaction

Fig. 10-6 shows the study result of the pH for the reaction in the hydrogen peroxide & Fe catalyst oxidation treatment stage using wastewater which had already been given biological and acid coagulation treatment. As a result, the removal efficiency of COD and color substances was highest at a pH of 4 in the experiment. This was higher than other study results which have been conducted using the A-Hipo method.

(2) Study on pH necissary for coagulation

In the hydrogen peroxide & Fe catalyst oxidation treatment, most of the oxidized organic substances were adsorbed on the Fe catalyst and discharged on removal of the Fe catalyst, rso that in many cases the pH for Fe catalyst coagulation removal had a big influence on the treatment effciency, like the pH for the reaction. Fig. 10 - 7 shows the relationship between the pH for coagulation and COD and color of the treated water after the reaction. As a result, the treatment efficiency of COD and color substances was the highest at a pH of 5, which was the same result as that of oxidation coagulation.

(3) Addition ratio of hydrogen peroxide to Fe catalyst

Fig. 10-8 shows the result of the study on optimum addition of hydrogen peroxide and Fe catalyst.

As a result, COD was the lowest at the addition ratio of Fe^{2+} / H_2O_2 as O between 4 - 5 and no hydrogen peroxide and ferrous sulfate remained. When the ratio was 4 or less, hydrogen peroxide remained in the treated water and when it was 5 or more, ferrous sulfate was remained; in both cases they increased COD in the treated water.

(4) Addition volume and treated water quality

Fig. 10-9 shows the treatment efficiency according to the change in addition volume of Fe^{2+} and H_2O_2 as O under optimum conditions from the A-Hipo method.

We found that the wastewater could be treated bringing about a COD value of 10 mg/ ℓ or less thruogh addition of 75 mg/ ℓ of Fe^{2+} and 15 mg/ ℓ of H_2O_2 as O.

The result was that after biological treatment the soy sauce manufacturing plant wastewater could be treated bringing Fe^{3+} to 200 mg/ ℓ through acid coagulation, and COD to 10 mg/ ℓ on addition of 75 mg/ ℓ of Fe^{2+} and 15 mg/ ℓ of H_2O_2 as O, via the A-Hipo method.

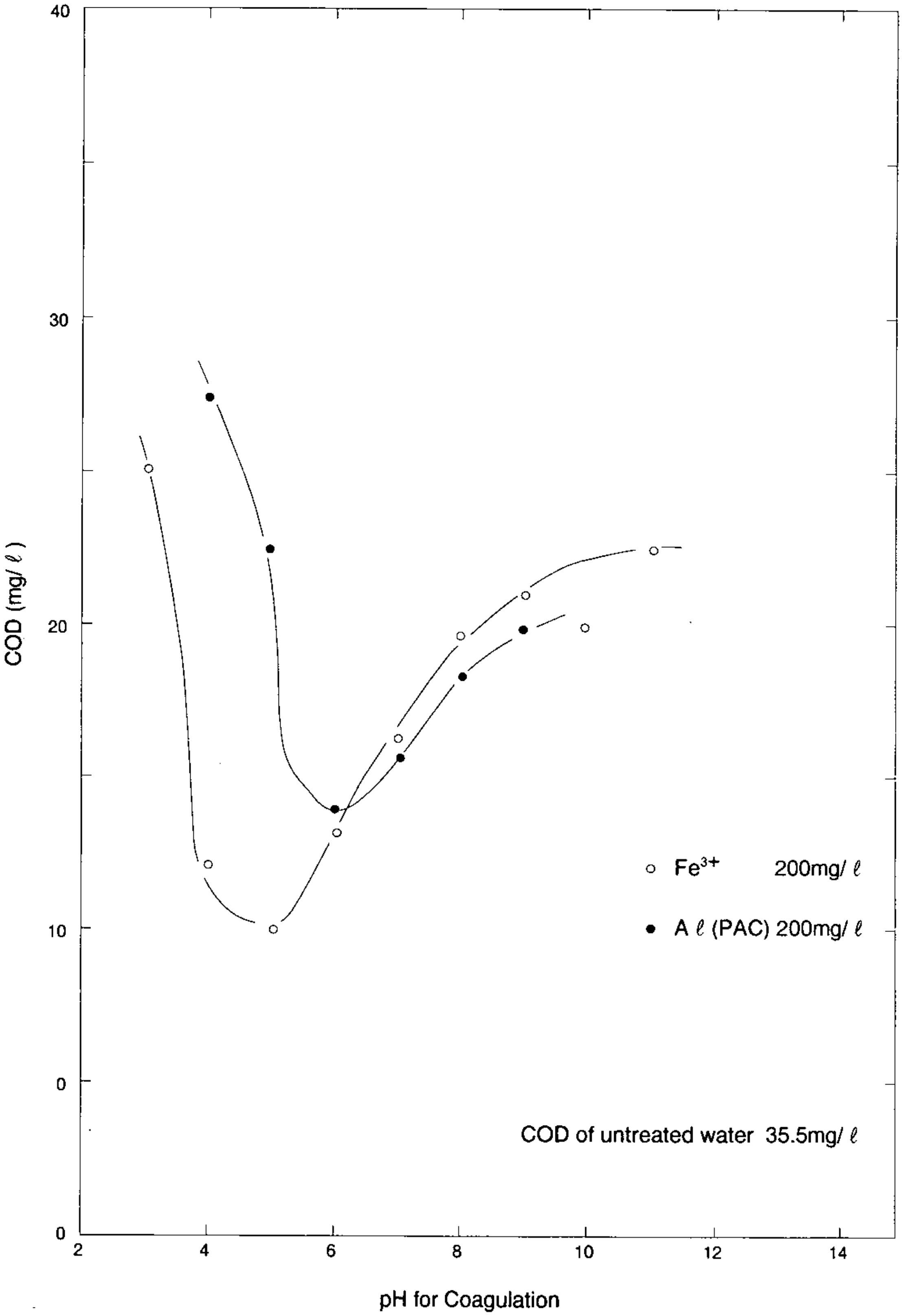


Fig 10-2 Relationship between pH for coagulation and COD of the treated water

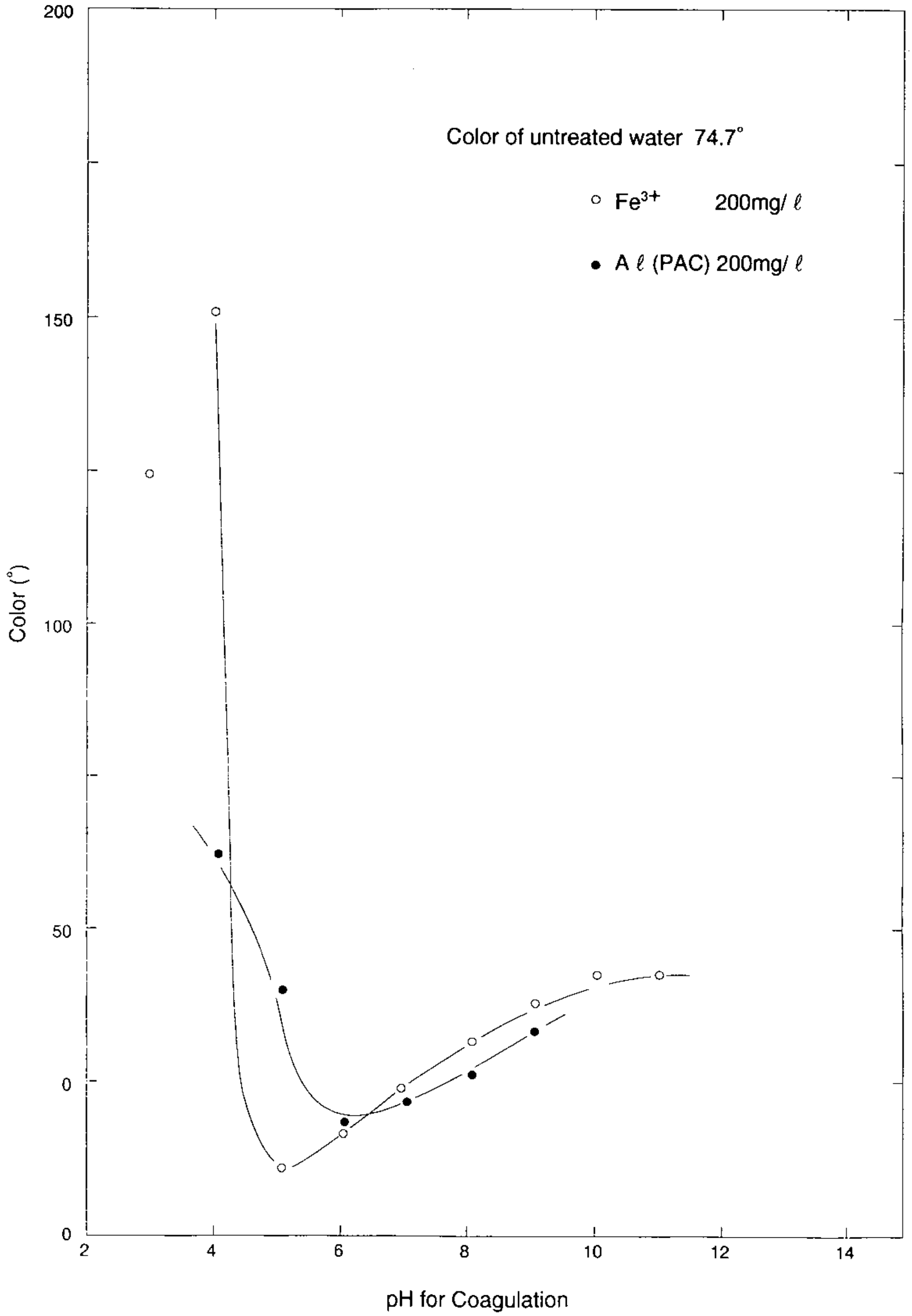


Fig 10-3 Relationship between pH for coagulation and color of the treated water

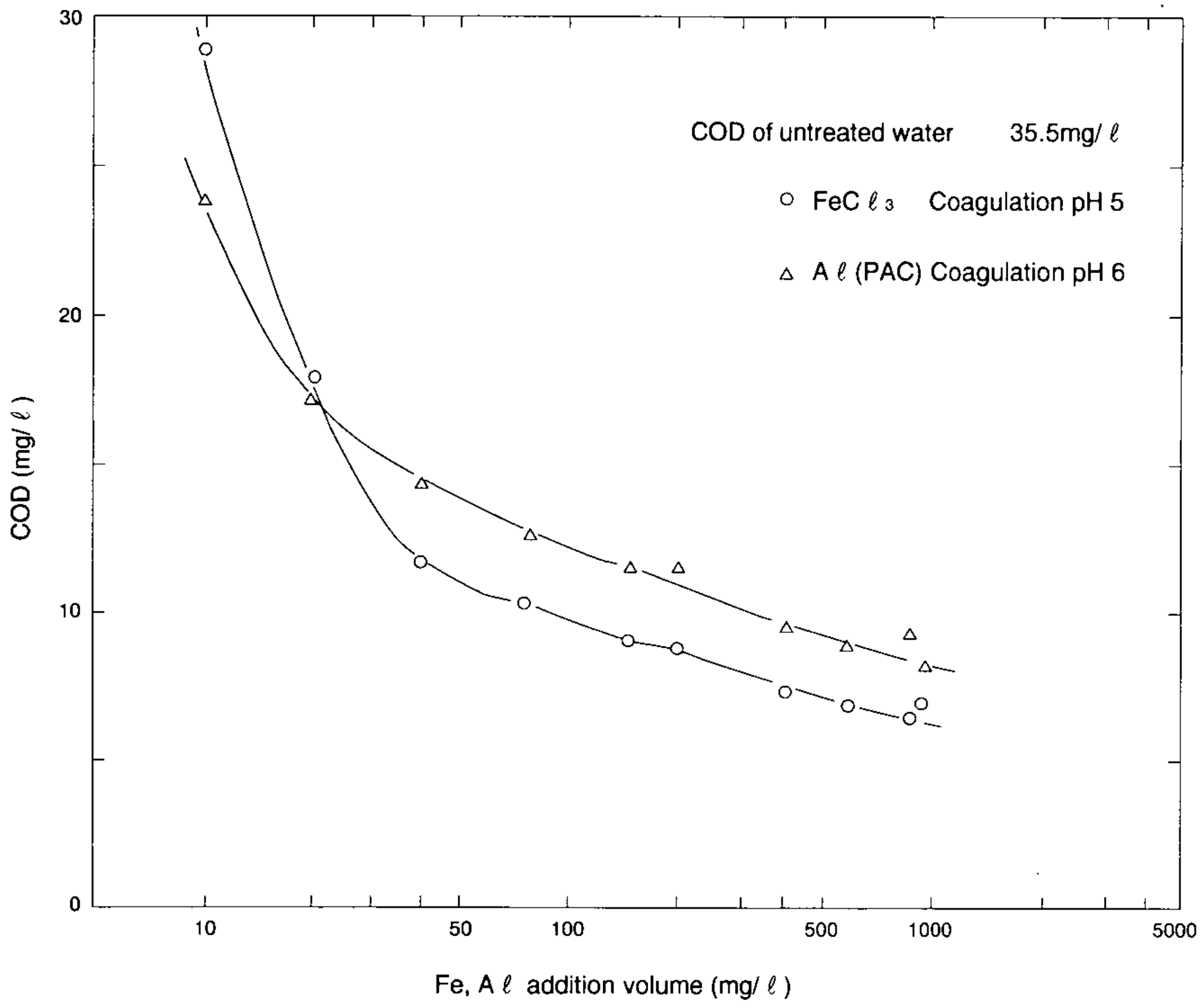


Fig 10-4 Relationship between addition volume and COD of the treated water

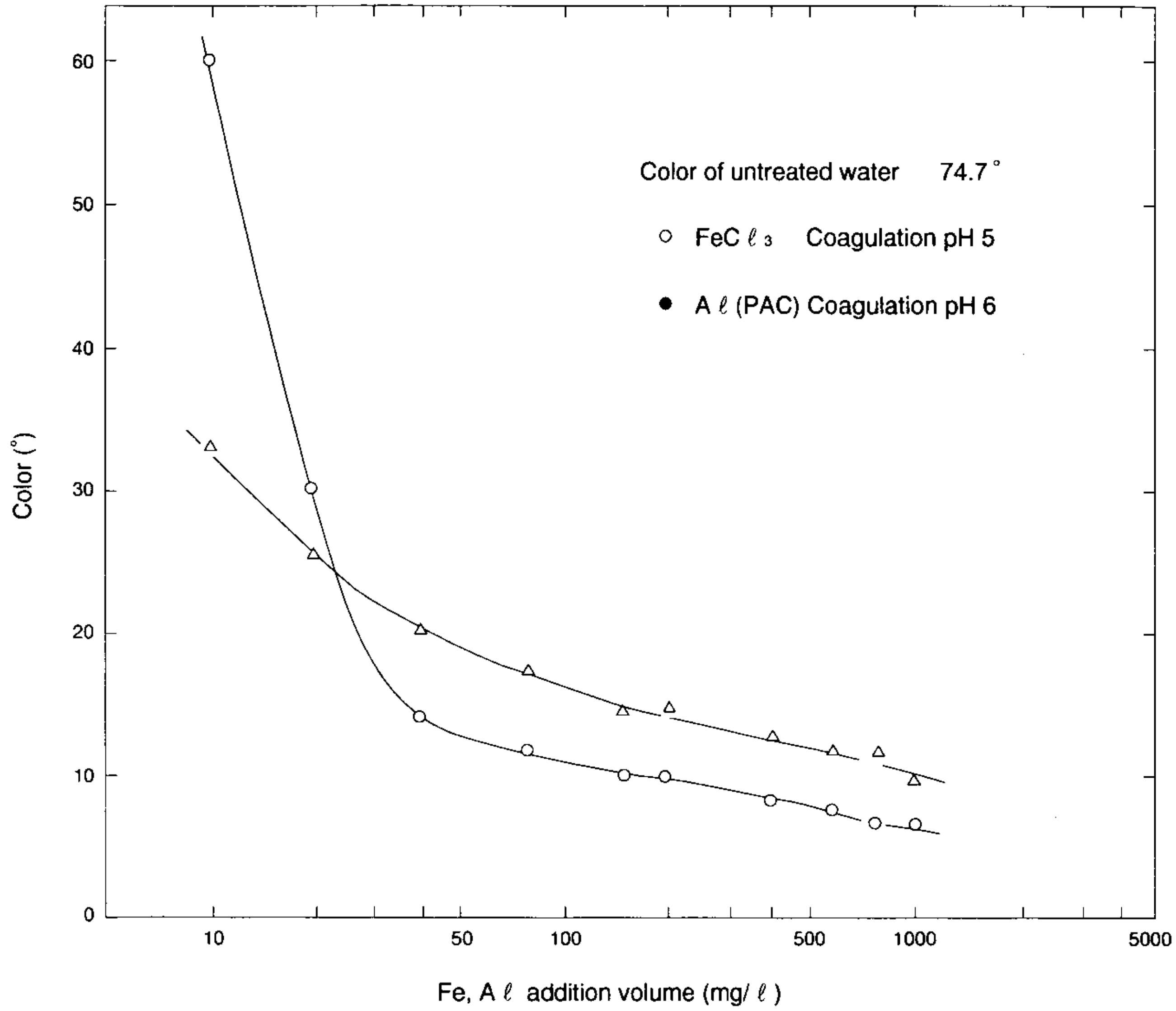


Fig 10-5 Relationship between addition volume and color of the treated water

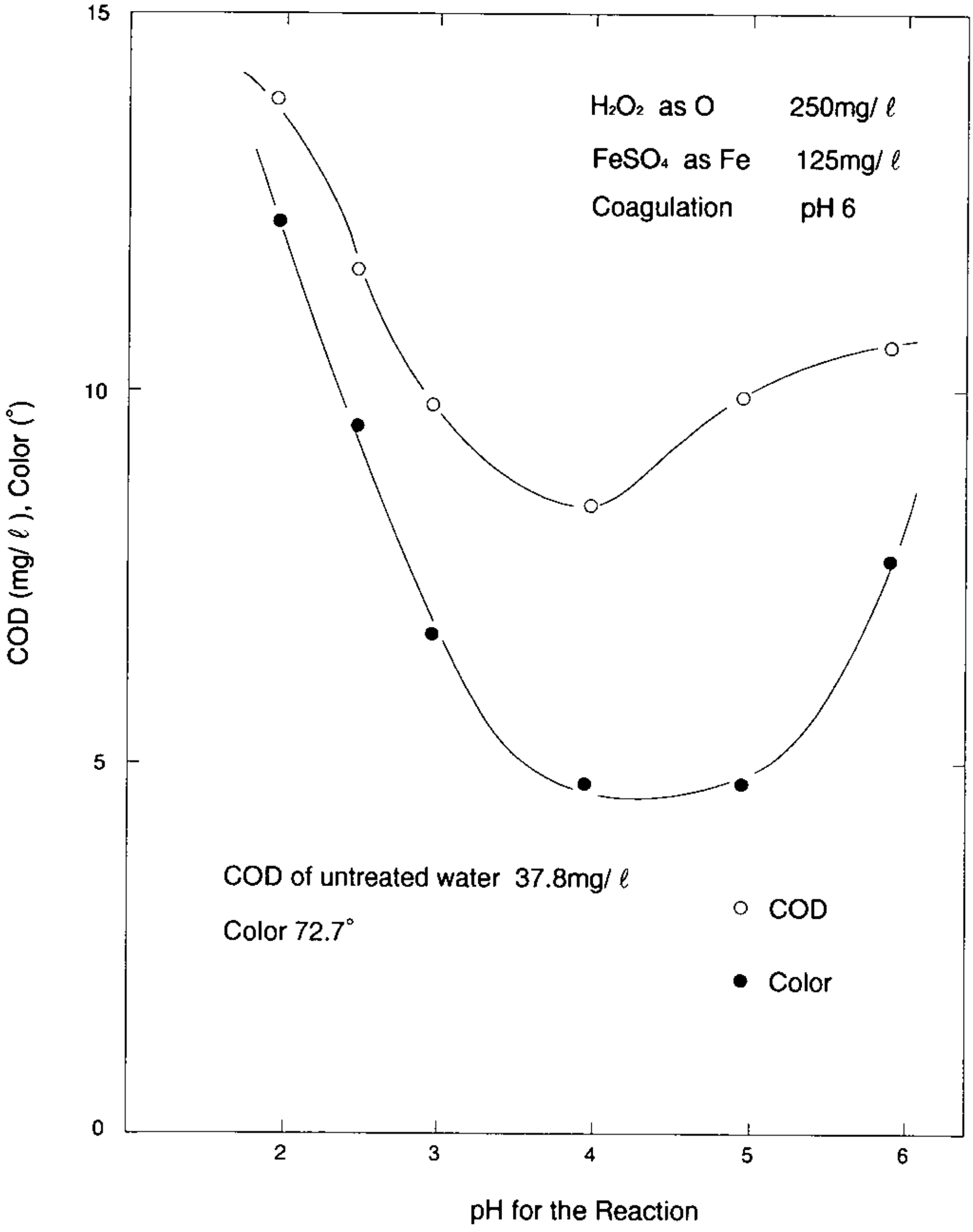


Fig 10-6 Relationship between pH for the reaction and COD & color

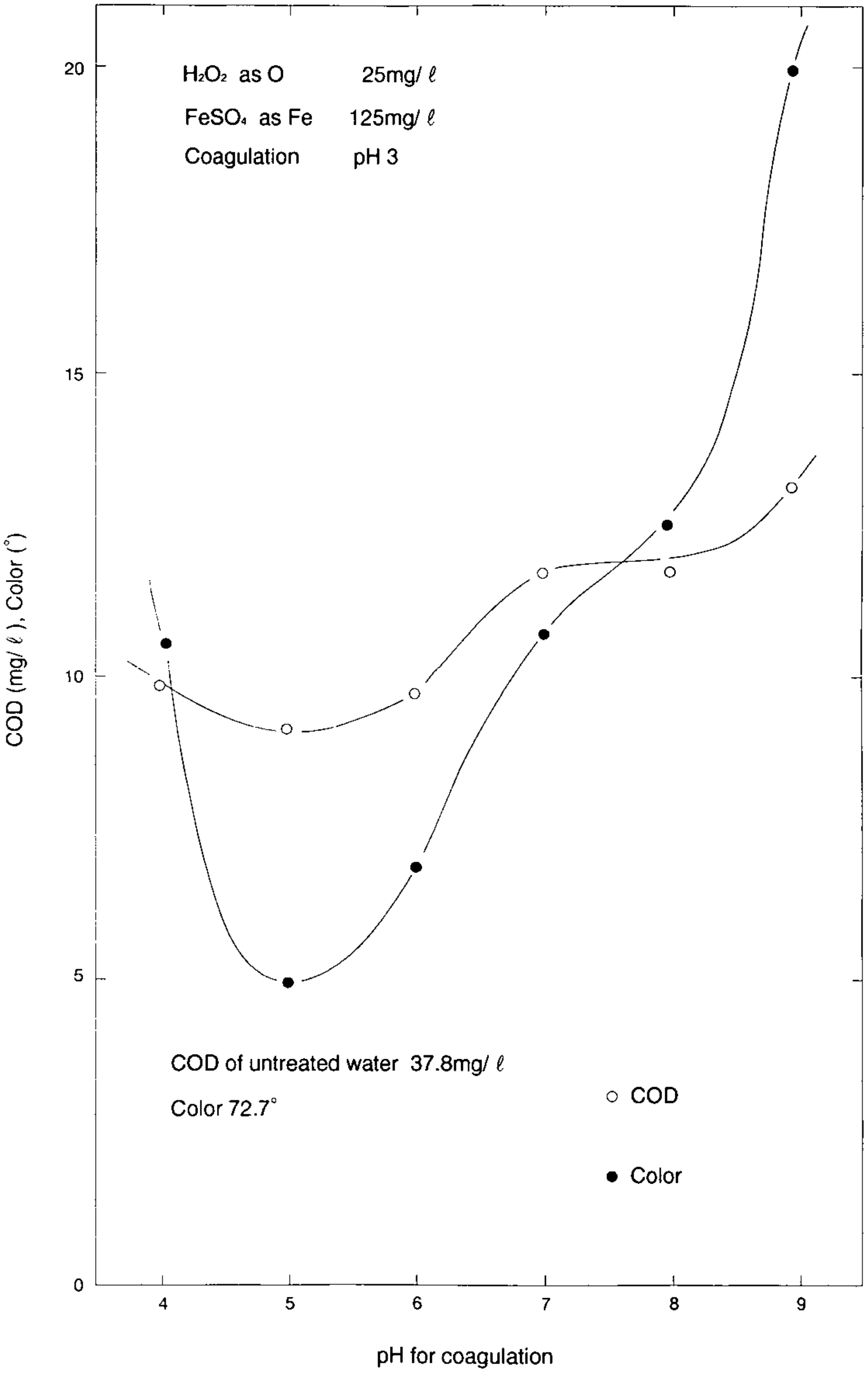


Fig 10-7 Relationship between pH for coagulation and COD of the treated water after the reaction

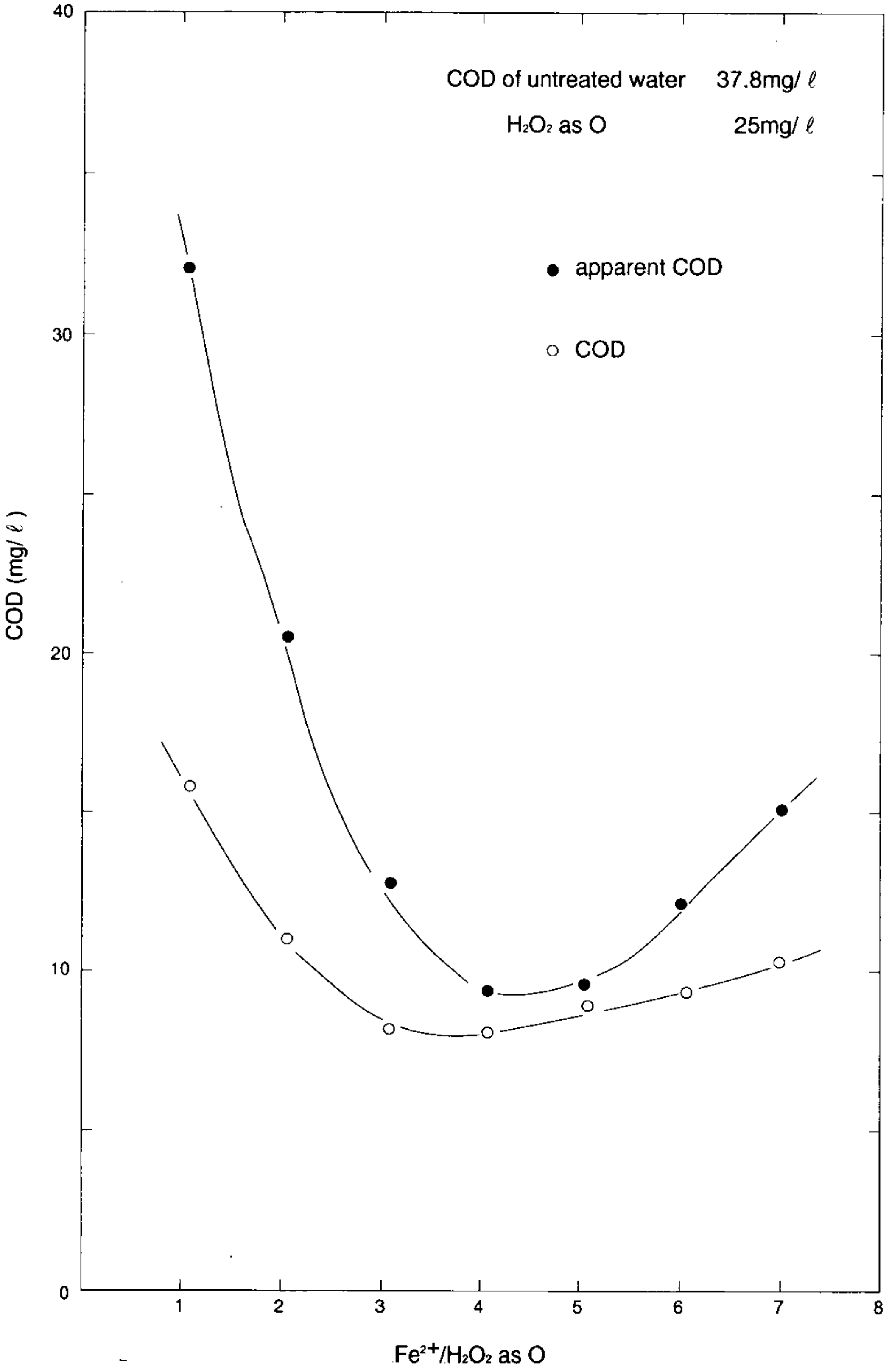


Fig 10-8 Behavior of COD in the treated water on change in the Fe additional ratio in the Fe-H_2O_2 treatment

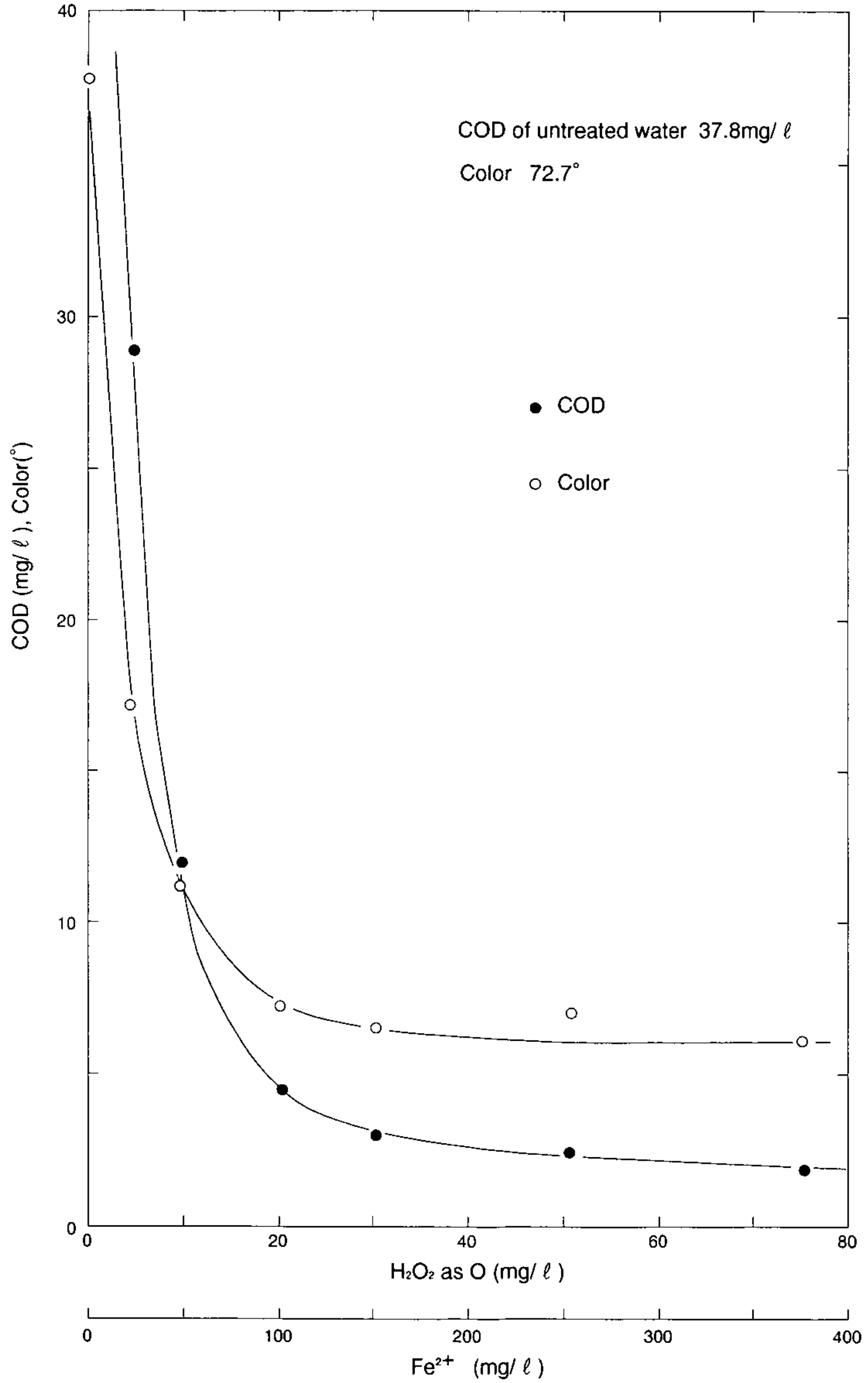


Fig 10-9 Relationship between chemical addition volume and treated water quality

10-4 Conclusion

The A-Hipo method was applied as an advanced treatment method for residual COD and color substantances in the biologically treated water from the soy sauce manufaturing plant and the optimum treatment condition were clarified.

1) The sampled wastewater quality was 35.5 mg/ ℓ of COD and a color of 75.5 degrees.

2) Optimum acid coaglutaion occured under acidic conditions, the pH was 5 for Fe^{3+} and 6 for Al^{3+}. To treat the wastewater to a COD level of 10 mg/ ℓ only through acid coagulation, addition of 200 mg/ ℓ or more of Fe^{3+} was necessary.

3) The optimum treatment conditions were Fe^{2+} / H_2O_2 as O = 4 - 5, a pH of 4 for reaction and a pH of 5 for coagulation utilizing the A-Hipo method.
To treat the wastewater to a COD level of 10 mg/ ℓ via the A-Hipo method, addition of 75 mg/ ℓ of Fe^{2+} and 15 mg/ ℓ of H_2O_2 as O was necessary.

11 Design of the treatment process

Based on the study, it was found that the treatment efficiency when utilizing the controlled aeration activated sludge method was highly satisfactory in achieving stable treatment through complete control sludge bulking and simultanous removal of nitrogen and phosphorus was possible by selecting a suitable time schedule for nitrification, denitrification and phosphorus removal.

The advanced treatment process of the controlled aeration activated sludge method, including nitrogen and phosphorus removal, was designed based on estimation of food industry wastewater with a capacity of 50 m^3/d, 400 m^3/d and 800 m^3/d.

And it was compared with an advanced process for nitrogen and phosphorus removal consisting of a continuous activated sludge method for nitrification and denitrification, and chemical coagulation for phosphorus removal.

11-1 Treated items and treated water quality target

Table 11-1 shows the treated water quality target for designed food industry wastewater treatment process.

Table 11-1 Treated water quality target for food industry wastewater

	Untreated water	Treated water		
Flow rate (m^3/d)	-	50 m^3/d	400 m^3/d	800 m^3/d
pH (-)	-	5.8~8.6	5.8~8.6	5.8~8.6
BOD (mg/ℓ)	1000 mg/ℓ	20 mg/ℓ or less	20 mg/ℓ or less	20 mg/ℓ or less
T-N (mg/ℓ)	120 mg/ℓ	20 mg/ℓ or less	15 mg/ℓ or less	10 mg/ℓ or less
T-P (mg/ℓ)	20 mg/ℓ	2.0 mg/ℓ or less	1.5 mg/ℓ or less	1.0 mg/ℓ or less
Alkali (mg/ℓ)	350 mg/ℓ	-	-	-

In principle, the treated water quality target was established based on the 'Eutrophication Prevention Ordinance' of Lake Biwa and Lake Kasumigaura and the targets for total nitrogen and total phosphorus were decided with respect to the the flow rate.

11-2 Establishment of the treatment process

Two treatment processes were designed; one utilizing the controlled aeration activated sludge method including nitrification, denitrification and phosphorus removal based on study results, and the other, a combination of the continuous activated sludge method including nitrification and denitrification, which is widely used, and coagulation treatment using PAC (poly aluminium chloride) for phosphorus removal.

(1) Controlled aeration activated sludge treatment process

This is an advanced food industry wastewater treatment facility utilizing the controlled aeration activated sludge method, and its components are very simple; storage tank, controlled aeration tank and treated water tank for nitrification, denitrification and phosphorus removal, and sludge treatment facility.

Fig. 11-1 shows the treatment time schedule.

For the rationalization of the treatment facility, the number of the aeration tanks differs according to the flow rate; 1 tank for 50 m^3/d, 2 tanks for 400 m^3/d and 4 tanks for 800 m^3/d.

One treatment cycle lasts 24 hours and the time schedule is the same in all facilities; 1 hour for untreated water inflow, 12 hours for aeration, 6 hours for anerobic mixing, 2 hours for reaeration, 2 hours for settling and 1 hour for discharge, and the treatment cycle is repeated successively.

Fig. 11-2 shows the flow diagram of the designed treatment facility and Table 11-2 shows the equipment list.

Figs. 11-3, 11-4 and 11-5 show the layout of the facility.

(2) Continous activated sludge treament & PAC coagulation treatment process

This is an advanced food industry wastewater treatment for nitrogen and phosphorus removal; ordinary treatment methods for nitrogen removal utilizing the haploid phase sludge method in the adjusting tank, nitrification tank, denitrification tank, reaeration tank and settling tank are all combined with the phosphorus removal process of coagulation sedimentation using PAC.

The components are the same regardless of the flow rate.

Fig. 11-6 shows the flow diagram of the designed treatment facility and Table 11-3 shows the equipment list.

Figs. 11-7, 11-8 and 11-9 show the layout of the facility.

In comparison of these two processes, the controlled aeration activated sludge process is very simple and rational because it consists of only an adjusting tank and aeration tank. This directly affects the maintenability; because in the controlled aeration activated sludge treatment process, the operation is easy so it is possible to reduce manpower, especially in small sized facilities, no dedicated personell are necessary.

For the ordinary method, the required area is 118m^2, 498m^2 and 770m^2 but for the controlled aeration activated sludge method it is 89m^2, 384m^2 and 603m^2, which means the required area of the controlled aeration activated sludge method is 75 - 78 % of the ordinary method, and the land area can be rationalized.

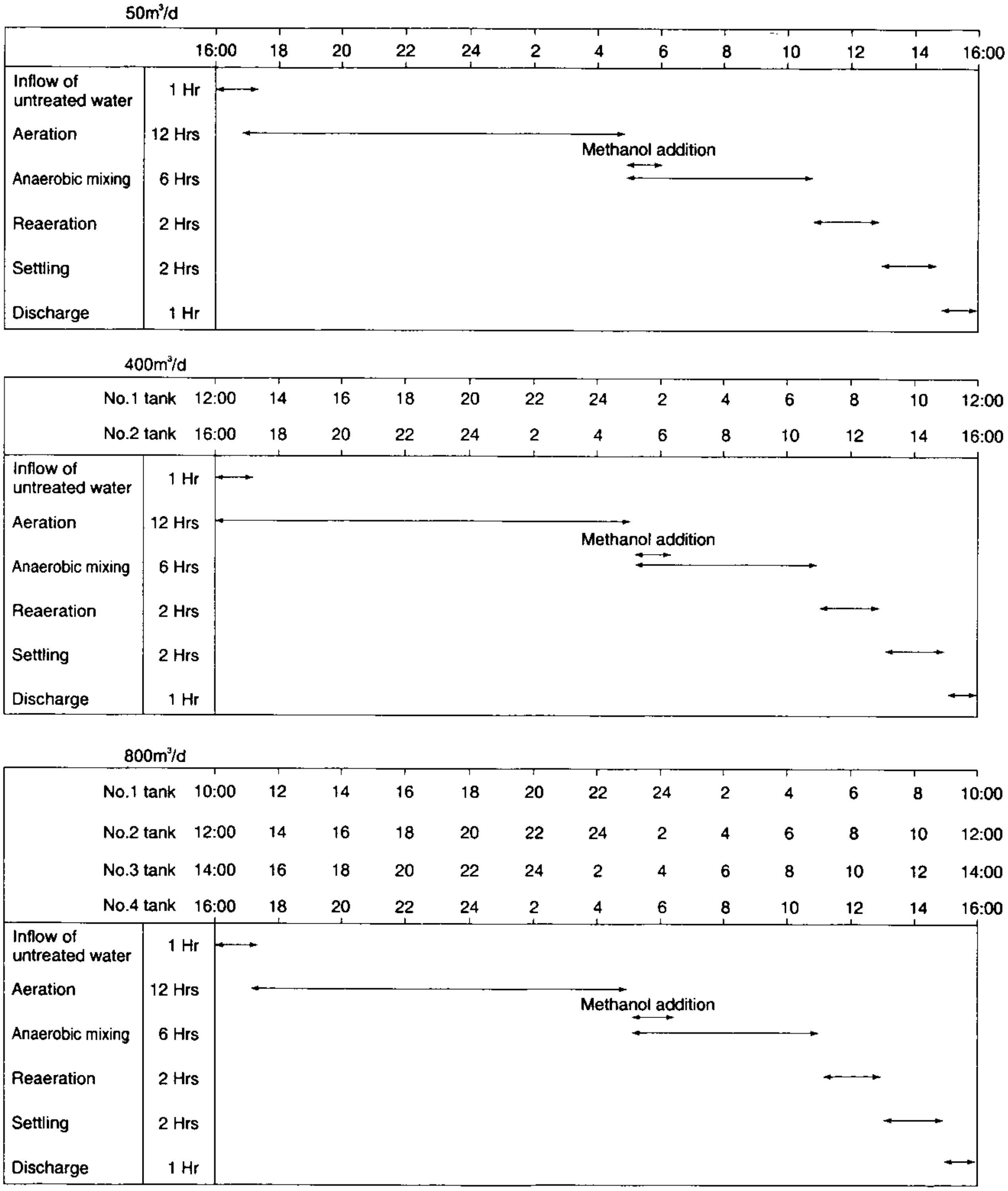


Fig 11-1 Treatmen time schedule

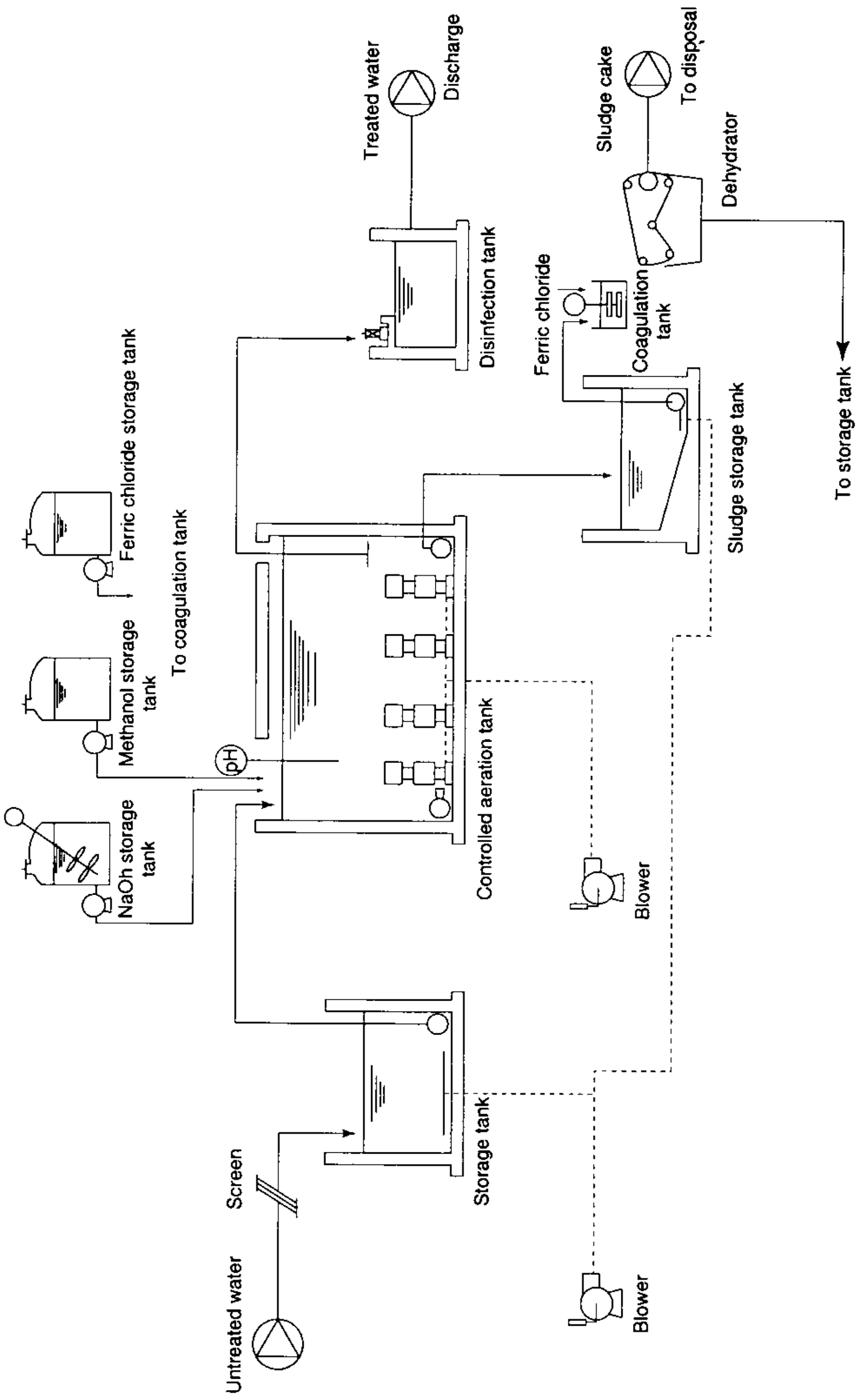


Fig 11-2 Flow diagram of the nitrogen and phosphorus advanced treatment facility for food industry wastewater

Table 11-2 Equipment list for the controlled aeration activated sludge process

No.	Equipment name	Quantity			Type	Remarks
		50 m^3/d	400 m^3/d	800 m^3/d		
1	Automatic screen	1	2	4	Conveyor screen	
2	Untreated water pump	2 (1)	2 (1)	2 (1)	Wastewater submerged pump	
3	Submerged mixer	1	2	4		
4	Sludge withdraw pump	1	2	4	Wastewater submerged pump	
5	Disinfection device	1	1	4	Solid chemical	
6	Sludge pump	1	1	1	Metering diaphragm	
7	Dehydrator	1	1	1	Belt press	
8	No.1 blower	2 (1)	2 (1)	2 (1)	Roots blower	
9	No.2 blower	2 (1)	3 (1)	5 (1)	Roots blower	
10	Static aerator	7	54	108	Vertical cylindrical type	
11	Caustic soda storage tank	1	1	1		
12	Caustic soda feeding pump	2 (1)	3 (1)	5 (1)	Metering diaphragm	
13	Caustic soda mixer	1	-	-	2 stage propeller type	
14	Methanol storage tank	1	1	1	Vertical square	
15	Methanol feeding pump	2 (1)	3 (1)	5 (1)	Metering diaphragm	
16	Ferric chloride storage tank	1	1	1	Vertical square	
17	Ferric chloride feeding pump	1 (1)	1	2(1)	Metering diaphragm	
18	Diffuser	4	17 (1)	19		
19	Belt conveyer	-	1	1		
20	Sludge cake hopper	-	1 unit	1 unit		

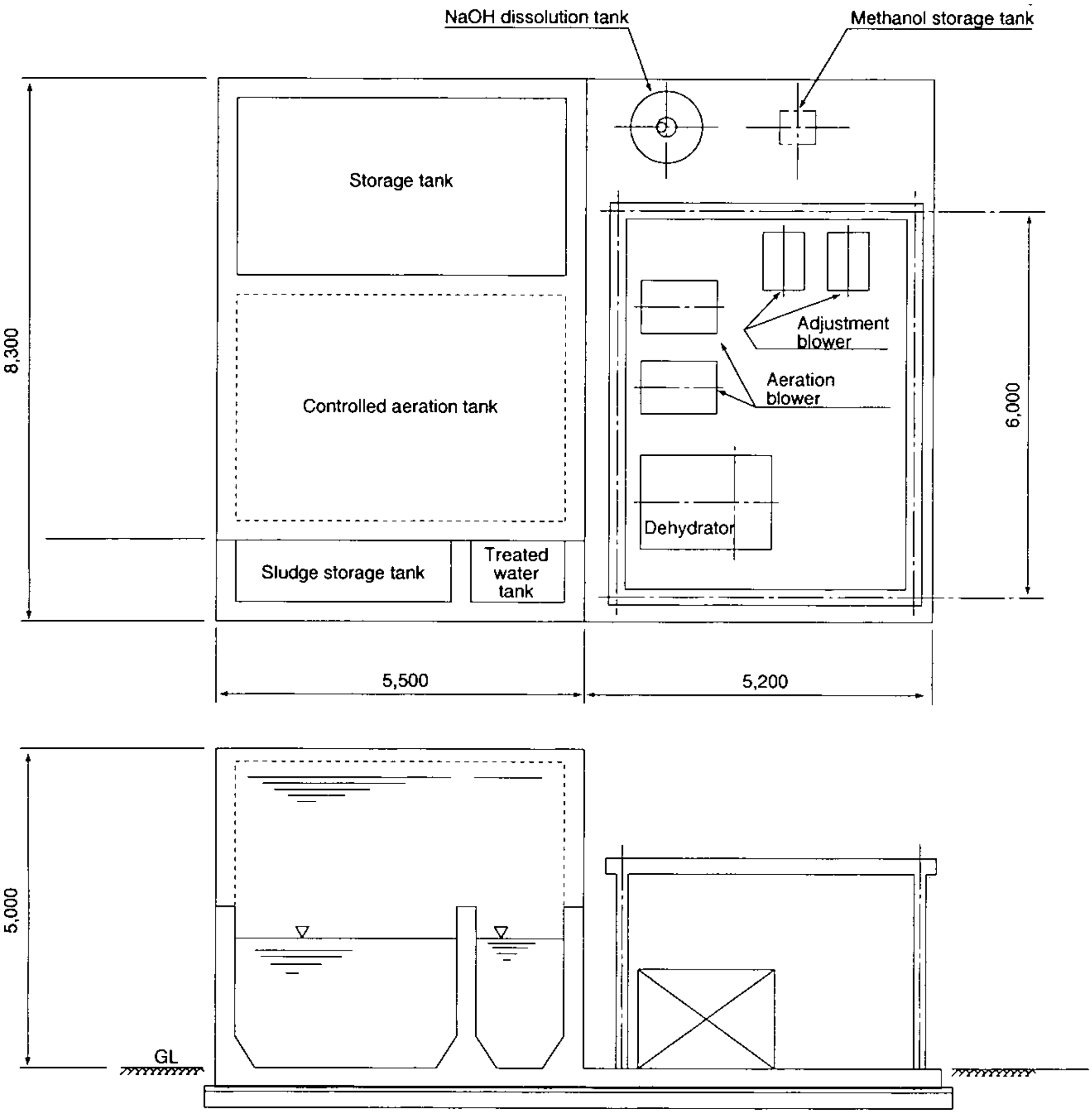


Fig 11-3 Layout of the controlled aeration activated sludge process facility ($50m^3/d$)

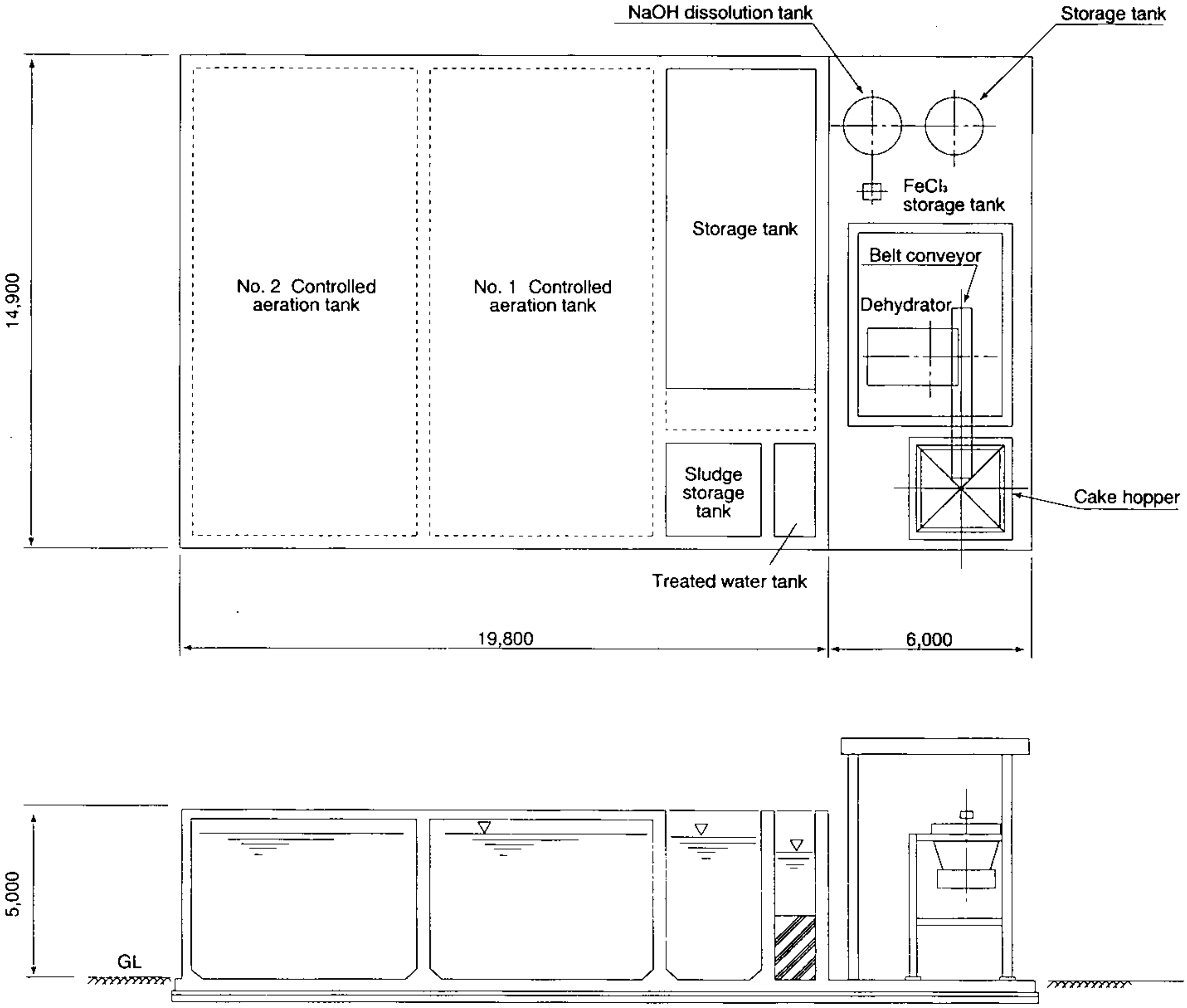


Fig 11-4 Layout of the controlled aeration activated sludge process facility (400m^3/d)

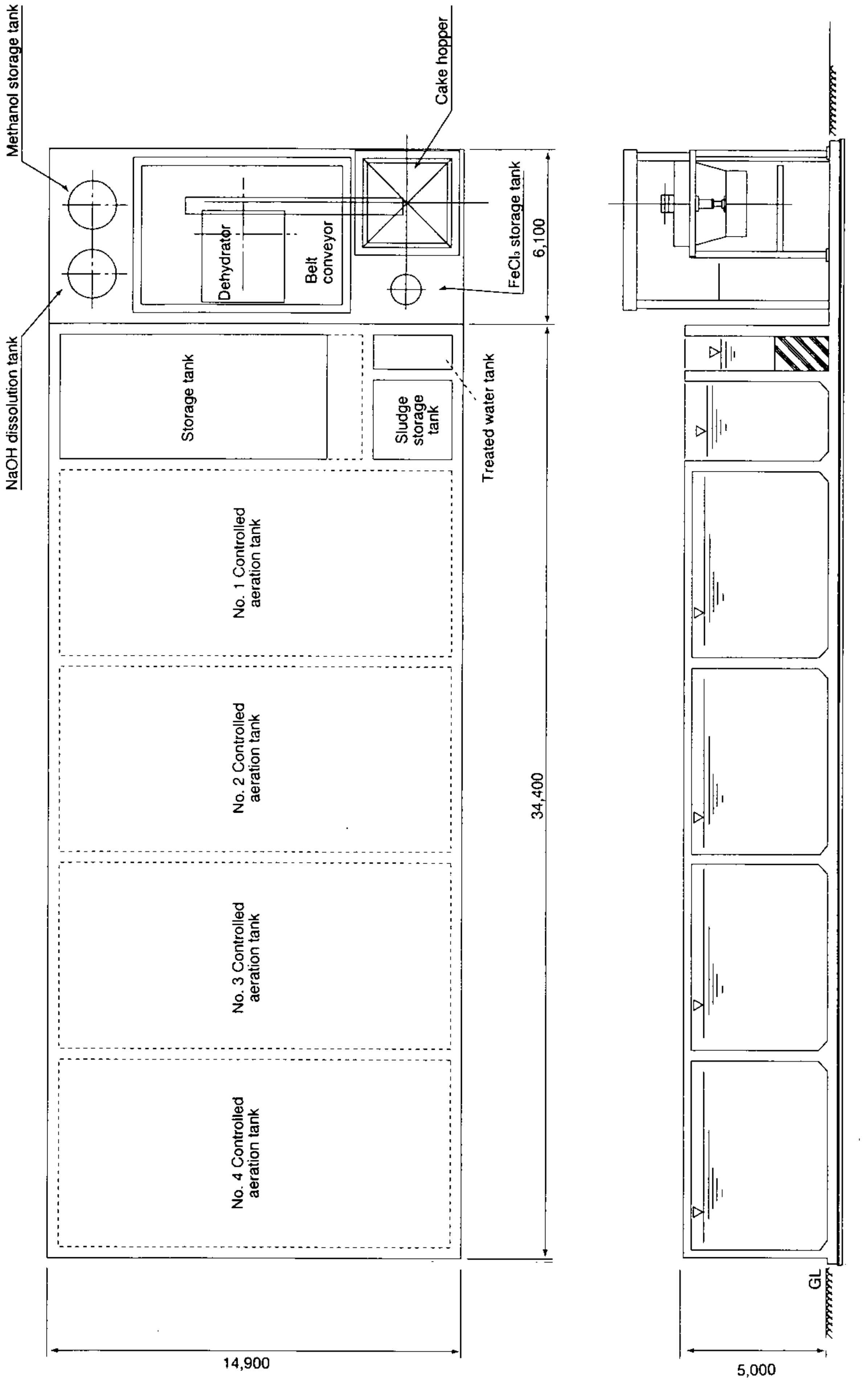


Fig 11-5 Layout of the controlled aeration activated sludge process facility (800m^3/d)

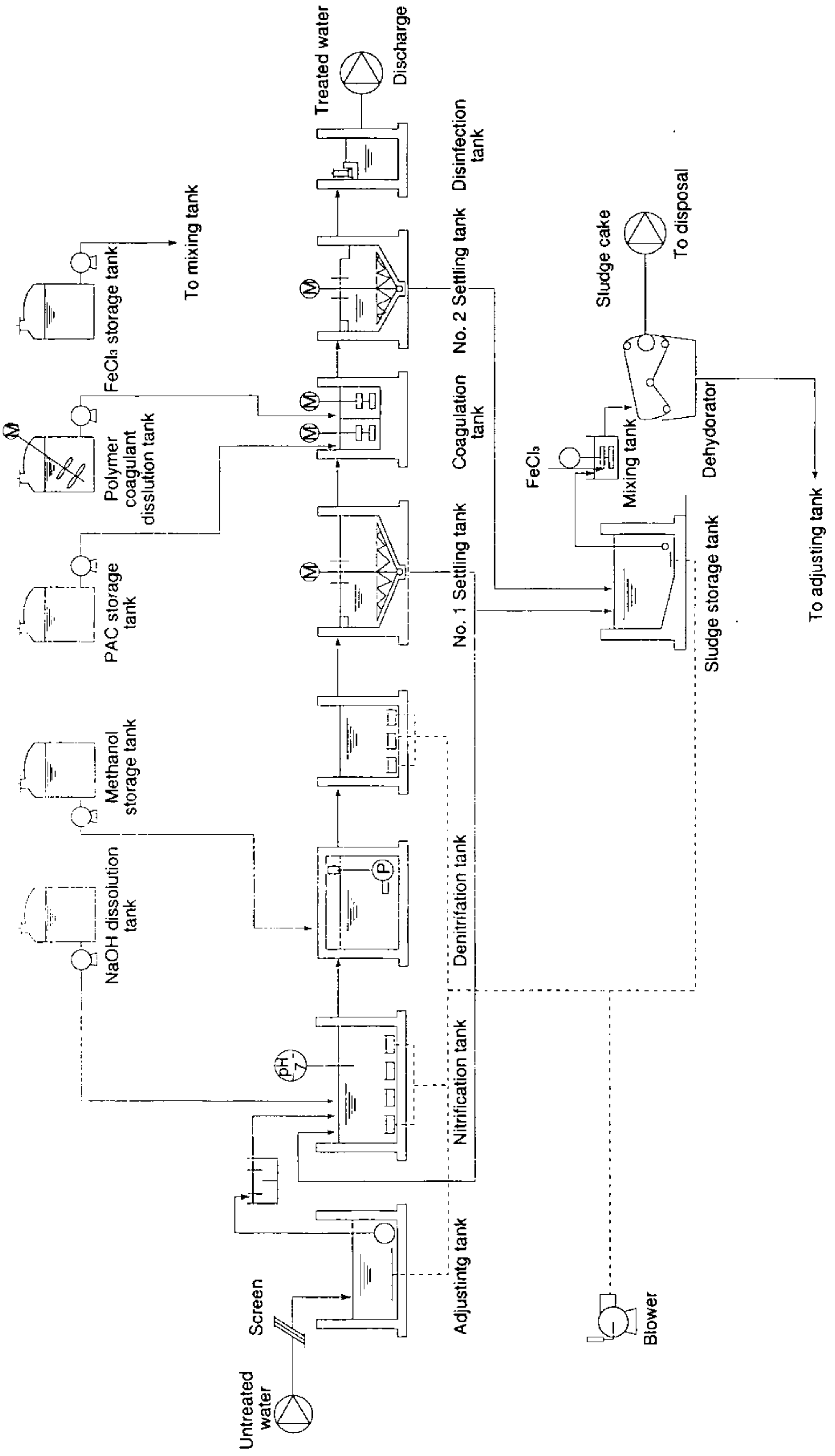


Fig 11-6 Flow diagram of the advanced treatment facility for food industry wastewater

Table 11-3 Equipment list of the continous activated sludge treatment & PAC coagulation treatment process

No.	Equipment name	Quantity			Type	Remarks
		50 m^3/d	400 m^3/d	800 m^3/d		
1	Automatic screen	1	2	4	Conveyor screen	
2	Adjusting tank pump	2 (1)	2 (1)	2 (1)	Wastewater submerged pump	
3	Flow equalization tank	1	1	1	V notch type	
4	Submerged mixing pump	1	1	1	Submerged aeration pump	
5	Mixing tank stirring device	1	1	1	2 stage puddle type	
6	Coagulation tank stirring device	1	1	1	2 stage puddle type	
7	Disinfection device	1	2	4	Solid chemical	
8	Blower	2 (1)	2 (1)	3 (1)	Roots blower	
9	Sludge pump	1	1	1	Air lift pump	
10	Dehydrator	1	1	1	Belt press	
11	Caustic soda storage tank	1	1	1	Vertical cylinder	
12	Caustic soda supply pump	2 (1)	2 (1)	2 (1)	Metering diaphram	
13	Caustic soda stirring device	1	-	-	2 stage propeller type	
14	Methanol storage tank	1	1	1	Vertical cylinder	
15	Methanol supply pump	2 (1)	2 (1)	2 (1)	Metering diaphram	
16	PAC storage tank	1	1	1	Vertical cylinder	
17	PAC supply pump	2 (1)	2 (1)	2(1)	Metering diaphram	
18	Polymer dissolution tank	2	2	2	Vertical cylinder	
19	Polymer supply pump	3 (1)	3 (1)	3 (1)	Metering diaphram	
20	Polymer stirring device	2	2	2	2 stage propeller type	
21	$FeCl_3$ storage tank	1	1	1	Vertical square	
22	$FeCl_3$ stupply pump	2 (1)	2 (1)	2 (1)	Metering diaphram	
23	Conveyor	-	1	1		
24	Cake hopper	-	1 unit	1 unit		
25	Diffuser	20	125	277	Disk type	
26	No.1 settling tank drive		1	1	Cycle reduction gear	
27	No.1 settling tank rake		1 unit	1 unit		
28	No.2 settling tank drive		1	1	Cycle reduction gear	
29	No.2 settling tank rake		1 unit	1 unit		
30	Compressor		1	1		

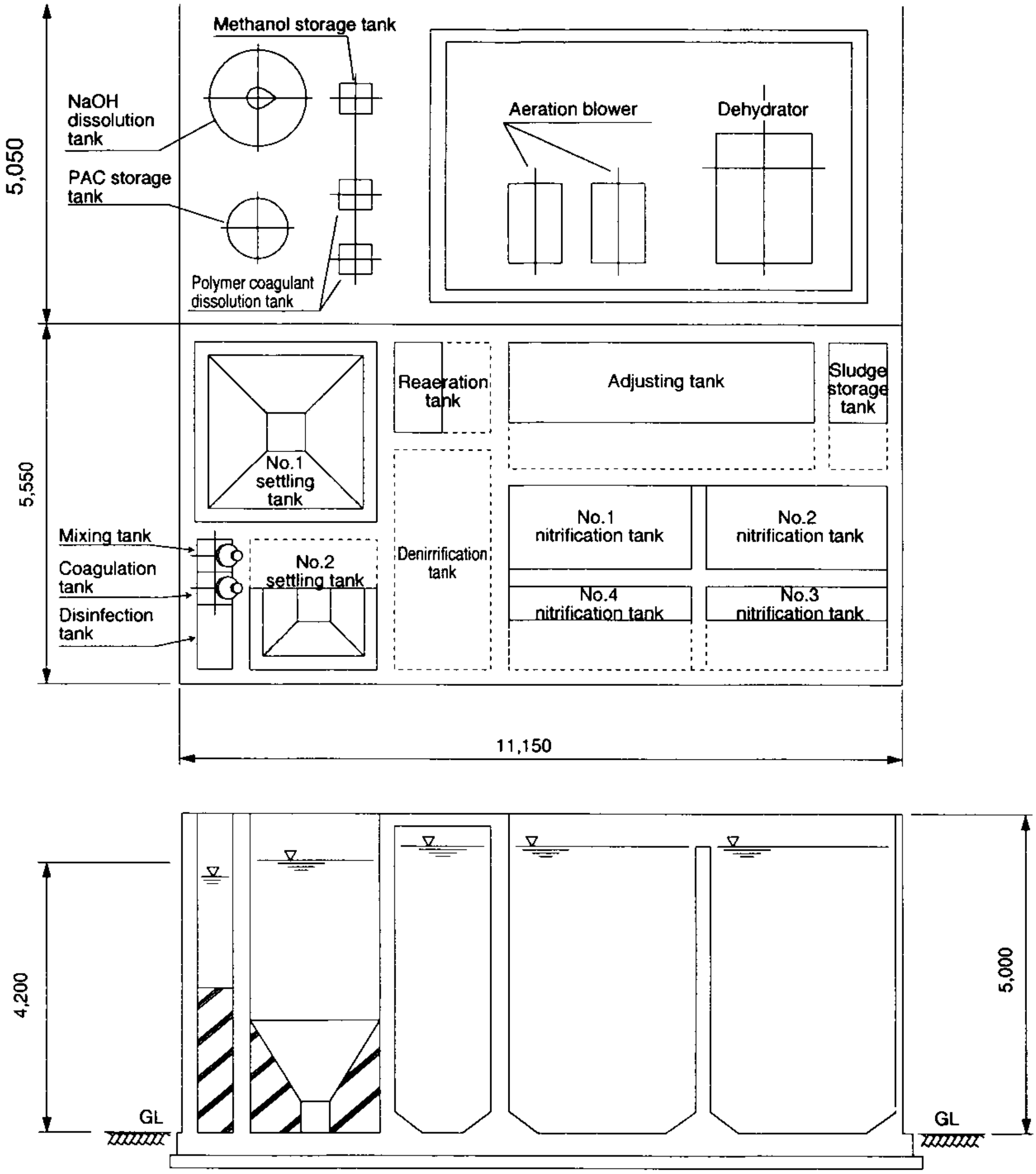


Fig 11-7 Layout of the continuous activated sludge treatment & PAC coagulation process facility (50m³/d)

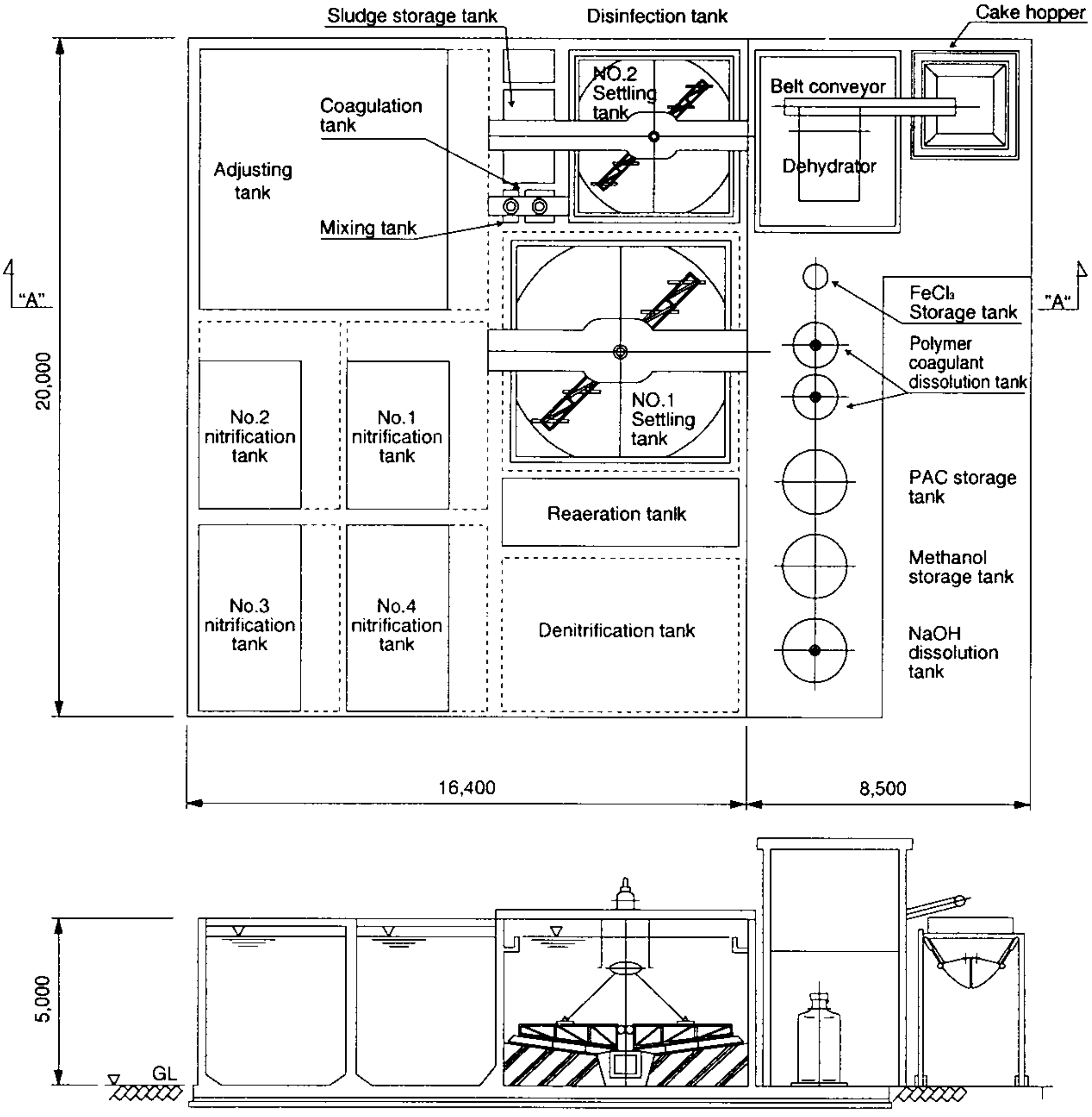


Fig 11-8 Layout of the continuous activated sludge treatment & PAC coagulation process facility ($400m^3/d$)

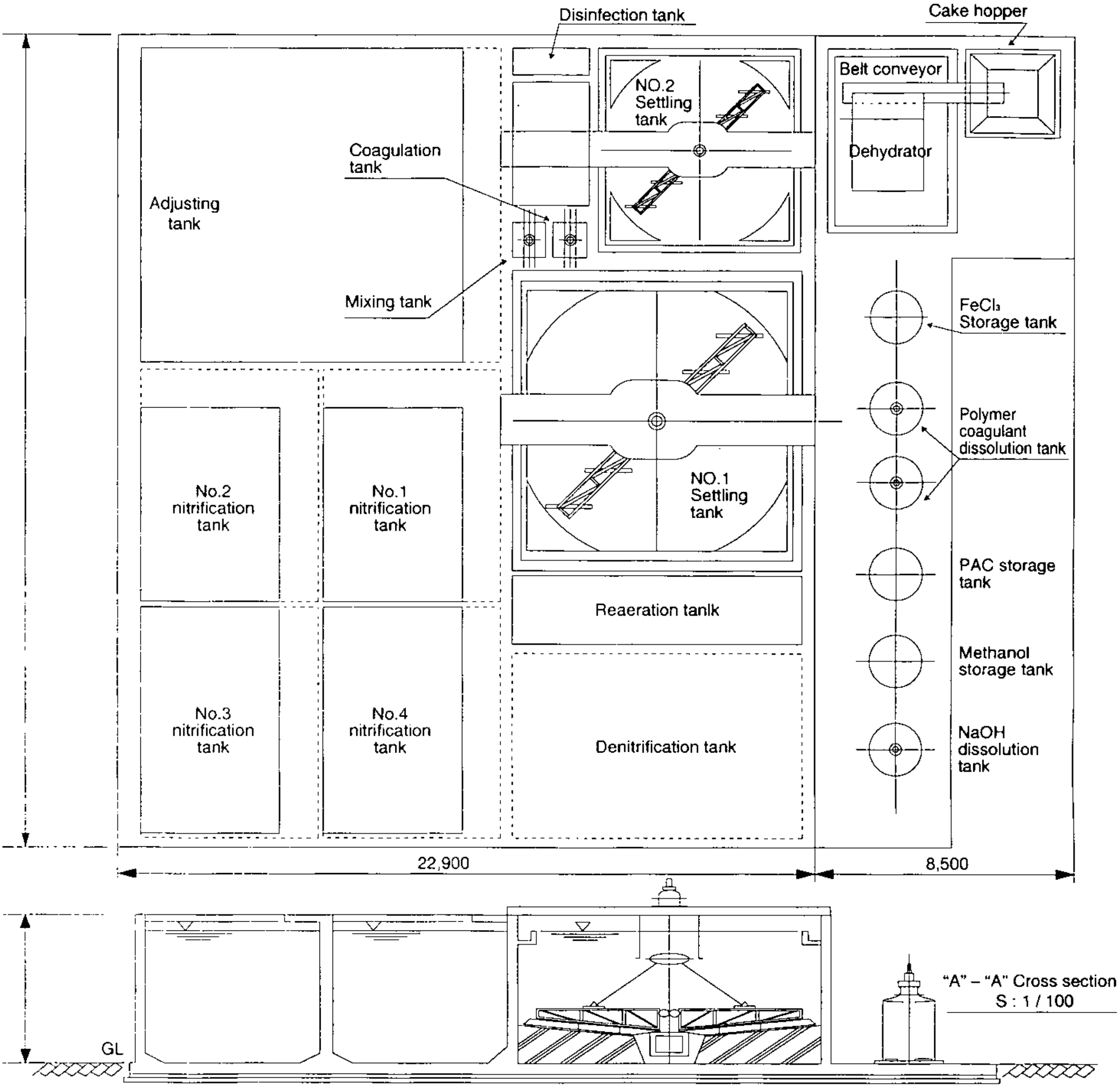


Fig 11-9 Layout of the continuous activated sludge treatment & PAC coagulation process facility ($800m^3/d$)

11-3 Operation cost

The operation cost was estimated by summing the chemical and electricity costs.
Table 11-4 shows the estimated price of the chemicals.

Table 11-4 Chemicals price

Name	Concentration · type · package	Price (yen/kg)
Caustic soda	97% · flake · paper bag (25 kg)	125
	35% · liquid · transferred by tank truck	30
Methanol	97% · liquid · oil can (14 kg)	135
	97% · liquid · transferred by tank truck	80
Poly aluminium chloride	10% (Al_2O_2) · liquid · polyethylene can (25 kg)	70
	10% (Al_2O_2) · liquid · transferred by tank truck	40
Ferric chloride	38% · liquid · polyethylene can (30 kg)	65
	38% · liquid · transferred by tank truck	35
Polymer coagulant	powder · paper bag (20 kg)	1300

Note) Research from March 1984 (Eastern Japan)

The electricity cost was estimated at ¥20 per 1 kWH with a motor load ratio of 70 %.
Table 11-5 shows the estimated operation cost of the food industry wastewater advanced treatment facility utilizing the controlled aeration activated sludge treatment process.
Table 11-6 shows the estimated operation cost of the food industry wastewater advanced treatment facility utilizing the conventional method of the continous activated sludge treatment & PAC coagulation treatment processes.

Table 11-5 Estimated operation cost of the controlled aeration activated sludge treatment process

Flow rate	50 m³/d		400 m³/d		800 m³/d	
Item / Item	Consumption (kg/d)	Cost (¥/d)	Consumption (kg/d)	Cost (¥/d)	Consumption (kg/d)	Cost (¥/d)
Caustic soda	8.4	1050	190	5700	380	11400
Methanol	14.8	1998	119	9520	237	18960
Ferric chloride	5.4	351	38.1	1334	76.2	2667
Total of chemical cost	¥3399/d		¥16554/d		¥33027/d	
Electricity cost	Consumption (kWH/d)	Cost (¥/d)	Consumption (kWH/d)	Cost (¥/d)	Consumption (kWH/d)	Cost (¥/d)
	128	¥2560/d	569	¥11380/d	1117	¥22340/d
Total operation cost	¥5959/d		¥27934/d		¥55367/d	

Table 11-6 Estimated operation cost of the continuous activated sludge treatment & PAC coagulation treatment process

Flow rate Item Item	50 m^3/d		400 m^3/d		800 m^3/d	
	Consumption (kg/d)	Cost (¥/d)	Consumption (kg/d)	Cost (¥/d)	Consumption (kg/d)	Cost (¥/d)
Caustic soda	16.8	2100	383	11490	766	22980
Methanol	14.8	1998	119	9520	237	18960
Poly aluminium chloride	32.9	2303	263	10520	526	21040
Polymer coagulant	0.057	74	0.43	559	0.85	1105
Ferric chloride	6.7	436	53.4	1869	106	3710
Total of chemical cost	¥6911/d		¥33958/d		¥67795/d	
Electricity cost	Consumption (kWH/d)	Cost (¥/d)	Consumption (kWH/d)	Cost (¥/d)	Consumption (kWH/d)	Cost (¥/d)
	203	¥4060/d	749	¥14940/d	1433	¥28660/d
Total operation cost	¥10971/d		¥48898/d		¥96455/d	

This estimation clarifies that the controlled aeration activated sludge process is a rational method because both the chemical and electiricity costs are cheaper and regardless of the flow rate, the total operation cost can be reduced by 43 - 46 % compared to the ordinary method.

In the study on the treatment cost per 1 m^3 of wastewater, in the controlled aeration activated sludge method, the cost becomes cheaper as the flow rate increases; ¥119 for 50 m^3/d and ¥70 for both 400 m^3/d and 800m^3/d. In the ordinary method, even for 800 m^3/d, the operation cost is ¥121/m^3, which is the same as that of the controlled aeration activated sludge method with a capacity of 50 m^3/d.

11-4 Conclusion

A advanced treatment process for food industry wastewater utilizing the controlled aeration activated sludge method including nitrogen and phosphorus removal was designed and compared with the ordinary method. The following is a summary of the study result.

(1) Based on estimation of food industry wastewater treatment, 50 m^3/d, 400 m^3/d and 800 m^3/d, to achieve the treated water quality target of the 'Eutrophication Prevention Ordinance' of Lake Biwa and Lake Kasumigaura, it was clarified that compared to the ordinary method utilizing the continous activated sludge & PAC coagulation treatment processes, the advanced treatment process of the controlled aeration activated sludge method including nitrogen and phosphorus removal was found to be simple and with easy maintenance.

(2) It was found that regardless of the flow rate, the operation cost of the controlled aeration activated sludge method was very cheap, ¥119/m^3 for a capacity of 50m^3/d and ¥70/m^3 for a capacity of 400m^3/d, 43 - 46 % cheaper than the ordinary method, allowing an economical treatment process incorporating tertiary treatment.

12. Conclusion

With the aim of application of an advanced treatment process for food industry wastewater, the controlled aeration activated sludge method was studied. It was confirmed that it allowed splendid control over bulking and stable treatment of organic substances, such as BOD and COD, was possible and the removal characteristics of nitrogen and phosphorus were clarified.
The result shows that compared to the ordinary advanced treatment method, this method is applicable to food industry wastewater treatment as a compact treatment method when easy maintenance is required and includes a low cost advanced treatment for nitrogen and phosphorus.
The following is the result of the experiment.

(1) The actual condition of the existing facilities of four food plants (soy sauce, chicken, tofu and noodle) were studied and the quantity and quality of the wastewater were measured.
In the soy sauce manufacturing plant, the main wastewater consisted of various washing wastewater generated from manufacturing processes and there was a daily and weekly fluctuation according to the work schedule. On the research day, the flow rate was 35 m^3/d , the wastewater quality was 770 mg/ ℓ of BOD and BOD : N : P = 100 : 8 : 1.6.
In the chicken processing plant, drain and various kinds of washing wastewater from the chicken cutting process were generated and thus the water quality and quantity were relatively stable. On the research day, the flow rate was 140 m^3/d , the wastewater quality was 580 mg/ ℓ of BOD and BOD : N : P = 100 : 20 : 2.3.
In the tofu manufacturing plant, since the main product was deep-fried tofu and the main wastewater was from soaking and compression, the water quantity and concentration were lower than typical tofu manufacturing plants. The flow rate on the research day was 60 m^3/d and the water quality was 3950 mg/ ℓ of BOD and BOD : N : P = 100 : 3.5 : 0.5.
In the noodle manufacturing plant, the main pollution source was wastewater from the boiler. The noodle washing & cooling wastewater and other various washing wastewater occupied about 85 % of the total volume. The flow rate on the research day was 73 m^3/d and the water quality was 360 mg/ ℓ of BOD and BOD : N : P = 100 : 4.3 : 0.5.

(2) Based on the study on the quality of the untreated water and treated water from the existing wastewater treatment facilities of the four food plants, knowledge on the treatment function was obtained.
In the soy sauce manufacturing plant, the average untreated water quality was 1400mg/ ℓ of BOD, 133mg/ ℓ of nitrogen and 17.4mg/ ℓ of phosphorus, and the water quality treated with the trickling method was 295mg/ ℓ of BOD, 42mg/ ℓ of nitrogen and 5.9mg/ ℓ of phosphorus because of exfloitation of the media sludge due to the low winter temperature.
In the chicken processing plant, the average untreated water quality was 900mg/ ℓ of BOD, 163mg/ ℓ of nitrogen and 17.3mg/ ℓ of phosphorus, and the water quality treated with the fixed bed activated sludge method was 49mg/ ℓ of BOD, 32mg/ ℓ of nitrogen and 6.8mg/ ℓ of phosphorus.
In the tofu manufacturing plant, the average untreated water quality was 3420mg/ ℓ of BOD, 136mg/ ℓ of nitrogen and 15.6mg/ ℓ of phosphorus, and the water quality treated with the contact aeration method was 20mg/ ℓ of BOD, 45mg/ ℓ of nitrogen and 4.8mg/ ℓ of phosphorus.
In the noodle manufacturing plant, the average untreated water quality was 1450mg/ ℓ of BOD, 22.9mg/ ℓ of nitrogenand 4.2mg/ ℓ of phosphorus, and the water quality treated with the batch type activated sludge method was 4mg/ ℓ of BOD, 2mg/ ℓ of nitrogen and 1mg/ ℓ of phosphorus.
It was found that, the existing facilities shared a common problem; maintenance trouble due to bulking and in many cases of the treatment facility was not being utilized sufficiently.

(3) Using the actual wastewater of the four food plants, the basic treatment characteristics of the controlled aeration activated sludge method was compared with that of the non-controlled aeration activated sludge method.

In the case of the soy sauce manufacturing plant, all organic substances could be sufficiently removed. As for the sludge property, SVI of the controlled aeration method was 100, but that of the non-controlled aeration method was 300 - 400, bulking condition.
In the case of the chicken processing plant, the COD value was increased by nitrous acid due to nitrification of nitrogen compounds. As for the sludge property, SVI of the controlled aeration method was about 100 and that of the non-controlled aeration method about 200.
In the case of the tofu manufacturing plant, since the wastewater substrate had a propensity to cause bulking, after a short period, about one week, bulking occured; SVI of the controlled aeration method was about 200 and that of the non-controlled aeration method 300 - 400, bulking condition.
In the case of the noodle manufacturing plant, the sludge property was stable, SVI of the controlled aeration method was 120, but that of the non-controlled aeration method was 300 and filamentous bacteria were observed.

(4) By measurement of the substrate removal rate constant, the characteristics of the controlled aeration activated sludge method were studied and compared with the existing treatment facility in the treatment of the noodle manufacturing wastewater.
The substrate removal rate constant was affected by the initial substrate concentration and water temperature, and in the existing treatment facility, when the substrate concentration increased by 100 mg/ ℓ , the substrate removal rate constant decreased by 0.1, and to increase it again, the substrate sludge loading had to be decreased by 0.08. But in the controlled aeration method, a decrease in the substrate sludge loading by 0.03 was enough to bring about the same effect.
In addition, from the view point of the respiration rate, it was confirmed that compared to the non-controlled aeration method, the substrate removal characteristics of the sludge and its activity were higher in the controlled aeration activated sludge method, so that stable treatment was possible even when fluctuation in the load occurred.

(5) Using the tofu manufacturing wastewater, basic treatment utilizing the controlled aeration activated sludge method was studied, and knowledge mainly on bulking control and other factors such as nutrients, sludge age and water temperature were obtained.
The nutrition balance, BOD loading of 0.5 - 0.9 $kg/m^3 \cdot d$, had no effect on the treated water quality but the excess nitrogen affected the settling characteristics of the sludge.
In the experiment, SRT ranged from 4 - 64 days, and the sludge load was high when SRT was 4 days and the treated water quality was worse.
The generated sludge volume was affected by water temperature and a (gross yield coefficient of sludge of removed BOD) was constant at 0.47, but b (autolysis coefficient by internal respiration) ranged from 0.02 to 0.07 according to the change in water temperature, from 10℃ to 20℃, which meant that the excess sludge volume increased at low water temperatures.
When excess nitrogen remained in the waterwater, the nitrification ratio of the controlled aeration activated sludge method was affected by water temperature and SRT, but about 95 % of the nitrification ratio could be expected at on SRT value of more than 8 days regardless of the water temperature.

(6) Using made-up wastewater, nitrogen and phosphorus removal was studied using an indoor bench-scale apperatus utilizing the controlled aeration activated sludge method, and knowledge on the treatment system was obtained.
In the controlled aeration method, nitrogen could be removed biologically through a combination of nitrification and denitrification generated by aeration and anaerobic mixing. Phosphrous could also be biologically removed by utilizing the phosphorus release and uptake ability of the sludge through a combination of anaerobic and aerobic conditions created by untreated water inflow and aeration.

(7) Using the actual wastewater of the soy sauce manufacturing plant, in the indoor bench-scale apperatus, the removal of BOD, nitrogen and phosphorus was studied in four different cases; non-controlled aeration,

controlled aeration, controlled aeration with anaerobic mixing and controlled aeration with methanol addition in the anaerobic mixing stage.

As a result, the removal efficiencies of organic substances - TOC, COD and BOD - were high regardless of the treatment method.

The nitrogen removal efficiency differed greatly according to the treatment method; 58.7 % for non-controlled aeration, 73.9 % for controlled aeration, 81.3 % for controlled aeration with anaerobic mixing and 94.4 % for controlled aeration with methanol addition in the anaerobic mixing stage. The efficiency of controlled aeration with methanol addition in the anaerobic mixing stage was stable; NO_3-N of the treated water was 1 mg/ ℓ or less and 5mg/ ℓ of T-N or less.

Phosphorus removal could not be clarified by the experiment because there were several factors besides the treatment time schedule, but there was a tendency in the removal efficiency as follows; non-controlled aeration < controlled aeration, controlled aeration method with anaerobic mixing process < controlled aeration with methanol addition in the anaerobic mixing stage.

(8) A pilot plant with a capacity of 2 m^3/d was established in the soy sauce manufacturing plant area and an on site treatment experiment was conducted.

Although influent SS and pollution load due to SS were high, BOD in SS of 50 %, it was found that a high removal efficiency was obtained through the installation of a conveyor type screen.

In the pilot plant, the removal efficiency of organic substances was 98 % of BOD, 91 % of TOC and 90 % of COD and TOC and COD non-biodegradable substances in the soy sauce manufacturing wastewater remained in the treated water.

In the ordinary time schedule of the controlled aeration method, the removal efficiency of nitrogen was 82 % and that of phosphorus 97 %.

(9) As an advanced treatment method for COD and color substances remaining in the biologically treated soy sauce manufacturing wastewater, the A-Hipo method was studied. It was found that the optimum condition was as follows; a pH for acid coaguration of 5, a reaction ratio Fe^{2+} /H_2O_2 as O of 4-5, a pH for the reaction of 4 and pH for coagulation of 5.

To decrease COD to 10 mg/ ℓ or less, 75 mg/ ℓ of Fe^{2+} and 15 mg/ ℓ of H_2O_2 as O needed to be added.

(10) For food industry wastewater, a controlled aeration activated sludge method with an advanced treatment for nitrogen and phosphorus removal was designed and compared with the ordinary method. It was found that the facility structure was simpler allowing easy maintenance, and the operation cost could be reduced by 43 - 46 %, compared to the ordinary method.

The operation cost of the controlled aeration activated sludge method was very cheap, ￥119/m^3 for a capacity of 50m^3/d and ￥70/m^3 for a capacity of 400m^3/d or more, and this proved it was an economical treatment process incorporating tertiary treatment.

The controlled aeration activated sludge method can also reduce the facility area by 22 - 25 % compared to the ordinary facility.

As a result, the study found the following points; in the controlled aeration activated sludge method, bulking can be controlled by the substrate concentration gradient formed in the aeration tank, and nitrification, denitrification and phosphorus removal are possible by maximum utilization of the physiological function of the activated sludge through creation of aerobic and anaerobic conditions in the aeration tank. / Consequently, as a treatment process suitable for food industry wastewater, a batch type compact treatment method with easy maintenance and a low cost advanced treatment for nitrogen and phosphorus was established.