

**PAPERS PRESENTED
FOR THE U.S.-JAPAN CONFERENCE
ON SEWAGE TREATMENT TECHNOLOGY**

APRIL, 1977

**WATER QUALITY CONTROL DIVISION
PUBLIC WORKS RESEARCH INSTITUTE
MINISTRY OF CONSTRUCTION,
JAPAN**

Foreword

Japan and the United States of America share a common concern for development of the sewage treatment technology. In the past six years, they have made a cooperative effort on problems of mutual concern through four earlier successful conferences. This publication includes seven technical papers which were submitted to the Fifth U.S.-Japan Conference on Sewage Treatment Technology, held in Tokyo in April 1977, by the members of the Public Works Research Institute. The Institute hopes that this publication will be of value to future efforts in this field.

April, 1977.

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I. Advanced Waste Treatment

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UPGRADING OF EXISTING SEWAGE TREATMENT PLANTS BY CHEMICAL ADDITION TO AERATION TANK

Tokuji Annaka

1.1 INTRODUCTION

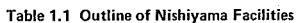
In Japan there are not yet any national water quality standards established for nitrogen and phosphorus. However, eutrofication is advancing in an increasing number of lakes, bays and other waters. It is therefore presumed that a substantial number of sewage treatment plants will be required in the near future to install themselves with facilities for removing phosphorus, nitrogen. But in our country it is considered extremely difficult, in many cases, to build additional facilities in the existing sewage treatment plants due to difficulty in securing tracts of land, although the situation is different in the case of newly planned plant.

This is the reason why attention is being focused into the method to upgrade the existing plants by adding metal salts to the existing facilities such as aeration tank. This method has already been in practical use in the Great Lakes region of the United States and some parts of Europe. But the situation in Japan is somewhat different from others; the strength of sewage is weak. On the average, domestic sewage in Japan contains 150 mg/l of BOD₅, 3 ~ 4 mgP/l of T-P, 30 mgN/l of T-N and 100 mg/l of total alkalinity as CaCO₃.

The Public Works Research Institute, the Ministry of Construction, in collaboration with the Sewage Works Bureau of Nagoya City, has been operating Nishiyama Sewage Treatment Plant in the city for two years for experimental purposes. Since then, experiments have been carried out by an addition of alum to the aeration tank to determine the effect of the alum addition on the entire functions of the treatment facilities. The results in the initial stage were reported at the previous, 4th conference. This report covers the performance in the ensuing period.

1.2 OUTLINE OF FACILITIES AND TESTING PROCEDURE

The Nishiyama Plant is a relatively small sewage treatment plant adopting a separate sewer system, having a design daily average flow of 20,000 m³/day (30,000 m³/day at maximum). Since the plant's served area is a residential area, incoming loadings fluctuate widely at times. There is no recycling of digester supernatant and other wastes from the sludge treatment facility, because sludge is treated at a separate plant. The conventional activated sludge process is adopted in the secondary treatment facility. Two bays — an alum bay and a control bay are used to compare their performance. There are three final sedimentation tanks. At the first two months, two of them were used one for the each bay. But they are now being used in a rather irregular manner — two on one and one on the other, to ensure the better quality of the plant effluent. The flow chart of the plant is shown in Fig. 1.1 and the dimension of the plant in Table 1.1.



Item Facility	Type	Dimension (m)	Number	Total volume (m ³)	Design detention time
Grit chamber	Rectangular	W L H 2.5 × 10 × 1.85	2		1.2 min.
Preparation tank	Diffused aeration	4.0 × 20 × 3.5	1	245	1.3 min.
Primary settler	Rectangular	5.0 × 28 × 30	4	1,680	1.3 hr.
Aerator	Diffused aeration	5.0 × 40 × 50 × 2 bay	2	4,000	3.2 hr.
Final settler	2 storied rectangular	5.0 × ^{1st} 22.5 ^{2nd} 27.5 × 3.0	3	2,250	1.8 hr.

Notes: 1. Influent coming in by gravity.
2. Sludge is being treated at the adjacent plant.

1.2.1 COAGULANT AND DOSING PROCEDURE

The coagulant used is liquid alum ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$) containing about 8 per cent of Al_2O_3 . It is dosed at the end of the aeration tank, and the dose rate is controlled to maintain the concentration of Al at the set level by use of a proportional pump. During the operational period of about 16 months, the dose concentration was from 8 to 6, 4, 3 mg/l of sewage in terms of Al (from about 100 to 75, 50, 32 mg/l of sewage in terms of alum). During this period, the concentration of phosphorus in the primary effluent changed from 2 to 7 T-Pmg/l in the daily average. The mole ratio of Al to P also proved to vary widely.

1.2.2 SAMPLING AND ANALYSIS

On a daily base, grab sampling is conducted every one or two hours by automatic samplers and 24 hour composite sample is adjusted in proportion to the flow rate. Samples are also taken manually as needed. Analyses are made two to four times a week.

1.2.3 AUTOMATIC CONTINUOUS WATER QUALITY ANALYZERS

The plant is equipped with several types of automatic water quality analyzers for continuous monitoring of the water quality of both influent and effluent and controls of the process.

There are ultra-sonic sludge density meters (3 units), TOC meter (1 unit, 6 points), UV meter (1 unit, 6 points), turbidimeters (5 units), phosphorus meters (3 units), ammonia nitrogen meters (3 units), PH meters (6 units) and pre-treatment units for these analyzers. Their operational performance is reported in a separate paper.

1.3 RESULTS AND DISCUSSION

The survey has been held continuously since February 1975. The period of survey, excluding the first two months, can be divided into seven experimental phases by the rate of alum dose and dosing methods. In Phase II, two of the three final sedimentation basins were used for control bay, and after Phase III, two of the three basins were used for alum bay. This switch was made because of a rise of MLSS in the alum bay which brought about massive solid wash-outs from the final settler under heavy hydraulic loading period. Summary of operational conditions in each phase is shown in Table 1.2. In Phase V, alum was dosed at a fixed rate determined by the daily average flow in order to test the situation under which flow proportional dose control is not possible. In Phase VIII, the point of addition of alum was moved from the end point to a point 3/4 of the entire length from the inlet (20 m from the terminal and about 60 min. in aeration time).

In each phase, efforts were made to maintain MLVSS of the two bays as close as possible, but this was not necessarily being achieved. Especially in the control bay, as temperatures went down, activated sludge began getting bulky, raising SS in the effluent and making it difficult to maintain MLSS of desired level. In general, MLSS was kept at low levels due to a low strength of sewage and a small capacity of the final settlers. The summary of the water qualities of influent and effluent in Phase II, IV, VI and VII is shown in Table 1.3.

Table 1.2 Summary of Operation

Item	Phase		Period		By		II		III		IV		V		VI		VII		VIII **)	
							1975.4.1 ~9.21		9.22~10.19		10.20~ 1976.1.7		1.8~2.7		2.7~3.31		4.1~6.30		8.23~9.2	
							Control	Alum	Control	Alum	Control	Alum	Control	Alum	Control	Alum	Control	Alum	Control	Alum
Flow rate (m ³ /d)							11,950		12,550		11,700		9,800		10,900		13,075		13,600	
Detention time (hr)							3.0	3.0	2.9	2.8	3.2	3.0	3.6	3.4	3.2	3.2	2.9	2.9	3.5	3.5
MLSS (mg/l)							1,025	912	1,403	1,002	768	1,546	765	1,496	631	1,333	743	1,810	659	1,231
MLVSS (mg/l)							719	589	946	634	620	1,000	673	1,136	517	968	477	1,238	432	737
MLVSS/MLSS (%)							70.1	64.6	67.4	63.3	80.7	64.7	88.0	75.9	81.8	72.6	77.5	67.0	65.5	59.8
SVI							94	112	76	89	115	72	136	76	164	68	78	58	96	61
BOD load (kg/kg/d)							0.41	0.46	0.21	0.29	0.64	0.32	0.68	0.35	0.75	0.36	0.59	0.25	0.41	0.23
SRT (d)							3.2	1.9			3.0	3.8			2.0	3.1	2.3	4.8	2.3	4.3
Settling time (hr)							3.6	1.8	1.7	3.4	1.8	3.6	2.2	4.3	2.0	3.9	1.4	2.8	1.5	3.1
Over flow rate (m ³ /d/m ²)							23.8	47.6	50.0	25.0	46.8	23.4	39.2	19.6	43.6	21.8	52.3	26.2	54.4	27.2
Alum dose (mg/Al/l)							-	8	-	8	-	6	-	4	-	4	-	3	-	6

*) Constant feed **) Point of dose was changed

Table 1.3 Summary of Performance

Item	Unit	Influent		Primary Effluent		Final Effluent (Control)		Final Effluent (Alum)		Removal Eff. Over Secondary (%)
		Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	
Phase II	PH	mg/l	6.88-7.30		6.86-7.60		6.26-7.60		6.62-7.3	
	Turb.	mg/l	93.8	67.0-132.0	72.0	52.0-92.0	8.0	4.1-11.3	7.4	4.9-11.6
	SS	mg/l	110	60-114	40	36-73	8.5	6.2-12.4	15.0	4.0-57.0
	T-ALK	mg/l	77.3	60.0-106.5	88.7	75.5-135	36.8	12.0-95.0	31.7	13.5-42.5
	T-BOD	mg/l	87	47-124	54	32-95	10.9	6.5-19.5	7.0	3.6-12.8
	S-BOD	mg/l	40	26-69	35	23-63	5.1	2.9-8.4	3.4	1.3-5.2
	T-COD	mg/l	59	44-90	43	27-74	14.0	9.3-16.4	9.8	8.2-18.9
	S-COD	mg/l	23	17-35	24	15-30	10.4	5.1-14.6	6.6	5.1-11.1
	T-TOC	mg/l	72	39-122	53	38-87	17.6	12.0-36	13.4	8.0-22.3
	S-TOC	mg/l	30	20-51	28	16-51	13.6	9.4-29.5	10.5	7.7-21.0
	TKN	mg/l	24.9	21.8-28.7	24.0	19.9-39.1	10.2	5.0-21.0	16.4	9.8-20.3
	NH3-N	mg/l	13.4	10.2-15.9	13.8	10.1-25.5	7.1	2.8-17.4	13.1	10.0-16.4
	NO2-N	mg/l	0.034	0.00-0.28	0.009	0.00-0.04	0.581	0.06-1.26	0.096	0.01-0.32
	NO3-N	mg/l	0.053	0.00-0.23	0.037	0.00-0.15	4.10	0.19-8.50	0.653	0.12-1.41
	T-P	mg/l	3.43	2.14-4.92	3.05	2.01-7.90	1.51	0.67-3.21	0.355	0.14-0.69
Phase IV	PH	mg/l	6.70-7.12		6.86-7.20		6.50-7.10		6.70-7.02	
	Turb.	mg/l	61.0	50.0-72.0	39.1	36.0-42.1	8.0	7.6-9.5	4.1	3.2-5.0
	SS	mg/l	128	90-174	42	34-49	12	6-20	4.7	0.2-12.3
	T-ALK	mg/l	81.3	59-104	89.1	79.3-94.5	55.4	23.4-84.5	48	40-56
	T-BOD	mg/l	133	97-168	79	64-102	22.7	1.12-28	4.5	2.5-6.9
	S-BOD	mg/l	47	39-57	46	38-60	4.7	2.2-6.4	2.8	1.9-4.6
	T-COD	mg/l	64	50-83	47	38-60	12.9	10.1-15.1	7.9	6.2-10.6
	S-COD	mg/l	20	16-28	22	17-31	9.1	6.8-10.8	6.1	4.7-6.9
	T-TOC	mg/l	75	42-110	52	25-71	18.4	6.2-34	10.9	4.0-17.0
	S-TOC	mg/l	23	12-32	23	12-32	9.7	4.3-15.0	6.6	3.5-9.0
	TKN	mg/l	26.0	24.2-34.6	23.7	21.0-28.2	15.0	6.9-20.2	17.1	14.2-20.4
	NH3-N	mg/l	13.7	12.0-14.6	15.0	13.2-16.5	11.3	5.4-15.3	14.5	12.3-16.5
	NO2-N	mg/l	0.023	0.00-0.05	0.01	0.00-0.02	0.243	0.12-0.30	0.035	0.02-0.08
	NO3-N	mg/l	0.25	0.00-0.82	0.133	0.00-0.41	3.03	0.18-6.45	0.488	0.07-0.83
	T-P	mg/l	3.15	2.06-4.88	3.00	1.86-3.86	1.93	1.29-2.73	0.168	0.14-0.21
Phase VI	PH	mg/l	6.70-7.12		6.86-7.20		6.50-7.10		6.70-7.02	
	Turb.	mg/l	98.5	79.0-120.0	51.7	49.0-54.0	8.5	5.7-7.0	5.3	3.7-7.0
	SS	mg/l	214	56-471	45	27-54	16.2	6.8-32.0	13.9	6.0-28
	T-ALK	mg/l	92.3	82-99.5	90.6	88-93.5	87.5	82-94.5	73.8	67.5-82
	T-BOD	mg/l	182	151-210	82	75-88	16.3	12.1-23	8.5	7.4-9.3
	S-BOD	mg/l	62	48-69	52	42-64	5.3	4.7-5.8	4.7	4.3-4.9
	T-COD	mg/l	87	72-120	57	48-76	15.3	12.9-21	12.4	10.4-19
	S-COD	mg/l	30	21-45	30	21-41	9.6	7.5-12.7	8.6	5.7-13.1
	TKN	mg/l	29.8	25.0-35.5	25.5	21.3-28.8	23.1	15.1-30	20.0	15.2-24
	NH3-N	mg/l	14.9	13.6-15.5	16.2	14.6-18.0	14.8	13.4-17	15.9	13.9-18
	NO2-N	mg/l	0.03	0.01-0.05	0.04	0.03-0.04	0.06	0.02-0.10	0.06	0.03-0.09
	NO3-N	mg/l	0.08	0.00-0.23	0.04	0.00-0.13	0.20	0.00-0.32	0.16	0.00-0.25
	T-P	mg/l	4.43	4.00-5.24	3.44	2.84-3.81	1.83	1.63-1.9	0.52	0.37-0.72
	Ort-P	mg/l	2.61	1.97-4.12	2.11	1.89-2.30	1.60	1.43-1.82	0.27	0.09-0.69
	S-T-P	mg/l	2.35	2.18-2.58	2.35	2.04-2.86	1.51	1.35-1.61	0.19	0.03-0.29
Phase VII	PH	mg/l	6.87-7.0		6.80-7.0		6.65-6.96		6.73-7.04	
	Turb.	mg/l	141	96-192	45	22-84	13	4-21	11	6-13
	SS	mg/l	66.8	55-80	77	68-87	46	30-69	61	50-67
	T-ALK	mg/l	108	88-149	68	62-96	26	14-34	12	6-16
	T-BOD	mg/l	40	23-53	35	23-48	7.2	6.3-8.8	6.1	5-8
	S-BOD	mg/l	61	47-76	38	29-53	13.8	11.2-16.7	12.3	10.5-14.1
	T-COD	mg/l	17	14-20	18	13-35	8.6	6.8-10.5	7.2	6.3-8.6
	S-COD	mg/l	63	53-69	41	26-48	13.9	11-17	10.8	9.0-12.0
	T-TOC	mg/l	20	13-24	19	13-22	9.5	8.3-10.9		
	S-TOC	mg/l	22.8	14.6-32.1	20.0	14.5-23.0	11.9	8.6-17.9	15.2	11.0-20.3
	TKN	mg/l	10.2	6.0-12.9	11.7	8.0-14.8	8.0	5.2-13.7	10.7	7.6-14.5
	NH3-N	mg/l	0.07	0.00-0.22	0.05	0.00-0.13	0.29	0.22-0.54	0.09	0.08-0.22
	NO2-N	mg/l	0.13	0.07-0.32	0.10	0.05-0.15	1.99	0.10-3.89	0.71	0.11-1.27
	NO3-N	mg/l	3.50	2.92-4.06	3.04	2.73-3.58	1.68	1.13-2.27	1.09	0.53-1.96
	T-P	mg/l	1.67	1.25-2.03	1.81	1.53-2.28	1.11	0.36-1.74	0.61	0.17-1.45
	Ort-P	mg/l	1.79	1.10-2.23	1.88	1.26-2.51	1.12	0.18-1.82	0.40	0.03-1.53
	S-T-P	mg/l	4.8	2.5-9.5	4.4	2.5-6.0	0.54	0.26-0.99	0.80	0.3-0.78
	E. coli	N/ml					1800	480-4500	840	200-1800
	ABS	mg/l					0.54	0.26-0.99	0.58	0.3-0.78

1.3.1 REMOVAL OF PHOSPHORUS

a. Phosphorus Removal and Mole Ratio

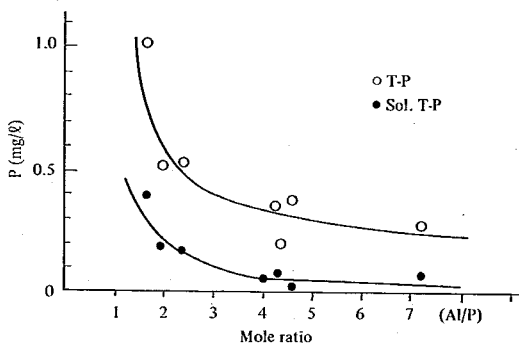
Phosphorus removal rate is raised drastically by an addition of alum. Table 1.4 shows the phosphorus removal efficiency in each phase. Fig. 1.2 shows relationships between the mole ratio of dosed Al to soluble phosphorus and residual phosphorus in effluent.

Table 1.4 Summary of Phosphorus Removal

Item \ Phase	II	III	IV	V	VI	VII	VIII
Primary Eff. T-P (mg/ℓ)	3.05	2.15	3.00	3.04	3.44	3.04	2.29
Primary Sol. T-P (mg/ℓ)	2.16	1.28	1.71	1.95	2.35	1.99	1.52
Al Dose (mg/ℓ)	8	8	6	4	4	3	6
Al/P Mole Ratio (T-P Base)	2.98	4.25	2.29	1.49	1.38	1.16	3.01
Al/P Mole Ratio (S-T-P Base)	4.25	7.18	4.03	2.35	1.95	1.74	4.53
Effluent T-P (mg/ℓ)	0.355	0.27	0.168	0.53	0.52	1.09	0.42
Effluent Sol. T-P (mg/ℓ)	0.087	0.09	0.045	0.17	0.19	0.40	0.03

Note: All values are average through the each phase.

Fig. 1.2 Residual Phosphorus V.S.
Al/P Mole Ratio (S-T-P Base)



The residual phosphorus is 0.5 mgP/ℓ in T-P and below 0.2 mgP/ℓ in soluble T-P in phases other than Phase VII in which the mole ratio was low. Fig. 1.2 shows that if the mole ratio is above 2 (Al 4 or alum about 50 mg/ℓ), effluent soluble phosphorus can be decreased below 0.2 mg/ℓ.

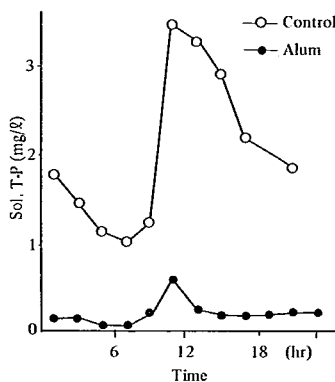
The residual phosphorus is 0.5 mg P/l in T-P and below 0.2mg P/l in soluble T-P in phases other than Phase VII in which the mole ratio was low. Figure 1-2 shows that if the mole ratio is above 2 (Al 4 or alum about 50mg/l), effluent soluble phosphorus can be decreased below 0.2mg/l.

Effluent PH varies with the rate of alum addition in the range from 6.6 to 7. It is not wise to dose alum at a mole ratio of more than 4, since the solubility of $AlPO_4$ is 0.01 mgP/l at PH6 and 0.3 mgP/l at PH7. However, as for total phosphorus removal a higher mole ratio seems to be effective in regards to floc formation. In the treatment of domestic sewage in our country where the daily average of phosphorus concentration is 3 ~ 4 mgP/l, an alum dose rate of 50 ~ 70 mg/l would be enough to lower T-P below 0.5 mg/l and soluble phosphorus 0.2 mg/l. Incidentally, at this particular sewage treatment plant, the phosphorus removal rate in the control bay is rather high with 40% ~ 50% probably due to a luxury uptake of bio-mass.

b. Phosphorus Removal Capability of Return Sludge

By an alum addition, the return sludge proves to remove (absorb) a substantial amount of phosphorus from the influent. Fig. 1.3 shows a comparison of hourly changes in the phosphorus concentration of supernatant of the mixed liquor immediately after return sludge was mixed with the influent in both control and alum bays.

Fig. 1.3 Diurnal Change in S.T.P. of Mixed Liquor Supernatant



(Phase IV) In this instance, a contact with return sludge removes about 80% of phosphorus. This is considered to be absorption of aluminum hydroxide contained in return sludge. Fig. 1.4 shows the results of a jar test in which the mixing ratio of return sludge and influent was changed in order to ascertain phosphorus removal capability. As the mixing ratio is raised, as shown in the figure, the rate of removing soluble phosphorus from the supernatant will increase, and the removal rate reaches 90% when MLSS is above 3,000 mg/l (Al concentration of sludge 10% Al/TS).

A similar test was conducted using alum sludge yielded in the water purification plant. Aluminum in sludge was 12.5% Al/TS. Fig. 1.5 shows the results of the jar test. As in the case of return sludge, a high phosphorus removal rate is attained with the alum sludge of the purification plant. This indicates an important role that alum sludge could play in removing phosphorus within the treatment process.

Fig. 1.4 P Removal Capability of Return Sludges

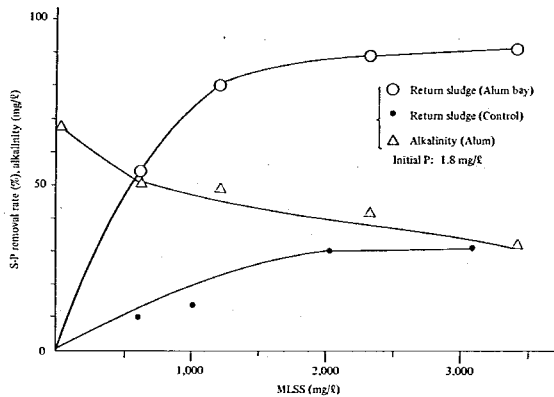
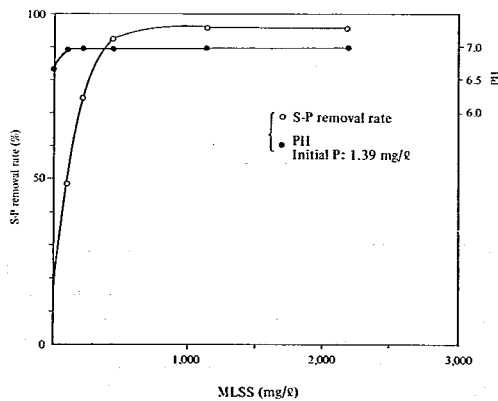


Fig. 1.5 P Removal Capability of Alum Sludge Yielded at Water Plant



Similar phenomena are observed in the pilot plants in Yokosuka and Kyoto treating secondary effluent with alum. They have stably attained a high phosphorus removal rate by returning sludge to the head of the plant.

As earlier stated, in Phase IV alum was dosed not in proportion to the inflow but a constant rate. As shown in Table 1.4, there seems little difference in phosphorus removal efficiency between flow proportional feed control and constant feed of alum. This indicates that the "secondary" phosphorus removing capability pertinent to return sludge plays an important role in overall phosphorus removal. In adding alum to the aeration tank, it would be more efficient and costly to use waste activated sludge from the alum bay for return sludge in other bays.

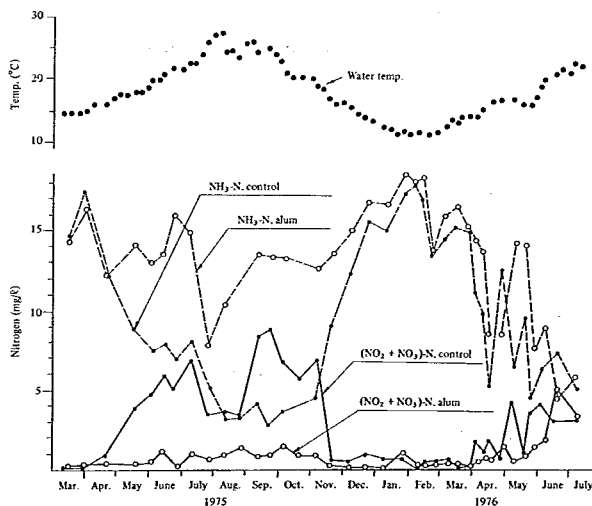
The Nishiyama plant is in the initial stage of practicing the mole ratio feed control by use of signals from automatic continuous phosphorus analyzers. If the phosphorus removal rate is determined by the mole ratio of phosphorus in the supernatant of mixed liquor at the point of addition, phosphorus removal capability of return sludge could be significant and affect the mole ratio feed control itself when influent phosphorus concentration is used as a base of P.

1.3.2 NITRIFICATION AND NITROGEN REMOVAL

In this project, removal of ammonia nitrogen by nitrification is just as important an objective as well as removal of phosphorus.

Fig. 1.6 shows changes in ammonia nitrogen, nitrite and nitrate in effluent of both bays as observed during a period from March 1975 to July 1976.

Fig. 1.6 Change in Nitrogen in Final Effluent



SRT was maintained in the range of 2 ~ 5 days. In both bays nitrification did not take place in winter when temperature was low, probably because SRT was not enough. In Phases II ~ IV in which temperatures were above 20°C, substantial nitrification took place only in the control bay, while nitrite and nitrate nitrogen was slightly observed in the alum bay.

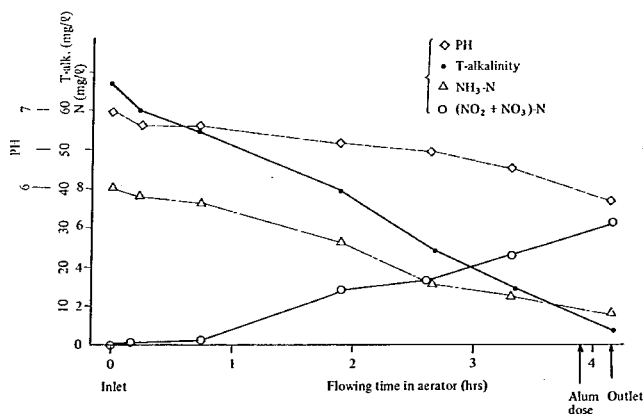
The absence of nitrification in the alum bay has been discussed from various angles; first, SRT required to maintain nitrifiers; second, interference of aluminum on the activity of nitrifiers; and third, depletion of alkalinity.

As to the interference of aluminum on nitrification, batch type laboratory tests show that an addition of 10 mgAl/l (120 mg/l of alum) causes no noticeable affect.

The fact that in Phase VII in which SRT is maintained higher (4.8 days), nitrification took place even in the alum bay seems to indicate that SRT has a large effect on nitrification, in conjunction with the effect of temperature. This, however, seems to have some relationships with a relatively low alum dose rate, which means a low consumption of alkalinity by alum addition. The nitrification of N1 consumes alkalinity by 7.1 (as CaCO_3). The influent of this plant shows an daily average T-N value of more than 25 mgN/l and the alkalinity is a high 80 mg/l. Complete nitrification, therefore, could not be expected without an addition of alkalis, even if other conditions are satisfactory.

Fig. 1.7 shows how the nitrogen, the PH and the alkalinity of the superatant of the mixed liquid will change as it flows down through the tank in the alum bay (Phase VII). In this instance of low loading night hours, the concentration of ammonia nitrogen is low. But complete nitrification does not take place as alkalinity is consumed by nitrification and alum addition.

Fig. 1.7 Change in Supernatant Quality in the Aerator (Alum Bay)



Thus, as in the case of non-chemical addition, the lowering in water temperature causes a problem in nitrifying the effluent in the alum bay, as shown in Fig. 1.6. Therefore, to keep desirable SRT is a major factor in conjunction with the capacity and structural improvement of the final sedimentation basin. It is also clear that complete nitrification cannot be achieved without adding alkalis in place where alkalinity is low, like the domestic sewage treatment of our country.

In the case where nitrified effluent is obtainable, it is known that fine scum appears to the surface of the final settler as a result of the generation of nitrogen gas by denitrification at the bottom of the settler. Through the experiment, it was observed during the nitrification in the control bay. An experiment in resettling by spraying of the effluent has been conducted. Since scum often flows out with the effluent, the installation of a scum collector is under consideration.

On the other hand, in Phase VII in which nitrification took place in the alum bay, the scum as mentioned above does not float at all and the surface of the settler is clear in the final settler, even if the level of oxidized nitrogen in the effluent is the same as that in the control level. There seem to be factors hampering denitrification in the alum dosing process.

In ordinary cases, at the plants where nitrification is taking place, there appear differences between the inflow and outflow of T-N, which results in a relatively high T-N removal rate probably due to denitrification. The T-N removal rate is generally lower in the alum bay than in the control bay even when same degree of nitrification is taking place. This is considered to have something to do with preventing the floating of scum.

1.3.3 ACCELERATION OF NITRIFICATION BY PH ADJUSTMENT

As mentioned earlier, when alum is added, it consumes alkalinity and prevents complete nitrification. Therefore, alkalis, such as sodium hydroxide and lime, need to be added in order to remove phosphorus and nitrify the effluent simultaneously in the system. There, it is difficult to use lime because of scale formation in pipes and other places. Therefore, sodium hydroxide will probably be better to be adopted for the purpose.

A bench scale laboratory test was conducted prior to the addition of sodium hydroxide to the main plant. About two months of operation demonstrated that it is possible to obtain an almost completely nitrified effluent by adding alum at the end section of the tank and sodium hydroxide at the inlet. Table 1.5, 1.6 show the operating conditions of the bench scale plant and the qualities of the influent and effluent. Almost complete nitrification and a T-N removal rate of about 70% are achieved by maintaining SRT at 8.2 days and PH at the inlet at 8.2. The problem of this process seems to be a somewhat low phosphorus removal rate due to rises in the PH of the effluent.

Table 1.5 Summary of Bench Scale Plant Operation

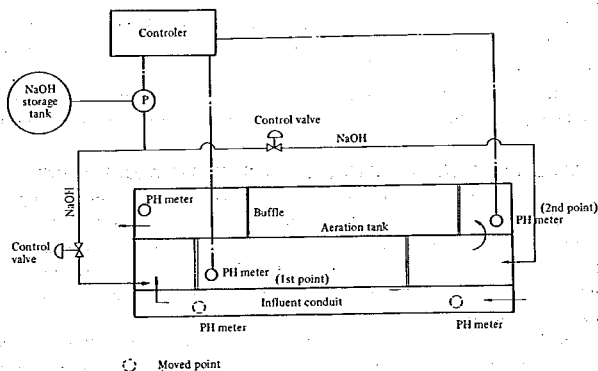
Flow (m ³ /d)	Al Dose (mg Al/l)	Adjusted PH	MLSS (mg/l)	BOD Load (kg/kg/d)	SRT (d)
2.5	≈ 4	8.2	3.030	0.17	8.2

Table 1.6 Summary of Bench Scale Plant Performance

		PH	T-alkalinity (mg/l CaCO_3)	SS (mg/l)	COD (mg/l)	TKN (mg/l)	$\text{NH}_3\text{-N}$ (mg/l)	$\text{NO}_3\text{+NO}_2\text{-N}$ (mg/l)	T-P (mg/l)
Inf.	Average	6.6~7.2	66	38	39	16.7	8.3	0.05	2.66
	Range		57~104	13~117	25~73	12~30	6~11	0~0.9	1.56~5.15
Eff.	Average	7.3~7.6	93	14	8	1.45	0.26	2.96	0.78
	Range		88~102	9~20	6~15	1.1~1.7	0.14~0.40	2.8~4.2	0.5~1.2

The addition of sodium hydroxide to the actual facilities began in mid December 1976. Since the aeration tank is of a conventional plug flow type, the caustic addition is controlled at two points. One point is immediately after the mixture of the influent with return sludge and the other at the middle section of the tank. Fig. 1.8 shows PH controls chart.

Fig. 1.8 PH Control Diagram



About six weeks have passed since the caustic addition began. The average MLSS concentration within the tank has kept 3,500 mg/l (SRT approx. 8 days). The dose rate of alum is 8 mg/l in terms of aluminum. The addition of sodium hydroxide (20% solution of NaOH) is controlled to raise PH at the first adjustment point up to 7.8 ~ 8.0. At the present stage, nitrification has not taken place as originally expected, because the water temperature is low - 10° ~ 12°C and acclimation to change in PH is insufficient.

Two problems have occurred as to the PH adjustment at the actual facilities. One problem is that PH rises momentarily to about 12 in limited portions around the inlet. The second problem is that as a result of this, a sticky foam substance appears to the surface of the aeration tank and that scum forms on the surface of the final settler.

The dose of sodium hydroxide is controlled using PH meters in the way that the dosing pump turns on at the set upper value (8.0) and turns off at the lower value by the signals of PH meters and that the dose rate is proportional to the inflow. There is a 15-minute time lag between the dose of sodium hydroxide and the response of the PH meter. This has been found to allow the dose of surplus sodium hydroxide and raise PH around some portion of the inlet up to 12.

A separately conducted indoor experiment shows that as PH exceeds 11, nitrogen in activated sludge resolubilizes and foam formation develops. Also at the batch test using return sludge of this treatment plant, as the PH of return sludge was raised to 12 organic substances in activated sludge resolubilizes into the supernatant, such high concentration as TOC of 1,000 mg/l and poly-saccharide of 600 mg/l. Thus, it was considered that this might have been the reason of upset of the entire process.

As a result, the point of sodium hydroxide addition was moved to the upper end of the influent waterway (approx. 40 meters); the method was changed to adjust PH at the tank inlet; and the outflow of the dosing pump was changed to a constant rate.

1.3.4 ORGANIC REMOVAL

The addition of alum raised removal rates for BOD₅, TOC and COD. Compared with control bay, the removal rate for BOD₅ rose by 30%~80%, that for COD 20%~40% and that for TOC 30%~40%. Similar results were attained for the removal of soluble organic substances.

1.3.5 SUSPENDED SOLID REMOVAL

In Phase II, effluent SS was higher in the alum bay. But it outrated that of the control bay after Phase III in which two final settlers were used. The debris of aluminum hydroxide floc tends to flow out more easily, in addition to rises in solid loading in the final settler. Therefore, it is necessary to provide a lower overflow rate than the ordinary design value. It is observed that as the alum dose rate is lowered, the density of the effluent SS tends to increase; this is probably because a decline in the dose rate will aggravate coagulation.

In Phase VIII in which the point of alum addition was moved to a point 3/4 of the entire length (20 meters from the end), the effluent became a little bit milky white as time passed, although there were no noticeable differences in the SS value between this and other phases. The change in the effluent colour has already been reported in other studies. As reported in some of them, it seems to be reasonable to assume that this has something to do with the point of alum addition. It is considered that a deflocculation caused by over-aeration after alum addition has a significant effect on this because such a phenomenon did not take place at all in experiments in which alum was dosed from the end point.

Table 1.7 is a comparison of the composition of condensed these substances and that of solids in effluent from the control bay.

In the control bay, substances of obviously different quality compared with activated sludge flows out, but in the alum bay, activated sludge including aluminum itself comes out in broken-up form.

Table 1.7 Component of Solids

	SS in Eff. (Control)	Return Sludge (Control)	SS in Eff. (Alum)	Return Sludge (Alum)
VSS/TS (%)	49.2	70.0	40.8	63.0
TKN/TS (%)	3.79	7.28	6.75	5.85
T-P/TS (%)	0.61	2.95	2.96	3.14
AQ/TS (%)	0	1.74	7.65	8.10

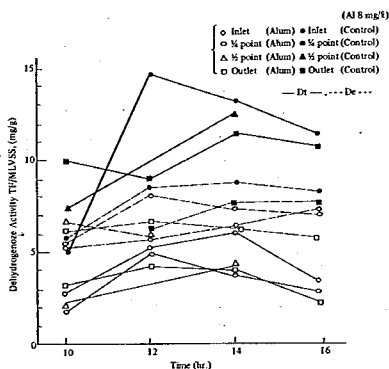
1.3.6 EFFECTS ON MICROORGANISMS

The effects alum have on activated sludge protozoa have been discussed from many angles.

In this project, survey was conducted from two points. One is the microscopic examination of activated sludge protozoa. The other is the measurement of dehydrogenizing activity, which is considered to have relationships with the metabolic activity of micro-organisms.

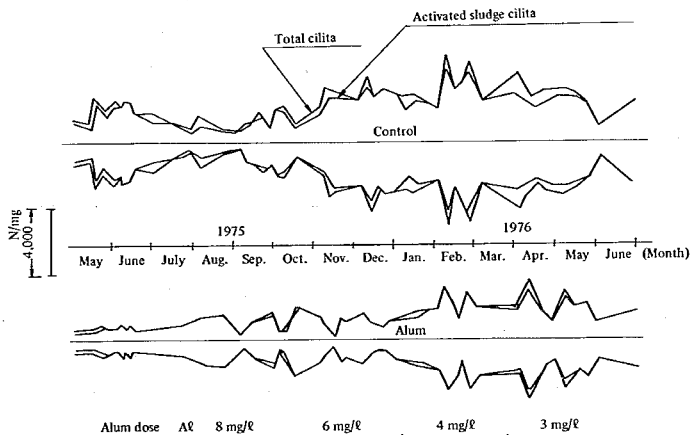
Fig. 1.9 is the comparison between the two bays of the dehydrogenizing activity of activated sludge when 8 mg/l of aluminum was added. It shows hourly changes at different points in the aeration tank. Dt on the figure shows total activity. De shows activity after substrates are washed out (that of endogenous respiration). On the control side, Dt is always higher than De, while De is higher on the alum dose side. In other words, activity rises after substrates are washed out. There is little difference in the De value between the two bays. This indicates that the addition of 8 mg/l of aluminum is interfering biological activities in one way or the other. Similar phenomena are often observed in sewage treatment plants where relatively large volumes of industrial waste flow in.

Fig. 1.9 Comparison of Dehydrogenase Activity



As for changes in protozoa, the numbers of species and population proved to decline in the alum bay comparing to the control bay when the concentration of added aluminum was high. Fig. 1.10 shows monthly changes in the population of total ciliata and activated sludge ciliata per unit of MLSS in both bays. Although alum addition reduces the population, the degree differs with the dose rate of aluminum. There is little difference between the two bays when aluminum is below 4 mg/l (below 50 mg/l as alum). Thus, it seems to be possible to assume that there is little practical effect on protozoa when added alum is below 50 mg/l. As mentioned earlier, this dose rate is also effective for phosphorus removal.

Fig. 1.10 Comparison of Ciliata Number in Activated Sludge



Alum addition would considerably reduce the population of swimming type ciliata (difference between total ciliata and activated sludge ciliata). But it is not yet clear — whether the reduction is a direct effect of aluminum or it is a result of the change in environment by advanced removal of organic substances.

1.3.7 MATERIAL BALANCE OF SLUDGE PRODUCTION

It is known that an increase in sludge production is a one of the most troublesome problems in the process. In this plant, continuous monitoring of primary sludge and waste activated sludge is being conducted in both control and alum bays to determine the material balance of sludge production. Sludge production is measured by electro-magnetic flow meters and solids by ultra-sonic sludge density meters.

The increase in sludge production by alum addition is theoretically calculated by the amount of $AlPO_4$ produced by the coagulation and $Al(OH)_3$ by hydrolysis. There is also the transfer of organic sludge as in the control bay.

Table 1.8 is the summary of daily influent loadings and primary sludge in daily average monitored by each phase during the whole experimental period. Shown on the Table is the material balances of sludge production of added aluminum of 8, 6, 4, 3 mgAl/l.

Table 1.8 Comparison of Sludge Production

Item	Phase Bay	II		IV		VI		VII	
		Control	Alum	Control	Alum	Control	Alum	Control	Alum
① Solids in Influent (kg/d)		562		491		491		588	
② Waste Activated Sludge (kg/d)		556	616	374	752	441	695	470	614
③ Solids in Effluent (kg/d)		77	336	140	55	177	152	169	143
④ Total Sludge Production (kg/d) ② + ③		633	952	514	807	618	847	639	757
⑤ Concentration* (mg/l)		53.1	80.0	43.9	68.9	56.7	77.7	48.8	57.9
⑥ Net Sludge Production (kg/d) ④ - ①		71	390	23	316	127	356	51	169
⑦ Concentration* (mg/l)		5.9	32.0	2.0	27.0	11.7	32.6	3.9	12.9
⑧ Increased Concentration (mg/l)		26.1		25.0		20.9		9.0	
⑨ Rate of Increase		1.51		1.57		1.37		1.19	
⑩ Alum dose as Al (mg/l)		8		6		4		3	

*) Divided by Inflow.

The net sludge production which is a difference between total sludge production and solids in influent is also shown in the Table together with a concentration based on the influent flow.

The sludge production in the alum bay increases as the alum dose rate rises. In comparison with the control bay, the sludge production is 1.57 times at 6 mg/l of Al, 1.37 times at 4 mg/l and 1.19 times at 3 mg/l. In terms of net production, the increase rates are much higher. This is because the net sludge production is generally very little in the conventional activated sludge process, in other words, the total sludge production and the solids loadings in the influent are just about the same. Providing that the difference in production rate between the control and alum bays is the amount of increase in inorganic sludge created by alum addition, the increase in concentration is 9.1 ~ 26.9 mg/l. Theoretically, the increase in concentration is about four times that of added aluminum. This corresponds to actual measurements that read 3 ~ 5 times. Therefore, the increase in sludge volume may be estimated by the alum dosing rate. In case the strength of sewage is weak like in our country increase in sludge production ranges from 20% to 60%, more than non-alum process.

As aluminum addition is changed from 8 mg/l to 6, 4, 3 mg/l, the accumulation of aluminum in sludge changes from about 12% to 6, 4.3, 4.0% Al/TS, respectively.

1.4 COSTS OF CHEMICALS

According to the purchase prices in Nagoya City, alum is 21 ¥/kg in terms of 14.5% Al_2O_3 (¥273 per kilogram of aluminum). The chemical cost required is 2.19¥/m³, 1.64¥/m³ and 1.09¥/m³ respectively when the rate of added alum is 100 mg/l, 75 mg/l and 50 mg/l.

Sodium hydroxide is ¥61.3 in terms of one kilogram of NaOH, which means 1.23¥/m³, 2.45¥/m³ and 4.9¥/m³ respectively when the alkalinity addition is 25, 50 and 100 mg/l (as CaCO_3).

Aluminum consumed in Japan is almost entirely imported from abroad. Therefore, the cost is rather high compared with other countries and its unit price is unstable. These are the factors that should be taken into account in using aluminum salts as coagulants. The situation is generally the same for iron salts. Therefore, it is strongly considered necessary to recover the used coagulants from sludges and the projects is now underway at the laboratory experiments.

1.5 SUMMARY

The following has been obtained through a series of experiments in which alum was added to the aeration tank treating typical domestic sewage in Japan, which is relatively weak strength.

- 1) When phosphorus contained in the influent is below 3 ~ 4 mgT-P/l, an alum addition of 50 mg/l reduces the residual phosphorus to less than 0.5 mg/l.
- 2) The phosphorus removal capability of return sludge is sufficient enough to be taken into account in controlling alum dose.
- 3) It is possible to obtain nitrified effluent while removing phosphorus. But in the case of a sewage of low alkalinity like one in Japan, it is necessary to add alkalis.
- 4) Adequate care should be taken in determining the method to dose alkalis to the aerator.
- 5) The alum addition of 50 mg/l has little practical effect on activated sludge protozoa.
- 6) The increase in sludge production varies with the alum dose rate, and in this particular study increase rate was about 60%.

FILTRATION STUDY AT THE KYOTO PILOT PLANT

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FILTRATION STUDY AT THE KYOTO PILOT PLANT

Shunsoku Kyosai

The followings are a summary on the suspended solid removal by filter and carbon contractor at the Kyoto pilot plant.

The section — 3.1.1 — deals with the solid removal by filter of secondary effluent and alum precipitated effluent under varying influent flow. The sewage inflow into a treatment plant varies every moment. Its variation is extremely great from a low in the night on dry weather to a high on storm weather.

There are two possible ways to meet the inflow variation — one, the constant filtration with flow equalization ponds and the other, the varying filtration allowing the influent flow variation. Because of a omission of a flow equalization pond, the varying filtration is superior to the constant filtration, if there is no great difference as to the quality of effluent and the suspended solid loading between the two. This report sums up the results from October, 1975 to March, 1976.

The section — 3.1.2 — is a study on the possibility of removing both organics and solids by granular carbon. The influents for testing here are filtered secondary effluent, secondary effluent and tertiary alum precipitated effluent.

In this method, there are questions as mentioned below.

- 1) Is the necessary filtration run length expected by carbon layer?
- 2) Is the suspended solids in the effluent satisfactory?
- 3) Is there a drop in organic removal efficiency of carbon by accumulated solids on the surface or in the micropore of carbon?
- 4) Is there a drop in carbon regeneration efficiency by accumulated solids on the surface or in the micropore of carbon?

The feasibility of this method could be judged when the necessary information is obtained. There had been no detailed report on this method in this country. Then the Public Works Research Institute began the study on this method on November 8, 1976, by using carbon contractors at the Kyoto pilot plant.

This report is an interim report summing up operational results in the two month period from November to December, 1976. Some data obtained on the questions, No. 1, 2, 3 is contained in this report. A study on the question No. 4 is planned for February, 1977.

3.2.1 SOLID REMOVAL BY FILTER UNDER VARYING FLOW

a. Experimental Procedure

Table 3.2.1 shows the specifications of the gravity, down-flow type filter used for this experiment at the Kyoto pilot plant. There are two filters of the same specifications, one is for the secondary effluent, and the other is for the effluent from alum precipitation.

Table 3.2.1 Specification of Filter

Filter

Surface Area (m ²)	1.0 x 1.2 = 1.2
--------------------------------	-----------------

Filter Media

Grain Size	Anthracite	E.S. (mm)	1.62
		U.C. (mm)	1.33
	Sand	E.S. (mm)	0.61
		U.C. (mm)	1.26
Depth (mm)	Anthracite	625	
	Sand	375	
	Total	1,000	

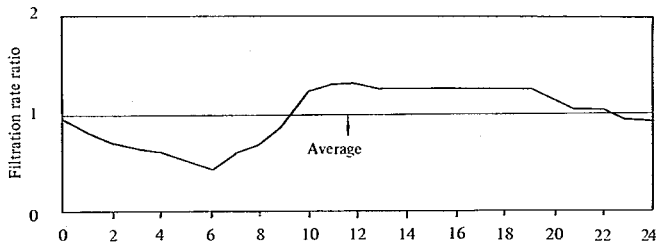
Support Media

Grain Size (mm)	Depth (mm)
19.1 ~ 12.7	50
12.7 ~ 6.73	50
6.73 ~ 3.36	50
3.36 ~ 2.00	50
Total	200

A flow-rate pattern transmitter is set to give flow variation. The circuit for controlling the inflow to the filter consists of two elements. One is the feedforward control of revolution numbers of the roots pump connected to the effluent pipe of the filter. The control works by electric signals from the above mentioned flow-rate pattern transmitter. The other is the feedback control by electric signals from the level meter, which is set on the triangle weir for the effluent flow measuring.

Fig. 3.2.1 shows the flow variation used for this experiment. The variation represents a typical pattern of the inflow into the Toba Sewage Treatment Plant where the pilot plant is located.

Fig. 3.2.1 Flow Variation



Time	Filtration rate ratio	Time	Filtration rate ratio	Time	Filtration rate ratio	Time	Filtration rate ratio
1	0.832	7	0.616	13	1.281	19	1.248
2	0.731	8	0.721	14	1.278	20	1.147
3	0.668	9	0.904	15	1.275	21	1.058
4	0.606	10	1.242	16	1.294	22	1.058
5	0.534	11	1.301	17	1.265	23	0.983
6	0.459	12	1.301	18	1.268	24	0.960

The filtration is terminated when the total head loss reaches 3 meters.

The turbidity in both influent and effluent was measured continuously by the surface-scatter type turbidimeter and then the turbidity was converted into suspended solids through the relation of suspended solids to turbidity shown in Fig. 3.2.2 and Fig. 3.2.3.

Fig. 3.2.2 Turbidity ~ SS (Secondary Effluent and Its Filter Effluent)

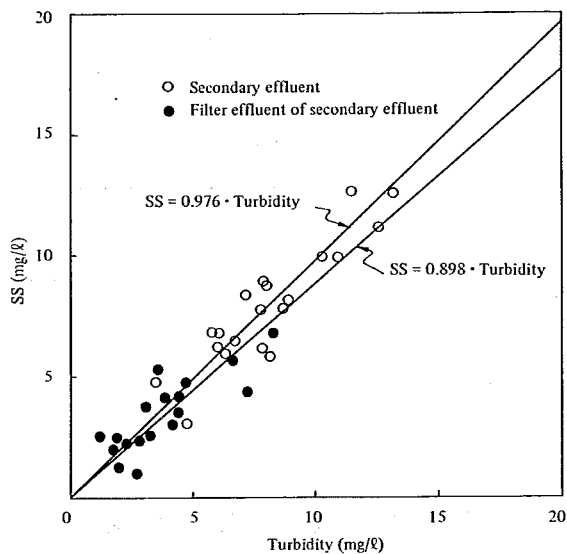
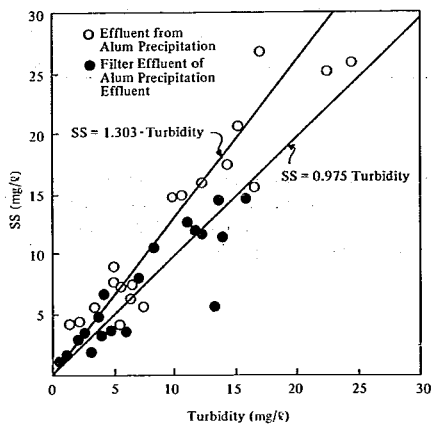


Fig. 3.2.3 Turbidity ~ SS (Alum Precipitation Effluent and Its Filter Effluent)



In discussing the experimental results, suspended solids are calculated from an average turbidity in every one hour from the beginning to the end of each case of filtration (a weighted average with filtration flow rate in the case of varying filtration). And the suspended solid loading is expressed by [g·SS captured/m²· sectional area of filter] and obtained by average suspended solids in influent and effluent, filtration run length and filtration flow rate.

The total head loss was measured continuously by the level meter and the head loss in the filter bed was measured at 10:00 and 16:00 at the depths of 10, 30, 50, 75, 100 cm from the surface of filter media.

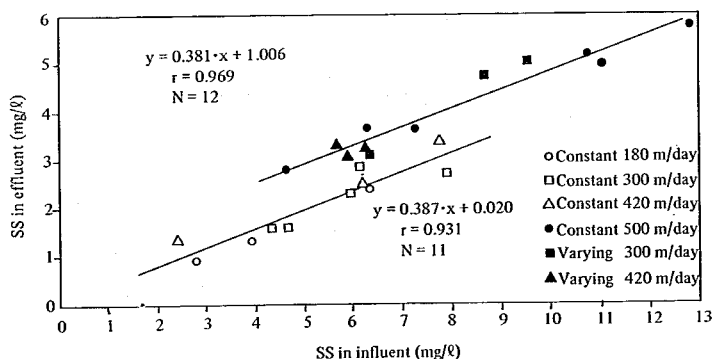
The washing of a filter consisted of nine minutes of surface washing (0.2 m/minute), nine minutes of back washing (1.03 m/minute) and seven minute overlap of the two washings.

The expansion ratio of media by backwashing was set at 20%. And the washing water volume needed for above condition was 11.2 m³.

b. Filtration of Secondary Effluent

Fig. 3.2.4 is the relationship between suspended solids in the influent and effluent. It shows that suspended solids in the effluent increase with the increase of those in the influent. Also seen in the figure is the presence of two groups with distinct difference in filtration flow rates. Group-A is of the rates of 180, 300, 420 m/day by constant filtration. Group-B is of the rate of 500 m/day by constant filtration and of the average rates by varying filtration of 300 m/day (flow rate range, 138 ~ 390 m/day) and 420 m/day (flow rate range, 193 ~ 546 m/day).

Fig. 3.2.4 SS Removal by Filter
(Influent: Secondary Effluent)



When the relationship of suspended solids in the influent and the effluent in each group is assumed linear, the regression lines obtained are:

Group-A $[\text{SS in effluent (mg/l)}] = 0.387 \times [\text{SS in influent (mg/l)}] + 0.020 \dots (1)$

Group-B $[\text{SS in effluent (mg/l)}] = 0.381 \times [\text{SS in influent (mg/l)}] + 1.006 \dots (2)$

The SS removal of Group-A obtained by eq. (1) is about 61% regardless of the SS in the influent. The gradient of eq. (2) almost equals to that of eq. (1). However, the intercept of eq. (1) is about zero against about 1 mg/l of eq. (2). This means that the SS in the effluent of Group-B is by about 1 mg/l higher than that of Group-A regardless of the SS in the influent. Accordingly, in Group-B, the SS removal as calculated by eq. (2) increases with the increase of the SS in the influent, standing at 42, 49, 54% respectively against the SS in the influent of 5, 8, 12 mg/l.

For a comparison between constant filtration and varying filtration, take the filtration flow rate of 300, 420 m/day common to the two methods. In this case, the SS of the effluent by varying filtration is estimated to be higher by about 1 mg/l than that of the effluent by constant filtration when the SS of the influent is the same. Because constant filtration belongs to Group-A and varying filtration to Group-B. However, it must be noted that varying filtration with an average rate of 300 m/day has the maximum rate of 391 m/day. Therefore, when only filtration rates are taken into consideration, it is hard to conclude that the effluent quality by varying filtration is worse than that by constant filtration. It is considered that the true problem lies in the change of filtration flow rate itself.

Fig. 3.2.5 shows the SS loading in the case of the total head loss set at 3 m. The SS loading increases with the increase of the SS in the influent. However, at the flow rate of 500 m/day, this tendency ends when SS in the influent exceed 10 mg/l. The SS loading also differs with the change in filtration flow rates. The readings at the rates of 180, 500 m/day are evidently smaller than those at the rates of 300, 420 m/day. For example, when the SS in the influent is 7.5 mg/l, the SS loading for each of the rates of 180, 300, 420, 500 m/day is about 2,300, 3,500, 3,500 and 2,300 g/m² respectively.

Fig. 3.2.5 SS Loading of Filter
(Influent: Secondary Effluent)

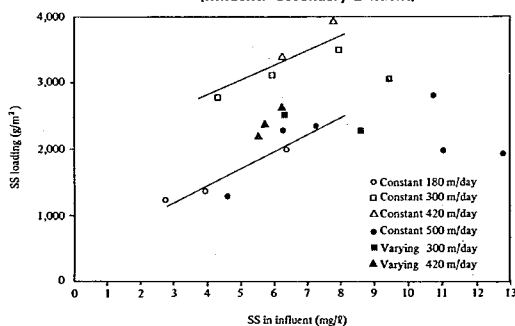


Fig. 3.2.6 shows an example of the relationship between solids in the washing waste and the washing time being obtained by the same procedure mentioned before. (Fig. 3.2.7) The SS loading obtained from Fig. 3.2.6 is $2,700 \text{ g/m}^2$. This value should agree with the SS loading captured by the filtration. However the former loading exceeds loading about 20% more than the latter one ($2,300 \text{ g/m}^2$). Only one example is shown here. But more study is planned for turbidity measuring of washing waste.

Fig. 3.2.6 Filter Washing

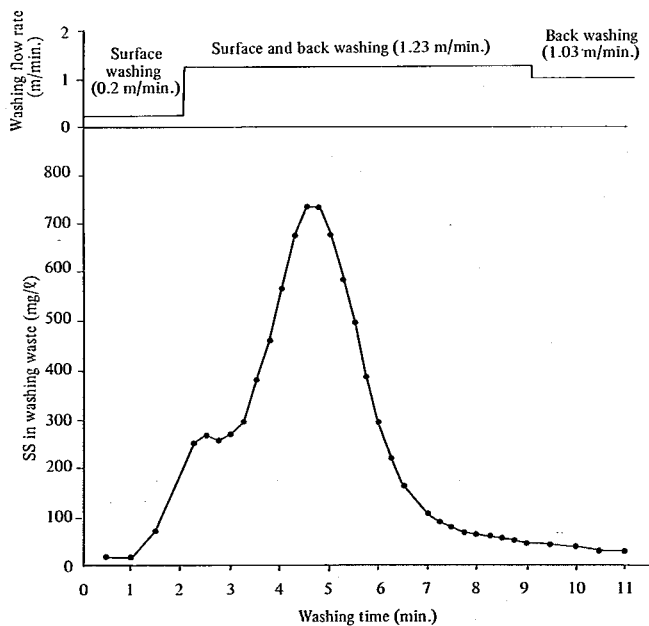


Fig. 3.2.7 Turbidity ~ SS (Filter Washing Waste)

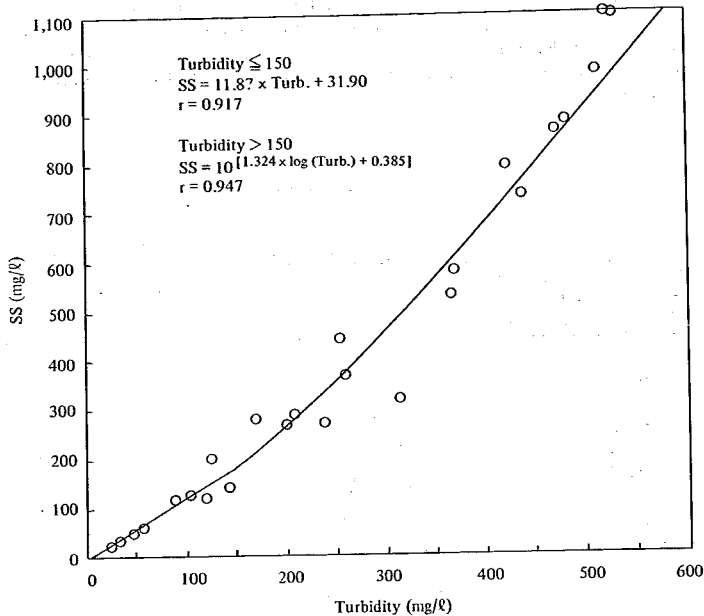


Fig. 3.2.8 is the relationship between suspended solids in the influent and the filtered volume. It shows that the filtered volume by constant filtration and varying filtration is almost the same at the flow rates of 300, 420 m/day. Accordingly, at the rates of 300, 420 m/day, the comparison between the SS loading by constant filtration and that by varying filtration is reduced to the comparison of the amount of SS removed. For example, in the case of 7.5 mg/l of SS in the influent, the amount of SS removed obtained from Fig. 3.2.4, are 4.6 mg/l for constant filtration and 3.6 mg/l for varying filtration. Therefore, the SS loading by varying filtration at the rates of 300, 420 m/day is about 80% of that by constant filtration ($3.6/4.6 = 0.78$).

Fig. 3.2.8 Filtered Volume
(Influent : Secondary Effluent)

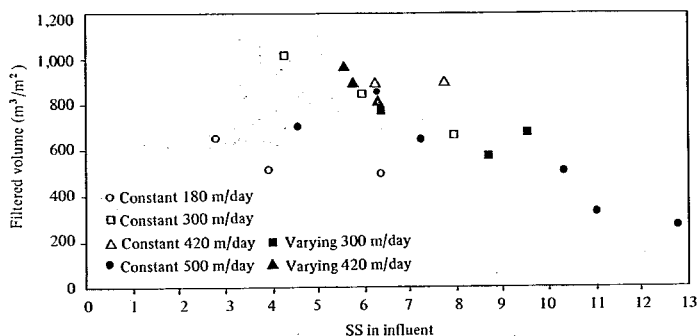
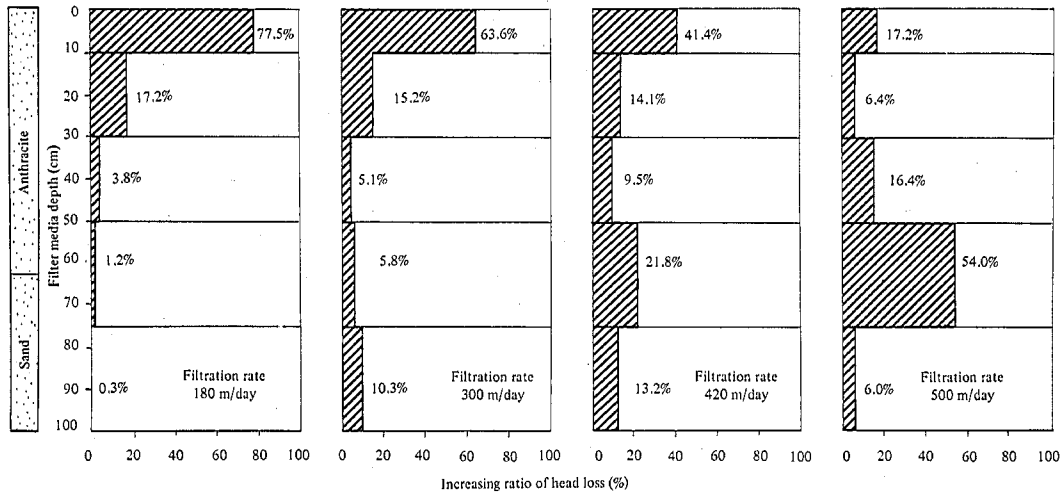


Fig. 3.2.9 gives the relationship between bed depth and the average increase ratio of the head loss in filter beds during constant filtration. The head loss increase ratio here is expressed by the ratio of the value of head loss minus initial head loss at a selected depth of filter bed against the similarly obtained value at the filter media depth of 1,000 mm. The figure shows considerably difference existing in the forms of suspended solids capturing, depending on filtration flow rates.

At the rate of 180 m/day, the form of filtration is the typical surface filtration with the head loss increase ratio standing at 78% in the anthracite surface layer and at a mere 1.5% in the anthracite-sand border and sand layers combined. At the rate of 300 m/day, the head loss increase ratio is still fairly high at 64% in the anthracite surface layer, but the ratios are almost uniform in the layers below. At the flow rate of 420 m/day, the ratio drops to 41% in the anthracite surface layer and the percentage is 22 in the anthracite-sand border, indicating that solids are removed more uniformly in every filter bed layer than in other rates. In the case of 500 m/day, the head loss increase ratio in the anthracite layer becomes small, while the ratio stands at 54% in the anthracite-sand border layer.

The findings would allow the estimation that filtration of secondary effluent by the filter media composition used this experiment, depends on the surface layer at the rate of 180 m/day, on all layers at the rate of 300 ~ 420 m/day and on the sand layer at the rate of 500 m/day. Because of the reason mentioned above, it seems, that the SS loading is small at the rate of 180 m/day, that the effluent quality is a little bad and SS loading is also small at 500 m/day and that both effluent quality and SS loading are good at the rates of 300 and 420 m/day.

Fig. 3.2.9 Head Loss ~ Filter Media Depth (Influent : Secondary Effluent)



Hour-by-hour measurement of the head loss in filter beds in the varying filtration has not yet been carried out. In this way of filtration, an average speed of 420 m/day has the speed range from 193 to 546 m/day, thus covering all filtration forms by constant filtration — the surface filtration, the in-depth filtration and the sand layer filtration. The hourly change of head losses in the varying filtration will be observed in the future. And the observation may explain the reason why the effluent quality by varying filtration is worse than that by constant filtration.

Fig. 3.2.10 The Time When the Total Head Loss Reached 3 m

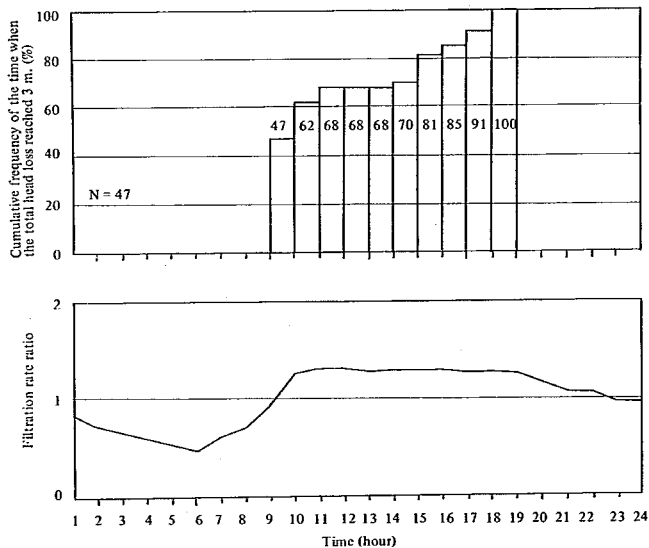
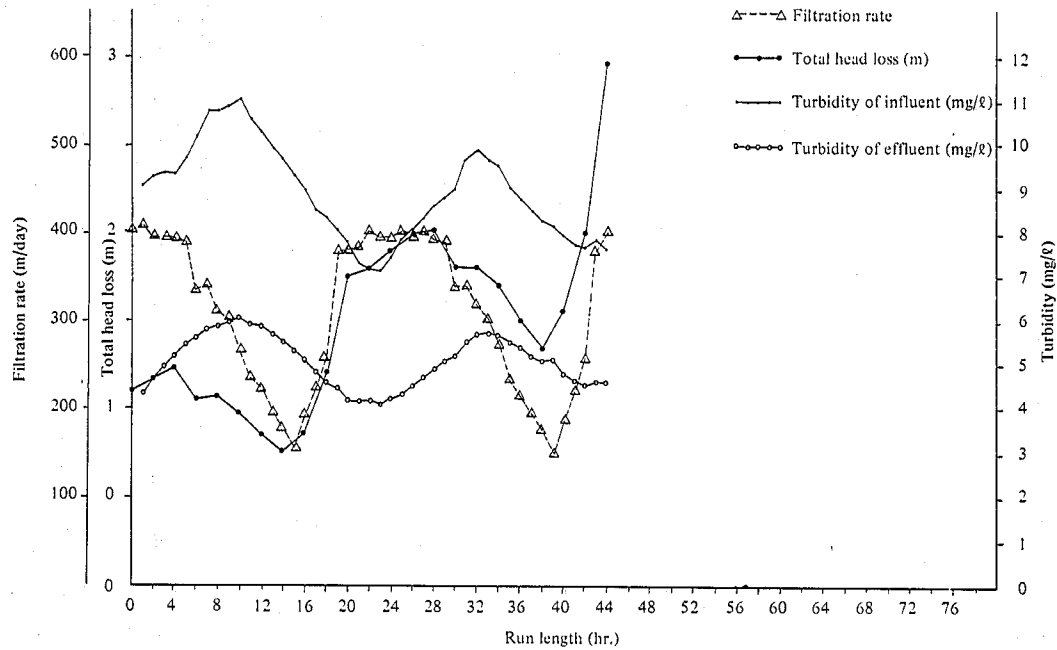


Fig. 3.2.10 shows the relationship between, the time of filtration termination in varying filtration and its cumulative frequency. The data used for this figure are not limited to the results obtained in the period of this experiment. The filtration start time was from 9:00 to 16:00. According to the figure, the times of the total head loss reaching 3 meters are limited to the closing periods of filtration flow rate increase and at the times of high filtration flow rate. Especially noteworthy is that about half the filtration runs stop in the closing period of filtration flow rate increase or within one hour from 9:00. See one example of varying filtration in Fig. 3.2.11.

Fig. 3.2.11 Varying Filtration



The results above indicate the possibility that in varying filtration, filters reach to the terminal head loss almost at the same time, during the time of influent flow rate increase, and the necessary capacity can't be maintained. In such a case, washing of the filters at the time of low influent flow or other preventive means would become necessary.

c. Filtration of Tertiary Alum Precipitated Effluent

Fig. 3.2.12 presents the relationship between suspended solids in the influent and in the effluent. It shows that suspended solids in the effluent increase linearly along with the increase of those in the influent. And there is no great difference in the effluent quality between constant filtration at the flow rates of 120 ~ 300 m/day and varying filtration at the rate of 180 m/day. The regression line obtained from the figure is:

$$[\text{SS in effluent (mg/l)}] = 0.521 \times [\text{SS in influent (mg/l)}] - 0.360 \quad \dots (3)$$

The SS removal obtained through eq. (3) is 66, 60, 55, 52, 50, 49% respectively for each SS in the influent of 2, 3, 5, 10, 20, 30 mg/l. This means that the lower the SS in the influent is, the greater the removal becomes.

Fig. 3.2.12 SS Removal by Filter (Influent : Effluent from Alum Precipitation of Secondary Effluent)

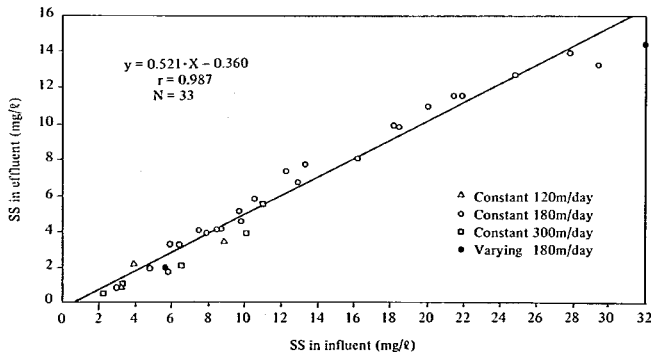


Fig. 3.2.13 shows the SS loading at the total head loss of 3 meters. The loading increases with the increase of suspended solids in the influent. There also is no evident difference in the SS loading between constant filtration at the rates of 120 ~ 300 m/day and varying filtration at 180 m/day. The regression line is:

$$[\text{SS loading (g/m}^2\text{)}] = 66 \times [\text{SS in influent (mg/l)}] + 320 \quad \dots (4)$$

Fig. 3.2.13 SS Loading of Filter (Influent : Effluent from Alum Precipitation of Secondary Effluent)

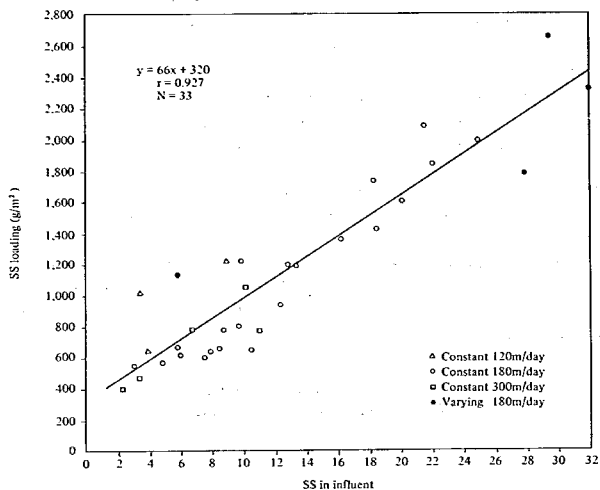
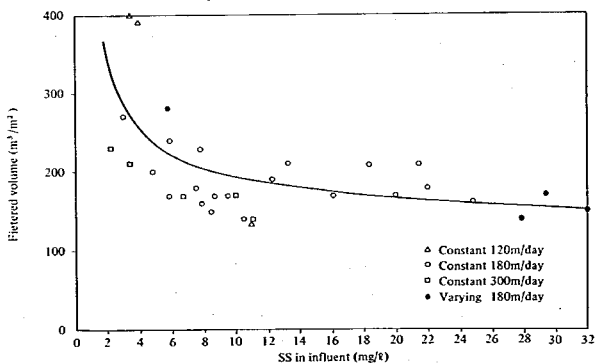


Fig. 3.2.14 is the relationship between suspended solids in the influent and the treated volume at the total head loss of 3 meters. The curve in the figure is calculated through eq. (3) and eq. (4) in accordance with the following equation.

Fig. 3.2.14 Filtered Volume (Influent : Effluent from Alum Precipitation of Secondary Effluent)



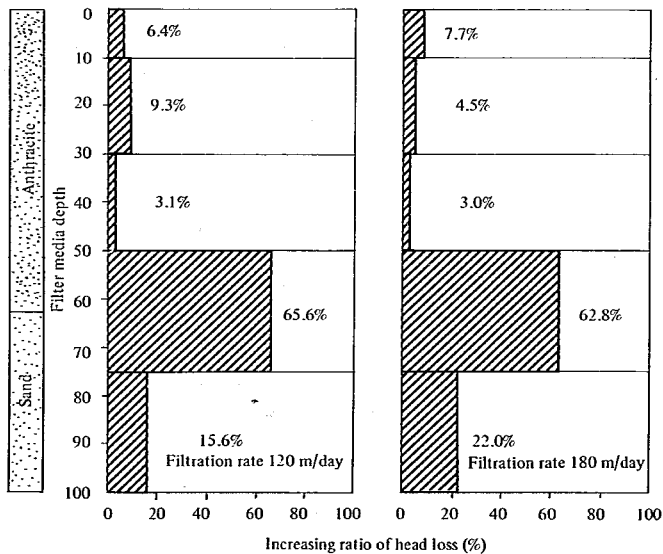
$$[\text{Treated volume (m}^3/\text{m}^2)] = \frac{[\text{SS loading (g/m}^2)]}{[\text{SS influent (g/m}^3)] - [\text{SS in effluent (g/m}^3)]} \dots (5)$$

The treated volume obtained by eq. (5) shows that the less suspended solids in the influent are, the more steeply the treated volume increases below a point of 10 mg/t of suspended solids in the influent. Above the point, the decrease in the treated volume caused by the increase in suspended solids in the influent is not very sharp.

Judging from the data obtained under the conditions of this experiment, it can be concluded that varying filtration is not less efficient than constant filtration in terms of the effluent quality and the SS loading in the case of filtration of alum precipitated effluent.

Fig. 3.2.15 shows the relationship between the filter media depth and the average head loss increase ratio obtained from the head loss distribution in the filter bed during constant filtration. The head loss increase ratio here means the same as defined in a.

Fig. 3.2.15 Head Loss ~ Filter Media Depth
(Influent: Effluent from Alum Precipitation of
Secondary Effluent)



According to the figure, the head loss increase is almost negligible in the anthracite layer but it occurs in the anthracite-sand border layer, standing at 65.6% and 62.8% respectively for 120 m/day and 180 m/day of the filtration flow rate, or almost 2/3. This means that most floc in the effluent from alum precipitation passes through the anthracite layer and is captured by the sand layer. This tendency is recognized even in the relatively low filtration flow rate of 120 and 180 m/day. Therefore, a conclusion is that anthracite with the effective size of 1.62 used for this experiment is too large for the filtration of the alum precipitated effluent.

3.2.2 SOLID AND ORGANIC REMOVAL BY CARBON CONTACTOR

a. Experimental Procedure

The carbon contactors used for this experiment are the gravity, down flow type contactors with a sectional area of $0.7 \text{ m} \times 1 \text{ m} = 0.7 \text{ m}^2$. The height of carbon filled is 3 meters. The water level above the carbon is 2 m. The underdrain is the Leopold Block.

There are six contactors, two each place in a series. Influent is filtered secondary effluent for the No. 1 contactor, secondary effluent for the No. 3 contactor and the tertiary alum precipitated effluent for the No. 5 contactor.

The carbon for the primary contactors (No. 1, 3, 5) is X-7000, which is spherical carbon made of coal by Takeda Pharmaceutical Company Ltd.. The carbons for the secondary contactors are Calgon-SGL for the No. 2 contactor, Calgon-CAL for the No. 4 contactor and Takeda's Shirasagi for the No. 6 contactor.

The primary contactors are for the study of suspended solid removal. X-7000 is used for them, because the X-7000 has a relatively large effective size (1.21 mm) and a small uniformity coefficient (1.32) among brands of carbon now available on the market. Table 3.2.2 points to considerable difference existing in the effective size and the uniformity coefficient from one brand to the other. The choice of different brands of carbon for the secondary contactors is for the continuation of carbon regeneration experiments, which have already been conducted four times.

Table 3.2.2 Activated Carbons Used for the Experiment

	Takeda X-7000	Takeda Shirasagi	Calgon SGL	Calgon CAL
Mesh	8 x 32	8 x 30	8 x 30	12 x 40
E.S. (mm)	1.21	0.82	0.72	0.52
U.C.	1.32	2.02	2.06	2.00
Total Surface (m^2/g)	900 ~ 1,200	970	980	1,065
Iodin Number (mg/g)	950 ~ 1,150	950	950	1,000
Methylene Blue Number (mL/g)	180 ~ 200	180	170	200
Material	Coal	Coal	Coal	Coal
Shape	Spherical	Crushed	Crushed	Crushed

The filtration flow rate for the experiment is 240 m/day (LV = 10) in constant filtration and 240 m/day on the average in varying filtration. The variation of varying filtration here is identical to that on Fig. 3.2.1. The run is terminated when the total head loss reaches 5 m.

The suspended solids was obtained by measuring turbidity with the surface-scatter type turbidimeter and feeding the turbidity to the equations on the relationship between suspended solids and turbidity. The equations are (cf. Fig. 3.2.2, 3.2.3):

for secondary effluent

$$[\text{SS (mg/l)}] = 0.969 \times [\text{turbidity (mg/l)}]$$

filter effluent of secondary, effluent contactor effluent of filtered secondary effluent, contactor effluent of secondary effluent.

$$[\text{SS mg/l}] = 0.878 \times [\text{turbidity (mg/l)}]$$

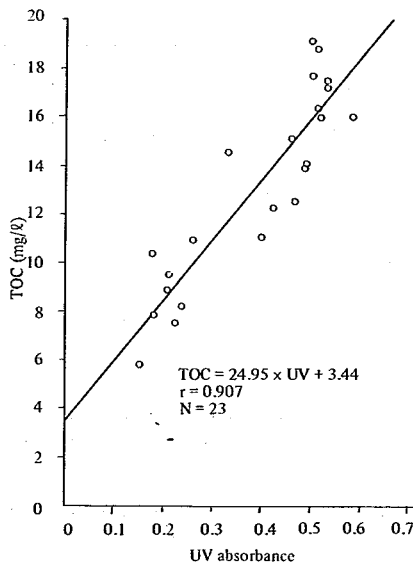
effluent of alum precipitation

$$[\text{SS (mg/l)}] = 1.303 \times [\text{turbidity (mg/l)}]$$

contactor effluent of alum precipitated effluent

$$[\text{SS (mg/l)}] = 0.975 \times [\text{turbidity (mg/l)}]$$

Fig. 3.2.16 UV Absorbance ~ TOC



The organics was obtained through the equation on the relations between TOC and UV (254 nm) (cf. Fig. 3.2.16). The UV absorbance needed for the equation was measured by the continuous UV monitor made by Tinsley Co., Ltd.. The equation is:

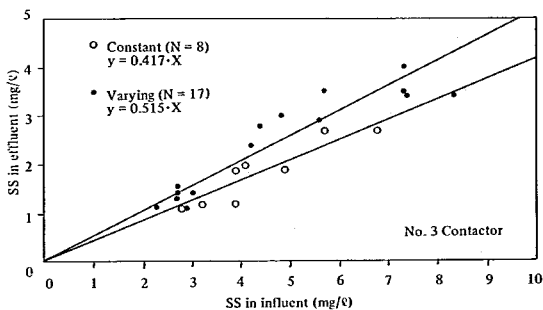
$$\text{TOC (mg/l)} = 25.0 \times \text{UV} + 3.44$$

The UV monitor is designed to measure the absorbance of visible rays too so as to erase the error resulting from the presence of suspended solids by reducing the visible rays absorbance from that of UV. Except for some special cases, measured values for discussing the result are average values in every case of run.

b. Solid Removal

Fig. 3.2.17 gives the relationship of suspended solids in the influent for the No. 3 contractor (secondary effluent) and in its effluent. The SS removal ratio is independent of suspended solid concentration in the influent by both constant and varying filtration. The ratio is about 58% in constant filtration against 49% in varying filtration. Constant filtration attained a better removal by about 10% than varying filtration. However, it is a matter for future problem whether this difference is of any significance, because the two methods were tested at different times – constant filtration in November and varying filtration in December.

Fig. 3.2.17 SS Removal by Carbon Contactor
(Influent : Secondary Effluent)



The comparison between SS in the effluent from the No. 1 contractor (influent – filtered secondary effluent) and that from the No. 3 contractor shows that the No. 3 contractor is a little less efficient than the No. 1 contractor. But the difference was only 9%. The average SS in the effluent from the No. 1 contractor was 2.0 mg/l against 2.2 mg/l in the effluent from the No. 3 contractor (Fig. 3.2.18). Therefore, it seems that as far as suspended solid removal no major problem will arise from omitting filter.

Fig. 3.2.18 Comparison of SS between No. 1 Contactor Effluent and No. 3 Contactor Effluent

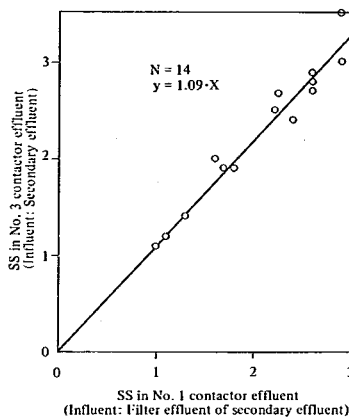
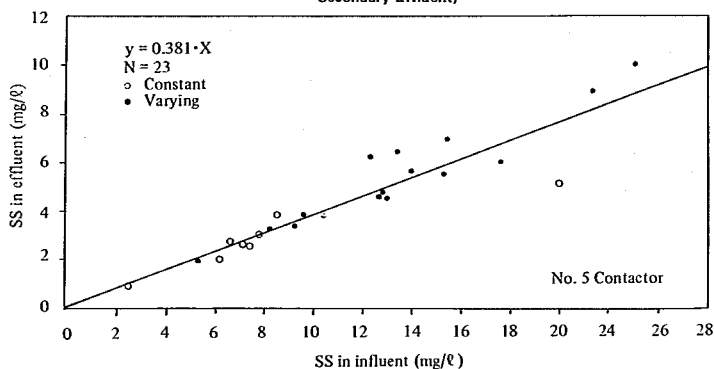


Fig. 3.2.19 shows the relationship of suspended solids in the influent of the No. 5 contractor (tertiary alum precipitated effluent) and in its effluent. When the effluent from alum precipitation was treated by the contractor, no difference was found with regard to the SS removal between constant and varying filtration with about 62% in both methods. In the two months of experiment, the average SS was 11.8 mg/l for the influent against 4.5 mg/l for the effluent.

Fig. 3.2.19 SS Removal by Carbon Contactor
(Influent : Effluent from Alum Precipitation of Secondary Effluent)



In most runs on the No. 3 contractor, washing was started before the total head loss reaching five meters. It was only once that the SS loading was measured at the point of the total head loss reaching five meters. However, it is possible to estimate the SS loading of constant filtration through measured values on the rate of the head loss against the SS loading on Fig. 3.2.21. And the value estimated is an average $3,700 \text{ g/m}^2$ ($2,100 \sim 4,600 \text{ g/m}^2$) against average SS in the influent being 4.8 mg/l .

Fig. 3.2.20 SS Loading of Carbon Contactor
(Influent: Effluent from Alum Precipitation of
Secondary Effluent)

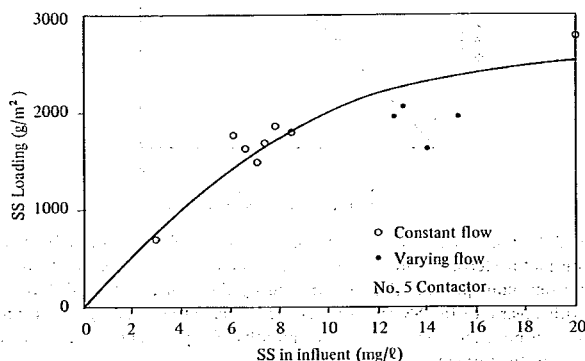
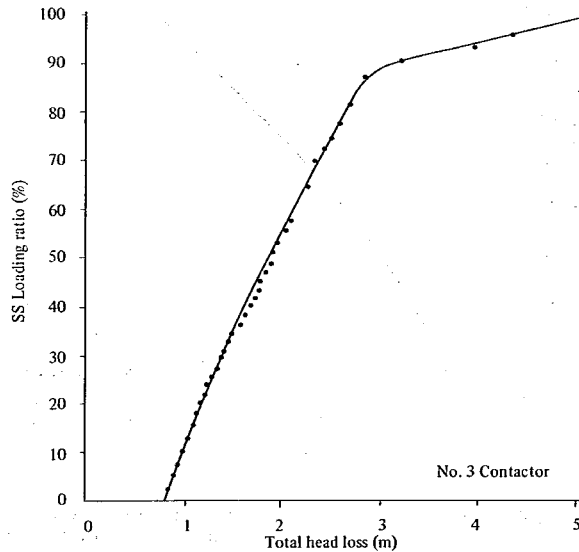


Fig. 3.2.20 shows the relationship of the SS loading to suspended solids in the influent at the total head loss of 5 m in the No. 5 contractor (influent — tertiary alum precipitated effluent). The SS loading rises with the increase of suspended solids in the influent in constant filtration. The loading of varying filtration is too limited to give any definite conclusion. But the value of varying filtration is estimated to be smaller than in constant filtration.

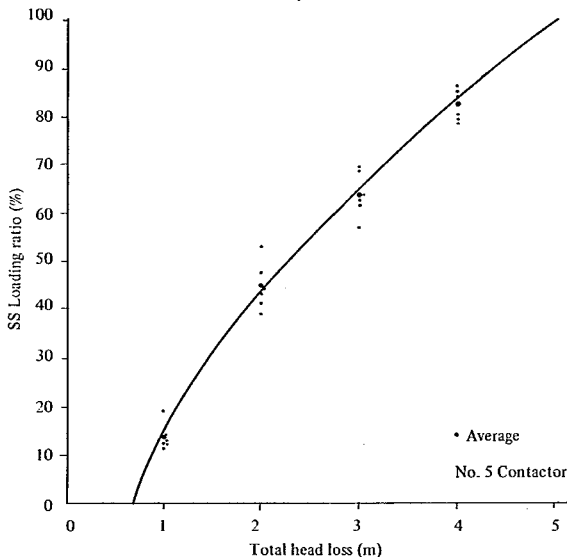
Fig. 3.2.21 and 3.2.22 show the SS loading ratio under lower total head loss than 5 m against 5 m. Fig. 3.2.21 gives results of the No. 3 contractor, while Fig. 3.2.22 is those of the No. 5 contractor.

Fig. 3.2.21 Total Head Loss ~ SS Loading Ratio
(Influent : Secondary Effluent)



In the case of the No. 3 contractor using the secondary effluent as influent, the SS loading goes up almost linearly with the increase of the total head loss up to 3 m. But when the total head loss exceeds 3 m, the SS loading increasing ratio for every unit total head loss drops sharply. About 90% of the SS loading at 5 m of the total head loss is achieved by 3 m. This may probably mean that the filtration goes into the complete surface filtration at the total head loss of about 3 m because of accumulated suspended solids in the surface area of carbon. But it must be repeated that there was only one case of the total head loss in the No. 3 contractor reaching to 5 m. Fig. 3.2.21 shows the results of this single case. More study is needed to know exactly about whether the downturn in the SS loading occurs at the total head loss of 3 m or whether 90% of the SS loading at the head loss of 5 m is accomplished already at the point of 3 m.

Fig. 3.2.22 Total Head Loss ~ SS Loading Ratio
(Influent : Effluent from Alum Precipitation of
Secondary Effluent)



Any development of this kind did not happen in the No. 5 contractor for which the effluent from alum precipitation was used as influent. The SS loading of the contractor increased in keeping pace with the increase of the total head loss to 5 m, indicating the effective use of the total head loss. This also means that the No. 5 contractor has more of the nature of in-depth filtration than the No. 3 contractor.

c. Organic Removal

Table 3.2.3 shows average of TOC removal in the two months of experiment. TOC in the effluent from the No. 1 contractor is 9.8 mg/l against 10.2 mg/l in the No. 3 contractor effluent. The difference was 0.4 mg/l, or 4%. In view of this, it could be concluded that there is little need of filter for TOC removal at present.

Fig. 3.2.23 shows the relationship between C/Co and BV in the contractors No. 1 and 2. Fig. 3.2.24 gives the ratio of TOC in the effluent from the No. 1 contractor to that from the No. 3 contractor. Judging from Fig. 3.2.23, carbon appears to be breaking, but this must be more precisely examined by future results. And at least up to Bed Volume (BV) of 5,000, there is no visible change in the ratio of TOC in the effluent from the No. 1 contractor to that from the No. 3 contractor.

Table 3.2.3 TOC Removal

Contactor No.*	1	2	3	4	5	6
Number of Data	20		20		15	
Influent to the Primary Contactor and its TOC (mg/l)	Filter Effluent of Secondary Effluent 14.1		Secondary Effluent 14.5		Effluent from Alum Precipitation of Secondary Effluent 15.0	
TOC of Effluent (mg/l)	9.8	4.6	10.2	5.1	8.7	4.6
TOC Removal	30	67	30	65	42	69

* Contactor Nos. 1, 3 and 5 are the primary contactors, and 2, 4 and 6 the secondary.

** To the influent to the primary contactor.

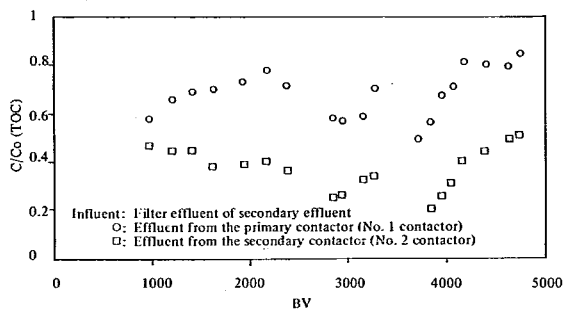
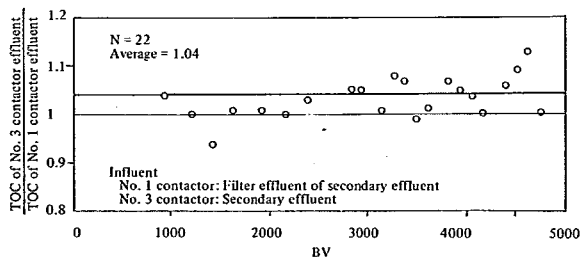
Fig. 3.2.23 $BV \sim C/Co$ 

Fig. 3.2.24 Comparison of TOC between No. 1 Contactor Effluent and No. 3 Contactor Effluent



3.2.3 SUMMARY

Table 3.2.4 gives the summary of the removal of suspended solids by the filter and the carbon contractor in terms of the SS removal ratio, the SS loading and the treated volume under specific operating conditions.

Followings are the findings of this study:

Table 3.2.4 Summary

	Influent	Filtration Method	Filtration Rate (m/day)	Suspended Solid Removal										Filtered Volume (m ³ /m ³)				
				Removal (%)					SS Loading (g/m ²)					SS in Influent				
				2.5	5	7.5	10	20	2.5	5	7.5	10	20	2.5	5	7.5	10	20
Filter	Secondary Effluent	Constant	180	61	61	61	-	-	-	1,700	2,300	-	-	-	560	500	-	-
				$y = 0.387 \cdot x + 0.02$														
			300	61	61	61	-	-	-	3,000	3,500	-	-	-	980	770	-	-
		Varying	420	61	61	61	-	-	-	3,000	3,500	-	-	-	980	770	-	-
				$y = 0.387 \cdot x + 0.02$														
			500	-	42	48	52	57	-	1,700	2,300	-	-	-	810	640	-	-
	Tertiary Alum Precipitated Effluent	Constant	300	-	42	48	52	57	-	3,100	2,800	-	-	-	980	770	-	-
				$y = 0.381 \cdot x + 1.01$														
			420	-	42	48	52	57	-	2,100	2,800	-	-	-	980	770	-	-
		Varying		$y = 0.381 \cdot x + 1.01$														
			120	62	55	53	52	50	490	650	820	980	1,600	310	240	210	190	160
				$y = 0.521 \cdot x - 0.36$														
Carbon Contractor	Secondary Effluent	Constant	180	62	55	53	52	50	490	650	820	980	1,600	310	240	210	190	160
				$y = 0.521 \cdot x - 0.36$														
			300	62	55	53	52	50	490	650	820	980	1,600	310	240	210	190	160
		Varying		$y = 0.521 \cdot x - 0.36$														
			180	62	55	53	52	50	490	650	820	980	1,600	310	240	210	190	160
				$y = 0.521 \cdot x - 0.36$														
	Tertiary Alum Precipitated Effluent	Constant		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
				$y = 0.417 \cdot x$														
			240	49	49	49	-	-	-	-	-	-	-	-	-	-	-	-
		Varying		$y = 0.515 \cdot x$														
			62	62	62	62	62	62	700	1,200	1,700	2,000	-	450	390	370	320	-
				$y = 0.381 \cdot x$														
Tertiary Alum Precipitated Effluent	Varying		62	62	62	62	62	-	-	-	-	-	-	-	-	-	-	
			$y = 0.381 \cdot x$															

* y: SS in Effluent (mg/l), x: SS in Influent

** y: SS Loading, x: SS in Influent

a. Varying and Constant Filtration

1) When the secondary effluent is used as influent for filter, the comparison between varying and constant filtration at the filtration flow rate of 300, 420 m/day leads to the following conclusions: The effluent by varying filtration contain more of suspended solids by about 1 mg/l than that by constant filtration. The SS loading by varying filtration becomes lower by 20 ~ 30%. The lower efficiency of varying filtration is also observed as to the SS removal ratio in carbon contractors using the secondary effluent as influent by 10% drop.

2) When the effluent from alum precipitation is used as the influent for filter or carbon contractor, there is little difference of the SS removal and the SS loading between varying and constant filtration in this study. In carbon contractors, varying filtration is a little less efficient in terms of the SS loading.

3) As seen in varying filtration experiments in the filter using the secondary effluent as influent, time when the total head loss reach to 3 m is limited to the closing period of influent flow increasing or to the time of high influent flow. About 50% of the runs it comes within one hour in the closing period of effluent volume increase.

b. Filtration of the Secondary Effluent by Filter (Constant Filtration)

1) In the filter media composition used for this experiment, the optimum filtration flow rates in terms of the effluent quality, and the SS loading are 300 ~ 420 m/day. This is understood by the fact that the head loss distribution in the filter bed came very close to that of in-depth filtration.

2) When the rates are 300, 420 m/day, and SS in the influent is 5 mg/l, the SS removal is 61% and the SS loading is 3,000 g/m².

3) Filtration at the rate of 180 m/day seems to be the surface filtration. The rate, when compared to the higher rates of 300, 420 m/day, provides no difference as far as the SS removal ratio. But the SS loading of this rate is about 60% of that of 300, 420 m/day.

4) The removal of suspended solids by the anthracite layer cannot be expected at the rate of 500 m/day. Most of the SS capture takes place in the sand layer. At this rate the SS in the effluent is by about 1 mg/l greater than at the rates of 300, 420 m/day. The SS loading is about 60% of the value for the rates of 300, 420 m/day.

c. Filtration of Alum Precipitated Effluent by Filter (Constant Filtration)

1) In the rates of 120 ~ 300 m/day, there is no difference in the SS removal and the SS loading. When the SS in the influent is 5 mg/l, the SS removal rate is 55% and the SS loading 650 g/m².

2) The SS removal by anthracite could not be expected. Most of the SS capture takes place in the sand layer. This means that the anthracite in this bed, having the effective size of 1.62, is large for the treatment of the effluent from alum precipitation.

d. Solid Removal by Carbon Contractor

1) When treated by the carbon contractors, the filter effluent of the secondary effluent and the secondary effluent itself make no great difference in their effluent quality. The quality difference is only 9% for suspended solids and 4% for TOC up to BV 5,000.

2) When compared to filter filtration of the secondary effluent, there is no great difference in the SS removal efficiency. The carbon contractor also is not inferior in terms of the SS loading.

3) When the effluent from alum precipitation with SS of 5 mg/l is used as influent, the SS removal ratio is 55% and the SS loading is 1,200 g/m² (the total head loss-5 m). When the total head loss is 3 m, the SS loading will be 65% of the

value at 5 m of the total head loss, or 780 g/m².

4) When compared to filter filtration by using the effluent from alum precipitation as influent, the carbon contractor is superior both in the SS removal ratio and the SS loading.

e. Filtration of Alum Precipitated Effluent and Secondary Effluent

1) In the case of the filter filtration at the flow rates of 180, 300 m/day, the SS removal and the SS loading is better in secondary effluent filtration. The SS loading of the effluent from alum precipitation was about 30% of that of the secondary effluent.

2) In the case of the carbon contractor, the SS removal rate of the effluent from alum precipitation was better by 3% but its SS loading was smaller than that of the secondary effluent.

f. Future Studies to be Conducted

1) Varying filtration experiments by changing the filtration rate gradient or by changing the ratio of the maximum flow rate to the minimum flow rate.

2) Dual or multi media filtration of the effluent from alum precipitation by using anthracite with the effective size smaller than 1.62 mm.

3) To compare constant and varying filtration by using the same filter to verify the results above. The experiment is now in progress.

4) To examine the carbon contractor filtration including the aspect of carbon regeneration. Up to now it is known that the treatment of sewage including suspended solids by the carbon contractor produces no major problem with regard to SS and TOC in the effluent. Also needed is to know the performance of the carbon contractor in treating the influent of high SS. The average SS in the secondary effluent used so far is low at 4.5 mg/l.

5) To check whether there is a drop in the absorption speed by using coarse carbon, which have proved to be efficient for the removal of suspended solids.

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EXPERIMENTAL STUDY ON REGENERATION OF GRANULAR ACTIVATED CARBON

Shigeru Ando

INTRODUCTION

In wastewater treatment, particularly in advanced wastewater treatment, it increases such a case that granular activated carbon is used as a means of removal of soluble organic substances.

The unit cost of granular activated carbon is extremely expensive because a good quality of bituminous coal as its raw material is difficult to obtain in Japan and the product yield from such raw material is very small. These are the principal defect of granular activated carbon when we used it for wastewater treatment. Consequently if spent carbon can simply be regenerated at the inexpensive cost, the utilization of granular activated carbon to wastewater treatment will be increased.

The regeneration of granular activated carbon is normally carried out by the manufacturers, but in the case of wastewater treatment which requires activated carbon is quantity equivalent to approximate 1/50 and (approximate 1/100 by weight) more of wastewater to be treated per day, more regeneration on site is required as the scale of wastewater treatment becomes larger.

The following are the results of our experiments we have conducted four items on the activated carbon used in advanced wastewater treatment of the Kyoto pilot plant by a multiple hearth regeneration furnace.

4.1 METHOD IN THE EXPERIMENTS

4.1.1 GRANULAR ACTIVATED CARBON USED FOR EXPERIMENTS

The brands and particle sizes of activated carbon used for our experiments are shown in the Table 4.1 and these types of activated carbon have been used for the adsorption of rapidly filtered secondary effluent in the Kyoto pilot plant. In our adsorption experiments, no fresh carbon has been added since we intended to observe the changing characteristics of the original carbon with repeat of regeneration. The approximate figures of adsorbed of COD_{Mn} obtained from the result of adsorption experiment is also shown in Table 4.1. The COD_{Mn} removal in treatment just before regeneration was approximately 30% in each case.

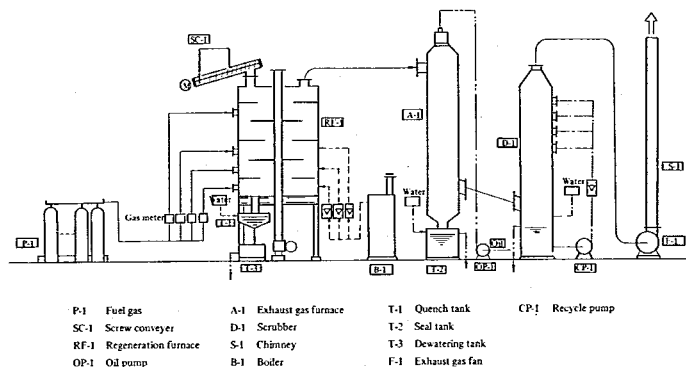
4.1.2 FACILITIES USED IN EXPERIMENTS

The facilities used for our experiments comprised a regeneration furnace, an equipment for feeding and collecting carbon, an equipment for treating exhaust gas and a steam generator. A general flow is as shown in Fig. 4.1. The regeneration furnace is a vertical type six stage hearth furnace having the inside diameter of 750 mm and 1,500 mm of the height which is equipped with eight gas burners. The arms of the furnace can be rotated within the range of 0.23 to 2.3 rpm by a 0.4 kW driving motor.

Table 4.1 Carbon Used in Experiment and Adsorbed COD_{Mn}

Number of Reactor	1	2	3	4	5	6
Name and Size						
Name	Calgon, SGL		Calgon, CAL		Takeda, Shirasagi	
Particle Size (Mesh)	8 x 30		12 x 40		8 x 30	
Adsorbed COD _{Mn} (COD _{Mn} kg/kg A.C.)						
1st	0.118	0.074	0.160	0.088	0.121	0.085
2nd	0.150	0.067	0.170	0.080	0.155	0.057
3rd	0.132	0.047	0.160	0.061	0.086	0.048
4th	0.165	0.067	0.202	0.079	0.125	0.072
Mean	0.141	0.064	0.189	0.077	0.122	0.066

Fig. 4.1 Flow Diagram of the Regeneration System



4.1.3 ITEMS MEASURED

The items indicating the characteristics of granular activated carbon that measured in this experiment are; physical characteristics (mean particle size, hardness number, ignition residue, specific surface area, mean micropore size, volume of micropore, micropore distribution), general adsorption characteristics (methylene blue decolorizing capacity, iodine adsorption capacity, molasses decolorizing capacity, phenole value, ABS value), adsorption capacity of organic substances in water and weight ratio of adsorbed matter to fresh carbon.* Measuring has been imple-

*: Weight ratio of adsorbed matter to fresh carbon can be obtained by the following; a 100 kg of dried sample of spent carbon will be heated for 90 minuts in an electrical furnace, the temperature of which was controlled to 900°C in N₂ gas flow, and the decreasing of weight are measured, then the weight ratio will be obtained according to the following formula;

$$\text{Weight Ratio of Adsorbed Matter to Fresh Carbon} = \frac{\text{Decreased Weight of Carbon (g)}}{\text{Weight of Recovered Carbon (g)}}$$

mented in accordance with JIS standards and Japan Water Works Association (AWWA) Standards as far as practicable, but the details of the method have been omitted because it was described in the previous report.

4.1.4 REGENERATING CONDITIONS

Regenerating efficiency of granular activated carbon in the regeneration furnace will be governed by the following factors;

- (1) Temperature and its distribution in furnace
- (2) Detention time of activated carbon in furnace
- (3) Atmosphere in furnace
- (4) Feed rate of steam for reactivation and its feeding position
- (5) Loading rate of carbon

In our experiments, the furnace temperature has been kept in 930 to 940°C at a maximum. Each stage of 4th, 5th and 6th hearth for activating has been so set as to be able to maintain nearly the same temperature. The detention time of activated carbon in the furnace has been set for 30 min. regardless of the type and loading quantity of carbon. Atmosphere in the furnace has been so controlled that O₂ for each stage should be kept below 0.1% to avoid the burning-off of carbon due to the entrance of air.

The activating temperature has been changed based on the type of activated carbon and apparent density which show the result for any change of loading quantity and can be measured easily. One third of the steam has been fed to the stage 4 and the remainder to the stage 6.

The loading rate of activated carbon has been set at from 11 to 15 kg/m² of furnace floor/hr on the basis of dry spent carbon by weight.

Total feeding weight or volume and loading quantity/hr in the regeneration experiments carried out four times are as shown in Table 4.2. The activated carbon

Table 4.2 Feeding Weight and Feeding Rate of Each Carbon in the Experiment

Items	Regeneration	Reactor					
		1	2	3	4	5	6
Weight of Fed Activated Carbon (DSC kg)	1st	836.0	836.0	696.7	727.5	809.0	835.9
	2nd	784.9	752.3	681.5	645.6	798.0	791.7
	3rd	670.9	601.9	577.6	567.7	735.8	693.3
	4th	618.5	546.5	596.2	550.5	733.3	686.3
	Mean	727.6	684.2	563.0	622.8	769.0	751.8
Weight of Fed Activated Carbon per Hour (kg DSC/Hr)	1st	39.5	34.3	33.6	32.1	35.6	34.0
	2nd	34.2	32.4	36.9	31.0	38.2	36.8
	3rd	33.5	31.7	28.1	28.8	35.0	32.8
	4th	34.4	33.0	32.5	30.2	36.1	33.9
	Mean	35.4	32.9	32.8	30.5	36.2	34.4

withdrawn from the reactor has been put into the hemp sack and dewatered when the specific gravity was stabilized in wet condition. The activated carbon has been loaded by weighing each sack of carbon.

In adsorption experiments at the pilot plant, each of the carbon was divided and packed into two vessels. And the vessels were operated in series. So, this regeneration experiment has been implemented by two vessels in a similar manner. The first experiment has been carried out in December, 1974, the second experiment in August, 1975, the third experiment in February, 1976 and the fourth experiment in August, 1976 respectively.

4.2 RESULTS OF EXPERIMENTS

4.2.1 RECOVERY RATE WITH REGENERATION

The recovery rate of activated carbon with regeneration can be expressed both gravimetrically and volumetrically. It is generally said that the reliability of the former is greater than that of the latter although the former has problems that we cannot grasp any change of particle size arising from mechanical and thermal losses and that we cannot distinguish the influence of accumulation of inorganic substances.

Gravimetric recovery rate (R_w) can be obtained from dry weight of spent carbon (W_s), weight ratio of adsorbed matter to fresh carbon (a) and dry weight of regenerated carbon (W_r).

$$R_w = \frac{W_r(1+a)}{W_s}$$

The volumetric recovery rate can further be obtained 1) from the height of packed carbon and cross sectional area of the reactor and 2) from volumetric figures calculated by dividing carbon weight with apparent density.

Each recovery rate obtained from this experiment is as indicated in Table 4.3. Each recovery rate varies by the type of carbon and by the frequency of use, but was approximately 85% and above.

The fluctuation of height of packed carbon in reactor and apparent density (measured by a 100 ml measuring cylinder) with repeat of regeneration is as shown in Fig. 4.2. In Fig. 4.2 and other diagrams, F, S and R on horizontal axis denote fresh carbon, spent carbon and regenerated carbon, respectively. The numbers show the frequency of adsorption and regeneration. From Fig. 4.2, it is noted that apparent density relatively reduces as the carbon is regenerated repeatedly and that the height of packed carbon lowers linearly. In accordance with that, carbon weight of each reactor is reduced to approximate 50% of the original carbon weight only by four times regeneration although it include a loss in back washing.

4.2.2 PHYSICAL CHARACTERISTICS CHANGE OF GRANULAR ACTIVATED CARBON

Out of physical characteristics of the activated carbon, Fig. 4.3 shows the change occurring from the repeated regeneration on mean particle size, hardness, ignition residue, specific surface area and mean micropore size of micropore 0 to 300Å. From these figures, it can be seen that by the repeat of regeneration, mean particle size and hardness have not been changed very much, but ignition residue,

Table 4.3 Recovery Rates in Regeneration Test (%)

Items	Reactor Regeneration	Reactor					
		1	2	3	4	5	6
Gravi- metric Recovery Rate	1st	96.2	94.0	102.3	98.1	100.2	97.0
	2nd	91.9	96.8	95.1	105.1	99.6	93.8
	3rd	94.7	93.0	98.5	89.7	87.7	98.7
	4th	90.8	91.9	99.8	94.1	89.6	95.1
	Mean	93.4	93.9	98.9	96.8	94.3	96.2
Volumetric Recovery Rate 1	1st	95.6	94.1	97.4	94.1	95.8	96.1
	2nd	88.0	89.6	90.0	91.1	93.4	91.8
	3rd	90.2	84.7	83.2	86.3	84.8	93.4
	4th	83.8	80.0	86.1	87.1	87.4	90.6
	Mean	89.4	87.1	89.2	89.7	90.4	93.0
Volumetric Recovery Rate 2	1st	99.3	96.1	107.7	98.2	99.8	98.5
	2nd	92.7	94.0	96.7	100.0	98.5	92.2
	3rd	100.6	95.7	105.2	90.0	90.8	101.4
	4th	93.0	95.9	103.0	94.5	92.2	95.2
	Mean	96.4	95.4	103.2	95.7	95.3	96.8

Fig. 4.2 Change of Thickness, Weight and Apparent Density of Carbons with Repeat of Regeneration

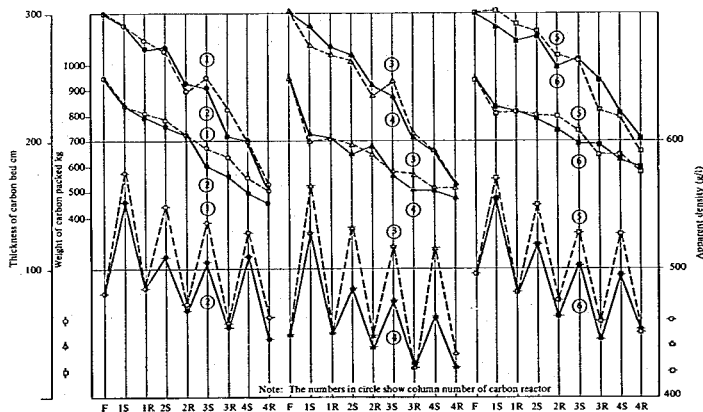
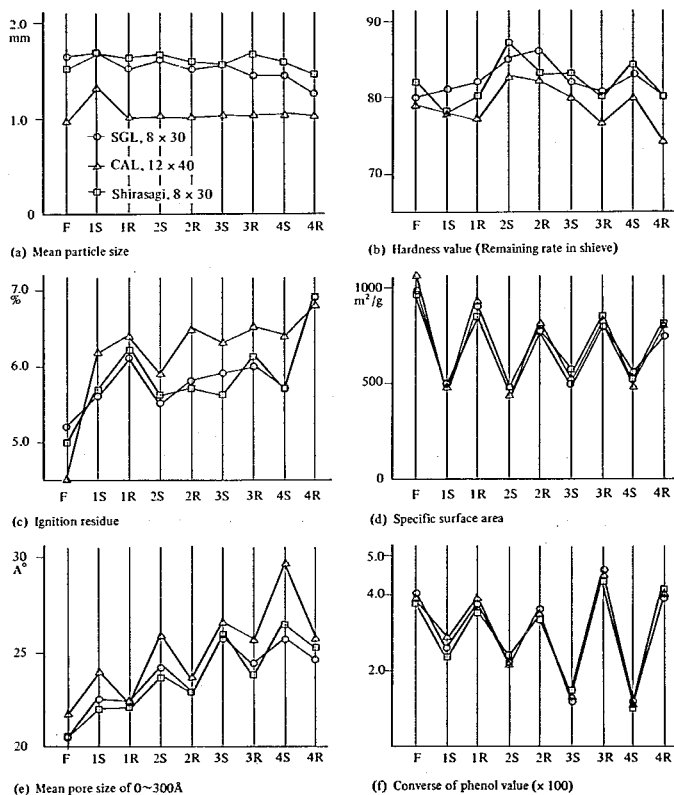


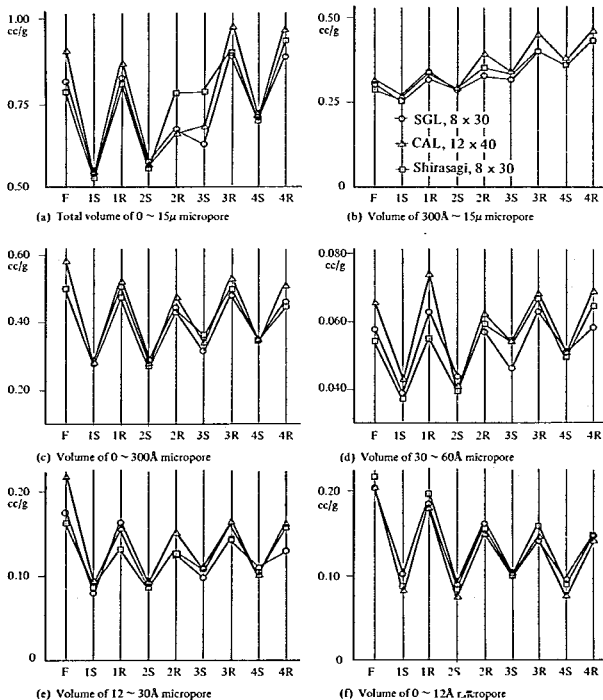
Fig. 4.3 Physical Characteristic Change of Granular Activated Carbons with Repeat of Regeneration



specific surface area, mean micropore size of micropore 0 to 300Å have been changed strikingly. Particularly specific surface area (Fig. 4.3 (d)) has been reduced to nearly a 50% of the original area just after the regeneration at the time when the carbon was spent. This explains well the mutual relationship between adsorption status and regenerating efficiency. Further, ignition residue (Fig. 4.3 (c)) and mean pore size of micropore 0 to 300Å increased little by little with the repeat of regeneration. The reduction of these values shows the progressing of the deterioration of the activated carbon considering the reduction of adsorption capacity

as will be described later on. From the investigation of another physical characteristics of micropore volume, the volume of each micropore size fraction varies with the repeat of regeneration as shown in Fig. 4.4. The total volume of micropore (Fig. 4.4 (a)) of the spent carbon showed a reduction of its value to 60 ~ 70% of fresh carbon or regenerated carbon. The difference in the micropore volume from 300Å to 15μ (Fig. 4.4 (b)) between fresh carbon and spent carbon is relatively small, but the volume increased gradually with repeat of regeneration. On the contrary the micropore volume (Fig. 4.4 (f)) up to 12Å varied considerably and the

Fig. 4.4 Micropore Characteristic Change of Granular Activated Carbons with Repeat of Regeneration



value reduced with repeat of regeneration. The difference in the value between spent and regenerated carbon is greater on the volume of micropore size fraction, but the value has not been noticeably increased nor decreased very much with repeat of use and regeneration.

From the above, we can consider that with repeat of use and regeneration, the total volume of micropore has not been changed very much, but micropore volume of 12Å and less has been reduced and in its stead micropore from 300Å to 15 μ has been increased. This indicates a deterioration of activated carbon.

Furthermore, in regard to micropore, the distribution has been measured in each regenerating experiment, but here as an example we have shown a change of micropore distribution after the second and the fourth regeneration in comparison with that of fresh carbon in Fig. 4.5.

From Fig. 4.5, it is noticeably that micropore reduced and micropore increased.

4.2.3 CHANGE OF GENERAL CHARACTERISTICS

As an index of adsorption capacity of the activated carbon, methylene blue decolorizing capacity, phenole value and ABS value are generally used. The change of such an index with repeat of regeneration in this experiment is as shown in Fig. 4.6.

Generally speaking each item has been much changed with repeat of regeneration and the value of spent carbon, fresh carbon, and regenerated carbon varied widely in each case.

The following is the study on the characteristics of each index;

Methylene Blue Decolorizing Capacity (Fig. 4.6 (a))

The fluctuation of the capacity has sometimes been reduced to 40 to 50% and was gradually reduced with repeat of regeneration. This index is proportionate to the specific surface area of micropore of 15Å and more, and is so much alike the fluctuation of the specific surface area in (Fig. 4.4 (d)) or micropore volume of 0 to 12Å in (Fig. 4.5 (f)).

Iodine Adsorption Capacity (Fig. 4.6 (b))

The fluctuation of the capacity is such that the capacity of fresh carbon has sometimes been reduced to 20 to 30%, but the value decreased with repeat of regeneration as shown in Fig. 4.5 (f) and Fig. 4.6 (a). This index is proportionate to the specific surface area of micropore of 10Å and more.

Molasses Decolorizing Capacity (Fig. 4.6 (c))

The fluctuation of capacity is such that the capacity of fresh carbon has been reduced to 25 to 50%, but the value shows a reverse trend of the above two items and increases with repeat of regeneration.

It is generally said that this index is proportionate to the specific surface area of micropore of 28Å and more, but judging from the trend on the diagram, the index is rather alike the change of micropore volume from 300Å to 15 μ as shown in Fig. 4.4 (b).

Phenole Value (Fig. 4.6 (d))

This index indicates the required amount of activated carbon to adsorb the unit amount of phenole. Consequently, the smaller this value, the greater the adsorption capacity. From Fig. 4.6 (d), the fluctuation of the value is greater, but even if the capacity considerably reduces by the spending, the original capacity can be restored by regeneration. The capacity will not be dropped much even after the repeated regeneration.

Fig. 4.5 Micropore Distribution Change of Granular Activated Carbons with Repeat of Regeneration

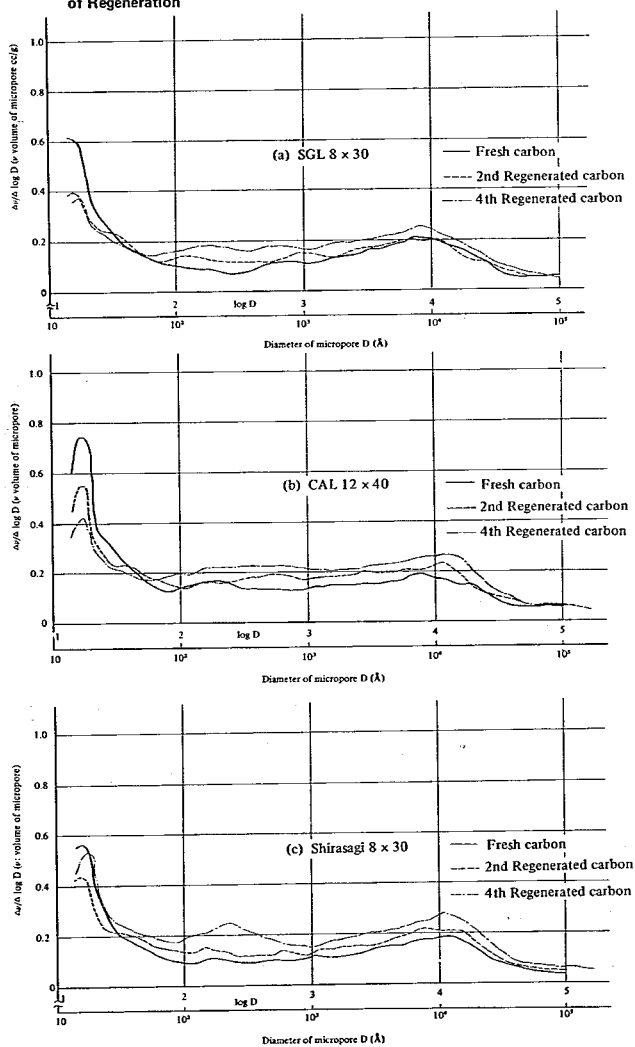
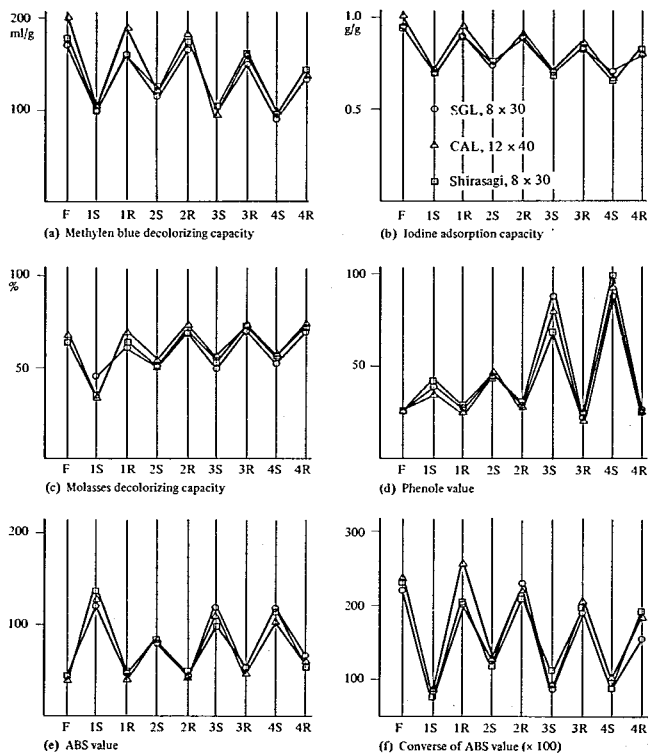


Fig. 4.6 Adsorption Characteristic Change of Granular Activated Carbons with Repeat of Regeneration



ABS Value (Fig. 4.6 (e))

This value is an index for the amount of activated carbon required for the removal of the required ABS as in the case of phenole value. The fluctuating status is therefore much alike that shown in Fig. 4.6 (d). As it was difficult to compare it directly with physical characteristics, we took the converses in consideration of the meaning of the index and obtained the result as shown in Fig. 4.6 (f). From this diagram, it is found that the converses of ABS value fluctuates quite alike specific surface area, micropore volume of 12Å and more, methylene blue decolorizing capacity and iodine adsorption capacity.

4.2.4 ADSORPTION CHARACTERISTICS OF ORGANIC MATTER IN WATER

The major objective of wastewater treatment by activated carbon is to remove organic matter in the wastewater. In order to study the organic substances adsorption characteristics of activated carbon which is used for advanced wastewater treatment, it is considered important to measure the adsorption capacity of the carbon for same kind of organic substances as contained in wastewater. In this experiment, therefore, an experiment on isothermal adsorption has been carried out with TOC as an index for organic matter by using secondary effluent sampled from a pilot plant.

We have consolidated the data according to Freundlich equation which was obtained from the experiments, but due to insufficient data for each experiment and unstable property of secondary effluent taken for sample, we could not grasp a clear change of adsorption characteristics for organic substances with repeated regeneration.

In order to analyze the adsorption characteristics of activated carbon against organic substances in wastewater, it is difficult to use the Freundlich equation because the concentration of the substances contained in secondary effluent is very low and varied. It is therefore felt necessary first to identify and measure the organic substances in secondary effluent to be treated and secondly to pick up some predominant organic substances and finally to study the adsorption characteristics with those pure substances.

4.2.5 DECLINE OF VARIOUS CHARACTERISTICS OF ACTIVATED CARBON

Various characteristics of activated carbon change little by little with repeated use and regeneration, but will not be improved to the level of fresh carbon by regeneration. This is clearly understood from Fig. 4.3 and Fig. 4.6.

Now on the assumption that some value of characteristics will be increased A fold by every regeneration, the value of characteristics after regeneration n times, which is expressed in P_n , will be;

$$P_n = P_o \cdot A^n \quad \text{Log } P_n = n \log A + \log P_o$$

where P_o = Characteristics Value of Fresh Carbon

Here from the various characteristics values of fresh, spent and regenerated carbon obtained from the four times regeneration, we have gotten the values of A and P_o by a minimum involution on the items which are likely to fit to the above equation and have gotten the result as shown in Table 4.4 (a). In the Table, r is a coefficient of correlation expressed in logarithms. Table 4.4 (b) indicates all C values taken from Table 4.4 (a). The degree of decline depends on the type of carbon. The degree of decline of various characteristics are lower than that of gravimetric recovery rate.

4.2.6 CORRELATION BETWEEN EACH CHARACTERISTIC OF ACTIVATED CARBON

As mentioned earlier in 4.2.3, there exists a greater correlation between physical characteristics and general adsorption capacity of activated carbons. For instance, specific surface area in Fig. 4.3 (d) and methylene blue decolorizing capacity in Fig. 4.6 (a) shows nearly the same fluctuation. We have then studied about correlation between various physical characteristics and general adsorption capacity

Table 4.4 (a) Coefficients which show the Characteristic Change with Repeat of Regeneration

$$\log P_n = n \cdot \log A + \log P_0 \quad A = 10^a, P_0 = 10^b, C = (A' - 1) \times 100$$

Item	Reactor Symbol	1 ~ 2						3 ~ 4						5 ~ 6					
		a	b	r	A	P ₀	C	a	b	r	A	P ₀	C	a	b	r	A	P ₀	C
Specific Surface Area	m ² /g	0.0295	2.980	0.9221	0.9343	955.0	Δ6.57	-0.0299	3.004	0.8789	0.9335	1009.3	Δ6.65	-0.0168	2.959	0.6769	0.9621	909.9	Δ3.79
Mean Pore Size of 0~300A Micropore		0.0195	1.321	0.9637	1.0459	20.94	4.59	0.0204	1.335	0.9680	1.0481	21.63	4.81	0.0207	1.317	0.9960	1.0488	20.75	4.88
Volume of Micropore	0~15μ cc/g	0.01021	0.0976	0.6129	1.0238	0.7987	2.38	0.01331	-0.0625	0.6578	1.0311	0.8660	3.11	0.01954	-0.1146	0.8742	1.0460	0.7681	4.60
	300A~15μ cc/g	0.03671	-0.5209	0.9347	1.0882	0.3014	8.82	0.0427*	-0.4962	0.9784	1.1035	0.3191	10.35	0.0423	-0.5303	0.9799	1.1023	0.2949	10.23
	0~300A cc/g	-0.01031	-0.3008	0.6126	0.9764	0.5003	Δ2.36	-0.0105*	-0.2615	0.5143	0.9759	0.5476	Δ2.41	0.0034*	-0.3257	0.1987	1.0080	0.4724	0.80
	0~12A cc/g	-0.04101	-0.6971	0.9421	0.9098	0.2008	Δ9.02	-0.0426*	-0.7035	0.9501	0.9065	0.1979	Δ9.35	-0.0437*	-0.6777	0.9189	0.9041	0.2100	Δ9.59
Apparent Density	g/g	-0.0077	2.686	0.9318	0.9824	485.3	Δ1.76	-0.0067	2.655	0.9002	0.9847	451.6	Δ1.53	-0.0110	2.694	0.9787	0.9750	494.3	Δ2.50
Mean Particle Size	mm	-0.02456	0.2154	0.9161	0.9450	1.642	Δ5.50	0.0082	0.0041*	0.4499	1.0191	1.0096	1.91	-0.00331	0.2020	0.2225	0.9924	1.592	Δ0.76
Methylene Blue Decolorizing Capacity	ml/g	-0.0228	2.237	0.9076	0.9489	172.6	Δ5.14	-0.0385	2.314	0.9762	0.9152	206.1	Δ8.48	-0.0188	2.248	0.8497	0.9576	177.0	Δ4.24
Iodine Adsorption Capacity	g/g	-0.0175	-0.02631	0.9582	0.9605	0.9412	Δ3.95	-0.0232*	-0.0005*	0.9958	0.9479	0.9988	Δ5.21	-0.01581	-0.0275	0.9714	0.9643	0.9386	Δ3.57
Molasses Decolorizing Capacity	%	0.0114	1.797	0.7418	1.0266	62.69	2.66	0.0090	1.825	0.7945	1.0210	66.90	2.10	0.0137	1.803	0.8745	1.0320	63.62	3.20
ABS Value		0.0340	1.6351	0.8170	1.0814	43.17	8.14	0.0317	1.594	0.9061	1.0757	39.26	7.57	0.0193	1.6452	0.9396	1.0454	44.18	4.54
Converse of ABS Value		-0.03391	0.3642	0.8169	0.9248	2.313	Δ7.52	0.0317*	0.4051	0.9072	0.9295	2.541	Δ7.05	-0.0162	0.3514	0.8728	0.9634	2.246	Δ3.66
Dry Weight of Carbon	kg	-0.0710*	2.9811	0.9915	0.8491	957.4	Δ15.09	-0.0682*	2.9519	0.9791	0.8547	895.2	Δ14.53	-0.0499*	2.9723	0.9922	0.8914	938.2	Δ10.86

n = time number of regeneration,

P_n = Value showing characteristic of the activated carbon after n th regenerationP₀ = Value showing characteristic of the fresh carbon

Δ = sign of minus

r = Coefficient of correlation

Table 4.4 (b) Decline of Granular Activated Carbon Characteristics with Repeat of Regeneration

Name of Carbon Items		SGL, 8 x 30		CAL, 12 x 40		SHIRASAGI, 8 x 30	
Specific Surface Area		0.9343	6.57	0.9335	6.65	0.9621	3.79
Mean Pore Size of 0~300Å Micropore		1.0459	-4.59	1.0481	-4.81	1.0488	-4.88
Volume of Micropore	0~15μ	1.0238	-2.38	1.0311	-3.11	1.0460	-4.60
	300Å~15μ	1.0882	-8.82	1.1035	-10.35	1.1023	-10.23
	0~300Å	0.9764	2.36	0.9759	2.41	1.0080	-0.80
	0~12Å	0.9098	9.02	0.9065	9.35	0.9041	9.59
Apparent Density		0.9824	1.76	0.9847	1.53	0.9750	2.50
Mean Particle Size		0.9450	5.50	1.0191	-1.91	0.9924	0.76
Methylene Blue Decol- orizing Capacity		0.9489	5.14	0.9152	8.48	0.9576	4.24
Iodine Adsorption Capacity		0.9605	3.95	0.9479	5.21	0.9643	3.57
Molasses Decolorizing Capacity		1.0266	-2.66	1.0210	-2.10	1.0320	-3.20
ABS Value		1.0814	-8.14	1.0757	-7.57	1.0454	-4.54
Converse of ABS Value		0.9248	7.52	0.9295	7.05	0.9634	3.66
Dry Weighs of Packed Carbon		0.8491	15.09	0.8547	14.53	0.8914	10.86

Note: Left number show recovery rate and right show declining rate (%). The numbers were calculated statistically from result of experiments.

as well as correlation among adsorption capacities.

Assuming that item Y and item X is in the relationship as $Y = AX + B$, we have obtained the values of A and B as well as coefficient of correlation R as shown in Table 4.5 (a). Further in order to make it easier to understand, we have expressed these values in matrix as shown in Table 4.5 (b). In Table 4.5 (a) and Table 4.5 (b), coefficient of correlation marked with double circles are 0.95 and above, coefficient of correlation marked with a single circle 0.85 to 0.95, coefficient of correlation marked with a triangle 0.70 to 0.85.

From the Table 4.5 (b), relatively high correlation can be noticed as follows;

- (1) Micropore volume from 0 to 300Å vs. specific surface area and total micropore volume.
- (2) Micropore volume from 30 to 60Å vs. total micropore volume from 0 to 15μ.
- (3) Methylene blue decolorizing capacity vs. specific surface area, micropore volume from 0 to 300Å, micropore volume from 12 to 30Å and micropore volume from 0 to 12Å.
- (4) Iodine adsorption capacity vs. specific surface area, micropore volume from 0 to 12Å and methyle blue decolorizing capacity.

- (5) Molasses decolorizing capacity vs. Micropore from 0 to 300Å
 (6) The converses of ABS value vs. specific surface area, micropore volume from 0 to 300Å, micropore volume from 0 to 12Å, methylene blue decolorizing capacity and iodine adsorption capacity.

4.2.7 PARAMETER AS A BASE FOR CALCULATION OF REGENERATING COST

The regeneration cost of activated carbon is a very expensive so, as the case may be, it is advisable to purchase fresh carbon, but in case of regeneration, it must be more in-expensive than purchasing fresh carbon if we can enhance recovery rate by reducing the costs for fuel, for electricity and for labor since we require no raw materials. Out of the three costs above, most important one is considered to be fuel cost so we have prepared Table 4.6 covering unit values of all the relevant items of fuel costs from the data obtained from this experiment. The moisture of spent carbon fed into a regeneration furnace in this experiment was 40 to 50%, but from Table 4.6, propane gas consumption for spent carbon with such water content was 50 to 55 g/kg wet weight of feeded carbon, 87 to 99 g/kg dry weight of feeded carbon while fuel oil consumption at after-burning room for treatment of exhaust gas was 0.1 to 0.14 g/kg dry weight of feeded carbon. Further, the feeding rate of

Table 4.5 (a) Correlation between Each Characteristic of Granular Activated Carbon

$$Y = AX + B$$

Carbon		SGL			CAL			Shirangi		
X	Y	A	B	R	A	B	R	A	B	R
△ Specific Surface Area m ² /g	Volume of Total Micropore cc/g	0.0005746	0.3148	0.8285	0.0006005	0.3652	0.8487	0.0005522	0.3706	0.7608
⊙ Specific Surface Area m ² /g	Volume of 0~300Å Micropore cc/g	0.0004767	0.07339	0.9676	0.0004919	0.08239	0.9738	0.0004899	0.06442	0.9535
○ Specific Surface Area m ² /g	Methylene Blue Decolorizing Capacity ml/g	0.1506	27.60	0.9186	0.1646	27.13	0.9200	0.1634	22.99	0.9272
○ Specific Surface Area m ² /g	Iodine Adsorption Capacity g/g	0.0004774	0.4665	0.9484	0.0004848	0.4711	0.9481	0.0004969	0.4499	0.9009
○ Specific Surface Area m ² /g	Converse of ABS Value (2)	0.002861	-0.4466	0.9036	0.002842	-0.3500	0.9328	0.003073	-0.5582	0.9448
○ Volume of Total Micropore cc/g	Volume of 0~300Å Micropore cc/g	0.6644	-0.08849	0.9364	0.6744	-0.1025	0.9447	0.6470	-0.08314	0.9141
⊙ Volume of Total Micropore cc/g	Volume of 30~60Å Micropore cc/g	0.06289	0.006752	0.9596	0.06782	0.005039	0.9317	0.07311	0.002073	0.9771
△ Volume of 300Å~15µ Micropore cc/g	Molasses Decolorizing Capacity %	121.6	17.85	0.7013	150.6	7.446	0.7549	168.6	2.293	0.7609
○ Volume of 0~300Å Micropore cc/g	Methylene Blue Decolorizing Capacity ml/g	293.2	13.67	0.8798	301.5	13.77	0.8510	289.5	19.37	0.8439
○ Volume of 0~300Å Micropore cc/g	Molasses Decolorizing Capacity %	88.57	23.05	0.8794	95.00	20.76	0.8485	110.1	14.80	0.8834
○ Volume of 0~300Å Micropore cc/g	Converse of ABS Value (2)	5.633	-0.7365	0.8753	5.496	-0.7054	0.9114	5.679	-0.7214	0.8971
○ Volume of 12~30Å Micropore cc/g	Methylene Blue Decolorizing Capacity ml/g	832.8	28.03	0.8576	835.5	26.08	0.8980	921.2	21.93	0.8446
△ Volume of 12~30Å Micropore cc/g	Iodine Adsorption Capacity g/g	2.677	0.4635	0.8983	2.488	0.4642	0.9358	2.649	0.4656	0.7762
△ Volume of 12~30Å Micropore cc/g	Molasses Decolorizing Capacity %	216.2	31.79	0.7368	219.1	30.83	0.7453	333.8	17.84	0.8422
○ Volume of 0~12Å Micropore cc/g	Methylene Blue Decolorizing Capacity ml/g	680.6	38.65	0.9186	788.0	42.56	0.9250	607.5	54.05	0.9224
○ Volume of 0~12Å Micropore cc/g	Iodine Adsorption Capacity g/g	2.175	0.4995	0.9565	2.336	0.5146	0.9596	1.932	0.5328	0.9373
○ Volume of 0~12Å Micropore cc/g	Converse of ABS Value (2)	12.75	-0.2121	0.8913	13.36	-0.05296	0.9218	11.34	-0.03731	0.9331
⊙ Methylene Blue Decolorizing Capacity ml/g	Iodine Adsorption Capacity g/g	0.002993	0.4036	0.9754	0.002829	0.4078	0.9903	0.003059	0.3775	0.9775
⊙ Methylene Blue Decolorizing Capacity ml/g	Converse of ABS Value (2)	0.01916	-0.9927	0.9923	0.01644	-0.6996	0.9657	0.01817	-0.9035	0.9845
⊙ Iodine Adsorption Capacity g/g	Converse of ABS Value (2)	6.103	-3.331	0.9699	5.644	-2.935	0.9475	5.674	-2.934	0.9621

Table 4.5 (b) Correlation between Each Characteristic of Granular Activated Carbon

		Converse of AMS Value	Molasses Decolorizing Capacity	Iodine Adsorption Capacity	Methylene Blue Decolorizing Capacity	Volume of Micropore					
						0~12A	12~30A	30~60A	0~300A	300A~15μ	Total Micropore 0~15μ
Specific Surface Area	m ² /g	90~95	-	90~95	91~93	-	-	-	95~98	-	76~85
Volume of Micropore	Total Micropore 0~15μ	cc/g	-	-	-	-	-	93~98	91~95	-	-
	300A~15μ	cc/g	-	70~77 △	-	-	-	-	-	-	-
	0~300A	cc/g	87~92 ○	84~89	-	84~88 ○	-	-	-	-	-
	30~60A	cc/g	-	-	-	-	-	-	-	-	-
	12~30A	cc/g	-	73~85 △	77~94 △	84~90 ○	-	-	-	-	-
	0~12A	cc/g	89~94 ○	-	93~96 ○	91~93 ○	-	-	-	-	-
	Methylene Blue Decolorizing Capacity		96~100 ◎	-	97~100 ◎	-	-	-	-	-	-
			94~97 ◎	-	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	-	-

Numbers in the frame show range of correlation coefficient (x 100).

steam for reactivation of carbon was 0.7 to 1.0 kg/kg while air blow rate for gas burning was approximate 21.1 liter per liter of propane gas.

Mean temperature distribution of atmosphere in furnace during regeneration is as shown in Fig. 4.7 and the temperature was controlled satisfactorily.

The concentration of CO, CO₂ and O₂ for atmospheric gas in the lowest stage which we analyzed is as shown in Table 4.7 and from this data, it is found that the reductive atmosphere was obtained.

4.2.8 OTHERS

In this experiment, component of exhaust gas, concentration of odor substances, and the fluctuation of content of inorganic substances in activated carbon before and after regeneration was measured.

Properties and Component of Exhaust Gas

Properties and component of exhaust gas from regenerating furnace itself, after-burning room and scrubber in regeneration of activated carbon are as shown in Table 4.8. From Table 4.8, it can be said that the dusts and odor strength are removed by after-burning, but sulphurous acid gas and NO_x rather increase. Scrubber is effective to remove dusts and sulphurous acid gas, but did not contributed to the removal of NO_x. The increase of odor strength at scrubber was due to the use of secondary effluent for scrubbing.

Concentration of Odor Substances

In our second and third regeneration, the concentrations of odor substances and dangerous substances contained in exhaust gas from regenerating furnace and after-burning room were measured. The result is shown in Table 4.9. From Table 4.9, it can be said that the concentration of odor substances at the outlet of regeneration furnace is considerably high, but after after-burning, such concentration was considerably reduced. This explains the favorable impact of after-burning to odor substances.

Fluctuation of Inorganic Substances Content with Repeat of Regeneration

Inorganic substances contained in carbon and fresh carbon before and after regeneration were measured and the fluctuation of content with repeat of regeneration was studied. Items measured were altogether nine covering calcium, cadmium, chromium, copper, mercury, magnesium, manganese, lead and zinc. The results of this measurement are as shown in Table 4.10. With the exception of Ca, Cd, Mn,

Table 4.6 Basic Data on Fuel Cost

Reactor Number Regeneration		1	2	3	4	5	6
Consumption Rate of Propane Gas to Wet Weight of Fedded Spent Carbon (g/kg WSC)	1st	48.3	47.7	49.0	43.4	44.3	43.4
	2nd	57.8	57.6	54.8	51.1	55.2	55.6
	3rd	49.7	52.3	62.3	54.4	63.4	51.8
	4th	55.5	53.4	53.1	49.6	62.1	50.7
	Mean	52.8	52.8	54.8	49.6	56.3	50.4
Consumption Rate of Propane Gas to Dry Weight of Fedded Spent Carbon (g/kg DSC)	1st	80.0	82.6	85.2	78.9	77.1	75.9
	2nd	95.2	101.3	94.4	93.4	93.3	93.9
	3rd	89.0	99.0	117.0	103.7	109.1	92.7
	4th	96.3	97.1	97.9	100.9	106.3	93.5
	Mean	90.1	95.0	98.6	94.2	96.5	89.0
Oil Consumption Rate for After Burning to Wet Weight of Fedded Spent Carbon (g/kg WSC)	1st	0.0832	0.107	0.107	0.121	0.0967	0.116
	2nd	0.144	0.163	0.145	0.151	0.121	0.161
	3rd	—	0.123	0.100	0.148	0.0946	0.120
	4th	0.121	0.133	0.112	0.141	0.0971	0.120
	Mean	0.116	0.132	0.116	0.140	0.102	0.129
Oil Consumption Rate for After Burning to Dry Weight of Fedded Spent Carbon (g/kg DSC)	1st	0.138	0.185	0.185	0.220	0.168	0.202
	2nd	0.237	0.287	0.249	0.277	0.204	0.216
	3rd	—	0.233	0.189	0.281	0.163	0.230
	4th	0.209	0.242	0.206	0.272	0.166	0.221
	Mean	0.195	0.237	0.207	0.263	0.175	0.217
Steam Feeding Rate to Dry Weight of Fedded Spent Carbon (kg/kg DSC)	1st	0.737	0.962	0.919	0.941	0.870	0.864
	2nd	0.535	1.006	0.899	0.919	0.819	0.823
	3rd	0.901	1.013	1.199	1.052	0.826	0.951
	4th	0.875	0.909	0.926	0.993	0.801	0.867
	Mean	0.762	0.973	0.986	0.976	0.829	0.876
Air Blowing Rate to Propane Gas (N-G/N-G)	1st	22.5	24.6	23.9	25.3	25.1	25.0
	2nd	20.2	18.9	18.4	19.0	18.1	17.2
	3rd	22.7	21.5	20.9	20.8	20.4	21.7
	4th	21.6	19.6	21.6	20.5	21.0	22.3
	Mean	21.8	21.2	21.1	21.4	21.2	21.6

Fig. 4.7 Distribution of Temperature in Furnace

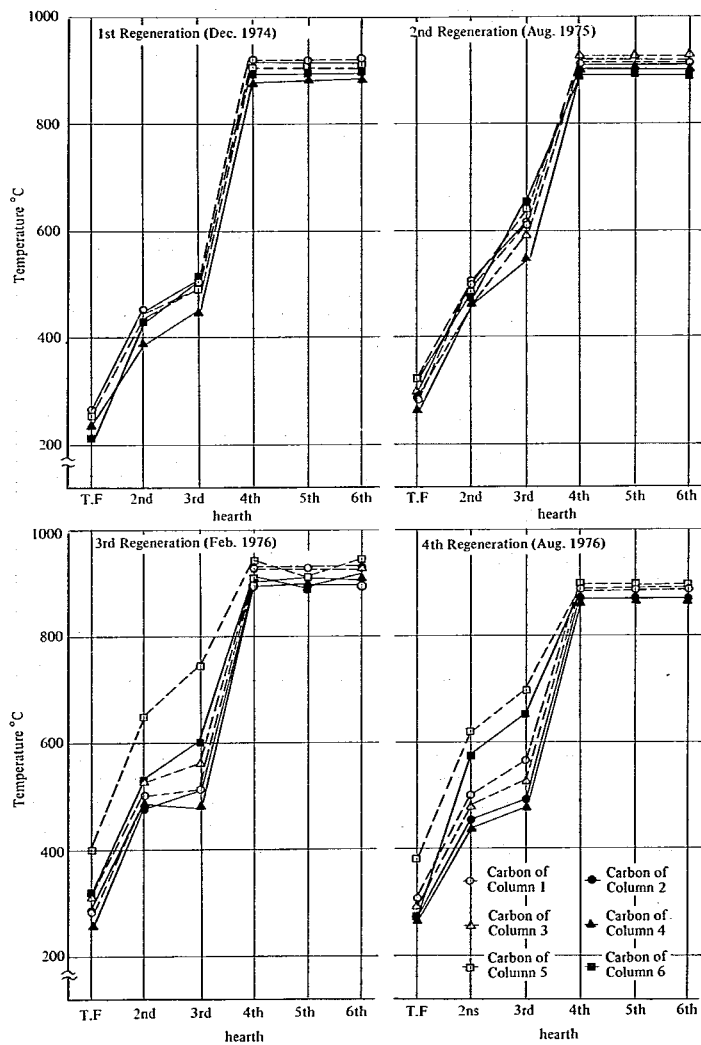


Table 4.7 Contents of Atmosphere Gas (%)

Item Times of Regeneration	CO	CO ₂	O ₂
1	2.0~3.4	12.0~12.2	0.1 or less
2	1.9~3.4	11.9~12.9	0
3	1.7~1.9	11.0~11.8	0
4	1.7~1.9	11.1~11.6	0

Table 4.8 Exhaust Gas Component

Items	Method of Analysis	Outlet of Re-generation Furnace			Outlet of After Burning Room			Outlet of Scrubber			
		1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	
Gas Temperature	°C	240	240	266	620	650	643	40	50	25	
Dry Gas Volume Nm ³ /H	JIS Z8808	69	83	88	675	272	185	373	294	229	
Moisture	V/V %	JIS Z8808	42.4	42.8	39.4	22.5	21.6	35.9	2.4	12.2*	13.1
Dust	g/Nm ³	JIS Z8808 Dust Tube Method	1.31	3.14	3.84	0.16	0.27	0.26	0.05	0.05	0.06
SO ₂	ppm	JIS K0103 Solution Conductivity Method	3	<5	<5	235 ~240	140 ~170	350 ~400	6~9	<5	<5
NO	ppm	JIS K0104 Chemical Radiation Method	62 ~74	66 ~70	—	100 ~110	85 ~89	—	113 ~123	107 ~111	—
NOx	ppm	JIS K0104	65 ~76	66 ~70	40 ~60	105 ~115	88 ~94	125 ~135	118 ~128	107 ~115	125 ~130
Power of Odor	(PO)	Equilibrium Method in Salt Water	11.9	11.9	10.4	2.6	1.0	0	5.3	2.3	5.1
CO ₂	V/V %	Orsat Method	10.9	10.4	9.6	11.4	7.6	10.2	8.3	5.8	9.9
O ₂	V/V %	Orsat Method	3.3	3.3	0.9	4.0	9.3	6.1	8.6	12.4	6.2
CO	V/V %	Orsat Method	—	3.3	2.9	—	0	0	—	0	0.2

and Pb, the content of each substance was greater in spent carbon than regenerated carbon and also normally greater in primary reactor than in secondary reactor. This explains that activated carbon has adsorbed metals to some extent and has accumulated part of metals without taking off it in regeneration. A high concentration of Ca was due to the impact from the regeneration of lime in the regenerating reactor.

Table 4.9 Concentration of Odor and Dangerous Substances in Exhaust Gas (ppm)

Items		Measuring Method	Threshold Value	Outlet of Furnace		Outlet of After Burning Room	
Name	Chemical Formula			2nd	3rd	2nd	3rd
Hydrogen Cyanide	HCN	JIS K0109 Pyridine Pyrazolon Method		4.2	5.2	<0.08	<0.006
Carbon Disulfide	CS ₂	E.A. Notification No.9 FPD-GC Method		120	90	<0.1	<0.02
Acetic Acid	CH ₃ COOH	FID-GC Method		280	370	40	<0.2
Formaldehyde	HCHO	JIS K0102 Acetylacetone Method	1.0	<0.7	0.19	<0.5	<0.01
Acetaldehyde	CH ₃ ·CHO	FID-GC Method	0.21	<30	19	<30	<0.3
Methane	CH ₄	FID-GC Method		1100	1.360	<10	35
Ethane	C ₂ H ₆	FID-GC Method		54	3.5	<10	<0.3
Ammonia	NH ₃	JIS K0099 Indo Phenol Test		990	680	0.49	0.25
Tri-methyl Amine	(CH ₃) ₃ ·N	E.A. Notification No.9	0.0021	<0.05	<0.08	<0.05	<0.008
Hydrogen Sulfide	H ₂ S	E.A. Notification No.9	0.005	<3	780	<0.03	0.15
Methyl Mercaptan	CH ₃ ·SH	E.A. Notification No.9	0.041	<1	<2	0.002	<0.05
Dimethyl Sulfide	(CH ₃) ₂ ·S	E.A. Notification No.9		<0.5	<0.1	<0.001	<0.03

Table 4.10 Change of Inorganic Matter Contents with Repeat of Regeneration

Unit: ppm

Carbon	Status of Carbon	Reactor		Primary										Secondary														
		Ca	Cd	Cr	Cu	Hg	Mg	Mn	Pb	Zn	Ca	Cd	Cr	Cu	Hg	Mg	Mn	Pb	Zn									
S G L	F	40	<0.5	<0.5	0.5	(0.1)	69	3	<5	7	40	<0.5	<0.5	0.5	(0.1)	69	3	<5	7									
	1S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-									
	1R	825	<0.5	12	16.5	0.02	131	82	<5	20.5	-	-	-	-	-	-	-	-	-									
	2S	650	<0.5	25	41.0	1.47	134	54.5	<5	120	335	<0.5	28	43.0	0.28	130	104	<5	124									
	2R	645	<0.5	10	31.0	0.05	118	62	<5	8.5	278	<0.5	8	19.5	0.04	100	77	<5	9									
	3S	1575	<0.5	12.1	45.7	0.10	194	52.3	<5	132	855	<0.5	9.7	37.1	0.13	149	68	<5	144									
	3R	1260	<0.5	6.7	25.7	<0.01	148	87.4	<5	7.5	995	<0.5	7.3	20.0	<0.01	144	106.1	<5	10.0									
	4S	1800	<0.5	25	49	0.02	260	82	<5	223	915	<0.5	15	31	0.04	161	103	<5	206									
C A L	4R	2100	<0.5	15	39	<0.01	244	105	<5	18	1270	<0.5	11	16	<0.01	171	127	<5	17									
	F	59	<0.5	<0.5	1.5	(0.11)	48	5	5	2	59	<0.5	<0.5	1.5	(0.11)	48	5	5	2									
	1S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-									
	1R	775	<0.5	24	37.5	0.03	141	195	<5	21.0	-	-	-	-	-	-	-	-	-									
	2S	725	<0.5	40	55.0	1.50	139	73	10	137	370	<0.5	37	39.5	0.15	135	162	<5	139									
	2R	755	<0.5	24	34.0	0.03	129	99	<5	13.5	330	<0.5	11	14.5	0.04	111	125	<5	11									
	3S	2115	<0.5	14.6	61.7	0.06	270	88.4	<5	156	1260	<0.5	12.8	42.8	0.10	198	99.0	<5	159									
	3R	1880	<0.5	12.1	49.1	0.01	244	156.5	<5	9.0	950	<0.5	9.1	14.3	<0.01	249	140.0	<5	206									
S H I R A S A G I	4S	2560	<0.5	28	70	0.10	385	140	<5	284	1235	<0.5	22	34	0.05	204	172	<5	7.0									
	4R	2240	<0.5	17	44	<0.01	328	156	<5	24	1200	<0.5	13	14	<0.01	174	150	<5	16									
	F	36	<0.5	<0.5	0.5	(0.09)	67	2.5	<5	4.5	36	<0.5	<0.5	0.5	(0.09)	67	2.5	<5	4.5									
	1S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-									
	1R	850	<0.5	12	23	0.02	135	86	<5	10.5	-	-	-	-	-	-	-	-	-									
	2S	655	<0.5	29	49	0.92	131	76	<5	126	388	<0.5	25	31.5	0.27	126	105	5	122									
	2R	605	<0.5	10	22	0.02	119	72	<5	9	273	<0.5	7	10.5	0.01	102	76	<5	8.5									
	3S	2125	<0.5	11.5	88.5	0.20	219	124.5	<5	122	790	<0.5	11.5	20.7	0.25	132	88.3	<5	145									
S H I R A S A G I	3R	1125	<0.5	4.8	17.7	<0.01	135	105.4	<5	7.0	750	<0.5	6.1	8.6	<0.01	120	108.5	<5	12.0									
	4S	2505	<0.5	11	64	0.10	309	157	<5	247	1215	<0.5	13	30	0.07	188	212	<5	156									
	4R	2225	<0.5	11	37	<0.01	269	192	<5	26	1200	<0.5	8	7	<0.01	157	149	<5	8.5									

The numbers in () are not exact.

4.3 SUMMARY

Repeat of regeneration experiments have been conducted on three types of activated carbon being used for an advanced wastewater treatment at Kyoto pilot plant and the following have been confirmed;

- (1) Recovery rate was 90 to 100% gravimetrically but 85 to 95% volumetrically.
- (2) Through the repeated regeneration, apparent density and micropore volume was decreased, but mean particle size of micropore from 0 to 300Å and micropore volume from 300Å to 15 μ was increased. The rest of the items have not been changed so much.
- (3) Out of general adsorption capacity, methylene blue decolorizing capacity and iodine adsorption capacity were decreased through the repeat of regeneration while molasses decolorizing capacity was slightly increased. Phenole value and ABS value were not fluctuated so much.
- (4) It was found that the following items had extremely high correlation each other;

Micropore volume from 0 to 300Å vs. specific surface area, micropore volume from 30 to 60Å vs. total micropore volume from 0 to 15 μ . Iodine adsorption capacity vs. methylene blue decolorizing capacity, the converses of ABS values vs. methylene blue decolorizing capacity and iodine adsorption capacity.

- (5) Propane gas consumption by dry weight of feeding activated carbon was 87 to 99 l/kg. Fuel oil consumption for after-burning was 0.1 to 0.14 l/kg. Steam injection quantity for reactivation of carbon was 0.7 to 1.0 kg/kg.
- (6) Due to after-burning, dust contained and odor strength of exhaust gas was decreased, but SO_x and NO_x were increased. Scrubber was effective for the reduction of SO_x, but not for NO_x.
- (7) Activated carbon adsorbes or removes metals in wastewater to some degree.

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II. Sludge Treatment and Disposal

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STUDIES ON SEWAGE SLUDGE PYROLYSIS

Mamoru Kashiwaya

4.1 INTRODUCTION

Sewage treatment plants in large municipalities and their environs are being subjected to increasing restrictions on the acquisition of land for sewage sludge landfill in Japan. For this reason, there are found many cases where sludge is incinerated at sewage treatment plant sites for the most effective use of the land acquired to their sludge filling.

However, the incineration of sewage sludge has been faced with several severe problems, which require an early settlement.

First, the more severe environmental quality standard on air pollution has established it indispensable for sewage treatment plants to set up incidental facilities of incinerators, such as electric precipitators, to prevent pollution causing by the exhaust gas. The construction and operation of such facilities require additional expenses.

Second, it has also become necessary to set up incidental facilities of incinerators for offensive odor control, such as exhaust gas combustion (after-burning) facilities, because of the strong demand from residents for preventing offensive odor arising from sludge incineration. The construction and operation of such facilities also require additional expenses.

Third, it has been found that lime used as a conditioner of sludge dewatering, and trivalent chromium compounds contained in municipal sewage sludge show a chemical reaction in the furnace at the time of incineration. The trivalent chromium compounds in sludge are oxidized into hexavalent chromium compounds which are soluble in water. Therefore, the filling of land with incinerated ash has a danger of causing the pollution of surface water and underground water by hexavalent chromium compounds. For the prevention of such pollution, it requires much expense for landfill.

Fourth, the operational cost for sludge incineration — fuel cost and electric power charge — has been increasing sharply every year due to the spirals in the prices of oil products in addition to the increased use of fuel and electric power for incidental facilities of incinerators. Sewage treatment plants in some areas are obliged to use better quality fuel than before to establish the environmental quality standard on air pollution.

Under these circumstances, it is expected to be more advantageous, for the following reasons, to reduce the volume of solid residue (ash) by pyrolysis than to incinerate it.

i) In pyrolysis, the furnace is operated naturally at the lower combustion air ratio than in incineration. Accordingly, the amount of exhaust gas is reduced and the construction cost and the operation cost (fuel cost and electric power charges) of the incidental facilities for the control of both air pollution and offensive odor

might be able to cut down.

- ii) Since the inside of the pyrolysis furnace is maintained in a reducing condition or in a condition close to it, there is little possibility of the trivalent chromium compounds in sewage sludge being oxidized into hexavalent chromium compounds.
- iii) Pyrolysis might require more fuel in the furnace itself than incineration. However, the amount of fuel used in the furnace might be able to reduce, if combustible gas obtained by pyrolysis is burned in the combustion chamber and steam generated in boiler is used for preliminary drying of sludge. Therefore, there is expected a strong possibility that fuel consumption for the pyrolysis as a whole system could be smaller than that for incineration.

So far, multi-hearth furnace have dominantly been used for sewage sludge incinerations at sewage treatment plants in Japan. Therefore, there are many skillful engineers and operators for design and operation of such furnaces. If the multi-hearth furnaces now in use are rebuilt for pyrolysis of sewage sludge, it will be expected of great benefit to the social and economical aspects in the nation.

For these reasons, the Ministry of Construction decided on the disbursement of the public works technology and development subsidy for fiscal 1976 to conduct practical study work on pyrolysis by applications of multi-hearth furnace. The ministry offered for public subscription to interesting organizations and, after screening application documents, decided to give the subsidy to a private firm (NGK Insulators, Ltd., Nagoya). The company, which has experiences of basic study works in the past (1), proposed to conduct additional basic study and new practical study at pilot plants. The Ministry of Construction organized a discussion group to have the views of users reflected on the study. The group is made some engineers of Kyoto University, Osaka Prefecture, Kyoto City, Hyogo Prefecture and the Japan Sewage Works Agency as well as the Ministry of Construction.

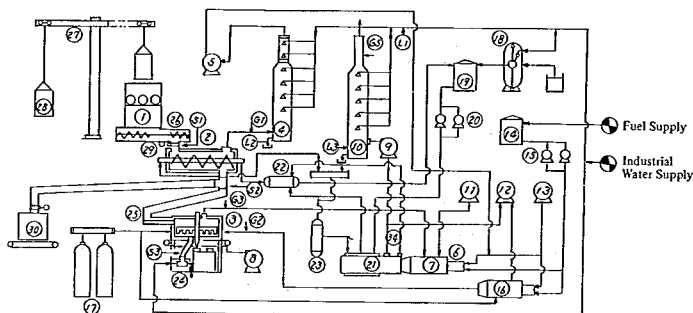
The Practical study was not completed at the time of this reporting. However, a series of experiments were concluded and their results were compiled. They were conducted at a pilot plant established in the Kawamata Sewage Treatment Plant site of Osaka Prefecture, using raw dewatered sludge carried from the Toba Sewage Treatment Plant in Kyoto. At present, the project is being examined from the economic viewpoint, and conditions for the designing of facility to be put to practical use are being discussed.

More experiments are to be conducted at the pilot plant, using heat-treated sludge taken from a sewage treatment plant in Osaka Prefecture and raw dewatered sludge separated from waste at a chromic tanning pre-treatment facility in Hyogo Prefecture.

4.2 PILOT PLANTS AND SLUDGE CAKES USED IN EXPERIMENTS

Basic study and practical study were conducted separately at different pilot plants. Used in the basic experiments was a pilot plant with a capacity to treat 2 tons of sludge cakes per day with the water content of 75%. The flow chart of this pilot plant is shown in Fig. 4.1. The Figure shows the sampling points for solid ($S_1 - S_3$), liquid ($L_1 - L_3$) and gas ($G_1 - G_5$) in addition to various sorts of machinery and instrumentation constituting the pilot plant.

Fig. 4.1 Pilot Plant Flow Chart Used for Basic Study



Explanation

① Cake feeder	⑥ Burner	⑪ Blower for combustion chamber	⑯ Heat source chamber	⑳ Exhaust gas boiler	㉒ Conveyer
② Paddle dryer	⑦ Combustion chamber	⑫ Blower for circulated gas	⑰ Nitrogen gas supply	㉓ Condensed water tank	㉔ Hoist
③ Single-hearth furnace	⑧ Blower for partial combustion	⑬ Blower for burner	⑱ Water softening installation	㉔ Condensed water circulator	㉕ Cake container
④ Dehumidifier	⑨ Blower for exhaust gas	⑭ Fuel tank	⑲ Soft water storage tank	㉕ Solid residue cooling tank and container	㉖ Double sealing damper
⑤ Blower for dryer	⑩ Scrubber stack	⑮ Fuel pump	⑳ Water supply pump	㉖ Screw type feeder	㉗ Dried cake container

Sampling point

Sampling point of solids

- S_1 Cake of dryer inlet
 S_2 Cake of dryer outlet
 S_3 Residue of pyrolysis

Sampling point of liquids

- L_1 Supplied water
 L_2 Wastewater of dehumidifier
 L_3 Wastewater of scrubber

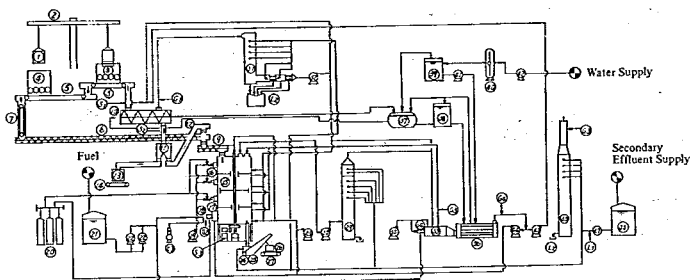
Sampling point of gases

- G_1 Outlet of dryer
 G_2 Outlet of pyrolysis furnace
 G_3 Inlet of combustion chamber
 G_4 Outlet of exhaust gas boiler
 G_5 Outlet of scrubber

The flow chart of the pilot plant used for practical study is shown in Fig. 4.2. It is different from the pilot plant for the basic study in the following points.

- The indirect steam dryer of paddle type was changed from a two-shaft dryer to a four-shaft dryer.
- The plant was designed so that dewatered sludge cakes could also be thrown into the furnace directly without passing through the indirect steam dryer of paddle type.
- The single-hearth furnace was changed to a four-hearth furnace.
- The heat source chamber was directly attached to the pyrolysis furnace in

Fig. 4.2 Pilot Plant Flow Chart Used for Practical Study



Explanation

① Cake container	⑪ Sieve machine	⑳ Fuel tank	㉓ No. 1 scrubber	㉙ Water supply tank
② Hoist	⑫ Dried cake conveyer	㉑ Fuel pump	㉔ Blower for dryer	㉚ No. 2 water supply pump
③ Cake feeder	⑬ Dried cake container	㉒ Compressor	㉕ Combustion chamber	㉛ No. 1 blower for exhaust gas
④ Dried cake feeder	⑭ Roller conveyer	㉓ Quenching tank	㉖ Burner for combustion chamber	㉜ Blower for circulation
⑤ No. 1 cake conveyer	⑮ Pyrolysis furnace	㉔ Residue carry conveyer	㉗ Blower for combustion chamber	㉝ No. 2 scrubber
⑥ No. 2 cake conveyer	⑯ Ignition burner for partial combustion	㉕ Residue container	㉘ Boiler	㉞ Water storage tank
⑦ No. 3 cake conveyer	⑰ Heat source chamber	㉖ Roller conveyer	㉙ Condensed water tank	㉟ No. 1 water supply pump
⑧ No. 1 screw conveyer	⑱ Heat source burner	㉗ Blower for pyrolysis	㉚ Condensed water circulator	
⑨ No. 2 screw conveyer	㉑ Blower for burner	㉘ No. 3 scrubber	㉛ Soft water tank	
⑩ Paddle dryer	㉒ Propane gas supply	㉙ No. 2 blower for exhaust gas	㉜ Water softening installation	

Sampling point

Sampling point of solids

- S_1 Cake of dryer inlet
 S_2 Cake of dryer outlet
 S_3 Residue of pyrolysis furnace

Sampling point of liquids

- L_1 Supplied water
 L_2 Wastewater of No. 1 scrubber
 L_3 Wastewater of No. 2 scrubber

Sampling point of gases

- G_1 Outlet of dryer
 G_2 Outlet of heat source chamber
 G_3 Outlet of pyrolysis furnace
 G_4 Outlet of combustion chamber
 G_5 Outlet of scrubber

order to reduce heat loss.

v) The pilot plant was designed so that experiments could be conducted with the drying-pyrolysis process as a continuous system.

vi) The system to deal with solid residue discharged from the furnace was changed so that it would drop into water to be scooped up automatically.

vii) A propane gas burner was attached to each hearth of the pyrolysis furnace as a supplemental heat source.

viii) The combustion chamber was designed to allow the automatic control of oxygen concentration in it.

Table 4.1 shows the details of main machinery and instrumentation of the pilot plants both for basic study and for practical study.

Table 4.1 Details of Pilot Plant

Name	Items	Pilot Plant for Basic Study	Pilot Plant for Practical Study
Indirect Steam Dryer	Type	Paddle Type	Paddle Type
	Numbers of Shaft	2	4
	Areas of Total Heat Transfer	8.1 m ²	10.1 m ²
	Numbers of Screw per Shaft	16	12
	Dimension (mm)	560 W x 850 H x 2,800 L	1,097 W x 1,125 H x 2,300 L
	Revolution of Shaft	12 rpm	15 rpm
Pyrolysis Furnace	Counter of Drain	Volumetric	Volumetric
	Method of Heating	Inner Heating	Inner Heating
	Type	Single-Hearth Furnace	4-Hearth Furnace
	Total Bed Areas	2.1 m ²	1.63 m ²
	Dimension (mm)	1,800 ID x 2,200 OD x 1,000 H	900 ID x 1,360 OD x 2,096 H
Heat Source Chamber	Attachment	—	Gas Burner 5,000 kcal/hr x 3
	Capacity of Burner	90,000 kcal/hr	80,000 kcal/hr
	Dimension (mm)	400 ID x 800 OD x 1,500 L	250 ID x 760 OD x 720 L
	Duct Length to Pyrolysis Furnace	4 m	0.5 m
	Attachment	Circulating Gas Flow Control Unit	Circulating Gas Flow Control Unit
Combustion Chamber	Type	Direct Combustion	Direct Combustion
	Capacity of Burner	90,000 kcal/hr	150,000 kcal/hr
	Volume of Chamber	0.2 m ³	0.25 m ³
	Dimension (mm)	400 ID x 800 OD x 1,500 L	400 ID x 800 OD x 2,412 L
Exhaust Gas Boiler	Type	Breeching 3 Pass	Breeching 3 Pass
	Areas of Total Heat Transfer	7.7 m ²	5.8 m ²
	Production of Steam	100 kg/hr	100 kg/hr
	Max. Pressure of Steam	7 kg/cm ² - G	9.5 kg/cm ² - G
	Drain Storage Tank	0.25 m ³	0.33 m ³
	Drain Circulator	0.03 m ³	0.038 m ³
	Soft Water Tank	0.2 m ³	0.2 m ³
	Softening Water Installation	200 kg/hr	200 kg/hr
	Water Supply Pump	660 ² /hr x 80 mH	200 ² /hr x 10 kg/cm ²

The dewatered cakes used in the experiments were taken from the vacuum filter room of the Toba Sewage Treatment Plant in Kyoto City. Table 4.2 shows the analytical results of dewatered cake samples. The compositions of ignition loss of the dewatered cake samples are shown in Table 4.3. The analytical results of the perfect ash in the dewatered cake samples are also shown in Table 4.4.

4.3 BASIC STUDY ON DRYING-PYROLYSIS PROCESS

4.3.1 EXPERIMENTS OF DRYING FOR DEWATERED CAKE USING BY INDIRECT STEAM DRYER

The dryer used in the experiments is an indirect steam dryer of paddle type shown in Fig. 4.3. Steam used for the dryer is supplied by the exhaust gas boiler (21). That is, after the pressure of steam is adjusted so that steam temperature will reach a fixed point, the steam is supplied to the jacket, screw and shaft of the dryer, as shown in Fig. 4.3. And, the steam is condensed into moisture after being used for drying dewatered cakes. The moisture was returned to the exhaust gas boiler after volumetric measurement. In the experiments, the Overall Heat Transfer Coefficient (U) was found by Equation-(1).

$$U = Q/A \cdot \Delta t \text{ (Kcal/m}^2 \cdot \text{hr} \cdot ^\circ\text{C)} \quad (1)$$

Where, $\Delta t = t_s - t_c$

$$Q = Y_s \times M_d$$

Q : Heat Transfer Capacity (Kcal/hr)

A : Total Heat Transfer Area of the Dryer (m^2)

t_s : Temperature of Supplied Steam ($^\circ\text{C}$)

t_c : Average Temperature of Dewatered Cakes in the Dryer ($^\circ\text{C}$)

M_d : Amount of Condensed Moisture Generated (kg/hr)

Y_s : Condensed Heat of Supplied Steam (Kcal/kg)

Some examples of relationship between the moisture content (%) of raw sludge cakes at the inlet of the dryer and the Overall Heat Transfer Coefficient (U) is shown in Fig. 4.4. There was no major difference in drying efficiency between raw sludge and digested sludge, and their Overall Heat Transfer Coefficients (U) are within the range of 70 ~ 100 Kcal/ $\text{m}^2 \cdot \text{hr} \cdot ^\circ\text{C}$. Similar experiments on heat-treated sludge showed that its Overall Heat Transfer Coefficient (U) was 215 Kcal/ $\text{m}^2 \cdot \text{hr} \cdot ^\circ\text{C}$. This is presumably because the fullness ratio of heat-treated sludge in the dryer is higher than that of raw sludge or digested sludge and because moisture contents in dewatered cakes exists in different conditions.

Fig. 4.3 Schematic Drawing of the Indirect Steam Dryer of Paddle Type Used for Pre-Treatment of Sludge Cake

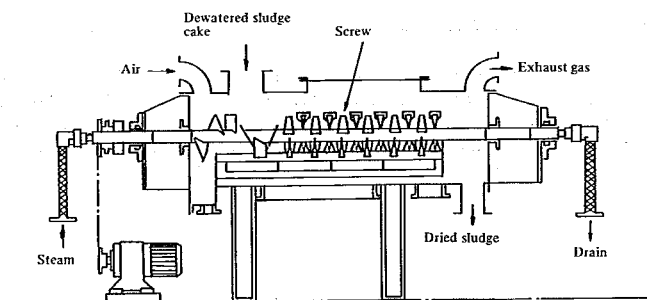


Fig. 4.4 Relationship between Moisture Content and Overall Heat Transfer Coefficient

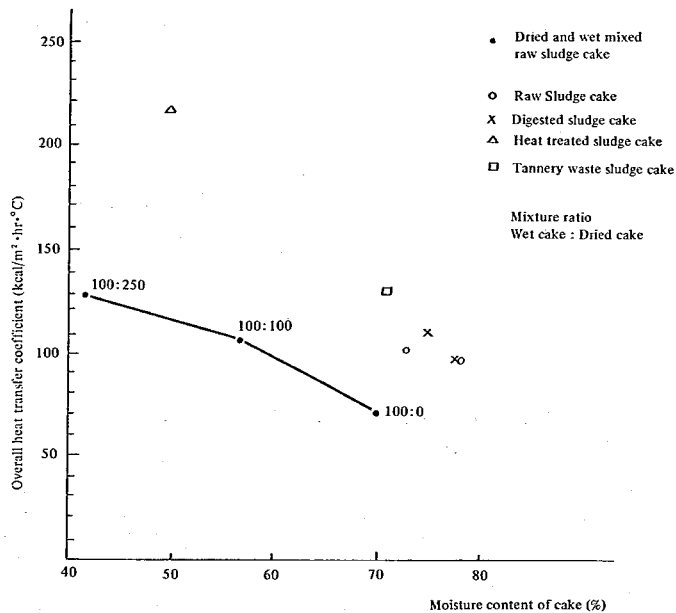


Table 4.2 Analytical Result of Dewatered Cake Samples

(Dry Base)

Date of Sampling	Moisture Content (%)	Ignition Loss (%)	Volatile Content (%)	Gross Calo- rific Value (kcal/kg-DS)	C (%)	H (%)	N (%)	S (%)	O (%)	Cl (%)	CN (ppm)	NH ₃ (ppm)	Hg (ppm)	Cd (ppm)
Aug. 9	74.6	55.0	53.2	2,470	24.8	4.1	2.8	0.71	25.2	—	—	—	—	—
Aug. 30	75.6	49.3	52.0	1,800	18.0	4.0	2.9	0.51	30	1.0	4	220	1.7	7.2
Date of Sampling	Pb (ppm)	As (ppm)	Total Cr (ppm)	Cr ⁺⁶ (ppm)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Al ₂ O ₃ (%)	CaO (%)	MgO (%)	Na ₂ O (%)	K ₂ O (%)	SO ₂ (%)	
Aug. 9	100	—	200	—	2,600	—	—	4.8	14.08	—	—	0.49	13.88	
Aug. 30	175	4.4	170	7.3	1,450	360	6.21	2.17	26.3	0.77	0.18	—	7.98	

Table 4.3 Compositions of Ignition Loss in Samples

Date of Sampling	Gross Calorific Value (kcal/kg-DS)	C (%)	H (%)	N (%)	S (%)	O (%)	Cl (%)	CN (ppm)	NH ₃ (ppm)
Aug. 9	4,491	45.1	7.5	5.1	1.3	45.8	—	—	—
Aug. 30	3,651	36.5	8.1	5.9	1.0	60.9	2.4	8.1	446

Table 4.4 Analytical Result of Perfect Ash in Samples

Date of Sampling	Total Cr (T-Cr) (ppm)	Cr ⁺⁶ (ppm)	Cr ⁺⁶ /T-Cr (%)	Soluble Cr ⁺⁶ (S-Cr ⁺⁶) (mg/l)	Soluble Rate of Cr ⁺⁶ (%)		CaO (%)
					$\frac{S-Cr^{+6}}{T-Cr^{+6}}$ (%)	$\frac{S-Cr^{+6}}{T-Cr}$ (%)	
Aug. 9	360	82	17.2	4.5	72.6	22.5	31.3
Aug. 30	355	190	53.5	0.36	1.9	1.0	51.9

4.3.2 EXPERIMENTS ON PYROLYSIS OF DRIED CAKES

In the experiments, dried cakes by the indirect steam dryer were stored in the feeder at first and then a constant amount of them was fed into the single-hearth furnace (3) by a screw feeder (25) shown in Fig. 4.1. The heat sources to the furnace were hot blast from the hot source chamber and heat of partial combustion proportionate to the ratio of fixed combustion air to sludge feed to furnace. Gas from the outlet of the furnace was sent to the combustion chamber (7), where combustibles was burned and such offensive odor components, HCN and NH₃ were decomposed, and then the heat was recovered as steam by the waste heat boiler (21). Part of the exhaust gas in the boiler was circulated to adjust hot blast in which oxygen concentration is almost zero.

The remainder of the waste gas was released into the air after being sent through the scrubber (10). The solid residue taken out of the pyrolysis furnace was cooled indirectly without contact with the air.

The conditions of these experiments were as follows.

- Ratio of theoretical amount of combustion air to actual amount of combustion air of fed sludge: 0 ~ 2.0
- Temperature in pyrolysis furnace: 600 ~ 900°C.
- Sludge feed loading into furnace: 10 ~ 40 kg-DS/m²·hr
- Estimated detention time of sludge in furnace: 15 ~ 60 min.
- Condition of decomposition of exhaust gas

Temperature in combustion chamber: 900 ~ 1,100°C

Oxygen concentration: 0 ~ 3%

The ratio of theoretical amount of combustion air to actual amount of combustion air of fed sludge (ratio of amount of combustion air) was adjusted by a partial combustion blower.

In order to evaluate the degree of decomposition of combustibles, the ignition loss of solid residue was measured and the decomposition rate of combustibles was estimated by Equation (2).

Decomposition Rate of Combustibles (%)

$$= \left[1 - \frac{\text{Ignition Loss of Solid Residue (\%)}}{100 - \text{Ignition Loss of Solid Residue (\%)}} \right] \div \frac{\text{Ignition Loss of Fed Cake (\%)}}{100 - \text{Ignition Loss of Fed Cake (\%)}} \times 100 \dots (2)$$

a. **Ratio of Theoretical Amount of Combustion Air to Actual Amount of Combustion Air of Fed Sludge (Ratio of Amount of Combustion Air)**

Three sorts of data were collected to investigate this problem. The first concerned the changes in the form of chromium in solid residue according to the ratio of amount of combustion air, which are shown in Fig. 4.5 and Fig. 4.6. Fig. 4.5 shows the results of experiments on raw sludge at the Toba Sewage Treatment Plant. Fig. 4.6 shows, for comparison, the results of experiments on sludge of chromium tanneries' waste which contained a large amount of trivalent chromium compounds. The second data concerned the relationship between the ratio of amount of combustion air and both ignition loss of solid residue and the decomposition rate for combustibles in sludge. It is shown in Fig. 4.7.

Fig. 4.5 and Fig. 4.6 show that, when the ratio of amount of combustion air is below 1.0, the ratio of $\text{Cr}^{+6}/\text{T-Cr}$ in solid residue is smaller than that of $\text{Cr}^{+6}/\text{T-Cr}$ in dewatered cake and that the lower the ratio of amount of combustion air, the higher is the decrease rate. Elution of hexavalent chromium from the solid residue was not observed. If the ratio of amount of combustion air is below 1.0, oxygen supplied to the pyrolysis furnace is consumed by the combustion of inflammable gas generated by pyrolysis and the combustion of carbon retained in solid residue, without causing the oxidization of new trivalent chromium compounds. In case the ratio of amount of combustion air is still lower, a part of the hexavalent chromium compounds already contained in sludge is reduced in the pyrolysis furnace by reducing gas, such as hydrogen and carbon oxide gases generated by pyrolysis.

In contrast, the ratio of $\text{Cr}^{+6}/\text{T-Cr}$ were fairly increased in solid residues when dewatered cake was dried and incinerated completely in an electric furnace and when it was incinerated at the furnace of pilot plant with the ratio of amount of combustion air set at 2.0, comparing to the ratio of $\text{Cr}^{+6}/\text{T-Cr}$ in dewatered cake itself. When the amount of the hexavalent chromium compounds eluted was measured by the Solubility Test Method as provided by the Ministerial Ordinance of the Prime Minister's Office, it has been found at some plants that the soluble concentrations of hexavalent chromium in solid residue exceed the limit of 1.5 mg/l sometimes, when dewatered cakes were incinerated in existing furnaces. This means that a high ratio of amount of combustion air, such as about 2.0, promotes the oxidization reaction of trivalent chromium compounds and a part of them changes hexavalent chromium compounds.

According to Fig. 4.7, the higher the ratio of amount of combustion air, the further promoted is the decomposition of combustibles in sludge. This means that

a high ratio of amount of combustion air promotes the combustion of carbon remaining in solid residue.

From the viewpoint of preventing the oxidization of trivalent chromium compounds in sludge, the appropriate ratio of amount of combustion air is considered to be around 0.5 ~ 0.7.

Fig. 4.5 Behaviour of Chromium in Each Solid Residue
(Raw Sewage Sludge in Toba Sewage Treatment Plant)

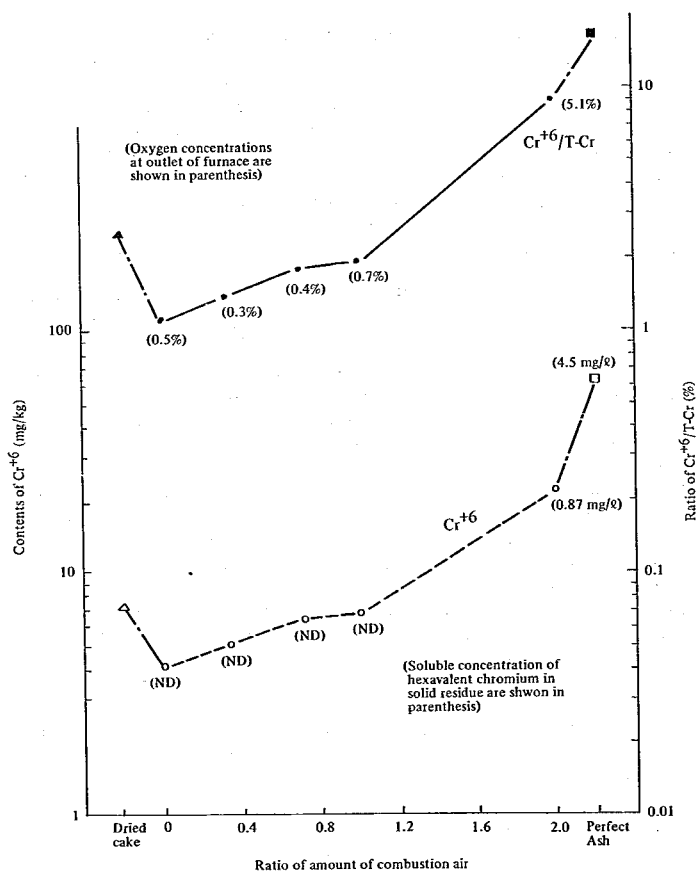


Fig. 4.6 Behaviour of Chromium in Each Solid Residue
(Raw Sludge of Tanneries Waste)

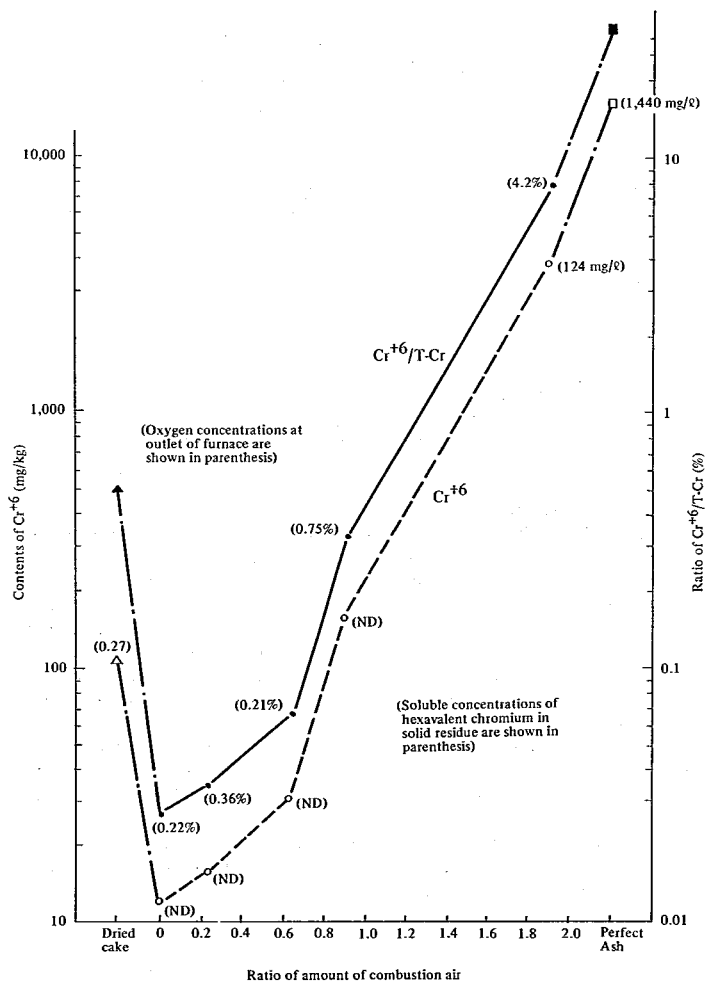
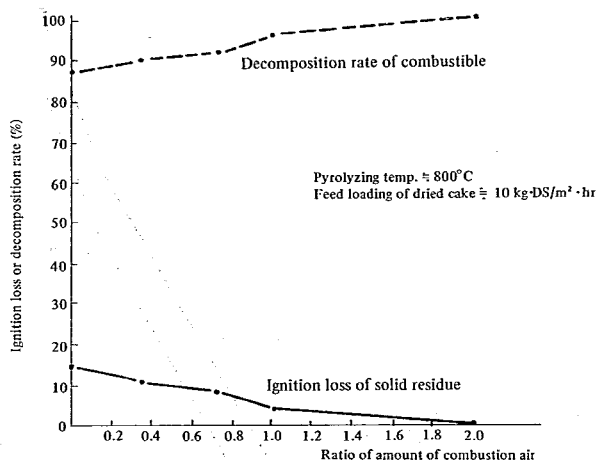


Fig. 4.7 Variation of Both Ignition Loss of Solid Residue and Decomposition Rate of Combustible to Ratio of Amount of Combustion Air



b. Pyrolyzing Temperature

Changes in pyrolyzing temperatures, ignition loss of solid residue and the rate of decomposition of combustibles are shown in Fig. 4.8. The Figures are given for pyrolysis when the ratio of amount of combustion air was 0.6 and 0. There is a tendency that the higher the pyrolyzing temperature, the higher is the decomposition rate of combustibles and the lower is the ignition loss of solid residue. At the pyrolyzing temperature of 900°C, the decomposition of combustibles was almost completed. When the ratio of amount of combustion air was 0, the decomposition rate tended to drop by about 5% compared with pyrolysis when the ratio of amount of combustion air was 0.6.

Shown in Fig. 4.9 is the relationship between pyrolyzing temperatures and the rates of carbon, hydrogen and nitrogen remaining in solid residue. When the pyrolyzing temperature was over 800°C, most of the ignition loss of solid residue was carbon. There is a difference of more than 5% in carbon content in solid residue between pyrolysis when the ratio of amount of combustion air was 0 and when the ratio was 0.6. There was also a slight difference each in the nitrogen and hydrogen contents in solid residue according to the differences in the ratio of amount of combustion air at 0 and 0.6.

c. Feed Loading of Dried Cake

Experiments were conducted on changing feed loading of dried cake (unit: kg-DS/m² · hr) with the pyrolyzing temperature set at 900°C and the ratio of

amount of combustion air at 0.6. Fig. 4.10 shows the changes in the ignition loss of solid residue and the rate of decomposition of combustibles caused by changes in feed loading of dried cake.

With the increase in the feed loading of dried cake, the ignition loss of solid residue goes up. If the ignition loss of solid residue is to be allowed at about 10% when filling land with solid residue, the adequate feed loading of dried cake is about $25 \text{ kg} \cdot \text{DS}/\text{m}^2 \cdot \text{hr}$.

d. Detention Time of Dried Cake in Pyrolysis Furnace

Fig. 4.11 shows the relationship between the detention time of dried cake in pyrolysis furnace and both ignition loss of solid residue and the rate of decomposition of combustibles. Details are not clear because the data of experiments are for the detention time of 15 min. and 60 min. only. Estimating from the Figure, however, the detention time of at least 45 minutes seems to be necessary to maintain the operating condition of ignition loss of solid residue below 10%.

e. Recombustion of Exhaust Gas

Experiments were conducted to grasp the operating conditions of recombustion of exhaust gas from the pyrolysis furnace in order to burn and decompose pollutants in the gas (HCN , NH_3). As a result, it became known that, when O_2 concentration is over 1%, HCN gas can be decomposed almost completely at the combustion temperature of over 900°C and NH_3 gas at over $1,000^\circ\text{C}$.

Fig. 4.8 Variation of Both Ignition Loss of Solid Residue and Decomposition Rate to Pyrolyzing Temperature

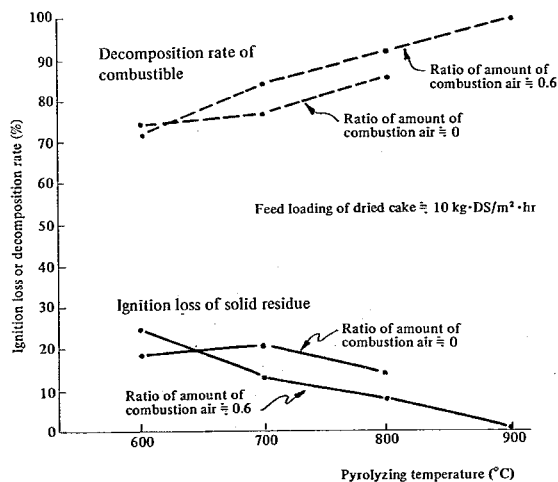


Fig. 4.9 Variation of Carbon, Nitrogen and Hydrogen in Solid Residue to Pyrolyzing Temperature and Ratio of Amount of Combustion Air

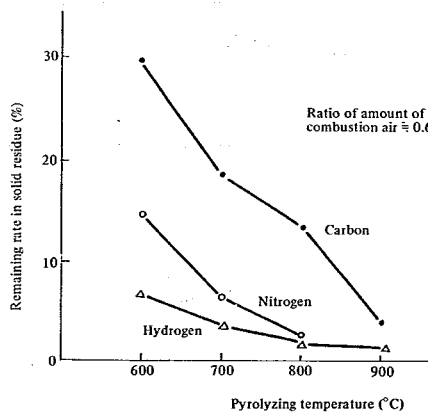
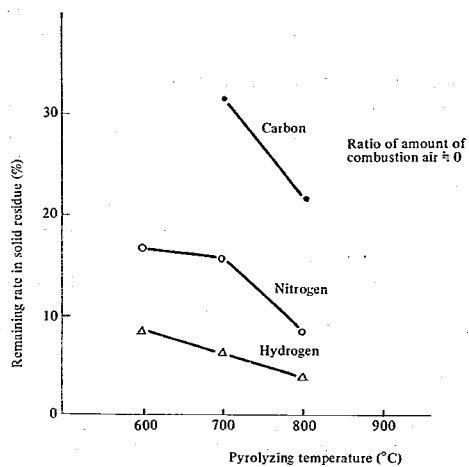


Fig. 4.10 Variation of Both Ignition Loss of Solid Residue and Decomposition Rate to Feed Loading of Dried Cake

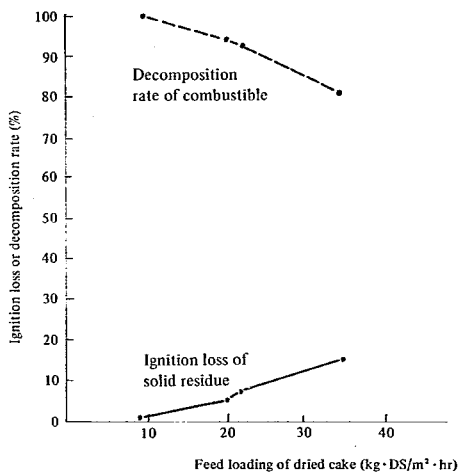
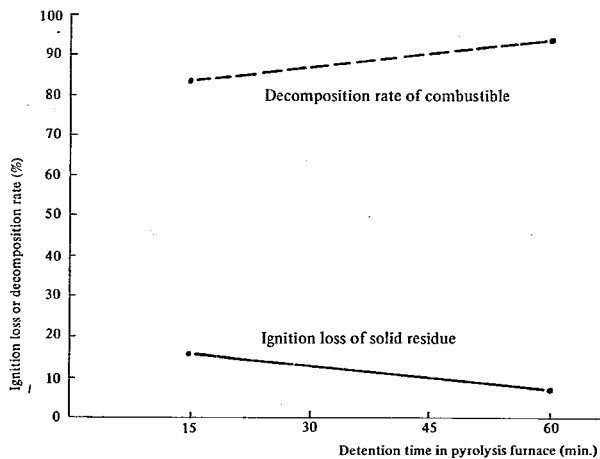


Fig. 4.11 Variation of Both Ignition Loss of Solid Residue and Decomposition Rate of Combustible to Detention Time in Pyrolysis Furnace



4.3.3 PRODUCTS OF DRIED CAKE PYROLYSIS

a. Remaining Rate of Each Element in Solid Residue

Table 4.5 shows the ratios of various elements remaining in solid residue to sludge cake. It also shows three operating conditions of pyrolysis and, for com-

Table 4.5 Remaining Rate of Each Component in Solid Residue

Run No.	Pyrolyzing Temp. (°C)	Ratio Amount of Combustion Air	Ignition Loss (%)	Gross Calorific Value (%)	C (%)	H (%)	N (%)	S (%)	O (%)	Cl (%)	Hg (%)	As (%)	Cd (%)	Pb (%)	Zn (%)	Cu (%)	Fe (%)	T-Cr (%)
1	765~800	0	23.6	14.4	30.4	6.6	9.5	95.5	39.5	65.4	<1.5	68.5	32.9	67.7	90.8	102.4	95.4	100.7
2	805~825	0.67	10.2	9.1	20.3	4.4	3.0	115.6	25.5	67.5	<1.7	77.7	28.7	53.9	113.8	125.1	82.4	135.2
3	880~910	0.75~0.77	2.8	0.9	3.8	3.9	0.5	86.7	12.1	62.2	<1.5	68.5	27.4	27.6	95.0	93.2	96.3	97.9
4	795~835	2.89	4.8	0	4.1	4.0	0	99.6	13.6	58.4	<1.5	54.2	31.7	33.3	84.3	85.4	97.5	90.6

parison, remaining rate of each element in solid residue.

The higher the pyrolyzing temperature and the ratio of amount of combustion air, the smaller becomes the ignition loss, thus decreasing the calorific value of solid residue. In other words, the solid residue becomes closer to that of incineration.

Analyses of six elements show that, in the case of pyrolysis, the amounts of carbon, hydrogen, nitrogen and oxygen remaining in solid residue differ, depending on pyrolyzing temperature and ratio of amount of combustion air, while the amounts of sulfur and chloride vary widely. Concerning chloride, there was a difference in amount remaining in solid residue between pyrolysis and incineration. Pyrolysis tends to vaporize less chloride than incineration.

Concerning such heavy metals as mercury, cadmium and iron, there is hardly any difference in amount remaining in solid residue between pyrolysis and incineration. But pyrolysis can slightly reduce the vaporization into the air of arsenic, zinc, copper and total chromium, compared with incineration. It was also found that the amount of lead vaporized into the air differs greatly, depending on operating conditions of pyrolysis.

b. Concentration and Particle Size Distribution of Dust

The concentration of dust at the outlet of furnace at the time of pyrolysis was a range between 0.5 ~ 2.87 g/Nm³, or almost at the same level as the concentration of dust in incineration. However, most of the dust particles generated by pyrolysis are more than 20 μ in size. A calculation of the efficiency of dust removal by the scrubber showed that the dust removal rate was a range between 75 ~ 97%.

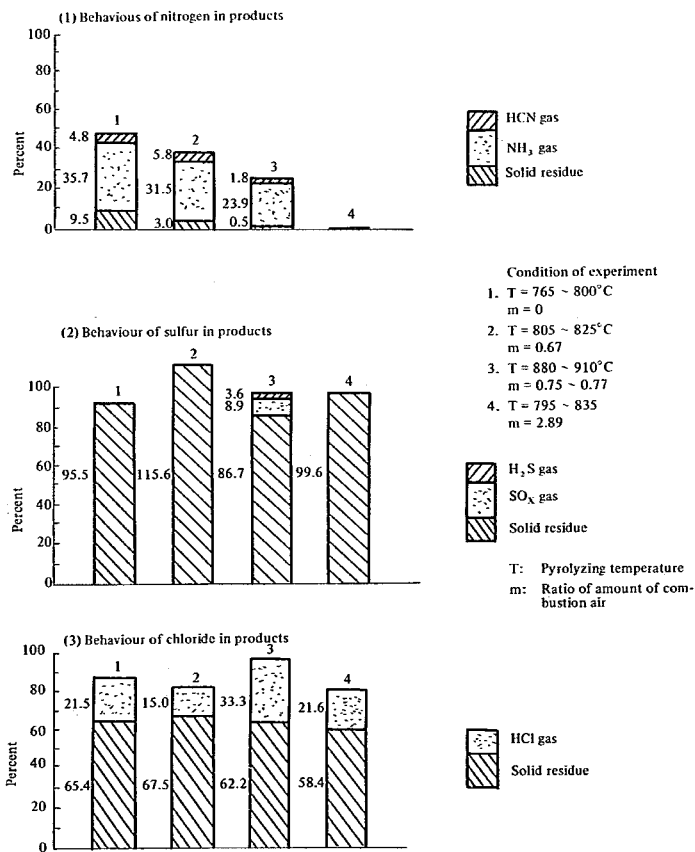
c. Behavior of Nitrogen in Products

How nitrogen in sludge changes form at the outlet of the furnace as a result of pyrolysis or incineration is shown in Fig. 4.12(1).

In the case of incineration, most of the nitrogen in sludge is estimated to have changed into nitrogen gas. In the case of pyrolysis, about 30% of the nitrogen in sludge exists in the form of ammonia gas, 2 ~ 5% in the form of hydrogen cyanide gas and 1 ~ 10% remains in solid residue, although the amounts differ, depending on

operating conditions. The remainder is estimated to turn into nitrogen gas. At the pyrolyzing temperature of 900°C, the amount of hydrogen cyanide gas generated by pyrolysis tended to get larger than at 800°C. These hydrogen cyanide gas and ammonia gas could be decomposed almost completely, when burned in the combustion chamber at the temperature of 1,000°C and at the oxygen concentration of 1 ~ 2% in the chamber.

Fig. 4.12 Behaviour of Nitrogen, Sulfur and Chloride in Products of Pyrolysis



d. Behavior of Sulfur in Products

How sulfur in sludge changes form by pyrolysis or incineration is shown in Fig. 4.12(2). With the exception of No.3 as shown by the Figure, the sulfur in sludge all remained in solid residue. In the case of incineration (No. 4), too, all the sulfur in sludge remained in solid residue.

Of the data shown in Fig. 4.12(2), No.3 shows an efficient and economical operating condition for pyrolysis, under which part of the sulfur in sludge turns into hydrogen sulfide and SO_x . Since hydrogen sulfide turns into SO_x when burned in the combustion chamber at the temperature of about $1,000^\circ\text{C}$, it is estimated that, under the operating condition of No. 3, about 12% of the sulfur is considered to change into SO_x .

e. Behavior of Chloride in Products

As shown by Fig. 4.12(3), about 60% of chloride in sludge remains in solid residue, while part of it is converted into hydrogen chloride. But it was not detected in the form of chlorine gas.

Compared with pyrolysis, incineration tends to generate a considerably large amount of hydrogen chloride. In either case, however, the integrated amount of chloride does not reach 100% and it is not known whether there was a measurement error or the remainder exists in the form of another compound.

f. Offensive Odor Components in Exhaust Gas

The results of measurement of offensive odor components in dry exhaust gas is shown in Table 4.6. The measurement was made only on the experiment condition No. 3 (at the pyrolyzing temperature of $880 \sim 910^\circ\text{C}$ with the ratio of amount of combustion air set at $0.75 \sim 0.77$). G_1 in the Table shows the sampling point for gas at the outlet of dryer, G_3 at the outlet of pyrolysis furnace and G_4 at the outlet of combustion chamber. Main offensive odor components at G_1 are acetaldehyde and ammonia, and a little amounts of methyl mercaptan, dimethyl disulfide, trimethylamine and carbon disulfide were also detected.

The main offensive odor components at G_3 are hydrogen sulfide, ammonia and formaldehyde. A little amounts of carbon disulfide, trimethylamine and acetaldehyde were also detected.

Exhaust gas sampled at G_4 after gas at G_1 and G_3 are burned and decomposed in the combustion chamber does not contain major offensive odor components at all. Only very small amounts of methyl sulfide, ammonia, acetaldehyde and carbon disulfide are contained in the exhaust gas.

Table 4.6 Analytical Results of Offensive Odor Component in Exhaust Gas

Run No.	Pyrolyzing Temp. ($^\circ\text{C}$)	Ratio of Amount of Combustion Air	Portion of Sampling	H_2S (ppm)	Methyl Mercaptan (ppm)	Methyl Sulfide (ppm)	Tri-Methylamine (ppm)	NH_3 (ppm)	Di-methyl Disulfide (ppm)	Ster-ane (ppm)	Acetaldehyde (ppm)	Formaldehyde (ppm)	Acetic Acid (ppm)	Carbon Disulfide (ppm)	Degree of Odor (Times)
3	$880 \sim 910$	$0.75 \sim 0.77$	G_1	0.02	0.006	<0.005	0.003	0.09	0.04	<0.02	1.8	<0.05	<2	0.09	100
			G_3	11	<0.006	<0.002	0.003	980	<0.001	<0.002	0.002	1.1	<3	0.15	25
			G_4	<0.02	<0.006	0.002	0.001	0.74	<0.001	<0.002	0.007	<0.04	<3	0.0005	1

g. Washed Waste Quality of Exhaust Gas and Their Countermeasure

The results of analysis of washed waste of dried exhaust gas are shown in Table 4.7. As shown in the Table, the washed waste contains a little amounts of zinc, copper and iron in addition to 0.002 ~ 0.006 mg/l of mercury. The problem involved in washed waste quality is that of pH. However, it became clear as a result of experiments for practical study.

Table 4.7 Washed Wastewater Quality Results of Exhaust Gas

Run No.	Pyrolyzing Temp. (°C)	Combustion Chamber O_2/CO (Vol %)	pH	BOD (mg/l)	SS (mg/l)	CN ⁻ (mg/l)	Phenol Compound (mg/l)	Hg (mg/l)	As (mg/l)	Cd (mg/l)	Pb (mg/l)	Zn (mg/l)	Cu (mg/l)	Fe (mg/l)	Y-Cr (mg/l)	Cr ⁺⁶ (mg/l)
1	1,050~1,090	1.4/o	4.3	2	30	<0.01	0.01	0.004	<0.01	<0.01	<0.05	0.22	0.02	7.6	<0.01	<0.01
2	990~1,050	1.3/o	4.7	2	16	<0.01	0.02	0.006	<0.01	<0.01	0.09	0.19	0.02	3.2	<0.01	<0.01
3	1,020~1,090	1.3~2.0/o	7.1	2	17	<0.01	<0.03	0.005	<0.01	0.01	0.05	0.26	0.01	3.9	<0.01	<0.01
4	1,060~1,100	1.8/o	3.5	2	9	0.03	<0.03	0.002	<0.01	<0.01	<0.05	0.14	0.01	3.7	<0.01	<0.01

4.4 PRACTICAL STUDY ON DRYING-PYROLYSIS PROCESS

Experiment for practical study were conducted on the basis of the results of the basic study mentioned in Section 4.3 by using the pilot plant shown in Fig. 4.2. In the experiments, an indirect steam dryer and a pyrolysis furnace were operated continuously, and the results of the experiments were compiled. The series of experiments were conducted by changing pyrolyzing temperature and feed loading of dewatered cake. The results of the experiments are shown in Table 4.8. Run No. 801 ~ 808 in the Table mean a series of continuous experiments on drying-pyrolysis process, and Run No. 809 was an experiment to feed into the pyrolysis furnace dried cakes stocked in the dry cake feeder. Analysis of products was done only on Run No. 803 and No. 804.

4.4.1 EXPERIMENTS ON DRYING FOR DEWATERED CAKE USING BY INDIRECT STEAM DRYER

The indirect steam drying of dewatered cakes was carried out more efficiently than in basic study. Its Overall Heat Transfer Coefficient (U) was 140 ~ 170 Kcal/m²·hr·°C, which means a sharp rise in efficiency compared with 70 ~ 110 Kcal/m²·hr·°C in the basic study.

The paddle type dryer used in the experiments for practical study was a four-shaft dryer whose mixing frequency is higher than the two-shaft paddle type dryer used in the basic study. It is presumed that, for this reason, the heat transfer efficiency was raised.

4.4.2 EXPERIMENTS ON PYROLYSIS

a. Pyrolyzing Temperature

Fig. 4.13 shows the variations in the ignition loss of solid residue and in the decomposition rate of combustibles, when pyrolyzing temperature was changed between 700 and 900°C. In the experiments, feed loading of dewatered cake was

Table 4.8 Operating Results of Drying — Pyrolysis Process at the Practical Study

Operating Condition	Items	Run No.	801	802	803	804	805	806	807	808	809
Samples of Dewatered Cake	Moisture Contents of Cake (%)		75.8	75.8	75.8	75.8	77.5	77.5	76.5	76.5	(77.5)
	Gross Calorific Value (Kcal/kg-DS)		2900	2900	2900	2900	3140	3140	3090	2960	(3140)
Indirect Steam Dryer	Ignition Loss of Cake (%)		59.5	59.5	59.5	59.5	61.4	61.4	59.6	59.5	(61.4)
	Pressure of Steam Used (kg/cm ² -G)		1.6-2.6	2.7-3.8	4.5-5.2	3.6-4.5	1.6-3.4	4.3-5.2	5.1-5.2	5.0-5.3	-
	Temperature of Steam Used (°C)		128-139	139-150	155-159	148-155	130-145	157	150-160	160	-
	Feed Rate of Dewatered Cake (kg/hr)		154.1	203.2	200.1	182.5	101.4	176.1	239.0	256.0	-
	Moisture Contents of Dried Cake (%)		34.9	36.3	35.1	37.1	34.7	37.1	43.6	40.4	-
	Amount of Dried Cake Discharge (kg/hr)		57.3	77.2	74.6	71.1	30.3	63.0	99.6	101.0	-
	Amount of Vaporized Water (kg-H ₂ O/hr)		96.8	126	125.5	113.7	71.1	113.1	139.4	155.2	-
	Amount of Condensed Water (kg/hr)		135	158	174	170	126	185.4	183	192	-
	Shaft and Screw Side (kg/hr)		82	95	105	103	75	113.9	147	119	-
	Jacker Side (kg/hr)		53	60	69	67	51	72.2	66	73	-
	Amount of Heat Transfer [Input] (Kcal/hr)		67,635	74,327	85,532	83,881	63,000	90,884	89,712	93,982	-
	Overall Heat Transfer Coef. (Kcal/m ² -hr-°C)		176.2	168.6	142.8	156.7	155.9	151.2	156.6	150.1	-
Combustion Chamber	Temperature of Combustion Chamber (°C)		1100-1170	1030-1120	1000-1090	1035-1110	960-1055	1070-1130	1080-1150	1090-1160	960-1000
	Fuel Consumption (t/hr)		19.3	8.6	4.6	5.9	5.2	8.3	10.2	9.9	5.0
Exhaust Gas Boiler	CO ₂		0.0-1.5	0.0-2.0	0.1-2	0.1-3	0.1-2	0.10-0.13	0.1-2	0.05-1.2	0-2.1
	Outlet Temp. of Exhaust Gas Boiler (°C)		204-210	208-226	230-240	219-235	190-198	215-225	216-245	238-245	-
No. 1 Scrubber and Dehumidifier	Pressure of Boiler (kg/cm ² -G)		3.6-4.1	4.3-5.3	6.0-6.5	5.4-6.0	3.2-4.5	5.8-6.6	5.2-7.0	7.2-7.6	-
	Amount of Steam Generated (kg/hr)		204.3	218.2	227.2	212.8	210.8	212.5	213.4	216.7	-
No. 2 Scrubber and Dehumidifier	Amount of Steam Discharged (kg/hr)		0	0	0	0	0	0	0	0	-
	Flow rate of Scrubbing Water (m ³ /hr)		3.6-3.9	2.0-2.1	3.8-3.9	2.8-3.2	0.9-2.3	1.2	3.6-3.9	3.4-3.5	-
Pyrolysis Furnace	Temperature at Outlet of Scrubber (°C)		24-30	28-30	28-32	27-30	21-31	20-30	32-35	31-36	-
	Amount of Exhaust Gas (m ³ /hr)		35-120	50-75	-	-	50-113	-	65-95	40-70	-
Pyrolysis Furnace	Flow rate of Scrubbing Water (m ³ /hr)		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	-
	Temperature at Outlet of Scrubber (°C)		22-27	45-48	42-50	46-52	32-45	42-52	41-59	32-36	47-52
Pyrolysis Furnace	Feed Rate of Dried Cake (kg/hr)		57.3	77.2	74.6	71.1	30.3	63.0	99.6	101.0	103.9
	Moisture Contents of Dried Cake (%)		34.9	36.3	35.1	37.1	34.7	37.1	43.6	40.4	28.4
Pyrolysis Furnace	Feed Loading of Dried Cake (kg-DS/m ² -hr)		23.0	30.4	29.9	27.6	14.1	24.4	34.7	37.2	43.8
	Amount of Combustion Air Supply (Nm ³ /hr)		83	80	86	86	49.5	92	108	128	148
Pyrolysis Furnace	Distribution Rate, 1:2:3:4		0.39:4.0	0.36:4.0	0.42:4.0	0.42:4.0	0.30:5.0	0.46:5.0	0.54:5.0	0.64:5.0	0.74:4.0
	Ratio of Amount of Combustion Air		0.77	0.56	0.61	0.66	0.68	0.74	0.62	0.72	0.66
Pyrolysis Furnace	Amount of Propane Gas Consumed (kg/hr)		0.3	0.5	0.7	0.7	1.4	1.9	0.9	0.5	0.3
	Temperature 1st Hearth (°C)		465-575	770-795	810-885	870-905	890-930	870-920	795-825	805-895	885-920
Pyrolysis Furnace	2nd Hearth (°C)		695-720	775-840	890-920	875-920	900-930	885-910	830-915	890-920	890-930
	3rd Hearth (°C)		775-810	815-830	910-935	880-905	815-930	880-920	920-940	910-965	890-905
Pyrolysis Furnace	4th Hearth (°C)		785-785	790-830	880-920	890-920	860-900	900-930	870-890	880-920	810-935
	Detection Time of Dried Cake (min)		60	60	60	60	60	60	60	60	60
Pyrolysis Furnace	Static Pressure (mmHg)		+3-+20	+0-+1.2	+7-+15	+15-+25	+7-+20	+2-+10	+10-+20	+10-+20	+1-+20
	Outlet Gas Vol. (t)		0.57, 0.12, 0.04	1.72, 0.99, 0.42	1.34, 1.64, 0.34	0.85, 1.35, 0.24	1.40, 1.62, 0.34	0.95, 0.37, 0.16	1.72, 1.90, 0.20	0.57, 0.21, 0.11	1.11, 1.73, 0.24
Pyrolysis Furnace	C ₂ H ₄ , C ₂ H ₆ , Vol. (t)		ND, ND, 0.21	0.19, ND, 0.27	0.11, ND, 0.17	0.12, ND, 0.26	ND, ND, 0.11	ND, ND, 0.53	1.04, ND, 0.20	ND, ND, 0.2	ND, ND, 0.1
	Calorific Value (Kcal/Nm ³)		24.8	181.2	139.6	110.7	124.3	21.9	131.4	23.7	92.1
Heat Source Chamber	Circulating Gas Temperature (°C)		202-210	208-226	230-240	219-235	190-198	215-226	216-245	238-245	186-204
	Flow Rate of Circulating Gas (m ³ /hr)		40	72.4	41.2	42.2	30	45.1	32.3	26.8	53.6
Heat Source Chamber	Amount of Fuel Consumed (t/hr)		3.5	4.6	8.1	7.3	7.3	4.5	7.7	7.0	6.7
	Amount of Air Supplied (Nm ³ /hr)		44	75.2	73.5	65.8	62.0	58.1	54.3	55.0	59.2
Heat Source Chamber	Temperature in Heat Source Chamber (°C)		760-890	860-940	1030-1100	1050-1130	1025-1075	920-990	1000-1100	1085-1190	940-1040
	Amount of Solid Residue (Dry-kg/hr)		18.9	23.5	21.3	19.8	8.9	15.8	24.7	26.8	31.2
Quality of Solid Residue	Ignition Loss (%)		20.0	15.2	8.1	8.5	0.9	3.3	7.9	9.3	12.3
	Decomposition Rate of Combustible (%)		83.0	87.8	91.0	93.7	99.4	97.9	94.2	93.0	91.2
Quality of Solid Residue	Solved Concentration of Cr ⁶⁺ (mg/g)		ND	ND	ND	ND	ND	ND	ND	ND	ND
	Cr ⁶⁺ Contents (mg/kg)		3.5	4.8	5.8	6.0	3.6	2.4	0.9	0.9	1.7
Fuel Consumption	(t/hr)		14.5	16.5	14.7	14.8	16.1	17.4	20.3	18.2	-
	(t/ton-Cake)		94.2	81.2	73.7	81.3	159.4	78.7	84.9	71.2	-

Remark: Run No. 809 is Experiment of Pyrolysis Process by Dried Cake Feed.

set at about 30 kg-DS/m²·hr and the ratio of amount of combustion air at about 0.6. As shown by the Figure, it was found that, if pyrolysis is done at temperatures of 900°C or more, the ignition loss of solid residue is below 10%.

And Fig. 4.14 shows the relationship between pyrolyzing temperatures and fuel consumption. Given in the Figure are the fuel consumption in the pyrolysis furnace alone and the total fuel consumption in the pyrolysis furnace and the combustion chamber. The amount of fuel consumed in the pyrolysis furnace can be divided into fuel consumed in the heat source chamber and fuel directly supplied in the pyrolysis furnace. Propane gas burners were used for direct heating of the pyrolysis furnace. Listed in the Figure is the amount of fuel which was converted, on the basis of calorific value, from the amount of propane gas used in the pyrolysis furnace for direct heating.

Fig. 4.13 Variation of Both Ignition Loss of Solid Residue and Decomposition Rate in Combustible to Pyrolyzing Temperature

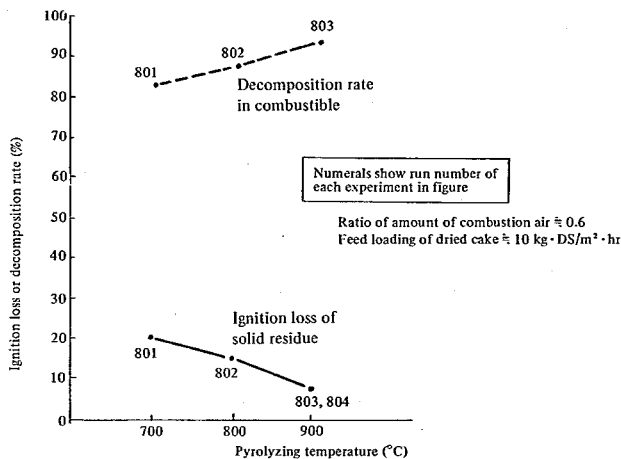


Fig. 4.14 Relationship between Pyrolyzing Temperature and Fuel Consumption

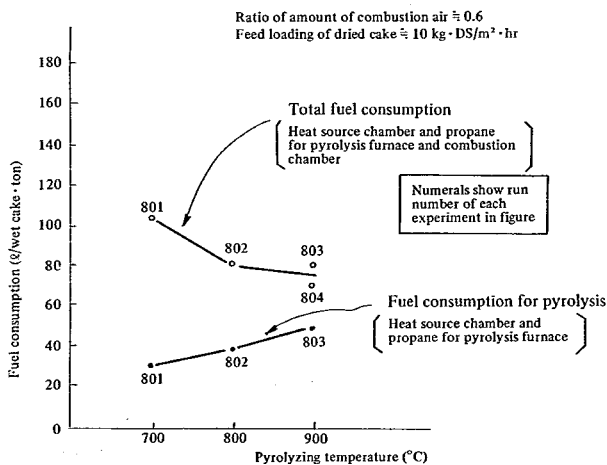


Fig. 4.14 shows that, if operation of pyrolysis is carried out at low temperatures, the amount of fuel supplied to the pyrolysis furnace is reduced, but the total amount of fuel used in the furnace and the combustion chamber tends to increase.

Considering from these results of experiments, it might be said that effective temperature of the dried cake pyrolysis is at about 900°C.

b. Feed Loading of Dewatered Cake.

In the experiments for practical study, the feed loading of dewatered cake was changed in the range of 14 ~ 44 kg·DS/m²·hr, while the pyrolyzing temperature was kept at about 900°C and the ratio of amount of combustion air at about 0.6. Fig. 4.15 shows the relationship between feed loading of dewatered cake, ignition loss of solid residue and the decomposition rate of combustibles. When the feed loading of dewatered cake was below 25 kg/m²·hr, as shown in the Figure, the ignition loss of solid residue could be decreased almost to the same extent as in the case of incineration. If the ignition loss is allowed to be 10%, the maximum feed loading of dewatered cake, in case the water content of the cake is around 30% at the inlet of the pyrolysis furnace, can be increased to 40 kg·DS/m²·hr. It means an increase of 60% over the 25 kg·DS/m²·hr, the feed loading of dewatered cake obtained in the basic study.

Fig. 4.15 Variation of Both Ignition Loss of Solid Residue and Decomposition Rate in Combustible to Feed Loading of Dried Cake

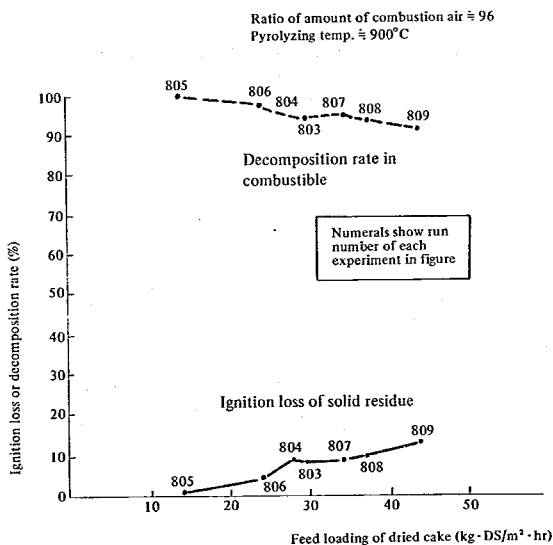
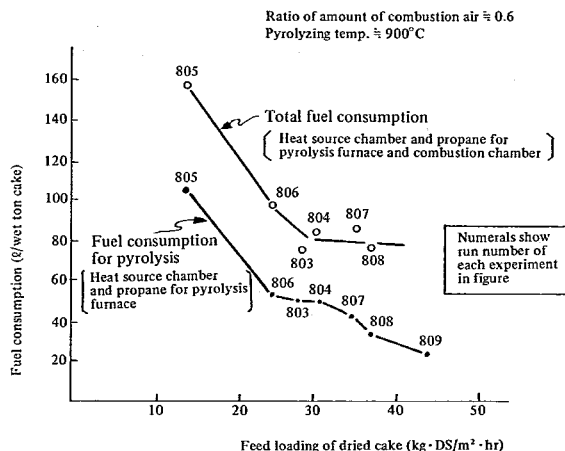


Fig. 4.16 shows the relationship between feed loading of dewatered cake and fuel consumption. The classification of the fuel consumed was made in the same method as in the foregoing Fig. 4.14. It is learned that fuel consumption is greatly influenced by feed loading of dewatered cake into the pyrolysis furnace. When feed loading of dewatered cake is small, fuel consumption increases. In case the feed loading of dewatered cake is larger than $25 \text{ kg} \cdot \text{DS}/\text{m}^2 \cdot \text{hr}$, fuel consumption is $80 \sim 90$ litre per ton-wet cake.

In case the allowable ignition loss of solid residue is set at 10% as mentioned earlier, and when the feed loading of dewatered cake is $40 \text{ kg} \cdot \text{DS}/\text{m}^2 \cdot \text{hr}$, the amount of fuel used for pyrolysis is about 30 litre per ton-wet cake and the total fuel consumption is about 80 litre per ton-wet cake.

Fig. 4.16 Variation of Fuel Consumption to Feed Loading of Dried Cake



4.4.3 PRODUCTS OF DRIED CAKE PYROLYSIS

a. Remaining Rate of Each Element in Solid Residue

The results of analyses of dewatered cake and solid residue are shown in Table 4.9. Table 4.10 shows the remaining rate of each element in solid residue calculated on the basis of Table 4.9. From Table 4.9 and Table 4.10, the elements other than those remaining in solid residue show the amount or rate of elements which are estimated to have gone out of the pyrolysis furnace. (Since exhaust gas is treated in the scrubber and combustion chamber, the amount of elements actually emitted into the air is decreased sharply.)

In the measurement of the amount remaining in solid residue or the remaining

rate, results different from those in the basic study were obtained regarding some elements. The elements found to have a high remaining rate in the experiments for practical study was chloride, whose remaining rate was about 20% higher than in the basic study. In contrast, the remaining rate of sulfur was about 30% lower than in the basic study. In other words, most of the sulfur remained in solid residue in the basic study, while the remaining rate of sulfur was below 60% in the experiments for practical study. With regard to heavy metals, the amounts of cadmium and lead remaining in solid residue decreased. It is considered that these changes are related to pyrolyzing temperature.

The remaining rate of each element in solid residue changes according to pyrolyzing temperature and it does not follow that pyrolysis is particularly superior to incineration.

However, shown in Table 4.9 is an example denoting the superiority of pyrolysis over incineration. It concerns the fact that part of the hexavalent chromium compounds in sludge is reduced by pyrolysis. This means that, unlike incineration, pyrolysis does not form any new hexavalent chromium compounds but can reduce even part of the compounds contained in sludge. This is a point where pyrolysis is extremely superior to incineration.

Table 4.9 Analytical Results of Both Dewatered Cake and Solid Residue

Items	Run No.	Ignition Loss (%)	Gross Calorific Value (Kcal/kg·DS)	C (%)	H (%)	N (%)	S (%)	O (%)	Cl (%)	CN (ppm)	NH ₃ (ppm)
Dewatered Cake	803	59.5	2,960	28.4	4.1	3.1	1.1	27.0	0.65	6.9	2,900
	804	59.5	2,860	28.3	4.2	3.1	1.0	27.0	0.63	3.5	1,400
Solid Residue	803	8.1	320	3.0	0.18	<0.5	1.5	13.0	1.26	0.23	910
	804	8.5	340	3.9	0.18	<0.5	1.3	13.0	1.26	0.20	170
Items	Run No.	Hg (ppm)	As (ppm)	Cd (ppm)	Pb (ppm)	Zn (ppm)	Cu (ppm)	Fe (ppm)	T-Cr (ppm)	Cr ⁺⁶ (ppm)	Cr ⁺⁶ / T-Cr (%)
Dewatered Cake	803	0.56	5.4	11	270	1,200	640	32,600	330	8.6	2.6
	804	0.54	5.0	10	240	1,300	610	31,500	290	7.8	2.6
Solid Residue	803	<0.05	6.9	3.4	98	2,500	1,500	75,200	590	5.9	1.0
	804	<0.05	8.1	3.6	100	2,900	1,500	75,800	730	6.0	0.8

Table 4.10 Remaining Rate of Each Element at the Cake of Drying — Pyrolysis Process

Run No.	Gross Calorific Value (%)	C (%)	H (%)	N (%)	S (%)	O (%)	CL (%)	CN (%)	NH ₃ (%)	Hg (%)	As (%)	Cd (%)	Pb (%)	Zn (%)	Cu (%)	Fe (%)	T-Cr (%)
803	4.8	4.6	1.9	<7.1	59.9	4.8	85.4	1.5	13.8	<1.5	56.3	13.6	16.0	91.8	103.3	101.7	78.8
804	5.3	6.2	1.9	<7.2	57.5	5.3	88.5	2.5	5.4	<1.5	71.7	15.9	18.4	98.7	108.8	106.5	111.4

b. Concentration and Particle Size Distribution of Dust

As shown by Table 4.11, the concentration of dust from the pyrolysis furnace is considerably high. The concentration of dust is lowered sharply after dust is sent through the scrubber, but it is necessary to install an electric precipitator or other equipment in order to hold down the dust concentration rate below 0.34 g/Nm^3 .

Much of the dust from the pyrolysis furnace has a relatively large particle size as shown in Table 4.12. Accordingly, it is considered to be comparatively easy to separate dust by an electric precipitator or other equipment.

Table 4.11 Characteristics of Exhaust Gas (Run No.803)

Sampling Site	Temp. of Gas (°C)	Velocity of Gas (m/sec.)	Moisture Contents (Vol. %)		Volume of Dry Gas ($\text{Nm}^3/\text{hr.}$)		Dust (g/Nm^3)	HCN (ppm)	NH_3 (ppm)	NO_x (ppm)	SO_x (ppm)	HCl (ppm)	Cl_2 (ppm)	Degree of Odor (Times)
			Actual	Calculation	Actual	Calculation								
G_2	—	—	—	14.5	—	103	—	—	—	170	130	—	<0.2	—
G_3	760	13.8	24.6	24.7	200	213	8.4	240	2,080	54	130	6.0	<0.2	400
G_4	215	16.1	20.8	21.8	330	308	3.1	<0.1	1.0	210	230	15.0	<0.2	2
G_5	49	1.4	10.3	10.4	280	275	0.34	<0.1	0.5	190	130	1.4	<0.2	2

Remark: G_2 : Exhaust Gas Samples from Heat Source Chamber

G_3 : Exhaust Gas Samples from Pyrolysis Furnace

G_4 : Exhaust Gas Samples from Exhaust Gas Boiler

G_5 : Exhaust Gas Samples from Gas Scrubber

Table 4.12 Dust Size Distribution in Exhaust Gas from Pyrolysis Furnace (Run No.804)

Size (μ)											(%)
Samples	>6.5	4.3~6.5	2.8~4.3	1.9~2.8	1.2~1.9	0.6~1.2	0.4~1.6	0.2~0.4	<0.2		
1	73.8	12.1	6.1	3.2	1.5	0.6	0.9	1.2	0.6		
2	70.2	12.9	5.8	3.6	2.1	0.9	1.0	1.3	2.2		

c. Components of Exhaust Gas

Table 4.11 shows the results of analyses of such exhaust gas components as hydrogen cyanide, ammonia, NO_x and SO_x . The amounts of various exhaust gas components generated in the pyrolysis furnace diminish sharply in the process of decomposition in the combustion chamber and cleaning by the scrubber. For this reason, hydrogen cyanide, ammonia and hydrogen chloride will do no harm. However, the amounts of NO_x and SO_x do not decrease. Especially, the concentration of NO_x is much higher in exhaust gas than at the outlet of the pyrolysis furnace, since it is treated in the combustion chamber at temperatures over $1,000^\circ\text{C}$. Thus it may become necessary to take steps to remove SO_x and NO_x , as in the case of incineration, where the environmental quality standard on air pollution is being enforced strictly.

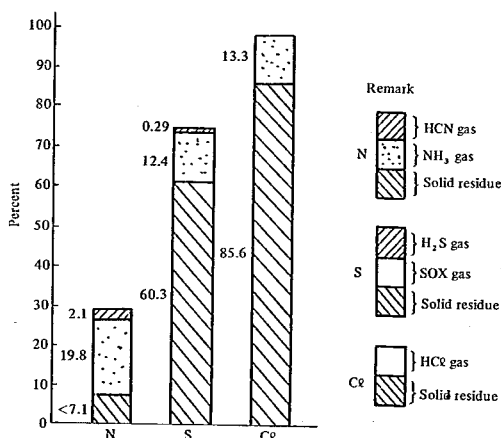
d. Behavior of Nitrogen, Sulfur and Chloride in Sludge

The forms of nitrogen, sulfur and chloride at the outlet of the pyrolysis furnace

is shown in Fig. 4.17. There is hardly any difference in the results of analysis of nitrogen between the experiments for practical study and the basic study (See Fig. 4.12). In the case of sulfur, the results of analysis differed from those in the basic study, with the whereabouts of about 27% of the substance unknown. As a result of measurement, it was found that the amount of sulfur remaining in solid residue decreased, while an increased amount of SO_x was generated.

The amount of chloride remaining in solid residue tended to go up by about 20% from the level recorded in the basic study.

Fig. 4.17 Forms of Each Element in Product of Pyrolysis



e. Offensive Odor Components in Exhaust Gas

Table 4.13 shows the results of analyses of offensive odor components in exhaust gas. Obtained from the analyses were numerical values almost similar to those in the basic study. The main offensive odor components generated in the indirect steam dryer are ammonia and acetaldehyde, and those generated in the pyrolysis furnace are high concentrations of ammonia, hydrogen sulfide and formaldehyde.

Although most of the components are decreased in amount through the decomposition in the combustion chamber, the amounts of ammonia, acetaldehyde and formaldehyde remaining in exhaust gas were found to be considerably higher than those recorded in the basic study.

Table 4.13 Analytical Results of Offensive Odor Component in Exhaust Gas

Sampling Site	H ₂ S (ppm)	Methyl Mercaptan (ppm)	Methyl Sulfide (ppm)	Tri-methyl Amine (ppm)	Ammonia (ppm)	Dimethyl Disulfide (ppm)	Sterane (ppm)	Acetaldehyde (ppm)	Formaldehyde (ppm)	Acetic Acid (ppm)	Carbon Disulfide (ppm)
G ₁	0.07	<0.005	0.08	0.005	8.7	0.5	<0.3	1.0	<0.15	<3.0	0.07
G ₂	5.0	<0.005	<0.003	0.002	2.080	0.03	<3	0.1	3.9	<3.0	0.6
G ₃	<0.008	<0.005	<0.003	0.002	1.0	<0.002	<0.02	0.07	0.44	<3.0	0.006

Remark: G₁: Exhaust Gas Sample from Indirect Steam Dryer
 G₂: Exhaust Gas Sample from Pyrolysis Furnace
 G₃: Exhaust Gas Sample from Exhaust Gas Boiler

4.4.4 COMPARISON OF DRYING-PYROLYSIS PROCESS, DIRECT PYROLYSIS PROCESS AND INCINERATION PROCESS

Experiments were conducted on the direct pyrolysis process and incineration process of dewatered cakes to find out the merits and demerits of the drying-pyrolysis process. The results of the experiments are shown in Table 4.14. It shows the results of the Run No. 808 as an example of the drying-pyrolysis process. The properties of the dewatered cake used in Run No. 808 in Table 4.14 is a little different from the dewatered cakes used in Run No. 903 and No. 904. The cake used in Run No. 808 has less combustibles than dewatered cakes used in Run No. 903 and No. 904 and, therefore, its calorific value is small. It was difficult to compare the three processes exactly, but it was concluded that a tentative comparison would be possible.

In Table 4.14, Column I shows empirical values and Column II the values revised for practical reasons. The revision was made in the following manners.

- In the drying-pyrolysis process, it was assumed that the temperature of returning water from the drain was 80°C and that measures were taken to prevent white smokes of exhaust gas from going out of the chimney.
- In the direct pyrolysis process and incineration process of dewatered cakes, it was assumed that heat exchange was done by a heat exchanger, in addition to the revision made in above Article i).

Under these revisions, fuel consumption for the drying-pyrolysis process rises higher than the empirical value and fuel consumption for direct pyrolysis process and incineration process goes down from the empirical values. Nevertheless, fuel consumption for the drying-pyrolysis process is about 1/2 of that needed for direct pyrolysis process and about 1/3 of that for incineration process.

The amount of exhaust gas generated by drying-pyrolysis process becomes considerably smaller than that generated by direct pyrolysis process or incineration process. This means that the drying-pyrolysis process could lower the costs of construction and operation of facilities to prevent air pollution, by a larger margin than direct pyrolysis process and incineration process.

Comparing direct pyrolysis process with incineration process, the former is also considered to be considerably more advantageous than the latter economically.

The experiments were conducted at a pilot plant, and the operation of a practical plant is expected to produce results considerably different from those obtained in the foregoing experiments. For example, in the experiments of Run

Table 4.14: Comparable Experimental Data of Drying-Pyrolysis Process, Direct Pyrolysis Process and Incineration Process

Items	Process		Drying-Pyrolysis	Direct Pyrolysis	Incineration
	Run No.		808	903	904
Moisture Contents of Dewatered Cake (%)			76.5	77.8	77.5
Ignition Loss of Cake (%)			59.5	66.0	66.0
Ash Contents of Cake (%)			40.5	34	34
Gross Calorific Value (Kcal/kg·DS)			2,900	3,300	3,300
Moisture Contents at Inlet of Pyrolysis Furnace (%)			40.4	77.8	77.5
Ratio of Amount of Combustion Air			0.71	0.60	2.0
Exhaust Gas Temperature at Outlet of Pyrolysis Furnace (°C)			850	393	485
Exhaust Gas Temperature at Outlet of Combustion Chamber (°C)			1,100	800	800
Fuel Consumption (l/ton·Cake)	I	Furnace	33	144	128
		Combustion Chamber	39	89	234
		Total	72	233	362
	II	Furnace	33	144	128
		Combustion Chamber	61	44	162
		Total	94	188	290
Dry Exhaust Gas (Nm ³ /ton·Cake)	I	Furnace	858	1,495	2,673
		Combustion Chamber	1,428	2,227	4,968
	II	Furnace	858	1,495	2,673
		Combustion Chamber	1,556	2,184	4,425
Wet Exhaust Gas (Nm ³ /ton·Cake)	I	Furnace	1,199	2,748	3,949
		Combustion Chamber	1,651	2,381	5,350
	II	Furnace	1,199	2,748	3,949
		Combustion Chamber	1,651	2,339	4,727

No. 903 and No. 904, the temperatures at the outlet of the furnace were considerably higher than at the outlet of the furnace for practical use.

For this reason, trial calculations were made on drying-pyrolysis, direct pyrolysis and incineration in a practical use furnace (Wet Base 50 t/day) by introducing the idea of designing a conventional multi-hearth furnace. The results of the calculations are shown in Table 4.15.

In the drying-pyrolysis process, as shown in the Table, no fuel is supplied to the pyrolysis furnace at all since sludge cake is in a dry state. And only a small amount of fuel is needed for the process because exhaust gas generated in the pyrolysis furnace is used as part of the heat source for boiler. In direct pyrolysis, fuel consumption for the pyrolysis furnace is the largest, but that for the combustion chamber is less than for the drying-pyrolysis process because no fuel is needed for the boiler in the combustion chamber. In incineration, less fuel is supplied to the furnace than in direct pyrolysis since combustibles are burned in the furnace, but the amount of fuel used in the combustion chamber for the combustion of exhaust gas is very large. But if there is no combustion of exhaust gas, the amount of fuel for incineration is the smallest. In reality, however, sewage treatment plants in most of the municipalities in Japan are equipped with facilities for

Table 4.15 Comparable Calculation Results of Drying-Pyrolysis Process, Direct Pyrolysis Process and Incineration Process

Items \ Process		Drying-Pyrolysis Process	Direct Pyrolysis Process	Incineration Process
Moisture Contents of Dewatered Cake (%)		78	78	78
Ignition Loss of Cake (%)		66.0	66.0	66.0
Ash Contents of Cake (%)		34	34	34
Gross Calorific Value (Kcal/kg·DS)		3,300	3,300	3,300
Moisture Contents at Inlet of Pyrolysis Furnace (%)		25	78	78
Ratio of Amount of Combustion Air		0.60	0.60	2.0
Exhaust Gas Temperature at Outlet of Pyrolysis Furnace (°C)		700	200	200
Exhaust Gas Temperature at Outlet of Combustion Chamber (°C)		1,100	800	800
Fuel Consumption (l/ton·Cake)	Furnace	0	44	27
	Combustion Chamber	52	33	120
	Total	52	77	147
Dry Exhaust Gas (Nm ³ /ton·Cake)	Furnace	338	879	2,023
	Combustion Chamber	1,302	1,467	3,302
Wet Exhaust Gas (Nm ³ /ton·Cake)	Furnace	542	1,985	3,172
	Combustion Chamber	1,408	1,636	3,638

the combustion of exhaust gas or for the deodorization by catalyzer in order to prevent the generation of offensive odor and the emission of white smokes from chimneys.

Pyrolysis process can decrease exhaust gas sharply, compared with incineration process. Therefore, pyrolysis process requires less costs of construction and operation of such exhaust gas control facilities as electric precipitators and alkali absorption scrubber. In this respect, pyrolysis process can be said to have a great economic advantage.

4.5 SUMMARY

Basic and practical studies were carried out on the drying-pyrolysis process in order to put to practical use the pyrolysis of sewage sludge by a multi-hearth furnace. The sampled sludge for use in these studies was dewatered cake of raw sludge at the Toba Sewage Treatment Plant in Kyoto. The pilot plant for the basic study was made up of a two-shaft indirect steam dryer, a single-hearth furnace (with a total furnace floor space of 2.1 m²) and its incidental facilities. The pilot plant for the experiments for practical study consisted of a four-shaft indirect steam dryer, a four-hearth furnace (with a total furnace floor space of 1.63 m²) and its incidental facilities.

The results of the studies can be summarized as follows.

- (1) As a result of the experiments for practical study, the Overall Heat Transfer Coefficient (U) of the indirect steam dryer for sludge cakes drying could be raised to 140 ~ 170 Kcal/m²·hr·°C. It is larger than the Overall Heat Transfer Coefficient of 70 ~ 110 Kcal/m²·hr·°C obtained in the basic study. This is ascribed to the increase in the number of shafts of the indirect steam dryer.

(2) For the drying-pyrolysis process, it is appropriate to set the ratio of amount of combustion air at 0.5 ~ 0.7 and pyrolyzing temperature at 900°C in order to keep the ignition loss of solid residue below 10%. According to the experiments for practical study, adequate feed loading of dewatered cake to maintain the same condition is estimated to be 40 kg·DS/m²·hr.

(3) Pyrolysis can completely prevent the oxidization into hexavalent chromium compounds, of trivalent chromium compounds contained in sludge cakes. And part of the hexavalent chromium compounds contained in sludge cake are reduced in the furnace by reducing gas generated in the pyrolysis furnace.

(4) At the basic and practical studies, there were found to produce slightly different results with regard to the remaining rate of each element in solid residue from pyrolysis. The difference relates to pyrolyzing temperature. The remaining rate of each element in solid residue is related to temperature, and it does not follow that pyrolysis is by far superior to incineration.

(5) The amount of dust generated in pyrolysis furnace is considerably large. Furthermore, many particles are large in size. Although most of the dust can be removed when passed through the scrubber, it is also necessary to install an electric precipitator for maintaining the concentration of dust at a very low level as same as the case of incineration process.

(6) Of the exhaust gas components generated in the pyrolysis furnace, hydrogen cyanide and ammonia are decomposed in the combustion chamber. Hydrogen chloride can be removed by means of a gas scrubber. Since SO_x and NO_x cannot be removed, however, it may become necessary to take measures to deal with the problem in areas where the environmental quality standard on air pollution is strictly enforced.

(7) The main offensive odor components in exhaust gas generated in the indirect steam dryer are ammonia and acetaldehyde, and those generated in the pyrolysis furnace are much amount of ammonia, hydrogen sulfide and formaldehyde. Most of these components are diminished through the decomposition in the combustion chamber, but small amounts of ammonia, acetaldehyde and formaldehyde remain in exhaust gas at the outlet of combustion chamber.

(8) The drying-pyrolysis process consumes the least amount of fuel in case there is combustion of exhaust gas. But, in case the combustion of exhaust gas is not needed, incineration process consumes the least amount of fuel.

The drying-pyrolysis process and direct pyrolysis process can reduce the generation of exhaust gas to below 1/2 of the amount of exhaust gas generated by incineration process. Therefore, pyrolysis process is expected to have a great economic efficiency in case steps are necessary to prevent air pollution and offensive odor.

REFERENCE

- (1) T. Majima et al, Studies on Pyrolysis Process of Sewage Sludge, Proceedings of the 8th International Conference on Water Pollution Research, Sydney, p. 381 (1976)

III. Storm and Combined Sewer Overflow

WATER QUALITY CHARACTERISTICS OF STORM & COMBINED SEWER OVERFLOW

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WATER QUALITY CHARACTERISTICS OF STORM & COMBINED SEWER OVERFLOW

Kazuo Takeishi

1.1 CURRENT STATUS OF THE COMBINED SEWER SYSTEM IN JAPAN

1.1.1 COMBINED SEWER SYSTEM

In Japan as of 1975, 583 municipalities had been practicing the sewage works. In 1976, 65 new municipalities are expected to enter upon sewage works.

The population served by sewers in 1975 is estimated to have been 22.8% of the total population.

In Japan, those cities which have a long experience in the sewage works have the combined sewer system. According to a 1972 survey conducted by the Ministry of Construction, the combined sewer system accounted for 73% of the total sewered area, covering 69% of the total sewered population.

As the problems of the combined sewer overflow come to the fore, the number of cities adopting the separate sewer systems is on a steady rise in recent years.

The Ministry of Construction is also a strong promotor of the separate sewer systems. Table 1.1 shows the changes in the past three years of the number of municipalities by type of sewerage.

The many municipalities which have combined sewer system adopt the separate sewer system in new sewered areas, so the share of the combined sewer system is decreasing gradually. Nevertheless, the significance of the combined sewer overflow on the contribution of pollution loads in waters has not yet been reduced at all. In large cities where the sewerage is making a large step toward improvement through secondary treatment, the contribution for water pollution by combined sewer overflow will be increased more and more.

Table 1.1 Relative Use of Combined Sewers of Local Governments

Sewer system \ Year	1973	1974	1975
Combined sewer	70	52	47
Hybrid	158	176	185
Separate sewer	217	287	351
Total	445	515	583

1.1.2 ON-GOING MEASURES AND RESEARCH ACTIVITIES FOR THE COMBINED SEWER SYSTEMS

1.1.2.1 MEASURES FOR THE COMBINED SEWER SYSTEM

In Japan, little has been reported of examples taking radical measures against

pollution caused by combined sewer overflow. Most of municipalities have been bending their efforts for the expansion of sewer-served areas. Although they have full knowledges on the problems the combined sewer system has, their efforts don't reach to the measures against them.

In the major cities where the sewerage system has long been used, improvement of overflow chamber and enlargement of sewer capacity are being pushed forward in order to recoup shortage of the capacity of the existing sewer system and to overcome the problem of reduced dilution ratio of wet-weather overflow. These improvements, however, are still in the stage of local scale practice, and come nowhere near providing a meaningful way against the water pollution by wet-weather overflow.

What is standing in the way of changing the combined system to the separate system lies in the vast sums of money required, narrow width of road in densely populated area, and the fact that storm water from storm sewer itself is polluted. Converting to the separate system is not considered to be the best solution.

Most of measures taken or being planned to control the water pollution by combined sewer overflow are either detention or sedimentation of wet-weather overflow.

A facility installed in Osaka is the only one example of this type now we can see in Japan, except for two additional facilities which are now under construction.

All these three are touched upon briefly in the next section. Some new districts which adopted combined sewer systems install storm water sedimentation basins in their sewage treatment plants in order to overcome the problems of wet-weather overflow.

1.1.2.2 Current Research Activities

For the purpose of studying the improvement measures for the combined sewer system, the Ministry of Construction established a research organization named "Research Committee on Sewer System Problems." The members of the Committee consist of the engineers from the Ministry of Construction, the Japan Sewage Works Agency, major municipalities and representative medium-sized municipalities. Of these municipalities, eleven adopt the combined sewer system, and one the separate sewer system.

The principal objective of this Committee is to investigate about the combined sewer system in each municipality by standardized manners, exchange findings and formulate practical improvement measures.

The Committee is scheduled to work from 1975 to 1980. For the first three years, the Committee will bend their energies to collect data with emphasis on the fact-finding survey.

The data obtained this way is significant not only for the improvement of the combined sewer system, but also as a basis for the planning of future sewer system.

Section 3 summarizes the findings acquired by the Committee in 1975.

The Urban River Section of the Public Works Institute, Ministry of Construction, developed a water quality simulation model of the combined sewer system. The mode which stands on the concept of the retention of pollution load gives the pollutograph from a given hydrograph.

It is corroborated by application of this model to some drainage areas that the simulated results agree well with actual measurements. The model is considered to become a useful tool in assessing the improvement of combined sewer system because it can estimate the pollutograph from the hydrograph calculated by the modified RRL method from the precipitation record.

The results of this study are discussed in the next chapter.

1.2 EXAMPLES OF MEASURES AGAINST COMBINED SEWER OVERFLOW PROBLEMS

In Japan, there are not so many practical examples of measures to control water pollution due to combined sewer overflow.

Briefed here are three examples in Osaka and Yokohama.

1.2.1 STORM WATER SEDIMENTATION TANK IN OSAKA

In 1975, the Osaka Municipal Government constructed storm water sedimentation tank consisting of two basins by taking advantage of the improvement work of Nakanoshima Pumping Station at the center of the city. The dimension of each basin is 3.5 m in width, 20.2 m in length and 4.5 m to 5.0 m in depth. In the future, four additional basins will be constructed. When all these tanks are completed, the storage capacity will become 2,000 m³ or worth 4.4 mm of rainfalls in the area. This facility is the only one example in Japan of measures against wet-weather overflow.

1.2.2 STORM WATER DETENTION TRUNK SEWER IN OSAKA

In Osaka, inundation frequently visits lowlands because of marginal use of catch basin and subsidence due to excessive use of ground water. In order to solve this problem, installation of a new interceptor was planned and has been under way since 1973.

Its major portion having an inside diameter of 6,000 mm will be installed 25 m deep with the length of about 3 km, and will provide a storage capacity of some 80,000 m³ or worth 6.6 mm of rainfalls in the area.

This trunk sewer is planned to serve for the control of water pollution due to wet-weather overflow without detriment to the original purpose of inundation control.

1.2.3 STORM WATER SEDIMENTATION TANK IN YOKOHAMA

The Yokohama Municipal Government is in the process of constructing storm water sedimentation tank consisting of eighteen 6.0 m wide by 35 m long by 6.0 m deep basins with a total capacity of 22,680 m³ equivalent to 6.4 mm of rainfalls in the area.

The tanks are of the underground type, and their covered top is planned to be an athletic ground open to the public. These tanks are expected to reduce the pollution loads by 10% or more in SS and almost the same degree in BOD as compared with the separation device.

1.3 INTERIM RESULTS OF BASIC SURVEYS BY THE RESEARCH COMMITTEE ON COMBINED SEWER SYSTEM PROBLEMS

1.3.1 METHOD OF SURVEY

For the purpose of collecting extensive data on the characteristics of wet-weather combined sewage, twelve drainage areas different in drainage system and land use were selected as the study areas in the eleven member municipalities. The designated areas have already been perfectly covered by the combined sewer system, have a sizable tract each, and also are favoured with conditions permitting hydraulic and hydrologic analysis with ease.

In one city which has adopted the separate sewer system, a survey area was also sited to fulfil similar conditions. A survey station was installed at the downmost end of the sewer in each survey area for flow measurement and sampling. At several spots in the survey area, rainfall gaging was also carried out. The sampled water was subjected to analysis according to analysis according to the unified methods.

In 1975, flow measurement and sampling were conducted one to two times in dry-weather and two to four times in wet-weather in the combined sewer survey areas and four times in wet-weather in the separate sewer survey area. In the separate sewer municipality, the survey area was relocated in 1976 to a suburb where three-times surveys were carried out in wet-weather.

In addition, geographical and social conditions, including land use patterns and demographic status, were also investigated in each survey area.

1.3.2 OUTLINE OF SURVEY AREAS

The combined sewer survey areas are outlined in Table 1.2 (a), and the separate sewer survey areas in Table 1.2 (b).

The following is a list of survey areas and a brief explanation of each.

Combined sewer survey areas

- A: Single-family residential area apart from the city center
- B: Populated urban area with a mixed consist of residential houses and stores
- C: Area with a mixed consist of small to medium factories, residential houses and stores
- D: Area with residential zones and shopping quarters
- E: Residential area on a terrace bordering on an urban area
- F: Area with low-story and medium-story shopping quarters and amusement quarters
- G: Area with low-story shopping quarters, amusement quarters and medium-story business quarters
- H: Dense area packed with low-story residential houses, stores and factories mainly of textile and dyeing
- I: Typical high-story civic and business center
- J: Area sited on a spit in the estuary, with residential quarters, and commercial quarters, wholesale markets and small factories along a trunk road
- K: Suburban residential area on a terrace with many company-owned residential

Table 1.2 (a) Summary of Surveyed District (Combined Sewer System)

Drainage district	Drainage system	Drainage area (ha)	Population		Sewer diameter (mm)	Max. flow rate in dry-weather (m ³ /s)	Land use						Road area		Impervious area	
			Daytime	Resident			Residential (ha) (%)	Commercial (ha) (%)	Industrial (ha) (%)				(ha) (%)		(ha) (%)	
A	Pumping	44.33	6,655	4,016	300~900	0.057	44.33 100	0 0	0 0				6.95 15.7		15.27 34.4	
B	Gravity flow	540.6	165,019	155,091	6000 × 4325	2.11	397.5 73.5	68.29 12.6	74.80 13.9				116.6 21.6		288.0 53.3	
C	Pumping	269.5	58,690	61,167	4000 × 3600	1.57	16.79 6.2	46.84 17.4	205.87 76.4				3.82 1.4		186.3 69.1	
D	Pumping	35.13	12,298	9,003	1650 × 1650	0.10	21.45 61.1	13.68 38.9	0 0				4.46 12.7		16.08 45.8	
E	Gravity flow	22.09	3,579	4,270	250~1200	0.052	21.38 96.8	0.71 3.2	0 0				2.39 10.8		7.68 34.8	
F	Gravity flow	68.37	38,268	8,358	230~1950 × 1950	0.282	0 0	68.37 100	0 0				21.05 30.8		55.43 81.1	
G	Gravity flow	39.5	12,800	1,780	250~1650	0.189	0 0	39.5 100	0 0				9.80 24.8		31.02 78.5	
H	Gravity flow	148.49	37,180	25,280	250~3000 × 1930	0.809	32.10 21.6	32.86 22.1	83.53 56.3				31.27 21.1		114.46 77.1	
I	Pumping	45.50	43,200	804	300~2000 × 1350	0.385	0 0	45.50 100	0 0				24.3 53.4		39.1 85.9	
J	Pumping	215.14	27,000	31,727	250~2200 × 2200	0.261	108.54 50.5	41.6 19.3	65.0 30.2				44.77 20.8		127.95 59.5	
K	Gravity flow	57.6	3,973	3,863	200~2100 × 1680	0.028	57.6 100	0 0	0 0				7.0 12.2		15.0 26.0	
L	Gravity flow	17.61	9,700 (day) 17,000 (night)	1,098	230~1360 × 1060	0.247	0 0	17.61 100	0 0				5.35 30.4		16.40 93.1	

Table 1.2 (b) Summary of Surveyed District (Separate Sewer System)

Drainage district	Drainage system	Drainage area (ha)	Population		Sewer diameter (mm)	Land use			Road area (ha) (%)	Imperious area (ha) (%)
			Day-time	Resident		Residential (ha) (%)	Commercial (ha) (%)	Industrial (ha) (%)		
M	Gravity flow	17.17	9,300	2,695	Ø1200x1030~Ø30x70	8.55 49.8	8.02 46.7	0.60 3.5	5.72 33.3	15.7 91.4
O	Gravity flow	26.75	2,420	3,227	Ø2500x1800	26.75 100	0 0	0 0	4.99 18.7	21.26 79.5

houses

L: Typical amusement quarters on a spit in the estuary, enticing extremely large night population compared with daytime one

Separate sewer survey areas

M: Tier on the sea, with business quarters, commercial quarters, hotels, public facilities, government institutions, multi-family residential houses

O: Newly developed residential area on a suburban terrace, with single-family houses

1.3.3 SURVEY RESULTS

1.3.3.1 Water Quality Characteristics of Combined Sewer

Summarized in the following are the results of dry- and wet-weather water quality survey made in 1975 of the twelve survey areas in the eleven municipalities in different localities in Japan.

(a) Findings of Dry-weather Survey

In each survey area, dry-weather around-the-clock survey was carried out once or twice. During the survey, sewage flow was measured and once-every-30 minutes sampling were conducted for water quality analysis.

Table 1.3 shows dry-weather average water qualities and concentration ranges in respective survey areas.

Followings are the water quality characteristics of respective survey areas in dry-weather and the factor that are considered attributable to them.

C: Industrial quarters account for 75% of total area, discharging high concentrations of heavy metals.

E: Residential, but high in BOD, COD and SS.

H: A good number of textile and dyeing factories in the area resulting high BOD, COD and SS.

I: Typical business quarters discharging weak effluents having a soluble-to-total BOD ratio of 14.4%.

K: Low BOD; quantities of pipeline desposits are suspected to be.

L: Densely built amusement quarters generating a large volume of sewage for the area; high BOD.

While these areas have different characteristics, they also have something in common with each other as follows.

Table 1.3 Dry Weather Average Concentration of Combined Sewage

Drainage district	Date	Dry Weather Average Concentration (Upper: Average, Lower: Range) mg/l										
		BOD	S-BOD	COD	SS	VSS	T-N	T-P	Zn	Cu	Pb	Coliform group x 10 ⁴ /ml
A	Oct. 22 ~23	136 21~560	79.9 19~468	37.2 6.2~158	55.0 14~163	40.0 3~128	15.8 ND~40.6	4.14 0.11~18.8	0.02 ND~0.08	0.017 ND~0.58	ND	2.91 0.05~14
B	Jul. 15	103 23~151	—	—	83.2 12~157	—	—	—	—	—	—	—
C	Sep. 21 ~22	127 12~229	42.1 5.8~72.9	53.0 10.0~136	88.3 12~205	60.9 3~123	14.7 5.17~27.7	4.31 0.94~8.24	2.23 0.16~9.13	0.844 0.02~10.2	0.04 0.01~0.09	—
D	Aug. 26 ~27	110 35~281	82.0 17~198	60.0 24~191	84.8 19~258	60.8 7~230	21.5 12~52	2.05 1.0~5.5	ND	ND	ND	80 20~280
E	Dec. 3	134 16~374	49.0 4~184	117 15~293	202 8~844	129 8~388	21.3 10.6~60.1	5.20 1.6~12.5	0.30 0.07~0.65	0.03 ND~0.08	0.006 ND~0.05	5.18 0.5~26
F	Sep. 2 ~3	84.8 34.7~147	31.6 9.9~53.6	41.1 11.9~67	76.0 26~184	51.9 26~90	12.4 5.49~21.1	4.13 1.4~8.7	0.25 0.15~0.47	0.057 0.02~0.14	0.01 ND~0.03	6.4 1.2~9.7
	Nov. 11 ~12	122 39.5~180	36.4 10.1~63.2	35.6 23.2~56.1	79.0 27~132	54.2 21~104	13.8 6.8~28.8	4.06 1.6~7.6	0.15 0.11~0.22	0.04 0.01~0.07	0.01 ND~0.03	6.5 2.8~9.2
G	Aug. 27 ~28	93.2 7.6~205	47.6 4.4~132	38.9 8.7~63	64.0 13~125	53.9 10~104	11.5 3.0~18.0	1.46 0.29~2.20	0.19 0.09~0.40	0.037 ND~0.15	ND	77 21~260
H	Oct. 23 ~24	321 66~691	208 44.3~311	232 35~359	120 22~194	86.3 19~129	15.3 9.56~29.7	5.04 2.08~8.20	0.663 0.10~1.51	0.079 0.02~0.16	0.01 ND~0.04	2.4 0.011~11
I	Jan. 12 ~13	101 11~180	14.5 4.0~29.3	45.6 16.3~75.7	95.7 19~202	60.4 14~109	17.9 1.60~30.7	2.57 1.01~3.42	0.12 ND~0.20	0.05 ND~0.07	ND	17 1.5~40
J	Oct. 31	116 14~203	68.4 10.6~152	74.2 17.3~148	78.2 12~187	57.0 10~140	21.5 11.2~47.4	10.6 2.7~23.1	1.5 0.05~27	ND	ND	5.7 1.6~20
K	Oct. 1	51.7 6.3~123	18.5 4.5~43.0	32.5 7.8~79.5	55.8 10~145	46.5 6~120	11.0 4.1~35.0	3.08 1.13~7.32	0.08 ND~0.6	0.013 0.007~0.025	ND	11 0.52~38
L	Aug. 4 ~5	143 21.4~297	56.3 10.7~109	47.9 14~80.4	107 35~540	52.0 15~214	15.2 4.32~26.4	2.27 0.95~3.24	0.18 0.09~0.49	0.02 ND~0.16	ND	80 1.1~820
	Feb. 2	180 31~494	—	70.1 15.8~150	100 18~203	—	22.0 5.97~32.5	3.13 0.85~5.13	—	—	—	—

- a. VSS/SS is in the range of 0.63 to 0.88, except for one survey area.
- b. Three survey areas (F, G, and L) show flow rate 10 to 30% less in winter than in summer, and an increase in BOD of 30 to 40% on the average in winter over summer.
- c. No definite differences by land use are noticed

Table 1.4 shows daily flow and loadings per capita discharged. In Japan, it has been generally accepted as a sewage works planning practice that the sanitary sewage volume and BOD load per day per person are about 500 lit. and 60 g, respectively. It is noteworthy that even in typical residential areas such as A and E, these standard values are exceeded by a large margin.

Table 1.4 Summary of Per Capita Runoff Loadings

(Per capita per day)						
District	Population*	Flow (ℓ)	BOD (g)	SS (g)	K-N (g)	T-P (g)
A	5,335	738	100	40.7	11.7	3.05
B	160,055	661	68.1	55.0	—	—
C	59,929	1,583	202	140	23.3	6.82
D	10,650	536	59.9	46.6	11.8	1.13
E	3,924	702	93.6	140	—	3.78
F	23,313	711	60.4	55.3	9.09	3.05
		510	62.3	40.5	7.21	2.15
G	7,290	882	82.2	56.2	10.2	1.29
H	31,230	1,155	367	140	18.1	5.88
I	22,002	429	43.4	41.1	7.68	1.10
J	29,363	487	56.6	38.6	10.5	5.35
K	3,918	356	18.3	19.7	3.94	1.09
L	9,266	1,352	192	145	20.5	3.06
		1,258	226	126	—	3.93

(Sep. 2~3)
(Nov. 11~12)

(Aug. 4~5)
(Feb. 2)

* Average of Daytime and Resident Population Shown in Table 1.2 (a).

(b) Findings of Wet-weather Survey

Wet-weather survey was conducted two times to four times in each survey area.

i) Wet-weather runoff and water characteristics

Fig. 1.1 shows the relationship between total rainfall and total runoff. The runoff coefficient is largely influenced by the impervious area ratio. As shown in Table 1.2, some survey areas have a large impervious area ratio of more than 90%. In these areas, the runoff coefficient is high. Taken altogether, however, the runoff coefficient lies in the range of 40 to 80%.

Table 1.5 shows average characteristics and concentrations of combined sewage in wet-weather conditions.

Figs. 1.2 (a) through (d) show wet-weather BOD, SS, T-P, and K-N in terms of

Table 1.5 Summary of Average Quality of Combined Sewage in Wet Weather

District	Date	Rainfall (mm)	Wet Weather Average Concentration (Upper - Average, Lower - Range) mg/l										Coliform Group #/100 ml
			BOD	5-BOD	COD	SS	VSS	K.N	T.P	Zn	Cu	Pb	
A	1 Nov. 15 ~16	26.5	57.0 10-265	37.1 6-152	40.8 18-90	115 44-325	44.0 12-235	8.61 0.07-14.9	2.68 0.04-0.18	0.069 ND	ND	ND	1.6 0.1-6.5
	2 Nov. 27	1.0	181 90-405	92.3 37-234	112 66-146	449 132-604	175 86-237	222 142-30.8	8.00 1.99-26.4	0.20 0.10-0.38	0.04 ND-0.05	0.05 ND-0.07	3.2 0.3-28
B	1 Jul. 10	6.5	120 76-185	-	-	117 75-174	-	-	-	-	-	-	-
	2 Jul. 12	8.3	106 76-185	-	-	208 68-590	-	-	-	-	-	-	-
C	1 Sept. 23 ~24	52.0	63.3 7.2-347	32.7 2.7-65.4	53.1 9.5-304	170 28-1250	113 11-691	9.37 2.23-28.3	2.18 0.16-11.8	0.931 ND-13.4	0.329 ND-7.70	0.049 ND-0.27	-
	2 Sept. 29	36.0	66.4 14-145	-	-	85.5 10-287	-	-	-	-	-	-	-
D	1 Nov. 14 ~15	9.1	99.7 35-190	31.9 15.7-59.3	60.8 28.1-105	148 42-385	112 12-265	11.4 6.12-21.4	4.12 1.58-8.56	0.930 0.36-1.69	0.341 0.09-1.13	0.064 0.02-0.15	-
	2 Oct. 3	2.25	83.2 30-182	60.0 24-120	43.7 24-68	129 56-240	88.0 38-200	19.0 9-35	3.52 1.5-6.4	0.20 0.1-0.3	ND	ND	18 4-50
E	1 Nov. 19	18.50	44.0 18-155	15.0 7-45	42.6 24-126	118 49-238	106 47-220	6.03 0.5-3.1	0.064 0.01-0.14	0.010 ND-0.11	ND	ND	41 19-76
	3 Feb. 5	11.07	53.6 34-128	30.0 24-60	36.7 28-60	130 83-183	40.0 11-68	8.07 5-17	0.74 0.4-2.2	0.38 0.18-0.58	0.061 0.02-0.12	ND	2.9 1.2-13
F	1 Oct. 24	6.5	89.8 25-329	29.7 12-68	51.8 27-186	207 13-915	29.7 17-515	40.6 2.3	4.30 1.9-15.6	0.46 0.33-1.76	0.016 ND-0.12	0.047 ND-0.16	3.64 0.53-12
	2 Feb. 5 ~6	29.0	65.3 13-503	54.8 5-173	67.0 16-278	168 42-385	71.0 9-614	12.8 4.1-101	2.10 1.13-15.4	0.45 0.13-1.54	0.044 ND-0.21	0.061 ND-0.37	3.2 0.2-34.6
G	3 Feb. 16	33.0	34.5 12-105	7.50 7-45	40.1 24-126	209 49-238	66.0 18-263	7.37 0.8-26.3	3.15 0.9-10.1	0.47 0.12-1.88	0.066 0.02-0.49	0.038 ND-0.24	1.51 ND-56
	1 Oct. 7	85.8	26.4 11.1-81.5	14.4 5.9-43.7	13.0 4.4-42.2	90.0 24-520	44.2 10-182	5.52 2.66-15.9	1.41 0.50-5.35	0.20 0.11-0.42	0.02 0.01-0.05	0.01 ND-0.04	0.01 1.3 0.5-6.6
H	1 Oct. 24	23.1	27.8 6.8-124	11.0 2.8-52.3	13.1 3.6-45.8	26.9 8-185	17.8 7-65	4.04 2.02-15.1	0.18 0.12-0.52	0.138 ND-1.01	0.004 ND-0.02	0.004 ND-0.02	1.3 0.5-6.6
	3 Nov. 7	40.1	27.1 9.2-247	12.8 6.1-45.8	9.8 5.8-45.8	84.9 8-565	54.4 7-220	5.25 2.08-16.6	1.64 0.13-5.21	0.12 0.04-0.18	0.01 ND-0.04	0.006 ND-0.11	1.3 0.8-5.2
I	1 Aug. 22	2.5	83.4 34-288	-	36.9 21.2-81.3	133 56-323	-	-	-	-	-	-	-
	2 Sep. 8	5.0	127 39.5-250	33.3 23.0-67.7	75.0 31.6-153	214 51-550	101 37-194	9.18 5.6-14.0	1.59 0.9-2.9	0.51 0.18-0.77	0.065 0.02-0.11	0.088 ND-0.18	49 20-79
J	3 Sep. 18	2.5	109 70.2-170	39.3 25.5-69.4	65.2 36.4-113	161 52-392	128 59-342	16.8 9.5-25.7	1.83 1.3-2.8	0.41 0.31-1.34	0.077 0.04-0.12	0.043 ND-0.12	41 5.9-140
	4 Oct. 7	5.0	147 97.3-256	31.2 20.2-74.9	55.7 48.8-146	357 14-118	211 91-376	2.91 5.4-12.0	2.33 1.4-3.3	0.57 0.21-0.74	0.06 0.03-0.10	0.075 ND-0.12	67 16-280
K	1 Jul. 7	15.5	138 58.9-365	67.9 28.0-190	92.2 47.5-237	192 41-571	104 34-323	8.16 4.41-17.8	1.15 0.37-3.42	0.97 0.30-2.23	0.19 0.06-0.43	0.033 ND-0.11	7.0 ND-23
	2 Aug. 6	24.0	117 56.4-349	70.8 23.1-213	88.1 35.6-265	203 39-668	93.1 25-328	10.1 4.13-28.6	1.16 0.30-2.40	1.44 0.41-4.60	0.37 0.05-0.48	0.02 ND-0.06	1.5 0.005-12
L	3 Feb. 5	14.2	280 51.3-222	88.3 36.0-187	104 18.9-217	207 14-572	138 16-372	16.4 8.00-29.7	2.97 2.07-5.98	1.60 1.13-9.0	0.04 0.02-0.29	0.01 ND-0.05	2.9 0.15-21
	1 Oct. 28 ~29	19.5	47.8 6.1-260	8.35 2.0-60.6	28.6 9.3-63.5	57.2 13.2-368	32.0 7.5-225	9.51 3.4-26.1	1.26 0.57-3.82	0.17 ND-0.50	0.08 ND-0.35	ND	4.3 0.20-40
M	2 Nov. 6 ~7	36.0	31.0 2.6-163	3.84 1.0-15.9	26.6 5.9-81.0	334 19.8-556	43.3 7.6-116	5.15 1.2-17.0	1.12 0.10-3.56	0.25 ND-0.58	0.093 ND-0.17	0.078 ND-0.16	0.78 0.034-6.7
	3 Nov. 27	8.0	58.4 31.4-123	9.92 6.2-17.0	49.7 39.6-77.7	121 67-355	73.7 46-129	18.9 10.1-26.0	2.95 2.30-4.04	0.33 0.13-0.57	0.14 0.08-0.20	ND	5.4 1.7-15
N	1 Feb. 5	1.0	170 109-314	91.9 76.9-118	131 91.4-167	172 70-294	94.2 41-148	27.0 19.2-25.3	4.70 3.17-9.37	1.16 0.11-1.58	0.14 ND-0.26	ND	4.0 1.2-7.7
	2 Feb. 18	18.0	21.2 10.3-92.4	8.74 5.4-29.7	30.6 18.2-104	106 32-177	42.3 10-86	0.66 7.5-12.9	0.66 0.40-1.82	0.335 0.173-0.598	0.01 ND-0.32	ND	1.4 0.40-9.9
O	3 Mar. 11 ~12	11.0	51.1 10.1-146	20.5 6.2-77.9	43.3 13.2-92.3	92.2 27-210	56.0 15-161	9.20 3.4-23.2	1.54 0.55-3.65	0.40 0.23-0.61	ND	ND	3.87 0.44-9.7
	1 Oct. 12	12.5	114 26-440	13.7 5-26	21.3 12.9-231	238 21-969	115 13-706	7.84 2.2-37.3	0.81 0.45-16.3	0.028 ND-1.1	0.03 ND-0.06	0.03 ND-0.06	1.4 1.1-180
P	2 Nov. 13	9.5	139 35-300	17.1 11.3-32.3	80.6 21.5-280	309 42-2130	182 7.45-61.1	19.9 7.65-61.1	2.70 0.63-9.61	0.30 0.05-0.79	0.045 ND-0.122	0.02 ND-0.06	26 2.09-120
	1 Nov. 18	6.0	91.4 56-157	11.4 13.2-46.5	11.4 45.0-158	167 176-2850	163 55-510	16.3 11.1-22.9	0.27 1.35-3.15	0.01 ND-0.10	ND	ND	13 2.4-54
Q	2 Feb. 5	2.8	75.7 23.1-1791	29.7 10.8-89.0	45.6 20.1-72.8	73.3 23-137	53.1 22-99	14.2 6.8-20.1	2.10 0.59-3.59	0.41 ND-1.24	0.03 ND-0.08	ND	24 1.4-190
	3 Feb. 17	27.0	107 9.5-282	53.2 4.9-184	67.2 8.0-97.2	125 20-374	73.0 14-242	10.1 2.01-42.0	1.69 0.30-5.07	0.29 0.09-0.53	0.19 ND-0.16	ND	3.0 0.010-250

Fig. 1.1 Total Runoff and Rainfall

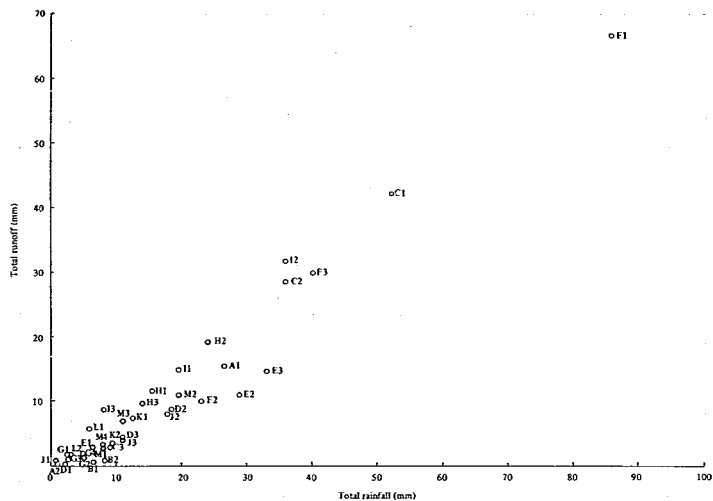


Fig. 1.2 (a) Discharge Volume and Average Concentration (BOD)

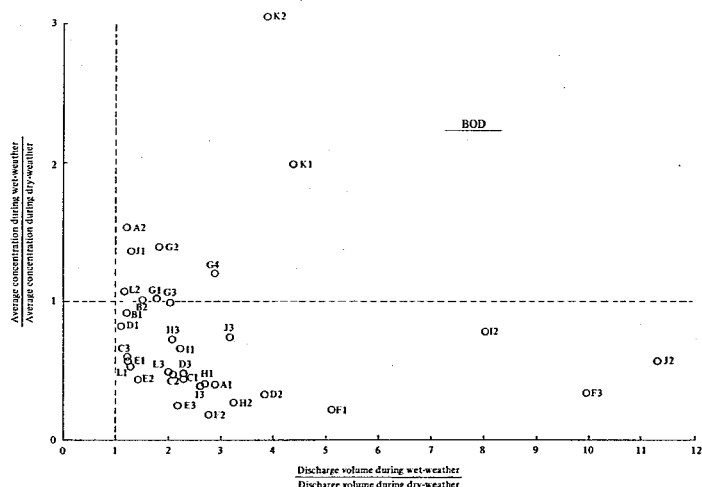


Fig. 1.2 (b) Discharge Volume and Average Concentration (SS)

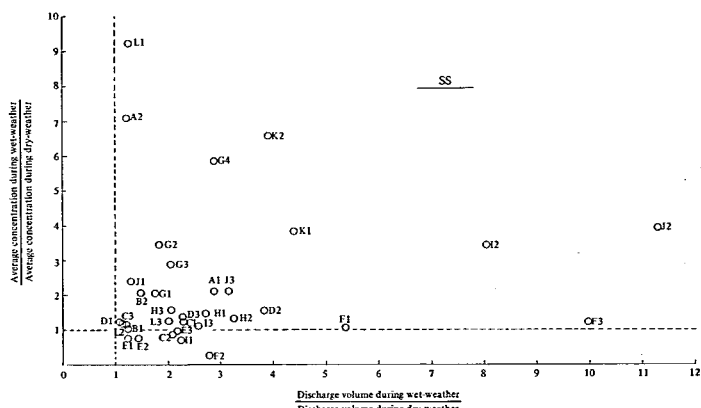


Fig. 1.2 (c) Discharge Volume and Average Concentration (Total-P)

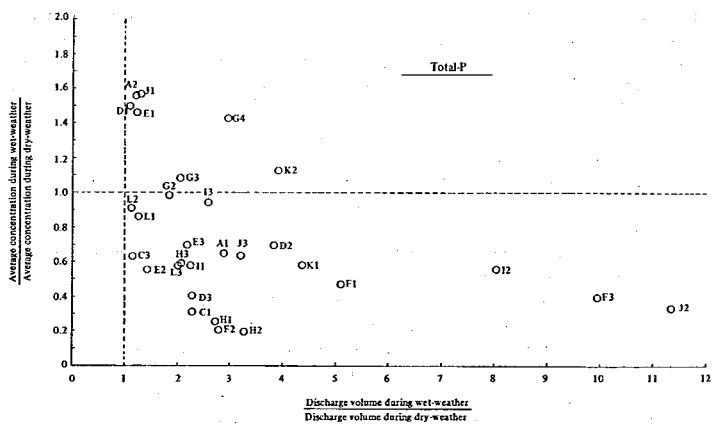
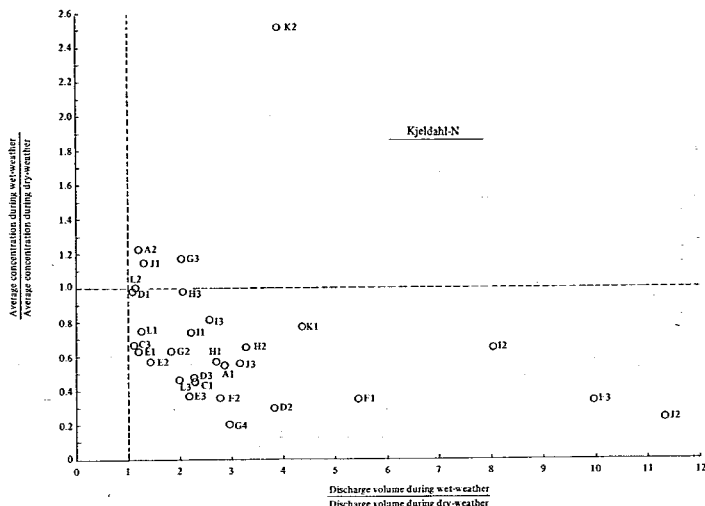


Fig. 1.2 (d) Discharge Volume and Average Concentration (K-N)



ratios to those in dry-weather. After a light rainfall, BOD, T-P and K-N become by some chance by far larger in concentration than in dry-weather. In case of a large scale storm, however, the concentrations are reduced by dilution effect and the loadings are generally held within several times those in dry-weather. As regard SS, however, the reduction of concentration is far less than others even in case of a large-scale rainfall. Namely, it remains almost the same as in dry-weather. This shows that the bulk of SS is conveyed into the sewer from the ground surfaces with unlimited sources of SS supply.

Fig. 1.3 shows the relationships between maximum storm water flow rates and runoff loadings of BOD and SS.

Although the runoff loadings of BOD and SS are different by an order or so among the survey areas, it is found that they have a significant relationship with flow rate.

As is clear from above, the mean values of most of water qualities can be said to decrease with increase in the scale of rainfall. However, the time change in runoff loadings is quite complicated, and defies rendition by mean qualities only.

Most of wet-weather records give the so-called "first flush."

Fig. 1.4 refers to the record in the survey area E in which the cumulative flow and cumulative loadings are shown in percentage.

It is highly suggestive of a large loading runoff in the early stage of rain runoff.

It should be noted however that compared with BOD and SS, the loading

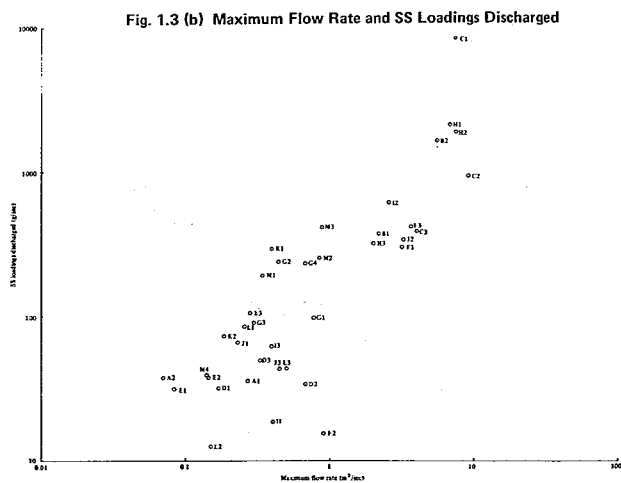
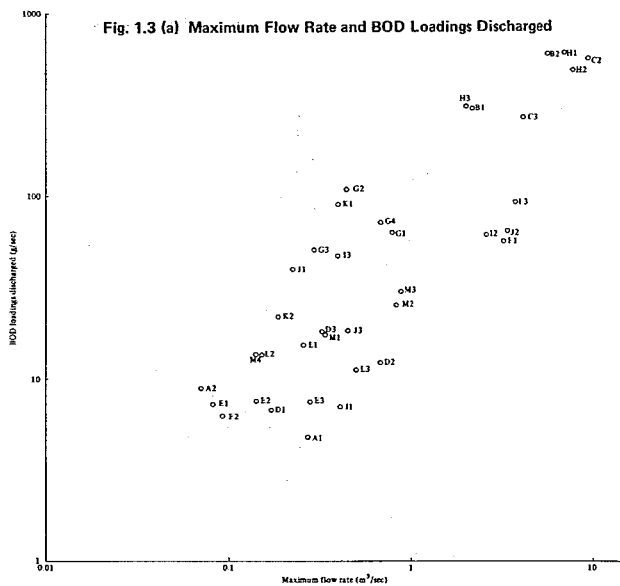


Fig. 1.4 Cumulative Flow Volume and Pollution Loadings Discharged

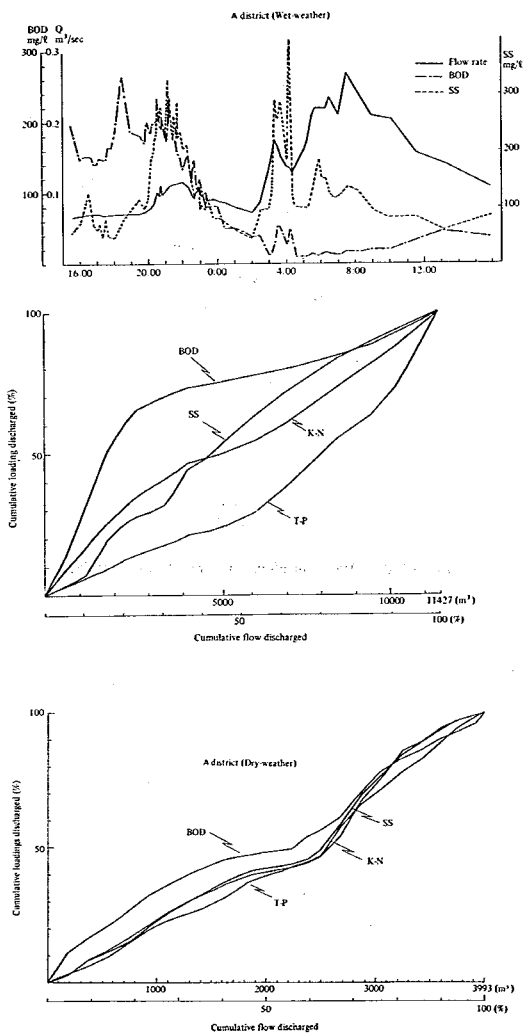


Fig. 1.5 (a) Variation of Water Quality in Combined Sewage (Dry-Weather)

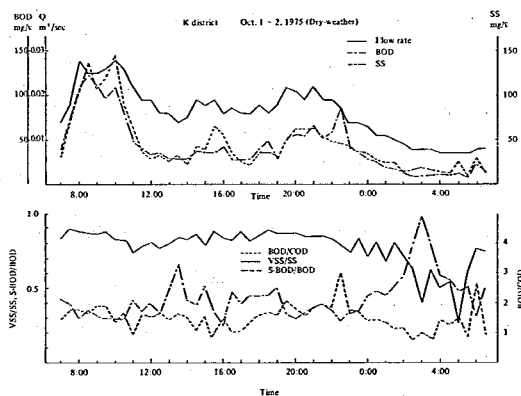
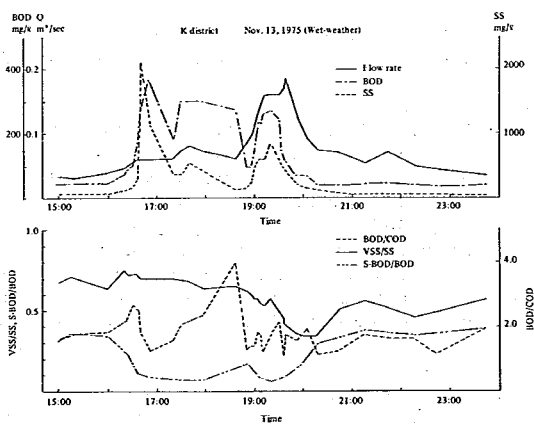


Fig. 1.5 (b) Variation of Water Quality in Combined Sewage (Wet-Weather)



runoff curves of T-P and K-N do not show so large a change with time, and this tendency is seen in most of rainfall observations. Hence it is inferred that the detention of wet-weather overflow by the storage tank in order to reduce pollution of waters will be ineffective in the removal of T-P and K-N as compared with BOD and SS.

Figs. 1.5 (a) and (b) show changes in water quality indices in the survey area K during dry- and wet-weather, respectively. With reference to dry-weather, BOD/COD, VSS/SS, S-BOD/BOD all are nearly constant in the daytime.

In the nighttime when the flow declines, VSS/SS decreases while S-BOD/BOD increases. On the other hand, BOD/COD does not show so conspicuous change. In wet-weather, every index shows a large change: in the rising period of runoff, S-BOD/BOD declines; in the first peak of SS runoff, VSS/SS shows no change, but in the second peak of SS when the sewage runoff has attained a maximum, VSS/SS falls largely.

The decrease in VSS/SS is considered due to supply of SS from ground surfaces.

With attention paid to the fact that VSS/SS is almost constant in dry-weather while it changes in wet-weather, a trial is made to divide SS runoff loading into ground-contributed component and the sewer deposit-contributed component which is supplied during dry-weather.

From the urban storm water discharge survey shown in 1.3.3.2, the ground-contributed SS is estimated at 0.2 in terms of VSS/SS.

The results of computation are shown in Fig. 1.6.

The first-peak showing "first flush" is chiefly contributed by SS runoff from the deposits in the sewer. In the second peak, however, SS is divided almost equally between the deposit component and ground component. With reference to the rainfall shown in Fig. 1.6, the ultimate SS discharge of 674 kg is broken down as follows.

408 kg (61%) by sewer deposit runoff; 240 kg (36%) by ground supply; and 26 kg (3%) by sewage. Namely, the sewer deposit is found most responsible for SS discharge.

ii) Local characteristics

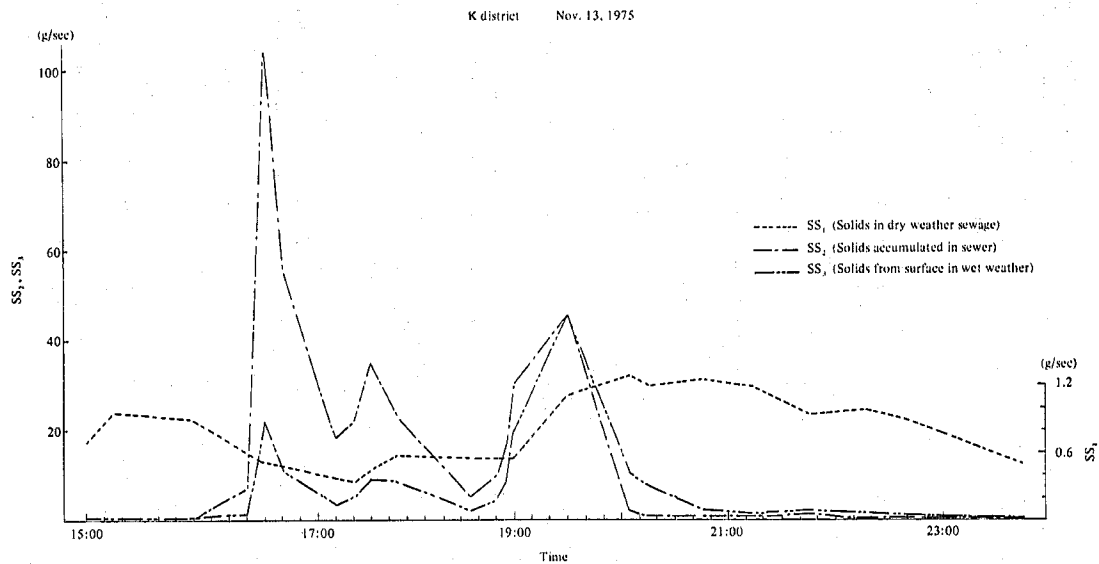
From the viewpoint of locality, what shows the most highest change in wet-weather as compared with dry-weather is the survey area K. In the second rainfall observation in the survey area K, for example, the average concentration is 2.7 times in BOD as much as that at the same hours in dry-weather, 5.6 times in SS as much, and the runoff loading is 10.5 times and 21.8 times, respectively.

The maximum concentration is 840 mg/l for BOD, and 2,129 mg/l for SS.

As shown in 1.3.3.1, the dry-weather concentrations in the survey area K are very small compared with the average concentrations in other survey areas. It is therefore conjectured that a considerable amount of loadings is deposited in the sewer during dry-weather and is flushed out in wet-weather to develop a salient increase in the loadings.

The survey area K is situated on a steep with a ground slope of 24.5%. Considering this high slope, it is very queer why such deposit is developed in the

Fig. 1.6 Comparison of Solids in Wet Weather Sewage by Sources.



sewer. The clarification of the causes is left to further study in the future.

In contrast to the survey area K, the survey area E which forms also residential quarters on a steep slope of 20.4‰ shows only a bit increase in the wet-weather runoff loadings. In the first rainfall observation in survey area K, for example, the average concentration is 0.78 times in BOD and 1.02 times in SS as much as that in the dry-weather and the runoff loadings also remain small.

As explained in 1.3.3.1, it is worth noting that in the survey area K, SS, COD, etc. are considerably high in dry-weather sewage.

For all that the survey areas K and E are almost the same in land use and geographical conditions, they present quite different phases both in dry- and wet-weather pollutant discharges. In the survey area K, it is no doubt that there is something promoting deposition in the sewer.

It is therefore hoped that the causes be clarified to reflect in the engineering of sewage pipeline system.

iii) Correlation between water characteristics

Figs. 1.7 (a), (b) and (c) show the correlation between the characteristics obtained by the analysis of both dry- and wet-weather surveys. Here are some interesting findings.

In many survey areas, the ratio VSS/SS becomes smaller in wet-weather than in dry-weather, and the inorganic suspended solids increase in wet-weather.

From the correlation between BOD and TOC, it is understood that the refractory organics increases in wet weather.

This is very important in dealing with the treatment of wet-weather combined sewer overflow.

Of the heavy metals, zinc is found in every survey area. In many survey areas, it is found that zinc has a significant correlation with SS, though no substantial difference is seen between dry- and wet-weather.

1.3.3.2 Characteristics of Urban Storm Water Discharge

Aside from the water pollution due to combined sewer overflow, the urban storm water discharge has come to be more and more recognized as a major contributor of water pollution.

In the separate sewer municipality, member of the Research Committee on Combined Sewer System Problems, a survey area was established for investigating urban storm water discharge. Survey stations were set at the storm sewers in the survey area M forming commercial quarters in the center of city in 1975 and in the survey area O forming newly developed suburban residential quarters in 1976, for the purpose of wet-weather storm water sampling and discharge observation.

(a) Local Characteristics

Table 1.6 shows the mean characteristics and concentration ranges of urban storm water discharges observed at the two survey areas. In the survey area M where amusement quarters exist, the water quality is very poor; the concentration on the average of four rainfall observations were 38.9 mg/l for BOD, 288 mg/l for SS. The maximum values were 309 mg/l and 1,180 mg/l, respectively, suggesting that the urban storm water discharge itself is considerably contaminated.

Fig. 1.7 Correlation between Water Qualities

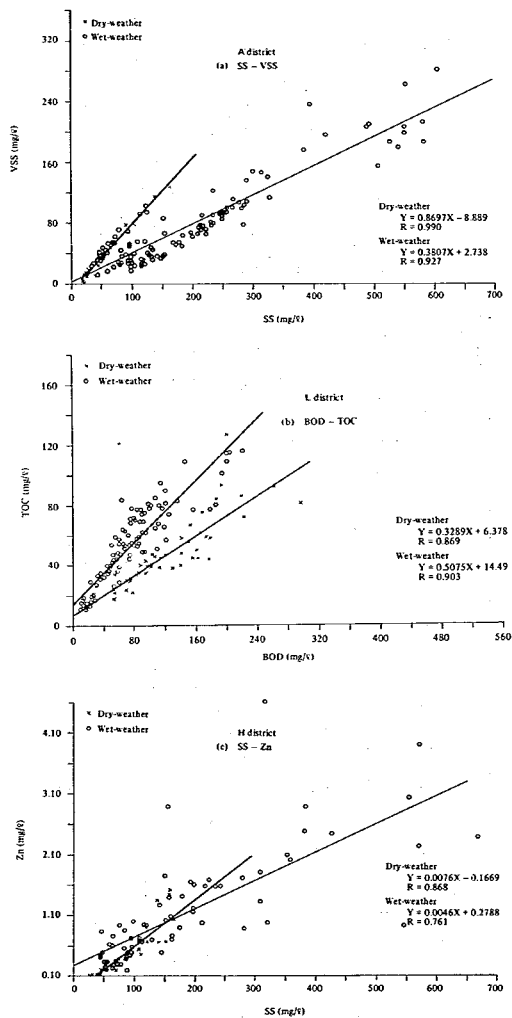


Table 1.6 Summary of Storm Runoff Water Quality from Urban Area

District	Date		Rain-fall (mm)	Wet Weather Average Concentration (Upper: Average, Lower: Range) mg/l														Coliform Group x 10 ⁴ /ml
				BOD	S-BOD	COD	SS	VSS	T-N	T-P	Zn	Cu	Pb	Cr	Ni	Cd		
M	1	4.6	8.0	56.7 7.2~142	11.1 5.6~17.9	43.9 9.9~77.1	420 10.4~863	91.9 4~226	7.23 3.75~18.8	0.24 0.053~0.556	0.956 0.11~1.75	0.149 0.030~0.36	0.277 0.028~0.740	0.025 0.004~0.046	0.038 0.006~0.057	0.0031 0.0014~0.0103	0.74 0.037~4.0	
	2	8.6	19.5	32.1 6.9~309	9.24 4.0~47.4	43.7 10.5~190	303 1.1~1180	98.1 9.3~460	5.31 1.7~25.9	0.24 0.09~1.45	0.670 0.06~1.80	0.299 0.026~1.93	0.212 0.015~0.550	-	0.021 0.004~0.073	-	0.38 0.081~6.2	
	3	9.8	11.0	30.5 12.5~72	7.69 6.4~12.5	40.7 17.5~73.5	347 20~715	71.2 14.2~101	3.45 2.62~3.77	0.41 0.36~0.89	0.54 0.19~0.70	0.12 0.01~0.14	0.101 0.018~0.130	-	0.018 0.006~0.022	-	0.46 0.011~0.71	
	4	12.4	8.0	62.2 9.7~114	14.3 6.1~42.3	50.8 10.4~80.8	182 16.3~280	95.6 8~148	8.81 2.28~14.9	0.48 0.09~1.73	0.734 0.12~1.07	0.136 0.031~0.192	0.114 0.015~0.151	-	0.019 0.008~0.027	-	0.88 0.042~1.5	
O	1	7.19	27.0	1.2~12.6	0.9~3.5	5.1~25.0	38.0~490	8.0~61.0	1.17~4.27	0.01~0.24	0.042~0.286	0.004~0.019	0.010~0.055	0.002~0.009	0.004~0.013	0.0006~0.0017	0.057~0.76	
	2	10.20	9.0	2.5~16.1	1.3~4.2	7.7~25.0	16.3~153	7.0~35.0	1.18~7.46	0.009~1.42	0.038~0.250	0.0067~0.022	0.0099~0.034	0.0006~0.0018	0.0011~0.045	0.0005~0.0020	0.22~0.76	

Fig. 1.8 shows the third rainfall observed in the survey area M. It also shows the relationship between the cumulative loadings of BOD, SS, T-P and K-N in percentage to the respective totals and the cumulative discharge.

The loading hydrograph shows a bell shape, significant of a large loading runoff in the initial stage of rainfall. Just as in Fig. 1.4, however, T-P and K-N are less in such tendency.

Figs. 1.9 (a) and (b) show the changes in water quality in the two survey areas.

While the water quality in the survey area M is very poor, that in the survey area O is very agreeable, proving that the water quality of storm water discharge is largely governed by the local conditions. In such a place as the survey area M where the social activities are vigorous, the effect of storm water discharge on the pollution of waters cannot be neglected, and the separate sewer system may have to be improved some way or other in the future.

Fig. 1.8 Cumulative Flow Volume and Loadings Discharged of Urban Storm Water

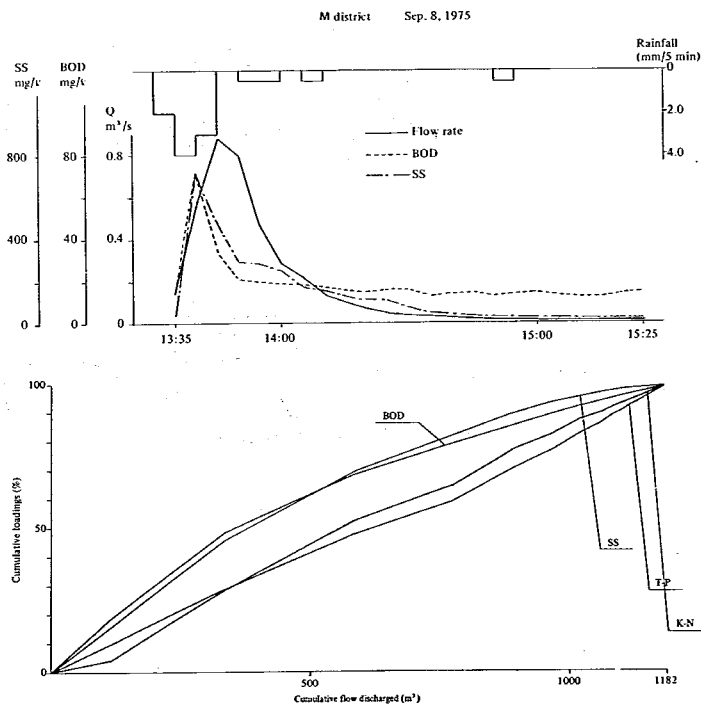


Fig. 1.9 (a) Variation of Water Quality in Storm Water Discharge (Urban Area)

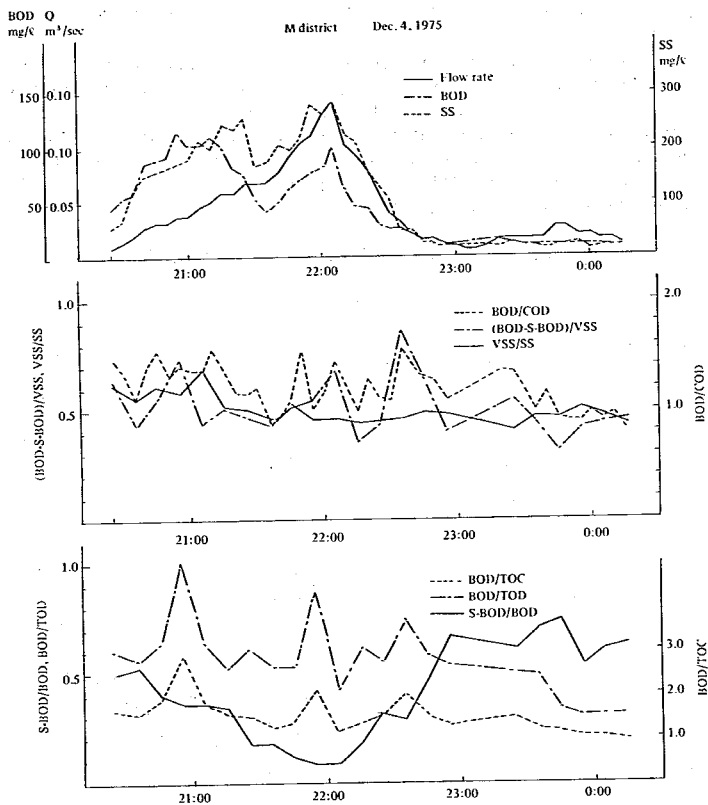
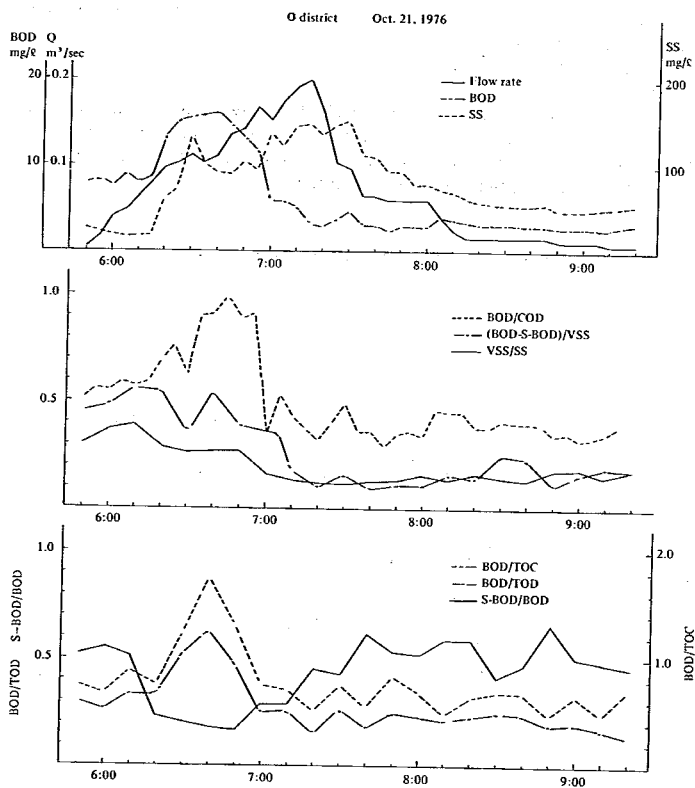


Fig. 1.9 (b) Variation of Water Quality in Storm Water Discharge
(Residential Area in the Suburbs)



(b) Characteristics of Water Quality

Fig. 1.10 shows the nitrogen forms in the urban storm water disclosed by the survey of the survey area M.

As the discharge comes close to an end, the ratio of $\text{NH}_3\text{-N}$ is reduced, while $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ rise.

Fig. 1.11 shows the correlation between SS and VSS on the one hand and heavy metals on the other.

Interestingly enough, the ratio of VSS/SS is smaller than that in the combined sewer.

There is a significant correlation established between SS and heavy metals. Assuming that all these heavy metals are present in SS, a comparison between them and the heavy metal concentrations usually found in soil shows that Zn, Pb and Cd in SS are more than 50 times those in natural state.

Fig. 1.10 Variation of Nitrogen Forms in Urban Storm Water Discharge

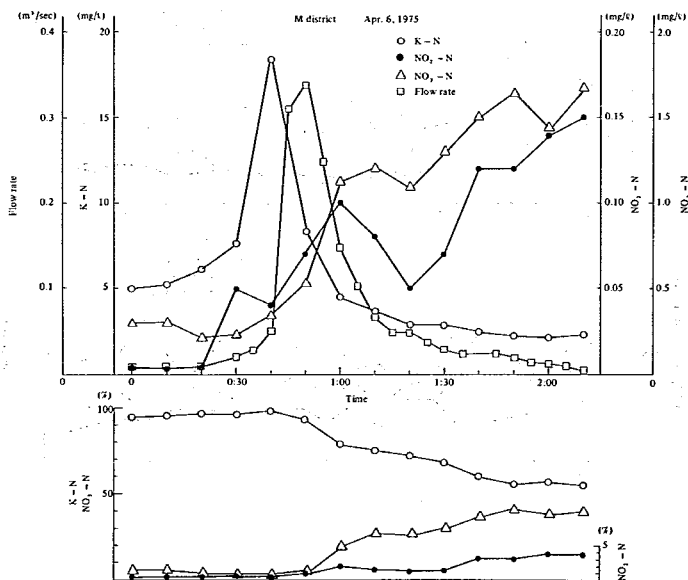


Fig. 1.11 (a) Correlation between SS and VSS

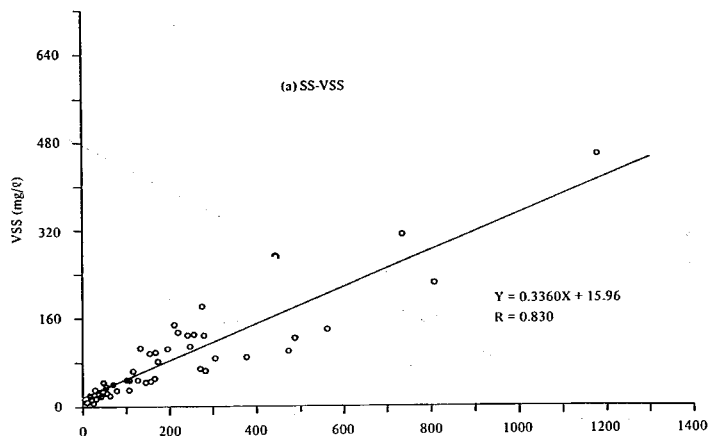


Fig. 1.11 (b) Correlation between SS and Heavy Metals

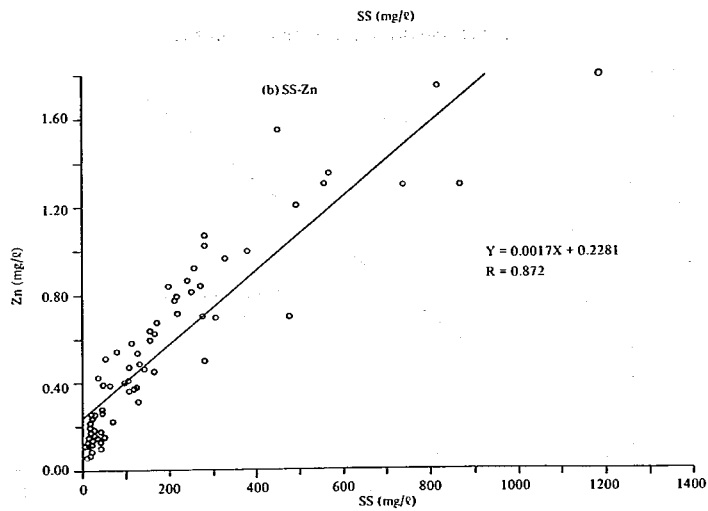


Fig. 1.11 (c) Correlation between SS and Heavy Metals

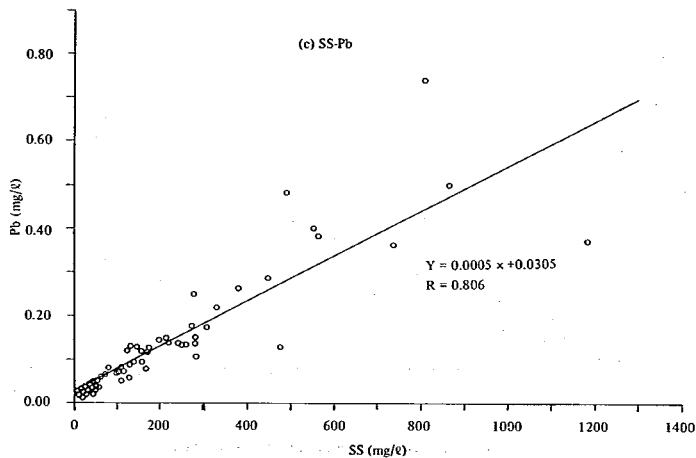


Fig. 1.11 (d) Correlation between SS and Heavy Metals

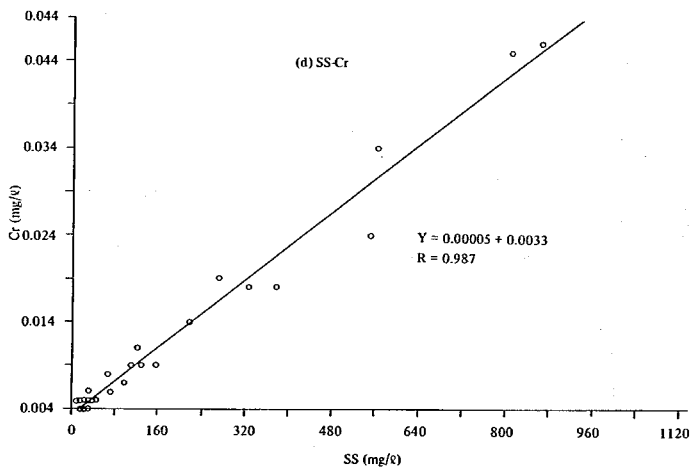


Fig. 1.11 (e) Correlation between SS and Heavy Metals

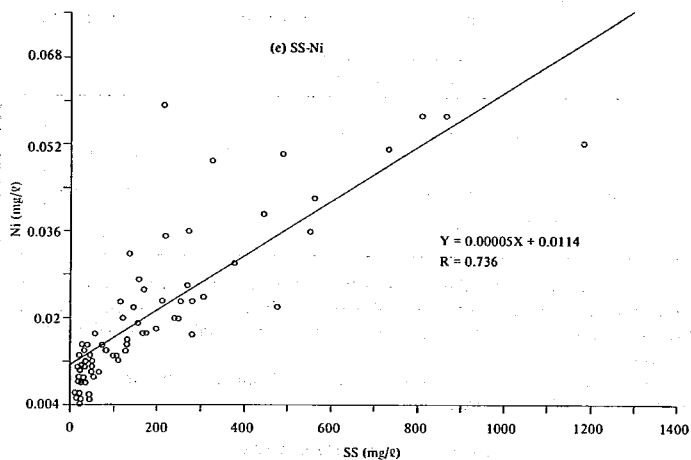
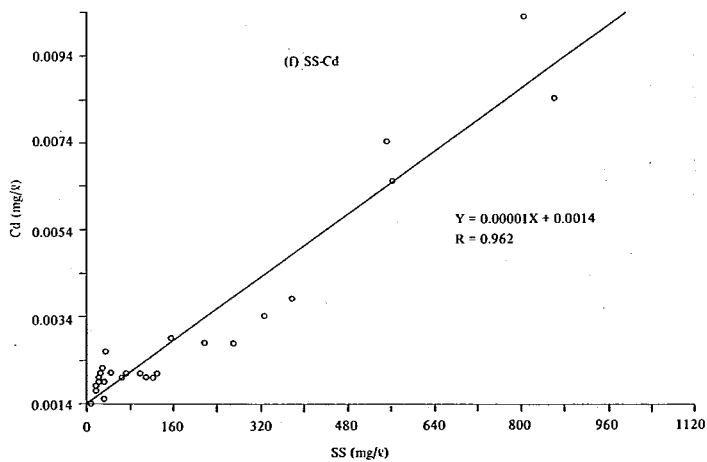


Fig. 1.11 (f) Correlation between SS and Heavy Metals



(c) Characteristics of Rainfall

Table 1.7 shows the results of rainfall analysis made in the survey area M.

In the urban area, the rainfall itself is fouled with air pollutants, including poisonous heavy metals such as Pb and Cd, posing serious threat to human health.

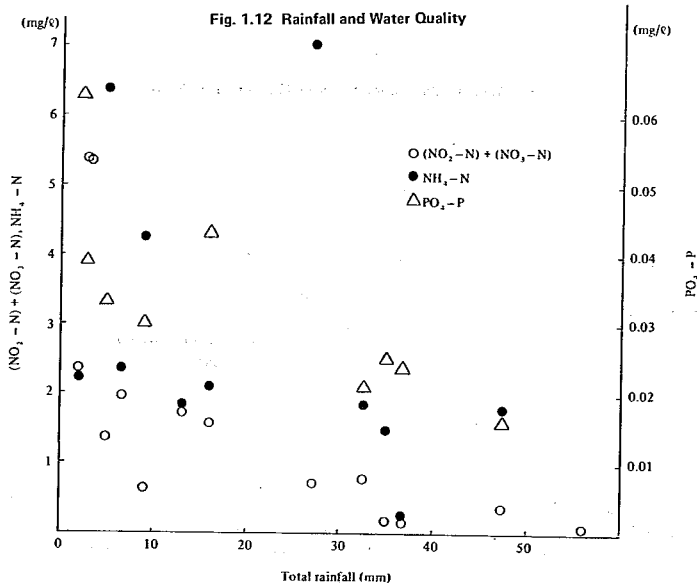
Table 1.7 Water Quality of Rainfall

M District April 6, 1975 Rainfall 8 mm

	COD	T-N	K-N	NO ₂ -N	NO ₃ -N	T-P	Total residue on evaporation	Volatile residue	Zn	Cu	Pb	Cr	Ni	Cd
Concentration (mg/l)	4.04	0.885	0.53	0.0125	0.343	0.044	79.2	22.2	0.014	0.013	0.0185	0.0026	0.0065	0.0006
Load (g/ha)	323	70.8	42.4	1.0	27.4	3.48	6330	1770	1.14	1.04	1.48	0.208	0.520	0.048

Fig. 1.12 shows the relationship between rainfalls and average concentrations which is obtained by analyzing the quality of rainfall in Tokyo. It is considered that the concentrations of rainfall decline with increase in rainfall to eventually saturate to a constant value.

The results of the surveys in the survey area M and in Tokyo are in agreement so long as the order of values is concerned.



1.3.3.3 Summary of Survey Results

The surveys on combined sewer overflow and urban storm water discharge in the twelve representative cities in Japan have disclosed the following.

- 1) It is generally seen in wet-weather that BOD, T-P and T-K are diluted significantly while SS remains no nearer being diluted.
- 2) Wet-weather discharge of T-P and K-N has less to do with the tendency of "first flush" than BOD and SS.
- 3) In wet-weather, the water quality in the combined sewer gets aggravated seriously, largely different though they may be with locality.
- 4) In wet-weather the combined sewer experiences an increase in inorganic SS and at the same time an increase in refractory organics.
- 5) The urban storm water discharge quality varies depending on land use; the discharge from urban areas such as amusement quarters is seriously contaminated.
- 6) In the urban area, the storm water itself is polluted; the degree of pollution is high, particularly in the early stages of precipitation.

1.4 POSTSCRIPT

A series of surveys of which this is part will be continued till 1973 for collecting more detail data which the authors are confident will provide something of a basis on which to build up more improved sewer systems meeting specific conditions of localities.

**COMBINED SEWER OVERFLOW SIMULATION – CASE
STUDY ON YABATA SEWER CATCHMENT AREA,
TOKYO –**

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COMBINED SEWER OVERFLOW SIMULATION — CASE STUDY ON YABATA SEWER CATCHMENT AREA, TOKYO —

Takayuki Yamaguchi

2.1 INTRODUCTION

A brief mention will be given hereunder to the problem of pollutants overflow from combined sewers. As is well known, the combined sewer transports domestic waste water to the sewage treatment plant during dry weather, and during storm weather, stormwater is added to the domestic waste water. It is impossible, however, to send all the water to the sewage treatment plant because of its limited capacity. Therefore, if storm water flow exceeds a discharge that is two or three times as much as dry weather flow, the excess is all discharged into the river. Originally, it was considered that no harm would result, since the pollutants overflow was diluted to some extent; but upon execution of such a method, it was found that more polluted water than dry weather flow owing to released deposits on the sewer was discharged into receiving waters. Regarding the magnitude of the problem, it is said in the United States that the released pollutants load by storm water into receiving water should be more or less equal to those from the secondary treatment plant (in terms of BOD). Because of this, the Japanese government is now directing cities to install separate sewers. However, since sewers in existing major cities like Tokyo, Nagoya and Osaka are of the combined sewer type, this problem has recently been taken up to be solved. Nevertheless simulation of pollutants overflow was scarcely attempted in the past, because the pollutant runoff pattern itself occurred not in a simple manner; and so far no adequate measures have been taken up.

The Urban River Section of River Division, Public Works Research Institute, has been carrying out the investigation of storm water runoff from the urban area since its inception 1969 with the cooperation of the Tokyo Metropolitan Government. From 1972 onward, the section has also been sampling and analyzing combined sewer overflow. Fortunately, the section was able to propose the simulation model of storm water runoff in 1973 and succeeded in the simulation of the pollutants runoff in 1975. Although the betterness of fit of the simulation still requires to be ascertained by applying it to the other basin, it has been decided to report on the simulation as it is at the present stage, to solicit the criticism of readers.

It may be necessary to be added here that the present report is concerned only with BOD.

2.2 OVERFLOW QUALITY CHARACTERISTICS

Since there are many detailed reports on the characteristics of overflow from the combined sewer, only their essence is extracted here for lack of space.

First, Fig. 2.1 ~ 2.3* show examples of observed hydrograph, pollutograph,

* The peak discharge of $49 \text{ m}^3/\text{sec.}$ on 10th November, 1973 in Fig. 2.2 is nearly equal to the design discharge.

and concentration of BOD at the Yabata-gawa Basin. In these figures, it may be pointed out that conversion from rainfall to runoff (Q : m^3/s) indicates comparatively simple correspondence, but then the relation between the concentration of BOD (C : mg/l) and BOD load discharge ($Q_s = CQ$: g/sec) is somewhat complicated. As a result, sampling intervals, from the initiation of runoff to the peak is short. For comparison, patterns during dry weather are also indicated by broken lines.

Fig. 2.1 Example of Observed Overflow Characteristics (Yabata-gawa, Tokyo)

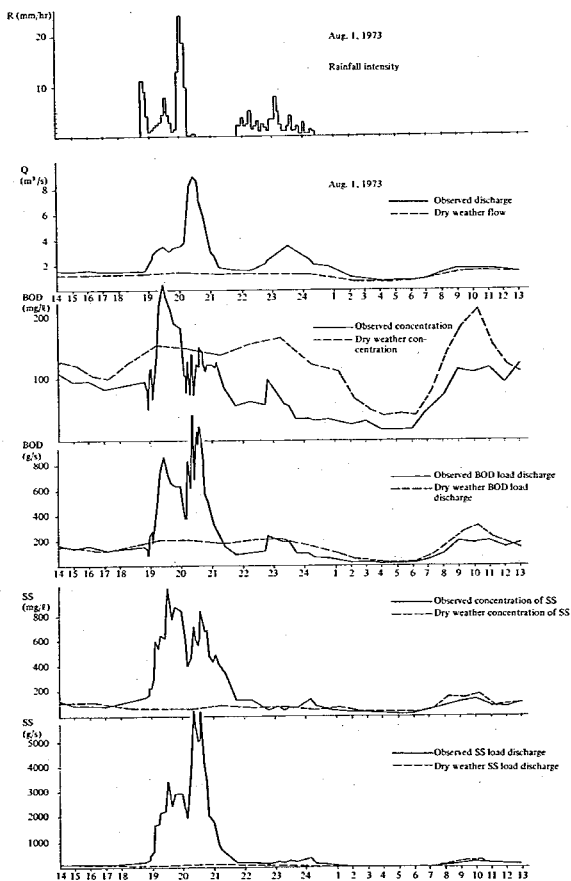


Fig. 2.2 Example of Observed Overflow Characteristics (Yabatagawa, Tokyo)

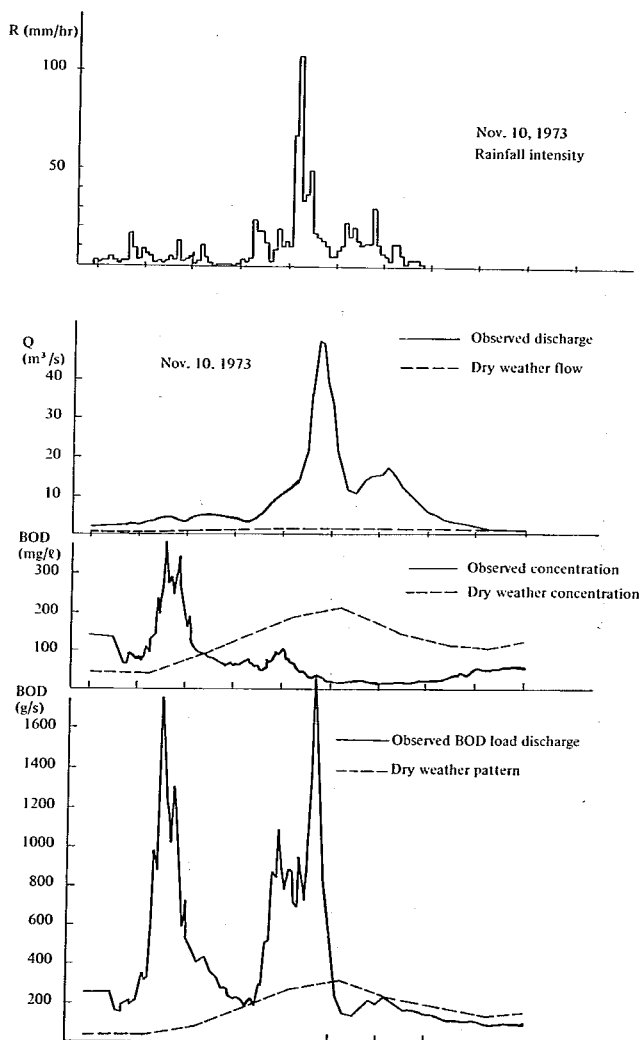
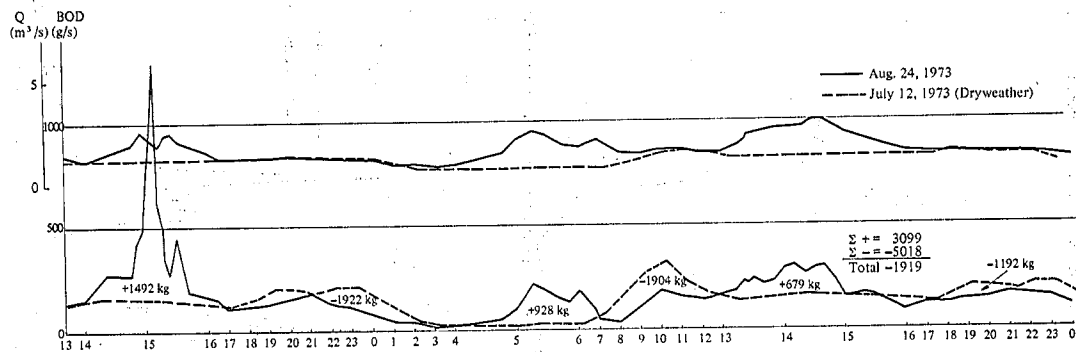


Fig. 2.3 Example of Observed Overflow Characteristics (Yabatawaga, Tokyo)

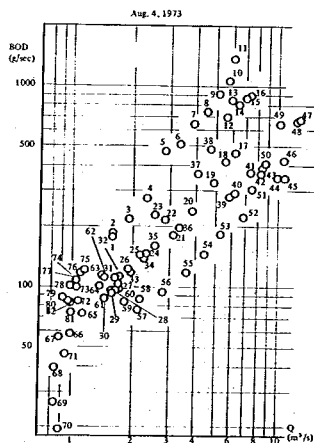
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These examples clearly show the high BOD concentration at the initial period (so-called "first flush") and the condition in which BOD load discharge does not decrease even if the magnitude of runoff increase (this condition cannot be explained by dilution alone). As for the reason, a concept is generally accepted that deposits accumulated on the sewer during dry weather are transported by storm water. In this respect, the Report on Storm Water Investigation at Northampton* is famous for verifying this concept by discharging a large quantity of clean water into the sewer during dry weather. Pollutants from the ground surface will be dealt with in Chapter 2.3.

The observed values of BOD load discharge are plotted with Q on a loglog scale according to the sequence of observations, and the curve naturally indicates a clockwise loop (Fig. 2.4 ~ 2.6). This phenomenon is understood to be the result of a decrease in the pollutant load deposited in the sewer (S), by storm water.

Fig. 2.4 BOD Load Discharge ~ Q
(Yabatatagawa, Tokyo)



* This report is one of the classics on this problem and worthy of a perusal.

Fig. 2.5 BOD ~ Q (Yabatatagawa, Tokyo)

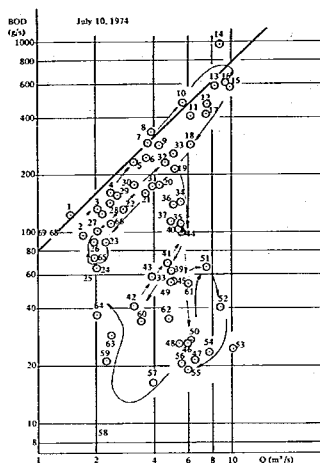
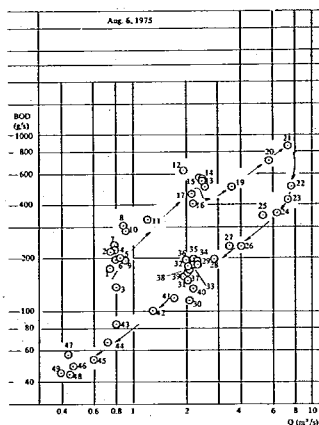


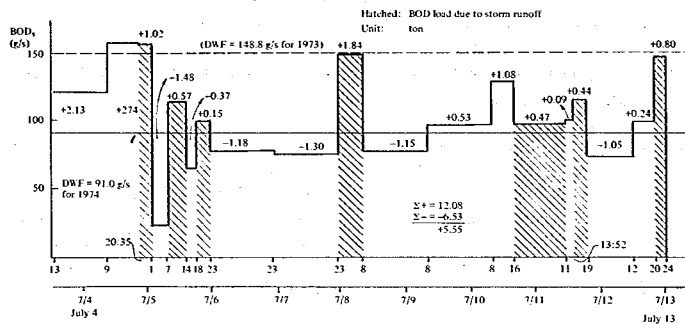
Fig. 2.6 BOD ~ Q (A city)



Another important phenomenon is that the pollutant load discharge during about one or two days after the termination of runoff becomes smaller than the dry weather load discharge. Considering that this phenomenon was found in older records, the author sampled and analyzed the load discharge for 12 to 24 hours after the termination of runoff in fiscal 1973 and this phenomenon was observed in every example analyzed. For the interpretation of this phenomenon, variation in the dry weather load can be considered, but according to the result of observations so far conducted, the dry weather pattern is comparatively stable, if a season is fixed. Therefore, the cause of the phenomenon is considered to be re-accumulation of dry weather load, that is, the recovery of the deposits. This accumulation may occur in the following way: Judging from the fact that the accumulation also seems to occur during later stage of runoff, it is inferred that gravel mounds and pits located on the sewer pipe act as a sort of load accumulation potentials, and even if the discharge at the later stage of runoff is a little greater than dry weather flow, pollutant load may accumulate on the gravel mound and in the empty pits on the sewer pipes. This can be easily understood if you imagine gravel pits of catch basins.

Finally, as for the pollutant load balance for one rainfall or during a certain period, 10 days' continuous water sampling and analysis were carried out for fiscal 1974 and 1975 on the basis of the survey results for fiscal 1973. The result of the field survey for fiscal 1974 is shown in Fig. 2.7. Regarding BOD, the pollutant load is more or less balanced, if +4.87 tons for about 1 day from 3rd to 4th July, 1974 is ignored. The same results were obtained in the survey for fiscal 1975. From the above, it is observed that pretty high accuracy can be expected of the simulation of BOD, even if supply of pollutants from the ground surface is ignored.

Fig. 2.7 Comparison with Dry Weather by 10 Days Observation
(Yabatatagawa, Tokyo)



2.3 FIELD SURVEY OF THE POLLUTANTS ON THE SOURCE

As can be understood from the above-mentioned observation, deposits of pollutants on the basin and, particularly on the sewer, are playing a considerably important role. For this reason, a field survey of pollutants on the sources has been carried out. Yabatatagawa basin was also chosen for the field survey. The area is 5.4 km² and is mainly residential. Its population is about 140,000 and population density is 260 person/ha. Detailed explanations on the survey are omitted here, and only the results of the survey so far conducted are shown in Table 2.1. An example of the survey is shown below for reference. In the case of survey on sewer manholes, 300 manholes were randomly sampled out of 6,000 manholes in the basin concerned and the number of the existence of pollutant deposits was checked and the quantity and quality of part of deposits were measured, thereby estimating the pollutant load for 6,000 manholes. In the case of the street surface, pollutant load was estimated from water sprinkling tests at only three places. From the results of the survey, it was found that the load potential at this point of time was around 5 tons and the deposits on the sewer accounted for the main part of the load potential, as shown in Table 2.1.

Table 2.1 Sources of BOD Load in the Basin (Surveyed)

Location	Accumulated Load (ton)
Street Surface	0.66
Street Inlet	0.77
Sewer	0.33
Sewer Man Holes	2.5
House Inlet	0.0
Pervious Area	0.05
Total	4.31

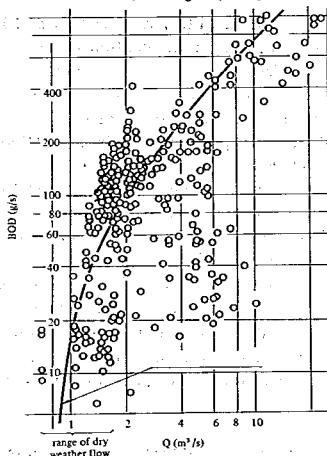
2.4 SIMULATION OF BOD LOAD DISCHARGE

Various characteristics which were used for simulation are briefly described here in the order of the equation of motion in items 2.4.1 and 2.4.2 and the equation of continuity for pollutants in item 2.4.3.

2.4.1 RELATIONSHIP BETWEEN DISCHARGE Q AND POLLUTANT LOAD DISCHARGE Q_s

It was pointed out by the author earlier that the relation between discharge Q and pollutant load discharge Q_s can be expressed by $Q_s \propto Q$ for BOD if the loop is ignored and the result is averaged, and $Q_s \propto Q^2$ for SS, in which the loop characteristics are weak owing to its properties. In dry weather, however, these relationships were not strictly maintained and particularly at night, a rapid decrease of Q_s became remarkable. All the observed values for fiscal 1974 totaling 500 are plotted in Fig. 2.8. Judging from this figure, it is clear that something like a concept of critical tractive force in sediment load had better be introduced.

Fig. 2.8 BOD $\sim Q$ (for 1974)
(Yabatatagawa, Tokyo)



The relationship can be expressed by the following equation.

$$Q_s = K' (Q - Q_c) \quad (1)$$

It is better not to think too seriously about what discharge should be taken as Q_c . Just consider as Q_c the lowest hourly discharge at the location concerned at dawn when the flow rate at each point in the basin drops and pollutants become difficult to move.

* This expression agreed with the formula for suspended sediment discharge. For instance, refer to "Applied Hydraulics" Vol. 2, 1, p.27.

2.4.2 INTRODUCTION OF BASIN RESIDUE LOAD (S)

As pointed out earlier in the item dealing with overflow quality characteristics and taking into consideration the results of water sprinkling tests on the street surface and sewer conducted by our section, a concept of basin residue load (S) is introduced and Q_s can be expressed as follows;

$$Q_s = K'' S^m \quad (2)$$

The quantity S can be defined as the total load in the basin that can be discharged out of the basin at each instant, and as can be seen from eq. (2), the smaller S becomes, the smaller will be Q_s . Particularly when $m > 1$, the decrease becomes very rapid. Values K'' and m will have to be obtained by simulation. Naturally this value S should not widely differ from the results of the field survey of pollutant sources mentioned earlier. From items 2.4.1 and 2.4.2, we can obtain an equation of motion as shown below:

$$Q_s = K S^m (Q - Q_c) \quad (3)$$

2.4.3 EQUATION OF CONTINUITY

Next, we need an equation of continuity, i.e., an equation which traces variation in time of the basin residue load.

This equation can be written as follows:

$$dS/dt = DWF - Q_s \quad (4)$$

and by approximation

$$\Delta S = S_{t+\Delta t} - S_t = (DWF - Q_s)\Delta t \quad (4')$$

$$= \left(\frac{DWF_{t+\Delta t} + DWF_t}{2} - \frac{Q_{s,t+\Delta t} + Q_{s,t}}{2} \right) \Delta t \quad (4'')$$

In eqs. (4) ~ (4''), DWF means dry weather BOD load discharge into the basin (Input), and observed values of BOD load discharge in dry weather are substituted for this supply because there is no other proper data of this kind.

2.4.4 INITIAL CONDITIONS (S_0)

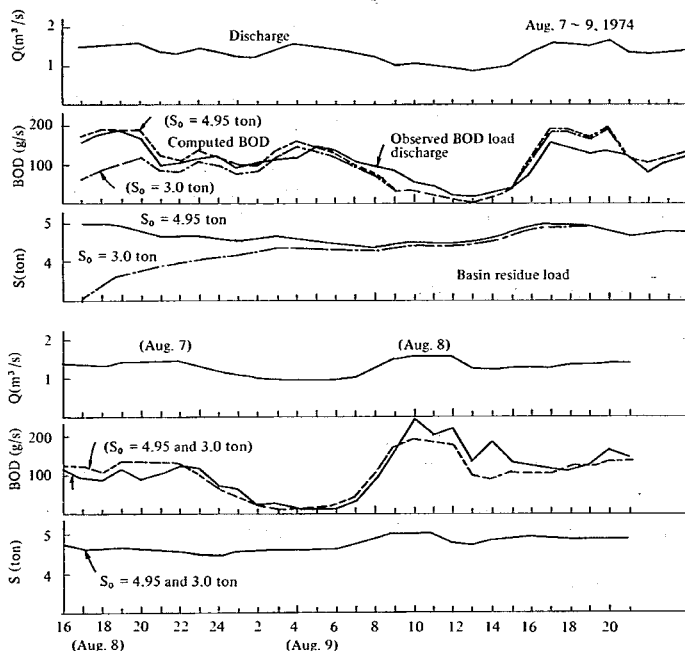
Eqs. (3) and (4) are already given. If Q is given from the observed value or rainfall runoff analysis, and an initial basin residue load (S_0) at the starting point of calculation is given, calculations can be made successively.

The value S_0 was obtained this time in the following way:

Namely, first, the values of exponent m and K with respect to pollutograph in storm weather were obtained approximately, and these values were applied to the data in dry weather (16 to 18 July, 1974). Then it was found that an equilibrium was reached within about 1 day irrespective of the magnitude of S_0 at initial time, and an S-curve in dry weather was obtained. The values of constants were obtained by a trial and error method and first exponent m was almost uniquely determined from the load discharge characteristics in storm weather and then there was almost no room for changing K . This was probably due to so many constraints such as average load and amplitude in dry weather.

The result of simulation is shown in Fig. 2.9. In Fig. 2.9 the range of S spreads from 4.5 tons to 5 tons. This figure unexpectedly shows near correspondence to the result of the field survey of pollutant sources.

Fig. 2.9 Simulation of Dry Weather BOD Load Discharge (Aug. 7 ~ 9, 1974)
(Yabata-gawa, Tokyo)



If values of K and m are determined, there is another way to determine the value of S_0 which will agree with the observed value at the initial stage (sometimes this method gave better agreement).

2.4.5 RESULTS OF SIMULATION

Figs. 2.10 ~ 2.14 show the results of simulation with $m = 2.0$, $K = 11.43$, $Q_c = 0.87 \text{ m}^3/\text{s}$ (for fiscal 1974) and $m = 2.0$, $K = 4.12$, $Q_c = 0.6 \text{ m}^3/\text{s}$ (for fiscal 1973) and using S at the same clock time in dry weather of Fig. 2.9 for S_0 . Fig. 2.10 shows the results of continuous sampling for 10 days from 3rd to 12th July, 1974 and gives comparatively satisfactory results. It indicates good agreement for storm weather and clearly expresses the decrease in BOD load discharge (recovery of deposition) after rainfall. Values of observed discharge are omitted from Fig. 2.10 for lack of space. Variation of S in time is also shown in Figs. 2.11 ~ 14, and rapid decrease during storm and slow recovery can be seen.

Fig. 2.10 Simulation Result of 10 Days' Observation
(Yabotagawa, Tokyo)

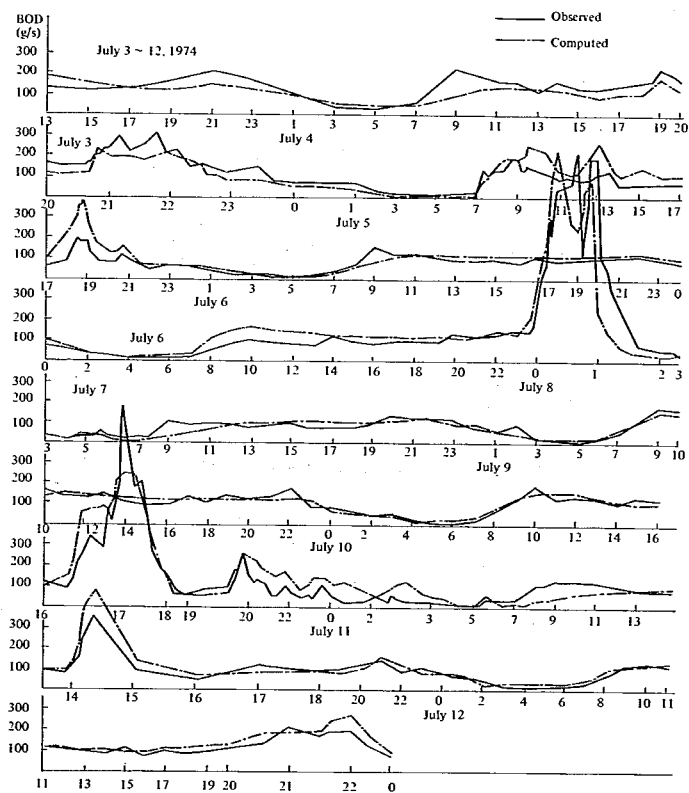


Fig. 2.11 Simulation Result (Yabatagawa, Tokyo)

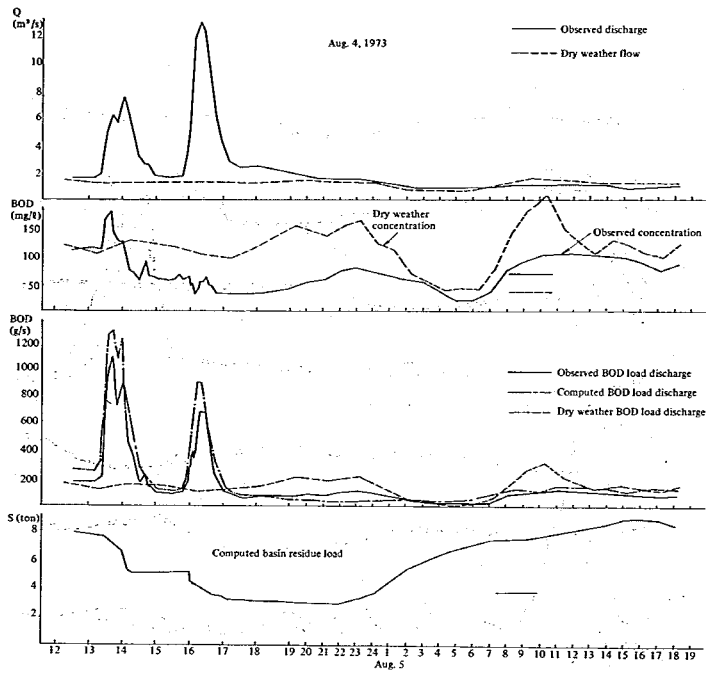


Fig. 2.12 Simulation Result (Yabata-gawa, Tokyo)

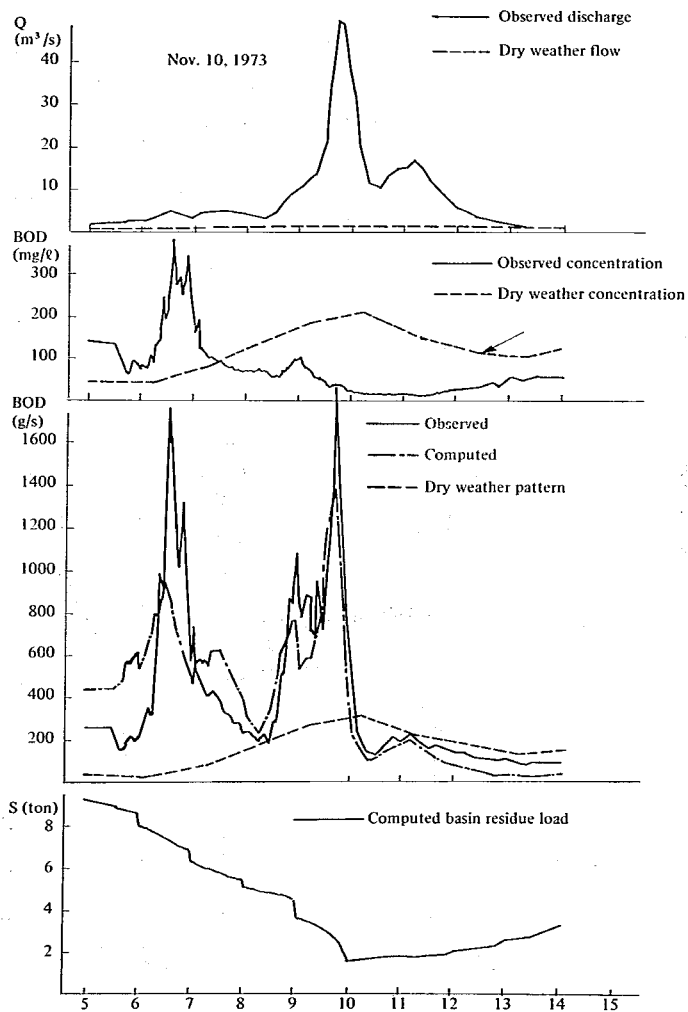


Fig. 2.13 Simulation Result (Yabatagawa, Tokyo)

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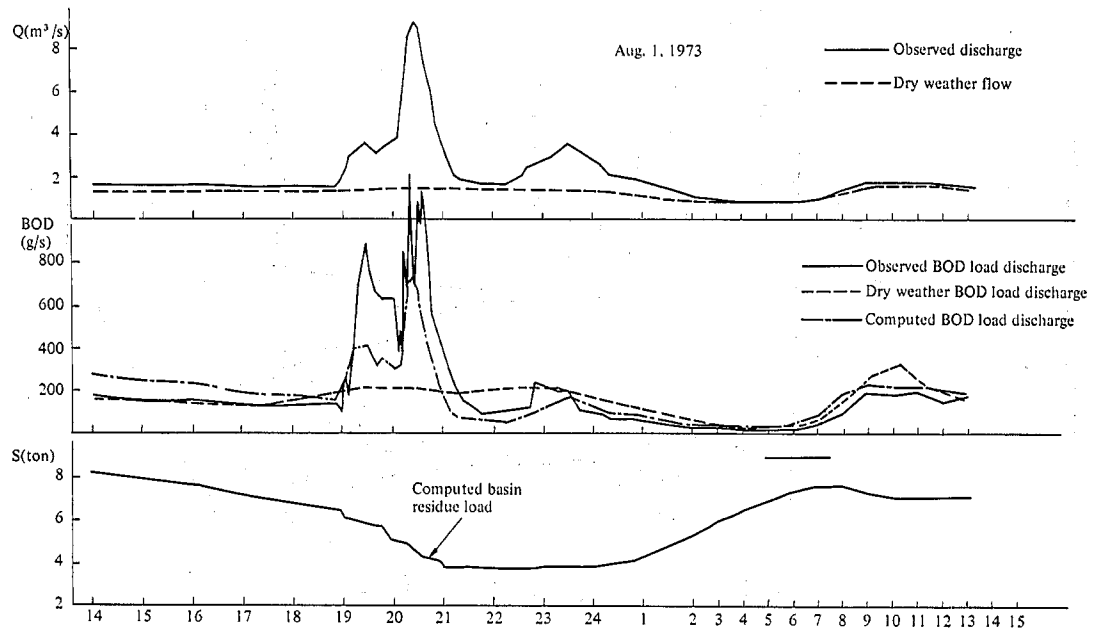
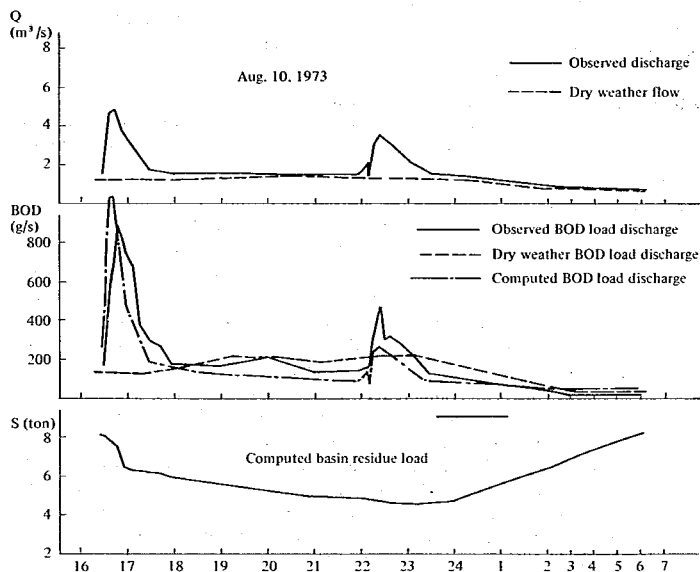


Fig. 2.14 Simulation Result (Yabata-gawa, Tokyo)



What poses a problem here is the difference in the values of constants between the simulation for fiscal 1973 and that for fiscal 1974. A little examination on this matter here will be justified. What should be first pointed out is that there is a difference between load discharge characteristics both in dry and storm weather for fiscal 1973 and fiscal 1974. First for dry weather, the average load discharge in fiscal 1973 is 149 g/s (BOD), whereas that in fiscal 1974 is 94 g/s (see Fig. 2.7), and the reason for this is unknown. The petroleum crisis may be a partial cause, but is considered insufficient to cause such a change. In addition, dry weather flow has hardly changed. The method of chemical analysis does not offer any cause. Next for storm weather, total load for one rainfall event for fiscal 1973, for instance, is 3 to 4 times as large as that for fiscal 1974. The cause for this is also not clearly known. One of the conceivable causes is that pebbles which has caused deposits on the sewer, were washed away by the great flood close to the design discharge on 10th November, 1973 (Fig. 2.3) and, as a result, the basin residue load potential for 1974 seemed to be reduced. This interpretation is not unfounded, because the range of S that was obtained by the simulation of the curve for dry weather in fiscal 1973

was 6.0 to 9.7 tons and the results of simulation made by using this value of S showed a good fit to observed values. It may be added here that the observed maximum value of total load for one rainfall event was 8 tons (BOD_5) on 15th July, 1967 and on 10th November, 1973, and the field survey of pollutants source had been carried out since the beginning of 1974.

2.5 PROBLEMS AND FUTURE PROSPECT

Although several problems are left unsolved, the simulation results are satisfactory than were expected. Hereunder several problems are pointed out and future prospect is reviewed for reference's sake.

2.5.1 PROBLEMS

- a. The first tough problem is that it should be remembered that the simulation is successful only for the Yabata basin. Further verification of the model must be made by applying the simulation to the other basins. Since the basin is located on a plateau, future investigation has to be made on the sewerage area with old pipelines and pumping stations. Such field investigation costs much and is very difficult work. However, if a field survey of pollutant sources and two or three times of field sampling can accomplish the work, this simulation model will be greatly beneficial.
- b. The difference in survey results between fiscal 1973 and 1974 poses another tough problem, which has to be checked in future. If deposition characteristics of pollutants in the basin (K and exponent m for S) should be assumed to change, the problem will become too difficult to be solved.
- c. In this simulation, the component of BOD , that is, the existence of $S-BOD$ (Soluble BOD), for instance, has not been given much attention. But there should be a model in which a part of such BOD does not contribute to the deposition and flows down. The supply from the ground surface also has to be included. It will be examined in the simulation of SS .
- d. Regarding the problem that the substance of BOD may vary from dry weather to storm weather, various checkings were effected by analysing the deoxygenation coefficient, COD and TOC both for the dry and storm weather, but there were hardly any differences between them.

2.5.2 FUTURE PROSPECT

- a. In this method, simulation can be carried out if the characteristics of the total basin load including S_0 and data of storm water discharge are available. The data of the discharge can be obtained from the rainfall data by using, for instance, the modified RRL method, which has been verified at the Yabata Basin and others. In such a case, simulation can be carried out with S_0 , rainfall data and the formula of Q_s .
- b. In this sense, simulation of the prevention measures of combined sewer overflow can be carried out, by using the rainfall data for about 10 years in the past, if the formula of Q_s and data concerning S_0 are given. At present, trial calculations are being made in respect to an increase in the dilution ratio and the retarding basin, etc.

- c. Even if simulation for 10 years and consequently simulation for countermeasures are carried out, it is a problem to determine what extent the countermeasures should cut off the pollutants over-flow to. At present, there are neither the standards nor the criteria to determine this matter. In future, its effect upon receiving waters should be investigated.

ACKNOWLEDGEMENT

In 1967, the Sewerage section of P.W.R.I. started investigation at the Yabata Basin. In 1969, the work was succeeded by the Urban River Section. Since then, with the cooperation of many persons, a large number of results were obtained in studies concerning urban runoff and pollutants discharge. Particularly, the author is grateful to the personnels of the Planning Department of Sewerage works Bureau, Tokyo Metropolitan Government for their generous financial assistance given to him in carrying out the studies. Out of these officials, the deepest gratitude of the author goes to Mr. Nagaharu Okuno, who is now with the Sewerage Works Agency, for his kind assistance and valuable advice. This paper is dedicated to him. Beside the above, the author would like to take this opportunity of expressing his deep appreciation to all the stuff of the section who gave their assistance and advice to him in carrying out the studies.

APPENDIX

After this paper was completed, the same simulation procedure described above was applied to the other two catchment area. (A and B cities) Fig. 2.15 ~ 2.24 show results of the study.

Fig. 2.15 Simulation Result (Dry Weather)
A City, Oct. 23, 1975

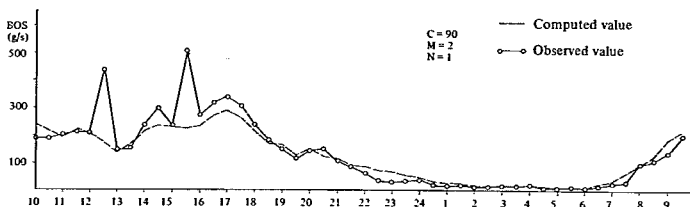


Fig. 2.16 Simulation Result
A City, Aug. 6, 1975

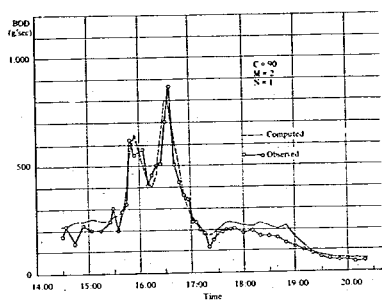


Fig. 2.17 Simulation Result
A City, July 7, 1975

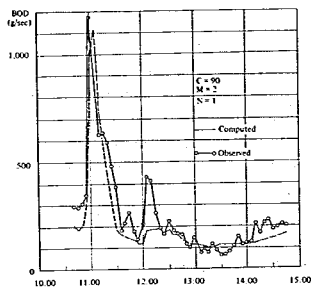


Fig. 2.18 Simulation Result
A City, Feb. 5, 1976

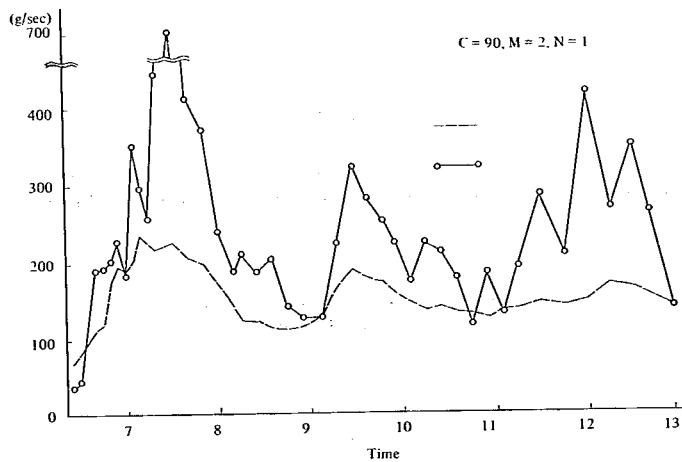


Fig. 2.19 Simulation Result.
B City, July 19, 1976

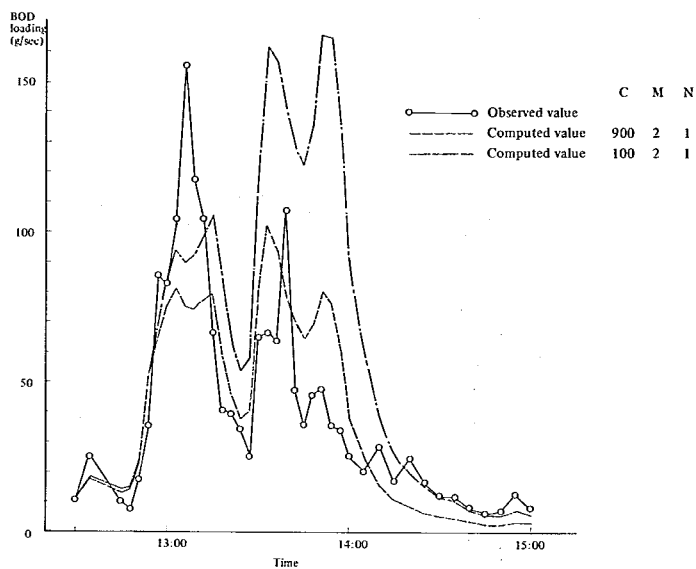
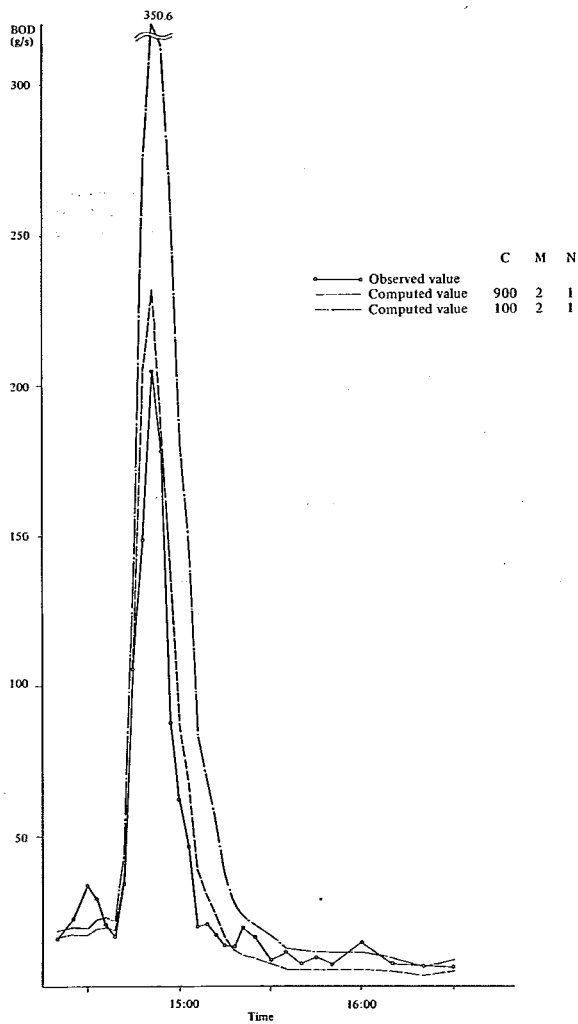


Fig. 2.20 Simulation Result
B City, Aug. 2, 1976



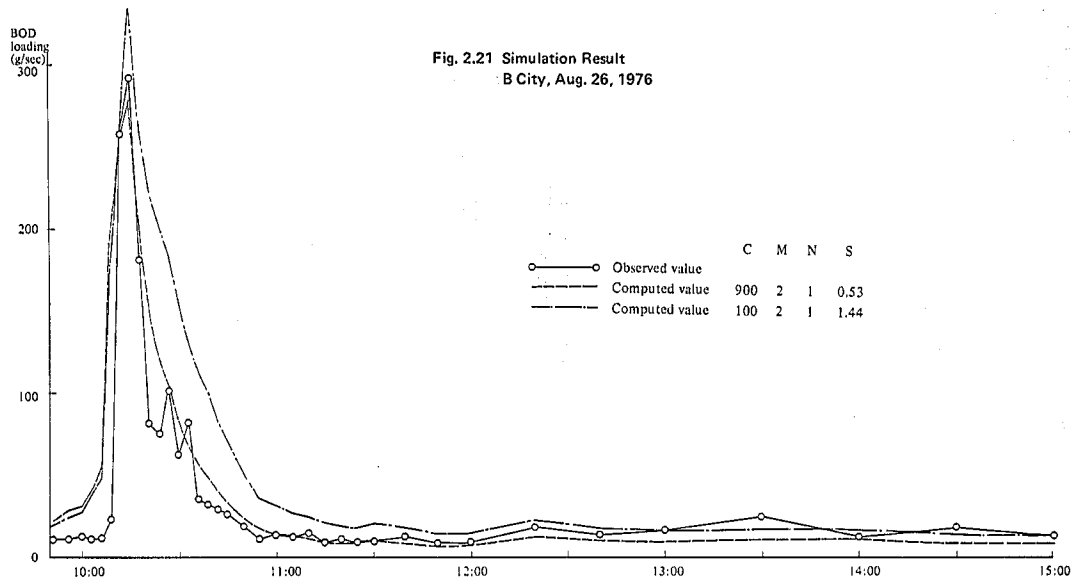


Fig. 2.22 Simulation Result
B City, Sept. 18, 1975

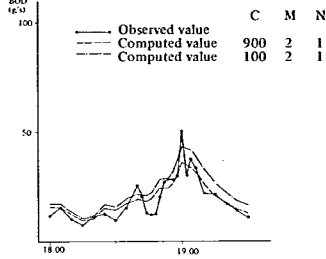


Fig. 2.23 Simulation Result
B City, Sept. 8, 1975

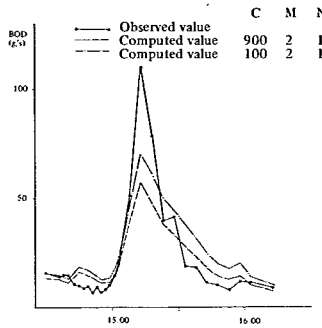
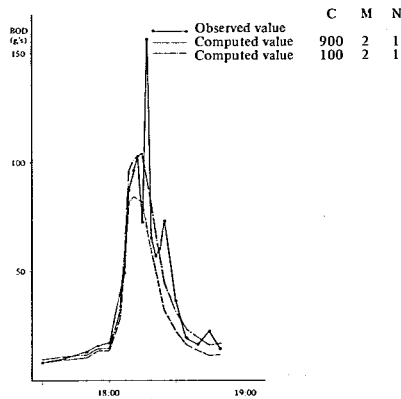


Fig. 2.24 Simulation Result
B City, Oct. 7, 1975



IV. Automation and Instrumentation

DEVELOPMENT AND EVALUATION OF AUTOMATIC WATER QUALITY MONITORING EQUIPMENT

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DEVELOPMENT AND EVALUATION OF AUTOMATIC WATER QUALITY MONITORING EQUIPMENT

Ken Murakami

1. FOREWORD

In the field of sewage works, there is a pressing need for the development of reliable automatic water quality measuring devices for monitoring sewage quality including industrial wastewater discharged into the public sewage system and for automatic control of treatment processes.

The Ministry of Construction gives high priority to the development of measuring devices for detecting toxic substances that may be contained in industrial wastewater discharged into the public sewage system. The development of such measuring devices are now being carried out by a contract research with the Association of Electrical Engineering.

The Electrical Engineering Association organized a committee composed of representatives from nine manufacturers and users for this purpose, and has been conducting field tests on the previously developed devices to seek for any possible technical improvement and developing new instruments with the cooperation of the manufacturers.

The development of measuring instruments for automatic control of treatment processes has also progressed considerably these days. Although their application to automatic control is not so popular yet, these instruments are being installed in many sewage treatment plants for manual control or monitoring.

This report summarizes the activities in the field of research and development of water quality measuring devices in Japan.

2. AUTOMATIC MEASURING DEVICES TO MONITOR QUALITY OF RAW SEWAGE

2.1 TOTAL CYANIDE MONITOR

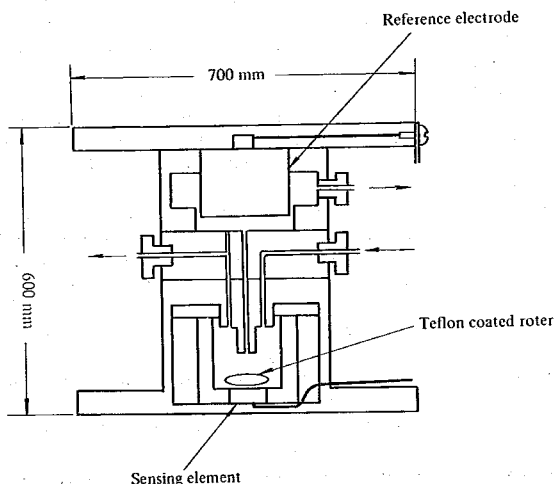
On a contract research basis entrusted to the Association of Electrical Engineering, work has begun to develop a total cyanide monitor from FY 1975. At that time, five models of automatic cyanide monitors from different manufacturers were on the market. Those units, however, were all designed for monitoring cyanides in industrial wastewater which is usually easy to deal with, and the applicability of these products to sewage was unclear. Therefore, field tests of these units were conducted at a sewage treatment plant for about three months. It was revealed that the two models were completely incapable of continuous operation and the other models, although giving comparatively good results, all had defects. Therefore, efforts were made to develop the New Standard Models by improving previous models. Three prototype models were assembled.

Models I and II are batch-type measuring instruments. Model I incorporates the method of removing sulfides during distillation while Model II employs the method

of removing sulfides after distillation. Type III, on the other hand, is of a continuous measuring type.

All of these prototype models utilize cyanide electrodes as the detector unit. Models I and II have two kinds of electrodes: conventional type electrode with an abrasive unit, and an electrode with the measuring cell itself being a sensing element as shown in Fig. 1.

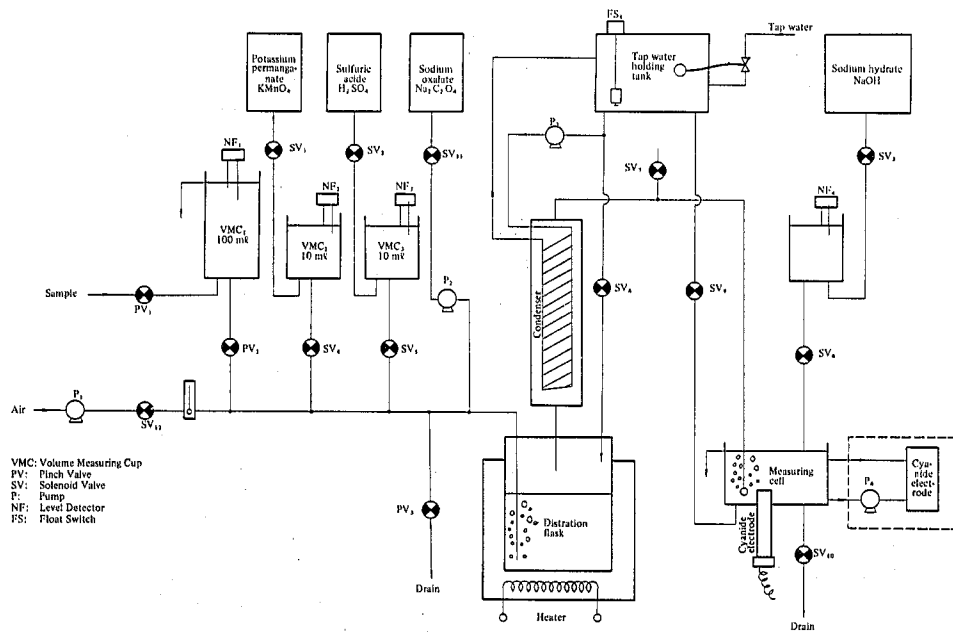
Fig. 1 New Type Cyanide Electrode



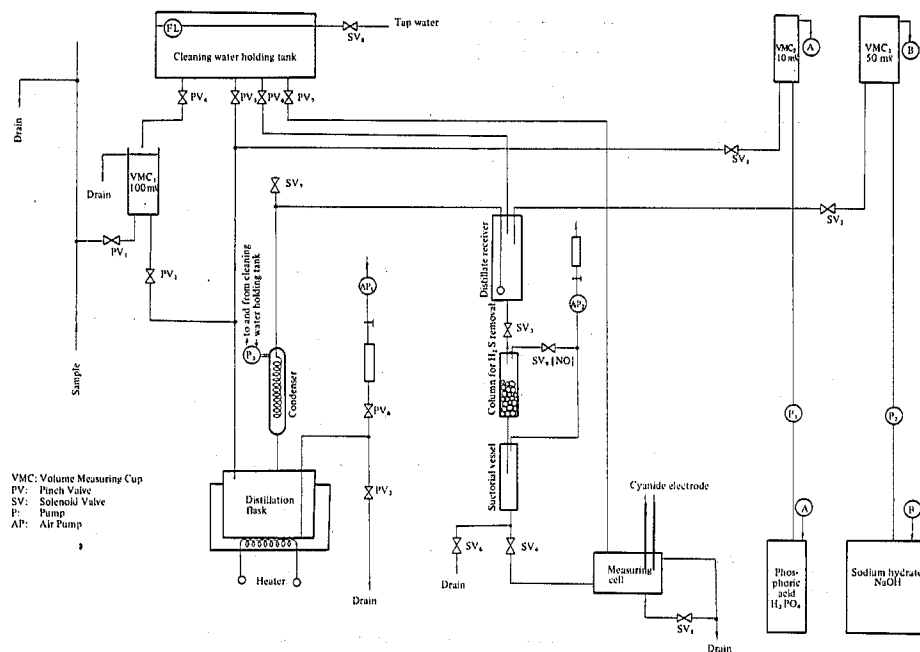
The surface of the sensing element of the latter type electrode is constantly cleaned by a rotor. This electrode, when compared with conventional ones, has a lower detecting limit giving a logarithmically linear output down to 0.01 mg/l.

Fig. 2 shows the flow diagram of Model I monitor. After measuring 100 ml of sulfuric acid (1 + 9) and 10 ml of N/10 potassium permanganate solution is added to oxidize sulfides and other interferences. Next, before raising the temperature too high, 10 ml of N/10 sodium oxalate is added to remove excessive potassium permanganate without decomposing cyanides. The distilled cyanide is absorbed in a 0.4% sodium hydrate solution and measured by cyanide electrodes. Measurements are done at 30 minute intervals.

Fig. 2 Flow Diagram of Total Cyanide Monitor, Model I



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VMC: Volume Measuring Cup
PV: Pinch Valve
SV: Solenoid Valve
P: Pump
AP: Air Pump

Model II is also of a batch type. As shown in the flow diagram in Fig. 3, the system consists of distillation under acidic condition with phosphoric acid and removal of hydrogen sulfide after distillation.

100 ml of sample water, added with 10 ml of phosphoric acid, is distilled and distilled cyanide is absorbed in 2% sodium hydroxide solution in the receiving flask. The hydrogen sulfide, distilled together with hydrogen cyanide, is removed by the column either filled with the bismuth treated chilate resin or granular lead peroxide. The bismuth treated chilate resin is a chilate resin reacted with 0.4 ~ 0.5 mM bismuth per 1 (one) ml resin. Theoretically it has a capacity to remove equivalent hydrogen sulfide.

The use of such resin prevents the heavy metal for sulfides removal from being discharged into the effluent.

Lead peroxide oxidizes hydrogen sulfide into sulfate ion without producing any complex ion of cyanide. The time interval of measurements by this model is one hour.

Model III is of a continuous measuring type as shown in the flow diagram in Fig. 4.

200 ml/hr of sample water is continuously supplied into the distillation flask and distilled almost instantaneously by heated phosphoric acid in the flask. 2% sodium hydrate solution at a flow rate of 10 ml/hr is added to the distillate, and the cyanide is measured by an electrode. Since non-distillated substances such as minerals accumulate in the distillation flask, phosphoric acid is replaced once every day to wash the flask.

Sulfides, as is in Model II, are removed after distillation by permeating the distillate through the desulfurizing column.

These three type units, completed in December 1976, are currently undergoing field tests at an actual sewage treatment plant. The influent to the plant is mainly composed of metal-finishing wastewater and contains very small amount of domestic sewage. The water sample presently used for the field test is the chemical clarified effluent from the plant.

Major troubles found during the field test were:

- (a) Distillation efficiency during night time deteriorated due to insufficient distillation heater capacity of Models I and II.
- (b) Cyanide recovery rate was inconsistent owing to dew drops developing in the tube linking the condenser with the distillate receiver. and
- (c) Some substance in the tap water which was used for wash water interfered the measurement. This substance is considered to be either free chlorine or the substance which forms a complex cyanide compound.

Modifications of the instruments were made, and field tests are presently conducted of the modified units.

After completing the test using clarified effluent, field tests will be continued using raw sewage as the sample.

2.2 SURFACE OIL DETECTOR

Contract research with the Association of Electrical Engineering also covers evaluation and development of surface oil detectors. Various types of oil detectors are already on the market. Two types of surface oil detectors were selected to carry out field tests for examining their applicability. One model is based on the fluorescence emitted from oils being irradiated by UV rays. The other model is based on the difference in reflectivities between oils and water. Both models have essentially the same structures. A pair of tubular floats support a light source and a light receiver, keeping a prefixed distance between the detector unit and the water surface.

In former type oil detector, an ultra-violet ray of 253.7 nm in wave length is projected and the fluorescence light is detected by a photo multiplier. It can detect crude oil, heavy oil and lubricants. However, it is not good for oils that do not produce fluorescence, such as gasoline, kerosene, vegetable oil and animal fat. As far as the detectable oils are concerned, the detector can measure the oil film thickness to a certain degree when the type of the oil is given. This detector has an automatic calibration mechanism that can correct the effects of the deterioration of light source and temperature changes.

The field test lasted for about a month and a half without producing any mechanical malfunctions thus satisfactory measurement results were obtained. Possible interferences may be detergent fluorescent and phenol contained in the sewage. However, the baseline drift during the field test was extremely small, and the interferences can be considered negligible.

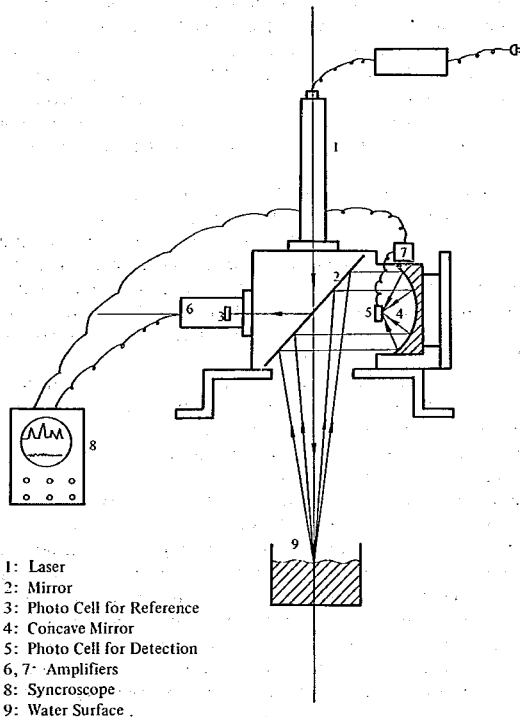
The principle of measurement of the other model is the difference in the reflectivities between water and oil. The water reflectivity is normally 2%, and that of oil is between 3.5 and 6% depending upon the type of oil. Hence, the existence of surface oil can be detected by merely measuring the reflectivity. The pulsed infrared beam is used to minimize the effect of the ambient light. Dissolved and suspended elements in the water do not interfere with the measurements.

During a month and a half long field test, no maintenance was necessary except when scum covered the whole water surface, and the performance was satisfactory.

Both oil detectors mentioned above has comparatively large floats and require a wide space to install. Therefore, it was planned to develop an oil detector which needs smaller space. The new model being developed is also based on the difference in reflectivities between water and oil but uses a laser as the light source. Since the intensity of laser beam is practically independent on the light path, the reflectivity measurement is scarcely affected by water level changes, which eliminates the necessity of the floats. The block diagram of the barrack model is shown in Fig. 5.

The light source is 1 mW He-Ne laser with wave length of 633 nm. The light beam from the laser is projected on the water surface via the mirror through a transparent part at the center. A part of the light reflected on the reverse side of the mirror goes into the photo cell on the left side as a reference. The reflected light from the water surface travels to the concave mirror via the central mirror and gathers at the photo cell for detection.

Fig. 5 Block Diagram of Surface Oil Detector Using Laser Beam



The barrack model employs a synchroscope to read the output from the photo cells. The intensity of the laser beam is comparatively strong, so that the effect of the ambient light seems to be small. But it may be necessary to use a pulsed beam by means of a chopper to put the model into practical use.

Further studies are being done on the output system and so on. Laboratory and field tests are currently under way. This model, upon completion for practical use, will enable measurement even in narrow manholes.

2.3 FUTURE DEVELOPMENT PROJECTS

The contract research entrusted to the Association of Electrical Engineering will include studies of (a) developing total-chromium and copper monitors based on automated colorimetric analysis, (b) developing a cadmium monitor based on ion selective electrode method and (c) conducting field test to examine the feasibilities of these devices for future practical use.

With regards to total chromium and copper monitors, automated colorimetric analysis would be a practical method since reagents appropriate for automation are available. Products based on this method are already on the market. Presently, researches are conducted on the pretreatment methods to maximize the dissolved fractions of chromium and copper in sewage.

Automated colorimetric analysis of cadmium does not seem to be practicable, as suitable reagents are not available yet. Ion selective electrode for cadmium, although promising, is interfered greatly by organic substances. Therefore, methods to effectively remove organic interferences are now being studied.

Furthermore, basic studies will be initiated to apply flameless atomic absorption spectrometry and anode stripping voltimetry methods to water quality monitors.

3. AUTOMATIC WATER QUALITY MEASUREMENT DEVICES TO CONTROL WASTEWATER TREATMENT PROCESS

3.1 TOC ANALYZER

Nishiyama Sewage Treatment Plant is utilized as a demonstration plant to evaluate the effect of chemical coagulant addition to the aeration tank. A continuous TOC analyzer was installed at the plant on March 1976 and has been operated successfully. This TOC analyzer is an improved version based on the experiences at the Morigasaki Sewage Treatment Plant and the Arakawa River Left Bank Sewage Treatment Plant, as presented at the 4th Conference.

The major purpose of this TOC analyzer installation is to study the conversion of dissolved organics into activated sludge in the biological treatment process. However, the sampling system is designed to feed the analyzer the following four kinds of samples at 90 min. intervals in turns by an automatic sample exchanger: primary effluent, secondary effluents from both control and chemical addition systems, and filtered secondary effluent.

Suspended solids in primary effluent is removed by a compact continuous centrifuge having a bowl capacity of 3 liters. This centrifuge requires manual intermittent operation to discharge centrifuged solids every two weeks. By conducting centrifugal operation under the feed rate of 2.5 l/min. at 4,000 rpm, 30 ~ 80 mg/l suspended solids in the primary effluent can be lowered to 5 ~ 10 mg/l.

Several minor troubles developed since commencing continuous operation of the analyzer. But none was so serious to stop the measurement, and data were obtained almost 100% of the period.

Troubles experienced so far are as follows:

- (1) The tubing at the inlet and outlet of the infrared analyzer deteriorated in quality faster than expected. The replacement of the tubing can be done only by the manufacturer.
- (2) The cleaning of the scrubber for IC removal is extremely difficult because of its ill-designed setup.
- (3) The sample feed pump clogged often.
- (4) The pipe at the outlet of the furnace corroded considerably, and should be replaced within one year.
- (5) The corrosion of the inside of the furnace was observed.
- (6) The humidity of the air used as the carrier gas was very high, resulting in frequent replacement of the dehumidifying silica gel.
- (7) The performance of dust filter in front of the infrared analyzer was poor. Thus it was replaced by a glass wool filter which caused a new trouble of condensation of moisture.

Samples were taken from the scrubber of the continuous TOC analyzer, and TOC was measured by a laboratory-type TOC analyzer. Fig. 6 shows the comparison of TOC thus obtained with that by the continuous analyzer. Fairly good correlation is observed.

Fig. 7 shows the comparison of TOC obtained by manual sampling and analysis of primary and secondary effluents with that obtained by the continuous TOC at the same time. The black circles and triangles in the Figure indicate total TOC manually analyzed, and the white ones represent dissolved TOC manually analyzed.

According to Fig. 7, the continuous TOC analyzer gives data close to the measurement of the dissolved TOC. As to the primary effluent, suspended solids removal is done by a centrifuge as mentioned before. However, with regards to other samples, no provision is made for SS removal except a coarse filter for removal of larger materials. Therefore, a considerable portion of SS seems to be removed in the sampling and IC removal system.

Fig. 7 also indicates that the correlation between dissolved TOC by manual analyses and TOC obtained from the continuous TOC analyzer is worse than that shown in Fig. 6, implicating not only loss of SS in the sampling system but also a possible change of water quality in other form may exist.

The TOC analyzer of this type is considered most appropriate for water sample containing high SS among the continuous TOC analyzers currently on the market. However, at this stage it can be concluded that the continuous measurement of total TOC is not practicable.

Fig. 6 Comparison of TOC, Manual and Automatic Analyses
 — Samples taken at the outlet of the scrubber in the TOC monitor —

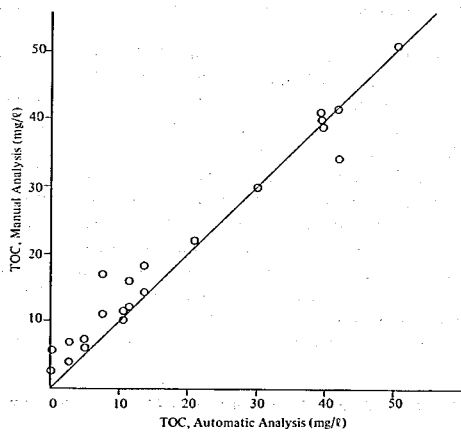
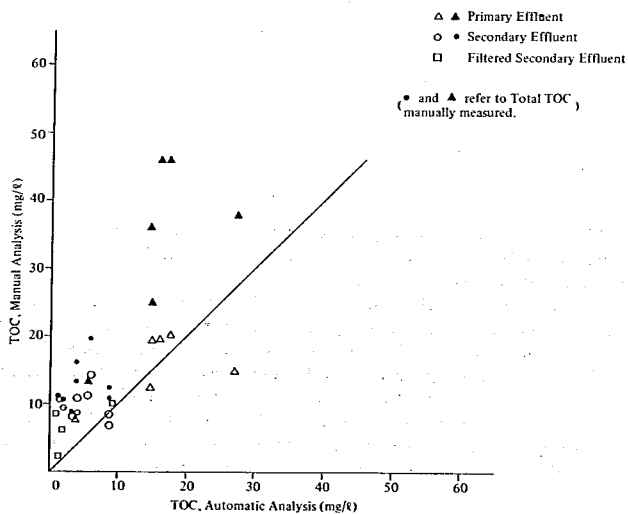


Fig. 7 Comparison of TOC, Manual and Automatic Analyses



3.2 CONTINUOUS UV PHOTOMETER

Most of the organic substances bear the nature of UV absorbance. Being based on this principle, continuous UV photometer is sold on the market as a organic content monitor.

The correlation between UV absorbance and TOC of various kinds of sewage was investigated extensively by laboratory analyses. It was found that comparatively good correlation was seen when water sample was of the same type. Therefore, continuous UV photometers were installed at the Nishiyama Demonstration Plant and Toba Pilot Plant for the field evaluation.

This continuous UV photometer measures the extinction of 254 nm UV beam. The turbidity influence is corrected by taking the ratio of transmitted light intensities of ultraviolet and visible rays. Soon after continuous operation was started, it was discovered that the ambient temperature variation affected the measurement significantly. The temperature characteristic of the detector unit is described in Fig. 8. Accordingly, the photometer was remodelled to put the detector unit in a constant temperature box of 40°C. An activated carbon column was installed at the exhaust pipe of the constant temperature box to remove ozone generated in the box.

Fig. 8 Effect of Ambient Temperature on UV Absorbance Measurement

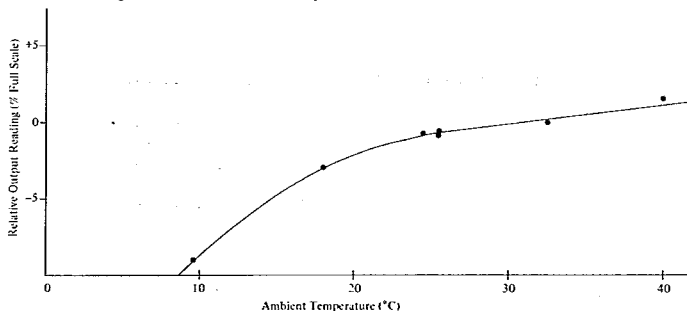


Fig. 9 shows the relationship between UV absorbance and TOC (value obtained by continuous TOC analyzer) at the Nishiyama Demonstration Plant, which seems relevant with the exponential function.

Fig. 10 shows the relationship between UV absorbance and turbidity with regards to primary effluent. Judging from this figure, there is no correlation between them, therefore, the influence of turbidity seems to be compensated.

Fig. 11 is the data obtained at the Toba Pilot Plant. Each datum represents an average of 12 values obtained from analyses of 24 hours composite samples. According to Fig. 11, the data tendencies of activated carbon effluent and other effluents differ slightly. This may be because the residual organic compounds in the activated carbon effluent are composed mainly of those with no UV absorbance, such as polysaccharides.

Fig. 9 Relationship between UV Absorbance and TOC (Automatic Analyzer)

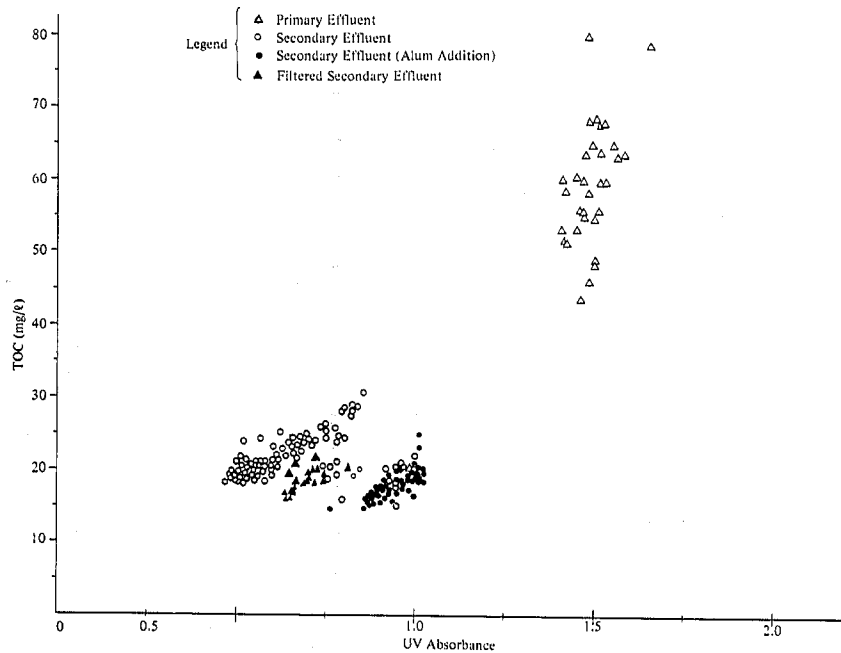


Fig. 10 Effect of Turbidity on UV Absorbance — Samples are primary effluent. —

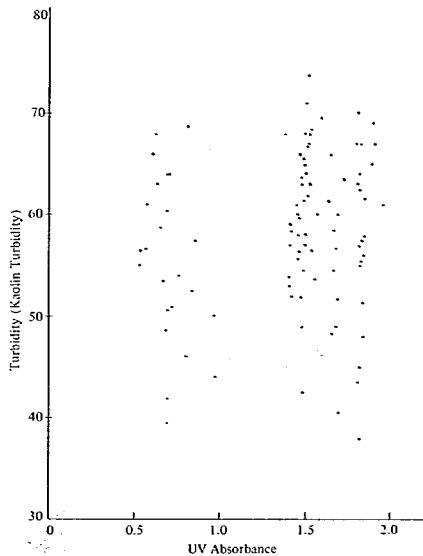
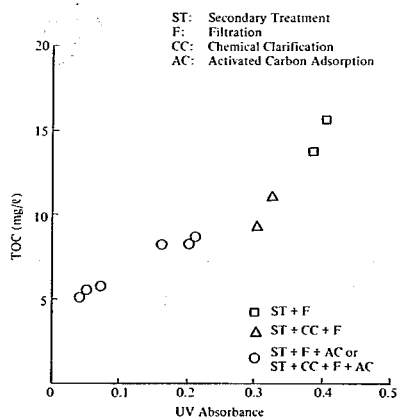


Fig. 11 Relationship between UV Absorbance and TOC, Toba Pilot Plant



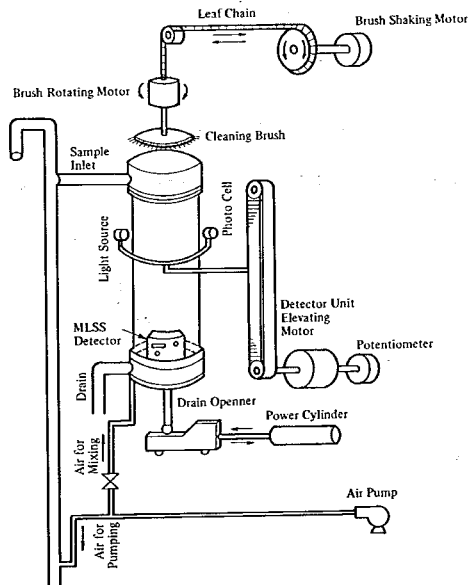
3.3 AUTOMATIC SV AND SVI METER

SV and SVI are useful indexes for operation and maintenance of the activated sludge process. A couple of SV and SVI meters are already on the market. Fig. 12 shows an example of a block diagram. The mechanisms of each SV and SVI meter is virtually the same.

After air lifting the water sample from the aeration tank into the settling tube of 170 mm in inside diameter, MLSS is first measured by the SS meter of the scattering light method with air being injected from the bottom for mixing. The meter reading is registered in the memorizing unit.

Next the stirring is stopped, to conduct SV measurement. Light source and photo cell installed outside the settling tube are descended by a motor until the transmitted light intensity becomes lower than the fixed level, thus the light source and the photo cell follow constantly the position of the sludge level. The SV value is detected by the potentiometer, connected to the motor, 30 min. after the start of settling. Based on these MLSS and SV measurements, SVI is computed electrically. At each measuring time, the inside of the settling tube is cleaned automatically by a brush to prevent interference by stain.

Fig. 12 Block Diagram of SV and SVI Meter



The SV and SVI meters are actually in use at many sewage treatment plants and are generally working well. Figs. 13 and 14 shows the comparisons of SV and MLSS obtained by an automatic meter and manual analyses at a sewage treatment plant in Aichi Prefecture. The figures indicate that both values agree fairly well.

It was observed, however, that color of the sewage sometimes effected the MLSS or the SVI measurements. Therefore, modification of the meter by mounting another SS meter on the top-side of the settling tube is being investigated in order to correct the effect of color variation.

Fig. 13 Comparison of SV, Manual and Automatic Measurement

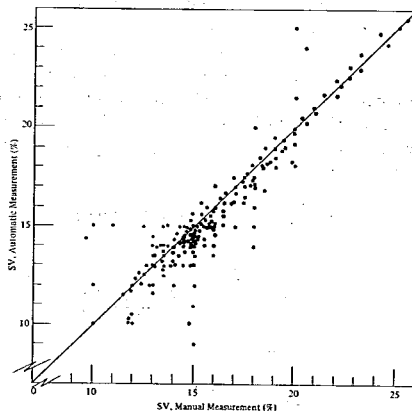
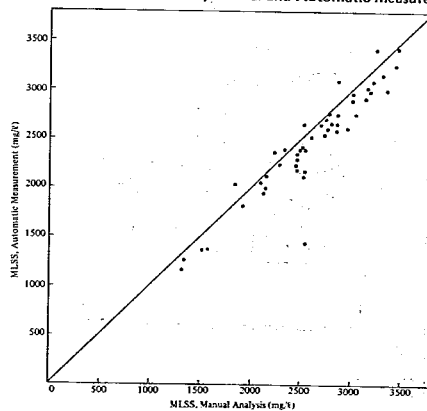


Fig. 14 Comparison of MLSS, Manual and Automatic Measurements



3.4 AUTOMATED COLORIMETRIC ANALYZER FOR PHOSPHORUS

At the Nishiyama Demonstration Plant, continuous measurement of dissolved hydriphosphoric phosphorus in primary and secondary effluents is carried out for the purposes of mole ratio control of chemical addition and others. The measuring device basically is the same as the automated colorimetric analyzer for ammonia, which was reported at the 4th conference, except that it uses a filter paper for filtration and a hydrogen peroxide solution for cleaning.

The measuring device, installed in December, 1976, has been operated for several months. This device has an automatic calibration mechanism, and it assures certain level of accuracy. Data obtained by the automatic analyser agreed well with those attained by manual analyses. However, the device developed a number of mechanical troubles as listed below, leaving room for further improvement.

- (1) For some reasons, when the flow ratio of sample and reagents or that of sample and air for separation is destroyed, unusual color development occurred.
- (2) The filtration of sample water is conducted continuously by using a filter paper. The filter paper, after use, tore occasionally. Leakage of water at the filter sometimes caused entrance of suspended solids into the filtrate. The back flushing of sulfuric acid caused by back pressure opened holes in the filter paper. Various attempts are being made to correct these defects, but substantial changes are deemed necessary.
- (3) In order to prevent formation of slime in the tubing, hydrogen peroxide solution was used for cleaning. But it was discovered that scales, which could not be removed by hydrogen peroxide solution, were formed inside the mixing coil. As these scales can be removed by sodium hydroxide solution, hydrogen peroxide and sodium hydrate solutions are used in turn to clean the tubing. However, alkaline solution causes unusual color development, so that it takes a long time to restart the normal operation.
- (4) When replacing the pump tube, sample water, containing sulfuric acid, back flowed due to internal pressure and wetted often the operators and the instrument.

3.5 OTHER MEASURING INSTRUMENTS

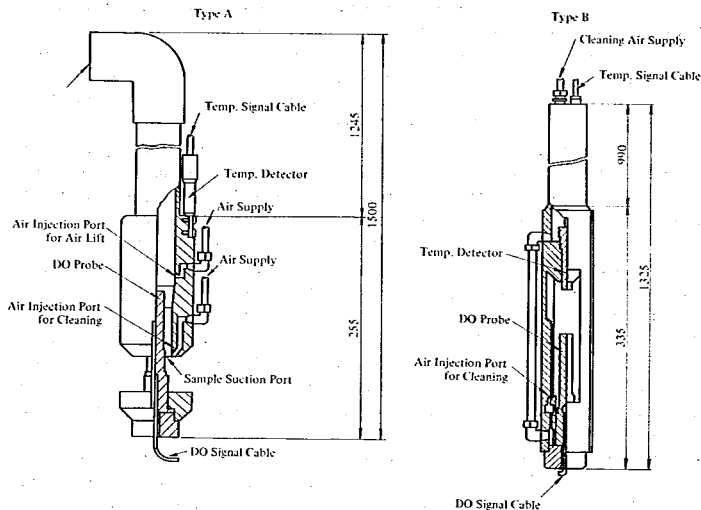
3.5.1 AUTOMATIC CLEANING UNIT FOR DISSOLVED OXYGEN ELECTRODE

When measuring dissolved oxygen in the aeration tank, it is important to prevent the formation of slime on the electrode surface. Recently, an automatic cleaning system employing air jet was introduced. Fig. 15 shows this new cleaning system. Type-A unit is designed to measure dissolved oxygen when flow velocity is insufficient for DO measurement. At measuring time, the air, from the upper air injection port, pumps up water to accelerate the velocity. And at cleaning time, the air is injected from the lower air injection port and clean the electrode surface by vigorous agitation.

Type-B unit is for the occasion that the flow velocity is sufficient for the DO measurement. It has large openings at the position of the DO electrode for the water to pass through and has only an air injection port for cleaning.

The effectiveness of this unit has been proved by field tests.

Fig. 15 DO Probe with Air Injection Cleaning System



3.5.2 ULTRASONIC WAVE SLUDGE DENSITY METER

An ultrasonic wave sludge density meter is installed at the Nishiyama Demonstration Plant. The meter, for the past two years, is continuously measuring the concentrations of primary sludge, excess sludge and return sludge. The sludge concentration agreed well with those attained by manual measurements. Especially, good results have been obtained with regard to excess sludge.

However, the variation in the sludge composition seems to pose some problems. To obtain good results in the measurement of the primary sludge, it is necessary to increase the frequency of calibration.

3.5.3 SLUDGE LEVEL METER

Sludge level meter, especially ultrasonic-meters, are becoming widely used at various sewage treatment plants for automatic sludge withdrawal control systems.