(8) Direct Filtration of Raw Sewage and Decomposition of Captured Organic Materials by Thermophilic Oxic Process

--下水の直接ろ過および捕捉有機物の高温好気処理

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ABSTRACT; The objectives of this research were to investigate the feasibility of direct filtration (DF) of raw sewage, and decomposition of captured organic matters by thermophilic oxic process (TOP). Feasibility of this process was assessed by determining removal efficiencies of SS, BOD, and the change in particle size distribution when filtration rates are changed. Wood chips of which size is 10 mm was used as media both for direct filtration and thermophilic oxic process. When the filtration rate ranged from 100-220 $m \cdot d^{-1}$, removal efficiencies of SS and BOD by the filtration were 70-80% and 40-50%, respectively. Approximately 70-80% of captured BOD was decomposed by TOP with the aeration rate of 100 $l \cdot m^{-3} \cdot min^{-1}$ and BOD load of 3.0 $kg \cdot m^{-3} \cdot d^{-1}$. The media can be reused both for filtration and thermophilic oxic process without backwash.

KEYWORDS; *filtration, medium, multistage filtration, decomposition, thermophilic oxic process*

1. Introduction:

High rate direct filtration of raw sewage is one of the innovative technologies which are expected to be applied to small sewage treatment system.[1] It is important to remove SS effectively before biological treatment, because BOD of influent is mainly due to suspended solids[2]. Direct filtration using granular media provides an alternative solid-liquid separation of raw sewage instead of sedimentation[3]. This process has been investigated for many years, some actual processes were applied to primary treatment[4]. The important points of this process are , how to select the suitable media and how to deal with the captured organic matter, especially in small scale wastewater treatment plant.

Thermophilic oxic process was applied to efficiently treat wastewater containing high concentration of organic matter and SS[5,6]. The characteristics of this process are that a minute amount of sludge is formed, and all water is evaporated by the heat generated by bio-reaction. It was considered that if SS is removed by the filtration, organic SS could be decomposed by thermophilic oxic process. After the decomposition of organic matter, the medium can be reused for the next filtration.

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Wood chips are assumed to be used as media for the direct filtration and the thermophilic oxic process. The effectiveness of a filter to capture SS depends on the physical and chemical characteristics of both the media and the particulates.[4)] Also in thermophilic oxic process, porous media is necessary to adjust water content, to improve the permeability of air and to supply good habitat for thermophilic microorganisms.[5,6)]

The objectives of this paper are: (1) to find suitable media both for the direct filtration and the thermophilic oxic process; (2) to investigate the removal efficiencies of SS and BOD by direct filtration; (3) to determine the decomposition efficiency of captured organic materials by thermophilic oxic process.

2. Materials and Methods:

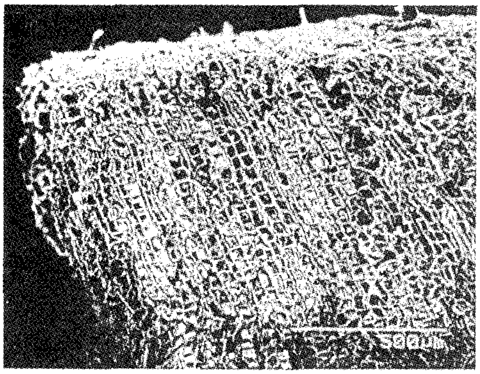
2.1 Medium

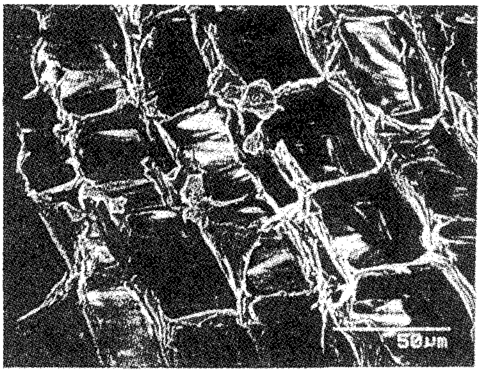
Two properties of the filter media are of major importance. These are (1) the specific surface area of the media; (2) the percent of void space. Considering these requirements, cedar chips were chosen as media in this research, because they offer the advantages of being lightweight, having large specific surface areas, and producing a filter with a great void space. Cedar chips, sized in 2.0, 5.0 and 10.0 mm were used in this research. The physical characteristics of three kinds of cedar chips were listed in table 1. The structure was observed by using a scanning electron microscope (SEM) as shown in photo 1 (a and b). Also, from SEM photographs, rough surface of cedar chips and 40-50 μm of pore space show that they can absorb high amounts of water and afford good habitats for microorganisms. Using these three kinds of media in thermophilic oxic process, thickened primary sewage sludge was successfully treated in laboratory scale.[7)]

Table 1 Physical characteristics of media

Wood chips	A	B	C
Normal size (mm)	2	5	10
Filling density (g/L)	400	410	349
Specific surface area (m^2/m^3)	1000	1025	873
Void space (%)	62.1	65.7	66.5
Pore size (μm)	40-50	40-50	40-50
Water holding capacity (g/g)	1.48	1.18	1.06

Before experiment, cedar chips were screened and washed to remove the fine wood particles. Upflow





a. Surface view b. Magnified section

Photo 1 Surface characteristics of cedar chips (section view) filtration was applied because of the density of wood chips was less than 1.0. Batch column (5 cm in diameter, 100, 60 and 40 cm in height) test was conducted to determine the suitable size of medium according to the SS removal efficiency, headloss and lasting time.

2.2 Apparatus

(1) Direct filtration

The flowchart of the experiment is shown in Fig.1. Filtering column was made of chloride polyvinyl, with internal diameter of 16 cm, height of 120 cm and its effective volume was 20 liter. Raw wastewater was introduced into filtering column through screen with the size of 5 mm by monoflex pump (Model FP-1/4BM). Because of media was lighter, two pieces of grit were set on the bottom and on the upper part of the column to avoid leaching cedar chips. Flow rate and headloss were monitored periodically. Coagulant PAC was added by metering pump (Model EP-B15 PC-100, IWAKI). This direct filtration experiment was conducted in a community wastewater treatment plant from June 1994 to May 1995.

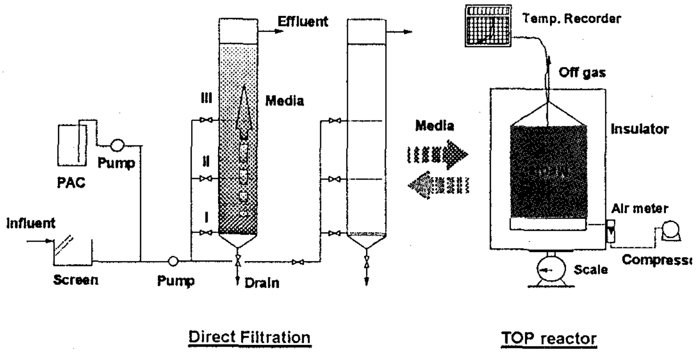


Fig.1 Flow diagram of multistage direct filtration and thermophilic oxic process for small sewage treatment plants

(2) Thermophilic oxic process

The thermophilic oxic reactor was a 20 *l* cylindrical container with a perforated plate at the bottom, surrounded by Styrofoam insulation (860mm by 800mm by 800mm). Air was supplied by a compressor (Hitachi, 0.20p-5S) through an air flow meter (ST-10A) The temperature was monitored by using thermometer which was inserted into media at the center of the reactor, and was recorded automatically (Chino, RH720-RNN).

2.3 Operation of process

Two kinds of direct filtration methods were carried out in this research in order to clarify the SS capturing capacity by direct filtration: one stage inlet method and multistage inlet method. In one stage inlet method, raw wastewater was introduced from the bottom of the column. In order to utilize the void space of media sufficiently, especially for the upper part of media, multistage inlet filtration was conducted. Wastewater was introduced first at the bottom of the column. When the headloss was reached to a designated data, the lower inlet was off and the upper one was on, alternately. When the headloss or effluent SS reached to an established data, the filtration step was stopped. In this experiment, three stage of inlet method was tested, which input position was at 0, 30 and 60 cm height of column, respectively. Addition of coagulant PAC was tested to improve the SS removal efficiency.

After filtration, the filter was drained for 1 day and the media was taken out of the filter. The moisture content of media including captured SS ranged 60-70%. Before starting the decomposition, the media was completely mixed with seed in the ratio of 10:1 to 10:2 (V:V) by hand outside the reactor, then transported into reactor. The seed was taken from the former products of thermophilic oxic process. Then started aeration and decomposed for 3-5 days, and within this period mixing was carried out by hand once a day. When the temperature of reactor decreased to room temperature and CO_2 evolution concentration in off-gas was similar to that of atmosphere, the aeration was stopped and decomposition step was finished.

The aeration rate was controlled at 50 to 100 $l \cdot m^{-3} \cdot min^{-1}$ based on the BOD loads which was caused by the quantity of captured organic materials from direct filtration. Additional energy sources such as rice bran was tested when the captured organic matter was not enough to increase the temperature and to check whether the high BOD removal efficiency can be done.

After finishing the decomposition, the media was taken out of the reactor and separated from the fine particles by the help of sieves, then filled into filtering column again to conduct next cycle.

2.4 Analysis

The following items were analyzed: BOD, dissolved BOD and SS in influent and effluent of direct filtration were determined according to standard methods (JIS K). Several kinds of testing sieves (SANPO) and membrane filters (MILLIPORE) with the pore size of 75, 20, 8.0, and 1.0 μm were used to distinguish the removal efficiency of SS with different particle size.[2)]

The moisture content of mixture was determined by the weight difference before and after drying at oven (105 °C) for 12 hours. CO_2 evolution in exhaust gas was determined by gas chromatography (Shimadzu, GC-14A) and by glass tube detector (GASTEC Company). Temperature and the change of the weight of mixture in reactor was monitored continuously. The BOD of mixture (media and captured organic SS) before and after the decomposition was determined by BOD Tester (100F TAIYO). Capturing capacity of SS and BOD by filtration, efficiency of decomposition of organic materials by thermophilic oxic process was determined by following procedures: About 10 g sample of media was washed with 100 ml of distilled water, after separation of cedar chips, washed off SS and BOD was determined in liquid according to the standard method.

Table 2 Characteristics of influent and filtrate with different media

Characteristic	Influent (mg/L)		Average filtrate (mg/L)			Average removal efficiency (%)		
	Range	Average	A	B	C	A	B	C
Suspended soild	133-402	190	32	36	40	84	81	79
Total BOD $_5$	114-378	212	97	103	106	54	51	49
Dissolved BOD $_5$	50-132	81	77	78	80	5	4	1
SS-BOD $_5$	60-306	131	28	30	33	78	76	75

A, B, C means three kinds of filter media

3. Results and discussions:

3.1 Removal efficiency by direct filtration process

The water qualities of influent and effluent are listed in Table 2. This table shows the treatment efficiencies by batch test using three kinds of medium. They possess similar void space, and no obvious difference in SS removal efficiency, but the headloss was high when small size of wood chips were used. Short circuiting easily occurred in small size of media when SS was captured on the lower part of filter. It caused the filtration time become shorter. However, using big size of wood chips could continue long time and collect more SS than small ones in one filtration. It is important to collect enough organic materials for the following thermophilic oxic process. Therefore, 10 mm size of cedar chips were used as the media both for the direct filtration and the thermophilic oxic process.

Based on the removal efficiencies of SS and BOD when the height of the filter varied from 40 to 100 cm. There had a little relation between the removal efficiency and the height of filter. Considering the convenience of decomposition by thermophilic oxic process and lasting time of filtration, 60 cm and 100 cm were determined as the height in one stage inlet direct filtration and multistage inlet direct filtration respectively.

Figure 2 shows the relationships between filtration rate and removal efficiencies of SS and BOD with the filter height of 60 cm. Approximately 70-80 % of SS and approximately 40% of BOD were removed in each filtration rate, though high filtration rate of 220 $m \cdot d^{-1}$ was used. With the same filtering height, the continuous time for the filtration decreased with the increase of the filtration rate and concentration of influent SS. For every filtration cycle, the total filtering volume are nearly same, so the total quantity of captured SS was almost same.

Figure 3 shows the relationship between SS removal efficiency and the particle size when filtration rates were changed. In each filtration rate, nearly 90% of >75μm, 80% of 75-20 μm and 60% of 20-8.0 μm particles were removed by the direct filtration. But the flow rate had no obvious effect on the removal of same particle size. From this figure, it was demonstrated that most of the SS which size was larger than 8.0 μm could be removed by the direct filtration.

In order to increase the removal efficiency of SS and BOD by direct filtration, addition of coagulant was tested. PAC was selected by considering its characteristics of floc forming performance and treatment capacity. The

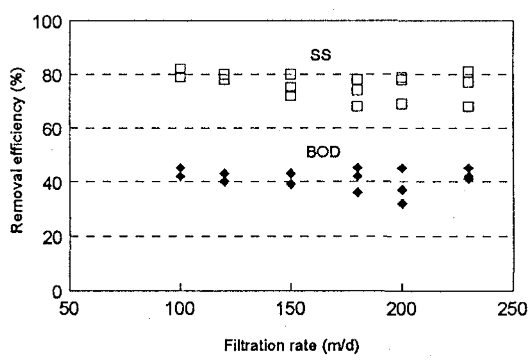


Fig.2 Removal efficienies of SS and BOD on varying filtration rate

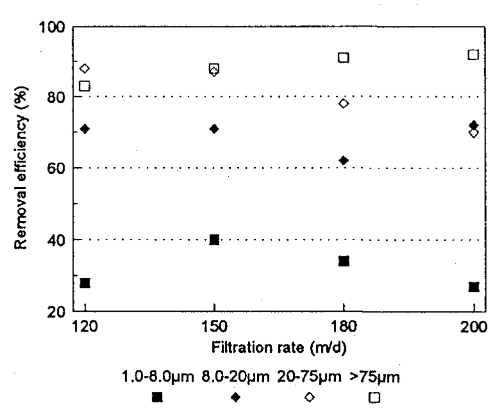


Fig.3 Effect of filtration rate and SS paticle size on removal efficiency

addition rate was designated as 3-5 ppm (as 10% of Al_2O_3) to raw wastewater by considering its mixing method and hydraulic elements of filter. However, with the addition of PAC, the removal efficiency only has a little increase, for SS around 75-85%, for BOD_5, around 45-55%. The reason why there were no obvious changes in removal efficiencies with and without the addition of coagulant may be that there are large amounts of cellulosic material such as toilet papers existed in raw sewage which was beneficial for the attachment of SS on the surface of cedar chips; also based on the result of distribution of SS particle size, there was only 4-8% of SS which particle size was smaller than 8.0 μm, which needed to be coagulated by PAC.

3.2 Effect of filtration time on headloss and SS removal efficiency

Figure 4 shows the change of removal efficiency and headloss in one stage direct filtration. And the average filtration rate was 200 $m \cdot d^{-1}$. From this figure, it is seen that with the change of influent concentration of SS, the effluent quality of was always lower than 50 mg·l. The average SS removal efficiency was around 70-80%. At the initial period, effluent SS was a little bit high due to uncompleted decomposition by thermophilic oxic process. As the filtration time had passed, headloss gradually increased by capturing amounts of suspended solids. When the headloss was higher than 120 cm, breakthrough happened after nearly 24 hours from the start of the filtration. The quantity of captured SS and BOD_5 for one stage direct filtration was ranged 10-18 $kg \cdot m^{-3}$, 4.0-7.2 $kg \cdot m^{-3}$ respectively.The reason why filtration time was short for one stage inlet method may be that the lower part of media collected a great amount of SS, causing short circuiting easily happened around boundrary when constant flow rate was maintained.

As shown in Fig.5, with the application of multistage inlet method, the SS removal efficiency ranged from 70-80%, the effluent SS was always lower than 50 mg/L. The headloss was gradually increased and the continue filtering time can be prolonged to 30-48 hours. The quantity of captured SS and BOD was bigger than one stage filtration, ranged 20-30 $kg \cdot m^{-3}$, 7.0-9.5 $kg \cdot m^{-3}$ respectively. The removal efficiency

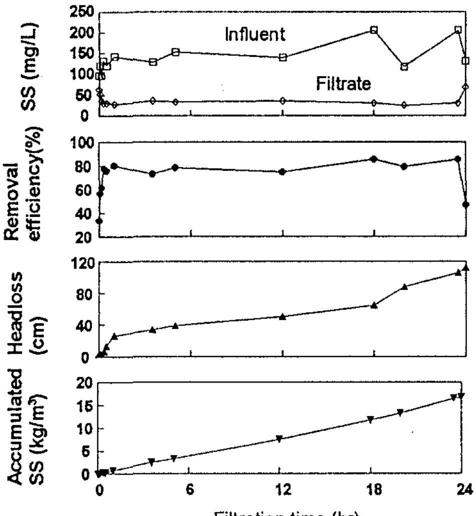


Fig.4 Removal efficiency in one stage filtration

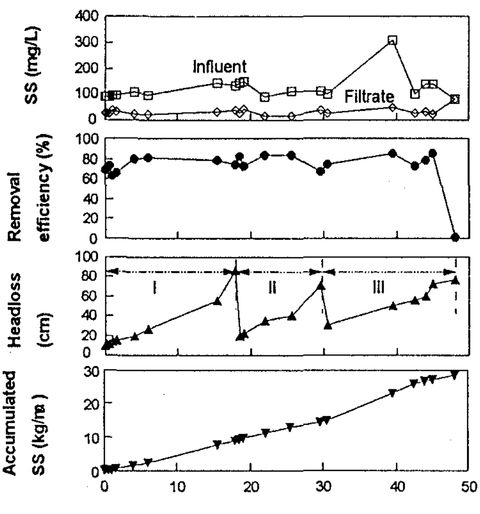


Fig.5 Removal efficiency in multistage filtration

and continuous filtering time were influenced by the average influent concentration of SS and BOD_5.

3.3 Efficiency of decomposition of organic SS by thermophilic oxic process

As explained in the above section, filtration process can effectively remove SS from raw wastewater, and at the same time wood chips absorbed water. Before starting decomposition, moisture content of media was adjusted to about 60% by the addition of seed chips which moisture content was around 50%. Figure 6 shows the change of temperature and CO_2 concentration in off gas. In this process the media was taken from one stage filtration. Temperature of reactor rose to higher than 45 °C at the aeration rate of 100 $l \cdot m^{-3} \cdot min^{-1}$. At the initial period, the CO_2 evolution rate was high due to the degradation of readily organic materials, and the temperature rose rapidly by the heat produced in decomposition, then both of them become stable. By determination of BOD_5 of the mixture before and after decomposition, it changed from 5.6 $kg \cdot m^{-3}$ to 3.0 $kg \cdot m^{-3}$, approximately 46% of organic matter was assumed to be decomposed by thermophilic oxic process.

Aerobic biological reaction generated the heat, resulting in the rise of the temperature of the media, and also increase the activity of microorganisms. When the organic material gradually decreased by the degradation, the generated heat could not increase and maintain high temperature in reactor. It was considered that one stage filtration could not supply enough organic matter or BOD load for the thermophilic oxic process.

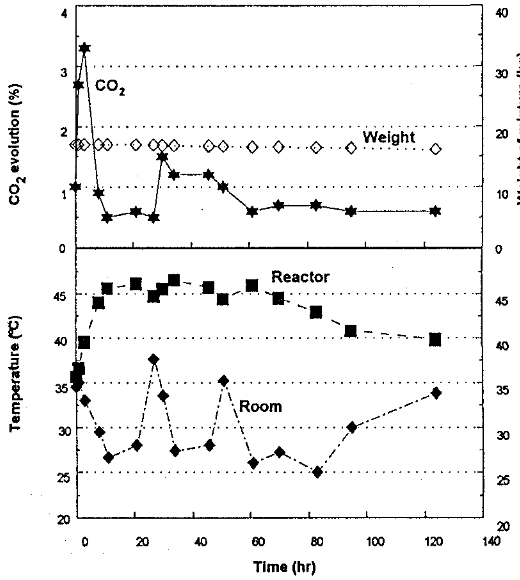


Fig.6 Change of temperature, weight and CO_2 in thermophilic oxic process after one stage filtration

Based on above analysis, there are two ways to be considered to increase organic concentration. One is to improve the capturing capacity of direct filtration such as multistage filtration as presented previously. The other is to add energy material such as waste oil or rice bran. As shown in Fig.7, after finishing multistage filtration, the organic SS was decomposed by thermophilic oxic process. Temperature rose to high than 50° C with the degradation of organic materials at the aeration of 100 $l \cdot m^{-3} \cdot min^{-1}$. Total evolution of CO_2 was bigger than that of the former one. With the determination of BOD_5 of the mixture, it changed from 8.5 $kg \cdot m^{-3}$ to 3.2 $kg \cdot m^{-3}$, nearly 62% of organic matters was decomposed by thermophilic oxic process. Compared with the former decomposition result, higher BOD removal efficiency was done. As explained previously, by the aerobic degradation of organic matter, the generated heat increased the

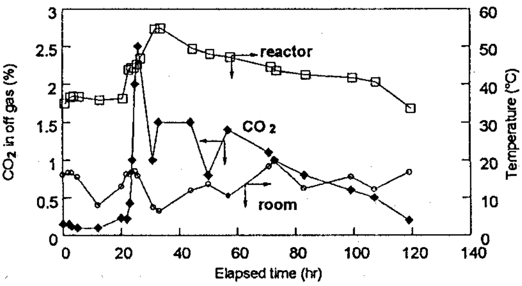


Fig.7 Decomposition of organic SS by thermophilic oxic process after multistage filtration

temperature of media and thermophilic microorganisms were actively reproduced. In this process, the quantity of organic materials captured by multistage filtration was more than that from one stage filtration. However, it was still not so high to supply enough organic matter for maintaining the activity of thermophilic microorganisms.

From above results, the captured organic materials from direct filtration could not supply enough energy for the thermophilic oxic process. Therefore, additional organic matter which contain high calories was needed as thermal energy source. Rice bran which is a readily degradable matter was added as an energy source. Addition of rice bran was conducted at the beginning of the thermophilic oxic process. Approximately 0.3 kg of rice bran, which BOD_5 is 450 $mg{\cdot}g^{-1}$ per dry weight, was completely mixed with media. The addition rate was 3 $kg{\cdot}m^{-3}{\cdot}d^{-1}$. By BOD analysis, before decomposition, BOD of mixture was 15 $kg{\cdot}m^{-3}$, in which nearly 50% of BOD was caused by added rice bran. Change of temperature and CO_2 evolution in thermophilic oxic process was shown in figure 8. The operational conditions of this test were: BOD load 3.0 $kg{\cdot}m^{-3}{\cdot}d^{-1}$, aeration rate 100 $l{\cdot}m^{-3}{\cdot}min^{-1}$ and reaction time 4-5 days. Temperature of reactor was increased to 60 °C and high temperature period was maintained more than 50 hours. it is clear that at this period, thermophilic microorganisms reproduced quickly with degradation of organic material and possessed high activity. After 5 days decomposition, BOD of mixture was changed to 2.3 $kg{\cdot}m^{-3}$, approximately 85% of organic matter was decomposed by thermophilic oxic process.

The control test was conducted by adding water and rice bran into the TOP reactor. From figure 8, CO_2 concentration in exhaust gas was higher for the reactor of captured SS and rice bran than that of control. This means that the difference of CO_2 concentration in off gas between two reactor was caused by decomposition of captured organic materials. Also from the change of temperature, the reactor with rice bran could maintain longer time than control one. It means that by the addition of thermal energy source, the temperature rose quickly and could be maintained for long time by degradation of energy source, but also stimulated the decomposition of captured organic material.

The above results shows that most of organic materials could be decomposed by thermophilic microorganisms in such suitable condition. However it was difficult to get high degradation efficiency in this work comparing with the result of Red bean and SHOCHU wastewater. It was considered that there is a threshold level or limitation for thermophilic oxic process in one cycle, at this point the degradation rate become low by the limitation of concentration of organic matter.

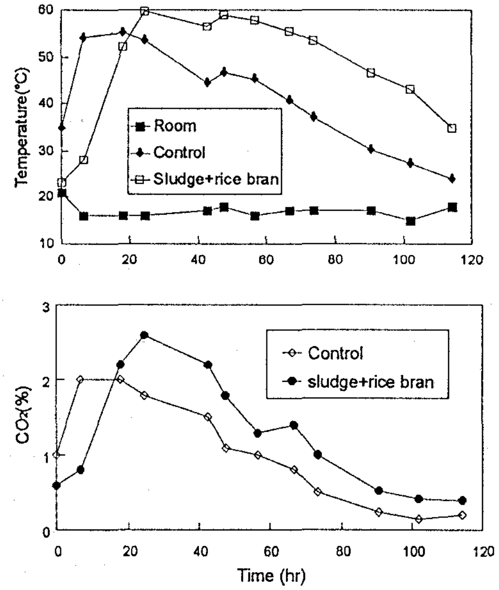


Fig.8 Thermophilic oxic process with addition of rice bran

3.4 Change of surface characteristics of media

With the help of SEM photographs, change of surface characteristics of cedar chips could be observed. As shown in photo 2, three kinds of sample were prepared in different periods: after direct filtration, within the decomposition at the temperature more than 55 ° C and after decomposition. It is clear that organic contaminants were effectively captured on media after direct filtration, suspended solids were covered on the surface of cedar chips (photo 2-a). From photo 2-b, within the decomposition period, a great amount of microorganisms which was considered as thermophilic bacteria was found in the cells or on the surface of cedar chips. They play a critical role in degradation of organic materials which captured by direct filtration. Through decomposition, few microorganisms existed and part of media surface was reappeared (photo 2-c). With the help of patterns of line scan and point analysis on media by Energy Dispersive X-ray (EDX), the phenomenon that undegradable matter and products of decomposition such as clay, $CaCO_3$, $Ca_3(PO_4)_2$ existed on the surface of medium was observed.

3.5. Filtering treatment efficiency for regenerated media

After decomposition by thermophilic oxic process, media was transferred to filter and conduct filtration again. As shown in figure 9, all the effluent SS was initially high and decreased rapidly within 30 minutes. From run 1 to run 3, one stage filtration was applied and the decomposition of mixture was conducted without additional energy source. From run 4 to run 10, multistage filtration was applied. The decomposition of mixture in run 4 to run 6 was conducted without additional energy source. Rice bran was added in thermophilic oxic process after the filtration from run 7. It means that most of captured organic SS was decomposed by thermophilic oxic process, only a little of residual organic matter and inorganic matter were leached out. The regenerated media can be reused after

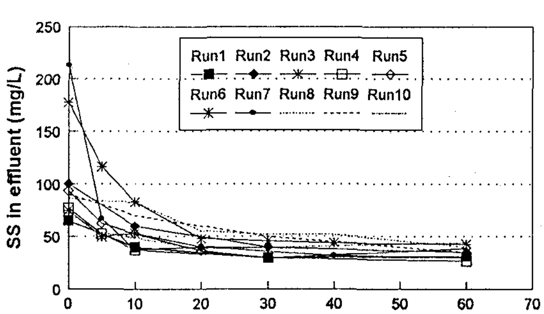
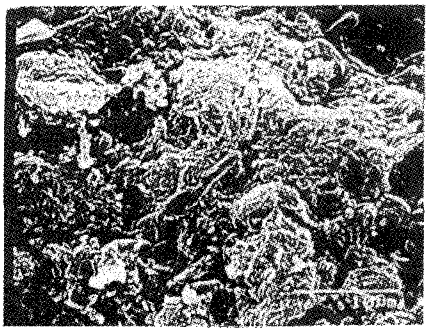
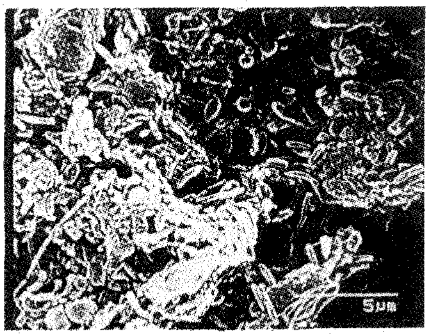


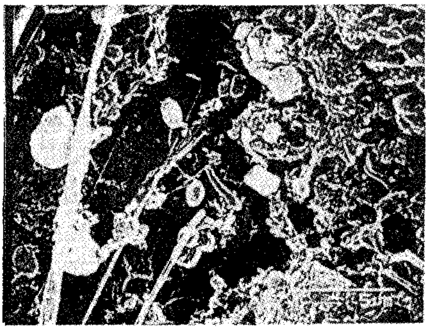
Fig.9 Changes in initial effluent SS depending on the recycle times



a. after direct filtration



b. within the decomposition



c. after decomposition

Photo2 Change of surface characteristics of media thermophilic oxic process decomposition. However, the undegradable matter and products of decomposition which were existed on the surface of medium caused the initial effluent SS increased in next filtration. It is suggested that part of media will be changed periodically by addition of new wood chips.

4. Summary

From the present research, following steps could be concluded:

(1) The wood chips of which size are approximately 10 mm can be effectively used as media for the filtration and the thermophilic oxic process. When the filtration rate ranged from 100 to 220 $m \cdot d^{-1}$, the removal efficiencies of SS and BOD were around 70-80%, 40-50% respectively.

(2) Approximately 50-70% of captured organic matter was decomposed by the thermophilic oxic process without addition of energy source, and 80-90% of total organic matter was degraded with the addition of energy source.

(3) The regenerated media can be reused more than ten times without backwash.

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