公 害 資 源 研 究 所 彙 報
第 18 巻 第 1 号, 昭 和 63 年 10 月
別 刷

Reprinted from
Bull. Nat. Res. Inst. Poll. & Res.
Vol. 18. No. 1 October 1988

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膜分離活性汚泥プロセスの運転操作条件が精密濾過膜の固液分離能に与える影響

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UDC 669.2

Effect of the Operational Conditions on Plugging of a Microfilter in an Activated Sludge Process with Cross-Flow Filtration

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Abstract

Effects of biological solid concentrations, pH conditions and organic loading on the plugging of a microfilter were examined when microfiltration was employed as the separation step in an activated sludge process. Plugging did not occur under any of the operational conditions examined when biological solids were retained in the reactor at a lower concentration. Serious plugging did occur at a lower pH conditions and higher organic loadings in an unit retaining a higher solid concentration. Based on the microscopic observation of activated sludge, it was suggested that the solid-liquid separation by microfiltration was impeded by significant amounts of non-flocculated cells.

(Received July 15, 1988)

1. Introduction

The activated sludge process incorporated with a cross-flow microfiltration as the solid-liquid separation step has been given great deal of attention, since the process has a compact wastewater treatment device which permits high volumetric loadings (1-7). The performance of the process depends on the efficiency of solid-liquid separation of the separation device as well as the biological activities of the process. We consider that two separate ways of the investigation are required to improve the efficiency of solid-liquid separation: i) improve the device itself and optimize its operational condition, and ii) investigate how to control biological characteristics of the activated sludge to achieve successful microfiltration as well as to obtain high biological activities allowing a good wastewater treatment.

Recently, some researchers have examined the operational conditions of separation device such as superficial liquid velocity (8, 9), bilogical solid concentration (4, 5, 8, 9) and operational pressure (8, 9) on the flux, and types of filters (5, 8, 9) in it to improve the performance of filtration, with aerobic (5) and

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anaerobic processes (4, 8, 9). And relatively little attention has been paid to the factors controlling biological characteristics of activated sludge which affect the efficiency of filtration.

In the present study, we examine the optimum operational conditions of this activated sludge allowing for a feasible microfiltration. We study the effects of biological solid concentrations, pH condition and organic loading on the plugging of a microfilter, by monitoring the suction pressure of the effluent and present optimum operational conditions of these factors to evade the plugging.

2. Materials and Methods

2.1 Apparatus

The activated sludge process with cross-flow microfiltration employed in this study is shown in **Fig. 1**. The microfiltration apparatus (3) was placed outside the 3 *l* reactor for solid-liquid separation; one separation apparatus was employed for a unit. unless otherwise stated. Cellulose nitrate membrane filter with 0.45 μm pore size (Toyo Roshi Co., Ltd., Tokyo, Japan) was employed for microfiltration. The mixed liquor onto the filter was agitated to obtain a sufficient superficial liquid velocity by a magnetic stirrer. The working filtration area of a separation unit was 36.5 cm². A constant flow rate was maintained using a tubing pump. Another pump was used for sludge circulation. The degree of plugging was monitored by the suction pressure of filtration measured by a pressure gauge at the outlet of the unit; a higher suction pressure indicates a higher degree of plugging. The microfilter was replaced by a new one when that one was damaged or the suction pressure was increased higher than *ca.* 600 mmHg.

2.2 Media

A diluted corn steep liquor used for influent was stored in refrigerator at 2°C, which was prepared every four or five days to prevent any further putrefaction.

2.3 Operation

Two activated sludge processes with microfiltration were operated. In unit A, a biological solid was retained at a concentration of 3,000 mg/*l* and in unit B at 15,000 mg/*l*. Sludge concentration was maintaned at a constant level by discharging solids four or five times a week equivalent to sludge production during the period. Suspended solids (SS) and volatile suspended solids (VSS) were determined as described in Gesui Shiken Ho-Hou (10), using a centrifuge at 3,000 rpm. In order to provide the same flow rate when the units were operated at the same organic sludge loading, concentrations of dissolved

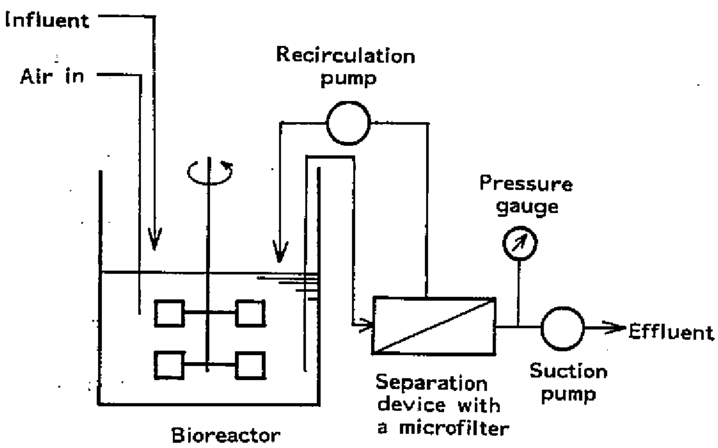

Fig. 1 Schematic diagram of an activated sludge process with membrane separation.

organic carbon of the influent which were imposed on the units were different; 3,000 mgBOD/*l* for unit A and 15,000 mgBOD/*l* for unit B. Therefore, the filtration flux is provided by the equation:

$$J_v = 0.82 \times L/N \tag{1}$$

where, J_v is the spectific flux rate (m^3/m^2/day) and L is organic sludge loading (kgBOD/kgVSS/day), and N is the number of separation apparatus employed.

Effect of organic loading was examined at pH 7.0 and 5.0 mg/*l* of the dissolved oxygen (DO) concentration. Effect of the pH condition was examined with an organic loading of 0.30 kgBOD/kgVSS/day at a DO concentration of 5.0 mg/*l*, unless otherwise stated; the pH was controlled by adding 1 N H_2SO_4 or 1 N NaOH. All experiments were conducted at 20°C.

2.4 Microscopic observation

Sludge morphology was observed using a differential interference micrescope (Nikon Microphot-FX, Nippon Kogaku K. K., Tokyo, Japan).

3. Results and Discussion

3.1 Effects of sludge concentration

Effects of organic loading, pH, and DO concentrations on plugging of a microfilter were examined by employing two units with different biological solid concentration. In unit A, which retained biological solids at 3,000 mg/*l*, successful microfiltration was achieved for all conditions examined. However, in unit B, which retained biological solids at 15,000 mg/*l*, plugging of microfilter was observed when the unit was operated with some pH and organic loading conditions, as will be described later. This indicates that the efficiency of microfiltration was affected by the biological solid concentration in the reactor.

3.2 Effect of pH values

Figure 2 shows changes in the suction pressure of the effluent when unit B was operated with organic loading of 0.30 kgBOD/kgVSS/day at various pH values. The filtration flux was 0.246 m^3/m^2/day throughout the experiment. The unit was operated at pH 7.0 during the first 7 days and the suction pressure was maintained at lower values. At the 7 th day of operation, the pH value was adjusted at 8.8 and the filter was replaced by new one at the 9 th day. The pressure increased and the microfilter was replaced by a new one on the 17 th day. Such an increase of suction pressur 'as not observed at this pH

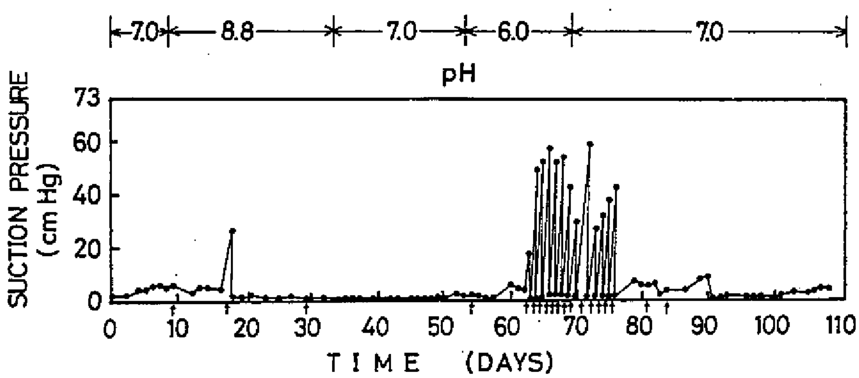

Fig. 2 Changes in the suction pressure of the effluent from unit B at various pH values. Unit B, retaining 15,000 mg/*l* of biological solids, was operated with 0.30 kgBOD/kgVSS/day at 5.0 mg/*l* of DO concentration for the first 81 days, and at 1.0 mg/*l* from the 81 st day to the 109 th day of operation. Renewal of a microfilter is indicated by the arrow (↑).

value thereafter, although the microfilter was replaced by new one at the 29 th day because the filter was damaged. On the 34 th day of operation, the pH value was adjusted to 7.0 again, and the unit was operated successfully for 20 days.

On the 54 th day, the pH value was lowered to 6.0 and the microfilter was renewed to ensure the effect of lower pH conditions on the plugging of the microfilter. As shown in Fig. 2, the pressure did not increase during the first 8 days, but abruptly increased on the 62nd day of operation. Although the plugged microfilter was replaced by a new one, performance of microfiltration was not improved and such a serious plugging observed until the 76th day of operation that was the 7 th day after controlling the pH value at 7.0. Then, it was shown that the performance of microfiltration was improved by operating the process at the neutral pH value; plugging was reduced on the 77 th day and was not observed thereafter at all, although the fillter was replaced by new one at the 81 st and the 84 th day of operation because the filter was damaged (Fig. 2).

DO concentration was decreased to 1.0 mg/l on the 81st day of operation. Successful filtration was achieved during this DO concentration (Fig. 2).

3.3 Effects of organic loading

Figure 3 shows changes in the suction pressure of the effluent when unit B was operated with various organic loadings. At lower loadings up to 0.25 kgBOD/kgVSS/day, the pressure did not increase for 40 days, although the filter was replaced by new one at the 31 st and the 38 th day of operation because the filter was damaged. For the next 13 days, the unit was operated without feeding but with a sufficient aeration (from the 40 th day to the 53 rd day). At the 53 rd day of operation, organic loading was increased to 0.29 kgBOD/kgVSS/day. Although the suction pressure did not increase during a few days, increased pressure was observed from the 57th day to the 61st day of operation. From the 61st day to the 68th day of operation, the performance of microfiltration was improved; the filter did not plugged up but the suction pressure decreased next several days without any renewal of a microfilter (Fig. 3).

Although no solid was produced, it is likely that the characteristics of the biological solids was changed when the unit was aerated without feeding (from the 40 th day to the 53 rd day). It is considered that the plugging observed from the 57 th day to the 61 th day was attributable not only to the abrupt increase of organic loading at the 53 rd day but to the aeration without feeding.

Since SRT (solids retention time) was 9.6 days when the unit was operated with 0.29 kgBOD/kgVSS/

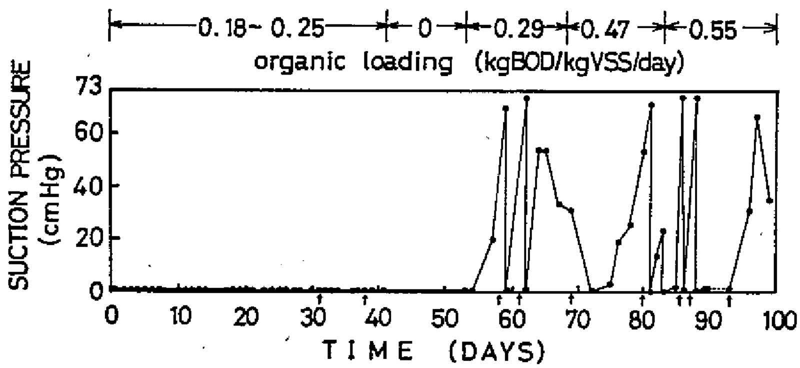

Fig. 3 Changes in the suction pressure of the effluent from unit B at various organic loadings. Unit B, retaining 15,000 mg/l of biological solids, was operated at 5.0 mg/l of DO concentration and pH 7.0. Renewal of a microfliter is indicated by the arrow (↑). Broken line (⋯) indicates duration of operation with the damaged microfilter.

day, a 1/9.6 of solid was turned over each day, the percentage of biological solids freshly produced under this condition increased day by day. At the 57 th day, when the plugging was observed, the value was 36%, and at the 67 th day, when the suction pressure decreased, the value exceeded 75%. Thus, the increased amount of biological solids freshly produced under this condition appears to improve the performance of the filtration during this period. Judging from this improvement and the successful microfiltration attained with a similar condition in the previous experiment (**Fig. 2**), we consider that the biological solids produced under 0.29 kgBOD/kgVSS/day did not necessarily cause serious plugging.

Organic loading was adjusted at 0.47 kgBOD/kgVSS/day by increasing the feeding rate 1.62-fold on the 68 th day of operation, and a microfilter was replaced by new one to ensure the effect of higher organic loadings on the 69 th day. The filtration flux was 0.385 m^3/m^2/day. As shown in **Fig. 3**, the suction pressure of the effluent gradually increased and the microfilter was plugged up on the 80th day. On the 81 st day of operation, organic loading was adjusted at 0.55 kgBOD/kgVSS/day by increasing the feeding rate and concurrently filtration area was doubled by employing two separation apparatuses to obtain a filtration flux similar to that obtained at lower loadings. With this condition, the filtration flux was 0.226 m^3/m^2/day. Although the flux was equivalent to the value by operating the process with 0.30 kgBOD/kgVSS/day, serious plugging was observed.

When the unit was operated with 0.47 kgBOD/kgVSS/day, SRT was 4.8 days. At the 80th day of operation, more than 90% of total solids were replaced by those freshly produced under this condition. Similarly, when the unit was operated with 0.55 kgBOD/kgVSS/day (SRT was 3.9 days), more than 80% of total solids were renewed at the 88 th day. Thus, we regarded that the plugging was led by the solids produced under the higher loading conditions, 0.47 and 0.55 kgBOD/kgVSS/day.

Agitation of the mixed liquor onto the filter was increased as high as possible on the 97th day of operation. Although the pressure was reduced significantly, plugging was not completely evaded by this apparatus when the stirrer was operated at the highest speed.

3.4 Microscopic observation of activated sludge

A microscopic observation of the morphological features of activated sludge revealed that significant amounts of non-flocculated cells were often observed and flocs were seemed fluffy, probably due to the dispersed growth of the microorganisms or degradation of microbial flocs, when a microfliter was plugged up at a lower pH value (**Fig. 4a**) and with a higher organic loading (**Fig. 4b**). Whereas, small and lobular shaped flocs predominated when successful microfiltration was achieved with unit B (**Fig. 4c**). This result suggests that successful solid-liquid separation by microfiltration was attained when microorganisms were flocculated sufficiently and the efficiency of the microfiltration was reduced by a significant amount of non-flocculated cells. It was considered that degradation of microbial flocs and dispersed growth of microorganisms were facilitated by lower pH values and higher organic loadings.

4. Conclusion

In oder to evade plugging of a microfilter when this process is operated with a high concentration of biological solids, it is recommended to operate the process imposing organic loading lower than 0.30 kgBOD/kgVSS/day at pH 7.0. Notably, this operational condition was consistent with the optimum condition to eliminate dissolved organic carbon (6) and nitrification (7). This indicates that successful microfiltration will be attained concurrently when the process is operated with the condition providing a good wastewater treatment.

When a microfilter was plugged up, the problem can be solved by dischaging a certain amount of sludge from the reactor to reduce non-flocculated cells and operating the process with organic loading lower than 0.30 kgBOD/kgVSS/day at near the neutral pH value to facilitate microbial flocculation. When a

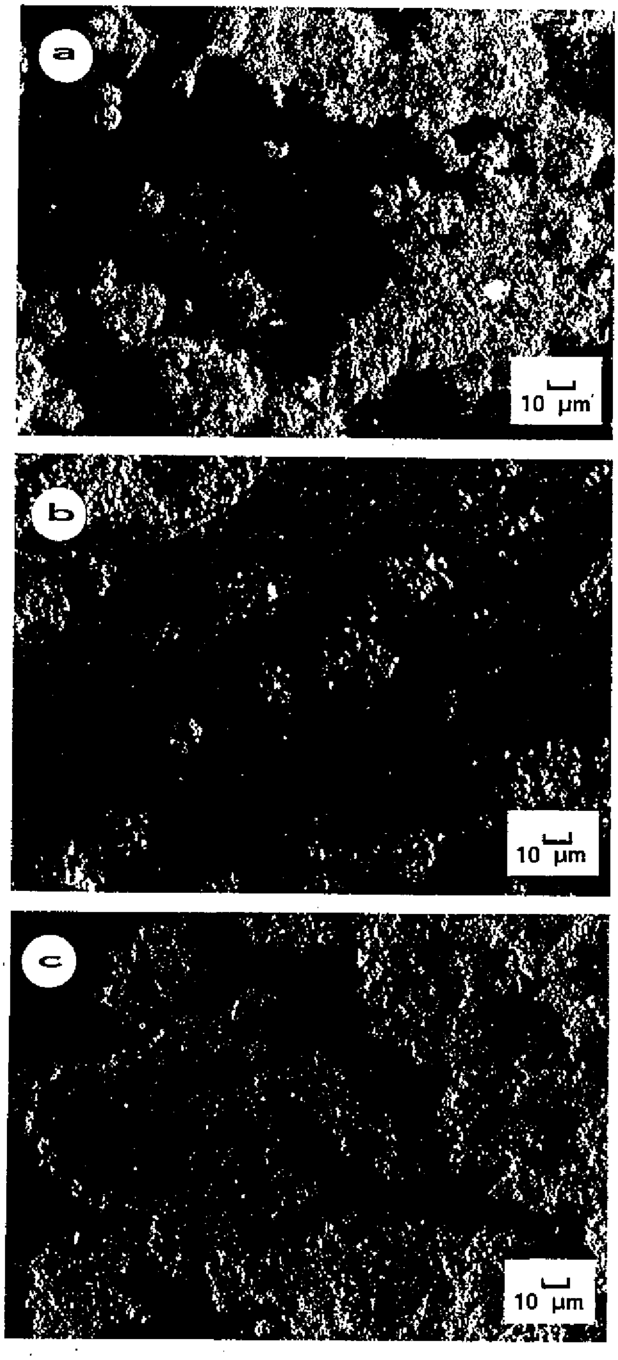

Fig. 4 Differential interference micrographs of the activated sludge in unit B. a) The unit was operated with 0.30 kgBOD/kgVSS/day at pH 6.0 (DO 5.0 mg/l). b) The unit was operated with 0.55 kgBOD/kgVSS/day at pH 7.0 (DO 5.0 mg/l). c) The unit was operated with 0.30 kgBOD/kgVSS/day at pH 7.0 (DO 5.0 mg/l).

microfilter was plugged at higher organic loadings, the feeding of BOD to the reactor had better not be stopped to reduce organic loading for a long time, because a microfilter was plugged when the loading was abruptly increased after long starvation (**Fig.** 3).

In managing of the activated sludge process, monitoring the amounts of non-flocculated cells will provide useful information to predict plugging of a microfilter.

Acknowledgments

We thank Dr. Y. Urushigawa of National Research Institute for Pollution and Resources for his critical reading of this manuscript. This research work was carried out as a part of MITI's large scale R&D project "New Wastewater Treatment System".

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Bull. Nat. Res. Inst. & Res., Vol. 18, No. 1, 1988

UDC 669.2

膜分離活性汚泥プロセスの運転操作条件が精密濾過膜の固液分離能に与える影響

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要　旨

膜分離活性汚泥法による廃水処理では，処理効率のみならず安定した膜分離が求められる。本研究では，リアクターの運転操作条件が膜分離能におよぼす影響について検討した。使用した膜分離活性汚泥プロセスを図1に示した。分離膜には精密濾過膜（孔径0.45 μm，硝酸セルロース製）を用いた。膜面の汚泥をマグネチック・スターラーで撹拌して膜面流速を得，透過側をポンプで吸引して透過流束を得た。汚泥濃度 3,000 mg/l（unit A）および，15,000 mg/l（unit B）の2系列の装置を運転した。これらの装置の膜分離能に対する BOD 負荷，pH および溶存酸素濃度の影響を検討した。膜分離能は膜透過側の吸引圧でモニターした。保持した汚泥濃度がより低い unit A ではいづれの実験条件でも膜分離能は低下せず，保持した汚泥濃度がより高い unit B でのみ分離能の低下が認められた。

unit B では pH 6.0 以下および BOD 負荷 0.47 kgBOD/kgVSS/day 以上の条件で吸引圧の上昇がみられ（図2および3）膜分離能が低下した。また，比較的長い時間空曝気を行った後，急激に負荷を上げて運転した場合にも分離能は低下した(図3)。溶存酸素の影響は明らかでなかった。活性汚泥の顕微鏡観察を行い，膜分離能が良好に保たれた場合は一般に微生物フロックが比較的大きく，一方，分離能が低下した場合はフロックの形成が不十分なことが示された(図4)。膜分離能は十分にフロック化されていない細胞で妨げられることが考えられた。

BOD 除去または硝化が十分におこる条件（6，7）と安定した膜分離が行える条件とは対応しており，良好な処理がおきているときは安定して膜分離が行えると考えられた。

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