0273-2289/96/5902—0125$07.50

Entrapped Mixed Microorganisms to Treat Organic Wastewater from Food Industry

JIN-HUEI HSU,*,[1] YI-CHANG LIN,[1] AND PING-YI YANG[2]

[1] *Institute of Public Health, College of Public Health, National Taiwan University, #1445, No. 1, Sec. 1, Jen-Ai Rd., Taipei, Taiwan, R.O.C.; and* [2] *Dept. of Agricultural Engineering, University of Hawaii at Manoa, Honolulu, Hawaii*

Received March 13 1995; Accepted August 18, 1995

ABSTRACT

Limited land and insufficient technicians to operate a wastewater treatment system are main restrictions for many factories. Therefore, an ideal wastewater treatment method for a small or land-limited factory must possess merits such as high performance efficiency, high organic loading rate, little odor, simple operation, easy maintenance, and little land required (simultaneously). An entrapment technique to immobilize mixed microorganisms to treat organic wastewater, which was developed in the present work, possesses these characteristics. This project was done on a laboratory scale. The microorganisms were activated sludge (an undefined mixture of microorganisms obtained directly from a domestic wastewater treatment plan) and the mixed microorganisms were immobilized in cellulose triacetate by means of an entrapment technique to treat organic wastewater from food industry. After wastewater was treated by this system, the SCOD (soluble COD) removal efficiency of 81% evaluated samples exceeded 80% in 1.5 ± 0.9 g SCOD/L/d of the volumetric loading rate and 7–10 h for the hydraulic retention time. This wastewater treatment method can be applied to other organic industrial wastewater.

Index Entries: Entrapped microorganisms; wastewater treatment; cellulose triacetate; packed bioreactor.

*Author to whom all correspondence and reprint requests should be addressed.

INTRODUCTION

There are food industries of many kinds, e.g., food processing and manufacturing, canning, wine, frozen food, starch, beverage manufacture, candy manufacture, lunchbox maker, and bakery. In general, the food industry wastewater is organic in nature. The food industry is distributed everywhere, especially in densely populated areas. Many industries located in densely populated municipal areas are small manufacturers; such small manufacturers invariably have limited land to construct wastewater treatment plants and insufficient technicians to operate treatment equipment appropriately. Therefore, an ideal wastewater treatment method for a small or a land-limited factory must possess some merits, such as high performance efficiency, high organic loading rate, little odor, simple operation, easy maintenance, and little land required (simultaneously). An entrapment technique to immobilize mixed microorganisms to treat organic wastewater, which was developed in the present work, possesses these characteristics.

Biological immobilization to treat wastewater involves adsorption (attachment), entrapment, encapsulation, or covalent binding technology to immobilize microbial cells, biomolecules, or enzymes, into the proper solid support. This solid support is used as a carrier to decompose the pollutant (*1*). The biological immobilization method for wastewater treatment is recognized as an attractive potential method for wastewater treatment.

The biological immobilization method for wastewater treatment can immobilize an enzyme, pure culture, or mixed cultures into a carrier (*2–5*). The disadvantages of an immobilized purifying culture for wastewater treatment are that it is time-consuming and expensive for a full-scale plant. The main disadvantage of an immobilized enzyme for wastewater treatment is that the activity of an immobilized enzyme cannot be sustained in the reactor in continuous operation over a long duration. Immobilized mixed microbial cells for wastewater treatment have several advantages, including low cost for purifying or isolating, application of multiple enzymes for biodegradation, and high operational stability over a long duration. In this work, the microorganisms were activated sludge (which was an undefined mixture of microorganisms obtained directly from a domestic wastewater treatment plan).

There are many reports about entrapment for wastewater treatment, but most of them are in the laboratory stage (*6,7*). Treating synthetic wastewater, operating during only a short period (several days or several weeks), or weakening the mechnical strength of a carrier are the restrictions to apply this technique to full-scale performance. To practice in the field, it is necessary to evaluate the performance of protracted operation and use industrially produced wastewater. For present work, using an entrapment technique to immobilize mixed microorganisms to treat organic wastewater from a food factory, the authors researched the performance of protracted operation in laboratory scale.

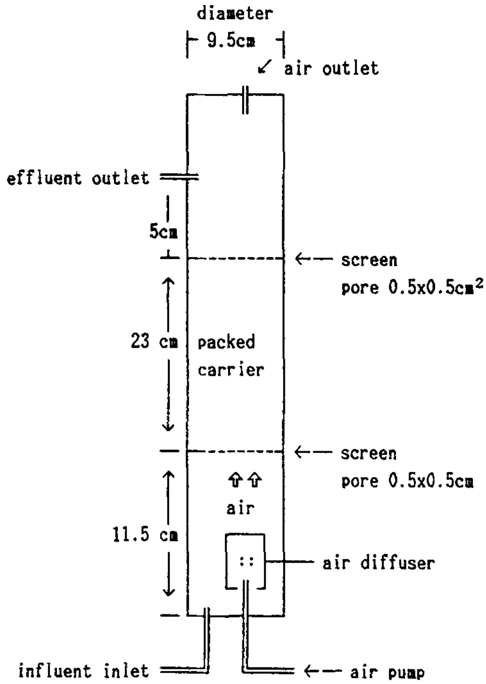

Fig. 1. Dimensional diagram of reactor.

MATERIALS AND METHODS

Materials

Cellulose triacetate was purchased from Eastman Chemical. Toluene and methyl chloride were obtained from ALPS Chemical.

Preparation of Carrier

Unacclimated activated sludge from a domestic wastewater treatment plant was used as the seed microorganisms. Cellulose triacetate was dissolved in methylene chloride. Dry activated sludge, centrifuged at 10,000*g* for 10 min, was mixed into the cellulose triacetate solution. The mixed liquid was spread into a plate with many pores; then the plate was immersed into toluene for a few seconds. The liquidized mixture was placed in a hood overnight for drying; then the solidified mixture was cut into cubes of about 1 cm^3 and washed with water for 24 h before this carrier was ready for use.

Packed Bioreactor

The reactor was constructed by acrylate. The dimensional diagram of the reactor appears in Fig. 1. Carriers were packed into the reactor.

Analytical Methods

The authors compared pollutant concentration of influent and effluent to evaluate removal efficiency of this system. Analyzed pollutant items included total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), suspended solid (SS), and nonpurgeable total organic carbon (nonpurgeable TOC). The concentration of TCOD, SS, and nonpurgeable TOC were measured according to ref. *8*. SCOD was determined as TCOD procedure, but water samples were filtered through the membrane first. The membrane was Millipore, Type HA, pore size 0.45 μm, purchased from Millipore. The TOC was measured by Beckman TOC analyzed, Model 915-B.

Experimental

The present work is a laboratory-scale project. The influent wastewater was collected from flow-equalization basina of a food factory that manufactures biscuits, sweets, and jelly. The collected wastewater was untreated except by simple settling equipment. Received in the laboratory, the collected wastewater was poured into a reservoir as influent for this work. The line diagram was shown as follows:

reservoir → peristaltic pump → 1st reactor → 2nd reactor → settling tank → effluent
(add N,P nutrient and adjust pH to 6–8) (retention time was 30–40 min)

In this wastewater treatment system, the flow was continuous, and two reactors were placed in series in order to broaden the microbial phase (*9*). The operating period was 147 d. Performance conditions and properties of influent are shown in Table 1.

RESULTS

The mean volumetric loading rate is 1.5 g SCOD/L/d. Compared with a volumetric loading rate of 0.3–0.6 g BOD_5 /L/d for traditional activated sludge method (*10*), the former is about twice the latter.

For activated sludge, microorganism concentration is expressed as mixed liquid suspended solid (MLSS), and the unit is mg/L. In this work, the microorganisms concentration, with unit mg/L, was obtained from the following formula:

mass of dry sludge in carrier (mg)/total available volume(L)

Microorganism concentration of the first reactor is about 16,000–23,000 mg/L, the second reactor is about 19,000–20,000 mg/L, and the MLSS in traditional activated sludge is about 1500–3000 mg/L (*10*). The microorganism concentration of the present method is greater than for tradi-

Table 1
Performance Conditions and Properties of Influent

Performance item	Value
Total available volume	5.9 L
Void volume	3.8 L
Flowrate of wastewater	~10 L/d
pH in reactor	6.2-8.2
DO value in reactor	2.0-7.0 mg/L
Water temperature	16-25°C
Hydraulic retention time	7.3-10.1 h
Volumetric loading rate	
Total	1.5 ± 0.9 g SCOD/L/d
1st reactor	2.4 ± 2.0 g SCOD/L/d
2nd reactor	0.7 ± 1.1 g SCOD/L/d
F/M ratio	
Total	0.06 ± 0.08
1st reactor	0.14 ± 0.10
2nd reactor	0.04 ± 0.06
Influent concentration of SCOD	866 ± 468 mg/L
Influent concentration of TCOD	1285 ± 596 mg/L
Influent concentration of BOD_5	689 ± 222 mg/L
Average BOD_5/SCOD ratio	99 ± 5%
Average BOD_5/TCOD ratio	64 ± 15%

Volumetric loading rate was based on SCOD loading rate of total available volume, which was calculated according to the following formula:

$$\frac{\text{influent SCOD conc. (mg/L)} \times \text{influent flowrate (L/d)} /}{\text{total available volume of reactors (L)}}$$

tional activated sludge; therefore, the organic loading of this method is higher.

SCOD Removal Efficiency

SCOD of influent and effluent, and SCOD removal efficiency are shown in Fig. 2. The concentrations of influent are variable; however, after wastewater treatment, the effluent concentrations are stable, and the SCOD concentrations are all less than 100 mg/L. The SCOD removal efficiencies of 81% (21/26) samples was >80%. In operations of 72 and 74 d, the removal efficiency decreased, because the organic loading was low; the SCOD influent concentrations were only 100 and 128 mg/L, respectively.

TCOD Removal Efficiency

The TCOD performance is presented in Fig. 3. In 28 evaluated samples, the removal efficiency of 82% samples exceeded 80%. The TCOD

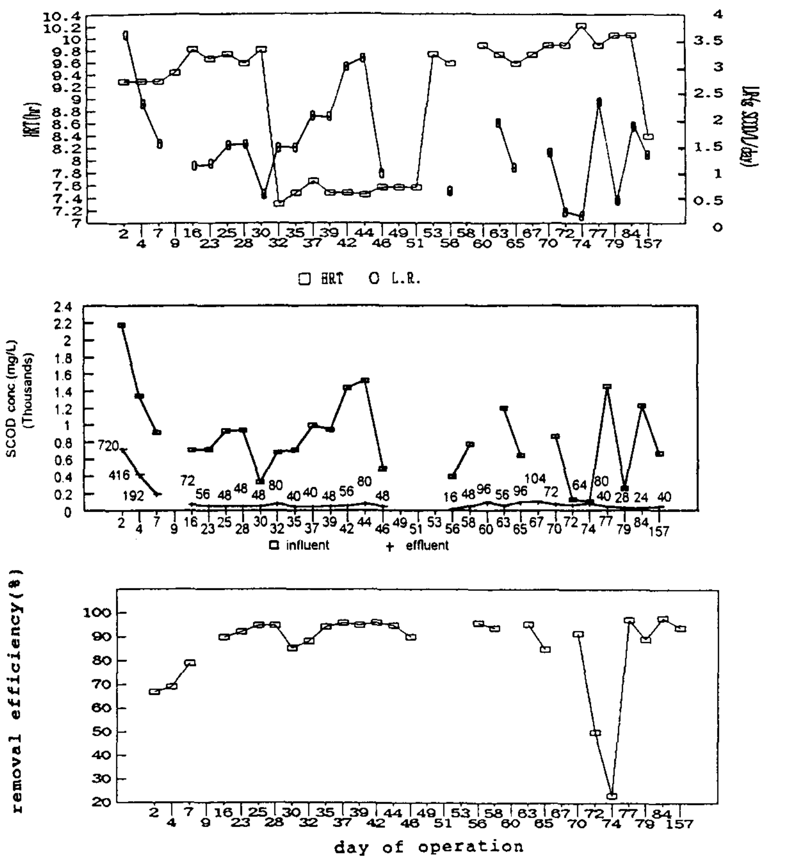

Fig. 2. Performance of SCOD: SCOD value, SCOD removal efficiency, hydraulic retention time, and volumetric loading rate. NOTE: The numerals in the figure are SCOD concentration of the effluent.

concentration of effluent was less than 100 mg/L in 61% analyzed samples, and less than 150 mg/L in 75% analyzed samples. There were seven (25%) effluent samples for which the TCOD concentration exceeded 150 mg/L. Two of the seven samples were in the second and fourth day after setup, before the operation reached a steady state; on the 44th operating day, TCOD influent concentration was raised to 2816 mg/L, and TCOD removal efficiency still sustained 82%, but the TCOD concentration of effluent exceeded 150 mg/L.

Nonpurgeable TOC

The performance of nonpurgeable TOC is shown in Fig. 4. Most effluent TOC concentrations were less than 50 mg carbon/L. There are 92% (12/13) analyzed samples for which TOC removal efficiency exceeded 70%, and 70% (9/13) analyzed samples for which TOC removal efficiency was >80%.

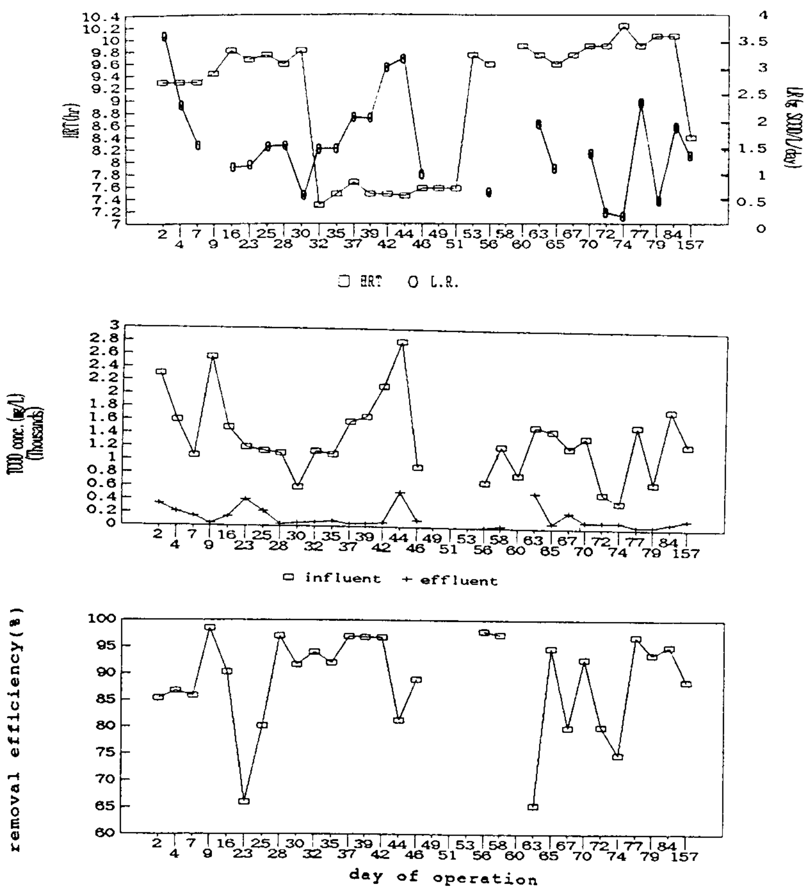

Fig. 3. Performance of TCOD: TCOD value, TCOD removal efficiency, hydraulic retention time, and volumetric loading rate.

SS Performance

SS performance is shown in Fig. 5. In 29 effluent samples, there were 52% effluents for which the SS concentration was less than 30 mg/L, and 82% effluents for which the SS concentration was less than 50 mg/L.

Influence of Concentration Shock Loading

Observe Fig. 2 (SCOD removal efficiency). On the 42th and 44th operating days, the SCOD concentration of the influent increased suddenly from 900 mg/L to 1500 mg/L, and the volumetric loading rate increased from 1.9 to 3.1 g SCOD/L/d. The SCOD removal efficiency decreased only slightly, from 95% to 90%. The preceeding information shows the influence of concentration shock loading to be slight for this method.

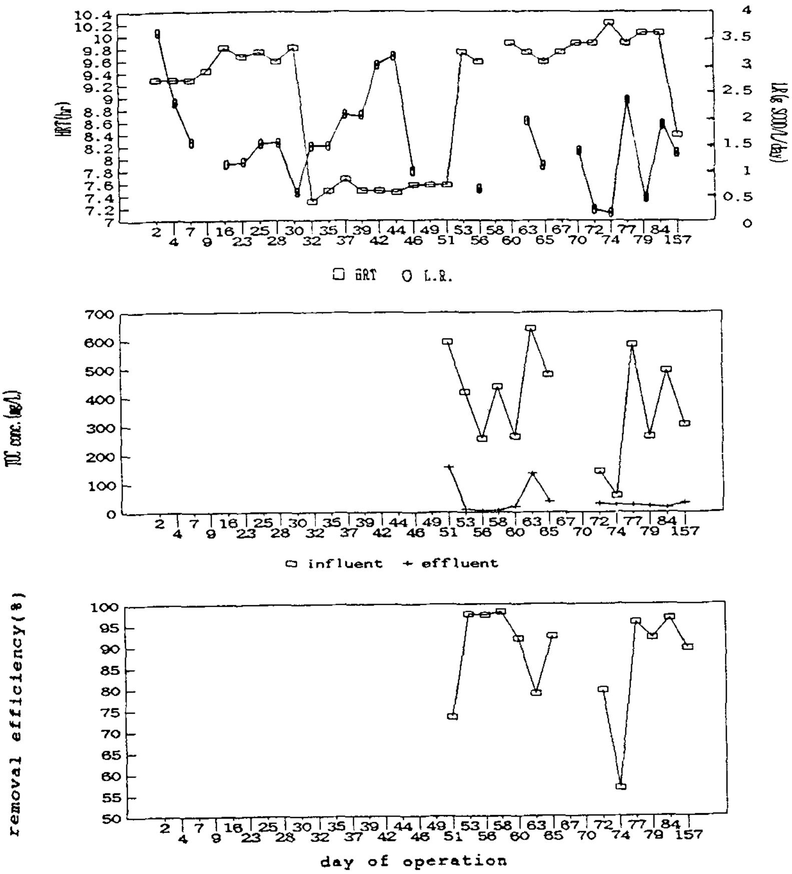

Fig. 4. Performance of nonpurgeable TOC: TOC value, TOC removal efficiency, hydraulic retention time, and volumetric loading rate.

Startup Period

The startup period is defined as the interval needed from system setup to the steady state. In this work, SCOD removal efficiency was 80% at the seventh operating day from setup, and SCOD removal efficiency reached 85% during the ninth day of operation. The startup period for this method is less than the 1-mo startup period for traditional activated sludge.

Sludge Production

Sludge production of this method is 0.16 ± 0.21 g sludge/g TCOD, equivalent to 0.23 ± 0.24 g sludge/g SCOD at volumetric loading rate 1.5 ± 0.9 g SCOD/L/d and with retention time 7-10 h. Compared with sludge production 0.5-0.7 g sludge/g BOD for traditional activated sludge, sludge production of this method is about half that of activated sludge.

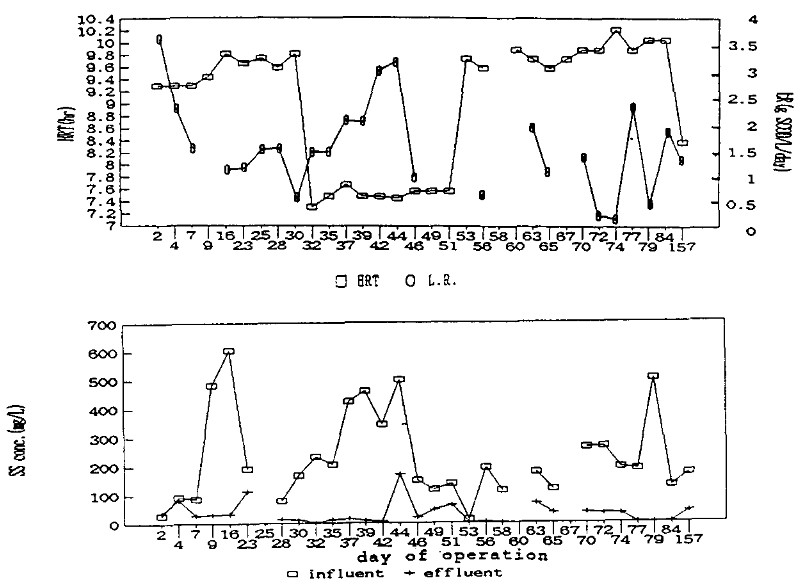

Fig. 5. Performance of SS: SS value, hydraulic retention time, and volumetric loading rate.

DISCUSSION

In this work, the activated sludge was obtained directly from domestic wastewater treatment, not treated with an acclimated process. However, the startup period was only 7–9 d. Therefore, it is unnecessary for this method to acclimate activated sludge, and this method is a conventional process to make carriers.

In this work, the hydraulic retention time in the final settling tank is only 30–40 min. If the authors increase the retention time in the final settling tank, the removal efficiency is promoted, and TCOD and SS concentrations in effluent become diminished.

The air supply that this method needs is more than that of activated sludge. Hence it is necessary to examine the geometry and size of the reactor to increase the rate of air absorption rate and to decrease energy consumption. The air supply should not be too great to wash out the sludge from the carrier; this increases the SS concentration in the effluent and diminishes the removal efficiency. The optimal air supply requires further investigation.

In this method, the immobilized microorganisms were entrapped within the carrier. However, after the carrier treated wastewater for some days, the immobilized microorganisms grew in outer-layer or absorbed on surface of the carrier.

The carrier used in this work was used for another project for about 1 yr. After operating 157 d in this project, there is neither degradation, dissolution, nor destruction of the carrier. The mechanical strength of the carrier is sufficient for full-scale wastewater treatment operating over a long time.

CONCLUSION

In this work, the SCOD removal efficiency of 81% of the evaluated samples exceeded 80% in 1.5 ± 0.9 g SCOD/L/d of volumetric loading rate and 7-10 h for hydraulic retention time. The removal efficiency is satisfactory. The wastewater with a high organic concentration cannot be treated with traditional activated sludge; however, our method can be used to treat such organic wastewater.

In this method, the volumes of the reactor and settling tank can be greatly decreased because the rate of organic loading is higher and retention time in the final settling tank is shorter. Besides, the geometry of the reactor is cylindrical so that a lesser area is needed. This method is suitable to practice in a land-limited plant or in a populated municipal area.

Sludge production of this method is little; therefore the cost of sludge treatment is also diminished.

This wastewater treatment method can be applied to other organic industry wastewater. This method can be used as wastewater treatment equipment alone, as a pretreatment system for high-strength wastewater, or as a pretreatment system before discharged to a sewer.

REFERENCES

1. Tyagi, R. D. and Vembu, K. (1990), *Wastewater Treatment by Immobilized Cells,* CRC, Boston.
2. Puhakka, J. A. and Jarvinen, K. (1992), *Wat. Res.* **26(6),** 765–770.
3. Caldwell, S. R. and Raushel, F. M. (1991), *Appl. Biochem. Biotech.* **31,** 59–73.
4. Lin, J. E., Wang, H. Y., and Hickey, R. F. (1991), *Biotech. Bioeng.* **38,** 273–279.
5. Livingston, A. G. and Willacy, A. (1991), *Appl. Microbiol. Biotech.* **35,** 551–557.
6. Yang, P. Y., Cai, T., and Wang, M. L. (1988), *Biol. Wastes* **23,** 295–312,
7. Yang, P. Y. and See, T. S. (1991), *J. Environ. Sci. Health* **A26(8),** 1494–1512.
8. Franson, M. A. N., Greenberg, A. E., Trussel, R. R., and Clesceri, L. S. (1985), *Standard Methods For the Examination of Water and Wastewater,* 16th ed., APHA, Washington, DC.
9. Tsubone, T., Ogaki, Y., Yoshiy, Y., and Takahashi, M. (1992), *Water Environ. Res.* **64(7),** 884–889.
10. Benefield, L. D. and Randall, C. W. (1980), *Biological Process Design for Wastewater Treatment,* Prentice Hall, Englewood Cliffs, NJ.