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BIOLOGICAL TREATMENT OF SOYA BEAN WASTE

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ABSTRACT

Soya bean beverages and "Tofu" are the major sources of protein in the Asian diet. Wastewater from soya bean food processing plant consisted of high concentration of BOD_5, COD, nitrogen and phosphorus. The wastewater should be pre-treated before discharging into the sewer or watercourses. Activated sludge process was an effective biological treatment process for soya bean wastewater. Up to 95% of BOD_5 can be removed by activated sludge process. The removal of nitrogen and phosphorus were 67% and 57% respectively. The treatment efficiency increased with higher mean cell residence time. The settleability of activated sludge was good, and suspended solids removal efficiency was well above 90%. The biological kinetic coefficients were also determined from the pilot study.

KEYWORDS

Soya bean waste; activated sludge process; mean cell residence time; settleability; treatment efficiency; bio-kinetic coefficients.

INTRODUCTION

In the Far East, soya beans have been used as one of the most important sources of protein and oil for over a thousand years. "Tofu" (soya bean curd) manufactured from soya beans is the common nutritious food for the Asians. Soya bean drink in the form of bottle or package is one of the most popular beverages in Asian countries. Most of the food processing plants in Singapore produce "Tofu" and soya bean drinks for the domestic market as well as exported to other countries.

Soya bean drinks are manufactured by soaking, grinding and cooking of clean soya beans, and filtering off the insoluble residue to obtain soya milk. Sugar is added to produce soya bean drink from soya milk. The soya bean drinks are bottled or packaged and sold. In the manufacturing of Tofu, a protein-oil curd is precipitated by adding coagulant to the warm soya milk. After the supernatant or whey is removed the curd is carefully pressed, sliced, packaged and sold. "Tofu" has a soft gelatinous texture and is perishable. Therefore the packaged "Tofu" are store in the refrigerator. Figure 1 shows the flow chart of the soya bean food processing.

The wastewater of the soya bean industry is mainly from the processing, bottle washing and packaging lines. The soya bean wastewater contained high concentrations of BOD_5, COD, phosphorus and nitrogen. In Singapore, allowable discharge limits for BOD_5 are stringent, not exceeding 400 mg/l into the sewer and 50 mg/l into the watercourses. As BOD_5 concentration of the soya bean waste is higher than the allowable discharge limits, pre-treatment of the wastewater is inevitable. Activated sludge process is one of the most efficient treatment methods for the food processing wastes. More than 95% of BOD_5 was removed from various food

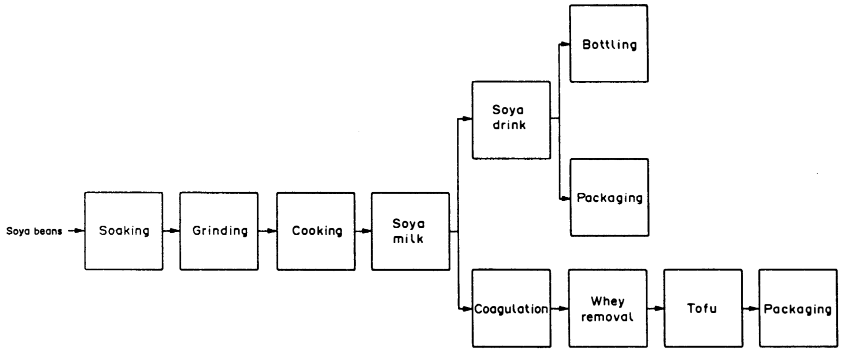

Fig 1 Flow chart of soya bean food processing

processing wastewaters by using activated sludge process. (Allen et al 1986, EPA 1969, 1971a, 1971b, 1971c, 1977, Frankel and Phongshetraratana 1986, Goronszy et al 1985, Hung 1981, 1984, Napoli 1979, Preston 1983, Sirrine 1978, Stalzer 1980). A treatability study of soya bean wastewater by an activated sludge process was conducted in the laboratory. This paper presents the results of the pilot study.

METHODOLOGY

Wastewater characterization study was carried out for the soya bean wastewater collected from the food processing plant. Fresh screened soya bean wastewater was collected daily, and analysed in the laboratory. The treatability study of soya bean wastewater by complete mixed activated sludge process was also conducted in the laboratory.

The bench scale continuous flow reactors were fabricated for the treatability study. The model consisted of aeration and settling units. Figure 2 shows the schematic layout of the pilot plant study. The aeration and settling tanks were separated by an inclined baffle. The volumes of the aeration and settling tanks were 11.5 liters and 2.8 liters respectively. Constant feeding rates of fresh screened wastewater were maintained by using a constant head device. The retention times of the aeration and settling tanks were 8 hours and 2 hours respectively.

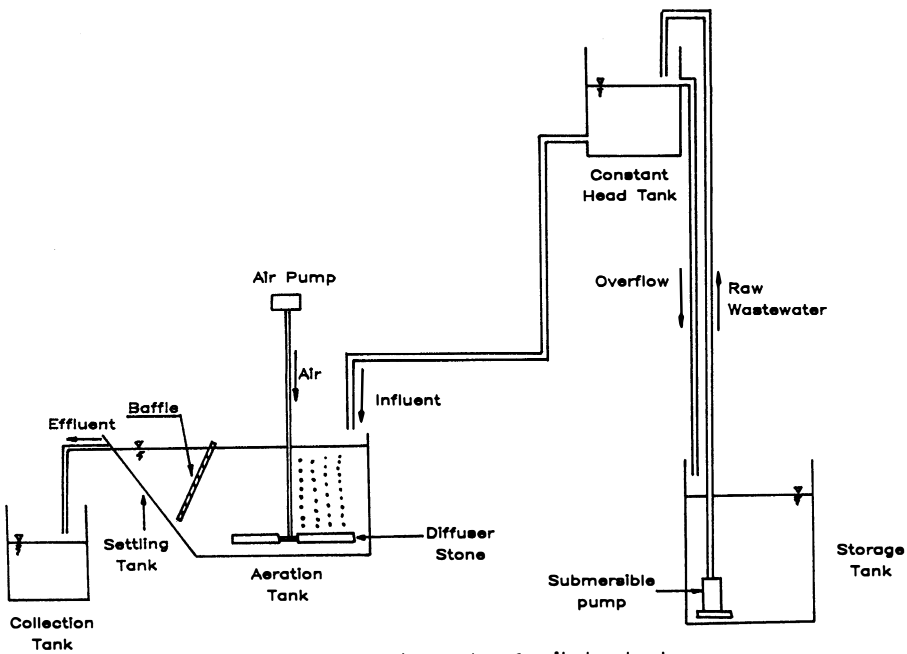

Fig 2 Schematic layout of pilot study

Air pumps were used to supply air into the aeration tank through porous stones. An oxygen concentration of 3 mg/l was maintained and adequate mixing was provided in the aeration tank. Returned sludge was controlled by varying the level of inclined baffle to achieve the desired effect. Various amounts of sludge were wasted daily to maintain the mean cell residence times (MCRT) of 5, 7.5, 10, 12.5 and 15 days. After steady state condition was obtained, daily composite samples were collected for analysis to evaluate the treatment performance of the activated sludge process. Samples analysis were carried out in accordance to the Standard Methods for the Examination of Water and Wastewater (APHA 1985).

RESULTS AND DISCUSSION

Table 1 shows the characteristics of the soya bean wastewater collected from the food processing plant. The wastewater was milky in color. The BOD_5 was 1325 mg/l with the range of 900 mg/l to 1740 mg/l. COD ranged from 2500 mg/l to 4100 mg/l with an average of 3065 mg/l. Nitrogen and phosphorus concentrations were very high. The total Kjeldahl nitrogen and phosphorus concentrations were 124 mg/l and 142 mg/l respectively. The suspended solids concentration ranged from 320 mg/l to 1140 mg/l with an average of 780 mg/l. The pH of the raw wastewater was 10.2. It was mainly due to the use of detergent and other basic chemicals in the bottle washing section. The temperature of wastewater was about 29^{o}C.

TABLE 1 Characteristics of Soya Bean Wastewater

Parameter	Range	Average
5-day BOD, mg/l	900 - 1740	1325
COD, mg/l	2500 - 4100	3065
Suspended Solids, mg/l	320 - 1140	780
Total Kjeldah Nitrogen (as N), mg/l	78 - 145	124
Phosphorus (PO_4^{2-}), mg/l	120 - 170	142
pH	9.3 - 10.8	10.2
Temperature, ^{o}C	28.5 - 29.3	29

The activated sludge was collected from the domestic wastewater treatment plant and used as seed for the start-up of pilot study. After steady state was obtained, composite samples were collected for analysis to monitor the characteristics of mixed liquor and to evaluate the treatment performance of the activated sludge process.

The characteristics of mixed liquor at various mean cell residence times are presented in Table 2. The ratio of volatile suspended solids to suspended solids in mixed liquor was about 0.84, indicating that 84% of the solids in the aeration tank was organics. The mixed liquor volatile suspended solids concentration (MLVSS) increased with the increase of mean cell residence time (θc). MLVSS concentration was about 2500 mg/l at θc of 5 days, and increased to 4000 mg/l at θc of 15 days. As the MLVSS increased, the air supply to the aeration tank was critical. Several occasions of bulking sludge were experienced when dissolved oxygen contents of the aeration tank were below 0.5 mg/l.

Better settleability of activated sludge was observed at higher θc or lower food to micro-organism ratio (F/M ratio). The sludge volume index (SVI) decreased at higher θc or lower F/M ratio. The SVI was 165 ml/g at θc of 5 days or F/M ratio of 0.5, and decreased to 95 ml/g at θc of 15 days or F/M ratio of 0.17 (Fig. 3). In order to have good settling behavior of activated sludge, the process should operate at θc of 10 days and above, or F/M ratio of 0.29 and below.

TABLE 2 Mixed Liquor Characteristics

Parameter	Mean Cell Residence Time (Days)				
	5	7.5	10	12.5	15
MLVSS, mg/l	2485	2950	3056	3114	3996
MLSS, mg/l	2958	3512	3650	3769	4700
MLVSS/MLSS	0.84	0.84	0.84	0.83	0.85
Sludge Volume Index, ml/g	165	145	120	110	95
F/M ratio	0.50	0.35	0.29	0.25	0.17

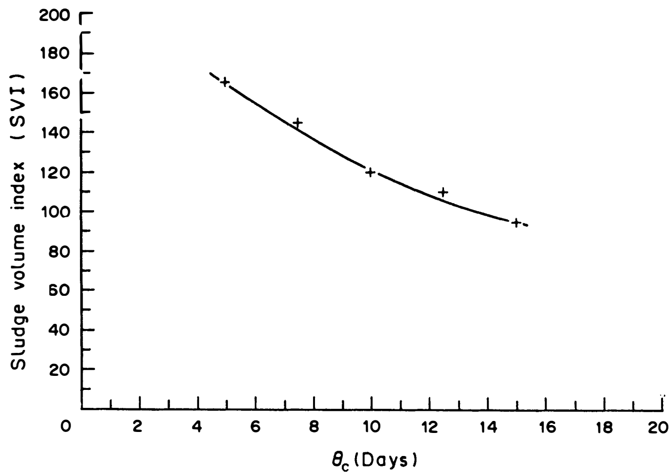

Fig 3 Sludge volume index Vs mean cell residence time.

The pH of above 10 did not have any detrimental effect on the activated sludge process for soya bean wastewater treatment. The system had the buffer ability to adjust the pH to 9 for the treatment process. Table 3 shows the quality of effluent from the treatment system. Effluent BOD_5 concentration decreased with higher mean cell residence time, indicating that treatment efficiency was higher at higher θc. BOD_5 of the effluent was 157 mg/l at θc of 5 days, and decreased to 66 mg/l at θc of 15 days. Fig. 4 shows that BOD_5 removal efficiency increased from 88% at θc of 5 days to 95% at Oc of 15 days. For θc of 10 days and above, more than 90% of BOD_5 was removed by the activated sludge process. Similar results were obtained for the COD removal efficiency. COD in the effluent decreased from 367 mg/l at θc of 5 days to 214 mg/l at θc of 15 days, indicated that COD removal efficiency increased from 88% to 93%.

Suspended solids removal was excellent. The suspended solids concentration in the effluent was 60 mg/l at θc of 5 days. As θc increased to 12.5 days and above, the effluent suspended solids concentration was below 10 mg/l. The removal efficiencies of the suspended solids were well above 90% as shown in Fig. 4. The removal efficiency of suspended solids was 99% at θc of 10 days or above. Even though the sludge volume index of activated sludge was 165 ml/g, it did not significantly affect the settling of solids in the settling tank (Fig. 5). The removal efficiency of suspended solids was 92% at SVI of 165 ml/g. The sludge in the settling tank was well compacted with solids concentration ranged from 0.5% to 0.8%. However, the sludge may have to be dewatered before disposal.

TABLE 3 Effluent Characteristics

Parameter	Mean Cell Residence Time (Days)									
	5		7.5		10		12.5		15	
	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.
5-day BOD, mg/l	120-190	157	100-160	145	95-140	119	82-105	92	46-95	66
COD, mg/l	190-390	367	150-320	337	220-295	276	190-290	245	150-290	214
Suspended Solids, mg/l	46-65	60	39-58	53	20-34	28	7-12	9	5-10	8
Total Kjeldahl Nitrogen, mg/l	42-54	53	40-49	45	35-50	44	15-45	37	20-40	25
Phosphorus (PO_4^{2-}), mg/l	55-80	69	40-85	67	45-72	60	40-65	56	45-59	54
pH	8.5-9.1	8.8	8.5-9.5	9.1	9.0-9.2	9.1	8.9-9.1	9.0	8.9-9.1	9.0

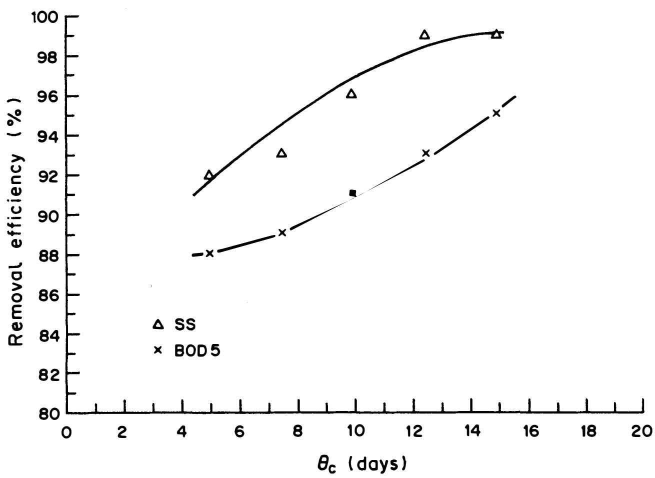

Fig 4 Removal efficiency of BODs and suspended solids.

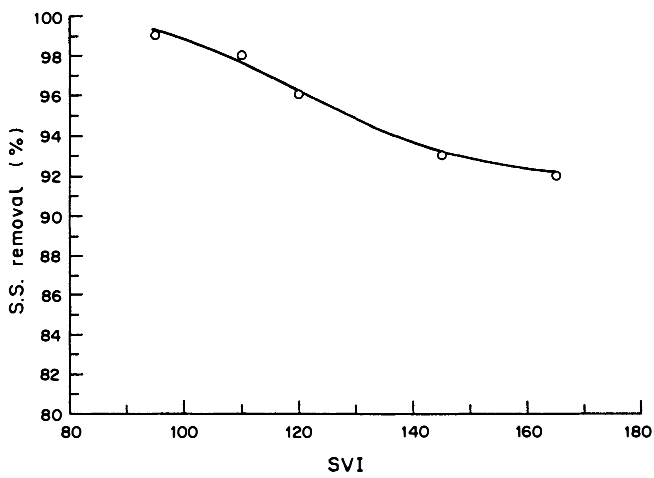

Fig 5 Removal Efficiency Of Suspended Solids

The total Kjeldahl nitrogen(TKN) removal efficiency ranged from 57% to 80% as shown in Fig. 6. The effluent TKN concentration ranged from 25 mg/l to 53 mg/l. The TKN removal efficiency increased with higher θc. The TKN removal efficiencies were 57% and 80% for θc of 5 days and 15 days respectively. The effluent phosphorus concentration ranged from 54 mg/l to 69 mg/l. The treatment efficiency was about 57%, and ranged from 52% to 62%. The treatment efficiency increased slightly at higher θ_c. The high concentrations of TKN and phosphorus in the effluent may create eutrophication problems in the receiving water.

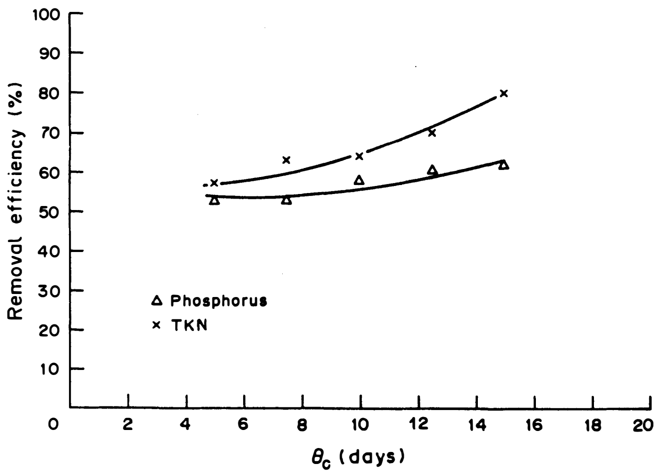

Fig 6 Removal efficiency of nitrogen and phosphorus.

The kinetic coefficients for biological treatment were determined from the pilot study. The procedure for the determination of biological kinetic coefficients was outlined in Metcalf & Eddy (1979). The following equations were used for the determination of the coefficients.

$$\frac{X\theta}{S_0 - S} = \frac{K_s}{K}\,\frac{1}{S} + \frac{1}{K} \qquad (1)$$

$$\frac{1}{\theta c} = Y\,\frac{S_0 - S}{X\theta} - K_d \qquad (2)$$

Where

X = MLVSS concentration
S_0 = influent BOD_5 concentration
S = effluent BOD_5 concentration
θ = hydraulic retention time
θc = mean cell residence time
K = maximum rate of substrate utilization
K_s = half-velocity constant
K_d = endogenous decay coefficient
Y = Yield coefficient

Least-square method was used to determine the coefficients from the results obtained. The values of biological kinetic coefficients were 0.78 mg VSS/mg BOD_5 for the yield coefficient Y, 0.095 day^{-1} for the endogenous decay coefficient K_d, 1.10 day^{-1} for the maximum rate of substrate utilization K, and 491.3 mg/l BOD_5 for the half-velocity constant K_s.

CONCLUSION

1. The wastewater from soya bean processing plant was milky in color. The wastewater had high concentration of BOD_5, COD, nitrogen and phosphorus. The concentrations of BOD_5, COD, total Kjeldahl nitrogen and phosphorus were 1325 mg/l, 3065 mg/l, 124 mg/l and 142 mg/l respectively. The pH of the wastewater was 10.2.

2. The wastewater can be treated by an activated sludge process. The treatment efficiency increased with higher mean cell residence time. The pilot plant study showed that up to 95% of BOD_5 can be removed by the activated sludge process. Treatment efficiency of COD was above 90%. The removal efficiency of total Kjeldahl nitrogen ranged from 57% to 80%, and phosphorus was removed by about 57%.

3. The settleability of activated sludge was good. The sludge volume index was below 120 ml/g when the system was operated at mean cell residence time of 10 days and above. The removal of suspended solids was excellent. The removal efficiency of suspended solids was well above 90%. The removal efficiency was 99% at mean cell residence time of 10 days and above.

4. The biological kinetic coefficients were 0.78 mg VSS/mg BOD for the yield coefficient Y, 0.095 day^{-1} for the endogenous decay coefficient K_d, 1.10 day^{-1} for the maximum rate of substrate utilization K and 491.3 mg/l BOD_5 for the half-velocity constant K_s.

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