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Characteristics and treatments of dairy industry wastewater in a suspended growth batch reactor

Abhishek Das[a], Pradyut Kundu[b] and Sunita Adhikari (nee Pramanik)*[a]

[a]Department of Food Technology and Biochemical Engineering, Jadavpur University, Kolkata-700 032, India

[b]Department of Food Processing Technology, Mirmadan Mohanlal Govt. Polytechnic, Plassey, Nadia-741 156, West Bengal, India

E-mail: sunitapramanik@gmail.com

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This research work was embraced to assess the kinetic coefficients values of a suspended growth type batch reactor for the dairy industry wastewater treatment. This examination was done in a research facility batch type arrangement which was comparable to the aeration tank of Effluent Treatment Plant (ETP). Wastewater samples were withdrawn on regular basis to characterize wastewater. Simulated dairy wastewater was made synthetically according to the characterization done which was found the COD of 640 mg/L and ammonium nitrogen concentration of 43 mg/L. Kinetic study was conducted to find kinetic coefficients (Y, K_s, k_d and k).

Keywords: Dairy wastewater, COD, kinetic coefficients, suspended growth system, ammonium nitrogen.

Introduction

Food manufacturing and processing industries pollute the environment and ecosystem adversely. Dairy industry is one of the major polluting industries among the food sector. Throughout the process chain of the dairy industry affect the environment[1]. Majority of the dairy plants perceive treatment of wastewater as an evil thing[2]. In general, they produce whitish to off white colour of waste water containing different types of carbohydrates, proteins, fats and other biological materials. Dairy industry wastewaters characteristics vary among the factories based on the products they formed and the processing technique[3]. Information regarding the actual dairy wastewater chemical composition is scarce[4]. Milk has a five day Biological Oxygen Demand (BOD_5) around 250 times higher than that of wastewater[5]. Dairy wastewaters contain high amount of organics, primarily lactose, proteins in terms of casein and fats, along with copious amount of nitrogen[3,6]. As dairy wastewater are full of organic pollutants they have the potential to increase the BOD_5, as well as Chemical Oxygen Demand (COD) of the water body where discharged which can create oxygen depleted environmental conditions and force the aquatic creatures to die off due to anoxia. Nutrient like nitrate and phosphate are also a major concern. Cleaning-In-Place system (CIP) in those dairy plants uses mostly phosphate containing detergents which ultimately end up in the aquatic body. Common CIP agents are nitric acid, caustic soda, phosphoric acid, and sodium hypochloride[6], all of those have impacts on environment. If the discharged water not treated adequately; goes into the aquatic system can lead to eutrophication in lakes and ponds. Eutrophication is a condition when the nutrient level in the system becomes very high which causes algal bloom and ultimately leads to anoxic condition due to the death and decomposition of algae. So, the dairy wastewater needs to be treated before discharge. The present study is based on the biological treatment of dairy industry wastewater. It was done to obtain the coefficients of kinetics for dairy wastewater treatment in a laboratory-based batch reactor. For this purpose, dairy wastewater samples were taken from the outlet of primary treatment plant and active sludge from the aeration tank from Mother dairy Calcutta plant, located in Dankuni. The collected wastewater and active sludge were stored in laboratory refrigerator at 4°C. The seed acclimatization process in our laboratory was made to make the bacterial seed accustomed to laboratory environment. It had continued for nearly two months until the growth stabilizes. Simultaneously the collected real-life dairy waste water was characterized and synthetic dairy waste water was prepared according to the concentration found from characterization. Then the time-concentration study was done to optimize the detention time and after finding that kinetic study was started by varying the initial biomass concentration (i.e. Mixed Liquor Suspended Solids or MLSS) around the optimum MLSS found while carrying out the time-concentration study. From this study the kinetic coefficients were obtained which would be necessary for reactor design in the later stages of the research program.

Experimental

Real-life wastewater samples were collected from dairy plant, Mother Dairy Calcutta located at Dankuni, West Bengal, India. Samples were collected from inlet of aeration tank into 2L plastic container and taken to the lab facility. Samples were subsequently kept at 4°C temperature in the refrigerator for further study of quality parameters like pH, COD, BOD_5, NH_4^+-N, Total Soluble Solid, Total Dissolved Solid, alkalinity following Standard Method[7].

For the dairy wastewater treatment in an activated sludge process, active seed was gathered from the existing effluent treatment plant (ETP) of Mother Dairy Calcutta and acclimatized separately in two separate 1 L conical flask, one for study of carbon oxidation and another for study of nitrification.

The process of seed acclimatization for the study of carbon oxidation:

The experiment was done in the conical flask of one litre volume as an acclimatization unit. Around 75 mL of concentrated biomass collected from dairy treatment plant was transferred into 800 mL of diluted medium (1:4 dilution) containing 25 mL of micronutrients solution. Total volume of the culture medium was 900 mL. Aquarium pumps were used to provide continuous aeration. pH of the medium was kept fixed within 7.0–7.5 with the addition of Na_2CO_3 and phosphate buffer.

Seed acclimatization for the study of nitrification:

This study was carried out similarly in a conical flask of 1.0 L size as an acclimatization unit. About 75 mL of concentrated biomass collected from dairy treatment plant was transferred into 800 mL of diluted medium (1:4 dilution) containing 25 ml of micronutrients solution. Aeration was provided through aquarium pumps. pH of the solution was kept around 7.0 to 7.5 by the addition of Na_2CO_3 and phosphate buffer.

Feed solution for carbon oxidation study contained milk powder, dextrose, peptone, beef extract, lactose as 1.00, 0.50, 0.25, 0.25 and 0.20 g per litre respectively and diluted for 4 times and feed solution for nitrification study contained ammonium sulphate, ammonium chloride, milk powder, peptone, dextrose, lactose, KNO_3 as 0.25, 0.25, 0.05, 0.05, 0.02, 0.05 and 0.05 g respectively and diluted for 4 times too. Aeration was done with the help of aquarium pumps by diffusing air in the system. During acclimatization pH was maintained between the range of 7 and 7.5 with the addition of required quantity of Na_2CO_3 solution. The acclimatization process was continued for around 2 months. The growth of biomass was measured by the concentration of MLSS in conical flask (1 L) and acclimatization period was over when a steady MLSS concentration was found.

A lab-scale batch reactor system was being set up for the treatment of synthetic wastewater. 1 L measuring cylinder was used as the aeration tank from which the sludge was manually removed from time to time. Air was supplied to the batch reactor with the help of two aquarium pumps. For further study, a simulated dairy wastewater was prepared synthetically emulating the real-life characteristics of collected dairy effluent of average concentration of Chemical Oxygen Demand around 640 mg/L and ammonium nitrogen concentration of 43 mg/L. Synthetic dairy wastewater was prepared in the laboratory using dry milk powder. Composition of milk powder (g/100 g) are as follows: fat - 20, protein - 20, carbohydrate - 50, sodium - 0.25, chloride - 0.3, phosphate - 0.3. The composition of synthetic dairy wastewater (g/L) are as follows: lactose - 0.5, dextrose - 0.5, peptone - 0.5, beef extract - 0.25, yeast extract - 0.25, potassium nitrate - 0.6, ammonium sulphate - 0.35, ammonium chloride - 1.4, di-potassium hydrogen phosphate - 0.2, di-hydrogen phosphate - 0.2 and then diluted to achieve the target concentration of real life wastewater.

Acclimatized mixed cultures (both for carbon oxidation and nitrification) were taken into different concentration such as 5%, 10% and 15% v/v and inoculated into the synthetic wastewater in 1 L batch reactor to observe the removal potential of COD and ammonia nitrogen (NH_4^+-N) in different inoculums concentration in a duration of 12 h detention period. It was found that 10% (v/v) inoculum exhibited maximum removal efficiency for both COD and NH_4^+-N. Further 9 to 11% (v/v) range of inoculum with the incremental spacing of 0.2% (v/v) (viz. 9.0%, 9.2%·····10.8%, 11.0%) was added in the same synthetic wastewater medium and was observed the substrate removal efficiency by measuring concentration of COD and NH_4^+-N within the period of 12 h. pH was varied in different batches but was kept between 6.5 to 8.5 by using sodium bi-carbonate[8,9]. Mixed liquor suspended solids (MLSS) concentration was also measured thoroughly throughout the whole tenure of the experiment along with other parameters such as COD, NH_4^+-N etc. Measurements were done following the Standard Method[8].

A reactor's performance can be assessed by evaluating its reaction kinetics. By conducting experiment, different values for kinetic coefficients for carbon oxidation and nitrification were estimated as steady state kinetics for stabilization of organic carbon, ammonium nitrogen (NH_4^+-N). Kinetic coefficients (viz. Y, K_d, K_s and k) were obtained on the basis of previous experiments by varying MLSS concentration within the range of 500 to 600 mg/L.

Results and discussion

An inoculum concentration of 10.2% (v/v) for COD removal and 10.6% (v/v) for ammonium-nitrogen removal was found to be optimum in time-concentration study in batch reactor. The maximum removal of COD and ammonium nitrogen (NH_4^+-N) was achieved 98.59% and 99.64% respectively after 12 h of retention time which has been shown in Figs. 1 and 2. The profile of variation in pH and MLSS concentration in the batch reactor has also been shown in Figs. 3 and 4. Kinetic study was done on the basis of Monod kinet-

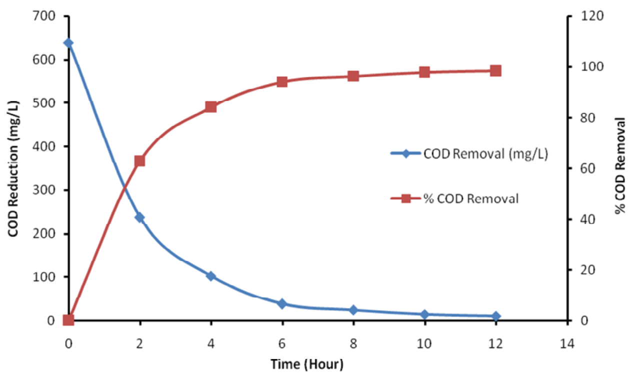

Fig. 1. Profile of COD removal.

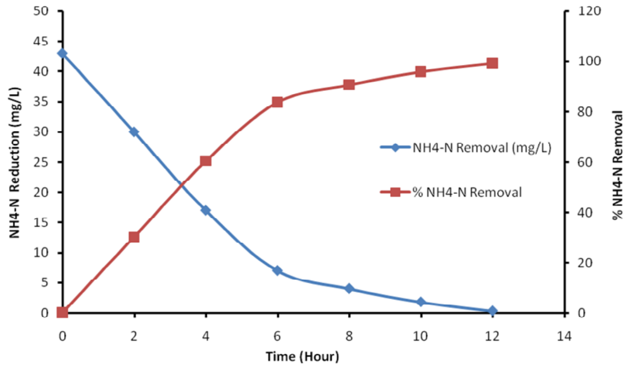

Fig. 2. Profile of ammonia nitrogen removal.

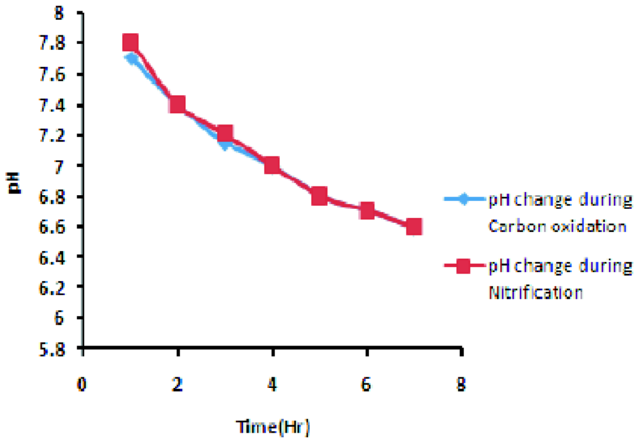

Fig. 3. Profile of pH.

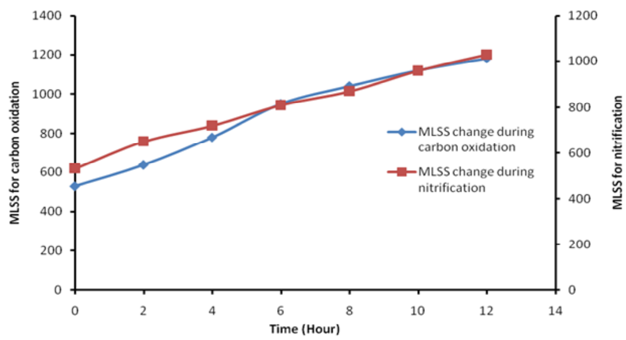

Fig. 4. Profile of MLSS.

ics model; both for the study of carbon oxidation and nitrification.

For carbon oxidation study experimentally obtained reciprocal values of U_C, the specific substrate utilization rate were plotted against (1/*S*) that is reciprocal of COD concentration. The substrate removal kinetics was prepared using the following straight-line equation:

$$1/U_C = (K_s/k)(1/S) + 1/k \quad (1)$$

Using least square approach a most fit graph was drawn. The graph was shown in Fig. 5. The value of K_s/k was obtained from the slope of the straight line and 1/*k* was found from the intercept. The value of substrate removal rate (*k*) was 8.47/day and the half velocity constant (K_s) 149.58 mg/L.

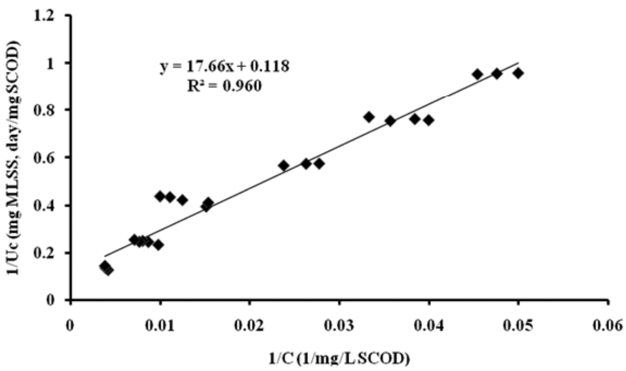

Fig. 5. Kinetics of substrate utilization for the study of carbon oxidation in batch scale (SCOD = 640±30 mg/L).

The inverse of the reaction time, θ values were plotted with respect to U_C, specific substrate utilization rate. The graph is shown in Fig. 6. The slope of the graph is Yield coefficient (*Y*) and its value was found as 1.748 mg MLSS/mg COD. The intercept of the best-fit straight line was endogenous decay coefficient (K_d) and its value was found as 0.059/day.

For the study of nitrification, inverse of specific substrate utilization rate, U_N were plotted with respect to the inverse of ammonium nitrogen, *N*. The kinetics for the removal of ammonium nitrogen was prepared using the following equation:

$$1/U_N = (K_s/k)(1/N) + 1/k \quad (2)$$

A most fit graph was drawn using the least square approach. It was shown in Fig. 7. The value of *k* and K_s were found 0.262/day and 3.853 mg/L respectively. Similarly, the inverse

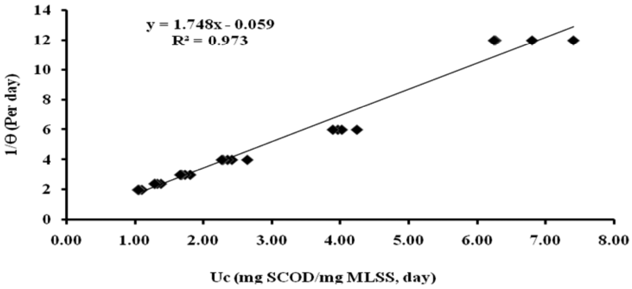

Fig. 6. Kinetics of microbial growth for the process of carbon oxidation in batch scale (SCOD = 640±30 mg/L).

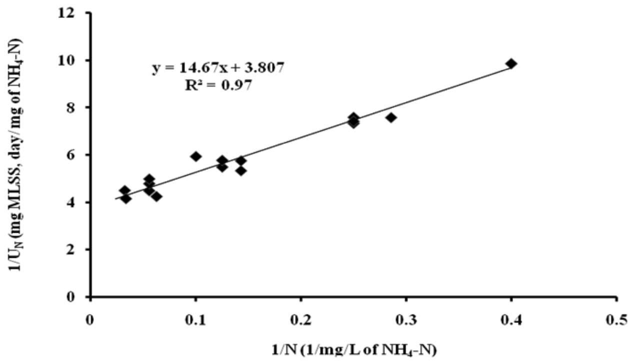

Fig. 7. Kinetics of substrate utilization for the study of batch nitrification (NH_4-N = 43±5 mg/L as N).

of the reaction time, θ were plotted with respect to specific substrate utilization rate, U_N. It was shown in Fig. 8. The yield coefficient (*Y*) values were found as 25.21 mg MLSS/mg NH_4^+-N and endogenous decay rate constant (k_d) was 0.082/day.

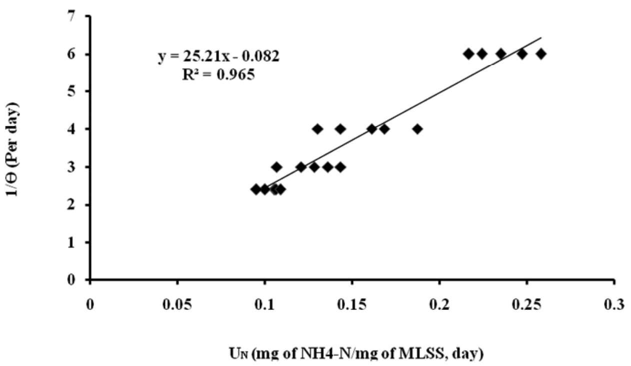

Fig. 8. Kinetics of microbial growth for the process of nitrification in batch scale (NH_4-N = 43±5 mg/L as N).

Conclusion

Laboratory test results showed that bioremediation of dairy wastewater for the removal of organic load and ammonium nitrogen (NH_4^+-N) in batch reactor unit was very efficient. More than 98% removal was obtained for a retention time of 12 h using an initial concentration of COD 640 mg/L and concentration of ammonium nitrogen (NH_4^+-N) 43 mg/L with an initial Mixed Liquor Suspended Solids concentration of 530 mg/L. The kinetic constants were reasonably corroborated with standard values and in future these values might be used in an aeration tank fabrication of an activated sludge unit of a dairy plant.

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