Treatability study of Bakery and Confectionery wastewater in suspended growth batch fed reactor

*A Thesis Submitted for the partial fulfillment of the continuous assessment of **Master of Technology** in **Environmental Biotechnology** course of **JADAVPUR UNIVERSITY** for the session 2017-2019*

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This **Thesis** titled **"Treatability study of Bakery and Confectionery wastewater in suspended growth batch fed reactor"** is prepared and submitted for the partial fulfillment of the continuous assessment of **Master of Technology** in **Environmental Biotechnology** course of Jadavpur University for the session 2017-2019.

It is declared that no part of this said thesis work has been presented or published elsewhere.

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ORGANIZATION OF THESIS

Chapter 1 includes the introduction of the work. **Chapter 2** includes comprehensive literature review on the characterization of bakery and confectionery wastewater, their sources, types of treatment techniques and removal studies. **Chapter 3** includes the objectives of the present study. **Chapter 4** includes the theoretical consideration for the present study such as different mathematical equation used to evaluate the kinetic coefficients. **Chapter 5** includes the materials and methods used for the present study. **Chapter 6** includes the results obtained from the present studies and their discussions. **Chapter 7** includes the conclusion. **Chapter 8** includes the limitation of the present study. **Chapter 9** includes the future scope of the present study. In **Chapter 10** all the references cited in the thesis are enlisted.

ABSTRACT

Bakery and confectionery industry in the last few decades have witnessed rapid diversion and investment in the food production and process sector. Coupled with the rapid growth of bakery and confectionery industries, pollution levels have also been shooting up due to release of effluent from this industry. This industry needs huge water supply for its proper functioning and simultaneously it vents out huge amount of waste water. The effluent of bakery and confectionery wastewater mainly constituted by fat, oil, nitrogen, glucose, starch etc. Bakery and confectionery wastewater treatment has received a little attention and very little information is available on treatment aspect of such wastewater. In view of its appropriate method of bioreactor for reduction of organic load. Bakery and confectionary wastewater are subjected to physiochemical or biological treatment but due to its very high organic loading and biodegradability, biological treatment is considered to be a preferred approach.

For designing of a full scale biological treatment system for above mentioned industry, a detailed investigation is required to be done in order to evaluate kinetic constants values which would be put into governing equation of design rational system.

The experimental studies were carried out with simulated pertaining to real life confectionary/bakery wastewater in batch-fed mode. Necessary characterization was done after collecting wastewater from the outlet of the real life plant. It was found that COD values within a range of 1300-1400 mg/L and BOD/COD ratio in between 0.68-0.71. The microbial seed was acclimatized for 4 days. Necessary batch kinetic studies were performed with acclimatized seed mixture in different proportion to the synthetic sample. The batch study was conducted both for synthetic and real life wastewater sample. A time concentration curve was plotted to observe its removal pattern. The batch study was also conducted for ammonia-nitrification study with real life sample only.

The experimental data set were utilized to determine various kinetic coefficients such as K, Y, k_d, K_s, U etc. for designing a real life activated sludge reactor system.

It was observed that about 90% removal of COD could be achieved after a contact period of 26 hours in corresponding to 1320 mg/L of initial COD.

Similarly 76% ammoniacal nitrogen removal was found after a contact period of 30 hours. Finally a model bioreactor dimension has been computed using the kinetic values.

With the view point of above, the present study was undertaken as with an aim to evaluate the necessary kinetic coefficients for designing of an activated sludge process as a model experimental bioreactor in laboratory scale, which can have a scope of real life application in future.

Chapter-1

INTRODUCTION

The food industry have one of the highest consumptions of water and is one of the biggest producers of effluents per unit of production, in addition they generate a large volume of sludge during biological treatment. Out of many varieties of food related plants, the confectionery /bakery industry is generally considered to be one of the largest sources of food processing wastewater which requires considerable degree of treatment before discharging in the water environment. In general, wastes from the bakery and confectionery industry contain high concentrations of organic material such as proteins, carbohydrates, and lipids, high concentrations of suspended solids, high biological oxygen demand (BOD) and chemical oxygen demand (COD), high nitrogen concentrations, high suspended oil and/or grease contents, and large variations in pH. Such contaminants are emanated for production of confectionery item such as cakes, pastry, biscuits, cookies, dalmoth (namkeen, fried bhujia), snacks etc which necessitates a special kind of treatment to prevent or minimize the environmental pollution. The production unit of such industries require plentiful of water as such water pollution is also high. Most of the above kind of plants are small scale establishments which are commonly found in India though there are some larger one of either owned by multinationals or some big business house. The treatment of wastewater containing high amount of organic and nutrient loads (BOD,COD,N,P and oily matter) emerging out from various production units of above industries needs for elaborated processing of treatment composed of primary and secondary units and in some cases tertiary also. For providing all such units, a huge amount of space is required along with high costs which are constraints for many small scale project/plants. A relatively low cost, technically feasible appropriate treatment particularly biobased technology is very much urged to environmental scientists and engineers to explore a cutting edge tools particularly on the basis of application of aerobic suspended reactor for getting rid of the above mentioned problem. The proposed research shall be addressed on biological treatment of food related units focusing on confectionery /bakery effluent treatment.

Though physicochemical processes removes emulsified components, the cost of the reagents required for chemical treatment makes the process highly expensive. Moreover, COD cannot be reduced to a remarkable extent in this process. Consequently, biological waste water treatment becomes the most acceptable form of treatment as these wastes include high concentration of biodegradable components. Contemporary bakery and confectionery wastewater treatment process includes the following five steps:

(a) Screening

(b) Sand trap/ Oil and grease separation in a tank

(c) Flow equalization in a tank

(d) Activated sludge process / Biological Reactor

(e) Tertiary treatment.

With the view point of above, a research study was undertaken to explore the performance of the suspended growth reactor for the treatment of bakery and confectionery effluent by development of acclimatized seed of mixed nature in laboratory condition and then evaluating the various kinetic parameters pertaining to removal of organics and nitrogenous pollutant. Finally, an activated sludge reactor is designed on the basis of kinetic evaluation. From the kinetic data obtained, the applicability of ASP models can have a scope for practical/real life application in future.

Chapter-2

LITERATURE SURVEY

2.1 Bakery and confectionery industry

Baking is a food cooking method that uses prolonged dry heat by convection, rather than by thermal radiation. Heat is gradually transferred from the surface of cakes, cookies and breads to their centre. As heat travels, it transforms batters and dough into baked goods with a firm dry crust and a softer centre.

Fig. 2.1: Baking of cake and cookies

2.2 Bakery wastewater

Wastewater in bakeries is primarily generated from cleaning operations including equipment cleaning and floor washing. It can be characterized as high loading, fluctuating flow and contains rich oil and grease. Flour, sugar, oil, grease, and yeast are the major components in the waste (**Chen et al., 2006**). Normally, half of the water is used in the process, while the remainder is used for washing purposes (washing of equipment, floor, and containers).

The wastewater from the cake plants has higher strength than that from bread plants. The pH is in acidic to neutral ranges, while the 5 day biochemical oxygen demand (BOD_5) is from a few hundred to a few thousand mg/L, which is much higher than that from the domestic wastewater. The suspended solids from cake plants are very high. Grease from the bakery industry is generally high, which results from the production operations. The waste strength and flow rate are very much dependent on the operations, the size of the plants, and the number of workers. The plants with products of bread, bun, and roll, which are termed as

dry baking, production equipment (e.g., mixing vats and baking pans) are cleaned dry and floors are swept before washing down. The wastewater from cleanup has low strength and mainly contains flour and grease. On the other hand, cake production generates higher strength waste, which contains grease, sugar, flour, filling ingredients, and detergents. Bakery wastewater lacks nutrients; the low nutrient value gives BOD_5 : N : P of 284 : 1 : 2 (**Yim et al., 1975**). This indicates that to obtain better biological treatment results, extra nutrients must be added to the system. The existence of oil and grease also retards the mass transfer of oxygen. The toxicity of excess detergent used in cleaning operations can decrease the biological treatment efficiency. Therefore, the pretreatment of wastewater is always needed.

2.3 General characteristics of bakery wastes

For purposes of wastewater characterization, the bakery industry may be divided into two groups: dry baking such as bread, bun, and roll baking and production of cakes, pies, doughnuts, cookies, and sweet rolls. In dry baking, production equipment, such as mixing vats and baking pans, are typically cleaned dry, and floors are swept prior to wash down. Wastewater is produced from general cleanup operations and is of low strength; its major contaminants are flour and some grease. The second type of baking operation, such as cake production, generates wastes of much higher strength, containing grease, sugar, flour, filling ingredients, and detergents. Most of the production equipment, such as baking pans and trays, mixing vats, mixers, and milk, and other liquid containers, are water cleaned. Pans and trays are washed with hot detergents and greased after each baking. The spent liquid from pan washers constitutes one of the most important sources of wastewater. The average wastewater qualities of bakery and confectionery production units are stated in Table 2.1.

Table 2.1: Wastewater quality of bakery and confectionery industries [Yim et al. (1974)]

Type of Confectionery plant	pH	BOD_5 (mg/L)	Suspended Solid SS (mg/L)	Total Solid TS (mg/L)	Oil &Grease (mg/L)
Bread Plant	6.9–7.8	155–620	130–150	708	60–68
Cake Plant	4.7–8.4	2,240–8,500	963–5,700	4,238–5,700	400–1,200
Variety Plant	5.6	1,600	1,700	–	630
Unspecified	4.7–5.1	1,160–8,200	650–13,430	–	1,070–4,490

Table 2.2: Comparison of Bakery Equipment Wastewater Characteristics

Bakery Equipment	Source	pH	BOD_5	SS (mg/L)	VSS (mg/L)	TS (mg/L)	TVS mg/L	Grease mg/L
Pan Washer	**Baird et al. (1972)**	8.8	17300	21700	_____	_____	_____	_____
Rotary Pan Washer	**Grove et al. (1969)**	10.5	8100	_____	_____	12272	_____	_____
Tunnel Pan Washer		10.5	8200	_____	_____	13550	_____	_____
Rotary Pan Rinse		9.5	1005	_____	_____	1526	_____	_____
Tunnel Pan Rinse		9.7	1210	_____	_____	1915	_____	_____
Rotary Pan washer	**Yim et al. (1974)**	10.2	2860	1400	1350	5380	2350	2370
Rotary Pan Rinse		9.9	1760	500	489	2620	1260	739
Boil Tank		9.2	3070	3140	3020	23650	15610	10960

Table 2.3: Summary of Waste Production from the Bakery Industry (Gainer et al., 1998)

Manufacturer	Products	Wastewater production (L/tonne)	COD (kg/tonne)	Contribution to total COD loading (%)
Bread and bread roll	Bread and bread roll	230	1.5	63
Pastry	Pies and sausage rolls	6000	18	29
Specialty	Cake, biscuits, donuts, and Persian breads	74	-	-

Confectionery industry generates high amounts of wastewater which contains high concentrations of readily biodegradable organic materials characterized with high COD and BOD (**Beal & Raman, 2000**; **Diwani et al., 2000**).

Orhon et al. (1995) determined the initial soluble inert COD percentage of confectionery industry wastewaters between 1.5-7.1% under aerobic conditions. Some examples from the literature for the characterization of the wastewater discharged from the confectionery industry were provided in Table 2.4.

Table 2.4: Characterization of the wastewater discharged from the confectionery industry

Parameters	(El- Gohary et al., 1999)	(Orhon et al., 1995)	(Diwani et.al., 2000)	(Ozturk & Altinbas, 2008)
COD (mg/L)	4475	2840-6220	5000	19900
$COD_{soluble}$ (mg/L)	-	2500-5400	-	-
BOD (mg/L)	2200	1840-4910	3200	-
TKN (mg/L)	100	33-55	-	-
TP (mg/L)	172		-	-
TSS (mg/L)	649	260-440	177	1050
VSS (mg/L)	490	-	-	-
pH (mg/L)	-	4-51	6	-
Oil and grease (mg/L)	367	-	-	-

2.4 Bakery wastewater treatment systems and processes

In general bakery wastewater contains high contents of organic pollutants, suspended solids (SS) and fats, oils and greases (FOG) which result in a high chemical oxygen demand (COD). Whether discharging direct or to a municipal plant, effectively treating wastewater with high COD requires a series of physical, chemical and biological treatment processes.

The main organic components in bakery wastewater are flour, sugar, oil, grease, and yeast. Primary treatment of bakery wastewater involves reducing the suspended solids and removing the floatable FOG. Secondary treatment involves removing the dissolved biodegradable components through a biological process using microorganisms/bacteria.

The volume and strength of the wastewater depends on the products/processes and varies according to the operational times of the bakery. For example, pastry produces the greatest volume of wastewater while cakes produce the strongest wastewater. Because the flow rate and loading of bakery wastewater will vary throughout the day, an equalization tank or buffer tank for temporary storage can help to meet the demands of peak discharge times.

Owing to the high organic content, it is not recommended that bakery wastewater be directly treated by aerobic treatment processes. However, there are a few cases of this reported in the literature, including a study from Keebler Company (**Givens et al., 1988**). The company produces crackers and cookies in Macon, Georgia. The fats oil and greasy matter as lump parameter as FOG and pH of the wastewater from the manufacturing facility were observed higher than the regulated values. Wastewater was treated by an "aerobic activated sludge process", which included a bar screen, nutrient feed system, aeration tank, clarifier, and sludge storage tank. Owing to the poor nutrient content in the influent, nutrient was fed directly into the aeration tank. Not all the added nitrogen was consumed in the treatment, thus the total Kjeldahl nitrogen (TKN) concentration in the effluent was higher than that in the influent. The high HRT(2.8 days) shows that the process was not in fact economical. The bakery wastewater treatment can be more cost-effective if the waste is first treated by an anaerobic process and then an aerobic process.

The Operational parameters in the keebler company was HRT = 2.8 day; MLSS =3300 mg/L; VSS=2600 mg/L; DO=2.2 mg/L; F/M = 0.07 1b BOD/1b VSS/day; Yield =0.32

Table 2.5: Summary of Wastewater Treatment in the Keebler Company (Givens et al., 1988)

Parameter	Influent: Design basis	Influent: Operation	Effluent
Flow rate (gpd)	51200	37000	-
pH	5.6	6.0	6.8
TCOD	1620	830	65
TBOD	891	500	39
TS	756	-	11
FOG	285	-	3
TKN	-	2	5
PO_4-P	-	3	3

2.4.1 Primary Treatment/Pretreatment

Pretreatment or primary treatment is a series of physical and chemical operations, which precondition the wastewater as well as remove some of the wastes. The treatment is normally arranged in the following order: screening, flow equalization and neutralization, optional FOG separation, optional acidification, coagulation–sedimentation, and dissolved air flotation (**Chen et al., 2006**).

Primary treatment requires a screening process to firstly remove any coarse particles in the bakery sewage. Screens vary in the size of the openings from micrometers to in excess of 100 millimeters. The right type of screen will depend on the characteristics of the wastewater and the requirements of the bakery.

The next step in the treatment process involves separating and skimming fat oil and grease (FOG) from the screened wastewater. Traditional treatment systems use mechanical scrapers to remove FOG from bakery wastewater. The FOG can be separated and recovered for possible reuse, as well as reduce difficulties in the subsequent biological treatment (**Givens et al., 1988**).

Acidification can further help to break down any remaining FOG by adding an acid such as sulfuric acid which helps to keep the pH at an optimal level. **Grove et al. (1969)** designed a treatment system using nitric acid to break the grease emulsions followed by an activated sludge process. A BOD_5 reduction of 99% and an effluent BOD_5 of less than 12 mg/L were obtained at a loading of 40 lb BOD_5/1000 ft^3 and detention time of 87 hour. The nitric acid also furnished nitrogen for proper nutrient balance for the biodegradation.

Coagulation and flocculation work on any remaining fine SS by making the particles clump together for easier removal with the addition of chemicals such as alum and ferric chloride combined with a mixing process. The pH and coagulant dosage are important in the

treatment results. **Liu and Lien (2001)** reported that 90–100 mg/L of alum and $FeCl_3$ were used to treat wastewater from a bakery that produced bread, cake, and other desserts. The wastewater had pH of 4.5, SS of 240 mg/L, and COD of 1307 mg/L. Values of 55% and 95–100% for removal of COD and SS, respectively, were achieved. The optimum pH for removal of SS was 6.0, while that for removal of COD was 6.0–8.0.

Dissolved air flotation (DAF) is usually implemented by pumping compressed air bubbles to remove fine SS and FOG in the bakery wastewater. The wastewater is first stored in an air pressured, closed tank. Through the pressure-reduction valves, it enters the flotation tank. Due to the sudden reduction in pressure, air bubbles form and rise to the surface in the tank. **Liu and Lien (2001)** used a DAF to treat a wastewater from a large-scale bakery. The wastewater was preconditioned by alum and ferric chloride. With the DAF treatment, 48.6% of COD and 69.8% of SS were removed in 10 min at a pressure of 4 kg/cm2, and pH 6.0. **Mulligan (1967)** used DAF as a pretreatment approach for bakery waste. At operating pressures of 40–60 psi, grease reductions of 90–97% were achieved. The BOD_5 and SS removal efficiencies were 33–62% and 59–90%, respectively.

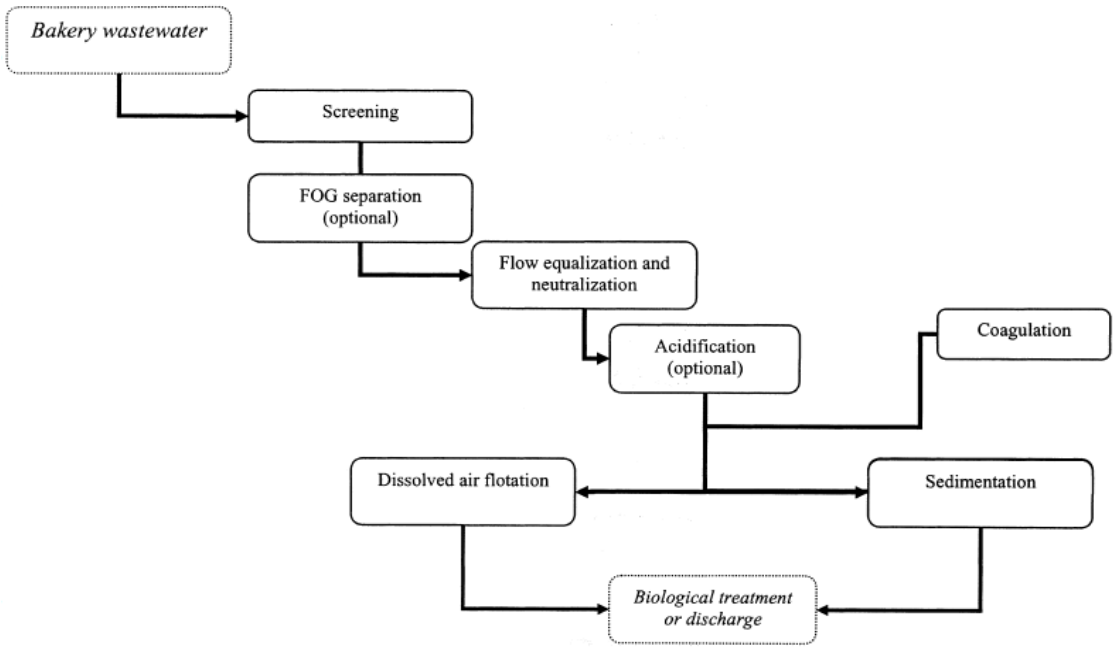

Fig. 2.2- Bakery wastewater pretreatment system process flow diagram [Chen et al., 2006]

2.5 Biological treatment of bakery wastewater

The objective of biological treatment is to remove the dissolved and particulate biodegradable components in the wastewater. It is a core part of the secondary biological treatment system. Microorganisms are used to decompose the organic wastes. With regard to different growth types, biological systems can be classified as suspended growth or attached growth systems. Biological treatment can also be classified by oxygen utilization: aerobic, anaerobic, and facultative. In an aerobic system, the organic matter is decomposed to carbon dioxide, water, and a series of simple compounds. If the system is anaerobic, the final

products are carbon dioxide and methane. Compared to anaerobic treatment, the aerobic biological process has better quality effluent, easies operation, shorter solid retention time, but higher cost for aeration and more excess sludge. When treating high-load influent (COD>4000 mg/L), the aerobic biological treatment becomes less economic than the anaerobic system. To maintain good system performance, the anaerobic biological system requires more complex operations. In most cases, the anaerobic system is used as a pretreatment process. Suspended growth systems (e.g., activated sludge process) and attached growth systems (e.g., trickling filter) are two of the main biological wastewater treatment processes. The activated sludge process is most commonly used in treatment of wastewater. The trickling filter is easy to control, and has less excess sludge. It has higher resistance loading and low energy cost. However, high operational cost is its major disadvantage. In addition, it is more sensitive to temperature and has odor problems. Comprehensive considerations must be taken into account when selecting a suitable system.

2.5.1 Activated Sludge Process

The basic concept of Activated Sludge Process was first developed in England in 1914. Wastewater containing high amounts of biodegradable organic wastes is treated with microbes in aeration basin. The microbes degrade the pollutants, thereby, reducing BOD of waste water. The microbes are separated out from the treated water in the final clarifier. This mass of microbes constitutes activated sludge.

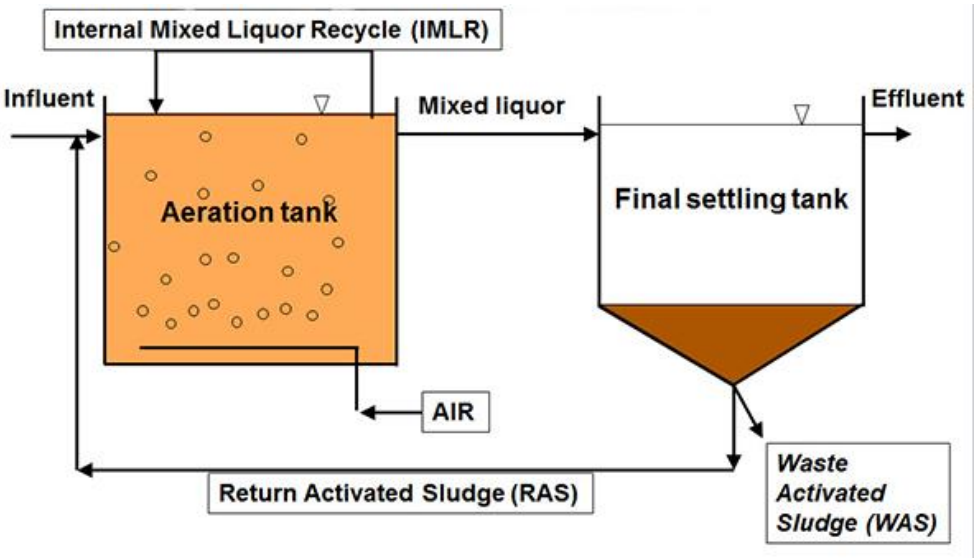

Fig. 2.3: Conventional activated sludge

- **Role of microbes in activated sludge process**

  The main functions of microbes in activated sludge process are detailed below:

- ❖ Reduction of BOD of waste water
- ❖ Degradation of dissolved and particulate organic matter into cell mass

- As water passes through the aeration basin, with time, decrease in BOD gets coupled with increase in microbial cell mass (MLSS).

• Influential Environmental Factors that affect microbial growth

Performance and efficiency of a waste water treatment plant directly depends on the strict maintenance of its controls. Environmental conditions like availability of food and space, maintenance of aseptic conditions, temperature conditions, availability of adequate amount of dissolved oxygen etc. play major role in activated sludge process. Few factors have been detailed below:

- **Food Availability:** The dissolved wastes in effluent of a waste water treatment plant serve as food for the microorganisms which feed on the waste and in turn grow and multiply in number. Evidently, higher the amount of biodegradable waste in effluents, more will be the growth of microbes. It must be noted here, that the microbes mainly feed on the soluble wastes. Thus, greater amount of soluble waste promote growth of microbial population. Approximate estimation of the mass of microbial population in an aeration basin after a certain time may be made by measuring the total BOD and the soluble BOD of the effluent.

- **Maintenance of BOD to Nutrient Ratio:** Apart from the soluble organic food that is available to the microorganisms as food, the microbes also require certain mineral nutrients or trace elements for their survival. These elements may or may not be present in the incoming effluents. In case these elements are absent or present in insufficient amounts, additional nutrient supplement must be supplied to the aeration basin because unavailability of nutrients may hinder microbial metabolism and growth. Nutrient supplements are generally rich in growth promoting substances like nitrogen, phosphorous, potassium etc. The average range of BOD: Nitrogen: Phosphorous = 100:5:1.

- **Speed of Effluent Flow:** The speed of effluents that flows through a waste water treatment plant must be sufficiently low. This is because the microorganism must be allowed the time to consume (or degrade) the organic wastes. Very high speed of effluents reduces the time of degradation and thereby, 'treats' water incompletely. It may also wash away a portion of microbial population, thereby, draining out a fraction of MLSS. Besides, the current of waste water produced due to its flow in aeration basin increases the mixing of atmospheric oxygen into the effluents, thus, helping microbial growth.

- **Oxygen Availability:** Availability of adequate amount of oxygen is a fundamental requirement for conventional activated sludge process. The microbes perform aerobic respiration and hence, require free or molecular oxygen to survive. Generally, the level of Dissolved Oxygen (DO) of an aeration tank should lie between 1.0 - 3.0 mg/L. In a treatment plant, the level of dissolved oxygen (DO) must be monitored on a regular basis.

- **Temperature Regulation:** Most of the solids, including proteins, non biodegradable / biodegradable waste, enzymes etc. used in waste water treatment are thermo-labile, that is these get degraded or deactivated on heating. Even exposure to higher temperature may kill the microbes entirely. It has been noted that cooler temperature generally slows down/ inhibits the growth of microbes because most of the reactant inactivates and metabolism decelerates. In higher temperature, metabolic rates in microbes accelerate and it exhibit increased performance up to a certain extent. The

optimum temperature which generally presents maximum microbial growth is 10°C to 20° C. Temperature condition must be regulated checked at all levels in a waste water treatment plant.

- **pH:** Chemical(or biochemical) reactions directly depends on the maintenance of its pH. Even slight alternation in the value may adversely affect the growth of microbes. These conditions should be rigorously maintained in a waste water treatment plant.
- **Toxicity:** The incoming effluent may contain toxins / poisonous chemicals that may directly or indirectly inhibit microbial growth. In such conditions, these chemicals must be immediately removed from the system, failing which the performance of the activated sludge process and the treatment plant will drastically fall.

- **Conditions favoring growth of filamentous organisms**
  - Low DO
  - Low food to microorganism (F/M) ratio
  - Low pH
  - High sulfides
  - Nutrient deficiency
  - Excessive grease

  (Source: Biological Treatment: Suspended Growth Processes Study Guide; Wisconsin Department of Natural Resources; August 2015 Wisconsin Department of Natural Resources Operator Certification Program PO Box 7921, Madison, WI 53707 http://.dnr.wi.gov)

- **Conditions favoring growth of nitrifying bacteria**
  - DO greater than 1.0 mg/L
  - pH between 7.0 and 8.5
  - Alkalinity greater than 50 mg/L
  - Temperature between 50ºF and 85ºF (10ºC to 30ºC)

  (Source: Biological Treatment: Suspended Growth Processes Study Guide; Wisconsin Department of Natural Resources; August 2015 Wisconsin Department of Natural Resources Operator Certification Program PO Box 7921, Madison, WI 53707 http://.dnr.wi.gov)

- **Conditions favoring growth of denitrifying bacteria**
  - DO less than 0.2 mg/L
  - pH between 7.0 and 8.5
  - Adequate organic matter (BOD)

- ❖ Temperature between 50ºF and 85ºF (10ºC to 30ºC)

(Source: Biological Treatment: Suspended Growth Processes Study Guide; Wisconsin Department of Natural Resources; August 2015 Wisconsin Department of Natural Resources Operator Certification Program PO Box 7921, Madison, WI 53707 http://.dnr.wi.gov)

2.5.1.1. Process variations of activated sludge process

- **Plug Flow Activated Sludge Process**

Plug flow activated sludge process is a conventional method in which the influent activated sludge [either Recycled Activated Sludge (RAS) or Wasted Activated Sludge (WAS)] is introduced into the aeration tank from the top portion and the sludge is made to flow through the system at a constant rate in a serpentine manner right up to the end point / discharge point. This type of sludge shows best performance if the sludge age is 3 - 10 days. Beyond 15 days of sludge age, it becomes inappropriate of usage.

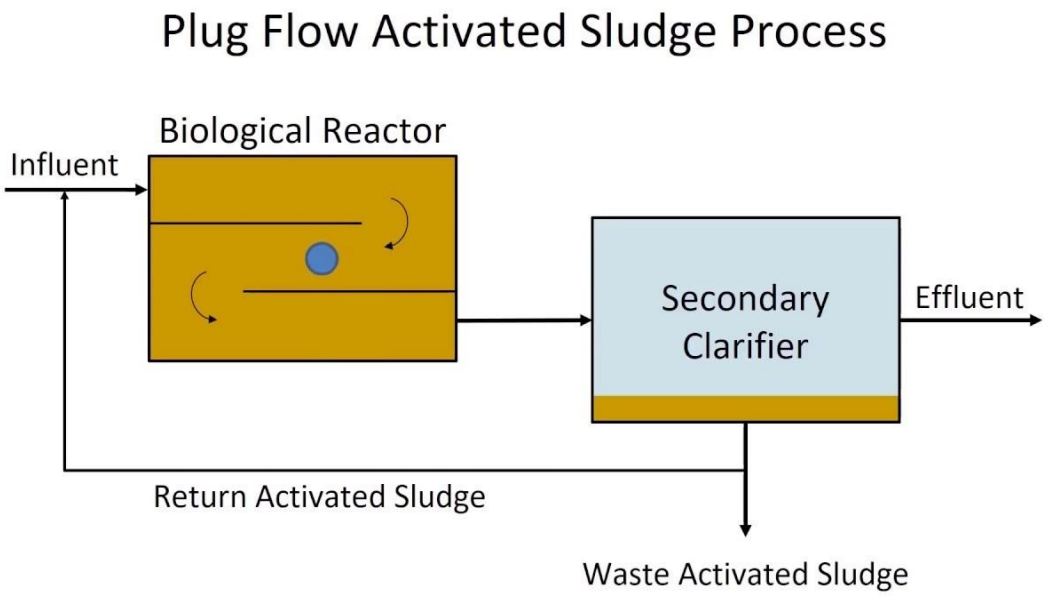

Fig. 2.4: Plug Flow Activated Sludge Process

- **Step Feed Activated Sludge Process**

Step feed activated sludge process is modification of the conventional activated sludge process. In step-feed aeration, primary effluent enters the aeration tank at several points along the length of the tank, rather than at the beginning or head of the tank and flowing through the entire tank in a plug flow mode.

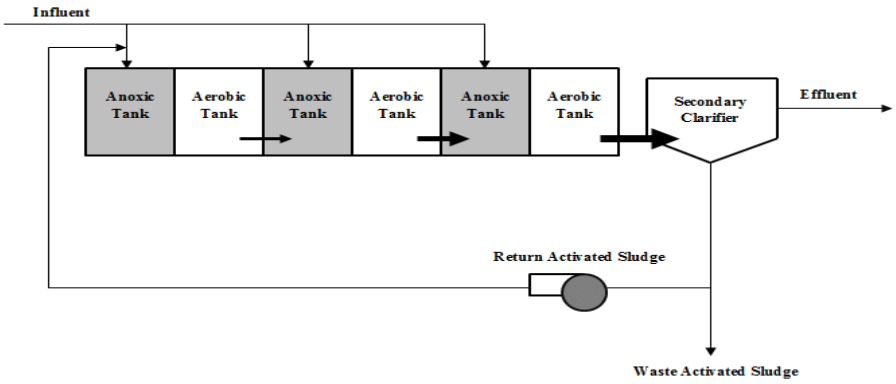

Fig. 2.5: Step feed Activated Sludge Process

- ## Extended Aeration Activated Sludge Process

This is the best conventional method if highly treated effluents and minimum wasted activated sludge (WAS) is required to be produced. In **extended aeration** process the raw sewage goes straight to the aeration tank for treatment. The whole process is aerobic. This simplification implies longer aeration time which has earned for the process the name "extended aeration". The BOD removal efficiency of the extended aeration process is higher than activated sludge process which makes it especially desirable to use where it is to be followed by tertiary treatment for reuse.

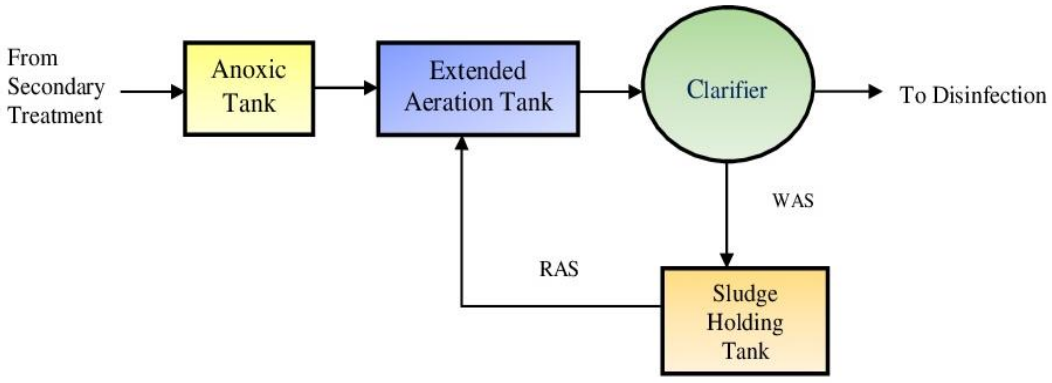

Fig. 2.6: Step feed Activated Sludge Process

- ## Completely Mixed Activated Sludge Process

Completely mixed activated sludge process is mostly used in industrial activated sludge plants where obtainment of high quality effluent is not a requirement. In the process, the contents of the aeration tank are readily mixed such that there might be a homogenized distribution of food (biochemical oxygen demand), microorganisms, dissolved oxygen (DO) etc. in the system. This ensures that the system suitably adjusts and works well even during surges in loading.

2.5.1.2 SBR for secondary treatment of bakery wastewater

A sequential batch reactor (SBR) is very effective biological treatment system that uses the activated sludge process. An SBR system treats batches of wastewater in a timed sequence. While the final clarifier is settling and decanting, the bioreactor is aerating and filling. Clear water collects in the top of the clarifier where it is now clean and suitable for discharge. SBR is just one method of biologically treating wastewater from a bakery; there are many other methods also. Again, the most suitable system will depend on the size of the bakery and the characteristics of the wastewater.

In the end, the most important thing to realize is that without a treatment system, bakery wastewater is harmful to the environment. It could potentially be harmful to the business too if discharging it without a license or failing to meet the conditions of an existing license. Installing a treatment plant in a bakery doesn't have to be a monumental task, a reliable wastewater treatment company will help to come up with a solution that meets the requirements of both the bakery and the discharge consent.

2.6 Basic Components of bakery wastewater treatment

- **Collection pit:** These pits are connected to plant where all waste water are collected it could be at different locations or a big tank at one place

- **Oil and Grease trap:** an Oil and grease trap separates the fat and oil content from bakery wastewater. It uses gravity concept for separation of oil & fat. Fat floats on the surface and is taken out manually through different tools.

- **Bar and screen Rack:** A bar and screen is a device with openings for removing bigger suspended or floating matter in sewage which would otherwise damage equipment or interfere with satisfactory operation of treatment units.

- **Equalization tank:** It's a settling tank which allows different stream of waste water mix properly prior to treatment. pH correction is done in this tank. Soda flakes are added to increase the alkalinity of the water. Quantity depends upon the volume of the water. Dosing pumps are used for automated discharge of quantity into the waste water.

- **Aeration tank**: Here this waste water is mixed with air through aerators submerged either in the surface or placed in the bottom. Air is generated through blowers and has enough pressure to come out from membranes attached in aerators. These tanks are sometimes packed with bio culture which enhances sludge formation and are called bioreactors. Different types of bio culture are available for wastewater treatment e.g. packed bed, moving media, fibrous bed and membrane. Some times for better performance anaerobic tanks are placed before these aeration tanks which improve the quality of the waste water. It has been observed that 60-70% reduction in BOD at anaerobic tanks with retention time up to 1- 4 days. Anaerobic

reactors have submerged media on which these microorganisms live and digest these bio degradable materials.

- **Clarifier**: These are settling tank where sludge are allowed to settle down and clear treated water are discharged either to main treatment plant which is further treated and discharge into river / sea or recycled and used for gardening or agricultural use.
- **Sludge drying bed**: The sludge settled in these tanks is then pumped through pumps on sludge drying bed. Beds could be four to six in numbers so that they can be used alternatively as sludge drying takes some times. This sludge is then disposed out in municipality approved sites.
- **Filter Units**: Sometimes activated carbon filters are attached after clarifiers to clear waste water from suspended solids and foreign particles. Flocculants are added in water prior to clarifier to further improve the quality of water.

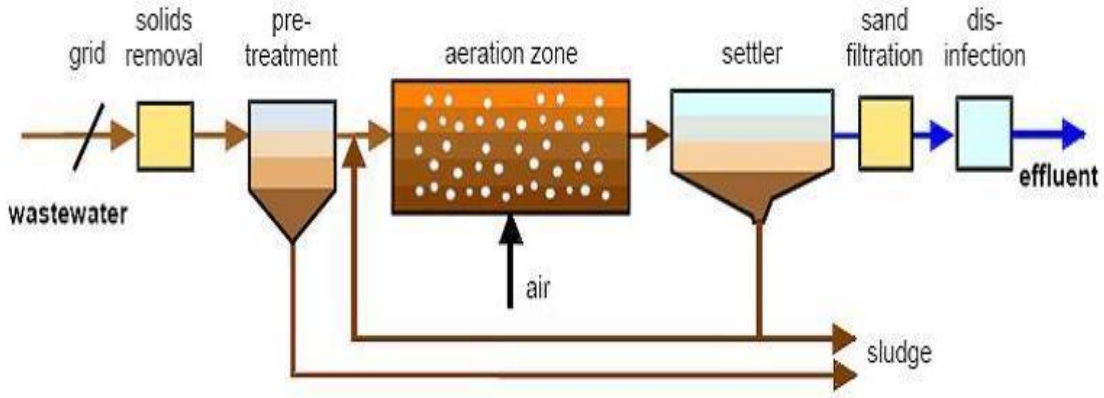

Fig. 2.7: Complete activated sludge process with pretreatment and post treatment

2.7 Literature survey on removal studies

Ohnishi (2002) described about confectionery wastewater treatment which released a wastewater volume of 160 m^3/day with average BOD quality of 4000 mg/L. In this context he suggested a flow sheet for treatment of such wastewater which is shown in Fig. 2.8. The nutrient balance in the wastewater is BOD: N: P = 100: 0.2: 0.1 for the castella (sponge cake) factory. The summarized result obtained by him is shown in Table 2.6.

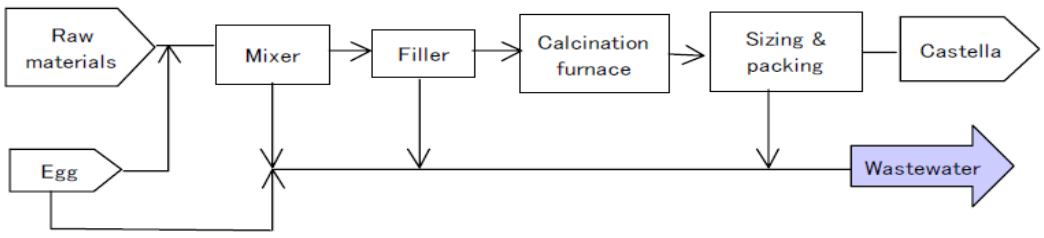

Fig. 2.8: Schematic flow of Castella (sponge cake) processing and wastewater (ohnishi M., 2002)

Table 2.6- Treatment output of confectionery effluent (Ohnishi M., 2002)

Waste water volume	Parameters	Influent (mg/L)	Effluent (mg/L)
160 M^3/Day	BOD	4000	10
	COD_{mn}	2500	20

Ozgun et al. (2012) conducted a treatability study on confectionery wastewater. They have mentioned very little information available about characteristics of the confectionery wastewater. In this context a detailed study had been carried out by them on characterization as well as performance evaluation of confectionery wastewater treatment system. They have treated the wastewater with an average COD value of 1900 mg/L and COD removal efficiency was 89.73%. The sludge age of the reaction was calculated as 22 days. F/M ratio was adopted as 0.01 and hydraulic retention time was 4.9 days. The summarized result as obtained by them is shown in Table 2.7.

Table 2.7- Treatment output of confectionery effluent (Ozgun et al. 2012)

Parameters	**Influent**	**Effluent**
Overall COD load (kg/day)	1900	195
COD load from equalization tank (kg/day)	1260	95
Total suspended solid (mg/L)	1240	110

Givens et al. (1988) conducted a case study in two confectionery and bakery production company at Macon, Georgia. In one such company influent COD and BOD was respectively 4560 mg/L and 2380 mg/L and effluent COD and BOD was 50 mg/L and 9 mg/L. The pH of influent and effluent wastewater was respectively 6.2 and 7.

In the wastewater of second company, COD and BOD in the influent wastewater were found to be 830 mg/L and 500 mg/L respectively. In the effluent wastewater the COD and BOD was 65 mg/L and 39 mg/L. The pH of influent and effluent wastewater was 6 and 6.8. The summarized result as obtained by them is shown in Table 2.8.

Table 2.8- Treatment output of confectionery effluent (Givens et al., 1988)

	Tom's Foods Inc. (1^{st})		Keebler company (2^{nd})	
Parameters	Influent	Effluent	Influent	Effluent
COD (mg/L)	4560	50	830	65
BOD (mg/L)	2380	9	500	39
pH	6.2	7	6	6.8

Chapter-3

OBJECTIVE AND SCOPE OF THE STUDY

3.1 Objective of the Study

The objective of the present investigation was to perform a treatability study of food processing waste water using a laboratory scale suspended growth reactor. The food processing unit has been considered as bakery and confectionery origin in the present investigation.

The specific objectives as scope of studies included are –

- Collection of real life wastewater of food related plant with reference to bakery and confectionery plant.
- Characteristic of above wastewater.
- Preparation of simulated wastewater sample for batch study.
- Development of acclimatized seeds.
- Batch kinetic studies for performance and removal studies [batch treatability study]
- Determination of various kinetic co-efficient for design of biological reactor.
- Theoretical design of bioreactor (suspended growth system) using evaluated kinetic constants.

3.2 Scope

- The scope of present study is to evaluate the performance efficiency of batch system in a suspended growth reactor, for COD removal and nitrification of simulated bakery and confectionery wastewater sample and determine the kinetic constants with varying input of process parameters.
- Study of the effect of various influencing factors like COD, MLSS, solid retention time(θ_C), influent concentration on removal efficiency
- Evaluation of carbon oxidation aspect in batch reactor for bakery and confectionery wastewater treatment.
- Evaluation of nitrification aspect in batch reactor for bakery and confectionery wastewater treatment.

Chapter-4

THEORETICAL CONSIDERATION

4.1 Organic Carbon Oxidation

Biological treatment of wastewater is employed for coagulation and removal of non-settleable fraction of organic colloids as well as stabilization of dissolved organic matter. The removal of carbonaceous BOD, the coagulation of non-settleable colloidal solids and stabilization of organic matter are accomplished by micro-organisms, sharing principally by bacteria. A typical biochemical reaction involved in the conversion of the colloidal and dissolved carbonaceous organic matter into simple end products and additional biomass is given **equation-4.1.**

In accomplishing such treatment, the chemoheterotrophic organisms are effective and of primary importance as they need substrate for fulfilment of both carbon and energy requirement, which they obtain from organic compounds. In aerobic respiration process molecular oxygen is used as electron acceptor in respiratory metabolism. A definite stoichiometric relationship exists between the substrate utilized, the amount of oxygen consumed during aerobic heterotrophic biodegradation and the observed biomass yield given hereunder.

4.1.1 Oxidation and Synthesis

v_1 [organic material (COHNS)] + v_2O_2 + v_3NH_3 + v4PO_4^{3-} + microorganisms v_5 (new cells) + v_6CO_2 + v_7H_2O …….... (4.1)

Where, v_i = stoichiometric coefficient.

However, if the organic matter is represented as glucose **($C_6H_{12}O_6$)** and new cells are represented as **$C_5H_7O_2N$** (**Hoover and Porges, 1952**), neglecting nutrients other than nitrogen.

Equation-4.1 can be written as:

$3C_6H_{12}O_6+8O_2+2NH_3 \longrightarrow 2\ C_5H_7O_2N+8CO_2+14H_2O$……..…(4.2)

The substrate (glucose) used is divided between that found in new cells and that oxidized. The yield based on the glucose consumed can be obtained as follows:

$Y=\Delta(C_5H_7O_2N)/\Delta(C_6H_{12}O_6)$ = 2×(113g/mole)/3×(180 g/mole)=0.42g cells/g glucose

In practice, COD and MLSS are used to represent the organic matter and the new cells, respectively owing to easiness of estimation methodology and restricted time requirement. To express the yield on a COD basis, the COD of glucose must be determined

by virtue of a balanced stoichiometric reaction for the oxidation of glucose to carbon dioxide as follows:

$$\mathbf{C_6H_{12}O_6+6O_2 \longrightarrow 6CO_2 +6\ H_20 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)}$$

The COD of the glucose is given by:

$$\mathbf{COD = \Delta(O_2)/\Delta(C_6H_{12}O_6)= 6\times(32g/mole)/(180\ g/mole)= 1.07g\ O_2/g\ glucose}$$

Thus, the theoretical yield expressed in terms of COD, accounting for the portion of the substrate converted to new cells, is

$$\mathbf{Y= \Delta(C_5H_7O_2N\ )/\Delta(C_6H_{12}O_6\ as\ COD)}$$

$$\mathbf{= 2\times(113gm/mole)\ /\ [3\times(180\ gm/mole)\ \times\ (1.07g\ COD/g\ glucose)]}$$

$$\mathbf{= 0.39g\ cells\ /g\ COD\ used}$$

In the case of endogenous respiration, although the reaction results in relatively simple end products and energy, stable organic end products are also formed.

4.1.2 Endogenous Respiration

$$\mathbf{C_5H_7O_2N+5O_2 + microorganisms \rightarrow\ 5CO_2 +2\ H_20 + NH_3 + energy\ \ldots..(4.4)}$$

The COD of the cell tissue is

$$\mathbf{COD = \Delta(O_2)/\ \Delta(C_5H_7O_2N\ ) = 5\times(32g/mole)\ /\ (113g/mole) = 1.42g\ O_2/\ g\ cells}$$

Thus, it can be concluded that, if all of the cells can be oxidized completely, the ultimate BOD of the cells is equal to 1.42 times the concentration of cells.

4.2 Nitrification

Nitrification is the two-step process for the conversion of ammoniacal nitrogen to nitrate or nitrite which is shown in **equation-4.5.** Ammonium nitrogen is oxidized to nitrite by **ammonia oxidizing bacteria (AOB)** and then to nitrate by **nitrite oxidizing bacteria (NOB).** In most of the cases, negligibly small amount of nitrite exists in a system because the conversion of ammonium to nitrite by AOBs is generally the rate-limiting step. Consequently, nitrite oxidation occurs quickly and the nitrate thus formed can be used as a nitrogen source or as an electron acceptor. Many domestic wastewater treatment systems terminate treatment of wastewater at this stage. However, nitrate can also have some detrimental effects on the environment. Therefore, nitrogen removal systems that incorporate denitrification are becoming more common regions where eutrophication of surface waterbodies is occurring.

$$NH_4^+ + O_2 \xrightarrow{\textbf{AOB}} NO_2^- + O_2 \xrightarrow{\textbf{NOB}} NO_3^- \textbf{.....(4.5)}$$

The total ammoniacal nitrogen **(TAN)** in the wastewater originates from the breakdown of urea by the enzyme urease, which is present in fecal matter, and the breakdown

of proteins in organic matter, which contain amine groups. The combination of the urine and feces releases a large amount of ammonia. Microorganisms responsible for nitrification are **Nitrosomonas, Nitrobacter, Nitrosospira, Nitrosolobus, Nitrosovibrio,** and **Nitrosococcus**. These generations of organisms are autotrophic, so their carbon source is carbon dioxide (CO_2). Ammonia oxidizing bacteria, such as **Nitrosomonas**, utilize the reduced nitrogen in ammonia as the electron donor, or energy source. They oxidize it to form nitrite (NO_2^-), using oxygen (O_2) as the terminal electron acceptor (TEA). Nitrite-oxidizing bacteria, such as Nitrobacter, then use the nitrite as their energy source with oxygen as the TEA to form nitrate (NO_3^-). Approximate equations for nitrification process are-

For **Nitrosomonas:**

$$\mathbf{55NH_4^+ + 76O_2 + 109HCO_3^- \rightarrow C_5H_7O_2N + 54NO_2^- + 57H_20 + 104H_2CO_3} \quad \mathbf{\ldots\ldots\ldots(4.6)}$$

For **Nitrobacter:**

$$\mathbf{400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO3^- + 195O_2 \rightarrow C_5H_7O_2N + 3\ H_20 + 400\ NO_3^-} \quad \mathbf{\ldots\ldots(4.7)}$$

One difficult thing about this process is that ammonia-oxidizers grow slower than typical heterotrophic organisms, which compete with them for oxygen. Nitrite oxidizers have a higher growth rate but are dependent on ammonia-oxidizers for supply of nitrite. Therefore, the magnitude of time over which microbial biomass must remain in a single reactor must be longer than treatment system designed for COD removal only in order to provide sufficient time for the nitrifying bacteria to grow. Removal of bio-solids from the waste treatment system at a high rate (short SRT) would cause the organisms to be flushed out before being able to establish the nitrogen removal process. Optimal nitrification occurs at a temperature range between 28° and 33° C, a dissolved oxygen content of at least 1 mg/L and a pH between 7.5 and 8.6 (**McGhee, 1991; Crites and Tchobanoglous, 1998).**

4.3 Biomass growth kinetics and substrate removal

❖ Growth kinetics

Bacterial growth phases can be schematically represented as follows:

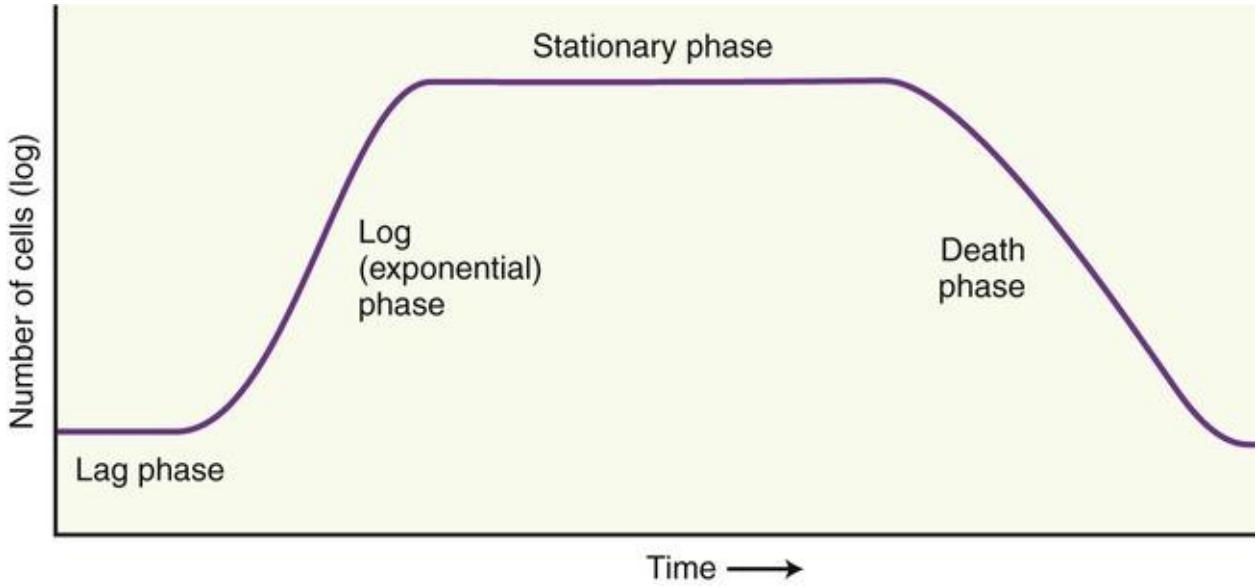

Fig. 4.1: Bacterial growth phases

It is seen that in log phase, bacterial mass or biomass increases proportionally with time. It can be mathematically expressed as: $\frac{dx}{dt} \propto X$

Where, $\frac{dx}{dt}$ = growth rate of biomass, mg/L-t.

X = concentration of biomass, mg/L

Introducing a constant, $\frac{dX}{dt} = KX$

Where, K= growth rate constant, t^{-1}.

The value of this growth rate constant can be evaluated from Monod Equation:

$$K = \frac{K_0 S}{K_s + S}$$

Where,

K_0 = maximum growth rate constant, t^{-1}

S = limiting substrate concentration in the solution, generally expressed as mg/L BOD.

K_s = half saturation constant, i.e., substrate concentration at growth rate constant equal to half the value of maximum growth rate constant, mg/L.

Now, rate of biomass growth can be written as

$$r_x = \frac{dX}{dt} = \left(\frac{K_0 S}{K_s + S}\right) X$$

CASE I: Considering excess substrate to be present and the system to be enzyme limited,

S>> K_s then the equation becomes $r_x = K_0 X$

CASE II: Considering the system to be substrate limited, $r_x = \frac{K_0}{K_s} X$

As microbes grow, they consume the substrate present in the reactor. The substrate consumption or utilization rate is thus inversely proportional to the growth rate of biomass.

Mathematically, $\frac{dx}{dt} \alpha \left(-\frac{ds}{dt}\right)$

Or, $\frac{dx}{dt} = Y\left(-\frac{ds}{dt}\right)$ which can be also represented as $r_x = -Y r_s$

Where, $r_s = \frac{ds}{dt} =$ rate of substrate utilization, mg/L.

Y = growth yield coefficient = $-\frac{r_x}{r_s}$ = decimal fraction of substrate converted to biomass, expressed as mg/L biomass produced/ mg/L substrate utilized.

Typical values of Y for aerobic reactions are about 0.4 to 0.8 kg biomass/kg BOD_5. Now, endogenous metabolism takes place towards the end of the log phase simultaneously with the growth of micro organisms. In that case, rate of growth will be inversely proportional to the rate of endogenous activity. Mathematically,

$$\frac{dx}{dt} \propto -X$$

$$\text{Or,} \quad \frac{dx}{dt} = -k_d X$$

Where, K_d = endogenous decay constant, t^{-1}

$\therefore \frac{dx}{dt} = \frac{K_0 SX}{K_s + s} - k_d X$

In initial phases of growth curve, endogenous metabolism has negligible effect and thus can be neglected.

Rate of oxygen uptake (r_o) is the rate at which oxygen is consumed by the microbes to degrade the organic matters and is related with substrate utilization rate, r_s as:

$$r_0 = -r_s - 1.42 r_x$$

Where, the terms used are in their usual meanings as stated earlier.

❖ Mass balance equation

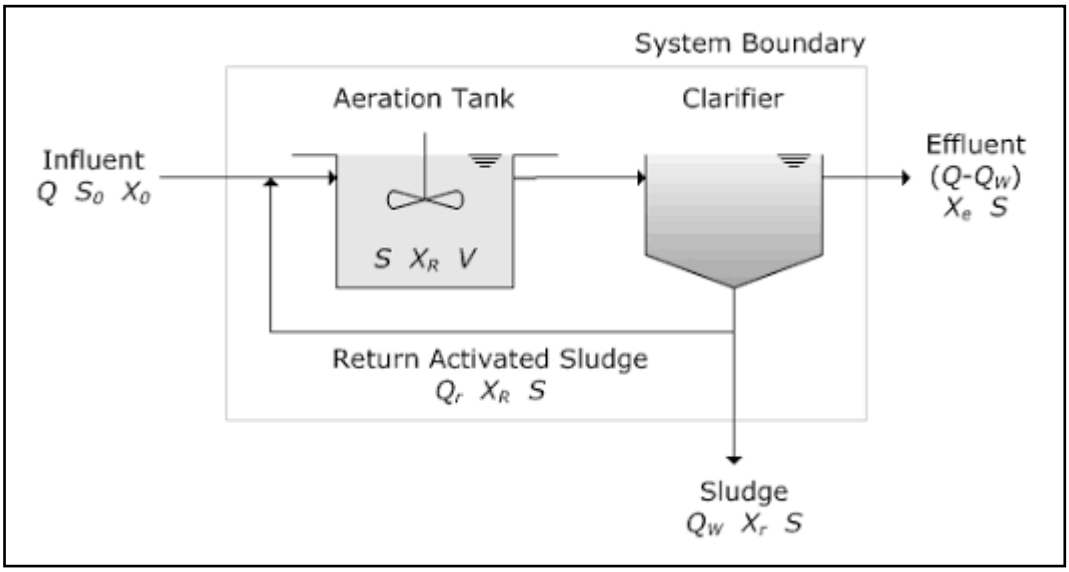

Fig. 4.2: Schematic diagram of activated sludge process (http://www.lenntech.com)

At steady state condition, when there is no change in biomass and food concentration with time, according to law of conservation of mass, mass balance equation of biomass gives,

(Biomass in) + (biomass growth) = biomass out (i.e. biomass in effluent + wasted sludge).

Or, $QX_0 + V\left(\frac{K_0SX}{K_s+S} - k_dX\right) = (Q - Q_w)X_e + Q_wX_r$

Mass balance equation of substrate gives,

Substrate in - substrate consumed = substrate out

Or, $QS_0 + \left(\frac{V}{Y}\right)\left(\frac{K_0SX}{K_s+S}\right) = (Q - Q_w)S + Q_wS$

Where,

Q, Q_W = influent and waste sludge flow rate, respectively m^3/d.

Q_r = sludge recycle flow rate, m^3/d.

X_O, X_R, X_r, X_e = influent, reactor, recycle and effluent biomass concentration, respectively kg/m^3

X_R is designated as only X for convenience

S_o, S = influent substrate concentration and substrate concentration after reactor, kg/m^3

V = volume of reactor, m^3

Now, considering the two factors:

i) Influent and effluent biomass concentration is negligible
ii) S_o is immediately diluted to S

The mass balance equation for biomass reduces to:

$$V\left(\frac{K_0 SX}{K_s+S} - k_d X\right) = Q_w X_r$$

Or, $$\left(\frac{K_0 SX}{K_s+S} - k_d X\right) = \frac{Q_w X_r}{V}$$

Or, $$\frac{K_0 SX}{K_s+S} = \frac{Q_w X_r}{VX} + k_d$$

And the mass balance equation for substrate becomes:

$$QS_0 - QS = \frac{V\ K_0\ SX}{Y\ (K_s + S)}$$

Or, $$\frac{Q}{V}(S_O - S)\frac{Y}{X} = \frac{K_0\ S}{K_S + S}$$

Combining equation 1 and equation 2:

$$\frac{Q_w\ X_r}{VX} = \frac{Q}{V}\frac{Y}{X}(S_O - S) - k_d$$

Now, $\frac{V}{Q} = \theta$, is known as **Hydraulic Retention Time (HRT)** in the reactor based on influent flow, defined as the average time for which a volume of water remains within the reactor.

And, $\frac{VX}{Q_w\ X_r} = \theta_C$, represents the average time for which the micro organisms remain inside the reactor and is known as the **Mean Cell Residence Time** or **Solid Retention Time (SRT)**

Thus, $$\frac{1}{\theta_C} = \frac{Q_w X_r}{VX} = \frac{Y}{X}\frac{1}{\theta}(S_O - S) - k_d$$

$$\therefore X = \frac{Y\theta_C(S_0 - S)}{\theta\ (1 + K_d\theta_C)}$$

This concentration of biomass is known as **Mixed Liquor Suspended Solids (MLSS)** defined as the concentration of suspended solids in the aeration tank which occurs during the treatment process, expressed as mg/L. MLSS ensures that there is sufficient quantity of active biomass available to consume the applied quantity of organic pollutant at any time.

From the above equations, SRT can be written as:

$$\theta_C = \left(\frac{K_S + S}{K_0 S}\right)\left(\frac{1}{X}\right)(S_0 - S)$$

Or, $$\frac{X\,\theta_C}{(S_0 - S)} = \frac{K_s}{K_0}\frac{1}{S} + \frac{1}{K_0}$$

From mass balance analysis of biomass,

Accumulation of biomass = inflow – outflow

$\therefore 0 = X(Q + Q_r) - (Q_r X_R) - (Q_W X_r) - (Q_e X_e)$.

Since, X_e is considered to be negligible and $Q_W X_r = \frac{VX}{\theta_C}$

The equation reduces to: $$Q_r = \frac{Q\,X - \left(\frac{XV}{\theta_C}\right)}{X_r - X}$$

Defining the term **recycle ratio** as $R = \frac{Q_r}{Q}$

$$\therefore R = \frac{XQ - \left(\frac{XV}{\theta_C}\right)}{(X_r - X)Q}$$

$$= \frac{1 - \left(\frac{V}{Q}\cdot\frac{1}{\theta_C}\right)}{\frac{X_r}{X} - 1}$$

Or, $$R = \frac{1 - \frac{\theta}{\theta_C}}{\frac{X_r}{X} - 1}$$

If influent solids are negligible, $Q_r X_r = X(Q + Q_R)$

Then, $$R = \frac{X}{X_r - X}$$

4.4 Derivation of design variables

In case of activated sludge process design, high biomass concentration and short aeration periods may produce good treatment efficiencies with respect to BOD. Design variables of an activated sludge process reactor include:

- Volumetric loading rates
- F/M ratio
- Mean Cell Residence Time
- Solid Loading Rate
- Sludge Volume Index

- **Volumetric Loading Rate (VLR)** is the mass of BOD in the effluent per unit volume of the reactor. It is also termed as organic loading rate (OLR). Mathematically, it is expressed as

$$\mathbf{V_L = \frac{Q S_o}{V}} \quad \textbf{in kg BOD /m}^3\textbf{ d.}$$

- **Food-to-microorganism Ratio or F/M ratio** is defined as the rate of BOD or COD applied per unit volume of mixed liquor. It is obtained by dividing the mass of BOD by biomass in the reactor.

Mathematically,

$$\textbf{F/M Ratio} = \frac{\mathbf{Q\,(S_o - S)}}{\mathbf{VX}} \quad \textbf{in kg BOD/kg biomass-d.}$$

- **Solid Loading Rate (SLR)** in an activated sludge process is defined as the total solids applied per unit area of the tank.

Mathematically,

$$\mathbf{SLR} = \frac{\mathbf{(Q+Q_r)X}}{\mathbf{A}}$$

Where,

SLR = solid loading rate, generally measured in kg/m^2 h

A= tank cross sectional area, expressed in m^2. (In a settling tank of fixed cross sectional area, the effluent quality will deteriorate if the solid loading is increased beyond the characteristic value of suspension.

- **Sludge Volume Index (SVI)** is another parameter used to quantify the settling characteristics of activated sludge. It is defined as the volume of 1g sludge after 30mins of settling. It is measured in ml/g. But because SVI is empirical, it may be subjected to errors.

Mathematically,

$$\mathbf{SVI} = \frac{\textbf{settled volume of sludge,ml/l}}{\textbf{suspended solids,mg/}\boldsymbol{l}}$$

Sludge production is the amount of net sludge to be disposed off for further treatment. Though its quantity is not directly related with reactor design, but for the complete design of an ASP it is essential. The observed yield values decrease as the SRT is increased.

Mathematically,

$$P_X = Y_{obs}\, Q\, (S_o - S)$$

Where,

P_x = net waste activated sludge produced each day, kg VSS/ d

Y_{obs} = observed yield, g VSS/ g substrate removal.

❖ **Effect of temperature and its correction:** Temperature dependence of the rate constants in a biological reaction is very important in assessing the efficiency of the process. Temperature not only influences the metabolic activities of the microbes but also greatly effects gas transfer rates and settling of suspended solid particles. The yield is lower with increasing temperature as a result of higher endogenous respiration rate at higher temperature. The effect of temperature on reaction rates is given as follows:

$$K_T = k_{20}\,\theta^{(T-20)}$$

Where,

k_T = reaction rate coefficient at temperature T, ℃

K_{20} = reaction rate coefficient at 20℃

θ = temperature activity coefficient.

For endogenous respiration,

θ = 1.04 (between 20 – 30 ℃)

= 1.12 (between 10 – 20 ℃)

4.5 Kinetic model and evaluation of kinetic coefficient

In this study, Lineweaver- Burk model is used while evaluating the parameters graphically. The plot provides a useful graphical method for the analysis of the Michaelis–Menten **equation:**

$$V = \frac{V_M\, S}{K_M + S}$$

which is analogous with the **Monod equation** for growth kinetics: $K = \frac{kS}{K_s + S}$ Thus, the analysis of Monod equation can be done graphically with the help of **Lineweaver-Burk model**. The reciprocal equation gives:

$$\frac{1}{U} = \frac{K_s}{k}\frac{1}{S} + \frac{1}{k}$$

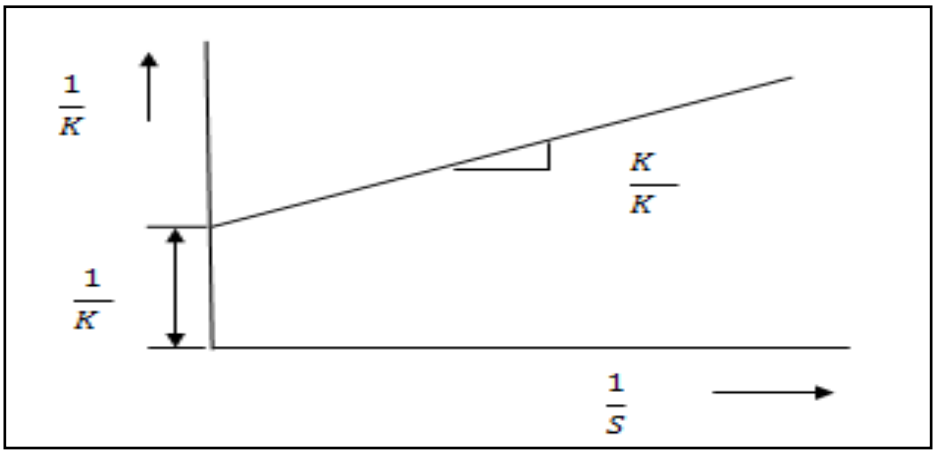

Fig. 4.3: Determination of K_S and k

Now, plotting a graph with $\frac{1}{U}$ in the Y- axis and $\frac{1}{S}$ in the X - axis will help to determine the values of the two important kinetic parameters K_0 and K_S. Here, the value of $\frac{S_o - S}{X\,\theta_C}$ is represented as U, known as specific substrate utilization ratio. Kinetics parameters (such as S_o, S and X) are evaluated from bench scale study for different HRTs. For the calculation of kinetic coefficients, the mean values of the parameters are to be used.

To find the value of Y and k_d the following equation can be used to plot a graph:

$$\frac{1}{\theta_C} = \frac{S_o - S}{X\theta_C}(Y - k_d)$$

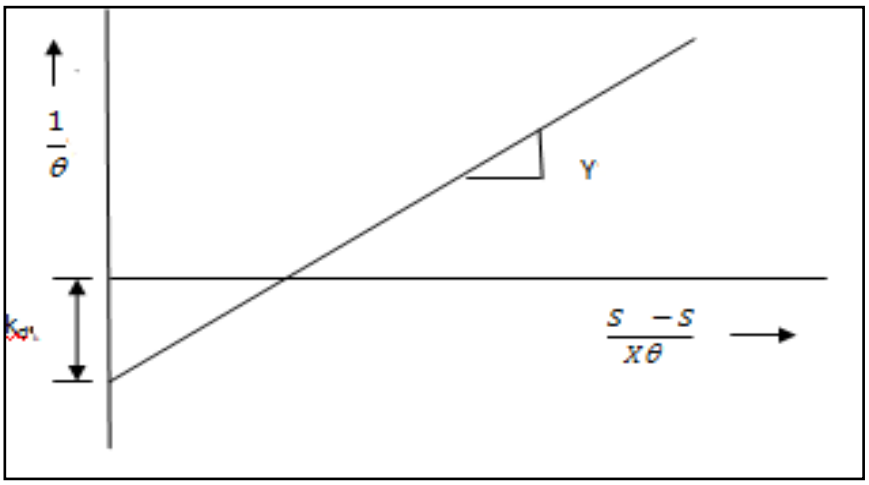

Fig. 4.4: Determination of K_d and Y

The graph is plotted by taking $\frac{1}{\theta_C}$ in the Y-axis and $\frac{S_o - S}{X\theta_C}$ in the X axis to find the values of Y and k_d. k_d is the intercept of the Y axis and the slope of the graph gives the value of Y.

Chapter-5

MATERIALS AND METHODS

5.1 Materials

- Beaker (Graduated and non-graduated)
- Burette (50ml)
- Pipette (1 ml)
- pH meter
- BOD container (300 ml)
- COD vessel (500 ml)
- Whatman filter paper
- Glass funnel
- Measuring cylinder (100 ml)
- Plastic container or silos for storage of sludge/ seed
- Refrigerator
- Aquarium pumps and diffusers
- Electronic weighing machine
- Conical (Graduated and non-graduated)
- Dropper / pipette
- Basic laboratory apparatus/ amenities

5.2 Methods

5.2.1 Preparation of synthetic feed

Synthetic feed was prepared for the purpose of acclimatization of previously stored microbial seed. The stock synthetic feed was prepared by dissolving the following chemicals in particular proportions in 1 liter of distilled water described in table 5.1.

Table 5.1: Preparation of stock synthetic feed

Serial Number	constituents	Amount (gram)
1	Dextrose	12.5
2	KH_2PO_4	1
3	K_2HPO_4	1
4	Ammonium chloride	1.5
5	Ammonium sulfate	0.4
6	Beef extract	0.8
7	Yeast extract	0.8
8	peptone	1

Sodium bicarbonate is added for pH adjustment and the pH must be maintained in the range of 6.5 to 7.5.

Some micronutrients were added for the nourishment of the microbial seed. Composition of microbial seed is given below.

Table 5.2: Composition of micronutrient

SERIAL NUMBER	TRACE ELEMENTS	MASS (mg) TO BE ADDED IN 1 LITRE OF WATER
1	$MgSO_4.7H_2O$	0.5
2	$FeCl_3.6H_2o$	0.71
3	$ZnSO_4.7H_2O$	0.0001
4	$CuSO_4.5H_2O$	0.0001
5	$MnCl_2.2H_2O$	0.008
6	$(NH4)_2Mo_7O_{24}$	0.00011
7	$CaCl_2.2H_2O$	0.1
8	$CoCl_2.6H_2O$	0.2
9	H_3BO_3	0.15
10	EDTA [Na_2 Salt]	0.1

Table 5.3: Characterization of synthetic sample

SERIAL NUMBER	SAMPLE	PARAMETERS		
		pH	COD [mg/L]	NH3-N [mg/L]
1	Synthetic feed	7.3 ± 0.3	13500 ± 200	550 ± 50

5.2.2 Seed acclimatization

- The pH of synthetic feed was adjusted between 7-8
- In a measuring cylinder of 1.0 L, 100 ml feed was taken. To it 50 ml of seed was mixed and allowed to grow under optimum environmental conditions. Rest amount was filled by distilled water.
- An observation was made after 4 days.
- Within 4 days, the biomass grew up to 150 ± 10 ml on an average.
- Acclimatized excess biomass was stored in a 2 liter conical flask with proper food and air.
- The same experimental steps were repeated in cycles sequentially until the total biomass obtained reached a minimum of 2.5 L
- This biomass served as sample for the next experiments of this present study
- Throughout the process, aquarium pumps and diffusers were used in the systems to ensure a constant DO (Dissolved Oxygen) is maintained and that sufficient amount of oxygen is available to the microbes.

Fig. 5.1: Growth of biomass in seed acclimatization (Observed after 4 days)

5.2.3 Experimental set up

Suspended Growth Reactors were chosen for carrying out the experiments. The experiments were made in a measuring cylinder of 1 liter volume. Aquarium pumps (Sobo aquarium air pump: model no SB 648A) were used for aeration purpose. Aquarium diffusers were used as spargers.

Fig. 5.2: Experimental Setup

- **Batch reactor setup**

  Adequately aerated measuring cylinder of 1 liter volume is used to grow the biomass. Aquarium pumps were used to ensure the DO level is appropriately maintained. Increase of MLSS in batch reactor setup shown in below Fig. 5.3 and Fig 5.4.

Fig. 5.3- Initial MLSS volume

Fig. 5.4- final MLSS volume (After 2 days)

5.2.4 Time–concentration study in synthetic wastewater

Seed preparation and seed acclimatization were done for both carbon oxidation study and nitrification experiments. Five sets of each carbon oxidation study were done in fed batch reactor. Original stock synthetic sample was diluted to make 5 different concentrations of COD. The COD concentrations used for time concentration study are 668.8 mg/L(set 1), 721.6 mg/L(set 2), 892.33 mg/L(set 3), 2030.4 mg/L(set 4) and 1352.16 mg/L(set 5) respectively. All the tests were replicated in three times and average values were taken.

Fig. 5.5 – Collection of sample for testing at 2 hours interval

5.2.5 Test of different parameters

The samples that were collected at different time from batch reactor were checked for various parameters like pH, COD, BOD, TSS, TDS and ammoniacal nitrogen. The protocols and standards that have been followed for evaluating these parameters have been listed below:

Table 5.4: Test of different parameters

SERIAL NUMBER	PARAMETERS EVALUATED	ANALYTICAL METHODS FOLLOWED	GUIDE LINES FOLLOWED
1	**pH**	Electrometric method (pH meter)	**IS 3025 - 11 (1983)**
2	**COD**	Open reflux method	**IS 3025 - 58 (2006)**
3	**BOD_5**	5 days BOD by DO determination	**IS 3025 - 44 (1993)**
4	**TSS**	Mechanical Filtration	**IS 3025 - 17 (1984)**
5	**TDS**	Evaporation (Hot Oven)	**IS 3025 - 16 (1984)**
6	**ALKALINITY**	Titration	**IS 3025 - 23 (1986)**
7	**MLSS**	Gravimetric method (103° - 105° C)	**APHA methods, part 2350, 2000**
8	**DISSOLVED OXYGEN**	Azide modified winkler method	**IS 3025 - 38 (1989)**

5.2.6 Collection of real life sample

Real life sample of bakery wastewater was collected from Kasba industrial area. The concerned bakery plant produces patties, sandwich, burger, pastry etc. The average rate of effluent production in the plant is estimated as 40 m^3/day. Samples were collected in 5 liter plastic container. Necessary guidelines were followed during collection of samples and persevering in an ice container.

5.2.7 Time concentration study of real life wastewater sample in batch fed reactor (for carbon oxidation)

Five set of each carbon oxidation study was done in fed batch reactor using real life sample. The COD concentrations in time concentration study were 1320 mg/L(set 1), 1313.2 mg/L(set 2), 1300 mg/L(set 3), 1260 mg/L(set 4) and 1400 mg/L(set 5) respectively. All the tests were replicated in three times and average values were taken. The results of time concentration study of real life wastewater for carbon oxidation in batch fed reactor are discussed in chapter 6.4.

5.2.8 Time concentration study of real life waste water sample in batch fed reactor (for nitrification)

Two sets of nitrification study were done in fed batch reactor using real life sample. The ammoniacal nitrogen concentration in time concentration study were 75.38 mg/L (set 1) and 60.48 mg/L(set 2)respectively. All the tests were replicated in three times and average values were taken. The results of time concentration study of real life wastewater for nitrification in batch fed reactor are discussed in chapter 6.6.

Chapter-6

Results and discussion

6.1 Time concentration study of synthetic wastewater for carbon oxidation in batch fed reactor

Evaluation of performance of batch fed reactor for carbon oxidation has been carried out using simulated synthetic wastewater samples of bakery and confectionery wastewater. The carbon oxidation study of synthetic wastewater has been carried out under varied COD and MLSS concentrations in batch fed reactor. All together 5 experiment Sets were done. The results are shown in both tabular and graphical form as the case may be here under.

6.1.1 Batch performance for Set 1

The result of carbon oxidation study for Set 1 with initial COD concentration value of 668.8 mg/L and other operating conditions are shown in Table 6.1. The result as obtained from time - concentration study within a contact period of 24 hours has been exhibited in Table 6.2. The experimental data are also plotted in Fig 6.1 and 6.2 showing residual COD remaining after different contact period.

From Fig 6.1, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 22 hour of contact time, maximum COD removal was achieved (94.73%) beyond which the COD removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of sample solution within the above reaction period.

Fig 6.2 demonstrates that there is a steady ascending in MLSS concentration up to a time period of 22 hours, from initial MLSS concentration 2700 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.1: Operating conditions of batch reactor for Set 1 [Initial COD concentration 668.8 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7-7.3
3	Max Retention Time (Hours)	24
4	Initial COD (mg/L)	668.8
5	Final COD (mg/L)	30.16
6	% COD removal (%)	95.49

Table 6.2: Variation in COD concentration, MLSS and percentage of COD reduction with time [initial COD concentration= 668.8 mg/L]

Time(hour)	COD(mg/L)	% COD reduction	MLSS(mg/L)
0	668.8	0.00	2700
2	565.24	15.48	2757
4	454.8	32.00	2785
6	349.2	47.79	2850
8	279.23	58.25	2895
14	166.58	75.09	2980
16	146.24	78.13	3025
18	104.35	84.40	3085
20	54.31	91.88	3120
22	35.26	94.73	3165
24	30.16	95.49	3210

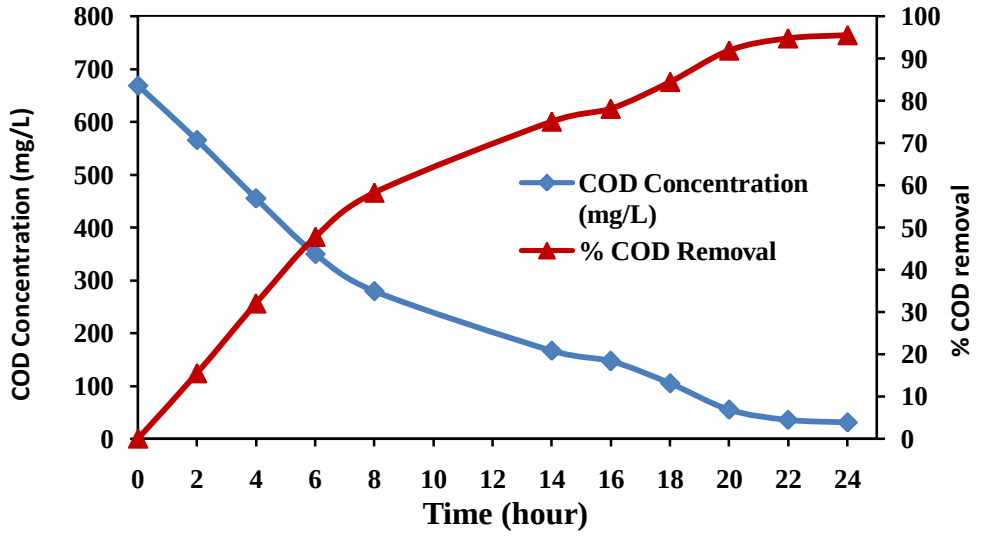

Fig. 6.1: variation in COD concentration and percentage of COD reduction with time [initial COD concentration= 668.8 mg/L]

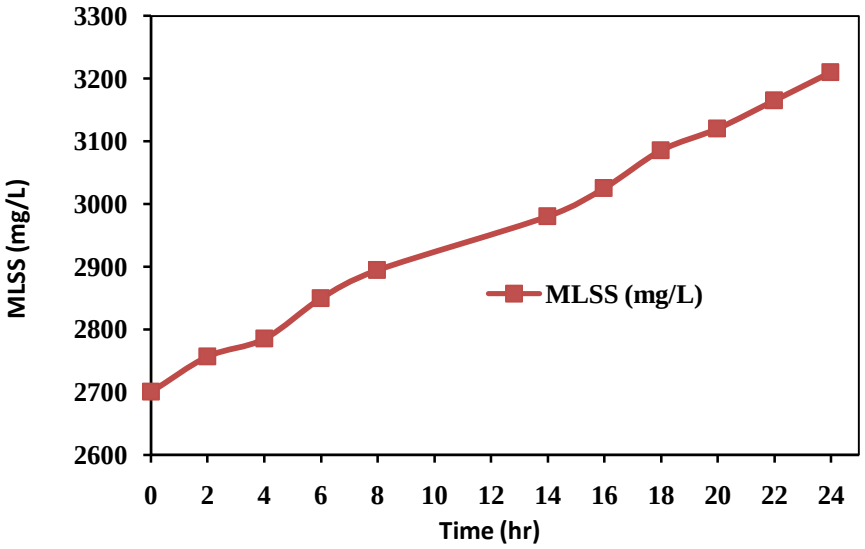

Fig. 6.2: variation of MLSS with time

[Initial MLSS concentration 2700 mg/L]

6.1.2 Batch performance for Set 2

The result of carbon oxidation study for Set 2 with initial COD concentration value of 721.6 mg/L and other operating conditions are shown in Table 6.3. The result as obtained from time concentration study within a contact period of 24 hours has been exhibits in Table 6.4. The experimental data are also plotted in Fig. 6.3 and 6.4 which is basically time concentration study.

From Fig. 6.3, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 22 hour of contact time, maximum COD removal was achieved (92.42%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

Fig. 6.4, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 22 hours, from initial MLSS concentration 2750 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.3: Operating conditions of batch reactor for Set 2 [Initial COD concentration 721.6 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7-7.3
3	Max Retention Time (Hours)	24
4	Initial COD (mg/L)	721.6
5	Final COD (mg/L)	50.68
6	% COD removal (%)	92.98

Table 6.4: Variation in COD concentration, MLSS and percentage of COD reduction with time [Initial COD concentration 721.6 mg/L]

Time(hour)	COD(mg/L)	% COD removal	MLSS(gm/L)
0	721.6	0.00	2750
2	629.6	12.75	2797
4	509.6	29.38	2845
6	404.24	43.98	2890
8	334.25	53.68	2935
14	200.25	72.25	3080
16	166.35	76.95	3125
18	130.25	81.95	3175
20	78.25	89.16	3230
22	54.69	92.42	3275
24	50.68	92.98	3320

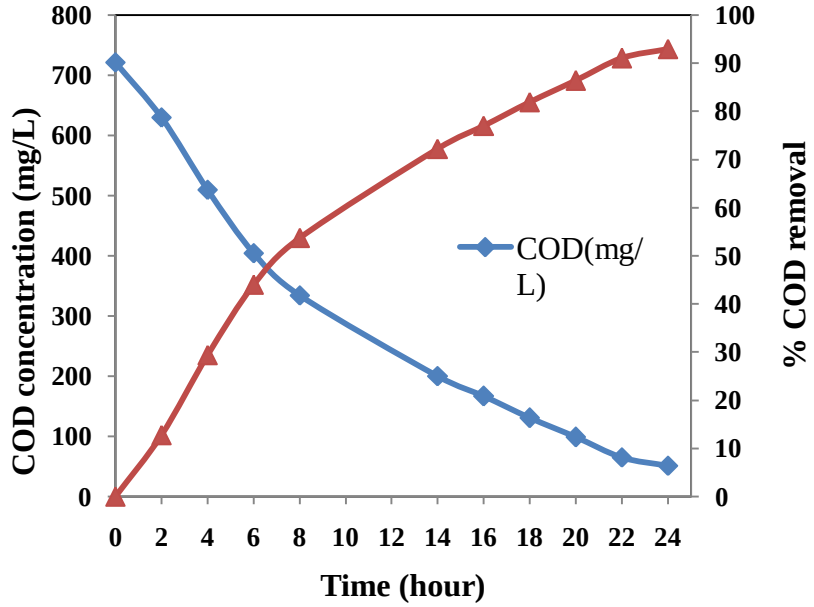

Fig. 6.3: variation in COD concentration and percentage of COD reduction with time [Initial COD concentration 721.6 mg/L]

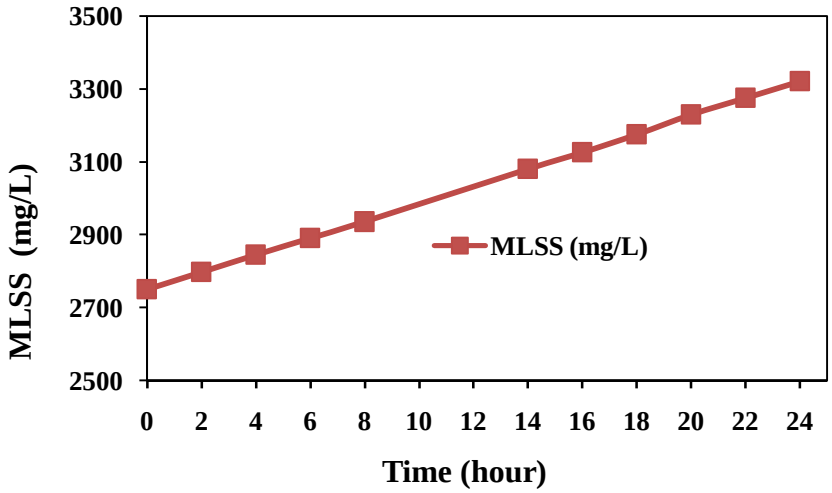

Fig. 6.4: variation of MLSS with time

[Initial MLSS concentration 721.6 mg/L]

6.1.3 Batch performance for Set 3

The result of carbon oxidation study for Set 3 with initial COD concentration value of 892.33 mg/L and other operating conditions are shown in Table 6.5. The result as obtained from time concentration study within a contact period of 24 hours has been exhibits in Table 6.6. The experimental data are also plotted in Fig. 6.5 and 6.6 which is basically time concentration study.

From Fig. 6.5, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 22 hour of contact time, maximum COD removal was achieved (89.85%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

Fig. 6.6, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 22 hours, from input MLSS concentration 2730 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.5: Operating conditions of batch reactor for Set 3 [Initial COD concentration 892.33 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7.28 - 6.94
3	Max Retention Time (Hours)	24
4	Initial COD (mg/L)	892.33
5	Final COD (mg/L)	85.67
6	% COD removal (%)	90.4

Table 6.6: Variation in COD concentration, MLSS and percentage of COD reduction with time [Initial COD concentration 892.33 mg/L]

Time(hour)	COD(mg/L)	% COD removal	MLSS(mg/L)
0	892.33	0.00	2730
2	794.62	10.95	2788
4	650.775	27.07	2832
6	530.775	40.52	2890
8	445.66	50.06	2942
14	275.66	69.11	3080
16	228.64	74.38	3145
18	175.84	80.29	3195
20	115.24	87.09	3240
22	90.57	89.85	3285
24	85.67	90.40	3350

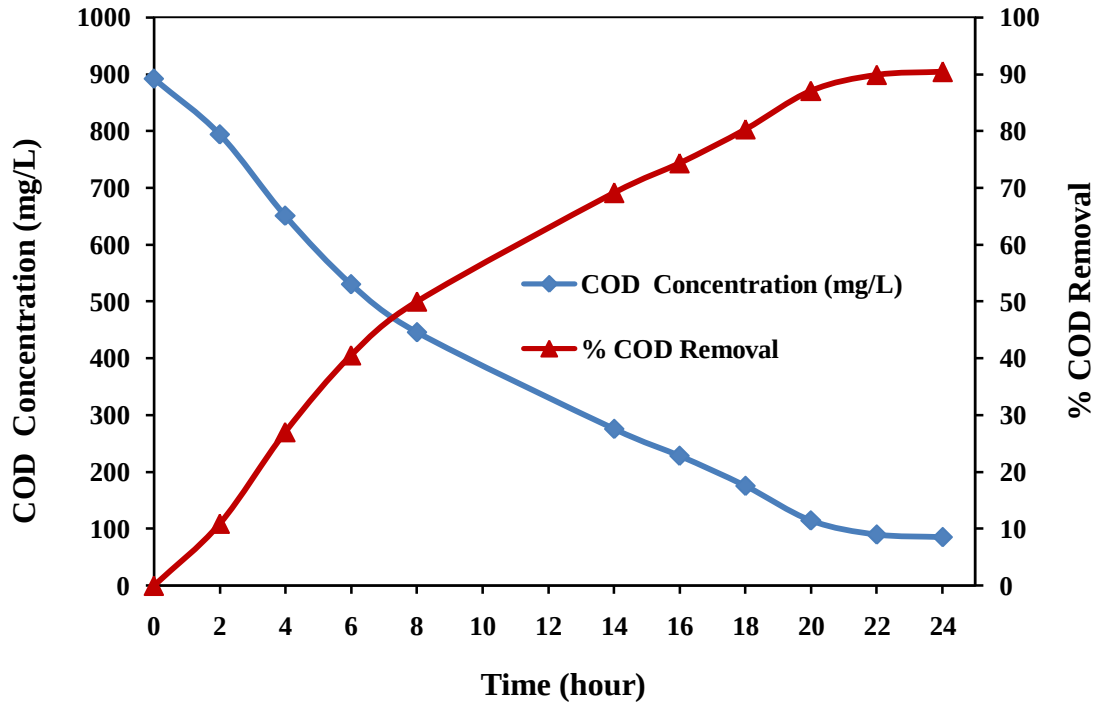

Fig. 6.5: variation in COD concentration and percentage of COD reduction with time [Initial COD concentration 892.33 mg/L]

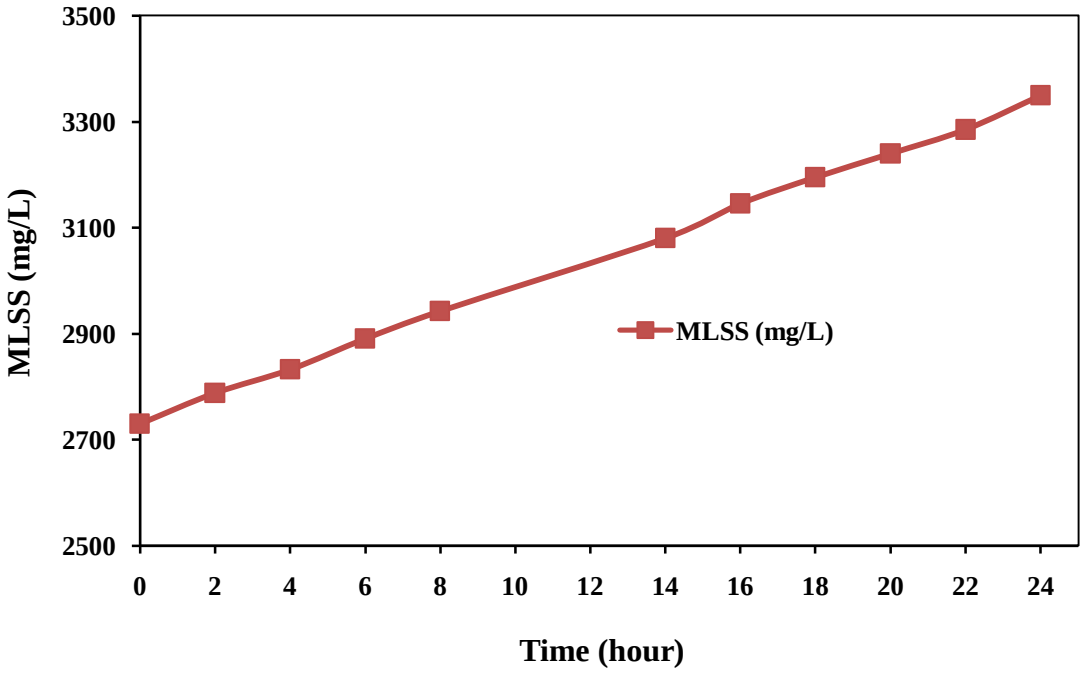

Fig. 6.6: variation of MLSS with time

[Initial MLSS concentration 2730 mg/L]

6.1.4 Batch performance for Set 4

The result of carbon oxidation study for Set 4 with initial COD concentration value of 2030.4 mg/L and other operating conditions are shown in Table 6.7. The result as obtained from time concentration study within a contact period of 24 hours has been exhibits in Table 6.8. The experimental data are also plotted in Fig. 6.7 and 6.8 which is basically time concentration study.

From Fig. 6.7, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 23 hour of contact time, maximum COD removal was achieved (93.67%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

In Fig. 6.8, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 23 hours, from initial MLSS concentration 2240 mg/L. After 23 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized. The results revealed that the mixed culture possesses excellent capacity to uptake higher organic removal under oxic condition.

Table 6.7: Operating conditions of batch reactor for Set 4 [Initial COD concentration 2030.4 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7-7.4
3	Max Retention Time (Hours)	24
4	Initial COD (mg/L)	2030.4
5	Final COD (mg/L)	119.38
6	% COD removal (%)	94.12

Table 6.8: Variation in COD concentration, MLSS and percentage of COD reduction with time [Initial COD concentration 2030.4 mg/L]

Time(hour)	COD (mg/L)	% COD removal	MLSS (mg/L)
0	2030.4	0.00	2240
1	1278.4	37.04	2340
2	1071.6	47.22	2380
3	864.8	57.41	2480
5	639.2	68.52	2584
6	545.2	73.15	2680
7	498.24	75.46	2745
16	320.54	84.21	3020
18	260.57	87.17	3090
20	210.57	89.63	3165
23	128.52	93.67	3200
24	119.38	94.12	3240

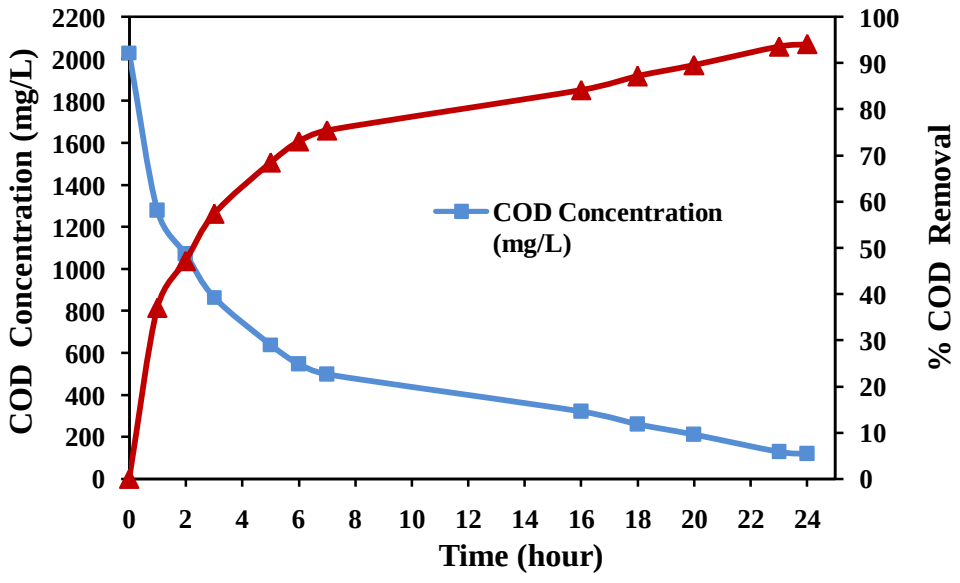

Fig. 6.7: variation in COD concentration and percentage of COD reduction with time [Initial COD concentration 2030.4 mg/L]

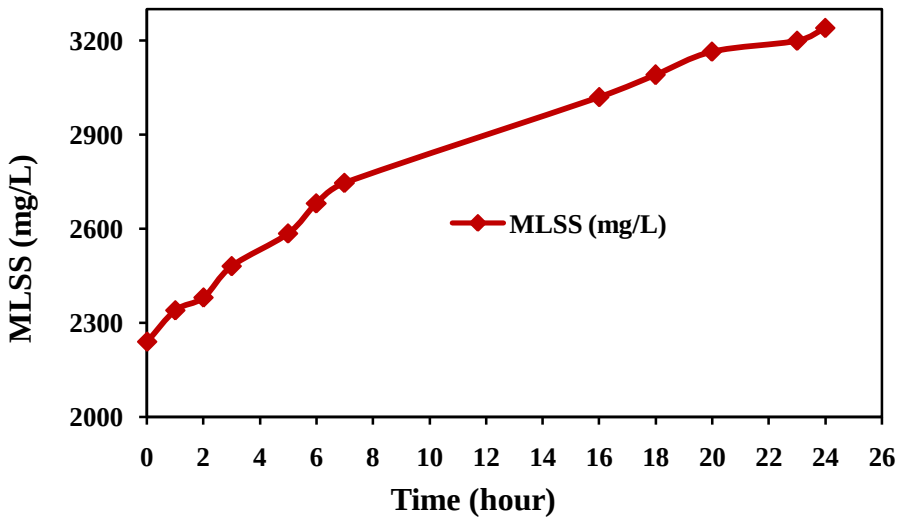

Fig. 6.8: variation of MLSS with time

[Initial MLSS concentration 2240 mg/L]

6.1.5 Batch performance for Set 5

The result of carbon oxidation study for Set 5 with initial COD concentration value of 1352.16 mg/L. close to a value of real life character and other operating conditions are shown in Table 6.9. The result as obtained from time concentration study within a contact period of 24 hours has been exhibited in Table 6.10. The experimental data are also plotted in Fig. 6.9 and Fig. 6.10.

From Fig. 6.9, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 22 hour of contact time, maximum COD removal was achieved (96.58%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

Fig. 6.10, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 22 hours, from initial MLSS concentration 2025 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.9: Operating conditions of batch reactor for Set 5 [Initial COD concentration around 1352.16 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7-7.5
3	Max Retention Time (Hours)	24
4	Initial COD (mg/L)	1352.16
5	Final COD (mg/L)	40.25
6	% COD removal (%)	97.02

Table 6.10: Variation in COD concentration, MLSS and percentage of COD reduction with time [Initial COD concentration 1352.16 mg/L]

Time(hour)	COD	% COD removal	MLSS(mg/L)
0	1352.16	0.00	2025
1	826.32	38.89	2100
2	582.18	56.94	2170
3	300.48	77.78	2250
4	244.14	81.94	2310
5	169.02	87.50	2360
6	150.24	88.89	2480
7	112.68	91.67	2550
16	80.25	94.07	2880
18	71.44	94.72	2970
20	58.41	95.68	3080
22	46.27	96.58	3158
24	40.25	97.02	3240

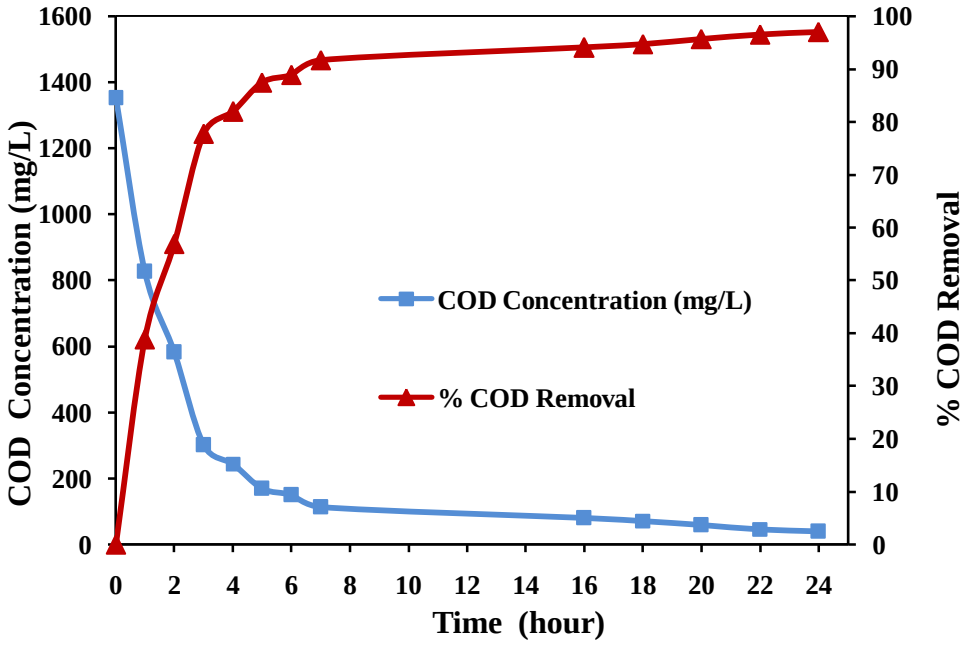

Fig. 6.9: variation in COD concentration and percentage of COD reduction with time [Initial COD concentration 2025 mg/L]

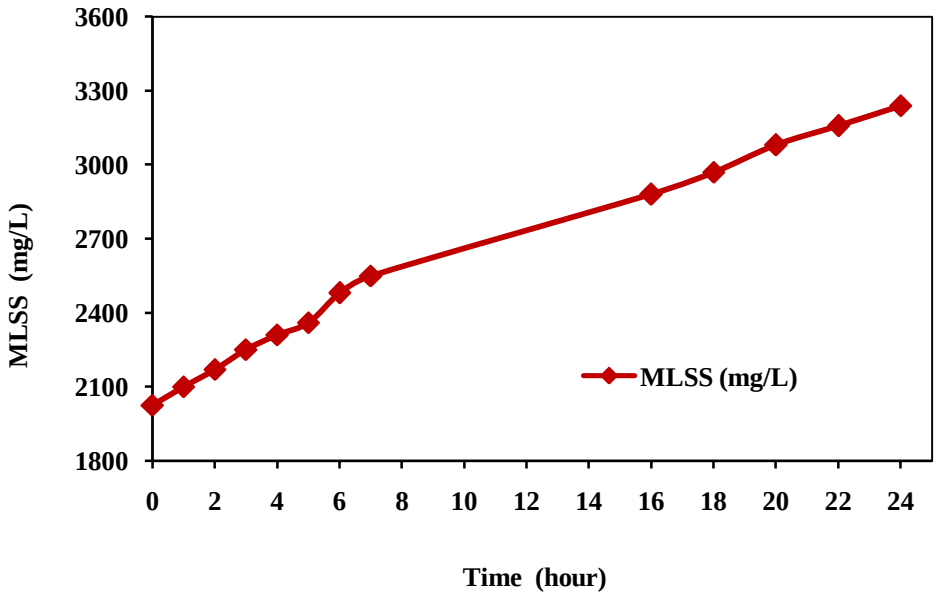

Fig. 6.10: variation of MLSS with time

[Initial MLSS concentration 2030.4 mg/L]

6.2 Determination of kinetic constants

Reaction kinetic plays a vital role for the evaluation of the performance of any reactor. Different experiments have been done to estimate the values of kinetic coefficients for combined carbon oxidation and nitrification of organic carbon and ammoniacal nitrogen (NH_4^+-N) using different equation as mentioned in chapter 3.

The values of the reciprocal of specific substrate utilization rate (1/U) were plotted against the reciprocal of effluent COD (1/S) and shown in Fig. 6.11.
Substrate removal kinetics was evaluated using simple linear equation

$$\frac{1}{U} = \frac{K_s}{k * S} + \frac{1}{k}$$

The slope and intercept of the straight line are $\frac{K_s}{k}$ and $\frac{1}{k}$ respectively.

Then, the values of the reciprocal of the reaction time $\frac{1}{\theta}$ were plotted against specific substrate utilization rate (U) and plotted in Fig. 6.11.
To find the value of Y and k_d the following equation can be used to plot a graph:

$$\frac{1}{\theta_C} = \frac{S_o - S}{X\theta_C} Y - k_d$$

The graph is plotted by taking $\frac{1}{\theta_C}$ in the Y-axis and $\frac{S_o - S}{X\theta_C}$ in the X axis to find the values of Y and k_d. k_d is the intercept of the Y axis and the slope of the graph gives the value of Y.

The yield coefficient (Y) was determined from the slope of the best-fit straight line and endogenous decay coefficient K_d was obtained from the intercept. Kinetic coefficients for activated sludge process are determined following Burk-Lineweaver model.

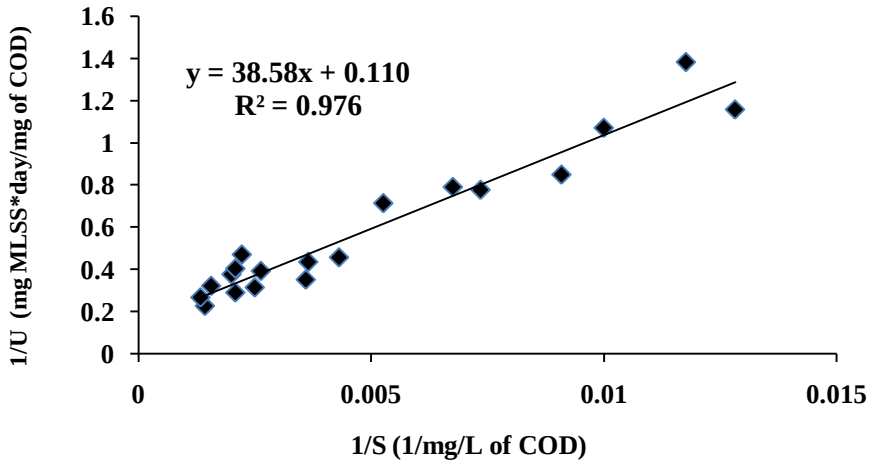

Fig. 6.11: Substrate Utilization kinetic for carbon oxidation study of synthetic sample in batch reactor

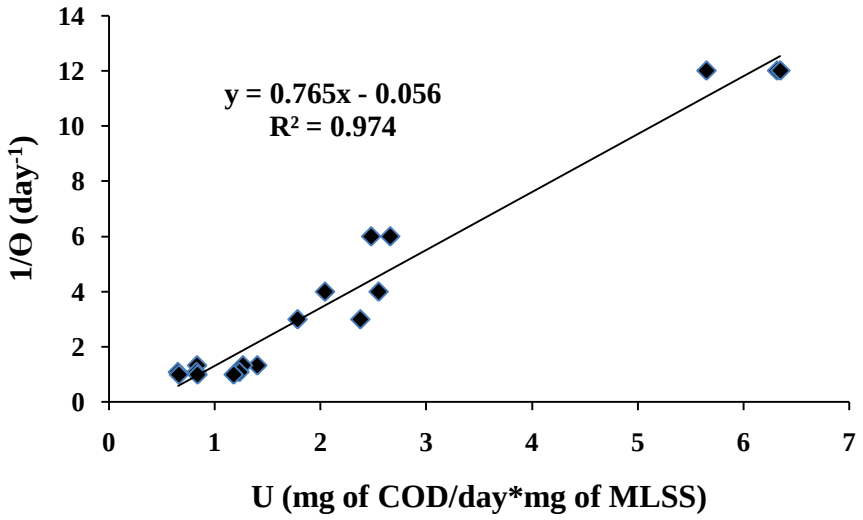

Fig. 6.12: Microbial growth kinetic for carbon oxidation study of synthetic sample in batch reactor

Table 6.11: Values of kinetic constants for carbon oxidation in synthetic sample

Sl. NO	Kinetic Coefficients	Values from Present Study	Typical kinetic coefficient for Municipal wastewater (Metcalf and eddy, 1995)
1	**Y**	0.765	0.4-0.8
2	**K_d**	0.056	0.025-0.075
3	**K**	9.09	2-10
4	**k_s**	350.69	25-100

Higher Y value suggests better rate of reaction. Higher value of k_d reduces the net production of sludge. The value of K_s illustrates the specific growth rate of bacteria with variation of substrate concentration. The magnitude of k affects the volume of the reactor.

6.3 Characterizations of real life wastewater sample

Before conducting the batch experiments in the laboratory, the characterization of field sample was carried out and the microbial seed was simultaneously acclimatized in similar feed solution. Table 6.1 shows the characteristics of the field sample collected at the outlet stream of pretreatment units operation.

Table 6.12: Characterizations of field sample

Sl No	Parameters	Values
1	COD (mg/L)	1350 ± 50
2	BOD (mg/L)	905 ± 50
3	TSS (mg/L)	550 ± 30
4	Ammoniacal Nitrogen (mg/L)	65 ± 5
5	pH	7.4

6.4 Time concentration study of real life wastewater for carbon oxidation in batch fed reactor

The carbon oxidation study of real life sample has been carried out under different valid COD and MLSS conditions in batch fed reactor. All together 5 experiment Sets are carried out. The results are shown in tabular and graphical form here under.

6.4.1 Batch performance for Real life sample Set 6

The result of carbon oxidation study for Set 6 with initial COD concentration value of 1320 mg/L and other operating conditions are shown in Table 6.13. The result as obtained from time concentration study within a contact period of 26 hours has been exhibits in Table 6.14. The experimental data are also plotted in Fig. 6.13 and 6.14 which is basically time concentration study.

From Fig. 6.13, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 22 hour of contact time, maximum COD removal was achieved (89.02%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

Fig. 6.14, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 22 hours, from initial MLSS concentration 2620 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.13: Operating conditions for real life sample batch reactor [initial COD concentration= 1320 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7.28 - 6.94
3	Max Retention Time (Hours)	26
4	Initial COD (mg/L)	1320
5	Final COD (mg/L)	125
6	% COD removal (%)	90.53

Table 6.14: Variation of COD concentration, MLSS and percentage of COD reduction with time [Initial COD concentration= 1320 mg/L]

Time(hour)	COD concentration (mg/L)	MLSS (mg/L)	% COD removal
0	1320	2620	0.00
2	920	2780	30.30
4	720	2950	45.45
6	600	3110	54.55
7	520	3200	60.61
16	360	3400	72.73
18	280	3450	78.79
20	210	3500	84.09
22	145	3520	89.02
24	125	3530	90.53
26	125	3535	90.53

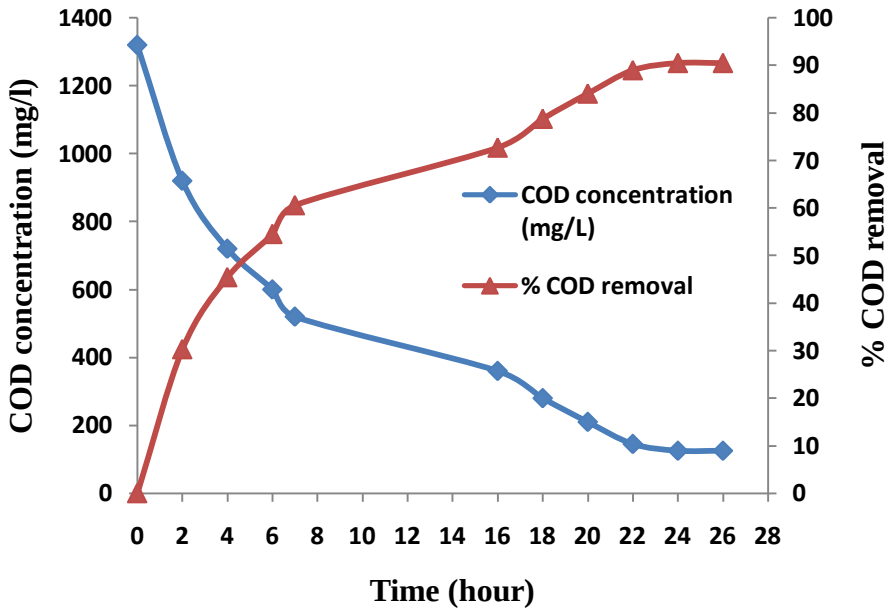

Fig. 6.13: variation of COD concentration and percentage of COD reduction with time [Initial COD concentration= 1320 mg/L]

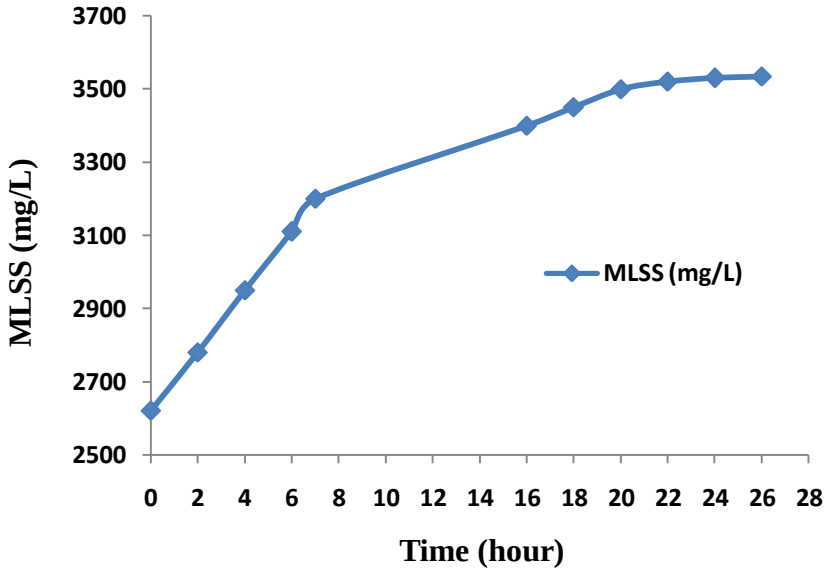

Fig. 6.14: Variation of MLSS with time [Initial MLSS concentration= 2620 mg/L]

6.4.2 Batch performance for Real life sample Set 7

The result of carbon oxidation study for Set 7 with initial COD concentration value of 1313.2 mg/L and other operating conditions are shown in Table 6.15. The result as obtained from time concentration study within a contact period of 26 hours has been exhibits in Table 6.16. The experimental data are also plotted in Fig. 6.15 and 6.16 which is basically time concentration study.

From Fig. 6.15, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 22 hour of contact time, maximum COD removal was achieved (89.03%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

Fig. 6.16, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 22 hours, from initial MLSS concentration 2560 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.15: Operating conditions for real life sample batch reactor

[Initial COD concentration= 1313.2 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7-7.4
3	Max Retention Time (Hours)	26
4	Initial COD (mg/L)	1313.2
5	Final COD (mg/L)	128
6	% COD removal (%)	90.25

Table 6.16: Variation in COD concentration, MLSS and percentage of COD reduction with time [Initial COD concentration= 1313.2 mg/L]

Time(hour)	COD concentration (mg/L)	MLSS mg/L	% COD removal
0	1313.2	2560	0.00
1	1019.2	2650	22.39
2	803.6	2880	38.81
3	705.6	2960	46.27
4	568.4	3080	56.72
5	509.6	3124	61.19
6	392	3180	70.15
16	255	3410	80.58
18	211	3480	83.93
20	172	3540	86.90
22	144	3570	89.03
24	128	3600	90.25
26	128	3620	90.25

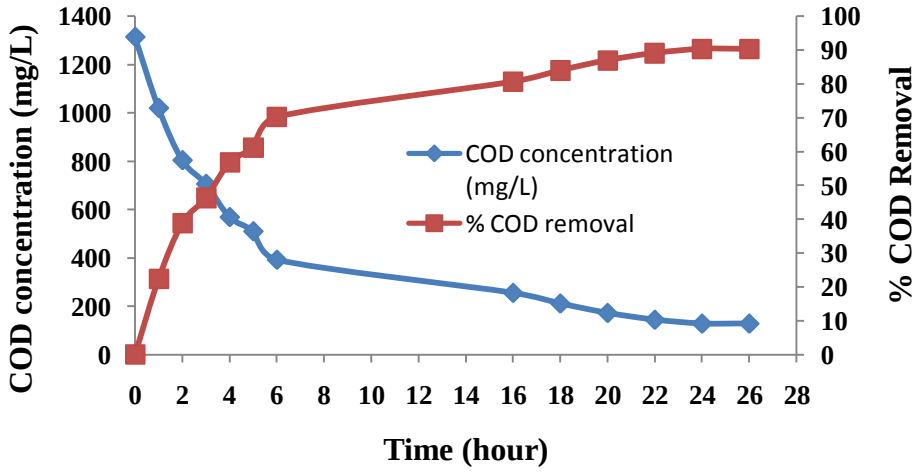

Fig. 6.15: variation in COD concentration and percentage of COD reduction with time [Initial COD concentration= 1313.2 mg/L]

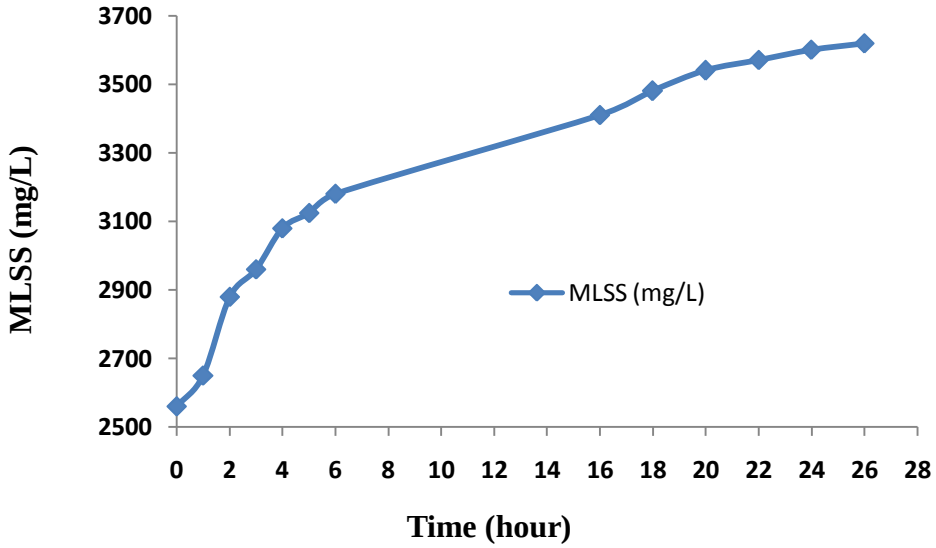

Fig. 6.16: variation of MLSS with time

[Initial MLSS concentration= 2560 mg/L]

6.4.3 Batch performance for Real life sample SET 8

The result of carbon oxidation study for Set 8 with initial COD concentration value of 1300 mg/L and other operating conditions are shown in Table 6.17. The result as obtained from time concentration study within a contact period of 26 hours has been exhibits in Table 6.18. The experimental data are also plotted in Fig. 6.17 and 6.18 which is basically time concentration study.

From Fig. 6.17, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 22 hour of contact time, maximum COD removal was achieved (81.53%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

Fig. 6.18, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 22 hours, from initial MLSS concentration 1900 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.17: Operating conditions for real life sample batch reactor [initial COD concentration= 1300 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7-7.4
3	Max Retention Time (Hours)	26
4	Initial COD (mg/L)	1300
5	Final COD (mg/L)	220
6	% COD removal (%)	83.07

Table 6.18: Variation in COD concentration, MLSS and percentage of COD reduction with time [Initial COD concentration= 1300 mg/L]

Time(hour)	COD concentration (mg/L)	MLSS (mg/L)	% COD removal
0	1300	1900	0
2	1060	1980	18.46
4	860	2045	33.84
6	750	2100	42.3
8	680	2160	47.69
16	400	2320	69.23
18	300	2400	76.92
20	260	2450	80
22	240	2510	81.53
24	220	2590	83.07
26	220	2600	83.07

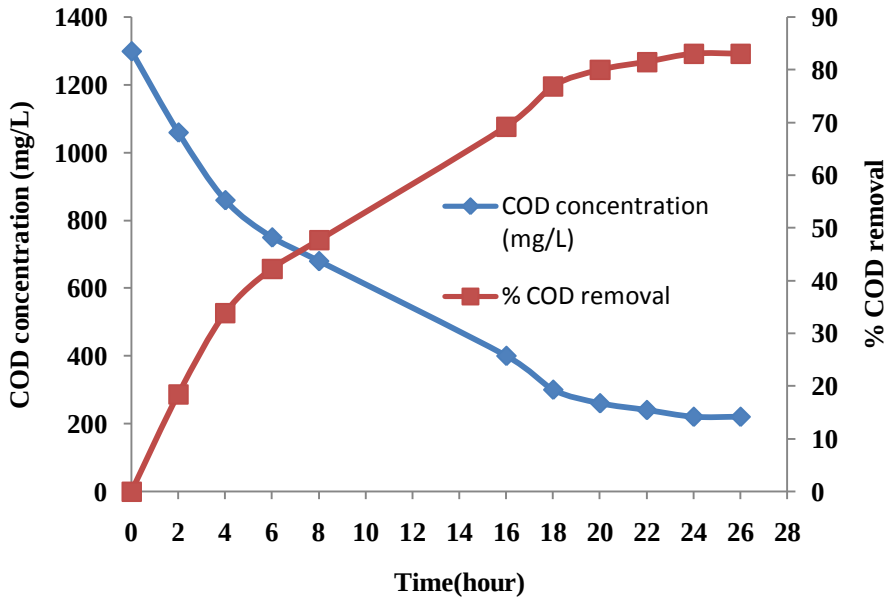

Fig. 6.17: variation in COD concentration and percentage of COD reduction with time [initial COD concentration= 1300 mg/L]

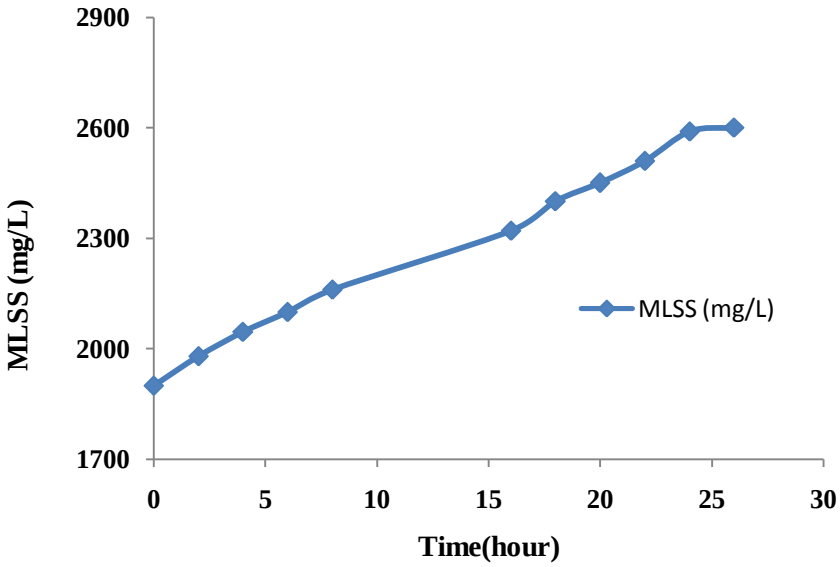

Fig. 6.18: variation of MLSS with time

[Initial MLSS concentration= 1300 mg/L]

6.4.4 Batch performance for Real life sample Set 9

The result of carbon oxidation study for Set 9 with initial COD concentration value of 1260 mg/L and other operating conditions are shown in Table 6.19. The result as obtained from time concentration study within a contact period of 26 hours has been exhibits in Table 6.20. The experimental data are also plotted in Fig. 6.19 and 6.20 which is basically time concentration study.

From Fig. 6.19, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 22 hour of contact time, maximum COD removal was achieved (83.33%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

Fig. 6.20, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 22 hours, from initial MLSS concentration 2100 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.19: Operating conditions for real life sample batch reactor [initial COD concentration= 1260 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7.1-7.5
3	Max Retention Time (Hours)	26
4	Initial COD (mg/L)	1260
5	Final COD (mg/L)	200
6	% COD removal (%)	84.13

Table 6.20: Variation in COD concentration, MLSS and percentage of COD reduction with time [initial COD concentration= 1260 mg/L]

Time(hour)	COD concentration (mg/L)	MLSS (mg/L)	% COD removal
0	1260	2100	0
2	960	2210	23.81
4	730	2290	42.07
6	650	2350	48.41
8	590	2400	53.17
16	400	2540	68.25
18	320	2590	74.6
20	240	2640	80.95
22	210	2690	83.33
24	200	2700	84.13
26	200	2700	84.13

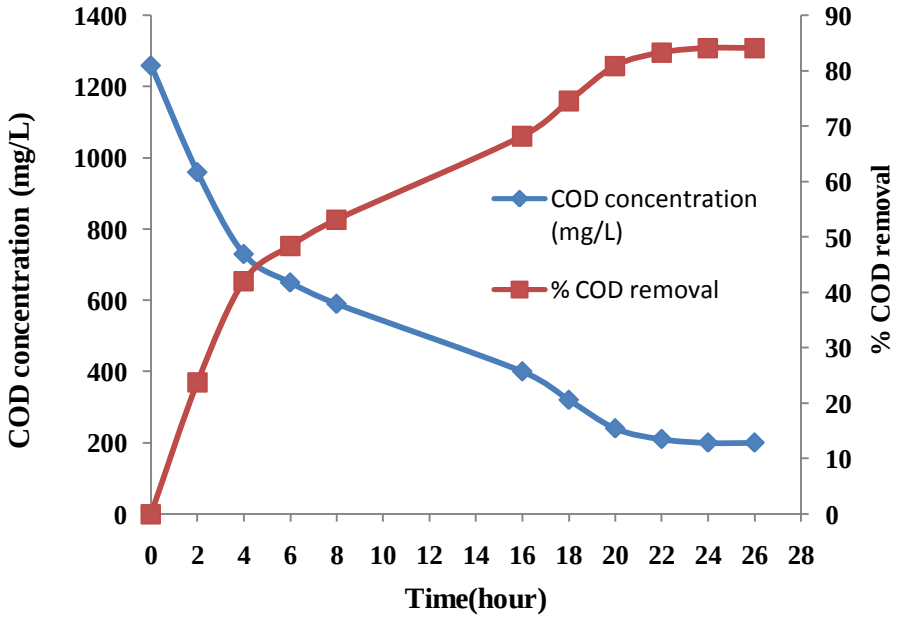

Fig. 6.19: Variation in COD concentration and percentage of COD reduction with time [initial COD concentration= 1260 mg/L]

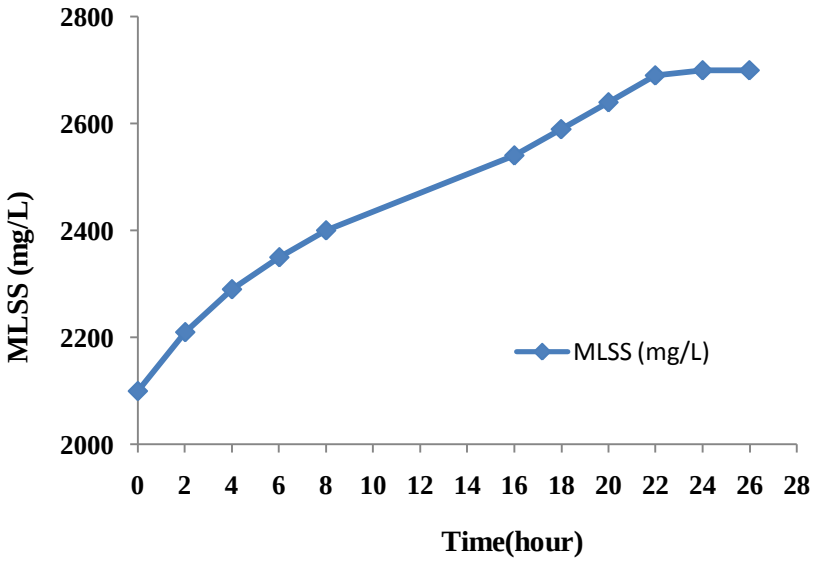

Fig. 6.20: variation of MLSS with time

[Initial MLSS concentration= 2100 mg/L]

6.4.5 Batch performance for Real life sample Set 10

The result of carbon oxidation study for Set 10 with initial COD concentration value of 1400 mg/L and other operating conditions are shown in Table 6.21. The result as obtained from time concentration study within a contact period of 26 hours has been exhibits in Table 6.22. The experimental data are also plotted in Fig. 6.21 and 6.22 which is basically time concentration study.

From Fig. 6.21, it is observed that concentration of COD decreases with the progress of reaction time. The plot also reveals that within a 24 hour of contact time, maximum COD removal was achieved (86.42%) beyond which the removal % is found to be marginal and the curve become asymptotic in nature which indicates maximum stabilization of organic matter of wastewater within the above reaction period.

Fig. 6.22, it demonstrates that there is a steady ascending in MLSS concentration up to a time period of 24 hours, from initial MLSS concentration 1700 mg/L. After 22 hours, the rate of increase of MLSS concentration found to be ceased and a steady state condition was achieved, which indicates enzymatic activity of carbonaceous microorganisms in the mixed culture are exhausted and fully utilized.

Table 6.21: Operating conditions for real life sample batch reactor [Initial COD concentration= 1400 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
3	pH	6.9-7.3
4	Max Retention Time (Hours)	26
5	Initial COD (mg/L)	1400
6	Final COD (mg/L)	180
7	% COD removal (%)	87.14

Table 6.22: Variation in COD concentration, MLSS and percentage of COD reduction with time [Initial COD concentration= 1400 mg/L]

Time(hour)	COD concentration (mg/L)	MLSS (mg/L)	% COD removal
0	1400	1700	0
2	1200	1780	14.28
4	1080	1870	22.85
6	880	1964	37.14
8	700	2027	50
16	330	2190	76.42
18	290	2260	79.28
20	250	2330	82.14
22	220	2370	84.28
24	190	2410	86.42
26	180	2410	87.14

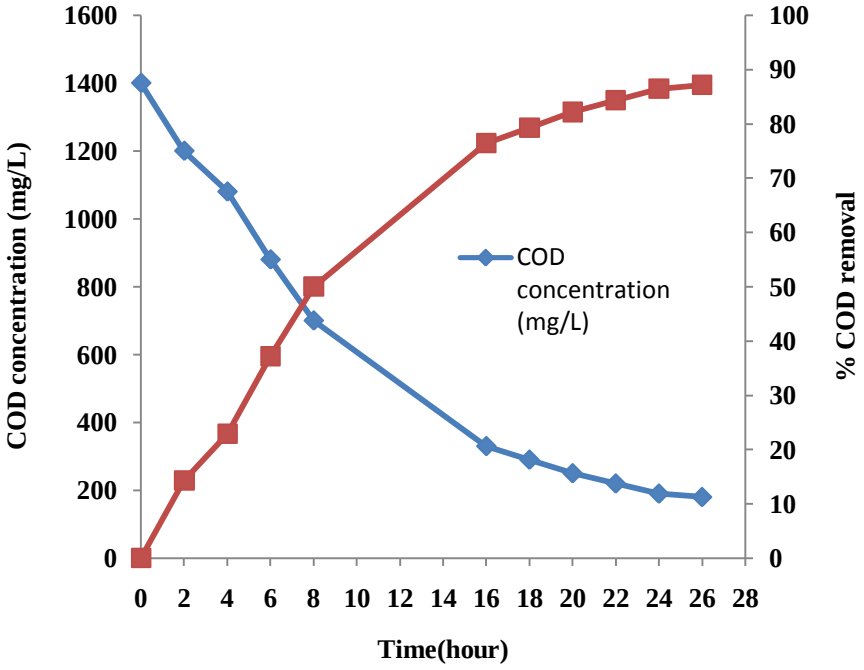

Fig. 6.21: variation in COD concentration and percentage of COD reduction with time [Initial COD concentration= 1400 mg/L]

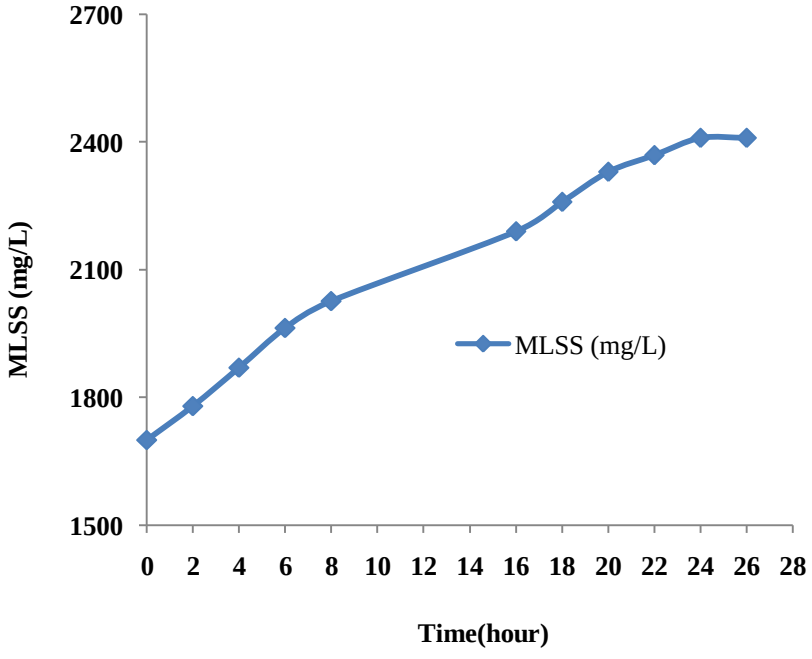

Fig. 6.22: variation of MLSS with time

[Initial MLSS concentration 1700 mg/L]

6.5 Determination of kinetics constants for real life sample

Reaction kinetics plays a vital role in the evaluation of the performance of any reactor. Different experiments have been done to estimate the values of kinetic coefficients for combined carbon oxidation and nitrification of organic carbon and ammoniacal nitrogen (NH_4^+-N).

The kinetic constants for real life sample are estimated by following Burk-Lineweaver model, as described previously.

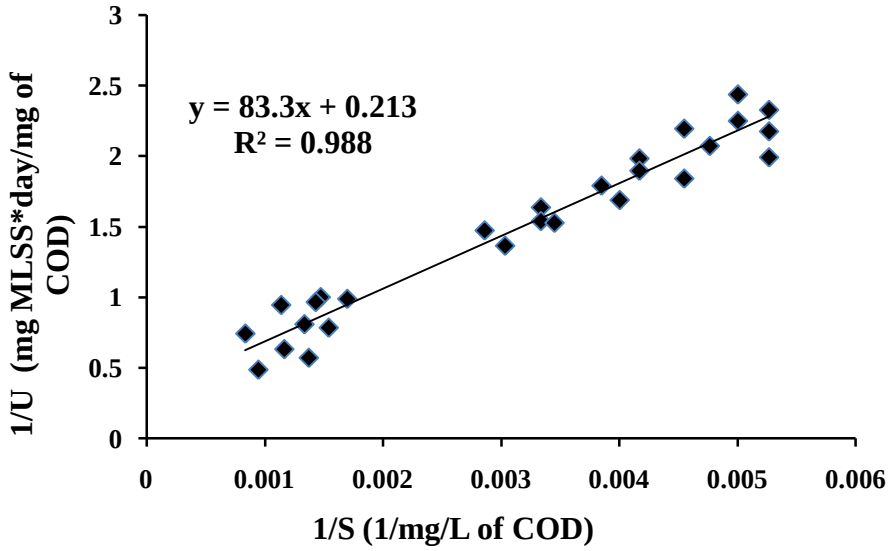

Fig. 6.23: Substrate Utilization kinetic for carbon oxidation study of real life sample in batch reactor

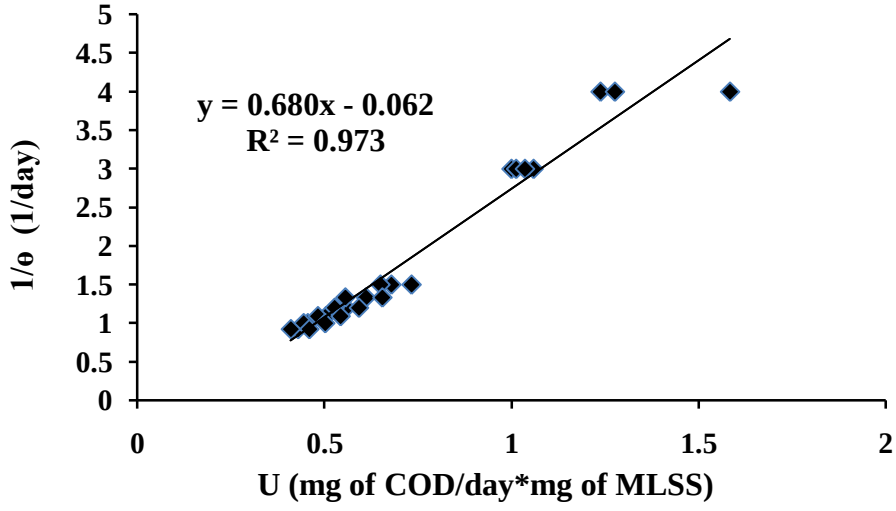

Fig. 6.24: Microbial growth kinetic for carbon oxidation study of real life sample in batch reactor

Table 6.23: Values of kinetic constants for carbon oxidation in real life sample

Serial no.	Kinetic Coefficients	Values from Present Study	Typical kinetic coefficient for Municipal wastewater (Metcalf and eddy, 1995)
1	**Y**	0.680	0.4-0.8
2	**K_d**	0.062	0.025-0.075
3	**K**	4.69	2-10
4	**k_s**	390.677	25-100

6.6 Time concentration study of real life waste water sample for nitrification in batch fed reactor

Evaluation of performance of batch fed reactor for nitrification study has been carried out in 2 separate operating conditions in Set 11 and Set 12 using real life wastewater sample.

6.6.1 Batch performance for Real life sample Set 11

The results of batch nitrification study for Set 11 with initial ammoniacal nitrogen concentration value of 75.38 mg/L and other operating conditions are shown in Table 6.24. The result obtained from the time concentration study within a contact period of 30 hour has been exhibited in Table 6.25. The experimental data are also plotted in Fig. 6.25 and 6.26.

From Fig. 6.25 it is observed that as time increases, the ammoniacal nitrogen concentration decreases with respect to initial ammoniacal nitrogen concentration of 75.38 mg/L and ultimately after 30 hour the residual ammoniacal nitrogen concentration inside the batch reactor reaches to a minimum level of 17.58 mg/L which correspondence to 76.68% removal of ammoniacal nitrogen from wastewater sample.

During nitrification process, the MLSS concentration in the reactor increases upto 3060 mg/L from the initial concentration of 2050 mg/L within a period of 30 hours of contact time. The increase of MLSS has been shown in Fig. 6.26.

Table 6.24: Operating conditions of batch reactor

[Initial ammoniacal nitrogen concentration 60.48 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7-7.5
3	Max Retention Time (Hours)	30
4	Initial Ammoniacal Nitrogen (mg/L)	75.38
5	Final Ammoniacal Nitrogen (mg/L)	17.58
6	% ammoniacal nitrogen removal (%)	76.68

Table 6.25: Variation in ammoniacal nitrogen concentration, MLSS and percentage of ammoniacal nitrogen reduction with time

[Initial ammoniacal nitrogen concentration= 75.38 mg/L]

Time (hour)	ammoniacal nitrogen concentration (mg/L)	% ammoniacal nitrogen removal	MLSS (mg/L)
0	75.38	0.00	2050
2	60.2	20.14	2350
4	47.04	37.60	2550
6	40.54	46.22	2630
16	33.51	55.55	2750
20	28.36	62.38	2830
22	23.25	69.16	2975
24	22.4	70.28	3030
28	18.56	75.38	3060
30	17.58	76.68	3060

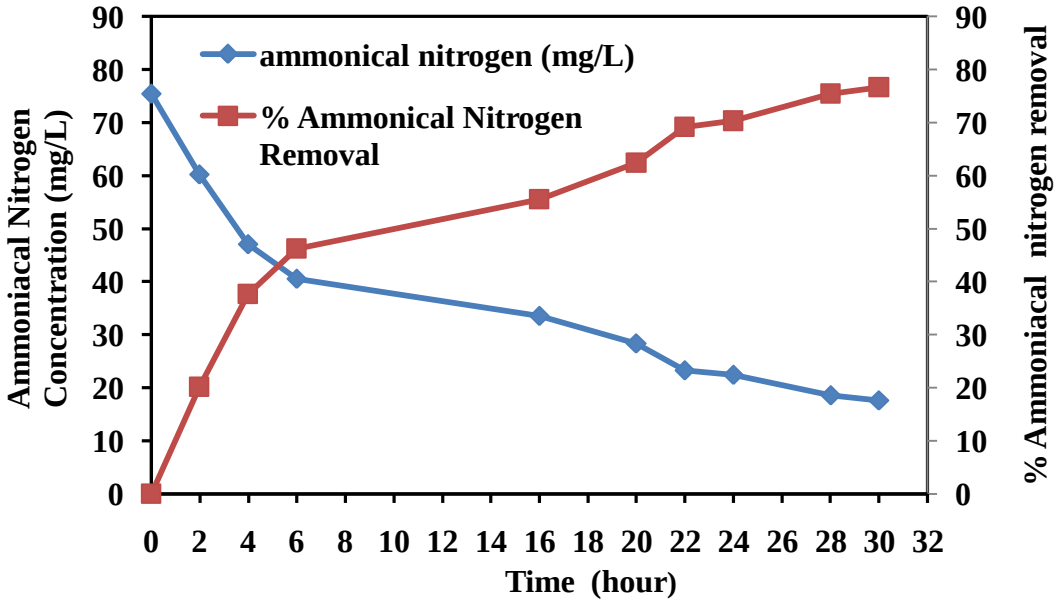

Fig. 6.25: variation in ammoniacal nitrogen concentration and percentage of ammoniacal nitrogen reduction with time [Initial ammoniacal nitrogen concentration= 75.38 mg/L]

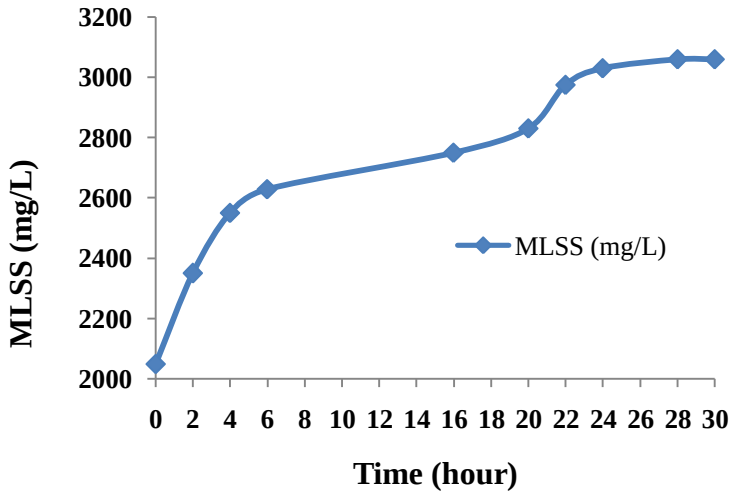

Fig. 6.26: variation of MLSS with time

[Initial MLSS concentration 2050 mg/L]

6.6.2 Batch performance for Real life sample Set 12

The results of batch nitrification study for Set 12 with initial ammoniacal nitrogen concentration value of 60.48 mg/L and other operating conditions are shown in Table 6.26. The result obtained from the time concentration study within a contact period of 30 hour has been exhibited in Table 6.27. The experimental data are also plotted in Fig. 6.27 and 6.28.

From Fig. 6.27 it is observed that as time increases, the ammoniacal nitrogen concentration decreases with respect to initial ammoniacal nitrogen concentration of 60.48 mg/L and ultimately after 30 hour the residual ammoniacal nitrogen concentration inside the batch reactor reaches to a minimum level of 10.12 mg/L which correspondence to 83.27% removal of ammoniacal nitrogen from wastewater sample.

During nitrification process, the MLSS concentration in the reactor increases upto 3140 mg/L from the initial concentration of 2000 mg/L within a period of 30 hours of contact time. The increase of MLSS has been shown in Fig. 6.28.

Table 6.26: Operating conditions of batch reactor
[Initial ammoniacal nitrogen concentration 60.48 mg/L]

SERIAL NUMBER	PARAMETERS	RANGE
1	Temperature (°C)	27 - 32
2	pH	7-7.4
3	Max Retention Time (Hours)	30
4	Initial Ammoniacal Nitrogen (mg/L)	60.48
5	Final Ammoniacal Nitrogen (mg/L)	10.12
6	% ammoniacal nitrogen removal (%)	83.27

Table 6.27: Variation in ammoniacal nitrogen concentration, MLSS and percentage of ammoniacal nitrogen reduction with time [Initial ammoniacal nitrogen concentration= 60.48 mg/L]

Time (hour)	ammoniacal nitrogen concentration (mg/L)	% ammoniacal nitrogen removal	MLSS (mg/L)
0	60.48	0.00	2000
2	43.6	27.91	2300
4	34.52	42.92	2550
6	26.54	56.12	2650
7	22.35	63.05	2675
16	18.45	69.49	2840
20	15.42	74.50	2980
24	12.35	79.58	3060
28	10.98	81.85	3140
30	10.12	83.27	3140

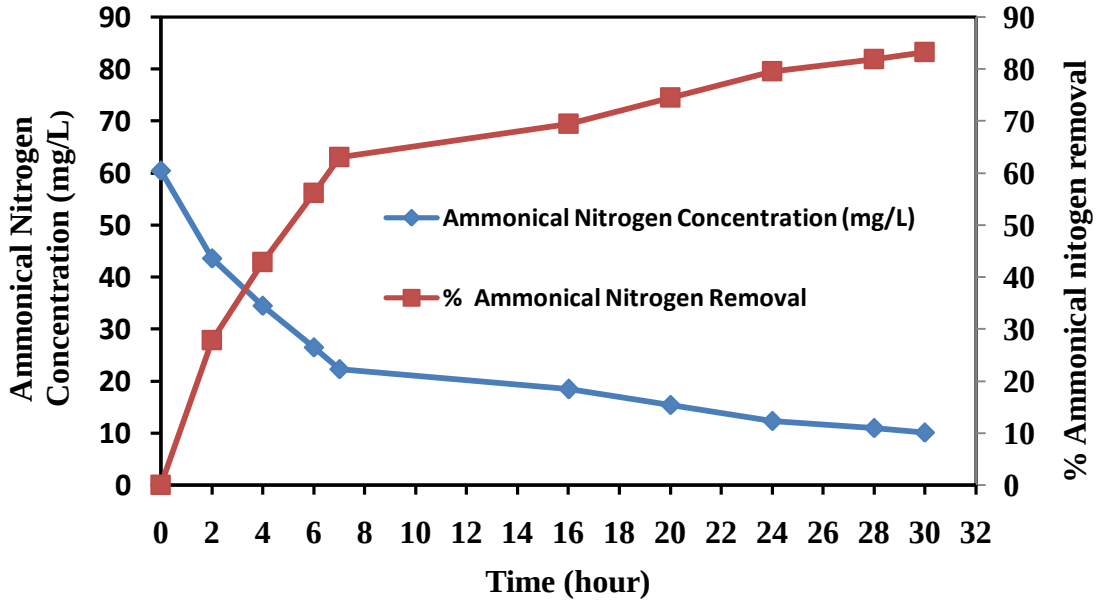

Fig. 6.27: variation in ammoniacal nitrogen concentration and percentage of ammoniacal nitrogen reduction with time [Initial ammoniacal nitrogen concentration= 60.48 mg/L]

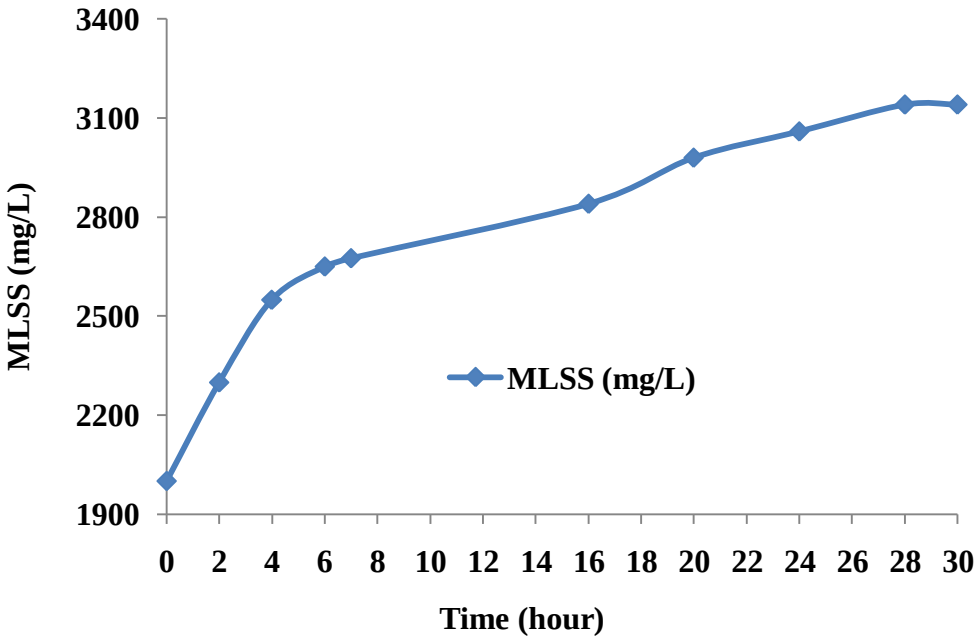

Fig. 6.28: variation of MLSS with time
[Initial MLSS concentration 2000 mg/L]

6.7 Kinetics for nitrification

The values for the reciprocal of specific substrate (NH_4^+-N) utilization rate (1/U) were plotted against the reciprocal of limiting ammonia nitrogen (1/N) and ammonia nitrogen removal kinetics were evaluated using equation

$$1/U = (K_s/k).(1/N) + 1/k.$$

A best fit graph was drawn by applying a least square method using experimental data. The slope and intercept of the straight line are K_s/k and 1/k respectively. The maximum substrate utilization rate (k) slightly decreased in case of high initial NH_4^+-N concentration as N indicates a gradual build up of substrate inhibition for autotrophs within the batch reactor. The initial ammonia concentration maintained all along the present study was very high. Consequently, the magnitude of half velocity constant (K_s) value was found to be higher.

The values of the reciprocal of the reaction time (1/θ) were plotted against specific substrate (NH_4^+-N) utilization rate (U). It is established that the substrate inhibition on the autotrophs took place at high NH_4^+-N value.

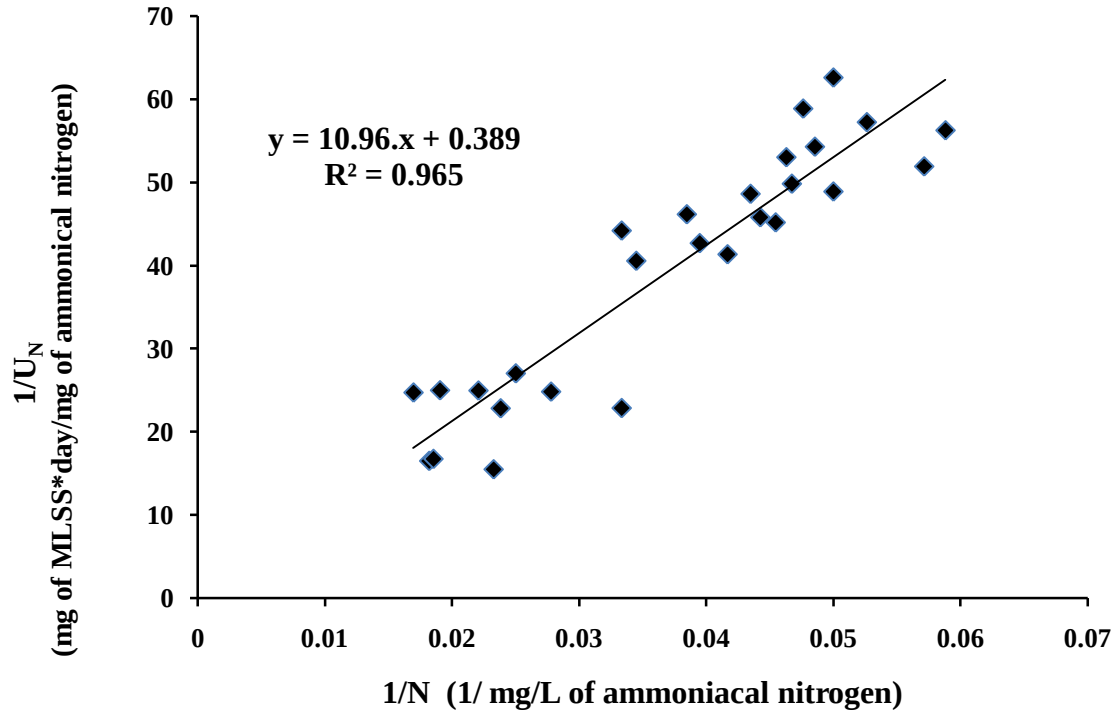

Fig. 6.29: Substrate Utilization kinetic for nitrification study of real life sample in batch reactor

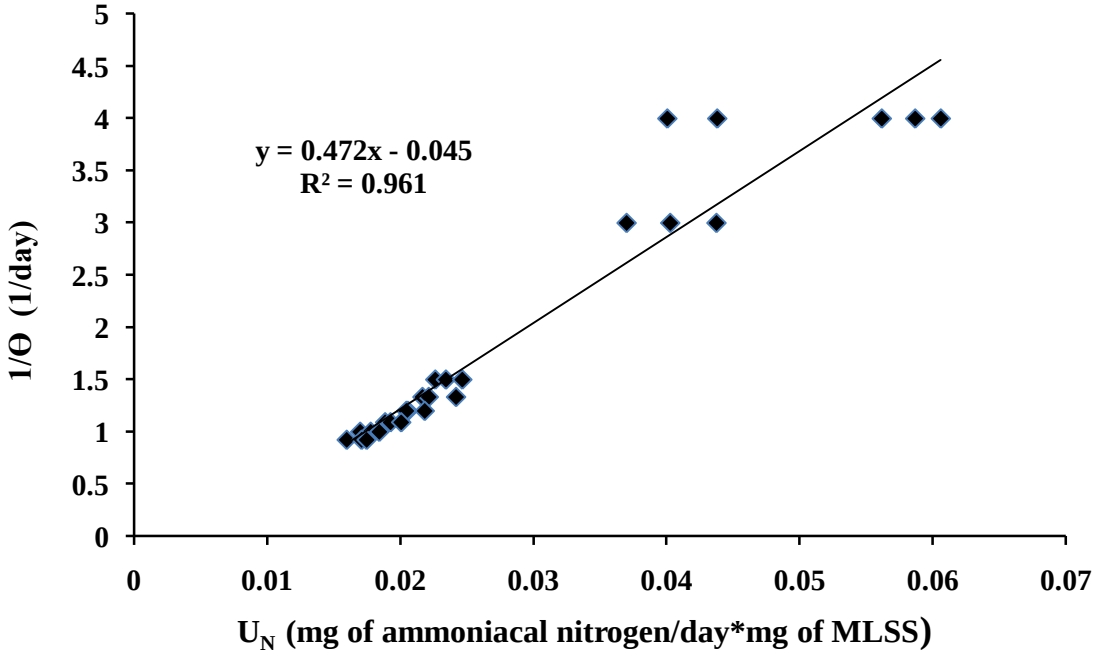

Fig. 6.30: Microbial growth kinetic for nitrification study of real life sample in batch reactor

Table 6.28: Values of kinetic constants for nitrification in real life sample

Serial no.	Kinetic Coefficients	Values from Present Study	Typical kinetic coefficient for Municipal wastewater (Metcalf and eddy, 1995)
1	**Y**	0.472	0.1-0.3
2	**K_d**	0.045	0.03-0.06
3	**k**	2.57	1-30
4	**k_s**	28.16	0.2-5

6.8. Designing of experimental activated sludge reactor on field scale

Based on the kinetic coefficients as obtained through different batch experiment sets in the present study, an activated sludge bioreactor has been designed aiming to implement in the field scale. Validation of the design has not been done in the present study, thus, before a practical application is made, further studies is proposed to be carried out in the pilot scale/ Lab base model reactor system.

Following are the basic design input of the proposed activated sludge model bioreactor in field scale:

- Influent COD [S_0] = 1400 mg/L
- Effluent COD [S] = 200 mg/L
- MLSS Concentration [X] = 2500 mg/L
- SRT(Θ_C) = 5 days
- K_d = 0.062 per day
- K_s=390.67 per day
- Flow rate [Q] = 40 m^3/day (The data is collected from an existing plant)
- Yield coefficient [Y] = 0.680 mg/mg

The first driving equation is,

$$\frac{1}{\theta_C} = YU - k_d$$

SO, $\frac{1}{5} = 0.68U - 0.062$

Or U=0.385

The second driving equation is,

$$U = \frac{Q(S_0 - S)}{VX}$$

So,

$$V = \frac{Q(S_0 - S)}{UX}$$

Putting the values we get,

Volume (V) = 49.87 m^3.

V Provided = 50m^3.

HRT (θ) = $\frac{V}{Q} = \frac{50}{40} = 1.25 \text{ days} = 30 \text{ hours}$

Assume height of reactor=3.5 m

Cross sectional Area=50/3.5=14.29 m^2.

Provided Area=16 m^2.

Assuming Length: width=3:1,

Provide Length=7m, width=2.3 m.

COD removed = Q [S_O-S] = 48 Kg/day.

$$Y = \frac{MLSS\ produced}{Mass\ of\ substrate\ utilized} = 0.68$$

MLSS Production=32.64 Kg/day.

[BOD / COD] ratio = [1000/1400] = 0.72

Oxygen Demand = [BOD_{in} - BOD_{out}]*Q

= [COD_{in} - COD_{out}]*0.72*Q
= 34.56 Kg/day

Density of air = 1.3 Kg/m^3

Volume of oxygen consumed = [34.56/ 1.3] = 26.59 m^3/day

Let 22% of oxygen be present in air

Volume of air required= $\left[100 * \frac{26.59}{22}\right] = 120.86\ {}^{m^3}/_{day}$

Assuming 200% of excess air supply = 120.86*2=241.72 m^3/day.

CHAPTER 7

CONCLUSION

Following conclusions are drawn from the present experimental investigation work.

- Confectionery and bakery plant wastewater is amenable for biological treatment using acclimatized mixed culture having carbonaceous and nitrifying bacteria.

- It has been observed that 97% COD removal was achievable in synthetic wastewater corresponding to initial COD concentration of 1352.16 mg/L. The HRT was 24 hours for COD removal.

- In case of real life wastewater sample 90% COD and 83.27% ammoniacal nitrogen oxidation were achievable corresponding to initial COD concentration of 1320 mg/L and initial ammoniacal nitrogen concentration of 60.48 mg/L. The HRT for obtaining such performance were 26 hours for COD and 30 hours for NH_4-N. Hence, a total of 30 hrs contact time is proposed for combined removal of COD and NH_4-N.in a single reactor.

- A marginal difference of treatment efficiency was observed due to presence of fat, oils and other recalcitrant element perhaps may be in case of batch fed study of real life sample.

- Based on batch experimental data, kinetic coefficients were evaluated.

- Kinetic constant values were corroborated with results of previous researchers who conducted study on combined COD and nitrogen removal.

- Finally a field scale model reactor on the basis of activated sludge process was designed using kinetic coefficients.

CHAPTER 8

LIMITATIONS OF THE PRESENT STUDY

A serious effort has been endeavored to achieve the target objectives of this study, yet this present study is not devoid of certain limitations.

- In the present study, the experiments were primarily made on the removal of COD and ammoniacal nitrogen. Concentrations of other nutrients and/ or pollutants like phosphorous, oil, grease, soluble organic waste, inorganic solutes have not been studied.
- The studies were made in the laboratory prepared samples collected from bakery and confectionery production plants. It is needless to mention that the experiments were typically made on a laboratory scale. Large volumes of effluents handling, collection, transportation and availability of the proper infrastructure were the main constraints. Thus, effectiveness of this project must be verified on implementing pilot scale/ onsite treatment facilities.
- SVI (Sludge Volume Index) parameters were not determined to examine the settlabilty aspect of sludge.
- The microorganisms that grew in the sludge were neither identified nor characterized. Thus, taxonomic study of the microbes does not fall in the purview of the present study.
- Real time performance investigation did not carry out.
- ASM (Activated Sludge Models) were not designed, though it may be obtained from the data deduced in the present study.
- The data obtained in the study must be validated on industrial scale in future before it is materialized to guarantee its effectiveness.

CHAPTER 9

FUTURE SCOPES OF PRESENT STUDY

- Laboratory based suspended growth reactor model will be fabricated and detailed performance study will be done with real life wastewater sample.
- The influent and effluent data should be validated with design model prepared on the basis of kinetic evaluation results.
- The reactor should be operated with initially batch followed by continuous mode of operation including sludge recirculation system.
- The deviations with calculated and observed results are to be noted to observe the gap between theoretical design and experimental evaluation.
- In the future study phosphorus, oil and greasy aspects are to be considered to explore the effects of the parameters in total removal process. In such cases, an integral treatment options may be required to be formulated, in such case anaerobic-aerobic/Sequencing batch reactor and physio-chemical treatment options are to be included.

CHAPTER 10

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ANNEXURE

Table 1A: Values for determination of kinetic constants for carbon oxidation in batch fed reactor of real life waste water

Time(hour)	COD	MLSS	ɵ (day)	1/ ɵ	U=(S_0-S)/(x* ɵ)	1/U	1/S
2	1060	1980	0.083333	12	2.0614	0.485107	0.000943396
4	860	2045	0.166667	6	1.584352078	0.631173	0.001162791
6	750	2100	0.25	4	1.238095238	0.807692	0.001333333
8	680	2160	0.333333	3	1	1	0.001470588
16	350	2320	0.666667	1.5	0.67887931	1.473016	0.002857143
18	300	2400	0.75	1.3333	0.611111111	1.636364	0.003333333
20	260	2450	0.833333	1.2	0.558367347	1.790936	0.003846154
22	240	2510	0.916667	1.090909	0.504165158	1.983477	0.004166667
24	220	2590	1	1	0.455598456	2.194915	0.004545455
26	190	2600	1.083333	0.9231	0.429585799	2.327824	0.005263158
4	730	2290	0.16667	6	1.7554585	0.569651	0.001369863
6	650	2350	0.25	4	1.276595745	0.783333	0.001538462
8	590	2400	0.33333	3	1.0125	0.987654	0.001694915
16	300	2540	0.66667	1.5	0.649606299	1.539394	0.003333333
20	240	2640	0.83333	1.2	0.527272727	1.896552	0.004166667
22	210	2690	0.91667	1.090909	0.482595471	2.072129	0.004761905
24	200	2700	1	1	0.444444444	2.25	0.005
26	200	2700	1.08333	0.923077	0.41025641	2.4375	0.005
6	880	1964	0.25	3	1.059063136	0.944231	0.001136364
8	700	2027	0.33333	3	1.036013814	0.965238	0.001428571
16	330	2190	0.66667	1.5	0.732876712	1.364486	0.003030303
18	290	2260	0.75	1.333333	0.654867257	1.527027	0.003448276
20	250	2330	0.83333	1.2	0.592274678	1.688406	0.004
22	220	2370	0.91667	1.090909	0.543153049	1.841102	0.004545455
24	190	2410	1	1	0.502074689	1.991736	0.005263158
26	190	2430	1.08333	0.923077	0.459639126	2.17562	0.005263158

Table 1B: Values for determination of kinetic constants for nitrification in batch fed reactor of real life waste water

Time (Hour)	NH_4-N	MLSS	T (day)	1/T	$U_N=(S_0-S)/x*T$	$1/U_N$	1/N
2	55	1980	0.0833	12	0.060606061	16.5	0.018181818
4	43	2045	0.1667	6	0.064547677	15.4924242	0.023255814
6	42	2100	0.25	4	0.043809524	22.826087	0.023809524
8	36	2160	0.3333	3	0.040277778	24.8275862	0.027777778
16	30	2320	0.6667	1.5	0.02262931	44.1904762	0.033333333
18	26	2400	0.75	1.333333333	0.021666667	46.1538462	0.038461538
20	23	2450	0.8333	1.2	0.020571429	48.6111111	0.043478261
22	21.6	2510	0.9167	1.090909091	0.018862731	53.0145929	0.046296296
24	21	2590	1	1	0.016988417	58.8636364	0.047619048
26	20	2600	1.0833	0.923076923	0.015976331	62.5925926	0.05
2	54	2210	0.0833	12	0.059728507	16.7424242	0.018518519
8	30	2400	0.3333	3	0.04375	22.8571429	0.033333333
16	25.33	2540	0.6667	1.5	0.023427165	42.6854886	0.039478879
18	22	2590	0.75	1.333333333	0.022136422	45.1744186	0.045454545
20	20	2640	0.8333	1.2	0.020454545	48.8888889	0.05
22	17.5	2690	0.9167	1.090909091	0.019263265	51.9122807	0.057142857
24	17	2700	1	1	0.017777778	56.25	0.058823529
2	59	1780	0.0833	12	0.040449438	24.7222222	0.016949153
4	52.53	1870	0.1667	6	0.040010695	24.9933173	0.019036741
6	45.33	1964	0.25	4	0.0400611	24.9618709	0.022060446
8	40	2027	0.3333	3	0.037000493	27.0266667	0.025
16	29	2190	0.6667	1.5	0.024657534	40.5555556	0.034482759
18	24	2260	0.75	1.333333333	0.024188791	41.3414634	0.041666667
20	22.6	2330	0.8333	1.2	0.02183691	45.7940252	0.044247788
22	21.4	2370	0.9167	1.090909091	0.020069045	49.8279817	0.046728972
24	20.6	2410	1	1	0.018423237	54.2792793	0.048543689
26	19	2430	1.0833	0.923076923	0.017473884	57.2282609	0.052631579