Performance Evaluation of Wastewater Treatment Plant for Milk Based Food Industry

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MASTER OF TECHNOLOGY
in

ENVIRONMENTAL SCIENCE & TECHNOLOGY

by

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Candidate's Declaration

I hereby declare that the work presented in the dissertation entitled **"Performance evaluation of wastewater treatment plant for milk based food industry"** in partial fulfillment of the requirement for the award of degree of **Master of Technology** in **Environmental Science & Technology**, Thapar University, Patiala, is an authentic record of my own work during the period of twelve months from August 2007 to July 2008, under the supervision of Dr. Rinku Walia and Dr. Anita Rajor, Lecturer, Department of Biotechnology and Environmental Sciences, Thapar University. This work has not been submitted to this or any other university till now for the award of any other degree, diploma or equivalent course.

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CERTIFICATE

This is to certify that the thesis report entitled **"Performance evaluation of wastewater treatment plant for milk based food industry"** submitted by Pooja Sharma in the partial fulfillment of the requirement for the award of degree of the **Master of Technology in Environmental Science & Technology** to the Thapar University, Patiala, is a record of student's own work carried out by her under my supervision and guidance. The report has not been submitted for the award of any other degree or certificate in this or any other university or Institution.

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ABSTRACT

Dairy industry is one of the major industries causing water pollution. In India, dairy industry generates about 6-10 L wastewater/L of milk processed depending upon the process employed and product manufactured. Considering the increased milk demand by 2020 A.D., the milk based food industries in India is expected to grow rapidly and have the waste generation and related environmental problems are also assumed increased importance. Poorly treated wastewater with high levels of pollutants caused by poor design, operation or treatment systems creates major environmental problems when discharged to surface water or land. Considering the above stated implications an attempt has been made in the present project to evaluate one of the WWTP for dairy waste. Samples were collected from six points; Raw effluent [P-1], Oil and grease trap [P-2], Equalization tank [P-3], Aeration tank 1 [P-4], Aeration tank 2 [P-5] and Secondary clarifier [P-6] to evaluate the performance of WWTP. Parameters analyzed for evaluation of performance of WWTP are COD, BOD_5 at 20° C, TSS, Total Nitrogen, Phosphorous, oil and grease, Chloride and Sulphates. Mass balance of COD, TSS and Nitrogen was performed to find the fate of pollutants in WWTP. Parameters like SAR, Na, Salinity, RSC, pH and oil & grease were used to access the suitability of secondary effluent for reuse in irrigation. The COD, BOD_5 at 20° C and TSS removal efficiency of WWTP were 96%, 95%and 94% respectively. The TDS, SAR, RSC, Chloride, Potential salinity of secondary effluent were 966.7 mg/L, 0.06 meq/L, -2.1 meq/L, 209.9 mg/L and 10.7 meq/L respectively, which are in acceptable range for irrigation.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Rapid growth of industries has not only enhanced the productivity but also resulted in the production and release of toxic substances into the environment, creating health hazards and effected normal operations, flora and fauna. These wastes are potential pollutants when they produce harmful effects on the environment and generally released in the form of solids, liquid effluent and slurries containing a spectrum of organic and inorganic chemicals. Thus pollution is a necessary evil of all development. To combat the plethora of environmental evils of present day society, efficient and environmentally safe organic waste treatment technologies are needed.

Beside like other industries that have serious waste disposal problem, the milk based food industry is faced with the prospect of having to erect a large number of relatively small treatment plants. Liquid effluent from milk based food industry pose environmental problems like water and soil pollution. Oil & grease in wastewater generated from milk based food industry poses a major threat to the environment besides lactose, another pollutant component considering the project demand by 2020 A.D., the milk based food industry in India is expected to grow rapidly and have the waste generation and related environmental problems are also assumed increased importance. Poorly treated wastewater with high levels of pollutants caused by poor design, operation or treatment systems creates major environmental problems when discharge to surface water or land. Such problems include

- Contamination and deoxygenating of streams and waterways by direct discharge or run off of inadequately treated wastewater
- Excessive concentration of nutrients such as nitrogen and phosphorous in surface and subsurface water bodies. This contribute to excessive growth of plants and algae

blooms, which makes the downstream water unsuitable for domestic, agriculture and industrial use

- Land degradation and damage to pastures and crops. Long term damage to soil production may arise from
- Excessive nutrient loading
- High salinity
- Low / High pH
- Over application of wastewater to land resulting in contaminated ground water
- Soil structure decline due to wastewater with high Sodium Adsorption Ratio
- Clogging of soil by fats / solids from irrigated wastewater.

In the present study an effort has been made to evaluate one of the WWTP provided for the treatment of wastewater generated by milk based food industry. The study was limited to the performance evaluation of the WWTP of milk based food industry. Characterization of wastewater from different units of processing plant and management strategies are not studied.

1.2 Objective and Scope

Objective of the present study can be explicitly stated as the following:

- To monitor performance of the WWTP
- To address wastewater compliance issues related to irrigation
- Evaluation of operating and design parameters of ASP.

The study included

- Characterization of combined wastewater to the WWTP
- Design and operating parameters of ASP
- COD, Nutrient and TSS mass balance to study the fate of organic matter, TSS and Nitrogen.

1.3 Contents of the Report

This M. Tech. dissertation includes five chapters.

Chapter 1 is introduction. It deals with the objective and scope of study. Overview of the contents of the report is also included in this chapter.

Chapter 2 is the literature review. The literature is presented on the following aspects

- Wastewater from milk based food industry and their treatment
- Land disposal of secondary effluent and legal requirements.

Methodology followed for the present study is described in Chapter 3. It includes work elements involved and analysis used in the present study. Brief description of various units of WWTP is also included in this.

Chapter 4 deals with results and discussion of the performance evaluation study.

Chapter 5 is conclusions.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

The project deals with **Performance Evaluation of Wastewater Treatment Plant (WWTP)** for **Milk based food industry**. The literature has therefore been scanned to review:

- Wastewater from milk based food industry and their treatment
- Land disposal of secondary effluent and legal requirements.

2.2 Wastewater from Milk based Food Industry and their Treatment

2.2.1 Operation of Milk based food industry and effluent generation [9]

The milk industry involves processing raw milk into products such as consumer milk, butter, cheese, yogurt, condensed milk, dried milk (milk powder) and ice-cream using processes such as pasteurization, bottling, filling in cans etc. The milk industry is one of the most widely spread of all the industries. These vary from small receiving stations to large plants where most of the products made from milk are manufactured. Figure 2.1 is a composite flow diagram showing the major operations for the processing of the more common milk products. The following is a brief description of these processes.

Milk is received at the plant or receiving station in standard 80- lb cans. It is dumped to a weigh vat and the cans are washed in a can washer and returned to the producer. From the weigh vat milk is pumped to a storage tank or, if the plant is a receiving station, the milk is cooled and pumped to a tank truck for hauling to a bottling or processing plant. About 50% of the milk produced in this country is used as whole milk. A small amount of this is bottled as raw milk, but the major portion is pasteurized prior to further handling. Pasteurization is accomplished by heating either to 143º F for 30 minutes or 160º F for 15 minutes. The milk may then be bottled for distribution, condensed to produce evaporated milk, or dried to milk powder. A small amount of whole milk is used in the manufacture of ice-cream mixes and in some type of cheese. About 41% of the milk supply is separated into cream and skim milk. Some of cream is bottled for distribution or is used for ice-cream mix. A considerable portion however is used, in the manufacture of butter. In some cases the producer may separate the cream and deliver it to the plant where it is cooled and processed. Butter milk is by-product of butter manufacture and may be condensed in the vacuum pan or may be dried on heated rolls with or without pre-condensing. Powdered butter milk is used mainly in the preparation of stock and poultry feed. Skim milk from the separator may be condensed in the vacuum pan and/ or dried to produce skim milk powder. Condensed and powdered whey are also used in food products and animal feeds. Some of the skim milk may be used for the manufacture of cottage cheese and casein.

Whey is a by-product of cheese manufacture and is used in small plants for hog feeding. If the operations are large enough to warrant, it may be condensed in the vacuum pan or dried in the spray drier. Condensed and powdered whey are also used in food products and in animal feeds. In a comparatively few plants condensed whey is used for manufacture of milk sugar, lactic acid, alcohol or vinegar.

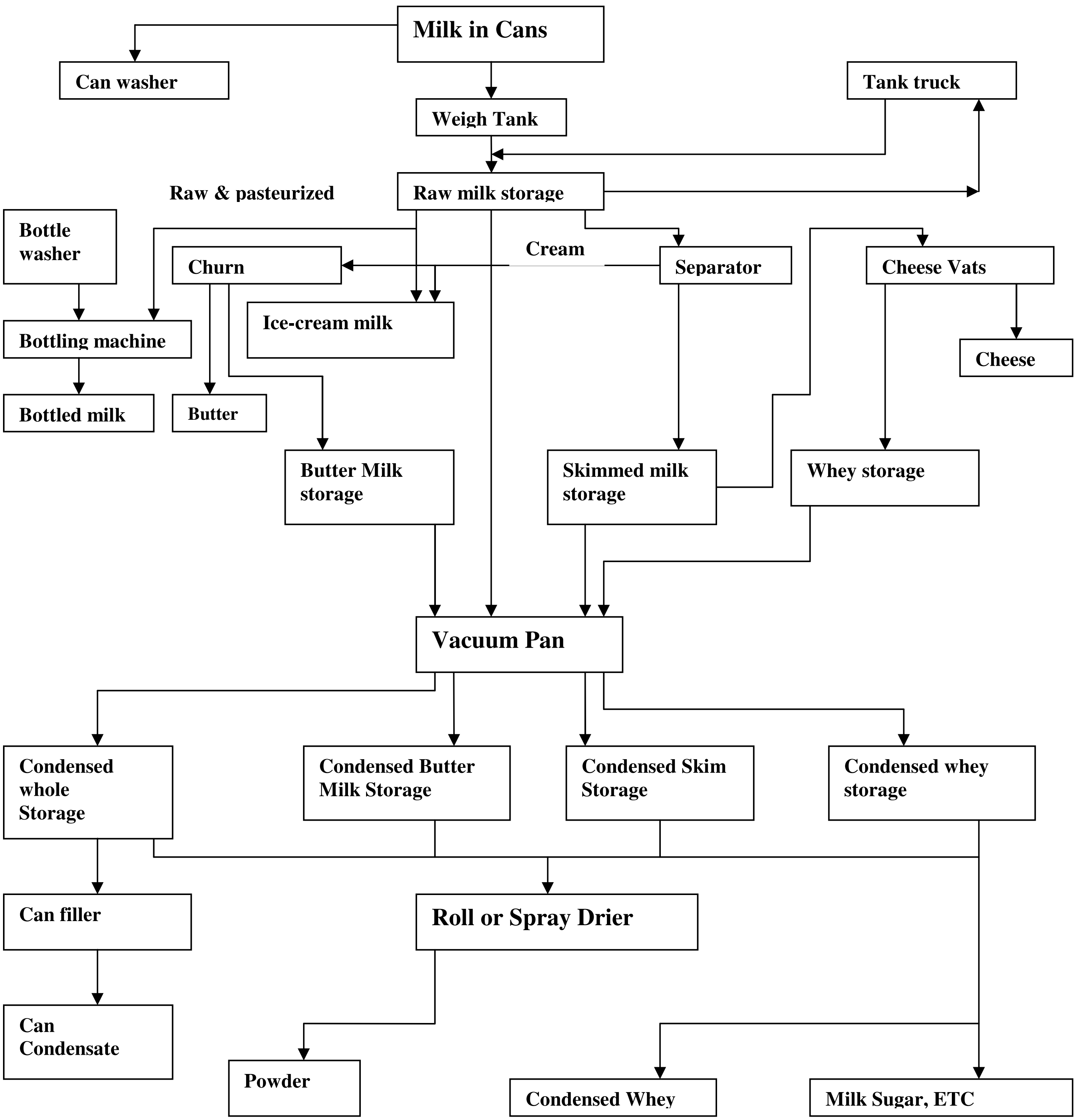

Figure 2.1: Composite Flow diagram of milk product operations [9]

2.2.2 Wastewater and their sources

Wastes from milk product manufacture contain milk solids in a more or less dilute condition, but in varying concentration. These solids enter the waste from almost all of the operations. Wastewater generated by milk based food industry is shown in Table 2.1. Contaminants expected in the wastewater from Milk based food industry are shown in Figure 2.2.

In general, the wastes generated from Milk based food industry are as follow

1. The washing and cleaning out of product remaining in the tank, trucks, cans, piping, tanks and other equipment is performed routinely after every processing cycle.
2. Spillage is produced by leaks, overflow, freezing-on, boiling over, equipment malfunction or careless handling.
3. Processing losses include:
    - Sludge discharge from clarifiers
    - Product wasted during pasteurized start-up, shut-down and product change-over
    - Evaporator entrainment
    - Discharges from bottles and washers
    - Splashing and container breakage in automatic packaging equipment
    - Product change-over in filling machines.
4. Spoiled products, returned products or by-products such as whey wasted.
5. Detergents and other compounds are used in the washing and sanitizing solutions that are discharged as waste.
6. Entrainment of lubricants from conveyors, stackers and other equipment appear in the wastewater from cleaning operations.
7. Routine operation of toilets, washrooms and restaurant facilities at the plant contribute waste.
8. Waste constituents may be contained in the raw water which ultimately goes to waste.

9. Non-dairy ingredients (such as sugar, fruits, flavors, nuts and fruit juices) utilized in certain manufactured products (include ice-cream, flavored milk, frozen desserts, yoghurt and others).
10. Milk by-products that are deliberately wasted, significantly whey and sometimes buttermilk

Uncontaminated water from coolers and refrigeration systems, which does not come in contact with the product, is not considered process wastewater. Such water is recycled in many plants. Sanitary sewage from plant employees and domestic sewage from washrooms and kitchens is usually disposed of separately from the process wastes and represent a very minor load of the plant.

Table2.1: Sources of wastewater from Milk based food industry [11]

Operations	Processes	Sources of waste
Preparation Stages	**Milk receiving/Storage**	• Poor drainage of tankers • Spills and leaks from hoses and pipes • Spills from storage silos/ tanks • Foaming • Cleaning operations
	Pasteurization/ ultra heat treatment	• Liquid losses/leaks • Recovery of downgraded product • Cleaning operations • Foaming • Deposits on the surfaces of pasteurization and heating equipment
	Homogenization	• Liquid losses/leaks • Cleaning operations
	Separation/ Clarification (Centrifuge, reverse osmosis)	• Foaming • Cleaning operations • Pipe leaks
Product processing stages	**Market milk**	• Foaming • Product washing • Cleaning operations • Overfilling • Poor drainage • Sludge removal from • Clarifier/Separators • Leaks • Damaged milk packages • Cleaning of filling machinery
	Cheese making	• Overfilling vats • Incomplete separation of whey from curd • Using salt in cheese making • Spills and leaks • Cleaning operations
	Butter making	• Vacreation and salt use • Product washing • Cleaning operations
	Powder manufacture	• Spills of powder handling • Start-up and shut-down losses • Plant malfunction • Stack losses • Cleaning of evaporators • Bagging losses

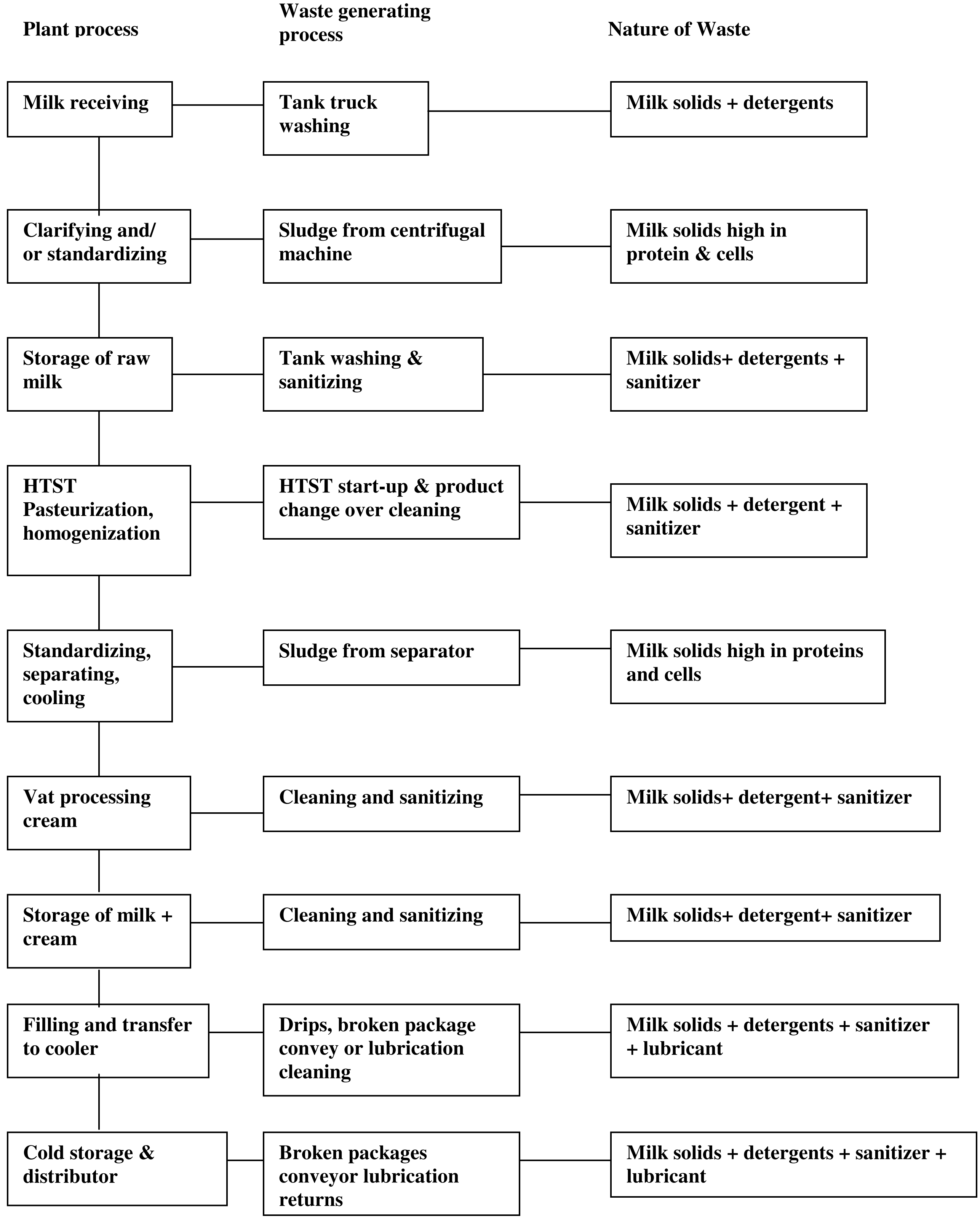

Figure 2.2: Contaminants present in wastewater from Milk based food industry

2.2.3 In-plant wastewater minimization strategies

Waste generation in dairy processing facilities is characterized by high daily fluctuations associated with washing procedures. High seasonal variations are also common and correlate with the volume of milk received for processing. Amount of wastewater generated depends on the management planning and efficiency of management supervision. In-plant waste minimization strategies employed for minimizing volume or strength of the wastewaters are shown in Table 2.2

Table 2.2: Suggested measures for reducing waste

Avoiding waste during Milk production		
Process	**Waste**	**Waste avoidance strategies**
Milk receiving / Storage	Milk	Purging of raw material and product lines
	CIP	-
	Sanitizer	-
Pasteurization/Ultra heat treatment	Wastewater	Prevent spillage recovery and reuse of raw material and Product
Homogenization	-	Recovery and reuse of raw material and products
Ultra Filtration	CIP chips	Automate CIP system
Packaged Milk	**-**	**-**
Way to Avoid waste during butter production		
Process	**Waste**	**Waste avoidance**
Milk, salt and Colorants	-	Prevent Spillages Maintain equipment
Vacrearion	Butter Milk	Correct preparation Dry and Reuse Use as stock feed
Salting	Butter wash water	-
Butter	-	-

Table 2.2: (contd…)

Ways to avoid waste during Cheese production		
Process	**Waste**	**Waste avoidance**
Milk, Salt and Culture	-	-
Salting	Wastewater	Reduce spillages
	Whey	collect and Whey and Cheese
	Curd	
Ripening	Pressings	Collect pressings By sweeping
Pressing	-	-
Cheese	**-**	**-**
Way to Avoid waste during powder production		
Process	**Waste**	**Waste avoidance**
Milk	**-**	**-**
Evaporation	Milk	Prevent product boil over
	Energy	Run to specified run length
	Wastewater	Avoid carry over of milk droplets during condensation Recirculate low concentration milk Reprocess rinsing >7% solids Use rinsing <7% for stock feed
Powder Production	Particulates	Air or Dry sweep
Milk powder	**-**	**-**

Source: Environmental Guidelines for the Dairy processing industry

2.2.4. Characterization of wastewater generated from milk based food industry

The major pollutants in wastewater discharges form Milk based food industry are Organic matter, Suspended Solids, pH, Nitrogen, Phosphorus and fats.

The **organic substances** in dairy wastewaters are contributed primarily by the milk and milk products wasted, and to a much lesser degree, by cleaning products, sanitizing compounds, lubricants and domestic sewage that are discharged to the waste stream.

The **inorganic constituents** of dairy wastewaters have been much less attention as sources of pollution than the organic wastes because product manufactured is edible materials which do not contain hazardous quantities of inorganic substances. However, the non-edible materials used in the process, do contain inorganic substances which by themselves, or added to those of milk products and raw water, potential pose a pollution problem. Such inorganic constitute include phosphates (used as deflocculants and emulsifiers in cleaning compounds), chlorine (used in detergents and sanitizing products) and nitrogen (contained in wetting agents and sanitizers). Table 2.3 shows there characterization of overall effluent generated.

Table 2.3: Characterization of the overall effluents generated in dairy factories, (composition in mg/L, expect for pH)

Origin	COD	BOD	Fats	N_t	P_t	pH	TS	VS	TSS	VSS	References
DF	4000	2600	400	55	35	8-11	-	-	675	635	[19]
DF	4000	2160	-	200	60	5-9	5100	4300	-	500	[5]
DF	2926	1580	294	36	21	6.7	2750	1880	-	-	[40]
DF	633	260	-	106	-	8.9	710	447	240	-	[26]
DF	2209	1112	60	-	-	7.2	-	-	278	-	[47]
DF	4500	2300	-	56	33	7.2	2540	1093	816	-	[16]
DF	-	285	-	296	-	8.1	-	-	943	-	[43]
DF	2125	1250	-	70	100	9.8	1500	-	280	250	[32]
DF	-	241	-	191	50.9	8.5	-	-	-	804	[32]
DF	4500	2300	350	60	50	-	-	-	800	-	[7]
DF	4000	2000	-	60	-	-	-	-	800	-	[22]
DF	1750	-	-	75	9.1	-	-	-	400	355	[22]

DF, Dairy Factory

2.2.5. Wastewater treatment technologies for Milk based food industry

Options For wastewater of Milk based food industry includes

- Treatment to a suitable standards for reuse or recycling
- Discharge to local authority sewers under a trade waste agreement (with pretreatment as necessary)
- Appropriate treatment and land discharge wherever practicable and environmentally beneficial

Best practice for wastewater systems is shown in Figure 2.3.

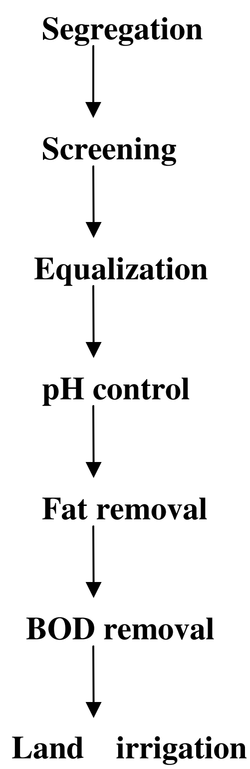

Figure 2.3: Practice for wastewater systems [11]

1. Segregation

Clean storm water should be separated from contaminated storm water and discharge directly into storm water drains. Waste streams from the plant should also be segregated e.g., whey can be reused to produce whey powder or stock feed. Spent cleaning solutions should be separated from other wastewater streams as they can be treated to recover cleaning agents. Highly saline wastewater should also be discharged separately to an evaporation pond where the salts can be removed and recycled. Suggested options for treatment of wastewater from milk based food industry are shown in Figure 2.4.

2. Pre-treatment

Pretreatment of wastewater from milk based food industry consists of screening, grit separation, flow balancing, pH control and removal of coarse solids. The settleable 60% of the suspended solids and 35% of the BOD, can be eliminated during primary treatment. Primary treatment is essential activity that needs to be undertaken for a proper application of various secondary treatment systems.

2. A. Screening

Wire mesh screens are advisable to prevent blockage of drains, particularly in bottling dairies to retain broken bottles, caps, labels and other solid material. Screens are also necessary at the cheese factories to remove cheese curd.

2. B. Fat removal

Coarse milk solids should be removed by screening. Fats can constitute up to 50% of the organic load. Its recovery is therefore significant in any treatment process. Dissolved air flotation is very effective method.

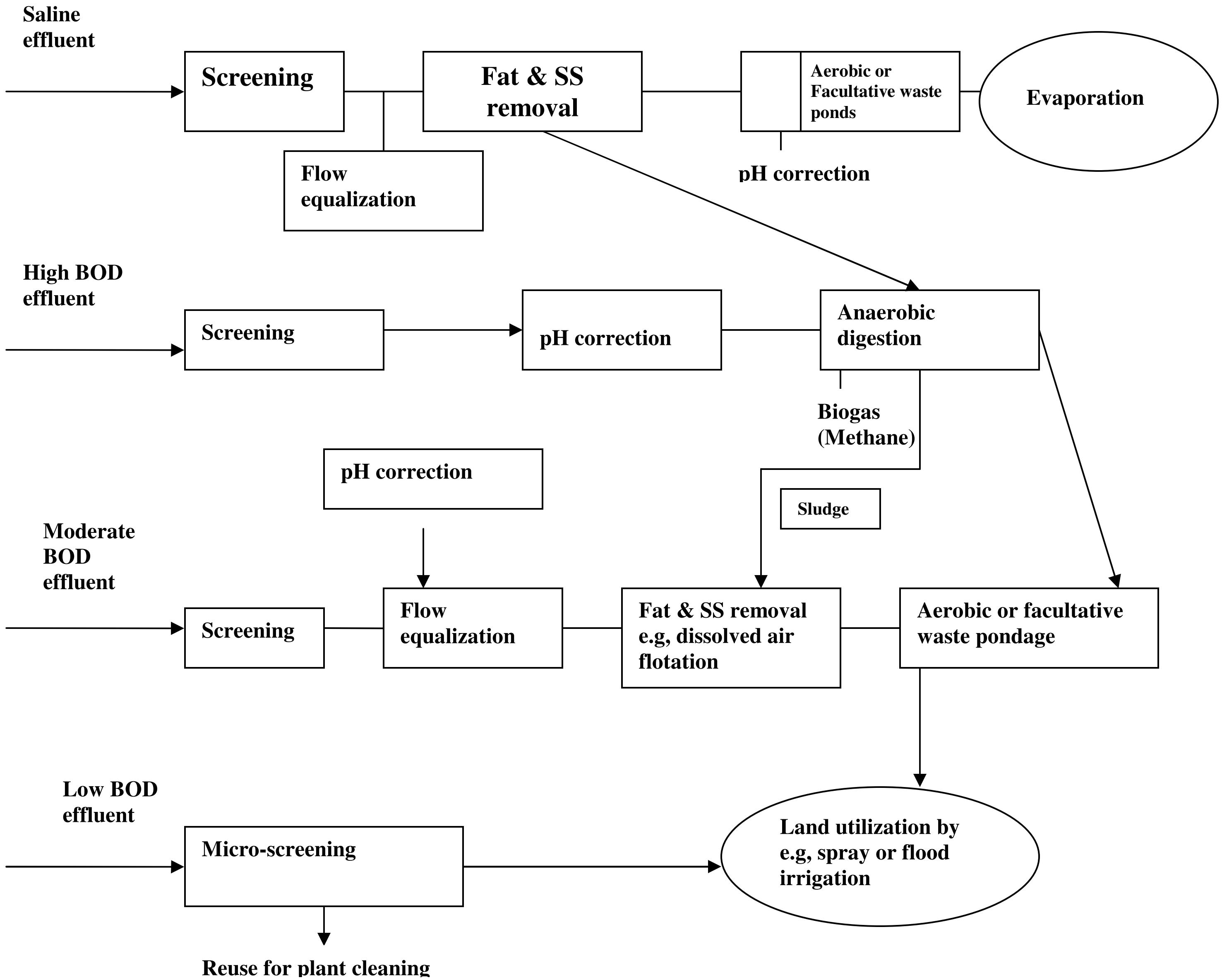

Figure 2.4: Suggested options for treatment of segregated waste streams

2. C. Balancing of Flow

The daily time table in the dairy industry causes wide fluctuations in effluent volume and strength. To maximize treatment plant efficiency it is necessary to operate it at constant flow rates with relatively consistent untreated wastewater composition. To achieve this objective a balance or equalization tank is essential, the size being governed by local operating conditions and the necessity of accommodating peak flows. Aeration has been included in balance tank to prevent the possibility of septic conditions and subsequent protein coagulation developing. Aeration can be achieved by passing air through diffuser pipes, by pumping the incoming effluent against a splash plate or, by a surface aerator.

3. Primary Treatment

Settlement

The amount of settleable material in the waste depends upon its origin; waste from a bottling dairy or collecting depot contains very little settleable solids, whilst the waste from a milk products manufacturing creamery can contain sufficient settleable material to warrant the inclusion of this type of treatment scheme. A detention time of 4-6 h was sufficient for the removal of easily settleable material, thereby reducing the BOD of the waste by some 10-20% and protecting the biological filter beds from overloading.

In more recent schemes, employing activated sludge treatment and biofilters, initial settlement has been eliminated to ensure that aerobic conditions are maintain all times [28].

4. Secondary Treatment or Biological treatment

There are basically two types of biological wastewater treatment systems; aerobic and anaerobic systems. In view of high BOD load in the wastewater from milk based food industry, aerobic processes (for low organic load) and anaerobic processes (for high organic loads) are adopted for the treatment of wastewater from milk based food industry. The selection of processes for any particular plant plant will depend upon the size of the problem, location of the plant and the necessary degree of treatment.

Anaerobic systems do not remove such nutrients as ammonium-nitrogen .If liquid and slurry are used as fertilizer, this does not need to pose specific problem. So nutrient removal system should be applied only if water authorities set limits for the discharge of nutrients.

Advantages and disadvantages of these systems are mentioned in table 2.4

Table 2.4: Advantages and disadvantages of Aerobic & Anaerobic Systems

Treatment	Advantage	Disadvantage
Anaerobic	• Possible production of energy • Low need for land • Power failure or shutdown will not affect the system • No energy consumption • Low production of excess sludge	• Optimal process temperature is about 30ºC • Post-treatment for BOD removal is often required
Aerobic	• Low process temperature • End treatment of wastewater	• Energy need for aeration • High need for land • Power failure or shutdown will affect the entire system • Post-treatment of further nutrient removal is often required • High production of excess sludge

Source: Hulshof Pol, 1993

The majority of Biological treatment methods can be applied to effluent from Milk based food industry

- If land is available, land treatment and pond systems
- Other biological treatment systems
  - Aerated lagoons
  - Activated Sludge Process
  - Extended aeration
  - Sequencing Batch Reactor
  - Biofiltration
  - Up flow anaerobic sludge blanket

Table 2.5: Biological treatment of wastewater from milk based food industry

Researcher	Type of waste	Biological treatment	Detention time	Treatment Efficiency					
				BOD_5	COD	TKN	TOC	VOM	VFA
Fang, H.P. and Herbert, (1990). A	Dairy wastewater	ASP	19.8 hrs	99%	-	91%	-	-	-
Fang, H.P. and Herbert, (1990). B	Whey processing plant	ASP	19.8hrs	99%	-	91%	93%	-	-
		Completely Mixed Anaerobic reactor	2 Days	87%	-	-	-	-	-
Nasr, A. *et al*. (1996).	Dairy wastewater	ASP	24 hrs	70%	71%	-	-	64%	-
		TF	-	-	-	-	-	90%	-
		UASB	-	96%	97%	-	-	-	-
Mohseni-Bandpi, A. et al.(2004)	Dairy wastewater	SBR	6 hrs	-	90%	-	-	-	-
Banu, *et al*. (1996)	Dairy wastewater	HUASB + Solar Photocatalytic oxidation methods	HUASB (110 Days)	-	95%	-	-	-	-
Omil, F. et al. (2003)	Dairy wastewater	Anaerobic filter reactor	-	-	90%	-	-	-	-
Durate, A. *et al.* (2005)	Dairy wastewater	UASB	6-12 hrs 12-16 hrs	- -	80% 80%	- -	- -	- -	60% 60%

Both aerobic and anaerobic processes have been used by various researchers for the treatment of wastewater from milk based food industry. These are summarized in Table 2.5. Lab scale aerobic treatment of dairy wastewater by the three stages of ASP, investigated by Fang and Herbert (1990) [12] . Dairy plant average BOD_5 of 1060 mg/L and an average TKN of 109 mg/L within the overall retention time of 19.8 hrs, the final effluent contained 9mg/L of BOD_5 and 10 mg/L of TKN, corresponding to respective reduction of 99% and 91%. Treatment of wastewater from whey processing plant using ASP and anaerobic process was investigated by Fang and Herbert (1990) [13]. He found ASP was more efficient in removing BOD_5. ASP removes 99% of BOD_5 as compared to 87% by anaerobic reactor. The chemical–biological treatment was carried out on dairy wastewater using ASP, TF and UASB by Nasr *et al*. (1996) [34]. ASP removed 64% of VOM, 71% COD and 70% BOD_5. 90% of VOM was removed by TF. Removal of COD and BOD by UASB was found to be 97% and 96% respectively.

A bench scale aerobic SBR was investigated by Mohseni-Bandpi *et al*. (2004) [31] to treat the dairy wastewater. Easy operation low cost and minimal sludge bulking condition make the SBR system an interesting option for the biological medium strength industrial wastewater treatment . The study demonstrated the capability of aerobic SBR for COD removal from dairy industry wastewater. The reactor was feed with milk factory and synthetic wastewater under different operating conditions. The highest COD removal efficiency was more than 90% and the sludge settling properties for milk factory wastewater were obtained at high sludge (20 days) and aerated period 6 hrs.

The study done by Banu *et al*. (1996) [4] aimed to treat the dairy wastewater by using anaerobic photocatalytic oxidation treatment. The optimum pH and catalyst loading for the solar photochemical oxidation was found to be 5 and 300 mg/L, respectively. The secondary solar photocatalytic oxidation using TiO_2 removed 62% of the COD from primary anaerobic treatment. Integration of anaerobic and solar photocatalytic treatment resulted in 95% removal of COD from the dairy wastewater. The findings suggest that anaerobic treatment followed by solar photocatalytic oxidation would be a promising alternative for the treatment of dairy wastewater.and solar photocatalytic oxidation methods. The anaerobic treatment was carried out in a laboratory scale hybrid up flow anaerobic sludge blanket reactor (HUASB) with a working volume of 5.9 L. It was operated at organic loading rate (OLR) varying from 8 to 20 kg COD/m^3 day for a period of 110 days. The maximum loading rate of the anaerobic reactor was found to be 19.2 kg COD/m^3 day and the corresponding chemical oxygen demand (COD) removal at this OLR was 84%. The anaerobically treated wastewater at an OLR of 19.2 kg COD/m^3 day was subjected to secondary solar.

Omil *et al.* (2003) [35] investigated anaerobic filter (AF) reactor, performance for the treatment of complex dairy wastewater. A full scale plant comprising of 12m^3 anaerobic filter (AF) reactor and a 28 m^3 sequential batch reactor (SBR) was used. The organic loading rates maintain in AF reactor were 5-6 kg COD/ m^3.d, with COD removal being higher than 90%. The effluent of the AF reactor was successfully treated in SBR reactor, and final effluent with COD content below 200 mg/L and total Nitrogen below 100mgN/L was obtained.

Durate *et al.* (2005) [33] assesses the possibility of using flocculated sludge in UASB reactors for the treatment of dairy wastewater and studies the effect of HRT (6, 8, 12, 16 hrs) on the performance of the reactor. UASB reactors were used with a height of 1170 m and a working volume of 31.71. The reactors were kept at temperature of 35ºC in a climate room. Initially the reactors were feed with wastewater from a dairy industry (COD 700-1200 mg/L; fats 75-150 mg/L; pH 9.5-11) supplemented with alkalinity and nutrients. It was observed by raising HRT from 6-12 hrs the performance of the system improved concerning the maximum applicable load, the COD removal efficiency and methane production, but by raising the HRT from 12-16 hrs the differences are not meaningful to attain soluble COD removals, VFA removals and protein mineralization near 80% and fat removal above 60%.

2.3. Land Disposal of Secondary Effluent and Legal Requirements

Land application of domestic and industrial wastewater is gaining momentum owing to the fact that land applications provides primary, secondary and tertiary treatment to the waste, all in a single operation with recycling and reuse benefits of wastewater and nutrients, besides preventing the pollution of streams and lakes, as shown in Figure 2.5

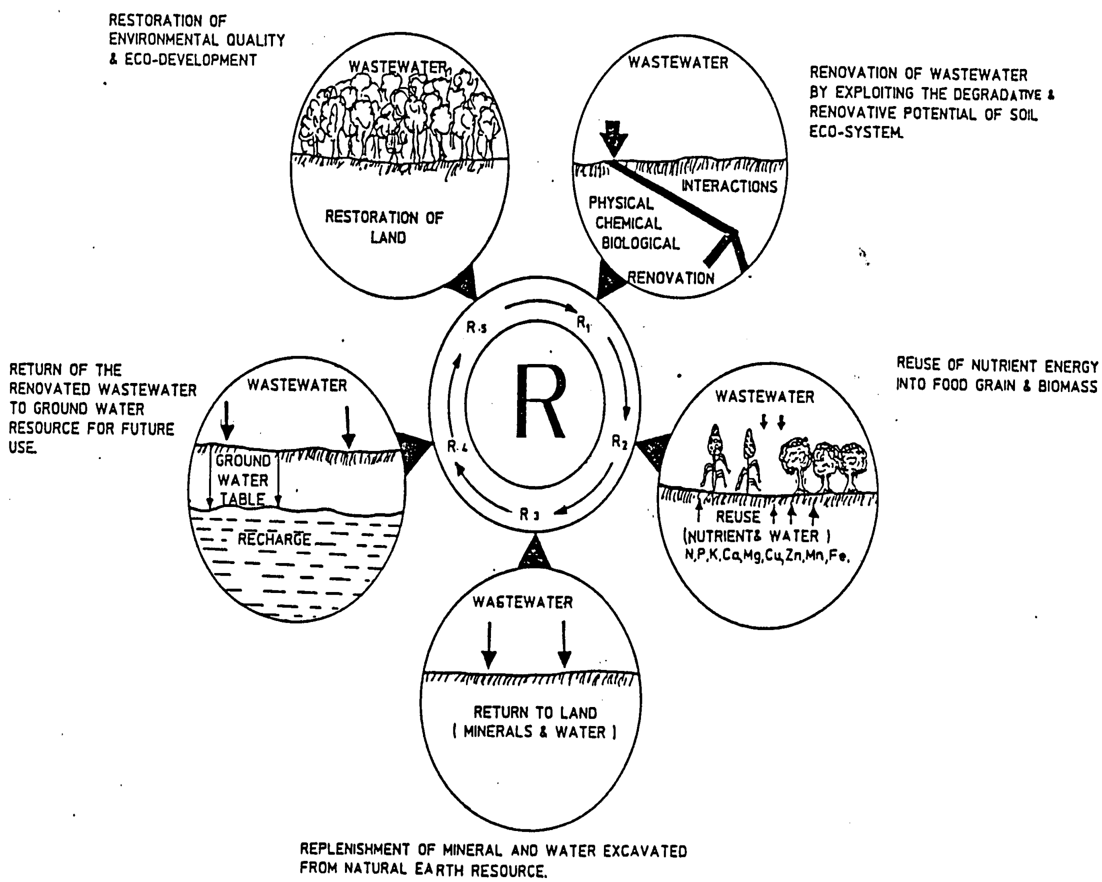

Figure 2.5: Concept of wastewater management and recycling, reuse and eco-development

Treatment efficiency of land application and conventional treatment systems (shown in Table 2.6) further confirmed the fact that land application provides the highest degree of renovation.

In the disposal of wastewater through crop irrigation, the soil works as a living treatment system. The soil and its associated ecosystem components act as physico-bio-chemical reactors capable of treating or stabilizing pollutants of solid and liquid origin through degradation, adsorption, precipitation and utilization by crops. The wastewater, while passing through the soil matrix, provides filtration on the soil surface leading to removal of coarse particles (primary clarifier). Degradation of soluble organic pollutants in the soil profile by microbial action, and mixing and aeration extended by macro soil habitant (earthworms and macro fauna) represent the waste treatment process occurring in the aeration tank. The wastewater from the soil reactor is subjected to final polishing/renovation for removal of metals through adsorption and ion exchange. The suspended solids and bacterial biomass removal through adsorption, ion exchange and precipitation with hydroxides and carbonate indicate reaction processes occurring in secondary clarifier. Removal of assimilable macro and micronutrients through plant utilization resembles tertiary waste treatment. All the renovative processes are nature's own treatment processes and thus land application is in fact an eco-friendly treatment and disposal system.

Thawale *et al*. (2006) [44] carried out the investigation to ascertain the efficiency f high rates transpiration system (HRTS) in the renovation of primary treated wastewater using D. strictus and c. equisitifolia species of plants. The result indicated that the removal efficiency of N was greater in the case of C. equisitifolia and ranged between 60 – 76%. Removal of phosphate was comparatively less and the ranged between 17.7- 70.3%. Levin *et al*. (1980) [25] also reported nitrogen removal to the extend of 30-65% and phosphorous removal 40-80% in a soil aquifer treatment system. Lance *et al*. (1972) formed that nitrogen removal was increased by 10-48.5% when vegetation was used.

Emongor *et al.* (2005) [10] evaluated the suitability of treated sewage effluent for irrigation of horticulture crops in Botswana. Based on the EC, SAR, Cl, NaCl, fecal Coliforms available plant nutrients and low concentration of heavy metals they concluded that effluent can be used for irrigation of horticulture crops.

Table 2.6: Typical characteristics of treated wastewater from conventional advanced wastewater treatment and land treatment systems

System	Residual effluent constituent (mg/L)						Pathogen removal (%)	
	BOD	SS	NH_3–N	NO_3–N	Total N	Total P	Bacteria	Viruses
Conventional treatment								
Aerated lagoon	35	40	10	20	30	8	90-95	16-94
Activated sludge	20	25	20	10	30	8	85-99	91-98
Advanced wastewater treatment								
Biological nitrification	12	15	1	29	30	8	-	-
Biological nitrification and denitrification	12	16	-	-	3	8	-	-
Tertiary, two-stage lime coagulation and filtration	5	5	20	10	30	0.5	99–99.9	90–99.7
Tertiary, two-stage lime coagulation, filtration, selective ion exchange	5	5	-	-	3	0.5	99–99.9	90–99.9
Land treatment systems								
Slow rate	1	1	0.5	2.5	3	0.1	99-100	97-99
Overland flow	5	5	0.5	2.5	3	5.0	90-100	89-99
Rapid infiltration	5	1	-	10	10	2.0	90-99	90-99

2.3.1 Legal requirements

Industrial effluent are varied and complex. This water affect, in some way or other, the normal life of a stream or normal functioning of sewerage and sewage treatment plants, unless pretreatment at the source point itself. If they are discharged directly to receiving waters, it may result in discoloring, foul smell and killing of aquatic life, apart for making the water unfit for various other purposes. Industrial wastewater disposal needs proper considerations.

Wastewater of milk based food industry from WWTP taken as study is in the present study has been used for land irrigation. Wastewater after treatment used for irrigation must meet certain guidelines as standards as per given below

- Guidelines for interpretations of water quality for irrigation given in Table 2.7.
- Environmental guidelines for effluent reuse [EPA 1993] given in Table 2.8.

Table 2.7: Guidelines for interpretations of water quality for irrigation

Potential irrigation Problem	**Units**	**Degree of restriction on use**		
		None	**Slight to moderate**	**severe**
Salinity (affects crop water availability):				
EC_w	dS/m or mmho/cm	<0.7	0.7-3.0	>3.0
TDS	mg/L	<450	450-2000	>2000
Permeability (affects infiltration rate of water into the soil. Evaluation using EC_w and SAR and adj R_{Na} together)				
Adj R_{Na} = 0-3		And EC_w >-0.7	0.7-0.2	<0.2
3-6		>1.2	1.2-0.3	<0.3
6-12		>1.9	1.9-0.5	<0.5
12-20		>2.9	2.9-1.3	<1.3
20-40		>5.0	5.0-2.9	<2.9
Specific ion toxicity (affects sensitive crops)				
Sodium (Na)				
Surface irrigation	SAR	<3	3-9	>9
Sprinkler irrigation	mg/L	<70	>70	
Chloride (Cl^-)				
Surface irrigation	mg/L	<140	140-350	>350
Sprinkler irrigation	mg/L	<100	>100	
Boron (B)	mg/L	<0.7	0.7-3.0	>3.0
Trace elements				
Miscellaneous effects (affects susceptible crops):				
Nitrogen (total-N)	mg/L	<5	5-30	>30
Bicarbonate (HCO_3)	mg/L	<90	90-500	>500
pH		Normal range 6.5-8.4		
Residual Chlorine	mg/L	<1.0	1.0-5.0	>5.0

Table 2.8: Environmental guidelines for effluent reuse [EPA 1993]

Sr. No.	Parameter	Standards		
		Inland surface water	**Public sewers**	**Land for irrigation**
		(a)	**(b)**	**(c)**
1.	Color and odor	All efforts should be made to remove color & unpleasant odor as far as practicable.		
2.	Suspended solids mg/L, Max	100	600	200
3.	Particle size of suspended solids	Shall pass 850 micron IS Sieve		
4.	pH value	5.5-9	5.5-9	5.5-9
5.	Temperature	Shall not exceed 5ºC above the receiving water temperature	-	-
6.	Oil & grease mg/L, Max	10	20	10
7.	Total residual Chlorine mg/L, Max	1.00	-	-
8.	Ammonical nitrogen as (N) mg/L, Max	50	50	-
9.	Total Kjeldahl nitrogen (as N) mg/L, Max	100	-	-
10.	Free ammonia (as NH_3) mg/L, Max	5.0	-	-
11.	Biochemical oxygen demand (5 days at 20ºC) mg/L, Max	30	350	100
12.	Chemical oxygen demand mg/L, Max	250	-	-
13.	Arsenic (as As) mg/L	0.2	0.2	0.2
14.	Mercury (as Hg) Mg/L, Max	0.01	0.01	-

Table 2.8: (contd…)

Sr. No.	Parameter	Standards		
		Inland surface water	Public sewers	Land for irrigation
		(a)	(b)	(c)
15.	Lead (as Pb) mg/L, Max	0.1	0.1	-
16.	Cadmium (as Cd) mg/L, Max	2.0	1.0	-
17.	Hexavalent chromium (as Cr^{+6}) mg/L, Max	0.1	2.0	-
18.	Total chromium (as Cr)	2.0	2.0	-
19.	Copper (as Cu) mg/L, Max	3.0	3.0	-
20.	Zinc (as Zn) mg/L, Max	5.0	15	-
21.	Selenium (as Se) mg/L, Max	0.05	0.05	-
22.	Nickel (as Ni) mg/L, Max	3.0	3.0	-
23.	Cynaide (as CN) mg/L, Max	0.2	2.0	0.2
24.	Fluoride (as F) mg/L, Max	2.0	15	-
25.	Dissolved Phoshates (as P) mg/L, Max	5.0	-	-
26.	Sulphide (as S)	2.0	-	-
27.	Phenolic compounds (as C_6H_5OH) mg/L, Max	1.0	5.0	-
28.	Radioactive materials a. Alpha emitters Micro-curie mg/L, Max b. Beta emitters micro-curie, mg/L, Max	10^{-7} 10^{-6}	10^{-7} 10^{-6}	10^{-8} 10^{-7}

Table 2.8: (contd…)

Sr. No.	Parameter	Standards		
		Inland surface water	Public sewers	Land for irrigation
		(a)	(b)	(c)
29.	Bio-assay test after 96 hours in 100% effluent	90% survival of fish	90% survival of fish	90% survival of fish
30.	Manganese (as Mn)	2 mg/L	2 mg/L	2 mg/L
31.	Iron (as Fe)	3 mg/L	3 mg/L	3 mg/L
32.	Vanadium (as V)	0.2 mg/L	0.2 mg/L	-
33.	Nitrate nitrogen	10 mg/L	-	-

These standards shall be applicable to industries, operations or processes

CHAPTER 3

METHODOLOGY

Background

The objective of this work is to Evaluation of pollution parameters of wastewater from milk based food industry and check whether the treatment units are working with designed efficiency or not. With in this view, the experimental work has been designed and is presented here with.

3.1 Work plan: An overview

The project was planned and divided into following work elements:

WE 1: Monitoring of WWTP and its performance evaluation

Samples were collected from WWTP at different sampling points of WWTP and characterize for parameters BOD, COD, Nitrogen, Phosphorus, Nitrogen, Oil & grease, pH, Acidity, Alkalinity etc. Overview of WWTP and location of sampling points is given in Section 3.2.

WE 2: Fate of organic matter and nutrients in WWTP

- Mass balancing of VSS, COD, Nutrient [Nitrogen] in ASP
- Design calculations of treatment units

3.2 Wastewater Treatment Plant: An overview

The WWTP of Glaxo Smith Kline Consumer Health Care Limited, Nabha, Distt. Patiala having capacity to treat 700- 1300 m^3/day of wastewater was selected for the study. A general systematic flow diagram of WWTP is shown in figure 3.7. The system was designed to handle to treat wastewater having high organic content and suspended solids.

The heart of the system is Aerobic biological reactor.

The system was designed to handle BOD_5 at 20°C of 800 mg/L and Suspended Solids (SS) 250 mg/L. The various point sources of wastewater is collected in a combined underground sewer and conveyed to the effluent sump, equalization take place, than feed the wastewater into the subsequent units. Than effluent passes through the oil separator, after that flow is divided into two parts and passes through the parallel combination of two aeration tanks. The combined effluent from the aeration tanks the passes through the secondary clarifier. The treated effluent from secondary clarifier is discharged to the land and use for irrigation.

The effluent treatment facility consists of the following units

- Effluent collection sump
- Oil & grease removal chamber
- Chemical solution dosing systems
- Aeration Tanks
- Secondary clarifier
- Sludge drying beds

Photographic presentation of above mentioned units are given in Figure 3.1-3.6. Dimensions and other details of various units of WWTP are summarized in Table 3.1.

Figure 3.1: Sampling point – Raw effluent collection Sump [P-1]

Figure 3.2: Sampling point – Oil and grease trapping unit [P-2]

Figure 3.3: Sampling point – Equalization tank [P-3]

Figure 3.4: Sampling point – Parallel arrangement of two aeration tanks [Aeration tank {P-4} and Aeration tank 2 {P-5}]

Figure 3.5: Sampling point – Secondary clarifier [P-6]

Figure 3.6 Sludge drying beds

Wastewater reaching the WWTP is allowed to pass through the effluent collection sump by opening the inlet valve. The equalized effluent feed into the subsequent units with the help of pump.

The equalized effluent passes through the oil separator, the free floating oil & grease is skimmed off into the slots of the rotatable skimmer pipe placed on top of downstream end, by manual operating hand wheel. The collecting oil & grease is disposed off. The effluent from the oil & grease is conveyed to aeration tank. Required amount of Urea and DAP as source of Nitrogen and Phosphorus are dosed. However nutrients are added only after confirming that effluent is deficient in N and P. The F/M ratio is maintained at about 0.16. The required Oxygen is supplied with the help of mechanical surface aerator driven by suitable size gear motor. Settled sludge from the final clarifier is pumped / recirculated back into aeration tanks for maintaining required MLSS.

The mixed liquor from the aeration tank is received in clarifier by gravity. This is a circular sedimentation tank with a circular chute inlet and peripherical overflow. The settled sludge is collected in a central circular channel, around the inlet chute by a scrapper connected to a rotating bridge driven by suitable size motor coupled to a gear box. The settled sludge is pumped recirculated into the aeration tank by the help of recirculated pump.

The excess sludge is pumped to the sludge drying beds by the help of recirculated pumps. The sludge drying beds comprises of coarse sand and broken stones as sand media support and under drain system. The sludge over the media bed dried up the natural drying and removed manually for disposal as landfill. The percolated water is pumped to the aeration tank. The treated effluent is discharge at the eco-plantation site and used for irrigation.

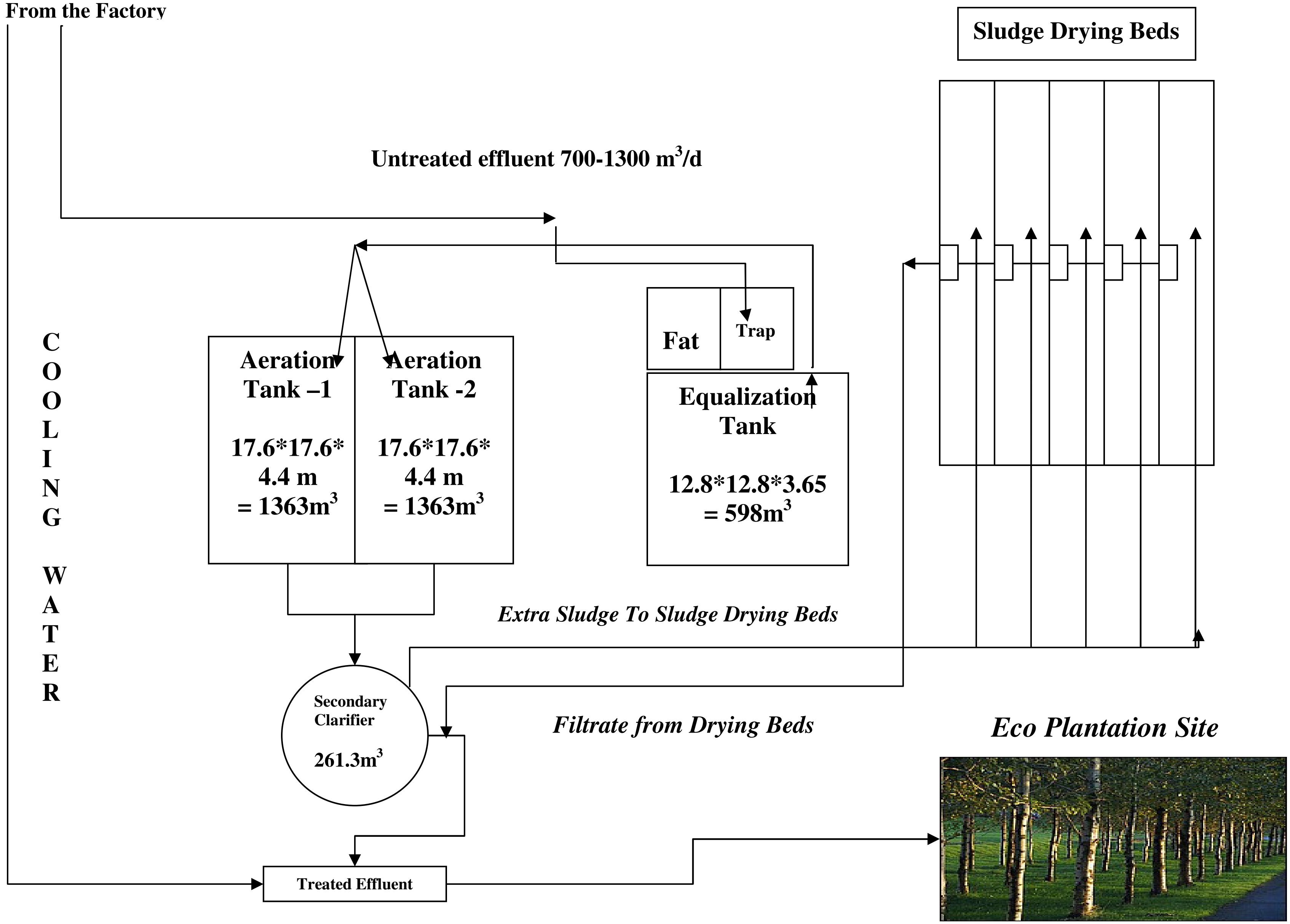

Figure -3.7: Process flow diagram of wastewater treatment plant

Table 3.1: Dimensions and other details of the facilities of the WWTP

Equalization Tank	
Description One rectangular tank of 6.8 m length, 6.8 m width and 2 m liquid depth. Liquid storage capacity is 92.75 m^3 Material of construction of tank is RCC	**Effluent transfer pump** Two pumps [one is working other is standby] Each of 60 m^3/hr pumping capacity for pumping wastewater. Type of pumps- Vertical submersible pump.
Oil separation channel	
Description One unit having size 3.5 m*0.5 m *0.8 m. Material of construction of tank is RCC. Detention time app. 90 seconds	**Oil collection arrangement** Manually operated slotted type skimmer pipe complete with right hand side worm gear fitting for movement of collector about axis, extension spindle and hand wheel
Aeration Tank	
Description Two units having size 17.6m*17.6m*4.4m Material of construction of tanks RCC Volume of each tank 1263m^3	**Aerators** One aerator in each tank Type- Mechanical Surface Aerator Diameter of each aerator 2.5m Oxygenated Capacity (each) 1.3kgs/oxygen/SHP/hr Geared motor for aerator – Vertical shaft geared motor

Table 3.1: (Contd..)

Clarifier	
Description No of units one Material of construction RCC Volume 261.3 m^3 Detention time 2.7 hr	**Sludge pumps** No of recirculating pumps two [one working+ one stand by] Capacity $400m^3/hr$
Sludge Drying Beds	
Description No of beds 5 Material of construction RCC Area $200m^2$ Total Area inclusive of 5 beds 1000 m^2 Sludge Thickenings in the drying beds 200-300mm Drying period of the beds app. 15-20 Days	**Filtrate Dewatering Pumps** No of pumps one
Chemical dosing tank	
Description No of Tanks one Material of Construction MSRL Volume $3m^3$	**Agitator** No of Agitator one
Eco- Plantation site	
Total area 27 Acres [11 hac]	**Plant Type** Eucalyptus / Poplar / Teak / Jatropha **No. of Plants** 10102

3.3 Sampling Schedule and frequency

Grab samples were collected once in a month from WWTP. Six sets of samples comprising of

- Raw effluent [P-1]
- Oil and grease trap [P-2]
- Equalization tank [P-3]
- Aeration tank 1 [P-4]
- Aeration tank 2 [P-5]
- Secondary Clarifier [P-6]

were collected and analyzed for the parameters shown in Table 3.2. Samples for BOD, COD, Nitrogen, Phosphorus, Chlorides and Solids etc were analyzed in accordance with the procedure laid down in

Standard Methods for the Examination of Water and Wastewater (APHA 1996) [1]

Table 3.2: Parameters to be characterized at different sampling points [1]

Sampling points	**P-1 to P-6**	**P-6**
Parameters	pH TCOD (Total Chemical Oxygen Demand) sCOD (Soluble Chemical oxygen Demand) Chlorides Total Solids Total Dissolved Solids Total Suspended Solids Alkalinity Acidity Oil & grease Phosphorus Total Nitrogen	Sodium Calcium Manganese Carbonates Bicarbonates Sulphates Electrical Conductivity

Samples were collected in plastic bottles. Procedure in Standard Method was followed for samples collection, preservation and transportation.

Table 3.3: Instruments used for measurement of different parameters

Parameters measured	**Instrument**
pH	pH meter
TCOD (Total Chemical Oxygen Demand) sCOD (Soluble Chemical oxygen Demand)	Closed reflux method Closed reflux method
Chlorides	Argentometric Method
Total Solids Total Dissolved Solids Total Suspended Solids	Drying Oven Drying Oven Drying Oven
Alkalinity	Titrimetric Method
Acidity	Titrimetric Method
Oil & grease	Partition – Gravimetric Method
Phosphorus	Stannous Chloride Method
Total Nitrogen • Ammonical-N • Organic-N • Nitrate-N • Nitrite-N	 Preliminary Distillation Step Macro-Kjeldahl Method Cadmium Reduction Method Colorimetric Method

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Samples were collected from six points. Sampling points are Raw effluent [P-1], Oil & grease Trap [P-2], Equalization tank [P-3], Aeration Tank 1 [P-4], Aeration Tank 2 [P-5] & Secondary Clarifier [P-6] to evaluate the performance of WWTP. Results have been summarized and discussed in the following sections:

1. Performance of WWTP

- Influent characteristics
- WWTP & ASP performance
- Mass balance of Flow rate, Nutrients, COD & VSS.

2. Operating and design parameters of ASP

3. Secondary effluent: reuse in irrigation

4.2 Performance of WWTP

4.2.1 Influent characteristics

The physio-chemical characterization of effluent from equalization tank is given in Table 4.1. The key pollutants in the wastewater from milk based food industry are organic compounds, fats, and suspended solids and biogeneous elements. Biodegradability may be estimated on the basis of ratio between BOD_5 & COD. BOD_5: COD ratio obtained from the literature data ranged between 0.47 – 0.67. Based on an extensive set of BOD_5: COD ratios obtained from milk products, milk constituents and dairy wastewater, Harper *et al*. (1974) [16] concluded that ratios below 0.6 can be interpreted to suggest a less efficient biological oxidation of milk based compare to pure milk; probably caused by the presence of non milk constituents. In the present case BOD_5: COD [691/1300] was found to be 0.53, which indicate that most of the organic compounds in the wastewater from milk based food industry should that be easily biodegradable.

Table 4.1: Characterization of effluent from equalization tank of milk based food industry

Parameters	Concentration
BOD_5 at 20^o C [mg/L]	620
pH	6.8
TCOD [mg O_2/L]	1290
sCOD [mg O_2/L]	611
Chloride [mg Cl^-/L]	108
Oil & grease [mg/L]	16
Acidity [mg/L]	Nil
Alkalinity [mg $CaCO_3$/L]	460
TS [mg of TS/L]	1956
TDS [mg of TDS/L]	1237
TSS [mg of TSS/L]	686.7
Phosphorous [mg/L]	3.6
TKN [mg/L]	18.6
Nitrate-N [mg/L]	0.36
Nitrite-N [mg/L]	0.4

Suspended solids in wastewater from WWTP was found to be 687 mg/L. Suspended solids in wastewater from milk based food industry originates from coagulated milk, cheese, curd or flavoring ingredients (Broiwn & Psco, 1979). The use of acid, alkali, cleansers and sanitizers in the milk based food industry typically results in highly variable wastewater pH values. Literature data indicated that pH value ranged between 4.7- 12, with an average of 7.2. In the present case value of effluent from equalization tank is 6.8. The present pH is quite favorable for the ASP process. The phosphorus in wastewater from milk based food industry originates from cleansing compounds and from milk or product spillages during processing. Total phosphorus concentration in the present study was 3.6 mg/L.

Four different Nitrogen analysis were performed on the equalized effluent: Nitrate-N, Nitrite-N, Organic-N and Ammonical-N. Nitrate Nitrogen concentration in equalized effluent is 0.36 mg/L and Nitrite-N is 0.4mg/L. TKN concentration in equalized effluent was found to be 19mg/L. Ammonical-N concentration was relatively low. This indicated that majority of TKN was present as organically bound Nitrogen (e.g., Protein) and the conversion of amino group to ammonia was incomplete.

4.2.2 WWTP & ASP Performance

Wastewater from milk based food industry was treated by Activated Sludge Process (ASP). Sequence of operations is explained in methodology. The performance of WWTP is evaluated by parameters COD, BOD, TN, TP, Oil & grease etc. The data given in Figure 4.1-4.3 represents the monthly variations in samples and numerical values are given in the appendix.

Data presented in figure 4.1 shows the monthly variation of TCOD at different sampling points. TCOD in the raw effluent was found to be 1304 mg/L, which is reduced to 60 mg/L after secondary clarifier. Standard Deviation (S: D) of 100 mg/L in TCOD was observed in raw effluent which can be attributed to flow variation and in plant waste minimization techniques.

Data presented in Figure 4.2 shows the monthly variation in TSS. TSS (825 mg/L) in raw effluent was reduced to 52.8 mg/L after entrapment in secondary clarifier. Increase in TSS was observed in aeration tank. Recycling of sludge and oxidation of substrate are the primary factors contributing to TSS in aeration tank.

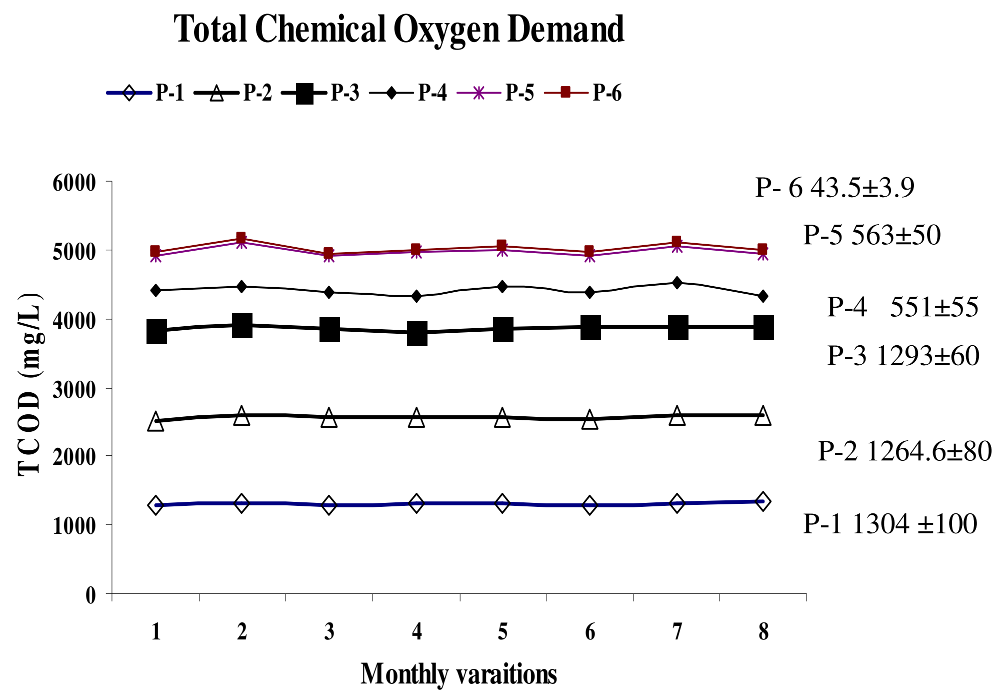

Figure 4.1: Monthly variation of TCOD at different sampling points

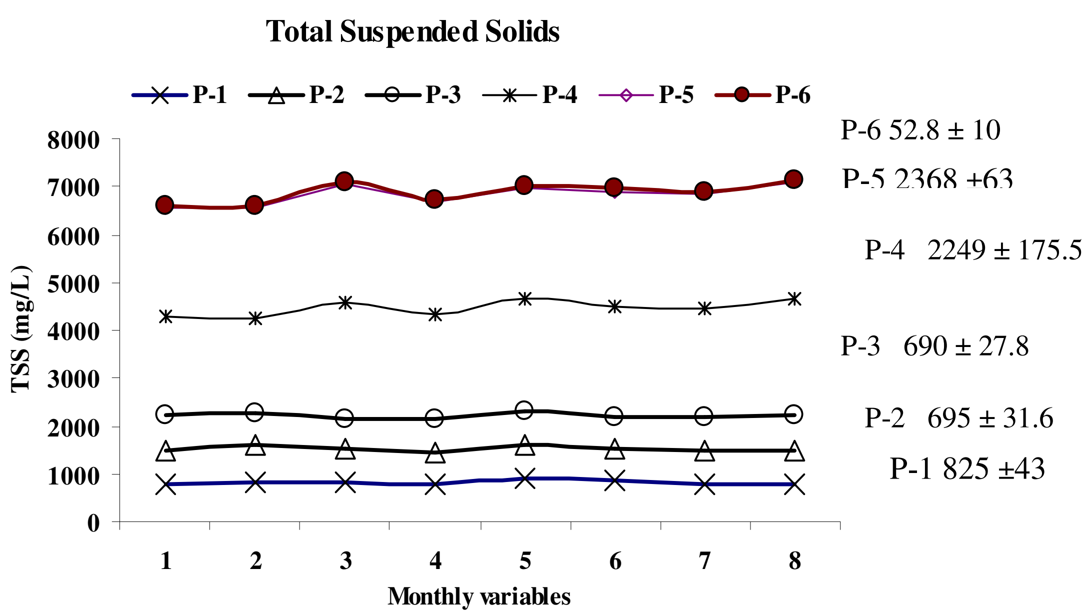

Figure 4.2: Monthly variation of TSS at different sampling points

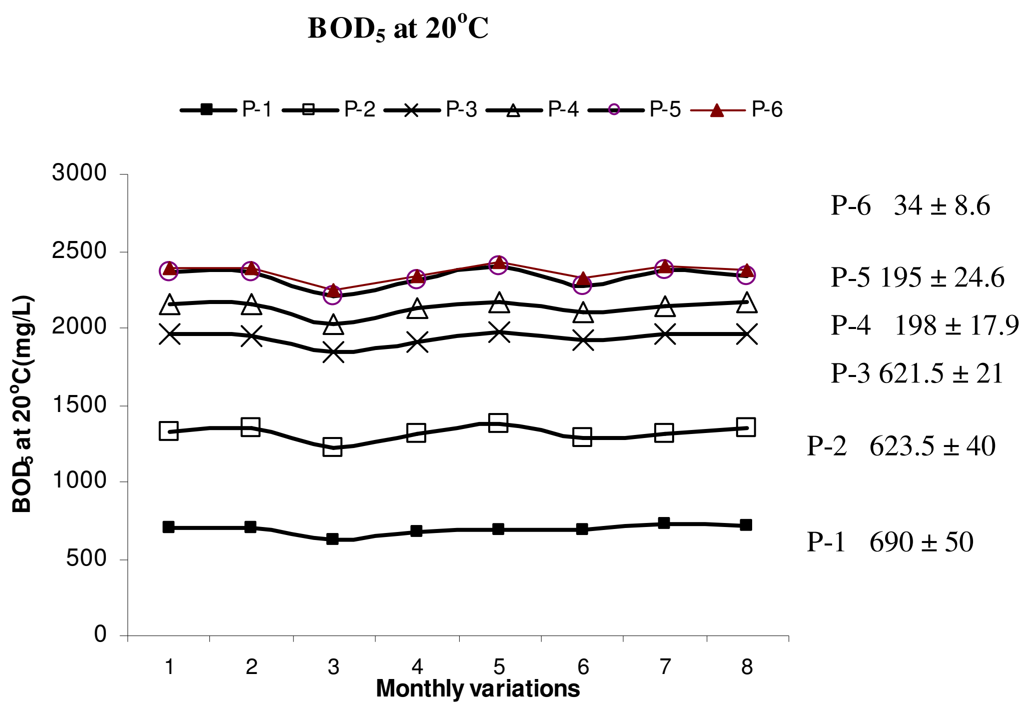

Figure 4.4: Monthly variation of BOD at different sampling points

Data presented in figure 4.3 shows monthly variation of BOD_5 at different sampling points. BOD_5 in raw effluent was found to be 690mg/L which is reduced to 34 mg/L after secondary clarifier.

The performance of WWTP in terms of average change (%) in the pollution parameters is given in Table 4.2. Histogram (Figure 4.4- 4.9) gives consolidated information in the characteristics of six sampling locations of WWTP.

Table 4.2: Removal efficiency of WWTP

Parameters	**Removal efficiency**	
	From raw effluent collection sump to Aeration Tank	**From Raw effluent collection sump to Secondary Clarifier**
TCOD	57%	96%
BOD_5 at 20º C	71%	95%
sCOD	90%	95%
Chloride	12%	30%
TS	-	42%
TDS	8%	24%
TSS	-	94%
Alkalinity	3%	2%
Oil & grease	31%	43%
Phosphorous	25%	41%
TKN	11%	83%
TN	19%	78%

Organic Matter

Figure 4.4 & Figure 4.5 represents the variation occurred in the concentration of BOD & COD matter at different sampling points. In ASP, the removal of dissolved and particulate carbonaceous BOD and stabilization of organic matter found in wastewater is accomplished biologically using a variety of microorganisms in the presence of oxygen. Three more or less distinct activities occur for removal of organic matter. First, a portion of the waste is oxidize to end products to obtain energy for cell maintenance and the synthesis of new cell tissue. Simultaneously, some of the waste is converted into new cell tissue using part of energy released during oxidation. Finally, when the organic matter is used up, the new cells begin to consume their own cell tissue to obtain energy for cell maintenance.

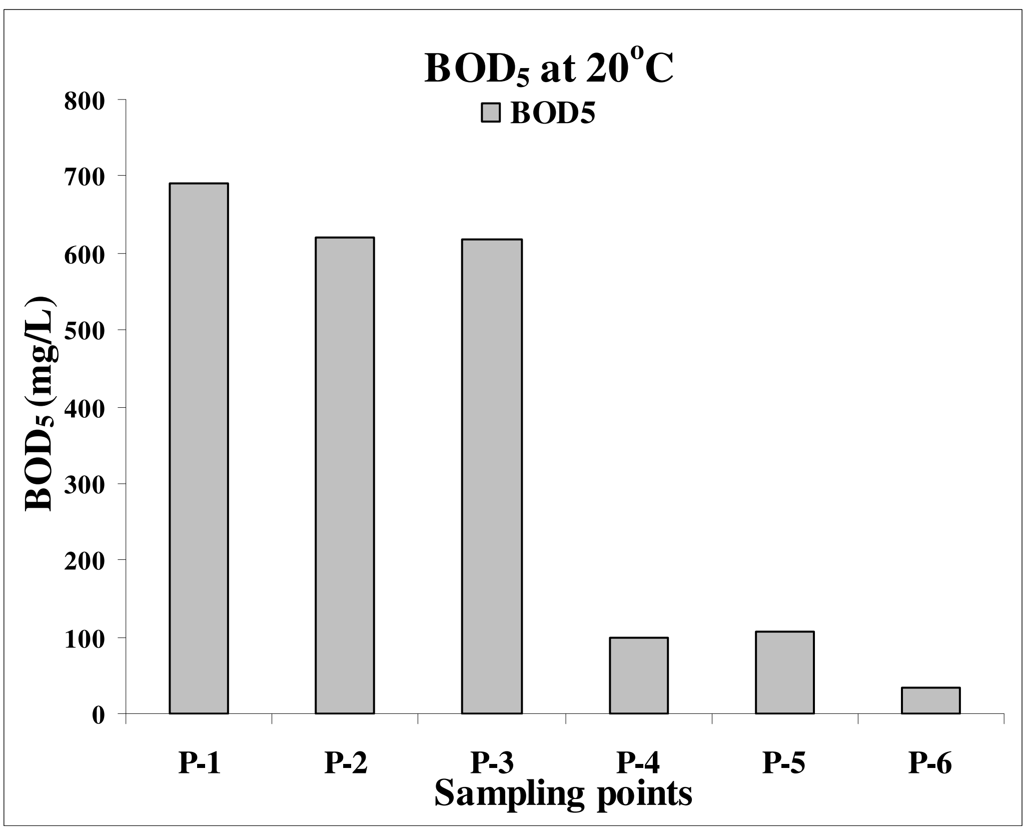

Figure 4.4: Biological Oxygen Demand at six sampling points of WWTP

BOD & TCOD removal percentage was found to be 95% and 96% respectively.

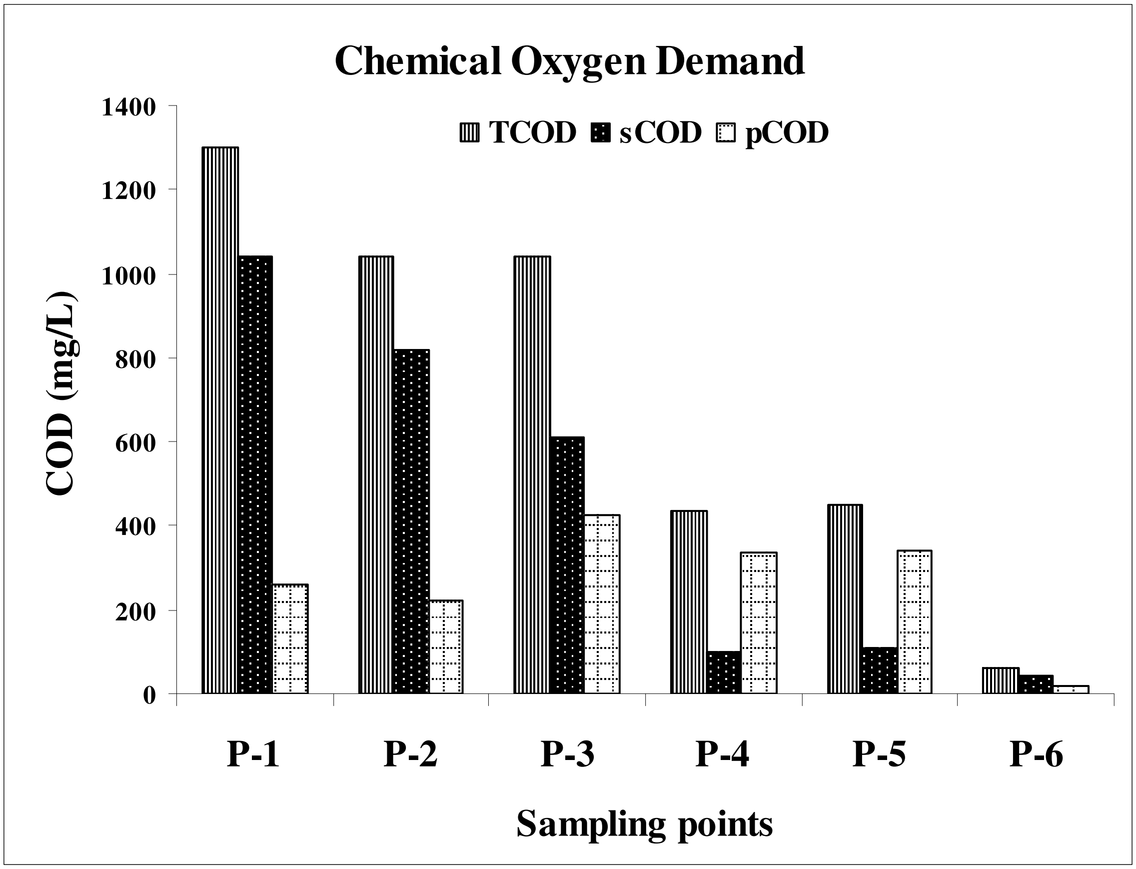

Figure 4.5: Chemical Oxygen Demand at six sampling points of WWTP

Suspended Solids

Figure 4.6 represent concentration of solids at various sampling points. In the present case, no primary treatment is provided, so whatever removal is there i.e. because of secondary clarifier. A certain rise of concentration of TSS at sampling points P-4 & P-5 was observed which is due to oxidation of substrate and production of biomass.

Nitrogen

Figure 4.7 represent the concentration of Nitrogen at six sampling points of WWTP. In present case TKN was reduced to 18.6 to 5mg/L. However Nitrate was found to be low after secondary treatment. It implies that TKN is not TKN that can be attributing to its conversion to Ammonical- Nitrogen is finally oxidized to nitrate. Reduction is due to stripping to atmosphere.

Oil & grease

Figure 4.8 represent the concentration of oil & grease at different sampling points. If grease is not removed before discharge of treated wastewater, it can interfere with the biological life in the surface water and create unsightly films. The concentration of oil & grease in raw effluent was 24 mg/L, as the effluent passes through oil & grease trapping unit the concentration reduced to 16 mg/L. At the end of the treatment unit concentration reduced to 9 mg/L.

Phosphorous

Figure 4.9 represent phosphorous concentration at different sampling points. The removal of phosphorous by biological means is known as biological phosphorus removal. Phosphorus is generally done to control eutrophication. Treatment plant effluent discharge limit have ranged from 0.10-2.0 mg/L. In the biological removal of phosphorus in the influent wastewater is incorporated into cell biomass, which subsequently is removed from the process as a result of sludge wasting. Phosphorous reduction in WWTP was observed to be 83%.

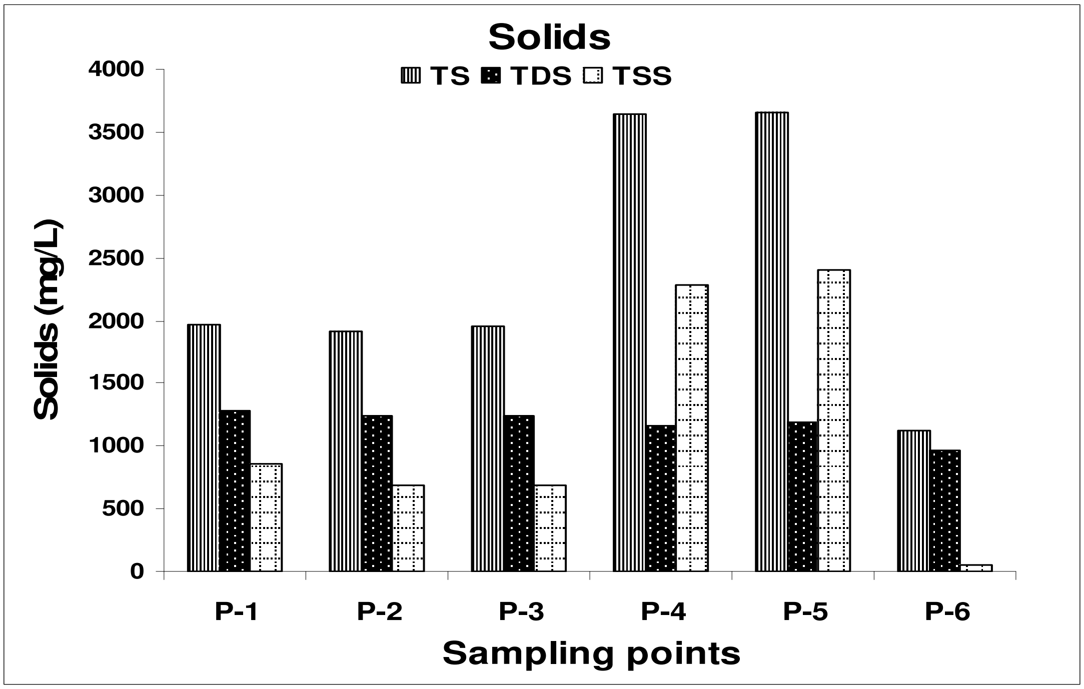

Figure 4.6: Concentration of solids at six sampling points of WWTP

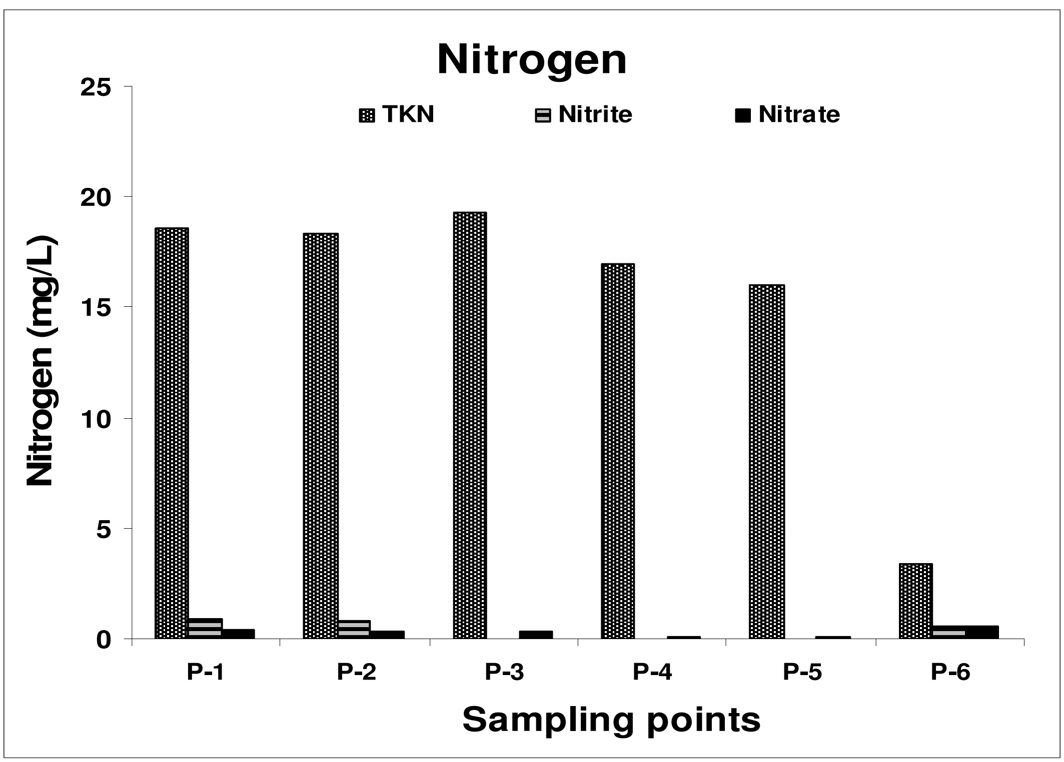

Figure 4.7: Nitrogen concentration at six sampling points of WWTP

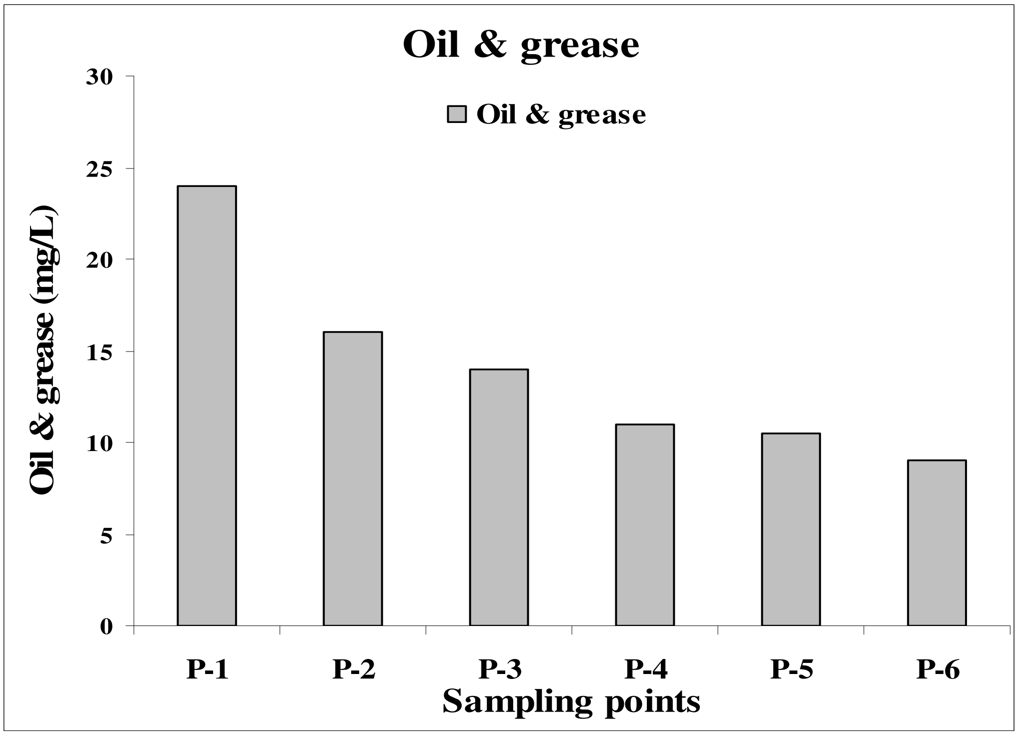

Figure 4.8: Oil & Grease concentration at six sampling points of WWTP

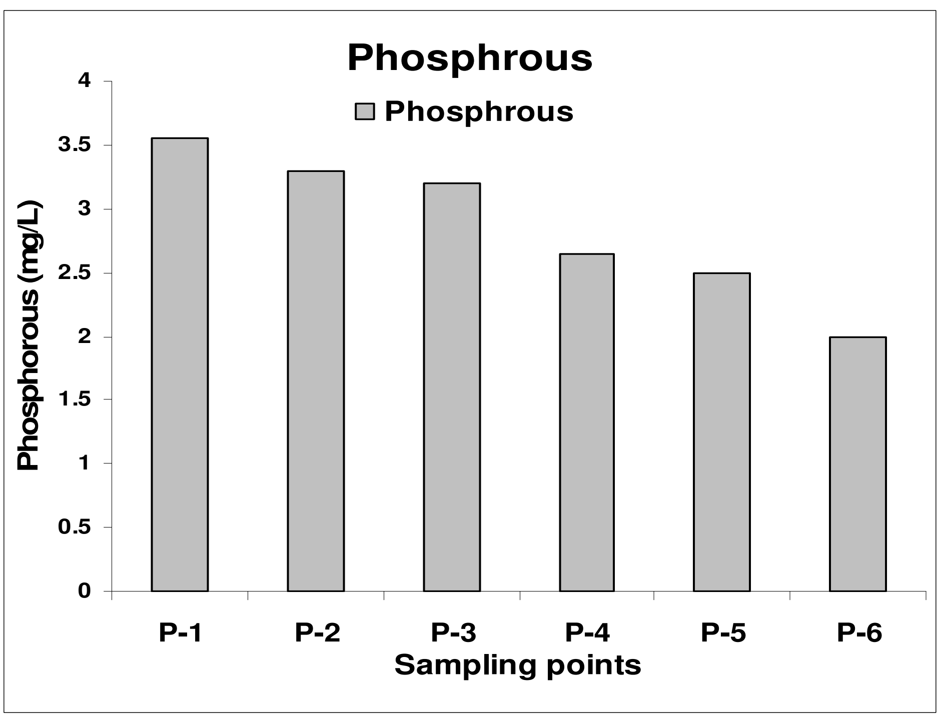

Figure 4.9: Phosphorous concentration at six sampling points of WWTP

4.2.3. Mass balance of COD, VSS, Flow rate & Nutrients

Overall Mass balances for COD for an activated sludge plant [28]

COD mass balance is based on the characterization of waste shown in figure 4.10 and explained in equation below:

TCOD = bCOD + nbCOD

nbCOD = nbsCOD + nbpCOD

bCOD = sbpCOD + rbCOD

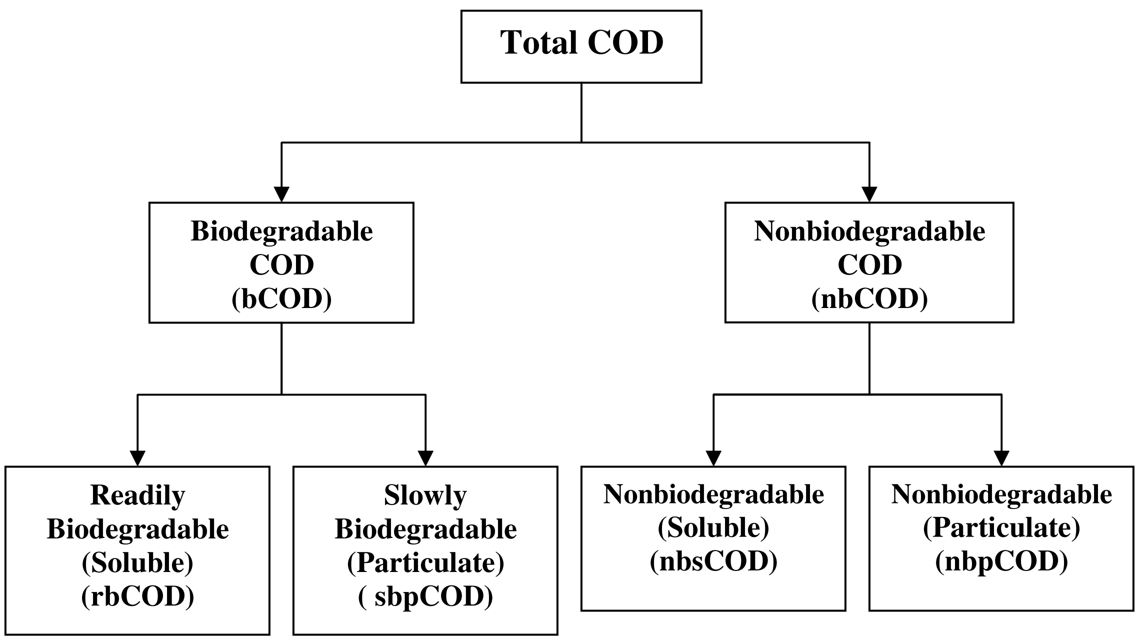

Figure 4.10: Fractionation of COD in wastewater

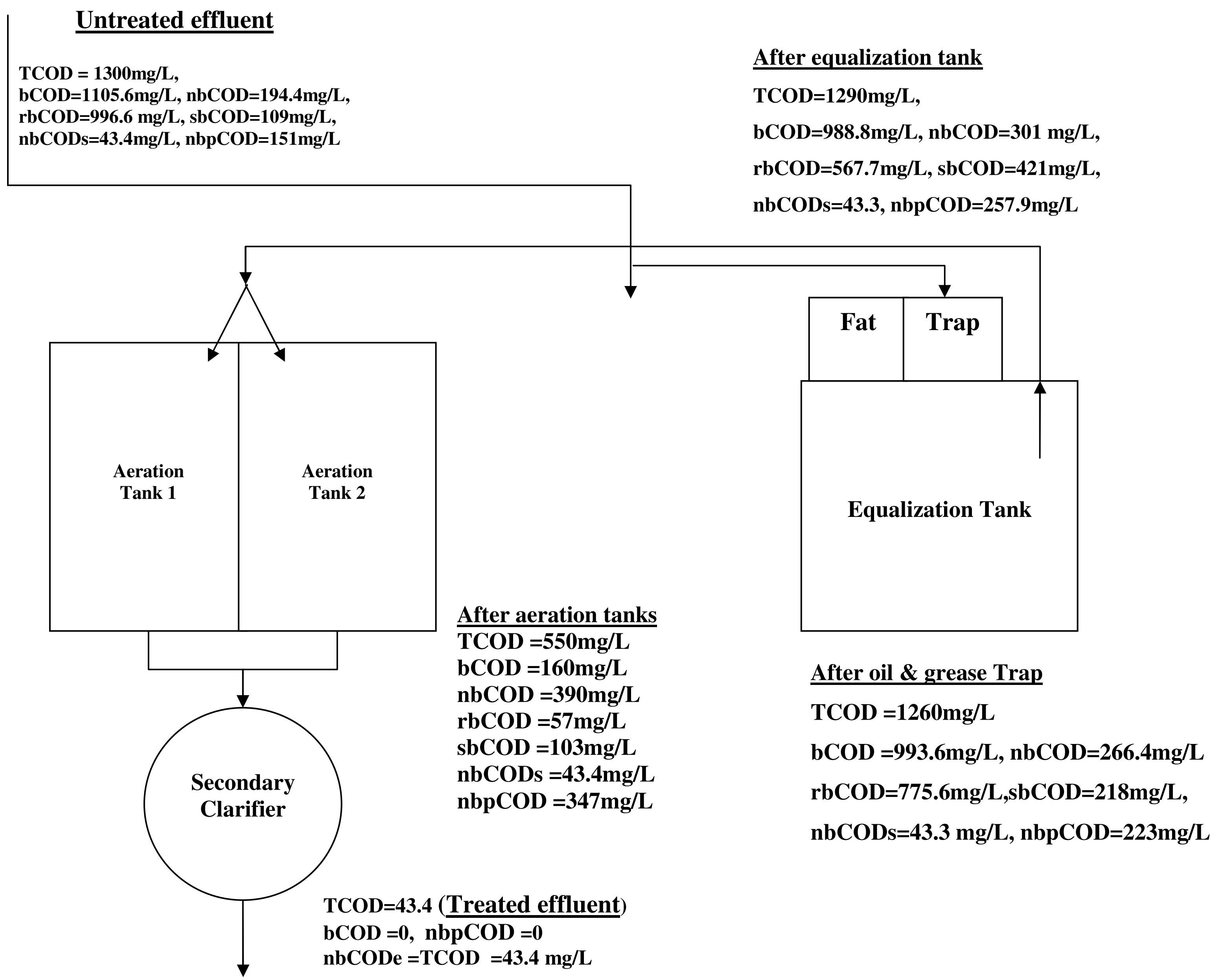

Figure 4.11: Overall Mass balances for COD for an activated sludge

The fate of carbonaceous material can be known from COD mass balancing shown in Figure 4.11. Figure represents the reduction in Chemical oxygen demand at various sampling points of WWTP. rbCOD in equalization tank was 567.7 mg/L and it reduces to 57 mg/L after aeration tank. Reduction of rbCOD and sbCOD by ASP 94% was and 76% respectively. rbCOD is quickly assimilated by the biomass, while the particulate and colloidal COD must be dissolved by extracellular enzymes and are than assimilated at much slower rate. In the present case even sbCOD reduction was found to be 76% which may be due to high SRT of 24 days. nbCOD consist of soluble and particulate fraction. Soluble fraction (43.9 mg/L) which can't be biodegraded was obviously found in the effluent of secondary clarifier. However the particulate fraction (i.e. 257.9 mg/L) was trapped in the secondary clarifier, as a result of finally treated effluent is devoid of that fraction.

Overall suspended solids balance for an activated sludge plant [39]

A primary variable selected for ASP was MLVSS in the aeration tank which is maintained by wasting a part of recycled sludge. Mass balance of VSS is shown in Figure 4.12. Xv,a is usually maintained between 2000 and 3000 mg/L. In the present case $Xv,_0$ was found to be 2186 mg/L and MLVSS in the recycled sludge was found to be 9970 mg/L. Sludge wastage was found to be 371.68 kg/day which is equal to the sludge generated in the reactor.

Overall flow rate balance for an activated sludge plant[39]

Mass balance for flow discharge is shown in Figure 4.13. Total flow rate of untreated effluent from the factory is 900 m^3/day to WWTP. Out of which 866 m^3/day of treated effluent is used for irrigation purposes on eco- plantation site, whereas 34 m^3/day is going along with wasted sludge.

Symbols

F, Fresh feed

o, combined feed

a, Reactor effluent

e, net effluent

u, Underflow from secondary clarifier

Flow rates

Q_F = Fresh feed;

Q_R = recycle;

Q_{o} = Combined feed;

$Q_o = Q_F + Q_R = Q_F\ (1+ r)$;

r = recycle ratio ($r = Q_R / Q_F$) ;

Q_e = net effluent;

Q_W = wastage;

Q_u = Clarifier underflow;

Concentrations (mg/L) of Volatile suspended solids (VSS)

$X_{V,F,}$ = VSS in fresh feed

$X_{V,o,}$ = VSS in combined feed

$X_{V,a,}$ = VSS in reactor

$X_{V,u,}$ = VSS in secondary clarifier underflow

$X_{V,e,}$ = VSS in net effluent

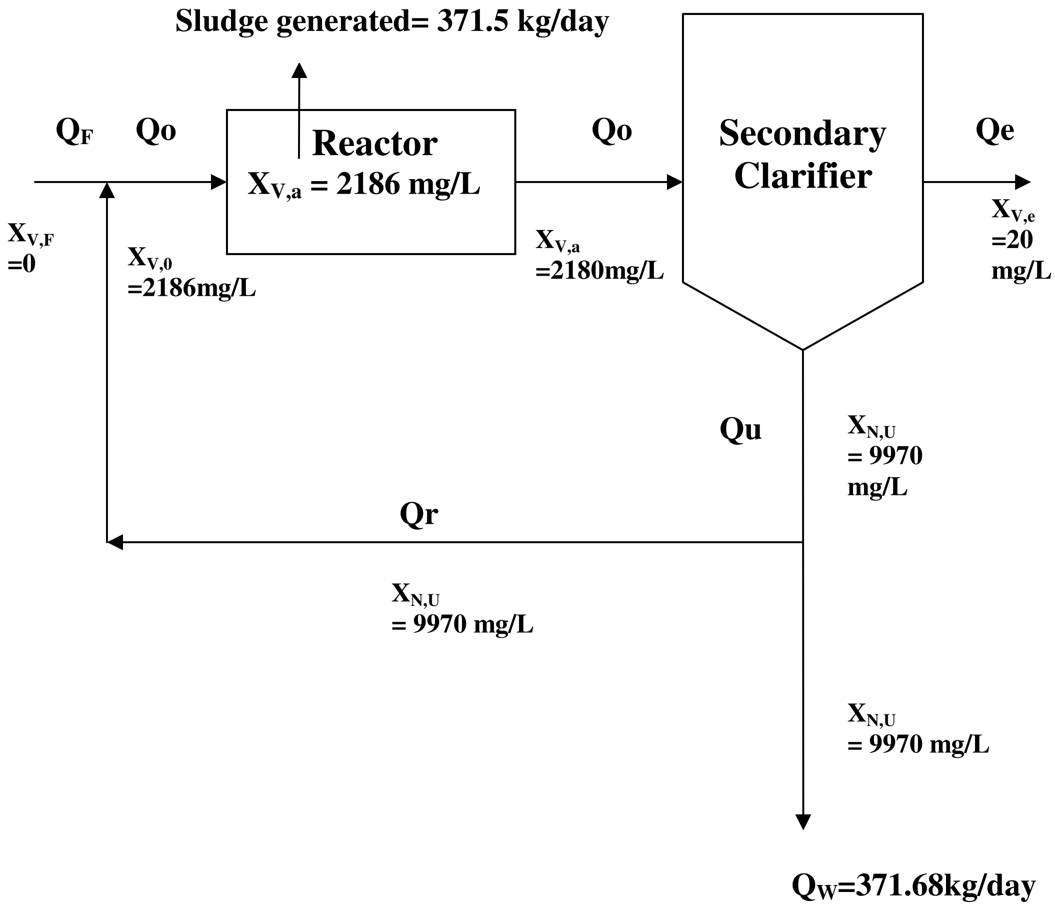

Figure 4.12: Overall suspended solids balance for an activated sludge plant

Sludge generated = Net Synthesis + Cell debris + Inorganic Fraction

= 371.5 Kg/d

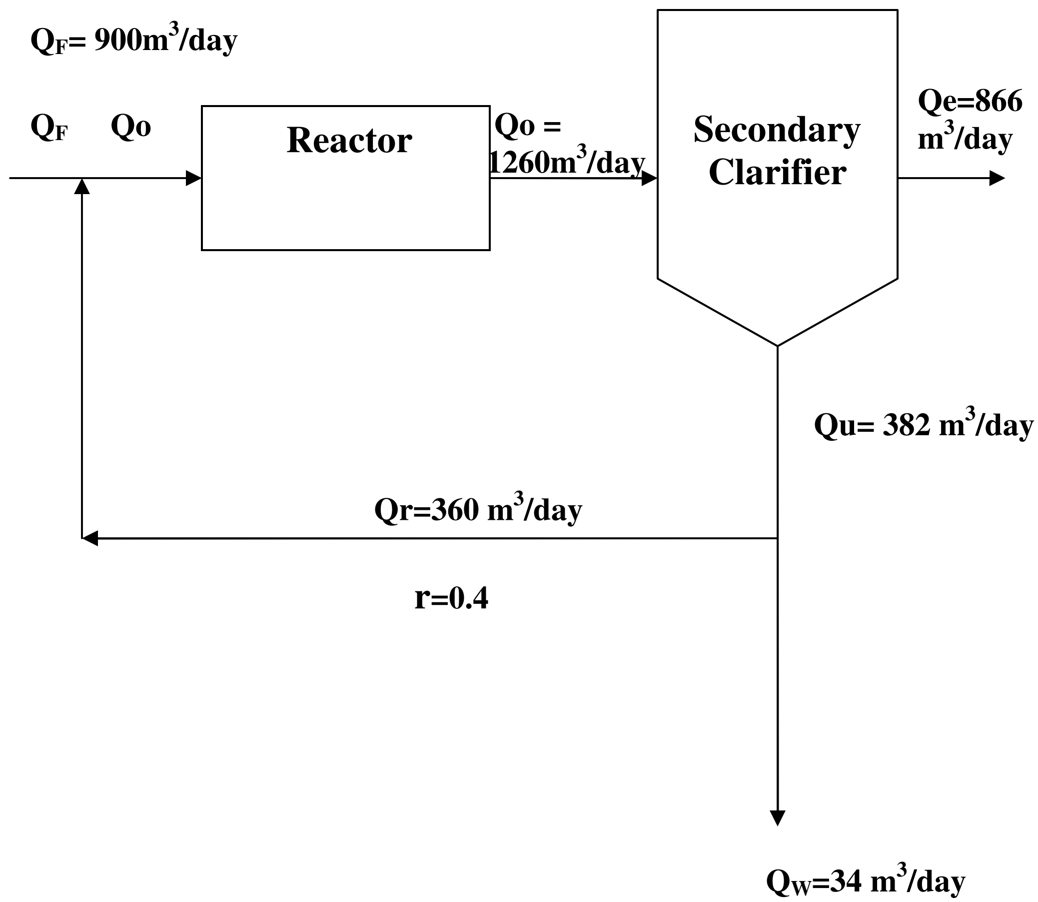

Figure 4.13: Overall flow rate balances for an activated sludge plant

Overall Nutrient balance for an activated sludge plant[28]

Nutrient balance includes the following:

1. TKN in the influent= 19 g/m^3
2. N used for synthesis = (0.12 g N/g VSS biomass)(119.77 kg/day) = 14.37 kg/day
3. Ammonical Nitrogen in effluent = 2 g/m^3

Daily Wasting = (Daily biomass + cell debris production) = 81.6 + 38.177
= 119.77 kg/day

Based on influent flow of N synthesis is N synthesis

= (14.37 kg/day)(1000 g/kg)/(900 m^3/day) = 15.97 g/ m^3

NO_x = TKN – Nsyn – $(NH_4\text{-}N)_e$

= 19 g/m^3 – 15.97 g/m^3 – 2 g/m^3

= 1.03 g/m^3

Nutrient addition is not required as the Nitrogen in the raw effluent is more than the Nitrogen utilized for cell production and sludge wastage.

4.3 Operating and Design parameters of ASP

Perusal of the data indicates that WWTP is working satisfactorily with COD & BOD removal efficiency of 96% & 95% respectively. However it is worthwhile to look into the operation and design parameters of ASP. The plant has been designed for the flow rate of 700-1300 m^3/day and total organic load of 840 kg/day. But presently it is working at 900 m^3/day.Kinetic parameters are given in Appendix. The operating parameters observed and summarized in table

Table 4.3: Design parameters for Activated sludge process [28]

ASP design parameters		
Solid retention time	$SRT = VX / [(Q-Q_w)X_e + Q_wX_R]$	24 day
Effluent dissolved substrate concentration	$S= [K_s(1+ K_d.SRT)] / [SRT(YK-K_d)-1]$	1.76 gbsCOD m^3
VSS production rate in terms of substrate removed	$P_{X,VSS}= [QY(S_o-S) /1+K_d.SRT] + [f_d.K_d.Y.Q(S_o-S).SRT/(1+K_d.SRT)]+ Q_{Xo,i}$	371.5 kg/day
Mass of MLVSS	$(P_{X,TSS})$ SRT	8904 kg
Mass of MLSS	$(P_{X,TSS})$SRT	15381 kg
MLVSS concentration	Fraction VSS=(MLVSS/MLSS)=0.6	2076mg/L, 2600mg/L*
Volume of tank	$Q_w= VX/ SRT.X_r$	2351 m^3, 2726m^3*
Food to microorganism ratio	$F/M=QS_o/VX$	0.09 g BOD/gVSS.day
Volumetric loading rate	$L_{org} =QS_o/V(10^3 g/kg)$	0.326 Kg BOD m^3/day
Gross Synthesis	Gross Synthesis=$Q(S_o-S)Y$	336 kg/day
Net Synthesis	Net synthesis=Gross Synthesis/(1+ K_d.SRT)	86.6 kg/d
Auto-oxidation	Ayto-oxidatio=Gross Synthesis - Net Synthesis	249 kg/day
Cell debris	Cell debris=Auto-oxidation* 0.15	37.38 kg/day
Inorganic fraction	Inorganic fraction=Q* TSSo	247.5 kg/day
Total Sludge	Total Sludge=Net Synthesis + Cell debris+ Inorganic fraction	371.68 kg/day

***Values Observed in laboratory**

The main parameters that affect the treatment efficiency and general performance of the ASP are SRT, F/M ratio and volumetric loading rate. In the present case F/M ratio was found to be 0.08 at SRT of 24 day. SRT of 20-40 day are desirable for sludge stabilization [28]**.** At SRT value of 20-30 day F/M value may range from 0.1-0.05g BOD/ gVSS.day respectively. Recycled ratio was observed to 0.4 which is in acceptable range (0.2-0.4). Organic loading may vary from 0.3 to more than 3.0 kg BOD or COD/ m^3.day. Volumetric organic loading in the present case was quite low i.e. 0.3 kg COD/ m^3.day. Sludge generated was observed to be 368 kg/day which constituted of net synthesis, cell debris & inorganic fraction. Inspite of low organic loading high HRT and SRT was provided leading to increase in operation cost. Two secondary clarifier were earlier working but due to reduced flow one has become obsolete.

4.4 Secondary effluent: Reuse in irrigation [14]

The Treated effluent is used for eco-plantation. The plants which are grown are Eucalyptus, Poplar, Teak and Jatropha. The high transpiration capacity of plants grown in soil matrix enables the system to serve as biopump. These plants transpire water equivalent of 7 to 13 times the potential evapo-transpiration from the soil matrix alone. Nutrients present in the water are used by the plants and partially retained in the soil matrix without affecting the soil ecosystem.

Irrigation agriculture is dependent upon adequate good quality irrigation water. Treated secondary effluent from WWTP and irrigation water quality guidelines are summarized in table 4.4.

Table 4.4: Secondary effluent from WWTP and irrigation water quality guidelines

Properties	**Secondary effluent**	**EPA Guidelines**
pH	8	5.5-9
Oil & grease	9	10
TDS	966.7 mg/L	2100 mg/L
SS	52 mg/L	200 mg/L
Fecal Coli forms	-	2.2-23/100ml
BOD_5 at 20^oC	34.5 mg/L	100 mg/L
Ammonical Nitrogen	3 mg/L	-

Source: Ayers and Westcot (1985)

The suitability of a given body of water is judged from the following characteristics

- Total Dissolved Solids (TDS)
- Relative proportion of sodium to other cations
- Residual carbonates
- Sulphate Salinity
- Organic loading
- Nutrient
- Microbiological aspects

1. **Total Dissolved Solids (TDS) –** The salt concentration can also be obtained indirectly by measuring the Electrical conductivity (EC) of agriculture water and using the empirical relationship

$$TDS\ (mg/L) = 0.64 * EC\ (\mu\ mho/cm) \qquad (i)$$

The main effect of high EC and TDS water on crop productivity is the inability of the plant to compete with ions in the soil solution for water. The higher the EC and TDS, the less water is available to plants, even through a Field may appear wet.

Table 4.5: Suitability of water for irrigation

Electrical conductivity µ mhos/cm	**Salinity**	**Uses**
<250	Low	Suitability for crops on most soils
250-750	Medium	Suitability in most cases with moderate drainage
750-2250	High	May be used for salt-tolerant crops on adequately drained soils
2250-5000	Very high	May be used with very tolerant plants and with excess leaching

Source: Ayers and Westcot (1985)

TDS concentration in the treated effluent was found to be 966.7 mg/L and EC was 151 µ mhos/cm. It‘s value is below the Indian Standard Guidelines as shown in Table 4.4.

2. **The Sodium hazard-** The soil structure is considerably affected in the long run by the sodium content in the irrigation water. Sodium enters into cation exchange relationships with clay particles in the soil, tends to break down the clays. Dispersed soils have poor infiltration and permeability.

Sodium Adsorption Relationship (SAR) as shown in the following equation defines the relationship between sodium, Ca^{++} and Mg^{++}. Typical recommended values are given in table 4.6.

$$SAR = \frac{Na^{+}}{[(Ca^{++} + Mg^{++})/2]^{0.5}} \qquad \text{(ii)}$$

In above equation the chemical symbols stands for the concentrations of respective elements in agriculture water, all expressed in meq/L.

Table 4.6: Typical recommended values are given for irrigation

SAR values (meq/L)	Sodium Hazard to soil
0-10	Low
10-18	Medium
18-26	High
Above 26	Very high

Source: Ayers and Westcot (1985)

Classification of irrigation waster based on SAR values, the secondary effluent from WWTP could be classified as low sodium hazard value. The SAR was found to be 0.06 meq/L. The % Na was found to be 30% as per Indian guidelines for irrigation.

3. Residual Sodium Carbonate (RSC) – Large amount of bicarbonates tends to precipitate out the Calcium, as Calcium Carbonate from water and soil. Magnesium enters the exchange complex of the soil, replacing the precipitated Calcium. As Calcium and Magnesium are lost from the soil water, the relative proportion of sodium is increased, with an attendant increase in sodium hazard. This is general evaluation in terms of RSC defined as in table 4.7.

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \qquad (iii)$$

Table 4.7: Typical recommended values for irrigation water are as follow

Water Quality	RSC (meq/L)
Safe	Less than 1.25
Marginal	1.35-2.5
Unsuitable	Over 2.5

Source: Ayers and Westcot (1985)

RSC value [-2.1meq/L] of secondary effluent from milk based food industry was found to be safe.

4. Chlorides – Chlorides are said to have no effect on a soil's physical properties. Certain plants, however, are sensitive to chloride ions. In Israel, for citrus fruits, chloride up to 15 meq/L on sandy- loamy soils and up to 7.5 meq /L on clayey soils is considered to be of low risk. In India some irrigation water standards allow up to 600meq/L (i.e.16.92 meq/L) but the soil conditions are not satisfied.

In our case, chloride = 209.9 mg/L [standards allow up to 600 mg/L]

5. Sulphates – The term 'Potential Salinity' of water has been suggested in terms of [Cl^- + 0.5 SO_4^{2-}] in meq/L and following values have been proposed to ensure sustainability.

Table 4.8: Potential Salinity of water

Potential salinity (meq/L)	Desirable soil permeability
5-20	Good
3-15	Medium
3-7	Low

Source: Ayers and Westcot (1985)

The Potential Salinity was observed to be 10.7 meq/L. Permeability of soil was found to be good.

6. pH- Soil pH affects the availability of nutrients to plant. Effluent pH was in the range of 6.5-9 is acceptable for irrigation.

In our case pH=8, acceptable.

7. Organic Content- Organic matter in effluent can be measured as BOD, COD or TOC. Organic matter when applied on an appropriate rate, can contribute to soil fertility.

Ordinarily, concentrations are low enough to preclude short-term detrimental affects on the soil or vegetation.

Continued overloading with organic matter can physically clog soil pores, favors anaerobic soil microbes and slimy bacterial scum coating the soil, blocking pores and closing up cracks. These changes could limit the effective life of the application site. Table 4.9 summarizes a few typical organic loading acceptable on land.

Table 4.9: Typical organic loading acceptable on land

Waste	**Organic Loading Kg BOD_5/hac/day**	**References**
Dextrose	1026	[12]
Raw domestic & Industrial Waste (India)	25-150	[11]
Secondary effluents	2-5	[11]
Milk wastes	12-125	[13]

Source: Ayers and Westcot (1985)

In the present case BOD load applied to land is 4 Kg/hac/day which is below loading rate acceptable.

8. Nutrients – Nitrogen (N) can be present in organic and mineral forms, the latter including gaseous (N_2), Ammonia (NH_3), Ammonium (NH_4^+), Nitrate (NO_3^-), Nitrite (NO_2^-) and Urea (NH_2CONH_2). Mineral forms of Nitrogen are readily transformed into other mineral forms. It is estimated that between 15% and 25% of applied Nitrogen in the form of Ammonia can be list to the atmosphere. Organic Nitrogen is converted to Ammonium and Nitrate through mineralization processes. Table 4.10. Shows the estimated mineralization rate of Organic – Nitrogen in soil.

Nitrate can be converted to Nitrogen gas through the process of denitrification Under most effluent irrigation conditions the amount of Nitrogen lost in this manner is not significant.

Table 4.10: Mineralization of organic nitrogen in wastewater sludge and effluent in soil

	% original organic nitrogen mineralized	
At end of year	**Raw wastewater sludge**1	**Effluent (estimated)**
1st year after application	40	60
2nd year after application	20	30
3rd year after application	10	10
4th year after application	5	0
5th and subsequent years	3	-

Source: Younos (1987).

Plant available Nitogen in the effluent during application year is given by equation 4.1

Available Nitrogen in application year

$[NE] = [NO_3\text{-}N] + (1\text{-}kv)[NH_4\text{-}N] + f_y\,[NO\text{-}N]$ (4.1)

Where:

[NE] = plant-available nitrogen in the effluent during the application year in mg/L or equivalently kg/ML effluent

$[NO_3\text{-}N]$ = concentration of nitrogen as nitrate in the effluent in mg/L

kv = fraction of ammonia volatilized

$[NH_4\text{-}N]$ = concentration of nitrogen as ammonium in the effluent in mg/L

f_y= mineralization fraction for organic nitrogen in each year

[NO-N] = concentration of nitrogen as organic nitrogen in effluent in mg/L.

NE=0.54 + (1-.392) (1.96) + 8.28*1.45=13.73768 mg/L

However because of continuous application of wastewater from last 10 years the mineralization of organic nitrogen will also add to available nitrogen given by equation 4.2.

$$TNE_y = [NO_3\text{-}N] + (1\text{-}kv)[NH_4\text{-}N] + f_y\,[NO\text{-}N]_y + f_y\,(1-f_{y-1})[NO\text{-}N]_{y-1} + f_y\,(1-f_{y-1})(1-f_{y-2})[NO\text{-}N]_{y-2} + \ldots + f_y\,(1-f_{y-1})\ldots(1-f_1)[NO\text{-}N]_1 \qquad (4.2)$$

Where:

y = number of years in the simulation where year 1 is the first year of irrigation;

TNE_y = total plant-available nitrogen in year y including mineralization of residual NO from the previous year in kg/ML; and

$[NO\text{-}N]_x$ = the concentration of nitrogen as organic nitrogen in year x in mg/L.

TNE = 13.73+2= 15.73 mg/l

Annual uptake of Nitogen [U] for poplar trees is 300 kg/ha/yr. So the annual effluent loading for the current year will be

$R_y = U/TNE_y$ = 300/15.73=19 ML/hac/yr

[Where: R_y = annual effluent loading in year y in ML/hac/yr

U = annual crop uptake of nitrogen in kg/hac/yr]

9. Microbiological aspects: Effluent irrigation may also lead to microbial contamination of soil and plants in the vicinity of the irrigation site. The potential risk of health hazard due to bacteria and viruses to farm workers and consumers depend on the degree of treatment received by the wastewater and persistence of pathogens in the soil and on crops. Further survival of bacteria and virus in the soil are governed by several environmental fractions viz. soil, pH, cations, soluble organics, moisture, organic matter and temperature. Thawale *et al*. (2006) studied the survival of pathogens in the soil irrigated with different types of wastewater. Survival of different pathogens in soil and crops are reported in table 4.11. The result indicated the degree of health hazard was more in the use of untreated and primary treated wastewater. However, survival of organisms was insignificant in case of secondary treated wastewater.

Table 4.11: Survival of pathogens in soils

Pathogen	Survival in days
Coli forms	38
Streptococci	38 to 63
Faecal streptococci	26 to 77
Salmonellae	15 to > 280
Salmonela typhi	1 to 120
Tubercle bacilli	>180
Leptospira	15 to 43
Entamoeba histolytica cysts	6 to 8
Enteroviruses	8 to 175
Ascaris ova	up to 7 years
Hookworm larvae	42
Brucella abortus	30-125
Q-fever organism	148

CHAPTER 5
CONCLUSIONS

Present study concerned with the performance evaluation of WWTP for milk based food industry and compliance with the standards for irrigation.

Salient features of the present study are as follow:

1. The COD, BOD and TSS removal efficiency of WWTP was observed to be 96%, 95% and 94% respectively in spite of the fact that raw sewage
2. BOD_5: COD was 0.53.
3. Characterization of the waste on the basis of biodegradability shows that biodegradable COD was 85%. Out of 85% bCOD, readily biodegradable COD (rbCOD) and soluble biodegradable COD (sbCOD) were 90% & 10% respectively. Obviously the 96% reduction in TCOD was due to the high fraction of rbCOD. sbCOD reduction in ASP was found to be 76% which can be attributed to high SRT value of 24 day.
4. Sludge wastage was observed to be 371.6 kg/day and is due to net synthesis, cell debris and inorganic fraction from raw effluent. Nutrient addition is not required as the Nitrogen in the raw effluent is more than the Nitrogen utilized for cell production and sludge wastage.
5. No doubt treated effluent from WWTP showed high removal efficiency of organic matter and TSS but higher SRT and HRT leads to high operational and running cost. The present flow rate was also less than the designed flow thereby making one secondary clarifier redundant.
6. The current result suggest that the secondary effluent is complying with the standards for unrestricted irrigation based on Sodium, Sulphates, Electrical conductivity, pH, TDS, SAR and organic loading.

APPENDIX-I

1. Total Suspended Solids (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	780	845	830	790	898	870	798	790
P-2	713	750	680	650	705	663	690	710
P-3	735	675	645	700	705	670	683	710
P-4	2050	1966	2436	2180	2350	2280	2272	2460
P-5	2280	2310	2450	2376	2299	2410	2400	2420
P-6	48	54	62	42	70	59	42	45

2. BOD_5 at 20°C (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	704	698	617	681	694	693	727	708
P-2	615	647	598	635	678	587	591	637
P-3	640	605	635	590	598	645	638	621.6
P-4	195	210	170	230	205	185	190	200
P-5	210	199	185	174	225	168	230	170
P-6	25	32	48	28	27.5	41	29	43.5

3. TCOD (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	1277	1310	1297	1318	1305	1278	1317	1333
P-2	1246	1287	1260	1244	1270	1267	1274	1269
P-3	1287	1318	1305	1246	1290	1345	1275	1280
P-4	613	542	525	530	610	490	649	450
P-5	490	654	518	617	534	528	546	618
P-6	41	44.7	40	41.7	47	51	43	39.5

4. pH

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	7.2	6.2	6.97	6.5	7	6.9	7	6.3
P-2	7	6.1	7	6.3	7.1	6.5	7	6.3
P-3	6.8	7.3	6.9	7.1	6.9	6.8	7	7.1
P-4	7.8	8	8.1	8	7.8	8	7.95	8.2
P-5	7.8	7.9	9.1	7.8	8	7.7	7.9	7.85
P-6	7.9	8	8.2	8	7.7	8.2	8	7.9

5. Total Solids (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	1880	1700	1850	2120	1990	2050	2160	1950
P-2	1980	1980	1960	2180	1760	1940	1860	1930
P-3	1780	1810	2050	1870	1990	2130	1850	2170
P-4	3740	3510	3746	3640	3548	3576	3752	3670
P-5	3280	3640	3960	3450	3766	3310	3966	3850
P-6	1080	1240	1120	1056	990	1276	1100	1140

6. TDS (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	1055	846	1060	1330	1296	1165	1290	1150
P-2	1247	1150	1250	1310	1290	1199	1180	1266
P-3	1038	1060	1290	1120	1266	1370	1156	1350
P-4	1690	1290	1130	1290	1166	1156	1478	1219
P-5	990	1230	1280	1078	1188	1210	1388	1100
P-6	986	990	1078	986	990	1228	890	980

7. Chloride (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	133	111	128	127	135	129	139	132
P-2	145	154	90	130	111	120	117	132
P-3	148.6	65.5	159	108	67.98	132	78	118
P-4	166.6	137	115	128	118	127	103	129
P-5	111	121	120	113	145	103	115	111
P-6	150	65.6	87	120	45.9	60	103	77

8. Alkalinity (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	429	433	448	458	437	445	413	438
P-2	457	428.9	439	428.5	432.9	436	438	433
P-3	456	421	418	433.6	426.7	443	425	453.5
P-4	408	398.9	446	373	399	437	405	452
P-5	393	394	421	413	438	438	435	428
P-6	401	416	407	415	431	399	411	411.5

9. Oil & grease (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	27	23	22.6	27	23.9	26.9	23	25
P-2	15.6	17	16.8	13	18	16.5	17.5	14
P-3	13.9	12.5	13.8	14.9	15	17	12	17
P-4	11	8.7	10.7	11.9	9.8	10	13	12.6
P-5	12	11.9	11.9	11	9.5	12.5	10.8	10
P-6	7.9	10	9	8.5	9	10	9	10

10. Total Nitrogen (mg/L)

Sampling points	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
P-1	21	19.5	18.9	22	21.9	23	19.9	19
P-2	21	21.8	19.9	22	20	21.8	21	20.9
P-3	18	20	18.7	19.5	19	21	18.9	19
P-4	15.8	16	17	16.9	15	15	16.7	18
P-5	14.5	15	15.7	13	16	14.6	13	17
P-6	2.9	3.8	3	4.7	4.5	4	3.9	3.97

APPENDIX-II

Design parameters of ASP

Activated Sludge Kinetic Coefficient

Coefficient	Unit	Range	Typical Value
μ_m	gVSS/gVSS.day	3-13.2	6
K_s	gbCOD/m^3	5-40	20
Y	gVSS/gbCOD	0.3-0.5	0.4
K_d	gVSS/gVSS.d	0.06-0.2	0.12
f_d	unitless	0.08-0.2	0.15
K	gbsCOD/gVSS.day	2-10	5

Microbial Growth Kinetics		
Rate of utilization of soluble substrate (r_{su})	$r_{su} = -KXS / (K_S + S)$	$-13359.57\ g/m^3.d$
Maximum Specific substrate utilization rate	$r_{su} = -\mu_m XS / Y(K_S + S)$	$-40078.7\ g/m^3.d$
Biomass production rate	$r_g = -Y\, r_{su} - K_d X$	$4907\ g\ VSS/\ m^3.d$
Specific growth rate	$\mu = r_g / X$	1.35 g VSS/gVSS.d
Rate of oxygen uptake	$r_o = -\, r_{su} - 1.42\, r_g$	$6391.63\ g\ O_2/m^3.d$
Rate of cell debris production	$r_{xd} = f_d(K_d)X$	$65.52\ g\ VSS/m^3.d$
Total volatile suspended solids	$r_{XT,VSS} = [-Yr_{SU} - K_d X + f_d (K_d)X + Q_{Xo}, i /V]$	$5063.6\ g/\ m^3.d$
Active biomass (Active fraction of biomass in MLVSS, g/g)	$F_{x,act} = (-Yr_{su} - K_d X) / r_{XT,VSS}$	0.97= 97%
Net Biomass Yield	$Y = - r_g / r_{su}$	.367 g biomass/ g substrate used
Observed Yield	$Y_{obs} = - r_{XT,VSS} / r_{SU}$	.38 g VSS produced/g substrate removed

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