Dissertation Report On

ANAEROBIC TREATMENT OF MUNICIPAL SOLID WASTE LANDFILL LEACHATE

Submitted To

THAPAR UNIVERSITY, PATIALA

In partial fulfillment of the requirements for the award of the degree of Master of Technology in Environmental Science and Technology

2009-2011

Submitted By

Ms. Keerti Raj

Roll No. 600901010

Under the Guidance of

Dr.S.Y.Bodkhe	**Dr.Anita Rajor**
Scientist	**Assistant Professor**
SHWM Division	**Deptt. of Biotech. And Env. Sc.**
NEERI,	**Thapar University**
Nagpur – 440020	**Patiala,Punjab**

Work Done At

NEERI National Environmental Engineering Research Institute, Nagpur

NATIONAL ENVIRONMENTAL ENGINEERING RESEARCH INSTITUTE, NAGPUR

CERTIFICATE

This is to certify that ***Ms. Keerti Raj*** has completed the Project "**Anaerobic Treatment of Municipal Solid Waste Landfill Leachate**" under my guidance and supervision, and submitted the project report as laid down by Thapar University, Patiala. The material that has been obtained from other sources is duly acknowledged in the dissertation. It is further certified that the work or its part has not been submitted to any other University for examination under my supervision. I consider this work worthy for the award of the degree of Master of Technology in Environmental Science and Technology.

12.07.2011

Dr. S.Y. Bodkhe
Sr. Scientist,
SHWM division,
NEERI, Nagpur

CERTIFICATE

This is to certify that thesis entitled; "**Anaerobic Treatment of Municipal Solid Waste Landfill Leachate**" submitted by **Ms. Keerti Raj** in partial fulfillment of the requirements for the award of **Masters in Technology** Degree in **Environmental Science & Technology** at **Thapar University, Patiala (Deemed University)** is an authentic work carried out by her under our supervision and guidance. To the best of our knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

Dr. Anita Rajor
Assistant Professor
Deptt. of Biotech. & Env. Sciences Thapar University, Patiala
(Internal Supervisor)

Head of Department
Deptt. of Biotech. & Env. Sciences
Thapar University, Patiala

Dean
Academic Affairs
Thapar University, Patiala

ACKNOWLEDGEMENT

One good reason to write acknowledgement is to express publicly one's gratitude for those who somehow offered their help during the difficult process of creating knowledge.

*I express my sincere gratitude to **Dr. S.R Wate**, Director, National Environmental Engineering Research Institute (NEERI), Nagpur for giving me permission to pursue the dissertation work and to avail the facilities for carrying out the work in the prestigious institute.*

*At the outset, I would like to express our deep sense of gratitude to our supervisor **Dr. A.N. Vaidya**, Head, SHWMD, NEERI, and **Dr. M.S Reddy,** H.O.D. of Biotechnology And Environmental Sciences Department, Thapar University., Patiala, for their keen interest and permitting us to carry out our project work in this esteemed Institute.*

*I sincerely express my deep sense of gratitude and immense respect to my guide **Dr. S.Y.Bodkhe**, Senior Scientist, SHWM Division, NEERI, Nagpur for his scholarly guidance, generous encouragement and suggestion throughout the course of my dissertation work.*

*I am extremely grateful to my guide **Dr.Anita Rajor**, Assistant Professor, Biotechnology & Environmental Sciences Department, Thapar University., Patiala for her keen interest and encouraging me in one way or other to carry out my dissertation in NEERI, Nagpur.*

*I am highly indebted to **Mr. J.K. Bhattacharya**, SHWM Division, NEERI, Nagpur for his constant encouragement and co operation in my hour of need. It was my pleasure to associate with **Dr.S.P.M.Prince William**, Scientist, SHWM Division, NEERI, Nagpur, whose healthy suggestions generated new ideas for which I show my deep heartfelt thanks to him. I also show my deep and sincere gratitude to **Mr. D. L. Sadafule**, Technical Officer,* *SHWM Division, NEERI, Nagpur for sparing his valuable time in attending to the minute scientific and technical details, without which the thesis would not have been possible in the present form.*

I also express my sincere thanks to ***Ms.Snehal Patki, Mr. Nikesh Banwade, Mr. Jagdish Gabhane, Ms. Priya Bhilawe, Mr.Anandkumar, Mr. Veerkumar, Mr.Afzal Ali, Ms. Pallavi Niswade****, SHWM Division, NEERI for helping me and providing their valuable co-operation and suggestions.*

I would be failing in my duties if I do not mention the role played by staff members of SHWM Division, NEERI, especially ***Mr. Badage, Mr. Joshi, Mr. Kishore, Mr. Shirish*** *for their generous help in various ways for the successful completion of this dissertation.*

I wish to express my heartfelt gratitude to my family, my mother, father, brother for their constant affection, inspiration, encouragement to put my all the best efforts for achieving betterment in life.

At last I express my special thanks to all my friends for their affectionate co-operation work without which would have not been possible.

Date: ***Keerti Raj***

Place: Patiala

DECLARATION

*I, the undersigned hereby declare that the research work presented in the M.Tech project entitled "**Anaerobic Treatment of Municipal Solid Waste Landfill Leachate**" has been carried out under the guidance of Dr. S.Y. Bodkhe, Sr. Scientist, SHWM Division, NEERI, Nagpur. Further, I declare that no part of this Dissertation has been submitted for a degree or any other qualification of any other university or examining body in India/elsewhere.*

Keerti Raj

ABBERIVIATIONS

OLR	-	Organic Loading Rate
HRT	-	Hydraulic Retention Time
MSW	-	Municipal Solid Waste
AD	-	Anaerobic digestion
LL	-	Landfill Leachate
COD	-	Chemical oxygen demand
BOD	-	Biological Oxygen demand
TS	-	Total Solids
TSS	-	Total Suspended Solids
VS	-	Volatile Solids
TVAs	-	Total Volatile Solids
CH_4	-	Methane
ND	-	Not Detected
mg/L	-	Milligram per liter
d	-	Day
ml	-	Millilitre
i.e.	-	That is/ to say (id est)

TABLE OF CONTENTS

List of Tables

List of Figures

ABSTRACT

Leachate is a liquid that is passing through matter, extracts solutes, suspended solids or any other component of the material through which it has passed. Leachate from a landfill varies widely in composition depending on the age of the landfill and the type of waste that it contains. The main environmental problems at landfill sites are the infiltration of leachate and its subsequent contamination of the surrounding land and aquifers, odour problems etc. Improvements in landfill engineering are aimed at reducing leachate production, collection and treatment prior to discharge.

A very wide range of landfill leachate treatment processes have been applied to leachate treatment with varying success. Biological treatment is treatment in its fullest sense, and will remove most contaminants, by a natural conversion into far less harmful substances. It is a natural process using organisms naturally available within the environment.

Due to various advantages of anaerobic biological treatment. we opt it for leachate treatment by means of UASB bioreactor.

In study, Reactor operated at 3 different processes i.e. batch process, semi-continuous process and continuous process. In which we found best results in semi-continuous process.

Following results were obtained at semi-continuous process at 3 day HRT with 96.6% COD reduction, TVA reduced from 954 mg/L to 20 mg/l, alkalinity increased from 160 mg/L to 1180 mg/L. Total solid reduction was 68.14 %, suspended solid reduction was 86 %, volatile solid reduction was 86.7% and biogas production was 2650 ml.

CHAPTER-1

INTRODUCTION

INTRODUCTION

In recent years, the management of solid wastes has become a greater concern. Disposing waste on open dumping ground may create environmental pollution problems (soil contamination, ground water contamination, health problems etc.). When solid wastes are incinerated they reduce the waste to ash and release potentially hazardous gases into the air causing public health risks. These wastes can be dumped into landfills, which are the source of large emissions of methane to atmosphere. Methane gas has a Global Warming Potential (GWP) that is over 20 times of CO_2 (Velmurugan.et.al, 2010).

Apart from this, the energy crisis is another problem faced by the world.The best possible option is biological conversion of solid wastes that contain higher percentage of organic matter and moisture content (i.e. about 45-50%).

1.1. SOLID WASTE

1.1.1 Definition

Volume 40 of The U.S. Code of Federation Regulations (40 CFR 240.101) defines a solid waste as:

Garbage, refuse, sludge, and other discarded solid materials resulting from industrial and commercial operations and from community activities. It does not include solids or dissolved material in domestic sewage or other significant pollutants in water resources, such as silt, dissolved or suspended solids in industrial wastewater effluents, dissolved materials in irrigation return flows or other common water pollutants.

1.1.2 Categories of Solid Waste

In order to implement cost-effective management strategies that are beneficial to public health and the environment, it is practical to classify wastes. For example, wastes can be designated by generator type, i.e., the source or industry that generates the waste stream. Some major classes of waste include:

- Municipal waste
- Hazardous waste

- Industrial waste
- Medical waste
- Universal waste
- Construction and demolition waste
- Radioactive waste
- Mining waste
- Agricultural waste

1.2. MUNICIPAL SOLID WASTE (MSW)

1.2.1 Definition

MSW, also known as domestic waste or sometimes household waste, is generated within a community from several sources, and not simply by the individual consumer or a household. MSW originates from residential, commercial, institutional, industrial, and municipal sources. Examples of the types of MSW generated from each major source are listed in **Table 1.1**. Municipal waste are highly heterogeneous and include durable goods (e.g., appliances), nondurable goods (newspapers, office paper), packaging and containers, food wastes, yard wastes, and miscellaneous inorganic wastes. For ease of visualization, MSW is often divided into two categories: garbage and rubbish. Garbage is composed of plant and animal waste generated as a result of preparing and consuming food. This material is putrescible, meaning that it can decompose quickly enough through microbial reactions to produce bad odours and harmful gases. Rubbish is the component of MSW excluding food waste, and is non-putrescible. Some, but not all, of rubbish is combustible.

Each year EPA produces a report on MSW generation, recycling, and disposal. In 2009, Americans produced about 243 million tons of MSW, or about 4.3 pounds of waste per person per day.

1.2.2 Main Sources of Municipal Solid Waste –

Table 1.1: Sources of MSW

Residential (Single and multi family home)	Foodscraps,food packageing,cans,bottles,newspaper, clothing, yard waste, old appliances.
Commercial (Office Buildings, Retail companies,Restaurants)	Office papers, corrugated waste, food waste, disposable table ware, paper napkins, yard wastes, wood pallets.
Institutional (School, Hospitals, Prison)	Office papers corrugated waste, cafeteria waste, restroom waste, classroom waste, yard waste.
Industrial (Packaging and Administrative ;not process water)	Office papers corrugated waste, cafeteria waste, wood pallets.
Municipal	Litter, street sweeping, abandoned automobiles, some construction and demolition waste.

1.2.3 Composition of Municipal Solid Waste

In India, the biodegradable portion dominates the bulk of Municipal Solid Waste. Generally the biodegradable portion is mainly due to food and yard waste.

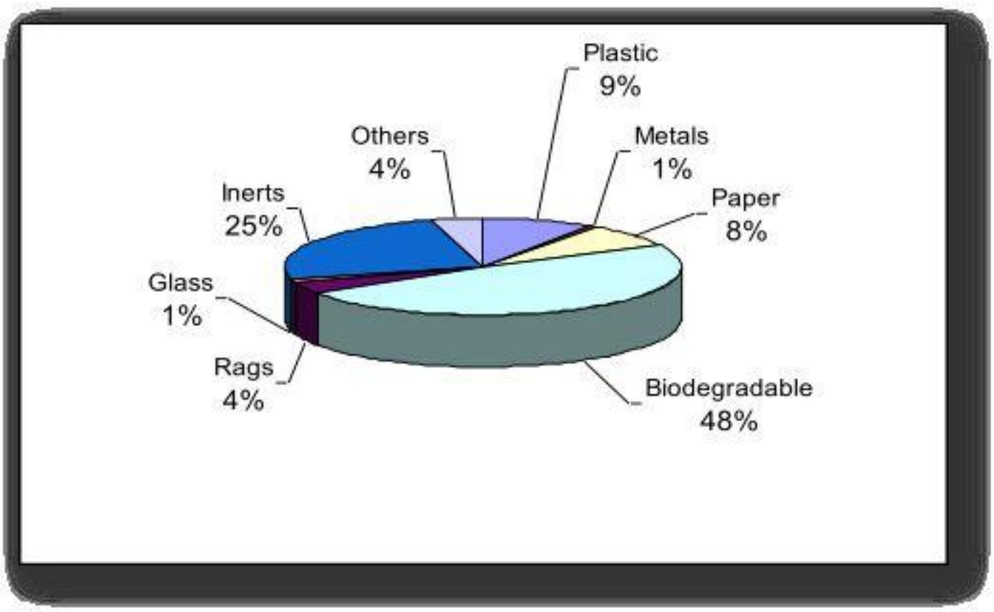


Fig 1.1: Composition of municipal solid waste

1.2.4 Generation of municipal solid waste

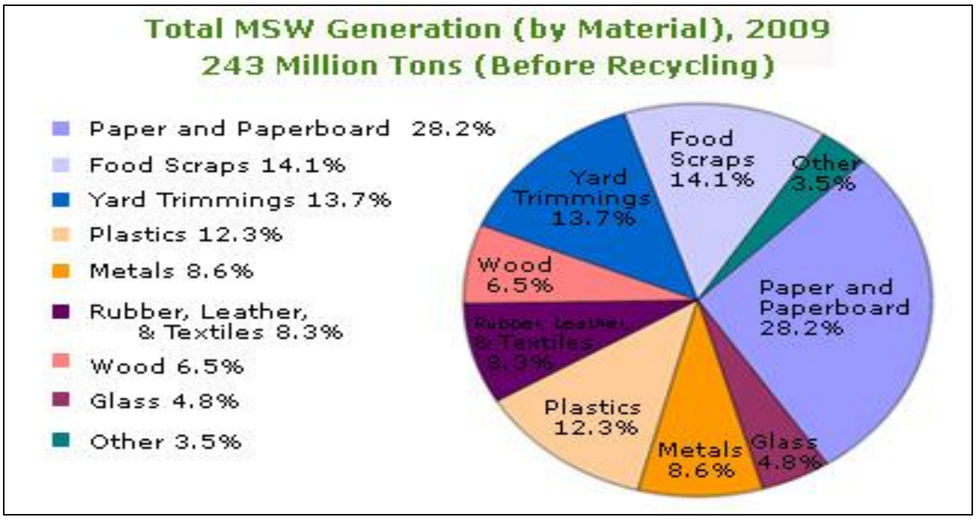


Fig 1.2: Generation of municipal solid waste

1.2.5 Municipal Solid Waste Management Practices in India

Management of municipal solid waste is most often the responsibility of Municipal or other Governmental authorities. Except in the metropolitan cities, SWM is the responsibility of a health officer who is assisted by the engineering department in the transportation work. The activity is mostly labour intensive, and 2-3 workers are provided per 1000 residents served. The municipal agencies spend 5-25% of their budget on SWM.
A typical waste management system in a low- or middle-income country like India includes the following elements:

- Waste generation and storage
- Segregation, reuse, and recycling at the household level
- Primary waste collection and transport to a transfer station or community bin
- Street sweeping and cleansing of public places
- Management of the transfer station or community bin
- Secondary collection and transport to the waste disposal site
- Waste disposal in landfills

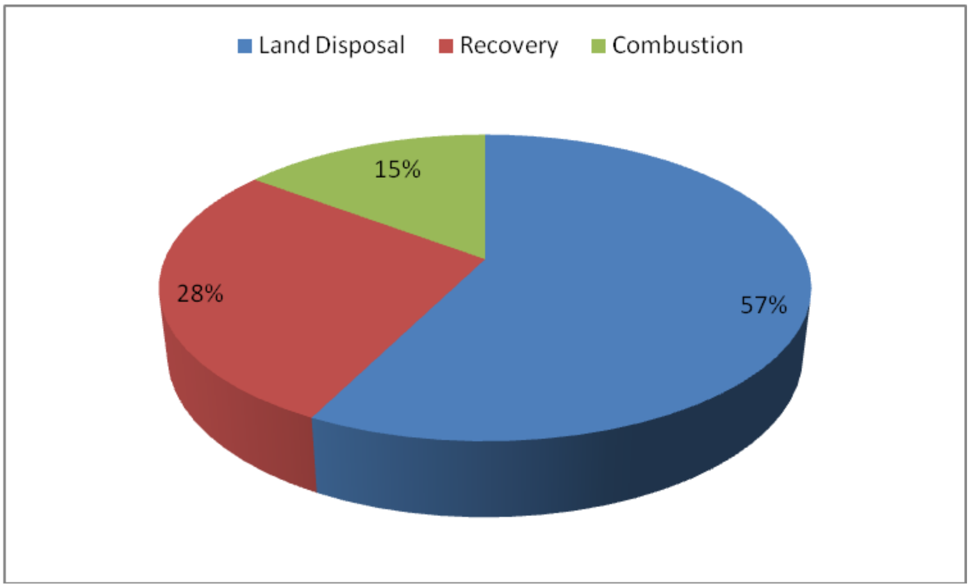


Fig 1.3: Current waste management Priorities (U.S.EPA. 2001)

1.2.6 MSW (Management and Handling) Rules

Municipal Solid Wastes (Management & Handling) Rules, 2000 (MSW Rules), CPCB are applicable to every municipal authority responsible for collection, segregation, storage, transportation, processing and disposal of municipal solid waste.

Table 1.2 : MSW Management and Handling rules by CPCB (2000)

The Rule contains four Schedules name:

*	Schedule-I	:	Relates to implementation Schedule
*	Schedule-II	:	Specifications relating to collection, segregation, storage, transportation, processing and disposal of municipal solid waste (MSW).
*	Schedule-III	:	Specifications for landfilling indicating; site selection, facilities at the site, specifications for landfilling, Pollution prevention, water quality monitoring, ambient air quality monitoring, Plantation at landfill site, closure of landfill site and post care.
*	Schedule-IV	:	Indicate waste processing options including; standards for composting, treated leachates and incinerations.

1.2. LANDFILL

1.3.1 Municipal solid waste landfill (MSWLF):

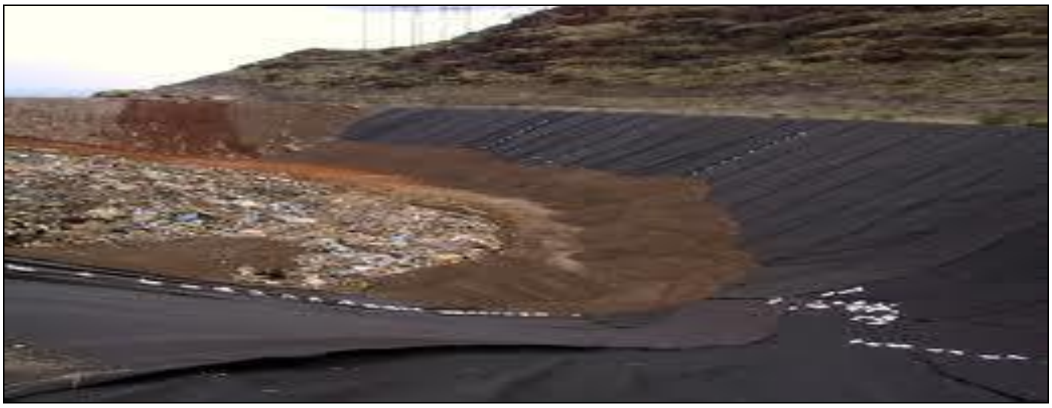


Fig 1.4: Municipal solid waste landfill site.

A discrete area of land or an excavation that receives household waste, and is not a land application unit, surface impoundment, injection well, or waste pile. A MSWLF unit may also receive other types of wastes as defined under Subtitle D of RCRA, such as, commercial solid waste, non hazardous sludge, small quantity generator waste, and industrial solid waste. Such a landfill may be publicly or privately owned.

But in most of the Indian cities land filling is the common practice which is adversely affecting on environment and public health.

1.3.2 Landfill Design

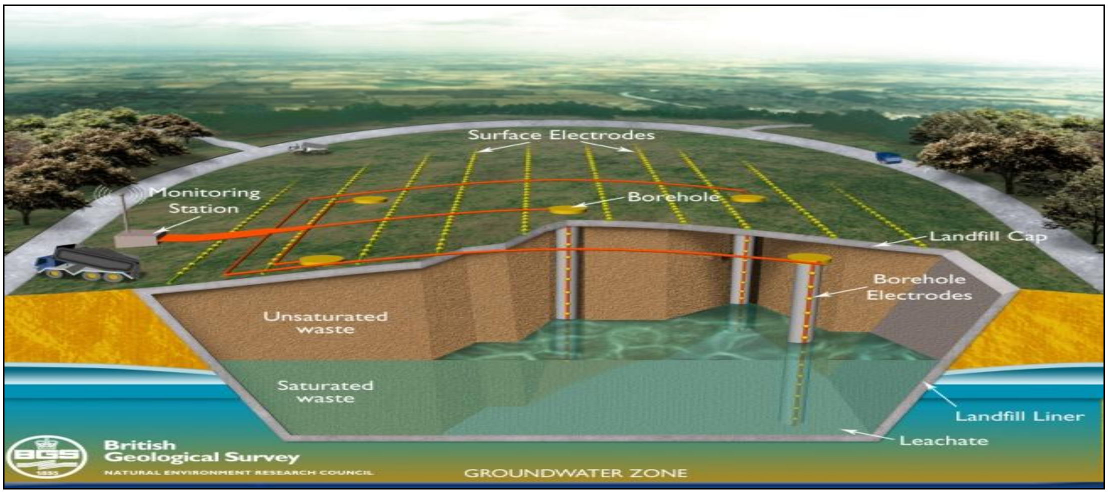


Fig 1.5: Design of Municipal solid waste landfill

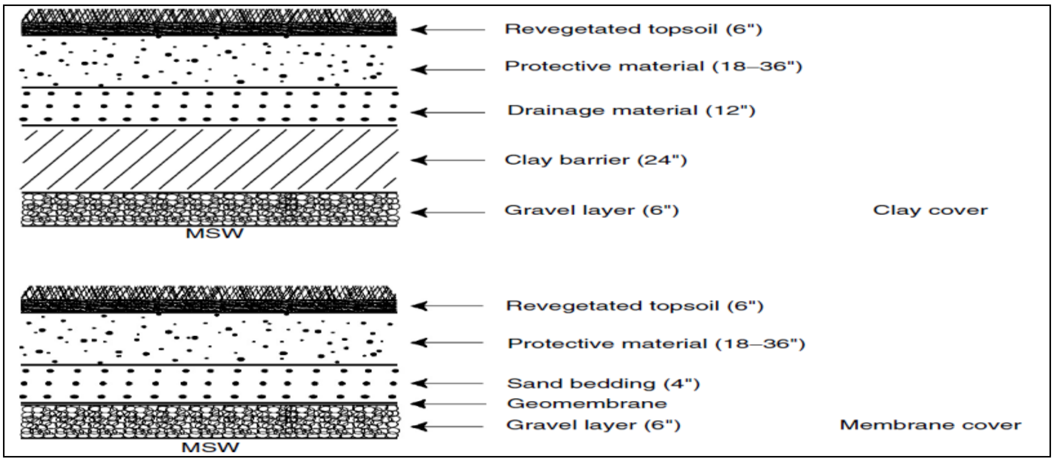


Fig1.6: Two different cover types for a MSW landfill (Vesilind *et al*., *Solid Waste Engineering* 1st Ed., 2002).

As a minimum, four basic conditions should be met by any site design and operation before it can be regarded as a MSW landfill:

- Full or partial hydrogeological isolation: if a site cannot be located on land which naturally contains Leachate security, additional lining materials should be brought to the site to reduce leakage from the base of the site (Leachate) and help reduce contamination of groundwater and surrounding soil. If a liner-soil or synthetic is provided without a system of leachate collection, all leachate will eventually reach the surrounding environment. Leachate collection and treatment must be stressed as a basic requirement.
- Formal engineering preparations: designs should be developed from local geological and hydrogeological investigations. A waste disposal plan and a final restoration plan should also be developed.
- Permanent control: trained staff should be based at the landfill to supervise site preparation and construction, the depositing of waste and the regular operation and maintenance.
- Planned waste emplacement and covering: waste should be spread in layers and compacted. A small working area which is covered daily make the waste less accessible to pests and vermin.

Landfill design in India is guided by notifications of the Government from time to time. Guidelines for the liners and covers to be adopted for municipal solid waste (MSW) landfills have been notified by the Ministry of Environment and Forests (MoEF (2000)) and

Ministry of Urban Affairs (MUA (2000)). Similarly, guidelines for liners and covers for hazardous waste (HW) landfills have been notified by the Central Pollution Control Board (CPCB (2001)).

1.3.3 Adverse Effects of Landfill

With the various advantages of landfill practice.There are some adverse effects also which need to be concerned. And these are as follows.

(a) Ground water contamination by the leachate generated by the waste dump

(b) Surface water contamination by the run-off from the waste dump

(c) Bad odour, pests, rodents and wind-blown litter in and around the waste dump

(d) Generation of inflammable gas (e.g. Methane) within the waste dump

(e) Bird menace above the waste dump which affects flight of aircraft

(f) Fires within the waste dump

(g) Erosion and stability problems relating to slopes of the waste dump

(h) Epidemics through stray animals

(i) Acidity to surrounding soil and

(j) Release of green house gas

However, landfill requires a close environmental engineering surveillance in its design and operation, as it is likely to generate leachate, which would potentially contaminate nearby groundwater and surface water. With the changing nature of domestic refuse composition over the years, the proportion of refuses available for decomposition has greatly increased and thus the organic strength of the leachate has increased, resulting in its greater potential to pollute water. Therefore, a need exist to focus on the environmental problems concerned with domestic landfill leachate disposal to protect the environment and prevent adverse health effects.

1.4 LANDFILL LEACHATE

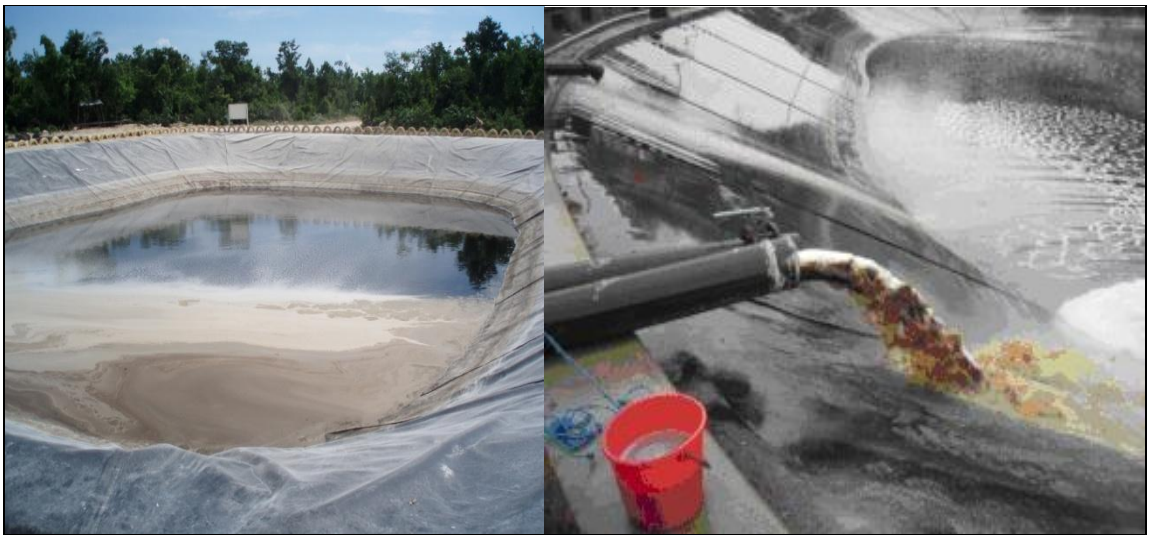


Fig 1.7: Landfill leachate collection pond

1.4.1 Definition

Leachate is any liquid that, in passing through matter, extracts solutes, suspended solids or any other component of the material through which it has passed. It is most commonly used in the context of land-filling of putrescible or industrial waste.

Leachate from a landfill varies widely in composition depending on the age of the landfill and the type of waste that it contains. It can usually contain both dissolved and suspended material. The generation of leachate is caused principally by precipitation percolating through waste deposited in a landfill. Once in contact with decomposing solid waste, the percolating water becomes contaminated and if it then flows out of the waste material it is termed leachate. Additional leachate volume is produced during this decomposition of carbonaceous material producing a wide range of other materials including methane, carbon dioxide and a complex mixture of organic acids, aldehydes, alcohols and simple sugars.

1.4.2 Composition of landfill leachate

When water percolates through the waste, it promotes and assists process of decomposition by bacteria and fungi. These processes in turn release by-products of decomposition and rapidly use up any available oxygen creating an anoxic environment. In actively decomposing waste the temperature rises and the pH falls rapidly and many metal ions which are relatively insoluble at neutral pH can become dissolved in the developing leachate. The decomposition processes themselves release further water which adds to the volume of leachate. Leachate also reacts with materials that are not themselves prone to decomposition such as fire ash, cement based building materials and gypsum based materials changing the chemical composition. In sites with large volumes of building waste, especially those containing gypsum plaster, the reaction of leachate with the gypsum can generate large volumes of hydrogen sulphide which may be released in the leachate and may also form a large component of the landfill gas.

Table 1.3: Components of landfill leachate

Parameter	**Typical Range (milligrams per litre, unless otherwise noted)**	**Upper Limit (milligrams per litre, unless otherwise noted)**
Total Alkalinity (as $CaCO_3$)	730–15,050	20,850
Calcium	240–2,330	4,080
Chloride	47–2,400	11,375
Magnesium	4–780	1,400
Sodium	85–3,800	7,700
Sulphate	20–730	1,826
Specific Conductance	2,000–8,000 µmhos/cm	9,000 µmhos/cm
TDS	1,000–20,000	55,000
COD	100–51,000	99,000
BOD	1,000–30,300	195,000

Parameter	Typical Range (milligrams per litre, unless otherwise noted)	Upper Limit (milligrams per litre, unless otherwise noted)
Iron	0.1–1,700	5,500
Total Nitrogen	2.6–945	1,416
Potassium	28–1,700	3,770
Chromium	0.5–1.0	5.6
Manganese	Not detected – 400	1,400
Copper	0.1–9.0	9.9
Lead	Not detected – 1.0	14.2
Nickel	0.1–1.0	7.5

SOURCE: Based on Canter *et al* (1988), McGinley and Kmet (1984), and Lee and Jones (1991)

Landfill design and operation have a major impact and influence on leachate generation. Leachate varies from one landfill to another with respect to space and time in a particular landfill. With fluctuations that depend on short and long-term periods due to variations in climate, hydrogeology and waste composition (Keenan et al., 1984).

1.4.3 Problems related with leachate treatment and disposal

The main environmental problems at landfill sites are the infiltration of leachate and its subsequent contamination of the surrounding land and aquifers, odour problems etc. Improvements in landfill engineering are aimed at reducing leachate production, collection and treatment prior to discharge (Farquhar, 1989).

1.4.4 Selection of leachate treatment

There are difficulties concerned with the treatment of the leachate.

- The variability and strength of the leachate.
- The changes encountered from landfill to landfill are such that waste treatment technology applicable at one site may not be directly transferable to other location.
- Fluctuations in the leachate quality, which occur over both short and long interval, must be accounted for in the treatment design.

Selection of a leachate treatment process is highly site specific. It depends on many factors.

- Effluent discharge alternatives and limitations
- Treatment process residuals
- Permit requirements
- Cost-Effectiveness of treatment

1.4.5 Treatment methods for leachate

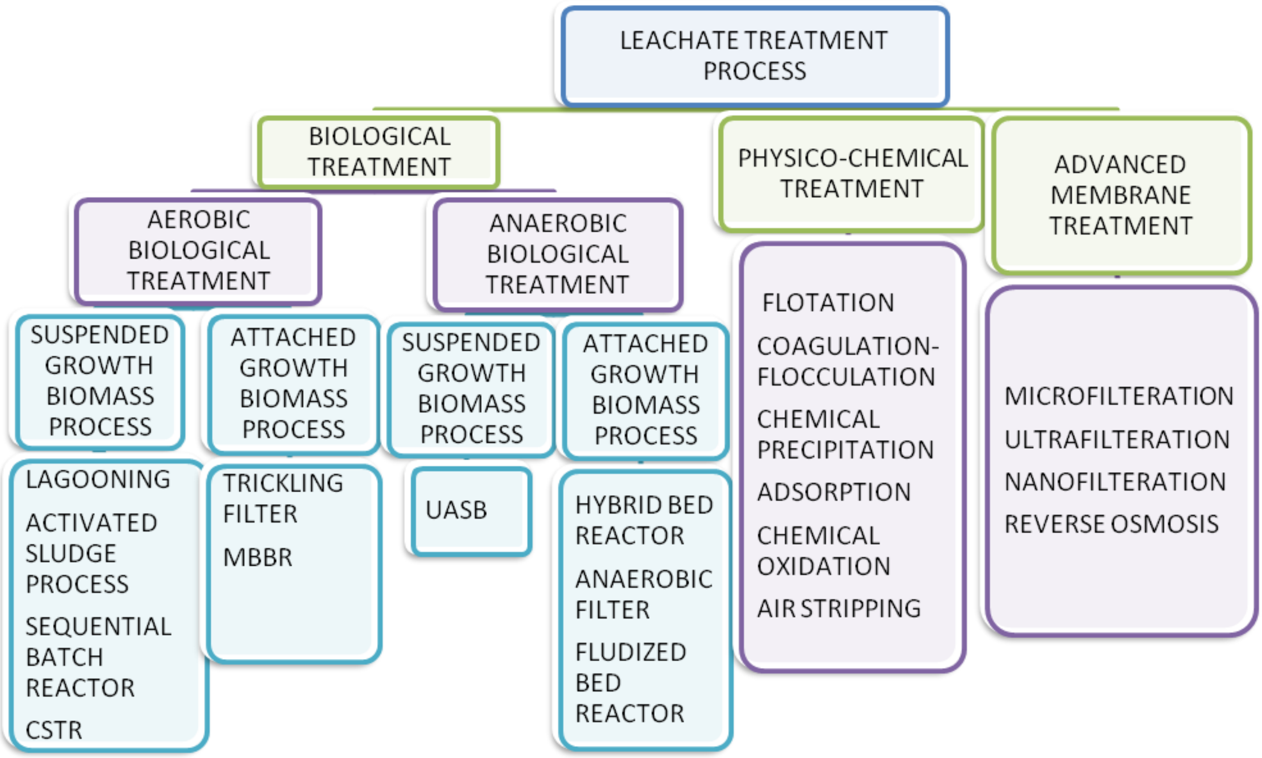


Fig1.8: Various treatment methods for landfill leachate treatment

1.4.5 Biological landfill leachate treatment

Very wide range of landfill leachate treatment processes have been applied to leachate treatment with varying success. The processes which have been the lowest cost and consistently successfully applied, for municipal waste landfill leachate from controlled landfills, are biological processes**.** The biological processes for the treatment of mature landfill leachates may be only partially effective in removing COD, and not at all effective in salinity reduction, but in reality this is seldom likely to present a risk of a negative impact on the receiving watercourse, (unless low flows are very low and provide little dilution).

By contrast, biological treatment is treatment in its fullest sense, and will remove most contaminants, by a natural conversion into far less harmful substances, and mostly carbon dioxide and water. It is a natural process using organisms naturally available within the environment. It is a true treatment process. In other words, biological treatment is much more than a separation process, it also converts organic (carbon based) materials by returning them back harmlessly into the place where they came from. That is the atmosphere, largely as carbon dioxide and nitrogen. There is no harm in that, as long as the carbon so discharged is part of the natural cycle. Even if you protest, perfectly reasonably, that indeed much of the carbon dioxide content will have been fossil fuel based originally; the atmosphere is the best place for the carbon dioxide and nitrogen from landfills to be disposed to. Overall, such emissions are tiny compared to global carbon dioxide emissions, and given that the leachate has to be treated somehow, the sustainability of such a discharge route is far better than emitting these substances through any other pathway.

It is perfectly logical that with leachate being in most respects just a much stronger version of foul sewage, biological treatment of leachate would also be the lowest cost and most sustainable treatment method for landfill leachate treatment. It produces very little if any waste products, unlike chemical treatments of leachate such as flocculation and coagulation, and ammonia stripping which produce large quantities of chemical sludge which themselves are likely to pose a disposal problem.

1.4.7 Benefits of anaerobic treatment

1. Less energy required

	Value, kJ/d	
Energy	**Anaerobic**	**Aerobic**
Aeration	-	-1.9×10^6
Methane produced	12.5×10^6	-
Increase temperature to 30°C	-4.2×10^6	-
Net energy, kJ/d	8.3×10^6	-1.9×10^6

Comparison of energy balance for aerobic and anaerobic processes for the treatment of a waste water with a flow rate of 100 m^3/day; waste water strength 10 kg/m3; and at 20^{o}C

a - Oxygen required = 0.8 kg/kg COD removed.

b - Aeration efficiency = 1.52 kg O_2/kWh and 3600 kj = 1 kWh.

c - Methane production = 0.35 m^3/kg COD removed.

d - Energy content of methane = 35,846 kj/m^3 (at 0°C and 1 atm).

For the conditions given, the aerobic process requires 1.9 x 10^6 kJ/d. On the other hand, the anaerobic process produces a total of 12.5 x 10^6 kJ/d. Of the total energy produced anaerobically, about 4.2 x 106 kJ/d is required to raise the temperature of the wastewater from 20 to 30°C, the low end of the mesophilic temperature range, a more desirable temperature for anaerobic treatment. Thus, the potential net energy production that can be achieved with anaerobic treatment is 8.3 x 10^6 kJ/d.

This is a very significant benefit, especially when the pressing need for the reduction in fossil fuel uses due to the severe consequences of current predictions of impending climate changes. A summary of the 3rd UNFCCC Climate Change report here reinforces this point.

2. Less biological sludge produced

3. Methane production:

    - Providing potential energy source with possible revenue both from sale of the energy, and benefit from government tax, and (Kyoto agreement) CDM etc. payments arising from renewable fuels/non-fossil fuel incentives
    - Anaerobic digestion contributes to reducing greenhouse gases by reducing demand for fossil fuels

4. Biomass acclimatisation allows most organic compounds to be transformed
5. Rapid response to substrate addition after long period without feeding
6. End product can be potentially saleable products biogas, soil conditioner and a liquid fertiliser.
7. Process more effectively provides sanitisation/removal of diseases.
8. Anaerobic processes may be net energy producers instead of energy users, as is the case for aerobic processes.

9. Fewer nutrients required

    Many industrial wastewaters lack sufficient nutrients to support aerobic growth. The cost for nutrient addition is much less for anaerobic processes because less biomass is produced.

10. Higher Volumetric Loadings

    Anaerobic processes generally have higher volumetric organic loads than aerobic processes, so smaller reactor volumes and less space may be required for treatment. Organic loading rates of 3.2 to 32 kg COD/m^3/d may be achieved which compares with 0.5 to 3.2 kg COD/m^3/d for aerobic processes.

So due to these advantages of anaerobic treatment over other treatments. We had chosen anaerobic treatment for MSW leachate treatment by means of bioreactor.

1.5. AIMS AND OBJECTIVES OF THE STUDY

The objectives of the study were to investigate the performance of UASB column bioreactor in MSW leachate treatment. The specific objectives are as follows:

1) To investigate and evaluate the performance of UASB column bioreactor for the treatment of MSW leachate containing high organic matter concentrations;

2) To compare the performance of reactor operated at different processes (Batch, Semi-continuous, Continuous) at 3 day HRT.

CHAPTER-2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Solid waste disposal methods include open dump, sanitary landfill, incineration, composting, grinding and discharge to sewer, compaction, hog feeding, milling, dumping, reduction, and anaerobic digestion. Sanitary landfill is the most common municipal solid waste (MSW) disposal method due to such advantages as simple disposal procedure, low cost, and landscape-restoring effect on holes from mineral workings (Bashir et al,2010a; Davis and Cornwell, 2008). However, the production of highly contaminated leachate is a major drawback of this method (Wiszniowski et al., 2007; Kurniawan et al., 2006).

Leachate is liquid formed primarily by the percolation of precipitation water through an open landfill or through the cap of a completed site. Leachate may contain large amounts of organic contaminants measured as chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia, halogenated hydrocarbons suspended solid, significant concentration of heavy metals, and inorganic salts (Foul *et al*., 2009; Aziz *et al*., 2009; Renou *et al*., 2008; Uygur and Kargi, 2004). It is also rich in phenol, nitrogen, and phosphorus. If not treated and safely disposed, landfill leachate could be a potential source of surface and ground water contamination, as it could seep into soils and sub soils, causing severe pollution to receiving waters (Oman and Junestedt, 2008; Lin *et al*., 2008; Sanphoti *et al*., 2006; Tatsi *et al*., 2003) or

Leachate is defined as the aqueous effluent generated as a consequence of rain water percolation through wastes, biochemical processes in waste cells and the inherent water content of water themselves. Leachate may contain large amounts of organic matter (biodegradable, but also refractory to biodegradation),where humic type constituents consist an important group, as well as ammonia-nitrogen, heavy metals, chlorinated organic and inorganic salts. The removal of organic material based on chemical oxygen demand (COD), Biological oxygen demand (BOD).and ammonium from leachate is the usual prerequisite before discharging the leachate into natural water (S.renou *et.al.*, 2007).

The chemical composition of leachate depends on many factors such as the initial composition of solid wastes, the particle size, the degree of compaction, the hydrology of the site, the climate, and finally the age of tip. The latter factor reflects the degree of stabilization of the wastes (Kouzeli- Katsiri *et al*., 1999).

MSW management constitutes today a major environmental, economical and social problem worldwide, mainly because the waste volume is growing faster than the world's population. Moreover, as stricter environmental requirements are continuously imposed regarding ground and surface waters, the treatment of landfill leachate becomes a major environmental concern.

Leachate characteristics

There are many factors affecting the quality of such leachate i.e., age, precipitation, seasonal weather variation, waste type and composition (depending on the standard of living of the surrounding population, structure of the tip). In particular, the composition of landfill leachate varies greatly depending on the age of the landfill (S.baig *et.al.*, 1999)

The characteristics of the landfill leachate can usually be represented by the basic parameters COD, BOD, the ratio BOD/COD, pH, suspended solids (SS), ammonium nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN) and heavy metals.

Leachate treatment has received significant attention in recent years, especially in municipal areas. High COD and ammonium content, high BOD/COD ratio and the presence of heavy metal ions present unique difficulties in biological treatment of landfill leachate (Park *et al*., 2001). Usually a combination of physical, chemical and biological methods are used for landfill leachate treatment, since it is difficult to obtain satisfactory treatment efficiencies by either one of these methods alone (Ahn *et al*., 2002; Chiang *et al*., 2001; Lin and Chang, 2000). Air stripping, adsorption and membrane filtration have been the major physical methods used for landfill leachate treatment (Bohdziewicz *et al*., 2001; Marttinen *et al*., 2002; Trebouet *et al*., 2001). Among the chemical treatment methods used for leachate treatment coagulation–flocculation, chemical or electrochemical oxidation is the major ones (Ahn *et al*., 2002; Chiang *et al*., 2001). Biological treatment methods used for leachate treatment are mainly aerobic, anaerobic and anoxic processes which are usually used in combination (Im *et al*., 2001).

Landfill leachate treatment usually involves a multistage system of chemical, physical and biological processes (Alessandro and Stefano, 2008), and its treatment cost is higher than that of municipal and industrial wastewater (Kjeldsen *et al*., 2002; Renou *et al*., 2008).

1. **Physical/chemical treatment**

Physical and chemical processes include reduction of suspended solids, colloidal particles, floating material, colour and toxic compounds by flotation, coagulation/flocculation, adsorption, chemical oxidation and air stripping. Physical/ chemical treatments for the landfill leachate are used in addition at the treatment line (pre-treatment or last purification) or to treat a specific pollutant (stripping for ammonia).

- **Flotation**- Flotation has been extensively used and focused on the decrease of colloids, ions, macromolecules, microorganisms and fibres. The use of flotation in column, as a post-treatment step for removing residual humic acids (non biodegradable compounds) from simulated landfill leachates. Under optimised conditions, almost 60% humic acids removal has been reached (Zouboulis *et al*., 2003).

- **Coagulation–flocculation**- Coagulation and flocculation may be used successfully in treating stabilized and old landfill leachates (A.C.Silva (2004), Y.W.Kang (2000)). It is widely used as a pre-treatment [A.A.Talsi *et al*(2003),A.Amokrane (1997), R.Zamora (2000)], prior to biological or reverse osmosis step, or as a final polishing treatment step in order to remove nonbiodegradable organic matter. Aluminium sulphate, ferrous sulphate, ferric chloride and ferric chloro-sulfate were commonly used as coagulants (A.Amokrane *et.al*., 1997).

- **Chemical precipitation**-. In the case of leachate treatment, chemical precipitation is widely used as pre-treatment in order to remove high strength of ammonium nitrogen (NH_4+-N). In a study, Li et al. [X.Z.Li.*et al* (1999)] confirmed that the performance of a conventional activated sludge process could be significantly affected by a high concentration of NH_4 +-N. The COD removal declined from 95 to 79%, when the NH_4 +-N concentration in wastewater increased from 50 to 800 mg /L.

- **Adsorption**. The adsorption of pollutants onto Activated Carbon in columns [A. Imai. *et al.*,(1998), J.Fetting *et al.*,(1996), B.Morawe *et al.*,(1995)] or in powder form [F.Karzi *et al.*,(2004), N.J.Horan.*et al.*,(1997)] provides better reduction in COD levels than the chemicals methods, whatever the initial organic matter concentration . The main drawback is the need for frequent regeneration of columns or an equivalently high consumption of powdered activated carbon (PAC). Adsorption by activated carbon has been used along with biological treatment for effective treatment of landfill leachate [F.Cecen *et al* (2003)].

- **Chemical oxidation-** Chemical oxidation is a widely used method for the treatment of effluent containing refractory compounds such as landfill leachate. Growing interest has been recently focused on advanced oxidation processes (AOP). Most of them, except simple ozonation (O_3), use a combination of strong oxidants, e.g. O_3 and H_2O_2, irradiation, e.g. ultraviolet (UV), ultrasound (US) or electron beam (EB), and catalysts, e.g. transition metal ions or photo catalyst.

- **Air stripping-** High levels of ammonium nitrogen are usually found in landfill leachates, and stripping can be successful for eliminating this pollutant, which can increase wastewater toxicity [Marttinen *et al.,* (2002)]. If this method is to be efficient, high pH values must be used and the contaminated gas phase must be treated with either H_2SO_4 or HCl. Performances of this process can be evaluated in term of ammonia-nitrogen removal efficiency.

2. **Membrane treatment**

Microfiltration, ultra filtration, nanofiltration and reverse osmosis are the main membrane processes applied in landfill leachates treatment.

- **Microfiltration (MF)**

MF remains an effective method is required to eliminate colloids and the suspended matter like, for instance, in pre-treatment for another membrane process (UF, NF or RO) or in partnership with chemical treatments. But, it cannot be used alone. No significant retention rate (COD reduction between 25 and 35%) was achieved.

- **Ultrafiltration (UF)**

UF is effective to eliminate the macromolecules and the particles, but it is strongly dependant on the type of material constituting the membrane. UF may be used as a tool to fractionate organic matter and so to evaluate the organic pollutants in a given leachate, UF was eliminated as a primary means for treating landfill leachate due to drastic existing regulations. UF can be used to remove the larger molecular weight components of leachate that tend to foul reverse osmosis membranes. The elimination of polluting substances is never complete (COD between 10 and 75%). More recently, UF has been applied to biological post-treatment of landfill leachate [J. Bohdziewicz *et al*., (2001).

- **Nanofiltration (NF)**

NF technology offers a versatile approach to meet multiple water quality objectives, such as control of organic, inorganic, and microbial contaminants. Few studies mention the use of NF to treat landfill leachate [D. Trebouet *et al* .,(1999), R. Rautenbachet *et al*., (1994)]. Nearly 60–70% COD and 50% ammonia were removed by NF, whatever membrane material and geometry (flat, tubular, or spiral wounded), with an average velocity of 3m/s and a transmembrane pressure between 6 and 30 bar. Physical methods were used in combination with nanofiltration and it was found satisfactory for removal of refractory COD from the leachate used. COD removal was 70–80% [D. Trebouet *et al* .,(2001)].

- **Reverse osmosis (RO)**

RO seems to be one of the most promising and efficient method among the new processes for landfill leachate treatment. In the past, several studies, performed both at lab and industrial scale, have already demonstrated RO performances on the separation of pollutants from landfill leachate [K. Linde.*et al*.,(2005), T. Bilstad.et.al (1992)]. Values of the rejection coefficient referred to COD parameter and heavy metal concentrations higher than 98 and 99%.

3. BIOLOGICAL TREATMENT

Due to its reliability, simplicity and high cost-effectiveness, biological treatment (suspended/attached growth) is commonly used for the removal of the bulk of leachate containing high concentrations of BOD. Biodegradation is carried out by microorganisms, which can degrade organic compounds to carbon dioxide and sludge under aerobic conditions and to biogas (a mixture comprising chiefly CO_2 and CH_4) under anaerobic conditions (J.M.Lema., 1988). Biological processes have been shown to be very effective in removing organic and nitrogenous matter from immature leachate when the BOD/COD ratio has a high value (>0.5). With time, the major presence of refractory compounds (mainly humic and fulvic acids) tends to limit process effectiveness.

I) Aerobic Digestion:

Aerobic digestion is the decomposition of organic matter such as sewage sludge by microorganisms in the presence of oxygen. The bacteria convert the organic matter it into carbon dioxide and water. The action of the microorganisms stabilizes the sludge and when there is no more organic material then microorganisms die. New effluent limits and new techniques that control the aerobic digestion process and accurately predict the performance of the system have made aerobic digest an attractive option. Used primarily as a process for the treatment of wastewater sludge, the capital costs of aerobic digestion plants are much lower than anaerobic digestion since it proceeds more quickly and tanks need not be as large. However, aerobic digestion does have higher operating costs as energy is required for aeration, the addition of oxygen, to the process.

Advantages

- Reduces volume and mass of sludge
- Reduces pathogens
- Lower capital investment
- Simpler to operate

II) Anaerobic digestion

Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen, used for industrial or domestic purposes to manage waste and/or to release energy. It is used as part of the process to treat wastewater. As part of an integrated waste management system, anaerobic digestion reduces the emission of landfill gas into the atmosphere. Anaerobic digestion is widely used as a renewable energy source because the process produces a methane and carbon dioxide rich biogas suitable for energy production, helping to replace fossil fuels. The nutrient-rich digestate which is also produced can be used as fertilizer.

There are four key biological and chemical stages of anaerobic digestion:

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

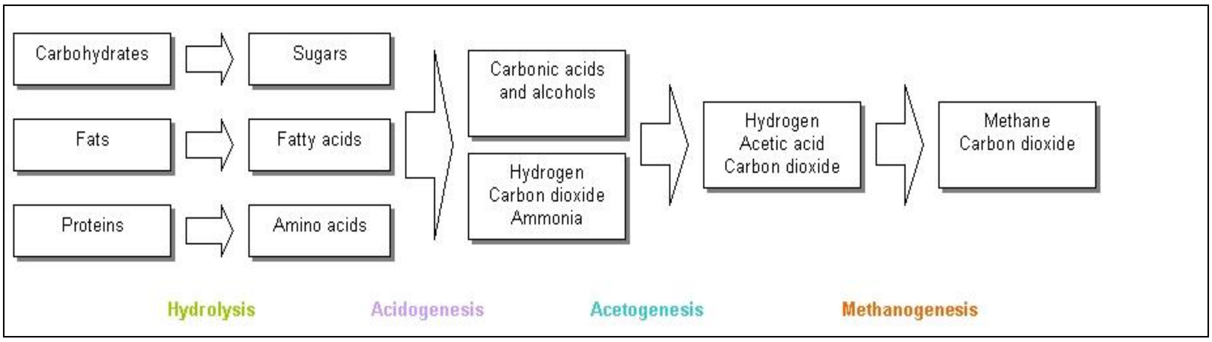


Fig 2.1: Process steps of anaerobic digestion

Hydrolysis

During hydrolysis, bacteria transform the particulate organic substrate into liquefied monomers and polymers i.e. proteins, carbohydrates and fats are transformed to amino acids, monosaccharides and fatty acids respectively. Equation 1 shows an example of a hydrolysis reaction where organic waste is broken down into a simple sugar, in this case, glucose (Ostrem, 2004).

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2 \quad \text{.......................................Eq. (1)}$$

Acidogenesis

In the second stage, acidogenic bacteria transform the products of the first reaction into short chain volatile acids, ketones, alcohols, hydrogen and carbon dioxide. The principal acidogenesis stage products are propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), acetic acid (CH_3COOH), formic acid ($HCOOH$), lactic acid ($C_3H_6O_3$), ethanol (C_2H_5OH) and methanol (CH_3OH), among other. From these products, the hydrogen, carbon dioxide and acetic acid will skip the third stage, acetogenesis, and be utilized directly by the methanogenic bacteria in the final stage Equations 2, 3 (Ostrem, 2004) and 4 (Bilitewski *et al*., 1997) represent three typical acidogenesis reactions where glucose is converted to ethanol, propionate and acetic acid, respectively.

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \quad \text{.......................................Eq.(2)}$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \quad \text{.......................................Eq.(3)}$$

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH \quad \text{.......................................Eq.(4)}$$

Acetogenesis

In the third stage, known as acetogenesis,the rest of the acidogenesis products, i.e. the propionic acid, butyric acid and alcohols are transformed by acetogenic bacteria into hydrogen, carbon dioxide and acetic acid. Hydrogen plays an important intermediary role in this process, as the reaction will only occur if the hydrogen partial pressure is low enough to thermodynamically allow the conversion of all the acids. Such lowering of the partial pressure is carried out by hydrogen scavenging bacteria, thus the hydrogen concentration of a digester is an indicator of its health (Mata-Alvarez, 2003). Equation 5 represents the conversion of propionate to acetate, only achievable at low hydrogen pressure. Glucose (Equation 6) and ethanol (Equation 7) among others are also converted to acetate during the third stage of anaerobic fermentation (Ostrem, 2004).

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2 \quad \text{.......................................Eq.(5)}$$

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad \text{.......................................Eq.(6)}$$

$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+$ ....Eq.(7)

Methanogenesis

The fourth and final stage is called methanogenesis. During this stage, microorganisms convert the hydrogen and acetic acid formed by the acid formers to methane gas and carbon dioxide (Verma, 2002). The bacteria responsible for this conversion are called methanogens and are strict anaerobes. Waste stabilization is accomplished when methane gas and carbon dioxide are produced.

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ ....Eq.(8)

$2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH$ ....Eq.(9)

$CH_3COOH \rightarrow CH_4 + CO_2$ ....Eq.(10)

Conditions and variables influencing Anaerobic Digestion

1.) Total solid content
2.) Temperature
3.) Retention time
4.) pH
5.) Carbon to Nitrogen ratio (C : N)
6.) Mixing
7.) Organic loading rate (OLR) / Volatile Solids (VS)

By Products of Anaerobic Digestion

There are three principal products of anaerobic digestion: Biogas, Digestate, and Treated effluent

- **Biogas**

  Biogas, a gaseous mixture comprising mostly of methane and carbon dioxide, but also containing a small amount hydrogen and occasionally trace levels of hydrogen sulphide. Biogas can be burned to produce electricity, usually with a reciprocating engine or micro turbine. The gas is often used in a cogeneration arrangement, to generate electricity and use waste heat to warm the digesters or to heat buildings. Excess electricity can be sold to electricity suppliers. Electricity produced by anaerobic digesters is considered to be green energy and may attract subsidies such as Renewable Obligation Certificates (ROC).

Since the gas is not released directly into the atmosphere and the carbon dioxide comes from an organic source with a short carbon cycle biogas does not contribute to increasing atmospheric carbon dioxide concentrations; because of this, it is considered to be an environmentally friendly energy source. The production of biogas is not a steady stream; it is highest during the middle of the reaction. In the early stages of the reaction, little gas is produced because the number of bacteria is still small in size. Toward the end of the reaction, only the hardest to digest materials remain, leading to a decrease in the amount of biogas produced.

Typical composition of Biogas

Table 2.1: Composition of Biogas

Matter	%
Methane ,CH_4	50-75
Carbon dioxide, CO_2	25-50
Nitrogen, N_2	0-10
Hydrogen,H_2	0-1
Hydrogen sulphide, H_2S	0-3
Oxygen, O_2	0-2

- **Digestate**

Acidogenic digestate

It is a stable organic material comprised largely of lignin and chitin. There is also of a variety of mineral components in a matrix of dead bacterial cells, some plastic may be present. This resembles domestic compost and can be used as compost or to make low grade building products such as fibre board.

Methanogenic digestate

It is a liquid (methanogenic digestate) rich in nutrients and can be an excellent fertilizer dependent on the quality of the material being digested. If the digested materials include low levels of toxic heavy metals or synthetic organic materials such as pesticides or PCBs, the effect of digestion is to significantly concentrate such materials in the digester liquor. In such cases further treatment will be required in order to dispose of this liquid properly. In extreme cases, the disposal costs and the environmental risks posed by such materials can offset any environmental gains provided by the use of biogas. This is a significant risk when treating sewage from industrialized catchments.

- **Treated Effluent**

The final output from anaerobic digestion systems was treated effluent. This water originates both from the moisture content of the original waste that was treated but also includes water produced during the microbial reactions in the digestion systems. This water may be released from the dewatering of the digestate or may be implicitly separate from the digestate.

Nearly all digestion plants have ancillary processes to treat and manage all of the by-products. The gas stream is dried and sometimes sweetened before storage and use. The sludge liquor mixture has to be separated by one of a variety of ways, the most common of which is filtration. Excess water is also sometimes treated in sequencing batch reactors (SBR) for discharge into sewers or for irrigation. Digestion can be either wet or dry. Dry digestion refers to mixtures which have a solid content of 30% or greater, whereas wet digestion refers to mixtures of 15% or less.

BIOLOGICAL TREATMENTS - Aerobic and Anaerobic treatment

AEROBIC TREATMENT

An Aerobic Treatment should allow a partial abatement of biodegradable organic pollutants and should also achieve the ammonium nitrogen nitrification. Aerobic biological processes based on suspended-growth biomass, such as aerated lagoons, conventional activated sludge processes and sequencing batch reactors (SBR), have been widely studied and adopted [X.Z.li (2001),S.H.Lin (2000),B.Bae (1999)]. Attached-growth systems have recently attracted major interest: the moving-bed bio film reactor (MBBR) and biofilters. The combination of membrane separation technology and aerobic bioreactors, most commonly called membrane bioreactor.

➢ **Suspended-growth biomass processes**

- ***Lagooning***

  Aerated lagoons have generally been viewed as an effective and low-cost method for removing pathogens, organic and inorganic matters. Their low operation and maintenance costs have made them a popular choice for wastewater treatment, particularly in developing countries since there is a little need for specialised skills to run the system (H.E.Maynard,1999]. Orupold *et al*., [2000] studied the feasibility of lagooning to treat phenolic compounds as well as organic matter. [R.Zaloum,1997] claimed that the temperature dependence of lagooning is a significant limitation because it mainly affects microbial activity.

- ***Activated sludge process***

  They are extensively applied for the treatment of domestic wastewater or for the co treatment of leachate and sewage. However, this method has been shown in the more recent decades to be inadequate for handling landfill leachate treatment [C.Y.Lin,2000]. Even if processes were proved to be effective for the removal of organic carbon, nutrients and ammonia content, too much disadvantages tend to focus on others technologies:

  - Inadequate sludge settleability and the need for longer aeration times [M.X. Loukidou et al, 2001].
  - High energy demand and excess sludge production [T.H. Hoilijoki et al, 2000],
  - Microbial inhibition due to high ammonium-nitrogen strength [J.M. Lema.et.al (1988)].

Consequently, only few works are recently available concerning landfill leachate treatment by activated sludge methods. Hoilijoki *et al*.,(2000) investigated nitrification of anaerobically pre-treated municipal landfill leachate in lab-scale activated sludge reactor, at different temperatures (5–10°C) and with the addition of plastic carrier material. Aerobic post treatment produced effluent with 150–500 mg COD/L, less than 7 mg BOD/L and on an average, less than 13 $mgNH_4$ +- N/L. Addition of PAC to activated sludge reactors enhanced nitrification efficiency on biological treatment of landfill leachate (O. Aktas et al., 2001).

- ***Sequencing batch reactor***

This system is ideally suited to nitrification–denitrification processes since it provides an operation regime compatible with concurrent organic carbon oxidation and nitrification [Diamadopoulos *et al.*, 1997]. Process characteristics, summarized by Diamadopoulos et al. [1997] and Dollerer and Wilderer [1996], resulted in a wide application for landfill leachate treatment [A.Ugyor *et al*.,(2004), M.Hosami *et al*., (1989)]. Many authors have reported COD removals up to 75%. Also, 99%NH4 +- N removal has been observed by Lo.et al (1996) during the aerobic treatment of domestic leachate in a SBR with a 20–40 days residence time. The greater process flexibility of SBR is particularly important when considering landfill leachate treatment, which have a high degree of variability in quality and quantity [K.J. Kennedy (2000)].

➢ ***Attached-growth biomass systems***

Due to main problems of sludge bulking or inadequate separability [Dolloror et al, 1994] in conventional aerobic systems, a number of innovative aerobic processes, called attached-growth biomass systems, using bio film, have been recently developed. These systems present the advantage of not suffer from loss of active biomass. Also nitrification is less affected by low temperatures [Knox et al, 1985] than in suspended-growth systems, and by inhibition due to high nitrogen content.

- ***Trickling filters (TF)***

This method has been investigated for the biological nitrogen lowering from municipal landfill leachate. Biofilters remain an interesting and attractive option for nitrification due to low-cost filter media [Jokela et al,2002].In a recent work, above 90% nitrification of leachate was achieved in laboratory and on-site pilot aerobic crushed brick filters with loading rates between 100 and 130 mgNH4 +-N L−1 day−1 at 25 ◦C and 50 mgNH4 +-N/ L/day even at temperatures as low as 5–10 ◦C, respectively [Jokela,2002]. In the last decade, maximum ammonia rejection of 97 and 75% in a trickling filter were, respectively, claimed by Knox and Jones (1985) and Martienssen and Schops (1997).

- ***Moving-bed biofilm reactor (MBBR) (or suspended-carrier biofilm reactor (SCBR) or fluidized bed reactor)***

MBBR process is based on the use of suspended porous polymeric carriers, kept in continuous movement in the aeration tank, while the active biomass grows as a biofilm on the surfaces of them. Mains advantages of this method compared to conventional suspended-growth processes seems to be: higher biomass concentrations, no long sludge-settling periods, lower sensitivity to toxic compounds [Laukidous *et al*.,2001] and both organic and high ammonia removals in a single process [Horan and Gohar .,1997]. For instance, Welander et al. [1998] reported nearly 90% nitrogen removal while the COD was around 20%. In case of treating high strength ammonia leachate, no inhibition of nitrification is encountered [Welander *et al.,* 1997]. Moreover, the use of granular activated carbon (GAC) as porous material offers an appropriate surface to adsorb organic matter and optimised conditions for enhanced biodegradation [Horan *et al* .,1997]. Imai *et al*., [1998] developed an efficient biological activated carbon fluidized bed process. Nearly, 70% refractory organics were removed by coupling biological treatment and adsorption process. After optimising the reactor operating regime, Horan *et al*.,[1997] and Loukidou and Zouboulis [2001] proved possible to reach 85–90% ammonia reduction and 60–81% COD reduction.

ANAEROBIC TREATMENT

An anaerobic treatment of leachate allows to end the process initiated in the tip, being thus particularly suitable for dealing with high strength organic effluents, such as leachate streams from young tips [Pokhrel *et al.,* 2004]. Contrary to aerobic processes, anaerobic digestion conserves energy and produces very few solids, but suffers from low reaction rates [Berrueta *et al*., 1992]. Moreover, it is possible to use the CH_4 produced to warm the digester that usually works at 35°C and, under favourable conditions, for external purposes.

➢ ***Attached-growth biomass processes***

- ***Anaerobic filter***

The anaerobic filter is a high rate system that gathers the advantages of other anaerobic systems and that minimizes the disadvantages. In an up-flow anaerobic filter, biomass is retained as bio films on support material, such as plastic rings (Nedwell, 1996). For instance, Henry *et al*., (1987) demonstrated that anaerobic filter could reduce the COD by 90%, at loading rates varying from 1.26 to 1.45 kgCOD/m^3/day, and this for different ages of landfill. Total biogas production ranged between 400 and 500 L gas /kg COD destroyed and methane content between 75 and 85%.

- ***Hybrid bed filter***

It consists on an up-flow sludge blanket at the bottom and an anaerobic filter on top. This device acts as a gas–solid separator and enhances solid's retention without causing channelling or short-circuiting (Timur *et al*., 1997). Enhanced performances of such a process results from maximization of the biomass concentration in the reactor. Nedwell and Reynolds [1996] reported steady-state COD removal efficiencies of 81–97% under methanogenic digestion, depending upon organic loading rate. One drawback of hybrid reactor, as well as anaerobic filter, is the added cost of the support media.

- ***Fluidized bed reactor***

Suidan *et al*.,(1993) and Imai *et al*.,(1998) reported studies on carbon-assisted fluidized beds. The combined biodegradation and adsorption process provide a means for removing a variety of organic compounds. Imai *et al*. [1998] found that the biological activated carbon fluidized bed process was much more effective for treating old leachate than the conventional one such as activated sludge and fixed film processes.

- ***Suspended-growth biomass processes***

Digester

Performances of conventional anaerobic suspended growth digester are reported . Typical values of 80–90% and nearly 55% COD removals were reached in anaerobic lab-scale tank at 35 ^{o}C and ambient temperature, respectively (Bull *et al*.,1983).

- ***Sequencing batch reactor***

These systems are able to achieve solid capture and organic lowering in one vessel, eliminating the need for a clarifier. Recently, nutrient reduction from pre-treated leachate was carried out using a lab-scale SBR by Uygur and Kargi [2004]. Sequential anaerobic–aerobic operations resulted in COD, NH_4+-N and PO_4−-P removal of 62%, 31% and 19%, respectively, at the end of cycle time (21 h). Also, in the initial period of the landfill, sufficient organic abatement in the anaerobic reactor through methanogenesis and denitrification can enhance better nitrification in the following aerobic reactor. Therefore, anaerobic–aerobic system is recommended to bring down simultaneously organic and nitrogen matter [Marteinssen *et al* 1997,Skishoswski *et al*.,1998] For instance, Kettunen and Rintala [1995] showed that COD removal was 35% in the anaerobic stage while in the combined process the COD and BOD_7 removals were up to 75% and 99%.

In last decades, the performance improvement of the existing anaerobic process was believed to be a promising option and so, high rate reactors have been designed in order to reduce long digestion time [Lin *et al*., 2000].

- ***Up-flow anaerobic sludge blanket (UASB) reactor***

UASB process is a modern anaerobic treatment that can have high treatment efficiency and a short hydraulic retention time [Lin *et al*, 2000]. UASB reactors, when they are submitted to high volumetric organic loading rate values [Garsia, 1996], have exhibited higher performances compared to other kinds of anaerobic reactors. The process temperatures reported have generally been 20–35 ◦C for anaerobic treatment with UASB reactors. In these conditions, the average performance of COD decrease efficiency (Table 9) was always higher than 70% at ambient temperature (20–23 ◦C) and 80% at 35 ◦C. Up to 92% COD decreases were obtained by Kennedy and Lentz [2000] at low and intermediate organic loading rates (between 6 and 19.7 gCOD/L/ day). Only a few studies have been conducted at temperatures between 11 and 23 ◦C [Kettunen *et al*,1998] although leachate may be cooler than that, especially in cold countries. Kettunen and Rintala (1998) showed that leachate can be treated on-site UASB reactor at low temperature. A pilot-scale reactor was used to study municipal landfill leachate treatment (COD 1.5–3.2 g/L) at 13–23 ◦C. COD (65–75%) and BOD_7 (up to 95%) removals were achieved at organic loading rates of 2–4 kg $CODm^{3/}$day. Garcia *et al*. (1996) concluded that COD rejection efficiency was not affected by temperature between 15 and 35 ◦C. These promising results show that high-rate treatment at low temperature may minimise the need for heating the leachate prior to treatment, which may thus provide an interesting cost-effective option . The main disadvantages of such a treatment stay sensitivity to toxic substances [sung sung *et al.*,1997].

Over the years, different authors have studied anaerobic treatment of landfill leachate. Kennedy *et al*., (1988) studied the treatment of leachate in an Upflow Anaerobic Sludge Blanket Reactor (UASB), obtaining COD removals of 88% for an Organic Loading Rate (OLR) of 44 kg COD/m^3 d and a Hydraulic Residence Time (HRT) of 10 h. Chang (1988) treated municipal leachate with very high COD (58.4 g/L), likewise in a UASB reactor, obtaining COD removals of 82–93% for OLR < 13 kg COD/m3 d and of 68% when increasing the OLR to 22 kg COD/m^3 d. Garcia et al. (1996) studied the anaerobic treatment of leachate generated at the Meruelo landfill site in Cantabria, Spain, using a laboratory scale UASB reactor operating at 35̊C and at ambient temperature (15–20 _C). Average COD removal was always higher than 82%, operating at OLR 630 kg COD/m3 /d at mesophilic temperature and at OLR 615 kg COD/m3/d at ambient temperatures. HRT were lower than 1 day. Kettunen and Rintala (1998) studied the anaerobic treatment of landfill leachate at low temperatures (13–23ᴼC) using a pilot-scale UASB reactor. The landfill leachate had a COD of 1.7–3.1 g/L and a BOD7 of 1.2–1.9 g/L, obtaining 60–74% COD removals and up to 95% BOD7 removals for OLR of 1.5–3.3 kg COD/m3 d.

Anaerobic treatment of leachate was also applied to the leachate generated at the Central Landfill of Asturias in a UASB at 35ᴼ C (Berrueta and Castrillón, 1992) **(Table**

2.2). The UASB was chosen as it has proven to be a high efficiency process and has been applied to the treatment of a broad range of organic wastewater with different COD concentrations under a wide range of conditions (Lettinga *et al*., 1984). The performance of the digesters was strongly affected by the composition of the leachate. Very good biodegradation of organic matter was obtained when treating leachate with COD between 11,000 and 16,500 mg/L (88% COD removal for HRT of 2.5 days), with biogas production close to the theoretical value of 0.35 m3 methane/kg COD removal. The performance of the reactor was not so good when treating leachate with lower COD (46% COD removal for similar HRT). Pre treatment with lime was carried out prior to the anaerobic process with the aim of determining the effect of the ammonium nitrogen content in the anaerobic treatment (Berrueta and Castrillón, 1997). **Table 2.3** compares the results obtained when feeding the reactor with untreated leachate and with pre treated leachate. Both leachate presented similar COD and the reactors operated at the same HRT (1.6 days). As can be seen, despite the fact that the content in ammonium nitrogen of the influent is very different (as a consequence of the pre-treatment), COD removal efficiency and the volume of biogas produced are similar in both.

Table 2.2: Results of anaerobic treatment of landfill leachate in a UASB reactor at 35^{o}C

HRT (days)	OLR (kg COD/m3d)	COD(mg/L) Influent	COD(mg/L) Effluent	COD removal(%)	Vgas (m3/kg COD)	CH4 (%)
Leachate with high COD						
1.4	7.8	11264	3005	73.3	0.34	85
1.6	7.5	11939	2440	79.5	0.38	85
1.8	7.3	13420	2069	84.5	0.38	86
2.4	8.8	16394	1940	88.2	0.34	87
Leachate with low COD						
2.6	21	5498	2972	46.0	0.11	-
5.1	1.2	6131	2533	58.7	0.13	-
5.1	0.85	4376	1919	56.1	0.30	85.5
12	0.3	3553	1331	62.5	0.45	81

Table 2.3: Results of anaerobic treatment (UASB, HRT 1.6days) applied to untreated leachate and to leachate pretreated with calcium hydroxide.

	COD influent (mg/L)	COD effluent (mg/L)	COD removal (%)	Vgas (m3/kg CODremoved)
Raw Leachate	11939	2440	79.5	0.38
Pretreated Leachate	11247	2205	80	0.33

Table 2.4: Performance data of different reactors in context of leachate treatment.

	1		2		3		4		5	
Name of Reactor →	**CSTR Digester**		**UASB**		**UA Fix Bed reactor**		**Semi-continuous reactor**		**UASB**	
References →	Chiu-Yue Lin 1999,		Hipolito Garcia (1996)		Olfa Ben Dhia (2009)		Satoto E. Nayono (2010)		Ruo He (2005)	
Parameters ↓										
Volume (L)	4		3.5		2		10		5.5	
HRT days	5.3 (SRT)		1		5		7.7			
OLR	315 g COD/mday		30 kgCOD/m3d				27.7 kgCOD/m3d			
	Inlet	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
pH	7.2	ND	7.5	8.1	6.4	ND	4.3	ND	ND	ND
Temperature (°C)	35	ND	35	ND	37	ND	37	ND	30	ND
COD mg/l	ND	ND	3200	400	43 g/l	ND	213 g/l	ND	38734	ND
COD red %	ND	ND	ND	ND	91	ND	75	ND	90	ND
COD Soluble	725	86%	ND	ND	30.2 g/l	ND	100 g/l	ND	ND	ND
TS mg/l	26992	ND	ND	ND	28.5 g/l	ND	168 g/l	ND	87.7 g/l	ND
TSS mg/l	ND	ND	ND	ND	8.5 g/l	ND	ND	ND	ND	ND
TDS mg/l	ND	ND	ND	ND	20 g/l	ND	ND	ND	ND	ND
TVS mg/l	11534	28%	ND	ND	ND	ND	117 g/l	ND	ND	ND
TVS red %	ND	ND	ND	ND	ND	ND	ND	ND	ND	27 g/l
NH3-N (mg/l)	103	2.8 g/m3d	ND	ND	ND	ND	0.72	ND	1457	ND
Biogas	ND	759 ml/d	ND	ND	ND	ND	ND	ND	ND	ND
Methane	ND		0.24 m3/kgCOD Rem		ND		686 m3/ ton VS d		ND	
Methane %		59	ND	ND	ND	ND	ND	67.6	ND	70
Alkalinity mg/l	3555	ND	ND	ND	ND	ND	ND	ND	ND	ND
TVA	257	ND	ND	ND	ND	ND	ND	ND	19560	ND

	6		7		8		9		10		11	
Name of Reactor →	**Granular sludgebed reactor**		**Anaerobic filter**		**UASB**		**Moving bed Biofilm Reactor**		**Anaerobic Membrane Biofilter**		**Combined Stripping ,Fenton, SBR**	
References →	Jianyong Liu (2010)		Z. Wang (2007)		R. H. Kettunen (1996)		Sheng Chen (2008)		Amal Zayen (2010)		Jin Song et.al(2010)	
Parameters ↓												
Volume (L)	6		4		0.38		4.2		50			
HRT days	2.8		3		10		1		7		5	
OLR	28.73 kg COD/m3 day		7.63 kg COD/m3 day		10 kgCOD/m3d		7.6 kgCOD/m3 d		6.27 g/COD/Lday			
	Inlet	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
pH	5.6	ND	8.7	6.94	7.2	7.1	6.8	ND	7.3	ND	7.9-8.4	ND
Temperature (°C)	35	ND	35	ND	37	ND	ND	ND	37	ND	ND	ND
COD mg/l	65000	ND	9892	ND	4300	ND	7665	578	41000	ND	3000-4500	280
COD red %	90	ND	57.7	ND	71	ND	92	ND	90.7	ND	ND	93%
COD Soluble	26228	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND
BOD	ND	ND	ND	ND	2800	79%	2900	ND	14662	ND	374-824	113.5
TS mg/l	15961	80%	2974	ND	ND	ND	ND	ND	ND	ND	ND	ND
TSS mg/l	ND	ND	ND	ND	ND	ND	375	ND	1109	ND	812-976	ND
TDS mg/l	ND	ND	263.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
TVS mg/l	ND	ND	ND	ND	9700	ND	ND	ND	3000	ND	ND	ND
TVS red %	231	ND	722	ND	ND	ND	ND	ND	ND	ND	ND	ND
NH3-N (mg/l)	11 L/d	ND	ND	ND	ND	ND	210	95%	ND	ND	1000-1750	20
Biogas	ND	ND	1855 ml/d	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methane	6.0 l (STP)/l day		0.081m3/kgCOD		320 ml CH4/ g COD rem		ND		0.46 L/gm		ND	
Methane %	ND	75	ND	ND	ND	ND	65	ND	ND	ND	ND	ND
Alkalinity	ND	ND	1590	ND	ND	ND	ND	ND	ND	ND	ND	ND
TVA	ND	ND	ND	ND	ND	ND	1270	ND	5470	ND	384-782	ND

	12		13		14		15		16		17	
Name of Reactor →	**UASB**		**RBC +UASB**		**Denitrifying Reactor**		**UASB + MBR**		**Thermophilic Batch Membrane Reactor**		**UASB and CSTR**	
References →	R.H. Kettunen, (1998)		Castillo.et.al (2007)		Huo.Shon Liang (2007)		Hua.Jia (2009)		Chowdhary .M (2005)		Osman Nuri (2004)	
Parameters ↓												
Volume (L)	9 m3		20		31.4		10.1		6		2.5,91	
HRT days	1		24		6				24		4.5	
OLR	5 g/COD/Lday		3273g/COD/m3/d						7.15-8.45 KgBODm3/day		4.3-16 kg COD/m3/day	
	Inlet	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
pH	5.15	ND	8.3	ND	6.8	7.7	5.15	7.15	6.3	ND	6.9	7.4
Temperature (°C)	35	ND	ND	ND	33±2˚C	ND	ND	ND	40-50°C	ND	37-42°C	ND
COD mg/l	59500	ND	14000	ND	57300	5940	59500	350	12000	ND	12000	2000
COD red %	80	ND	ND	52%	ND	ND	ND	40-80%	ND	62-79%	ND	89%
COD Soluble	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BOD	ND	95% rem	7782	ND	ND	ND	27500	600	ND	ND	ND	ND
TS mg/l	60132	82% rem	16230	85%rem	ND	ND	ND	ND	ND	ND	ND	ND
TSS mg/l	ND	ND	ND	"	ND	ND	2500	170	ND	ND	ND	ND
TDS mg/l	ND	ND	ND	"	ND	ND	ND	ND	18900	ND	ND	ND
TVS mg/l	10833	ND	7264	ND	ND	ND	ND	ND	ND	ND	ND	ND
TVS red %	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NH3-N (mg/l)	1090	ND	ND	9	ND	90% removal	1090	25	1700	ND	258-679	99.6%rem
Biogas	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND
Methane	ND		0.29-0.38 m3 CH4/COD removal		ND		ND		ND		ND	
Methane %	75.50%	ND	ND	50-80%	ND	40%	ND	ND	ND	ND	64%	ND
Alkalinity mg/l	ND	ND	ND	6210	ND	ND	ND	ND	ND	ND	ND	ND
TVA	11500	ND	ND	ND	15100	ND	11500	ND	ND	ND	2200	ND

CHAPTER-3

MATERIALS AND METHODS

MATERIAL AND METHODS

3.1 Experimental set up

3.1.1 Reactor set up

A laboratory scale reactor of total volume of 24 L was used. The reactor was made of cylindrical column of fibre plastic. The effective volume of reactor was maintained at 24 L. The reactor was provided with suitable arrangements for feeding, gas collection and draining of residues. The reactor was operated at ambient temperature. Daily gas production was measured using water displacement method.

3.1.2 Feed Stock (Leachate)

MSW landfill leachate was chosen as a substrate in experiment. For which Municipal solid waste was collected from dumping site of NEERI into large drums and add hot water into it. Allow it to leach out. Then the leachate samples were collected from the lower port of container which is used as feed to the reactor. Leachate collection and sampling shown in **Fig 3.1 .**The characteristics of leachate and cow dung slurry are shown in **Table 4.1** and **4.2**

The basic characteristics of cow dung slurry were estimated and then that it is feeded firstly to the reactor in start up phase. The reactor was operated at ambient temperature**.**

Fig 3.1: Collection and sampling of leachate

3.1.3 Reactor design

Design of reactor shown in **Fig 3.2**

1. Pressure drops due to sudden contraction and expansion in the organic matter present inside the reactor. Also eddies formation create sufficient turbulence to help in retaining the solid mass in suspension by preventing settling of particles.

2. The upflow pattern of liquid in the upflow column reactor help in the stratification of individual type of biomass such as hydrolytic, acidogenic biomass and methanogenic biomass. In other words, the partial phase segregation can be made possible by maintaining up flow pattern of column reactor. The liquid flow velocity should be maintained in such a way that the possible phase segregation should not be disrupted due to complete mixing of reactor content. Hence, the flow pattern should be between laminar to turbulent, preferably in a laminar flow range.

3. The density difference of water/liquid and biomass/solids creates the velocity difference at the same pumping energy due to difference in densities and viscosities. The difference in viscosities may help in maintaining the content in suspension in the column.

4. Although the clarified liquid is desired to be treated as effluent, it may not be possible. To have this, a separate settler may be provided.

5. The clarified effluent may be consumed/ recycled for slurry preparation and the settled sludge may be considered as compost.

6. The biogas production has its own benefits to make the treatment more cost effective.

3.1.4 Aims of column reactor study

1. Increase in the solid content of sludge.

2. Methane production.

3. Optimization of operational parameters.

4. Water recovery (treated effluent) from leachate and recycling it.

5. Control the economics of the process.

3.1.5 Reactor Dimensions

Table 3.1: Dimensions of the Reactor

Height of reactor	Approx. 6 feet
Diameter of pipes used	20 mm, 10mm
Volume of reactor	24 litres
Diameter of reactor	23 cm

3.2 Method

The anaerobic treatment process of leachate follows following steps.

A. Preparation of inoculums (cow dung slurry)

B. Start up of reactor

C. Operation of reactor

A. Preparation of inoculum

Cow dung was collected and brought to the laboratory. After this approximately 300g cow dung was mixed with 3 Litre of water. In the same ratio we mix cow dung with around 20 litres of water. The cow dung solution was then sieved with a cotton cloth. It is important to repeat sieving two to three times to get quality slurry and to remove larger particles. This cow dung slurry was stored in capped bottle for maintaining anaerobic condition. Cow's rumen contains millions of methanogenic bacteria; therefore cow dung was selected as a source of methanogenic bacteria. Methanogens have slow growth rate and faster decay rate. So bacteria those are present in cow dung slurry take time to develop. It is also important to maintain cow dung slurry under anaerobic condition.

B. Start up of reactor

After 20 days ,nearly 12 litres of cow dung slurry mixed with 12 litres secondary sludge of treatment plant in 50:50 ratio and inoculated to the reactor (as the reactor volume is 24 L). Then left for stabilization (there should be development of sufficient microbial population) by recirculation process. After stabilization period, the slurry turned blackish in colour and the reactor was ready for the operation.

C. Operation of reactor

After stabilization, the reactor was fed with leachate at HRT of 3 days. The HRT can be determined on the basis of total volume of reactor. Hydraulic Retention Time can be defined as the time needed to achieve the complete degradation of organic matter. It is generally expressed in Days. HRT is calculated by using formula.

$$HRT = V/Q$$

Where, HRT = Hydraulic retention time

V = Volume of the reactor

Q = Flow rate

A peristaltic pump was connected to the reactor for recirculation. Direction of recirculation could be changed according to the requirement. Peristaltic pump pumped leachate from bottom to top and then again back to bottom of reactor. A bottle (filled with ammonium hydroxide solution) was connected to the reactor for collection of biogas. Liquid displacement method was used to calculate amount of methane produced as shown in **Fig 3.3.**

In this way operation study was carried out at HRT of 3 days in different treatment processes i.e. Batch process, Semi-continuous process and continuous process.

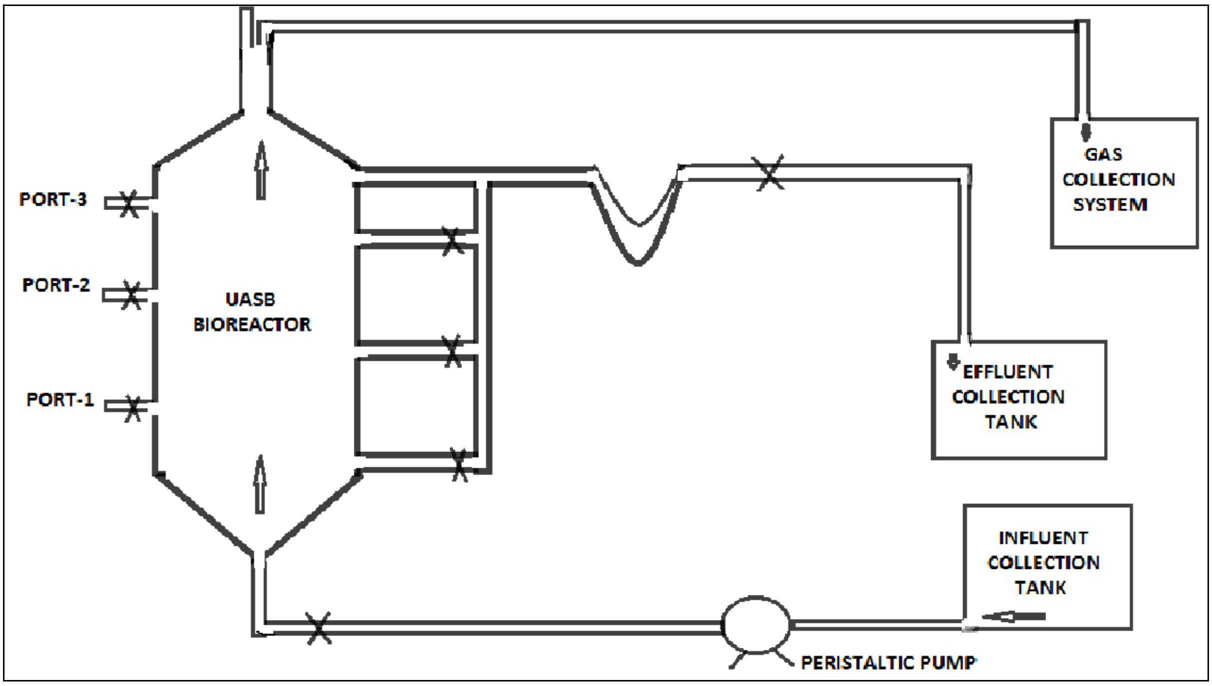


Fig 3.2: Reactor set-up of laboratory scale reactor for treatment of MSW leachate.

Fig 3.3: Liquid displacement method for biogas (ml) measurement.

3.3 Procedures for determination of parameters

The physic-chemical characteristics of the influent and effluent are determined as per **Standards Methods, APHA, 1995**.

3.3.1 pH

For most practical purposes , the pH of aqueous solutions can be taken as negative logarithm of hydrogen in activity .pH values from 0 to 7 are diminishingly acidic. 7 to 14 increasing alkaline and 7 are neutral.

3.3.2 Alkalinity

Alkalinity of samples are determined as per standard methods.APHA,1995

3.3.3 Chemical oxygen demand(COD)

COD can be done by open reflux method as per standard methods,APHA.

3.3.4 Total Volatile solids (TVAs)

TVA can be done by Distillation method as per standard methods,APHA.

3.3.5 Total Solids, Suspended Solids and Volatile solids

TS,SS can be done by Filtration Method as per standard methods APHA.

3.3.6 Estimation of Sodium (Na) and Potassium (K)

Sodium and Potassium can be estimated by Flame photometer method

3.3.7 Estimation of Phosphate

Phosphate can be estimated by Turbidimetric method (UV spectrophotometer) as per standard methods, APHA.

3.3.8 Estimation of sulphate

Sulphate can be estimated by Turbidimetric method (UV spectrophotometer) as per standard methods, APHA.

3.3.9 Estimation of Nitrate

Nitrate can be estimated by Turbidimetric method (UV spectrophotometer) as per standard methods, APHA**.**

3.3.10 Estimation of Heavy metals

Digestion can be done as per APHA .then heavy metal estimation done by ICP (Inductively Coupled Plasma) method.

Principle

An ICP source consists of a flowing stream of argon gas ionized by an applied radio frequency field typically oscillating at 27.1 MHz. This field is inductively coupled to the ionized gas by a water cooled coil surrounded a quartz “torch” that supports and confines the plasma. A sample aerosol is generated in an appropriate nebulizer and spray chamber and is carried into plasma through an injector tube located within the torch. The sample aerosol is injected directly into the ICP, to 8000 K. The high temperature of plasma excites atomic emission efficiency. Ionization of high percentage of atoms produces ionic emission spectra. The ICP provides an optically “thin” source that is not subject to self-absorbance except at very high concentrations. Thus linear dynamic ranges of four to six orders of magnitude are observed for many elements.

The efficient excitation provided by the ICP results in low detection limits for many elements. This, coupled with the extended dynamic range, permits effective multielement determination of metals. The light emitted from the ICP is focused onto the entrance slit of either a monochromator that effects dispersion. A precisely aligned exit slit is used to isolate a portion of the emission spectrum for intensity measurement using a photomultiplier tube. The monochromator uses a single exit slit/photomultiplier and may use a computer-controlled scanning mechanism to examine emission wavelengths sequentially. The polychromator uses multifixed slits and corresponding photomultiplier tubes; it simultaneously monitors all confrigurated wavelengths using a computer- controlled readout system. The sequential approach provides greater wavelength selection while the simultaneous approach can provide greater sample throughout.

Apparatus

ICP source: The ICP source consists of a radio frequency (RF) generator capable of generating at least 1.1 KW of power , torch, tesla coil, load coil, impedance matching network, nebulizer, spray chamber and drain. High quality flow regulators are required for both nebulizer argon and the plasma support gas flow. A peristaltic pump is recommended to regulate sample flow to nebulizer. The type of nebulizer and spray chamber used may depend on the samples to be analyzed as well as on equipment manufacturer.

Spectrophotometer: The spectrometer may be of the simultaneous (polychromator)or sequential (monochromator) type with air- path, inert gas purged, or vacuum optics. A spectral bandpass of 0.05 nm or less is required. The instrument should permit examination of the spectral background surrounding the emission lines used for metals determination. It is necessary to be able to measure and correct for spectral background at one or more positions on either side of the analytical lines.

Microwave digester, sample bottles.

Reagent- Conc. $HNO_{3.}$

Procedure

1. Sample preparation: Take 45 ml sample in digester container. Add 5 ml conc. HNO3.
2. Digest the samples in microwave digester for 20 min acc to the programme.
3. Analyze the samples through ICP process.

CHAPTER-4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

During the experiments, the anaerobic treatment of municipal solid waste leachate was carried out and analysed by different parameters at different processes at HRT of 3 days. Initially the treatment process was carried out at batch process by the reactor, later it was carried at semi-continuous and continuous process respectively.

4.1. Characteristics of Leachate

Table 4.1: Average composition of Municipal solid waste landfill leachate.

Sr .No.	**Parameter**	**Range (mg/L)**
1	pH	5.36 -6.97
2	Alkalinity	140 -1280
3	Total COD	6400 -16000
4	Soluble COD	4000 – 12540
5	BOD:COD	0.1 -0.5
6	TS	1273 – 2560
7	TSS	272 -1612
8	TVS	188 -748
9	Sodium	5.36 – 6.97
10	Potassium	13 – 287
11	Nitrate	0.62 – 8.63
12	Sulphate	105.2 - 633.8
13	Phosphate	1.08 – 40.33

14	Heavy metals -Fe	0.014 – 8.87
15	Cr	0.199 – 0.395
16	Cu	0.032 – 0.124
17	Zn	0.14 - 0.395
18	Pb	0.015 – 0.785
19	Ni	0.126 - 0.268
20	Cd	0.024 - 0.372
21	Co	0.001 - 0.029
22	Mn	0.92 - 1.98
23	TVA	84 – 356

All the values from Alkalinity to TVA are in mg/L except pH.

4.2. Characteristics of inoculum (cow dung slurry)

The inoculum was analysed at the beginning of experiment for parameters like pH, COD, TS, etc.

Table 4.2: The characteristic of cow dung slurry

pH	6.6 - 8.4
Total Solids (mg/L)	6800-17000
Alkalinity (mg/L)	1040-2000
COD (mg/L)	1120-8400

4.3. Evaluation of different biochemical parameters in different treatment processes.

The parameters like pH, COD TVA, Alkalinity, Solids etc were examined daily for both leachate feed as influent and treated effluent of reactor in different treatment processes i.e. Batch, Semi-continuous and Continuous process. The performance data of the reactor for specific processes are reported in **Table 4.3 to 4.18.**

4.3.1. Estimation of pH

The optimum pH for methanogenic microorganism is 7. The reactor shows pH oscillation at start up phase. Two phases (acidic and alkaline) were observed during the test period. At start pH of reactor showed oscillation due to acid formation in acid phase. It is due to CO_2 stripping by air; a decrease in CO_2 leads to decrease in carbonic acid (H_2CO_3) and bicarbonate ion concentration (HCO_3-) consuming H+ ions. The pH range of effluent (outlet) varies from 7.33 to 7.94.the results are supported by literature values. **Figure 4.1, 4.2, 4.3**, shows the pH variation throughout the processes i.e. Batch, Semi-continuous, Continuous respectively, In batch process pH of effluent varies from 7.5-7.7 ,in semi-continuous pH varies from 7.3-7.94 ,in continuous process pH varies from 7.4-7.6 and **Fig.4.4** shows pH profile of reactor throughout the whole process and **Table 4.3** summarizes the values of pH of different days of operation at different processes at HRT of 3 day. Lower pH conditions are unfavourable for anaerobic digestion since low pH conditions provides accumulation of VFAs and consumption of Alkalinity.(Forster et al.,2008).

4.3.2. Estimation of Alkalinity

Alkalinity is the measure of buffering or acid neutralization capacity of digester or reactor. pH and alkalinity are closely linked. If alkalinity drops, pH will also fall. The variation in alkalinity of influent and treated effluent at HRT of 3 days in different treatment processes i.e. Batch, Semi-Continuous and Continuous process are shown in **Fig. 4.6,4.7,4.8,4.9** and **4.10** respectively.

From Fig **4.6**, it was observed that alkalinity of influent fluctuate drastically .These fluctuation could be related with pH or composition of leachate. It varies from 360-1280mg/l and alkalinity of effluent is in the range of 1300-1660 in batch process. so the treatment efficiency of reactor is satisfactory in batch process.

A minimum alkalinity of about 300 mg/l is required to neutralize the acidity of dissolved carbon dioxide gas and to form buffer of within optimum pH range .Higher alkalinities are sometimes helpful, especially during start-up, to neutralize the initial acidity of larger than normal level of Volatile fatty acids, until the contents of reactor age. A major source of alkalinity is ammonical nitrogen which is released by cell lysis (breakdown of cell protein) **(Forster et al.,2008).**

From **Fig 4.7**, it was observed that alkalinity of influent is very low varies from 140-380 mg/l. it is due to high bicarbonates and carbonates present in the influent and alkalinity of treated effluent varies from 900 - 1200 mg/l .and shows stability in treated effluent. Difference between influent and effluent alkalinity is higher so that treatment efficiency of reactor is quite higher in semi continuous than batch and continuous process.

From **Fig 4.8**, it was observed that alkalinity of influent varies from 280 -520 mg/l .and effluent alkalinity varies from 880-980 mg/l. Here the treatment efficiency is quite lower than batch and semi continuous process. So treatment efficiency is poor.

From **Fig 4.9**, it was observed that treatment efficiency is higher in semi-continuous process than batch and continuous process. It is due to increased activity of acidogens .

From **Fig 4.10**, it was observed that alkalinity of the feed is increased as it up flows within the reactor. And alkalinity increases port wise within the reactor from influent to effluent.

4.3.3. Estimation of COD (Chemical Oxygen Demand)

Chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in waste water.

The COD concentration of influent and effluent were examined daily at HRT of 3 day, in different processes i.e., Batch, Semi-continuous and Continuous process. In batch process Influent COD is 6400 mg/L which reduced to 560 mg/L in 3 days and 10400 mg/L which is reduced to 3392 mg/L and the set up runs only for 3 days. The COD concentration shows variation according to the variation in leachate composition. Variations in Total COD conc. for Batch, Semi-continuous and continuous process are shown in **Fig 4.11, 4.12, 4.13, 4.14, 4.15** and **4.16.**

From **Fig 4.11**, it was observed that COD conc. of influent fluctuate drastically from lower conc. 4560 -14400 mg/l. it is due to leachate composition varies with time and COD conc. of treated effluent varies from 560-3784 mg/l. and difference between influent and effluent concentration is quite noticeable in batch process. Batch process treatment is satisfactory for leachate treatment in reactor, because % removal efficiency of leachate in batch is minimum 45% in 5^{th} day and max. 92.36% in 10^{th} day**(Table 4.5).**

From **Fig 4.12**, it was observed that COD conc. varies from 10400-16000 mg/L in influent and treated effluent conc. varies from 488-2016 mg/L so it shows higher COD removal efficiency than Batch (55.18 – 96.60 %).

From **Fig 4.13**, it was observed that COD conc. of influent ranges within 8000-16800 mg/L and effluent varies from 860-1440 mg/l. The minute fluctuations were observed in continuous process. The leachate composition was kept constant to avoid fluctuation in influent conc. The COD concentration of effluent was stable till the end of continuous process. But treatment efficiency of reactor is lower than semi-continuous process (86.9 - 94.80%).

From **Fig 4.14**, it was observed that COD conc. of leachate varies throughout the process. But effluent conc. fluctuate in batch process then it becomes steady throughout the process i.e. semi continuous and continuous process. And treatment efficiency of reactor is quite higher in semi continuous process.

From **Fig 4.15**, it was observed that COD conc. of leachate in reactor is decreased with the upflow movement of leachate in reactor. It was observed from the graph that COD conc. reduced from port 1 to port 3 then lower in treated effluent in all the three cases.

From **Fig 4.16**, it was observed that COD removal efficiency is highly fluctuated in batch process. Then became stable in semi-continuous and continuous process and treatment efficiency of reactor is quite higher in semi-continuous process which is about 96% than batch 92.26% and continuous process 91.7% **(Table 4.5).** This indicates that efficiency of semi-continuous is better followed by batch and then continuous.

4.3.4. Estimation of Soluble COD (Chemical Oxygen Demand)

The COD concentration of influent and effluent were examined daily at HRT of 3 day, same as above. The COD concentration shows variation according to the variation in leachate composition. Variations in Soluble COD conc. for Batch, Semi-continuous and continuous process are shown in **Fig 4.17, 4.18, 4.19** and **4.20.**

From **Fig 4.17**, it was observed that Soluble COD values of leachate as influent varies each day due to variations in its composition .The values of effluent were lower than influent, and fluctuate drastically every day. These fluctuations were observed as the reactor performance was low due to low temp. During winter .so the feed was not digested properly in batch process. There is no effect of temperature in COD estimation mention this here.

From **Fig 4.18**, it was observed that soluble COD conc. of influent shows fluctuation but effluent conc. remains stable and considerable. The conc. of soluble COD is less than Total COD since the influent was filtered. The COD here was always less compared to total COD as the filtrate contains less organic matter. For Anaerobic Digestion, less the organic matter less is the oxygen demand.

From **Fig 4.19**, it was observed that soluble COD conc. of influent shows fluctuation but effluent conc. remains stable and considerable. The conc. of soluble COD is less than Total COD since the influent was filtered.

From **Fig 4.20**, it was observed that COD removal efficiency of reactor in batch process is not stable and varies within the range of 44 to 90%.then in semi-continuous process it was higher about 95% COD reduction and in continuous process it was observed about 91% maximum.

The pattern of graph reported by Forster et al (2008) for COD removal shows step-wise increase from 0-44% without any fluctuation. Relation of this graph with reactor graph suggests that COD reduction pattern of semi continuous process was suitable for anaerobic digestion process for the treatment of leachate within the reactor.

Mohan et al (2009) reported that COD reduction efficiency depends on substrate degradation and can be evidenced by H_2 production and can be suggested that substrate had participated as primary carbon source in metabolism. The higher degradation of substrate in non pulpy waste, attributed to relatively easy degradation due to absence of much cellulosic material (organic matter). COD reduction is linked to methane production- for every kilogram of COD reduced, 0.35 m^3 methane is formed (Ann, 2003).

4.3.5 Estimation of BOD: COD ratio

From **Fig 4.21**, It was observed that BOD:COD ratio of influent varies from 0.1 to 0.6 .which means leachate requires biological treatment to reach safe disposable limits.

4.3.6 Estimation of TVAs (Total Volatile Acids)

TVA accumulation in anaerobic reactors was the result of process imbalance, not the cause of inhibition, thus justifying the use of TVA as process indicators.

The TVAs for influent leachate ranges from 148 to 954 mg/L throughout the study of different treatment processes. These variations were observed due to variation in leachate composition. Variation in TVAs conc. in Batch, Semi-continuous and continuous processes are shown in **Fig 4.22, 4.23, 4.24, 4.25** and **4.26**.respectively.

From **Fig 4.22**, it was observed that TVAs conc. of leachate decreases then increase until 15 days but again decreases up till 24 days then increases marginally . But effluent TVAs conc. is steady or in stable range of 4-8 mg/l.

From **Fig 4.23**, it was observed that TVAs conc. of leachate fluctuates throughout the Semi-continuous process due to leachate composition variation from range of 100 -1000 mg/l and maximum removal was observed 24% in 7 days. But effluent TVAs conc. is steady or in stable range of 4-24mg/l. but removal efficiency is comparatively higher in semi-continuous process.

From **Fig 4.24**, it was observed that TVAs conc. of leachate fluctuates throughout the Continuous process due to leachate composition variation. But in effluent TVAs conc. is maximum12% in 2nd day where as stable as 8 mg/l throughout the experimentation.

From **Fig 4.25**, it was observed that influent leachate TVAs conc. varies in range of 100 -950 mg/l throughout the processes. But the effluent conc. is much lower than influent i.e. 4-24 mg/l throughout the processes and stable. The difference between influent and effluent conc. is quite noticeable. Treatment efficiency is quite higher in Semi-continuous process than batch and Continuous process**. (Table 4.8)**

From **Fig 4.26**, It was observed that TVAs conc. is rapidly decreased in the reactor .due to upflow movement of leachate in reactor, at each column of reactor maximum TVAs were removed .maximum removal observed in port 1 lower column of reactor.

An increase in TVAs without increase in alkalinity shows adverse conditions within the reactor. acetate is precursor for most of the methane formation. When volatile acid production occurs more rapidly than TVAs consumption become slow and it (i.e. methane production), upset condition occurs within the reactor, making it acidic .

4.3.7. Estimation of Solids

(i) Total Solids

Total solids are the sum of suspended solids and dissolved solids. Total solids analysis were important for assessing wastewater treatment processes such as digester efficiencies and sludge cake processing parameters

From **Fig 4.27, 4.28, 4.29**, it was observed that Total solids present in leachate or influent varies in a higher range. This fluctuation was due to organic matter variation and composition variation of leachate**.(Table 4.9)**

From **Fig 4.30**, it was observed that in batch process reduction of solids were very low and conc. of total solids of influent and effluent is almost in close range. The same pattern was observed in continuous process of treatment. While in semi-continuous reduction of total solid is higher than batch and continuous process**.(Table 4.9)**

From **Fig 4.31**, it was observed that Total solid removal (%) is higher or maximum in semi-continuous process i.e. 70.24% reduction in 6th days where as minimum 12.7 on 5th day. while in batch and continuous process maximum value of solid reduction are 59.84 % and36.1 % respectively in 7th days. So semi-continuous mode of operation is best for treatment of leachate within the reactor. TS removal should be higher since reactor with smaller quantity of solid showed high production methane % in total volume of Biogas (52% methane between 22 to 60 days).

(ii) Suspended Solids

From **Fig 4.32, 4.33, 4.34, and 4.35**. It was observed that there were fluctuations in concentration of Suspended solids. These fluctuations were due to initial fluctuation in Total Solids.

From **Fig 4.35**, it was observed that there was fluctuation in conc. of SS in batch process. Fluctuation is maximum in influent conc. and effluent conc. is almost nearer on the 10^{th} day. The influent range is 272 to 1030 whereas influent it is 192-488. Where comparatively lower. In semi-continuous process, effluent SS conc. is lower than batch and continuous process of treatment. **(Table 4.10)** In continuous same pattern like batch process were followed except lower variation of influent conc. of SS.(396-768) and (178-512) in effluent.

From **Fig 4.36**, it was observed that in batch process maximum suspended solid reduction (%) efficiency is 73%.while in semi-continuous process it was 92.7% and in continuous process is was only 58.2 %. So semi-continuous process operation is better than batch and continuous mode operations of reactor at HRT of 3 days**. (Table 4.10) and (Fig.4.36).**

(iii) Volatile Solids

From **Fig 4.37, 4.38, 4.39 and 4.40**, it was observed that volatile solids follow the same pattern of Total solids and Suspended solids. It is due to the initial fluctuation of Total solids concentration. The variation and fluctuations are same as in total and suspended solids.

From **Fig 4.41**, it was observed that in batch process maximum suspended solid reduction (%) efficiency is 68.39 %.while in semi-continuous process it was 92.7% and in continuous process is was only 64.1 %. So semi-continuous process operation is better than batch and continuous mode operations of reactor at HRT of 3 days. **(Table 4.11)**

4.3.8 Estimation of Sodium (Na)

The inorganic compounds like sodium, potassium, calcium, magnesium etc acts as nutrient element for the organisms. Lusk,(1998) reported that the total conc. of these nutrients will not change significantly during digestion. K is necessary for organisms as it is the main cellular inorganic cation and co factor for certain enzymes while Na maintains the osmotic balance within bacterial cells.

From **Fig 4.42, 4.43, 4.44**, It was observed that sodium conc. of influent is in stable range of 5-7 mg/l throughout the processes i.e. Batch, Semi-continuous and Continuous process. while effluent conc. higher than the influent conc.

It was observed from **Fig 4.45** that sodium conc. of influent is lower than effluent sodium conc. because we use cow dung as sludge blanket in reactor for treatment process. When leachate passes through reactor in treatment process conc. of sodium and potassium increased due to available inorganic compound conc. effluent sodium conc. is higher in batch then reduced in semi-continuous and continuous processes. It varies from 7.3-7.94 mg/L. **(Table 4.12)**

Full form has reported of being sensitive to toxicants and moreover methanogenesis is reported to be most sensitive step (Speece and Parkin, 1983).The presence of such inorganic substances is also related to toxic effects when present in higher concentrations. Inorganic cation such as Ca, Mg, Na, K, Fe, NH_4 which have a stimulatory effect at low or normal concentration, exhibit inhibitory effect at higher concentrations.

4.3.9. Estimation of Potassium (K)

The inorganic compounds like sodium, potassium, calcium, magnesium etc acts as nutrient element for the organisms. Lusk, (1998) reported that the total conc. of these nutrients will not change significantly during digestion. K is necessary for organisms as it is the main cellular inorganic cation and co factor for certain enzymes while Na maintains the osmotic balance within bacterial cells.

From **Fig 4.46, 4.47 , 4.48 and 4.49** it was observed that Potassium follow the same pattern of sodium concentration within the reactor treatment process. In **Fig 4.49**, it was clearly observed that influent conc. varies within range of 13-963 mg/l except few days having influent potassium conc. is in range of 800-903 mg/L in semi-continuous process from 6th to 10th day of incubation the effluent conc. is higher than influent conc. and decreased with the increased days of operation in all treatment processes. But higher in semi-continuous process **(Table 4.13)**

4.3.10. Estimation of Nitrate

It was observed nitrate estimation is an important factor. Nitrate have an inhibitory effect while ammonia growing of meth nogens that nitrate conc. varies in the range of 0.5-3.0 mg/L throughout the processes of treatment,

The nitrate conc. varies from 2.77 - 4.93 mg/l which decreased from starting of batch process. And effluent conc. varies from 3.01-2.13 decreased with the increase operation days of batch process**. (Fig 4.50)**

Nitrate conc. varies from 0.62-2.19 mg/l as decreased from starting of semi-continuous process .and effluent conc. also decreased from 1.86 to 0.15 mg/l. in semi- continuous process**.(Fig 4.51)**

Nitrate conc. fluctuates and varies from 2.21-9.75 mg/l **Fig 4.52** .This fluctuation is due to composition of leachate .and effluent varies from 0.66 – 2.23 mg/l in Continuous process.

It was observed that influent conc. varies in higher range of 0.5-9.75 mg/l throughout the treatment process **Fig 4.53**. While effluent conc. decreased in different treatment processes. In semi-continuous process nitrate removal is maximum than batch and continuous process. So for reactor semi-continuous process of treatment is more efficient than batch and continuous**.(Table 4.14).**

4.3.11. Estimation of Sulphate

Sulphate is used as micro nutrient for bacteria the excess of sulphate is not good for anaerobic digestion. It has an inhibitory effect.It generally has a stimulatory effect. It was observed from the **Fig 4.54, 4.55, 4.56 and 4.57** that sulphate conc. fluctuates in the higher range of 82 - 633 mg/l throughout the treatment processes. In **Fig 4.54** or in batch process influent sulphate conc. increases with days of operation due to the leachate composition variation and treated effluent conc. dec. from 79.94 to 31.89 mg/l. In **Fig 4.55**, or in semi-continuous process, influent conc. varies from higher value of 494.74 mg/l to lower value of 82 mg/l. while effluent conc. is within the stable range of 46 – 60 mg/l. In **Fig 4.56** or in continuous process effluent conc. varies from 112 – 319 mg/l which shows minimum reduction of sulphate in continuous process.

From **Fig 4.57**, it was observed that sulphate reduction efficiency is higher in semi continuous process than batch and continuous process. So semi continuous process is most suitable for treatment of leachate within the reactor. The maximum fluctuation is observed in influent concern rather than effluent conc**.(Table 4.15)**

4.3.12. Estimation of Phosphate

The organisms require phosphates and sulphates as nutrients because inorganic phosphates (PO_4) are the constituents of nucleic acids, nucleotides, phospholipids, teichoic acids.SO_4 ,H_2S and organic sulphur compounds constituents to cysteine, methionine, glutathione and several coenzymes. Concentration of these compounds varies according to the composition of leachate or wastes.

From **Fig 4.58, 4.59, 4.60 and 4.61**, it was observed that phosphate removal efficiency is quite lower in batch and continuous process than semi-continuous process. In batch process influent conc. varies from 1.08 - 11.48 mg/l. and effluent conc. 0.3 -1.68 mg/l. In semi-continuous process influent conc. varies from 1-08- 40.33 mg/l and effluent conc. varies from 0.17 – 14.58 mg/l. and In Continuous process influent conc. varies from 4.3 -13.38 mg/l and effluent conc. varies from 4.1-6.78. So treatment efficiency is higher in semi- continuous process**.(Table 4.16)**

4.3.13 Estimation of Heavy Metals

The trace metal requirement of methanogens has helped to improve the condition required for growth, both in pure culture and mixed culture fermentations. In addition to iron, zinc and manganese. It also requires trace amounts of cobalt and nickel.

From **Figure 4.62, 4.63 and 4.64 and Table 4.17**, it was observed that Heavy metal removal efficiency of reactor is satisfactory.

From **fig. 4.62**, it was observed that Zn conc. reduced from 0.395 to 0.186 mg/L in semi-continuous process and 0.194 to 0.101 mg/l in continuous process. Pb conc. reduced from1.01 to 0.809 mg/l in semi-continuous process while in continuous it reduced from 0.558 to 0.248 mg/L and also shows minimum conc. which are not detected in last days of operation. Cd conc. reduced from 0.268 to 0.03 mg/l in semi-continuous process while in continuous process it reduced from 0.423 to 0.158 mg/L.

From **fig. 4.23**, it was concluded that that Ni conc. reduced from 0.307 to 0.256mg/L in semi-continuous process and 0.206 to 0.149 mg/l in continuous process. Co conc. reduced totally from 0.039mg/L in semi-continuous and continuous process because min. conc. of Co is not detected in effluent readings. Mn conc. reduced from1.34 to 0.319 mg/l in semi-continuous process while in continuous process it reduced from 1.98 to 0.49 mg/L.

From **fig. 4.24**, it was concluded that that Fe conc. reduced from 8.87to 0..881 mg/L in semi-continuous process and 2.68 to 0..398 mg/l in continuous process. Cr conc. reduced totally from 0.398 mg/L in semi-continuous and continuous process because min. conc. of Co is not detected in effluent readings. Cu conc. reduced from 0.124 to 0.0.094 mg/l in semi-continuous process while in continuous process it reduced from 0.064 to 0.038 mg/L**.(Table 4.18)**

4.3.14 Estimation of Biogas Production

Anaerobic digestion process is an age old process used for the stabilization of sludge. It involves the decomposition of organic and inorganic matter in the absence of molecular O_2. In this process the organic matter present in the wastes is biologically converted to methane and carbon dioxide.

This process is capable of treating high strength organic waste. This is not an energy consumer process; it instead generates a huge quantity of gaseous energy in the form of methane. Table 4.1 shows the high amount of BOD and COD in MSW leachate. This leachate pollute the ground water if continuously perchlorate in the ground. So the process of batch, semicontinous and continuous compared by using anaerobic process for the production of biogas from the leachate.

It was observed from the **Fig 4.65** that maximum biogas production are in semi-continuous process i.e. 540-2650 ml while in batch and continuous process biogas production are 960-1290 ml and 580- 1650 ml respectively. It shows constant increase in biogas production in different treatment processes. Comparing the above graph with methane production pattern shown by (Neves et al, 2008), it suggested that the biogas production pattern should follow curved graph against days of operation. (Velmurugan *et al.,* 2010 reported 0.78 L/day biogas for ambient batch reactor at 25 days HRT .Biodegradability of feed stock is indicated by biogas production (Zhang *et al.,* 2007).Faster the degradation, faster is the rate of biogas production.

Table 4.3: Values of pH of influent and effluent throughout the process at 3 day HRT.

Days of Operation↓	BATCH PROCESS (3 day operation)		SEMI-CONTINUOUS PROCESS		CONTINUOUS PROCESS	
	INF	EFF	INF	EFF	INF	EFF
1	6.02	7.68	6.38	7.76	5.87	7.58
2	6.9	7.5	6.69	7.68	6.21	7.55
3	6.05	7.57	6.97	7.7	5.73	7.58
4	5.97	7.53	6.73	7.71	5.76	7.58
5	6.14	7.61	6.78	7.72	5.89	7.59
6	6.25	7.64	5.86	7.6	5.87	7.48
7	6.03	7.62	5.39	7.44	6.34	7.52
8	6.4	7.7	5.37	7.36	6.33	7.41
9	6.38	7.56	5.48	7.33	5.89	7.45
10	6.34	7.66	6.38	7.33	6.09	7.41
11	-	-	5.78	7.37	6.09	7.43
12	-	-	5.55	7.45	5.92	7.47
13	-	--	5.36	7.77	6.09	7.49
14	-	-	6.15	7.94	6.39	7.59
15	-	-	5.73	7.94	6.05	7.62
16	-	-	5.74	7.87	6.06	7.65

Table 4.4: Values of Alkalinity (mg/L of CaCO3) of influent and effluent throughout the process at 3 day HRT.

Days of Operation↓	BATCH PROCESS (3 day operation)		SEMI-CONTINUOUS PROCESS		CONTINUOUS PROCESS	
	INF	EFF	INF	EFF	INF	EFF
1	660	1420	380	1160	280	980
2	500	1360	360	1120	400	880
3	760	1620	360	1000	320	900
4	1280	1660	260	1060	340	960
5	1280	1580	360	1060	340	980
6	580	1420	360	1000	340	880
7	420	1380	500	1140	460	880
8	360	1300	560	1180	440	880
9	400	1400	140	1180	360	920
10	500	1420	160	1020	400	900
11	-	-	260	1000	520	920
12	-	-	260	960	460	920
13	-	-	280	980	520	960
14	-	-	300	860	520	980
15	-	-	180	900	520	980
16	-	-	280	900	520	980

Table 4.5: Values of total COD of influent and effluent throughout the process at 3 day HRT.

Days of Operation↓	BATCH PROCESS (3 day operation)			SEMI-CONTINUOUS PROCESS			CONTINUOUS PROCESS		
	INF	EFF	% removal	INF	EFF	% removal	INF	EFF	% removal
1	6400	560	91.25	13600	6096	55.18	8000	880	89.00
2	10400	3392	67.38	10400	1712	83.54	8800	800	90.90
3	4560	2080	54.39	10560	2016	80.91	9600	800	91.70
4	9520	1336	85.97	10720	1160	89.18	9620	880	90.90
5	6960	3760	45.98	15440	1230	92.03	16800	860	94.90
6	14400	3784	73.72	11360	488	95.70	16000	880	94.50
7	12360	1896	82.66	16000	544	96.60	16800	880	94.80
8	13120	2160	83.54	15840	816	94.85	16800	1360	91.90
9	13200	1024	92.24	11600	912	92.14	12000	1380	88.50
10	13400	1024	92.36	16000	720	95.50	12800	1440	88.80
11	-	-	-	10400	1360	86.92	10400	1360	86.90
12	-	-	--	10400	1040	92.00	10400	880	91.50
13	-	-	-	12000	960	92.00	9600	880	90.80
14	-	-	-	-	-	-	10400	880	91.50
15	-	-	-	-	-	-	10400	880	91.50
16	-	-	-	-	-	-	10600	880	91.70

Table 4.6: Values of Soluble COD (mg/L) of influent and effluent throughout the process at 3 day HRT

Days of Operation↓	BATCH PROCESS (3 day operation)			SEMI-CONTINUOUS PROCESS			CONTINUOUS PROCESS		
	INF	EFF	% removal	INF	EFF	% removal	INF	EFF	% removal
1	4000	200	44.19	8800	2864	67.45	6400	560	91.3
2	8600	1800	79.07	9680	1152	88.1	7200	640	91.1
3	4160	1776	45.15	5760	1312	77.22	6400	640	90
4	5280	1120	70.27	3360	688	79.52	6420	720	88.8
5	5920	1680	53	9040	980	89.16	11800	740	93.7
6	8000	1632	93.65	9520	376	96.05	11820	740	93.7
7	6800	1600	52.85	12240	504	95.88	12560	752	94
8	9840	1520	86.67	9680	440	95.45	12540	960	92.3
9	9600	944	90.17	8640	436	94.95	10400	880	91.5
10	9600	940	90.21	9680	450	95.35	10160	1200	88.2
11	-	-	-	8620	420	95.13	8800	1120	87.3
12	-	-	-	8620	380	95.59	8000	880	89
13	-	-	-	8760	380	95.66	4800	480	90
14	-	-	-	-	-	-	5600	480	90.4
15	-	-	-	-	-	-	5800	480	90.7
16	-	-	-	-	-	-	5620	460	90.8

Table 4.7: Values of BOD/COD of Influent feed to reactor.

Days	INF .(BOD:COD)
1	0.52
2	0.61
3	0.55
4	0.62
5	0.51
6	0.11
7	0.33
8	0.37
9	0.61
10	0.61
11	0.28
12	0.22
13	0.27
14	0.40
15	0.21
16	0.54
17	0.39
18	0.40
19	0.59

Table 4.8: Values of TVA (mg/L) of influent and effluent throughout the process at 3 day HRT.

Days of Operation↓	BATCH PROCESS (3 day operation)		SEMI-CONTINUOUS PROCESS		CONTINUOUS PROCESS	
	INF	EFF	INF	EFF	INF	EFF
1	268	4	96	4	252	8
2	212	8	84	16	204	12
3	304	4	268	4	352	8
4	348	8	260	8	356	8
5	428	4	80	4	328	8
6	300	4	268	8	330	8
7	192	4	280	24	232	8
8	148	4	295	20	236	8
9	184	4	268	8	212	8
10	184	4	148	12	216	8
11	-	-	176	12	300	8
12	-	-	180	16	204	8
13	-	-	212	12	392	8
14	-	-	192	4	260	8
15	-	-	280	4	272	8
16	-	-	412	4	280	8

Table 4.9: Values of Total solids (mg/L) of influent and effluent throughout the process at 3 day HRT

Days of Operation↓	BATCH PROCESS (3 day operation)			SEMI-CONTINUOUS PROCESS			CONTINUOUS PROCESS		
	INF	EFF	% removal	INF	EFF	% removal	INF	EFF	% removal
1	3660	2640	27.87	1594	773	51.51	1273	1124	11.7
2	1810	1410	22.10	1450	843	41.86	1760	1590	9.7
3	3820	3130	18.06	1630	796	51.17	2210	1400	36.7
4	2560	2230	12.89	1606	1220	24.03	2230	1396	37.4
5	2260	1920	15.04	1409	1230	12.7	2190	1903	13.1
6	1920	940	51.04	3696	1100	70.24	2450	1946	20.6
7	1850	743	59.84	3692	1336	68.14	2630	1680	36.1
8	2090	976	53.30	3623	1229	66.08	2190	1692	22.7
9	1960	1020	47.96	1409	786	44.22	2140	1730	19.2
10	1980	1020	48.48	-	-	-	2240	1720	23.2
11	-	-	-	-	-	-	1526	1460	4.3
12	-	-	-	-	-	-	1564	1452	7.2
13	-	-	-	-	-	-	1650	1420	13.9
14	-	-	-	-	-	-	1658	1420	14.4
15	-	-	-	-	-	-	1680	1416	15.7
16	-	-	-	-	-	-	1656	1408	15.0

Table 4.10: Values of SS (mg/L) of influent and effluent throughout the process at 3 day HRT

Days of Operation↓	BATCH PROCESS (3 day operation)			SEMI-CONTINUOUS PROCESS			CONTINUOUS PROCESS		
	INF	EFF	% removal	INF	EFF	% removal	INF	EFF	% removal
1	572	488	14.69	602	80	86.71	568	430	24.3
2	482	402	16.60	630	46	92.70	582	374	35.7
3	1030	462	55.15	532	236	55.64	396	182	54.0
4	402	304	24.38	732	226	69.13	426	178	58.2
5	494	230	53.44	856	126	85.28	598	364	39.1
6	730	192	73.70	1012	212	86.85	668	398	40.4
7	276	252	8.70	1042	466	55.28	692	456	34.1
8	568	382	32.75	949	126	86.72	680	432	36.5
9	298	256	14.09	856	124	85.51	592	302	49.0
10	272	247	9.19	-	-	-	578	302	47.8
11	-	-	-	-	-	-	740	511	30.9
12	-	-	-	-	-	-	760	512	32.6
13	-	-	-	-	-	-	732	492	32.8
14	-	-	-	-	-	-	742	498	32.9
15	-	-	-	-	-	-	756	482	36.2
16	-	-	-	-	-	-	768	474	38.3

Table 4.11: Values of Volatile Solids (mg/L) of influent and effluent throughout the process at 3 day HRT

Days of Operation↓	BATCH PROCESS (3 day operation)			SEMI-CONTINUOUS PROCESS			CONTINUOUS PROCESS		
	INF	EFF	% removal	INF	EFF	% removal	INF	EFF	% removal
1	382	322	15.71	570	61	86.71	250	160	36.0
2	390	324	16.92	568	38	92.7	384	138	64.1
3	768	440	42.71	468	122	55.64	228	160	29.8
4	392	218	44.39	626	166	69.13	236	178	24.6
5	382	246	35.6	466	154	85.28	386	160	58.5
6	620	196	68.39	732	145	86.85	384	172	55.2
7	188	140	25.53	748	148	55.28	420	234	44.3
8	318	126	60.38	610	130	86.72	412	238	42.2
9	270	226	16.3	578	128	85.51	266	116	56.4
10	270	229	15.19	-	-	-	268	116	56.7
11	-	-	-	-	-	-	298	186	37.6
12	-	-	-	-	-	-	326	178	45.4
13	-	-	-	-	-	-	286	154	46.2
14	-	-	-	-	-	-	288	152	47.2
15	-	-	-	-	-	-	282	132	53.2
16	-	-	-	-	-	-	288	138	52.1

Table 4.12: Values of Sodium (mg/L) of influent and effluent throughout the process at 3 day HRT.

Days of Operation↓	BATCH PROCESS (3 day operation)		SEMI-CONTINUOUS PROCESS		CONTINUOUS PROCESS	
	INF	EFF	INF	EFF	INF	EFF
1	6.02	7.68	6.38	7.76	5.87	7.58
2	6.9	7.5	6.69	7.68	6.21	7.55
3	6.05	7.57	6.97	7.7	5.73	7.58
4	5.97	7.53	6.73	7.71	5.76	7.58
5	6.14	7.61	6.78	7.72	5.89	7.59
6	6.25	7.64	5.86	7.6	5.87	7.48
7	6.03	7.62	5.39	7.44	6.34	7.52
8	6.4	7.7	5.37	7.36	6.33	7.41
9	6.38	7.56	5.48	7.33	5.89	7.45
10	6.34	7.66	6.38	7.33	6.09	7.41
11	-	-	5.78	7.37	6.09	7.43
12	-	-	5.55	7.45	5.92	7.47
13	-	-	5.36	7.77	6.09	7.49
14	-	-	6.15	7.94	6.39	7.59
15	-	-	5.73	7.94	6.05	7.62
16	-	-	5.74	7.87	6.06	7.65

Table 4.13: Values of Potassium conc. of influent and effluent in reactor throughout the process.

Days of Operation↓	BATCH PROCES (3 day operation)		SEMI-CONTINUOUS PROCESS		CONTINUOUS PROCESS	
	INF	EFF	INF	EFF	INF	EFF
1	287	720	26	419	195	219
2	272	753	26	431	201	205
3	56	744	27	415	119	198
4	56	672	15	360	121	181
5	109	621	13	360	137	228
6	36	558	19	351	142	231
7	36	511	22	412	140	226
8	25	427	24	413	140	214
9	59	460	24	412	68	218
10	26	425	-	-	76	213
11	-	-	-	-	47	220
12	-	-	-	-	47	213
13	-	-	-	-	66	218
14	-	-	-	-	67	200
15	-	-	-	-	68	216
16	-	-	-	-	65	202

Table 4.14: Values of Nitrate conc of Influent and Effluent in reactor throughout the process

.

Days of Operation↓	BATCH PROCESS (3 day operation)		SEMI-CONTINUOUS PROCESS		CONTINUOUS PROCESS	
	INF	EFF	INF	EFF	INF	EFF
1	4.86	3.01	2.19	1.86	2.21	1.52
2	4.93	3.1	1.92	1.86	2.63	1.59
3	3.9	2.71	1.87	1.63	3.72	2.01
4	3.8	2.7	1.95	1.63	3.78	2.23
5	3.32	2.76	1.91	1.6	3.86	0.71
6	2.96	2.53	1.24	0.15	3.75	0.66
7	2.85	2.29	1.34	0.23	3.44	0.66
8	2.23	2.13	1.24	0.25	3.46	1.72
9	2.71	2.14	0.62	0.15	3.63	1.73
10	2.77	2.14	-	-	3.67	1.81
11	-	-	-	-	3.26	1.82
12	-	-	-	-	3.32	1.64
13	-	-	-	-	2.97	1.64
14	-	-	-	-	2.97	1.65
15	-	-	-	-	3.22	1.66
16	-	-	-	-	3.26	1.63

Table 4.15: Values of Sulphate conc of influent and effluent in reactor throughout the process.

Days of Operation↓	BATCH PROCESS (3 day operation)		SEMI-CONTINUOUS PROCESS		CONTINUOUS PROCESS	
	INF	EFF	INF	EFF	INF	EFF
1	212.84	79.94	447.26	48.2	306.51	261.28
2	193.07	84.49	418.43	46.1	633.79	262.01
3	105.11	37.69	437.31	47.9	638.8	264.42
4	105.2	39.94	494.74	49.4	609.35	260.6
5	306.51	34.49	417.7	49.8	610.86	246.33
6	301.2	31.89	122.16	53.88	368.47	319.5
7	359.03	34.17	135.37	60.37	583.25	319.49
8	299.04	44.46	128.48	58.68	583.27	259.7
9	457.57	44.4	82.12	48.37	265.01	260.1
10	447.26	44.6	-	-	266	112.78
11	-	-	-	-	215.65	113.18
12	-	-	-	-	224.89	171.98
13	-	-	-	-	321.27	176.7
14	-	-	-	-	323.23	119.13
15	-	-	-	-	206.23	119.03
16	-	-	-	-	206.28	118.21

Table 4.16: Values of Phosphate conc. of influent and effluent in reactor throughout the process.

Days of Operation↓	BATCH PROCESS (3 day operation)		SEMI-CONTINUOUS PROCESS		CONTINUOUS PROCESS	
	INF	EFF	INF	EFF	INF	EFF
1	1.72	0.42	1.08	0.19	10.94	6.58
2	1.78	0.3	1.36	0.17	6.5	4.5
3	1.8	0.3	1.47	0.18	6.57	4.5
4	1.8	0.68	15.52	14.58	5.88	4.48
5	1.62	0.83	11.47	10.6	5.89	4.26
6	1.62	0.3	2.09	0.71	6.76	6.66
7	1.08	0.4	2.5	1.6	13.38	6.78
8	3.39	1.68	3.76	1.32	13.36	5.66
9	4.32	1.27	4	1.28	5.86	5.46
10	2.16	0.42	-	-	5.88	3.56
11	-	-	-	-	4.28	3.54
12	-	-	-	-	4.3	4.2
13	-	-	-	-	5.08	4.16
14	-	-	-	-	5.1	4.18
15	-	-	-	-	5.18	4.12
16	-	-	-	-	5.24	4.1

Table 4.17: Variation of heavy metals concentration in different processes.

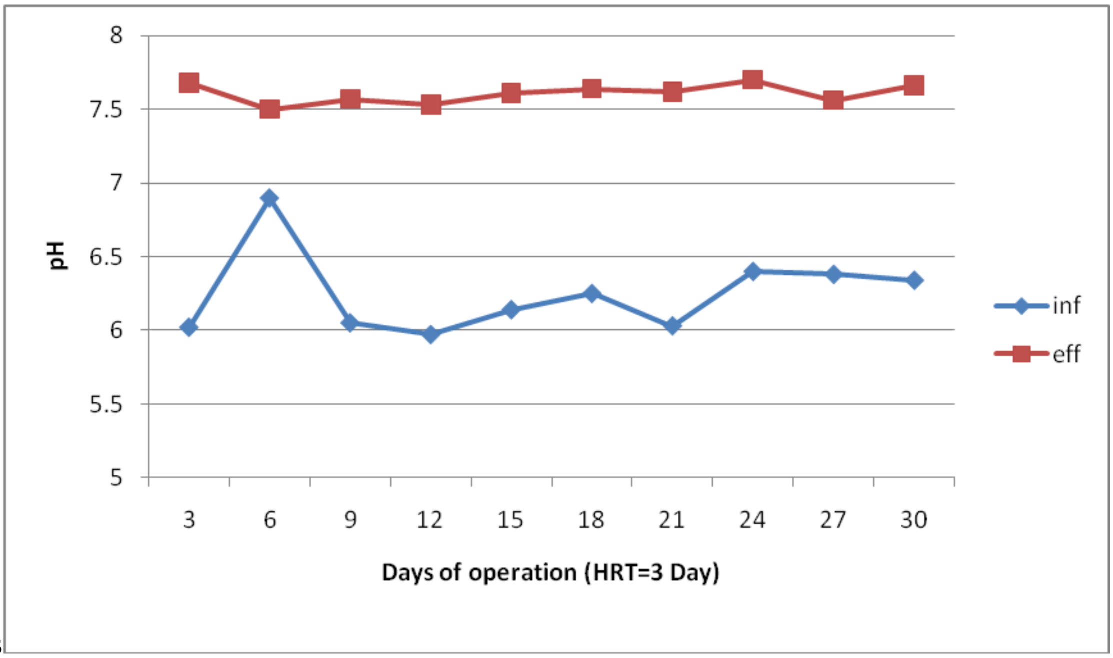
	Days	Zn		Pb		Cd		Ni		Co	
		INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF
Semi-continuous	1	0.209	0.195	0.785	0.63	0.268	0.03	0.259	0.183	0.039	ND
	2	0.202	0.197	0.61	0.55	0.259	0.061	0.228	0.206	0.037	ND
	3	0.224	0.202	0.781	0.551	0.268	0.161	0.239	0.225	0.039	ND
	4	0.237	0.212	0.721	0.696	0.269	0.136	0.237	0.217	0.022	ND
	5	0.2	0.186	0.716	0.696	0.251	0.195	0.237	0.228	0.035	ND
	6	0.279	0.234	0.716	0.695	0.195	0.101	0.253	0.228	0.045	ND
	7	0.378	0.227	0.896	0.766	0.201	0.116	0.283	0.276	0.029	ND
	8	0.395	0.233	1.01	0.809	0.228	0.11	0.307	0.256	0.019	ND
	9	0.29	0.231	0.901	0.798	0.071	0.051	0.242	0.196	0.002	ND
Continuous	1	0.285	0.232	0.173	0.098	0.15	0.078	0.134	0.07	0.024	ND
	2	0.174	0.162	0.625	0.098	0.223	0.075	0.202	0.138	0.023	ND
	3	0.14	0.132	0.546	0.246	0.228	0.157	0.206	0.149	0.005	ND
	4	0.196	0.186	0.558	0.248	0.22	0.153	0.174	0.156	0.006	ND
	5	0.162	0.136	0.564	0.416	0.224	0.207	0.134	0.123	0.001	ND
	6	0.194	0.18	0.568	0.418	0.405	0.203	0.128	0.088	0.004	ND
	7	0.168	0.146	0.543	0.193	0.402	0.155	0.126	0.008	0.012	ND
	8	0.178	0.166	0.184	0.12	0.423	0.158	0.132	0.05	0.016	ND
	9	0.155	0.134	0.225	0.128	0.2	0.078	0.164	0.08	0.014	ND
	10	0.156	0.112	0.228	0.227	0.204	0.091	0.145	0.023	0.024	ND
	11	0.118	0.103	0.363	0.224	0.225	0.094	0.124	0.024	0.009	ND
	12	0.117	0.101	0.378	ND	0.256	0.084	0.162	0.049	0.016	ND
	13	0.157	0.103	0.426	ND	0.372	0.082	0.156	0.046	0.018	ND
	14	0.16	0.101	0.456	ND	0.372	0.084	0.158	0.049	0.018	ND
	15	0.157	0.101	0.426	ND	0.372	0.084	0.164	0.049	0.018	ND
	16	0.157	0.101	0.426	ND	0.372	0.088	0.167	0.048	0.018	ND

Contd….

	Days	Mn		Fe		Cr		Cu	
		INF	EFF	INF	EFF	INF	EFF	INF	EFF
	1	1.34	0.319	2.98	0.928	0.243	ND	0.124	0.094
	2	1.23	0.386	2.51	0.738	0.283	ND	0.059	0.046
	3	0.924	0.372	2.78	1.6	0.317	ND	0.056	0.048
	4	0.977	0.398	3.85	0.744	0.292	ND	0.057	0.03
	5	0.867	0.279	2.33	0.644	0.292	ND	0.046	0.03
	6	0.938	0.361	6.23	1.54	0.343	ND	0.081	0.023
	7	1.55	0.479	6.15	0.881	0.233	ND	0.082	0.046
	8	1.5	0.56	8.87	0.815	0.199	ND	0.092	0.071
Semi-continuous	9	0.633	0.49	7.04	0.812	0.322	ND	0.071	0.046
	1	1.98	0.674	3.68	1.33	0.223	ND	0.049	0.033
	2	0.89	0.659	1.72	0.893	0.331	ND	0.048	0.033
	3	1.25	0.638	3.57	1.86	0.253	ND	0.028	0.036
	4	1.26	0.643	3.46	0.821	0.259	ND	0.032	0.027
	5	1.1	0.653	2.54	1.92	0.243	ND	0.034	0.024
	6	1.23	1.2	2.68	1.72	0.256	ND	0.038	0.034
	7	0.997	0.748	2.53	1.89	0.236	ND	0.043	0.032
	8	0.998	0.258	2.59	1.85	0.248	ND	0.048	0.05
	9	1.09	0.246	4.95	2.46	0.208	ND	0.034	0.024
	10	1.42	0.067	4.67	2.86	0.218	ND	0.045	0.029
	11	0.561	0.256	4.63	2.56	0.395	ND	0.035	0.028
	12	0.568	0.259	4.54	2.68	0.398	ND	0.042	0.038
	13	0.824	0.268	4.59	2.36	0.286	ND	0.064	0.032
	14	0.825	0.273	4.34	2.38	0.286	ND	0.064	0.038
	15	0.824	0.26	4.57	2.49	0.286	ND	0.064	0.038
Continuous	16	0.824	0.284	4.53	2.42	0.286	ND	0.064	0.032

Table 4.18: Biogas production (ml) in different treatment processes of reactor at 3 day HRT.

Days of operation↓	Batch process (3 day operation)	Semi-Continuous process	Continuous process
1	960	540	580
2	1200	560	590
3	1070	570	600
4	1150	960	700
5	880	1080	750
6	980	1900	780
7	1230	2110	850
8	1230	2160	920
9	1290	2650	1000
10	1290	-	1080
11	-	-	1150
12	-	-	1180
13	-	-	1400
14	-	-	1420
15	-	-	1620
16	-	-	1650



S

Figure 4.1: pH of influent and effluent in the reactor at 3 day HRT in Batch process.

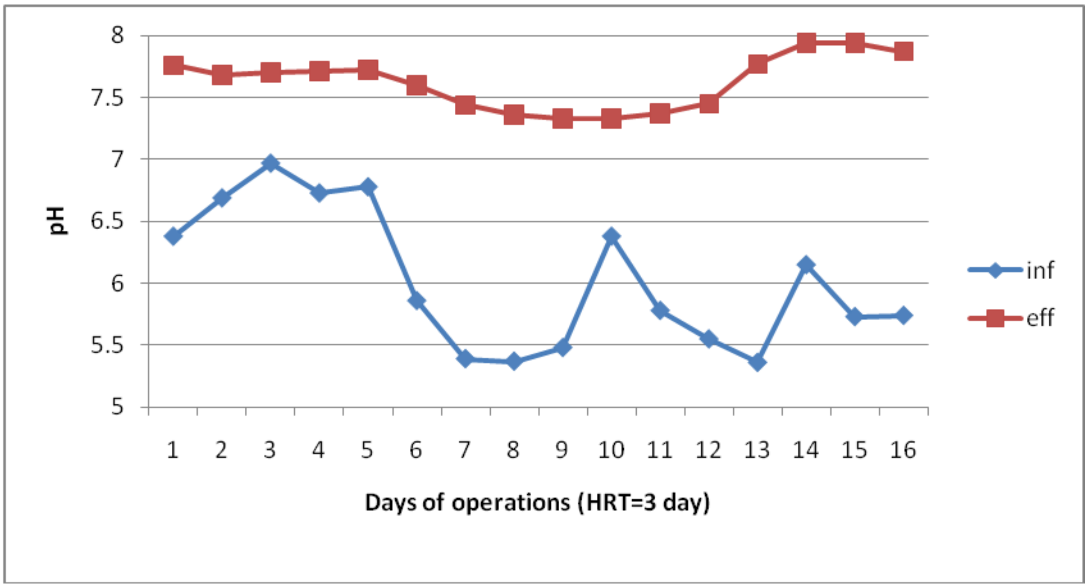


Figure 4.2: pH of influent and effluent in the reactor at 3 day HRT in Semi-continuous process.

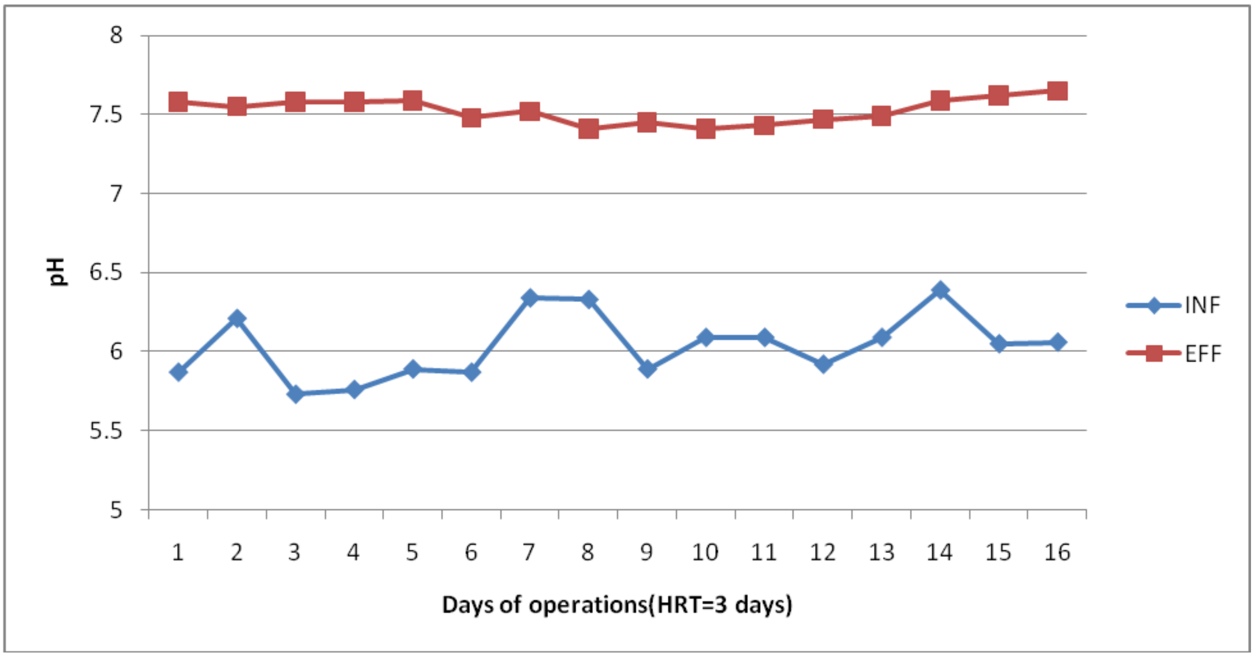


Figure.4.3: pH of influent and effluent in the reactor at 3 day HRT in Continuous process.

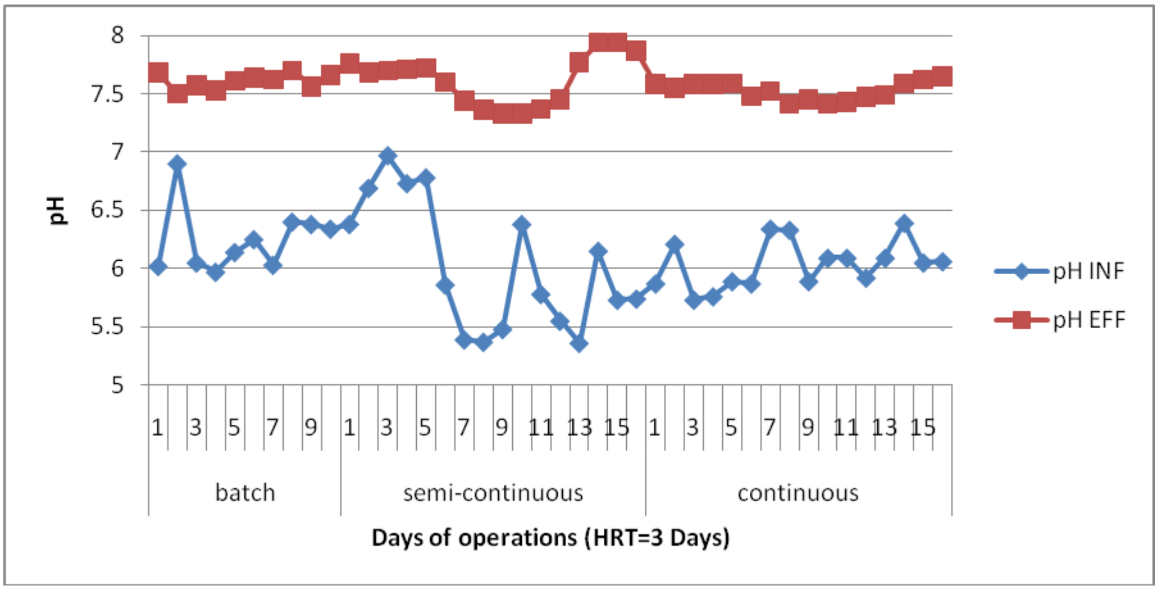


Figure .4.4: variation in pH of influent and effluent thorough out the process at 3 day HRT.

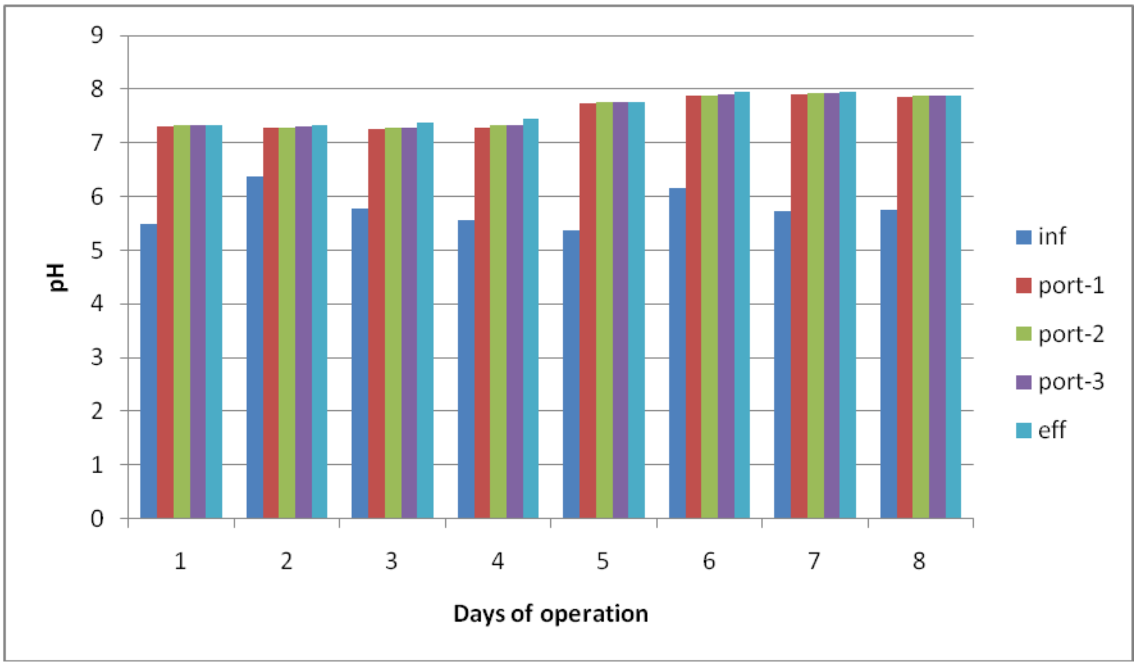


Figure 4.5: Variation in pH at diff ports of reactor.

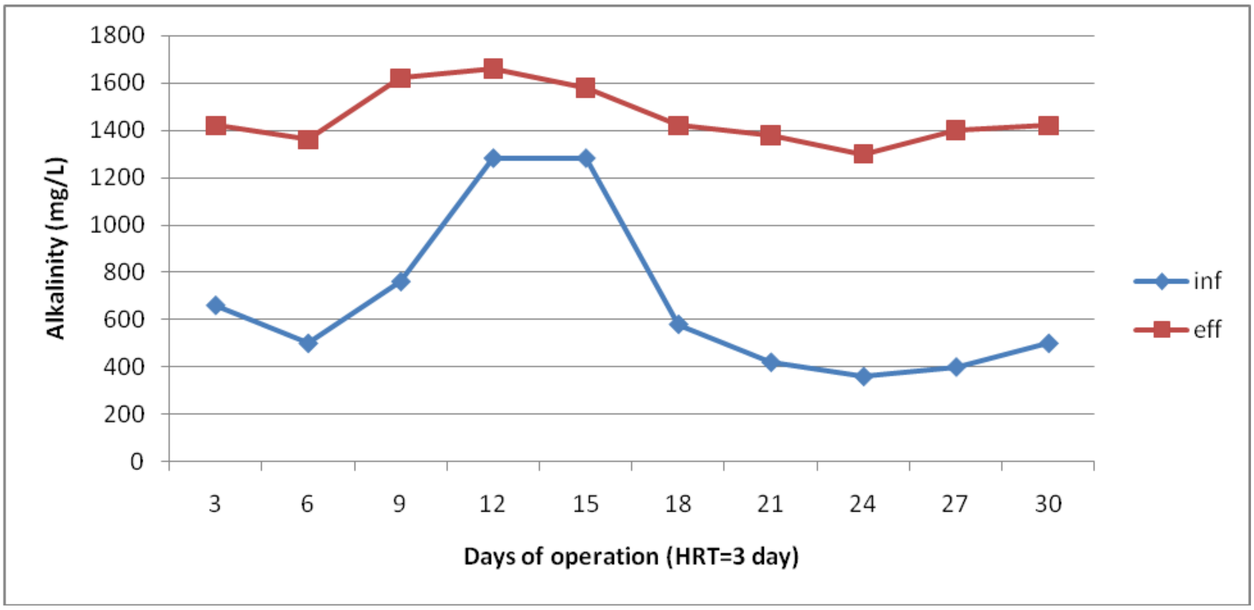


Figure 4.6: Alkalinity (mg/L as CaCO3)of influent and effluent at 3 day HRT in Batch process.

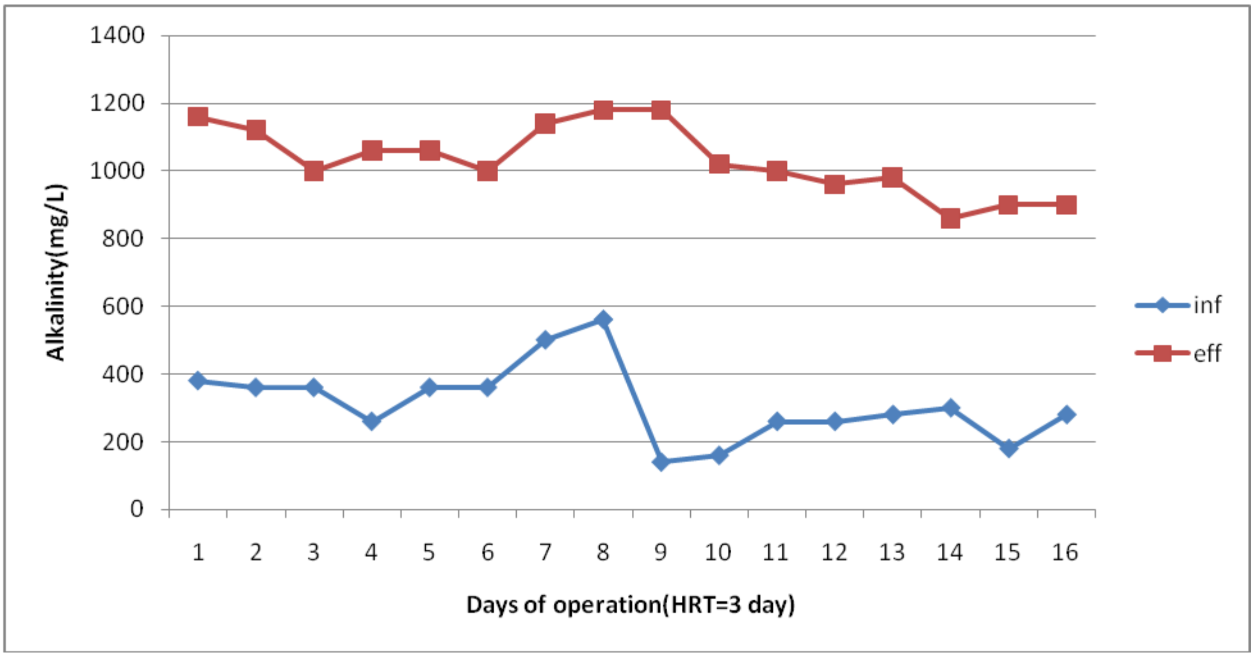


Figure 4.7: Alkalinity (mg/L as CaCO3)of influent and effluent at 3 day HRT in Semi-continuou process

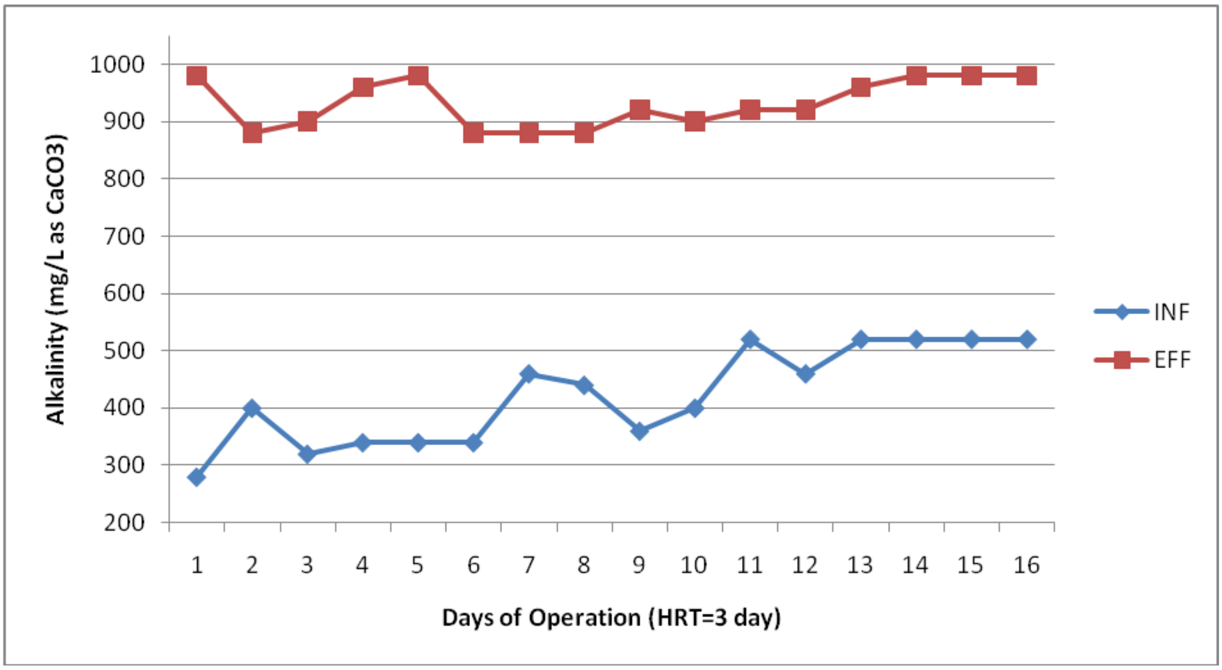


Figure 4.8: Alkalinity (mg/L as CaCO3) of influent and effluent at 3 day HRT in Continuous process

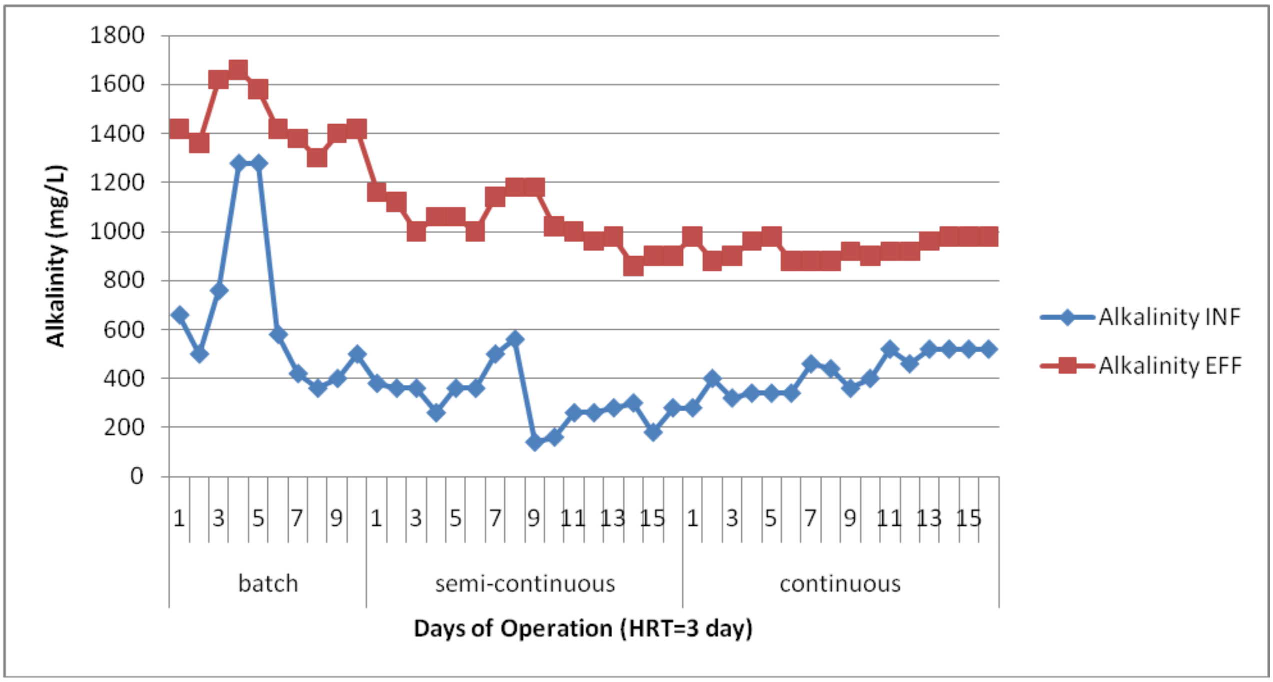


Figure 4.9: Variation in alkalinity profile throughout the process at 3 day HRT.

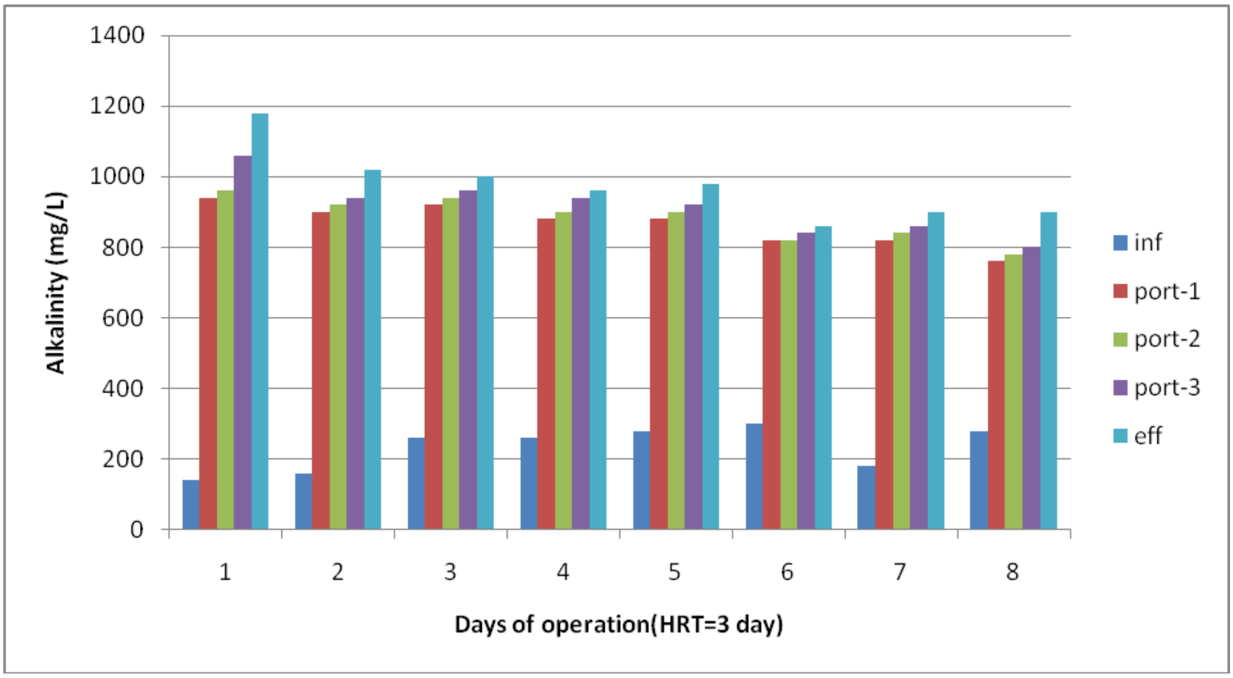


Figure.4.10: Variation in alkalinity at different ports of reactor at 3 day HRT.

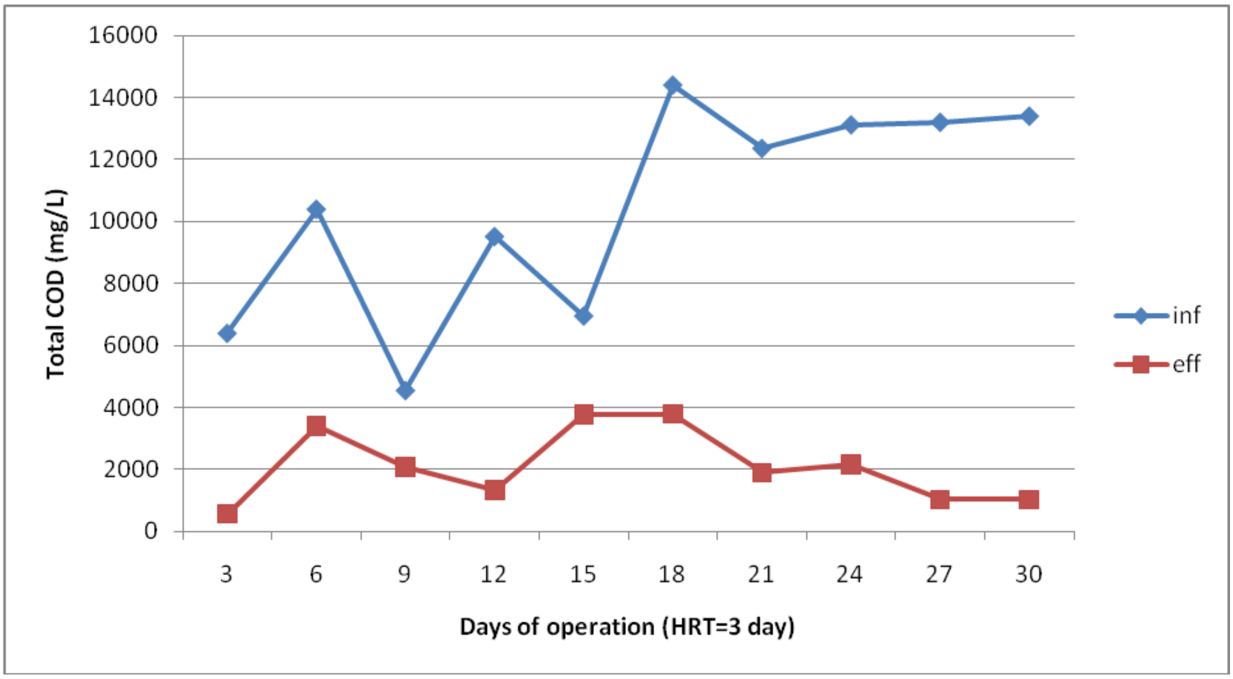


Figure 4.11: Total COD (mg/L) of influent and effluent at 3 day HRT in Batch process.

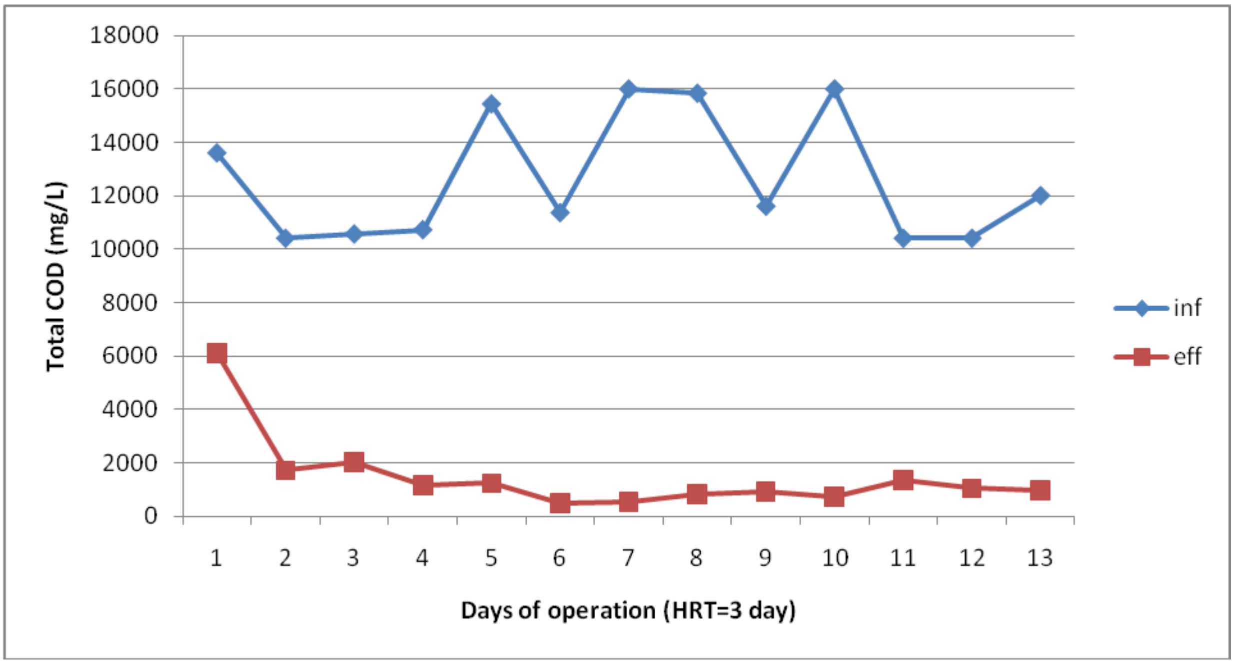


Figure 4.12: Total COD (mg/L) of influent and effluent at 3 day HRT in Semi-continuous process.

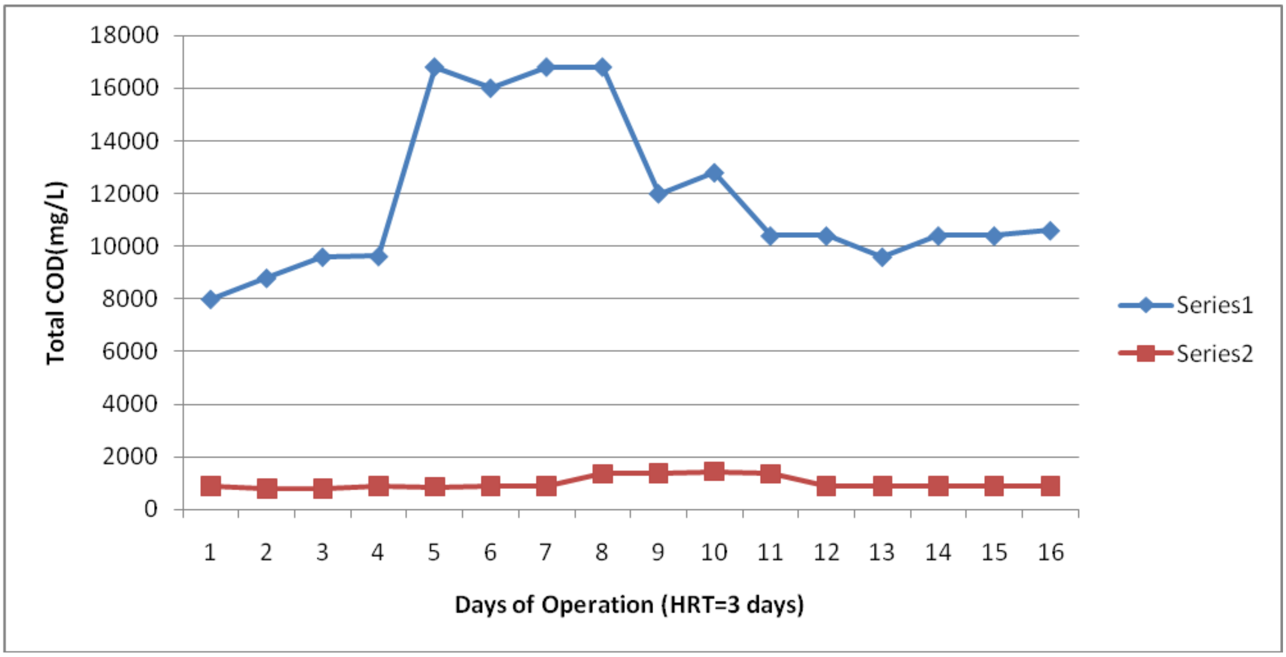
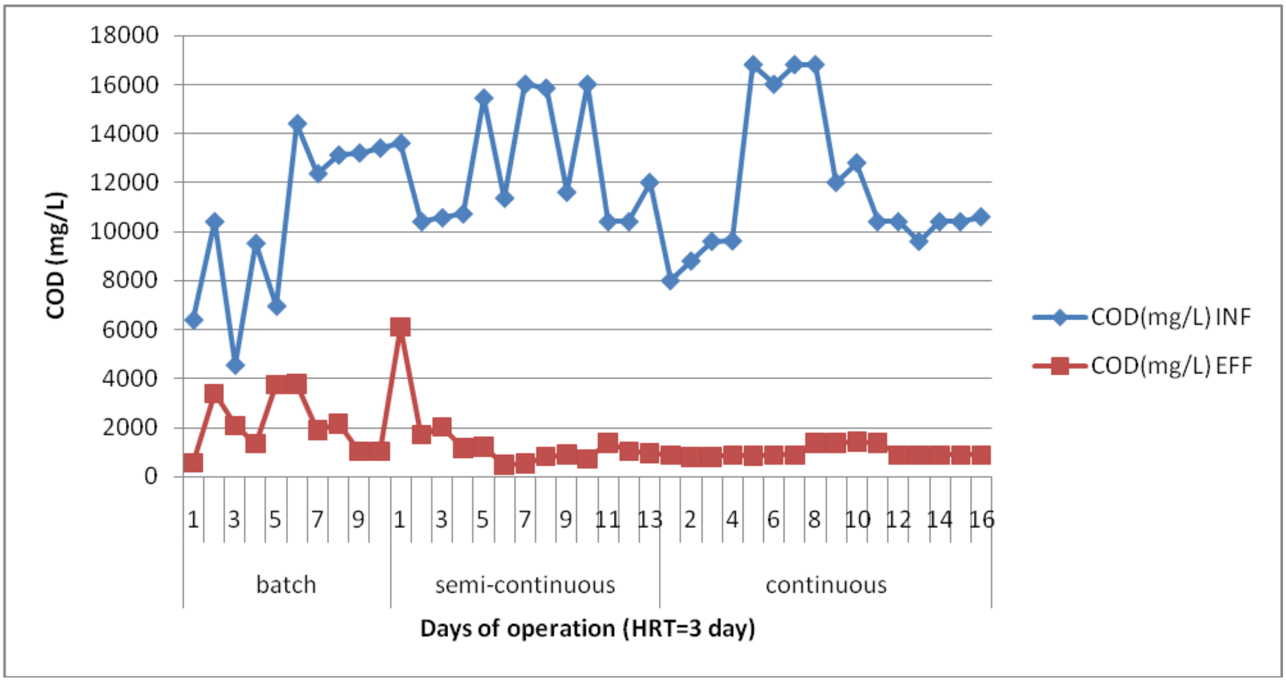


Figure 4.13: Total COD (mg/L) of influent and effluent at 3 day HRT in Continuous process .



\

Figure 4.14: Variation in Total COD profile throughout the process at 3 day HRT.

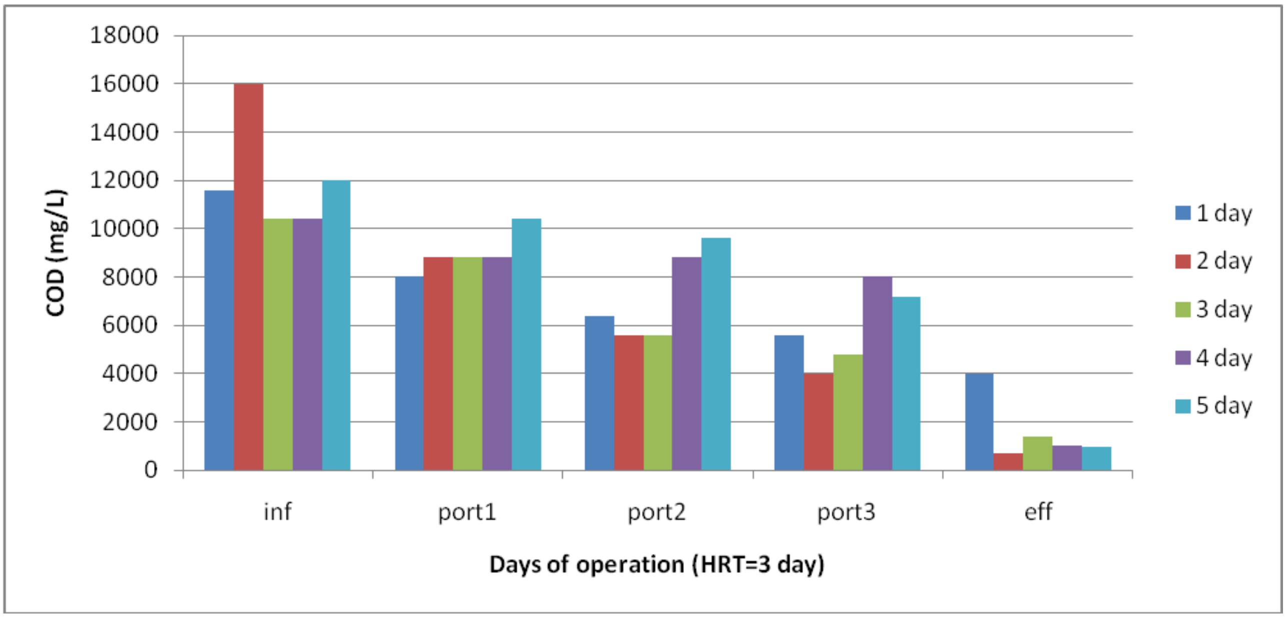


Figure 4.15: Variation in COD at different ports of reactor.

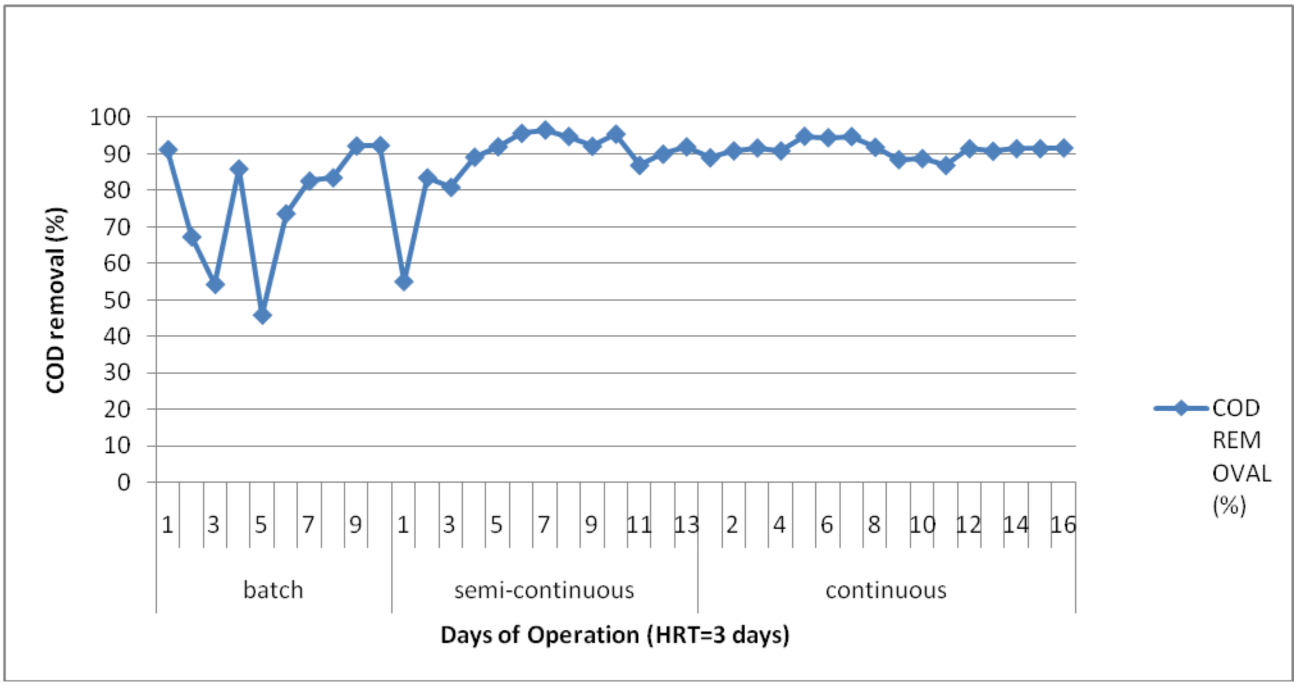


Figure 4.16: COD removal (%) profile throughout the process.

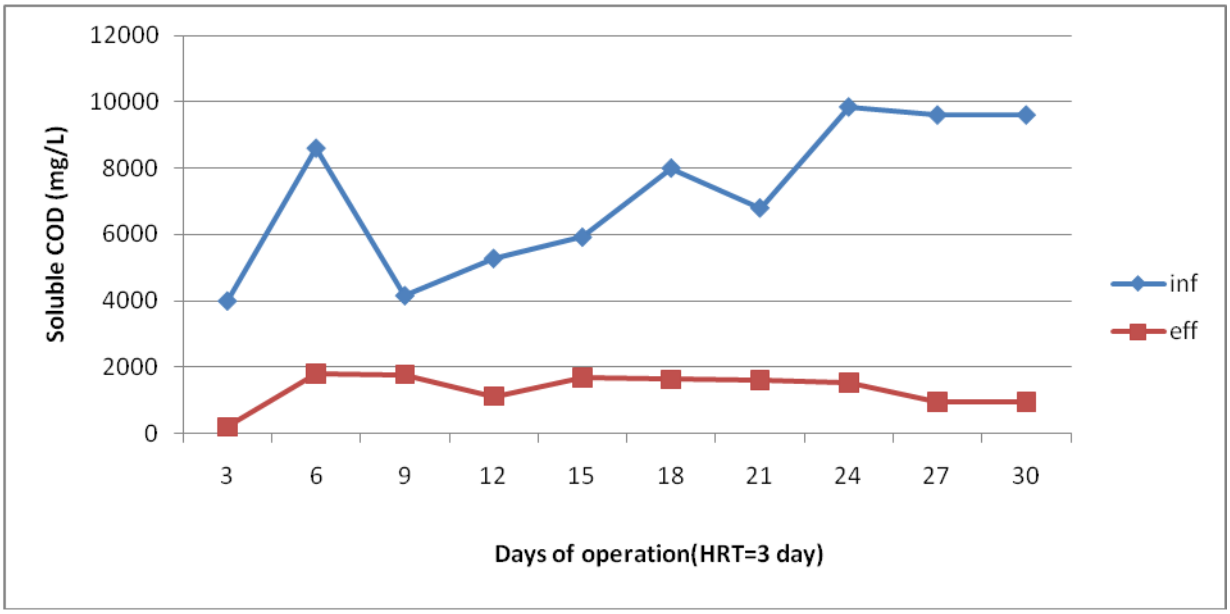


Figure 4.17: Soluble COD (mg/L) of influent and effluent at 3 day HRT in Batch process .

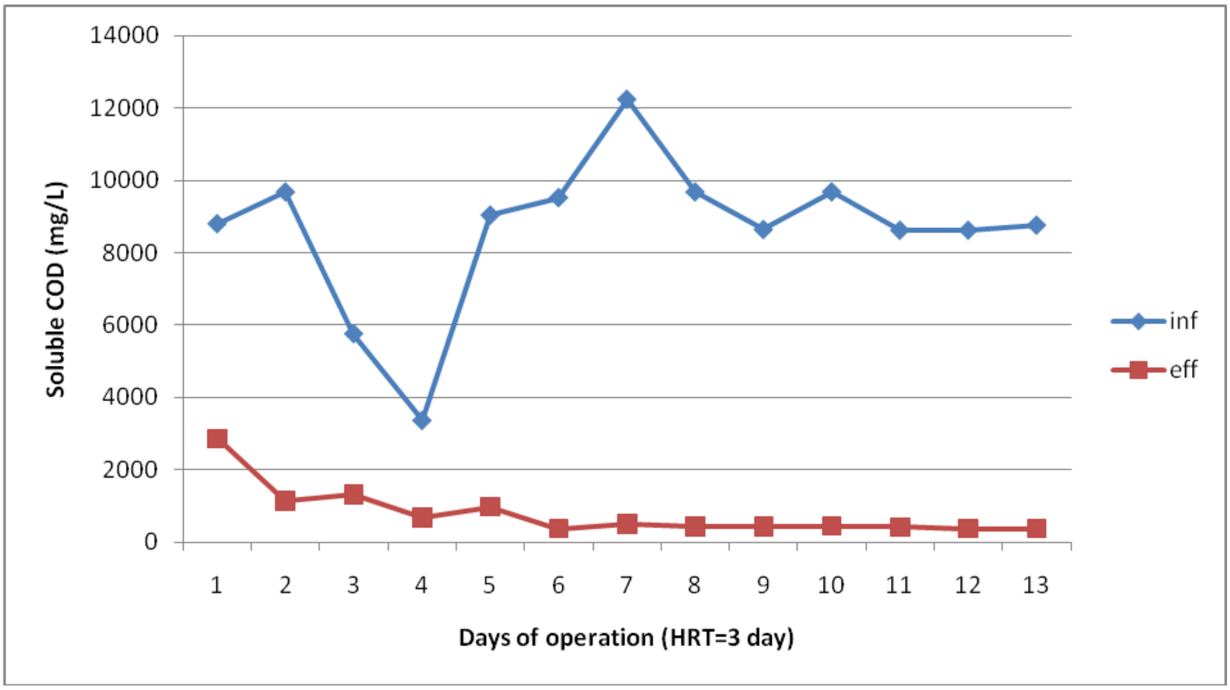


Figure 4.18: Soluble COD (mg/L) of influent and effluent at 3 day HRT in Semi continuous process.

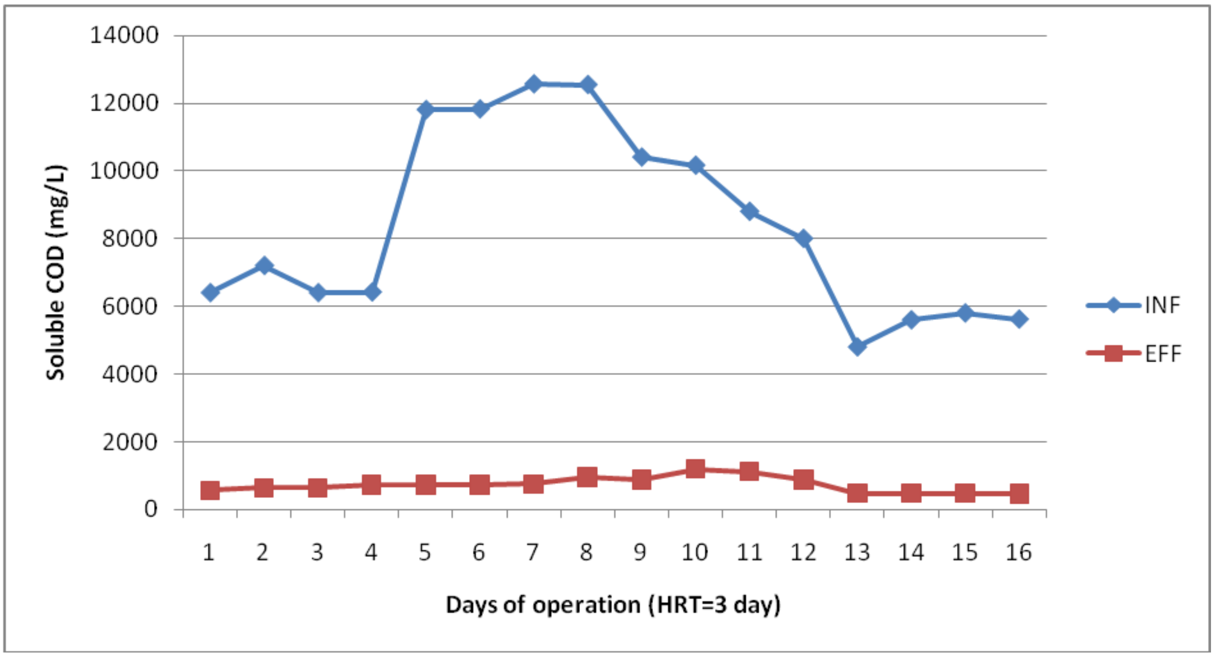


Figure 4.19: Soluble COD (mg/L) of influent and effluent at 3 day HRT in Continuous process

.

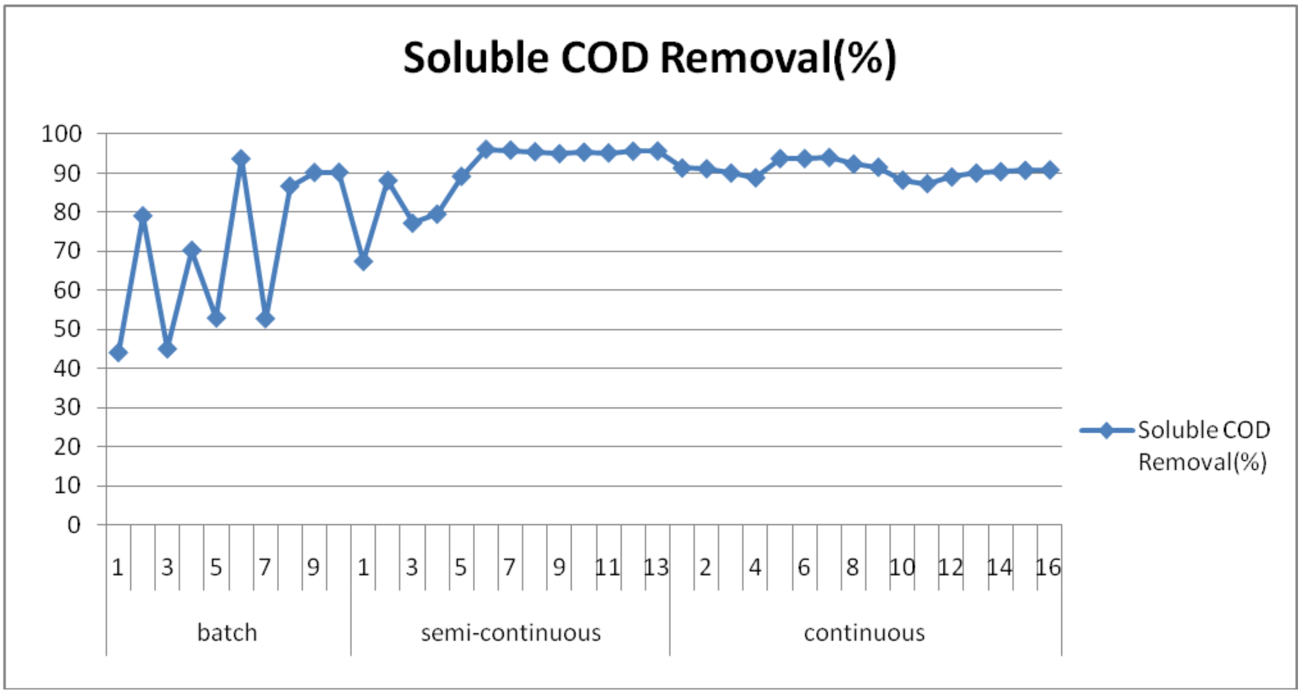


Figure 4.20: Soluble COD removal (%) profile throughout the process.

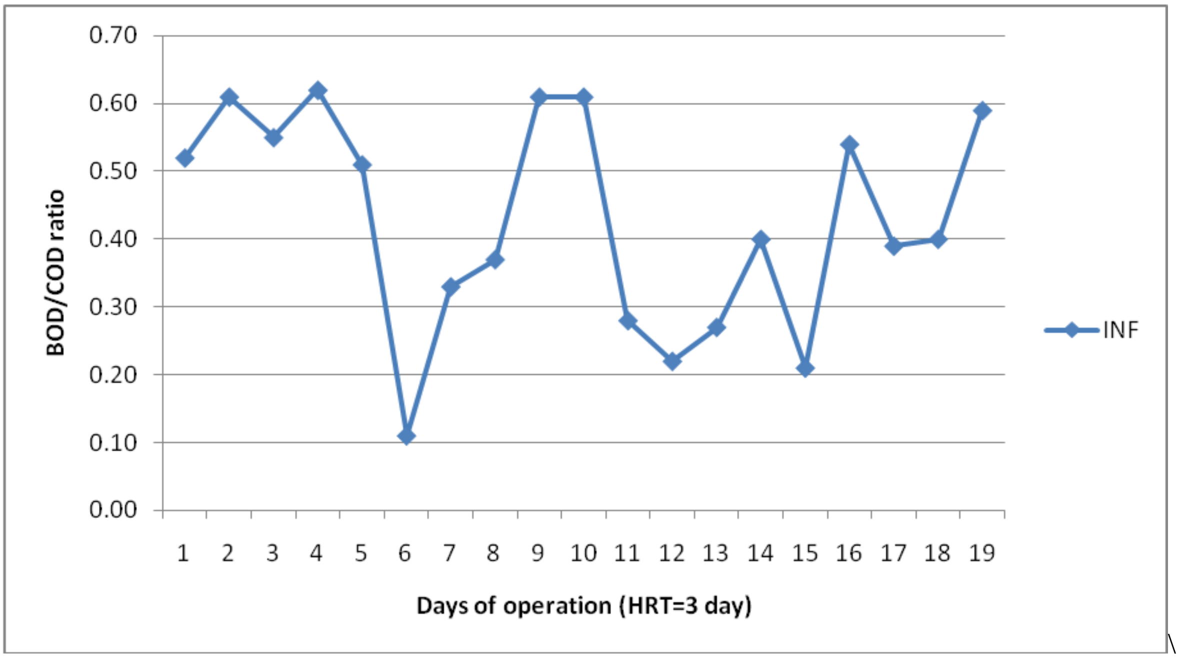


Figure 4.21: Variation in BOD/COD ratio of influent feed to the reactor.

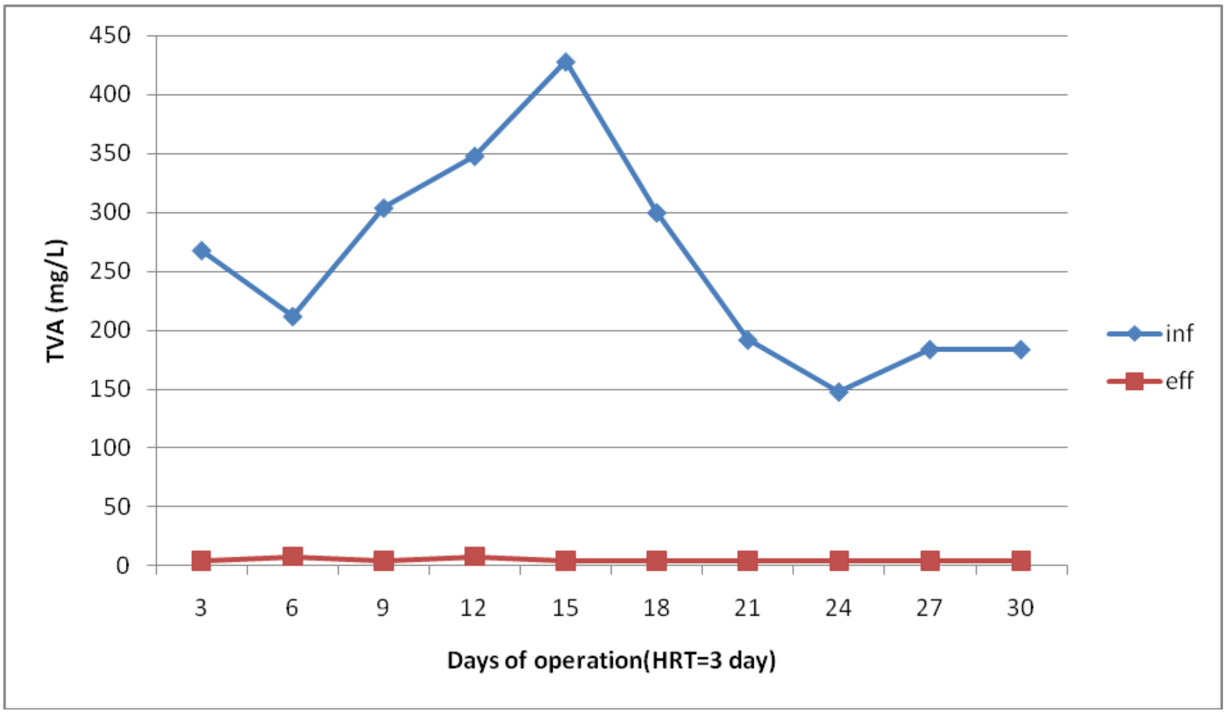


Figure 4.22: TVA (mg/L) of influent and effluent at 3 day HRT in Batch process.

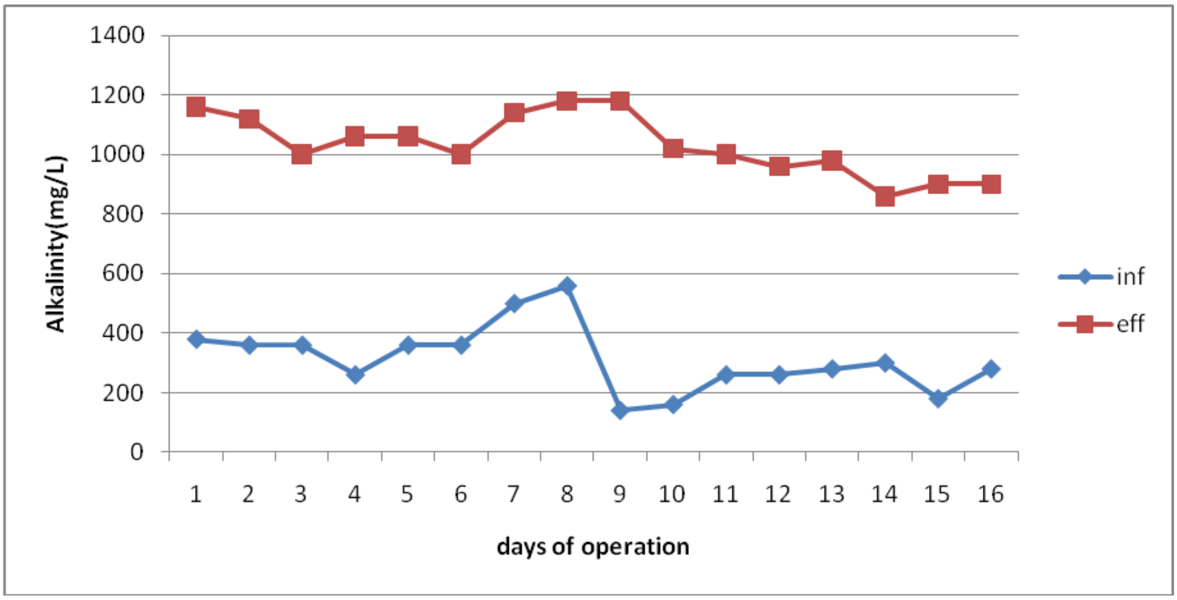


Figure 4.23: TVA (mg/L) of influent and effluent at 3 day HRT in Semi continuous process

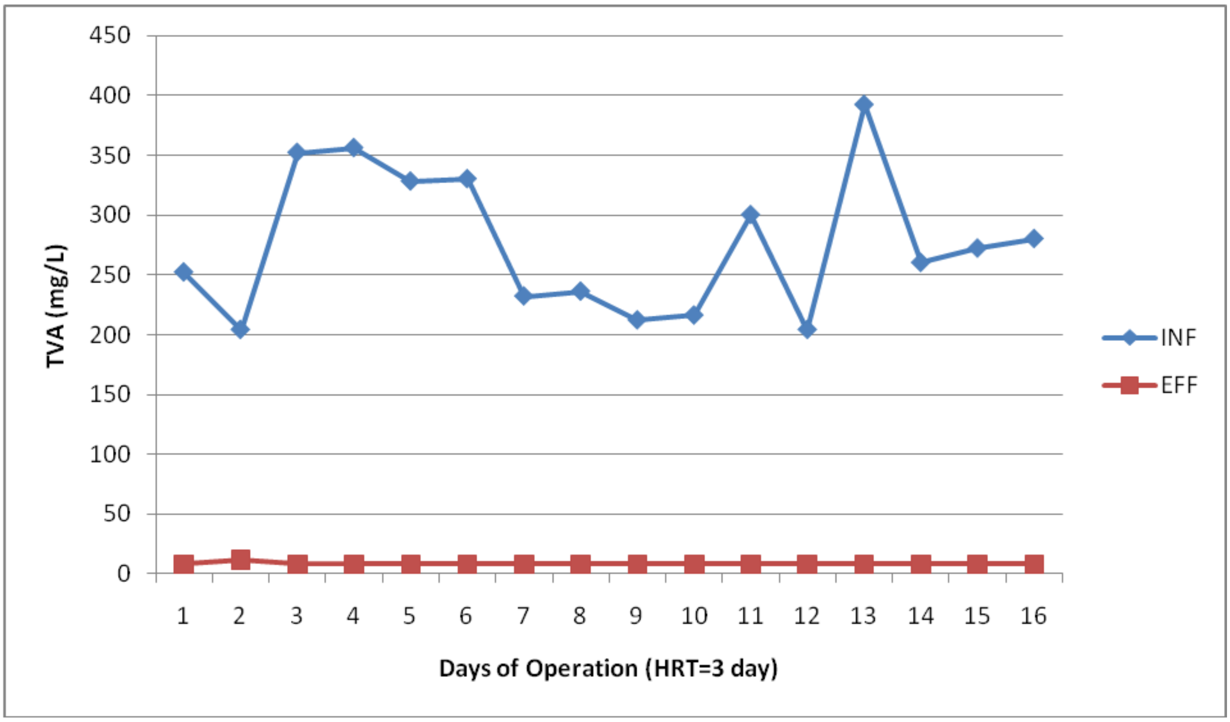


Figure 4.24: TVA (mg/L) of influent and effluent at 3 day HRT in Continuous process .

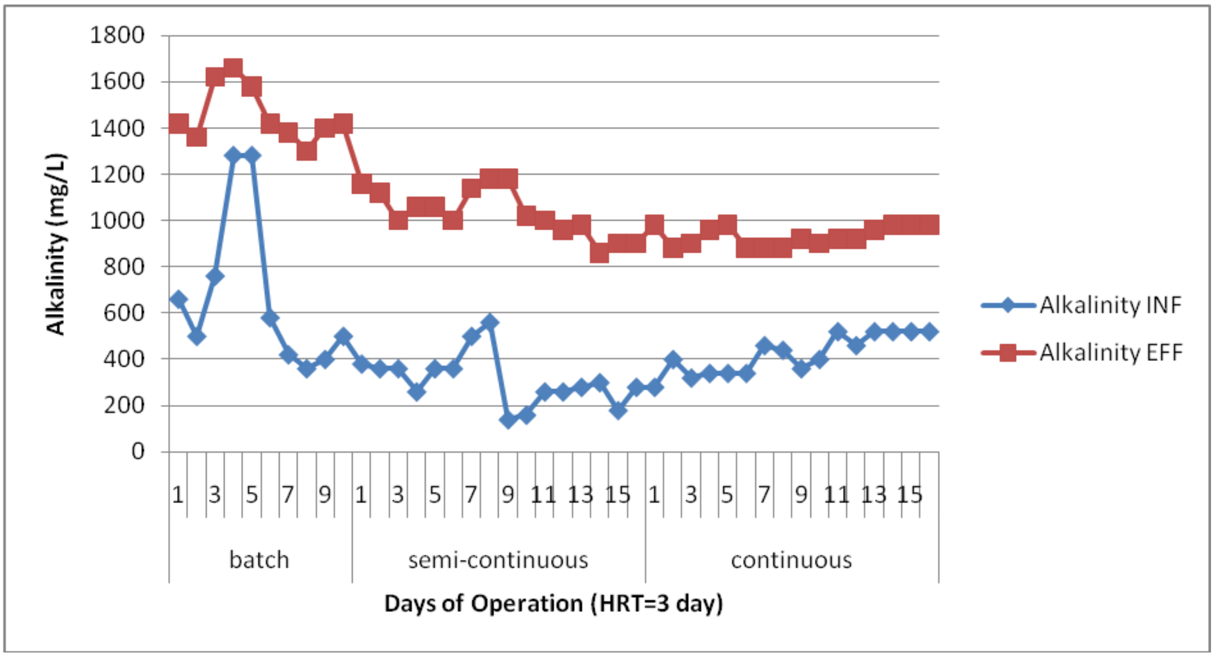


Figure 4.25: Variation in Total Volatile Acids profile throughout the process at 3 day HRT

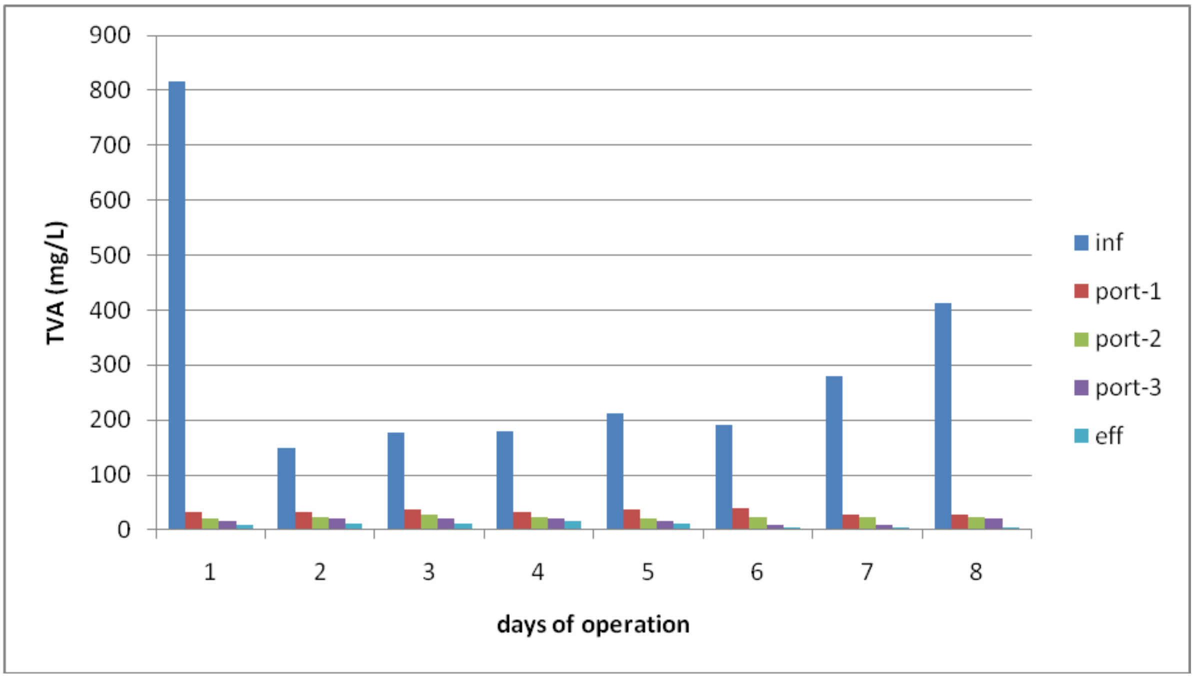


Figure 4.26: Variations in TVA (mg/L) conc. At different ports of reactor

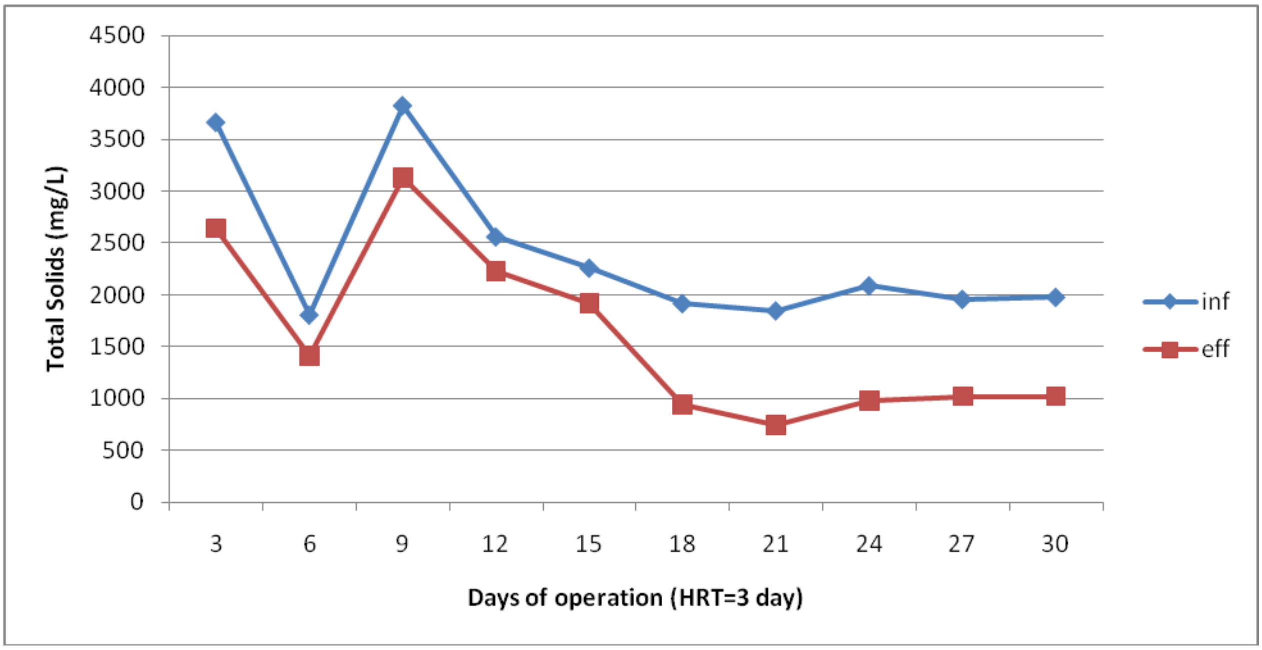


Figure 4.27: Total solids (mg/L) of influent and effluent at 3 day HRT in Batch process.

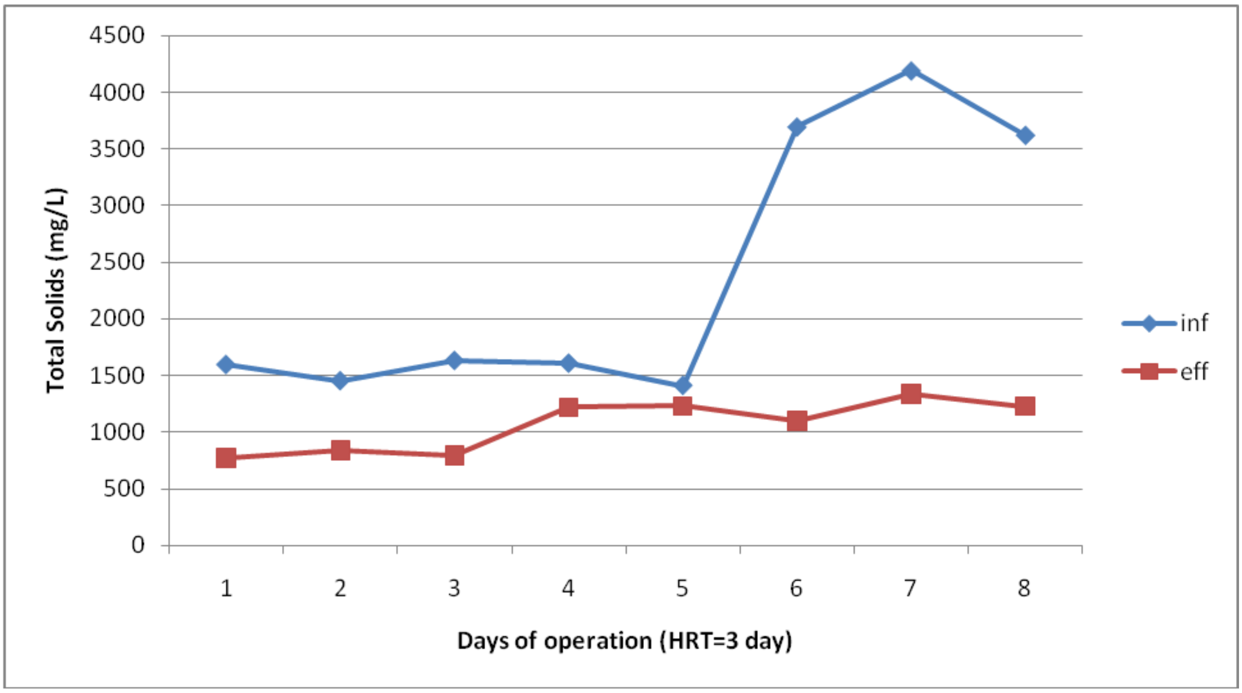


Figure 4.28: Total solids (mg/L) of influent and effluent at 3 day HRT in Semi continuous process.

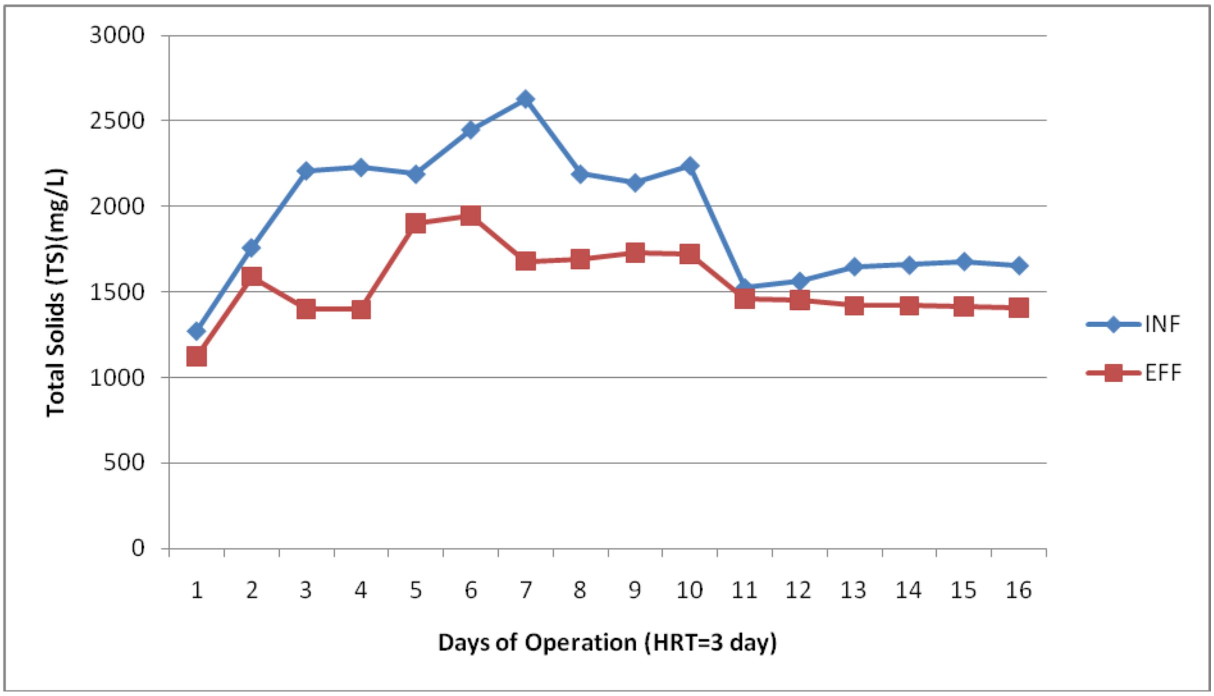


Figure 4.29: Total solids (mg/L) of influent and effluent at 3 day HRT in Continuous process.

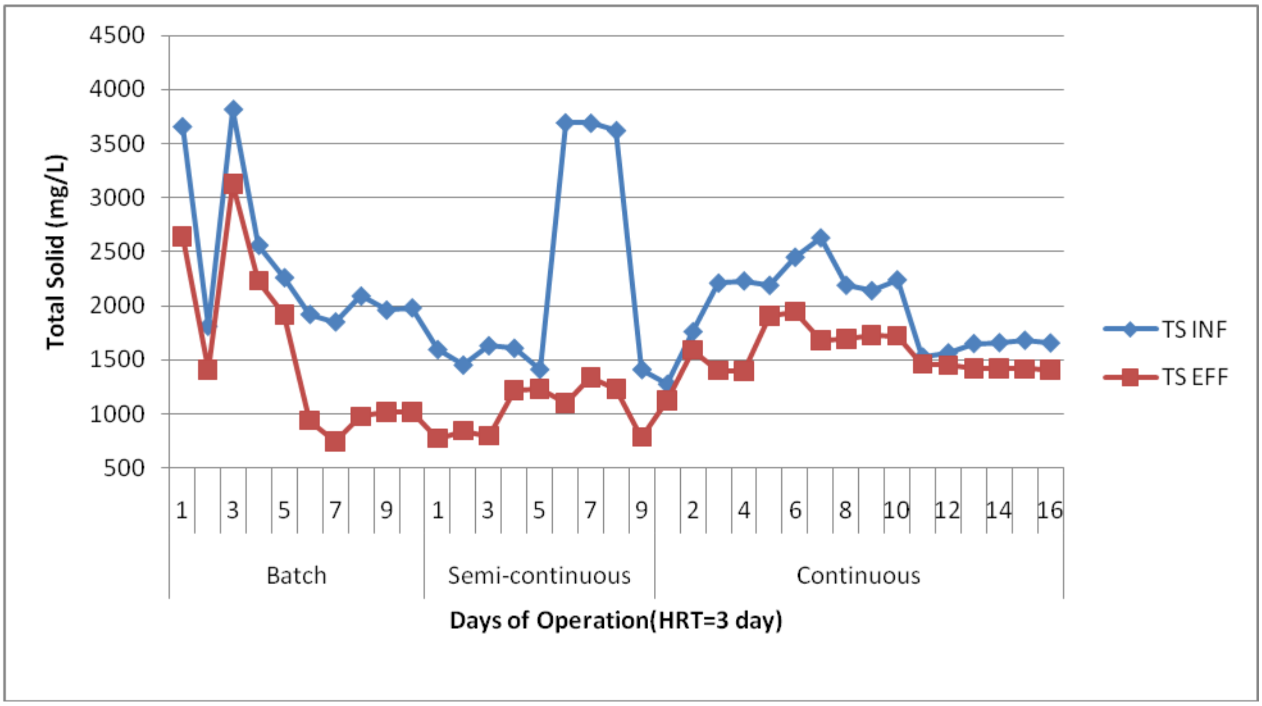


Figure 4.30: Variation in Total Solids (mg/L) conc. in reactor throughout the process.

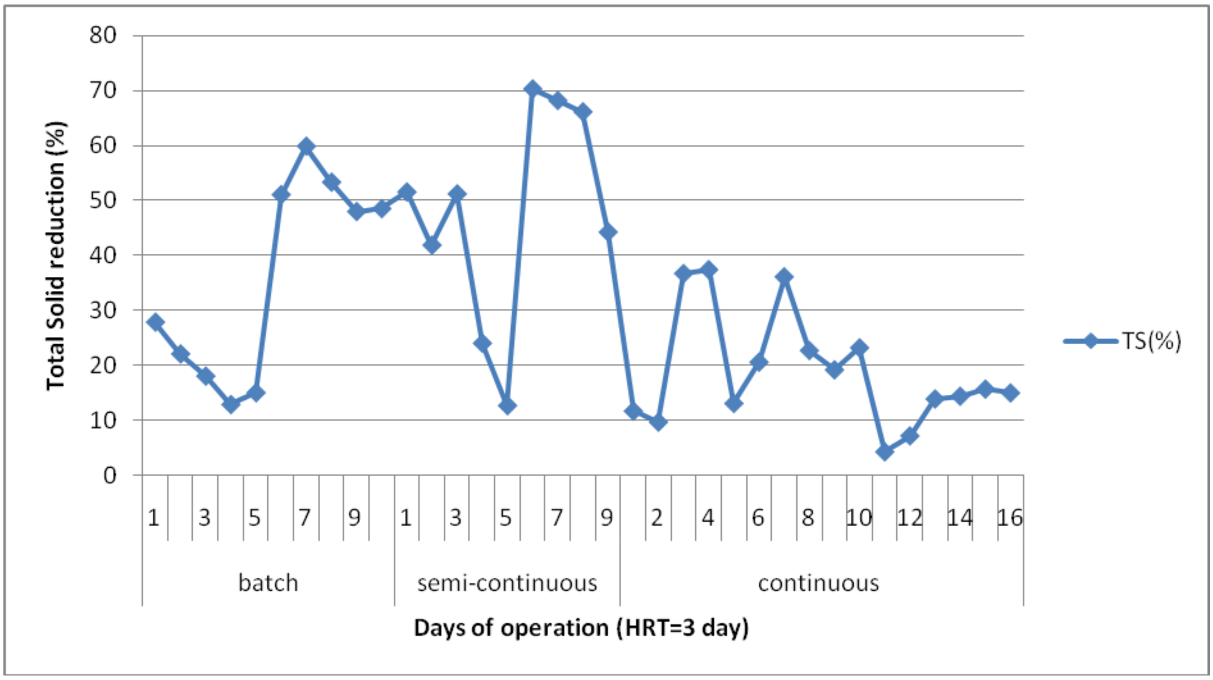


Figure 4.31: Variation in TS reduction (%) in reactor throughout the process.

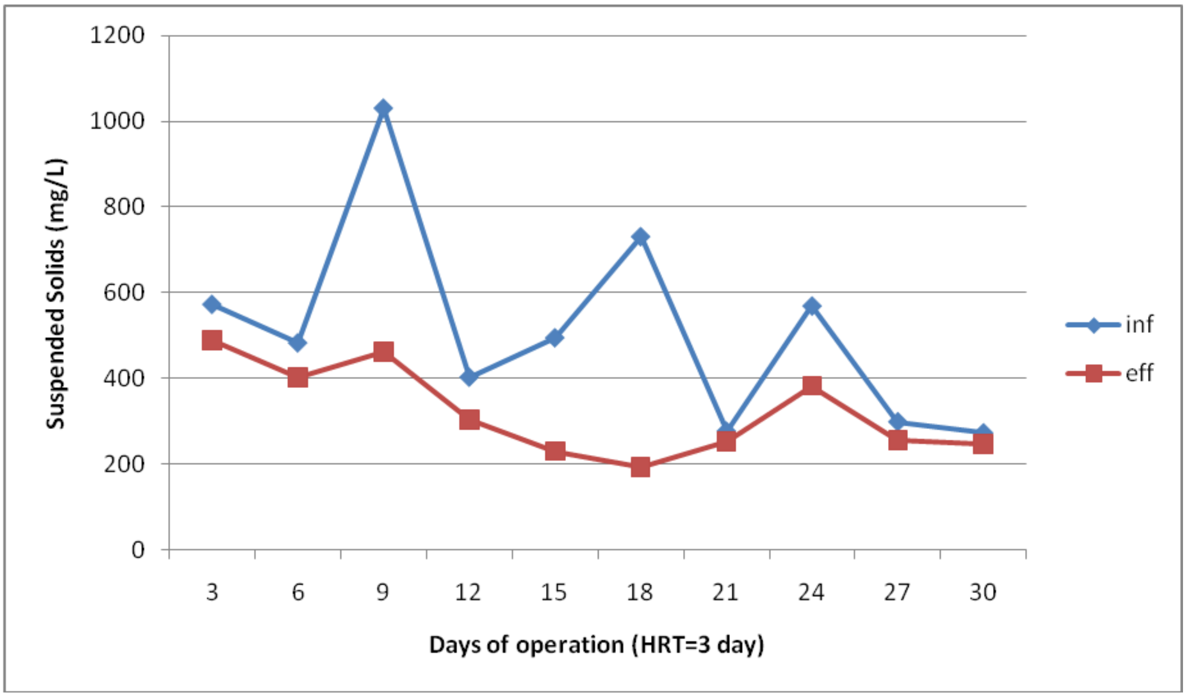


Figure 4.32: Suspended solids (mg/L)of influent and effluent at 3 day HRT in batch process

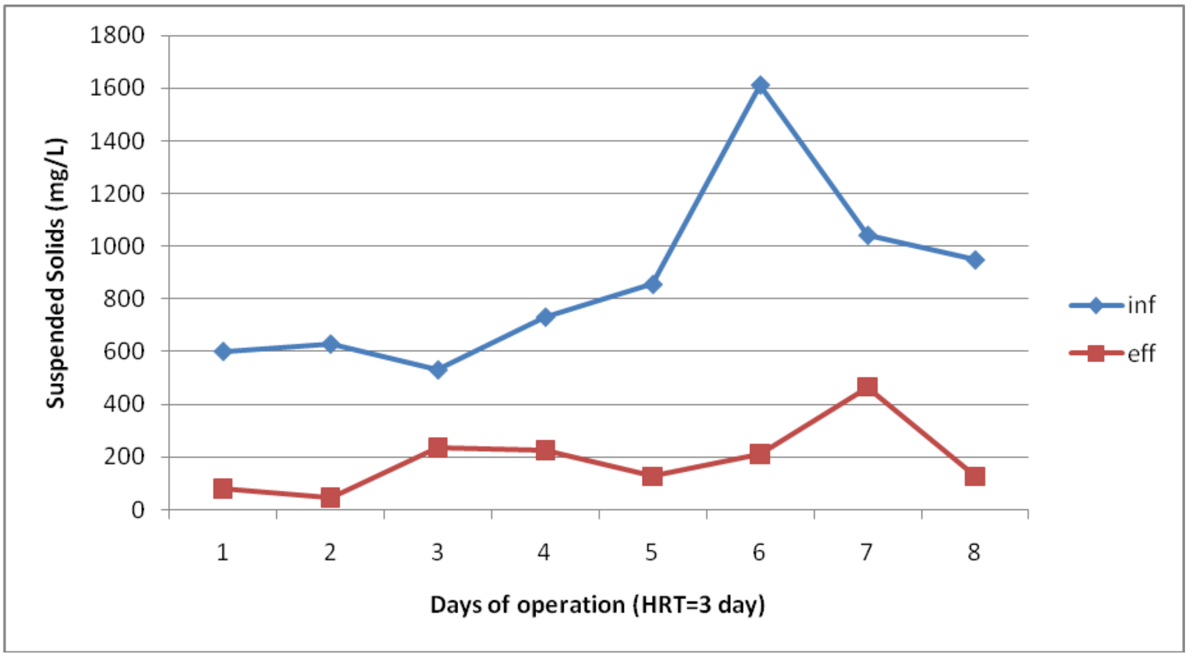


Figure 4.33: Suspended solids (mg/L)of influent and effluent at 3 day HRT in Semi continuous process.

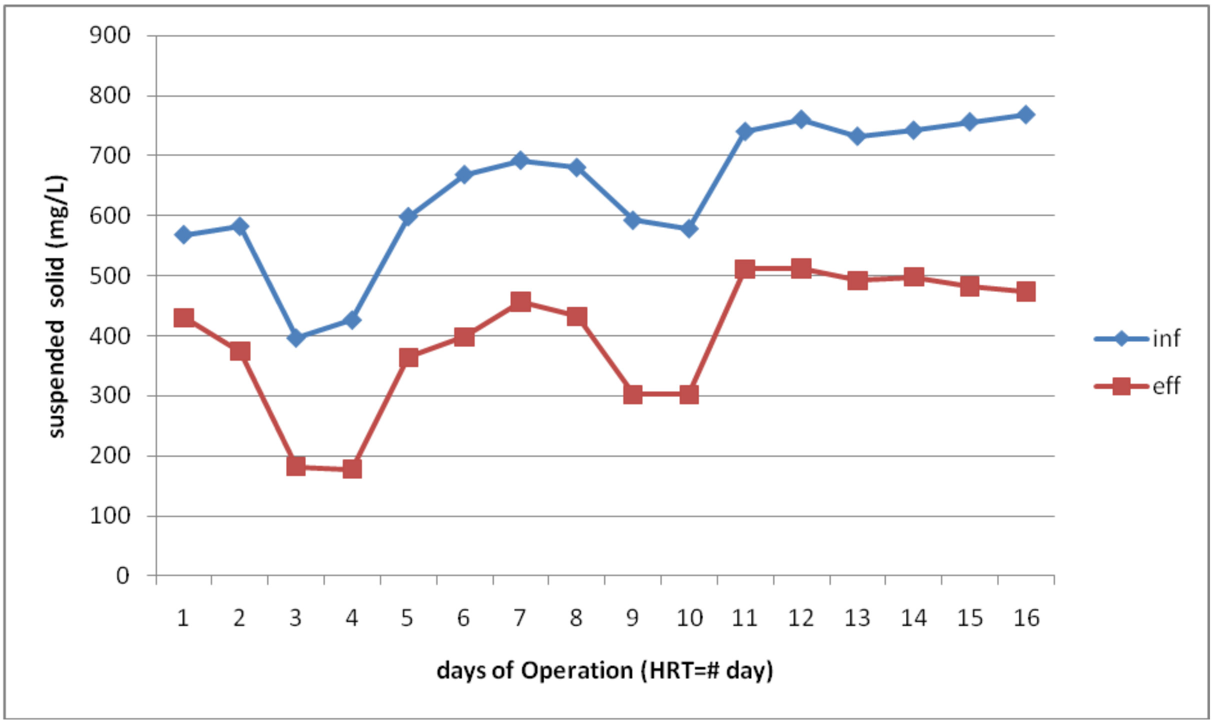


Figure 4.34: suspended solids (mg/L) of influent and effluent at 3 day HRT in Continuous process.

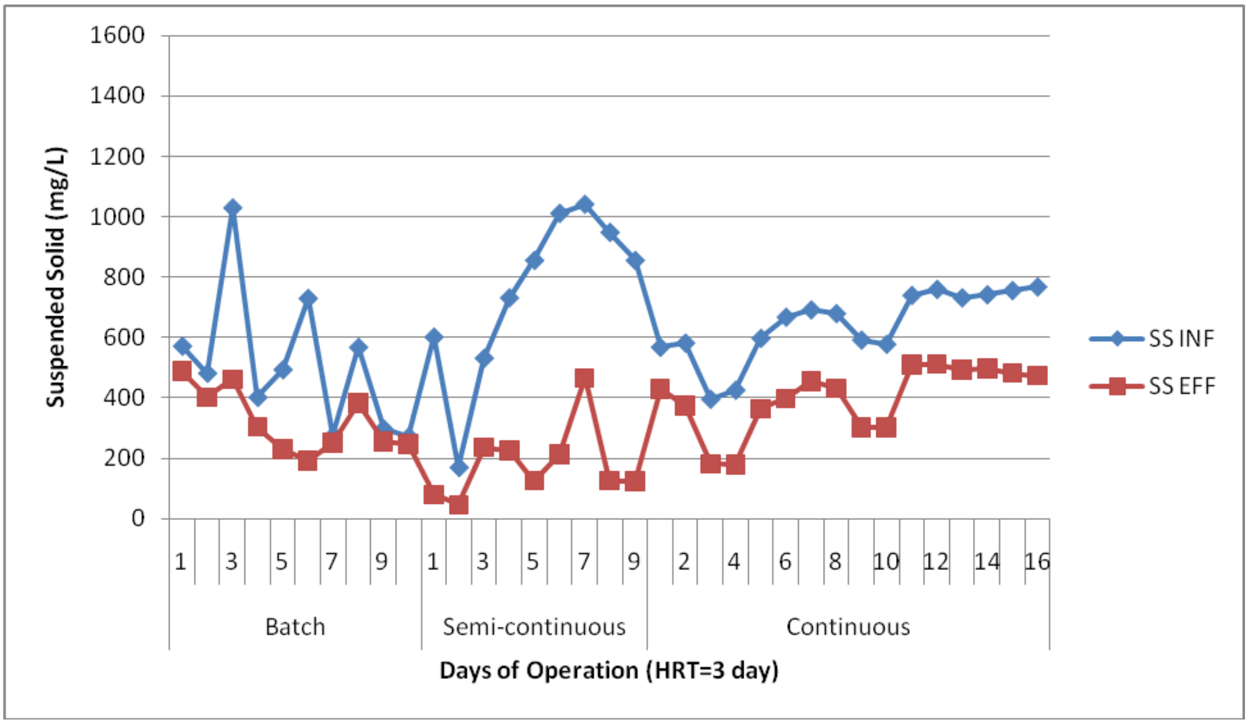


Figure 4.35: Variation in Suspended Solids (mg/L)conc. in reactor throughout the process

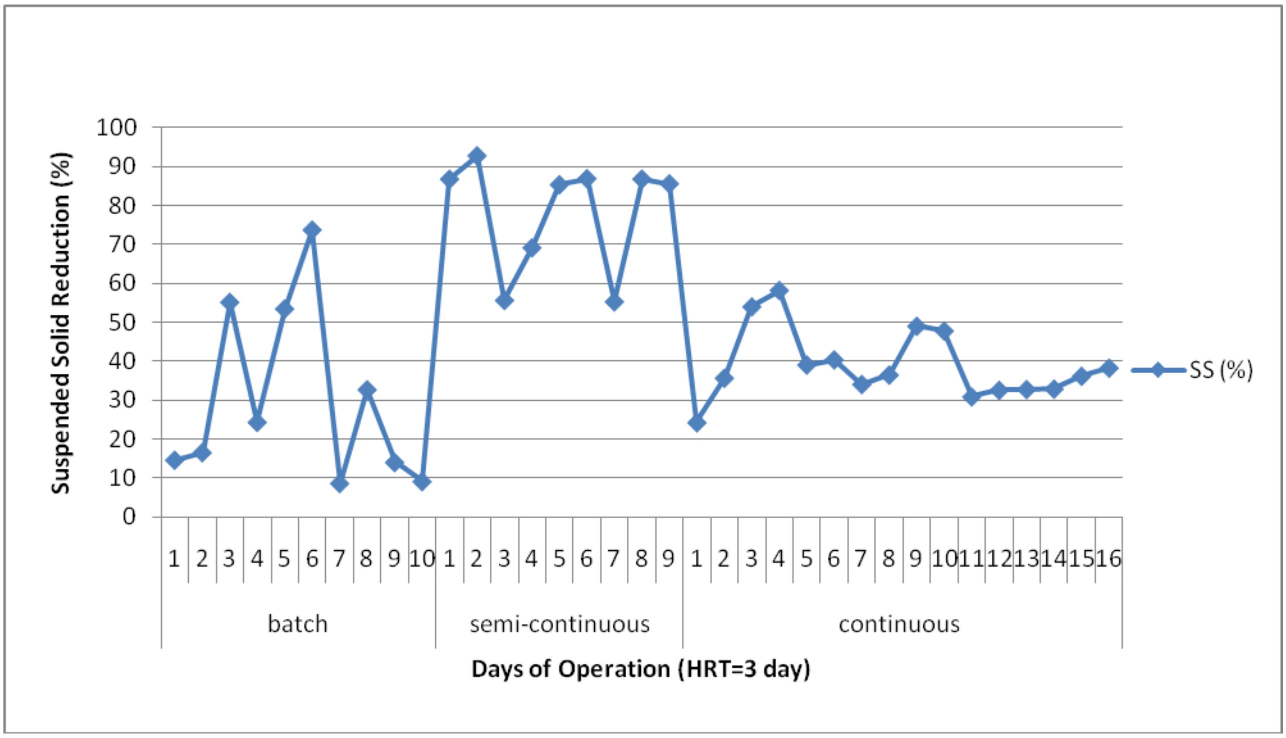


Figure 4.36: Variation in Suspended solid reduction (%) in reactor throughout the process.

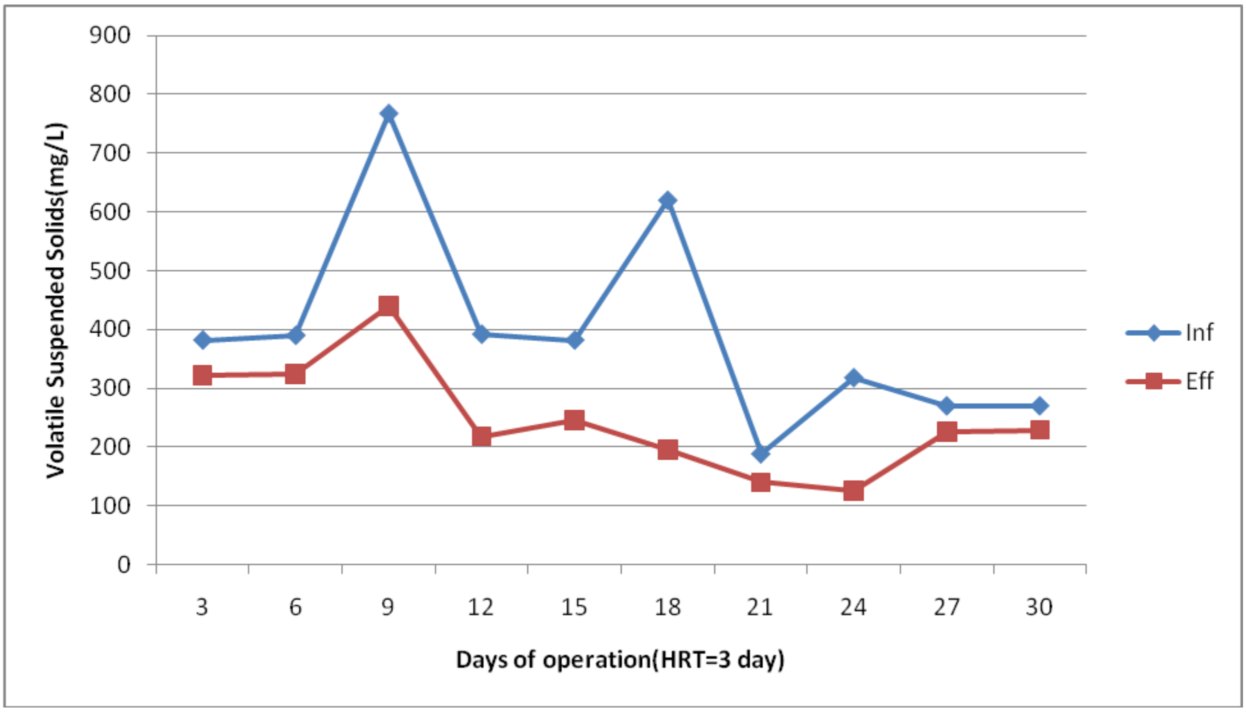


Figure 4.37: Volatile solids (mg/L) of influent and effluent at 3 day HRT in batch process.

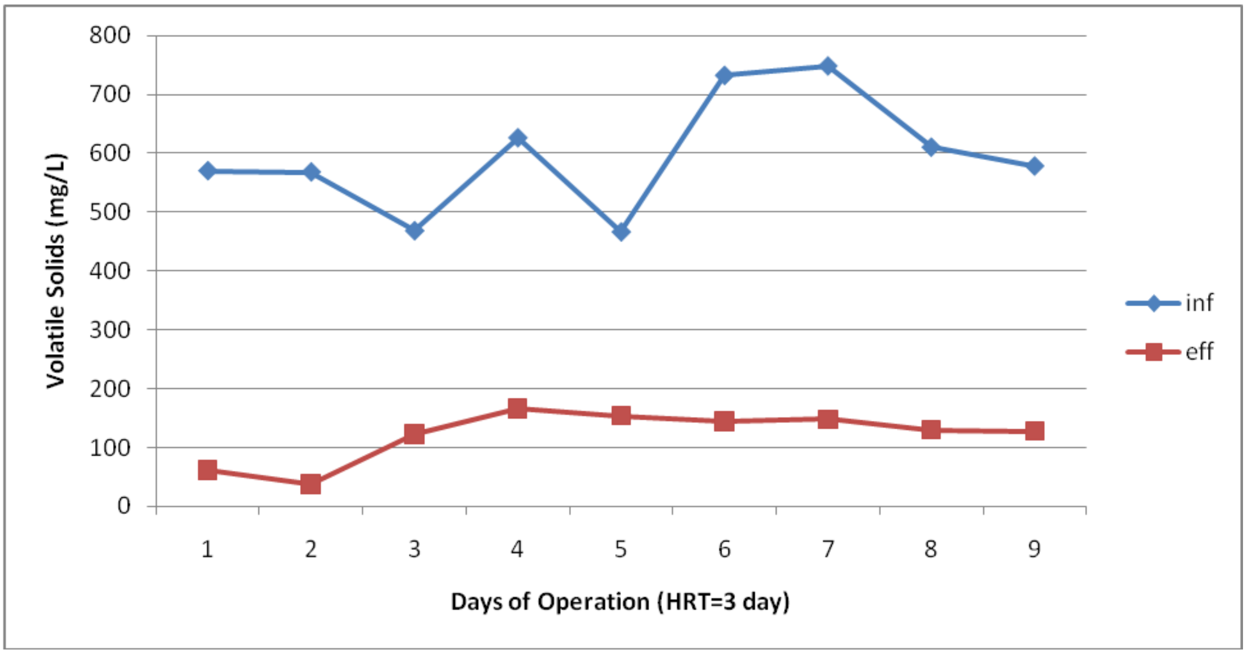


Figure 4.38: Volatile solids (mg/L) of influent and effluent at 3 day HRT in semi continuous process.

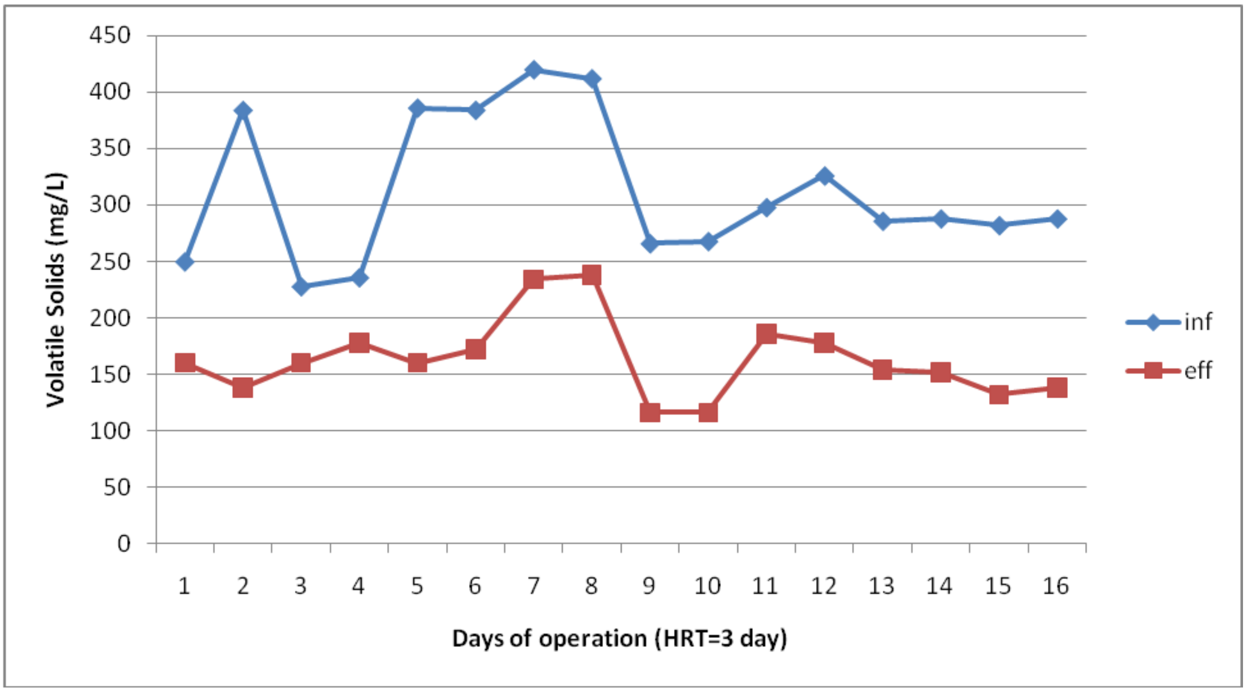


Figure 4.39: Volatile solids (mg/L)of influent and effluent at 3 day HRT in Continuous process.

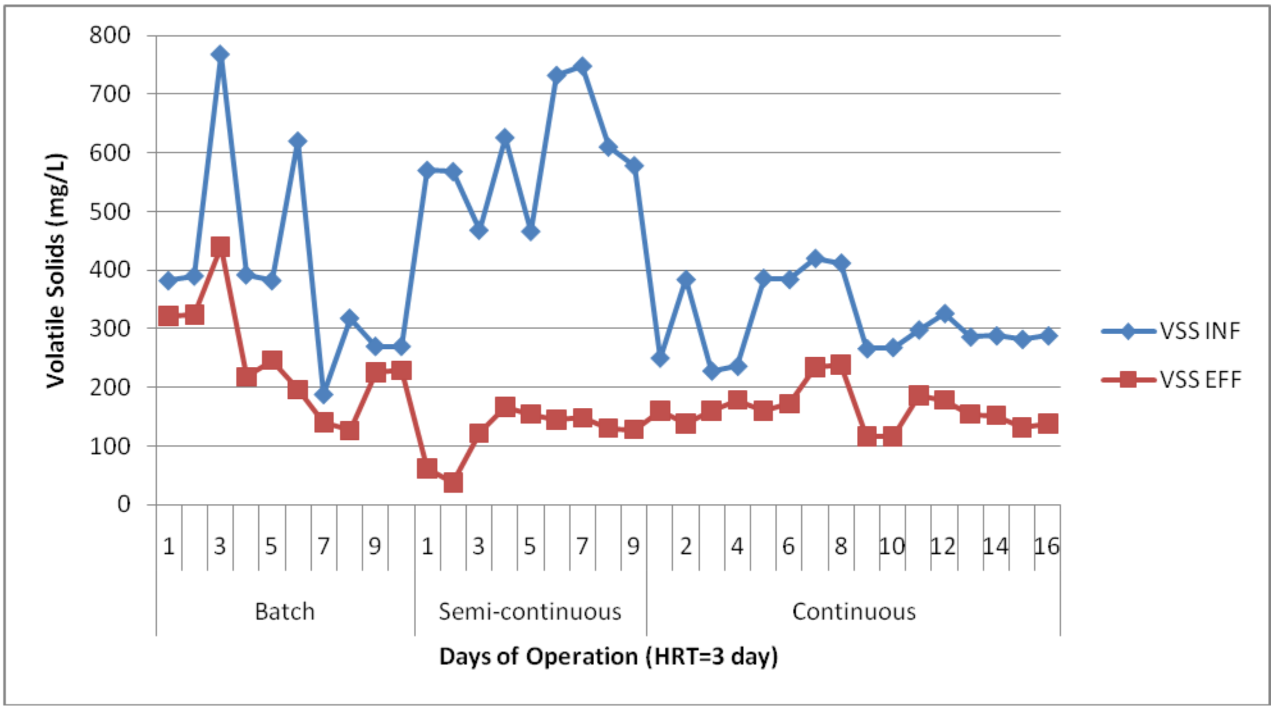


Figure 4.40: Variation in volatile solid conc. in reactor throughout the process.

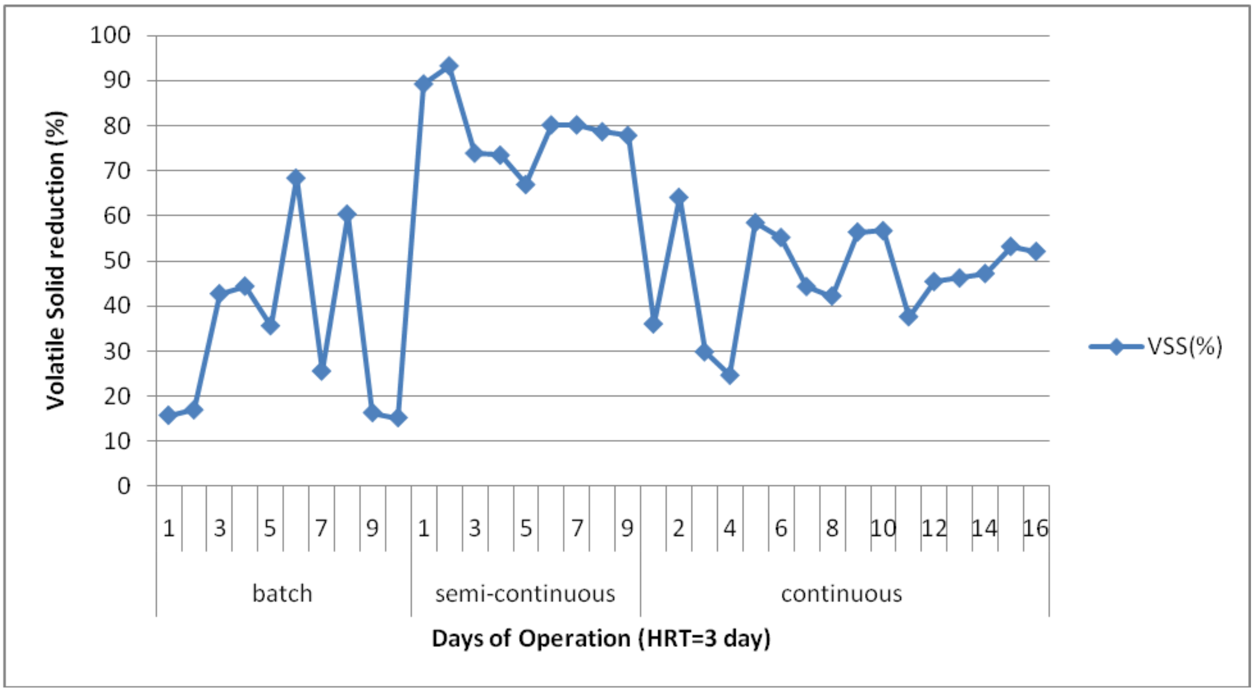


Figure 4.41: Variation in Volatile solid reduction (%) in reactor throughout the process.

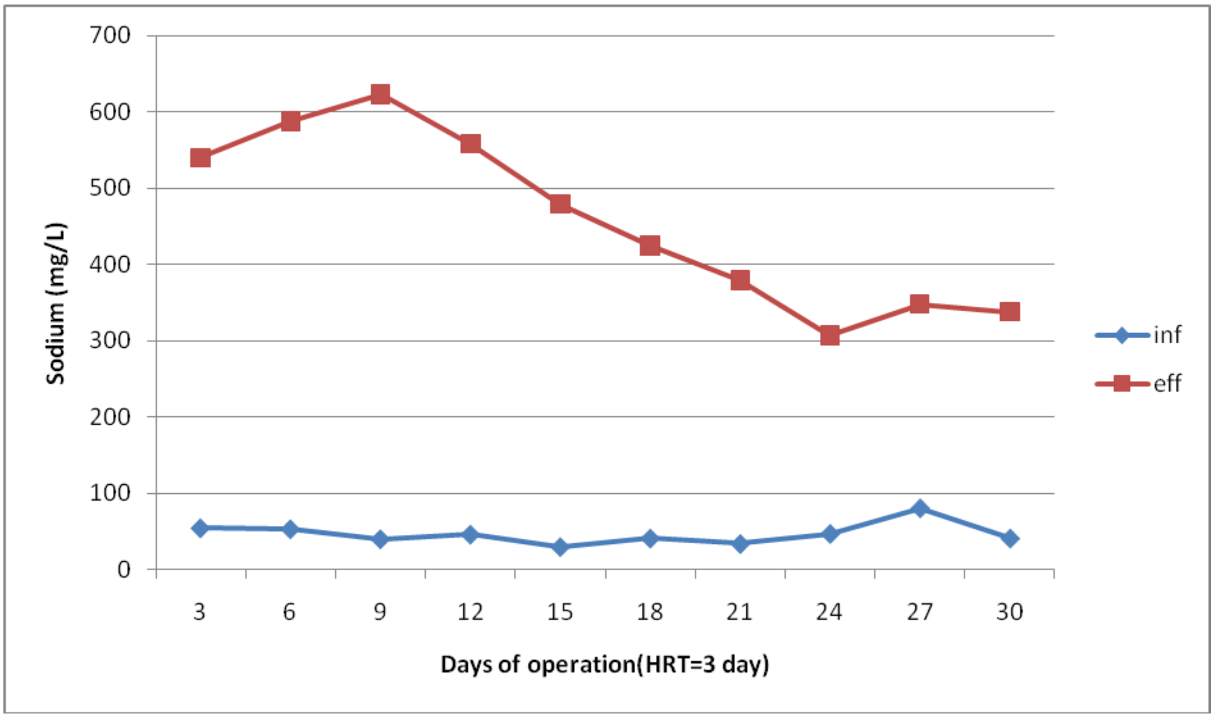


Figure 4.42: Sodium (mg/L) of influent and effluent at 3 day HRT in batch process.

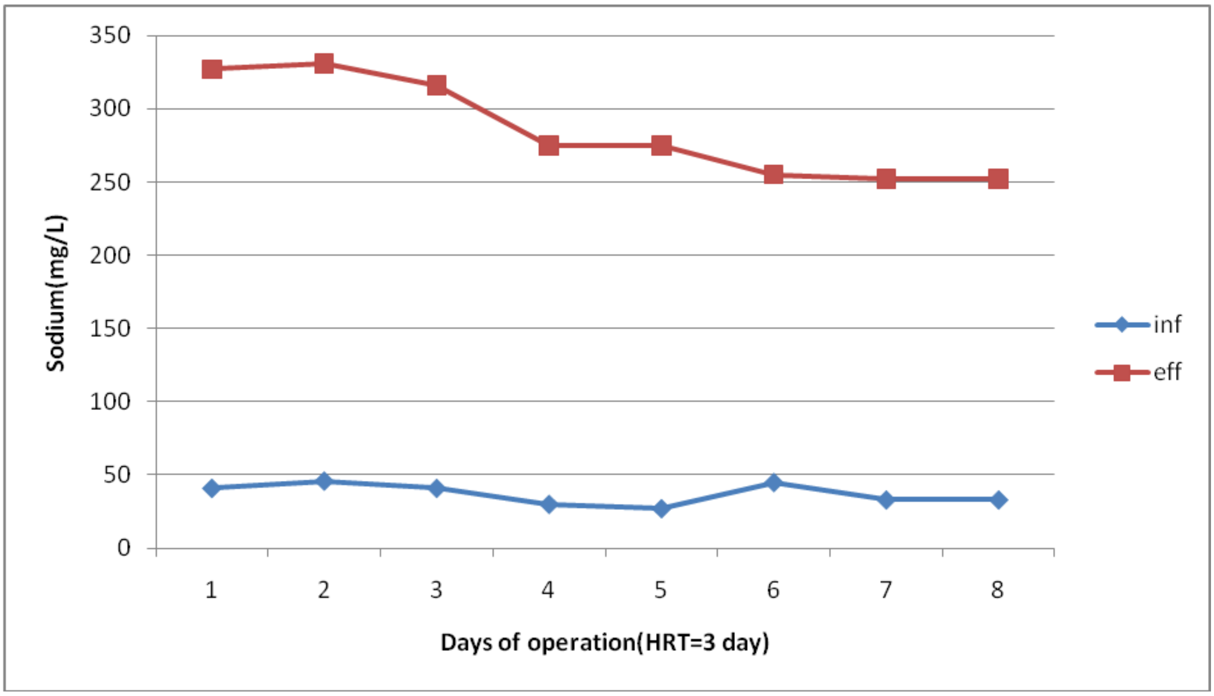


Figure 4.43: Sodium (mg/L) of influent and effluent at 3 day HRT in Semi-continuous process.

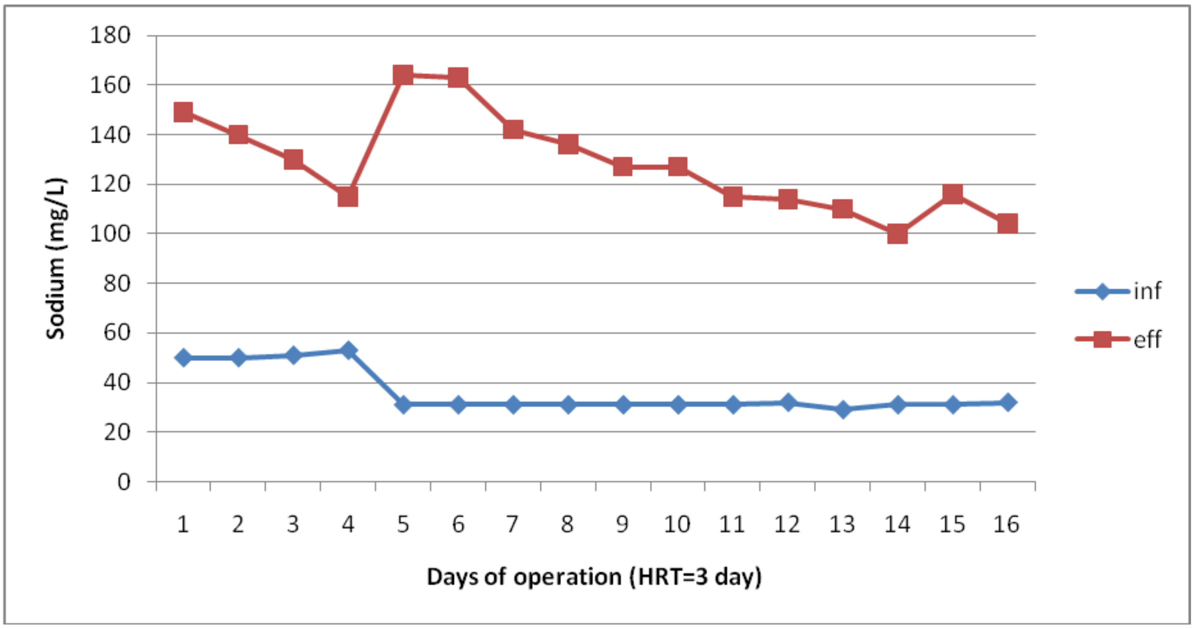


Figure 4.44: Sodium (mg/L)of influent and effluent at 3 day HRT in continuous process.

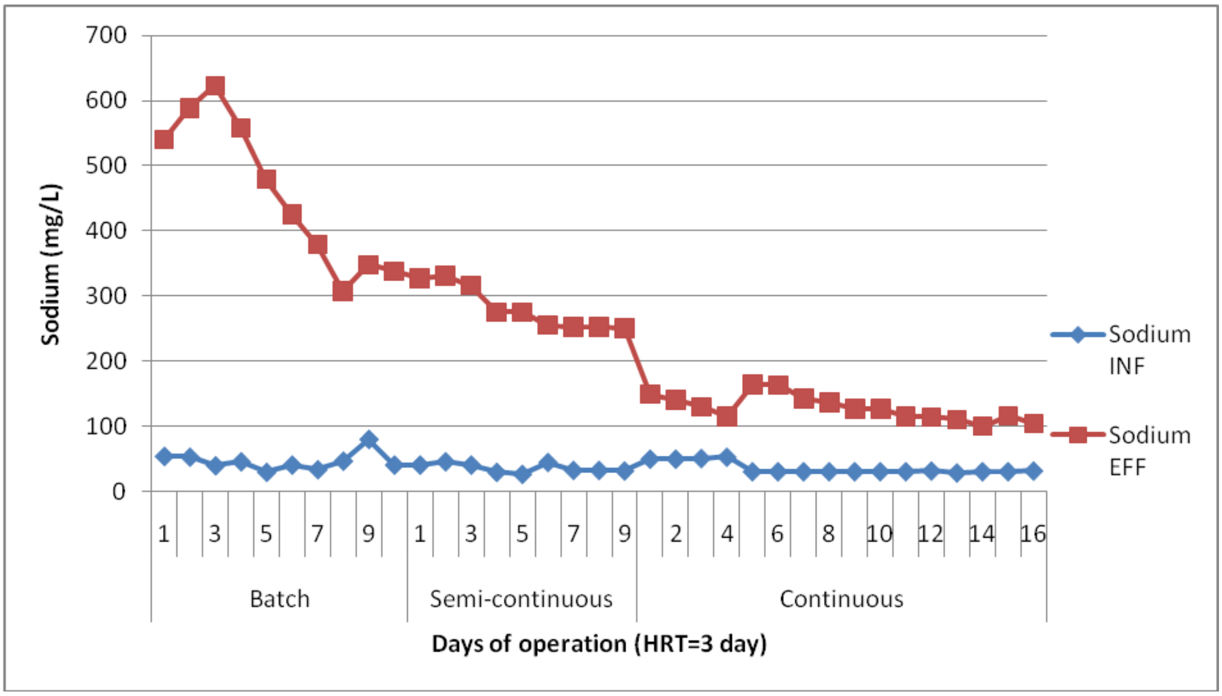


Figure 4.45: Variation in sodium conc. in reactor throughout the process.

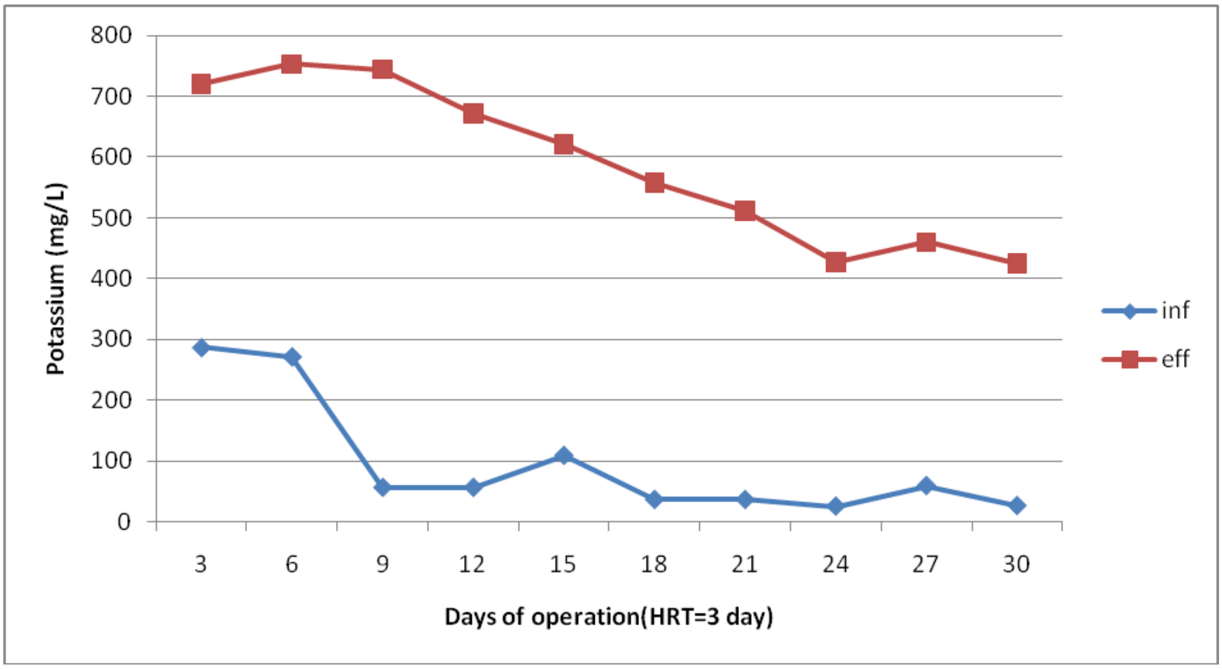


Figure 4.46: Potassium (mg/L)of influent and effluent at 3 day HRT in Batch process.

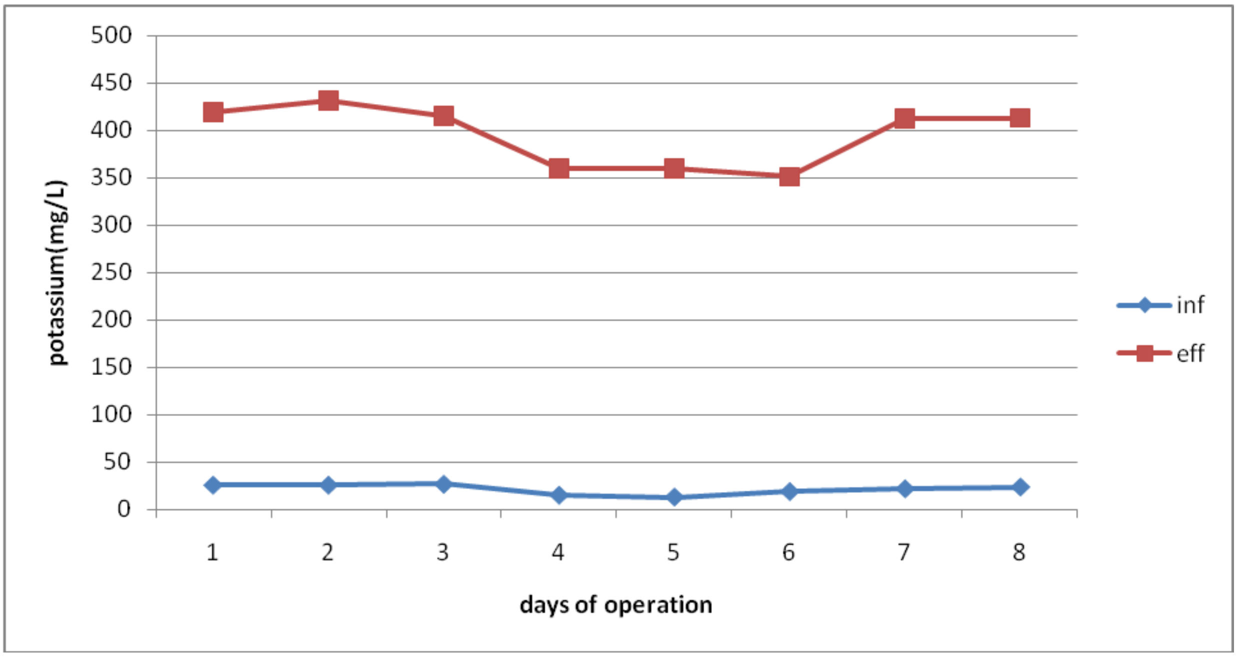


Figure 4.47: Potassium (mg/L) of influent and effluent at 3 day HRT in Semi- continuous process.

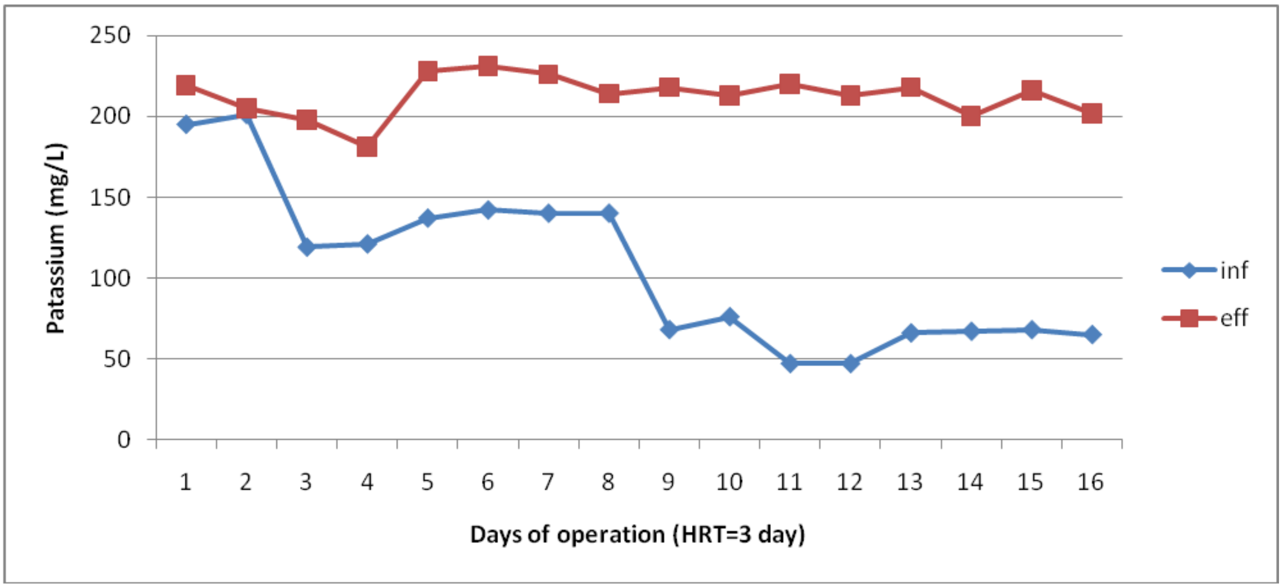


Figure 4.48: Potassium (mg/L)of influent and effluent at 3 day HRT in continuous process.

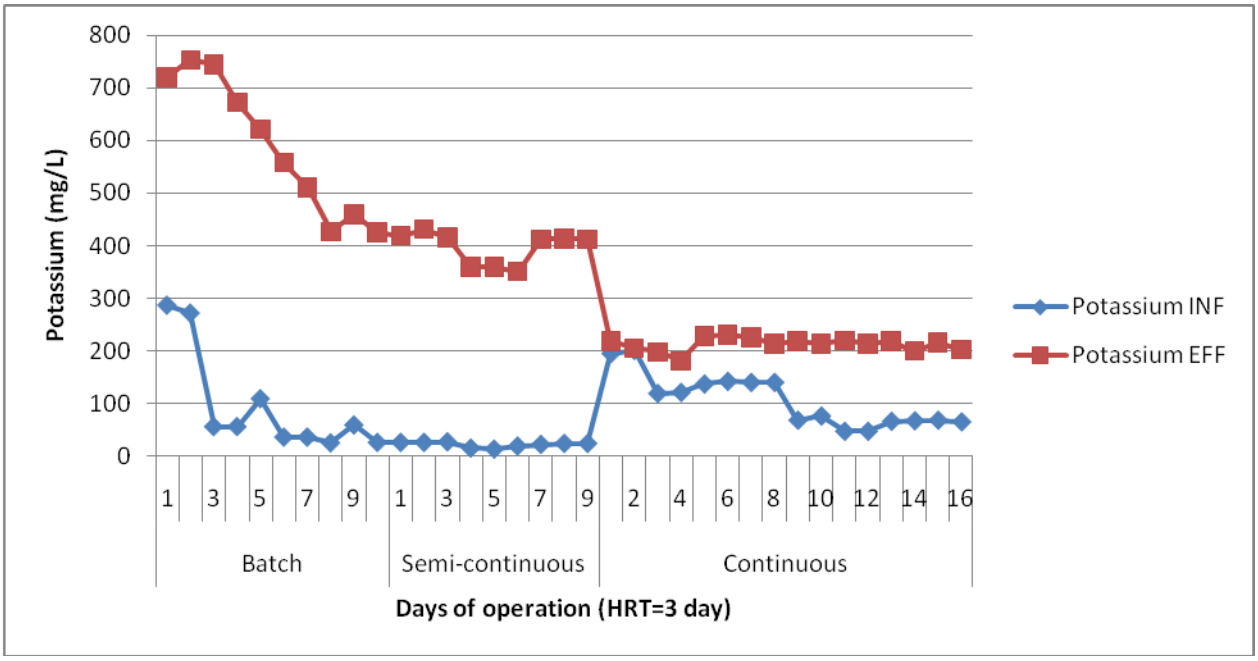


Figure 4.49: Variation in potassium conc.(mg/L) of influent and effluent in reactor throughout the process.

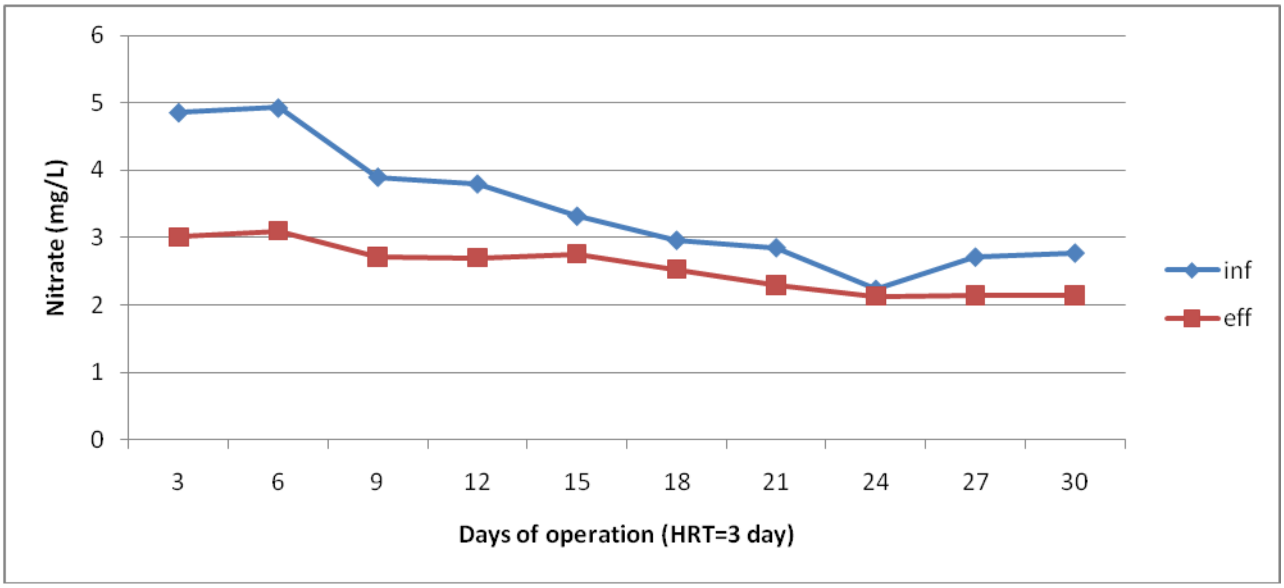


Figure 4.50: Nitrate (mg/L) of influent and effluent at 3 day HRT in Batch process.

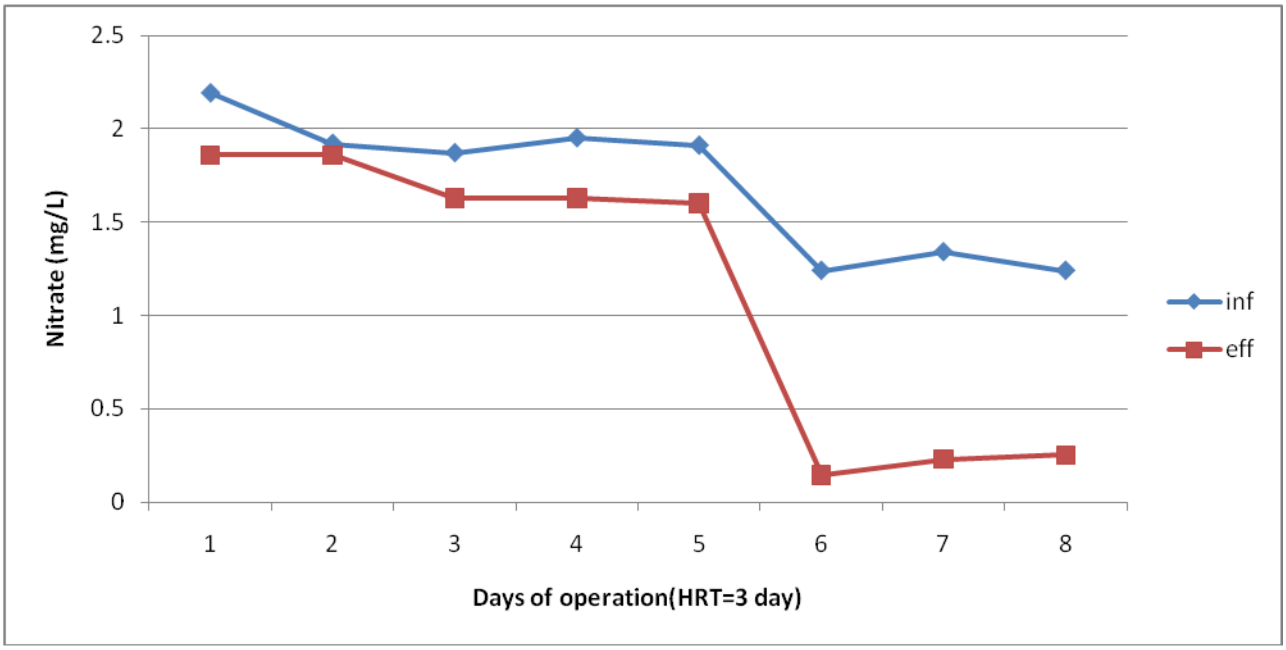


Figure 4.51: Nitrate (mg/L)of influent and effluent at 3 day HRT in Semi-continuous process

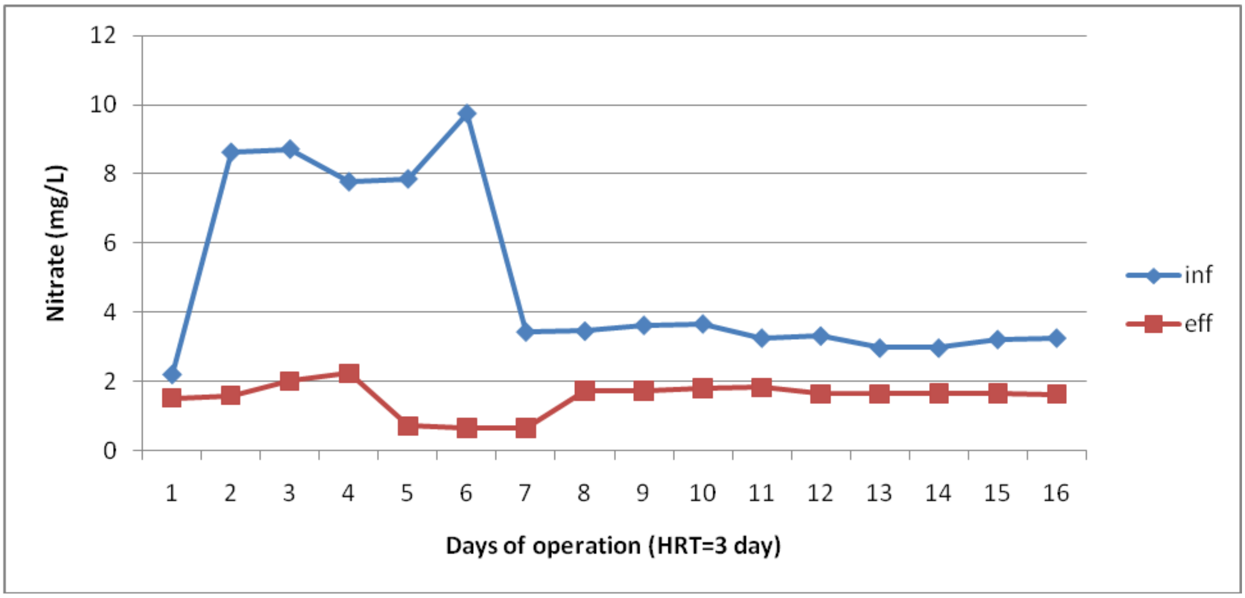


Figure 4.52: Nitrate (mg/L)of influent and effluent at 3 day HRT in continuous process.

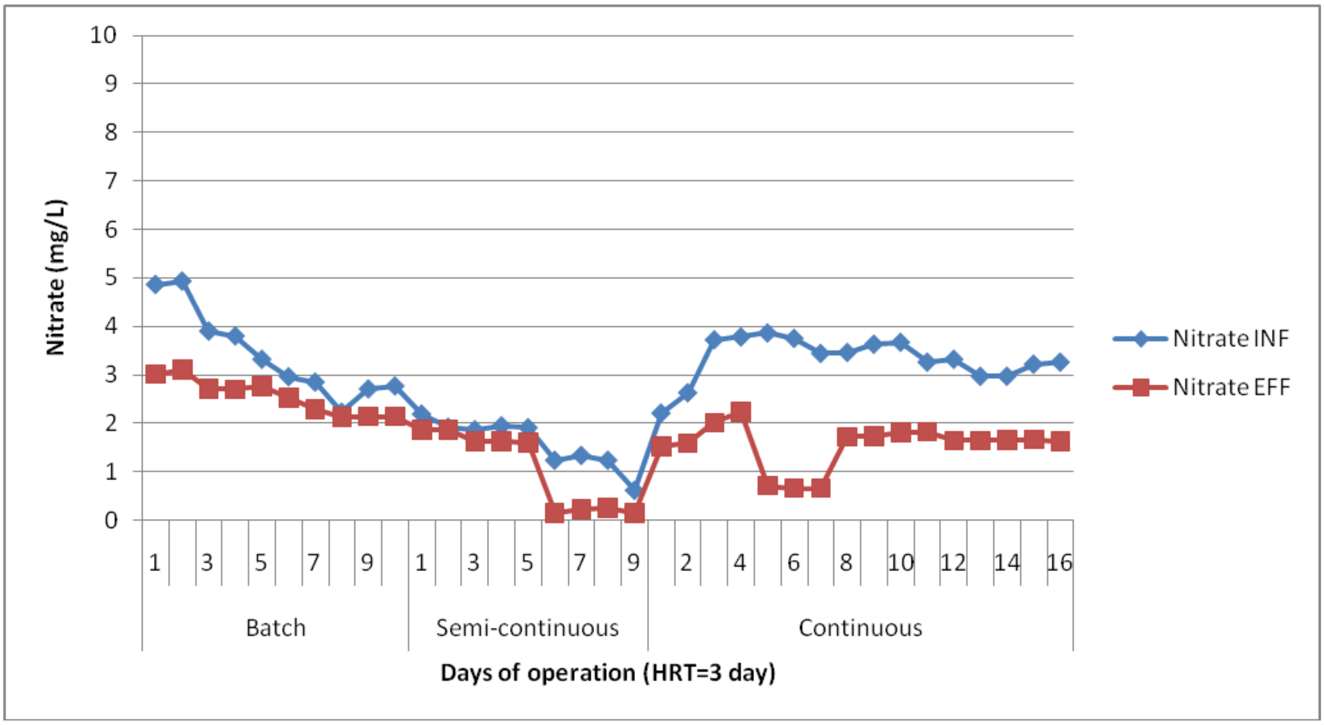


Figure 4.53: Variation in Nitrate conc. (mg/L) in reactor throughout the process.

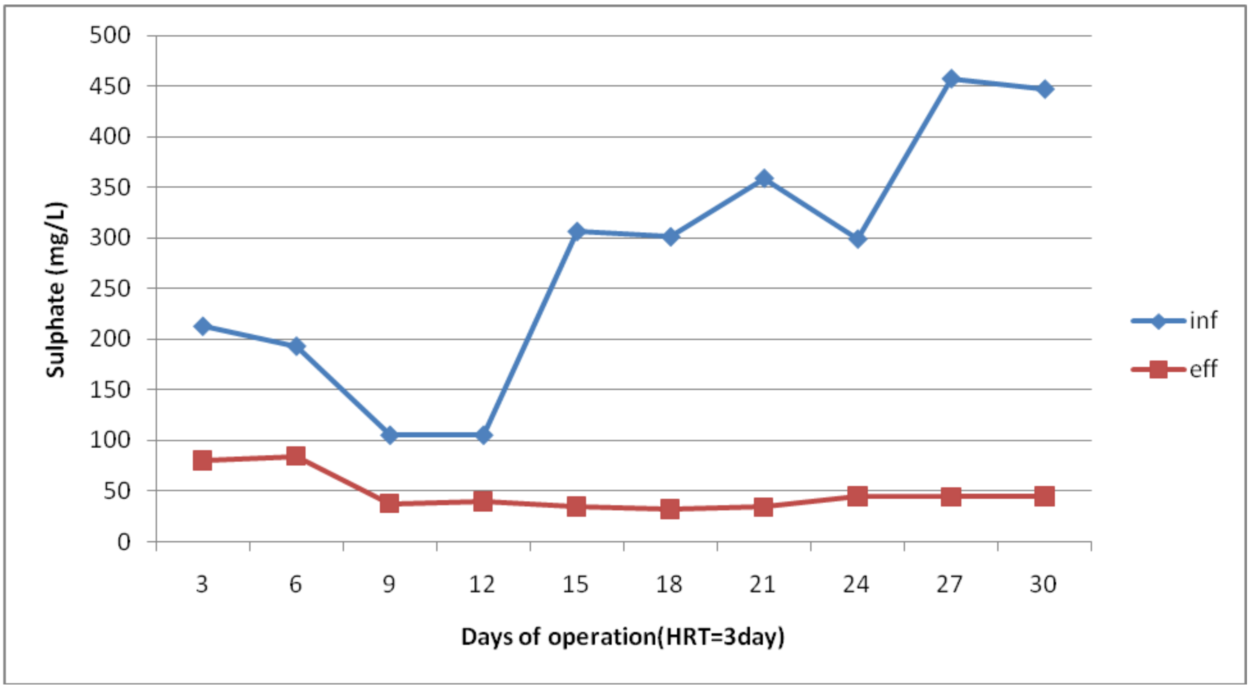


Figure 4.54: Sulphate (mg/L)of influent and effluent at 3 day HRT in Semi-continuous process

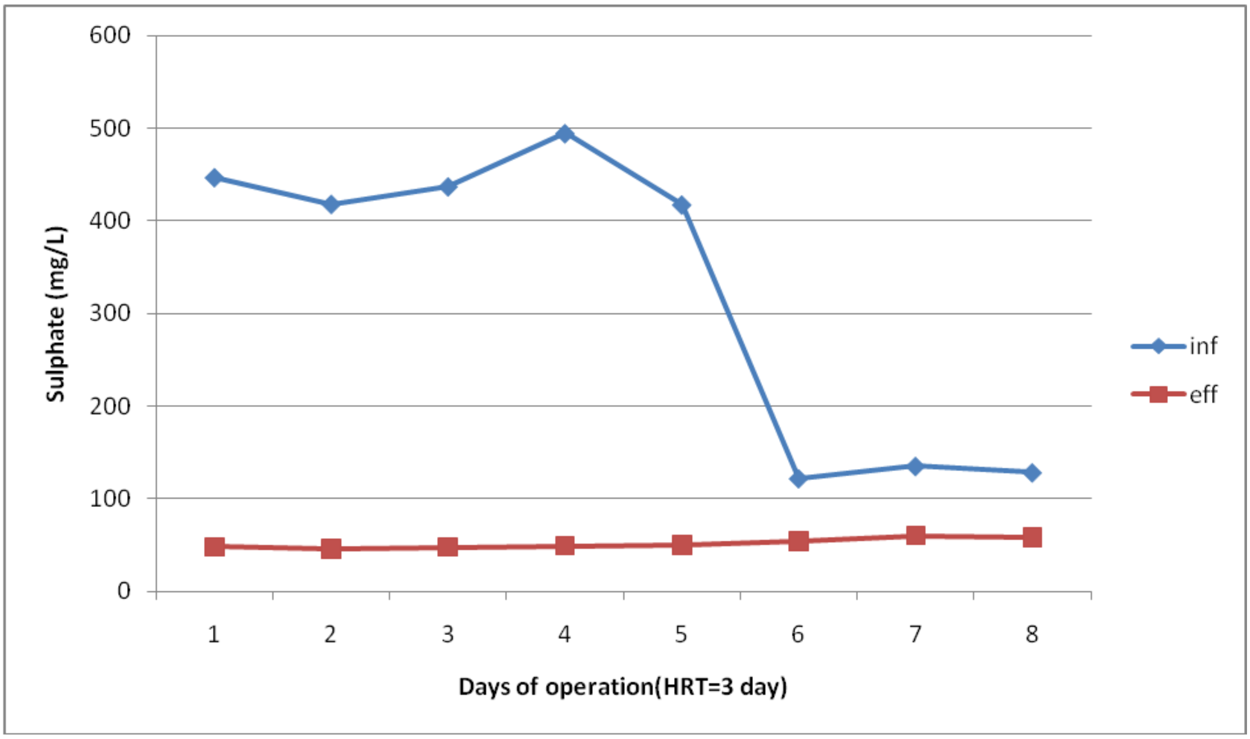


Figure 4.55:Sulphate (mg/L)of influent and effluent at 3 day HRT in Semi-continuous process

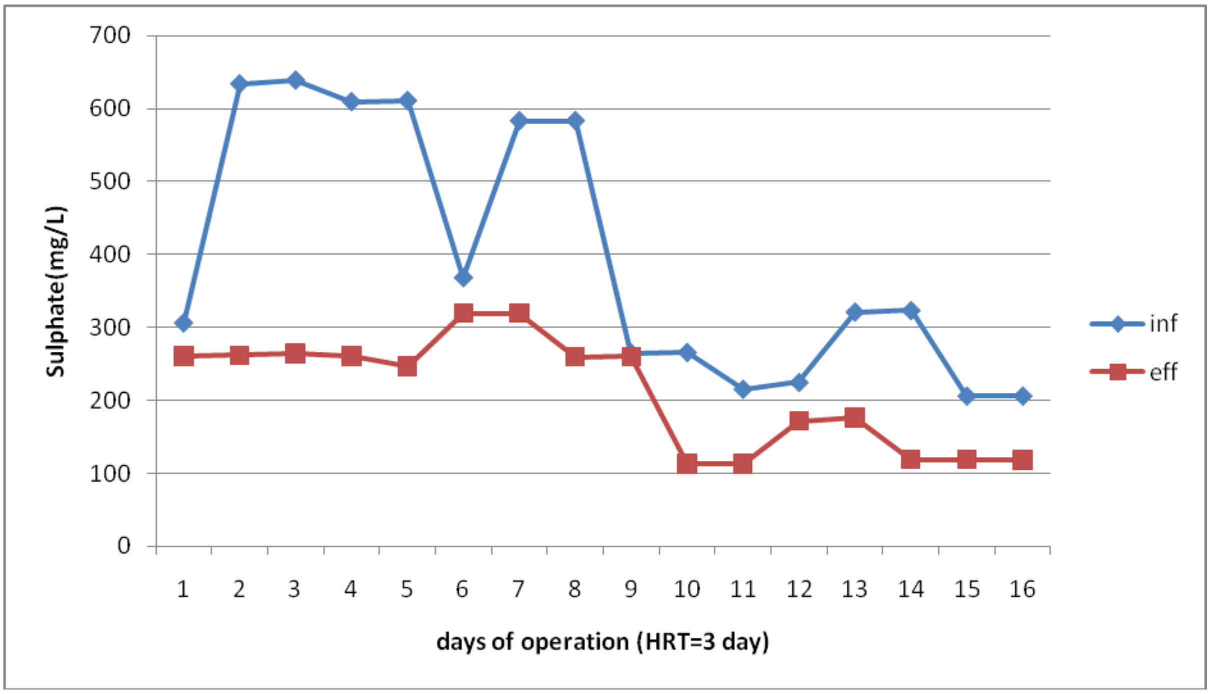


Figure 4.56:Sulphate (mg/L)of influent and effluent at 3 day HRT in Semi-continuous process

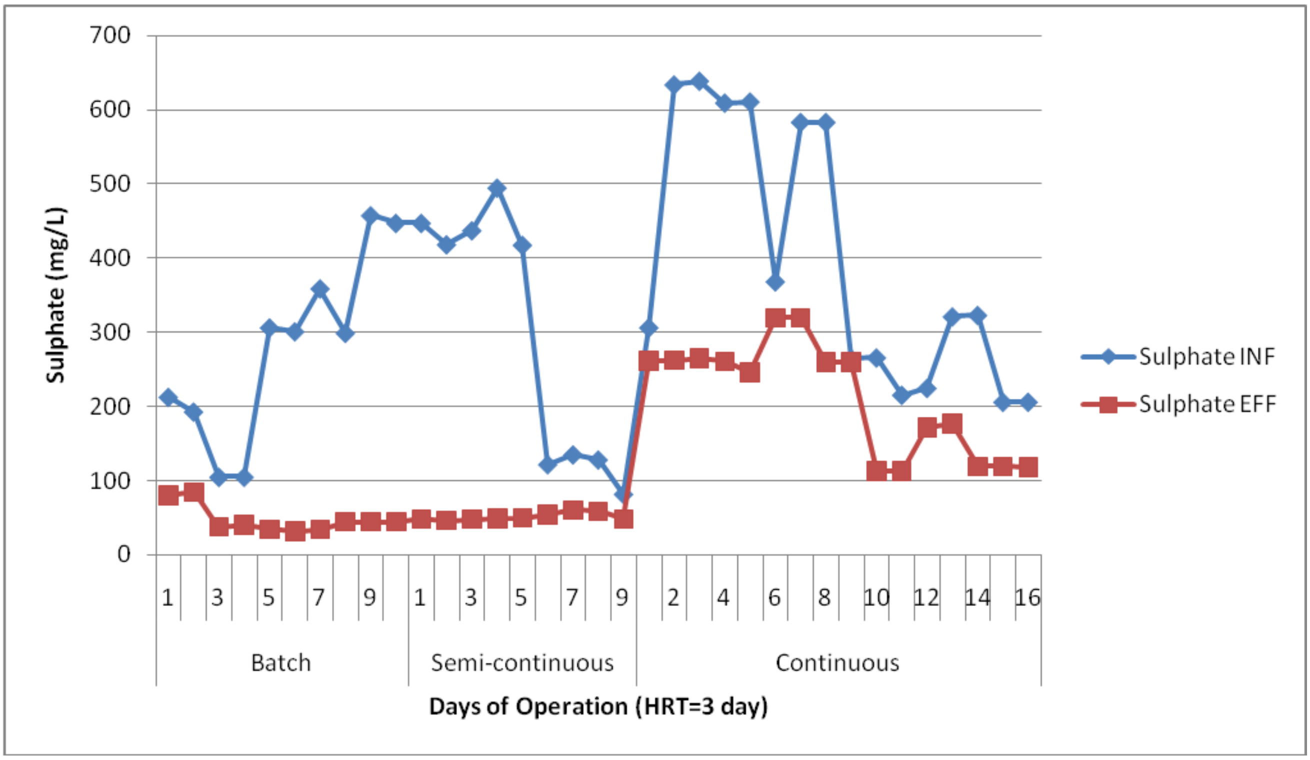


Figure 4.57: Variation in sulphate conc. in reactor throughout the process.

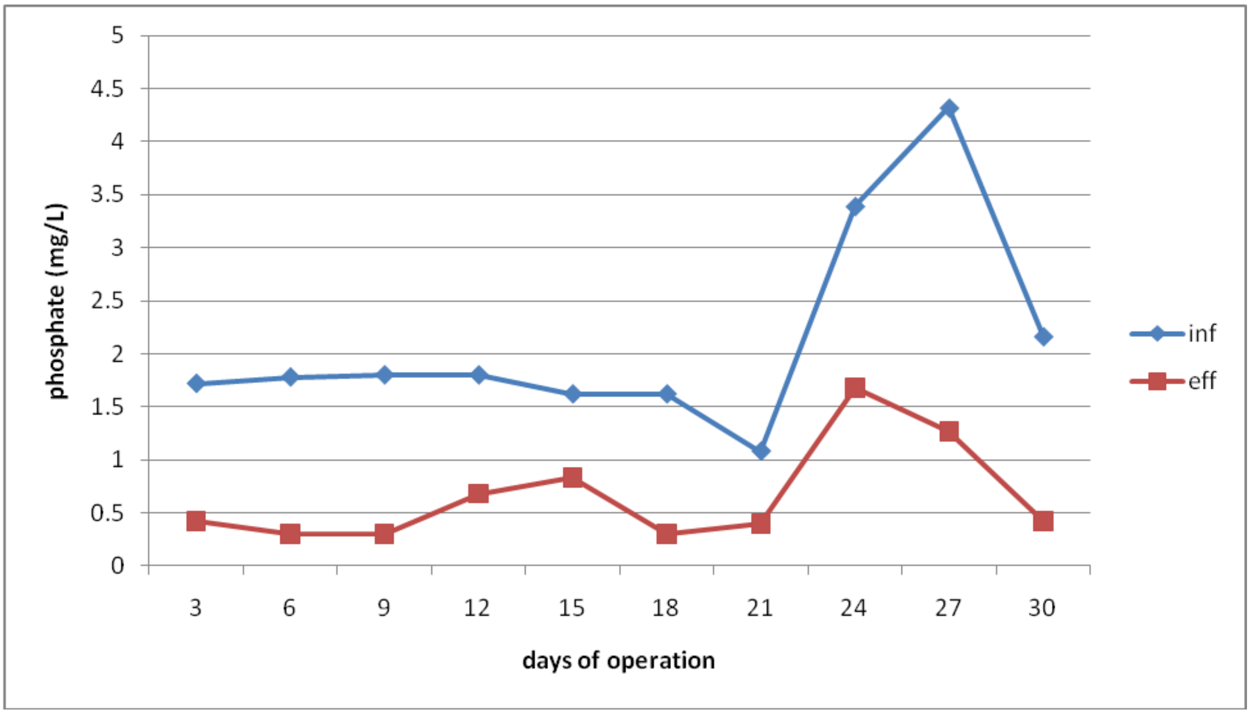


Figure 4.58: Phosphate (mg/L)of influent and effluent at 3 day HRT in Batch process

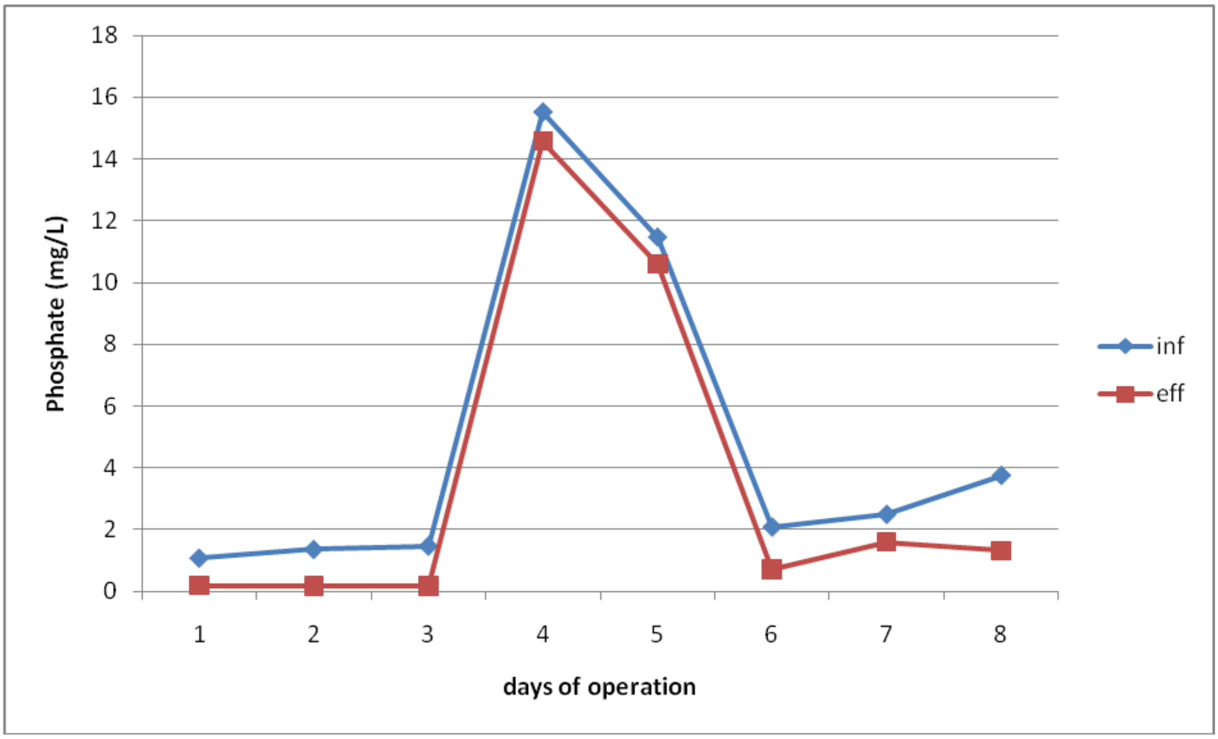


Figure 4.59: Phosphate (mg/L)of influent and effluent at 3 day HRT in Semi-continuous process

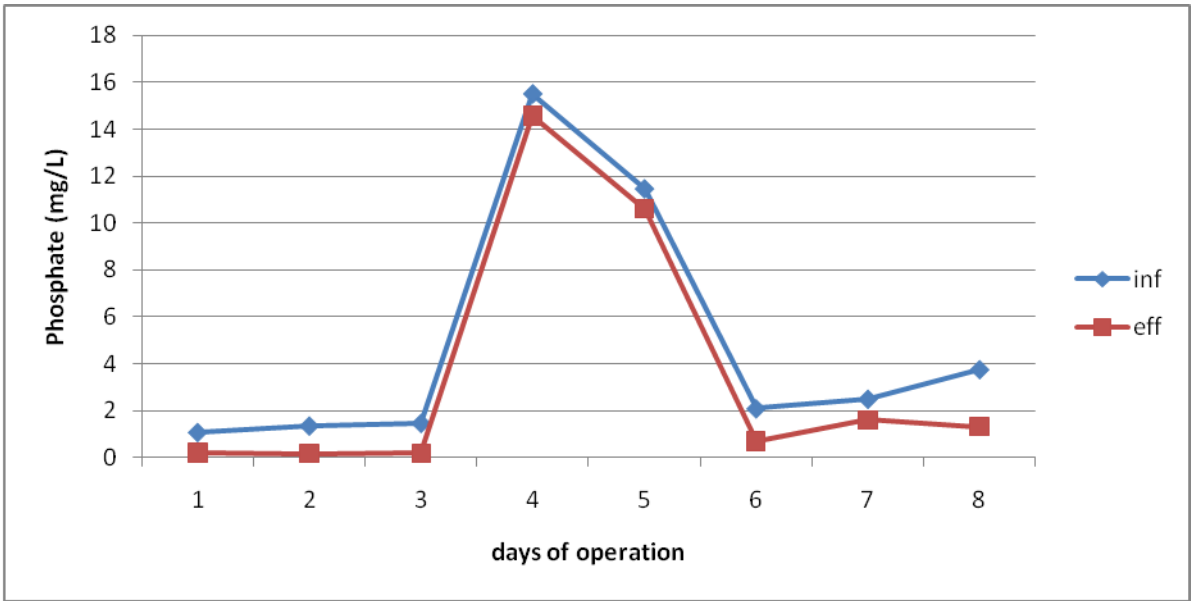


Figure 4.60: Phosphate (mg/L)of influent and effluent at 3 day HRT in Continuous process

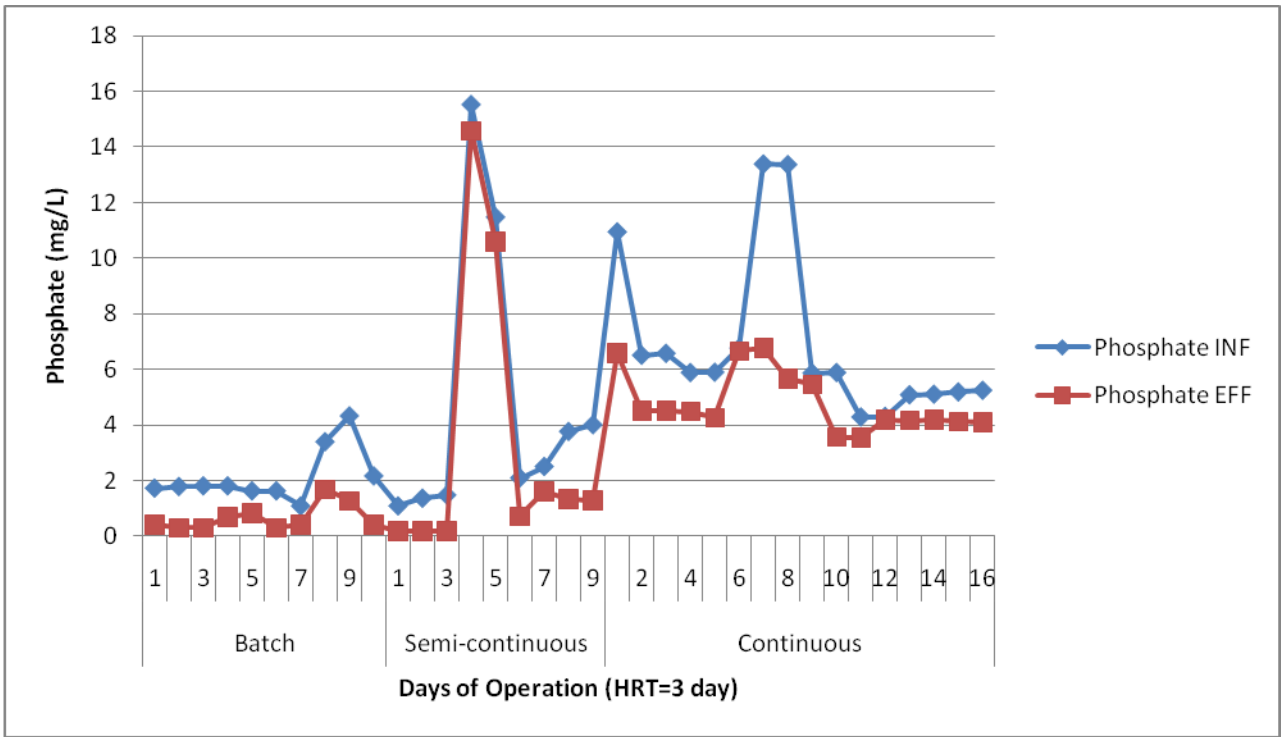


Figure 4.61: Variation in phosphate conc (mg/L) of influent and effluent in reactor throughout the process.

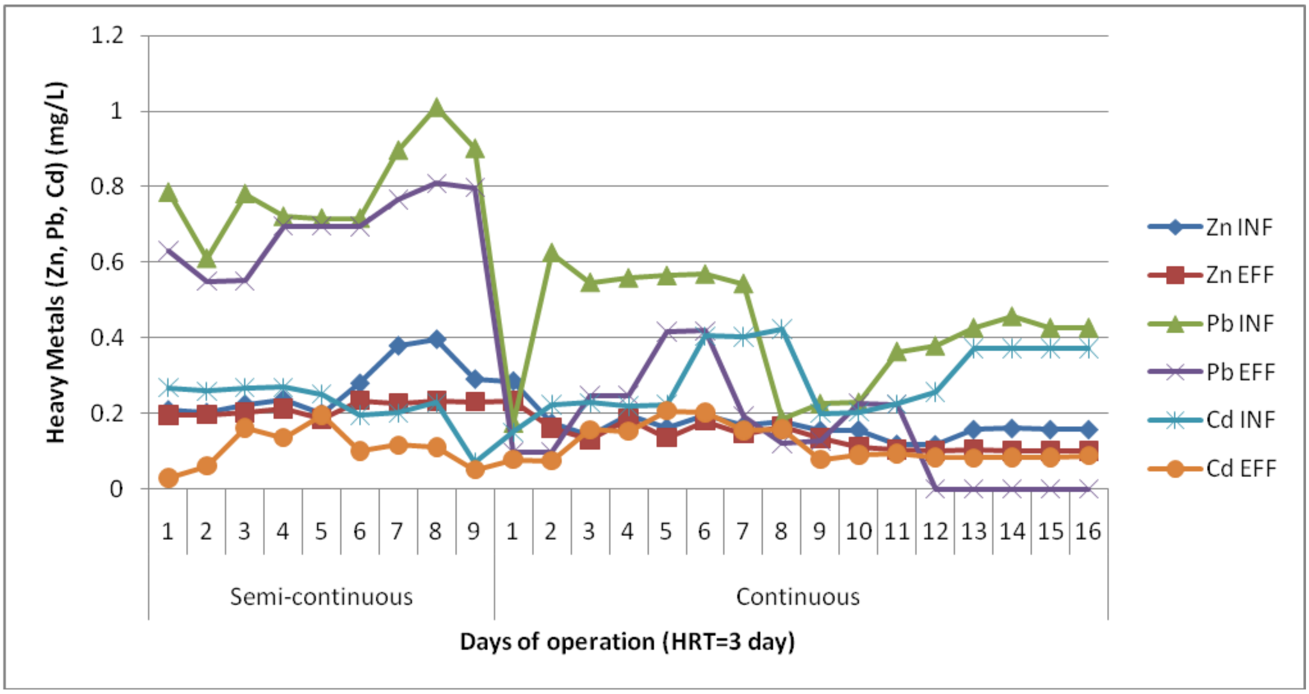


Fig 4.62: Variation in heavy metals(Zn,Pb,Cd) conc. of influent and effluent in different processes.

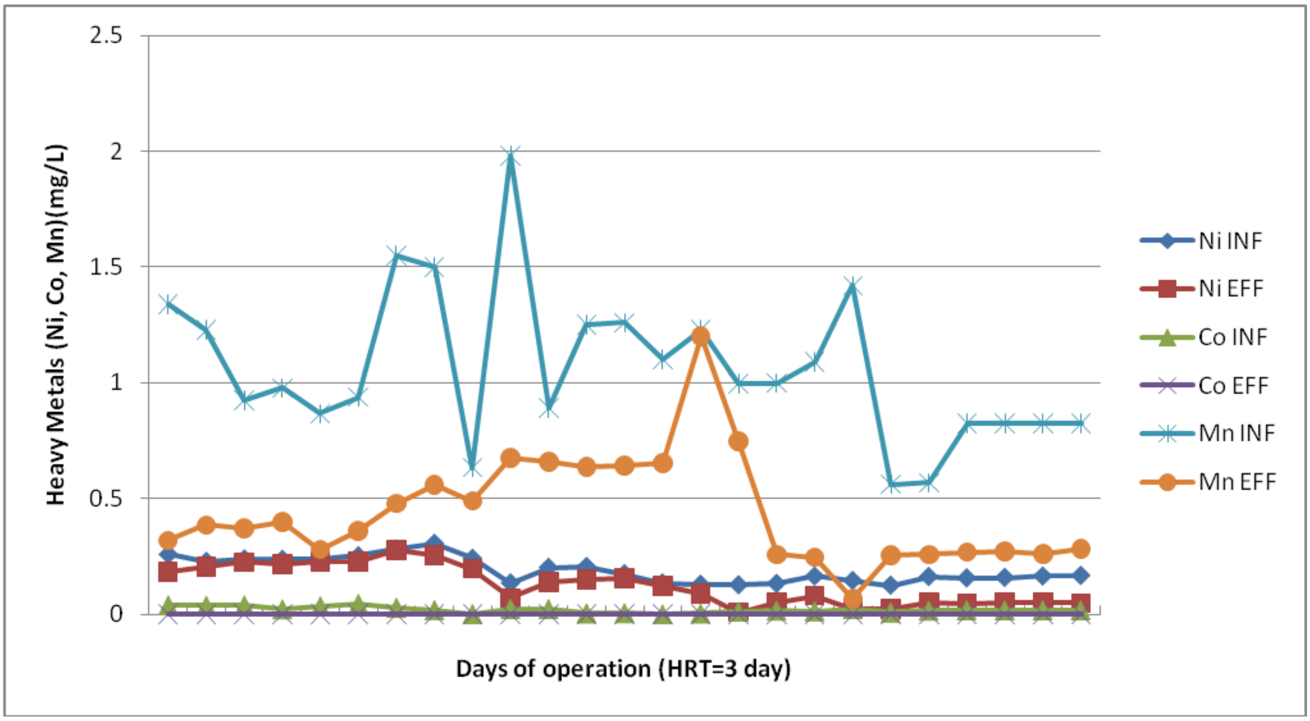


Fig 4.63: Variation in heavy metals (Ni, Co, Mn) conc. of influent and effluent in different processes

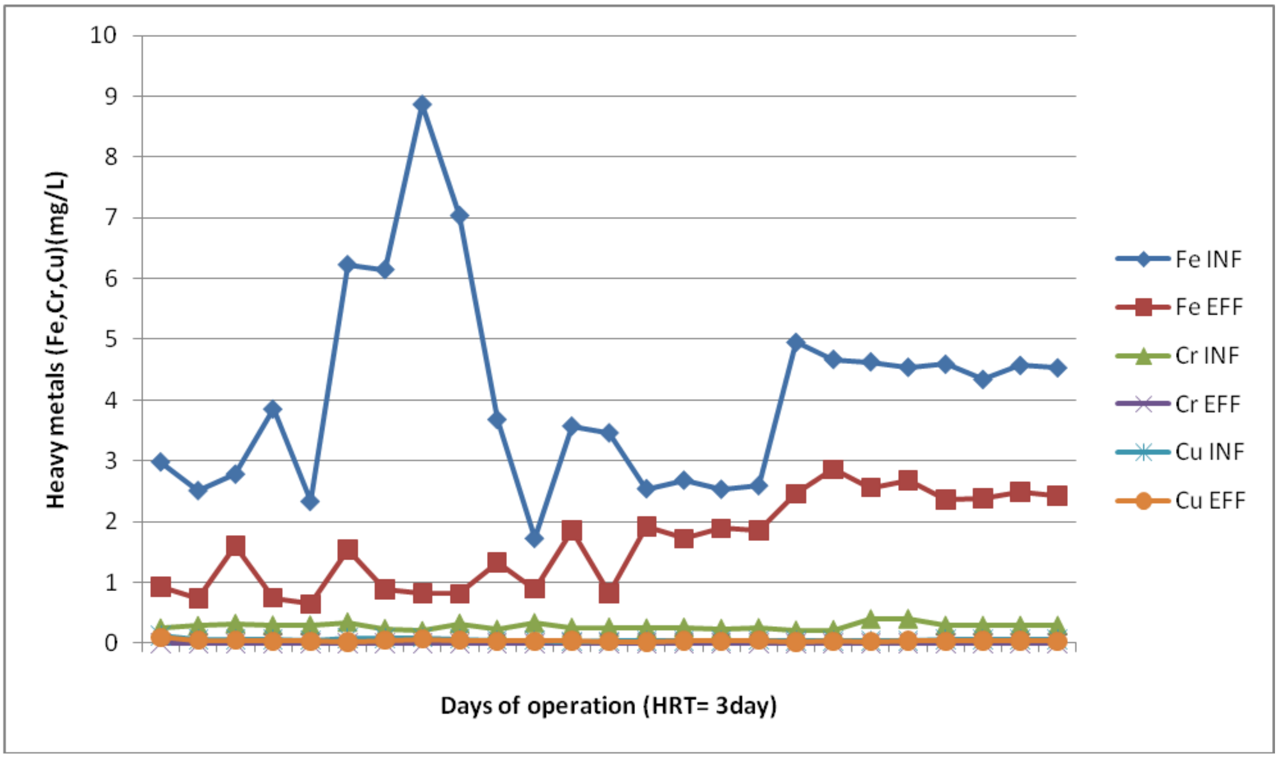


Fig 4.64: Variation in heavy metals (Fe, Cr, Cu) conc. of influent and effluent in different processes.

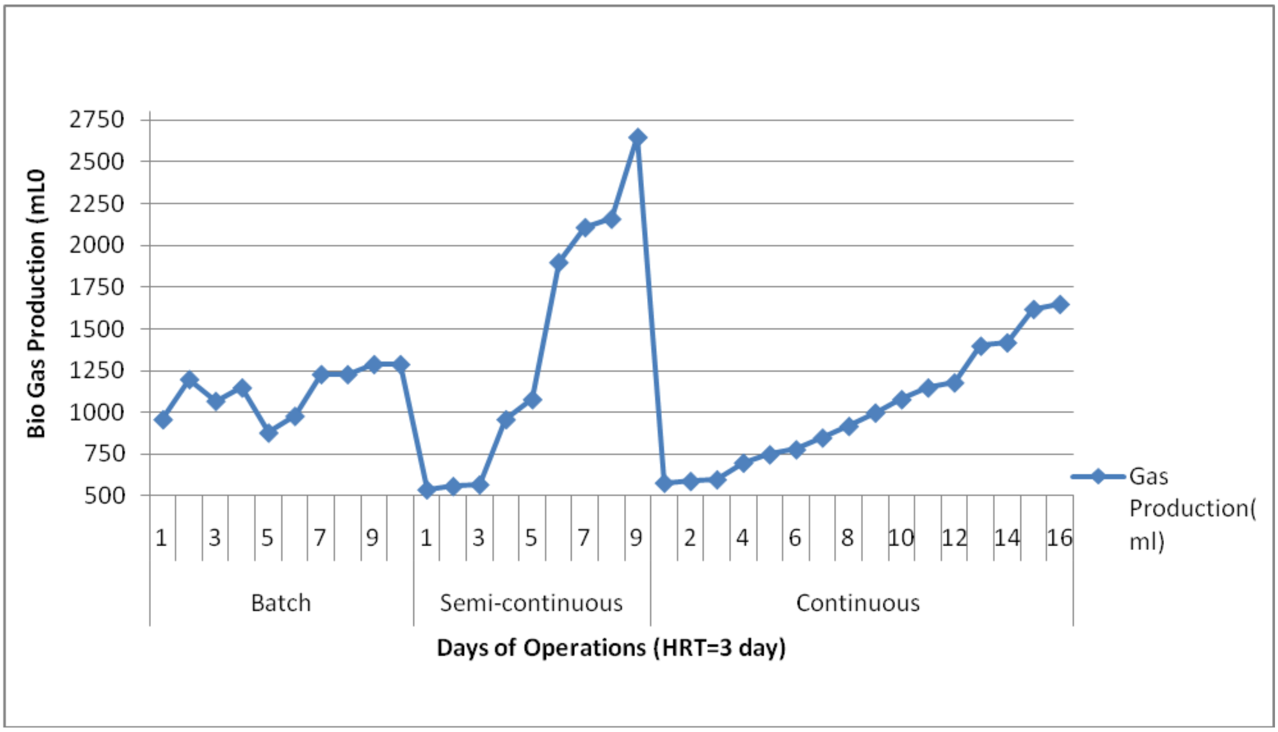


Fig 4.65: Graph showing Biogas production throughout different processes.

CHAPTER-5

CONCLUSION

CONCLUSION

The main environmental problem at landfill sites are the infiltration of leachate and its subsequent contamination of the surrounding land. Due to its higher strength, landfill leachate could be a potential source of surface and ground water contamination, as it could seep into soils and sub soils, causing severe pollution to receiving waters and also cause odour problems at site. So treatment of landfill leachate is necessary. Mainly anaerobic biological treatment processes were preferred due to following reasons:

- Fewer nutrients and energy required, higher volumetric loading rate.
- Less biological sludge is produced after treatment
- End product can be potentially saleable products biogas, soil conditioner and a liquid fertiliser.
- Process more effectively provides sanitisation/removal of diseases.
- Cost effective.

In this study, treatment of leachate was performed at 3 day HRT in different processes i.e. batch process, semi-continuous and continuous process. In which, maximum reduction efficiency was obtained in semi-continuous process. The COD reduction was maximum in semi-continuous i.e. 96.6%. whereas in batch it was 92 % and in continuous it was 91% and biogas production is maximum in semi-continuous was 2650 ml and 1290ml,1650 ml in batch and continuous processes respectively. Other parameters also showed same variations according to the treatment processes.

The best performance of reactor in treatment of landfill leachate was obtained at semi-continuous process at 3 day HRT with 96.6% COD reduction, TVA reduced from 954 mg/L to 20 mg/l, alkalinity increased from 160 mg/L to 1180 mg/L. Total solid reduction was 68.14 %, suspended solid reduction was 86 %, volatile solid reduction was 86.7% and biogas production was 2650 ml.

From this study, it is concluded that the anaerobic treatment of municipal solid waste landfill leachate is feasible.

CHAPTER-6

REFRENCES

REFERENCES

1. Ahn.D.H., Yun-Chul.C., Won-Seok.C.,(2002). Use of coagulant and zeolite to enhance the biological treatment efficiency of high ammonia leachate. J. Environ. Sci. Heal., 163–173.

2. Aktas.O, Cecen.F., (2001) Addition of activated carbon to batch activated sludge reactors in the treatment of landfill leachate and domestic wastewater, J. Chem. Technol. Biotechnol. 76 ,793–802.

3. Alessandro, S., Stefano, M.L., (2008). Nitrogen removal via nitrite in a sequencing batch reactor treating sanitary landfill leachate. Bioresour. Technol. 99, 609– 614.

4. Amokrane.A., C. Comel., J. Veron., (1997), Landfill leachates pretreatment by coagulation–flocculation, Water Res. 31, 2775–2782.

5. APHA., (2005). Standard Methods for the Examination of Water and Waste Water, twenty first ed. American Public Health Association, Washington, DC.

6. Aziz, H.A., Daud, Z., Adlan, M.N., Hung, Y.T., (2009). The use of polyaluminium chloride for removing colour, COD and ammonia from semi-aerobic leachate. Int. J. Environ. Eng. 1, 20-35

7. Bae.B, Jung.E., Kim.Y., Shin.H, (1999), Treatment of landfill leachate using activated sludge process and electron-beam radiation, Water Res. 33, 2669–2673.

8. Baig.S, Coulomb.I.., Courant.P., Liechti.P., (1999) Treatment of landfill leachates: Lapeyrouse and Satrod case studies, Ozone Sci. Eng. 21, 1–22.

9. Bashir,M.J.K., Aziz, H.A., Yusoff,M.S., Adlan,M.N., (2010a). Application of response surface methodology (RSM) for optimization of ammoniacal nitrogen removal from semiaerobic landfill leachate using ion exchange resin. Desalination 254, 154-161.

10. Berrueta.J, Castrillon.L., (1992), Anaerobic treatment of leachates in UASB reactors, J. Chem. Technol. Biotechnol. 54 33–37.

11. Bernd Bilitewski; Georg Härdtle; Klaus Marek (1997): Waste Management. Springer, Berlin, ISBN: 3-540-59210-5

12. Bilstad.T, Madland.M.V.,(1992) Leachate minimization by reverse osmosis, Water Sci. Technol. 25: 117–120.

13. Bohdziewicz, J., Bodzek, M., Gorska, J.,(2001). Application of pressure driven membrane techniques to biological treatment of landfill leachate. Process Biochem. 36, 641–646.

14. Bull.P.S., Evans.J.V.,Wechsler.R.M., Cleland.K.J., (1983), Biological technology of the treatment of leachate from sanitary landfills,Water Res. 17,1473–1481.

15. Canter et al.(1988)., McGinley and Kmet (1984)., and Lee and Jones (1991).,landfill designing.

16. Cecen.F, Erdincler.A, Kilic.E,(2003), Effect of powdered activated carbon addition on sludge dewaterability and substrate removal in landfill leachate treatment, Adv. Environ. Res. 7, 707–713.

17. Cecen.F., Aktas.O, (2001) Effect of PAC addition in combined treatment of landfill leachate and domestic wastewater in semi-continuously fed-batch and continuous-flow reactors, Water SA 27, 177–188.

18. Chang JE.,(1988)., Treatment of landfill leachate with an up-flow anaerobic reactor combining a sludge bed and a filter. Water Sci Technol ;21:133–43.

19. Cheung.K.C., Chu.L.M.,Wong.M.H.., (1997), Ammonia stripping as a pretreatment for landfill leachate, Water Air Soil Pollut. 94, 209–221.

20. Chiang, L., Chang, J., Chung, C.,(2001). Electrochemical oxidation combined with physical–chemical pretreatment processes for the treatment of refractory landfill leachate. Environ. Engg Sci. 18, 369–378.

21. Davis, M.L., Cornwell, D.A., (2008). Introduction to Environmental Engineering. International Edition, fourth ed. McGraw Hill, New York.

22. Diamadopoulos.E., Samaras.P., Dabou.X., Sakellaropoulos.G.P.,(1997): Combined treatment of leachate and domestic sewage in a sequencing batch reactor, Water Sci. Technol. 36 : 61–68.

23. Dollerer.J, Wilderer.P.A., (1996), Biological treatment of leachates from hazardous waste landfills using SBBR technology, Water Sci. Technol. 34 437–453.

24. Ehrig.H.J., (1984), Treatment of sanitary landfill leachate: biological treatment, Waste Manage. Res. 2, 131–152.

25. Farquhar, G.J. (1989). Leachate production and characteristics. Canadian Journal of Civil Engineering, 16: 317-325.

26. Fettig.J, Stapel.H, Steinert.C, Geiger.M, (1996) , Treatment of landfill leachate by preozonation and adsorption in actived carbon columns, Water Sci. Technol. 34 ,33–40.

27. Foester – carneiro., Perez.T, Romero.M.L.I. (2008).,Thermophilic anaerobic digestion of source- sorted organic fraction of municipal solid waste. Bioresource technology 99,6994-6770.

28. Foul, A.A., Aziz, H.A., Isa, M.H., Hung, Y.T.,(2009). Primary treatment of anaerobic landfill leachate using activated carbon and limestone: batch and column studies. Int. J. Environ. Waste Manag. 4, 282-298.

29. Garcia.H, Rico.J.L, Garcia.P.A. (1996) Comparison of anaerobic treatment of leachates from an urban-solid-waste landfill at ambient temperature and at 35 ◦C, Bioresour. Technol. 58 273–277.

30. Henry, J.G., Prasad, D., Sidhwa, R., and Hilgerdenaar, M. (1987). Treatment of landfill leachate by anaerobic filter. Water Pollution Research Journal, Canada ,17: 45-56.

31. Hoilijoki.T.H., Kettunen.R.H., RintalaJ.A., (2000), Nitrification of anaerobically pretreated municipal landfill leachate at low temperature, Water Res. 34 ,1435–1446.

32. Horan.N.J., Gohar.H., Hill.B., (1997) , Application of a granular active carbon-biological fluidized bed for the treament of landfill leachates containing high concentrations of ammonia, Water Sci. Technol. 36, 369–375.

33. Hosomi.M., Matsusige.K.,Inamori.Y.,Sudo.R Yamada.K.,Yoshino.Z, (1989) Sequencing batch reactor activated sludge processes for the treatment of municipal landfill leachate: removal of nitrogen and refractory organic compounds, Water Sci. Technol. 21 1651–1654.

34. Im, J., Woo, H., Choi, M., Han, K., Kim, C., (2001). Simultaneous organic and nitrogen removal from municipal landfill leachate using an anaerobic–aerobic system. Water Res. 35, 2403–2410.

35. Imai., K. Onuma., Y. Inamori., R. Sudo., (1998) Effects of pre-ozonation in refractory leachate treatment by the biological actived carbon fluidized bed process, Environ. Technol. 19 213–221.

36. John Pichtel(2005),Waste management practices: Municipal, hazardous and industrial.

37. Jokela.J.P.Y, Kettunen.R.H, Sormunen. K.M,Rintala.J.A., (2002), Biological nitrogen removal from municipal landfill leachate: low-cost nitrification in biofilters and laboratory scale in-situ denitrification, Water Res. 36 ,4079–4087.

38. Kang.Y.W., Hwang.K.Y., (2000) Effects of reaction conditions on the oxidation efficiency in the Fenton process, Water Res. 34, 2786–2790.

39. Kargi.F., Pamukoglu.M.Y.,(2004) Adsorbent supplemented biological treatment of pre-treated landfill leachates by fed-batch operation, Bioresour. Technol. 94 ,285–291.

40. Keenan,J.D.,Steiner,R.l.,Fungaroli,A.a(1984).Landfill leachate treatment.,J.WPCF.56 (1):33-39.

41. Kennedy.K.J.,Lentz.E.M, (2000), Treatment of landfill leachate using sequencing batch and continuous flow upflow anaerobic sludge blanket (UASB) reactors, Water Res. 34 3640–3656.

42. Kettunen.R.H., Rintala.J.A, (1998) , Performance of an on-site UASB reactor treating leachate at low temperature, Water Res. 32, 537–546

43. Kettunen.R.H., RintalaJ.A., (1995),Sequential anaerobic–aerobic treatment of sulphur rich phenolic leachates, J. Chem. Technol. Biotechnol. 62 177–184.

44. Kjeldsen, P., Barlaz, M.A., Rooker, A.P., (2002). Present and long-term composition of MSW landfill leachate: a review. Crit. Rev. Environ. Sci. Technol. 32, 297–336.

45. Knox.K, (1985), Leachate treatment with nitrification of ammonia, Water Res. 19 895–904.

46. Kouzeli-Katsiri A.,Bosdogianni.A.,Christoulas D.(1999);Pridiction of leachate quality from sanitary landfills.ASCE Journal of Environmental Engineering .125(10):950-958.

47. Lema.J.M., Mendez.R, Blazquez.R, (1988), Characteristics of landfill leachates and alternatives for their treatment: a review, Water Air Soil Pollut. 40, 223–250.

48. Lettinga, G., Hulshoff, L.W., Koster, I.W., Wiegant, W.M., Zeeuw, W.J., Rinzema, R.E.,Hobma, S.W., 1984. High-rate anaerobic wastewater using the UASB reactor under a wide range of temperature conditions. Biotechnology and Genetic Engineering Reviews 2, 253–284.

49. Li.X.Z., Zhao.Q.L., (2001) Efficiency of biological treatment affected by high strength of ammonium-nitrogen in leachate and chemical precipitation of ammonium-nitrogen as pretreatment, Chemosphere 44 ,37–43.

50. Li.X.Z., Zhao.Q.L., Hao.X.D., (1999) , Ammonium removal from landfill leachate by chemical precipitation, Waste Manage.19, 409–415.

51. Lin, S.H., Chang, C.H., (2000). Treatment of landfill leachate by combined electro-fenton oxidation and sequencing batch reactor method. Water Res. 34, 4243–4249.

52. Lin.C.Y., Chang.F.Y., Chang.C.H., (2008), Co-digestion of leachate with septage using a UASB reactor, Bioresour. Technol. 73 175–178.

53. Lin.S.H.,Chang.C.C, (2000) , Treatment of landfill leachate by combined electro-Fenton oxidation and sequencing batch reactor method, Water Res. 34 4243–4249.

54. Linde.K., Jonsson.A.S..,Wimmerstedt.R, (1995) Treatment of three types of landfill leachate with reverse osmosis, Desalination 101, 21–30.

55. Lo.et al., (1996) Characteristics and treatment of leachates from domestic landfills, Environ. Int. 22,433–442.

56. Loukidou..M.X., Zouboulis.A.I., (2001) Comparison of two biological treatment process using attached-growth biomass for sanitary landfill leachate treatment, Environ. Pollut. 111, 273–281.

57. Martienssen.M, Schops.R, (1997), Biological treatment of leachate from solid waste landfill sites—alterations in the bacterial community during the denitrification process, Water Res. 31,1164–1170.

58. Marttinen,.S.K., Kettunen, R.H., Sormunen, K.M., Soimasuo, R.M., Rintala, J.A., (2002). Screening of physical–chemical methods for removal of organic material, nitrogen and toxicity from low strength landfill leachates. Chemosphere 46, 851–858.

59. Mata-Alvarez, J. 2003: Biomethanization of the organic fraction of municipal solid wastes.

60. Maynard.H.E.,Ouki.S.K.,Williams.S.C.,(1999), Tertiary lagoons: a review of removal mechanisms and performance, Water Res. 33, 1–13.

61. Morawe.B., Ramteke.D.S.,Vogelpohl.A, (1995), Activated carbon column performance studies of biologically treated landfill leachate, Chem. Eng. Process. 34 ,299–303.

62. Nedwell.D.B, Reynolds.P.J, (1996) Treatment of landfill leachate by methanogenic and sulphate-reducing digestion, Water Res. 30 ,21–28.

63. Oman, C.B., Junestedt, C., 2008. Chemical characterization of landfill leachatese400 parameters and compounds. Waste Manag. 28, 1876-1891.

64. Orupold.K, Tenno.T, Henrysson.T, (2000), Biological lagooning of phenolscontaining oil shale ash heaps leachate, Water Res. 34 4389– 4396.

65. Ostrem, K. 2004: Greening Waste: Anaerobic Digestion For Treating The Organic Fraction Of Municipal Solid Wastes. Earth Engineering Center Columbia University.

66. Pokhrel.D, Viraraghavan.T, (2004), Leachate generation and treatment—areview, Fresenius Environ. Bull. 13,223–232

67. Rautenbach.R, Mellis.R., (1994),Waste water treatment by a combination of bioreactor and nanofiltration, Desalination 95 171–188.

68. Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F., Moulin, P., (2008). Landfill leachate treatment: review and opportunity. J. Hazard. Mater. 150, 468-493.

69. Sanphoti, N., Towprayoon, S., Chaiprasert, P., Nopharatana, A.,(2006). The effects of leachate recirculation with supplemental water addition on methane production and waste decomposition in a simulated tropical landfill. J. Environ.Manage. 81, 27-35.

70. Silva.,A.C. Dezotti.M., Sant'Anna Jr.G.L.., (2004), Treatment and detoxication of a sanitary landfill leachate, Chemosphere 55,207–214.

71. Suidan.M.T., Schroeder.A, Nath.R., Krishnan.E., Brenner.R., (1993), Treatment of cercla (comprehensive environmental response, compensation, and liability act) leachates by carbon-assisted anaerobic fluidized beds, Water Sci. Technol. 27 273–282.

72. Sung Sung.M, Chang.D., Lee.H.Y, (1997), Performance improvement of an unstable anaerobic leachate treatment system in an industrial waste landfill, Water Sci. Technol. 36, 333–340.

73. Tatsi.A.A., Zouboulis.I, Matis.K.A.,Samaras.P, (1992), Coagulation–flocculation pretreatment of leachate, 25 117–120.

74. Tatsi, A.A., Zouboulis, A.I., Matis, K.A., Samaras, P.,(2003). Coagulation–flocculation pretreatment of sanitary landfill leachates. Chemosphere 53 (7), 734–744.

75. Timur.H., Ozturk.I, (1997), Anaerobic treatment of leachate using sequencing batch reactor and hybrid bed filter,Water Sci.Technol. 36 ,501–508.

76. Trebouet, D., Schlumpf, J.P., Jaounen, P., Quemeneur, F., (2001). Stabilized landfill treatment by combined physicochemical-nanofiltration processes. Water Res. 35, 2935–2942

77. Trebouet.D, Schlumpf.J.P, Jaouen.P, Maleriat.J.P., Quemeneur.F., (1999), Effect of operating conditions on the nanofiltration of landfill leachates: pilotscale studies, Environ. Technol. 20 587–596

.

78. Uygur.A., F. Kargi.F., (2004) Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor, J. Environ. Manage. 71, 9–14.

79. Velmurugan.B., Arathy.E.C.,(2010),Anaerobic codigestion of fruit and vegetables wastes and primary sewage sludge, Environ. Sc. And engg,Vol.52,No. 1,19-22.

80. Verma, S., 2002: Anaerobic Digestion Of Biodegradable Organics In Municipal Solid Wastes. Department of Earth & Environmental Engineering (Henry Krumb School of Mines) Fu Foundation School of Engineering & Applied Science Columbia University

81. Vesilind et al., (2002) *Solid Waste Engineering* 1st Ed.

82. Welander.U., T. Henryson.T., Welander.T., (1997) Nitrification of landfill leachate using suspended-carrier biofilm technology, Water Res. 31, 2351–2355.

83. Wiszniowski, J., Surmacz-Gorska, J., Robert, D., Weber, J.-V., (2007). The effect of landfill leachate composition on organics and nitrogen removal in an activated sludge system with bentonite additive. J. Environ. Manage. 85, 59-68.

84. Zaloum.R., Abbott.M., (1997) Anaerobic pretreatment improves single sequencing batch reactor treatment of landfill leachates, Water Sci. Technol. 35 ,07–214.

85. Zamora.R, Moreno.A., Orta de Velasquez.M., Ramirez.I., (2000) Treatment of landfill leachates by comparing advanced oxidation and coagulation–floculation processes coupled with activated carbon adsorption, Water Sci. Technol. 41 ,231–235.

86. Zouboulis,W., Jun, A., Katsoyiannis, (2003), Removal of humic acids by flotation, Colloids Surf. A: Physicochem. Eng. Aspects 231 ,181–193.

s