

CHAPTER II

BACKGROUND AND LITERATURE SURVEY

2.1 Wastes from Petroleum Industry

2.1.1 Waste Characteristics

The petroleum industries generate a number of wastes during oil exploration, production and refining. The primary wastes generated by drilling oil well are drilling fluids and cutting. Wastes generated by field production are produced water and oil sludge. The secondary wastes include hydraulic fluid, weighting agents, acids, solvents, tank bottoms and oil debris. The contaminants from petroleum refinery are also considered a major problem. Along with the refining activities, environmental problems such as the accumulation of oil sludge and heavy metals as well as the generation of various kinds of wastewaters containing petroleum hydrocarbons, phenol, ammonia, sulfur and other unwanted parameters become inevitably (Wisjuprpto and Karden, 2000). Nowadays, where people awareness on environmental health is increasing, effort to minimize the impact caused by release of wastes should also be maximized (Bounicore and Wayne, 1998). Wastes generated from petroleum refinery around the world are mainly oil sludge and liquid wastes. Both sludges and liquid wastes contain various kinds of petroleum hydrocarbons. Many hydrocarbons present in oil sludges are insoluble in the aqueous phase (Janiyani *et al.*, 1992).

2.1.1.1 *Oil Sludge*

Oil sludge may be generated from exploration as well as refinery activities. Separation of crude oil from water commonly produces sludge containing heavy oil and soil particles which can not be further separated. Storage tank can also accumulate oil sludge at the bottom of the tank that requires cleaning regularly. There is no official data on how much sludge is produced per unit time in the oil and gas production. However, it has been realized that the sludge production is in the level that could create both environment and management problems. This sludge can not be just open-dumped because it has great potential to leach and become persistent sources for environment. The sludge needs treatment to reduce its potential and to be

isolated. The isolation of sludge by storing in small storage tanks nevertheless can cause another difficulty since that tank may occupy spaces.

2.1.1.2 Liquid Wastes

Liquid wastes are referred to both liquid waste generate from processes in petroleum refinery activities and produced water. The quality of these wastes may vary from one industry to another depending on the treatment system applied in each industry.

There are major components between different crude and refined oils. Some oils contain toxic hydrocarbons, which may prevent microbial attack; some refined oil have additives, for example; lead that can inhibit microbial degradation of polluting hydrocarbon. Barathi and Vasadevan (2001) showed that the oils contain the complex mixture of alkanes, aromatics, resins and asphaltenes. Both of the rates and extent of biodegradation are depend on the relative proportions of these classes of hydrocarbons.

2.1.2 Source of Wastes

There are four characteristics of the wastes: ignitability, corrosivity, reactivity, and toxicity. The variety of the petroleum wastes at various locations is shown in Table 2.1 (Mcketta, 1992). Table 2.2 shows the limit of each parameter that can discharge from the petroleum refinery (Bounicore and Wayne, 1998).

Table 2.1 Types of the wastes applied to the full scale refinery

Oil- water separator sludge
Dissolved air floatation sludge
Induced air floatation sludge
Tank bottom sludge
Slop oil emulsion solids
Filter clays
Biological sludge
Cooling tower sludge
Lime Sludge
Coker blowdown sludge

Table 2.2 Effluents from the petroleum refinery

Parameter	Maximum Value (mg/l)
pH	6 to 9
BOD	30
COD	150
TSS	30
Oil and grease	10
Chromium	
Hexavalent	0.1
Total	0.5
Lead	0.1
Phenol	0.5
Benzene	0.05
Benzo(a)pyrene	0.05
Sulfide	1
Nitrogen(total)	10
temperature increase	< 3°C

2.1.3 Treatment Techniques for Petroleum Wastes

2.1.3.1 *Landfill Solution*

The landfill is the most common and widely used method for the disposal of many kinds of the wastes (Kharbanda and Stallworthy, 1990). The distinction between a dump and landfill is not really clear-cut. The landfill is an operation where the waste is used to fill up excavation or natural hollow in the ground. A dump may well serve this purpose, but not always. Waste can be dumped on the ground, as well as tipped into pits and covered, making it a sort of crude landfill. Currently, landfill must be the largest repository of both municipal and industrial waste worldwide. Landfill and dump are one of oldest ways of disposing of wastes.

The advantage of landfill is cheap and effective way of disposing a large volume of wastes and contaminants. In the disadvantage ways, the general publics tend to view it as a nuisance on account of the smells and the vermin, and there may be migrations of hazardous wastes or hazardous wastes constituents to groundwater, surface water, soil, or air. To minimize such spread of contamination, certain categories of wastes have been targeted to be banned from the land disposal (Mcketta, 1992).

The landfilling and the long-term storage have similar advantages and disadvantage. Since there is no manipulation of the toxic material, cost is generally minimal as long as reasonably close location can be identified for the storage locker or landfill site. The major cost can be extreme if the distance is very great. Further complication is now frequently encountered because of local public resistance to the development of long- term storage facilities. The possibility of insufficient maintenance followed by possible leaching into soil or groundwater has increased the public concern. With increased concern has come legislation and regulation on container and landfill design, and thus, increasing costs.

Kharbanda and Stallworthy (1990) indicated that there is not only possible to dispose of wastes quite safety by landfill, but the environment can be protected as well. To ensure protection of the ground water, a water quality monitoring program is normally put in hand well before work on the landfill area is commented. Landfill is used for the disposal of two distinct types of industrial

wastes: the non-toxic type, as discussed above and which is generally similar to municipal waste, and toxic chemical waste. Lefebvre *et al.* (1998) showed that the sanitary landfill dumping of the lipid residues are now prohibited by French legislation, but new treatment ways such as biodegradation or incineration have to be developed.

2.1.3.2 Incineration

The incineration of waste may appear to be convenient and safe means of disposal. The combustible material in the waste is converted to gaseous oxide, leaving an incombustible residue which should be non-toxic and quite suitable for disposal via landfill. Incineration furnaces can handle waste in a wide variety of forms: solid, paste, sludge, slurry, liquid, and even gas, provided the appropriate design is used. In all cases, the objective is same: to ensure the safe disposal of the waste. Unfortunately, safe disposal depend largely upon the way in which the incineration part is operated. Due to the ignorance of operator, such plants are at times fed with materials which will not burn under the condition obtaining in the incinerator, causing the waste to pass into the ash unchanged. At other times, the temperature maintained at the incinerator is not sufficiently high to ensure complete combustion, and a poisonous chemical can then pass out into the atmosphere via the flue gas.

The incineration process as such is simple enough, involving the combustion of carbon and hydrogen, these two elements that are present in practically all combustible organic material. The other essential element is, oxygen or air, and if the temperature is high enough combustion can be complete. The end-products of combustion are carbon dioxide and water, both of themselves harmless.

For the incinerator design, integrated systems are becoming available with more advanced technologies and sophisticated computer controlled systems. This result in the trend toward more environmentally benign solutions to this particular approach to waste disposal. There are a wide range of alternatives available when we come to consider the type of incinerator that may be appropriate for a particular situation. Much depends not only on the character of the waste to be dealt with, but on the volume coming forward. The various types of incinerator in current use can be broadly classified in accordance with their basic design feature.

Incineration has the advantage of decreasing the amount of toxic material existing. It consumes energy and may also lead to production of additional toxic materials, which requires costly scrubbing before release into the atmosphere.

2.1.3.3 Land Treatment

Land treatment can protect human health and the environment from wastes as diverse as liquid municipal wastewater, liquid and dewatered municipal sludge, and petroleum industry wastes (Mcketta, 1992). This basic technology also can be used for bioremediation of contaminated soil. The use of land treatment under controlled and well-design and operated conditions should continue to be applicable to the petroleum and other industries. Land treatment is a manage technology that involves the controlled application of a waste on the soil surface and the incorporation of the waste into the upper soil. It is not the indiscriminate dumping of waste on land, and differs significantly from landfilling. This method stores wastes in man-made or natural excavations and use a combination of liners and leachate collection systems to control the migration of the waste. Land treatment relies on the dynamic physical, chemical, and biological processes occurring in the soil. As a result, the constituents in the applied wastes are degraded, immobilized, or transformed to environmentally acceptable components.

2.1.3.4 Biological Treatment

Other technologies take advantage of the ability of microorganism engineered to detoxify compound. There have many reviewed the various treatment methods and the modification in biogas digester, anaerobic digestion technology, and managerial aspects that result in more efficient sewage plant operation. Early studies led to the use of gravel as a percolating filter. Toxic wastes were retained by the gravel, in many cases enabling indigenous organism to degrade them. It was followed by the development of more efficient anaerobic digesters and aerobic digesters. Aerobic digestion is simply the addition of air to the digestion mixture, thus, increasing growth and oxidative abilities of the microbes. One of the earliest practices of genetic selection was the discovery that the use of inoculants from previous digestions greatly enhanced the degradation process. Modification in the process for degradation shortened the time period needed,

sometimes to only 5 to 10 days. Table 2.3 shows the comparison of various treatment methods (Morris and Michael, 1993).

Table 2.3 Comparison of waste treatment methods

Type of treatment	Cost per cubic yard (\$)	Time required (months)	Additional factor/expense	Safety issue
Incineration	250-800	6 to 9	Energy	Air pollution
Fixation	90-125	6 to 9	Transport;long-term monitoring	Leaching
Landfill	150-250	6 to 9	Long-term monitoring	Leaching
Biotreatment	40-100	18 to 60	Time commitment of land	Intermediary metabolites and polymerization

2.2 Biodegradation of Hydrocarbon Compounds

Biodegradation or microbial degradation is the decomposition of substances by microorganism activities to clean-up contaminated environments and often used in sewage treatment (Watanabe, 2001). It refers to natural process where bacteria or the microorganism change and break down the organic compounds into other substances. Microbial attacks on petroleum have been shown to occur toward n- and branched alkanes or toward several aromatic compounds; the high molecular weight aromatics, resins, and asphaltenes generally being considered to be recalcitrant to biodegradation (Sugiura *et al.*, 1997). Bacteria are microorganisms which are found virtually everywhere: in soil, water, plants, animals and rocks. The average size of these single-celled organisms is one micron, one-10,000th of a centimeter. Their microscopic size means that bacteria can easily move compounds in and out of their cells. This makes them perfect processing units. After death, all organisms decompose to their base elements: water, carbon, nitrogen, phosphate, and trace

elements. There are more than 27,000 species of bacteria. Several different types are capable of breaking down both simple and complex hydrocarbons. Two of major families in which these microbes are found are *Pseudomonas* and *Bacillus* (Soveran and Hill, 1999). *Pseudomonas* and *Bacillus* are commonly found in areas that contain oil or contaminated by hydrocarbons, such as; near underground oil deposits. However, the bacteria can also be found where there is no oil. This is because the ability to break down hydrocarbons is not always the bacteria's main function, so these traits may lie dormant. The oil industry is using hardy oil-eating bacteria in a number of ways. The most common applications are in bioremediation (using microbes to clean-up the pollutants) of oil spill or reduction of the environmental impact of waste products from oil production.

2.2.1 Types of Microbial Degradation

Petroleum is chemically very complex, consisting of hundreds of individual organic compounds. For microorganisms to biodegrade petroleum completely or attack even simpler refined oils, thousands of different compounds may be involved, which can be metabolized (Barathi and Vasudevan, 2001). The chemical nature of these petroleum components varies from the simple n-paraffin, monoalicyclic, and monoaromatic compounds, to much more complex branched chains and condensed ring structures. Individual components of petroleum and organisms capable of degrading them are given in Table 2.4.

2.2.1.1 *Aerobic Degradation*

Aerobic degradation is dominated by a variety of organisms, including bacteria, actinomycetes, and fungi, which require oxygen during chemical degradation. This process involves oxidation-reductions in which molecular oxygen serves as the ultimate electron acceptor, while the organic component of the contaminating substance functions as the electron donor or energy source in heterotrophic metabolism.

Table 2.4 Fuel components/hydrocarbons microorganisms capable of biodegradation/biotransforming (modified from Riser-Roberts, 1992)

Fuel Component/Hydrocarbon	Microorganism
n-Alkanes (C1 to C4) gaseous	<i>Mycobacterium ketoglutamicum</i>
n-Alkanes (C3 to C16)	<i>Mycobacterium rhodochrous</i>
n-Alkanes (C8 to C16)	<i>Mycobacterium fortitum, M. smegmatis</i>
n-Alkanes (C12 to C16)	<i>Mycobacterium marinum, M. tuberculosis, Corynebacterium</i>
n-Alkanes (C5 to C16)	<i>Arthrobacter, Acinetobacter, Pseudomonas putida, yeasts</i>
n-Alkanes (C10 to C14)	<i>Corynebacterium</i>
n-Alkanes (C8 to C20)	<i>Acinetobacter</i>
n-Alkanes (C11 to C19)	<i>Prototheca zopfii, Pseudomonas sp.</i>
Alkanes (straight chain)	<i>Pseudomonas putida</i>
Alkenes (C6 to C12)	<i>Pseudomonas oleovorans</i>
Anthracene	<i>Flavobacterium, Beijerinckia sp., Cunninghamella elegans, Pseudomonas/Alccaligenes sp., Acinetobacter sp., Arthrobacter sp.</i>
Aromatics	<i>Pseudomonas sp.</i>
Benzene	<i>Pseudomonas putida, P. rhodochrous, P. aeruginosa, methanogens, anaerobes, Acinetobacter sp., Methylosinus trichosporium, Nocardia sp.</i>
Benzo(a)anthracene	<i>Beijerinckia sp., Cunninghamella elegans, Pseudomonas sp.</i>
Benzo(a)pyrene	<i>Candida lipolytica, C. tropicalis, C. guiliermondii, C. maltosa, Debaryomyces hansenii, Bacillus megaterium, Beijerinckia sp., Cunninghamella elegans, Pseudomonas sp., Neurospora crassa, Saccharomyces cerevisiae</i>

Most aerobic bacteria use oxygen to decompose organic compound into carbon dioxide and other inorganic compounds. Aerobic processes of biological treatment are generally preferred to degrade substances, due to the low

costs associated with this option. Aerobic biodegradation of many classes of aromatic compounds is common and proceed through the key intermediate (Nora and Juan, 2001). Lefebvre *et al.*, (1998) showed that their work carried out on domestic grease demonstrates the effect of their saponification on their aerobic biodegradation. Aerobic biodegradation occurs via more efficient and rapid metabolic pathway than anaerobic reaction. Therefore, most site decontaminations involving refined oils and fuels are conducted under aerobic condition (Riser and Roberts, 1992).

2.2.1.2 Anaerobic Degradation

Anaerobic degradation is the transformation of organic compounds that are important in the environment. There is usually occur in any habitat in which the oxygen consumption rate exceeds its supply rate and is a common phenomenon in many natural aquatic environments receiving organic material. Petroleum can be microbially degraded anaerobically by the reduction of sulfates and nitrates. Aromatic hydrocarbons, common to many fuels, that can be biodegraded without the presence of molecular oxygen, include toluene, xylene, alkylbenzenes, and possibly benzene.

2.3 Surfactant-Enhanced Biodegradation of Hydrocarbon Compounds

The hydrocarbons present in oil sludges are usually insoluble in the aqueous phase and hence are not available to hydrophilic microorganisms when subjected to biodegradation. It requires special mechanisms to facilitate the uptake of hydrocarbon by microorganisms. Low molecular weight hydrocarbons such as alkanes are partially soluble in water and are utilized easily by microorganisms. However, high molecular weight hydrocarbons require being solubilized in the aqueous phase by physical means such as addition of surface active agents (surfactant), incorporation of organic solvent, and co-metabolism. The growth of microorganism on low molecular weight alkanes can also induce the production of bioemulsifiers which facilitate their utilization by microorganisms. Surfactant has also been reported to be produced by microorganisms on carbohydrate substrates (Janiyani *et al.*, 1993). Moreover, long chain alkanes and aromatic hydrocarbons present in oil and sludges have not been shown to support the production of

surfactant or similar compounds. Consequently, degradation of high molecular weight hydrocarbons has normally been studied in oil- aqueous environments, in organic solvent, or by the addition of microbial surfactant.

The biodegradation of polycyclic aromatic hydrocarbons (PAHs) may be enhanced by the use of the surfactants such as non-ionic surfactant (In *et al.*, 2001). The PAHs solubility was linearly proportional to the surfactant concentration when above the critical micelle concentration (CMC), and increased as the hydrophile-lipophile balance (HLB) value decreased. Rhaman *et al.* (2003) showed that the enhancement of biodegradation was achieved through bioaugmentation and biostimulation. Their purpose was to investigate possible methods to enhance the rate of biodegradation of oil sludge from crude oil tank bottom. The sludge samples were treated with bacterial consortium, rhamnolipid biosurfactant and nitrogen, phosphorus and potassium (NPK) solution. Maximum n-alkane degradation occurred in 10% sludge contaminated samples.

2.3.1 Use of Surfactant to Enhance Solubilization and Biodegradation

The surfactant (a construction of the term surface-active agent) is a substance that, when presence at low concentration in a system, has the property of adsorbing onto the surfaces or the interfaces of the system and of altering to a marked degree the surface or interfacial free energies of those surface (or interface). The enormous market demand for surfactants is currently met by numerous synthetic, mainly petroleum-based, chemical surfactants. Figure 2.1 show some examples of commercial surfactants.

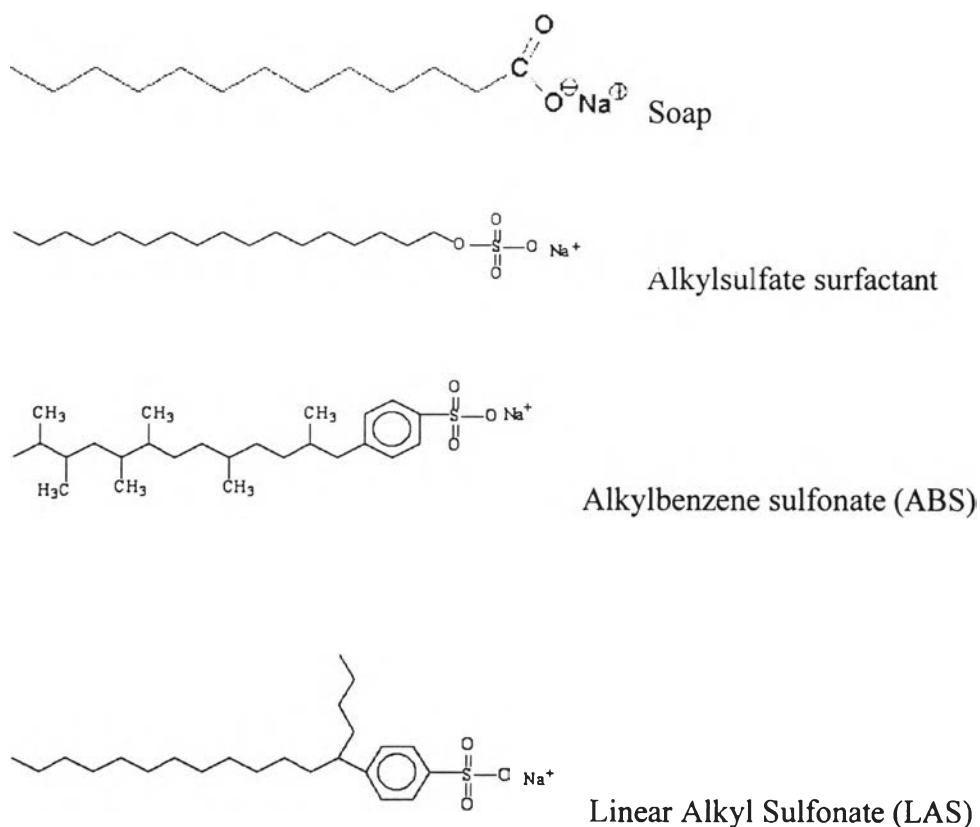


Figure 2.1 Example of surfactants

Surfactants can generally be classified into 3 types: nonionic, anionic and cationic surfactant.

2.3.1.1 Nonionic Surfactant

The surface-active portion of nonionic surfactants bears no apparent ionic charge, for example; monoglyceride of long-chain fatty acid, and polyoxyethylenated alkylphenol. The advantage of nonionic surfactant is compatible with all other types of surfactants. Generally, available as 100% active material free of electrolyte that can be made resistant to hard water, polyvalent metallic cations, and electrolyte at high concentration; soluble in water and organic solvents, including hydrocarbons. The disadvantage of this surfactant is; the products are liquid or pastes, rarely nonstick solid. Another example of nonionic surfactant is LAEs (linear alcohol ethoxylates) that are also commercially significant as they are extensively used in industry. LAEs as other nonionic surfactants could be removed from wastewater by biodegradation process (Mezzanotte *et al.*, 2002). In *et al.*

(2001) indicated that Brij 30, a nonionic surfactant, was the most effective surfactant tested when compared with Triton X-100 and Tween 80, in the enhancement of biodegradation of polycyclic aromatic hydrocarbons (PAHs) using nonionic surfactants in soil slurry.

2.3.1.2 Anionic Surfactant

The surface-active portion of anionic surfactant the molecule bears a negative charge. The example of this type of surfactant is soap and alkylbenzene sulfonate. Linear alkylbenzenesulfonate (LAS) is anionic surfactants used in detergent formulations which is also the main component of the effluent discharges (Eichhorn *et al.*, 2001).

Anionic, cationic and nonionic surfactants are particularly used for soil washing and flushing. They contain both hydrophobic and hydrophilic portions, making them ideal for solubilization of hydrophobic compounds. Numerous studies have indicated that pretreatment of soil with surfactant washing enhanced solubilization of hydrophobic compound (Mulligan *et al.*, 2001). In another study, Suchanek *et al.* (2000) indicated that the use of sodium dodecyl sulphate can stimulate the biodegradation of n-alkanes without residual contamination. The tested microorganism, a soil bacterium *Pseudomonas C12B*, was investigated for *in situ* bioremediation and was also tested in a preliminary field experiment.

2.3.1.3 Cationic Surfactant

The surface-active portion of the cationic surfactant bears a positive charge, such as; salt of long chain amine, and quaternary of ammonium chloride. Surface-active moiety has a positive charge that absorbs strongly onto most solid surfaces (which are usually negatively charged). It can impart special characteristics to the substrate. This absorption also makes possible formation of emulsions that break in contact with negatively charged substrates and allowing deposition of active phase onto substrate. Most types are not compatible with anionics (amine oxides are an exception). Generally, cationic surfactants are more expensive than anionic or nonionic, and thus, rarely used in the biodegradation study.

2.4 Bioreactor

The bioreactor is the center of all biochemical processing. It can be defined as a vessel in which biological reactions are carried out by microorganisms or enzymes contained within the reactor itself. In hazardous, municipal, or industrial waste treatment, bioreactors are used primarily to reduce the concentration of contaminants in incoming wastewater to acceptably low levels. In particular, biological treatment appears to be especially versatile and cost effective when the concentration of pollutants in the wastewater is relatively low and the volumes to treat are large. A number of measurements indicating the level of concentration of pollutants have been devised and are commonly used in industrial practice. The most common measurements are biological oxygen demand (BOD) and chemical oxygen demand (COD). The bioreactor simulates the bioremediation process of accidental oil spill (Jussara and Francisca, 1999).

Quan *et al.* (2004) constructed an airlift inner-loop bioreactor packed with honeycomb-like ceramic as the carrier was developed and its capacity to immobilize microorganism was studied through adding bacteria, *Achromobacter sp.*, capable of degrading 2,4-dichlorophenol (2,4-DCP), directly to the reactor under continuous operation. The results showed that the pure strain could be easily immobilized on the carrier and proliferated using 2,4-DCP as the sole carbon source.

The following comparison will aid the understanding of the advantages and disadvantages of each class of reactors:

2.4.1 Anaerobic vs. Aerobic Reactors •

Anaerobic reactors differ from aerobic reactors because the former must be closed in order to exclude oxygen from the system, since this could interfere with anaerobic metabolism. An additional reason to require closed anaerobic reactors is odors associated with anaerobic fermentation. This reactor can also be provided with an appropriate vent or collection system to remove the gases produced during an aerobiosis.

Conversely, aerobic reactors containing suspended biomass almost require the use of an air-sparging or bubbling system to provide the microorganism

with oxygen. One of main drawbacks of oxygen as a key substrate is its low solubility in water as opposed to most other substrates, which have much higher saturation concentration. The vast majority of existing biological treatment plants is aerobic. The reasons for this preference over anaerobic system are the greater range of wastewater that can be treated, easier control, greater stability of the process, and more significant degree of removal of BOD, nitrogen and phosphorus. Because of the slower metabolism, anaerobic systems require a longer residence time of the waste in the reactor.

Gallego *et al.* (2003) worked on biodegradation of phenolic compounds by using pure and mixed indigenous cultures in aerobic reactor. Biodegradation of a mixture of persistent compounds: 2-chlorophenol, phenol, m-cresol was studied by using in both batch and continuous flow fluidized-bed aerobic reactors. The result of this study showed that the biodegradation in batch reactor is more efficient than in continuous reactor and the degradation in mixture of bacteria of each compound were similar to those observe in isolated bacteria, which demonstrates that the presence of the other microorganisms does not affect the process of individual degradation.

Sponza and Atalay (2004) compared the treatment of trichlorotoluene was compared between anaerobic and aerobic reactors. In anaerobic reactor, they used the upflow anaerobic sludge blanket reactor (UASB) and in aerobic reactor, they used completely stirred tank reactor (CSTR). UASB reactors are important in the treatment of various industrial wastewater containing toxic substances due to the compact structure of granules which protects the bacteria from inhibitory pollutants. The results suggested that a combination of UASB and CSTR reactor may be the best solution.

2.4.2 Continuous vs. Batch Reactors

Most large-scale wastewater treatment systems are operated in a continuous mode, in which a waste stream is continuously fed to the plant and a clarified stream is continuously removed. This is a common requirement; especially the waste is generated at the continuous rate. An important concept associated with

continuous reactors is that of residence time, defined as the average amount of time spent by a fluid element in the reactor.

In batch system, the waste is charged to the reactor and the process is allowed to proceed to completion. In addition, batch systems are generally simpler, require minimal support equipment, and well suited to treat small amounts of waste. Batch reactors are also used, when the residence time required for the decontamination reaction is exceedingly large and when solids are treated. However, batch processes are rather labor-intensive, and require the presence of storage facilities to temporarily store the incoming waste material while the treatment process is proceeding in the reactor. An intermediate mode of operation between batch and continuous processes is semi-batch process, in which the waste material is continuously fed to an otherwise batch-operated reactor. Once the detoxification process is complete, the reactor is emptied and the process is start anew. In wastewater treatment, this approach is extensively used in time-stepped processes utilizing sequencing batch reactors (SBRs), as discussed more in the next section.

Collins and Andrew (1996) reported that a two phase organic-aqueous system was used to degrade phenol in both batch and fed-batch cultures. The two phase partitioning bioreactor used 500 ml of 2-undecanone loaded with high concentrations of phenol to deliver the exnobiotic to *Pseudomonas puttida* in 1 liter aqueous phase. The biodegradation of haloacetic acid by bacterial enrichment culture used the two 1 liter batch reactors, which was inoculated with biomass from the aeration tank (Bethany *et al.*, 2003).

Nora *et al.* (2001) studied the phenol biodegradation by using a repeated batch culture of *Candida tropicalis* in multistage bubble column. In many other microorganisms, the growth rate of *C. tropicalis* is affected by phenol. Moreover, when the yeast was aerobically cultivated in a medium containing phenol, using a bubble column, the yeast cell floatation phenomenon occurs, which made the continuous operation of this type of reactor difficult. Therefore, a system of phenol degradation, which recycles the biomass separated by flotation. In order to reduce the substrate toxicity observed at high phenol concentrations, the bubble column used in the biodegradation studies was fed in a semi-batch mode. So, a semi-continuous system was implemented to treat effluents with relatively high

concentrations (>9,000 ppm) of phenol, by replacing periodically about 22% of the bioreactor operational volume. The phenol removal efficiencies obtained with this system were higher than 98.7%. Mezzanotte *et al.* (2002) presented the paper dealing with a laboratory-scale study of anaerobic treatment of two commercial mixtures (LS2, LT7) of alcohol ethoxylates with 8-14 carbon atoms and 2 and 7 ethoxy groups. The tests were carried out in batch, with a 2 g/L single dose, and in removal process for LS2, while adsorption was less significant and biodegradation was more important for LT7. These differences appeared to be mainly related to ethoxy portion length determining the extent of biodegradability and adsorption.

2.4.3 Sequencing batch reactors

A sequencing batch reactor (SBR) is a reactor in which an activated sludge process is carried out in a time-oriented, sequential manner using a single vessel for all the phases of the process. The same steps involved with a conventional, continuous activated sludge process, such as; aeration, pollution oxidation, sludge settling, and now conducted in one batch after the other. The main advantage of SBRs is that they can accommodate large fluctuations in the incoming wastewater flow and composition without failing.

Tomei *et al.* (2004) reported the investigation of the biodegradation kinetics of 4-nitrophenol (4NP) in lab-scale sequencing batch reactor fed with the compound as the sole carbon source. The experimental results showed that complete 4NP removal can be easily achieved with acclimatized biomass, even if inhibition kinetics is observed. Furthermore, an improvement in the removal kinetics is obtained if the substrate concentration peak, reached in the reactor at the end of the filling time, is maintained at quite a low value.