2. REVIEW OF LITERATURE
Waste water treatment and collection has followed paths of both historic and scientific discoveries. From a historic perspective, as communities have grown, so has the need for quality water. The need to supply safe water, remove wastes from water, and to protect public health, have been the endeavors and concern of many generations. Scientifically, as public health issues and the understanding of what causes outbreaks of disease such as cholera and dysentery have been discovered, the building of infrastructure and development of processes that can be used to end these issues has followed. According to Wildere, (2001), Sewage concentrated treatment obviously has its
limitations, at present many water treatment scientists actively advocate “in situ treatment in situ, and to realize the reuse water balance and water circulation system”. According to Qin et al. (2013), sewage in situ collection, processing and recycling, is economic and feasible then processing at centralized system. Thus, the water pollution not only can be controlled, but also in situ treatment after specific reuse, saving a large amount of the water resources in order to meet the requirements of sustainable development.

2.1 History

Crittenden et al. (2005) have described the history of wastewater treatment in chronological order. Webster, (1962); Kirby et al. (1956), described the technologically advanced urban drainage systems that
the Indus civilization constructed for several of their more important cities. Ruins from two cities in particular provided a detailed glimpse of the Indus urban drainage systems. The ruins from Harappa and Mohenjo-Daro, two Indus cities separated by about 350 miles, suggest that they were arranged according to a plan and that the urban drainage system was coordinated with the layout of the town sites. Connections were built from most residences to open channels constructed in the centre of the streets. The channels were either excavated into the ground or constructed above the ground with burnt brick.

The Romans were the only civilization in all of western Asia and Europe from antiquity to the 1800s to build a carefully planned road system with properly drained surfaces (Hill, 1984). In England one of the first
public Acts that addressed the sewerage issue was passed in 1427 (Sidwick, 1977). The first large-scale urban drainage systems in North America were constructed in New England cities during the colonial era (APWA, 1976). The beginning of modern urban drainage practices was initiated in European cities during the nineteenth century. The Paris sewer system was improved by the initial efforts of the engineer Pierre-Emmanuel Bruneseau (Reid, 1991). Experimentation of two Dutch spectacle makers experimented with object magnification led to the discovery of the microscope by Antonie van Leeuwenhoek in the 1670s. He grinded and polished lenses and thereby achieved greater magnification. The invention enables scientists to watch tiny particles in water. In 1676, Leeuwenhoek first observed microorganisms in water.
In the 1700s the first water filters for domestic application were applied. These were made of wool, sponge and charcoal. In 1804 the first actual municipal water treatment plant designed by Robert Thom was built in Scotland. The water treatment was based on slow sand filtration, and horse and cart distributed the water. Three years later, the first water pipes were installed. The suggestion was made that every person should have access to safe drinking water. In Germany the first comprehensively planned sewage system was constructed for a major city Hamburg in 1843 (Metcalf and Eddy, 1928). William Lindley was commissioned to plan and design the system after a fire destroyed a large part of the city during 1842. The success of the Hamburg sewer system led to the comprehensive design of sewer
systems for other cities in Europe and the United States. The comprehensive sewer system of London, designed by Joseph Bazalgette, was constructed between 1859 and 1865 (Kirby and Laurson, 1932). In the 1890s America started building large sand filters to protect public health. These turned out to be a success. Instead of slow sand filtration, rapid sand filtration is now applied. Filter capacity was improved by cleaning it with powerful jet steam. In 1902 calcium hypo chlorite and ferric chloride were mixed in a drinking water supply in Belgium, resulting in both coagulation and disinfection. In 1906 ozone was first applied as a disinfectant in France.

2.2 Alternatives, Biofilm and Biofilters

In 1980’s biofilters were used to reduce odour from livestock operation in the Netherlands and Sweden
(Noren, 1985; Scholtens et al., 1987). These biofilters were based on the Zeisig design and decreased hydrogen sulfide and ammonia by 50%. Cernuschi and Torretta (1996), reported that the number of installations has significantly increased in Japan, growing from about 40 in the 1980s to 90 in the 1990s in the last two decades. On the contrary, in other European countries, including Italy, Switzerland and Austria, the number of biofilter installations has been quite limited. Cetkauškaite and Jakstaite (1999), reported that biofilters were the first wastewater treatment technologies developed in Western Europe, starting since 1890 as a contact filter process. They were called percolating beds (in Europe) or trickling filters (in the United States) and further development of high rate trickling filters with recirculation of treated wastewater took place about the
1930s. Biofilters were the first biological WWTPs to be built in Lithuania, mostly in 1960-1970.

According to Narmada and Mary Selvam Kavitha (2012), the main species involved in effective wastewater treatment include Lactic acid bacteria - *Lactobacillus plantarum*, *L. casei*, *Streptococcus lacti*, Photosynthetic bacteria – *Rhodopseudomonas palustrus*, *Rhodobacter spaeroide*, Yeasts – *Saccharomyces cerevisiae*, *Candida utilis*, Actinomycetes – *Streptomyces albus*, *S. griseus* and Fermenting fungi – *Aspergillus oryzae*, *Mucor hiemalis*. Min jin et al. (2005), studied the role of *Bacillus megatherium* as external source of organism for bioremediation of sewage. According to Ottengraf (1983), the great advantage of the heterogeneous population present in the
biofilter is the excellent ability to survive long periods (up to 2 months) without activity, provided that periodic aeration is ensured. Most of the microorganisms growing in biofilters treating organic pollutants are heterotrophic eubacteria, actinomycetes and fungi, which was revealed by plate counting in nutrient agar (Leson and Winer, 1991). More frequently, the bacteria detected in biofilters are soil bacteria, such as *Bacillus cereus var. mycoides* and several strains and species of actinomycetes belonging to the genus *Streptomyces*. Helmer (1972), did a microbiological characterization of compost filter population and observed abundant growth of eubacteria ($10^9$CFU/g), actinomycetes ($2 \times 10^6$ CFU/g) and fungi ($10^6$ CFU/g) along the whole filter height with higher density of fungi at the bottom. Adamse *et al.* (1984), stated that the composition of
activated sludge treating municipal sewage comprises *Pseudomonas*, *Flavobacterium*, *Alcaligens*, *Acinetobacter* and *Zooglea sp*. Other researchers have found *Pseudomonas*, *Acinetobacter sp* and *Enterobacteriaceae* to be the dominant bacteria (Kappesser *et al.*, 1989). Under oxygen restriction conditions, the dominant species are from the genera *Acinetobacter*, *Aeromonas* and *Flavobacterium* (Autheunisse and Koene, 1987). *Nitrosomonas* and *Nitrobacter* are chemolithotrophic bacteria present in activated sludge process (Hughes and Stafford, 1976). According to Wood and Wang (1985), 30 of the 92 elements that comprise the periodic table have been found to be essential to the sum total of microbes.

Members of Bacteroides group are able to degrade various refractory bio macromolecules such as
cellulose, chitin, DNAs, lipids and proteins, which are abundant in a biofilm, in which dead organisms are trapped and these species produce exo-polysaccharide slime that has an important role in biofilm formation and development (Kolenbrander et al., 1985). Paracoccus sp is a quite biochemical versatile genus able to display wide range of degradative capabilities such as aerobic denitrification and heterotrophic nitrification and some strains of this group grow anaerobically using thiosulfate carbon disulfide, methanol or formate as energy sources and nitrate as final electron acceptor (Baker et al., 1998). Yang et al. (2004), described that the major drawback in the bioreactor based on anaerobic digestion of soluble substrate is the slow growth rate of methanogens and the desirable organic matter degradation is achieved after along residence time in the reactor. He studied the
methods of immobilizing microbial cells on various supports or medium, to maintain high microbial cell densities in the anaerobic bioreactor. Adhesive growth supports high cell density and thus high activity. Akther et al. (2003), developed a new biosorbant, micro algal – luffa sponge, *Chlorelle sorokinian* immobilized disc for the removal of nickel from aqueous solution.

Stouthamer et al. (1997), described that some heterotrophic nitrifiers such as *Thiosphaera panatropha* and *Paracoccus denitrificans* can denitrify nitrate or nitrite under aerobic growth conditions by expressing a periplasmic nitrate reductase, which catalyzes nitrate reduction to nitrous oxide. Bock et al. (1986), reported that several strains of *Nitrobacter sp* could denitrify during anoxic, heterotrophic growth. Abbas et al. (2008),
described the immobilization of the denitrifying bacterium, *Pseudomonas stutzeri* in microbial cellulose to remove nitrate from synthetic influent that has increased the adsorption capacity, decreased the cell leakage from the beads, resulted in higher activity of the immobilized cells and allowed better operation and control. Biofilters may be self inoculating, inoculated with activated sludge or compost or induced with bacterial species. The microbial ecology and performance of a biofilter was studied by Ding *et al.* (2000). The work of Ding *et al.* (2000), demonstrated the ability of the microbial community to respond to changes in the inlet gases without affecting treatment of those gases. Bioaugmentation with a complex inoculum, which naturally occurs in metal work fluids and contains strains of *Clavibacter sp.*, *Rhodococcus sp.*, *Methyllobacterium*
sp. and Pseudomonas sp. is very effective in degrading COD in wastewater. The augmented consortium degraded 67% of the COD (48 g/L) and was therefore 50%–60% more effective than the indigenous flora. In-situ analysis showed that 100 h after the introduction, the augmented consortium constituted more than 90% of the population (Van et al., 2003). Miao et al. (2005), used pseudomonas sps, to reduce the rapeseed oil smoke emissions from the restaurant using biofilter.

Chung et al. (2000 and 2001), reported that a gas mixture of NH$_3$ and H$_2$S are removed by biofilters packed with immobilized cells (Nitrosomonas europea for NH$_3$ and T. thioparus CH$_{11}$ for H$_2$S and Arthrobacter oxydans CH$_8$ for NH$_3$ and Pseudomonas putida CH$_{11}$ for H$_2$S).
Zinebi et al. (1994), reported that a variety of bacterial genera including *Acinetobacter, Enterobacteriaceae, Aeromonas, Flavobacterium, Alkaligenis, Pseudomonas and Moraxella sps*, have been found during the processing of wastewater with biological aerated filters. Lorenzo et al. (2006), used silica based beads for packed bed biofilm reactor and found various genera of microorganisms including *Rhodobacterales, Bacteroidales, Pseudomonadales, Enterobacterales, Rhodocyclales and Paracoccus, Pseudomonas, Acinetobacter and Enterobacter sps.*, at the end of experimentation.

Anneli (2006), used rock wool media for immobilization of *Hypomicrobium* species to reduce sulphur compounds from a paper and pulp industry.
Kyung-suk et al. (2000), used porous lava as biofilter material for the immobilization of *Thiobacillus thiooxidans* to deodorize hydrogen sulfide in a laboratory scale biofilter. They achieved 100% removal efficiency of hydrogen sulfide during the process of treatment. The relevance of the temperature to ammonia oxidizing bacteria was investigated by Park et al. (2009), using redundancy analysis demonstration and he reported that temperature was more significant than salt concentration which shows effects on AOB compositions and dynamics.

In a study conducted by Gopinath et al. (2005), on thirty four wild fungal species associated with edible oil mill wastes, the species *Absidia corymbifera, Aspergillus fumigatus, Aspergillus japonicus,*
Aspergillus nidulans, Aspergillus terreus, Cunninghamella verticillata, Curvularia pallescens, Fusarium oxysporum, Geotrichum candidum, Mucor racemosus, Penicillium citrinum, Penicillium frequentans, Rhizopus stolonifer and Trichoderma viride were found to exhibit the maximum lipase activity. It is known from literature that lipase producing fungi can utilize oil as a main carbon source, which has approximately twice the energy value of glucose, and are capable of reducing COD of the oil effluent (Koritala et al., 1987; Ratledge, 1992).

According to Nicolella et al. (2000), wastewater treatment processes are based on the use of three types of microbial aggregates viz., static biofilms (e.g. in trickling filters), particulate biofilms (e.g. biofilm
fluidized bed reactors, upflow anaerobic sludge blanket reactors and biofilm airlift suspension reactors) and flocs (in activated sludge processes). According to the studies of Seneviratne et al. (2007), fungal-bacterial biofilm (FBB) are more effective than monocultured or bacterial-bacterial biofilms or even a mixed culture of bacteria and fungi. Biofilter thicknesses of 1-1.5 feet are usually most economical and the contact time required to remove most of the odorous gases should be between 5-15 seconds (Janni et al., 1999). Cioci et al. (1997), investigated a new engineered packing material that consists of a highly porous inorganic matrix coated with active carbon. The major important factor that strongly influences the performance of biofiltration is the composition of the heterogeneous micro flora.
Benedusi et al. (1993), reviewed the distribution of microbial population along biofilters. In their studies, the microbial loads of about $10^5$, $10^4$, $10^3$ colony forming units per gram of support (CFU/g) have been reported for oligoheterotrophic, heterotrophic, and autotrophic metabolic types. The growth and activity of the microorganisms in the biofilter are strongly influenced by the availability of oxygen and nutrients, the degree of moisture, temperature and pH and so on. Stensel et al. (1988), suggested that the clogging of the biofilter with accumulated suspended solids is prevented by backwash procedure. Isaka et al. (2007), reported that the application of cell immobilization techniques to the wastewater treatment process has recently gained much attention. One of the more recent procedures to reduce odour emission is the use of biofilter. Biofilter is not a
new technology, but is an adaptation of natural atmosphere cleaning processes. According to Nicolai and Janni (2000), biofilter use microorganisms to convert gaseous contaminants to carbon dioxide, water vapor and organic biomass and thus making biofilter effective to reduce emissions. Biofilters were used in wastewater treatment plants, chemical manufacturing facilities, composting and other industrial air pollution schemes. In 1960s biofilters were first applied to live stock facilities in Germany to reduce odour emissions from live stock facilities (Zeisig and Munchen, 1987).

Downing and Nerenberg (2008), used microsensors to measure nitrogen forms produced by biofilms on aerated submerged membranes. McLamore et al. (2010) used noninvasive, microsensor techniques
to quantify real time changes in oxygen and proton flux for *Nitrosomonas europaeae* and *Pseudomonas aeruginosa* biofilms following exposure to environmental toxins in membrane-aerated bioreactors. Andersson *et al.* (2008), stated that medium composition has a strong effect on biofilm formation. He observed that strongest biofilm formation was formed when mixtures of 13 bacteria were grown together. Bjerkey and Fiksdal (2009), studied biofilm structure on curved membrane surfaces, such as hollow fiber membranes using Fluorochrome stains, CLSM, and an image analysis program to calculate thickness, volume of biomass, porosity, and roughness of biofilms. Delatolla *et al.* (2008), described a simple, rapid and reliable technical procedure that enabled biofilm samples attached to polystyrene beads to be characterized in
terms of the biofilm mass and nitrogen content and proposed a protocol that demonstrated 99.9% removal of the biofilm from polystyrene beads. The application of molecular techniques to the study of wastewater treatment systems by Wojnowska et al. (2010), suggested that microbial groups may be organized in various spatial structures such as activated sludge flocs, biofilm or granules and represented by single coherent phylogenic groups such as ammonia-oxidizing bacteria (AOB) and polyphosphate-accumulating organisms (PAO). Advances in biofilm reactors were investigated by Cheng et al. (2010). He summarized a review on biofilm reactors with novel applications and designs. In order to monitor and control engineered microbial structure in wastewater treatment systems, it is necessary to understand the relationships between the microbial
community structure and the process performance. Wojnowska et al. (2010), published a review on bacterial communities in wastewater treatment processes, the quantity of microorganisms and structure of microbial consortia in wastewater treatment bioreactors. Biofilm advantages include cell-associated hydrolytic enzymes concentration at the biofilm substrate interface to increase reaction rates, a layered multiple species microbial structure which may sequentially convert complex substrates and co-ferment hexose and pentose as hydrolysates diffuse outward, and the possibility of fungal-bacterial symbioses allowing delignification and saccharification. Environmental factors shaping the ecological niche of ammonia oxiding archaea (AOA) were studied by Ergurder et al. (2009), They proposed that AOA might be important, even predominant,
biological actors within the nitrogen cycle in low nutrient, low pH and sulfide-containing environments.

Depending on the surface area and space availability, horizontal media beds (up or down flow) and vertical media beds (horizontal flow) are used (Lefers and Nicolai, 2005). They reported that optimum biofilter moisture content for compost or woodchip mixture is 50%. Lefers and Nicolai (2005), reported that the biofilter moisture and contact (residence) time are the two important factors influencing the performance of biofilter for odour removal biofilters. According to Reyes and Ergas (2000), the main problem up to 75% of all biofiltration is due to lack of control over media moisture for odour removal biofilters. Wanni et al. (1998), described that the microorganisms in the biofilter
that treat the odorous compounds also degrade biofilter media and due to this the biofilter settles and becomes compacted over time, reducing component interchange surface and increases the resistance to flow. Boltz and Daigger (2010), studied uncertainty in bulk liquid hydrodynamics and biofilm dynamics in biofilm reactor design. They considered the uncertainties of liquid hydrodynamics on biofilm thickness control, surface area and development of biofilm, its dynamics and influence on biofilm structure, thickness and function.

There are very few models reported in the literature that can predict the performance of a biofilter. Most of these models are based on the assumption of steady state condition (Rittmann, 1990; Rittmann and Manem, 1992; DiGiano and Speitel, 1993). Rittmann
and McCarty (1980), first introduced a steady state biofilm model in which, the mass transport and the microbial kinetics were expressed by Fick’s second law and Monod equation respectively. It was assumed that minimum bulk substrate concentration is required to maintain the steady state biofilm in the filter. The model describes the fundamental biological processes but does not take into account the biofilm growth with time.

Chang and Rittmann (1987), developed a model for the kinetics of biofilm on activated carbon (BFAC) incorporating film mass transfer, biodegradation, and adsorption of a substrate, as well as biofilm growth. All the fundamental biological processes have been included in this model. However, the non-steady state condition due to backwashing, change in the filter bed porosity and hence the filter depth have not been considered in this
model. The concept of dimensionless empty bed contact time (EBCT), which allows comparison of results among different surrogate parameters such as AOC and BDOC (Biodegradable dissolved organic carbon) was developed by Zhang and Huck (1996a), utilizing the steady state biofilm model of Rittmann and MaCarty (1980). Huck et al. (1994), developed a first order biofilm model. The model is more practical than accurate in predicting the performance of a biofilter.

It assumes that the organic removal in a biofilter is directly proportional to the influent concentration. Billen et al. (1992), developed the CHABROL model to predict BDOC removal. The model incorporates the major microbial processes and substrates of different biodegradabilities. The model showed that BDOC
removal is directly proportional to influent BDOC and EBCT. The three kinds of interaction, (i) interaction with dissolved organic matter, (ii) interaction with the solid support, and (iii) the mortality and grazing of bacteria have been incorporated in the model to describe the dynamics of the bacterial community colonizing on the support (filter media). The model consists of six state variables, namely viz., concentrations of rapidly and slowly hydrolysable biodegradable macromolecules of organic substances, concentrations of directly usable monomeric substances, bacterial biomass actively attached to the solid support, the bacterial biomass reversibly adsorbed to the support, and free bacterial biomass in interstitial water.
Most of the models describe the biological processes in a biofilter. There are no complete models that can predict the efficiency of the biofilter at different operating conditions. Boon et al. (1997), conducted pilot scale biofilter experiments with sewage and developed empirical equations to predict the biochemical oxygen demand (BOD₅) and ammonia removal by the biofilters. It was observed that organic and hydraulic loading rates of the biofilter can limit the organic removal efficiency of the biofilter. Hozalski and Bouwer (2001a), developed a numerical model called BIOFILT, to simulate the non-steady state behavior of biologically active filters used for drinking water treatment. The model is capable of simulating substrate (biodegradable organic matter) and biomass (both attached and suspended) profiles in a biofilter as a function of time. The model also has
capability to simulate the effects of a sudden loss in attached biomass due to filter backwash on substrate removal efficiency (Hozalski and Bouwer, 2001b). The model is very practical and it incorporates most of the fundamental processes of the biofiltration. Some of the limitations reported on this model are (i) It is a single substrate model, (ii) It assumes that there is no mixing of the filter media during backwashing, (iii) It does not incorporate the adsorption of substrate that occurs when GAC is the filter media of the biofilter, and (iv) The model requires data on parameters to perform the simulation.

Open biofilters are more commonly used for animal agricultural (animal husbandry practices). They are less expensive than closed systems and relatively thin
layers of media to reduce backpressure on the air handler and are usually quite large in terms of surface area exposed to the atmosphere. Horizontal media beds (up or down flow) and vertical media beds (horizontal flow) are used, depending upon surface area and space availability (Lefers and Nicolai, 2005).

The biofilter media should provide a suitable surface for quick biomass growth, larger surface area for biomass growth and good surface texture to hold biomass against shear and sloughing. It is important to select an appropriate filter backwashing technique for successful operation of a biofilter. The biomass attached to the filter media has to be carefully maintained during backwashing (Ahmad et al., 1998; Bouwer and Crowe, 1988; Bablon et al., 1988; Graese et al., 1987; Miltner et
Ahmad et al. (1998), found that biological particles (measured as heterotrophic plate counts and cellular adenosine triphosphate), which are usually hydrophobic in nature, are attached to filter media (GAC) with a greater force than non biological clay particle, which was measured as turbidity.

The major advantages of biofiltration are, being simple, low construction cost, energy saving, flexible to load variation, inexpensive and easy operation and maintenance. The aerated biofilter (ABF) process appears to be well suited to the requirements of small wastewater treatment plant (Iwai et al., 1990). The ABF combines aeration and clarification in one unit by using an inert support material for both biofilm attachment and filtration. The performance of the ABF process has been
proven to be an effective process for treating domestic effluent (Stensel et al., 1988). The efficiency of lab scale biofilters has been widely investigated by Paca and Koutsky (1994). They have obtained a degradation exceeding 95% when removing toluene and xylene. Ho et al. (1995), have found an efficiency over 90% for two full scale biofilters reating ethanol, butyraldehyde and ethyl acetate. Klapana et al. (2012), reported the characteristics of pH, BOD and COD of wastewater generated in Bhopal and the values are ranging from 7.5 – 7.8 for pH, 58.2 – 86.8 mg/lit for BOD and 270 – 440 mg/lit for COD for raw sewage. Britt-Marie et al. (2011), reported that filter material with high adsorption capacity and other different properties are needed, to handle various types of pollutants which differ considerably with respect to their chemical structure.
Lukavsky (1986), tried immobilization of microalgae with sodium alginate for sewage treatment. There are no long term studies on compost or woodchip biofilter to determine the length of media life, but most biofilter media will remain effective without causing a large pressure drop for 3-10 years or more. The selection of an appropriate biofilter packing material for methane oxidation was investigated by Streese and Stegmann (2003a and 2003b). At first, fine grained compost was tested as packing material, which exhibited high degradation rates in the beginning but severe material clogging due to the accumulation of exopolymeric substances (EPS) was observed after few months. After testing different other biofilter materials, a mixture of compost, woodchips and peat was developed. Because of its structural properties, this material was not subjected
to clogging and showed stable degradation rate over a period of one year. Tolu Olufunmilayo Ajayi and Atoke Olaide Ogunbayo (2012), reported that wastewater can be treated using water hyacinth (*Eichhornia crassipes*). Patel and Kanungo (2012) reported that submerged and free floating aquatic plants like hydrilla and pistia has a potential to treat wastewater. They also reported that domestic wastewater characteristics vary not only from city to city but also from season to season and even hour to hour.

The materials used for biofilter construction include compost, soil peat, chipped brush and bark, sometimes blended with a biologically inert material such as gravel to maintain adequate porosity. Biofilter bed depths typically range from 1-1.5 meters deep, with
shallower beds subject to short circuiting of gas flow and deeper beds more difficult to keep uniformly moist. According to Pekdemir et al. (2003), *L. cylindrica* showed suitable characteristics for use as a support matrix for formation of a *Thiobacillus ferrooxidans* biofilm for bio oxidation of ferrous iron (Fe$^{+2}$) from strongly acidic industrial wastewater with a high Fe$^{+2}$ content.

Pekdemir et al. (2003), demonstrated that *L. cylindrica* has a promising potential as an ecological and sustainable alternative to the existing synthetic support materials. Sisal fibre waste from Agaves species are strong, rough, hard, durable fibre, chemical resistant, and contains two steroidal saponins-yuccagenin and ruizgenin that act as natural chelating agents (Romero et
These characters make sisal fibre waste a potential biomaterial for microbial cell immobilization. Fang et al. (2004), suggested the use of several natural materials like agar, agarose, collagen, alginites and chitosan and synthetic polymer materials like polyacrylamide, polyurethane, polyethylene glycol and polyvinyl alcohol for microbial immobilization. He also stated that the type of support media used for anoxic biomass immobilization can affect the efficiency of a bioreactor. Streeese and Stegmann (2005), developed a structured biofilter material after testing different materials. He used a mixture of compost, wood fibres and peat was developed and successfully tested. Because of its structural properties, this material was not subject to clogging and showed stable degradation rates over a period of one year Soares and Abeliovich (1998),
reported that when wheat straw was used as the carbon source for biological denitrification all the water soluble components and a significant portion of the cellulose and hemicellulose had been lost by the end of the experiment, while lignin and mineral components remained unchanged. For the treatment of aquaculture and other wastewaters with high nitrate concentrations, Saliling et al. (2007), described the use of wood chips and wheat straw as biofilter media. Jignesh et al. (2008), reported that the corn cobs powder can be used in wastewater treatment process for removal of metal ions and is a good absorbent for mercury with greater sorption capacity. Biofilter use a porous solid medium consists of inert substances which ensure large surface areas for attachment and additional nutrient supply to support microorganisms and the media include peat, soil,
compost, woodchips, straw or a combination of two or more (Nicolai and Janni, 2001).

In a study of various types of packing media, Phillips et al. (1995), concluded that packing media such as heather, mixture of heather and coconut fiber, mixture of heather and fibrous peat, bean straw, coconut fiber, linseed straw and screened wood chips for biofilters wood chips over 75 mm screen size appeared to be the most promising because of the lowest pressure drops and least compressibility. The influence of carrier type on adhesion and biofilm formation of pure and mixed cultures was studied by Gjaltema et al. (1995). He used packing material of type, roughened, hydrophobic and positively charged glass beads, sand and basalt grains in laboratory airlift reactors for his study. The results
clearly show that in airlift reactors hydrodynamic conditions and particle collisions control biofilm formation. Increased surface roughness of the carriers promoted biofilm accumulation on suspended carriers, whilst the physico-chemical characteristics of the carrier surface proved to be less important. Process and technology development was attempted by Thistlethwayte et al. (1973), who utilized a trickling filter column packed with river gravel or glass balls and seeded with activated sludge. Waste air contaminated by \( \text{H}_2\text{S} \), \( \text{C}_2\text{H}_5\text{SH} \), \( (\text{C}_2\text{H}_5)_2\text{NH} \), and \( \text{C}_4\text{H}_9\text{CHO} \) was purified, in countercurrent with a nutrient solution, with removal yields ranging from 40% to almost 100%. Liu et al. (1994), studied extensively granulated activated carbon and reported that granulated activated carbon (GAC) is used for its adsorption property and it may be useful
when the feeding is subject to strong shock loadings as adsorption has a buffering effect. In biological trickling filters the packed bed consists only of inert materials (glass, ceramics and plastics), while the liquid phase, containing inorganic nutrients, flows downward over the packaging material in countercurrent with the contaminated gaseous stream and is continuously recirculated through the bioreactor. Small particles of natural organic materials, such as compost, peat, soil, or mixtures of these materials with bark, leaves, wood chips, heather branches, humus earths, or brushwood (less than 10 mm in diameter), are widely used as packing media in biofilters.

José et al. (2008), conducted a laboratory-scale submerged attached growth bioreactor using Luffa
cylindrica as support material for the immobilization of nitrifying bacteria and observed that the efficiency of nitrification varied within the range of 82 - 95% with a mean of 88%. Pak et al. (2000), used ceramic beads as biofilter media for simultaneous removal of nitrogen and phosphorus. Basiakine (1925), reported that various types of filter materials including cotton, hemp, copper gauze, galvanized iron gauze, brush wood, veneer, sand and wood were tested as media. In an increasing search for low cost adsorbents various substances such as coal based adsorbents and bituminous coal has been reported. Various industrial solid wastes, agricultural by-products and discards and similar products have adsorption affinity for heavy metals. Coffee grounds (Pandey and Choudhari, 1982), china clay (Macchi et al., 1986), apple wastes (Yadava et al., 1991), peanut skins
(Maranon and Sastre, 1991) etc., have also been tested with varying degree of success for removing metals from wastewater.

Anthony et al. (2008), studied various types of carrier materials as biofilter media like sisal fiber waste, pumice stone and porous glass beads. They obtained good results for sisal fiber waste with 80 – 93% of chemical oxygen demand removal efficiency. Anneli and Kerstin (2001), used rock wool as biofilter material to treat waste gases of rapeseed oil from restaurants and isolated mixed cultures including mesophilic, aerobic, gram-ve rods from the filter material.

For H₂S removal, the packing material media used in conventional biofilter beds consist mostly of peat
and compost, however many authors add other materials as wood chips or perlite to avoid the bed compaction (Jones et al., 2004). Also other carrier materials such as polypropylene pall rings (Jin et al., 2005; Potivichayananon et al., 2006), porous lava (Chitwood et al., 1999) ceramics (Lee et al., 2005), active carbon (Duan et al., 2007) and polyurethane foam (Gabriel et al., 2004) have been used in biotrickling filters. Literature contains few accounts of the use of polyurethane foam for removal of malodorous gases with biotrickling filters.

Monroy et al. (2000) and Vieira (1988), reported the successful application of UASB reactor for sewage treatment at a various lab scale, pilot scale and full scale sewage treatment plant. The UASB reactor was reported
to give COD reduction efficiency between 60-80% at loadings between 0.4 kg COD/m$^3$d and 3.0 kg COD/m$^3$d in the temperature range of 15-25°C. Mahmoud et al. (2004), investigated the advantage of combination of a UASB reactor and a sludge digester that resulted in higher methane production and very low sludge production rate. Chen et al. (2000), reported that the capacity of the upflow packed bed reactor could be improved by increasing the biomass retention time using an immobilized cell system.

Basing on the configuration and flow sequence, the biofilters are categorized into open or closed and up-flow, down-flow or horizontal flow. According to Devinny et al. (1999), a closed system controls both the biofilter outlet and inlet gas streams whereas an open
system discharges treated gas from the biofilter directly to the atmosphere and these systems may be either up or down flow, depending upon the moisture application system. The air passing through the filter must contact the filter media for a given amount of time in order to get maximum odor reduction from a biofilter. This amount of time is known as the residence time or empty bed contact time (EBCT). Devinny et al. (1999), defined it as the empty bed filter volume divided by the rate of airflow.

To treat municipal sewage with an average BOD of 314 mg O₂/L with hydraulic retention time of 10.3 hrs, Orozo (1997), achieved 70% removal efficiency with a full scale anaerobic baffled reactor (ABR). The efficiency of lab-scale biofilter has been investigated
widely. Paca and Koutsky (1994), obtained a degradation exceeding 95% when removing toluene and xylene. Ho et al (1995), have found over 90% efficiency of biofilters treating ethanol, butyraldehyde and ethyl acetate. The packing medium, after use is unlikely to be classified as hazardous waste. Scholtens et al. (1987), reported an average filter efficiency of about 70% ammonia removal from biofilters on piggeries and calf sheds in Sweden.

Simultaneous removal of nitrogen and phosphorous by two biofilter system operated under alternate conditions of anaerobic and aerobic was investigated by Pak and Chang (2000). Song et al. (2005) and Ovez et al. (2006), has proved that the biological denitrification is one of the most
feasible, advanced, selective, and cost effective processes for removing nitrate by dissimilatory reduction, which transforms it into nitrogen gas using biodegradable carbon compounds as the energy source. According to Hao and Chen (1994), under aerobic conditions when the nitrogen loading increases beyond a certain level, partial nitrification may occur in the biological process that results in nitrite buildup.

Ghekiere et al. (1991), reported that the nitrite buildup has a deleterious effect on microbial phosphorous release as well as microbial phosphorous uptake in the system. Wentzel and Ekama (1997), reported that the phosphorus removal is increased with an increase in sludge which, is resulted in an increase in heterotrophic biomass producing degradable COD for
microbial phosphorous release and uptake of polyphosphate accumulating biomass.

Morgenroth and Wilderer (1999), reported that the phosphorous removal decreases with an increase in sludge age. Malollari et al. (2003), suggested that the sewage wastewater is a rich source of phosphorous which can be reused for agriculture. Gensicke et al. (1998), described that nitrate and nitrite are the main nitrogen load in wastewater of food and metal industries. Wild et al. (1971), reported that the ammonia oxidation starts only if BOD5 concentration in the water is <110mg/lit.

According to Rheinheimer et al. (1988), the alkalinity of the wastewater increases slightly during
nitrification due to CO₂ consumption for autotrophic growth and it decreases drastically due to nitric acid formation from ammonia in the counter reaction and the further nitrification by autotrophic nitrifiers is prevented due to weak buffer capacity of the wastewater. For the reduction of NO₃⁻ - N, < 2.85g COD is required in the wastewater treatment plants (Bernet et al., 1996). Danesh and Oleszkiewicz (1997), reported that for biological removal of 1mg phosphorous, approximately 6 to 9 mg volatile fatty acids are required. In order to permit good growth of the poly phosphate accumulating bacteria and for optimal biological phosphate removal, the COD/P ratio in the wastewater should be about 20g CODg-1 phosphate (Smolders et al., 1996). Metal ion contaminants in wastewater can be removed by microorganisms either by direct or indirect influence on
the redox state of metal ions or through biosorption of metal ions in the cell surface (Lovely and Coates, 1997).

Nitrate is a common water contaminant that can cause health problems in humans. Also, eutrophication or groundwater contaminations by nitrate, which cause serious social and economical problems, are related to an increase of nitrate concentration in the aquatic environment (Foglar et al., 2005). Biological denitrification has proved to be one of the most feasible, advanced, selective, and cost effective processes for removing nitrate by dissimilatory reduction (Song et al., 2005), which transforms it into nitrogen gas using biodegradable carbon compounds as the energy source (Ovez et al., 2006). Denitrification can be achieved either in suspended or attached growth systems. Since
the 1980s, biological denitrification has been performed using immobilized cells (Nakano et al., 2007). Since then, many studies of denitrification using immobilized cells have been undertaken (Li and Logan, 2004). The treatment of wastewater in packed bed bioreactors using immobilized cells is attracting increasing interest and has prompted the examination of different immobilization methods and a variety of carriers (Kariminiaae-Hamedaani et al., 2003; Hsu et al., 1996). This process has been applied to nitrate removal of wastewater and contaminated groundwater, with the technology achieving a high removal rate per volume (Cao et al., 2004; Peres et al., 1999). Joshi et al. (2000), studied the gaseous ammonia removal of laboratory scale biofilters. Their work showed that 95% of ammonia was degraded
to NO$_3$ and NO$_2$ in the quarter of the biofilter closest to the inlet gas stream after eight days of operation.

A full scale study was conducted by Boon et al. (1997), employing six biofilter columns of different diameters (6-26m) with blast furnace slag and granite as filter media. The BOD$_5$ and ammonia-N removal efficiency of the filters varied from 85%-97% and 55%-98% respectively. An experimental study conducted by Chaudhary et al. (2001) showed that GAC biofilter can be operated for a long time without regeneration of GAC. In this study, synthetic wastewater was prepared using three organic and seven inorganic substances (Organics: glucose, peptone, yeast extract; Inorganics: MnSO$_4$, CaCl$_2$, NaHCO$_3$, NaCl, MgSO$_4$·7H$_2$O, KH$_2$PO$_4$, (NH$_4$)$_2$·SO$_4$,) and the GAC bed was acclimatized with
relatively lower filtration rate (1m/h). The organic removal efficiency of the biofilter remained constant at 50-55% even after 77 days of continuous run.

Many microorganisms have been used for removal of hydrogen sulphide, principally *Acidithiobacillus* and *Thiobacillus*. In this group we found acidophilic bacteria such as *Acidithiobacillus thiooxidans* (Aroca et al., 2007), neutrophilic bacteria such as *Thiobacillus novellus* (Chung et al., 1998), *Thiobacillus thioparus* (Oyarzun et al., 2003) and *Thiobacillus denitrificans* (Ma et al., 2006). Heterophilic bacteria such as *Xantomonas sp.* (Cho et al., 1992), *Pseudomonas putida* CH11 and *Arthrobacter oxidanas* CH8 (Chung et al., 2004) have been used in biofilter for hydrogen sulphide removal. Other bacteria such as
Hyphomicrobioum (Hirai et al., 2001) have been used for H₂S removal with very good results. The optimum operating temperature for the microorganisms in the biofilter is between 30-40°C (Janni and Nicolai, 2000). According to Narmada and Mary selvam Kavitha (2012), treated wastewater can be reused as drinking water, in industry (cooling towers), in artificial recharge of aquifers, in agriculture and in the rehabilitation of natural ecosystems. As far as reuse of treated water is concerned, Friedler et al. (2004), reported that Israel is the country for the sewage in situ reuse and it is 100%. In North America there are 357 cities that reuse treated sewage and it contains 536 regeneration recycling stations. According to Asano et al. (2004) Japanese government put forward the “water” concept, in 1990, and setup 1369 reuse engineering all over the country.
Abu-Rizaiza (2004) reported that there are 50,000 metric tons of recycled water which is used for landscaping and industrial use every day in Mecca and Jeddah in Saudi Arabia. Bakopoulou (2004) reported that the water supply reaches 1.13 million tons per day, of which 85% is for the use of urban sewage water each day, 94000 tons of drinking water from regenerative waterworks in Johannesburg, Republic of South Africa. The low polluted sewage is directly used as irrigation, and has achieved good economic benefit in Thessaly, Greek (Abdul et al., 2010), Wastewater reuse is a useful tool in minimizing the amount of wastewater in the environment and it can be used for irrigation. Al-Hamaiedeh, H. and Bino, M., (2010), stated that wastewater is a valuable source of plant nutrients and organic matter.
Christenson and Sims (2011) and Rehman et al. (2012), have reported that domestic wastewater can be bioremediated in waste stabilization ponds using microalgae and bioproducts can be produced. Britt-Marie et al. (2011), used low cost biofilter material made up of peat and carbon containing ash in 3:1 ratio as filter material for the treatment of different types of wastewaters like car washes, landfill leachate and storm water. Sudipta and Somnath (2010), used a laboratory scale aerobic fixed film bioreactor packed with glass beads for biofilm growth to evaluate the removal efficiencies of COD and phenol for a carbohydrate - phenol mixture in wastewater. Monteiro et al. (2010), reported that biofilm reactor is a popular method for biological treatment of wastewater to combat high organic strengths owing to enhanced mean cell residence.
time and economical oxygen supply. They also reported that COD removal from wastewater can be obtained by either pure culture organism or mixed culture system. Papadimitriou et al. (2006), and Movahedyan et al. (2009), reported that activated sludge reactors have been widely used for COD and phenol removal from industrial wastewater. They stated that immobilized cell reactors offer several advantages over suspended cell reactors. These include higher biomass concentrations, allowing higher loading rates, and resistance to shock loading of inhibitory compounds, and requiring less time to revert to normal operation. Kennedy and Droste (2004), Srinivasan et al. (2009) and Ganesh et al. (2010), reported that fixed film reactors are receiving increasing interest in wastewater treatment. Most of the works on fixed bed reactor have been done in anaerobic condition.
They also stated that few works have been done on combined aerobic-anaerobic fixed film reactor system for COD removal. Zheng et al. (2009), reported that the treatment of wastewater by biological technology has been widely adopted because of its easy operation and low pollution generation. Raquibul and Delwar (2009), used various packing materials like coal, plastic ring, stone chips and wood chips for removal of ammonia by air stripping process from the wastewater from natural gas fertilizer factory. Raquibul and Delwar (2009), have obtained good results for removal of ammonia by 87.82% for coal chips, 91.61% for plastic rings, 85.24% for stone chips and 84.5% for wood chips.

Scanning electron microscopy (SEM) is a useful technique for the investigation of surface structure of biological samples (Duckett and Ligrone, 1995; Minoura
et al., 1995; Motta et al., 1994). For instance, much of the current knowledge about biofilms is due to the advances in imaging studies, especially the SEM. Early microscopic techniques used in biofilm monitoring, mainly applied during the 1980s, include scanning electron microscopy. SEM has been previously used to show a clear visualization of bacteria within a biofilm and is capable of demonstrating even a single bacterium and the relation of the biofilm to the underlying surface. SEM is a well established basic method to observe the morphology of bacteria adhering on a material surfaces, the morphology of the material surface, and the relationships between them (Peters et al., 1982). SEM has been used for enumeration of adhered bacteria or tissue in large number of samples. It is as a key technique that also provides information about the
morphology of biofilm, presence of EPS and the nature of corrosion products.

Busscher et al. (2008); Rodrigues and Elimelech (2009) have reported the role of cell surface polymers, flagella appendages and exocellular polymers, during cell adhesion and biofilm formation using electron microscopy. Bragadeewaran et al. (2010) reported that adhesion phenomena has been evaluated as function of substratum, liquid medium, carbon source, pH and hydrodynamics parameters including flow rate. Many of the conclusions about biofilm development, composition, distribution, and relationship to substratum have been derived from scanning electron microscopy. Hamadi et al., (2005) have investigated the role of surface topography as a parameter influencing microbial
adhesion. They worked on adhesion of *Staphylococcus aureus* ATCC 25923 to glass at different pH values using scanning electron microscopy and image analysis. Kouider *et al.*, (2010), experimented using SEM to determine the effect of stainless steel surface roughness on *Staphylococcus aureus* adhesion and showed that adhesion level was found to largely depend on the substrate roughness with maximum at $Ra = 0.025m$ and minimum at $Ra= 0.8m$. Mallouki *et al.*, (2007) have studied the anti-adhesive effect of fucans by SEM and a MATLAB program to determine the number and characteristics of adhered cells. Scanning electron microscopy (SEM) is one of the many methods available for the visual effect of antibacterial or antifungal on biofilm development (Camargo *et al.*, 2005; Sasidharan *et al.*, 2010; Sevinç and Hanley, 2010; Zameer and
Gopal, 2010). Sasidharan et al., (2010) used SEM to study the effects of potential antifungal extracts from natural sources in *Candida albicans* biofilm. Park *et al* (2008), investigated the fate of activated sludge extracellular proteins in sludge digestion using SDS PAGE. Hussain *et al*., (2010) and Park *et al*, (2011), reported that microorganisms are extensively used to degrade anthropogenic waste prior to release into the environment. The study of mixed microbial communities within their natural environment is key to the investigation of the diverse roles played by microorganisms, and to the identification of the microbial potential for biotechnological application, including but not limited to: pharmaceutical, diagnostics, waste treatment, bioremediation and renewable energy generation. An emerging field of research in microbial
ecology encompasses system approaches, whereby all levels of biological information are investigated (DNA, RNA, proteins and metabolites) to capture the functional interactions occurring in a given ecosystem and to identify characteristics that could not be accessed by the study of isolated components (Raes and Bork (2008) and Röling et al., 2010). Recent technological advances, including the development of high-throughput ‘omics’ methods, make such system approaches possible, where mixed microbial communities are viewed as one meta-organism. Metaproteomics, which is the identification of all the proteins expressed at a given time within an ecosystem (Wilmes and Bond, 2004), is an indispensable element of system approaches and plays a key role in the determination of microbial functionality. Wilmes & Bond (2006), applied metaproteomics to activated sludge
originating from the end of the anaerobic and aerobic cycles of the same sequencing batch reactor (SBR) during stages of enhanced biological phosphorus removal (EBPR) and non-EBPR (nEBPR).

Saumya and Pauk (1983), developed a simple and rapid method for the extraction of proteins from both pathogenic and nonpathogenic bacteria. Chen and Pramanik (2008), has stated that liquid chromatography (LC)/mass spectrometry (MS) has become a powerful technology for protein characterization. Kuhn et al., (2011) studied microbial dynamics and enzymatic activities of activated sludge processes with 2D gel and nano-HPLC-ESI-MS/MS and reported that human serine protease is a significant constituent of municipal wastewater. Daniela et al., (2011) developed a rapid analytical method for quantification of acylglycines in
urine by liquid chromatography coupled with tandem mass spectrometry (LC–MS/MS).

Research on microbial biofilms is proceeding on many fronts, with particular emphasis on elimination capabilities of pollutants specifically expressed by biofilm associated organisms. In the present study, various aspects of biofilms and biofilters were cited including type of microorganisms present, role of microbes in pollutants removal through biofilm formation, various kinds of filter materials and their applicability an attempt was made to utilize novel and economic filter materials and set of consortium by following footsteps of literature survey.