1. 1. INTRODUCTION TO INDUSTRIAL WASTE WATER

Industrialization has its inevitable consequences in terms of pollution, depletion of natural resources, health hazards etc., (Joghand, 1995). Along with industrial effluents, urbanized modern society generates phenomenal quantity of domestic waste. These industrial and domestic wastes, due to their enormous volume and chemical complexity are often reported to cause serious and often irreversible damage to the environment. Of the various eco-systems, water being used in human and industrial activities, is one of the most vulnerable systems for pollution and very often it acts as a vector for the transmission of a wide range of human and animal diseases (Sivasubramaniam and Mahadevan, 1995). Hence, it becomes imperative to treat the effluent (industrial and domestic) before discharging it into different water ways, so as to ensure the continued availability of safe water for animal and human consumption and utilization which is the essence of life.

Most industrial effluents are toxic or hazardous and their level of toxicity depends on the type of industry and the industrial process. These effluents exhibit
wide variations in their physico-chemical characteristics, which necessitate a highly individualized approach in effluent treatment for safe disposal or effective recycling of the same. The ease of effluent treatment is greatly influenced by the chemical nature of the effluent. More often, industrial wastewater rich in organic content (e.g. paper mill effluent, food processing industry effluent, etc.) provides an opportunity for designing effluent treatment strategies as they are principally composed of bio-degradable compounds vulnerable to biological transformations (Sastiy and Agamuthu, 1995). Hence, it becomes absolutely necessary to undertake a detailed analysis of any industrial effluent and plan suitable treatment strategies before discharging it into the environment.

1.2. WASTE WATER TREATMENT SYSTEMS

Industrial wastewater treatment systems, most often employ three levels of effluent treatments. viz., primary, secondary and tertiary treatments. Primary treatment is essentially a simple physical operation wherein the effluent is allowed to standstill for a prescribed period of time thereby settlable and floating solids, oils are removed. Secondary treatment is either chemical or biological or both which depends on the nature of the effluent. This stage is signified by the transformation of organic and inorganic matter thereby reducing the toxicity of the effluent, modifying its physico-chemical characteristics to the stipulated levels thereby making the effluent safe for discharging into the environment. Tertiary treatment is a fine polishing treatment system, not frequently employed in all
industries and is usually employed for the reuse and recycling in industrial processes (Kularni et al., 1991). Ion exchange, reverse osmosis, and electro-dialysis are some of expensive tertiary treatment methods. In short, to attain a different standard level for disposal of treated waste water, laid down by Pollution Control Board as per act “Water Prevention and Control of Pollution act 1974” and “Environmental Protection act 1986”, it requires a rational combination of these treatment methods (Fig. 1.1).

WASTE WATER TREATMENT METHODS
1. 2. 1. PHYSICAL TREATMENT OF INDUSTRIAL EFFLUENTS

This involves the employment of various techniques such as screening, skimming and sedimentation. Screening is a simpler form of physical treatment wherein it employs a wire mesh of differential porosities thereby ensures the removal of suspended solids and floating particles. Skimming is often used to remove oil and greasy particles in the wastewater through skimming process in a skimming tank. Sedimentation is yet another physical method, in which the wastewater is allowed to stand quiescent enabling the suspended solids to settle at the bottom (Metcalf and Eddy Inc, 1974).

1. 2. 2. CHEMICAL TREATMENT OF INDUSTRIAL EFFLUENTS

Physical treatments remove large solids and particulate materials nonetheless, they often fail to alter the chemical nature of the effluent to the prescribed levels of detoxification. This has prompted the evolution of chemical treatment procedures which include neutralization, coagulation etc.

Neutralization is a process designed to alter the pH of the wastewater to a desired level with the addition of acid or alkali. Fine, dispersed suspended and colloidal solids that are not removed by physical methods are often removed through a process of coagulation. Alum, ferric chloride and lime are some of the most commonly used coagulants in wastewater treatment. In the treatment of industrial effluents that are loaded with toxic compounds such as cyanides, phenols or microbes, chlorination is employed. Chlorination detoxifies such effluents with
desirable reduction in COD, odor and destruction of microbial flora (Rao and Datta, 1979).

1. 2. 3. BIOLOGICAL TREATMENT OF INDUSTRIAL EFFLUENTS

While physical treatment often results in partial reclamation of the effluent, chemical treatment inspite of its selective detoxification properties, more often increases the chemical load (solid waste) of the treated effluent thereby warranting further treatment of the partially treated effluent.

Realizing these limitations of physical and chemical wastewater treatment methods, biological treatment of industrial wastewater is being actively pursued from the late 19th century. Biological treatments of effluent frequently meet the ultimate objective of wastewater treatment in terms of detoxification, and desired changes in the physico-chemical properties and provides an opportunity for safe disposal of the effluent. Woldridge and Standfast (1933) were the first to demonstrate the beneficial effects of bacteria when they were used in the oxidation of domestic sewage for the removal of organic matters. Biological treatment provides an array of advantages over the conventional treatment methods. It can perform well in a wider pH range of the effluent, and can be modified to handle varying load and complexity of wastewater. Apart from being economical, it warrants relatively less infrastructure, space and does not contribute to the physical and chemical characteristics of the treated effluent in the form of solid waste unlike chemical treatment procedures (Eckenfelder and Connor, 1966).
1.3. ROLE OF MICROORGANISMS IN INDUSTRIAL EFFLUENT TREATMENT

Microorganisms due to their ubiquitous nature and metabolic versatility are frequently used as candidate organisms in biological effluent treatments. Microbes detoxify industrial effluents either through extra-cellular transformation mechanisms or through intra-cellular or periplasmic accumulation of toxic compounds. Hence, employment of microbes could bring about effective reclamation of wastewater either through direct transformation of suspended organic/inorganic compounds or by removal of the substrates through intra-cellular accumulation. The type of microorganisms to be employed in a biological treatment of industrial effluent depends largely on the physical, and chemical nature of the target effluent, the treatment conditions and the required standard of final effluent.

The microbial process of wastewater treatment employs two groups of organisms viz., aerobes and anaerobes. The microbial effluent treatment be it aerobic or anaerobic process is principally aimed at the removal of organic matters in effluent resulting in the reduction of biological oxygen demand (BOD), chemical oxygen demand (COD) and total organic content (TOC) of the effluent. Further, depending on the chemical composition of the effluent microbes could proceed with biochemical changes like nitrification, de-nitrification and ultimately stabilize the wastewater fulfilling the standards stipulated by Pollution Control Board.
1.4. AEROBIC BIOLOGICAL TREATMENT PROCESS

This wastewater treatment procedure involves the use of aerobic and facultative bacteria, in presence of oxygen, for the biodegradation of organic materials in the effluent. The chemical composition of the effluent would influence the choice of the microorganisms. The microbes employed in aerobic treatment of industrial wastewater could be a mono or poly species of bacteria, fungi, protozoa and rotifers (Arceivala, 1990). Even though, heterotrophic bacteria are the most preferred class of microbes in effluent treatment, chemo organotrophs (facultative) are also used in effluent treatment. Most often, in the aerobic process, the candidate microbes oxidize the organic compounds through normal respiratory chain with \( O_2 \) as the electron acceptor, thereby utilize the energy evolved for cellular growth and reproduction.

1.4.1. TYPES OF AEROBIC TREATMENT SYSTEMS

Aerobic wastewater treatment processes are mainly classified into two types on the basis of their effluent treatment potential. They are high rate process and low rate process (Fig. 1.2). High rate processes are those which have the capability of treating the effluent in a relatively short time duration compared to low rate process.
AEROBIC TREATMENT METHODS

Activated sludge is an aerobic degradation of effluent in which microbial outgrowth is removed though physical process as sludge, whereas the treated water is further aerated before discharge. The sludge stored in a secondary settling tank is used as an inoculum for the treatment of fresh effluent.

Trickling filter involves a system of immobilized cells wherein the candidate bacteria are allowed to grow as a slimy mass on a fixed bed of packing materials such as granite, plastic or other support materials, which are not degraded by the bacteria. The trickling filter consists of rotating arm that sprays the wastewater over a circular bed of microbes coated support material. Loose packing of support materials provide an opportunity of easy air movement within the surface. Microbes complete the transformation of the organic compounds present in the wastewater as it flows over the surface of the solids support material attached with microbes (Eckenfleder, 1963).
1. 4. 2. **ROTATING BIOLOGICAL TREATMENT**

In this process, the rotating discs submerged in wastewater provide physical support to microbes thereby facilitate the formation of biofilm over their surface. These discs are usually made using asbestos, PVC, polystyrene or polythene sheets. Apart from providing solid support to the microbes, these discs enforce effective oxygen distribution in the wastewater by virtue of agitation through their continuous rotation.

1. 4. 3. **AERATED LAGOONS**

Aerated lagoons are simple earthen or masonry basins, usually two to four metres deep with continuous supply of oxygen. The aerated lagoons are seeded with same type of organisms that are used in the activated sludge process. The oxygen is supplied to the basin by mechanical surface aeration units. Aerated lagoons provide one of the popular low cost biological treatments for municipal and industrial wastewater.

1. 4. 4. **WASTE STABILIZATION PONDS**

Stabilization ponds are open, flow through earthen basins specifically designed and constructed to treat sewage and biodegradable industrial wastewater. Stabilization ponds provide comparatively long detention periods extending from a few to several days. Waste stabilization ponds are as simple as septic tanks but are as effective as sludge units (Lawrence and McCarty, 1970).
1.5. ANAEROBIC WASTEWATER TREATMENT SYSTEM

This type of wastewater treatment is a low rate process and chemooorganotrophs, the anaerobic microorganisms are used in this process. This process involves anaerobic incomplete oxidation of organic compounds in the wastewater wherein the end products are usually \( \text{CO}_2 \) and methane when the bacteria employed are methanogenic. The variation in the nature of end product depends on nature of the suspended organic compounds in the effluent and the physiology of the candidate microbes.

1.5.1. BIOMETHANATION

Biomethanation is an anaerobic treatment process in which organic compounds in effluent are partially oxidized to methane which being a high energy, combustible gas can be used for domestic or industrial processes as a fuel.

Biomethanation requires the interaction of two groups of microorganisms. The first group, non-methanogenic bacteria such as *Bacteroides* sp., *Clostridium* sp., *Butylovibrio* sp., *Eubacterium* sp., and *Ruminococcus* sp., are cellulolytic and proteolytic organisms which carry out fermentative metabolism of complex organic substrates in the effluent. This fermentative action results in the evolution of simpler carbon compounds such as glucose and organic acids which are in turn utilized by the methanogenic bacteria resulting in the evolution of \( \text{CO}_2 \) and methane. The low rate nature of the anaerobic process, biomethanation is largely due to an extremely slow growth rate of the methanogenic organisms (Sixt, 1982).
1.5.2. ADVANTAGES OF ANAEROBIC WASTEWATER TREATMENT PROCESS

Even though most of the aerobic treatment processes are swift with high efficiency of wastewater reclamation, the carbon content is usually converted to cellular carbon, hence, it is not available for recycling, in utilizable form. On the other hand, in anaerobic process, despite its being a low rate process, results in the evolution of utilizable form of carbon such as methane.

The production of methane (biomethanation) by this system has high calorific value and it can operate at high organic loading rate as well. Apart from this, anaerobic system is less energy intensive and produces less sludge. This greatly reduces the burden of sludge disposal as accumulation of sludge on its own can cause serious environmental and health problems by serving as a reservoir for protozoans like hookworms, flies and mosquitoes.

Realizing the potentials and advantages, anaerobic wastewater treatment systems are actively pursued in most industrial and domestic wastewater treatment systems. Over a period of time, this system had undergone a series of modifications to improve its efficiency and to overcome its inherent deficiencies. Solid separation and subsequent digestion of sludge were enhanced by the provision of internal baffles in the digestion tanks (Ghosh et al., 1978). The rate of digestion was improved by the incorporation of solid support media for microorganisms growth and increase retention time of biomass in the digesters.
On the basis, an array of reactors was developed including fixed film reactors, upflow anaerobic sludge blanket reactors, and fluidized bed reactors.

1. 5. 3. FIXED FILM ANAEROBIC REACTORS

An inert medium or biomass carrier is added to the treatment vessel for favouring the growth of microorganisms on the surface of medium. This physical attachment prevents biomass washout and leads to high density of microorganisms and mean cell residence time of biomass. Young and McCarty (1972) had developed up-flow anaerobic filter system for wastewater containing moderate to high organic solids substances. They passed wastewater, with high organic load, upward through a bed of stones for achieving the treatment in a short retention time.

1. 5. 4. UPFLOW ANAEROBIC SLUDGE BLANKET (UASB)

In UASB, the active methanogenic bacteria, in high density, form a granular sludge, which is retained in a digester tank, despite the gas formation and up-flow velocity of wastewater. The formation of the granulation is a complex process, related to bio-chemical factors, feed stock characteristics and reactor conditions. The granulation is favored by high proportion of short chain organic acids, formed during the bio-methanation process (Lettinga, 1980). This UASB reactor contains a unique device, gas solid separation unit, which separates the gas from viable microorganisms, in the form of sludge.

1. 5. 5. FLUIDISED BED ANAEROBIC REACTOR

This type of hybrid reactor was developed by Switzenbaum and Jewel
In this reactor the wastewater with high velocity is passed upwards, through the reactor, to keep the settleable solids in fluidized motion. The advantages of the fluidized bed anaerobic system include, high bio-mass concentration with long solid retention time (SRT), non-requirement of mechanical mixing and relative stable operation in a variable feed condition.

1.6. SIZING MILL INDUSTRY

Sizing mill is one such industry generating moderate quantity of effluent rich in organic contents. Basically, sizing mill is an auxiliary component of textile industry. Sizing process forces the cotton yarn to obtain required physical properties so as to enable it to withstand the stresses during weaving and other textile operations. This is achieved with the help of sizing mixture, a paste like compound composed of adhesives, softeners, preservatives, weighing agents and wetting agents (Zoonenberg, 1951). Adhesives such as starch, gum arabic, gum karaya, carboxymethyl cellulose, acrylic polymers, vinyl polymers etc., are compounds with binding properties. When mixed with yarn they form a coating over the exterior surface of the yarn thereby making it much stronger with less chance of snapping off during weaving process. Structural rigidity and coarse nature of the yarn due to the addition of adhesives are corrected with the addition of softeners or lubricants (Shah, 1960). This includes vegetable and mutton tallow, hydrogenated mahua fat, stearic acid emulsions, mineral oil, sulphonated fatty acids etc.
The presence of organic compounds in the form of adhesives and softeners on the yarn makes it an excellent medium for microbial growth and hence it becomes absolutely necessary to incorporate antiseptics or preservatives in the yarn. The most commonly used preservatives are zinc chloride, copper sulfate, salicylic acid, and sodium penta chloro phenate etc., (Datta and Basu, 1970).

Apart from these major ingredients, materials such as china clay, talc, barium sulfate and glober salt are also added in the sizing process as a part of sizing mixture. These materials are basically fillers, which are meant to increase the weight of the yarn and to ensure smooth consistency of the same. To provide hygroscopic properties, Deliquiscent materials such as magnesium chloride, glycerol and zinc chloride are added to the sizing mixture to premill hydroscopic properties (Anon, 1959) (Plate. 1.1).

In short, sizing mill would determine the ultimate thickness; smoothness and softness of the warp yarn and in turn of the cloth. A modest increase in 10 – 20 % of yarn weight after sizing is termed as moderate sizing and an increase of 30 – 40 % of yarn weight is called heavy sizing. The overall process involves the passage of warp yarn from creels, move through sow box, guided rollers and squeeze roller (Plate. 1.2 and 1. 3). After these operation, sheath of warp yarn carrying size mixture are dried in drier drum (Plate. 1.4) (Kulkarni, 1959). During
Plate 1.1. Size mixture containing adhesives, softners, fillers and preservatives for sizing.
Plate 1. 2. Sow box containing size mixture for sizing the sheath of yarn.
Plate 1. 3. Passage of warp yarn from creels moves through guide roller and squeeze roller.
Plate 1.4. Sheath of warp yarn carrying size mixture dried in dryer drum.
wet steam passed through the size mixture, for coating. After two-three days of continuous operation, steam gets condensed over size mixture, which leads to loosing its adhesive property. Thereby it is essential to wash sow box and beck (cooking vessel) where size mixture stored in hot condition.

Sizing process is a water intensive process that involves the generation of over 1 – 5 KL of waste water/day (Plate. 1.5). Further, due to the chemically complex nature of the sizing mixture (discussed elsewhere), it generates waste water loaded with organic compounds such as starch, cellulose, fatty acids and inorganic compounds like magnesium sulfate, zinc chloride etc. The presence of such high concentration of organic and inorganic compounds predictably imparts higher BOD and COD to the effluent thereby necessitating suitable treatment procedures. Since, this effluent is composed primarily of biodegradable organic compounds, it provides an opportunity for employing treatment procedures for effective carbon conversion either directly in terms of bio-energy generation or indirectly through its irrigational applications.

1. 7. SIZING MILL EFFLUENT – TREATMENT OBJECTIVES

The major objectives of sizing mill effluent treatment are a) removal of suspended solids, b) degradation of organic compounds and c) safer disposal or recycling of the effluent. As with any other industrial effluent rich in organic compounds, sizing mill effluent provides an opportunity for effective treatment adopting either one of the two treatment systems viz., aerobic or anaerobic. As
Plate 1. 5. Sizing mill effluent discharged through the channel to outside the premises of factory.
explained earlier, anaerobic system provides distinct advantages over aerobic system especially in terms of lower operational expenses, production of bio-gas, and less sludge etc., Low rate conventional anaerobic treatment system and high rate anaerobic method were used in this study. A modified up-flow fixed film reactor was designed to accommodate the idiosyncrasies of the sizing mill effluent, which was comparable with treatment study of effluent from sago mill, sugar mill, and distillery by Sastry and Subramanian (1988). The efficiency of this reactor, the extent of sizing mill effluent treatment, and bio-gas production are analyzed extensively and discussed in the ensuing chapter.