LOW-COST MUNICIPAL WASTEWATER TREATMENT OPTIONS FOR USE IN PAKISTAN – A REVIEW

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ABSTRACT

Pakistan has now essentially exhausted its available water-resources and is on the verge of becoming a water-deficit country. The per-capita water availability has dropped from 5,600 m^3 to 1,000 m^3. The public water-requirement has risen manifolds, as population is increasing, industry is growing and we are bringing more area under cultivation to meet the increasing demand for agriculture-products. The quality of groundwater and surface-water is low and is further deteriorating because of unchecked disposal of untreated municipal and industrial wastewater and excessive use of fertilizers and insecticides. This paper presents an overview of various low-cost treatment options for the treatment of municipal wastewater-treatment.

Keywords: *Biological Treatment, Low-cost Treatment, Municipal Wastewater, Water Availability*

1. INTRODUCTION

Pakistan's current population of 170 million is expected to grow up to about 221 million by the year 2025. This increase in population will have a direct impact on the water-sector for meeting the domestic, industrial and agricultural needs. Pakistan has now essentially exhausted its available water-resources and is on the verge of becoming a water-deficit country. The per-capita water availability has dropped from 5,600 m^3 to 1,000 m^3. The quality of groundwater and surface-water is low and is further deteriorating because of unchecked disposal of untreated municipal and industrial wastewater and excessive use of fertilizers and insecticides. Water quality monitoring and information management is lacking, even though it's crucial to any water-quality improvement programme.

Results from various investigations and surveys indicate that water-pollution has significantly increased in Pakistan. The pollution-levels are higher particularly in and around the big cities of the country where clusters of industries have been established. The water-quality deterioration problems are caused by the discharge of hazardous industrial wastes, including persistent toxic synthetic organic chemicals, heavy metals, pesticides and municipal wastes and untreated sewage water into natural water-bodies. These substances mixed with water then cause widespread water-borne and water-washed diseases (Chandio and Abdullah, 1998).

According to Chandio and Abdullah (ibid), the public water-requirement has risen manifolds as a result of population increase, industrial growth and bringing more area under cultivation, to meet the increasing demand for agriculture-products. All the above factors forced the water-managers to explore the quality of existing freshwater- resources. It has been estimated that about 27% of world population does not have access to clean drinking water.

The conditions become more adverse in developing countries, where there is lack of resources and the water-protection schemes are given least priorities. A study by Zahid and Baig (1997) concluded that about 80% people living in the main cities of Pakistan lack access to really clean, potable water. The environmental profile of Pakistan indicates that about 40% of deaths are related to waterborne diseases that spread by water-pollution that is caused mainly due to the sewage and industrial wastewater contamination of drinking-water distribution systems.

Continuing urbanization, growing populations and increasing industrialization have increased water-consumption, correspondingly generating higher volumes of wastewater. Untreated wastewater and poor solid-waste management are threats to human health and natural environment. Regrettably, the public-and the private-sectors, in developing countries, including Pakistan, are not focusing on the wastewater-treatment practices at domestic and industrial level. Lack of interest even extends to controlling water-borne diseases, which causes severe environmental and health problems. Most of the wastewater is not treated and, with the expansion of urban settlements without wastewater-treatment facilities, it will continue to adversely impact the natural environment and public health. The worst impact is evident in areas that are close to industrial sites.

Saeed and Bahzad (2006), had reported that more than 28 m^3/sec wastewater was being disposed off into the River Ravi without any treatment from Lahore, the second largest city of Pakistan. The river pollution is frequently associated with the disposal of untreated effluents from municipal, industrial and agricultural wastes into the natural streams, which is always considered as an easy way to dispose off many kinds of effluents. The people's psychology is that the wastes are washed away and are not visible after dumping.

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A study (by Balfours, 1987) revealed that about 18 m^3/sec of wastewater from Lahore city was being disposed off into the River Ravi and it is estimated that wastewater flow would increase to 35m^3/sec by the year 2017. This wastewater is accompanied by a biochemical oxygen demand (BOD) of upto 240 mg/L.

It is difficult to propose conventional systems of wastewater-treatment to apply for the treatment of municipal wastewater in Pakistan, because there is no separate drainage system for domestic and industrial wastewater. All types of wastewater are moving towards to single drain. Therefore, there is a tremendous need to select a most economical treatment-system that should be able to treat municipal wastewater containing industrial wastewater as well. There are many options to use; natural biological, CEPT and AOP need so as to be tested to select one most appropriate and economical system. The problem with such kind of wastewater is variations in COD and BOD from 200 to 2000 mg/L. Sometimes, simple CEPT, direct treatment with hydrogen peroxide, hydrogen peroxide/UV and anaerobic treatment process may be required individually, or with combination, to overcome the high variation in COD in municipal wastewater stream. Separate installation of treatment-facility at each source may not be feasible to overcome this problem, at present status.

Over a billion people around the world lack access to safe drinking-water, when around 80% of all diseases are due to poor drinking-water quality in developing countries; this lead to 1.7 million deaths annually (UNDP, 1996). In Pakistan, water availability has already fallen from 5,000 m^3 per capita to 1,100 m^3 in 2005. According to government statistics, 88% of the districts (urban population) and 62% of rural residents have access to water supply. But, in fact, only 33% people has water supply at their homes and 67% rely on outdoor sources. The water-quality analysis report 2005-06 says: 55% samples were found with coliform contamination (IUCN, 2009). Accordingly, we present a Review of some low-cost options for water-treatments. Some of that more sophisticated ones are suitable only for use in the larger metropolitan cities.

2. LOW-COST TREATMENT OPTIONS FOR PAKISTAN

2.1 Sewage-treatment

Sewage-treatment, or domestic wastewater treatment, is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes, to remove physical, chemical and biological contaminants. Its objective is to produce a waste-stream (or treated effluent) and a solid waste or sludge suitable for discharge or reuse back into the environment. This material is often inadvertently contaminated with many toxic organic and inorganic compounds (Nidal, 2008).

2.2 Process Overview

Sewage can be treated close to where it is generated (in septic tanks, bio-filters or aerobic treatment systems), or collected and transported via a network of pipes and pumping stations to a municipal treatment plant. Sewage collection and treatment is typically subject to local, state and federal regulations and standards.

Conventional sewage-treatment may involve three stages, called primary, secondary and tertiary treatment. Primary treatment consists of temporarily holding the sewage in a quiescent basin, where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment.

Secondary treatment removes dissolved and suspended biological matter. This treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. The treatment may require a separation-process, to remove the micro-organisms from the treated water, prior to discharge or tertiary treatment.

Tertiary treatment is sometimes defined as anything more than primary and secondary treatment. Treated water is sometimes disinfected chemically or physically (for example, by lagoons and micro-filtration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes (Roland, 1997).

2.3 Pre-treatment

Pre-treatment removes materials that can easily be collected from the raw wastewater, before they damage or clog the pumps and skimmers of primary treatment clarifiers. Pre-treatment includes the following steps:

2.3.1 Screening: The influent sewage-water is strained to remove all large objects carried in the sewage stream, such as rags, sticks, tampons, cans, fruit, etc. This is most commonly done with an automated mechanically raked bar screen, in modern plants serving large populations, whilst in smaller or less modern plants a manually cleaned screen may be used. The raking action of a mechanical bar screen is typically paced according to the accumulation on the bar screens and/or flow-rate. The solids are collected and later disposed off in a land-fill or incinerated (Hammer, 2004; Roland, 1997).

2.3.2 Grit removal: Pre-treatment may include a sand or grit channel or chamber (sometimes called a de-gritter) where the velocity of the incoming wastewater is carefully controlled to allow sand, grit and stones to settle, while keeping the majority of the suspended organic material in the water-column. Sometimes there is a sand washer (grit classifier), followed by a conveyor that transports the sand to a container for disposal. The contents from the sand-catcher may be fed into the incinerator in a sludge-processing plant, but in many cases, the sand and grit is sent to a land-fill.

2.3.3 Primary treatment: In the primary sedimentation stage, sewage flows through large tanks, commonly called "primary clarifiers" or "primary sedimentation tanks". The tanks are large enough so that the sludge can settle and floating material, such as grease and oils, can rise to the surface and be skimmed off. The main purpose of the primary sedimentation stage is to produce both a generally homogeneous liquid capable of being treated biologically and a sludge that can be separately treated or processed. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank, from where it can be pumped to further sludge-treatment stages (Hammer, 2004; Roland, 1997).

2.3.4 Secondary treatment: Secondary treatment is designed to substantially degrade the biological content of the sewage, such as the ones derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage-liquor, using aerobic biological processes. For this to be effective, the biota requires both oxygen and a substrate on which to live. There are a number of ways in which this is done. In all these methods, the bacteria and protozoa consume bio-degradable soluble organic contaminants (e.g. sugars, fats, organic short-chain carbon molecules, etc.) and bind much of the less soluble fractions into flock. On the basis of biomass present, secondary treatment systems are classified as:

- Fixed-film or;
- Suspended-growth.

Fixed-film or attached-growth system treatment process, including trickling filter and rotating biological contactors where the biomass grows on media and the sewage passes over its surface.

In suspended-growth systems, such as activated sludge, the biomass is well-mixed with the sewage and can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal-rates for organic material and suspended solids than suspended-growth systems.

Roughing filters are intended to treat particularly strong or variable organic loads, typically industrial, to allow them to then be treated by conventional secondary treatment-processes. Its characteristics include typically tall, circular filters, filled with open synthetic filter media to which wastewater is applied at a relatively high-rate. They are designed to allow high hydraulic loading and a high flow-through of air. On larger installations, air is forced through the media using blowers. The resultant wastewater is usually within the normal range for conventional treatment processes. The final step in the secondary treatment-stage is to settle out the biological floc or filter material and produce sewage water containing very low levels of organic material and suspended matter.

2.3.5 Up-flow anaerobic treatment reactor: Up-flow anaerobic treatment reactor has been successfully used to treat a variety of industrial as well as domestic wastewaters. It can briefly be described as a process in which substrate in water passes through sludge-bed containing biomass. This sludge is present in the form of granular or flocculent form. Influent enters into the system from bottom of the reactor and leaves from upper side of the reactor. Uplift velocity of the influent is very critical to allow sufficient time to uptake the substrate through the biomass without uplifting the sludge-granules. This is the most attractive treatment-system due to its no-sludge excess sludge-production because substrate convert into biogas (Ghangrekar, 2005).

2.4 Bioreactors

2.4.1 Membrane bioreactors: Membrane bioreactors (MBR) combine activated sludge-treatment with a membrane liquid-solid separation process. The membrane component uses low-pressure micro-filtration or ultra-filtration membranes and eliminates the need for clarification and tertiary filtration. The membranes are typically immersed in the aeration tank (however, some applications utilize a separate membrane tank). One of the key benefits of a MBR system is that it effectively overcomes the limitations associated with poor settling of sludge in conventional activated system (CAS) processes. The technology permits bioreactor operation with considerably higher mixed-liquor suspended solids (MLSS) concentration than CAS systems, which are limited by sludge-settling. The process is typically operated at MLSS in the range of 8,000–12,000 mg/L, while CAS is operated in the range of 2,000–3,000 mg/L. The elevated biomass concentration in the MBR process allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. Thus increased Sludge Retention Times (SRTs)—usually exceeding 15 days—ensure complete nitrification, even in extremely cold weather.

The cost of building and operating a MBR is usually higher than conventional wastewater-treatment, however, as the technology has become increasingly popular and has gained wider acceptance throughout the industry, the life-cycle costs have been steadily decreasing. The small footprint of MBR systems and the high-quality effluent produced, makes them particularly useful for water-reuse applications (Judd, 2006; Verstraete, 2005).

2.4.2 Rotating biological contactors: Rotating biological contactors (RBCs) are mechanical secondary-treatment systems, which are robust and capable of withstanding surges in organic load. RBCs were first installed in Germany in 1960 and have since been developed and refined into a reliable operating unit. The rotating disks support the growth of bacteria and micro-organisms present in the sewage, which breakdown and stabilize organic pollutants. To be successful, micro-organisms need both oxygen to live and food to grow. Oxygen is obtained from the atmosphere as the disks rotate. As the micro-organisms grow, they build up on the media until they are sloughed off due to shear forces provided by the rotating discs in the sewage. Effluent from the RBC is then passed through the final clarifiers, where the micro-organisms in suspension settle as sludge. The sludge is withdrawn from the clarifier for further treatment.

A functionally similar biological filtering system has become popular as part of home aquarium filtration and purification. The aquarium-water is drawn up out of the tank and then cascaded over a freely spinning corrugated fiber-mesh wheel, before passing through a media-filter and back into the aquarium. The spinning mesh wheel develops a biofilm coating of micro-organisms that feed on the suspended wastes in the aquarium water and are also exposed to the atmosphere as the wheel rotates. This is especially good for removing waste urea and ammonia urinated into the aquarium water by the fish and other animals (Leslie et al. 1998).

2.4.3 Lagooning: Lagooning provides settlement and further biological improvement through storage in large man-made ponds or lagoons. These lagoons are highly aerobic and colonization by native macrophytes, especially reeds, is often encouraged. Small filter-feeding invertebrates, such as Daphnia and species of Rotifer, greatly assist the treatment by removing fine particulates (Hammer, 2004).

2.4.4 Constructed wetlands: Constructed wetlands include engineered reed-beds and a range of similar methodologies, all of which provide a high degree of aerobic biological improvement and can often be used instead of secondary treatment for small communities. Constructed wetland is fed in at the inlet and moved in laminar regime through porous medium, until it reaches the outlet zone where it is collected before the outlet. During this flow-regime wastewater is in contact with aerobic, anoxic and anaerobic zones. Rhizomes and plant roots release the oxygen and develop aerobic conditions. Constructed wetlands have long been used for domestic and municipal wastewater (Vymazal, 2009; Cooper et al., 1996; Brix et al., 1987).

2.4.5 Nutrient removal: Wastewater may contain high levels of the nutrients nitrogen and phosphorus. Excessive release of waste-water to the environment can lead to a build-up of nutrients, called eutrophication, which can in turn encourage the overgrowth of weeds, algae, and cyanobacteria (blue-green algae). This may cause an algal bloom, a rapid growth in the population of algae. The algae numbers are unsustainable and eventually most of them die. The decomposition of the algae, by bacteria, uses up so much of oxygen in the water that most or all of the animals die, which creates more organic matter for the bacteria to decompose. In addition to deoxygenatoin, some algal species produce toxins that contaminate drinking-water supplies. Different treatment-processes are required to remove nitrogen and phosphorus. Removal of nutrients has been studied for different reactors. Sequential-batch reactor, for biological nutrient removal from municipal wastewater, was found very effective in reducing BOD_5, TSS and ammonium nitrogen upto 98, 90 and 89 % at 12 hours cycle time. It consists of a sequencing operation, including the steps of "fill, react, settle, decant and idle" (Kargi and Uygur, 2003).

2.4.5.1 Nitrogen removal: The removal of nitrogen is effected through the biological oxidation of nitrogen from ammonia (nitrification) to nitrate, followed by denitrification the reduction of nitrate to nitrogen gas. Nitrogen gas is released to the atmosphere and thus removed from the water.

Nitrification itself is a two-step aerobic process, each step facilitated by a different type of bacteria. The oxidation of ammonia (NH_3) to nitrite (NO_2^-) is most often facilitated by Nitrosomonas sp. Nitrite oxidation to nitrate (NO_3^-), though traditionally believed to be facilitated by Nitrobacter sp., is now known to be facilitated in the environment almost exclusively by Nitrospira sp. (Verstraete, 2004).

Denitrification requires anoxic conditions to encourage the appropriate biological communities to form. It is facilitated by a wide diversity of bacteria. Sand filters, lagooning and reed-beds can all be used to reduce nitrogen, but the activated-sludge process, membrane-aerated biofilm reactor (MABR) (if designed well) can do the job most easily. Since denitrification is the reduction of nitrate to di-nitrogen gas, an electron-donor is needed. This can be, depending on the wastewater, organic matter (from faeces), sulfide, or an added donor, like methanol. Sometimes the conversion of toxic ammonia to nitrate alone is referred to as tertiary treatment (Terada et al., 2003).

2.4.5.2 Phosphorus removal: Phosphorus removal is important, as it is a limiting nutrient for algae growth in many fresh-water systems (for negative effects of algae, see Nutrient removal). It is also particularly important for water-reuse systems where high phosphorus concentrations may lead to fouling of downstream equipment, such as reverse osmosis (Landner, 1976).

Phosphorus can be removed biologically in a process called 'enhanced biological phosphorus-removal'. In this process, specific bacteria, called polyphosphate-accumulating organisms (PAOs), are selectively enriched and accumulated large quantities of phosphorus within their cells (up to 20% of their mass). When the biomass enriched in these bacteria is separated from the treated water, these biosolids have a high fertilizer value (Verstraete, 2004).

Phosphorus removal can also be achieved by chemical precipitation, usually with salts of iron (e.g. ferric chloride), aluminum (e.g. alum), or lime. This may lead to excessive sludge-productions, as hydroxides precipitates, and the added chemicals can be expensive. Chemical phosphorus-removal requires significantly smaller equipment-footprint than biological removal, is easier to operate and is often more reliable than biological phosphorus-removal. Once removed, phosphorus, in the form of a phosphate-rich sludge, may be stored in a land-fill or resold for use in fertilizer (Tchobanoglous et al., 2003).

2.5 Tertiary treatment

The purpose of tertiary treatment is to provide a final treatment stage, to raise the effluent-quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.). More than one tertiary treatment-process may be used at any treatment plant. If disinfection is practiced, it is always the final process. It is also called "effluent polishing". It includes micron filtration, ozonation, reverse osmosis and UV treatment (IBWA, 1995).

2.5.1 Filtration: Sand filtration removes much of the residual suspended matter. Filtration over activated carbon removes residual toxins.

2.5.2 Disinfection: The purpose of disinfection in the treatment of wastewater is to substantially reduce the number of micro-organisms in the water to be discharged back into the environment. The effectiveness of disinfection depends on the quality of water being treated (e.g., cloudiness, pH, etc.), the type of disinfection being used, the disinfectant dosage (concentration and time), and other environmental variables. Cloudy water will be treated less successfully, since solid matter can shield organisms, especially from ultra-violet light or if contact-times are low. Generally, short contact-times, low doses and high flows all militate against effective disinfection. Common methods of disinfection include ozone, chlorine, or ultra-violet light. Chloramine, which is used for drinking water, is not used in wastewater-treatment because of its persistence. Chlorination remains the most common form of wastewater-disinfection in North America, due to its low cost and long-term history of effectiveness. One disadvantage is that chlorination of residual organic material can generate chlorinated-organic compounds that may be carcinogenic or harmful to the environment. Residual chlorine or chloramines may also be capable of chlorinating organic material in the natural aquatic environment. Further, because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment.

Ultra-violet (UV) light can be used instead of chlorine, iodine, or other chemicals. Because no chemicals are used, the treated water has no adverse effect on organisms that later consume it, as may be the case with other methods. UV radiation causes damage to the genetic structure of bacteria, viruses, and other pathogens, making them incapable of reproduction. The key-disadvantages of UV disinfection are the need for frequent lamp-maintenance and replacement, and the need for a highly treated effluent to ensure that the target micro-organisms are not shielded from the UV radiation (i.e., any solids present in the treated effluent may protect micro-organisms from the UV light). In the United Kingdom, light is becoming the most common means of disinfection, because of the concerns about the impacts of chlorine in chlorinating residual organics in the wastewater and in chlorinating organics in the receiving water (IBWA, 1995).

Ozone (O_3) is generated by passing oxygen (O_2) through a high-voltage potential, resulting in a third oxygen atom becoming attached and forming O_3. Ozone is very unstable and reactive and oxidizes most organic material it comes in contact with, thereby destroying many pathogenic micro-organisms. Ozone is considered to be safer than chlorine because, unlike chlorine, which has to be stored on-site (highly poisonous in the event of an accidental release), ozone is generated onsite as needed. Ozonation also produces fewer disinfection by-products than chlorination. A disadvantage of ozone disinfection is the high cost of the ozone-generation equipment and the requirements for special operators (Pillai, et al., 2009).

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