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# APPROPRIATE TECHNOLOGY OPTIONS FOR WASTEWATER TREATMENT IN TROPICAL DEVELOPING COUNTRIES

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## ABSTRACT

A wide range of biological processes are available for treatment of domestic and industrial wastewater. In developing countries treatment technologies are generally imported from the economically developed world. However, instead of finding out the most appropriate solution to suit the local conditions, the designers are inclined to apply the "Stock-in-trade" models of treatment processes. The conventional sewage treatment plants, employing trickling filters and activated sludge process, are expensive, energy intensive, costly to operate, sophisticated and require well-trained operators. These treatment processes are generally not relevant to the developing countries as, in addition to being costly, they are inefficient in removal of pathogens, which is of primary concern in tropical countries for protection of public health. In Pakistan, like other developing countries, the experience of conventional treatment plants has not been good and generally their performance remained unsatisfactory.

High ambient temperatures in tropical and sub tropical countries make it possible to use simple and economical treatment processes. For developing countries with hot climates the most realistic and appropriate technology options are: stabilization ponds, aerated lagoons and oxidation ditches. Pond systems are appropriate for both small and large communities, whereas aerated lagoons and oxidation ditches are generally used in large cities. The salient features of these treatment processes and their application in tropical countries are discussed in the paper. It also describes the recently developed new technology of Root-zone method, which is simple, cheaper than conventional treatment plants, and may be suitable for developing countries.

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## INTRODUCTION

In Pakistan the collection, treatment and disposal of wastewater is becoming increasingly difficult due to high population growth and rapidly expanding industrial sector. It is reported that in Karachi some 34 tonnes/day of suspended solids and about 47 tonnes/day of organic matter, besides other pollutants, are being discharged into Lyari River by some 1605 industrial units of Sind Industrial Trade Estate[1]. River Malir receives BOD load of about 1237 tonnes/day including 1045 tonnes/day from Industries in the area of Landhi Industrial Trading Estate. Some 2 to 6 cusecs untreated industrial effluents are discharged into Deg Nullah from industrial complex at Kala Shah Kaku, Lahore, destroying aquatic life downstream of the discharge points. These few examples would give an idea about the magnitude of the pollution problem caused by untreated effluents from industrial concentrations.

Presently, in this country wastewaters are rarely treated before disposal. Untreated municipal wastewaters are either used for agricultural irrigation or discharged into water courses or other natural water bodies. Similarly, industrial effluents are either discharged into streams/rivers or applied to land without giving any treatment. Uncontrolled waste discharges are causing serious water pollution and degradation of human environments. The direct use of raw sewage for irrigation of crops, particularly those eaten raw or handled, poses potential health hazards. According to the standards/guidelines set by WHO such a direct use of sewage effluents for irrigation of edible crops is not permitted. The spill-over effects/offsite costs of damages caused by industrial effluents such as fish kills in rivers/streams could more than offset the economic gains from the industries discharging pollutants. Treatment of domestic and industrial wastewaters is thus necessary for controlling water pollution and safeguarding public health and our living environments.

The principal object of wastewater treatment is to allow domestic and industrial effluents to be disposed of without danger to human health or with acceptable damage to the human environments. A numbr of treatment technologies are available for purification of domestic and industrial wastewaters. The key consideration in selection of a treatment method is the cost. For developing countries the choice of an appropriate and workable technology is very important because of the economic consequences of the decision. Unnecessarily costly treatment will divert scarce resources away from other development uses. It is generally not advisable for the developing countries to adopt sophisticated conventional sewage treatment methods, which are expensive and require

skilled manpower for operation.

The success rate of traditional technologies of trickling filters and activated sludge process have been poor in the developing countries[2]. Also, in this country performance of the conventional wastewater treatment plants installed at Karachi (trickling filters) and Islamabad (activated sludge system) has been quite unsatisfactory. We should learn from the past unwelcome experience and avoid the mistakes of practising conventional treatment processes evolved in the west in different set up of socio-economic and climatic conditions.

Treatment technology in hot climates is very different to that used in temperate climates. High ambient temperatures in tropical and sub-tropical countries make it possible to use simple and economical treatment processes that not only can produce effluent of the desired quality but can also be easily maintained by the local available labour. From considerations of economy and ease of operation/maintenance, the most realistic and appropriate methods for the developing countries in order of preference are: waste stabilization ponds, aerated lagoons and oxidation ditches. The case for selecting stabilization ponds for wastewater treatment in developing countries would be overwhelming if sufficient land is available at a reasonable cost. However, aerated lagoons may be a cost-effective and useful option for places where large land areas for ponds system are not available. The oxidation ditch process is a well-tried system for efficient and economical biological treatment of wastewater. The carrousel system of oxidation ditch process is very suitable for application in tropical countries because of many advantages which include: low construction costs, simple operation, high BOD removal and production of a minimum quantity of 'stable' sludge.

In the developing countries the need for safe, cheap and efficient wastewater treatment techniques is quite obvious. The application of low-cost technologies can lead to conservation and safe reuse of treated effluents for agricultural purposes in water scarce developing countries with arid and semi-arid climates.

In recent years advances have been made in the field of wastewater treatment and new technologies evolved in the western countries. The Root-Zone Method (RZM) of sewage treatment developed in west Germany may be suitable for the developing countries because of its advantages of simple construction, robustness and low maintenance costs.

## SELECTION OF TREATMENT TECHNOLOGY

### FACTORS AFECTING SELECTION

The choice of wastewater treatment process depends upon may factors, only some of which are quantifiable in financial terms. Capital costs and operating costs are relatively easy to estimate. However, the other factors which are equally or even more important such as process reliability and stability or robustness, are very difficult to assess in economic terms. To select the most appropriate technology it is, therefore, imperative to carefully evaluate all these factors. The main factors in selection of treatment technology are:

- Capital costs;
- Operating and maintenance costs;
- Simplicity and realiability of treatment process;
- Efficiency in removal of pathogens;
- Level of operator skills available; and
- Optimum use of local resources (labour, materials and equipment).

### CONVENTIONAL TREATMENT METHODS AND THEIR PERFORMANCE IN PAKISTAN :

Conventional treatment technologies of trickling filters and activated sludge process are primarily concerned with achieving effluent standards for BOD and suspended solids. However, these traditional treatment processes do not provide for any degree of pathogen removal. Moreover, conventional sewage treatment plants are normally energy-intensive with mechanical treatment system, costly to operate, requiring skilled operator and generally lead to sludge disposal problems. For these reasons conventional processes are generally not relevant in developing countries which require low-cost and simple technologies with superior removal of pathogens for protection of public health.

Some 25 years ago the conventional technology for treatment of wastewater was imported in this country. The performance of two 20 mgd sewage treatment plants, employing high rate trickling filter process, installed at Karachi in 1963 and 1965, have been quite unsatisfactory, and biological units often remained out of operation. Treated effluent BOD ranged from 55 to 156 mg/1, and suspended solids from 41 to 191 mg/1, against the designed standard of 30 mg/1 (3). Islamabad activated sludge plant of 5mgd capacity constructed in 1962 is also reported not to be functioning properly. Plant

performance over 9 years period from 1975 to 1988 indicates average effluent suspended solids and BOD concentrations of 71 mg/1 and 85 mg/1, against desired effluent quality of 30:30 mg/1 for BOD and suspended solids. The major factors responsible for poor performance of these plants are reported to be: unskilled operating staff, unawareness about process philosophy, and inadequate aeration of biological units.

## NON-CONVENTIONAL TREATMENT METHODS :

Stabilization ponds employ the most rudimentary process of biologial wastewater treatment. They have been developed to produce an effluent suitable for discharge to most receiving waters and for water reclamation at low cost and with unskilled labour.

A properly designed system is a reliable, efficient, economical and simple process for treating sewage and industrial wastewaters. The major advantage of pond system is the ability to provide enhanced removal of pathogens, which is of great benefit to health. The effluent is much safer than conventional processes, allowing it to be reused in agriculture and aquaculture. With low construction and operation costs, pond process is well suited to the needs of developing countries and design of such installations can easily be modified to suit a large variety of climatological and other local conditions. For these reasons, the stabilization ponds will normally be the first choice in process selection for developing countries under most circumstances. However, aerated lagoons would be useful in certain situations where there is insufficient land for stabilization ponds. They should always be followed by a settling pond and, where necessary, to reduce the pathogens to the acceptable level, by maturation ponds. Oxidation ditches are used when enough land is not available for an aerated lagoon system. Their major advantages are low construction costs and minimum sludge production but their disadvantgages are high level maintenance requirements, and more seriously, poor removal of faecal bacteria. The faecal bacteria in the effluent is usually reduced by chemical disinfection. Table 1 gives a comparison of various sewage treatment processes.

It could be seen that conventional treatment processes are comparatively expensive, and the pollution problems are not satisfactorily solved by these techniques. In developing countries with tropical or sub-tropical climates the most realistic and preferred methods are : stabilization ponds, aerated lagoons and oxidation ditches.

## APPROPRIATE WASTEWATER TREATMENT TECHNOLOGY

### WASTE STABILIZATION PONDS :

Waste stabilization ponds are a cost-effective technique for wastewater treatment for small to medium-size communities and industries that produce organic wastes. They have become popular because they offer the advantages of low capital and operating costs compared with conventional treatment methods, simplicity of operation, and their ability to handle fluctuating organic and hydraulic loads.

The three different types of ponds, which differ in design and operation, are aerobic, anaerobic and facultative. An aerobic pond has dissolved oxygen throughout its depth, whereas oxygen is completely absent in an anaerobic pond, and the facultative pond has dissolved oxygen in the upper zone of the water and no oxygen in the lower zone. Most ponds are facultative since these are loaded higher than aerobic ponds, yet few odours are produced because the upper pond depth is aerobic.

**Table - 1. Advantages and Disadvantages of Various Sewage Treatment Systems[4]**

| Criteria | Package Plant. | Activated Sludge Plant. | Extended Aeration Plant | Activated Sludge Trickling Filter | Oxidation Ditch | Aerated Lagoon | Waste Stabilization Pond System. |
|---|---|---|---|---|---|---|---|
| BOD Removal | F | F | F | F | G | G | G |
| FC Removal | P | P | F | P | F | G | G |
| SS Removal | F | G | G | G | G | F | F |
| Helminth Removal | P | | F | P | P | F | F |
| Virus Removal | P | F | F | P | F | G | G |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Simple and cheap construction | P | P | P | P | F | F | G |
| Simple operation | P | P | P | F | F | P | G |
| Land Requirement | G | G | G | G | G | F | P |
| Maintenance cost | P | P | P | F | P | P | G | G |
| Energy Demand | P | P | P | F | P | P | G | G |
| Sludge Removal costs | | P | F | F | F | P | G |

Key :

| | | |
|---|---|---|
| FC | = | Faecal coliforms |
| SS | = | Suspended Solids |
| G | = | Good |
| F | = | Fair |
| P | = | Poor |

Stabilization ponds are particularly suited to the warm climates that provide an ideal environment for natural treatment of domestic sewage to the extent of safe reuse of treated effluent for irrigation and fish culture. A major disadvantage with ponds is the large land area requirement. However, land use could be made most efficient with a properly designed multi-cell pond system of anaerobic, facultative and matguration ponds.

The anaerobic ponds have a short detention time, the organic loading is high and under the correct conditions very high organic removals can be achieved. The use of anaerobic ponds reduces considerably the organic load on facultative and maturation ponds and thus size of units can be considerably reduced. It is reported that under conditions typical of Northern Pakistan, the land-take to produce an effluent of a given quality can be reduced by half with the introduction of anaerobic pond[5]. In most areas of Pakistan, the mean temperature during the coldest month (usually January) does not fall below about 11°C. At this ambient temperature, the contents of an anaerobic pond can be expected to maintain a temperature of about 14 - 15°C, and the methanogenic process, whilst slow will not cease altogether. With a design loading of about 0.15 kg $BOD_5/m^3/day$ the pond contents will remain anaerobic and $BOD_5$ removals of 60 percent can be expected, rising to 80 percent or more during the summer months.

By detaining the raw sewage in a multi-cell pond system of anaerobic, facultative and maturation ponds for two to three weeks a significant level of both BOD and pathogen removal can be achieved. The natural action of storage and sunlight promotes the rapid

growth of microorganism which remove BOD both aerobically and anaerobically. The die-off of pathogens in stabilization ponds depends on the environmental and climatological parameters, as well as on the detention time within the pond system.

The work of Shuval *et al* suggests that ponds treatment produces a better effluent than conventional treatment processes, in terms of helminth removal and reduction of bacterial and viral pathogens. Arceivala reported[7] that studies on stabilization ponds in India have shown that treatment in waste stabilization ponds has given practically complete removal of salmonella and helminths. Also, the research studies conducted on pilot stabilization ponds system in Lahore indicate that performance of anaerobic and facultative pond was satisfactory[3]. Reportedly the removal of faecal coliforms by maturation ponds was more than 99.99%.

Stabilization pond effluents are nutrient-rich because of the high algal content, but are generally low in excreted pathogens and other faecal organisms. This is particularly relevant in hot climates where the spread of gastro-enteric and other diseases by excreted pathogens presents very serious problem, especially in densely populated urban areas and where-ever reuse is considered. Hence this type of treatment will be able to produce an effluent which meets the recomended quality guidlines for unrestricted irrigation, both at low cost and with minimal operational and maintenance requirements. However, it requires extensive land, which is not a serious handicap in arid and semi-arid areas where land is normally available and cheap.

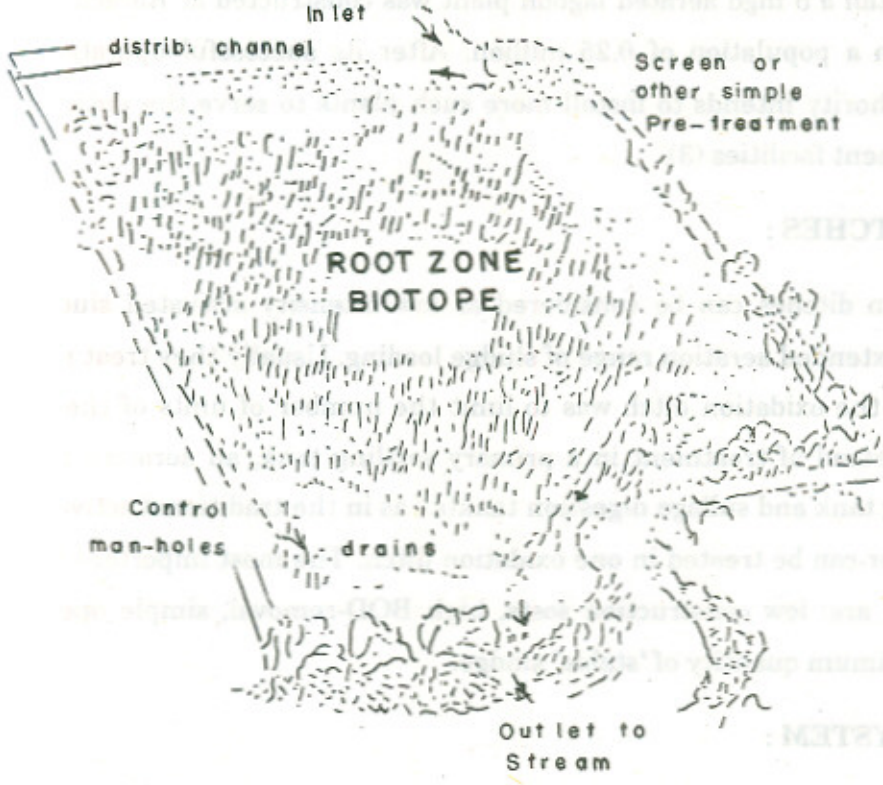
## AERATED LAGOONS :

The major constraint in the application of stabilization ponds is large land area required. An additional disadvantage may be high cost of land near the wastewater generation site. In such a situation wastewater will have to be pumped to the suburban areas where land is usually available. The additional cost of pumping and sewer transmission lines could more than offset the savings in construction of stabilization ponds over other treatment methods. The surface area of stabilization pond system is for transmission of oxygen from the atmosphere and of sunlight for photosynthesis. The land area could be reduced if oxygen is introduced into the pond by mechanical aerators or diffusers. This type of lagoon system is known s aerated lagoon.

Aerated lagoons occupy a position in between stabilization ponds and activated sludge process. In fact it is the extended aeration form of activated sludge process without sludge recirculation. Aerated lagoons will be a useful option for places where sufficient

## ROOT ZONE BIOTECHNOLOGY BY KITCKUTH METHOD

PERSPECTIVE:

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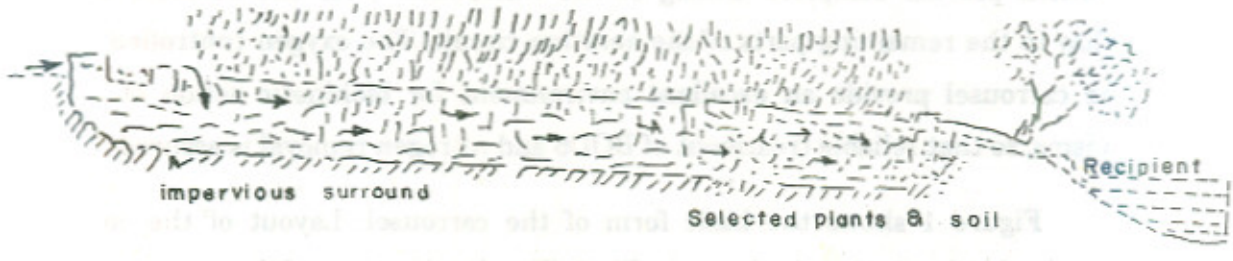


Fig. 3. Perspective and section of typical root zone installation

Source: Oceans International Services Ltd, Bradford, England

land was not available for ponds system. With 4 days retention BOD removal of 85% - 90% can be achieved in aerated lagoons[8]. However, removal of faecal coliforms is poor, only 85% - 95%. Further treatment in maturation ponds would be necessary for effluent reuse in agricultural irrigation.

In Pakistan a 5 mgd aerated lagoon plant was constructed at Karachi in 1985 to treat sewage from a population of 0.25 million. After its successful operation Karachi Development Authority intends to install more such plants to serve the entire city with wastewater treatment facilities (3).

## OXIDATION DITCHES :

Oxidation ditches can be considered as low intensity activated sludge system operating in the extended aeration range of sludge loading. Usually they treat raw sewage. The basic idea of the oxidation ditch was to limit the number of units of the treatment system to one. Instead of treatment in a primary settling tank, an aeration reservoir, a secondary settling tank and sullage digestion tank(s), as in the traditional activated sludge system, wastewater can be treated in one oxidation ditch. The most important advantages of oxidation ditch are: low construction sosts, high BOD-removal, simple operation and production of minimum quantity of 'stable' sludge.

## CARROUSEL SYSTEM :

The distinctive feature of the carrousel is that instead of high speed aerators or mammoth rotors as in oxidation ditch, it has one or more surface aerators with vertical axes which provide complete mixing of the wastewater near the aerators and induce plugflow in the remaining parts of the aeration circuit. The oxygen controlled conditions in the carrousel provide an excellent environment for biokinetic action of the micro-organisms, so that reliable treatment of BOD5 and nitrogen removal is assured.

Figure 1 shows the basic form of the carrousel. Layout of the conventional carrousel oxidation system is shown in Fig.2. The development of the carrousel has made it possible to build far larger plants of this type for the treatment of domestic or industrial wastewater, or a combination of the two.

The carrousel wastewater treatment system is simple to operate and the treatment process gives excellent results. It is a well-tried system for efficient and economical biological treatment of wastewater and is at present in operation for hundreds of treatment plants with capacities ranging from 500 to 10,000,000 population equivalents (9).

Carrousel system are designed on the basis of long sludge retention times, 20-30 days so that stabilized sludge is produced, which makes sludge digestion superfluous. In (sub-) tropical climates these retention times can be greatly reduced. The mixed liquor suspended solids (MISS) concentration generally varies between 3000 and 4000 mg/1, but may be higher. The oxygenation capacity(OC) load must be between 2.0 and 2.5 kg $O_2$ per kg BOD5.

The sludge synthesized in the activated sludge process contains a large amount of organic matter, which can cause nuisance and even damage if it is disposed of in the environment without stabilization. Most of the organic matrial will be eliminated by aerobic processes in the aeration tank, if the retention time of the sludge in the treatment system is long enough. In these conversion processes the organic material is mineralized or stabilizedto inert organic and inoraganic materials.

The carrousel system provides sufficient stabilization of the sludge. The aerators not only cause complete mixing of the wastewater coming in within the activated sludgem they also initiate a circular flow of the activated sludge through the carrousel.

The BOD-removal ifficiency in the carrousel - more than 98% is greater than in any other single stage activated sludge or trickling filter system (9). The $BOD_5$ content of the effluent is very low.

## APPLICATION OF CAROUSEL IN TROPICAL COUNTRIES :

One of the basic aims of the carrousel system is to obtain stabilized sludge that can be handled without nuisance to the environment. The degree of stabilization of the activated sludge depends on the sludge retention time in the aeration circuit. In moderate climates a sludge retention time of 25 days based on the load of 0.054 kg $BOD_5$ /kg Mixed Liquor Suspended Solids (MLSS), is sufficient to obtain stabilized sludge. In tropical countries water temperatures of 20°C and more are common. At these temperatures aerobic conversion processes occur faster and the time to reach stabilization will be shorter. It is possible to obtain stabilized sludge with a sludge retention time of 10 days and a sludge load of about 0.12 kg $BOD_5$/kg MLSS per day. It is reported that excellent results are obtained in hot climates with a sludge load of 0.10 - 0.15 kg $BOD_5$/kg MLSS per day (10). Therefore, the aeration circuit of carrousel plants in hot climates may be designed with a capacity of only 40 to 50 % of those in countries with a moderate climate, which have a sludge load of 0.054 kg $BOD_5$/kg MLSS per day. The general features of the carrousel make the system very suitable for application in tropical countries. Many of the

advantages of the carrousel system are of importance to operation in tropical countries:

- the production of a stabilized sludge;
- low construction costs;
- simple operation;
- reliable operation; and
- reduction in the volume of the aeration circuit due to high ambient temperatures

## THE ROOT ZONE METHOD FOR SEWAGE TREATMENT :

The Root Zone Method (RZM) is a wetland method of sewage treatment developed over the past twenty years by prof. Dr. Kickuth at Kassel University, West Germany (11). It depends upon the flow of sewage through soil in which common reeds (Phragmites Australis) are growing. The perspective and typical root zone installation is shown in Fig. 3.

The key features of the RZM process are:

- Rhizomes of the reeds grow verticvally and horizentally opening up the soil to provide a "hydraulic pathway".
- Wastewater is treated by bacterial activity. Aerobic treatment takes place in the rhizosphere with anoxic and anaerobic treatment taking place in the surrounding soil.
- Oxygen is passed from the atmosphere to the rhizosphere via the leaves and stems of the reeds through the hollow rhizomes and roots.
- Suspended solids in the sewage are aerobicaly composted in the above ground layer of straw formed from dead leaves and stems.

The following advantages have been claimed for RZM.

(i) Simple construction, no mechanical or electrical equipment;
(ii) Low maintenance cost;
(iii) Robust process able to with stand wide range of operating conditions;
(iv) Consistent effluent quality; and
(v) Environmentally acceptable with potential for wild life conservation.

The land area needed for treatment of screened, degritted sewage is about 2 to $4m^2$/person to achieve an effluent with BOD less than 20 mg/1. The method can also be

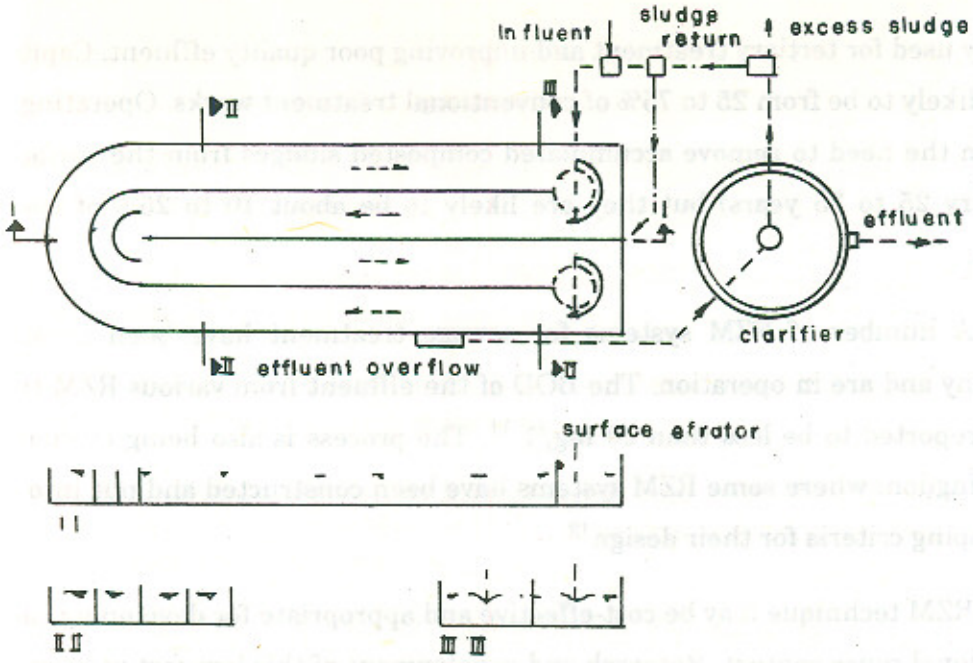


Fig 1- Basic form of the Carrousel

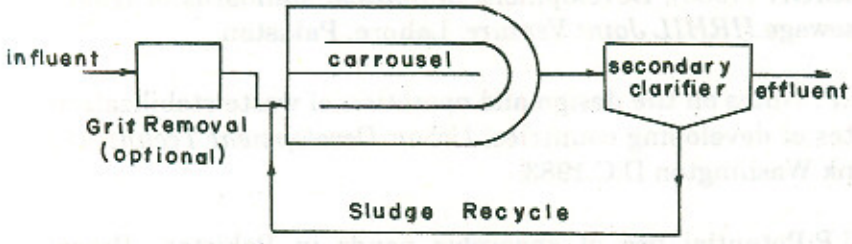


Fig 2- Conventional Carrousel oxidation system

effectively used for tertiary treatment and improving poor quality effluent. Capital costs of RZM are likely to be from 25 to 75% of conventional treatment works. Operating costs will depend on the need to remove accumulated composted sludges from the surface of RZM beds (every 25 to 35 years) but they are likely to be about 10 to 25% of conventional processes.

A number of RZM systems for sewage treatment have been constructed in W.Germany and are in operation. The BOD of the effluent from various RZM treatgment works is reported to be less than 20 mg/1 [11]. The process is also being evaluated in the United Kingdom where some RZM systems have been constructed and put into operation for developing criteria for their design.[12]

RZM technique n.ay be cost-effective and appropriate for developing countries in an irrigational reuse context. Research and development of this low-cost process should be undertaken in this country to assess its performance and suitability under our climatic conditions.

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