# A STUDY OF DECENTRALIZED WASTEWATER SYSTEMS IN INDIA

A MAJOR PROJECT REPORT

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## CANDIDATE'S DECLARATION

I, Puneet Pathak, Roll No. 2K17/ENE/12 student of M. Tech (Environmental Engineering), hereby declare that the project dissertation titled "A Study of Decentralized Wastewater Systems in India" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title of recognition.

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# CERTIFICATE

I hereby certify that the project dissertation titled "A Study of Decentralised Wastewater Systems in India" which is submitted by PUNEET PATHAK, 2K17/ENE/12, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi | **Dr. BHARAT JHAMNANI**

Date: 23 JULY, 2019 | **SUPERVISOR**

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# ABSTRACT

Being a developing nation, India needs large quantities of water for meeting all the different types of water demands. This is not possible with the available amount of water sources as the demand is huge. But this problem is solvable if we reuse the wastewater by treating it upto required standards of Central and State Pollution Control Boards. This is not feasible at large due to various contraints like land availability, money and political will. But this can be solved at local levels by decentralising the wastewater systems using technologies like MBBR, MBR, SBR, etc. In this study we will be studying such STPs in different locations of India to have a better insight about these technologies. A number of parameters like plant capacity, capital cost composition, operation costs composotion, BOD removal, COD removal and TSS removal along with different cost compositons will be studied. This is carried out to find the most suitable technology for the purpose of treating wastewater a local levels. This will help in increasing the wastewater treatment efficiency in India as the currently available wastewater treatment efficiency in India is just about 33 percent.

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## List of Abbreviations

MLD : Million Litres Per Day

KLD : Kilo Litres Per Day

MGD : Millions of Gallons Per Day

ETP : Effluent Treatment Plant

STP : Sewage Treatment Plant

CPCB : Central Pollution Control Board

MBBR : Moving Bed Biofil Reactor

MBR : Membrane Bio-Reactor

SBR : Sequencing Batch Reactor

BOD : Biological Oxygen Demand

COD : Chemical Oxygen Demand

TSS : Total Suspended Solids

MP : Member of Parliament

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Being a developing country with ever increasing population India no longer has the luxury to delay meeting its ever increasing potable water needs. In all industrial activities and for meeting daily needs water of required quality is an everyday demand and lack in supply of water cannot be tolerated in a developing country like India.

As government plans to improve the economy it should also consider that without giving needful consideration to water availability their every effort will be fruitless. This is because water is the fundamental need in every sphere of a country's functionality. But it is impossible without proper planning and political will. A large part of any public problem can be solved with these two measures.

But meeting the needs of water for $2^{nd}$ most populous country of the world is not an easy task. It requires proper consideration on each and every aspect of the problem in hand. Firstly, it needs to be understood that water sources of India are depleting at exponential rate. Secondly, there are not enough sources to preserve these sources and finally, that while preserving our water resources the available technologies are obsolete and are not efficient enough to handle the sewage produced.

## 1.2 Drinking water challenges in India

India has only 4 percent of world's fresh water resources but we have 17.5 percent of total population of the world, whose supply along with its quality are decreasing at tremendous rates. Before the population explosion in India the available water sources were considered safe and usable but since then the case is not same anymore. A number of problems like meeting agricultural needs, depleting ground water and urban water stress have been assoiated since then.

Drinking water quality has become a serious issue in India since it has been estimated that around 377 lakhs people are affected from water related diseases annually. There have been deaths amounting in millions due to diseases like dysentery, diarrhoea, etc in India. This problem of contamination is not only with surface water but the case is same with ground waters too.

More than 7000 lakhs Indians depend upon ground water resources for their basic daily needs which is getting depleted very fastly in present along with that it is also contaminated with fluoride, arsenic and other metals.

More than half of the Indian population depends upon surface waters for their survival and water needs. So, its availability and quality are an important factor in meeting the needs of urban population. In order to assure water needs of this strata of population it is to be assured that these surface waters are having quality and quantity to meet their needs.

In order to meet the domestic consumption needs the BIS water standards needs to be followed. These standards are presented by Bureau of Indian Standards in order to ensure the health of the consumers.

Some of the major physio-chemical parameters of the IS 10500-2012 are given below in Table 1.1. Here the engineer needs to implement acceptable limits and permissible limits are to be used in case of absence of alternative sources.

**Table 1.1 : Important physio-chemical parameters of water as per IS 10500-2012**

| Parameter | Unit | Acceptable Limit | Permissible Limit |
|---|---|---|---|
| Colour | Hazen Units | 5 | 15 |
| Odour | - | Agreeable | Agreeable |
| pH | - | 6.5 - 8.5 | - |
| Taste | - | Agreeable | Agreeable |
| Turbidity | NTU | 1 | 5 |
| TDS | mg/l | 500 | 2000 |
| Calcium | mg/l | 75 | 200 |
| Chloride | mg/l | 250 | 1000 |
| Fluoride | mg/l | 1 | 1.5 |
| Iron | mg/l | 0.3 | - |
| Magnesium | mg/l | 30 | 100 |
| Manganese | mg/l | 0.1 | 0.3 |
| Nitrate | mg/l | 45 | - |

| | | | |
|---|---|---|---|
| Sulphate | mg/l | 200 | 400 |
| Total Alkalinity as Calcium Carbonate | mg/l | 200 | 600 |
| Total Hardness as Calcium Carbonate | mg/l | 200 | 600 |
| Zinc | mg/l | 5 | 15 |

If all these parameters are followed while discharging sewage into rivers and other surface water sources then there will be no problem of water pollution. But it is not the case with Indian waste water treatment facilities. Most of such facilities are either using obsolete technologies or their operation and maintenance is not efficient.

As per Excreta Matters's report of 2012, it has been found that only 30 percent of the daily produced sewage is treated effectively. The total sewage produced daily in India is over 38000 MLD. In actual only around 8000 MLD of which is treated and the remaining 70 percent of waste water is disposed of directly in the nearby natural waters without proper treatment.

If we consider Delhi only then it is estimated to produce more than 600 MGD of sewage and the capacity of treating sewage in Delhi is only about 500 MGD. This untreated waste in dumped into River Yamuna through twenty two between barrages of Wazirabad and Okhla. This confirms CPCB's report of 2012 stating that only 63 percent of STPs are operational in Delhi region.

### 1.3 Need of Treating Wastewater

Without proper treatment of waste water in any area the nearby community will be suffering from a number of health diseases that may lead to degrading economy. So, a sufficient number of STPs are necessary for treating such huge amounts of sewage produced on a daily basis. Due to lack of which the rivers in which this sewage is dumped are getting choked and aquatic life in them is bound to get extinct. But the problem with providing STPs in highly populated countries like India are financial constraints as well as improper planning.

This indicates a centralized Sewage treatment plant is not a feasible option in Indian market and to meet the needs of our population. This is because all the cities producing huge amount of sewage are all ready of the verge of saturation and rehabiliting them for planning the sewerage system is an impossible deed. A STP of large size also includes huge costs with it as well as skilled labour that needs to be paid constantly for operation and maintenance of the plant.

So, a viable option seems decentralizing this whole process of sewage treatment. It will involve public inclusion by telling them the need of decentralization of this whole process. This is possible for planned colonies and colonies or instituions still to be constructed.

Provision of an STP for residential and office buildings and ETP for industries are being made a compulsion due to increasing pollution of water by central as well as state pollution boards. This is done to curb the increasing level of the poor quality of effluent being discharged from these facilities.

### 1.4 Objective

The purpose of this study is to have to detailed insight of small-scale sewage treatment technologies being used in India and highlighting the key features of their function.

- To understand the working and terminologies of decentralized wastewater systems.
- To compare conventional and decentralized wastewater treatment technologies.
- To compare various parameters related to treatment among different technologies in decentralized wastewater treatment systems.
- To find out the best available proposition based on above comparisons and studies.

### 1.5 Thesis Layout

The 1st chapter of this thesis is focussed on highlighting the need of small scale waste water treatment technologies in India. It will support the statement that why such treatment technologies are necessary for us.

The engineering details of the remaining thesis is divided further into 4 remaining chapters and references.

Chapter 2 contains review of the available literature on small scale sewage treatment. After that studies and researches carried out on the same topic are studied and their observations are highlighted. Three major types of small scale sewage treatment technologies will be discussed along with their advantages and disadvantages.

In Chapter 3, the methodology of the report will be presented. Also the various types of data used and their sources will be discussed.

Chapter 4 includes using all the data from primary sources and other reliable sources to show credibility of various technologies. This is done in order to justify what type of technology is suitable when and where.

The last and fifth chapter of this thesis will conclude the thesis by summarizing the findings and highlights of this study.

Appendix A includes the format of the questionnaire in which data was collected from various sources for our study and Appendix B includes supporting documents used in this study various findings.

## 1.6 New Contributions

As we proceed in our work, following meaningful contributions will be made which are quite noteworthy :

- Highlighting the need and benefits of separate or private small scate sewage treatment units
- Showing suitability of a given technology while selecting one as per the local and current needs
- Comparing a number of relevant parameters with each other so that an easy decision can be made for selecting a STP method

## 1.7 Summary

This study is carried out to have an detailed assessment of the various small scale and decentralized wastewater treating techniques. So that the problem of untreated sewage being dumped into the surface waters or the percolation of same into ground water gets solved within a few years.

From next chapter onwards the main part of this thesis starts wherein review of the available literature is being carried out.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter involves study of already available theory on small scale sewage treatment technologies and to highlight the necessary and important points in them. This will help us in getting a line to follow in order get an idea that what type of data needs to be collected for showing our expected results.

## 2.2 Sewage Treatment Process

Treating sewage is not a single stage process it involves a lot of planning and distribution of the waste removal process into various stages. In most of the treatment processes the sewage is treated in 3 stages, namely :

- Primary treatment
- Secondary treatment
- Tertiary treatment

So the general flow chart of sewage treatment is as below :

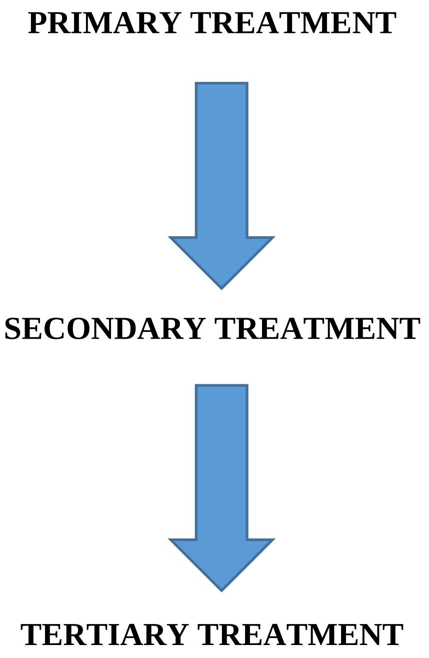


**Figure 2.1 : General flow diagram of sewage treatment**

Now we will try understanding each of these processes in details so that we can find out at what stages small scale technologies are to be applied :

Generally, physical, chemical or biological means of waste treatment means are utilized in combination or separately. If we decide upon means used to treat waste, treatment methods are classfied as :

- Unit operations
- Unit processes

Unit operations involves use of physical forces mainly, so units like bar screeing, mixer and sedimentation chambers, etc are involved here.

Unit processes whereas have chemical or biological treatment of waste which is carried out by using chemicals or microbes respectively.

These processes of biological treatment are of 2 types, namely :

1. Suspended one
2. Attached one

The examples of the first one are ASP, aerated ponds, oxidation ponds and other digesters, while examples of the second type are TF, RBCs and bio-towers.

Now before proceeding to modern technologies of small-scale sewage treatment technologies we have to understand the conventional sewage treatment process in order to compare the two types for better understanding.

The process flow diagram of a typical conventional plant is as below :

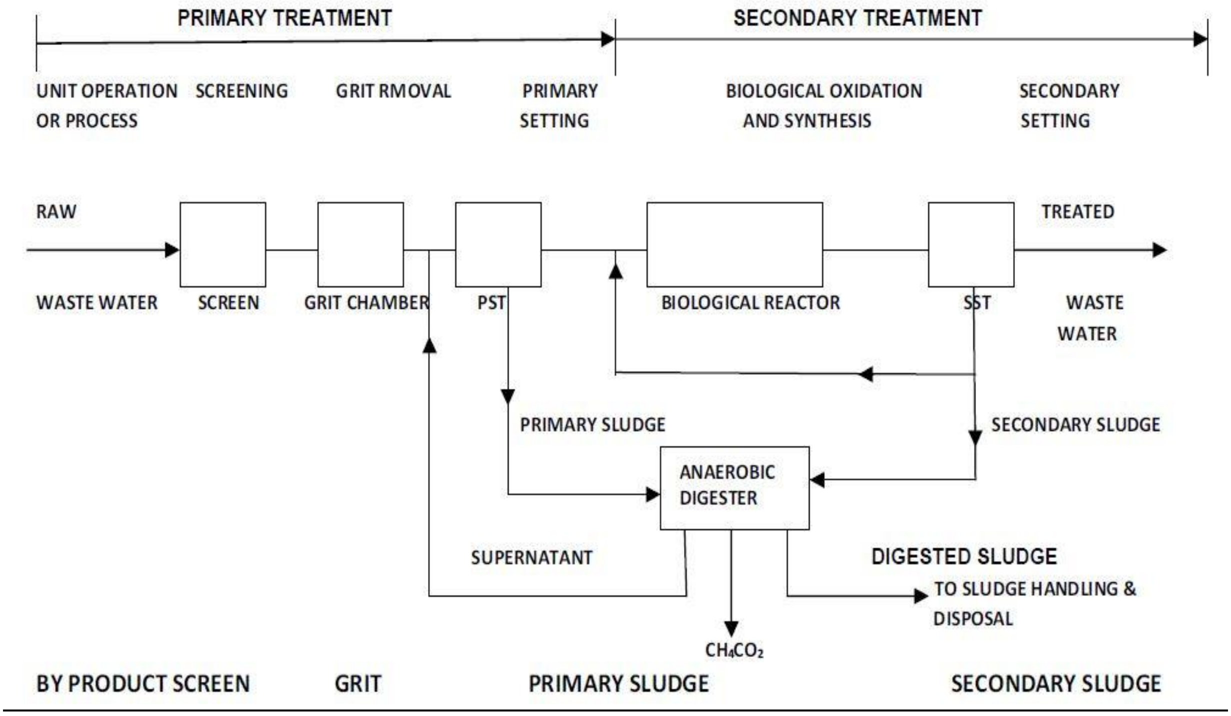


**Figure 2.2 : Conventional STP flow chart**

<u>Primary Treatment :</u>

This is the first stage of treatment and involves mainly the physical methods of removing large-sized particles that are to be removed to prevent further clogging of the equipments in series. However sometimes if floating matter is present if the influent then preliminary treatment is also provisioned in the treatment process. The major components of this system are bar screen chamber, chamber for grit removal and oil & grease traps.

Following are the highlights of any primary clarifier :

1. Removing suspended solids from incoming sewage
2. It will allow passing of colloids and dissolved impurities which will be treated in further stages.
3. Provision of grinders might be made to shred the large sized debris so that filters work properly further in series.
4. Now the inorganic and organic suspended solids load is removed by grit chamber and sedimentation tanks respectively.
5. This stage filters roughly 60-70 percent of the suspended solids from influent.
6. Also the biochemical demand gets removed by 30 percent.

Secondary Treatment :

As only suspended matter was removed from primary stages, it is time to take care of colloids and suspension type impurities of the sewage.

There small sized impurities are impossible to remove physically as was the case with suspended ones. So we need to break them chemically by biological disintegration of the compounds.

In order to do this we need to maixmize the contact between suspended waste and the decomposing bacterias by attached or suspended system as discussed before.

The general process flow diagram for any of these systems is discussed below :

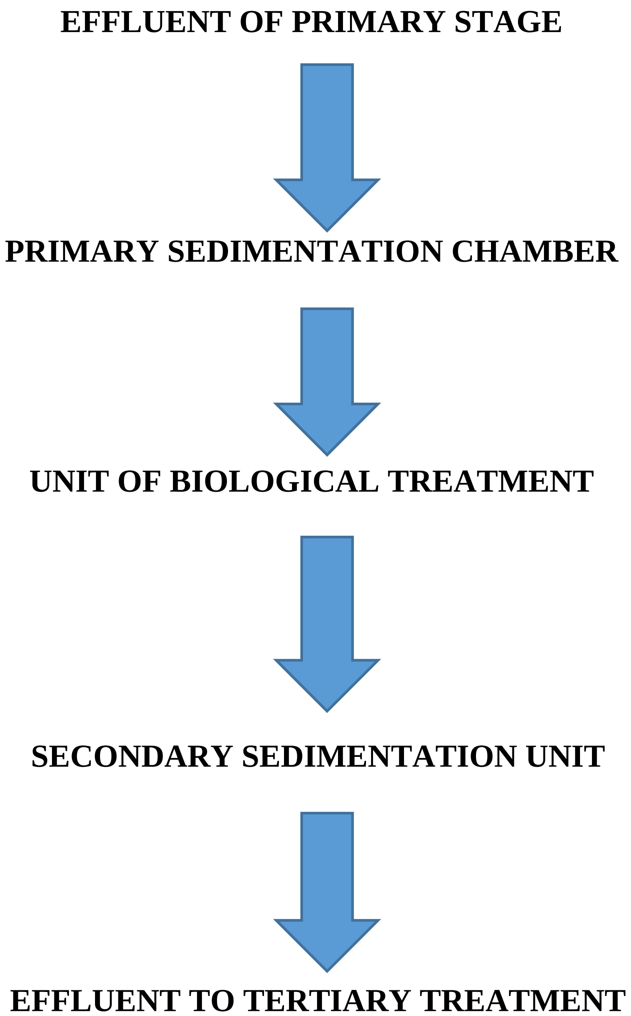


**Figure 2.3 : Flow of secondary treatment systems**

There a provisions of seeding in biological units where we try to use the various types of units for recirculating the active sludge so that efficiency of our system remains high as desired.

The classical examples of biomass systems are trickling filters and activaed sludge processes but these methods are mostly obsolete nowadays due large costs incurred in their installation and maintenance. Various technologies available for small scale treatment are MBBR, MBR, FBR, UASBR and SBR.

Tertiary treatment :

After secondary treatment, tertiary treatment is given to the wastewater for making it usable as per the needs of end user.

These uses include drinking, agriculture, gardening, washing, flushing etc. So treatment is given as per the needs of our requirements.

### 2.3 Small Scale Wastewater Treatment

If not designed for a city or a large community then the plant must be a small scale treatment unit. The general size of such units is less than or equal to one hundred KLD (kilo litres per day).

For our thesis the technologies used in the analysis will Moving bed Biofilm Reactor, Membrane Bioreactor and Sequencing Batch Reactor. Now will try to study these technologies in a detailed manner as these three are mostly used in India as per the primary data research.

These technologies are being adopted at a faster rate than any other alternatives like FBR, UASBR, etc. So if we can provide a way to select the type of technology used in any system then it will be helpful in solving the immense problem of sewage treatment in India.

A huge gap between the total sewage generated in Delhi and the sewage that is actually treated was found i.e. 1706.4 million liter per day (MLD).The problem is not just that there is inadequate treatment capacity in Delhi, but proper management of the existing STPs is also required. (12)

So, we need have a knowledge about the small scale sewage treatment technologies in order to solve the above problem. Before doing that the various factors that need to be studied for such an index are installation costs, maintenance and operation costs, cost of labour, cost of instrumentation, time available, need of end users, area requirements, etc.

Now we can discuss those 3 technologies used extensively in India for small scale waste treatment :

## 2.3.1 : MBBR (Moving Bed Biofilm Reactor) :

MBBRs are extensively used nowadays in Indian market for both domestic as well as industrial wastewater treatment purposes. The high tolerance to changes in temperature and substrate concentration (organic pollutants) allows their use for the treatment of water reservoirs (1).

However for know-how of their working and complete treatment process we need to understand their working procedure completely.

This understanding of any technology can only made after understanding their process flow diagram. So, the general process flow diagram of a MBBR is given below. It shows the positioning of various units employed in a MBBR while it works.

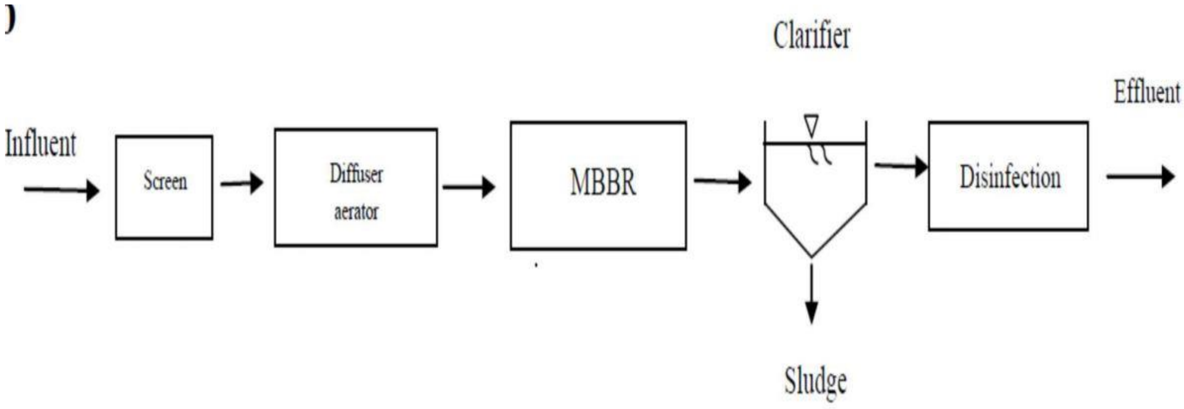


**Figure 2.4 : General process diagram of MBBR process**

The MBBR technology can be used in a number of ways in the treatment unit. It is used for both municipal as well as industrial purposes in the field. Going on the paths of a Trickling Filter (TF), MBBR is also an attached growth microorganisms process. This means that bacteria or the biodegrading organisms are attached to the membranes provided for waste stabilization. They are NOT moved inside the tank or suspended in it. So their concept is similar to trickling filters or rotating biological contractors system.

For the purpose of wastewater treatment MBBR uses a carrier media made of plastic which has its density approximately equivalent to water i.e, around one gram per cubic cm. This is done in order to keep the carrier media floating in water so that no settlement occurs in the tank, because this decreases the tank efficiency and increases maintenance costs.

Conventional attached treatment systems have a plate on which the bacterias or the microorganisms get attached for decomposition of waste, but but for MBBR technology the same organisms get attached on the plastic carriers we mentioned above. The biological growth of the microorganisms increases on the media itself and increases as the tank ones starts working properly.

For keeping the media in suspension and preventing settling air blowers are provisioned as per the requirements and flow given. In order to prevent the small sized media from escaping the tank sieves of suitable sizes are provided at the outlet of the tank.

Unlike conventional systems of attached media treatment these MBBRs have no provision of any recycling of wastewater for purposes of seeding and activation, or other purposes. But units like primary sedimentation or clarification are essentially same. Their purpose is to reduce the load on the systems of MBBR to prevent their blocking etc.

There is no need of recycling the solidified waste because there is sufficient bacteria in attached form in the tank.

Below are shown two choices of MBBR available in the market :

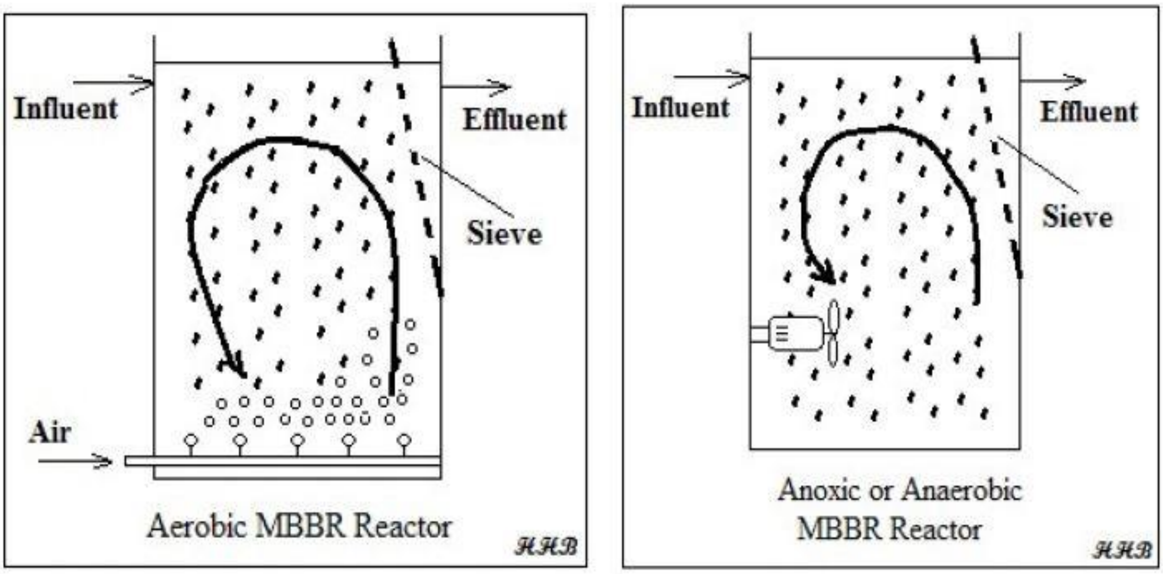


**Figure 2.5 : Types of MBBR systems**

Carrier system of MBBR :

The main purpose of any media form must to have maximum efficiency possible. This is attained by using a carrier which is designed to give maximum possible specific surface area. This provides a lot of area for our bacterias to flourish on the media carriers.

In addition with high specific surface area having a high void ratio is also a desirable requirement of our carrier media for the tank of MBBR to work properly in a given condition.

The specific surface area for a media is defined as area provided by a media carrier per unit volume of the media in the tank. It should be available between 300 to 1100 m2/m3. The final design values are selected by the designer for satisfying the requirements at hand.

After specific surface area, we need to define what the meaning of surface area is for media of MBBR tank.

The void ratio is defined as the ratio empty volume or volume of voids to the volume of solids available in a media. It is measured in percentage. Its value must lie between 60 – 90 percent for maximum output from the tank.

Below we can see the MBBR carrier media used commercially in the market :


**Figure 2.6 : MBBR media used commercially**

The range or exact value of above mentioned properties must be mentioned by the suppliers for easy reckoning by the user.

The advantages of these small scale treatment techniques and of course of MBBR are that they are quite flexible in operation. This means that they can be used in a number of ways by the end user as per their specific requirements.

Following are the various options available in market for MBBR use :

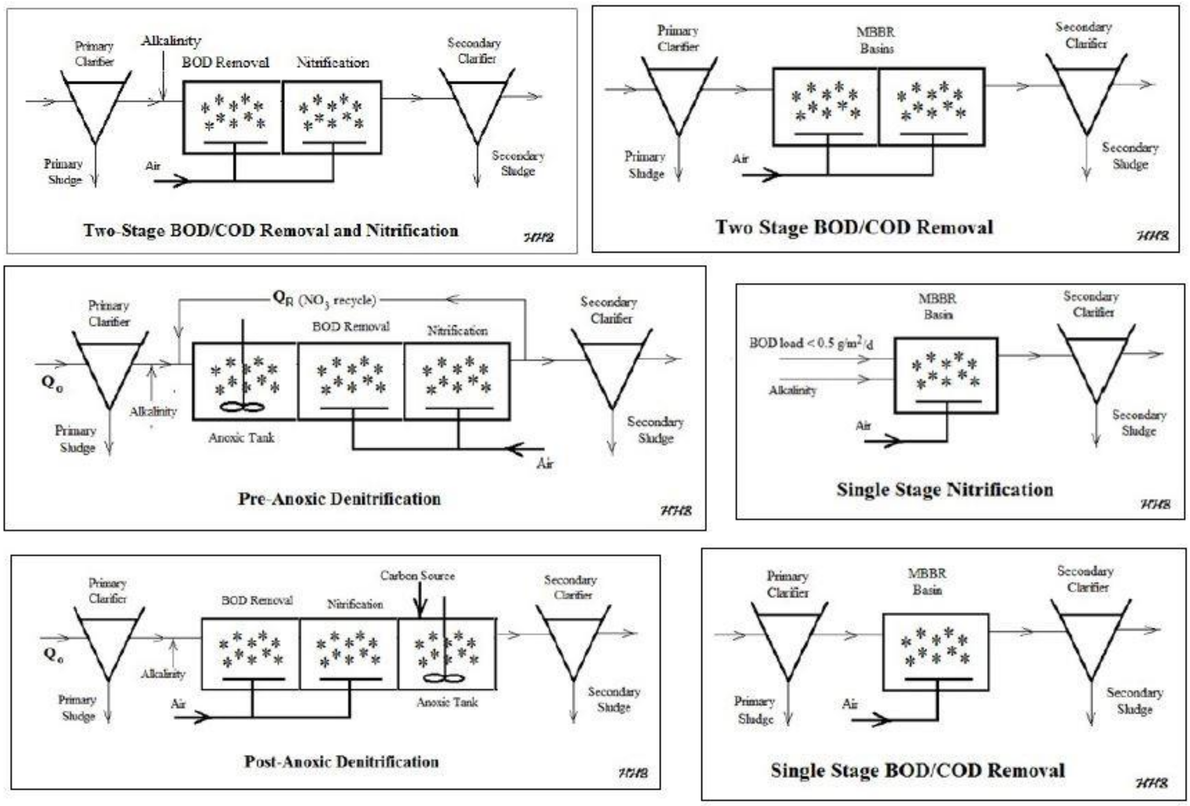


**Figure 2.7 : Various options available with MBBR technology**

So we can see from above illustration that a number of ways are available for MBBR use, namely, if one wants single stage BOD and / or removal or it is required in 2 stage etc, whether nitrification is required in single stage along with BOD and COD removal or not.

It can also depend on whether denirification is required by the users or not and it is before anoxic tank or after that.

Once the selection of type of modification or technology gets specified to the designer he/she gets to design the plant for required use. This includes calculation of vaious tanks, their capacities, water depth, actual depth and number with types of mechanical equipments required.

In addition to improved efficiency the physio-chemical requirements of the effluents are also satisified by the tank. The COD and BOD of the effluent after treatment gets reduced to less than 100 ppm and 20 ppm respectively, whereas total suspended solids and oil & grease concentrations are decreased to 30 ppm and 5 ppm respectively.

Working of a MBBR :

The influent gets completely mixed while flowing continuously without the negative effects of any conventional process for the same. Any type of system like aerobic or anaerobic can be used on which our plastic media carriers carry bacteria in order to disintegrate the wastewater.

The materials used for bio-media are plastic, polypropylene or ceramic which can have hollow curved or cylindrical shapes. The cross-sectional dimensions of media varies between 10 to 15 mm.

## 2.3.2 : MBR (Membrane Bio-Reactors) :

After MBBRs we are going to discuss the same important parameters of Membrane Bio-Reactors (MBR) technology in this study. An advanced level of inorganic (suspended grit) and organic (biologically degradable) removal can be attained with the use of MBRs. Both carbon and nitrogeen related demands of oxygen can be reduced using MBRs.

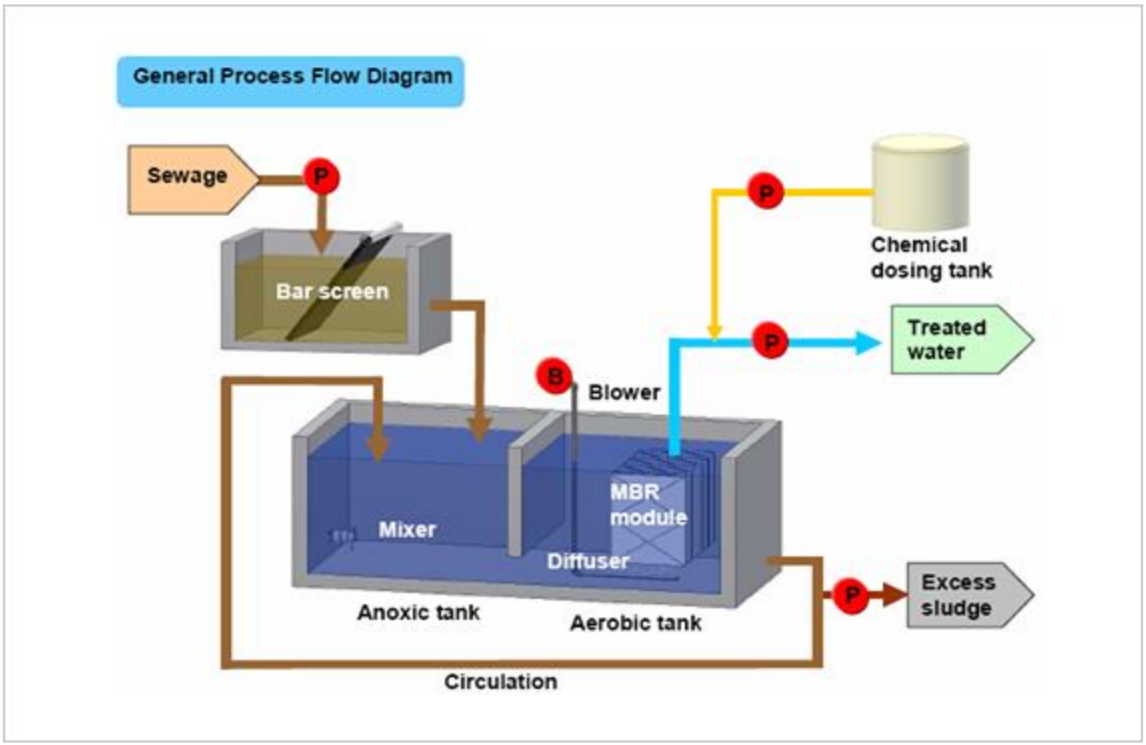


**Figure 2.8 : General Process Flow Diagram of a MBR**

In figure 2.8 above, we can see the most general process flow diagram of a MBR used in the Sewage Treatment System.

If we observe from start of the tank, we can see that the tank number 1 holds bar screen which is designed as per flow velocities between 0.75 m/s to 1.5 m/s. The bar screen we use should have supports at each side with Indian Standard Angle sections so that shock loading does not disturbs the orientation of the screen. As these screens are inclined at angles of 45 to 60 degrees with respect to the horizontal. It should be observed that fine screens are placed after the coarse ones.

The second tank in the series is anoxic tank, which is given the responsibilities of denitrification. This is because nitrogen is the main source of eutrophication in aerobic or anaerobic treatment systems and it needs to be removed for betterment.

MBR Reactor

The MBR reactors are of types based upon the location of where membrane is placed; namely :

- Submerged MBR
- External MBR

We can the diagrams depicting them, in the Figure 2.9 below :

First we will discuss the MBR system in which membrane is submerged completely inside the MBR tank.

In this system membrane is placed under negative pressure to achieve the cleaning force. Also backwashing is used for the puurpose of membrane cleaning, in backwashing certain chemicals are used for whose dosing provisions are made near membrane area. In order to inhibit eutrophication in the tank there are tanks without oxygen supply in order to remove extra available nutrients.

Apart from above components there are coarse and fine diffusers present so that no settling occurs at the tank bottom.

Now after submerged ones the external MBRs can be discussed. In external MBRs mixed liquor suspended solids are made to recirculate because the membrane is placed outside the tank. Here the cleaning force can be obtained by maintaining good flow velocity through our filter's membranes.

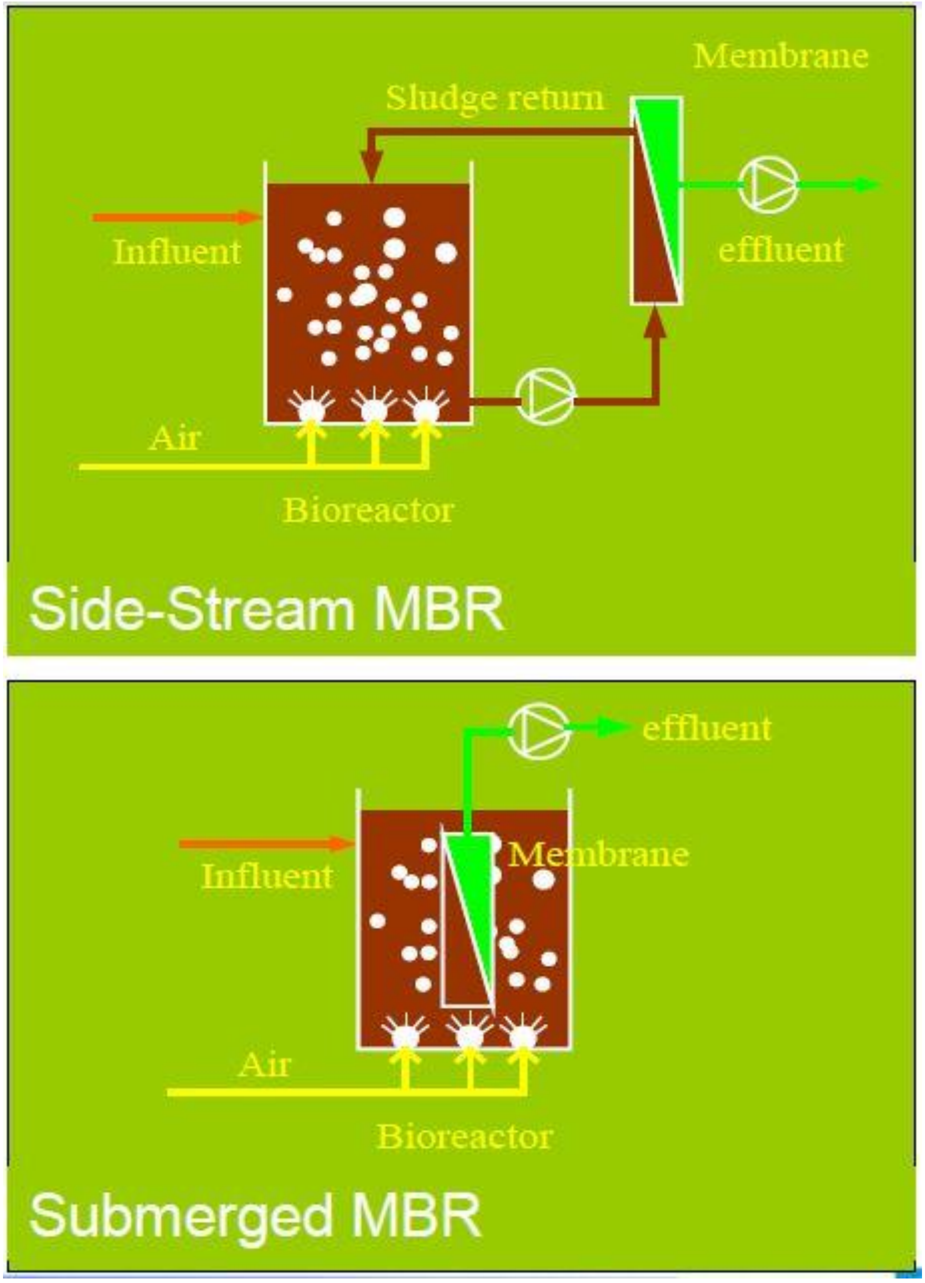


**Figure 2.9 : Types of MBR systems**

<u>Properties of MBR membranes :</u>

The membranes for MBR can be made of both organic as well as inorganic materials. So, for organics membranes natural polymers are used and for inorganic ones ceramic or other materials are used.

Now we need to understand various properties of these membranes so that an optimum membrane can be selected for our tank. Two of the major properties of any such membrane are their flux rate and permeability.

So, flux rate of a membrane is defined as the ratio of permeation flow rate and surface area of the membrane used. The membranes are in process mode most of the time. Depending on the membrane type, a relaxation and/or a back-pulse mode is required for cleaning purposes. These procedures affect the next flux of the system, which is therefore lower than the gross flux. (2)
After flux rate, the permeability can be defined as the ratio of flux of membrane and net membrane pressure (NMP).

Net Membrane Pressure is defined as the difference of static and dynamic pressures through membranes. All the pressures are measured in 'Bar' here, which is the unit of pressure.
All these parameters are temperature specific, i.e., they are defined at a given temperature for a condition. Permeablilty of a membrane represents the working condition of the MBRs membrane. Permeability is case of wastewater systems is a function of biological activity occuring in the MBR membranes. It often decreases with increasing biological activities and is maintained at required level by periodic backwashing of the membranes.

The standard temperature to be maintained in the tank must be in the range of 15 to 20 degree Celcius in order to maintain proper viscosity of the fluids in operation. Otherwise, improper temperature can lead to reduced flow through the membranes. This happens when the water or fluid passing through the membrane gets cooler. As at this happens (temperature decreases) viscosity of the fluid gets increased exponentially, which is to avoided at any cost.

Filtration Process in MBR :
It can be seen in the Figure 2.10 below that how filtration happens in a Membrane Bio-Reactor of any type. The process of getting clear fluid from filter is called Process Mode. It is sometimes interrupted due to backwashing or back-flush we can say. Backwashing is necessary to prevent the filters from getting brittle or useless. As after getting brittle these filters start getting cracked leading to short-circuiting of the fluid.
After this there is a relaxation mode during which filters are rested by decreasing the rate of flow through them. This is done in order to maintain the flexibility of the membranes. Because their flexibility is important for their durability.

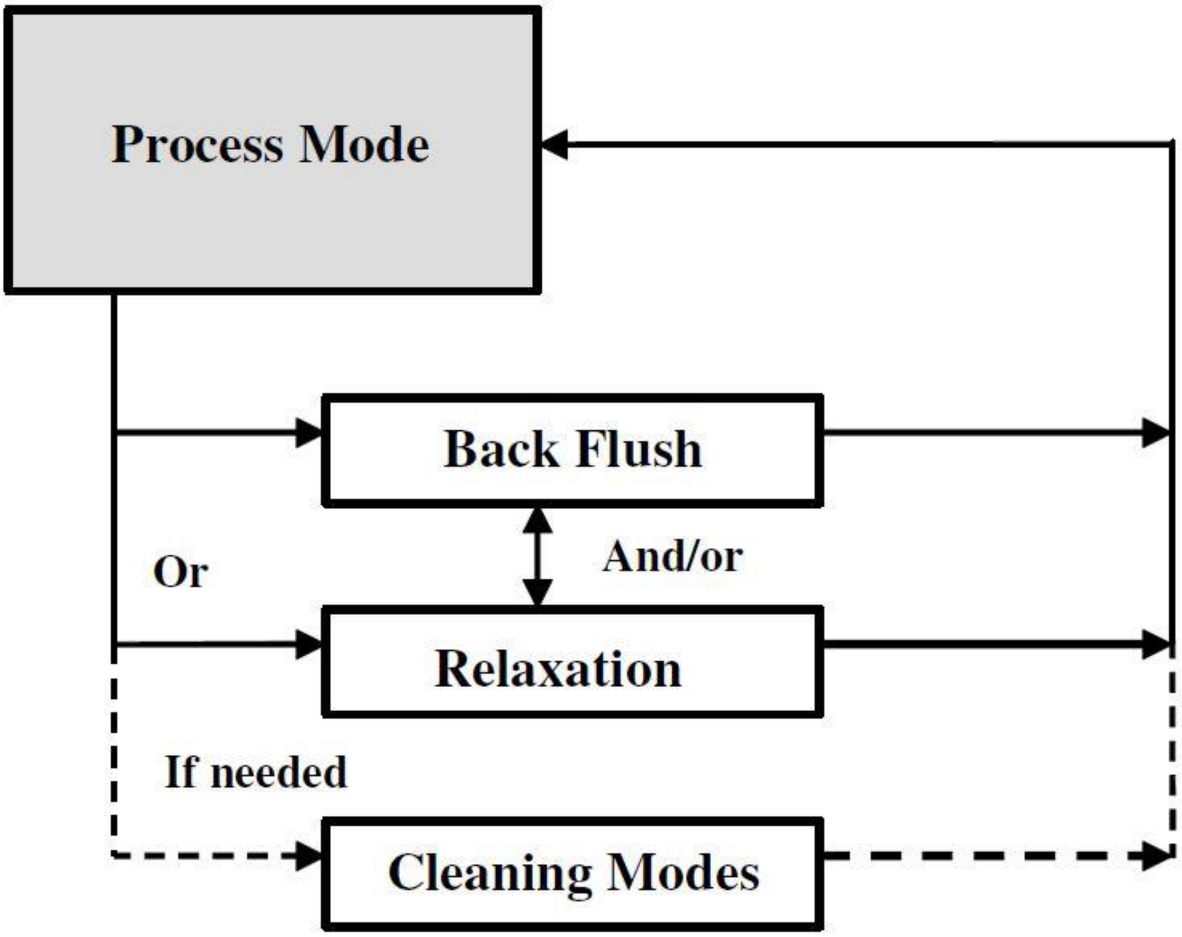


**Figure 2.10 : Various modes in a Membrane Bio-Reactor system**

There are membranes which can be used continuously as well as intermittently with provisions of backwashing. However, the designer has option to incorporate both back-washing and relaxation mode simlutaneously or separately.

It should also be noted that the membranes used must be treated with suitable chemicals. If the pH of water in treatment is acidic, then chemicals like sodium chloride or sodium hypochloride are used. But if the pH is basic then we need to use chemicals of acidic nature like citric acid or HCl, etc.

The various industries where MBR is suitable are :

1. Domestic or municipal waste water treatment
2. Industrial waste water treatment
3. Sludge digestion
4. Landfill leachate treatment

In Table 2.1 below we can see the applications outputs of MBR systems in treatment of domestic sewage :

**Table 2.1 : Use of MBR in Domestic STPs**

| Membrane type | Configuration | Size of operation | Treatment efficiency | Country of application |
|---|---|---|---|---|
| Ceramic Ultrafiltration | External membrane | Full scale 125 $m^3/d$ | Effluent COD 5 mg/l | Japan |
| Polymeric Ultrafiltration | External membrane | Pilot scale 360-840 $m^3/d$ | Effluent TC 12 mg/l | Netherlands |
| Ceramic Ultrafiltration | External membrane | Bench scale 0.16 $m^3/d$ | COD removal 98% | USA |
| Polymeric Ultrafiltration | Submerged membrane | Pilot scale 6-9 $m^3/d$ | COD removal 95% | Germany |
| Polymeric Ultrafiltration | Submerged membrane | Full scale 750 $m^3/d$ | Effluent BOD 1 mg/l | USA |
| Polymeric Ultrafiltration | Submerged membrane | Pilot scale 9000 $m^3/d$ | COD removal 95% | USA |

In Table 2.1 below we can see the applications outputs of MBR systems in treatment of industrial sewage :

**Table 2.2 : Use of MBR in Industrial STPs**

| Source of wastewater | Membrane configuration | Size of operation | Treatment efficiency | Country of application |
|---|---|---|---|---|
| Landfill leachate | Ultrafiltration external | Full scale 50 $m^3/d$ | Not available | France |
| Landfill leachate | Ultrafiltration external | Full scale 264 $m^3/d$ | COD removal 80% | Germany |
| Landfill leachate | Ultrafiltration external | Full scale 250 $m^3/d$ | COD removal 90% | Germany |
| Sludge digestion (anaerobic) | Microfiltration external | Pilot scale 0.13 $m^3/d$ | Not available | South Africa |

`

In Table 2.1 below we can see the applications outputs of MBR systems in treatment of domestic sewage :

**Table 2.3 : Use of MBR in Leachate Treatment**

| Wastewater source | Membrane configuration | Size of operation | Treatment efficiency | Country of application |
|---|---|---|---|---|
| Various sources | Ultrafiltration external | Pilot scale 0.2-24.6 $m^3/d$ | COD removal 97 % | Germany |
| Paint industry | Ultrafiltration external | Full scale 113 $m^3/d$ | COD removal 94 % | USA |
| Tannery industry | Ultrafiltration external | Full scale 500-600 $m^3/d$ | COD removal 93 % | Germany |
| Cosmetic industry | Ultrafiltration external | Full scale | COD removal 98 % | France |
| Electrical industry | Ultrafiltration external | Full scale 10 $m^3/d$ | COD removal 97 % | Germany |
| Food industry | Microfiltration | Full scale 600 $m^3/d$ | Effluent TSS 9 mg/l | USA |

The source of reference used for Tables 2.1, 2.2 and 2.3 is mentioned at third point in References of this report.

These tables illustrate what type of industry requires what type of membranes and also at what rate of flow. It also shows what percentage of COD and suspended solids removal is provided by these systems.

### 2.3.3 : SBR (Sequencing Batch Reactors) :

Since their inception in late 1920s, SBR have become an ideal method to treat both domestic sewage as well as sewage from industries also. They suit best at places where a constant flow of wastewater is NOT guaranteed. This means that SBRs can be used in areas of varying flow rates.

These waste treatment systems are modification of any conventional Activated Sludge Treatment process being used. In SBR, the advantage is with control over our aeration system and that the system with SBR can be operated using computers. The major difference between a SBR and an ASP is that all the processes of treatment of sewage are combined into a single tank, which is not the case with STPs based on activated sludge process.

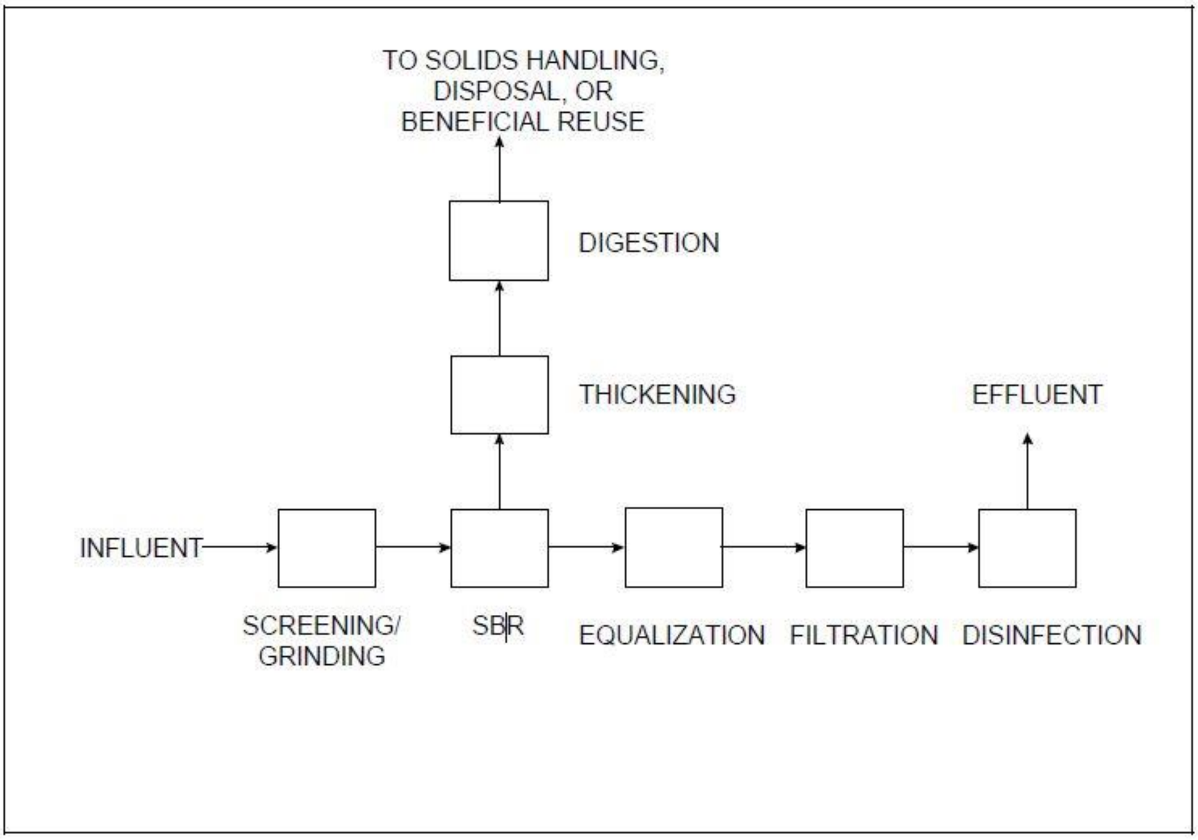


**Figure 2.11 : Process flow of a Sequencing Batch Reactor System**

From the general process flow diagram of this system we can see that once the wastewater enters into the STP, SBR is the tank present as second unit. It is present after the bar and screen arrangement.

SBR is type of system to treat sewage in which fill and draw processes occur in series for a number of times in the Figure 2.12 below we can see the cycle of major phases of the Sequencing Batch Reactors.

The major phases involved in SBR’s complete operation are :

1. Fill
2. React
3. Settle
4. Decant
5. Idle

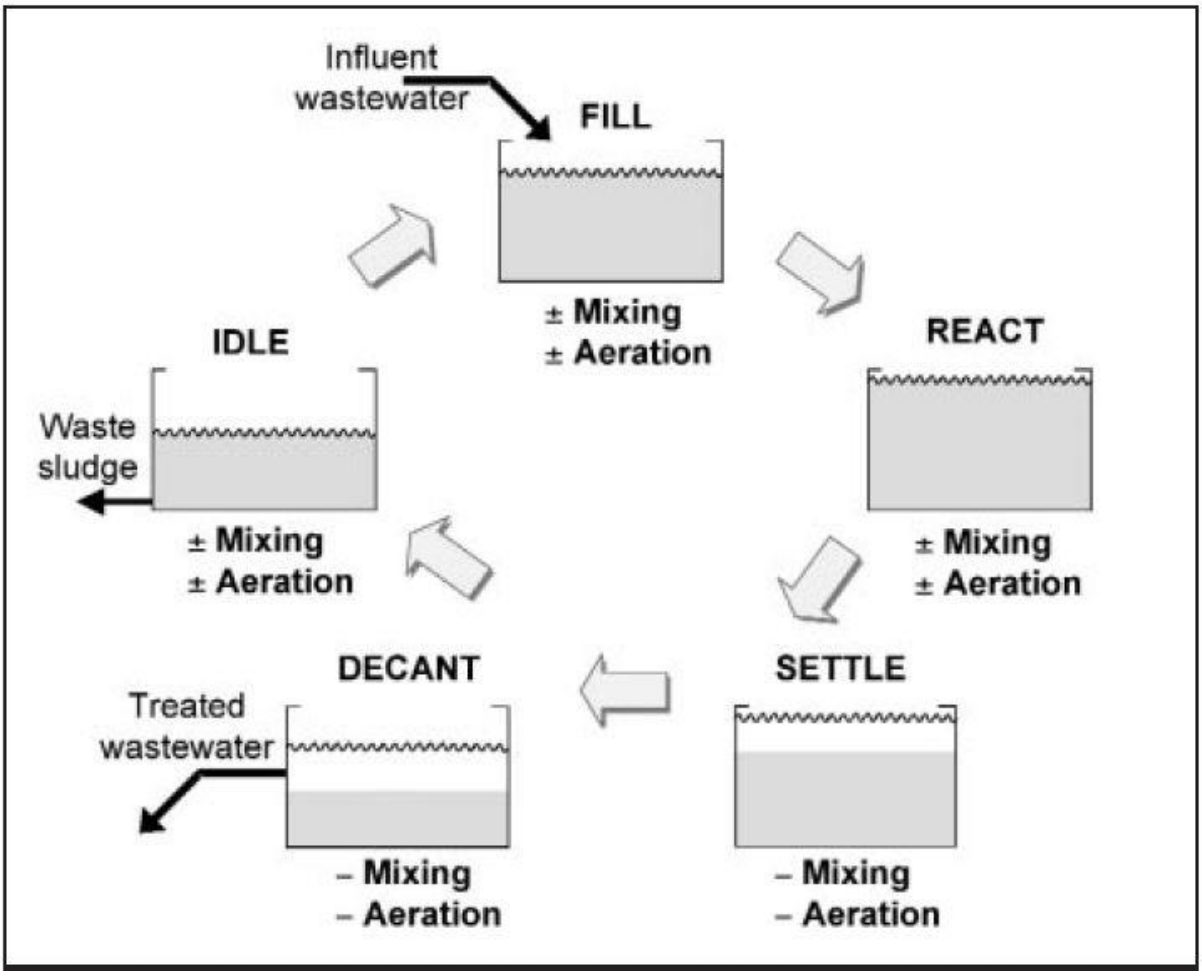


**Figure 2.12 : Major operational phases of a Sequencing Batch Reactor System**

Basic process of treatment in SBR's :

As we can refer from above figure, there are 5 major phases of operation in a SBR system.

These phases can be inter-changed as per the immediate requirements.

1. FILL :
   This is the first phase of SBR treatment process. In this phase SBR recieves the water from the supply source. This is the source of food for the micro-organisms further in the line ahead.
   There can be made conditions of anoxic and/or oxic type depending on the influent type. In order to maintain anoxic conditions the concentration of dissolved oxygen must be monitored. It must NOT exceed 0.2 mg/l in any condition.

2. REACT :

   The main role of this phase is to reduce the carbonaceous BOD of influent. Here polishing of the effluent takes place, which means further reduction of harmful parameters like BOD, COD, etc. In addition to oxygen demand related to carbon, the demands of nitrogen as well as phosphorus are also well reduced effectively.

3. SETTLE :

   Here sludge in activated form is allowed to settle as there are no provisions of any aerators or blowers here. The settlement of the solid mass occurs due to flocculation in this tank area. This leads to formation of a blanket of sludge in the tank. A part of this sludge needs to be removed in the next phase for the purpose of seeding.

4. DECANT :

   Decanters are employed for this phase of the SBR, done in order to remove our supernatant liquor. Decanters are available in two configurations, namely, floating one and other one of fixed-arm type. In the first type, operator has the flexibility to vary the volumes during operation. The decanter must be placed suitably above the tank bottom such that it does NOT interferes with our settled sludge.

5. IDLE :

   This is the last phase of the whole treatment process of SBR treatment system. It takes place between our filling phase and decanting phase. However, its duration depends upon the rate of flow of influent and the skills of the operator at plant. A process known as wasting occurs in this stage of the process in order to remove sludge settled at tank bottom.

# CHAPTER 3
# STUDY AREAS AND DATA COLLECTION

## 3.1 Introduction

In this chapter we are going to study various companies and their products which are related in the business of decentralised or small scale waste water treatment facilities. For making this study fruitful we will be using a questionnaire based method for our study. The company representatives will be contacted through phone calls, e-mails, data available on company websites and/or personal interviews.

## 3.2 Data Collection

Before proceeding to the main analysis of plants there is a need for the data to be analysed. For this purpose we have interview a number of companies in the field of wastewater management who manufacture and/or provide services of STPs.

The data that needs to be taken from these companies will be related to every aspect of wastewater engineering. This set of data will help us in finding our results and conclusions. Results can be inferreed from any type of data using co-relation and regression techniques using Microsoft Excel.

Now we are going to list out the data that needs to be interviewed from company representatives of various STPs. The data to be collected will be taken from primary as well as secondary sources for the study.

Data for the purpose of interview can be classified into many groups based on the department involved as well as on the general understanding of the situation in hand.

Points to be kept in mind while collecting data:

- Obtaining data at a suitable scale which is reliable enough.
- Asking for data related to physio-chemical parameters of both influent as well as efffluent.
- Understanding broad range of equipments involved in the small scale sewage treatment systems.
- Trying to know about the costs involved in various components of the project.

- Learning about the exact configurations of the systems involved with various technologies.
- Trying to know about requirements of the end users involved in using the plant after construction.
- Mainly we will try to learn about projects in urban areas which have commisioned recently.

So the study data is given below along with their classification :

1. Treatment Data
    - Influent and effluent BOD concentrations
    - Influent and effluent COD concentrations
    - Influent and effluent TSS concentrations
    - BOD removal (%)
    - COD removal (%)
    - TSS removal (%)
    - Sludge volume produced ($m^3$/day)
2. Operation and Maintenance Data
    - Chemical costs
    - Energy costs
    - Labor costs
3. Capital Costs Data
    - Civil Costs
    - Hardware Costs
4. Site Data
    - Area used by the plant
    - Capacity of the plant

Apart from these data there are certain others data which are not classified above such as location of plant, state and location of plant. This is because such informations are NOT necessary to have any inference.

But such data can be used if any demographic finding is required at any stage of the project.

In the next section of this chapter we will try finding relations that can be interrelated in order have some suitable inferences.

### 3.3 Procedure for Data collection

The data mentioned in above section are to be collected from various company executives as mentioned above. The ways of collecting data is mentioned above in previous sections.

For this purpose we have prepared a questionnaire mentioning all the questions necessary for our research purposes. There are provisions made for adding other suitable data if the company personnal thinks that data can help us in improving the results.

A total of 11 companies were contacted via various means of communication for our study purposes. All these companies are presently involved in the field of wastewater treatment using one or more of the above mentioned technologies.

However, after contacting them many companies contacted did not responded. So out of them only 8 companies responded to our query. From these organisations data was provided for a total of 63 small scale STPs of all types.So, in the next section we are going to list out all those organisations who responded to our request of providing the necessary data.

Out of the data collected above suitable inputs can be taken out by comparing parameters as per the below comparisons :

- Land required versus Plant Capacity
- Sludge produced versus Plant Capacity
- Energy consumption versus Plant Capacity
- Total Capital Costs versus Plant Capacity
- Cost break-up of operation cost components
- Operation costs versus Plant Capacity
- BOD, COD & TSS removal versus Total Plant Capacity

In addition we can also present the comments and suitable observations at necessary places of the report.

### 3.4 Organisations involved in the study

The companies involved in the business of wastewater treatment at small scale in India who responded positively to our queries are mentioned in this section.

Following is the list of companies used in the research activity along with their main speciality in the STP field :

**Table 3.1 : List of companies interviewed along with technologies involved**

| Name of the Company | Technology Adopted |
|---|---|
| Klaro India | SBRs |
| HydroTherm | SBRs |
| Sainath Envirotech | SBRs |
| Grey Water Solutions | SBRs, MBRs, MBBRs |
| ENViCARE Technologies | SBRs, MBBRs |
| WABAG India | SBRs, MBBRs |
| Xylem India | SBRs, MBBRs |
| G.E.T. Water Solutions | SBRs, MBBRs, MBRs |

Many engineers and experienced persons were contacted from the above listed companies for our study purpose and necessary details were collected through various means. But there was no such representative of research and development department available in some of these companies so persons like sales executives, public relation officers and other similar people were available to interact. But it was found that after being involved in the field of water and sewage treatment for so many years they were capable enough to respond to all our queries.

In the next section we are going to show details about some of these plants which were allowed to be visited in Delhi. These include one plant based on each of the technology we are interested to study about, i.e.; SBR, MBBR and MBR based plants.

### 3.5 Study of surveyed STPs

With the help of all the data sources, either primary or secondary we were able to collect the following data from the STPs surveyed. In the Table 3.0 below we tried providing data about the number oaf technologies studied of each type.

Apart from infering results from data collected with the help of above STPs we visited some of the STPs. The main purpose of visiting these plants is to validate the data received via phone calls, e-mails, interviews and data from websites. So after visiting these sites we compared the data from these visits and tried comparing data obtained from secondary sources.

EXAMPLES :

Below is the study of the sewage treatment plants that were visited while carrying out this study in a questionnaire format. The same questionnaire was used to collect data from all the available sources :

1. **160 KLD STP , MP RESIDENTIAL QUARTERS, BD MARG, DELHI**

**Table 3.2 : Data of a MBBR based plant**

| A survey of small scale STPs in India | | |
|---|---|---|
| **Question Number** | **"Questions to be answered"** | **ANSWERS (Please write 'X' if data is NOT available or if it cannot be shared)** |
| 1 | **State of Construction** | DELHI |
| 2 | **End User Type** | MP RESIDENTIAL QUARTERS DR. BD MARG |
| 3 | **Technology Adopted** | **MBBR** |
| 4 | **Installation Year** | 2019 |
| 5 | **Capacity of Plant (KLD)** | 160 |
| 6 | **Expected life of system (Years)** | 40 |
| 7 | **Expected life of membrane (Years), if applicable** | 10 |
| 8 | **Footprint of the plant (sq.m.)** | 280 |
| 9 | **Influent BOD (mg/l)** | 225 |
| 10 | **Influent COD (mg/l)** | 475 |
| 11 | **Influent TSS (mg/l)** | 275 |
| 12 | **Effluent BOD (mg/l)** | 10 |
| 13 | **Effluent COD (mg/l)** | 100 |
| 14 | **Effluent TSS (mg/l)** | 30 |
| 15 | **Electro-Mechanical Components Used in Plant** | |
| 16 | a)Bar screen` | 2 No, 750mm x 650 mm |
| 17 | b)Raw sewage transfer pump | 1 HP, 15mm solid handling |
| 18 | c)Air blower | Twin lobe type, 5 HP/ 1430 rpm |

| | | |
|---|---|---|
| 19 | d)Coarse and fine air diffusers | Disc type (150mm); tubular (63mm x 550mm) |
| 20 | e)MBBR media | Spherical type, PVC, 400m2/m3 |
| 21 | f)Tube deck media | Hexagonal type, PVC, 200m2/m3 |
| 22 | g)Sludge transfer pump | Centrifugal monobloc type, 7-10mm solid handling |
| 23 | h)Filter feed pump | Centrifugal monobloc type |
| 24 | i)Multigrade sand filter | Vertical flow type, MSEP, fabricated |
| 25 | j)Sludge feed pump | Screw type, 10-12mm solid handling |
| 26 | **Energy consumed by the plant (kWh/day)** | 450 |
| 27 | **Operation & Maintenance Costs per month per KLD (Rupees)** | 1050 |
| 28 | **Total Cost per KLD(Rupees in thousands)** | 24.5 |
| 29 | Others : AC filter | Vertical flow type, MSEP, fabricated |
| 30 | Others : Chlorine dosing system | 0-6 lph, PP |
| | | |
| | Anything else, you want to let us know for the research (kindly mention below) :- | |
| | Filter press | Manual type, 12’x12”x12 No of plates |
| | | |

## 2. 65 KLD STP, GUJARAT BHAWAN, DELHI

**Table 3.3 : Data of a MBR based plant**

| A survey of small scale STPs in India | | |
|---|---|---|
| **Question Number** | **"Questions to be answered"** | **ANSWERS (Please write 'X' if data is NOT available or if it cannot be shared)** |
| 1 | **State of Construction** | DELHI |
| 2 | **End User Type** | GUJARAT BHAWAN |
| 3 | **Technology Adopted** | **MBR** |
| 4 | **Installation Year** | 2019 |
| 5 | **Capacity of Plant (KLD)** | 65 |
| 6 | **Expected life of system (Years)** | 40 |
| 7 | **Expected life of membrane (Years), if applicable** | 10 |
| 8 | **Footprint of the plant (sq.m.)** | 120 |
| 9 | **Influent BOD (mg/l)** | 185 |
| 10 | **Influent COD (mg/l)** | 580 |
| 11 | **Influent TSS (mg/l)** | 195 |
| 12 | **Effluent BOD (mg/l)** | 18 |
| 13 | **Effluent COD (mg/l)** | 45 |
| 14 | **Effluent TSS (mg/l)** | 15 |
| 15 | **Electro-Mechanical Components Used in Plant** | |
| 16 | a)Bar Screen | 900mm x 900mm |
| 17 | b)Mechanical Fine Screen | 2mm opening |
| 18 | c)Oil Skimmer | 500 l , LDPE tank |
| 19 | d)Raw sewage transfer pump | 1 HP, 35mm solid handling |
| 20 | e)Air Blower | 5 HP/ 1430 rpm ; 3 HP/ 1425 rpm |
| 21 | f)Coarse and fine air diffusers | Disc type (150mm); tubular (63mm x 550mm) |
| 22 | g)MBR Module | 65 KLD, PVDF |
| 23 | h)UV system | 425 W, 3 lamps, 60,000 uw-sec/cm2 |
| 24 | i)Sludge Recirculation Pump | 1 HP, 7mm solid handling |
| 25 | j)MBR permeate pump | 1 HP, 2900 rpm |

| | | |
|---|---|---|
| 26 | **Energy consumed by the plant (kWh/day)** | 250 |
| 27 | **Operation & Maintenance Costs per month per KLD (Rupees)** | 1750 |
| 28 | **Total Cost per KLD(Rupees in thousands)** | 70 |
| 29 | Others : hypo and citric dosing system | 200 L each |
| 30 | Others : centrifuge | 300 mm basket dia |
| | Centrifuge feed pump | 1 HP, 605 rpm, screw type |
| | Anything else, you want to let us know for the research (kindly mention below) :- | |
| | pH meter, rotameter, electro-magnetic flow meter, sight tube | Instrumentation |
| | Control Panel | Front operated, cubical type with compartments. |

### 3. <u>175 KLD STP (SBR based), SAFDARJUNG AIRPORT, DELHI</u>

**Table 3.4 : Data of a SBR based plant**

| **A survey of small scale STPs in India** | | |
|---|---|---|
| **Question Number** | **"Questions to be answered"** | **ANSWERS (Please write 'X' if data is NOT available or if it cannot be shared)** |
| 1 | **State of Construction** | DELHI |
| 2 | **End User Type** | SAFDARJUNG AIRPORT |
| 3 | **Technology Adopted** | **SBR** |
| 4 | **Installation Year** | 2018 |
| 5 | **Capacity of Plant (KLD)** | 175 |
| 6 | **Expected life of system (Years)** | 40 |
| 7 | **Expected life of membrane (Years), if applicable** | 10 |
| 8 | **Footprint of the plant (sq.m.)** | 250 |
| 9 | **Influent BOD (mg/l)** | 44.5 |
| 10 | **Influent COD (mg/l)** | 475 |
| 11 | **Influent TSS (mg/l)** | 74 |

| | | |
|---|---|---|
| 12 | **Effluent BOD (mg/l)** | 8.5 |
| 13 | **Effluent COD (mg/l)** | 80 |
| 14 | **Effluent TSS (mg/l)** | 12.5 |
| 15 | **Electro-Mechanical Components Used in Plant** | |
| 16 | a)Bar screen | 1000mm x 750mm |
| 17 | b)Air blowers | 5 HP/ 1430 rpm |
| 18 | c) Coarse and fine air diffusers | Disc type (150mm); tubular (63mm x 550mm) |
| 19 | d)SBR package | 175 KLD, SS-304 |
| 20 | e)Submersible sewage transfer | Non-clog, 20mm solid handling |
| 21 | f)AC filter | Working pressure : 4kg/cm2 |
| 22 | g)Centrifuge | 500m dia basket |
| 23 | h)UV sterilizer | 425 W, 3 lamps, 60,000 uw-sec/cm2 |
| 24 | i)Sludge screw pump | 1 HP, 605 rpm |
| 25 | j)Sludge recirculation pumps | 1 HP, 7mm solid handling |
| 26 | **Energy consumed by the plant (kWh/day)** | 350 |
| 27 | **Operation & Maintenance Costs per month per KLD (Rupees)** | 900 |
| 28 | **Total Cost per KLD(Rupees in thousands)** | 65 |
| 29 | Others : pH meter, rotameter, electro-magnetic flow meter | Instrumentation |
| 30 | Others : drainage sump pump | Non-clog type, 12mm solid handling |
| | | |
| | Anything else, you want to let us know for the research (kindly mention below) :- | |
| | Control panel | Front operated, cubical type |

| | | |
|---|---|---|
| | | with compartments. |
| | | |

The data obtained from both the sources are found to be in coherence and it had made us sure of using the data from other sources being useful in this study.

Now in the next chapter we are going to present the results and findings of this study.

# CHAPTER 4

# RESULTS AND FINDINGS

## 4.1 Introduction

In this chapter were going to present the results obtained from previous studies and the data collected. The data collected will be used to plot various types of graphs and plots in order to infer something useful. We know that while comparing two entirely different entities corelation and regression are to be adopted. We will be them also while plotting the graphs. Also, we will try to find the cost breakups in order to find gaps where the current systems can be optimized.

## 4.2 Comparison of Collected Data

First of all, we are going to compare and analyse various related factors of these STPs in relation to the total plant capacity. This is done is order to find the scaling effect of any type, i.e., whether the size or capacity of the plant has any effect on the related factors or not.

So the various comparisons carried out with total plant capacity being the dependant variable are given below :

### 4.2.1 Land Requirement (sq.m.) and Total Plant Capacity :

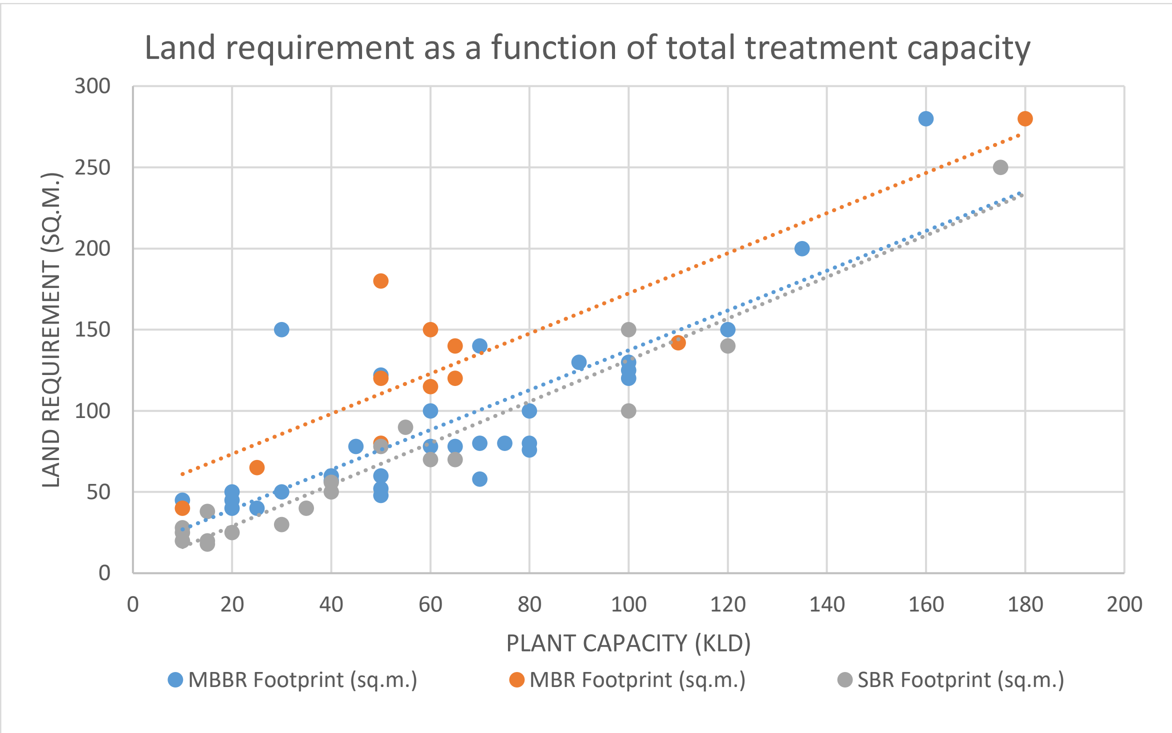


**Figure 4.1 : Comparison of Land Requirement with Total Plant Capacity**

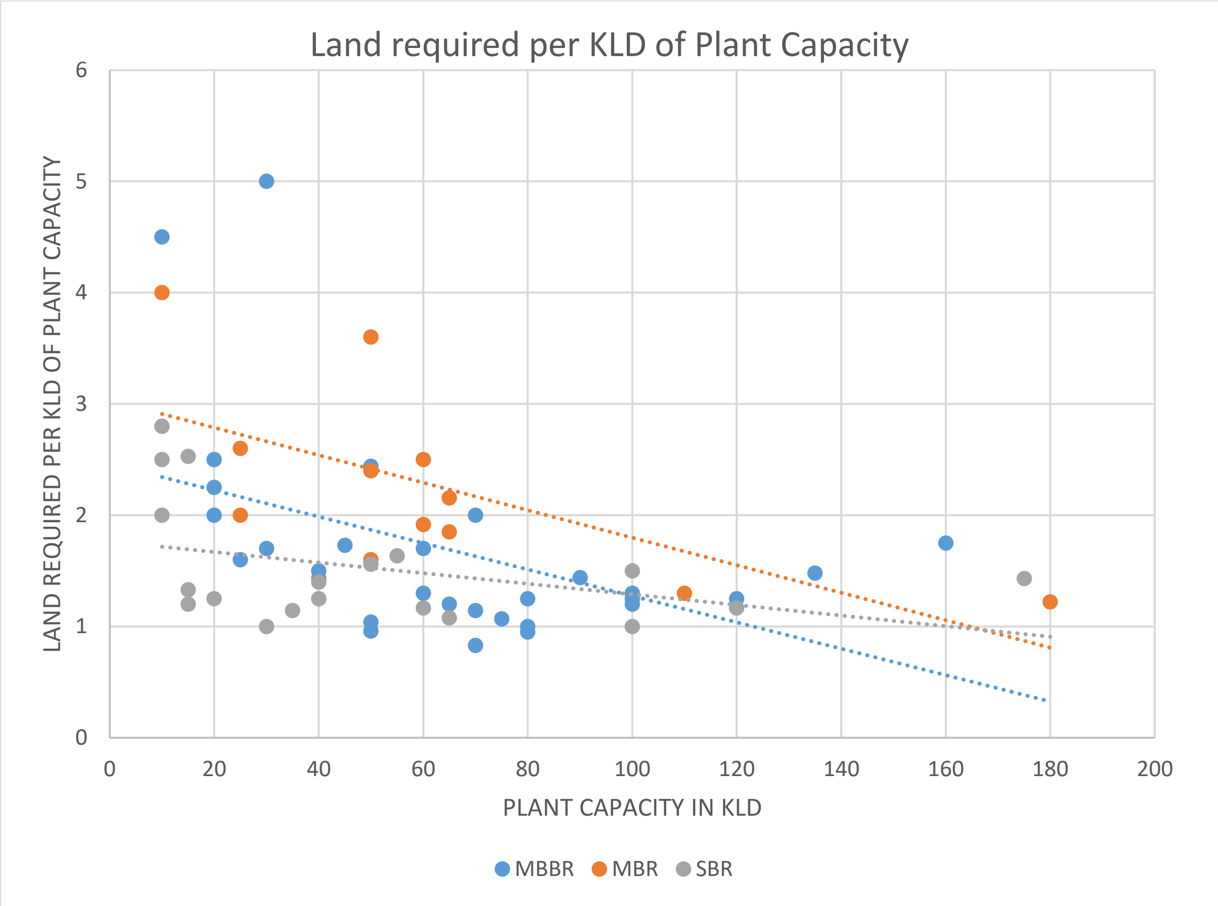


**Figure 4.2 : Comparison of Land Requirement per KLD with Total Plant Capacity**

<u>Findings :</u>

As it can be observed from Figure 4.1, the land requirement or footprint was found to be almost similar for MBBR and SBR. However, MBBR have little bit more land requirements for plants of smaller capacities when compared to SBRs. Among the three technologies MBRs were found to have the largest land requirements. So, we can say that for STPs of large capacities MBBR or SBR are suited whereas for plants of capacity less than 50 KLD MBR can be opted for. It is alos to be noted that as the

### 4.2.2 Sludge Volume Generated and Total Plant Capacity :

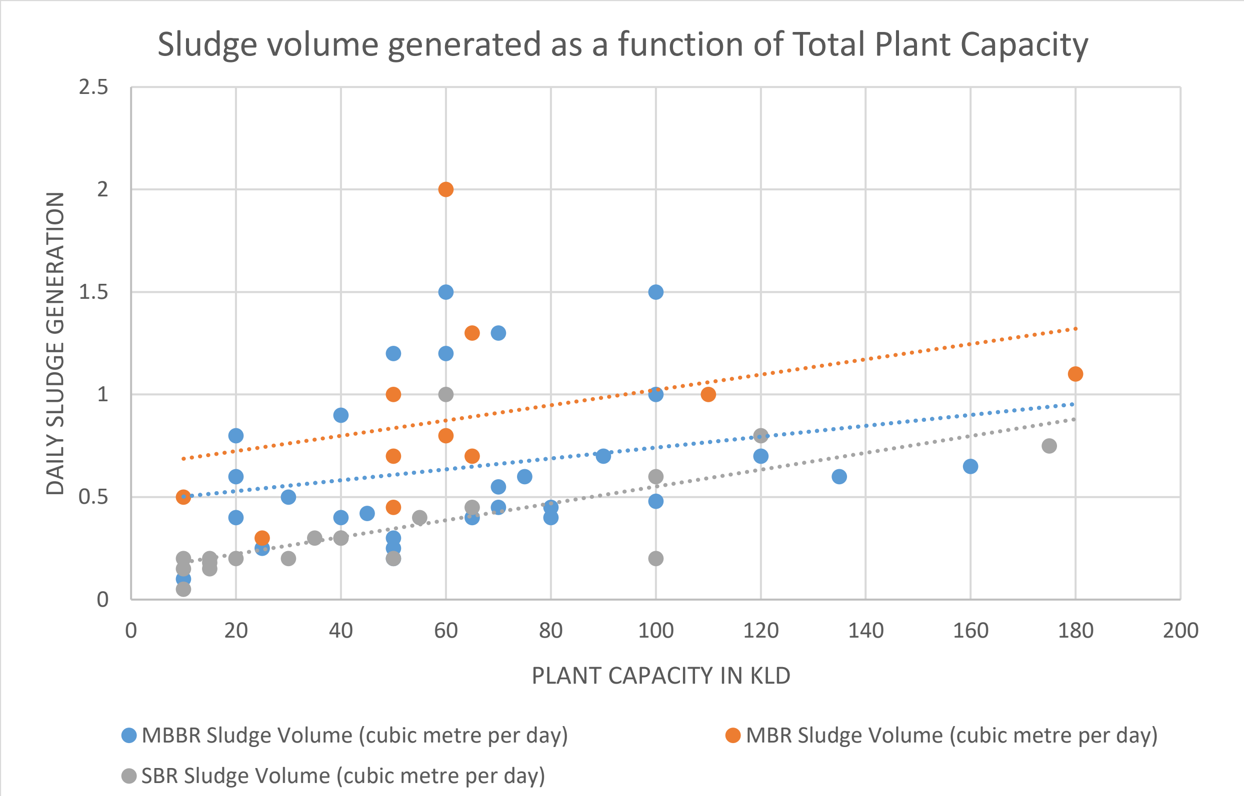


**Figure 4.3 : Comparison of Sludge Generated per day with Total Plant Capacity**

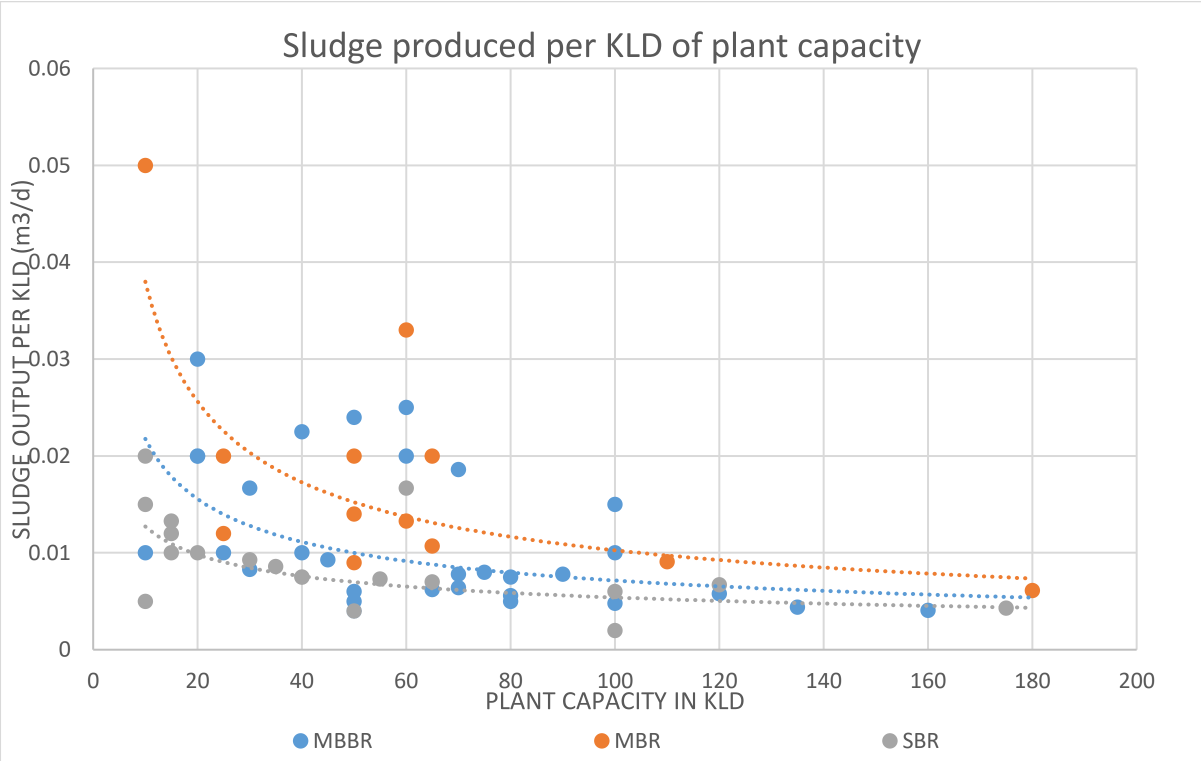


**Figure 4.4 : Comparison of Sludge Generated per KLD per day with Total Plant Capacity**

Findings :

The technology with least sludge generation is Sequential Batch Reactor (SBR) while Membrane Bio-reactors were found to have the maximum rate of sludge production. It is to be noted that the consistency of the sludge in all the STP types is around 1.5% to 3.0%. So, in the technologies studied the sludge generation was found to be increasing along with the capacity with SBR producing the least amount of sludge. However, in case of MBR result may be less accurate as less number of plants were available for study. These systems have decreasing sludge generation as the plant's treatment capacity increases. The output of SBR was found be relatively flat over the entire range of plant capacities meaning that sludge output remains almost same in case of SBRs.

### 4.2.3 Energy Requirements and Total Plant Capacity :

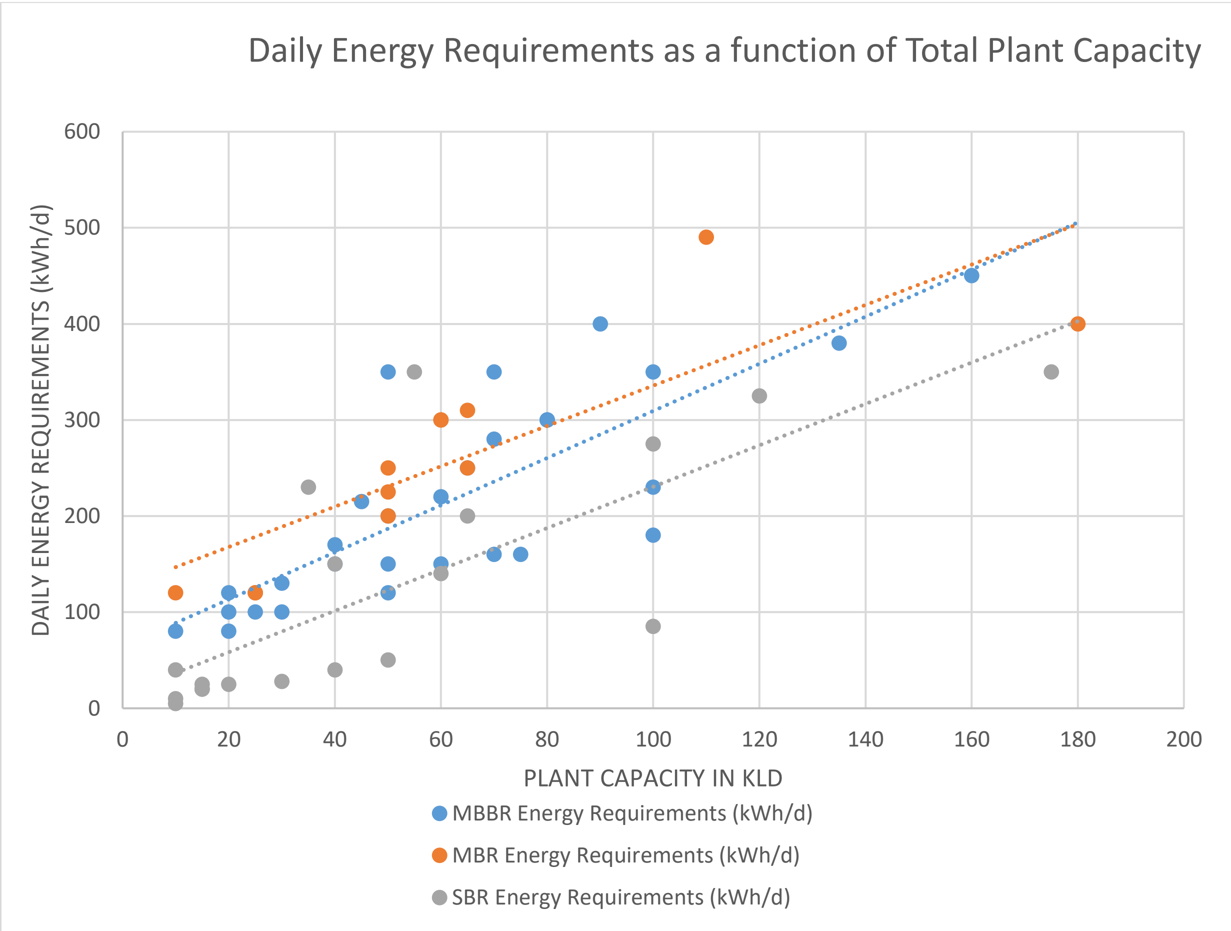


**Figure 4.5 : Comparison of Energy Requirements with Total Plant Capacity**

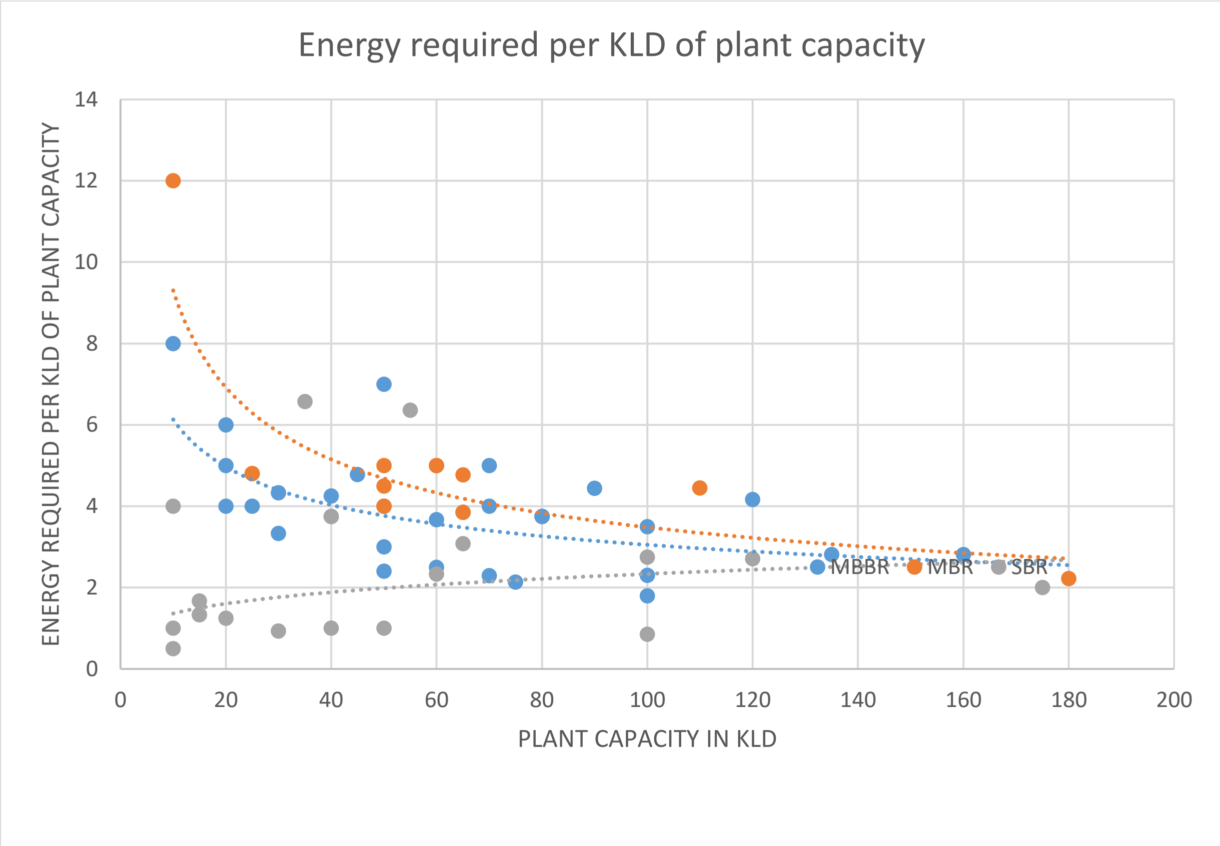


**Figure 4.6 : Comparison of Energy Requirements per KLD with Total Plant Capacity**

Findings :

It can be observed from Figure 4.6 that MBRs have maximum energy requirements among all the three technologies studied, whereas SBRs reported minimum energy needs for plants upto 100 KLDs. This was because some of the SBR based STPs were found to be extremely energy efficient while the survey was carried out.

The remaining set of SBR based STPs were found to consume energy in the range of MBBR based STPs. However, the general trend of energy requirements per KLD was found to be decreasing with increasing plant capacity.

### 4.2.4 Capital Cost Break-up study

Now, with general observations it can be said that cost is the deciding factor in each and every project of any project. It affects every aspect whether it is materials, labor or land. So we tried finding a relation between cost and other collected data to have some insight about small scale STPs.

Any sewage treatment plant requires capital for two main components, namely the cost involved in construction of tanks made of Reinforced Cement Concrete (RCC) and in procurement of hardware components such air blowers, pumps, media, etc. The capital costs of any STP includes the cost of designing, supply of materials and machine, their installation to the end user and commisioning of the project. The civil costs will also include the cost of foundations for different machines.

<u>MBBR :</u>

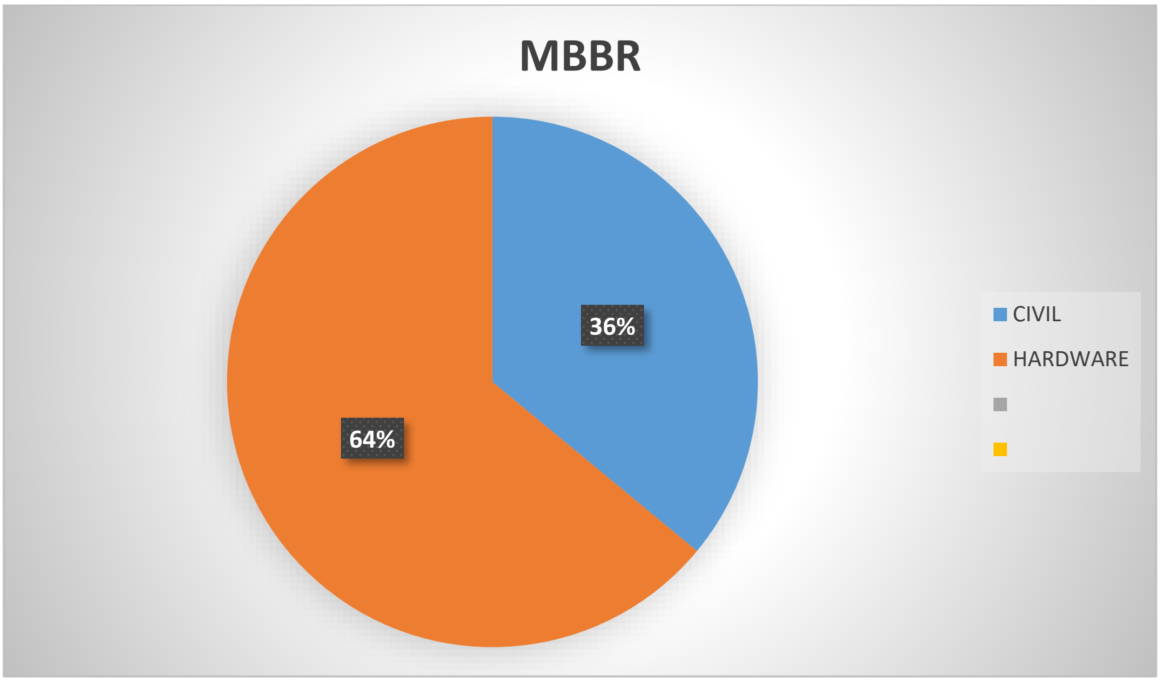


**Figure 4.7 : Capital Cost Break-up of MBBR**

<u>Findings :</u>

The major part of MBBR based STPs was found to be civil construction costs which may include construction of various tanks and foundations for different machines. The same thing is observed in case of SBRs also. However, the costs of civil construction is a little bit higher in case of MBBR based systems. Within the civil construction costs the major part involves construction of RCC tanks.

MBR :

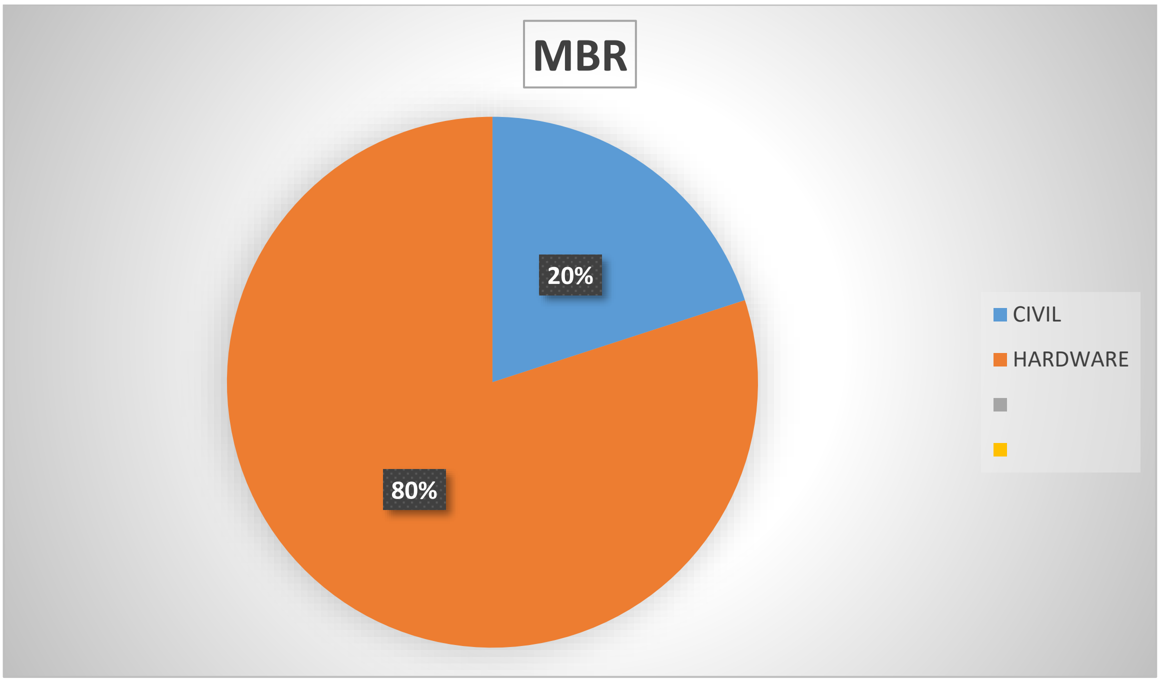


**Figure 4.8 : Capital Cost Break-up of MBR**

Findings :

MBR based STPs were found to have extremely less civil construction costs because the tanks mostly used in this case are made of steel or fibre-reinforced plastic (FRP) materials. This 20 percent contribution of civil costs indicated costs incurred in construction of foundations, drains, etc. This differentiation of costs was not given by the personnels during the survey.

SBR :

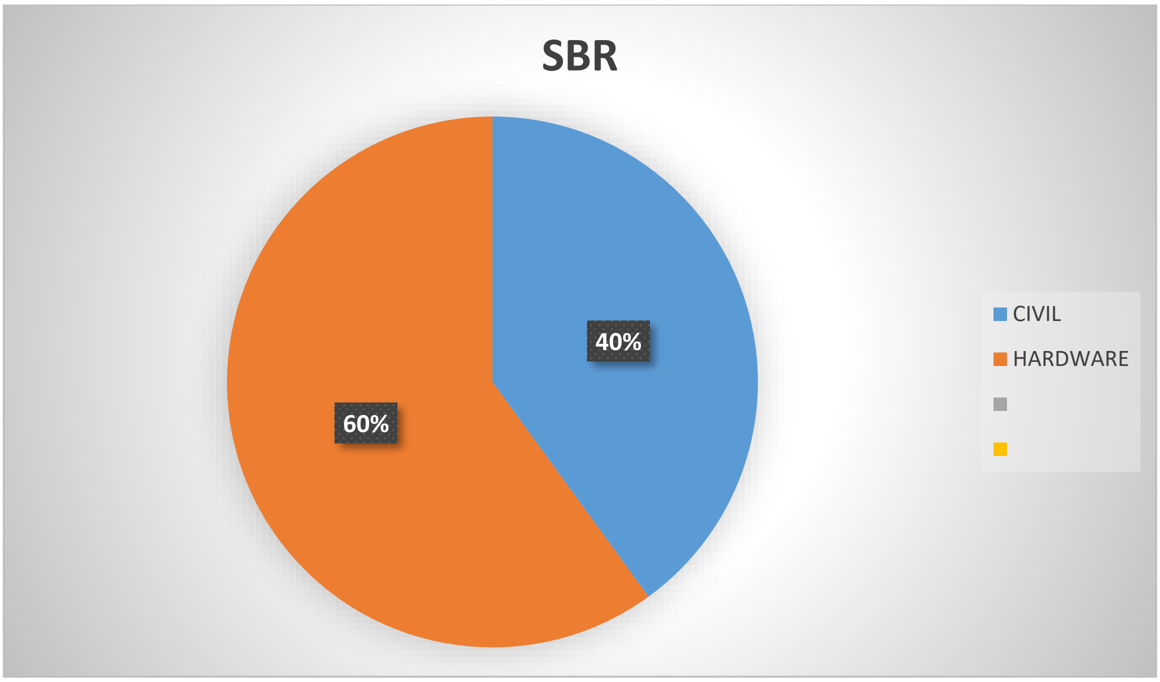


**Figure 4.9 : Capital Cost Break-up of SBR**

Findings :

SBR based STPs indicate a trend similar to that of MBBR based STPs, i.e.; major part of capital costs is covered by civil construction costs. However, SBR based STPs have slightly lesser civil costs than MBBR baes STPs.

The hardware costs in all the three types of STPs include the costs of bar screens, fine screens, air blowers, filters, coarse and fine air diffusers, instrumentation and piping costs.

### 4.2.5 Total Capital Cost and Total Plant Capacity :

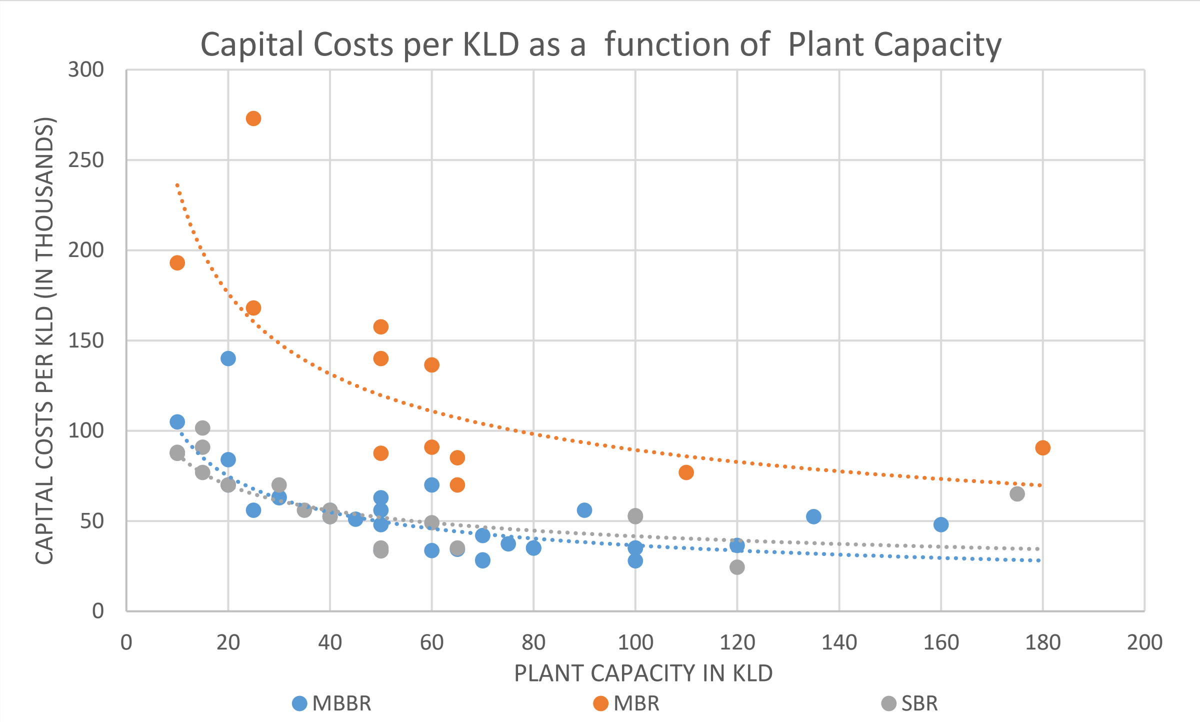


**Figure 4.10 : Total Capital Costs and Total Plant Capacity**

<u>Findings :</u>

**Table 4.1 : Capital Cost Curve Equations and $R^2$ Values**

| Technology | Capital Cost Curve Equation | $R^2$ Value |
|---|---|---|
| MBBR | $y = 284.83x^{-0.446}$ | 0.5326 |
| MBR | $y = 623.23x^{-0.422}$ | 0.5375 |
| SBR | $y = 183.01x^{-0.322}$ | 0.5344 |

As it can be observed from Figure 4.10 and Table 4.1, the cost curve equations are presented along with their $R^2$ Values, all of which are larger than 0.5. This indicates that these equations can be trusted for having a satisfactory analysis of capital costs of all the three types of sewage treatment plants.

It can be seen that all the three curves have similar shapes for capital costs. MBBR and SBR based STPs have similar capital costs across all plants of different capacities. The STPs based on MBR technology have maximum capital costs. It can also be observed that the range of variation of capital costs is large in case of MBR based plants.

### 4.2.6 Operation Costs Break-up Study

Operations cost of a STP is defined as the algebraic sum of the chemical costs, electricity costs and labor costs. The chemicals used in general are sodium hypochlorite and citric acid.

MBBR :

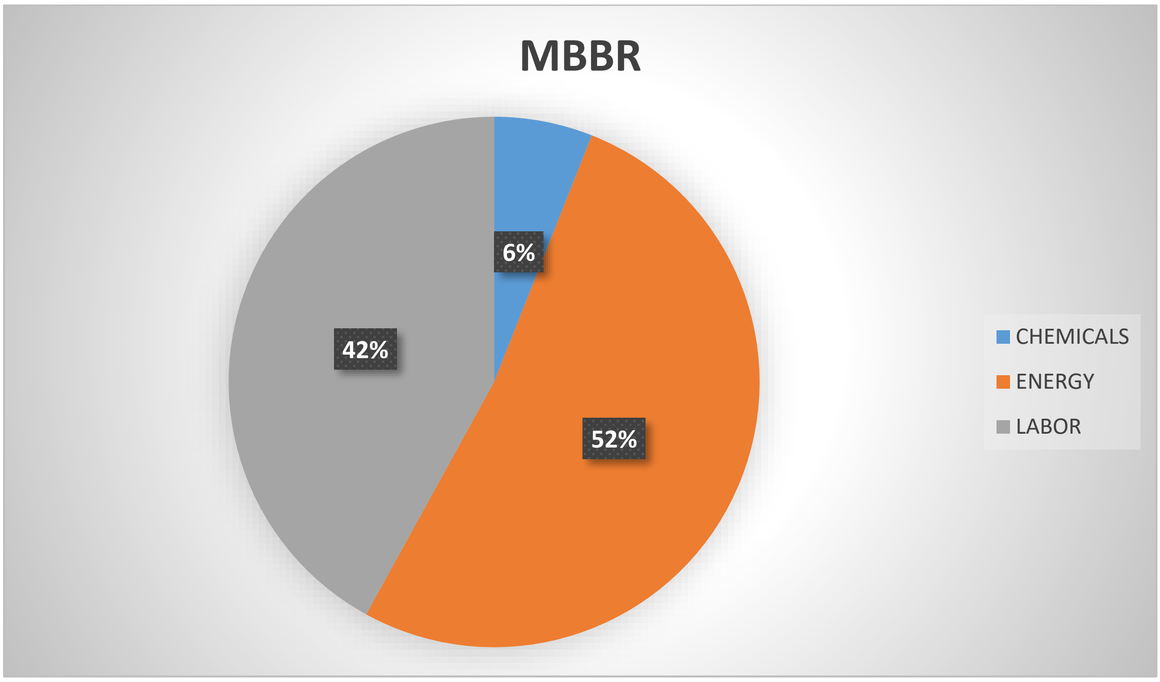


**Figure 4.11 : Operation Costs Break-up of MBBR**

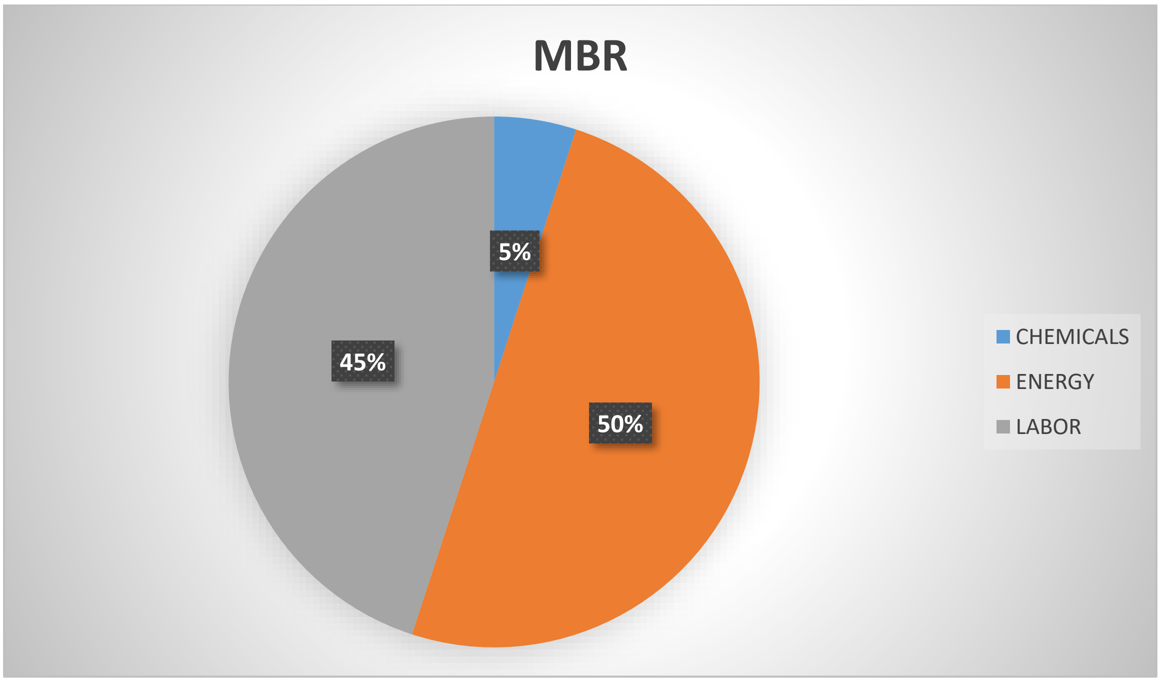


**Figure 4.12 : Operation Costs Break-up of MBR**

SBR :

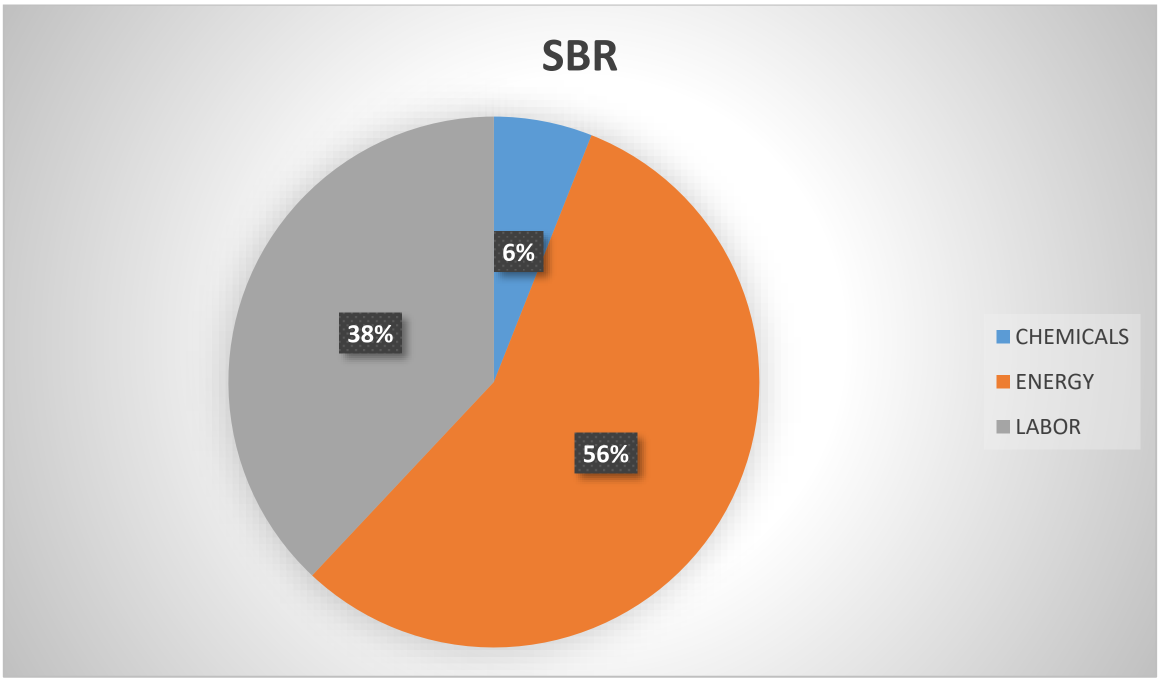


**Figure 4.13 : Operation Costs Break-up of SBR**

These chemicals are useful for balancing pH of the water that has been treated. The electricity costs are related with functioning of the electro-meachanical components used in the plant, namely: pumps, blowers and different instrumentations involved. Finally, the labor costs involve the costs incurred for the STP operators and the labortory technicians in case of completely manual sewage treatments plants.

Findings :

It is to be observed from Figures 4.11-13, that the energy costs for all the three technologies is more than 50 percent of the total operation costs. However, the in general composition of operation costs is same for all the three technologies studied.

After energy costs the second largest contribution comes from labour costs in all the three types of STPs, whereas the chemical costs have minimum contribution in all the three STP types. It is around 5 percent in al the three cases.

It is to be noted that maintenance costs have not been involved in overall operation costs or the labour costs because the values of these costs are highly dynamic in nature.

### 4.2.7 Operation Costs and Total Plant Capacity

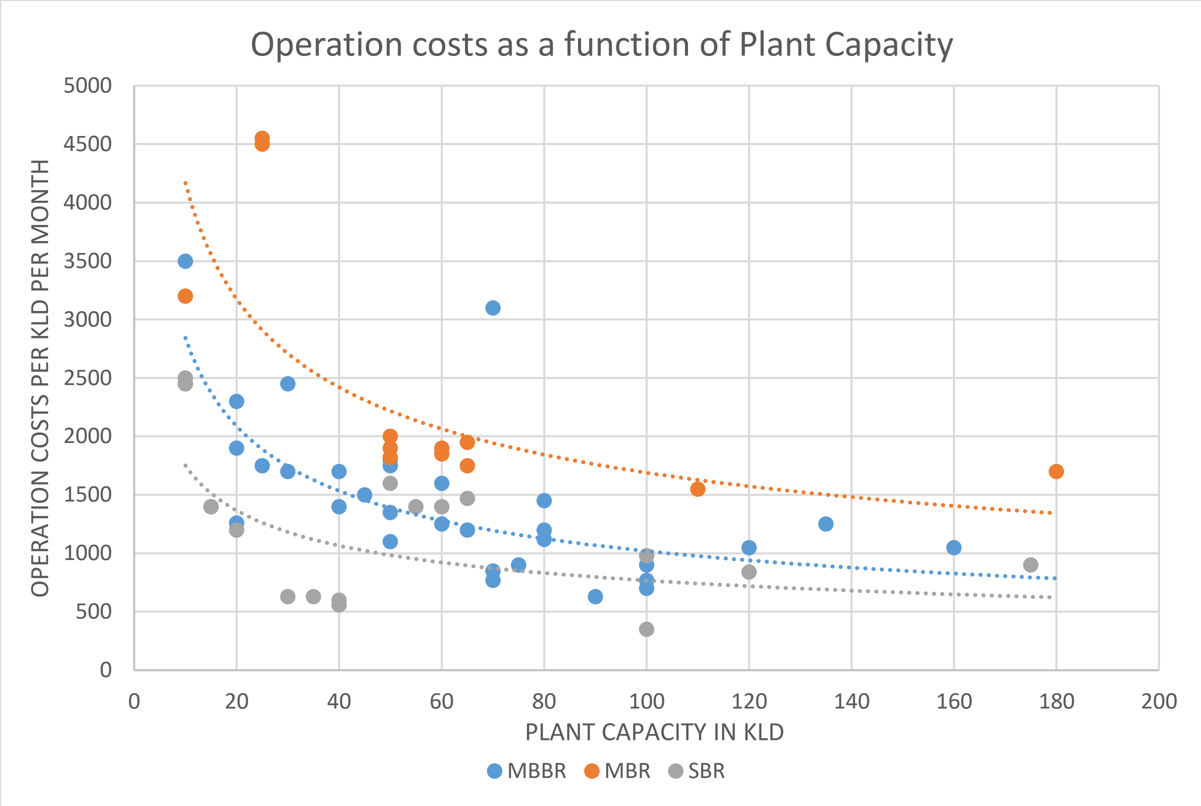


**Figure 4.14 : Operation Costs and Total Plant Capacity**

<u>Findings :</u>

**Table 4.2 : Operation Costs Curve Equations and $R^2$ Values**

| Technology | Operation Costs Curve Equation | $R^2$ Value |
|---|---|---|
| MBBR | $y = 7924.7x^{-0.445}$ | 0.5697 |
| MBR | $y = 10275x^{-0.392}$ | 0.5951 |
| SBR | $y = 3993.8x^{-0.358}$ | 0.5482 |

As it is clear from Figure 4.14 that the operation costs are maximum for MBR based plants and least for SBR types. But the operations costs are almost similar for plants larger than 100 KLD in MBBR and SBR type plants. From previous article 4.2.6 it is clear that chemical costs are same over all the types of STPs. So their contribution is negligible in these curves.Therefore, for all the types of STPs over the entire range of plant capacities this reduction in operation costs with increasing capacity is a result of scaling effect due to energy and labour costs incolved.

### 4.2.8 Operation Cost Composition of the 3 technologies

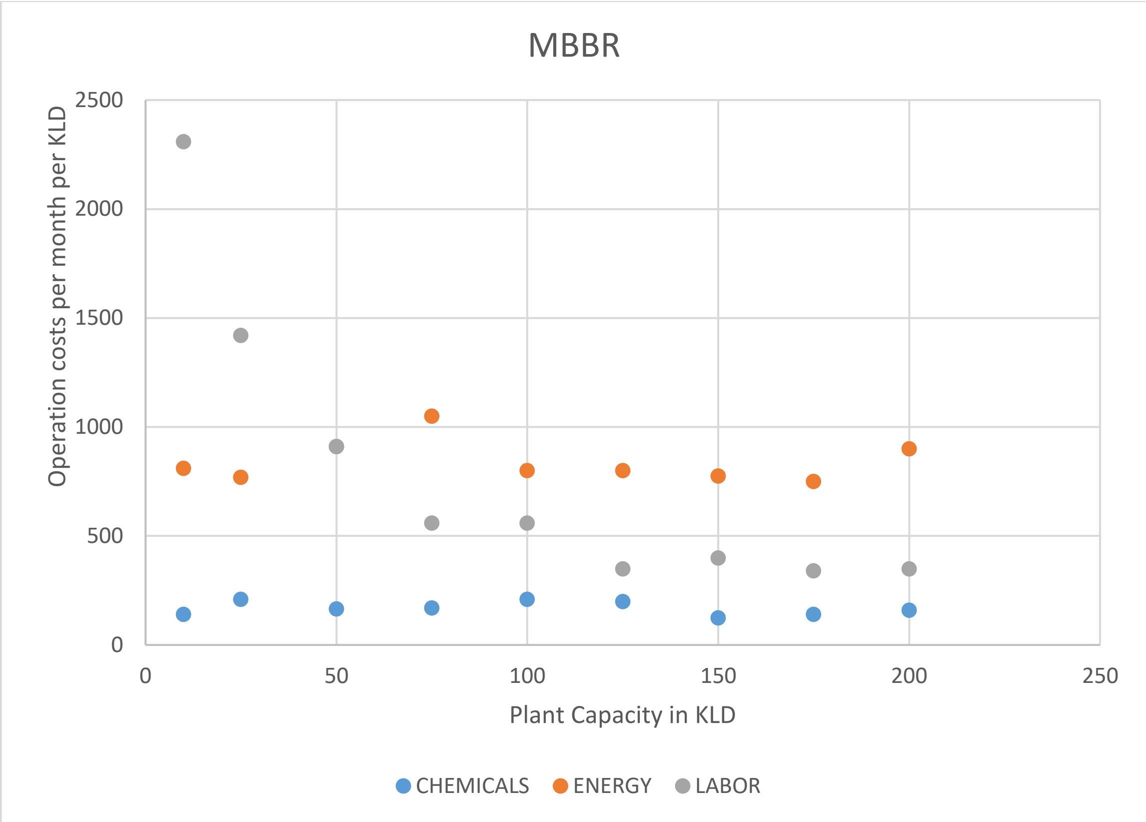


**Figure 4.15 : MBBR Operation Costs Composition**

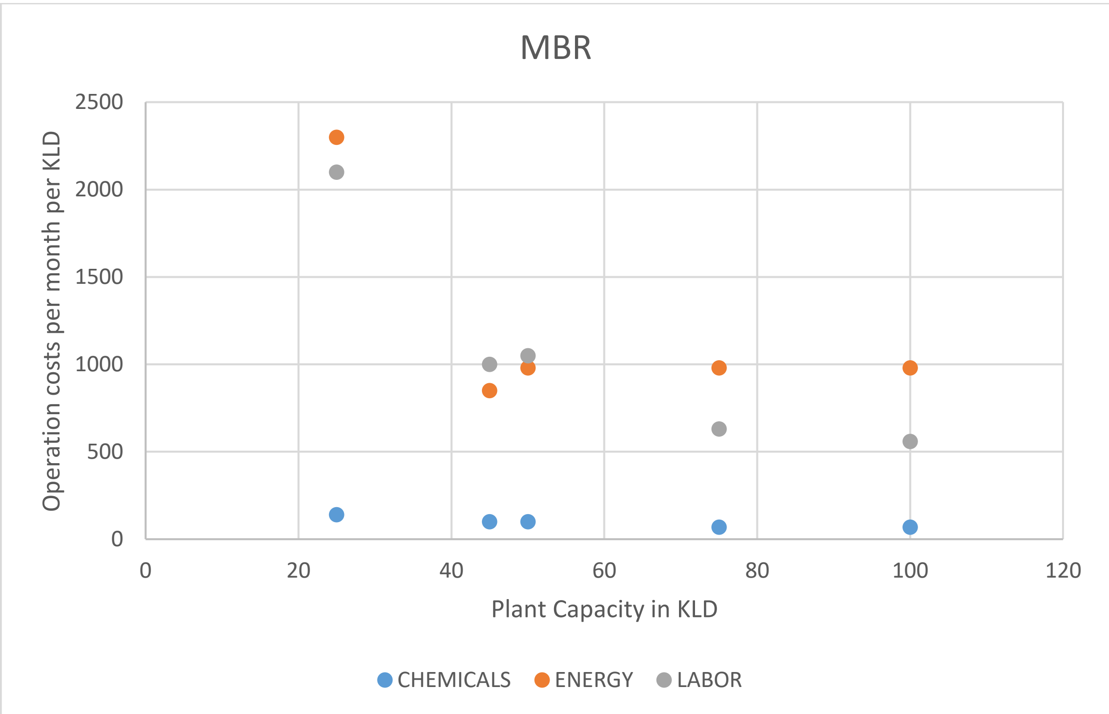


**Figure 4.16 : MBR Operation Costs Composition**

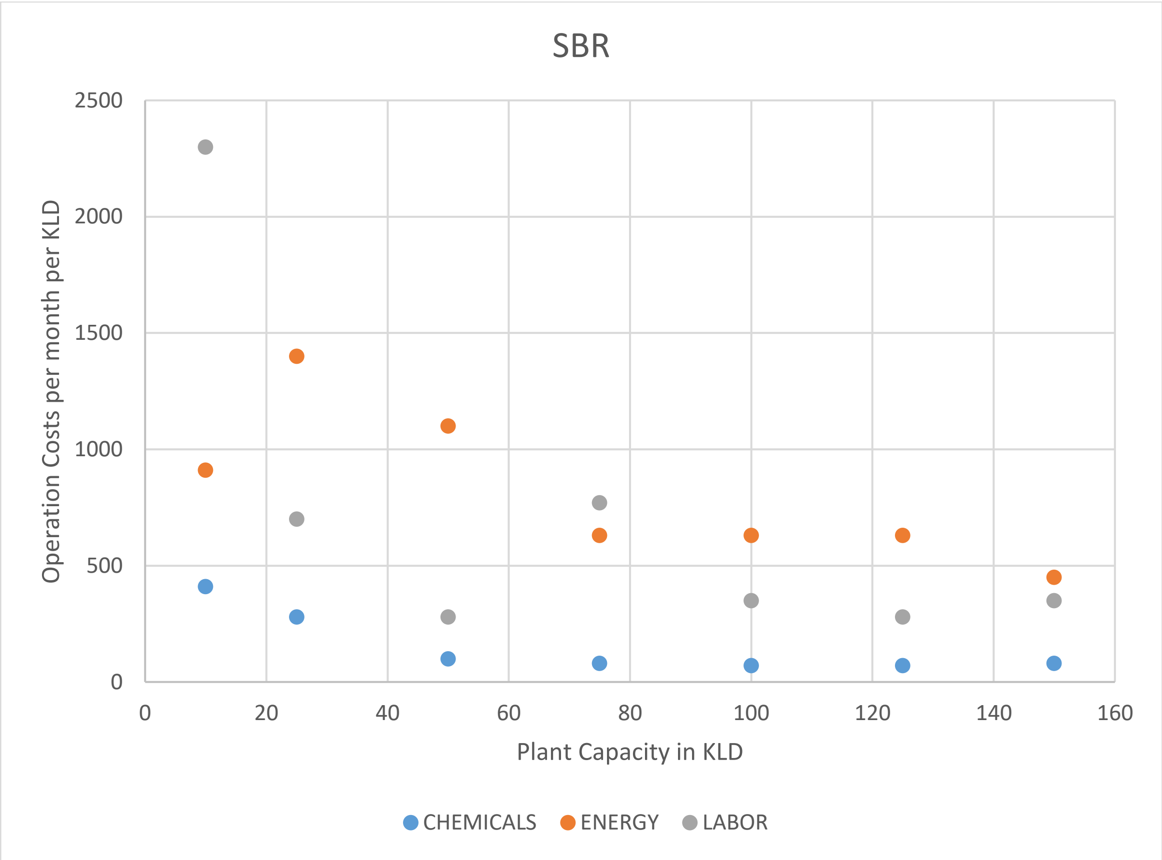


**Figure 4.17 : SBR Operation Costs Composition**

<u>Findings :</u>

From Figure 4.15-17 it is observed that as the plant capacities decrease the cost of labour is influencing the operation costs in all the three types of STPs. Along with that the energy costs also show the same trends with decreasing plant capacities.

Now if we observe the chemical costs in all the three figures, they are increasing with decreasing plant capacities. However, there is so scaling effect due to these costs because the amount of chlorine or other chemical to be added into the system does not vary much in case of small scale STPs.

### 4.2.9 BOD, COD and TSS Removal

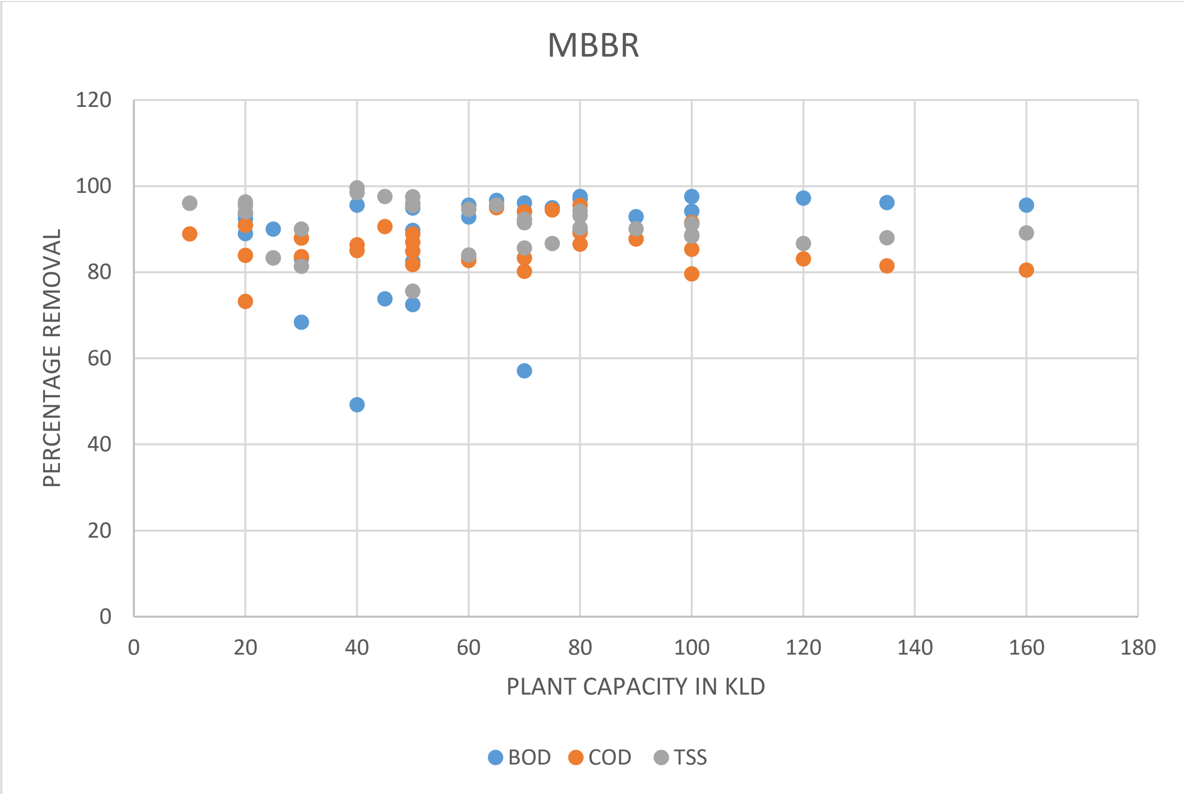


**Figure 4.18 : BOD, COD and TSS removal with MBBR**

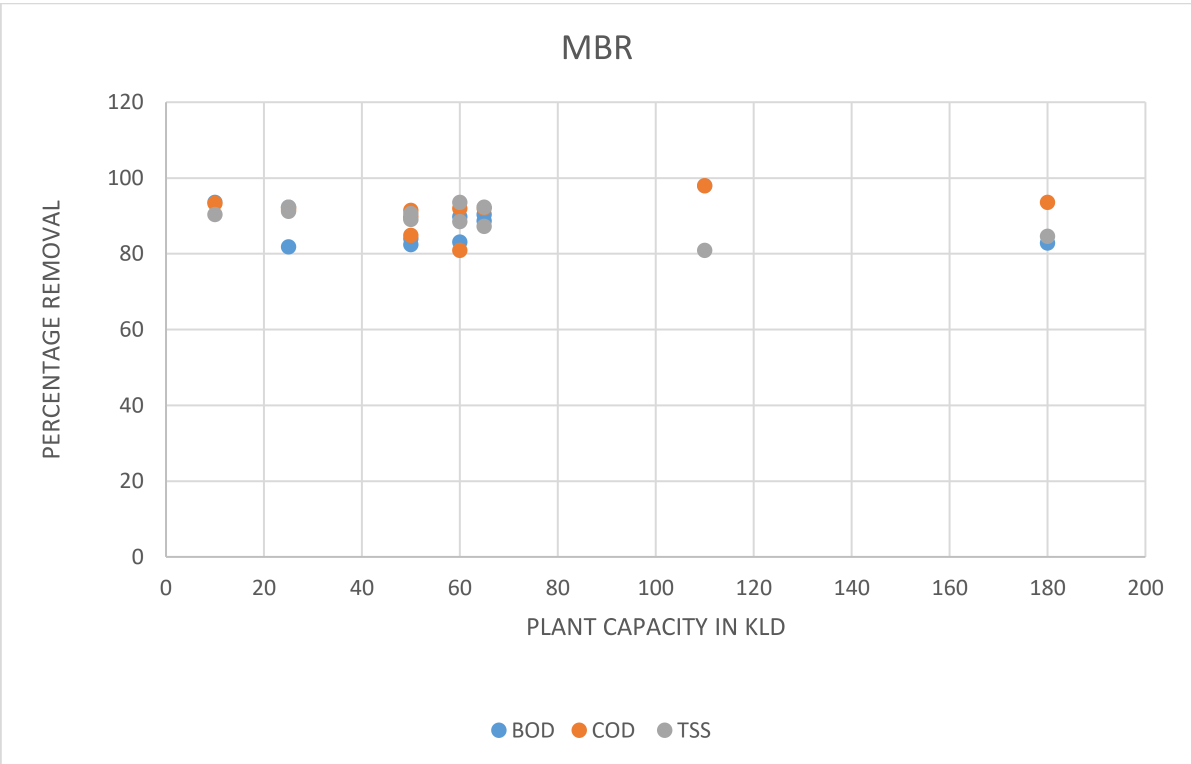


**Figure 4.19 : BOD, COD and TSS removal with MBR**

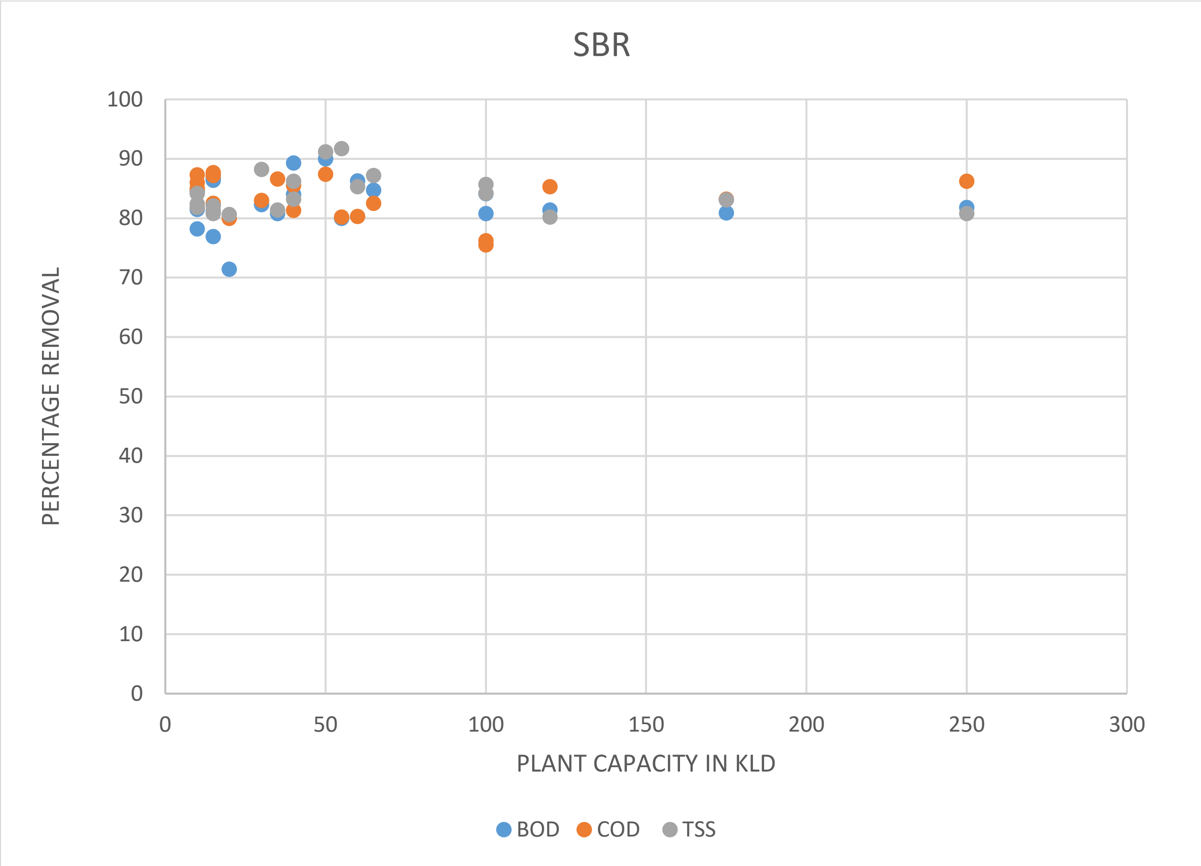


**Figure 4.20 : BOD, COD and TSS removal with SBR**

Findings :

From Figure 4.18-20 the removal of BOD, COD and TSS is to be observed for all the three types of technologies we have studied.

The BOD removal was found to be maximum for MBR based wastewater systems and much varying for MBBR based ones. This indicates that MBR give maximum BOD removal inspite of having larger footprint than other types of wastewater treatment systems.

The COD removal was found to be similar in all the three types of STPs present here. It is more than 80 percent in all the STPs studied above. A slight variation can be seen in MBBR based STPs but it is a result of variation in their BOD values itself.

The TSS removal was found to have greater than 80 percent removal in all the three types if STPs studied. There was not a single case of TSS removal being less than 80 percent. It is result of good quality media and membranes being used in these systems.

# CHAPTER 5

# CONCLUSION

## 5.1 Summary of Investigations

In this study, a number of decentralised wastewater systems were studied, main results of which have been presented in Chapter 4.

This study highlights the use of small scale decentralised wastewater systems to have a better insight of such STPs. This will help the end users and related persons to have a better knowledge while selecting any such technology.

## 5.2 Main Conclusions

Data collected during our study was analysed and various results relating important parameters of decentralised wastewater systems were compared. In this study plant ranging upto 200 KLD were studied. Different variants of technologies like MBBR, MBR and SBR were studied. As most of the researchers in the same area have used first-order equations, we also related parameters like total capital and operations costs with total plant capacity on the same basis. It was found that MBRs require less land if capacity is large but more land is needed for small plants in comparison to other STP types. So if land availability is a constraint then SBR or MBR based plants have to be studied. Among MBBR and MBR type plants, when compared to MBR type MBBR have less capital investment and land requirement, also lesser operational problems and screenings requirement. Also between MBBR and SBR type plants, SBRs have more retention time (around 5 hours), which is much greater than MBBRs (around 1 hour). However, most of the MBBRs are found self-operating and in SBRs operator adjusts the MLSS levels.

SBR based STPs were found to be most economical whereas MBR based STPs were most expensive ones. The MBBR based STPs were slightly costlier to SBR types. However, the quality of effluent from SBRs was found to be comparable with MBRs. MBBRs also had similar economy like SBRs, but their effluent quality was not satisfactory. So, SBRs can be considered as the most effective technology for treating wastewater at small scale in India.

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# APPENDIX – A

This appendix includes the questionnaire format that was used while conducting this study while collecting data from various sources.

**Table A.1 : Questionnaire Prepared for the study**

**A survey of small scale STPs in India**

| Question Number | "Questions to be answered" | ANSWERS (Please write 'X' if data is NOT available or if it cannot be shared) |
|---|---|---|
| 1 | State of Construction | |
| 2 | End User Type | |
| 3 | Technology Adopted | |
| 4 | Installation Year | |
| 5 | Capacity of Plant (KLD) | |
| 6 | Expected life of system (Years) | |
| 7 | Expected life of membrane (Years), if applicable | |
| 8 | Footprint of the plant (sq.m.) | |
| 9 | Influent BOD (mg/l) | |
| 10 | Influent COD (mg/l) | |
| 11 | Influent TSS (mg/l) | |
| 12 | Effluent BOD (mg/l) | |
| 13 | Effluent COD (mg/l) | |
| 14 | Effluent TSS (mg/l) | |
| 15 | Electro-Mechanical Components Used in Plant | |
| 16 | a) | |
| 17 | b) | |
| 18 | c) | |
| 19 | d) | |
| 20 | e) | |
| 21 | f) | |
| 22 | g) | |
| 23 | h) | |
| 24 | i) | |
| 25 | j) | |
| 26 | Energy consumed by the plant per month (kWh/day) | |
| 27 | Operation & Maintenance Costs per month (Rupees in Lakhs) | |

| | | |
|---|---|---|
| 28 | **Total Cost (Rupees in Lakhs)** | |
| 29 | Others : | |
| 30 | Others : | |
| | | |
| | Anything else, you want to let us know for the research (please mention below) :- | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

# APPENDIX - B

This appendix contains the data that was collected for each treatment technology considered in the study.

## MBBR :

**Table B.1 : Data Collected for MBBR systems**

| | PLANT DETAILS | | | | | | | | Influent Characteristics (mg/l) | | | Effluent Characteristics (mg/l) | | | Percentage Removal (%) | | | VASTE | E & M | ECONOMY | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial No. | Tech. Used | Client | State | Installation Year | System Lifetim | Membrane Lifetime | Capacity(KLD) | System Footprint | BOD | COD | TSS | BOD | COD | TSS | BOD | COD | TSS | Sludge Volume (cubic | Energy requirements(kV | O&M Costs per KLD per | Total Cost per KLD (in |
| 1 | MBBR | NHPC ALCHI LEH | J & K | 2018 | 40 | 10 | 10 | 45 | 250 | 450 | 500 | 10 | 50 | 20 | 96.0 | 88.9 | 96.0 | 0.1 | 80 | 3500 | 105 |
| 2 | MBBR | NOT AVAILABLE | HARYANA | 2016 | 40 | 10 | 20 | 40 | 115 | 280 | 250 | 7.5 | 75 | 15 | 93.5 | 73.2 | 94.0 | 0.6 | 80 | 1260 | 140 |
| 3 | MBBR | NOT AVAILABLE | GUJARAT | 2016 | 40 | 10 | 20 | 45 | 185 | 310 | 410 | 14 | 50 | 15 | 92.4 | 83.9 | 96.3 | 0.8 | 120 | 1900 | 70 |
| 4 | MBBR | NOT AVAILABLE | M.P. | 2015 | 40 | 10 | 20 | 50 | 210 | 550 | 450 | 23 | 50 | 20 | 89.0 | 90.9 | 95.6 | 0.4 | 100 | 2300 | 84 |
| 5 | MBBR | VINAYAK SQUARE BETA PLAZA NOIDA | U.P. | 2018 | 40 | 10 | 25 | 40 | 300 | 600 | 300 | 30 | 100 | 50 | 90.0 | 83.3 | 83.3 | 0.25 | 100 | 1750 | 56 |
| 6 | MBBR | NOT AVAILABLE | M.P. | 2019 | 40 | 10 | 30 | 50 | 95 | 365 | 300 | 30 | 60 | 30 | 68.4 | 83.6 | 90.0 | 0.25 | 100 | 1700 | 63 |
| 7 | MBBR | NOT AVAILABLE | U.P. | 2016 | 40 | 10 | 30 | 150 | 89.5 | 290 | 215 | 15 | 35 | 40 | 83.2 | 87.9 | 81.4 | 0.5 | 130 | 2450 | 63.33 |
| 8 | MBBR | DRDO GUEST HOUSE JAISALMER | RAJASTHAN | 2018 | 40 | 10 | 40 | 57 | 550 | 1100 | 2650 | 24 | 150 | 10.4 | 95.6 | 86.4 | 99.6 | 0.9 | 150 | 1400 | 52.5 |
| 9 | MBBR | NOT AVAILABLE | H.P. | 2016 | 40 | 10 | 40 | 60 | 65 | 300 | 800 | 33 | 45 | 12 | 49.2 | 85.0 | 98.5 | 0.4 | 170 | 1700 | 56 |
| 10 | MBBR | NOT AVAILABLE | U.K. | 2017 | 40 | 10 | 45 | 78 | 80 | 320 | 755 | 21 | 30 | 18 | 73.8 | 90.6 | 97.6 | 0.42 | 215 | 1550 | 51.11 |
| 11 | MBBR | NIA CGO COMPLEX | DELHI | 2017 | 40 | 10 | 50 | 48 | 34.6 | 384 | 82 | 9.5 | 50 | 20 | 72.5 | 87.0 | 75.6 | 0.2 | 120 | 1100 | 48 |
| 12 | MBBR | ASHRAM HARIDWAR | U.K. | 2017 | 40 | 10 | 50 | 52 | 57 | 370 | 257 | 10 | 56 | 10.4 | 82.5 | 84.9 | 96.0 | 0.25 | 350 | 1350 | 56 |
| 13 | MBBR | NOT AVAILABLE | T.N. | 2015 | 40 | 10 | 50 | 60 | 195 | 495 | 955 | 20 | 55 | 24 | 89.7 | 88.9 | 97.5 | 0.3 | 200 | 1750 | 56 |
| 14 | MBBR | NOT AVAILABLE | RA | 2016 | 40 | 10 | 50 | 122 | 235 | 688 | 1100 | 12 | 125 | 50 | 94.9 | 81.8 | 95.5 | 1.2 | 150 | 1800 | 63 |
| 15 | MBBR | DELHI POLICE HOUSING SEC-19 DWARKA | DELHI | 2018 | 40 | 10 | 60 | 78 | 225 | 550 | 125 | 10 | 95 | 20 | 95.6 | 82.7 | 84.0 | 1.5 | 220 | 1250 | 33.66 |
| 16 | MBBR | NOT AVAILABLE | U.P. | 2018 | 40 | 10 | 60 | 100 | 180 | 450 | 650 | 13 | 75 | 35 | 92.8 | 83.3 | 94.6 | 1.2 | 150 | 1600 | 70 |
| 17 | MBBR | RBI RESIDENTIAL | DELHI | 2016 | 40 | 10 | 65 | 78 | 300 | 600 | 225 | 10 | 30 | 10 | 96.7 | 95.0 | 95.6 | 0.4 | 250 | 1200 | 34.4 |
| 18 | MBBR | NOT AVAILABLE | DELHI | 2014 | 40 | 10 | 70 | 58 | 35 | 325 | 450 | 15 | 64.5 | 65 | 57.1 | 80.2 | 85.6 | 0.45 | 160 | 770 | 28 |
| 19 | MBBR | NOT AVAILABLE | A.P. | 2016 | 40 | 10 | 70 | 80 | 258 | 450 | 325 | 15 | 75 | 25 | 94.2 | 83.3 | 92.3 | 0.55 | 280 | 850 | 42 |
| 20 | MBBR | NOT AVAILABLE | W.B. | 2015 | 40 | 10 | 70 | 140 | 322 | 750 | 355 | 12.5 | 45 | 30 | 96.1 | 94.0 | 91.5 | 1.3 | 350 | 3100 | 28.6 |
| 21 | MBBR | NOT AVAILABLE | W.B. | 2015 | 40 | 10 | 75 | 80 | 222 | 650 | 488 | 11 | 36 | 65 | 95.0 | 94.5 | 86.7 | 0.6 | 160 | 900 | 37.33 |
| 22 | MBBR | NOT AVAILABLE | CHHATISGAR | 2018 | 40 | 10 | 80 | 76 | 265 | 553 | 289 | 8 | 25 | 20 | 97.0 | 95.5 | 93.1 | 0.4 | 300 | 1120 | 35 |
| 23 | MBBR | NOT AVAILABLE | M.P. | 2019 | 40 | 10 | 80 | 80 | 310 | 480 | 257 | 7.5 | 65 | 25 | 97.6 | 86.5 | 90.3 | 0.45 | 300 | 1450 | 35 |
| 24 | MBBR | NOT AVAILABLE | JHARKHAND | 2014 | 40 | 10 | 80 | 100 | 211 | 600 | 516 | 22 | 65 | 30 | 89.6 | 89.2 | 94.2 | 0.6 | 300 | 1200 | 35 |
| 25 | MBBR | NOT AVAILABLE | BIHAR | 2015 | 40 | 10 | 90 | 130 | 210 | 650 | 685 | 15 | 80 | 68 | 92.9 | 87.7 | 90.1 | 0.7 | 400 | 630 | 56 |
| 26 | MBBR | NOT AVAILABLE | U.P. | 2016 | 40 | 10 | 100 | 120 | 259 | 475 | 258 | 15 | 40 | 30 | 94.2 | 91.6 | 88.4 | 0.48 | 180 | 700 | 28 |
| 27 | MBBR | NOT AVAILABLE | RAJASTHAN | 2015 | 40 | 10 | 100 | 125 | 450 | 905 | 354 | 11 | 185 | 40 | 97.6 | 79.6 | 88.7 | 1 | 230 | 770 | 35 |
| 28 | MBBR | NOT AVAILABLE | RAJASTHAN | 2018 | 40 | 10 | 100 | 130 | 115 | 375 | 565 | 10 | 55 | 50 | 91.3 | 85.3 | 91.2 | 1.5 | 350 | 900 | 35 |
| 29 | MBBR | NOT AVAILABLE | GUJARAT | 2019 | 40 | 10 | 120 | 150 | 360 | 885 | 415 | 10 | 150 | 55 | 97.2 | 83.1 | 86.7 | 0.7 | 500 | 1050 | 26.5 |
| 30 | MBBR | NOT AVAILABLE | DELHI | 2014 | 40 | 10 | 135 | 200 | 275 | 540 | 375 | 10.5 | 100 | 45 | 96.2 | 81.5 | 88.0 | 0.6 | 380 | 1250 | 45.5 |
| 31 | MBBR | M.P. RESIDENCE B.D. | DELHI | 2019 | 40 | 10 | 160 | 280 | 225 | 475 | 275 | 10 | 92.5 | 30 | 95.6 | 80.5 | 89.1 | 0.65 | 450 | 1050 | 24.5 |
| 32 | MBBR | NKG INFRA SANGRUR | PUNJAB | 2017 | 40 | 10 | 350 | 500 | 275 | 425 | 300 | 10 | 78.5 | 10 | 96.4 | 81.5 | 96.7 | 0.8 | 500 | 1150 | 58 |

MBR :

**Table B.2 : Data Collected for MBR systems**

| | PLANT DETAILS | | | | | | | | Influent Characteristics (mg/l) | | | Effluent Characteristics (mg/l) | | | Percentage Removal (%) | | | WASTE | E & M | ECONOMY | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial No. | Tech. Used | Client | State | Installation Year | System Lifetime (Years) | Membrane Lifetime (Years) | Capacity (KLD) | System Footprint (sq.m.) | BOD | COD | TSS | BOD | COD | TSS | BOD | COD | TSS | Sludge Volume (cubic metre per day) | Energy requirements(kWh/ day) | O&M Costs per KLD per month | Total Cost per KLD (in thousands) |
| 1 | MBR | IOCL BOKARO | JHARKHAND | 2016 | 40 | 10 | 10 | 40 | 115 | 375 | 310 | 7.5 | 25 | 30 | 93.5 | 93.3 | 90.3 | 0.5 | 120 | 3200 | 193 |
| 2 | MBR | IOCL TATANAGAR | JHARKHAND | 2015 | 40 | 10 | 25 | 65 | 324 | 655 | 226 | 25 | 55 | 20 | 92.3 | 91.6 | 91.2 | 0.3 | 120 | 4500 | 273 |
| 3 | MBR | IOCL GUWAHATI | ASSAM | 2018 | 40 | 10 | 25 | 50 | 55 | 604 | 453 | 10 | 48 | 35 | 81.8 | 92.1 | 92.3 | 0.5 | 120 | 4550 | 168 |
| 4 | MBR | ISI TEZPUR | ASSAM | 2017 | 40 | 10 | 50 | 80 | 85 | 388 | 366 | 15 | 40 | 40 | 82.4 | 89.7 | 89.1 | 0.7 | 200 | 1820 | 87.5 |
| 5 | MBR | NOT AVAILABLE | DELHI | 2015 | 40 | 10 | 50 | 120 | 78 | 165 | 229 | 12.5 | 25 | 25 | 84 | 84.8 | 89.1 | 1 | 250 | 1900 | 140 |
| 6 | MBR | NOT AVAILABLE | M.P. | 2019 | 40 | 10 | 50 | 180 | 135 | 523 | 350 | 14 | 45 | 33 | 89.6 | 91.4 | 90.6 | 0.45 | 225 | 2000 | 157.5 |
| 7 | MBR | NOT AVAILABLE | H.P. | 2018 | 40 | 10 | 60 | 115 | 195 | 493 | 310 | 20 | 40 | 20 | 89.7 | 91.9 | 93.5 | 2 | 300 | 1850 | 136.5 |
| 8 | MBR | NOT AVAILABLE | DELHI | 2017 | 40 | 10 | 60 | 150 | 59 | 115 | 65 | 10 | 22 | 7.5 | 83.1 | 80.9 | 88.5 | 0.8 | 300 | 1900 | 91 |
| 12 | MBR | NIPCCD MOHALI | PUNJAB | 2017 | 40 | 10 | 65 | 140 | 220 | 426 | 78 | 25 | 34 | 10 | 88.6 | 92 | 87.2 | 0.7 | 310 | 1950 | 85 |
| 9 | MBR | GUJARAT BHAVAN | DELHI | 2019 | 40 | 10 | 65 | 120 | 185 | 580 | 195 | 18 | 45 | 15 | 90.3 | 92.2 | 92.3 | 1.3 | 250 | 1750 | 70 |
| 10 | MBR | DELHI HIGH COURT | DELHI | 2019 | 40 | 10 | 110 | 142 | 241 | 964 | 34 | 5 | 20 | 6.5 | 97.9 | 97.9 | 80.9 | 1 | 490 | 1550 | 77 |
| 11 | MBR | DELHI DISTRICT COURT | DELHI | 2018 | 40 | 10 | 180 | 220 | 145 | 755 | 65 | 25 | 49 | 10 | 82.8 | 93.5 | 84.6 | 1.1 | 400 | 1700 | 80.2 |

SBR :

**Table B.3 : Data Collected for SBR systems**

| PLANT DETAILS | | | | | | | | Characteristics (mg/l) | | | Characteristics (mg/l) | | | Percentage Removal (%) | | | WASTE | E & M | ECONOMY | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial No. | Tech. Used | Client | State | Installation Year | System Lifetime (Years) | Capacity(KLD) | System Footprint (sq.m.) | BOD | COD | TSS | BOD | COD | TSS | BOD | COD | TSS | Volume (cubic metre per day) | Energy requirements(kWh/day) | O&M Costs per KLD per month | Total Cost per KLD (in thousands) |
| 1 | SBR | NOT AVAILABLE | DELHI | 2015 | 40 | 10 | 25 | 65 | 215 | 95 | 10 | 30 | 15 | 84.6 | 86 | 84 | 0.05 | 10 | 2500 | 88 |
| 2 | SBR | NOT AVAILABLE | U.P. | 2018 | 40 | 10 | 28 | 55 | 200 | 66 | 12 | 30 | 12 | 78.2 | 85 | 82 | 0.15 | 40 | 2450 | 87.5 |
| 3 | SBR | NOT AVAILABLE | U.P. | 2017 | 40 | 10 | 20 | 54 | 315 | 85 | 10 | 40 | 15 | 81.5 | 87.3 | 82 | 0.2 | 5 | 2450 | 87.5 |
| 4 | SBR | NOT AVAILABLE | ASSAM | 2015 | 40 | 15 | 20 | 50 | 286 | 112 | 6.8 | 50 | 20 | 86.4 | 82.5 | 82 | 0.2 | 20 | 1400 | 101.5 |
| 5 | SBR | NOT AVAILABLE | J & K | 2018 | 40 | 15 | 18 | 75 | 195 | 65 | 10 | 25 | 12.5 | 86.7 | 87.2 | 81 | 0.15 | 20 | 1400 | 91 |
| 6 | SBR | NOT AVAILABLE | RAJASTHAN | 2018 | 40 | 15 | 38 | 65 | 325 | 120 | 15 | 40 | 22.5 | 76.9 | 87.7 | 81 | 0.18 | 25 | 1400 | 77 |
| 7 | SBR | NOT AVAILABLE | RAJASTHAN | 2015 | 40 | 20 | 25 | 35 | 400 | 90 | 10 | 80 | 17.5 | 71.4 | 80 | 81 | 0.2 | 25 | 1200 | 70 |
| 8 | SBR | NOT AVAILABLE | GUJARAT | 2018 | 40 | 30 | 30 | 56.5 | 265 | 85 | 10 | 45 | 10 | 82.3 | 83 | 88 | 0.2 | 28 | 630 | 70 |
| 9 | SBR | SALAL POWER STATION DHYANGARH | J & K | 2015 | 40 | 35 | 40 | 36.5 | 186 | 35 | 7 | 25 | 6.5 | 80.8 | 86.6 | 81 | 0.3 | 230 | 630 | 56 |
| 10 | SBR | GLOBAL CERAMICS PVT LTD NEEMRANA | RAJASTHAN | 2017 | 40 | 40 | 56 | 46.8 | 310 | 74.5 | 7.5 | 45 | 12.5 | 84 | 85.5 | 83 | 0.3 | 150 | 600 | 56 |
| 11 | SBR | BADARPUR POLICE STATION | DELHI | 2016 | 40 | 40 | 50 | 74.6 | 455 | 235 | 8 | 85 | 32.5 | 89.3 | 81.3 | 86 | 0.3 | 40 | 560 | 52.5 |
| 12 | SBR | DAHEJ MODULAR PLANT | GUJARAT | 2017 | 40 | 50 | 78 | 95 | 460 | 164 | 9.5 | 58 | 14.5 | 90 | 87.4 | 91 | 0.2 | 50 | 1600 | 33.5 |
| 13 | SBR | NOT AVAILABLE | DELHI | 2015 | 40 | 55 | 90 | 45 | 329 | 240 | 9 | 65 | 20 | 80 | 80.2 | 92 | 0.4 | 350 | 1400 | 35 |
| 14 | SBR | AAI GORAKHPUR | U.P. | 2015 | 40 | 60 | 70 | 40 | 558 | 68 | 5.5 | 110 | 10 | 86.3 | 80.3 | 85 | 1 | 140 | 1400 | 49 |
| 15 | SBR | NOT AVAILABLE | DELHI | 2019 | 40 | 65 | 70 | 58 | 457 | 78 | 8.9 | 80 | 10 | 84.7 | 82.5 | 87 | 0.45 | 200 | 1470 | 35 |
| 16 | SBR | NOT AVAILABLE | DELHI | 2019 | 40 | 100 | 100 | 75.6 | 510 | 115 | 12 | 125 | 16.5 | 84.1 | 75.5 | 86 | 0.6 | 275 | 980 | 52.5 |
| 17 | SBR | GAIL TOWNSHIP JHABUA | M.P. | 2018 | 40 | 100 | 150 | 65 | 357 | 95 | 12.5 | 85 | 15 | 80.8 | 76.2 | 84 | 0.2 | 85 | 350 | 53 |
| 18 | SBR | HSCC HOSPITAL PRAYAGRAJ | U.P. | 2017 | 40 | 120 | 140 | 35 | 645 | 48 | 6.5 | 95 | 9.5 | 81.4 | 85.3 | 80 | 0.8 | 325 | 840 | 24.5 |
| 19 | SBR | SAFDARJUNG AIRPORT | DELHI | 2017 | 40 | 175 | 250 | 44.5 | 475 | 74 | 8.5 | 80 | 12.5 | 80.9 | 83.2 | 83 | 0.75 | 350 | 900 | 65 |
| 20 | SBR | NHPC CHAMERA | H.P. | 2019 | 40 | 250 | 350 | 55 | 254 | 78 | 10 | 35 | 15 | 81.8 | 86.2 | 81 | 0.8 | 355 | 950 | 59 |