# CRITICAL EVALUATION OF EFFLUENT TREATMENT PLANTS AND DEVELOPMENT OF ANALYTICAL MODELS FOR REUSE OF WASTE WATER IN CENTRAL GUJARAT REGION

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# Certificate

This is to certify that the thesis entitled **"CRITICAL EVALUATION OF EFFLUENT TREATMENT PLANTS AND DEVELOPMENT OF ANALYTICAL MODELS FOR REUSE OF WASTE WATER IN CENTRAL GUJARAT REGION"** submitted to The Maharaja Sayajirao University of Baroda, Vadodara for the award of the degree of **DOCTOR OF PHILOSOPHY IN CIVIL ENGINEERING** is the result of original work completed by Mrs. Komal P. Mehta under my supervision and guidance in Civil Engineering Department, Faculty Of Technology & Engineering, M. S. University of Baroda, Vadodara and work embodied in this thesis has not formed earlier the basis for award of any degree or similar title of this or any other university or examining body.

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**This work is dedicated to my Husband Parag and my dear son Rushil who took so much pain for completion of my Ph.D, especially during last six months for motivating me and being constantly with me.**

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Last but not the least, thanks to GOD and thanks to all those who directly or indirectly supported me, for my research work.

# Executive Summary

**It is stated that the water crisis in the world is so severe, that there will be war for water rather than a land in future. We have experienced the dispute for water of river KAVERI between Karnataka and Tamil Nadu.**

Communities across the world face water supply challenges due to increasing demand, drought, depletion, contamination of groundwater and dependence on single source of supply. Water reclamation, recycling and reuse address these challenges by resolving water resource issues and creating new sources of high-quality water supplies. The future potential for reclaimed treated effluent is enormous.

Two case studies are taken for exploring possibilities of reuse of waste water, Domestic Sewage Treatment Plant (Atladra), VMSS and CETP, Umraya, Padra. The downstream area of the city faces scarcity of water as they are not having any good quality water source. The main aim of the project is to find how reuse can reduce the load on fresh water source and meet with water quality requirement. For the research work literature review, around 285 research papers of national and international journals, books, reports, articles etc. are refereed. Data collection is done from: State Water Data Center, Gandhinagar, for rainfall; Population Research Center, M.S.University of Baroda, for population; VMSS for parameters of secondary outlet for last 9 years; parameters of Common Effluent Treatment Plant from M/s. Environ Infrastructure Pvt. Ltd., for last 9 years.

The lab scale studies are undertaken for finding parameters of secondary outlet of domestic sewage treatment plant and final outlet of Common Effluent Treatment Plant. For domestic waste water from secondary outlet, three alternative sequences of primary, secondary and tertiary treatments are tried. It is found that waste water is of good quality which can be reused easily by downstream side industries. It can reduce the load of uses of fresh water as well as it can be a permanent solution for the industries facing problem to get water for industrial purpose. Design and estimation considering basic operating and maintenance cost for proposed treatment plants for all the three options has been done. A common or separate Effluent Treatment Plant is proposed to show techno economical solution to get their required quantity and quality of water. From three treatment trains, the first option of primary, secondary

and tertiary, coagulation-flocculation-sedimentation-filtration-chloriantion-sofening-activated carbon filter is found techno economical solution. It is also analyzed that if the treatment plant for reuse of domestic waste water is constructed for industrial reuse purpose, within a time period of one and half year the cost can be recovered.

Models are prepared for representation of specific problems which illustrates significant relationships, they aid in predicting relevant consequences of choosing each alternative. The prediction of usability of waste water quality, based on the mathematical model, will help to save trials of lab scale experiments. For case study of domestic sewage treatment plant, the models are based on the multiple regression analysis, i.e. as per equation:

$P = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$.

The four independent variables which are having impact on the waste water quality in this case are BOD, COD, TSS, $P^H$ for domestic sewage treatment plant. From the statistical analysis it is found that if P value meets standards for disposal, the prediction is that the waste water is of reusable quality. The mathematical model shows that the treated waste water is of quite a good quality, which is reusable for the nearby industrial area, for industrial purpose. The relationship between all four parameters is found and is represented in following mathematical model. The relationship is between each two parameters.

Y= 32.15257 -0.34463 * X (BOD & COD)

Y=6.98644 – 0.34463 * X (BOD & TSS)

Y= 34.3644 + 0.0549 * X (BOD& $P^H$)

Y= -305.098 + 48.8223 * X ($P^H$ & TSS) indicates soft water i.e. alkaline.

Y= 7.3195 – 0.1041 * X (COD & TSS)

Y= 62.24096 – 8.25 * X (COD& $P^H$)

After treatment, the relationship between parameters and P value is shown by following mathematical models.

P= 21.85978 + 4.283 * Q (TSS & P)

P= 54.6211 -0.89208 * Q (COD & P)

P= 49.44941 + 0.064945 * Q ($P^H$ & P)

P= 20.30886 + 1.01 * Q (BOD & P)

Looking to models, it is clear that relation of $P^H$ and TSS before treatment does not exist. After treatment, all the four parameters have impact on the value of P and BOD has highest impact on quality of domestic waste water. Sufficient quantity of waste water is available for treatment for reuse purpose. It is recommended that industries can reuse treated domestic waste water.

The second case study is Common Effluent Treatment Plant. Data collection for parameters of final outlet is done to judge water quality. It is observed that in final outlet, all parameters are under control except Total Dissolved Solids. The Final Treatment tried is reverse osmosis at lab scale. After number of trials, it is found that with Reverse Osmosis, the TDS is reduced to less than 2100 mg/lit, which is acceptable for reuse of waste water for agricultural purpose. It is also technically and hygienically feasible solution as farmers are drawing waste water from ECP canal. Also treated wastewater can be given at reasonable price to industries in nearby area and cost of RO plant may be recovered. For proposed plant, the IMS design solution, Hydranautics Design Software version 2012, is used to get detailed design. The test conditions and design specifications for the membrane selected (LFC3-LD) is also discussed in depth in chapter 5. The flow diagram is proposed with cost and estimation for the same.

The statistical analysis is done and the mathematical model that gives the required pressure for the value of TDS is: $Y= 0.0208x – 88.295$, $R^2 = 0.5166$. When design is proposed, the only variable parameter remains is TDS. Other parameters or values are fixed after installation of plant.

It is recommended that the downstream side industrial area can reuse treated domestic waste water instead of purchasing water every day. Nearby area of CETP, industries and agricultural, may opt for the option of reusing treated water from CETP final outlet, rather than purchasing fresh water or withdrawing untreated waste water illegally from ECP canal.

The results and model of domestic sewage treatment plant can be useful to nearby industries, for reuse of waste water, if efficiency and flow of plant is maintained and the plant is at same location (nearby industrial area). In case if industry or plant shifts, the results may not be effective for other location. For Domestic treatment, possibilities of potable reuse can also be explored. For CETP, quality of treated waste water may be different, if different type of membranes are tried or if there is variation in pressure, filter stage, filter pass or quantity of waste water.

Results and models of case studies of research work, shows that after treatment, the waste water meets with criteria of reuse and it can be practically implemented in the field to save the source of fresh water.

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## ABBREVIATIONS

R.O.: Reverse Osmosis

*T*: Feed water temperature and t : Operating time

*P*: Hydraulic pressure differential across the membrane

*A*: Membrane area

*Kw*: Membrane permeability coefficient for water.

ζ: Membrane thickness

*Mi*: Molality of the $i^{th}$ ionic or nonionic materials.

ΔΠ: Osmotic pressure differential across the membrane

*Cf*: Salt concentration in the feed

*Cp*: Salt concentration in the product

*J*2: Salt flux

*K*2: Salt transport coefficient

*J*1: Water flux

*K*1: Pure water transport coefficient, i.e. the flux of water through the membrane/ unit driving force

DP: Distillate produced

LSBL: Last stage brine level

m: A negative exponent whose value depends on the membrane, operating pressure, tem.

MF: Make-p flow rate

Qf: Feed flow

Qp: Product flow

RBF: Recirculating brine flow rate

STF: Low pressure steam

STT: Low pressure steam temperature

SWIT: Seawater inlet temperature

SWOT: Seawater outlet temperature

SWRC: Seawater recirculating flow rate

SWRJ: Seawater reject flow rate

TBT: Top brine temperatures

Lpcd: Liters per capita per day

# CONTENTS

# 1. INTRODUCTION

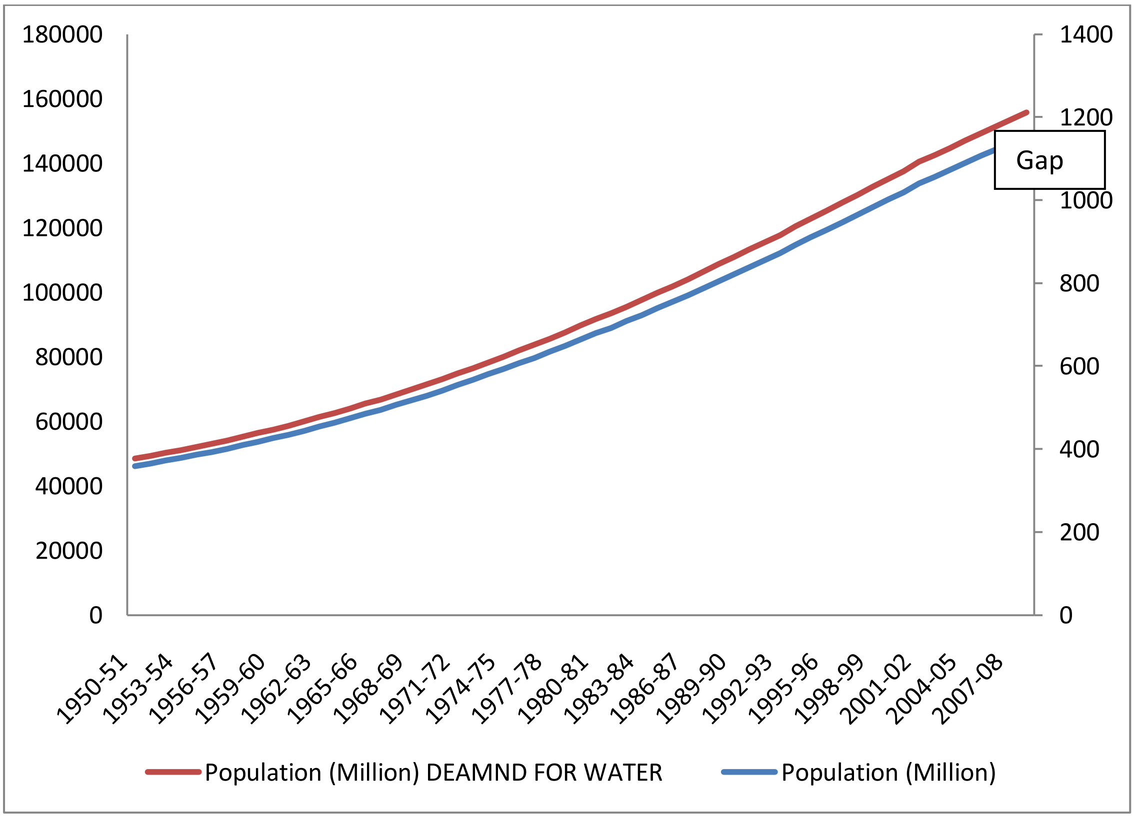
## 1.1 OVERVIEW

Water problems are increasingly recognized as one of the most immediate and serious environmental threats to humankind. Water use has increased more than three times globally since 1950 and one out of every six person does not have regular access to safe drinking water. Because of not having access to a safe water supply and sanitation, the health of 1.2 billion people is affected annually [259].

Existing sources of water can be saved with numerous approaches, both modern and traditional, that exist throughout the world for efficiency improvements and augmentation, with options such as conservation of water, ground water recharge, reuse of waste water, virtual water requirement etc. Among such approaches, wastewater reuse has become increasingly important in water resource management for both environmental and economic reasons. Wastewater reuse is having a long history of applications, primarily in agriculture and additionally it is becoming more prevalent in industrial, household and urban areas. Wastewater reuse for agriculture represents the large reuse volume and this is expected to increase further, particularly in developing countries [259].

Looking to Indian scenario, we are going to suffer huge depletion in water availability on per capita cubic meter per year. **"India is going to face per capita decline from 1730 to 1240 cubic meter**. (Report, June 2010). By 2030, India will face depletion of almost 275 billion cubic meters (BCM) of annual renewable water. "Water balance will shrink almost half to 200-260 BCM in India". The research work was started with the fact that water availability is going to be the most critical issue in all areas of the country. By working together and cooperating across municipalities the challenges of addressing wastewater management can be met and potential benefits realized.

Global populations are rapidly expanding with urban populations expected to double in the next 40 years (UNFPA, 2009), increasing demands on food, water resources and wastewater infrastructure. The graph below shows that in the Central Gujarat region, increase in population and the demand for water will have a major gap, which needs to be addressed right now.




**Graph 1.1 Gap Between Population And Water Demand For Central Gujarat Region**

(Source: RBI Handbook of statistics on Indian Economy)

## 1.2 CONCEPT OF REUSE

The major pathways of water reuse include irrigation, industrial use, surface water replenishment and ground water recharge. The quantity of water transferred through each pathway depends on the watershed characteristics, climatic and geohydrology factors, the degree of water utilization for various purposes, the degree of direct and indirect water reuse. Water reuse loop should be dependent on public health criteria, Engineering, economics, aesthetics and more importantly public acceptance. Considering the complexity of waste water reuse projects, following aspects are to be taken care for successful implementation of project for reuse of waste water.

### 1.2.1 Need Of Water Reuse

Water is a very precious source and basic requirement for survival of mankind. So it is necessary to meet with requirement of water availability according to increase in population. The appropriate ‘BALANCING ACT’ would be ‘RECYCLE and

REUSE' of wastewater. This will bring water back for use rather than disposing it considering as 'waste'.

### 1.2.2 Reasons For Considering Reuse Of Waste Water

The following are the reasons for reuse of waste water as a viable option:

- Wastewater is a resource which is readily available
- Water is an issue – availability is an issue – there is a competitive demand from all the sector – the available source is wastewater
- Cities are facing problem to get required quantity of water because of high urban growth and increasing water demand
- Lack of natural source of water within city

Considering all these facts, recycle and reuse of water should be made mandatory and the needed work should be prioritized. Factors like availability of needed technology and its affordability, environment friendly technology, funding pattern, compliance with guidelines and regulations etc. should be considered before installing the wastewater treatment plant.

**Table 1.1: Technology Requirement For Reuse**

| Sr. No. | Purpose | Technology Requirement |
|---|---|---|
| 1 | Irrigation | Secondary treatment |
| 2 | Restricted Urban use | Tertiary treatment |
| 3 | Industrial non potable use | Fourth level treatment |
| 4 | Indirect potable use | Fifth level treatment |
| 5 | Direct use | Sixth level treatment with RO |

(Source: Water And Wastewater Reuse, An Environmentally Sound Approach For Sustainable Urban Water Management, booklet, January 2009)

#### 1.2.2.1 General aspects of water reuse

The general aspects of water reuse are as follows:

- Increase in efficiency of water use
- Reduction of water loss
- Reduction of evaporation/transpiration, particularly in agriculture and industrial water use.

#### 1.2.2.2 Foundation of successful water reuse programs

The foundation of successful water reuse program depends on:

- Providing reliable treatment to meet water quality requirements and environmental regulations for the intended reuse

- Protection of public health and the Environment
- Gaining public acceptance.
- Economic viability

#### 1.2.2.3 Factors to be considered while designing water reuse plant

The factors to be considered while designing water reuse plant are:

- Water quality requirements
- Monitoring requirements
- Treatment process requirements
- Treatment reliability requirements
- Operational requirements
- Cross-connection control provisions
- Use area controls

### 1.2.3 Reuse of Treated Sewage

Reuse of treated sewage after necessary treatment to meet industrial water requirements has been in practice for quite some time in India. Disposal of sewage from the rapidly growing cities of India has become a nightmare for civic authorities and planners. The common problems with urban area are urban sewage mismanagement, lack in treatment facility, unavailability of correct data, ineffective as well as very costly treatment poor recovery of cost and centralized functioning. To meet the water requirement of a particular region, sewage is the constant and reliable source which cannot be ignored.

Reuse is the technique of water conservation. In India, reuse of treated sewage is considered important on account of two advantages:

- Reduction of pollution in receiving water bodies
- Reduction in fresh water requirement for various uses

There are several towns in the state, where partial network of underground drainage is available, which is being upgraded, and cities like Surat, Ahmedabad, Vadodara, Rajkot and Bhavnagar are having one of the best kinds of underground drainage network in the country, with most efficient sewage conveyance system of liquid waste, managed by respective Municipal Corporations.

### 1.2.4 Reuse Of Industrial Waste Water

To meet with the growing water requirements, along with the waste water from municipal sewage treatment plant, it is going to be a need for thinking the reuse of waste water from the industries wherever possible. It has already been started in some of the big industries especially in metro cities and it must be implemented at all level (small, medium and large scale) of industries. Examples are textile industry, pharmaceutical industry, food and beverage industry where reuse of waste water is in consideration at few places, Shiva Pharma Chem Ltd. Vadodara, Barmoli STP in Surat is a source for Pandesara users, Ultrafiltration (UF), reverse-osmosis (RO) and a membrane bioreactor (MBR) will all be part of a 32,420 $m^3/d$ effluent treatment and recycling plant to be built in India by Chennai-based VA Tech Waba.

## 1.3 WORLD WATER AVAILABILITY

If the next world war happens; it may well be triggered by water scarcity across the continents. It has been already found that the third world is suffering from water shortages. Increasing demand for water with rapidly growing rate of population, inadequate rainfall, uncontrolled use of water and climate change are some of the reasons behind it.

### 1.3.1 Water Scarcity

The word water scarcity describes the relationship between demand for water and its availability. There are several factors that influence the availability and consumption of water. Hence the definition for the availability and consumption is different in various regions. Water scarcity will be in variation according to geography. Therefore it is little difficult to adopt a global figure to indicate water scarcity but simply we can say water availability of less than 1000 $m^3$/capita as a water scarcity. **"As per the UN estimate, water scarcity already affects every continent. Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity, and 500 million people are approaching this situation. Another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage**". (Source: UN, Water For Life Report) [221]

### 1.3.2 Indian Scenario

The thirst of water for India's rapid development is growing day by day. Water supply of the 90% of India's territory is served by inter-state rivers. It has created growing number of conflicts across the states and to the whole country on water sharing issues.

Urban water requirement has reached up to 200 lit/capita/day due to urbanization, industrialization etc. while in medium level city or area it is @ 135 lit/capita/day and in rural area 75 lit/capita/day. So in the urban area the requirement is almost double than rural area. To meet with these facts and save fresh water resources, we have to think for the option of proper use of water and option can be reuse of waste water.

Some of the major reasons behind water scarcity are:

- Population growth and Food production (Agriculture)
- Increasing construction/ infrastructure development
- Massive urbanization and industrialization throughout the country
- Climatic change and variability
- Lack of implementation of effective water management systems

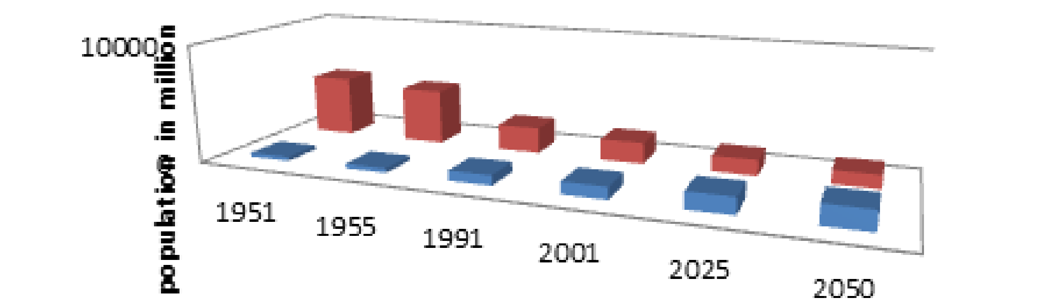
**Table 1.2: Water Resources In India**

| Water | Quantity |
|---|---|
| Average annual rainfall | 1170 mm |
| Total available water | 4000 $bm^3$ |
| Water losses | 1047 $bm^3$ |
| Net available water | 1953 $bm^3$ |
| Surface water (net available) | 1521 $bm^3$ |
| Ground water(net available) | 432 $bm^3$ |
| Net utilizable water (net utilizable) | 1123 $bm^3$ |
| Surface water(net utilizable) | 728 bm3 |
| Ground water (net utilizable) | 395 $bm^3$ |

(Source: Water scarcity & security in India, Report, Narayan G. Hegde BAIF Development Research Foundation, Pune, 2011)

#### 1.3.2.1 Per capita water availability in India

From last 5 decades, the variation for increase in population and decrease in available water is noticeable. Following graph shows the statistics for population of India.

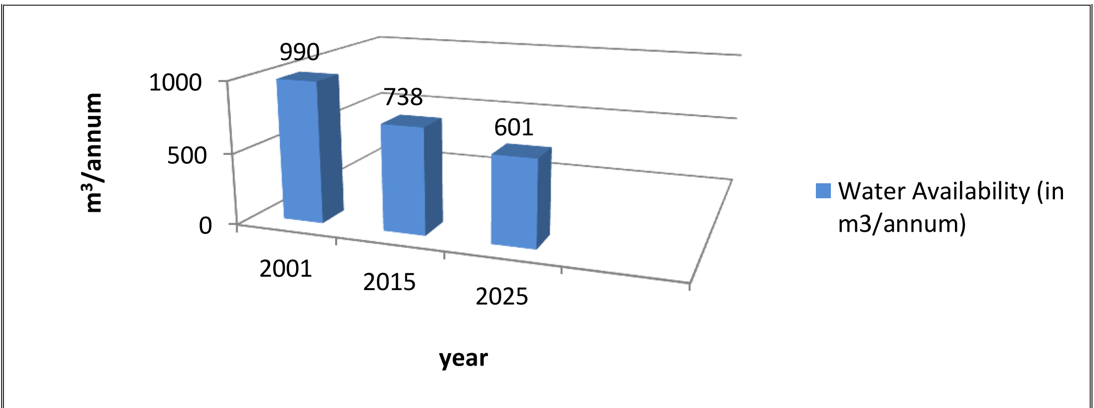



| | 1951 | 1955 | 1991 | 2001 | 2025 | 2050 |
|---|---|---|---|---|---|---|
| Population in millions | 361 | 395 | 846 | 1027 | 1394 | 1640 |
| Per capita water availability(m3/year) | 5177 | 4732 | 2209 | 1820 | 1341 | 1140 |

**Graph 1.2 Per Capita Water Availability In India**
(Source: Govt. Of India, Ministry of Water Resources (2009))

### 1.3.3 Scenario Of Gujarat

The per capita water availability in the state is considerably low and is likely to go down further by 2015. Therefore, the state needs to focus on the effective planning and management of its water resources. With the urban water needs being higher than that in rural areas and Gujarat being an urbanized state, the demand and supply ratio may get skewed in the future according to the government's own estimate. [25]




**Graph 1.3 Water Availability In Gujarat**
(Source: Prof B.N.Navalawala.(2005))

The state's per capita water availability in 2001 was 990 $m^3$/annum against the country's 1901 $m^3$/annum. This is already considered as **chronic water scarcity**, which is estimated to go down to 738 $m^3$/ annum by 2015 and 601 $m^3$/annum by 2025. In the current era, the per capita availability of water in north Gujarat, Saurashtra, Kutch, south and central Gujarat is 343, 540, 730 and 1880 $m^3$/annum respectively (as per 2001 estimate, Department Of Irrigation, Gujarat state).

"According to the latest estimates by the state irrigation department, the annual availability of utilizable water resources in the state is about 50.10 billion cubic meters, out of which 38.10 billion cubic meters is surface water. The rest, i.e. 12 billion cubic meters, is available as ground water. As the average per capita availability of water in the state stands at around 900 cubic meters, Gujarat falls in the category of states facing water scarcity as per the norms laid by the UN." Natraj (2005)

### 1.3.4 Need For Addressing Water Scarcity

India's population is expected to increase drastically by 2050. Out of the total population, the urban population is expected to grow from 29.2% of the total population in 2007 to 55.2% by 2050.

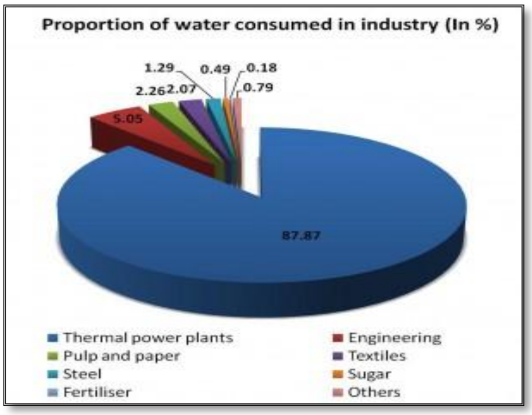
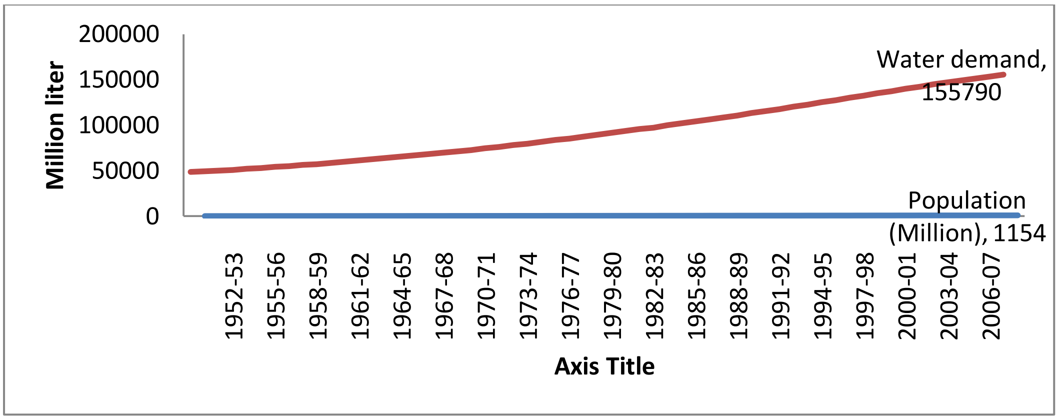



**Figure 1.1 Proportion Of Water Consumed In Industry (in %)**
(Source: "India – the water story" , report 2010, Grail Research)

Another area of concern is the industries using water exhaustively. India's economic growth has been gargantuan in the last decade. Foreign direct investment equity inflow in the industrial sector has grown to $17.68 Bn in 2007–2008. Annual per capita consumption of power is expected to reach its maximum level as compared to present installed power generation capacity. Industrial water consumption is expected to shoot up its growth between 2000 and 2050. If the conditions remain same; water will turn out to be the world's most precious resource soon.

## 1.4 INCREASE IN POPULATION IN GUJARAT

As per provisional data of the census report 2011, Gujarat's latest figure of population is 6,03,83628. Gujarat state has average population of 308 people per square km. Gujarat's share in nation's population is: 4.99%. Following graph shows the increase in population. Population is increasing in cumulative way while rainfall is not, so day is not far when water availability is going to be a major concern for survival.

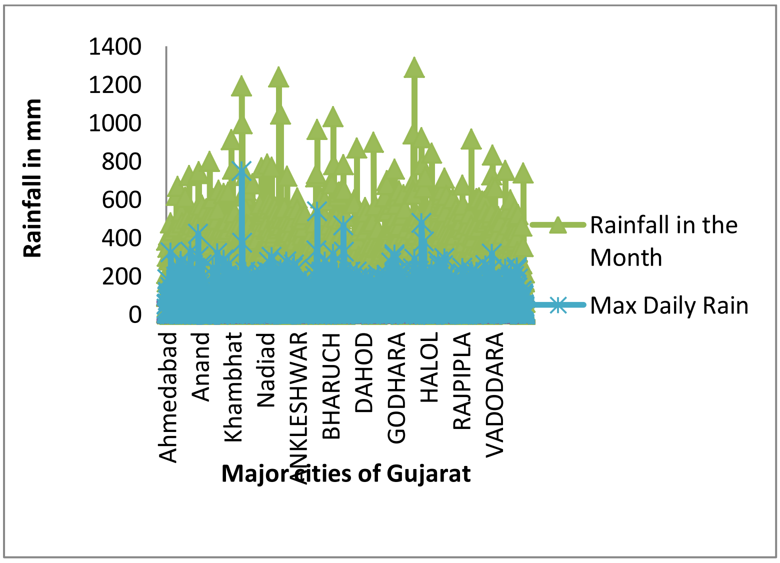



**Graph 1.4 Population And Increase In Demand For Water In Central Gujarat Region**

(Source: RBI Handbook of Statistics on Indian Economy, 2011)

### 1.4.1 Water Resources In Gujarat

The average rainfall in Gujarat varies from 330 to1520 mm. The southern region of the state has an average rainfall ranging from 760 to 1520 mm, Dang district has the highest average of about 1900 mm, northern districts has rainfall from 510 to 1020 mm, southern highlands of Saurashtra and the Gulf of Cambay has approximately 63 mm while the other parts of Saurashtra has rainfall less than 63mm.




**Graph 1.5 Average Rainfall In Cities Of Gujarat**

(Source: State water data center, Gandhinagar)

Water is a critical resource for Gujarat. In the past, water resource constraints have often been perceived to be an impediment to growth and the State accordingly accords highest priority to investments in the water sector. Traditionally, for the purposes of planning in the State water policy of Gujarat, four different segments are considered separately for the water sector:

- Bulk water supply schemes
- Water supply schemes for rural and smaller urban areas.
- Water supply schemes for larger urban areas, implemented by Municipal Corporations
- Supply of water to large industrial users and industrial estates by GIDC

The state has faced at least 3 drought years in the last 10 years. During the drought affected years, the Government has to incur large sums of money to bulk water lines. Providing drinking water on a sustainable basis to the rural and urban masses of the people of Gujarat is an issue of major concern to the Government. There is an urgent need to implement integrated water supply schemes, which would provide long-term solution to the water problem.

## 1.5 FEASIBILITY & NECESSITY OF REUSE OF WATER

Wastewater reuse strategy for industries is a cost-effective solution. It is an alternative to act upon when industries are affected with resource depletions and variability of the water quality. For most of the industry water availability and its cost are serious factors in the production sectors. The notion of unlimited water availability is unreal. Therefore for any industry using water for the production, the sources of water are seawater, industrial and municipal effluents.

The municipal secondary treated wastewater and treated industrial wastewater is preferred for reuse due to its lower concentration of impurities as compared to seawater and its proximity to the occasion of demand.

Waste water consist only 1% impurities and 99% water. So if this water is reused, it has large environmental and socio-economic benefits. In all urban areas of the state, this water can be reused in an easy manner and used for industrial and horticultural purpose. If water reuse is done in urban areas of Gujarat, the value of water made available for use could be as high as Rs. 1,800 crore per year. So it is feasible to opt for the option of reuse of waste water in central Gujarat region. According to the data collected during Census 2011, more than 29% of the total number of households in Gujarat, receive untreated drinking water.

“It is the intention of the Legislature that the state undertakes all possible steps to encourage development of water recycling facilities so that recycled water may be made available to help meet the growing water requirements of the state." Due to technically proven waste water treatment technologies, water reuse has a rightful place and has an important role in the planning and efficient use of water resources. However, public concerns about public health and environmental issues will need to be addressed in a more rigorous and transparent manner than has occurred in past.

### 1.5.1 Motivation Factors For The Reuse Of Water

Following are the motivation factors for the reuse of water:

- Industry Continued population growth, contamination of both surface water and ground water, uneven distribution of water resources, periodic droughts
- Use of highly treated wastewater effluent from municipal wastewater treatment plants, is receiving more attention as a reliable water resource.
- The reuse of water is just one source of water that has potential for use in an agricultural setting. Reused water does, however, have a major advantage in that it is usually a constant and reliable supply, particularly with sources such as treated sewage effluent or industrial discharges.
- Being a constant source of water, many water sources suitable for reuse is produced in large volumes, which if not used would be merely discharged into the environment.
- The discharge of effluents, treated or non-treated, into the environment, particularly natural water bodies such as lakes, rivers and the coastal marine environments can cause severe degradation of these water ways.
- Reusing discharged effluents can have a significant impact on reducing or completely removing the impact of these effluents from receiving environments. In addition, the reuse of wastewaters for purposes such as agricultural irrigation reduces the amount of water that needs to be extracted from environmental water sources (Gregory 2000, USEPA 1992).

## 1.6 BENEFITS OF WASTE WATER REUSE

Waste water reuse is not only the requirement but it provides eco-friendly benefits like:

- A dependable locally-controlled water supply
- Environmental benefits like decreasing wastewater discharges
- Reducing and preventing pollution
- To create or enhance wetlands and riparian habitats, etc.

- To decrease the diversion of water from sensitive ecosystems
- Decreases Discharge to Sensitive Water Bodies
- Reduction in Pollution
- Saving Energy

## 1.7 THE FUTURE OF WASTE WATER REUSE

Advances in wastewater treatment technology and health studies of indirect potable reuse have led many to predict that planned indirect potable reuse will soon become more common. Reuse of waste water and gray water requires far less energy than treating salty water using a desalination system. Reuse of waste water can be a sustainable approach and cost-effective in the long term, the treatment of wastewater for reuse and the installation of distribution systems at centralized facilities can be initially expensive compared to such water supply alternatives as imported water, ground water, the use of gray water onsite from homes.

## 1.8 TYPES OF REUSE AND APPLICATIONS

Possible types of reuse are as under:

- Commercial Reuse – for fire-fighting, air conditioning, toilet flushing, sewerage, construction activities etc.
- Industrial Reuse – cooling, process making, cleaning, rinsing etc.
- Groundwater recharge – spreading basins, direct injection into ground
- Agricultural Reuse – irrigation practices
- Environmental and Recreational Reuse – golf courses, parks, playgrounds, street augmentation, etc.
- Construction reuse
- Domestic reuse for potable or nearly potable purposes

## 1.9 FORMULATION OF THE PROBLEM

The present study being carried out is for the feasibility study of the treated effluent from the sewage treatment plant for the reuse purpose for some of the industries at nearby area of domestic effluent plant and the treatment of waste water for common effluent treatment plant for agricultural purpose in nearby area.

Treated Waste water of secondary effluent can be reused for the purposes in the nearby area of sewage treatment plant. The city is facing nearly 100 lpcd water shortage. The effluent plant is running on its full capacity and it can be a promising source for solution of industrial water usage as it is nearby available.

In the nearby area of CETP (Common Effluent Treatment Plant), agricultural activity is being done by illegal withdrawal of waste water from channel carrying combined waste water of all industries. The plants are studied and the data for past possible years is taken. The study area is selected on the basis of purposive grab sampling.

The treatability study was mainly conducted for following treatment plants:

- Vadodara municipal sewage treatment plant at Atldra, Vadodara. (Domestic sewage treatment plant)
- Common effluent treatment plant, Umraya, Padra.

According to the characteristics of the final outlet of both treatment plants, the treatments are tried for rese of waste water.

# 2. LITERATURE REVIEW

## 2.1 OVERVIEW

Water withdrawal statistics indicate that annual global water withdrawals have increased by more than six times and the rate of increase in developing countries is 8% [110]**.** Water is a very basic requirement for the well-being of human kind, vital for economic development and essential for the healthy functioning of all the world's ecosystems. Reasons for limited availability of resources to use for people include: lack of distribution networks, excessive extraction of groundwater resource and risk from the contamination by the pollutants. Many freshwater resources have become increasingly polluted, resulting in the shrinking of freshwater availability.

In some places groundwater levels continue to fall and the options for increasing supplies have become costly and are often environmentally damaging [79]**.** Water conflicts are worsening around the world, rivers are drying up and pollution is unabated. The root cause of these problems is poor water governance, which has often been neglected in the past. Rapid urbanization and industrialization has resulted in the squeeze on freshwater supplies for agricultural uses and this necessitates reliable, alternative sources of supply. Consequently, the water crisis situation has engendered new directions for water governance and development and use of urban wastewater as an alternative source of supply.

### 2.1.1 Fresh Water Availability

Exponential growth of population, rapid industrialization, urbanization, higher cultivation intensities, and poor water management practices over the past century has made freshwater availability a limiting factor in agricultural development [199]. The options for increasing supply have become expensive and often environmentally damaging [79]**.** "The insufficiency of water is primarily driven by an inefficient supply of services rather than by water shortages. Lack of basic services is often because of mismanagement, corrupt ion, lack of appropriate institutions, bureaucratic inertia and a shortage of new investments in building human capacity, as well as physical infrastructure"[250] water managers and policy makers around the world are compiled to continually look for alternatives to supplement limited and depleting freshwater resources. In such situations, 'source substitution ' appears to be the solution as it allows higher quality water to be reserved for domestic supply and poor quality water may satisfy less critical uses . Urban wastewater (treated) is now considered as a reliable alternative water source without compromising public health and wastewater management is prominent in the water management agenda of many countries [17]**.**

Following are the key points which needs to be considered for water sector [39]

- **Key drivers:** Demand-Supply gaps, Urbanization, Regulations
- **Opportunities:** Efficiency in water supply, reuse of waste water and energy from waste
- **Technical :** Challenges, , Lack of raw water, Changing water use patterns, Lack of adequate availability of technical expertise
- **Financial Challenges:** Capital intensive, Tariffs are too low
- **Social Challenges:** Water is a state subject; Water is a highly political issue.

## 2.2 WATER SCENARIO IN STATE UNDERTAKEN FOR STUDY

The share of groundwater in the total supply is projected to decrease in future as large surface water schemes are commissioned, most notably the Sardar Sarovar-based Narmada Main Canal. The shortfall in urban areas is even more critical and requires substantial investment to develop new sources of water and strengthen the water supply distribution network. The demand for drinking water in the six municipal corporations is projected to outstrip the supply 986 mld, calling for an investment of Rs. 8609 million by 2010. Additional investments are also required to rehabilitate the existing distribution network. In Central Gujarat, water availability can be challenging in future, so to meet with water requirement option of reuse has to be explored.

### 2.2.1 Water Conflicts

Severe water shortages have already led to growing more number of conflicts across the country.90 per cent of India’s territory is drained by inter-state rivers. The conflict over the Cauvery river water between Karnataka and Tamil Nadu, the Godavari river conflict between Maharashtra and Karnataka and the Narmada water conflict between Madhya Pradesh and Gujarat are all ongoing conflicts. On the international front, India has clearly demarcated water rights with Pakistan through the Indus Waters Treaty [111].

Climate change projections show that India's water problems are only likely to worsen. With more rain expected to fall in fewer days and the rapid melting of glaciers – especially in the western Himalayas – India will need to gear up to tackle the increasing incidence of both droughts and floods. There is clearly an urgent need for taking action for the observed situation of water. First, India needs a lot more water infrastructure. Compared to other semi-arid countries, India can store relatively small quantities of its fickle rainfall. Whereas, India's dams can store only 200 cu.m. of water per person, other middle-income countries like China, South Africa, and Mexico can store about 1000 cu.m. per capita.

### 2.2.2 Wastewater Treatment And Reuse

To ensure sustainable and successful wastewater reuse applications, the following requirements must be fulfilled:

- The potential public health risk associated with reuse of wastewater are evaluated and minimized
- The specific water reuse applications meet the water quality objectives
- In order to meet the requirements, it is necessary to treat the wastewater prior to reuse applications
- Ensure an appropriate level of disinfection to control pathogens

Little work was done before the mid-1990s for the economics of reuse of wastewater in irrigation. [58]Analysis of the optimal treatment of municipal wastewater before its reuse for irrigation purpose was provided. [106] They determined monthly optimal treatment levels and of the mix crops calculated to maximize agricultural incomes, according to farmers' point of view. Among the literature on IWRM the conceptual approaches to wastewater management with focus on the reuse of wastewater are represented by Harremoes(1997), Huibers and van Lier (2005), Nhapi, Siebel and Gijzen (2005), van Lier and Huibers (2007), Neubert (2009) and Guest et al. (2009).

### 2.2.3 A Reliable Source Of Water - Urban Wastewater

The agricultural activity is the largest consumer of freshwater resources, currently accounting for about 70% water withdrawals globally and over 90% in the developing world [255]. With increasing population, urbanization, rapid industrial development, the availability of freshwater is likely to be one of the major limits to economic development in the decades to come. It is expected that water now used for agriculture will be diverted to the urban and industrial sectors. So there is a need to find a reliable new source of supply that can augment the freshwater supplies and reduce the pressure on existing resources. The use of wastewater also helps to close the loop between water supply and wastewater disposal [1]**.** Wastewater use for non-potable purposes particularly for irrigation is a centuries-old practice. [68]. In many developing countries wastewater (untreated) is a highly important productive resource and is a substantial and sometimes even primary source of income for thousands of small farmers [218]**.** The reasons for this include: increasing water scarcity, lack of funds for treatment and clear willingness by farmers to use untreated wastewater [68]**.**Among the different applications of wastewater, it is believed that the agricultural activity/ irrigation is the best use of wastewater after treatment [188]and the presence of crop nutrients in wastewater benefits crop production [68]**.** Urban wastewater reuse experiments around the world have demonstrated the feasibility of water reuse on a large scale and its role in the sustainable management of the world's total water [14].

## 2.3 HISTORY OF WASTEWATER REUSE

The ancient practice of applying wastewater containing human excreta to the land has maintained soil fertility in many countries of Eastern Asia and the Western Pacific for over 4,000 years and remains the only agricultural use option in areas without sewerage facilities [258]**.** Europe has examples of rainwater reuse since the Minoan time, ca. 3,000-1,100 B.C [15]. Reuse of waste water has been practiced since the Ancient Greek and Roman civilizations**.** Land application of wastewater is an old and common practice, which has gone through different development stages with time, knowledge of the processes, treatment technology and regulations evolution. Wastewater has also been used by the Mediterranean civilizations[15], like in the $14^{th}$ and $15^{th}$ centuries in the Milanese Marcites and in the Vlencia huerta and the North European ones, like in Great Britain, Germany, France, and Poland[229]**.**The systems have been widely employed in the treatment/disposal of municipal wastewater since 1850 (Folsom, 1876).As urban areas began to encroach on sewage farms and the scientific basis of disease became more widely understood, concern about possible health risks associated with the use of wastewater for irrigation increased among public health officials. This led to the establishment of controls on the use of wastewater for agricultural irrigation, which was the first reclaimed water application to be regulated. The first standards adopted by the Californian State Board of Health in 1918, entitled Regulation Governing Use of Sewage for the Irrigation Practices, prohibited the use of raw sewage for crop irrigation and limited the use of treated effluents to irrigation of nonfood crops and food crops that were cooked before being eaten or did not come in direct contact with the wastewater. [45]California further modified their water reuse legislation seven times up to year 2000.Nightsoil has been used to fertilize the crops and replenish depleted soil nutrients since the ancient times in China and in other areas of Asia. With industrialization and subsequent water carriage sewerage system, interest and effort in wastewater utilization through farming and land application grew.

### 2.3.1 Key Issues Related To Use Of Wastewater

Wastewater has high potential for reuse in agriculture; an opportunity for increasing food and environmental security, avoiding direct pollution of rivers, canals surface water; conserving water and nutrients, thereby reducing the need for chemical fertilizer and disposing of municipal wastewater in a low-cost, sanitary way. Wastewater use poses a number of health and environmental risks for the users and communities in prolonged contact with wastewater; for consumers of such produce, neighboring populations due to contamination of groundwater and creation of habitats for mosquitoes and other disease vectors. Important health risks include the transmission of intestinal infections to workers of agricultural activity in wastewater-irrigated fields and to consumers of waste-water irrigated produced due to worms and the transmission of faecal bacterial diseases, like diarrhea, dysentery, typhoid and cholera. The key issues pertaining to the treatment, use, application and impact of wastewater are dovetailed with livelihoods, health, environment and policy concerns. It is important to look at mitigating the negative impacts on the beneficiaries of wastewater use and link up use with sustainable livelihoods outcome.

## 2.4 FACTORS TO BE ADDRESSED FOR REUSE OF WASTE WATER

Following are the important factors related to implement successful reuse of waste water.

### 2.4.1 Water Governance Directions

Water governance is a significant aspect of the international development policy making. The United Nations World Water Development Report-2 [250] recognizes that water crisis is largely a crisis of governance, outlines many of the leading obstacles to sound and sustainable water management. There is an increasing consensus on the need to improve water governance so as to achieve the Millennium Development Goals [125]. So, good governance which often receives less attention than it merits is an essential aspect of effective water resource management [31]**.** The situation demands a change or shift in water governance – the process of managing water resources. It [87] describes this shift or change as 'the changing water paradigm'. Some aspects of theory of governance are that, concerned not only with the State but also with relationships between the State and civil society and its private sectors. It was said that "governance embraces the relationship between a society and its government" [206]. The Dublin Water Principles (1992), through its participation clause, states that water development and management should be based on a participatory approach, involving users, planners, the community, policy-makers at all levels. The same notion is stressed in the Hague Ministerial Declaration (1998), and the Bonn Ministerial Declaration (2001).

### 2.4.2 Institutional Challenges

Wastewater collection, treatment and effluent use normally encompass a large range of interests at different levels of administration. So the scope and success of any reuse scheme will depend to a large extent on the institutional organization [188]**.** In any natural resource management regime, coordination complexity results in problems, due to the varying roles and responsibilities and overlapping concerns among the public agencies managing the resources [154]**.** Previous studies related to wastewater use [17, 18] have identified similar conflicting agendas among water agencies: addressing water rights issues; dealing with opponents to recycling or reuse; modifying existing regulations; acquiring funding, are the institutional challenges facing successful development of this dependable resource.

### 2.4.3 Public Perceptions And Acceptance

For successful implementation of reuse schemes, public acceptance is a very important [17,18]parameter that tendency of people to be motivated by a set of long-term goals, but to act in the short term towards those things that they control, is what affects wastewater reuse projects**.** Failure to gain public acceptance has led to vocal opposition, at times, has resulted in schemes being stalled. Public concerns about real or perceived risks are weighted against the use of reclaimed water [205]. The following factors influence community's acceptance of the reuse scheme [189]:

- Disgust or 'yuck' factor
- The perception of risks associated with using recycled water
- The specific uses, cost of recycled water
- The sources of water to be recycled,
- Issues of choice
- Trust and knowledge
- Attitudes toward environment
- Socio-demographic factors

If wastewater resources are to become an integral component of water and waste management policies, the acceptance of reclaimed water must be comprehensively tackled; this is more critical if the application is for potable uses.

### 2.4.4 Community Participation

Wastewater reuse history is marked with the failure of reuse schemes mainly because of lack of community involvement [189]**. 'Working with a community that does not have wastewater as a highest priority requires building participation through a combination of discussions about community outcomes, more detailed action steps of technology identification, design work, and management'.** [136].The lack of community participation results in a wide gap between what is desired from wastewater reuse and what is necessary to get there, inability to bridge this gap is the primary reason for failure of locally driven wastewater projects. Since it is public, who will be served by and pay for them, the policies on wastewater use and management must include the human dimension [205]**.** For a reuse scheme to be sustainable, community involvement and/or participation are very important. Asano[17, 18] suggests that waste water reuse project(s) should be built upon three principles:

- Providing reliable treatment of wastewater to meet strict water quality requirements
- Protecting the public health
- Gaining public acceptance.

### 2.4.5 Market Imbalance

The best application for the use of wastewater after treatment is in agriculture [188] and use of this water for agriculture purposes can relieve a great deal of pressure on fresh water resources. This implies that the largest market for reclaimed water is in the agriculture sector. Although there is a market for this valuable resource, it is imbalanced, as is explained by [7]**: "The market for reusable water is unbalanced and it is due to a growth on the supply side of the market, revealed by increasing number of wastewater treatment plants and stagnancy on the demand side revealed by the substantial proportions of resource being discharged without proper utilization".**

### 2.4.6 Financial Feasibility And Technicality

Financing a reuse scheme is a challenge because acquiring funds to develop water reuse scheme is an onerous task. **"More often than is usually believed, individually rational behavior is compatible with the socially desirable outcomes"** [246]. Therefore, public perceptions and acceptance of wastewater, community participation and willingness to pay are all interlinked. Willingness to pay for reclaimed water is also influenced by the tariff structure, which should be such that community being served should perceive it to be appropriate, as well as taking into account the long term viability of the service provider. Sound technicality is another factor to be considered while implementing reuse projects. This is important because the effluent should be treated to a quality acceptable to the end user and matched to particular application.

### 2.4.7 Economics Of Water Reuse

Reuse projects initiated by the private sector are often driven by need for water or a perceived marketing edge. Projects initiated by the wastewater utility are often driven by a need to meet reuse target and to avoid water based disposal as per Environmental Protection Authority (EPA) guidelines. The client base must be developed by the wastewater utility. This has led to a number of reuse projects where reuse water was priced at a considerably lower level than the potable water. One of the potential outcomes of this type of pricing strategy is the over-use of reuse water. In a first best world, whenever prices are set at less than full cost, efficiency considerations dictate that the rationale for doing this needs to be revealed and a process for returning to full cost pricing needs to be put in its place. [238]

### 2.4.8 Global Trends Open Up New Investment Opportunities

Adequate water quality supply and insufficient quantities is one of the major challenges facing the modern society. In many countries the available water reserves are now being over exploited to such an extent that the negative consequences can no longer be ignored. The situation will become even more critical in years ahead. Demand for water is increasing to an extent that it would not be available for basic requirements of individuals. Major investments will therefore be required in the short term to upgrade ageing water mains and sewer systems in particular, higher standards for water quality. Solution also needs to be found out to meet the fresh challenges arising from new micro pollutants that are becoming a problem in industrialized countries. Climate change will cause significant variations in the hydrological regime in many regions, culminating in the water crisis in some areas. These mega trends will intensify the pressure to manage existing water resources far more efficiently in the years ahead. This situation opens up attractive opportunities to all businesses offering products and services for the treatment, supply or use of water. [216]

### 2.4.9 Reuse Of Waste Water: Impact On Water Supply Planning

A procedure for analyzing water reuse alternatives has been prescribed [84] within a framework of regional water supply and waste water disposal planning and management by modeling. He also suggested that planners should address the question of when and in what context waste water should be upgraded for reuse as additional sources of supply. water from several origins or categories of supply can be allocated to satisfy the demand of various water using sectors or destinations the concepts of water reuse, fits closely the format of the transportation or trans-shipment problem from linear programming as applied by Bishop and Hendricks (1971) to evaluate water reuse potential within the framework of water supply availabilities and water demands of a region and waste water management considerations. A waste treatment plant may be the destination of municipal effluent, while at the same time it becomes an origin for treated waste water available for reuse purpose. Optimal (least cost) solutions can be generated which contain following information:

- Allocation from primary water supply sources to satisfy user demands
- Operating levels for water treatment plants for municipal supplies
- Capacity levels for the use of waste water treatment plants
- Capacity timing reuse of waste water
- Specific reuse made of effluent supplies

### 2.4.10 Key Objectives For Water Reuse Concepts

Scientists working [62] closely on the issues of water reuse are far from having solved all concerns related to the practice. From Decision Support Systems to the simplest analytical tools, all knowledge is valuable. Detailed studies must be undertaken to identify necessary technologies, schemes, control tools. As public health concerns are normally among the main constraints for reuse any scenario will need to include detailed risk assessments. Once the basic calculations were performed, after that a final decision whether the scheme can be implemented should be based on three phases of risk assessment; analysis, calculation and communication. This will allow fulfilling the key objectives of reuse of waste water: increasing the amount of water resources available, under an acceptable risk with a public full knowledge. Although wastewater reclamation and reuse has gained approval as a necessary tool to be included in sustainable integrated water resources management, there are still several key points to be developed for safe use of the resource. Among the most important items to be developed by adequate research and development (R&D), the risk approach appears to be paramount at present for several reasons

- It could finish the old controversy on restrictive or not so restrictive standards
- It can allow qualifying a reclamation treatment depending on quality of water obtained
- It is a good tool to define the acceptable risk for a given society with its particular conditions

### 2.4.11 Factors Responsible For Reuse Of Municipal Waste Water

Reuse of municipal wastewater reuse was "inadvertent reuse" or the unplanned addition of the wastewater to water supply. Due to the vastness of knowledge and communications in modern societies, this inadvertent reuse is seldom the case. In modern societies almost all reuse is planned and takes the form of either "indirect reuse" or "direct reuse." Throughout the past two decades the United States and much of the world have witnessed a growing awareness of the concept of water reuse. Baumann and Dworkin (1975) attribute the awareness to four factors which has taken place in the recent history as below:

- The increasing urbanization and industrialization which have resulted in a scarcity of freshwater in many areas
- More and more communities have been forced to turn to polluted sources to meet their need of water supply (i.e., indirect reuse)
- The cost of wastewater disposal has been growing as a result of the desire to limit the amount of pollutants released into our nation's existing water sources

- Technological developments in advanced wastewater treatment have lowered the actual costs of treating water.

### 2.4.12 Environmental Assessment Of Urban Wastewater Reuse: Treatment Alternatives And Applications

The main function of a Wastewater Treatment Plant is to minimize the environmental impact of discharging untreated water into natural water systems. [162]. Wastewater Treatment Plant may get a resource from wastewater carrying out a tertiary treatment on the treated wastewater which can be reused in non-potable applications. Water reuse strategies are intended to address problem of water scarcity without aggravating other environmental problems, thus reflecting the need of their environmental assessment. Comparison of environmental impact was done of producing 1 $m^3$ of water for non-potable uses from reclaimed water, potable water and desalinated water sources. The calculation has used the current operating data from a Wastewater Treatment Plant located in the Mediterranean area, although the results can be applied to any other plant with similar technology. The ozonation and ozonation plus hydrogen peroxide disinfection treatment technologies have similar environmental profiles. Most of the indicators are about 50% higher than the ultraviolet disinfection, except for the acidification (100% higher) and photochemical oxidation (less than 5%). Non-potable uses (both agricultural and urban uses) of reclaimed water have environmental and economic advantages.

### 2.4.13 Quality Issues Of Wastewater Reuse

Despite a long history of wastewater reuse in many parts of the world, the question of safety of wastewater reuse still remains an enigma mainly because of the quality of reuse water. Public health concern is the major issue in any type of reuse of wastewater, be it for irrigation or non-irrigation utilization, especially long term impact of reuse practices. It is difficult to delineate acceptable health risks and is a matter that is still hotly debated. Adequate treatment schemes must always be designed to eliminate, or at least minimize the potential risks of disease transmission. Consideration of hydro-geologic conditions helps to compare the reuse water quality and the quality of alternative sources intended for the same kind of use.

#### 2.4.13.1 Pathogen Survival

Public health concerns center around pathogenic organisms that are or could be present in wastewater in great variety. Survival of pathogens in wastewater and in environmental conditions other than their host organisms (mainly humans) is highly variable. Other water quality parameters of concern in wastewater reuse have been toxic metal accumulation and salinity of wastewater. The availability of heavy metals to plants, their uptake and their accumulation depend on a number of soil, plant and other factors. The soil factors include, soil $P^H$, organic matter content, cation exchange capacity, moisture, temperature and evaporation.

**Table 2.1 Survival Of Pathogens**
(Source: Feachem R. G., Bradley D. J., Garelick H. and Mara D. D. (1983))

| Type of Pathogen | Survival time in days | | | |
|---|---|---|---|---|
| | In feces and sludge | In sewage and freshwater | In soil | On crops |
| 1. Viruses | | | | |
| Enteroviruses | <100 (<20) | <120 (<50) | <100 (<30) | <60 (<15) |
| 2. Bacteria | | | | |
| Fecal coliforms | <90 (<50) | <60 (<30) | <70 (<20) | <30 (<15) |
| Salmonella spp. | <60 (<30) | <60 (<30) | <70 (<20) | <30 (<15) |
| Shigella spp. | <30 (<10) | <30 (<10) | - | <10 (<5) |
| Vibrio Cholerae | <30 (<5) | <30 (<10) | <20 (<10) | <5 (<2) |
| 3. Protozoa | | | | |
| Entamoeba-hystolyticaCysts | <30 (<15) | <30 (<15) | <20 (<10) | <10 (<2) |
| 4. Helminths | | | | |
| Ascaris-lumbricoides Eggs | many months | many months | many months | <60 (<30) |

(Note: Figures in bracket shows the normal survival time)

### 2.4.13.2 Effluent Quality Standards

Considering the wide-ranging potential for wastewater reuse, it may be difficult to set some common quality standards for all types of reuses. For many countries in Europe, either the guidelines of World Health Organization (WHO) or the US Environmental Protection Agency (USEPA) standards form the basis for any decision or for granting permission to any kind of reuse. Standards or guidelines for other possible reuses such as groundwater recharge, industrial uses etc., are not common, mainly because such types of reuses are not widespread. First water quality criteria for reuse of wastewater in irrigation were set in 1933, by the California State Health Department. These standards are for microbiological parameters that indicate the presence of pathogenic organisms in wastewater.

**Table 2.2 The 1989 Who Guidelines For The Use Of Treated Wastewater In Agriculture**

(Source: Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture)

| Category | Reuse Conditions | Exposed group | Intestinal nematodeb (arithmetic mean no. eggs per litre) | Faecal coliforms (geometric mean no. per 100ml) | Wastewater treatment expected to achieve the required microbiological guideline |
|---|---|---|---|---|---|
| A | Irrigation of crops likely to be eaten uncooked, sports fields, public parks | Workers, Consumes, public | <=1 | <= 1000 | A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment |
| B | Irrigation of cereal crops, industrial crops, fodder crops, pasture and treese | Workers | <=1 | No standard recommended | Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal |
| C | Localized irrigation of crops in category B if exposure to workers and the public does not occur | None | Not applicable | Not applicable | Pretreatment as required by irrigation technology, but not less than primary sedimentation |

(Note: Arithmetic mean no. of eggs, per 100 ml Geometric mean no. per 100 ml ,In case of fruit trees, irrigation should cease 2 weeks before fruit is picked)

## 2.4.14 Quality Parameters Of Importance In Agricultural Use Of Wastewater

Following are the quality parameters to be considered for reuse of waste water. [210]

### 2.4.14.1 Parameters of health significance

Organic chemicals usually exist in municipal wastewaters at very low concentrations and ingestion over prolonged periods would be necessary to produce detrimental effects on human health. The principal health hazards associated with the chemical constituents of wastewaters, therefore, arise from the contamination of crops or ground waters. Hillman (1988) has drawn attention to the particular concern attached to the cumulative poisons, principally heavy metals, and carcinogens, mainly organic chemicals. World Health Organization guidelines for drinking water quality (WHO

1984) include limit values for the organic and toxic substances based on acceptable daily intakes (ADI). [226]

Pathogenic organisms give rise to the greatest health concern in agricultural use of wastewaters, yet few epidemological studies have established definitive adverse health impacts attributable to the practice. Shuval et al. (1985) reported on one of the earliest evidences connecting agricultural wastewater reuse with the occurrence of disease. It would appear that in areas of the world where helminthic diseases caused by Ascaris and Trichuris spp. are endemic in the population and where raw untreated sewage is used to irrigate salad crops and/or vegetables eaten uncooked, transmission of these infections is likely to occur through the consumption of such crops. Indian studies, reported by Shuval et al. (1986), have shown that sewage farm workers exposed to raw wastewater in areas where Ancylostoma (hookworm) and Ascaris (nematode) infections are endemic have significantly excess levels of infection with these two parasites compared with other agricultural workers in similar occupations. In respect of the health impact of use of wastewater in agriculture, Shuval et al. (1986) rank pathogenic agents in the order of priority.

**Table 2.3 Relative Health Impact Of Pathogenic Agents**

(Source: Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture)

| | |
|---|---|
| **High Risk (high incidence of excess infection)** | **Helminths (Ancylostome, Ascaris, Trichuris and Taenia)** |
| **Medium Risk (low incidence of excess infection)** | Enteric Bacteria (Cholera vibrio, Salmonella typhosa, Shigella and possibly others) |
| **Low Risk (low incidence of excess infection)** | Enteric Viruses |

## 2.5 TREATMENTS OF DOMESTIC WASTE WATER

Sewage can be treated close to where it is created by centralized system. A decentralized system like septic tanks, bio filters or aerobic treatment systems can be collected to municipal treatment plant. Sewage collection and treatment is typically subject to local, state and federal regulations and standards. Industrial sources of sewage often require specialized treatment processes (see Industrial wastewater treatment).Sewage treatment generally involves total three stages, called primary, secondary and tertiary treatment [163].

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

- **Secondary treatment** removes the dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro-organisms from the treated water prior to discharge or tertiary treatment.
- **Tertiary treatment** is sometimes defined as anything more than primary and secondary treatment in order to allow the rejection into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers, coral reefs) Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes.

### 2.5.1 Disinfection

The purpose of disinfection in the treatment of waste water is to substantially reduce the number of microorganisms in the water to be discharged and back into the environment for the later use of drinking, bathing, irrigation, etc. The effectiveness of disinfection depends on the quality of the water being treated (e.g., cloudiness, $P^H$, etc.), the type of disinfection being used, the disinfectant dosage (concentration and time) and the other environmental variables. Cloudy water will be treated less successfully, since solid matter can shield organisms, especially from ultraviolet light or if contact times are low. Generally, short contact times, low doses and high flows all militate against effective disinfection. Common methods of disinfection include ozone, chlorine, ultraviolet light, sodium hypochlorite. Chloramine, which is used for drinking water and it's not used in the treatment of waste water, because of its persistence EPA, Washington (2004).

**Chlorination** is the most common method for disinfection. One disadvantage is that the chlorination of residual organic material can generate chlorinated-organic compounds that may be carcinogenic or harmful to the environment. Residual chlorine or chloramines may also be capable of chlorinating organic material in the natural aquatic environment. Because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment.

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

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

## 2.5.2 A Review of Wastewater Treatment By Reverse Osmosis

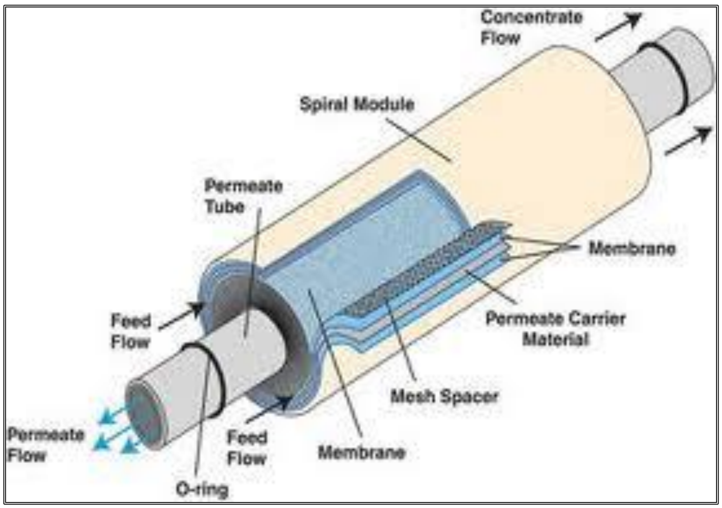



**Figure 2.1 Reverse Osmosis Membrane**

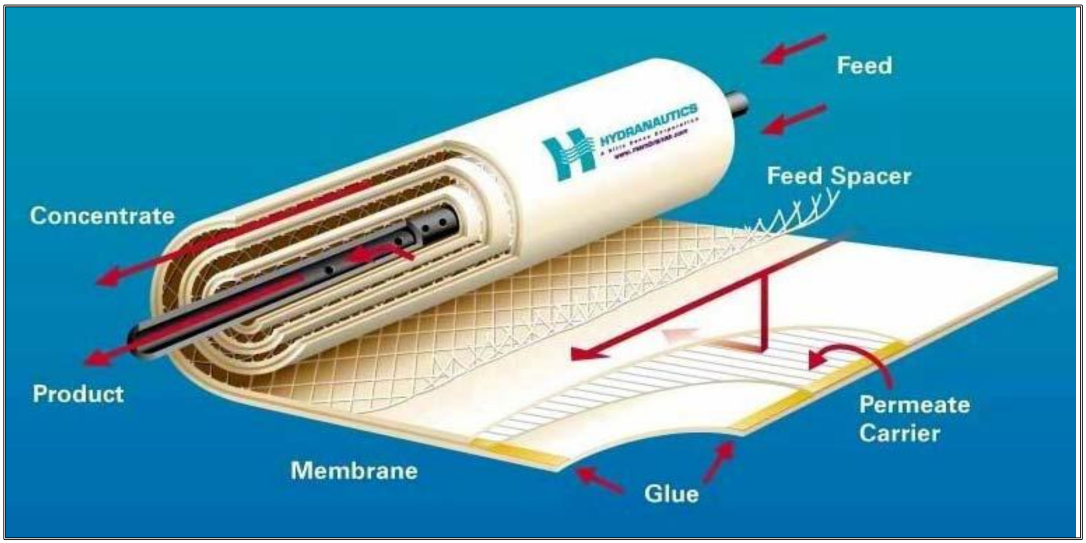



**Figure 2.2 Process Of Treatment Inside Membrane**
(Source: Hydranautics Design Software version 2012)

Since the development of first practical cellulose acetate membranes in the early 1960's and the subsequent development of thin-film, composite membranes, the uses of reverse osmosis have expanded to include not only the traditional desalination process but also a wide variety of the Wastewater treatment applications. Several advantages of the RO process that make it particularly attractive for dilute aqueous wastewater treatment include: [40]

- RO systems are simple to design and operate, they have low maintenance requirements, and are modular in nature, making expansion of the systems easy
- both inorganic and organic pollutants can be removed simultaneously by the RO membrane processes

- RO systems allow recovery/recycle of waste process streams with no effect on the material being recovered
- RO membrane systems often require less energy, offer lower capital and operating costs than many conventional treatment systems
- RO processes can considerably reduce the volume of waste streams so that these can be treated more efficiently and cost effectively by other processes such as incineration

RO systems can be replaced or used in conjunction with others treatment processes such as oxidation, adsorption, stripping, or biological treatment to produce high quality product water that can be reused or discharged. Applications that have been reported for RO processes include treatment of organic matter containing wastewater, wastewater from electroplating, metal finishing, pulp and paper, mining, petrochemical, textile, food processing industries, radioactive wastewater, municipal wastewater, and contaminated groundwater [28].

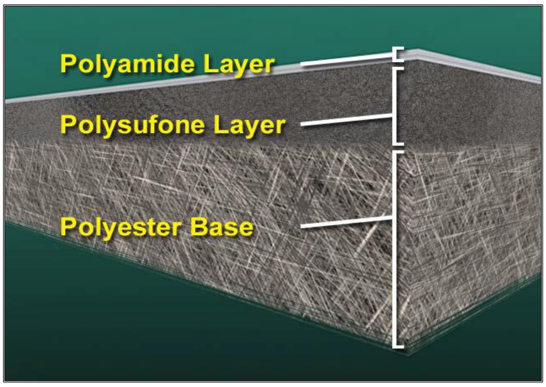



**Figure 2.3 Layers Of Membrane**
(Source: Hydranautics Design Software version 2012)

They [228] have compiled separation and flux data of cellulose acetate membranes for a large number of the organic compounds, including many organic pollutants. They found that organic separation can vary widely (from <0% to 100%) depending on the characteristics of the organic (polarity, size, charge, etc.) and operating conditions (such as feed $P^H$, operating pressure, etc.). It was, [14] reported that some of the factors influencing separation of the several different organics (including acetone, urea, phenol 2, 4-dichlorophenol, nitrobenzene) by cellulose acetate membranes. Rejections varied considerably for the different solutes, and rejections of ionizable organics were greatly dependent on degree of dissociation; non ionized and hydrophobic solutes were found to be strongly sorbed by the membranes and exhibited poor rejection. Duvel and Helfgott (1975) found organic separations varied with molecular size and branching; they postulated organic separation was also a function of the solute's potential to form hydrogen bonds with the membrane.

### 2.5.3 Low Fouling Technology

The first technological advancement came in the late part of 1998, with the introduction of the Low Fouling Composite (LFC) membrane. This membrane is characterized with the same or better flux rate of most composite membranes and also with a higher or equivalent salt rejection. This membrane is primarily suited for the treatment of difficult feed waters, municipal wastewater and other unique feed water, which up to now required significant pretreatment prior to subjecting them to any composite RO membrane. When treating surface water or municipal effluents, RO membranes, even with conventional pretreatment, foul very readily. This phenomenon is generally characterized by the formation of a dense layer on the membrane surface, comprising of an excess layer of dissolved organics and suspended organic matter near the membrane surface. The rate of fouling matter converges on it is directly proportional to the permeate flux. The rate of formation of a fouling layer and its bondage to the membrane surface depends, in addition to the flux rate, on the affinity of the membrane surface to the dissolved organic matter. Composite RO membranes, using the aromatic polyamide polymer, are strongly hydrophobic. Therefore, they are prone to high fouling rates and significant reduction in permeate flux, during the treatment of feed waters containing high concentration of organic matter. To significantly reduce fouling tendency, an LFC membrane was developed. The LFC is characterized by a low surface charge and a hydrophilic membrane surface characteristic [122].

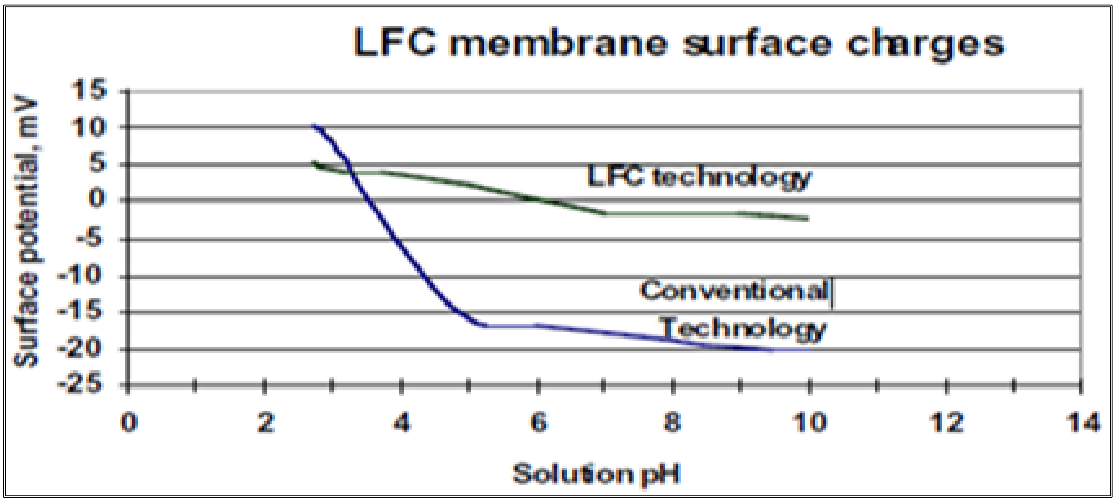



**Figure 2.4 The Difference Between The Surface Charge Potential Of A Conventional Composite Polyamide RO Membrane And The New LFC Membrane, Both As A Function Of P$^H$**

The surface charge of the LFC membrane is significantly less negative (more neutral) as compared to the surface charge of conventional composite membranes. This characteristic can be directly translated to the affinity of the LFC membrane to dissolved organic constituents.

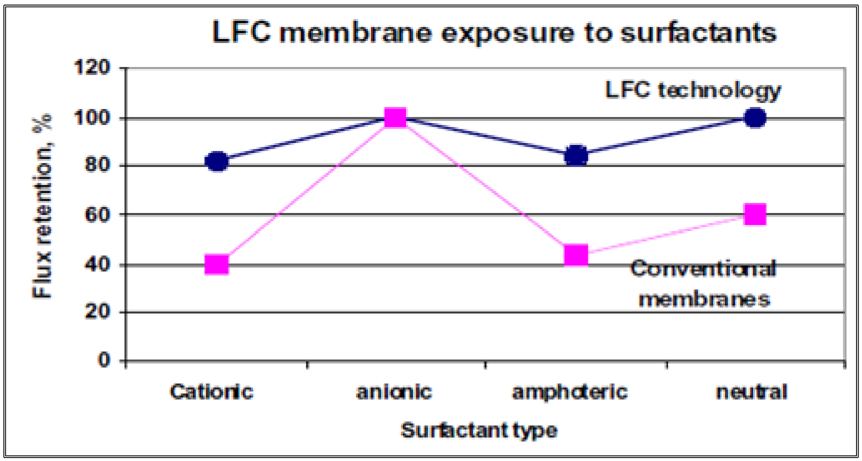



**Figure 2.5 LFC Membrane Exposure To Surfactants**

When subjected to a wide range of surfactants, the LFC retained its flux significantly better than conventional RO membranes. To confirm this observation, the LFC membrane was operated opposite a conventional low pressure composite polyamide membrane. Both membranes were subjected to municipal effluents treated by ultrafiltration capillary membrane technology at Water Factory 21, CA.

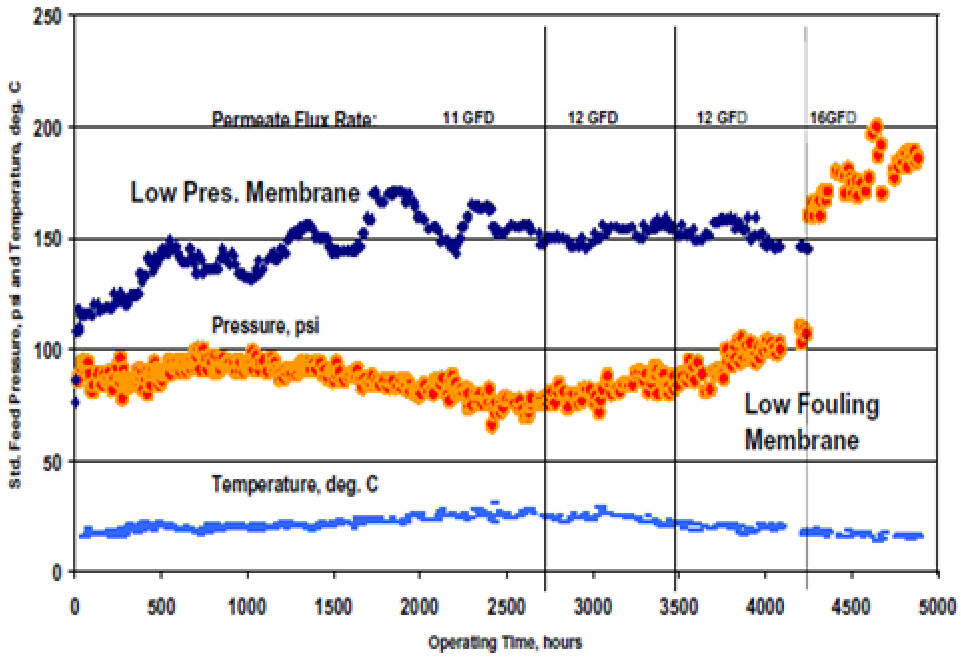



**Figure 2.6 The Operation Of Both Membrane Types With Respect To Feed Pressure And Temperature V/S Time**

(Source: New Membrane Research and Development Achievements)

The specific flux of the LFC is lower than the specific flux of the low pressure RO membrane; therefore the initial feed pressure was about 90 psi, which is slightly higher than the initial pressure of the low pressure membrane at similar operating conditions. The low pressure membrane permeate flux decreased very rapidly, almost doubling, within the first 2000 hours of operation. The feed pressure had to be increased from approximately 70 psi to more than 160 psi, to maintain a constant permeate flux of 10 gfd. The LFC membrane, on the other hand, operating at an even higher permeate flux rate of 12 gfd remained very stable at a level of 90-100 psi for the duration of the opera ting period.

## 2.6 LFC MEMBRANE EXPOSURE TO SURFACTANTS

Conventional membrane results point to the fact that the LFC membrane experienced little to no fouling when operated on municipal effluents, which are generally considered problematic for conventional RO membranes. The LFC membrane was not cleaned, during the 8 month operating period, due to the phenomenal performance stability. After the completion of field test, The LFC's resistivity to fouling was confirmed by testing the performance of the elements at standard test conditions. The results, depicted in table below, indicate that after 8 months of operation without any cleaning, the average flux decline was only about 10%-20% as compared to the ex-factory test data. After flushing the LFC membrane elements with a high $P^H$ cleaning solution, the permeate flux was restored completely, back to the original ex-factory values. The effective restoration of the permeate flux indicates a weak bonding effect between the dissolved organic matter and the membrane surface, a characteristic of hydrophilic surface character.

**Table 2.4 Performance Change Of 4 Inch LFC On UF Treated Municipal Effluent**

| | Flux, gfd | Flux, m3/d | Rejection, % |
|---|---|---|---|
| Ex-Factory | 2082 | 7.88 | 99.6 |
| After cleaning operation | 1578 | 5.97 | 99.6 |
| After cleaning | 1708 | 6.46 | 99.2 |

The following are the extraordinary benefits realized with the use of either technology as compared to conventional pretreatment:

- Significantly better Filtrate Quality — through the use of ultrafiltration membrane technology with respect to membrane chemistry and module design, the quality of the filtrate achieved is significantly better as compared to conventional pretreatment.
- Increased efficiency of RO system design and membrane operation. RO membrane operation is dependent on the quality of the filtrate produced by the pretreatment system. The better the filtrate quality from the pretreatment, the better the RO membranes will operate.

### 2.6.1 Sewage Treatment In Developing Countries

In many developing countries the bulk of domestic and industrial wastewater is discharged without any treatment or after primary treatment only. In Latin America about 15% of collected wastewater passes through treatment plants (with varying levels of actual treatment). In Venezuela, a below average country in South America with respect to wastewater treatment, 97 percent of the country’s sewage is discharged raw directly into the environment. In a relatively developed Middle Eastern country such as Iran, the majority of Tehran's population has totally untreated sewage injected to the city’s groundwater [Haughey, A. (1968)].The construction of major parts of the sewage system, collection and treatment, in Tehran is almost complete, and under development, due to be fully completed by the end of 2012. In Isfahan, Iran's third largest city, sewage treatment was started more than 100 years ago. In Israel, about 50 percent of agricultural water usage is provided through the reclaimed sewer water [58].

## 2.7 DEVELOPMENT OF ANALYSIS TOOLS FOR SOCIAL, ECONOMIC AND ECOLOGICAL EFFECTS OF WATER

A decisive factor to achieve a higher percentage of the water reuse is the establishment of effective incentives, which in many instances will be of either an economic or a regulatory nature. The limiting factor for the water reuse can in many circumstances be the quality of the water available linked to the treatment processes (technology) and potential hazards for secondary users. Its economic viability needs a careful cost-benefit analysis for various parties involved to be carried out. However, some water reuse implementation projects have failed because some other key factors, such as social awareness or associated ecological effects, were not accounted [264].

### 2.7.1 General Modeling Strategy

The formulations of modeling aspects are inspired by work done [205]. In overview, the modeling of any system occurs in five distinct steps (Murthy et al., 1990). Steps are to delineate the system being modeled as a functional specification. A quantitative understanding of the structure and parameters describing the process is required. Five steps for ideal strategy are:

- Functional process specification
- Select the modeling objectives
- Select model type
- Validation of the Model
- Model construction methodology
- **Modeling Objectives** - Any given process may have the different 'appropriate' models. These prior decisions about the model must be made before the model construction can start. Some of the more relevant objectives concern model purpose, system boundaries, time constraints and accuracy.
- **Model Purpose** - A wide variety of models are possible, each of which may be suitable for a different application. e.g., simple models which may be suitable for model-based control algorithms.
  - **Design** - Models allow exploration of the impact of changing system parameters and development of plants to meet the desired process objectives at minimal cost.
  - **Research** - Models serve as a tool to develop and test hypotheses and thereby gaining new knowledge about the processes.

## 2.8 WORLD WATER VIEW FOR REUSE OF WASTE WATER

### Table 2.5 Examples of Waste Water Reuse Experiments Around The World

(Source: [Asano (2001), US EPA (2004), Anderson (2003), Salgot and Tapias(2004) and Van Der Hoek (2004), NEWater (2002)] [17][18])

| Year | Location | Purpose / Usage | Year | Location | Purpose / Usage |
|---|---|---|---|---|---|
| 1912 | Golden Gate Park, San Francisco, California, USA | Water lawns and supplying ornamental lakes | 1976 | Orange Country Water District, California, USA | Ground water recharge by direct injection into the aquifers |
| 1926 | Grand Canyon National Park, Arizona, USA | Toilet flushing, lawn sprinkling, cooling water | 1977 | Dan Region Project, Tel Aviv, Israel | Ground water recharge and unrestricted crop irrigation |
| 1929 | City of Pomona, California, USA | Irrigation of lawns and gardens | 1984 | Tokio Metropolitan Government, Japan | Toilet flushing |
| 1942 | City of Baltimore, Maryland, USA | Metals cooling and steel processing at the Bethlehem Steel Company | 1985 | City of El Paso, Texas, USA | Ground water recharge by direct injection into aquifers and power plant cooling |
| 1960 | City of Colorado Springs, Colorado, USA | Landscape irrigation for golf courses, parks and free ways | 1987 | Monterey Regional Water Pollution Control Agency, California, USA | Monterey waste water reclamation study for agriculture-irrigation of food crops |
| 1961 | Irvine Range Water District, California, USA | Irrigation, Industrial and domestic uses, toilet flushing | 1989 | Shoalhaven Heads, Australia | Irrigation of gardens, toilet flushing in private residential dwelling |
| 1962 | La Soukra, Tunisia | Irrigation with reclaimed water for Citrus plants, reduce salt water intrusion into G.W | 1989 | Consorci de la, Costa, Brava, Girona, Spain, Northern Adelaide Plains, South Australia | Golf course irrigation<br>Class'A' water used to irrigate horticulture crops |
| 1968 | City of Windhaek, Nambia | Advanced direct waste water reclamation system to augment portable water supplies | 1999 | Willaunga Basin, Adelaide, South Australia<br>Mawson Lakes Reclaimed Water Scheme | Class'B' water used to irrigate premium quality grapes<br>A dual water reticulation system, recycled w.w used for toilet flushing, garden watering |
| 1969 | City of Wagga Wagga, Australia | Landscape irrigation of sporting fields, lawns cemeteries | 2000 | Rouse Hill Recycled Water Scheme | A dual water supply system, with the recycled w.w. used for toilet flushing, car washing and garden watering |
| 1970 | Sappi Pulp and Paper Group, Enstra, South Africa | Industrial use for pulp and paper processes | 2003 | Singapore | The 'NEWater' project provides safe, reliable source of high quality drinking water |

- **Process control** – Models allow for the development of new control strategies by investigating the system response to a wide range of inputs without endangering the actual plant.
- **Forecasting** – Models are used to predict the future plant performance when exposed to foreseen input changes and provide a framework for testing appropriate counteractions.
- **Performance analysis** – Models allow for the analysis of total plant performance over time when compared with laws and regulations and what the impact of new effluent requirements on plant design and operational costs will be.
- **Education** – Models provide students with a tool to actively explore new ideas and improve the learning process as well as allowing plant operators training facilities and thereby increasing their ability to handle unforeseen situations.

### 2.8.1 Wastewater Reuse In Australia

The scope for Australia to recycle water was first identified during 1977-78 in a report commissioned for the Victorian Government on potential for water recycling (GHD, 1978). This failed to attract the attention of the policy makers and hence had little impact until the 1980s, when issues of environmental health, sustainability, water availability and water quality for consumptive uses emerged as significant political issues [235]**.** Australia is currently experiencing highest ever amount of pressure on its water resources. It has been stated that **"substitution of water used in agriculture and urban irrigation with reclaimed water will free up water and help make appropriate allocations to the environment, thus ensuring good environmental condition for stressed water supplies"** [104]. Reclaimed water can definitely become major resource for the agriculture sector, since irrigated agriculture accounts for around 67% of Australia's total water usage (ABS, 2004). The practice of disposing municipal effluent to land at Melbourne's Western Treatment Plant, Werribee, has a history of more than 100 years[55].In the City of Wagga-Wagga, where the reclaimed water was being used in 1969, for landscape irrigation of sporting fields, lawns, and cemeteries [17]**,**water recycling received a greater push when the issues of environmental health, sustainability, water availability and water quality for consumptive uses emerged as significant political issues during the 1980s [235]. The Council of Australian Governments (COAG) reforms adopted in 1994 have further accentuated the importance of the water reuse, and have also resulted in attracting private sector investment in water infrastructure [55]. As a result, by 2001-02, more than 500 wastewater treatment plants were recycling some or all of their treated wastewater [197]. Sustainable practice in water management is being institutionalized within corporations, with government intervention [156].

Water recycling was brought within National Water Reform Framework in 2003. This framework is an inter-governmental agreement aimed to encourage water conservation in cities through better use of storm water and recycled water [120]. series of events in the late 90 's provided powerful incentives for cities and town to consider including water recycling in their water development plans and ultimately converged to accelerate the implementation of water recycling [56]. Australia is today a world leader in the use of treated wastewater. According to ABS (2004) data for 2000-2001, around 27 .8% (511.3 GL) of the total volume of effluent produced (1,837.2 GL) was reclaimed. However, because of differences in definitions, these estimates of reclaimed water use sometimes vary considerably [104]. With around 18% of water being directly reused [197], South Australia stands second after Victoria (45.2%) in the country (ABS, 2004), per capita, has the highest level of wastewater reuse in the country [57].

### 2.8.2 Feasibility Of Reclamation Of Water From Wastes In The Los Angeles Metropolitan Area

About 40 % of the sewage was wasted to the ocean from the Los Angeles area could have been economically reclaimed for beneficial purposes. The remainder of the sewage is of such poor mineral quality that economic reclamation is not feasible. Planned reclamation of water in Los Angeles Metropolitan Area can be accomplished at costs comparable to, or less than, the costs of present and future supplies imported to the area. The use of water so reclaimed for ground water recharge and certain industrial purposes would conserve high quality local and imported water for domestic supplies and repel sea-water intrusion into the coastal ground water basins would indirectly serve most beneficial uses.

### 2.8.3 Europe

Compared to other regions of the world, Europe has maximum plentiful water resources. However, droughts experienced in the early 90s and in 2003 changed the situation in Europe, resulting in growing water stress, both in terms of quantity and quality [113]. To counter water scarcity challenges, European Union and its member states have enacted the Water Framework Directive (WFD1) which highlights an integrated approach to water resources management. The WFD favor municipal wastewater reclamation and reuse to augment water supply and decrease the impact of human activities on environment [28].

### 2.8.4 Israel

Israel's national policy aims to gradually increase the fraction of reclaimed wastewater used instead of fresh water for agricultural use. This is reflected by the fact that Israel occupies second place in the overall wastewater reuse after California and has the highest percentage of wastewater reused for agricultural irrigation in the world [8]. It is estimated that by the year 2020, 50 % of agricultural water consumption will be provided by treated wastewater. The focus in Israel is directed towards maximizing saving or replacing freshwater for consumptive uses other than drinking.

### 2.8.5 Wastewater Reuse Criteria In Greece

Parameters that affect the wastewater reuse criteria in Greece are evaluated, concerning among others reuse priorities, available treatment plants and effluent characteristics and recommendations are made for developing future guidelines or regulations for Greece in relation to reuse practices (agricultural, urban, etc). The recommendations are presented in relation to the different types of reuse, with appropriate specific standards and recommended treatment systems wherever applicable. A mathematical model for activated sludge system was constructed based on ASM2. State Point Analysis was used to analyze condition of the Secondary Settling Tanks of the (Yinchuan) wastewater treatment plant [295].

### 2.8.6 Wastewater Reclamation And Reuse In France

Wastewater reuse is not widely applied in France, because water resources match most of the needs. Only 6 projects were there in operation in 1989. But more than 15 new projects were found to have been set up 7 years later. The enforcement of the recommendations of the Ministry of Health resulted in a slowing down of the development of wastewater reuse and the implementation of wastewater treatments - long residence time lagooning or chlorination and ultra violet radiations - providing water quality higher than required by the standards. France total annual renewable freshwater capacity is estimated equal to 185 Billion (Bn) $m^3$ but decreases to lower figures during dry periods. In the late 1980's wastewater reuse was limited to sewage farms of Achères and Reims, relics of the treatment practices of the XIX$^{th}$ century, and recently set up four small projects, three of which are located on islands off the Atlantic and Mediterranean coasts (Rodierand Brissaud, 1989).Despite the poor development of wastewater reuse, the Ministry of Health (MoH) started the elaboration of regulations on irrigation wastewater reuse in 1989.Guidelines issued in 1991 (CSHPF, 1991) are currently used as a provisional regulation [205].

### 2.8.7 Water Reuse Technology In South Korea

In South Korea, 73.2 percent of supplied water is discharged (16 million $m^3$/day) from municipal wastewater treatment plants. Calculation simply tells that 0.58 billion $m^3$/year can be available if only 10 percent of wastewater could be reused. The effluent of MBR satisfied the medium level water regulation in South Korean except total coliform and residual chlorine. The chlorine disinfection could easily satisfy the others. The residual chlorine in the regulation could limit the various alternated disinfectants. Water quality standards were suggested for the purpose of industrial cooling water generation from the wastewater in South Korea. The results of membrane technology trains with MBR-RO and MBR-NF suggested the NF had great potential for the water reclamation and reuse.

### 2.8.8 Agricultural Waste Water Reuse In Southern Italy

Within a strategic R&D project, since April 2002, membrane filtration, simplified treatments, storage reservoirs and constructed wetlands technologies are under investigation at field scale to evaluate their effectiveness for treating municipal effluents to be reused in the agriculture [3]. So far, the main results recorded have been the following:

**Simplified treatment** - In order to save the agronomic potential of organic matter and nutrients present in urban wastewater, olive trees were irrigated with effluents produced by skipping biological processes, resulted in a yield increase of 50%;

**Membrane filtration** - The microbial quality of treated effluents was higher than that of benchmark (i.e., local well-water conventionally used for irrigation). Total coliforms were the only microorganisms found on the irrigated crops (tomato, fennel and lettuce). Referring to soil contamination, particularly during summer periods, the irrigation with membrane filtered effluents caused an increase of Na+, Ca2+, EC, SAR and ESP.

**Storage reservoirs** - After appropriate storage periods: TSS, $BOD_5$, COD and nutrients concentrations achieved in force Italian limits for WW agricultural reuse; Pathogens indicators showed an average decrease of 2–3 log units; Salmonella, from a mean value of 28.2 MPN/100 mL decreased up to 4 MPN/100 mL; Helminth eggs, detected in inflow wastewater with an average value of 4.1/L, were not detected in outflow effluents

**Constructed wetlands -** Recorded average efficiencies for TSS, $BOD_5$, COD, TN and TP removal resulted 85%, 65%, 75%, 42% and 32%respectively. Microorganisms indicators showed an average decrease around 2 log units; Helminth eggs, detected with an average value of 12/L, were not detected in the effluent; Salmonella, found in influent with a mean value of 3 MPN/100 mL, was never detected in effluent.

### 2.8.9 Wastewater Use in Irrigated Agriculture: Management Challenges In Developing Countries

Cities in developing countries are experiencing unparalleled growth, rapidly increasing water supply and sanitation coverage, which will continue to release growing volumes of wastewater. In many developing countries, untreated or partially treated wastewater is used to irrigate the cities' own food, fodder, and greens paces. Farmers have been using untreated wastewater for centuries, but greater numbers now depend on it for their livelihoods. The diversity of conditions is perhaps matched only by the complexity of managing the risks to human health and environment that are posed by this practice. An integrated stepwise management approach is called for, one that is pragmatic in the short- and medium terms and that recognizes fundamental economic niche and users' perceptions of the comparative advantages of wastewater irrigation that drive its expansion in urban and peri-urban areas. Comprehensive management approaches in the longer term will need to encompass treatment, regulation and farmer user groups, forward market linkages that ensure food, consumer safety and effective public awareness campaigns.

### 2.8.10 Waste Water Reuse In India

For ages, the marginalized communities in India have relied on the indirect use of wastewater to grow vegetables, fruits, cereals, flowers, fodder [272]**.** In recent years, as a result of rapid population growth, massive industrialization and the growing number of cities that dispose of large amounts of sewage into bodies of water, the indirect use of wastewater has increased even further. Most wastewater irrigation, in the peri-urban and rural areas of India, occurs along the rivers that flow through such rapidly growing cities. The Musi River in Hyderabad is one such river, where around 250 households within the city use wastewater directly from drains or from the river to irrigate their lands [32].

One of the latest crises of modernity is water scarcity. It has been established that this crisis is not a true water scarcity problem but a crisis of governance [206]. More recently, wastewater management and use is considered seriously as an integral part of water management policy in many water-scarce countries. Wastewater from point sources, such as the sewage treatment plants and industries, provides an excellent source of reusable water and is usually available on a reliable basis, has a known quality, and can be accessed at a single point [52]. Urban wastewater use reduces the amount of waste discharged into watercourses and hence improves the environment. It also conserves water resources by lowering demand for freshwater withdrawal. The development of sustainable water reuse schemes often encounter technical, financial, commercial, regulatory, policy, social and institutional impediments [32].The potential benefits of water recycling, water conservation have been identified as two of the greatest challenges [52]. Most wastewater reuse studies in the past have adopted a scientific and biophysical approach [32] and the dearth of institutional studies using a combination of social, quantitative and qualitative methodologies impedes the formulation of recommendations that could enhance the benefits and ease the concerns of all groups involved with wastewater reuse.

#### 2.8.10.1 Status of wastewater generation and treatment in India

Urban centers in India lack infrastructure for sanitation and the wastewaters generated are not managed appropriately.[267, 268] The Central Pollution Control Board carried out studies to assess the status of wastewater generation and treatment in Class I cities (population > 100,000) and Class II towns (population between 50,000 and 100,000) during 1978-79, 1989-90, 1994-95 and 2003-04. The latest study indicates that about 26 254 million liters per day (Ml/d) of wastewater are generated in the 921 Class I cities and Class II towns in India (housing more than 70% of urban population). **There is urgent need to plan strategies and give thrust to policies giving equal weighting to augmentation of water supplied and development of wastewater treatment facilities.** The future of urban water supplies for potable uses will grossly depend on the efficient wastewater treatment systems, as the treated wastewater of upstream urban centers will be the source of water for downstream cities [189,191].

In India, as a result of rapid population growth and massive industrialization, the growing number of cities as well as large amounts of sewage is disposed into bodies of water. According to UNDP's World Water Development Report (2003), 70 percent of industrial wastes in developing countries are dumped into waters without treatment, polluting the usable water supply. Over the past two decades wastewater use in agriculture has increased significantly. With the growing population and increased industrial use of water, use of wastewater for irrigation is going to increase even further. But, these unregulated wastewater irrigation practices reveal a range of associated problems that outweigh the benefits. This highlights the failures of policies and lack of agricultural extension services.

### 2.8.11 Waste Water Reuse In Major Cities

Waste water reuse is already in consideration. Following are some references for reuse of waste water in India.

#### 2.8.11.1 Ahmedabad

Ahmedabad is a seventh largest city in India registering a population of 4519278 (census 2001). Population growth is result of natural increase in population, net migration and merging of adjacent areas to the municipal limits. The city lies in region of North Gujarat, which is dry and sandy. The sea is 80.65 km far, at the Gulf of Cambay. Sabarmati, one of the longest rivers of Gujarat, bifurcates the city into eastern and western parts. Though the river is perennial, it practically dries up in summer; leaving very little water. Major expansion in the textile industry boosted its development – once known as the "**Manchester of India**". The major strain was on water supply. There are a number of commercial establishments and private residences/societies with their own bore wells. Public water is supplied by the Ahmedabad Municipal Corporation (AMC), the Ahmedabad Urban Development Authority (AUDA). AUDA supplies only to those areas that fall within its town planning scheme. Although the supply of water has increased from 20.24 MGD in 1951 to 104.83 MGD in 2001,35 the per capita consumption has decreased. It is estimated that almost 80 percent of the water supplied for domestic use passes out as wastewater.

#### 2.8.11.2 Kolkata

The city limits expanded after Kolkata Municipal Corporation Act, 1983, was passed. River Hooghly flows past the western part of Kolkata. The demographic density during 1981 was 22,260 people per sq km; during 1991, this increased to 23,670 persons per sq. km in Kolkata. The residents get their water supply from the three main sources: The KMC, supplying treated water through an underground pipeline network. Roadside public bore wells dug by KMC. Innumerable private bore wells dug by the residents. The municipal corporation supplies about 750-800 MLD from its surface water sources and 136 MLD from groundwater [39]. Additionally, it also supplies 300 MLD of unfiltered but chlorinated water.

#### 2.8.11.3 Tamil Nadu

Waste stabilization ponds (WSP) have been used extensively all over Tamil Nadu over the last few years for the treatment of municipal and industrial wastewaters. Anaerobic WSP are single stage, continuous- flow, anaerobic reactors operating at ambient temperatures and low volumetric organic loading as a pretreatment method. On a wastewater management scheme, involving reuse for agriculture, the zero-energy demand of a waste stabilization pond series for effective removal of organic and microbiological loading under existing legislation and guidelines will remain a valuable tool for sustainable development.

#### 2.8.11.4 Wastewater Irrigation In Vadodara

Wastewater is gaining the popularity as a source of irrigation water in different countries around the world. Its economic benefits and its importance as a coping strategy for the poor have had little recognition. An interesting case study is presented for the rural areas downstream of Vadodara in Gujarat, India, where wastewater supports annual agricultural production worth Rs. 266 million. Both food crops and cash crops are irrigated by domestic wastewater and industrial effluent. In this area one of the most lucrative income-generating activities for lower social strata is the sale of wastewater (and renting pumps to lift it). The lack of alternative sources of water has generated viable markets for wastewater. Increased disposable incomes have resulted from the catalytic use of wastewater that was formerly not socially acceptable, i.e. the farmers considered it unhealthy and unclean. The use of the wastewater to grow food crops poses uncertain risks to the health of both consumers and those who actually handle the wastewater. [271]

### 2.8.12 Case Studies For Reuse Of Waste Water

Following are some reference studies, in which reuse of waste water is followed for different uses.

#### 2.8.12.1 Assessment Of Reclaimed Municipal Wastewater Application On Rice Cultivation

[77]The research was carried to assess the effects of application of reclaimed municipal wastewater on rice cultivation in Thessaloniki, Greece during a 2-year period (1999–2000). Effects on production cost, soil composition, and health risk were examined. A randomized complete block design was used for the paddy field with three treatments and four replicates. The treatments were (1) River irrigation water with N–P fertilization, (2) Reclaimed wastewater irrigation with surface N fertilization (3) irrigation with reclaimed wastewater irrigation without fertilization. The results showed that total production cost decreased 8.8%and 11.9% by applying the second and third treatments, respectively, compared to the first treatment, without significant differences in the agronomic and rice quality traits.

#### 2.8.12.2 Agricultural Waste Water Desalination By Reverse Osmosis

[90]In investigations made by the San Joaquin District of the California Department of Water Resources (DWR) on desalination of subsurface tile drainage water between 1976 and 1979. Throughout 1977, the RO plant was operated to supply product and brine waters for other activities at the WWTEF, and product water recovery was as high as 90 percent. Between May 1977 and August 1978, a silica solubility study and flow-reversal tests were run at the RO plant. Between August and November 1978, the 500-tube plant was reequipped with the new membranes, and from February to August 1979, a system optimization study was conducted at the plant in cooperation with UCLA. DWR personnel operated the equipment, collected the data, forwarded their findings to UCLA for analysis. Data obtained from the studies were used to develop a computer program that provided an optimization model of the 500-tube RO plant. The RO plant developed unstable operating conditions at recovery levels of about 95 percent because of low brine flow rates and extremely high brine concentrations. The flow-reversal procedure should be investigated as a means for reducing instability condition caused by the low brine flow and high brine concentration at very high recovery operation. The bench-scale IX tests indicated that RO brine TDS content ranging from 50000 to 60000 milligrams per liter was most suitable for regeneration of IX resins. Also, the effectiveness of calcium (Ca) removal from the feed water by ion-exchange was reduced considerably because of large amount of magnesium (Mg) present in the feed water. The regeneration with RO

process brine was shown to be technically feasible, offering an acceptable alternative to the conventional method of resin regeneration.

## 2.9 WATER SCENARIO IN INDIA

India is the 2nd country in the world having the highest amount of precipitation. In our country 85% of water is used for farming, 10% for industry and 5% for domestic use. The competition between these is increasing day by day. Due to increasing population and pollution due to human activity, the supply of water is reducing. As per the World Water Institute, India will be a highly water stressed country from year 2020 onwards. The meaning of water stress is **that less than 1000 cubic meter of water will be available per person per annum**(water scenario in India proceedings of Trombay symposium on desalination and water reuse, 2007). On an average the rainfall received in our country is 1200 mm, with maximum of 1100 mm in Cherrapunji and the minimum average rainfall in West Rajasthan of @ 250-300 mm.

The urban water supply and sanitation sector in the country is suffering from inadequate levels of service, an increasing demand-supply gap, poor sanitary conditions, deteriorating financial and technical performance. According to Central Public Health Engineering Organization (CPHEEO) estimates, as on 31stMarch, 2000, 88 per cent of urban population has access to a potable water supply. But this supply is highly erratic and unreliable.

### 2.9.1 Indian Water Technology Systems

In most of the cities, centralized water supply systems depend on surface water sources like rivers and lakes. Chennai, for instance, has to bring in water from a distance of 200 km whereas Bangalore gets its water from the Cauvery River, which is only 95 km away. Where surface water sources fail to meet the rising demand, groundwater reserves are being tapped, often to unsustainable levels. Delhi: The nation's capital is perpetually in the grip of a water crisis; more do during the dry season, when the situation gets particularly worse. As demand-supply gap widens, more groundwater is being exploited. Of the water supplied by the municipality, approximately 11 per cent comes from the groundwater reserves and remaining from the Yamuna River. It is, however, difficult to establish the total quantity of groundwater extracted because of a large number of tubewells (owned by individuals, industries and bottled water companies) remain unregistered. Chennai: The main sources of public water supply in the city are the three reservoirs – Poondi, Redhills and Cholavaram – with an aggregate storage capacity of 175 MCM. Even when the reservoirs are not full, they get inflows from intermittent rains. On the other hand, losses due to the process of evaporation from the reservoirs result in the effective availability being lower than the storage.

### 2.9.2 Bangalore

With a population of 5,686,000, Bangalore is India's fifth largest city. As per estimates of the Bangalore Water Supply and Sewerage Board (BWSSB), the total demand of water is 840 million liters per day (MLD) (assuming a population of 6 million and a supply rate of 140 liters per capita per day [lpcd]). The demand works out to be 1200 MLD, at standard rate of 200 lpcd set by the Bureau of Indian Standards (BIS) for water.

According to the latest census, India's population is about 1020 million, which is projected to go up to 1333 million by AD 2025 and further to 1640 million by AD 2050. It is projected that per capita water availability in India may reduce to about 1200 $m^3$/year by 2047.

### 2.9.3 Steps To Meet Water Requirements

Following are the steps to meet water requirement.

- Educate to change consumption and lifestyles
- Invent new water conservation technologies
- Recycle the wastewater
- Improve irrigation and agricultural practices
- Appropriately price the water
- Develop energy efficient desalination plants
- Improve water catchment and harvesting
- Look to community-based governance and partnerships
- Develop and enact better policies and regulations
- Holistically manage ecosystems
- Improve distribution infrastructure
- Shrink corporate water footprints
- Build international frameworks and institutional cooperation
- Address pollution
- Public common resources / equitable access

### 2.9.4 Application Of A Combined UF/RO System For The Reuse Of Filter Backwash Water From Treated Swimming Pool Water

Results are studied from the full-scale application of a combined ultrafiltration (UF) and reverse osmosis (RO) treatment process for reuse of spent filter backwash water (SFBW) from treated swimming pool water[75]. Ultrafiltration treatment showed a significant reduction of particulate matter. Turbidity decreased from values between 5 and 25 FNU in the feed (SFBW) to values below 0.02 FNU. At plant investigated in this study, filtration periods up to 90 min were achieved. With this configuration, efficiencies of more than 97% for the UF plant were obtained. In order to avoid an increasing concentration of salts and dissolved compounds, up to one-third of the UF filtrate was directed to the RO plant. As a result, there is no deterioration of the swimming pool water quality especially the concentration of disinfection by-products did not increase. The results of this study indicated an almost complete removal of particulate matter due to UF treatment. As a consequence of the accumulation of TSS, COD in the concentrate of the UF plant, respective threshold values of the German federal receiving wastewater utility regulation cannot be met, and either the discharge of concentrate into the sewer will be extra-charged or alternative disposal options must be considered.

### 2.9.5 A Mini-Review Of Modeling Studies On Membrane Bioreactor (MBR) Treatment For Municipal Wastewaters

[10]Membrane bioreactor (MBR) technology is a promising method for water and wastewater treatment because of its ability to produce high-quality effluent that meets water quality regulations. A mini-review of modeling studies on the application of MBR for the treatment of the municipal wastewaters was conducted to assess current MBR, modeling efforts. Models describing biomass kinetics in an MBR include the ASM model family, SMP model, ASM1-SMP hybrid model. The ASMs were developed to model the activated sludge process and their ability to accurately describe the MBR process that has not been verified by in-depth experiments. Research suggests that SMPs are important components in describing biomass kinetics due to the high SRTs in MBR systems. Accordingly, the SMP model demonstrated the capability of characterizing the biomass with a reasonable to high degree of accuracy. The modified version of ASM1 that incorporates SMPs

demonstrated fairly reasonable accuracy in quantifying COD and soluble nitrogen concentrations but underestimated MLSS concentrations.

The empirical hydrodynamic model is too simple to describe the membrane fouling phenomenon, and the sectional resistance model lacks accuracy. Both the fractal permeation model and resistance-in-series model by Lee et al provide good scientific insight, but specific experimental verification is necessary for general use of models. The resistance- in-series model developed by Winitgens et al. shows the most promise, as it is fairly accurate, accounts for cleaning cycles, and can predict permeability changes over time. Further tests are needed to determine whether the model requires calibration or if the model parameters are applicable to other MBR systems.

### 2.9.6 Baffled Membrane Bioreactor (BMBR) For Efficient Nutrient Removal From Municipal Wastewater

The feasibility of treating municipal wastewater [142] was examined by a baffled membrane bioreactor (BMBR), particularly in terms of nitrogen removal. Submerged membrane bioreactors (MBRs) are now widely used for various types of wastewater treatment. One drawback of submerged MBRs is the difficulty in removing nitrogen because intensive aeration is usually carried out in the tank and the MBRs must therefore be operated under aerobic conditions.

To examine the applicability of BMBR, pilot-scale experiments were carried out using real municipal wastewater. Although neither external carbon addition nor mixed liquor circulation was carried out in the operation of the BMBR, average removal rates of total organic carbon (TOC), total phosphorus (T-P) and total nitrogen (T-N) reached 85%, 97% and 77%, respectively, with the hydraulic retention time (HRT) of 4.7 h. It was found that denitrification was limiting step in removal of nitrogen in the BMBR in this study. Various types of monitoring carried out in the BMBR also demonstrated the possibility of further improvements in its performance Nutrient removal by the BMBR was more efficient than that by other MBRs previously reported, despite the fact that the feed water in this study was ‘‘weak’’ wastewater with a low concentration of organic carbon, which is considered to be disadvantageous for the denitrification process. Without adding the external carbon, concentrations of T-N and T-P in the treated water could be continuously lowered to

0.5 and 0.1 mg/L within a HRT of 4.7 h, respectively. Even when the BMBR was operated under relatively low temperatures (10–15$^0$C), the reactor continuously showed good performance, which indicates the reliability of the reactor.

### 2.9.7 Integrated Water Resource Management Model For Process Industry In Lithuania

A structured ‘‘integrated water resources management’’ (IWRM) model [135], for the water management is a useful tool for research into complex water using production systems in industries.

The comparative analysis of water usage in industry has revealed that Lithuanian enterprises use 3 x $10^5$ (in some cases 10) times more water per unit of production compared to best examples from other parts of the world. This is especially true in the textile, pulp and paper, metal processing, chemistry and food industries. The IWRM model is useful to assess and systematically evaluate ways of reducing freshwater usage and opportunities for wastewater reuse. By applying this model to the enterprise there are possibilities to create various scenarios for the optimal management of water resources within single production processes or within the entire multi-process system of the entire company.

IWRM helps in water savings of 52% per ton of product. In the case of a small textile enterprise, water savings of 62% were calculated. By applying the IWRM model under free market conditions, the industrial company gains by: a) optimization of freshwater usage in technological processes; b) improving the choice of optimal production modes; and c) forecasting freshwater rates and wastewater quantities.

### 2.9.8 Comparison Of Tertiary Treatment By Nano filtration And Reverse Osmosis For Water Reuse In Denim Textile Industry

The wastewaters resulting from different baths of a dyeing factory specialized in denim fabric are collected and treated by an activated sludge plant. This study investigated coupling of activated sludge treatment with either nanofiltration (NF) or reverse osmosis (RO) to recycle water and reuse it in the process. NF experiments were first conducted with a HL membrane in different configurations: dead end and cross flow for flat sheets and also in spiral wound form. Results on water permeation and salt rejection show that performances are configuration dependent.

For the study of the NF/RO textile waste water treatment, experiments were conducted with spiral wound membranes in order to be closest to the industrial configuration. After analyzing the removal efficiencies of suspended solids and chemical oxygen demand (COD) of treatment plant, experiments were conducted using an HL2514TF spiral wound membrane preceded by ultrafiltration (UF) treatment, RO membrane (AG2514TF) to compare performances in water yield and quality for the same pumping costs.

The results show that NF allows higher yield, while respecting the Tunisian standard of water reuse (COD< 90mg L−1). Above 9 bar, the TDS rejection reaches 60% and the hardness is lower than the factory constraint (100mgL−1 CaCO3), allowing reuse of the water in the process. The tests with the Sepa CF cell allow one to achieve higher performances in terms of water permeation and salt rejection. The NF experiments conducted with the HL 2514 membrane showed that 11 bar is a suitable operating pressure. It allows a yield of9%and a COD reduction and TDS rejection of 62%, values in conformity with the Tunisian water reuse standards.

### 2.9.9 Removing Of Urea And Ammonia From Petrochemical Industries With The Objective Of Reuse, In A Pilot Scale

Seyed Ahmad et.al., 2010 designed a pilot plant was based on five stages: two aerobic, two anaerobic and sedimentation. When the pilot was installed the connections for loading and circulation were made. After installation of the pilot the recycling operation of sediment sludge from the bottom of the settler to the aerobic vessel was started. Since this sludge contains active microorganisms, it could enhance the efficiency of purification process in comparison with those without active sludge. Sampling from vessels was done every two days, and tests were made for measurement of total alkalinity, ammonia, ammonium ion, suspended solids, COD, nitrogen dioxide and acidity, in which after 30 days from the first circulation, the samples were found to be without ammonia or its derivatives. The trend of ammonia changes throughout the different stages is like the TA changes. Hence, wastewater ultimately will be free of ammonia contamination as a result of the complete ammonia changes (100%) in the second aerobic sampling vessel The removal and purification of the system is highly dependent on the $P^H$ changes. $P^H$ parameter changes along with TA and ammonia parameters change and will increase to less than 8.3 after the removal process.

## 2.10 WASTEWATER RECYCLE, REUSE, AND RECLAMATION OF DOMESTIC WASTEWATER

The summary of reuse of waste water in the world is presented over here in different countries.

### 2.10.1 USA

The city of Altamonte Springs, near Orlando in Florida, USA has a long established sewage reuse scheme for non-potable residential and other uses, through dual reticulation systems [209]. The incentives to build reuse scheme came from concerns about maintaining the quality of the lake which received the treated wastewater of the city, and from the need to limit withdrawals of potable water from the Central Florida groundwater aquifer. Wastewater for the reclamation is withdrawn from the isolated sewer lines collecting wastewater predominantly from residential sites. It is low in salinity. The treatment train includes:

- Primary sedimentation tanks
- Secondary biological treatment which includes nitrification systems
- Chemical coagulation, filtration, reaeration and high-level disinfection
- Polishing for dechlorination and $P^H$ control
- Trenchless technology was used to retrofit the city with small-diameter pipes for delivery of reclaimed water

This scheme serves a population of some 45,000 people, and the reclaimed water is used for the irrigation of lawns in industrial, commercial and public buildings (including the grounds of a public hospital), as well as open space irrigation. Some of the reclaimed water is being supplied to office and apartment buildings for toilet flushing, once through cooling in industries. The water is also used for water level control in the lake, automobile washing, public fountains and water falls. About 30–40% of the total water use is provided by the dual reticulation system, which produces about 45 Ml per day of reclaimed water. Extensive public consultation combined with a mixture of forceful advocacy on the part of city’s water supply authority has resulted in a general public acceptance. The city ordinance was amended to enforce compulsory connection to reclaimed water distribution network. Initial apprehensions about public health risks proved to be misplaced, as no public health impact had been detected in the first six years of operation from 1989 to 1995.

### 2.10.2 Japan

Japan has a long history of planned wastewater reclamation and reuse, the first of which dates back to 1951, when secondary treated effluent of the Mikawashima wastewater treatment plant in Tokyo was experimentally used for paper manufacturing in a paper mill nearby. Today, Japan has well developed policies and programs for wastewater recycle and reuse, to promote water pollution control, environmental protection, and amenities for urban environment. Treated wastewater has also been used for washing passenger trains, and as plant water in solid waste incineration plants. The water reuse projects are favored as they stimulate private sector investment in such works as installing drainage and flush-toilet facilities, thereby creating economic side benefits.

### 2.10.3 Tokyo

The water demand for this newly developed business district has been largely coped-up with the supply of reclaimed wastewater through a dual reticulation system. Secondary treated wastewater forms the influent to the water recycling system. The recycling system is made up of rapid sand filters, pumping facilities, force mains, recycling center that house distribution reservoir and distribution pump, distribution network. The Shinjuku water distribution center is located in the basement of a hotel. Because of its location, noise, odor and other nuisances are strictly controlled. The system supplies reclaimed water to the 19 high-rise buildings that house commercial and office premises, up to a daily maximum of 8000 KL, since 1991. The Tokyo Metropolitan Government, in an effort to promote water conservation, and wastewater reclamation, introduced increasing block rate structure of water and waste charges. All new buildings were requested to provide dual system, for the use of reclaimed water. By setting up 20% lower water charge for the reclaimed water; its use has been encouraged. The Fukuoka city comprises a population of over 1.3 million, and covers an area of about 340 sq.km. Due to the non-availability of stable water source either through large rivers or groundwater, for domestic and industrial water supply, the Fukuoka City Council started vigorously promoting a water conservation plan since 1979, which included wastewater reclamation and reuse. The city reclaimed water supply amounting to 4500 KL per day in 1995, is planning to achieve the rate of 8000 KL/day by the end of the century.

### 2.10.4 Australia

Recycling reclaimed water and storm water for residential non-potable uses has been estimated to have potential to reduce residential water demands by an average of 40—50% in most Australian cities. There are many pilot scale dual reticulation schemes in Australia. Social surveys conducted in Melbourne indicated that people support recycling of bathroom and laundry wastewater. In Western Australia, domestic gray water reuse has been an accepted option for future urban expansions. Commercial scale systems have been installed in Rouse Hill, a suburban area near Sydney, and New Haven in South Australia. The Rouse Hill scheme is Australia’s first full-scale application the domestic non-potable reuse through a dual reticulation system.

## 2.11 HYDRANUTICS DESIGN SOFTWARE

Since its founding in 1975, Hydranautics has been committed to the highest standards of technology research, product excellence, customer satisfaction. Hydranautics entered the reverse osmosis (RO) water treatment field in 1970, and is now one of the most respected and experienced firms in the membrane separations industry. Hydranautics became part of the Nitto Denko Corporation when it was acquired in 1987[120].

Hydranautics software is continuously involved in research and technology, result of which is ongoing development of a range of specialized membrane products. Hydranautics' products are currently in use for diverse applications as potable water, boiler feed water, industrial process water, wastewater treatment, surface water treatment, seawater desalination, electronic rinse water, agricultural irrigation and pharmaceuticals.

Hydranautics is first membrane manufacturer to meet the highest quality standards with ISO 9001 Quality System Certification.

Hydranautics, membrane separation technology, provides two software programs:

- IMSDesign - a comprehensive software design program that allows the user to design a membrane system using Hydranautics' membranes.

  Hydranautics, offers latest comprehensive system design software package. The realistic expectation of the performance over time and under a variety of conditions is clearly demonstrated. Parameters such as salt passage increase and flux decline due to fouling are easily accessible to the user - not obscured within the framework of the program. IMS Design gives users complete control over the information used in the membrane selection process. This control assures user full confidence in the projected performance of any Hydranautics membrane.

- RO Data - an easy to use the normalization program that tracks the performance of any RO system to assure optimum performance.

It tracks RO system performance and specifically designed to be a user-friendly interface for RO system operators. RO Data for Windows is a powerful RO normalization program. The program allows users to input, edit, display, print reference, operational and normalized data tables. Graphs of operational and normalized parameters can be displayed and printed from these tables or the data can be exported to MS EXCEL spreadsheets for developing custom graphs. To assure the highest standards of data integrity, normalization program is in compliance with ASTM Standard D 4516-85, "Standard Practice for Standardizing Reverse Osmosis Performance Data."

## 2.12 ENERGY CONSERVATION IN WASTEWATER TREATMENT FOR AGRICULTURAL REUSE, RESOURCES AND CONSERVATION

A study was conducted [22] which prepares the ground for energy savings at the treatment plants themselves. The study consisted of two parts: a survey of different types of the treatment plants and a more detailed analysis of an activated-sludge and an aerated-lagoons plant. Results show that energy utilization ranges from 140 to 800 W h/m$^3$ and a properly managed activated-sludge plant can spend less energy than an aerated-lagoon plant.

A possible reduction of 20% in plant energy utilization may bring about up to 8% reduction in the effluent cost and promote its agricultural application. A total of 100 million m$^3$/y of wastewater is now being treated in Israel consuming 20 million kW/h of electricity per year. By the end of this decade 300 million m$^3$/y will be undergoing treatment demanding 80-100 kW h/y. Due to problem of water scarcity in Israel, most of the effluents will be recycled for agriculture use. Results show that energy utilization in plants falls in the ranges of 40-800 W h/m$^3$ and 0.53-2.8 kW h/kg BOD removed. Aerated lagoons generally utilize 350-400 W h/m$^3$ while for activated sludge the range is 600-800 W h/m$^3$.

Facultative recirculation ponds and trickling filters plant investigated utilized only 160-170 W h/m3. Economic calculations show that the energy cost of recycled effluents for irrigation is about 30-40% of the total; the above 20% reduction means a 6--8% reduction in water cost, which will result in significant savings for the farmer.

### 2.12.1 Management And Reuse Of Local Water Resources In Residential Developments In Adelaide

Water sensitive urban design (WSUD) typifies an approach to the planning and design of urban development which seeks to integrate the urban water systems with natural systems associated with the hydrological cycle; (Annette B. Barton , 2005)it aims to replace wasteful and environmentally harmful conventional water management practices with methods which are more sustainable and ecologically compatible. WSUD has two broad divisions: Storm water management which focuses on flood control, pollution control and water harvesting (or reuse); wastewater management - which focuses on "on-site" (or local) treatment and reuse. In the area of residential development, some effort has been made to apply WSUD principles, particularly in the area of storm water quantity and quality management, but reuse of storm water and wastewater has not been so actively pursued. In 1997 the Brisbane City Council commissioned the case study into water sensitive urban design, which had as its key objective: a comparison of lot yield, construction cost, maintenance cost and environmental implications of a 'conventional' and 'water sensitive' design layout for a parcel of land of approximately 3.3 hectares in area. (McAlister, 2000) The study, undertaken by WBM Oceanics Australia, has been reported in McAlister (1997a) and McAlister (1997b). It involved application of WSUD principles to a site, adjacent Bulimba Creek, for which a conventional design had already been undertaken and partly completed. WSUD Best Planning Practices and Best Management Practices were reviewed and shortlisted, by multi-disciplinary study team, and a site layout developed. Features of the WSUD design included: 40 allotments with an average size of approximately 590 $m^2$;rooftop runoff disposal using on-site rainwater tanks overflowing to on-site infiltration trenches which overflow to the street; 'Mini' roadside detention basins, leaky wells; a larger 'bottom of the catchment' detention basin overflowing to the creek.

### 2.12.2 Status of Surface and Ground Water Resources in Gujarat

Gujarat's total water resource potential is 50,000 MCM (Million Cubic Meters) of which the surface water is about 38,000 MCM (76 percent) and groundwater is about 12,000 MCM (24 percent).The groundwater resources of Gujarat are hardly one fourth of the total water resources. The over exploitation of groundwater, in terms of both magnitude and intensity, not only depletes the water tables and increases per unit cost of water supply, but also leads to deterioration of the water quality. This is occurring mostly in the alluvial areas of North and Central Gujarat. There has been a decline in the total utilizable groundwater, from 17365.40 MCM in 1984 to 12848.27 MCM in 1977.

The polluted water reduces net utilizable safe water and aggravates the problem of water scarcity in Gujarat. The Gujarat Ecological Commission (2005) report observes: "The six corporation cities of the state release about 933 million liter per day (MLD) of waste water into rivers, while other towns release about 1400 MLD. The core principle of its water policy is "**user pays, polluter pays.**" And this policy works well in South Africa. Mexico dared raise water rates (water fees) and as a result, now it generates revenue more than US $ 1 billion (Rs. 47,000 crore) annually. This has enabled the Mexican water institutions to invest in managing and upgrading their water infrastructure.' [92, 93]In Gujarat, as in India, water charge for canal irrigation is not based on the volume of water used by the farmers, but charged at flat rate. In the absence of volumetric water charge, farmers have little incentive to value and use water efficiently. Also, the subsidized electricity charges tempt the farmers to exploit and overuse water. This also leads to the problem of water logging and shift in the nature of crops to water based ones, which sometimes do not suit the geo-climatic conditions of the land. Also, this not only depletes the water tables, but also compels to use the depleted water, which exerts a heavy burden both on the exchequer and the power sector of Gujarat.

## 2.13 GUJARAT'S WATER SECTOR

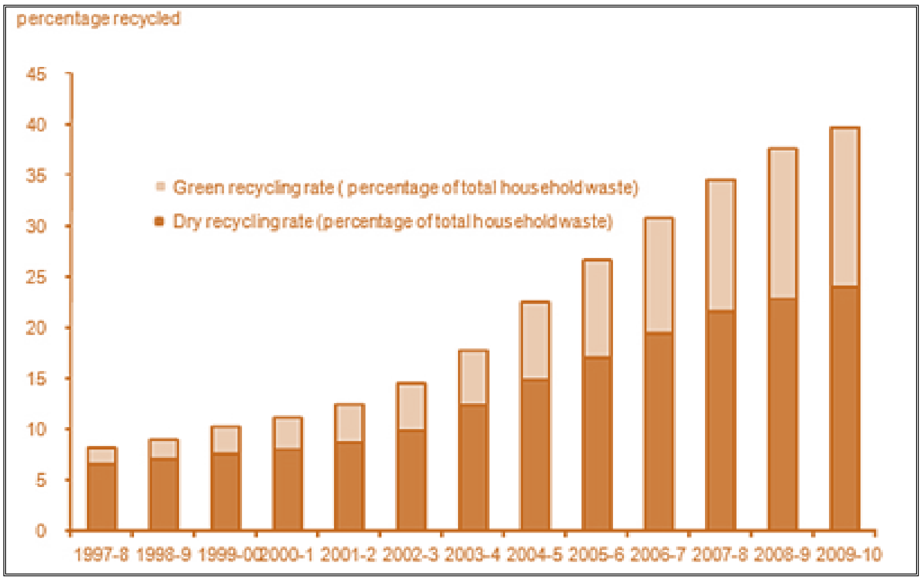



**Figure 2.7 Statistics Of Recycling Of Waste In Gujarat**
(Source: Waste Data Flow)

While south Gujarat has abundant water resources, north Gujarat, Saurashtra, Kutch are water-deficient areas. The share of groundwater in the total supply is projected to decrease in the future as large surface water schemes are commissioned, most notably the Sardar Sarovar-based Narmada Main Canal. Even after accounting for the availability of ground and surface water, a significant shortfall in water supply is expected which it is possible to meet by water conservation and recycling activities. The shortfall in urban areas is even more critical, requires substantial investment to develop new sources of water and strengthen the water supply distribution network. The demand for drinking water in the six municipal corporations is projected to outstrip supply by 986 mld, calling for investment of Rs 8609 million by 2010. Additional investments are also required to rehabilitate the existing distribution network [78, 79].

## 2.14 FUTURE DIRECTIONS FOR WATER REUSE

In many parts of the world, agricultural irrigation using reclaimed water has been practiced for many centuries. Landscape irrigation such as irrigation of golf courses, parks, playgrounds has been successfully implemented in many urban areas for over 30 years. Salt management in irrigated croplands may require special attention in many arid and semi-arid regions. Beyond irrigation and non-potable urban reuse, indirect or direct potable reuse needs careful evaluation, close public scrutiny. It is obvious from public health and acceptance standpoints that non-potable water reuse options must be exhaustively explored prior to any notion of indirect or direct potable reuse.

Groundwater recharge with reclaimed water and direct potable water reuse share many of the public health concerns encountered in drinking water withdrawn from polluted rivers and surface water reservoirs. Three classes of constituents are of special concern where reclaimed water is used in such applications:

- enteric viruses and other emerging pathogens
- organic constituents including industrial, pharmaceutical chemicals, residual home cleaning and personal care products and other persistent pollutants
- salts and heavy metals

The ramifications of many of these constituents in trace quantities are not well understood with respect to long-term health effects. For example, there are concerns about exposure to chemicals that may function as the endocrine disruptors; also the potential for development of antibiotic resistance is of concern. As a result, regulatory agencies are proceeding with extreme caution in permitting water reuse applications that affect potable water supplies. Figure below shows typology of waste water usage for all purposes [14].

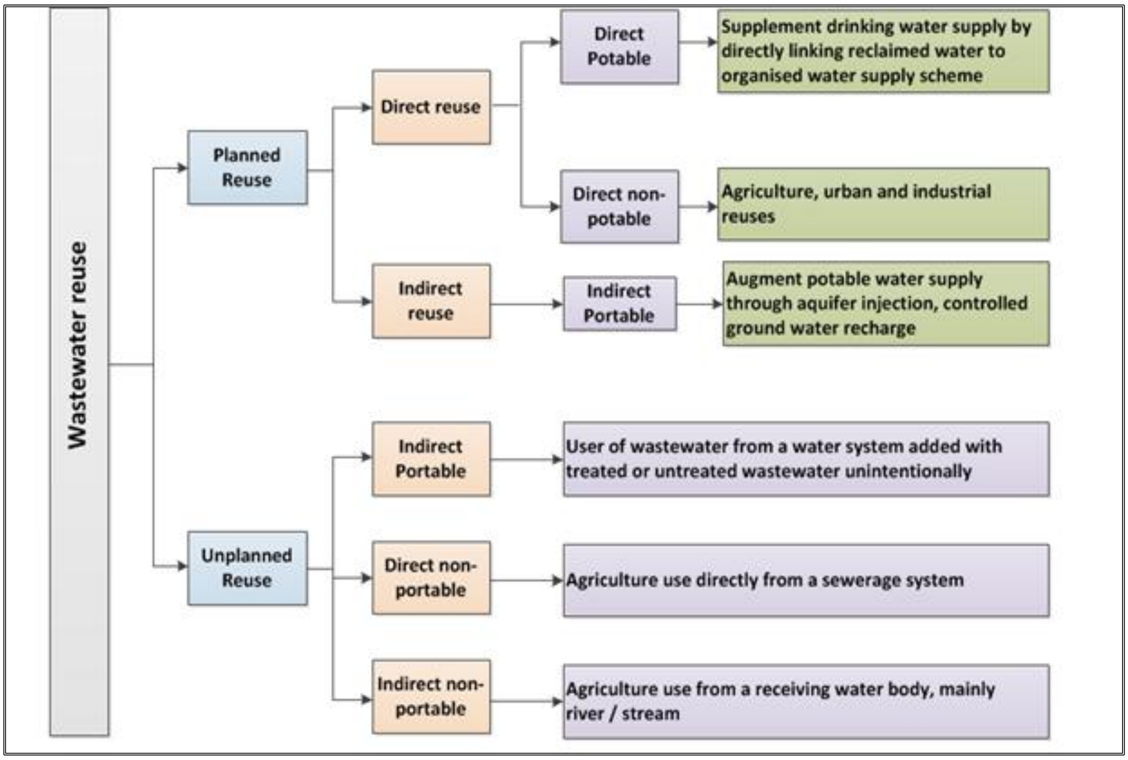



**Figure 2.8 Typology Of Wastewater Usage For All Purposes**

(Source: Anderson (2003), Salgot and Tapies (2004) and Van der Hock (2004))

## 2.15 IDENTIFYING THE GAP BETWEEN WORK DONE AND THE RESEARCH WORK

The provision of safe and adequate drinking water to all in an equitable manner is a complex issue. "In the past 75 years, 26 years were declared as drought years in Gujarat. The State government spends about 125 to 150 crore rupees annually on making the emergency arrangements for drinking water to overcome the scarcity.

"The People spend about Rs. 700 to 800 crore, on water and the social cost of paucity of water is estimated to be Rs. 2000 crore per annum." [92, 93] 75 percent of the water needs are met through the groundwater. "The Gujarat Water Supply and Sewerage Board (GWSSB) has declared more than75 percent villages in State as ***'No Source Villages'*** implying villages with no dependable or sustainable source of water" [111]**.** As per the Urban Progress Phase III, Ahmedabad drew about 432 million liters per day (MLD) in 2002 for citizens.

The water was supplied at a rate of 135 lpcd and 76 percent of city's households were provided with individual taps. This depleted the groundwater table at an annual rate of 2 to 3 meters. This provision has now increased to 160 lpcd with water withdrawal of 650 MLD.[9] The slum dwellers and urban poor, who do not have water tap connections, have to be satisfied with inferior quality of water at a relatively higher price. [282] The measures like transfer of water from water surplus areas by Sardar Sarovar Project, interlinking of State's rivers and the Water Supply Grid for Gujarat, Sujalam SufalamYojana, check dams and rainwater harvesting schemes and the Regional Water Supply Schemes for rural-urban areas, are not adequate to reach some parts of Saurashtra and Kutch and to assure safe and adequate drinking water for all in an equitable manner [93, 94, 95, 96, 97].

There is a considerable gap between the supply and demand for water in the State. The supply of water was estimated at about 800 MCM/year in 2025 against the demand of water at around 1462.2 MCM/year. The water deficit would be about 662.2 MCM/year (TAHAL Committee report of the Government of Gujarat).

A literature review shows the following research gaps:

- To identify opportunities and constraints to reuse of waste water

- Providing flexibility for individual industries to vary the requirements to suit local circumstances of affordability and risk
- Need for a uniform approach to assess the feasibility of reuse
- Test commercial feasibility for the wastewater treatment and recycling
- Lack of decision support tools to efficiently allocate water and wastewater resources among different sectors

With issues of climate change, increases in urban population and increased demand for water from competing sectors, wastewater reuse is becoming an important strategy to complement existing water resources for both developing and developed countries and there are lessons, experiences, data and technology that can be shared for mutual benefit. With the aim to avoid water scarcity condition in central Gujarat region, the present study is undertaken. Here mainly two treatment plants are observed closely to identify possibilities of reuse of waste water which can prove techno economical solution for the nearby area. The testing is done at small scale to recommend it on a larger scale and proved a promising solution to meet with the current requirements of water usage [159].

One model is stated here which explains the process of ongoing development of waste water reuse.

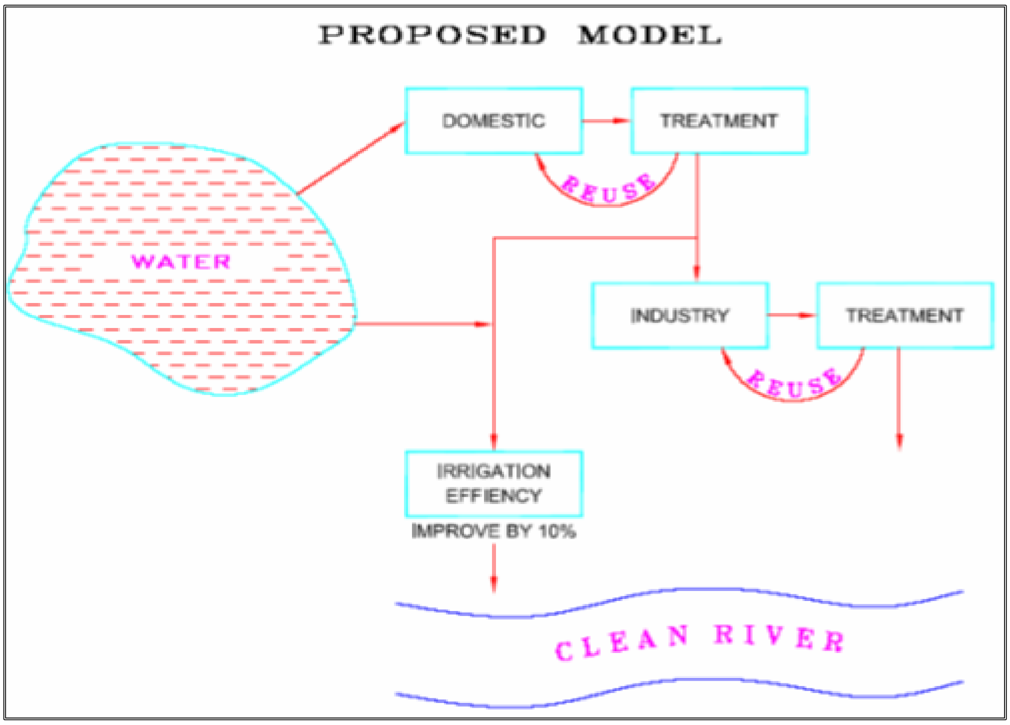



**Figure 2.9 Options For Industrial & Municipal Wastewater Reuse**
(Source: Crook J 2005. The ongoing evolution of water reuse criteria. James Crook)[45, 31]

This model shows the path for exploring options for reuse of industrial and municipal waste water for which study has been carried out.

In the first case study, three treatment options are tried and one is suggested as techno economical solution which can save freshwater quantity. CETP waste water shows results in desirable limit that meet with standards for reuse, after treatment of reverse osmosis. If these proposed plants are constructed, then it will prove a solution for industries or farmers to get water. It will save considerable amount of freshwater quantity which may be utilized for potable purposes.

# 3. DATA COLLECTION

## 3.1 DATA COLLECTION

Systematic data collection helps for effective outcome of research work. Record of the data helps to identify the characteristics of the selected plant. In the present work, the selection is done as follows:

- Out of the total available domestic effluent plants in Central Gujarat, the Atladra Sewage Treatment Plant, Vadodara City, is selected looking at the availability of the data of last 9 years.
- Also CETP, village Umaraya, Tal. Padra is selected for industrial wastewater reuse looking to the performance of the plant, which shows the promising quality of the waste water which can be reused.

From the state water data center, Gandhinagar the data for rainfall of different cities is selected. The population data is collected from the population research center, The M.S. University of Baroda.

Following are the details for the data collection and duration. The data collection is attached in CD (soft copy) along with thesis for reference. The parameters of domestic sewage treatment plant are provided by Vadodara Municipal Corporation. The parameters of Common Effluent Treatment Plant are collected from Environ Infrastructure Cooperative Private Limited.

## 3.2 DATA COLLECTION AGENCIES

In below table the names of agencies are listed, from which data collection has been made.

**Table 3.1 Data Collection From Various Agencies**

| Type of data | Duration | Agency from which the data is collected |
|---|---|---|
| Characteristics of the Domestic Sewage Treatment | 2003 to 2011 | Sewage Department, Vadodara Municipal Corporation |
| Population Data For Central Gujarat | 1960 to 2010 | Population Research Center, Science Faculty, M.S.University of Baroda. |
| Rainfall Of Cities Of Central Gujarat | 1960 to 2010 | State Water Data Center, Gandhinagar |
| Characteristics Of The Common Effluent (average) | 2001 to 2011 | M/S Environ Infrastructure Co. Ltd. |

The domestic sewage treatment plant is located in Atladra, on the downstream side of which many industries are located that face water problems for industrial purpose. The present study has been carried out to find the suitability for reusing the treated effluent from the sewage treatment plant and for some of the waste water from industries, located towards the downstream side of the final disposal point of domestic sewage treatment plant. There are industries located in nearby area facing water shortages. They purchase fresh water every day for the industrial process. Considering the fact that the domestic effluent treatment plant, that has sufficient quantity of water to supply for industrial purpose, the treatability studies were tried on treated wastewater of plant and the findings are discussed with techno economical solution.

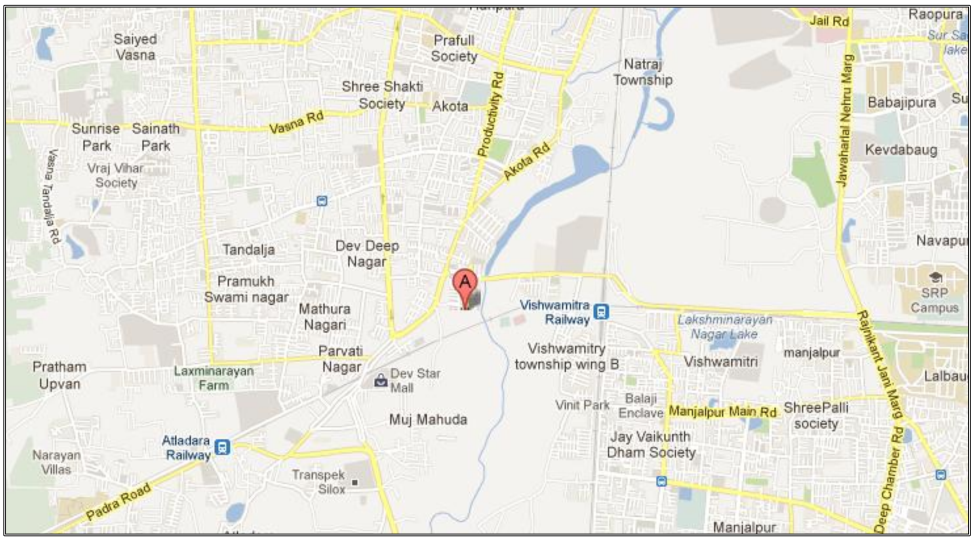
## 3.3 CASE STUDY 1: DOMESTIC SEWAGE TREATMENT PLANT

Following are the basic details of selected plant. The recent trend towards the use of reclaimed municipal wastewater for purposes such as landscape, various non-potable industrial, food crop irrigation, ground water recharge and recreational impoundment often requires tertiary or advanced wastewater treatment.

### 3.3.1 Preamble: Case Study 1

The domestic sewage treatment plant is selected based on grab sampling. The characteristics of last 9 years are studied and the step wise experimental work and treatability studies are stated in Chapter 4. The Domestic effluent treatment plant is located nearby Atladra, as shown in the figure 3.1.

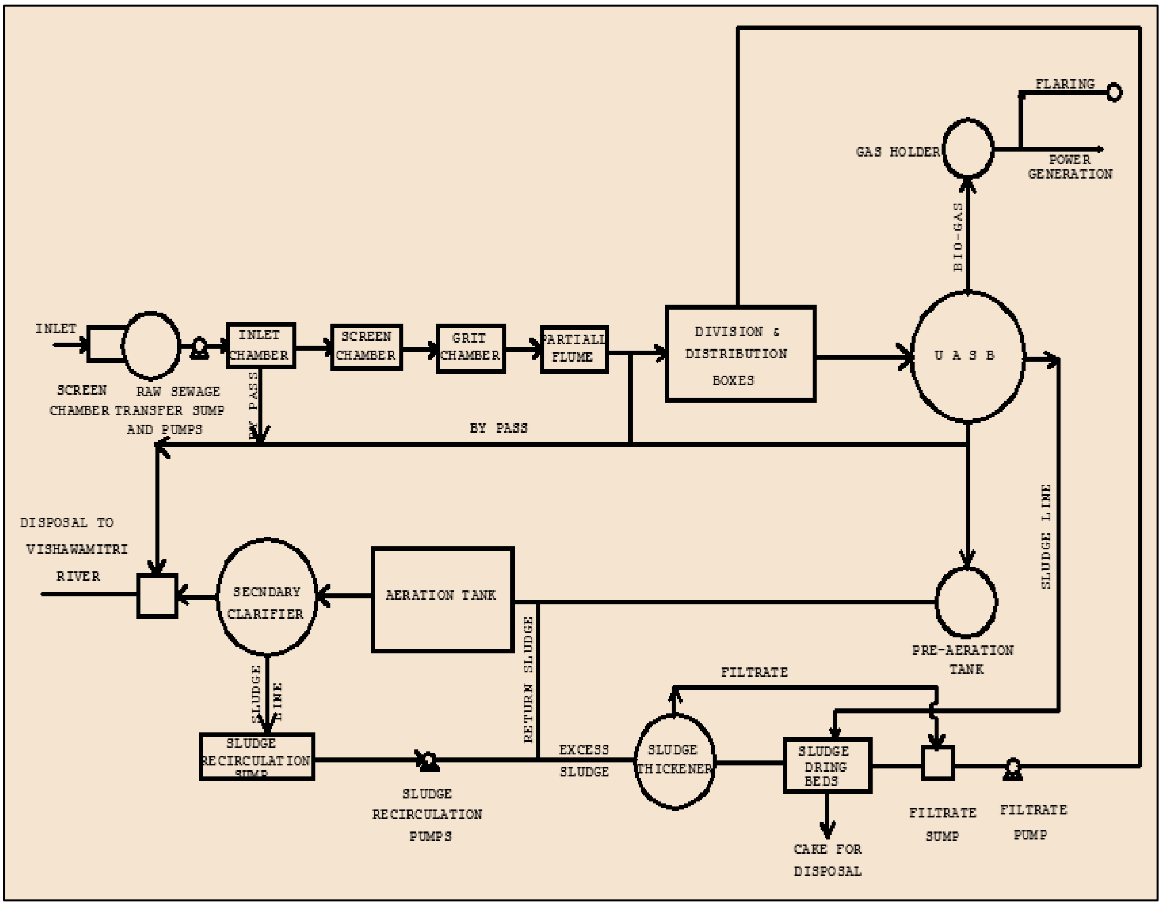
Water reuse applications result in exposing the public reclaimed wastewater, thus assurance of microbiological and particularly, virological safety is of utmost importance. The principal treatment processes and operations for reuse in these situations are similar to surface water treatment for potable water supply; both normally include chemical coagulation, sedimentation, filtration and disinfection. The high degree of pathogen removal achieved by a properly operated treatment system ensures the safety of the reclaimed wastewater.




## Figure 3.1 Location Of Domestic Sewage Treatment Plant

## 3.3.2 Process Flow Diagram for Domestic Sewage Treatment Plant

The figure below shows the flow diagram of the selected domestic sewage treatment plant.




## Figure 3.2 Process Flow Diagram Of Domestic Sewage Treatment Plant

### 3.3.3 Details Of Sewage Treatment Plant

The sewage treatment plant selected for the study is 43 MLD sewage treatment plant, with a technique of UASB (Up flow Anaerobic Sludge Blanket), a State of Art technique, which was started by Vadodara Municipal Corporation in 2001.Sewage treatment plant receives about 32 % (i.e.70 MLD) of the sewage generated by the city covering about 35 % city area. A 53 MLD new sewage treatment plant is installed in 2010 for meeting the requirements of the treatment. With the commissioning of this treatment plant in year 2001, rest of the capacity (43 MLD) out of 70 MLD of sewage is treated by means of advanced treatment based on UASB technology, with treated sewage meeting the Gujarat pollution Control Board norms. The various sources contributing to the wastewater to this new 43 MLD STP is as follows:

- Domestic wastewater from the west zone (drainage zone III) of City
- Industrial effluent from the cluster of industries

**Table 3.2 Salient Features Of The 43 Mld Sewage Treatment Plant**

| Feature | Value |
|---|---|
| Capacity | 43 MLD |
| Population served | 5 Lacks |
| Area served | 38 sq.km |
| Total cost | Rs.12.22 crores |
| Technical | Sewage flow: 43,000 cum./day. |

**Table 3.3 Design Sewage Characteristics (Avg.)**

| Sr. No. | Parameters | Value of raw sewage | Value of treated sewage |
|---|---|---|---|
| 1 | $P^H$ | 6.5 to 8.0 | 6.5 to 7.5 |
| 2 | Suspended Solids (mg/lit) | Less than 360 | Less than 20 |
| 3 | $BOD_5$ (mg/lit) | Less than 350 | Less than 20 |
| 4 | Total COD (mg/lit) | Less than 650 | Less than 100 |

### 3.3.4 Characteristics Of Sewage Treatment Plant

Following table shows the characteristics of the domestic sewage treatment plant. Data from year 2003 is collected and utilized for statistical analysis.

**Table 3.4 Characteristics Of Sewage Treatment Plant**

| Year | RAW SEWAGE (COMPOSITE) | | | | U.S.A.B. Outlet | | | | Secondary Clarifier Outlet/Final Outlet | | | | MLSS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P^H | TSS (mg/l) | BOD (mg/l) | COD (mg/l) | P^H | TSS (mg/l) | BOD (mg/l) | COD (mg/l) | P^H | TSS (mg/l) | BOD (mg/l) | COD (mg/l) | A.T. - 1 | A.T. - 2 |
| | 6.5 - 7.8 | < 456 | < 412 | < 655 | | | | | 6.5 - 7.8 | < 30 | < 20 | < 100 | | |
| Jan-03 | 7 | 465 | 199 | 376 | 7 | 171 | 82 | 146 | 7 | 63 | 17 | 15 | 4104 | 4187 |
| Feb-03 | 7 | 425 | 161 | 286 | 7 | 200 | 99 | 156 | 7 | 68 | 17 | 15 | 4118 | 6936 |
| Mar-03 | 7 | 482 | 131 | 267 | 7 | 198 | 105 | 151 | 7 | 61 | 15 | 15 | 4091 | 6642 |
| Apr-03 | 7 | 428 | 180 | 273 | 7 | 168 | 93 | 147 | 7 | 60 | 16 | 15 | 4135 | 6980 |
| May-03 | 7 | 239 | 154 | 285 | 7 | 192 | 87 | 149 | 7 | 59 | 15 | 15 | 3970 | 6772 |
| Jun-03 | 7 | 321 | 140 | 280 | 7 | 214 | 100 | 158 | 7 | 60 | 16 | 16 | 4102 | 6984 |
| Jul-03 | 7 | 329 | 154 | 267 | 7 | 198 | 105 | 151 | 7 | 57 | 13 | 13 | 4061 | 4158 |
| Aug-03 | 7 | 402 | 188 | 271 | 7 | 168 | 93 | 147 | 7 | 58 | 11 | 15 | 4070 | 5011 |
| Sep-03 | 7 | 447 | 189 | 269 | 7 | 211 | 89 | 163 | 7 | 58 | 12 | 11 | 4051 | 5600 |
| Oct-03 | 7 | 457 | 132 | 277 | 7 | 195 | 101 | 143 | 7 | 59 | 12 | 15 | 4135 | 3310 |
| Nov-03 | 7 | 455 | 138 | 276 | 7 | 178 | 80 | 150 | 7 | 58 | 12 | 11 | 4000 | 5306 |
| Dec-03 | 7 | 310 | 162 | 265 | 7 | 179 | 95 | 153 | 7 | 59 | 12 | 12 | 4139 | 3610 |
| Jan-04 | 7 | 273 | 160 | 324 | 7 | 90 | 51 | 46 | 7 | 58 | 12 | 15 | 4097 | 2790 |
| Feb-04 | 7 | 273 | 160 | 324 | 7 | 90 | 51 | 46 | 7 | 58 | 12 | 15 | 4097 | 2790 |
| Mar-04 | 7 | 346 | 156 | 272 | 7 | 72 | 16 | 17 | 7 | 59 | 12 | 12 | 4137 | 2590 |
| Apr-04 | 7 | 460 | 273 | 306 | 7 | 73 | 17 | 17 | 7 | 58 | 12 | 11 | 4054 | 3030 |
| May-04 | 7 | 421 | 291 | 289 | 7 | 72 | 16 | 17 | 7 | 58 | 11 | 11 | 4064 | 2910 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jun-04 | 7 | 485 | 227 | 343 | 7 | 70 | 16 | 17 | 7 | 58 | 12 | 11 | 4023 | 2630 |
| Jul-04 | 7 | 427 | 200 | 308 | 7 | 61 | 16 | 16 | 7 | 58 | 11 | 11 | 4064 | 2890 |
| Aug-04 | 7 | 239 | 119 | 387 | 9 | 41 | 12 | 17 | 7 | 58 | 12 | 11 | 4077 | 5011 |
| Sep-04 | 7 | 239 | 119 | 387 | 9 | 41 | 12 | 17 | 7 | 58 | 12 | 11 | 4077 | 5011 |
| Oct-04 | 7 | 329 | 171 | 341 | 7 | 56 | 16 | 17 | 7 | 58 | 12 | 11 | 4038 | 2830 |
| Nov-04 | 7 | 314 | 138 | 302 | 7 | 49 | 16 | 18 | 7 | 58 | 12 | 11 | 4060 | 4030 |
| Dec-04 | | | | | | | | | 7 | 58 | 12 | 11 | 4030 | 4880 |
| Jan-05 | | | | | | | | | 7 | 58 | 12 | 11 | 4054 | 4900 |
| Feb-05 | 7 | 371 | 144 | 354 | 7 | 161 | 58 | 187 | 7 | 58 | 12 | 11 | 4035 | 4516 |
| Mar-05 | 7 | 371 | 144 | 354 | 7 | 161 | 58 | 187 | 7 | 58 | 12 | 11 | 4035 | 4516 |
| Apr-05 | 7 | 371 | 194 | 385 | 7 | 153 | 70 | 166 | 7 | 60 | 18 | 18 | 4646 | 4585 |
| May-05 | 7 | 374 | 178 | 299 | 7 | 156 | 72 | 138 | 7 | 66 | 17 | 16 | 4610 | 4604 |
| Jun-05 | 7 | 354 | 150 | 276 | 7 | 166 | 74 | 134 | 7 | 60 | 17 | 17 | 4061 | 4217 |
| Jul-05 | 7 | 350 | 177 | 268 | 7 | 144 | 68 | 117 | 7 | 68 | 16 | 18 | 4101 | 4601 |
| Aug-05 | 7 | 424 | 170 | 280 | 7 | 164 | 87 | 115 | 7 | 66 | 17 | 17 | 3645 | 4070 |
| Sep-05 | 7 | 310 | 132 | 277 | 7 | 135 | 54 | 126 | 7 | 61 | 17 | 18 | | 5600 |
| Oct-05 | 7 | 310 | 132 | 277 | 7 | 135 | 54 | 126 | 7 | 61 | 17 | 18 | | 5600 |
| Nov-05 | 7 | 350 | 155 | 289 | 7 | 175 | 79 | 132 | 7 | 61 | 16 | 16 | 4707 | 4615 |
| Dec-05 | 7 | 345 | 171 | 260 | 7 | 135 | 65 | 123 | 7 | 68 | 16 | 18 | 3749 | 4349 |
| Jan-06 | 7 | 405 | 176 | 292 | 7 | 179 | 90 | 127 | 7 | 68 | 17 | 17 | 4069 | 4064 |
| Feb-06 | 7 | 380 | 186 | 300 | 7 | 158 | 78 | 154 | 7 | 73 | 17 | 17 | 3885 | 4004 |
| Mar-06 | 7 | 408 | 193 | 288 | 7 | 168 | 93 | 147 | 7 | 75 | 17 | 18 | 4455 | 3713 |
| Apr-06 | 7 | 394 | 185 | 277 | 7 | 177 | 99 | 165 | 7 | 71 | 14 | 16 | 3832 | 3851 |
| May-06 | 7 | 385 | 176 | 288 | 7 | 164 | 79 | 170 | 7 | 70 | 17 | 16 | 4666 | 4635 |
| Jun-06 | 7 | 353 | 150 | 278 | 7 | 173 | 68 | 125 | 7 | 60 | 17 | 17 | 4061 | 4217 |
| Jul-06 | 7 | 345 | 178 | 269 | 7 | 142 | 73 | 127 | 7 | 67 | 16 | 17 | 4101 | 4601 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug-06 | 7 | 379 | 159 | 292 | 7 | 224 | 81 | 126 | 7 | 70 | 17 | 17 | 4092 | 4093 |
| Sep-06 | 7 | 331 | 185 | 268 | 7 | 157 | 103 | 141 | 7 | 67 | 14 | 14 | 4308 | 4163 |
| Oct-06 | 7 | 329 | 139 | 304 | 7 | 131 | 69 | 130 | 7 | 65 | 16 | 16 | 4009 | 4279 |
| Nov-06 | 7 | 348 | 156 | 273 | 7 | 149 | 86 | 128 | 7 | 65 | 16 | 15 | 4032 | 6740 |
| Dec-06 | 7 | 346 | 136 | 268 | 7 | 136 | 69 | 120 | 7 | 63 | 14 | 14 | 4042 | 4192 |
| Jan-07 | 7 | 323 | 127 | 258 | 7 | 133 | 55 | 126 | 7 | 54 | 13 | 13 | 4044 | 4132 |
| Feb-07 | 7 | 312 | 119 | 284 | 7 | 122 | 52 | 114 | 7 | 50 | 12 | 13 | 4147 | 4139 |
| Mar-07 | 7 | 327 | 126 | 295 | 7 | 127 | 52 | 119 | 7 | 49 | 11 | 12 | 4170 | 4130 |
| Apr-07 | 7 | 339 | 141 | 289 | 7 | 138 | 51 | 123 | 7 | 51 | 11 | 11 | 4181 | 4177 |
| May-07 | 7 | 342 | 125 | 288 | 7 | 125 | 53 | 115 | 7 | 52 | 15 | 12 | 4163 | 4250 |
| Jun-07 | 7 | 347 | 126 | 292 | 7 | 127 | 54 | 113 | 7 | 58 | 12 | 12 | 4077 | 4165 |
| Jul-07 | 7 | 331 | 136 | 282 | 7 | 119 | 52 | 108 | 7 | 52 | 12 | 12 | 4013 | 4260 |
| Aug-07 | 7 | 335 | 139 | 288 | 7 | 123 | 51 | 111 | 7 | 54 | 11 | 11 | 3927 | 4100 |
| Sep-07 | 7 | 335 | 141 | 289 | 7 | 129 | 59 | 115 | 7 | 56 | 11 | 11 | 4055 | 4250 |
| Oct-07 | 7 | 346 | 148 | 288 | 7 | 128 | 58 | 115 | 7 | 58 | 12 | 15 | 4079 | 4190 |
| Nov-07 | 7 | 343 | 145 | 294 | 7 | 128 | 58 | 116 | 7 | 58 | 12 | 12 | 4076 | 4220 |
| Dec-07 | 7 | 316 | 133 | 312 | 7 | 127 | 62 | 123 | 7 | 38 | 14 | 41 | 4243 | 4301 |
| Jan-08 | 7 | 316 | 133 | 312 | 7 | 127 | 62 | 123 | 7 | 38 | 14 | 41 | 4243 | 4301 |
| Feb-08 | 7 | 225 | 207 | 457 | 7 | 122 | 170 | 240 | 8 | 19 | 17 | 64 | 4245 | 4500 |
| Mar-08 | 7 | 225 | 206 | 457 | 7 | 122 | 169 | 239 | 8 | 19 | 17 | 64 | 4250 | 4490 |
| Apr-08 | 7 | 234 | 205 | 465 | 7 | 122 | 169 | 236 | 8 | 19 | 17 | 65 | 5678 | 4562 |
| May-08 | 7 | 234 | 205 | 465 | 7 | 122 | 169 | 236 | 8 | 19 | 17 | 65 | 5678 | 4562 |
| Jun-08 | 7 | 259 | 215 | 532 | 7 | 121 | 172 | 299 | 7 | 20 | 16 | 79 | 4142 | 4167 |
| Jul-08 | 7 | 214 | 223 | 442 | 7 | 205 | 170 | 233 | 8 | 19 | 15 | 75 | 4127 | 4249 |
| Aug-08 | 7 | 225 | 223 | 483 | 7 | 147 | 167 | 253 | 8 | 19 | 16 | 68 | 4088 | 4308 |
| Sep-08 | 7 | 250 | 213 | 472 | 7 | 141 | 157 | 251 | 8 | 18 | 15 | 68 | 4127 | 4326 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct-08 | 7 | 266 | 239 | 409 | 7 | 125 | 161 | 233 | 7 | 17 | 17 | 66 | 4190 | 4306 |
| Nov-08 | 7 | 280 | 218 | 462 | 7 | 121 | 153 | 240 | 7 | 16 | 16 | 66 | 4274 | 4330 |
| Dec-08 | 9 | 273 | 210 | 439 | 7 | 120 | 146 | 232 | 7 | 17 | 21 | 66 | 4311 | 4346 |
| Jan-09 | 7 | 293 | 229 | 442 | 7 | 129 | 161 | 235 | 7 | 19 | 18 | 65 | 4319 | 4463 |
| Feb-09 | 7 | 231 | 214 | 437 | 7 | 132 | 157 | 238 | 8 | 19 | 17 | 63 | 4239 | 4389 |
| Mar-09 | 7 | 226 | 208 | 458 | 7 | 124 | 167 | 239 | 8 | 19 | 17 | 65 | 4258 | 4507 |
| Apr-09 | 7 | 233 | 204 | 469 | 7 | 124 | 171 | 238 | 8 | 19 | 17 | 64 | 5690 | 4500 |
| May-09 | | | | | | | | | | | | | | |
| Jun-09 | 7 | 194 | 190 | 446 | 8 | 119 | 114 | 252 | 8 | 22 | 17 | 60 | | 3596 |
| Jul-09 | 7 | 220 | 204 | 428 | 7 | 101 | 107 | 232 | 8 | 23 | 16 | 58 | 3751 | 4033 |
| Aug-09 | 7 | 220 | 219 | 466 | 7 | 106 | 118 | 227 | 8 | 21 | 19 | 70 | 4028 | 4122 |
| Sep-09 | 7 | 233 | 212 | 417 | 7 | 117 | 126 | 230 | 8 | 19 | 17 | 65 | 4181 | 4184 |
| Oct-09 | 7 | 217 | 187 | 430 | 7 | 117 | 177 | 238 | 8 | 19 | 18 | 72 | 3970 | 4002 |
| Nov-09 | 7 | 225 | 223 | 480 | 7 | 125 | 130 | 246 | 8 | 23 | 19 | 80 | 4194 | 4191 |
| Dec-09 | 7 | 214 | 217 | 458 | 7 | 163 | 141 | 249 | 8 | 28 | 18 | 81 | 3847 | 3804 |
| Jan-10 | 7 | 206 | 227 | 493 | 7 | 130 | 135 | 256 | 8 | 28 | 18 | 71 | 3368 | 3469 |
| Feb-10 | 7 | 174 | 202 | 424 | 7 | 107 | 111 | 224 | 8 | 27 | 17 | 62 | 3120 | 3189 |
| Mar-10 | 7 | 232 | 199 | 431 | 7 | 119 | 121 | 234 | 8 | 27 | 17 | 75 | 3367 | 3436 |
| Apr-10 | 7 | 199 | 205 | 457 | 7 | 130 | 117 | 304 | 8 | 27 | 17 | 69 | 3372 | 3555 |
| May-10 | 7 | 178 | 196 | 386 | 7 | 113 | 111 | 193 | 8 | 27 | 17 | 65 | 3240 | 3519 |
| Jun-10 | 7 | 180 | 199 | 415 | 7 | 124 | 108 | 248 | 8 | 27 | 17 | 68 | 2960 | 3075 |
| Jul-10 | 7 | 206 | 211 | 385 | 7 | 125 | 118 | 185 | 8 | 25 | 17 | 55 | 3196 | 3088 |
| Aug-10 | 7 | 211 | 215 | 397 | 7 | 124 | 116 | 136 | 7 | 26 | 17 | 52 | 3403 | 3572 |
| Sep-10 | 7 | 214 | 218 | 439 | 7 | 128 | 118 | 138 | 7 | 27 | 18 | 55 | 3554 | 3649 |
| Oct-10 | 7 | 218 | 261 | 416 | 7 | 126 | 118 | 127 | 7 | 26 | 17 | 66 | 3791 | 4861 |
| Nov-10 | 7 | 216 | 223 | 442 | 7 | 123 | 117 | 129 | 7 | 27 | 17 | 58 | 3909 | 3966 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-10 | 7 | 226 | 224 | 452 | 7 | 131 | 119 | 136 | 7 | 25 | 18 | 61 | 3818 | 3874 |
| Jan-11 | 7 | 217 | 225 | 426 | 7 | 125 | 121 | 136 | 8 | 23 | 17 | 57 | 3396 | 3343 |
| Feb-11 | 7 | 241 | 230 | 445 | 7 | 139 | 128 | 144 | 8 | 24 | 18 | 61 | 3686 | 3758 |
| Mar-11 | 7 | 226 | 220 | 434 | 7 | 122 | 116 | 136 | 7 | 23 | 17 | 58 | 3269 | 3300 |
| Apr-11 | 7 | 228 | 219 | 437 | 7 | 129 | 120 | 133 | 8 | 23 | 17 | 59 | 3051 | 3049 |
| May-11 | 7 | 228 | 223 | 421 | 7 | 125 | 118 | 125 | 8 | 25 | 17 | 57 | 3030 | 3041 |
| Jun-11 | 7 | 228 | 225 | 431 | 7 | 156 | 119 | 129 | 8 | 22 | 17 | 56 | 3111 | 3110 |
| Jul-11 | 7 | 239 | 226 | 442 | 7 | 130 | 120 | 136 | 8 | 23 | 17 | 54 | 3003 | 2986 |
| Aug-11 | 7 | 239 | 228 | 439 | 7 | 134 | 145 | 138 | 8 | 23 | 17 | 58 | 3279 | 3285 |
| Sep-11 | 7 | 249 | 236 | 450 | 7 | 135 | 135 | 151 | 8 | 24 | 17 | 55 | 2925 | 2957 |
| Oct-11 | 7 | 248 | 228 | 450 | 7 | 138 | 137 | 197 | 8 | 26 | 18 | 65 | 3111 | 3073 |
| Nov-11 | 7 | 244 | 220 | 444 | 7 | 137 | 137 | 147 | 8 | 25 | 18 | 61 | 3358 | 3452 |
| Dec-11 | 7 | 251 | | 446 | 7 | 145 | 132 | 150 | 8 | 26 | 18 | 64 | 3297 | 3420 |

## 3.4 CASE STUDY 2: COMMON EFFLUENT TREATMENT PLANT

For the second case study Common Effluent Treatment Plant, the following are the parameters to be treated and the treatment options are as follows.

### 3.4.1 Preamble

M/s Environ Infrastructure Co. Ltd. (EICL), village Umaraya, Tal. Padra has set up a Common Effluent Treatment Plant (CETP). The plant is located on Effluent Channel Road. The CETP was commissioned on 1$^{st}$ May 2000. CETP was set up to cater Small and Medium scale industries situated in and around Padra & Jambusar Districts. The company is promoted by 27(twenty-seven) industrial units. All these members have taken equity participation in the Company. At present, it has 91(Ninety one) member units. Though, the facility like Effluent Channel is available in this area, this CETP was established mainly for the benefit of Small & Medium scale industries. Being a member of the CETP the small-scale unit has to provide primary treatment facility to meet CETP inlet norms. The CETP is partly financed by the State & Central Govt. This is one of the only two CETPs in operation, financed by the World Bank under Industrial Pollution Prevention Project (IPPP) scheme. CETP accepts effluent from members units as per inlet norms. The CETP is designed for 2250 $M^3$ per day of effluent treatment. Effluent from member units is collected by means of rubber lined tankers with GPS system. As per GPCB directive the facility of Effluent transportation is provided by EICL rubber lined tankers. Wastewater Manifest system is followed. On arrival of tanker from member unit at CETP, a sample is drawn from the tanker. The same is analyzed at EICL laboratory. For efficient monitoring of the influent quality received from members, a full-fledged laboratory is set-up. Analysis of Effluent samples of each & every tanker received from member units for $P^H$, COD, BOD, SS, TDS, $NH_3N$, Oil, Grease and of Heavy metals is also being carried out at this laboratory. This is also helpful in monitoring of treatment process at plant.

Location Of The Plant:

The CETP is located nearby Padra district, whose location is as shown in below figure (as B):

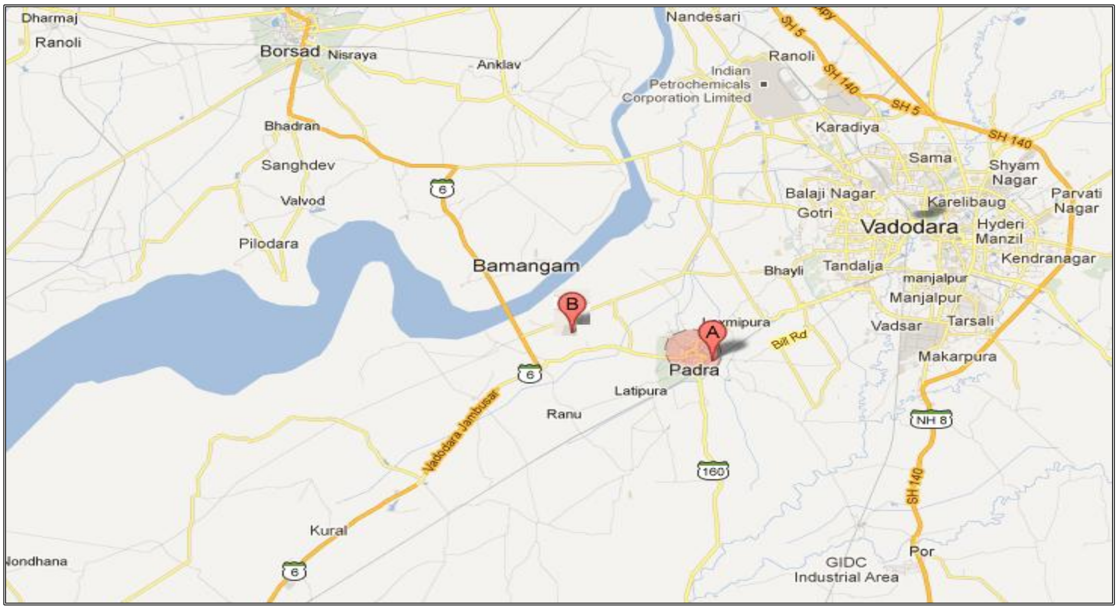



**Figure 3.3 Location Of Common Effluent Treatment Plant**

## 3.4.2 Details of Common Effluent Treatment Plant

The effluent received from members through tanker is unloaded in the Equalization tank after checking COD. For thorough mixing & homogenization of effluent received from various industries, at bottom of Equalization tank, HDPE piping grid is installed. 25/15 HP air blowers are installed at the tank for complete homogeneous mixing of the effluent received from member units. From here, the effluent is lifted to Flash Mixer. At this tank, continuous dosing of hydrated lime and Aluminum Sulfate (Alum) slurry is done for flocculation & coagulation. A high-speed stirrer is provided to get complete mixing of dosing chemicals with effluent. After mixing the effluent is transferred to Primary Settling Tank. Sludge Pumps remove the settled sludge from the bottom of the tank. The supernatant from this tank flows by means of gravity to Aeration Tank for biological Treatment.

The sludge generated at Primary and Secondary treatment is collected, dewatered and sun dried in Sludge Drying Beds. Total 864 Sq.mt. of sludge drying area is provided. The filtrate/Leachate is collected in Filtrate Sump. The same is then pumped and send to Aeration Tank for further biological treatment. The dried sludge is then packed in the HDPE bags and to aerobic Secured Land Fill Site of GEPIL, Surat. The Company is a member of GEPIL, Surat and NECL, Nandeseri.

As per Treatment scheme for flow of 2250 $M^3$/day, two stage Aeration followed by Secondary Clarifier treatment process is provided. Total Six Nos. of 25 HP Surface Aerators and one tank with surface aeration (Mechanical), aeration system by two nos. of air blowers are installed for biological treatment. However, as the present effluent quantity is less, only two of Aeration Tank (capacity1980 $M^3$) is taken in operation. The MLSS by Vermi composting and Micro active Enzymes has been developed. This is a unique method of bacterial development. It is very effective against any shock load at the Aeration Tank. They are able to maintain 3500-4000 mg/L MLSS level at Aeration Tank. This makes biological system more effective. At tertiary treatment, four Dual Media Filter tanks are provided. Each tank is designed for 69 $M^3$ per hour flow rate. The filter media comprises granular Activated Carbon, coarse sand and pebbles. The tertiary system is useful for final clarification, filtration and polishing of the effluent before final disposal. The tertiary treatment is provided with the extensive piping arrangement. It is helpful in operation of the filters in parallel and in series as per the requirement. Chlorination system is also provided as and when required before disposal. They are able to maintain the disposal norms of the GPCB. Final treated effluents are disposed off to ECPL canal.

### 3.4.3 Flow Diagram Showing Detailed Treatment Scheme

Following is the process flow diagram showing details of treatment for CETP:

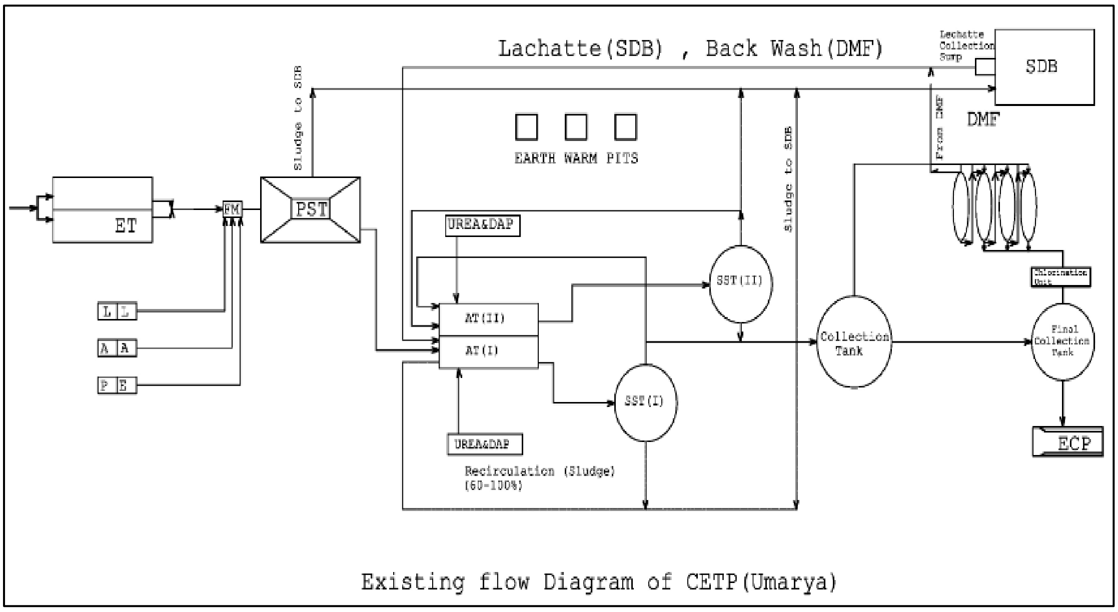



**Figure 3.4 Process Flow Diagram Of CETP**

**Figure 3.5 Lime And Alum Solution Tank**

**Figure 3.6 Aeration Tank**

**Figure 3.7 Pressure Sand Filter**

**Figure 3.8 Aeration Tank**

**Figure 3.9 Secondary Clarifier**

**Figure 3.10 Primary Clarifier**

### 3.4.4 Water Balance Diagram Of CETP

At present, the water is balanced at CETP as shown in figure 3.11. Major quantity is thrown to ECP canal which can be avoided and reuse of wastewater can be a practiced for the benefit of near by area.

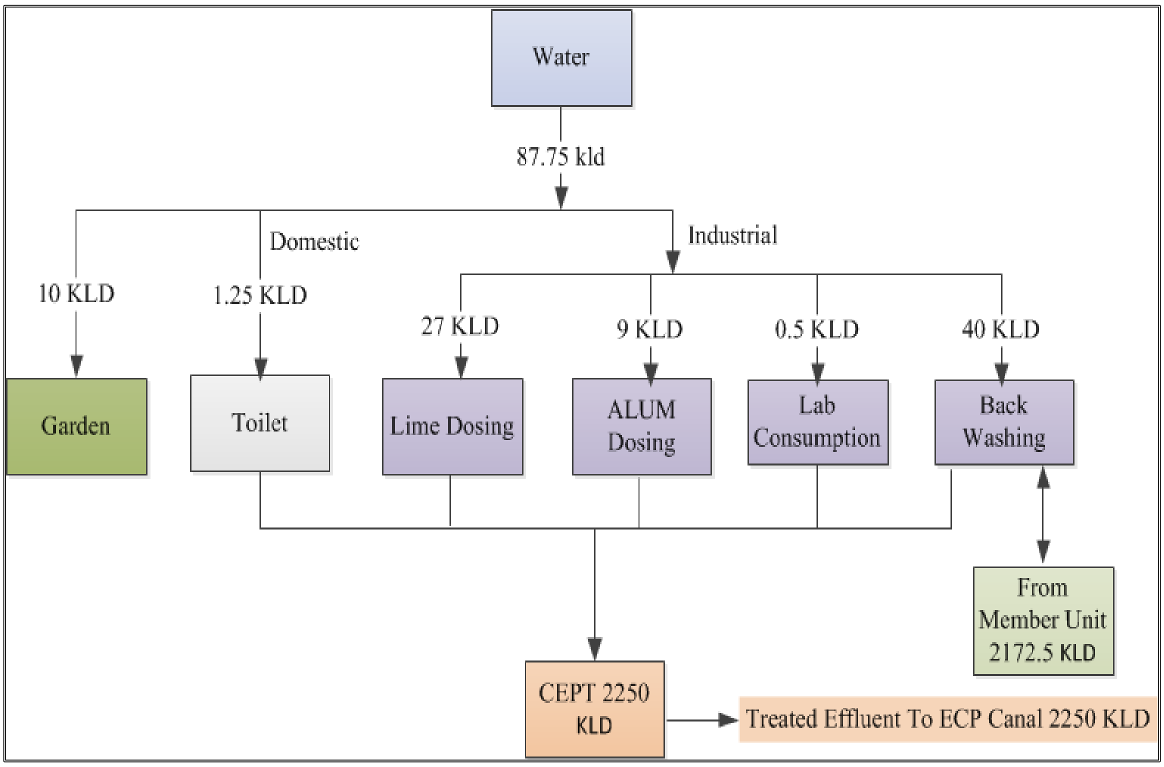



**Figure 3.11 Water Balance Diagram Of CETP**

## 3.4.5 Layout Of Infrastructural Diagram Of CETP

Flow diagram of the plant is as under:

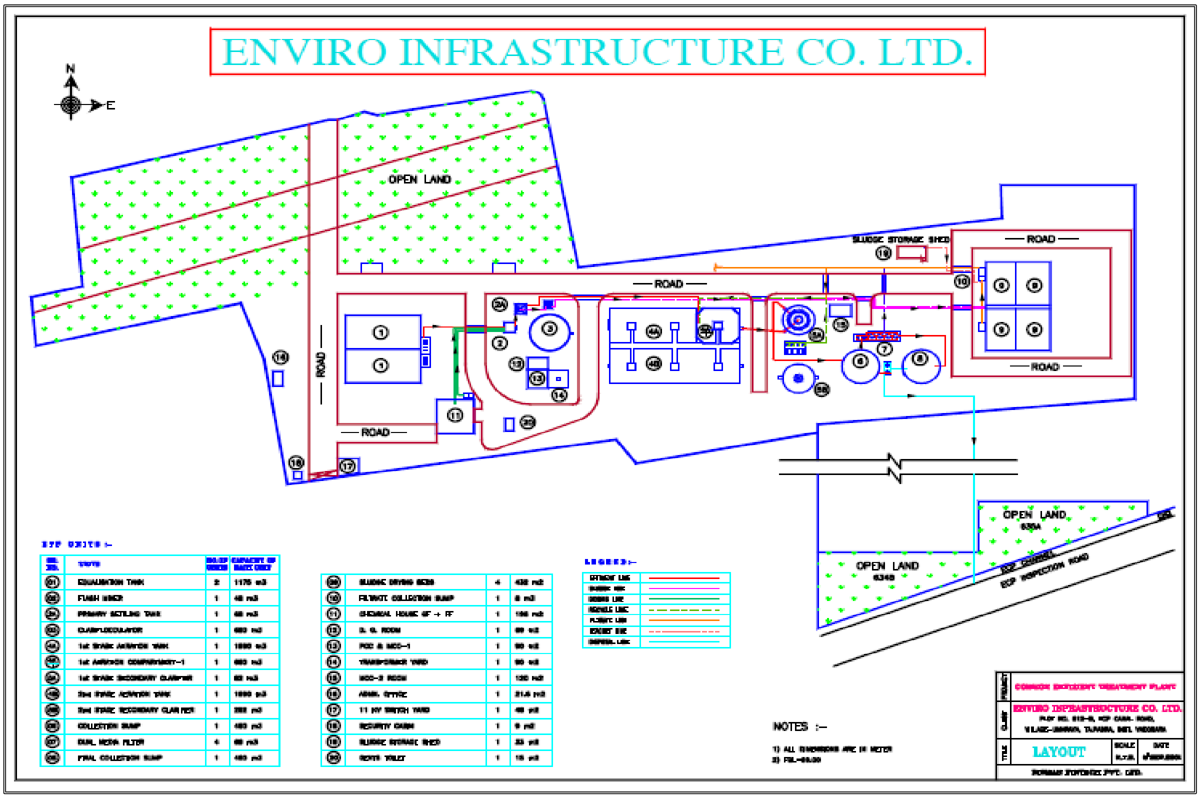



**Figure 3.12 Layout Plan Of Environ Infrastructure Pvt. Ltd.**

M/s Associated Environmental Engineers, Vadodara has executed the work of Common Effluent Treatment Plant of this Company on Turnkey basis. The CETP is situated at Village Umaraya, Tal. Padra, Dist. Vadodara. The capacity of the plant is 2250 $M^3$ per day. The plant is designed to treat effluent as per following norms.

**Table 3.5 Norms For CETP**

| Parameter | Inlet Norms | Outlet Norms |
|---|---|---|
| $P^H$ | 6.5 to 9.5 | 6.5 to 9.5 |
| COD(mg/l) | 2000 | 250 |
| BOD(mg/l) | 600 | 100 |
| SS(mg/l) | 200 | 100 |
| TDS(mg/l) | 4000 | NA |
| O & G(mg/l) | 10 | 10 |
| $NH_3N$(mg/lit) | 50 | 50 |

Common Effluent Treatment Plant is performing the task of treatment of effluent from its member units as per inlet norms. CETP provides primary, secondary and tertiary treatment to the composite effluent and disposing treated effluent to effluent channel of ECP Ltd. as per GPCB permission. The characteristics of CETP of last ten years are as shown in Table 3.6.

## 3.5 RAINFALL AND POPULATION FOR CENTRAL GUJARAT REGION

The rainfall data is collected by state water data center, Gandhinagar and it contains more than 2500 data, so it is represented in CD. Population is shown in graph from the data collected. Rainfall and population data are collected to justify the need of the problem. A graph has been shown in chapter 1 ‘Introduction’, to show the gap between population and rainfall. Increase in population is in cumulative way and rainfall is not increased, so reuse is going to be at compulsion level in near future.

**Table 3.6 Characteristics Of CETP**

| Parameters | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 30 | 28 | 29 | 28 | 27.2 | 26.7 | 30.1 | 30.2 | 26.1 | 27.8 | 25.8 |
| BOD | 54 | 58 | 65 | 61 | 59 | 70 | 80 | 72 | 69 | 55 | 58 |
| COD | 148 | 193 | 294 | 236 | 235 | 284 | 250 | 228 | 215 | 243 | 248 |
| SS | 8500 | 10000 | 15000 | 12570 | 11652 | 13500 | 9875 | 11225 | 13250 | 12450 | 11650 |
| Sulfide | 714.2 | 0.03 | 0.008 | 0.018 | 0.012 | 0.03 | 0.07 | 2.9 | 1.3 | 1.6 | 1.8 |
| oil & grease | 6 | 6.8 | 5.87 | 3.98 | 2.86 | 2.56 | 6.03 | 8.7 | 9.5 | 4.9 | 4.6 |
| Nitrogen | 0 | 13 | 13.85 | 16.9 | 15 | 59 | 38 | 142 | 45 | 39 | 42 |
| Phe comp | 9.78 | 0.38 | 0.41 | 0.34 | 0.26 | | 0.25 | 0.51 | 0.56 | 0.62 | 0.46 |
| Iron | 0.2 | 0.13 | 0.23 | 0.65 | 0.95 | 4.05 | 0.232 | 6.34 | 1.875 | 2.314 | 1.895 |
| Copper | 3.53 | 0 | 0 | 0 | 0 | 0.14 | | 0.654 | | 0.423 | 0.312 |
| Lead | 0 | 0.113 | 0.1 | 0 | 0 | 0.279 | 0.059 | 0.223 | | | |
| Nickel | 0.05 | 0.032 | 0.021 | 0 | 0 | 0.296 | 0.087 | 0.305 | 0.128 | 0.104 | 0.185 |
| Zinc | 0 | 0.049 | 0.031 | | 0 | 3.099 | 0.124 | 6.372 | 1.514 | 1.65 | 2.154` |
| Cadmium | 0 | | 0.1 | 0 | | | | 0.210 | | | |

# 4. EXPERIMENTAL WORK

## 4.1 EXPERIMENTAL WORK

Looking to the present status of water supply of industries in the downstream side of the Atladra Sewage treatment plant, the option of waste water coming from secondary outlet of domestic sewage treatment plant is explored. The parameters were tested and data collection of last 9 years is done. At lab scale, treatability studies are tried and it is found that the domestic sewage is considerable source of waste water for industrial reuse purpose.

### 4.1.1 Present Status Of Water Supply

The daily water consumption by the industry is about 600 cu.m. 90% of the total raw water demand is supplemented by means of Tankers from outside local bore wells. The cost of purchase of the water is Rs. 1250 /- per tanker of 10 cu.m capacity. Thus the company incurs huge investment on purchase of raw water from outside bore wells [157].

A possibility of using the treated sewage water from one of the municipal plant nearby i.e. Vadodara Municipal Corporations Atladra Sewage Treatment Plant was explored, as an alternative source of water demand.

This study is carried out to find the solution of getting required quantity of water for industrial purpose everyday, to explore the possibility of replacing the existing raw water demand from bore wells by the Reuse of Treated Sewage Water from one of the Sewage Treatment Plant by giving suitable Polishing Treatment, thereby finding out a technically suitable and economically viable solution in the interest of the company and conservation of the water, a precious natural source of life [158].

## 4.2 STEPS FOLLOWED FOR EXPERIMENTAL WORK

The experiments and designing work carried out for exploring the possibility of reuse of the treated sewage water for industrial use is done as follows:

- Sample Collection
- Analysis of the Samples and comparison with standards
- Treatability Studies on the samples collected using various treatment options
- Basic Designs of each scheme of treatment options as evaluated

- Budgetary Capital and Operating Cost Evaluation of each treatment scheme selected
- Working out the most techno-economical comparison of each treatment scheme
- Selection and Recommendation of the most techno-economical solution
- Modeling for judging water quality for the purpose of reuse

### 4.2.1 Sample Collection

Composite samples were collected for a period of one year during day time from the secondary clarifier of the Atladra Sewage Treatment Plant. A composite sample was then prepared from the hourly samples and tested for initial analysis of the treated sewage water. [161]

## 4.3 ANALYSIS OF THE COLLECTED COMPOSITE SAMPLES

The Detailed analysis of the five samples was carried out for various parameters. The results are presented in following tables. On weekly basis seven samples were collected and average was found out and such five average characteristics samples were treated at lab scale to explore the possibility of reuse.

These five samples were decided to be treated, based on the average characteristics of seven samples collected on weekly basis. The samples which were treated were selected based on the average characteristics of all samples collected.

**Table 4.1: A Detailed Characterization Of The First Average Sample collected From Secondary Outlet**

| Parameters | Sample 1.1 | Sample 1.2 | Sample 1.3 | Sample 1.4 | Sample 1. 5 | Sample 1.6 | Sample 1.7 | Average Value |
|---|---|---|---|---|---|---|---|---|
| $P^H$ | 7.8 | 8 | 8.65 | 8.25 | 8.8 | 8.5 | 8.7 | 8.38 |
| D.O. | 6 | 5.8 | 6.8 | 4 | 5 | 6 | 7 | 5.8 |
| Temp. | 25.6°C | 25.9°C | 25.8°C | 25.12°C | 25.10°C | 25.8°C | 25.10°C | 25.9°C |
| Turbidity | 12 | 16 | 14 | 18 | 22 | 20 | 24 | 18 NTU |
| Odor | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable |
| T.S. | 728 | 730 | 715 | 744 | 727 | 729 | 731 | 729 |
| T.D.S. | 695 | 700 | 690 | 992 | 698 | 696 | 694 | 695 |
| S.S. | 34 | 20 | 25 | 30 | 48 | 43 | 38 | 34 |
| T.H. | 249 | 249 | 250 | 252 | 254 | 255 | 254 | 252 |
| C.H. | 472 | 472 | 477 | 469 | 472 | 467 | 475 | 472 |
| C.O.D. | 30 | 34 | 38 | 42 | 50 | 54 | 46 | 42 |
| B.O.D. | 17.5 | 18 | 18.5 | 19 | 18.5 | 19.5 | 18.5 | 18.5 |
| Sulphate | 51 | 53 | 54 | 53 | 57 | 55 | 53 | 53 |
| Phosphate | 5.2 | 5.2 | 5.1 | 5.2 | 5.3 | 5.4 | 5 | 5.2 |
| Chlorides | 120 | 123 | 127 | 130 | 124 | 124 | 126 | 125 |
| $NH_3$-N (Ammonical Nitrogen) | 33 | 33 | 35 | 35 | 30 | 37 | 36 | 34 |
| Org. Nitrogen | 23 | 23 | 29 | 29 | 24 | 27 | 27 | 26 |
| MPN | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 |
| Total Bacterial Count | 34250 | 34250 | | | | | | 34250 |

**Table 4.2: A Detailed Characterization Of The Second Average Sample Collected From Secondary Outlet**

| Parameters | Sample 2.1 | Sample 2.2 | Sample 2.3 | Sample 2.4 | Sample 2.5 | Sample 2.6 | Sample 2.7 | Average Value |
|---|---|---|---|---|---|---|---|---|
| $P^H$ | 9.20 | 9.20 | 9.24 | 9.24 | 9.23 | 9.20 | 9.21 | 9.22 |
| D.O. | 4.7 | 4.65 | 4.65 | 4.75 | 4.75 | 4.69 | 4.71 | 4.7 |
| Temp. | 29.1°C | 29.5°C | 29.2°C | 29.2°C | 29.4°C | 29.4°C | 29.3°C | 29.3°C |
| Turbidity | 13 | 13 | 16 | 16 | 10 | 12 | 16 | 14 NTU |
| Odor | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable |
| T.S. | 675 | 671 | 673 | 673 | 672 | 674 | 673 | 673 |
| T.D.S. | 655 | 655 | 646 | 653 | 651 | 650 | 654 | 652 |
| S.S. | 20 | 20 | 22 | 24 | 19 | 21 | 21 | 21 |
| T.H. | 288 | 282 | 282 | 283 | 285 | 283 | 285 | 284 |
| C.H. | 425 | 426 | 415 | 415 | 421 | 416 | 419 | 420 |
| C.O.D. | 111 | 119 | 115 | 114 | 115 | 116 | 115 | 115 |
| B.O.D. | 45 | 45 | 55 | 55 | 51 | 51 | 48 | 50 |
| Sulphate | 54 | 55 | 54 | 58 | 60 | 61 | 55 | 57 |
| Phosphate | 5.2 | 5.2 | 5.1 | 5.3 | 5.2 | 5 | 5.4 | 5.2 |
| Chlorides | 88 | 88 | 91 | 90 | 88 | 87 | 91 | 89 |
| $NH_3$-N | 7.5 | 7.4 | 7.4 | 7.6 | 7.7 | 7.8 | 7.4 | 7.5 |
| Org. Nitrogen | 38.2 | 38.2 | 38.8 | 38.5 | 38.3 | 38.4 | 38.4 | 38.4 |
| MPN | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 |
| Total Bacterial Count | 34500 | | 34500 | | | | | 34500 |

**Table 4.3: A Detailed Characterization Of The Third Average Sample Collected From Secondary Outlet**

| Parameters | Sample 3.1 | Sample 3.2 | Sample 3.3 | Sample 3.4 | Sample 3.5 | Sample 3.6 | Sample 3.7 | Average Value |
|---|---|---|---|---|---|---|---|---|
| $P^H$ | 8.38 | 9.22 | 8.4 | 8.23 | 8.7 | 9.22 | 8.23 | 8.4 |
| D.O. | 5.8 | 4.7 | 3.9 | 3.9 | 4.1 | 5.8 | 3.9 | 3.9 |
| Temp. | 25.9°C | 29.3°C | 28.75°C | 29°C | 26°C | 29.3 °C | 25.9 °C | 28.75°C |
| Turbidity | 18 NTU | 14 NTU | 26 NTU | 27 NTU | 5 NTU | 27 NTU | 5 NTU | 26 NTU |
| Odor | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable |
| T.S. | 729 | 673 | 1238 | 842 | 2430 | 2430 | 673 | 1238 |
| T.D.S. | 695 | 652 | 690 | 672 | 1442 | 1422 | 652 | 690 |
| S.S. | 34 | 21 | 548 | 170 | 988 | 988 | 21 | 548 |
| T.H. | 252 | 284 | 276 | 268 | 260 | 284 | 252 | 276 |
| C.H. | 472 | 420 | 555 | 492 | 480 | 555 | 420 | 555 |
| C.O.D. | 42 | 115 | 190 | 132 | 8 | 190 | 8 | 190 |
| B.O.D. | 18.5 | 50 | 120 | 80 | 6 | 120 | 6 | 120 |
| Sulphate | 53 | 57 | 75 | 35 | 8.2 | 74 | 8.2 | 75 |
| Phosphate | 5.2 | 5.2 | 7.8 | 3 | 1 | 7.8 | 1 | 7.8 |
| Chlorides | 125 | 89 | 161 | 183 | 160 | 182 | 87 | 161 |
| $NH_3$-N | 34 | 7.5 | 24.6 | 21 | 20 | 34 | 7.5 | 24.6 |
| Org. Nitrogen | 26 | 38.4 | 11.4 | 8.1 | 6.5 | 38.4 | 6.5 | 11.4 |
| MPN | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 |
| Total Bacterial Count | 34250 | 34500 | 26600 | 33700 | 12150 | 36000 | 12200 | 26600 |

**Table 4.4: A Detailed Characterization Of The Fourth Average Sample Collected From Secondary Outlet**

| Parameters | Sample 4.1 | Sample 4.2 | Sample 4.3 | Sample 4.4 | Sample 4.5 | Sample 4.6 | Sample 4.7 | Average Value |
|---|---|---|---|---|---|---|---|---|
| $P^H$ | 9.38 | 8.22 | 11.4 | 5.23 | 9.38 | 8.54 | 9.38 | 8.58 |
| D.O. | 6.8 | 3.7 | 6.9 | 0.9 | 4.78 | 5.12 | 6.8 | 4.48 |
| Temp. | 26°C | 29.3 °C | 25.9°C | 29.3°C | 28.75°C | 29°C | 26°C | 27.8 °C |
| Turbidity | 26 NTU | 27 NTU | 18 NTU | 14 NTU | 5 NTU | 27 NTU | 26 NTU | 18 NTU |
| Odor | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable |
| T.S. | 730 | 672 | 1241 | 839 | 2430 | 2429 | 730 | 1182 |
| T.D.S. | 696 | 651 | 693 | 669 | 1442 | 1421 | 696 | 830 |
| S.S. | 35 | 20 | 551 | 167 | 68 | 988 | 35 | 352 |
| T.H. | 253 | 283 | 279 | 265 | 260 | 283 | 253 | 268 |
| C.H. | 473 | 419 | 558 | 489 | 480 | 554 | 473 | 484 |
| C.O.D. | 43 | 114 | 193 | 129 | 8.68 | 189 | 43 | 97 |
| B.O.D. | 19.5 | 49 | 123 | 77 | 6.68 | 119 | 19.5 | 55 |
| Sulphate | 54 | 56 | 78 | 32 | 8.88 | 73 | 54 | 46 |
| Phosphate | 6.2 | 4.2 | 10.8 | 0 | 1.68 | 7.12 | 6.2 | 4.4 |
| Chlorides | 126 | 88 | 164 | 180 | 160 | 181 | 126 | 143 |
| $NH_3$-N | 35 | 6.5 | 27.6 | 18 | 20 | 33 | 35 | 21 |
| Org. Nitrogen | 27 | 37.4 | 14.4 | 5.1 | 7.18 | 37.72 | 27 | 18 |
| MPN | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 |
| Total Bacterial Count | | | | | | | | 28200 |

**Table 4.5: A Detailed Characterization Of The Fifth Average Sample Collected From Secondary Outlet**

| Parameters | Sample 5.1 | Sample 5.2 | Sample 5.3 | Sample 5.4 | Sample 5.5 | Sample 5.6 | Sample 5.7 | Average Value |
|---|---|---|---|---|---|---|---|---|
| $P^H$ | 11.38 | 6.22 | 11.06 | 5.56 | 9.64 | 8.28 | 11.38 | 8.58 |
| D.O. | 6.8 | 3.7 | 6.9 | 0.9 | 4.78 | 5.12 | 6.8 | 4.48 |
| Temp. | 26°C | 29.3 °C | 25.9°C | 29.3°C | 28.75°C | 29°C | 26°C | 27.8 °C |
| Turbidity | 26 NTU | 27 NTU | 18 NTU | 14 NTU | 5 NTU | 27 NTU | 26 NTU | 18 NTU |
| Odor | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable |
| T.S. | 730 | 672 | 1241 | 839 | 2430 | 2429 | 730 | 1182 |
| T.D.S. | 696 | 651 | 693 | 669 | 1442 | 1421 | 696 | 830 |
| S.S. | 35 | 20 | 551 | 167 | 58 | 49 | 35 | 352 |
| T.H. | 253 | 283 | 279 | 265 | 260 | 283 | 253 | 268 |
| C.H. | 473 | 419 | 558 | 489 | 480 | 552 | 473 | 484 |
| C.O.D. | 43 | 114 | 193 | 129 | 8.68 | 189 | 43 | 97 |
| B.O.D. | 19.5 | 49 | 123 | 77 | 6.68 | 119 | 19.5 | 55 |
| Sulphate | 54 | 56 | 78 | 32 | 8.88 | 73 | 54 | 46 |
| Phosphate | 6.2 | 4.2 | 10.8 | 0 | 1.68 | 7.12 | 6.2 | 4.4 |
| Chlorides | 126 | 88 | 164 | 180 | 160 | 181 | 126 | 143 |
| $NH_3$-N | 35 | 6.5 | 27.6 | 18 | 20 | 33 | 35 | 21 |
| Org. Nitrogen | 27 | 37.4 | 14.4 | 5.1 | 7.18 | 37 | 27 | 18 |
| MPN | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 |
| Total Bacterial Count | 28200 | | | 28200 | | | | 28200 |

**Table 4.6: Composite Samples As Collected From Atladra New Sewage Treatment Plant –SST Outlet**

| Parameters | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Maximum Value | Minimum Value | Average Value |
|---|---|---|---|---|---|---|---|---|
| $P^H$ | 8.38 | 9.22 | 8.4 | 8.23 | 8.7 | 9.22 | 8.23 | 8.58 |
| D.O. | 5.8 | 4.7 | 3.9 | 3.9 | 4.1 | 5.8 | 3.9 | 4.48 |
| Temp. | 25.9°C | 29.3°C | 28.75°C | 29°C | 26°C | 29.3 °C | 25.9 °C | 27.8 °C |
| Turbidity | 18 NTU | 14 NTU | 26 NTU | 27 NTU | 5 NTU | 27 NTU | 5 NTU | 18 NTU |
| Odor | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable | Objectionable |
| T.S. | 729 | 673 | 1238 | 842 | 2430 | 2430 | 673 | 1182 |
| T.D.S. | 695 | 652 | 690 | 672 | 1442 | 1422 | 652 | 830 |
| S.S. | 34 | 21 | 548 | 170 | 988 | 988 | 21 | 352 |
| T.H. | 252 | 284 | 276 | 268 | 260 | 284 | 252 | 268 |
| C.H. | 472 | 420 | 555 | 492 | 480 | 555 | 420 | 484 |
| C.O.D. | 42 | 115 | 190 | 132 | 8 | 190 | 8 | 97 |
| B.O.D. | 18.5 | 50 | 120 | 80 | 6 | 120 | 6 | 55 |
| Sulphate | 53 | 57 | 75 | 35 | 8.2 | 74 | 8.2 | 46 |
| Phosphate | 5.2 | 5.2 | 7.8 | 3 | 1 | 7.8 | 1 | 4.4 |
| Chlorides | 125 | 89 | 161 | 183 | 160 | 182 | 87 | 143 |
| $NH_3$-N | 34 | 7.5 | 24.6 | 21 | 20 | 34 | 7.5 | 21 |
| Org. Nitrogen | 26 | 38.4 | 11.4 | 8.1 | 6.5 | 38.4 | 6.5 | 18 |
| MPN | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 | >1600 |
| Total Bacterial Count | 34250 | 34500 | 26600 | 33700 | 12150 | 36000 | 12200 | 28200 |

(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count)

**Table 4.7: Comparison Of The Values Of Various Parameters (min, max and average values) With Standards**

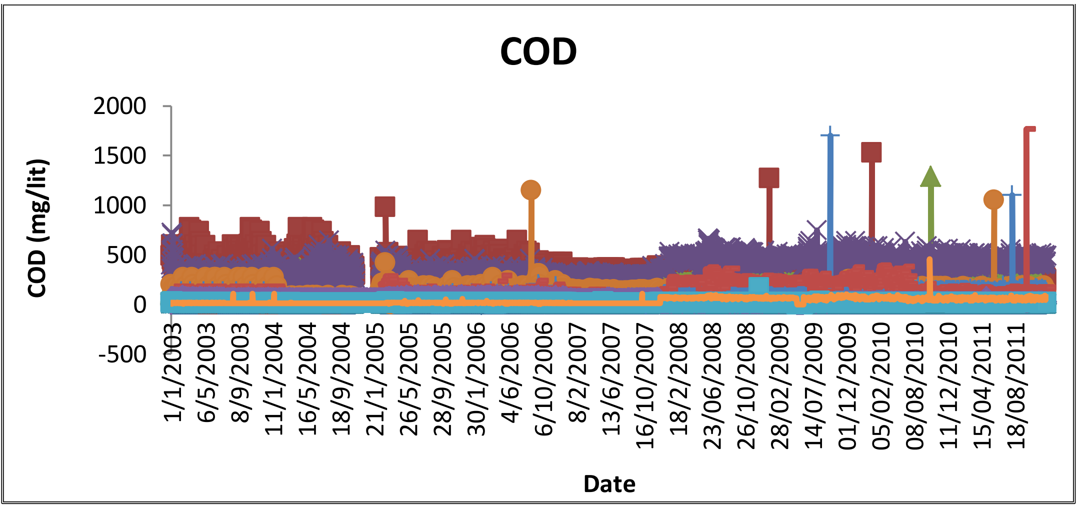
| Parameters | Range of Values (Min and Max) of Samples. | Average Value | Drinking water standards IS 10500 | Drinking water standards WHO | Cooling Water standards | Irrigation water standards IS 2490 | Remarks |
|---|---|---|---|---|---|---|---|
| $P^H$ | 8.23 - 9.22 | 8.58 | 6.5 – 8.5 | 7 – 8.5 | 6.8 –7.0 | 5.5-9.0 | Within Limits |
| D.O. | 3.9 - 5.8 | 4.48 | N. S. | N. S. | N. S. | N. S. | - |
| Temp. | 25.9 °C - 29.3 °C | 27.8 °C | N. S. | N. S. | 24°C | N. S. | Within Limits |
| Turbidity | 5 NTU - 27 NTU | 18 NTU | 5 NTU | 5 NTU | <5 NTU | N. S. | Out of Limits |
| Odor | Objectionable | Objectionable | Unobjectionable | Unobjectionable | N. S. | N. S. | Out of Limits |
| T.S. | 673 – 2430 | 1182 | N. S. | 500 | N. S. | N.S. | Out of Limits |
| T.D.S. | 652 – 1422 | 830 | N. S. | N. S. | N. S. | 2100 | Within Limits |
| S.S. | 21 – 988 | 352 | N. S. | N. S. | <25 | 200 | Out of Limits |
| T.H. | 252 – 284 | 268 | 300 | - | <50 | N. S. | Out of Limits |
| C.H. | 420 – 555 | 484 | N. S. | N. S. | N. S. | N. S. | Out of Limits |
| C.O.D. | 8 – 190 | 97 | N. S. | N. S. | N. S. | N. S. | - |
| B.O.D. | 6 – 120 | 55 | N. S. | N. S. | N. S. | 100 | Out of Limits |
| Sulphate | 8.2 - 74.19 | 46 | 150 | 150 | N. S. | 480 | Within Limits |
| Phosphate | 1 - 7.8 | 4.4 | N. S. | N. S. | N. S. | N. S. | - |
| Chlorides | 88.72- 182.44 | 143 | 250 | 200 | <175 | N. S. | Within Limits |
| $NH_3$-N | 7.5 – 34 | 21 | 45 | 50 | N. S. | N. S. | Within Limits |
| Org. Nitrogen | 6.5 - 38.4 | 18 | N. S. | N. S. | N. S. | N. S. | - |
| MPN | >1600 | >1600 | <2 | <2 | N. S. | N. S. | Out of Limits |
| Total Bacterial Count | 12150 - 36000 | 24705 | 1 per 100ml | 1 per 100 ml | As low as possible | N. S. | Out of Limits |

(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count. N. S. Indicates Not Specified.)

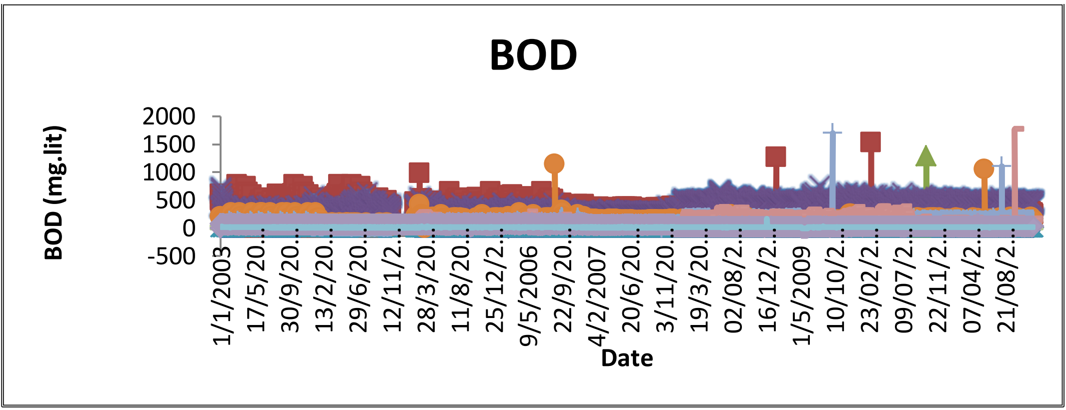
In the present waste water characterization, turbidity, odour, total solids, suspended solids, total hardness, carbonate hardness, BOD, MPN, TBC are the parameters to be treated according to the purpose of reuse by industries.

## 4.4 CHARACTERISTICS OF THE PLANT FOR ATLADRA SEWAGE TREATMENT PLANT

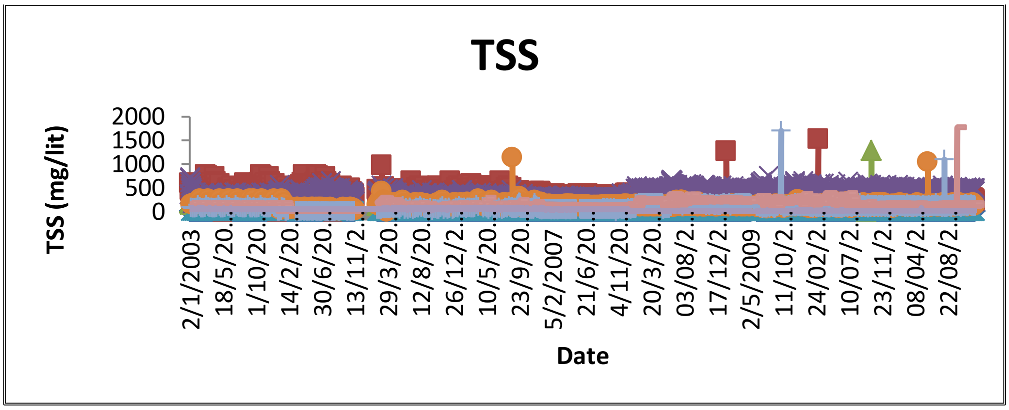
From collected data for year 2003-2011, values of parameters are plotted in graphs 4.1 to 4.5, which represent values of each parameter of domestic sewage treatment plant. Graph 4.4 shows the relation between BOD and COD along with mathematical model.



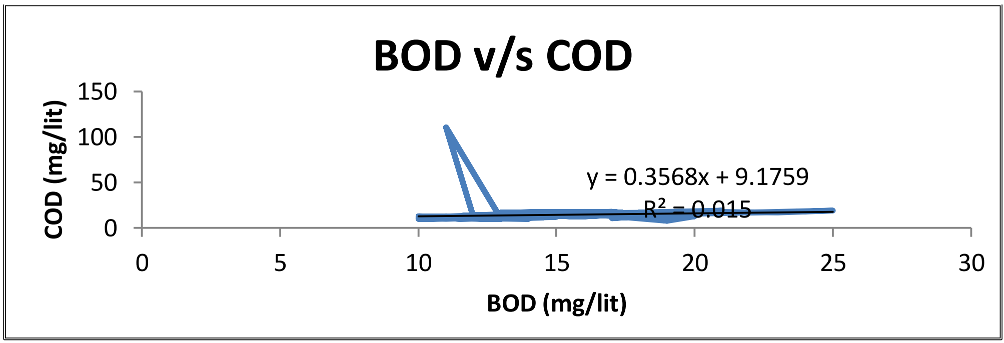

**Graph 4.1: Characteristics Of COD From 2003-11 For Atladra Sewage Treatment Plant**



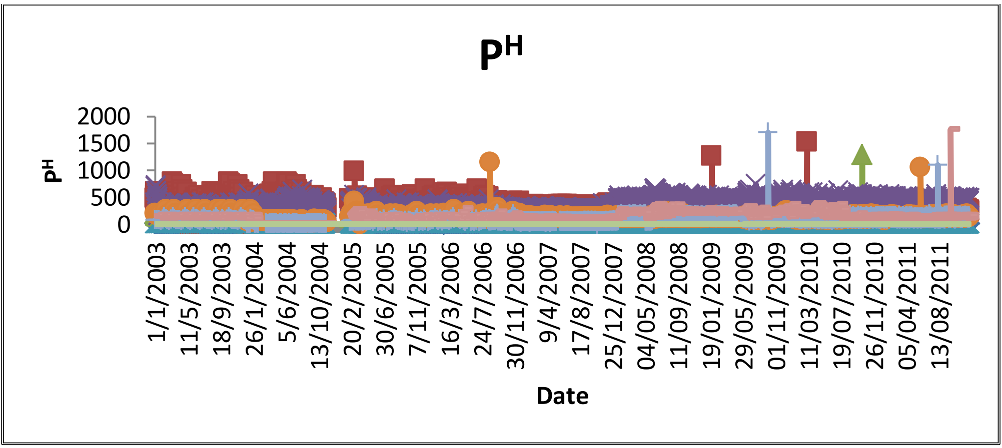

**Graph 4.2: Characteristics Of BOD From 2003-11 For Atladra Sewage Treatment Plant**




**Graph 4.3: Characteristics Of TSS From 2003-11 For Atladra Sewage Treatment Plant**

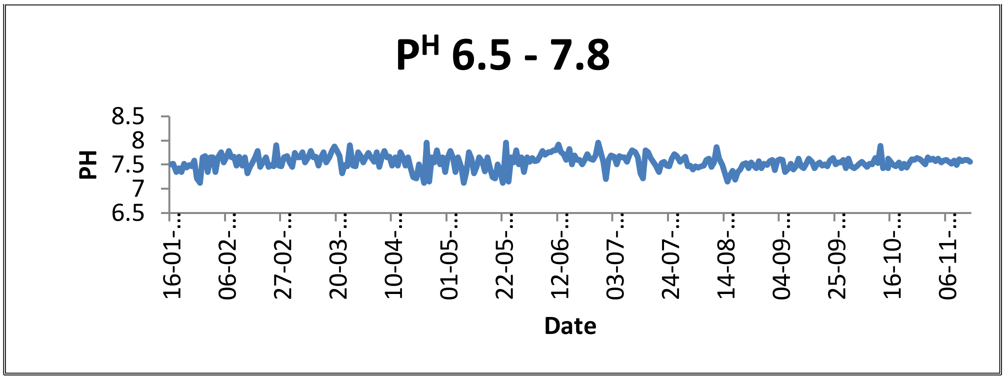



**Graph 4.4: Relation Between BOD & COD**

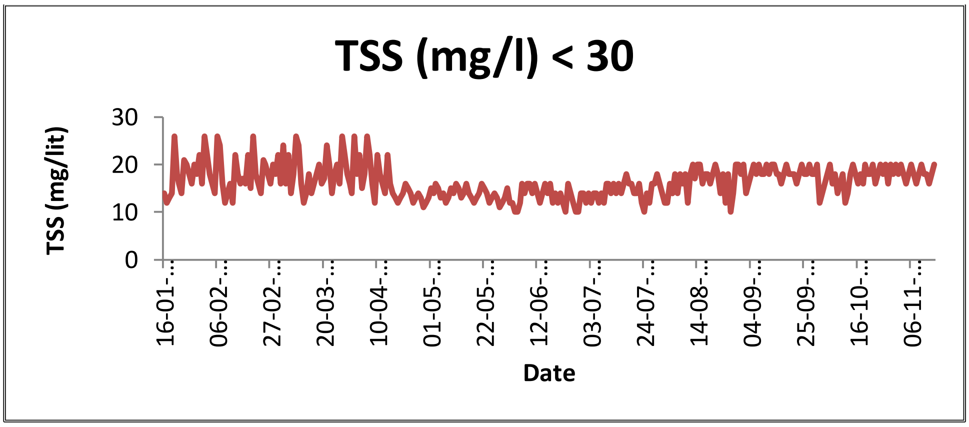



**Graph 4.5: Characteristics Of $P^H$ From 2003-11 For Atladra Sewage Treatment Plant**

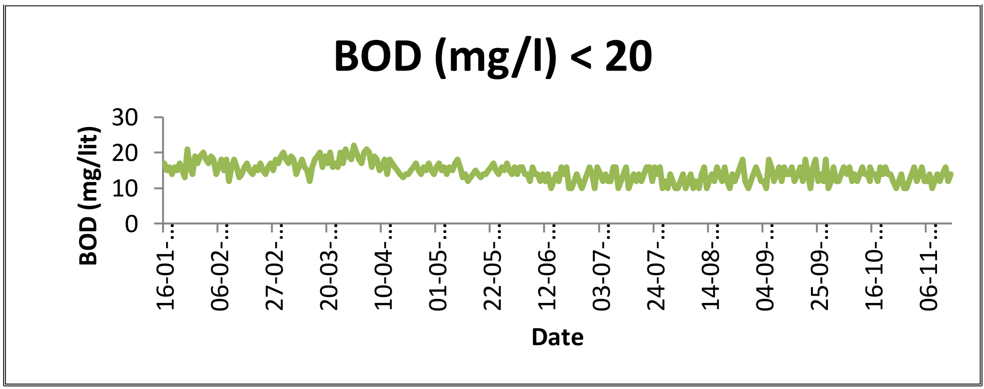
Following graphs show the characteristics of new plant which has been constructed adjoining to the existing plant to meet with requirement of treatment of waste water.



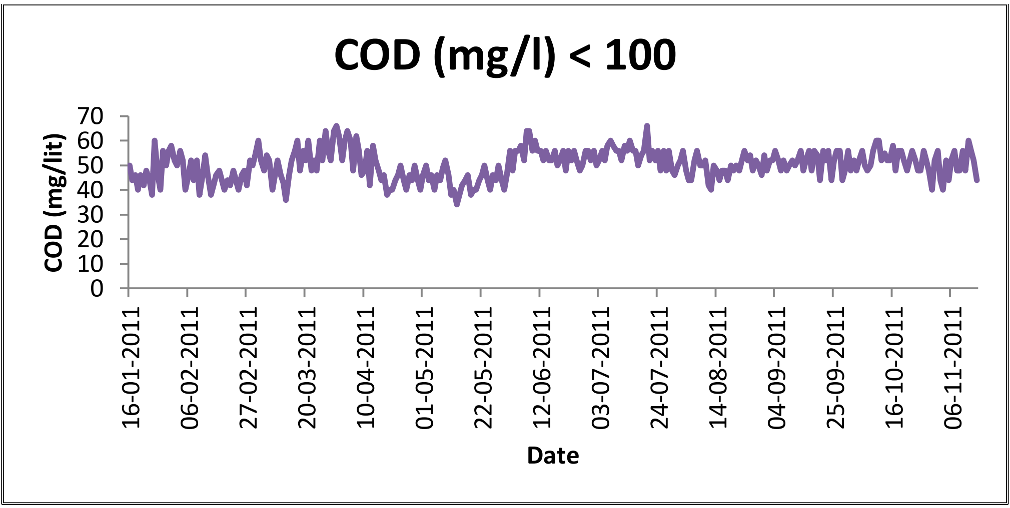

**Graph 4.6: Characteristics Of $P^H$ For Atladra New Sewage Treatment Plant**




**Graph 4.7: Characteristics Of TSS For Atladra New Sewage Treatment Plant**




**Graph 4.8: Characteristics Of BOD For Atladra New Sewage Treatment Plant**




**Graph 4.9: Characteristics Of COD For Atladra New Sewage Treatment Plant**

## 4.5 TREATABILITY STUDIES

For the treatability, samples were taken from secondary outlet and alternative treatments are tried. The detail for the same is as under:

### 4.5.1 Aim Of The Treatability Studies

The main aim is to meet with the water quality standards.

- MPN and Bacterial Count
- BOD and COD
- Suspended Solids
- Total hardness
- Carbonate Hardness
- Odor and Color

These are the parameters to be treated to have results within desired limit. Various treatments carried out are as stated below:

- Coagulation, Flocculation, Sedimentation and Filtration (Primary)
- Softening using Ion Exchange Columns (Secondary)
- Softening using the Lime Soda Process (Secondary)
- Chlorination at various chlorine doses (Tertiary)
- Ultra Violet Treatment (Tertiary)
- Ozonation (Tertiary)

### 4.5.2 Lab Scale Tests Carried Out For Treatability Studies

For the sample taken from secondary clarifier of Atladra sewage treatment plant, the following tests / treatments were carried out at lab scale.

### 4.5.3 Coagulation, Flocculation and Sedimentation

In addition to fine suspended matter, wastewater also contains electrically charged colloidal matters, which are continuously in motion and never settle down under the force of gravity because of stability forces like electrical double layer, charge intensity and water of hydration. To find out the optimum dose of coagulant, jar test was done. The apparatus used for Coagulation and Flocculation is a Jar Test.

### 4.5.4 Filtration

Filtration of wastewater is most commonly used for the removal of residual floc and colloidal matter in settled effluent. Filtration is also used to remove residual precipitates from the metal salt or lime precipitation of phosphate and is used as a pretreatment operation before wastewater is discharged to activated carbon induced applications. The filter column used for treatment is of following specifications:

**Depth of sand bed** - The depth of sand bed should be between 600-900 mm. for organic matters and bacteria to pass through the filter. Here 1.18-1.7 mm fine sand and 1.7-2.36 mm course sand is used.

**Gravel for filter** - Sand bed is supported on the gravel bed. Gravel bed has several functions. It supports the sand and allows the filtered water to move freely to under – drain. It allows wash water to move upward uniformly on sand. The gravel is placed in 4-5 layers having finest at top. Here 2.36 –3.25 mm gravel size is used.

**The procedure adopted for the treatment of wastewater filtration is as follows**

- Determination of the optimum coagulant dose at optimum $P^H$
- Application of the optimum coagulant dose to about 5 lit of sample and collection of the supernatant
- Washing the filter column with distilled water and then with the sample.
- Passing the sample and adjusting the flow rate at 10 ml/min.
- Passing the supernatant collected after coagulation and flocculation through the filter, determine MPN and the turbidity of the effluent as well as influent.
- Specifications of the Filter column:

**Rate of Filtration = 10 ml/min**

Length of base = 955.5 mm

| | |
|---|---|
| Length of bed | = 500 mm |
| Diameter | = 48 mm |
| Gravel size | = 2.36 – 3.25 mm |
| Coarse sand size | = 1.7 – 2.36 mm |
| Fine sand size | = 1.18 –1.7 mm |
| Area of filtration | = 1808 $mm^2$ |

**Figure 4.1: Waste Water From Secondary Clarifier**

**Figure 4.2: Jar Test Apparatus**

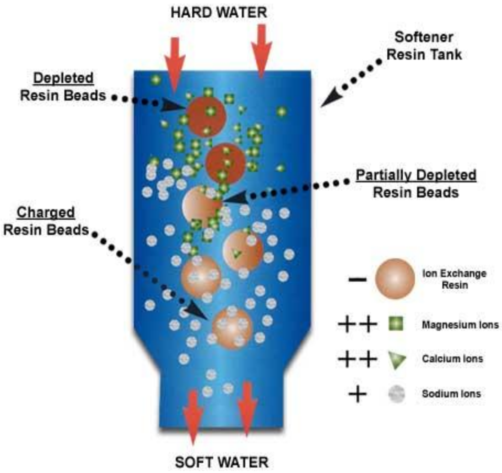



**Figure 4.3: Ion Exchange Process**

**Figure 4.4: Field Test Ozonation**

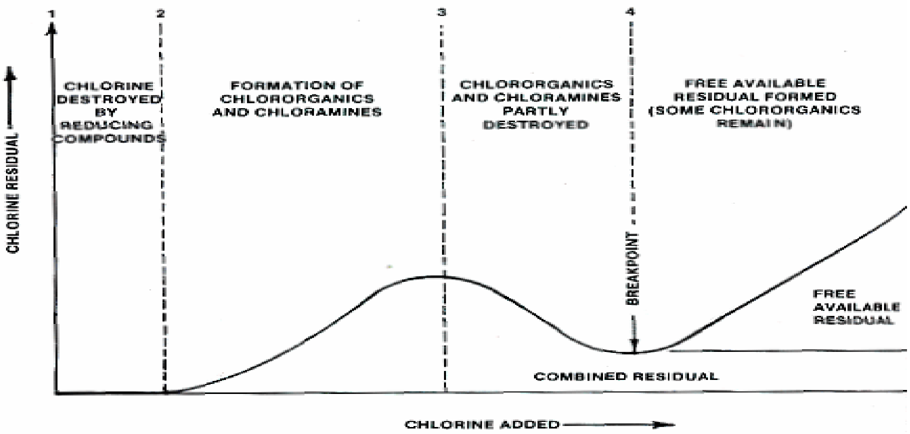



**Figure 4.5: Theory Of Break Point Chlorination**

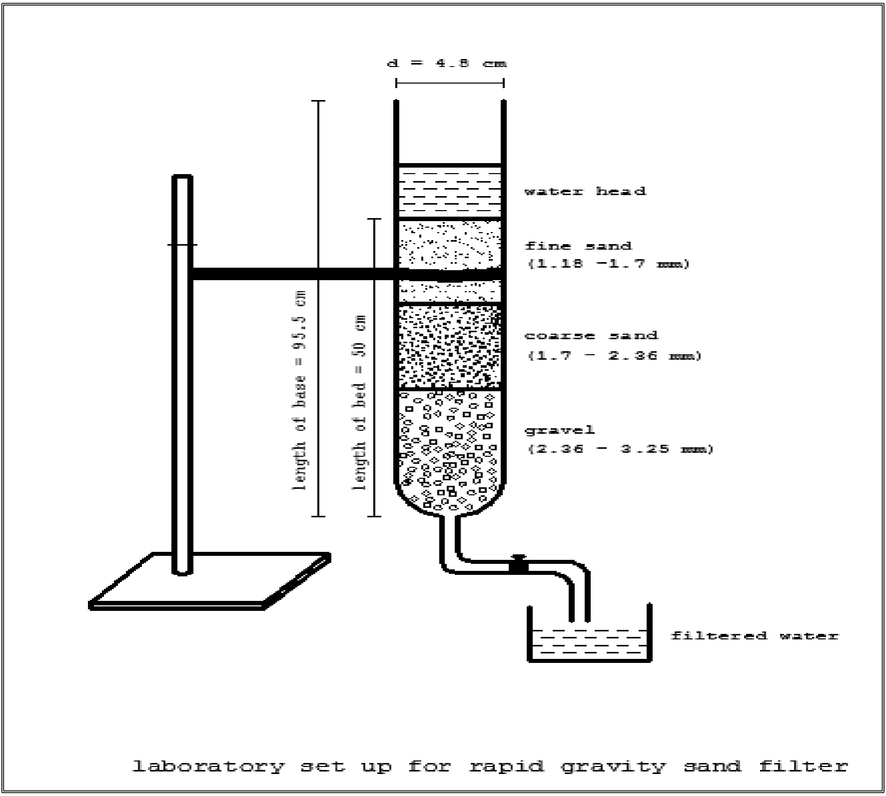



**Figure 4.6: Filter Column**

### 4.5.5 Ion Exchange

First passing of water through a bed of cation exchange can carry out removal of minerals present in the water resins bed, then through a bed of anion exchange resins. For treatment at lab scale the cation and anion exchange columns have been used. Details of columns are as under.

**Table 4.8: Details Of Lab Scale Exchange Columns**

| Sr. No | TYPE OF COLUMN | LENGTH OF COLUMN (cm). | RATE OF SAMPLE- ml of sample /min | RATE ml/min |
|---|---|---|---|---|
| 1 | Cation exchange | 48.5 | 0.1 – 0.2 | 10 |
| 2 | Anion exchange | 36 | 0.1 – 0.2 | 6.5 |

### 4.5.6 Softening

1 lit of sample was taken and the calculated amount of lime or soda ash was added. It was stirred continuously and heated to have better precipitation formation.Ca hardness reduction was found at the first stage. After that addition of 1 N NaOH or hydrated lime was done with $P^H$ adjustment 10.8 or 11. The Mg hardness reduction was determined in second stage removal.

### 4.5.7 Chlorination

Chlorination is commonly added to wastewater treatment plant effluent; it reacts with ammonia to be predominantly mono chloramines and dichloramine. Chlorination was carried out both directly on the sample and after filtration to find the dose of chlorine to be applied. The sample was treated to find out the breakpoint chlorination and the residual chlorine at different concentrations. MPN as well as total bacterial count before and after chlorination was determined. Here NaOCl of 6 % purity is used for treatment.

### 4.5.8 Ultra-Violet Rays Treatment

The wastewater sample without and with filtration was allowed to flow through the UV lamp: G36T5L with a given contact time. This treatment was done to remove all pathogenic organisms and some organic matter was oxidized. The treated wastewater, which was subjected to the radiation, was free from turbidity. Radiation of UV lamp provides 30000-micron watts seconds/$cm^2$ of 2537 Angstrom. Wavelength (254 Nanometer) of Ultra violet energy across fluid medium for Silica Quartz Jacket (quartz and silica made in France), provide 99.9 % efficiency due to its pure crystal clear transparency, so it can kill contaminated micro-organism of water.

### 4.5.9 Ozone Treatment

This treatment was tried with two different detention time at same ozone dose and oxygen supply rate, using field test equipment consisting of ozone generator & air pretreatment unit.

### 4.5.10 MPN-E-COLI [Multiple Tube Fermentation Technique For Coliform Group]

Presumptive test is done with use of Macconkey's broth. The fermentation tubes were arranged according to requirement for treated effluents and series: $10^{-1}$, $10^{-2}$, $10^{-3}$ was prepared.

### 4.5.11 Total Bacterial Count

Heterotrophic plate count (H.P.C.), commonly known as standard plate count is a procedure for estimating number of Heterotrophic bacteria (organic carbon utilizing bacteria) in a sample. This data is useful for estimating bacteria present into raw water, polluted water, in wastewater or in biomass. It also helps in estimating the characteristic of organic matter in wastewater, if biodegradable or not by comparing the count in the wastewater like sewage.

The various treatments carried out on each sample are explained in detail as below.

## 4.6 TREATABILITY STUDIES

For the selected wastewater samples, the treatability for primary, secondary and tertiary level treatment was tried.

**Table 4.9: Sample First Having Average Characteristics**

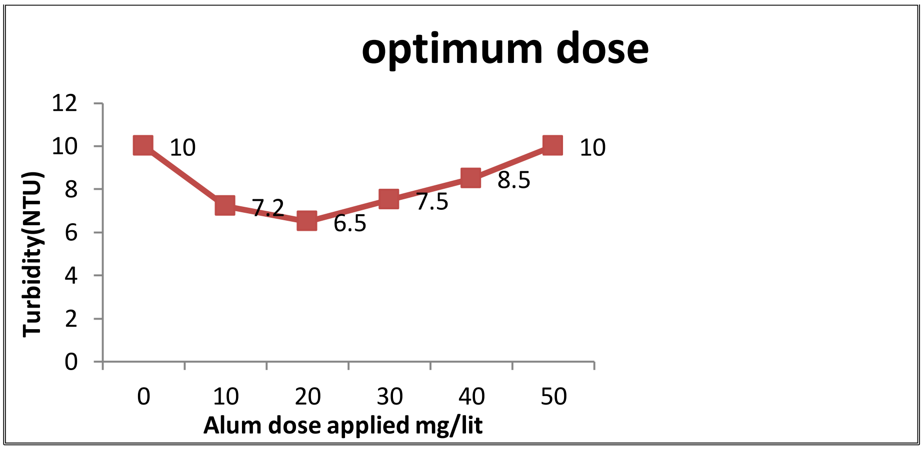
| Parameters | Sample | Parameters | Sample |
|---|---|---|---|
| $P^H$ | 8.38 | C.H. | 472 |
| D.O. | 5.8 | C.O.D. | 42 |
| Temp. | 25.9°C | B.O.D. | 18.5 |
| Turbidity | 18 NTU | Sulphate | 53 |
| Odor | Objectionable | Phosphate | 5.2 |
| T.S. | 729 | Chlorides | 125 |
| T.D.S. | 695 | $NH_3$-N | 34 |
| S.S. | 34 | Org. Nitrogen | 26 |
| T.H. | 252 | MPN | >1600 |
| | | Total Bacterial Count | 34300 |

(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count)

### 4.6.1 Coagulation, Flocculation and Sedimentation Treatment

The Treatment of coagulation was carried out for Optimum dose and optimum $P^H$ ranges to get maximum efficiency for removal of the pollutants in a Jar Test Apparatus.

#### 4.6.1.1 Optimum Dose for sample 1

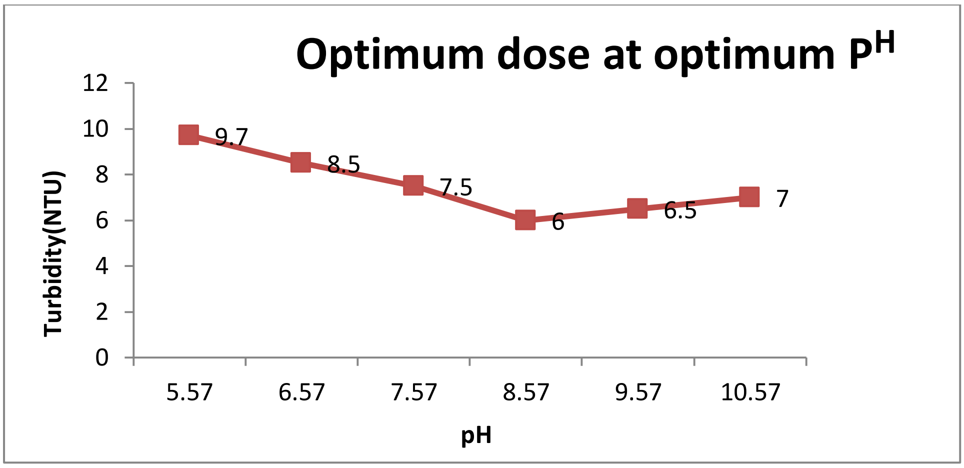



**Graph 4.10: Optimum Dose Determination For First Sampling**

From the graph optimum dose of alum is 20 mg/lit.

#### 4.6.1.2 Optimum dose at optimum $P^H$

$P^H$ is adjusted with 1N HCL and 1N NaOH and optimum dose of turbidity is found out.




**Graph 4.11: Optimum Dose For First Sampling**

It can be seen from the above that at an optimum dose of 20 mg/lit and at an optimum $P^H$ of 8.57 we get maximum efficiency of removal of pollutants.

### 4.6.1.3 Filtration Treatment

After sedimentation the supernatant was collected and was further subjected to filtration for removal of colloidal and suspended particulate fraction.

**The analysis results after filtration was observed as follows:**

- Turbidity = 4.5 NTU
- Temperature = 27.6°C
- $P^H$ = 8.05
- SS. = 34 mg/lit
- % Reduction in solids = 56.41 %
- Hardness = 250 mg/lit

**Table 4.10: Results of Filtration For Sample 1**

| | Before treatment | After treatment | % Reduction |
|---|---|---|---|
| Turbidity | 18 NTU | 4.5 NTU | 75 % |
| SS. | 34 mg/lit | 19.17 mg/lit | 56.41 % |
| Hardness | 252 mg/lit | 250 mg/lit | - |

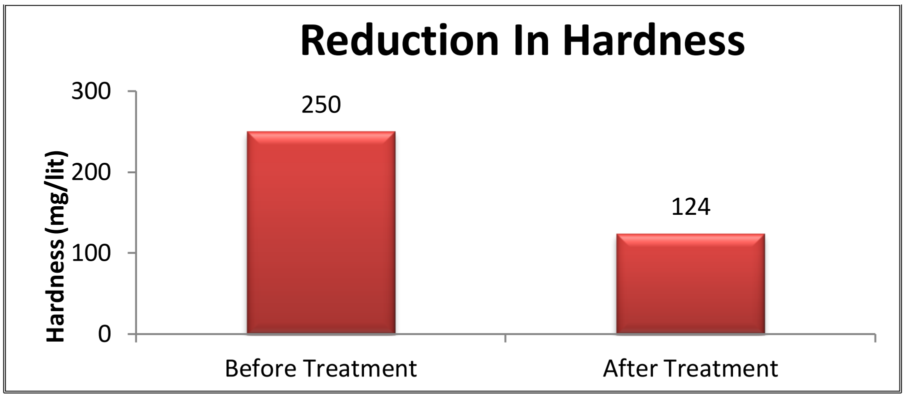
The wastewater still contained the hardness and suspended solids and hence was further subjected to softening treatment (Lime and Soda Process) for removal of the hardness.

### 4.6.1.4 Softening

The treatment of softening was given using hydrated lime and sodium carbonate.

Amount of hydrated lime required = 310.80 mg/lit

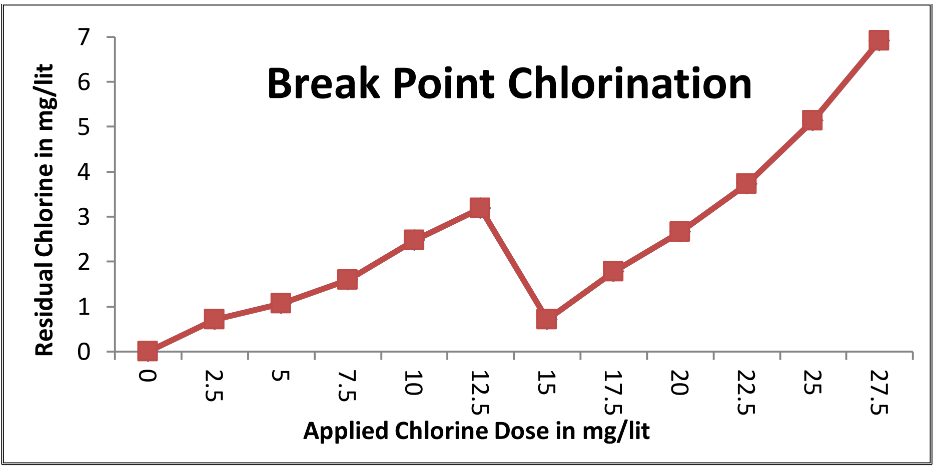
% Removal in Hardness = 50 %




### Graph 4.12: Removal Of Hardness Using Lime Soda For Sample 1

#### 4.6.1.5 Treatment- Chlorination

200 ml sample was taken in number of bottles and chlorine dose was given in different concentrations using NaOCl dosing. A Break Point Chlorination was established for an optimum dose of chlorine as shown below. Various chlorine doses were applied to determine optimum dose of chlorine and 15 mg/lit was the optimum dose.




### Graph 4.13: Residual Chlorine V/S Applied Chlorine Dose For Sample 1

It can be seen from the above table when an optimum dose of 15 mg/lit is applied. The results after chlorination treatment are shown as below:

Reduction in MPN:

- Before Treatment >1600

  After Treatment <2

**Table 4.11: The Inlet And Final Outlet characteristics After Chlorination For Sample 1**

| Parameters | Composite Sample Characteristics | Outlet Characteristics | Parameters | Composite Sample Characteristics | Outlet Characteristics |
|---|---|---|---|---|---|
| $P^H$ | 8.38 | 7.90 | C.O.D. | 42 | 32 |
| D.O. | 5.8 | - | B.O.D. | 20 | 12 |
| Temp. | 25.9°C | - | Sulfate | 53 | 45 |
| Turbidity | 18 NTU | 16 NTU | Phosphate | 5.2 | 4.8 |
| Odour | Objectionable | Unobjectionable | Chlorides | 125 | 260 |
| T.S. | 729 | 850 | $NH_3$-N | 34 | 30 |
| T.D.S. | 695 | 825 | Org. Nitrogen | 26 | 15 |
| S.S. | 34 | 20 | MPN | >1600 | Nil |
| T.H. | 252 | 184 | Total Bacterial Count | 34250 | Nil |
| C.H. | 472 | 465 | | | |

(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count)

## 4.7 TREATABILITY STUDIES ON SECOND SAMPLE

For the second average sample, parameters are determined. Primary treatment is tried as coagulation, flocculation, and sedimentation. After this treatment, filtration is carried out. For secondary treatment, softening is done. For tertiary treatment, ultra violet is done for disinfection.

**Table 4.12: Characterization Of Sample 2**

| Parameters | Sample | Parameters | Sample |
|---|---|---|---|
| $P^H$ | 9.22 | C.H. | 420 |
| D.O. | 4.7 | C.O.D. | 115 |
| Temp. | 29.3°C | B.O.D. | 50 |
| Turbidity | 14 NTU | Sulphate | 57 |
| Odor | Objectionable | Phosphate | 5.2 |
| T.S. | 673 | Chlorides | 89 |
| T.D.S. | 652 | $NH_3$-N | 7.5 |
| S.S. | 21 | Org. Nitrogen | 38.4 |
| T.H. | 284 | MPN | >1600 |
| | | Total Bacterial Count | 34500 |

(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count)

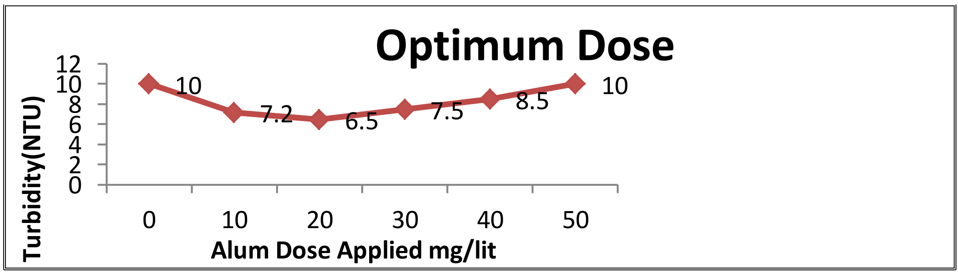
**TREATMETN TRAINS**

1. Coagulation➔Flocculation ➔ Sedimentation ➔ Filtration ➔ Softening.
2. Coagulation➔Flocculation ➔ Sedimentation ➔ Filtration ➔ Ion exchange.
3. Coagulation➔Flocculation ➔ Sedimentation ➔ Filtration ➔U.V.

### 4.7.1 Coagulation, Flocculation and Sedimentation Treatment

The treatment of coagulation using alum followed by flocculation and sedimentation and filtration was carried out on the composite sample. The Treatment of coagulation was carried out for Optimum dose and optimum $P^H$ ranges, to get maximum efficiency for removal of the pollutants in a Jar Test Apparatus.

**A. Optimum Dose for sample 2**

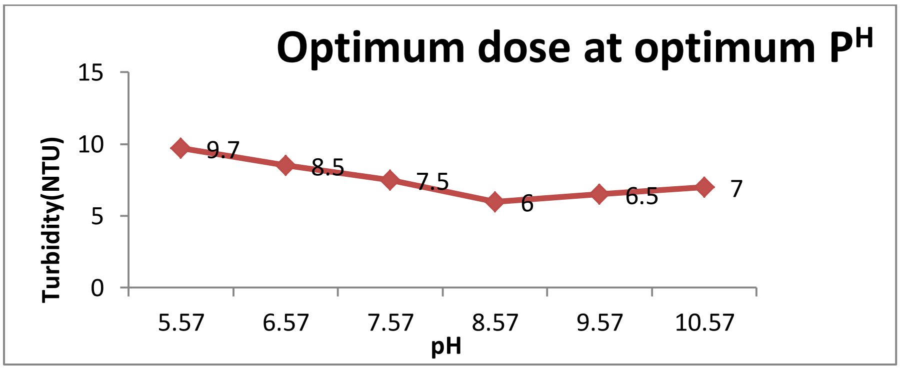



**Graph 4.14: Optimum Dose Determination For Sample 2**

From the above graph, Optimum dose = 20 mg/lit

**B. Optimum dose at optimum P$^H$**

P$^H$ is adjusted with 1N HCL and 1N NaOH




### Graph 4.15: Optimum P$^H$ at Optimum Dose For Sample 2

It can be seen from the above that at an optimum dose of 20 mg/lit and at an optimum P$^H$ of 8.57 we get maximum efficiency of removal of pollutants, turbidity reduces to 4.5 and SS reduces to 19.17 mg/lit.

## 4.7.2 Filtration Treatment

After sedimentation the supernatant was collected and was further subjected to filtration for removal of colloidal and suspended particulate fraction. This was carried out in a Filtration Column of the specification as stated.

**The analysis results after filtration was observed as follows:**

- Turbidity = 4.5 NTU
- Temperature = 27.6°C
- P$^H$ = 8.05
- SS. = 34 mg/lit
- % Reduction in solids = 56.41 %
- Hardness = 280 mg/lit

**Table 4.13: Treatment Results Of Filtration For Sample 2**

| Parameters | Before treatment | After treatment | % Reduction |
|---|---|---|---|
| Turbidity | 14 NTU | 4.5 NTU | 67.85 % |
| SS. | 78 mg/lit | 34 mg/lit | 56.41 % |
| Hardness | 284 mg/lit | 280 mg/lit | - |

The wastewater still contained the hardness and suspended solids and hence was further subjected to softening treatment (Lime and Soda Process) and treatment of ion exchange for removal of the hardness.

### 4.7.3 Ultra Violet Treatment

Ultra Violet Treatment was tried on the composite sample for removal of the bacteriological contamination after filtration. This treatment was tried batch wise and in continuous flow conditions, giving suitable detention time.

**Batch wise treatment:**

- Sample amount = 2 lit
- Contact time = 10 min
- After treatment total bacterial count = Nil

**Table 4.14: Reduction In Biological Impurities With U.V. Treatment (Batch Wise) For Sample 2**

| Parameter | Before treatment | After treatment |
|---|---|---|
| Total Bacterial Count | 34500 | Nil |
| MPN | >1600 | Nil |

**Continuous Flow Condition:**

At the outlet rate of collecting the sample = 10 ml/min

MPN before treatment >1600

MPN after treatment = Nil

Total Bacterial count before treatment = 34500mg/lit

Total Bacterial count after treatment = Nil

### 4.7.4 Softening

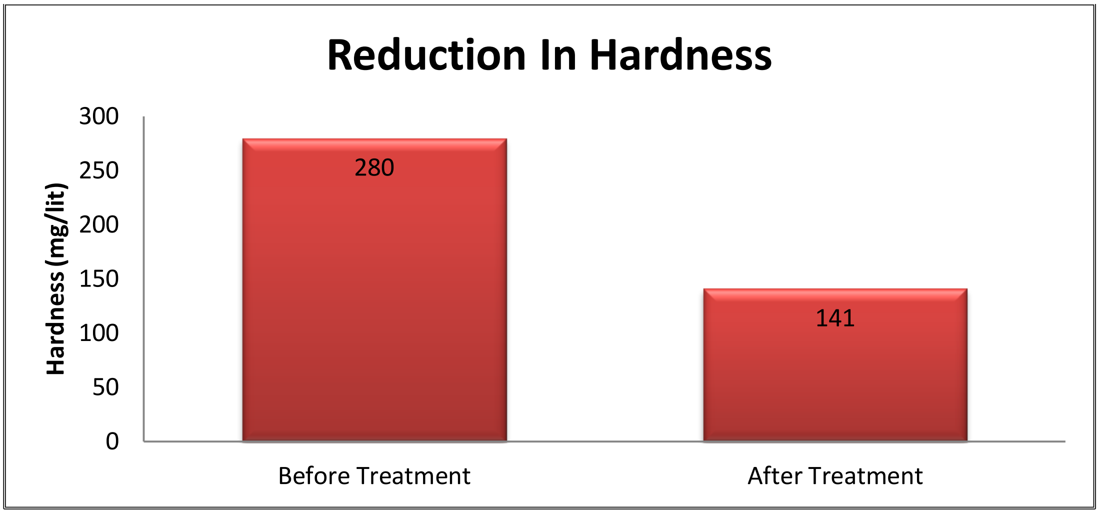
The treatment of softening was given using hydrated lime and sodium carbonate.

Amount of hydrated lime required = 310.80 mg/lit

Before softening Hardness = 280 mg/lit (T.H.),

After softening Hardness = 141 mg/lit (T.H.)

% Removal in Hardness = 50 %

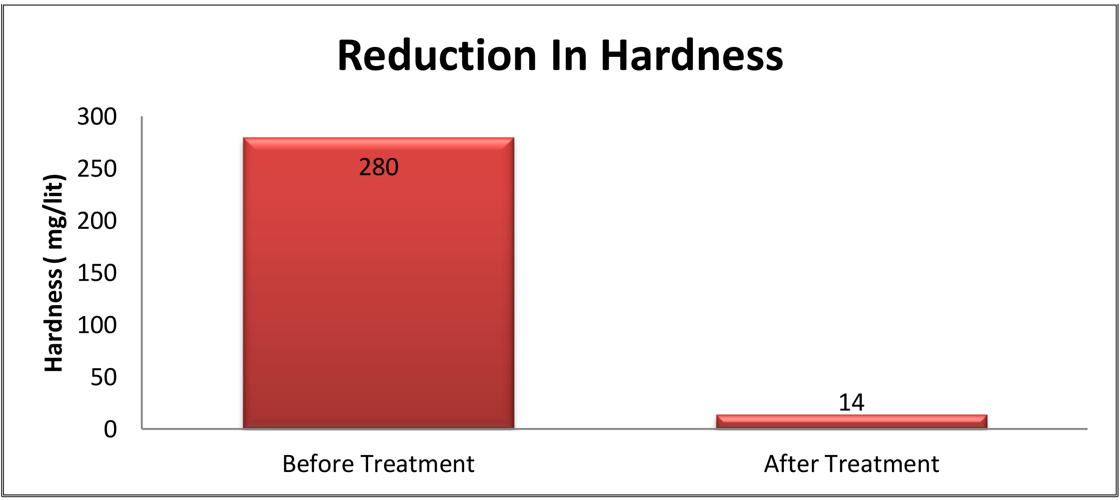



**Graph 4.16: Reduction In Hardness With Lime Soda For Sample 2**

The specifications of the Ion Exchange Column are as below:

**Cation Exchange Column**

- Length of column = 48.5 cm
- Column regeneration with 3N $HNO_3$
- Rate of sample – ml of sample/ml of resin per min = 0.1 – 0.2
- Rate of passing the sample = 10 ml/min.
- Total Hardness before treatment = 280 mg/lit
- Total Hardness after treatment = 14 mg/lit
- % Reduction in Hardness = 95 %




**Graph 4.17: Reduction in Hardness By Ion-Exchange For Sample 2**

A Table below shows the overall removal in parameters after each stage of treatment carried out on second sampling.

**Table 4.15: Reduction In Parameters After Each Stage Of Treatments Carried Out For Sample 2**

| Parameters | Sample | Characteristics after Coagulation, Flocculation and Sedimentation | Characteristics after Filtration | Characteristics after Softening using Ion-Exchange Process | Characteristics of filtered effluent after Ultra Violet Radiations |
|---|---|---|---|---|---|
| $P^H$ | 9.22 | 8.57 | 8.5 | 7.6 | 7.2 |
| D.O. | 4.7 | 4.2 | 4.0 | 3.5 | 3.0 |
| Temp. | 29.3°C | 29 °C | 29 | 29 | 29 |
| Turbidity | 14 NTU | 6 NTU | 2 NTU | 2 NTU | 2 NTU |
| Odor | Objectionable | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable |
| T.S. | 673 | 856 | 870 | 655 | 652 |
| T.D.S. | 652 | 846 | 865 | 650 | 647 |
| S.S. | 21 | 10 | 5 | 5 | 5 |
| T.H. | 284 | 280 | 279 | 14 | 280 |
| C.H. | 420 | 415 | 413 | 8 | 414 |
| C.O.D. | 115 | 95 | 52 | 35 | 50 |
| B.O.D. | 50 | 42 | 24 | 12 | 15 |
| Sulphate | 57 | 68 | 72 | 71 | 75 |
| Phosphate | 5.2 | 4.2 | 4.2 | 3.9 | 4.0 |
| Chlorides | 89 | 124 | 134 | 130 | 135 |
| $NH_3$-N | 7.5 | 7.0 | 7.0 | 6.9 | 7.0 |
| Org. Nitrogen | 38.4 | 35 | 35 | 34 | 30 |
| MPN | >1600 | >1600 | >1600 | >1600 | Nil |
| TBC | 34500 | 34500 | 34500 | 34500 | Nil |

(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count)

## 4.8 TREATABILITY STUDIES ON THIRD SAMPLE

For the third average characteristics sample, the primary and secondary treatment was tried same as for second sample and for disinfection, chlorination is tried as tertiary treatment.

**Table 4.16: Characterization Of Sample 3**

| Parameters | Sample | Parameters | Sample |
|---|---|---|---|
| $P^H$ | 8.4 | C.H. | 555 |
| D.O. | 3.9 | C.O.D. | 190 |
| Temp. | 28.75°C | B.O.D. | 120 |
| Turbidity | 26 NTU | Sulphate | 75 |
| Odor | Objectionable | Phosphate | 7.8 |
| T.S. | 1238 | Chlorides | 161 |
| T.D.S. | 690 | $NH_3$-N | 24.6 |
| S.S. | 548 | Org. Nitrogen | 11.4 |
| T.H. | 276 | MPN | >1600 |
| | | Total Bacterial Count | 26600 |

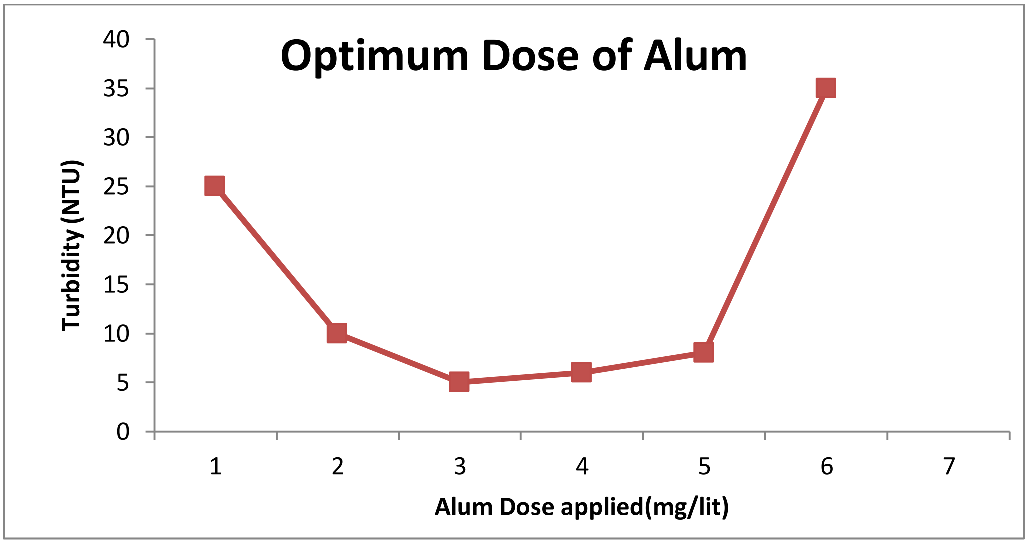
(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count)

**TREATMENT TRAINS:**

1. Coagulation➔Flocculation ➔ Sedimentation ➔ Filtration ➔ Chlorination ➔ Softening.

2. Coagulation➔Flocculation ➔ Sedimentation ➔ Filtration ➔ Chlorination ➔ Ion exchange.

### 4.8.1 Coagulation, Flocculation and Sedimentation

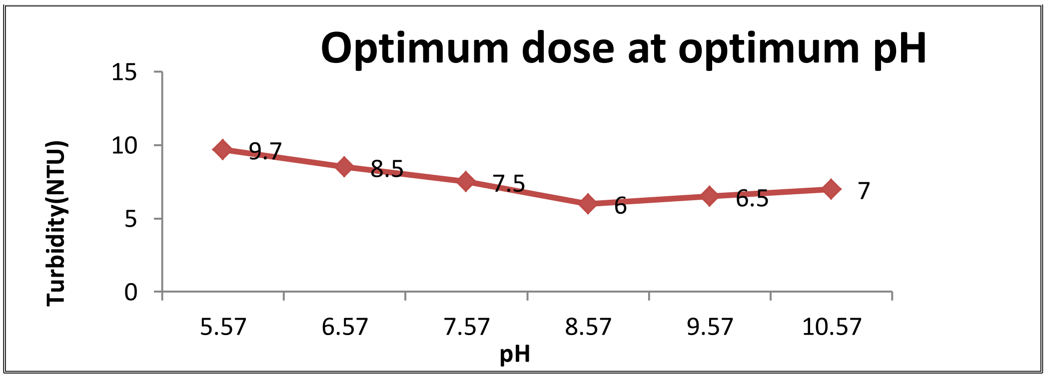



**Graph 4.18: Optimum Dose For Sample 3**

From the above results, for third sample, Optimum dose = 20 mg/lit

### 4.8.2 Optimum Dose At Optimum P$^H$ With Jar Test For Sample 3

Here P$^H$ is adjusted with 1N HCL and 1N NaOH. It can be seen from the graph that at an optimum dose of 20 mg/lit and at an optimum P$^H$ 8.57 we get maximum efficiency of removal of pollutants in form of COD and SS values.




**Graph 4.19: Optimum Dose at Optimum P$^H$ For Sample 3**

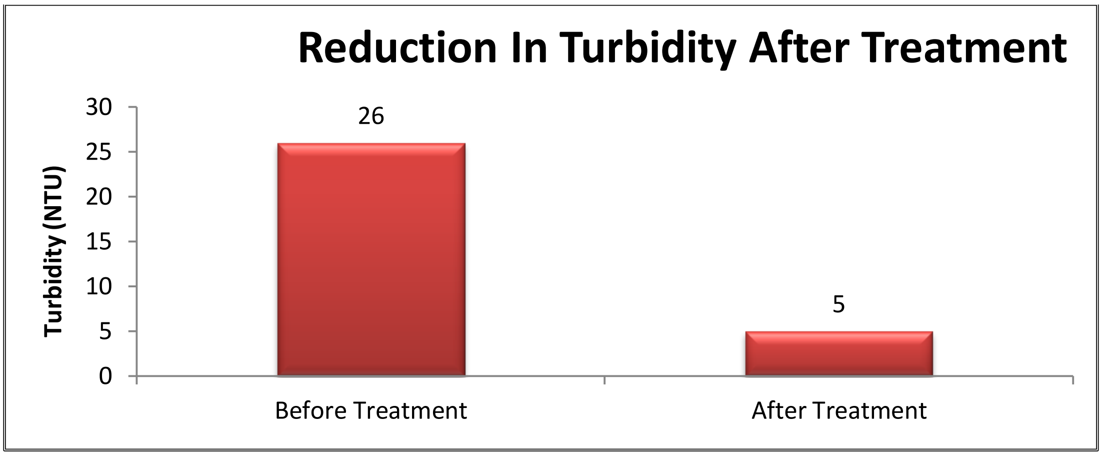
### 4.8.3 Filtration Treatment

The analysis results after filtration was observed as follows:

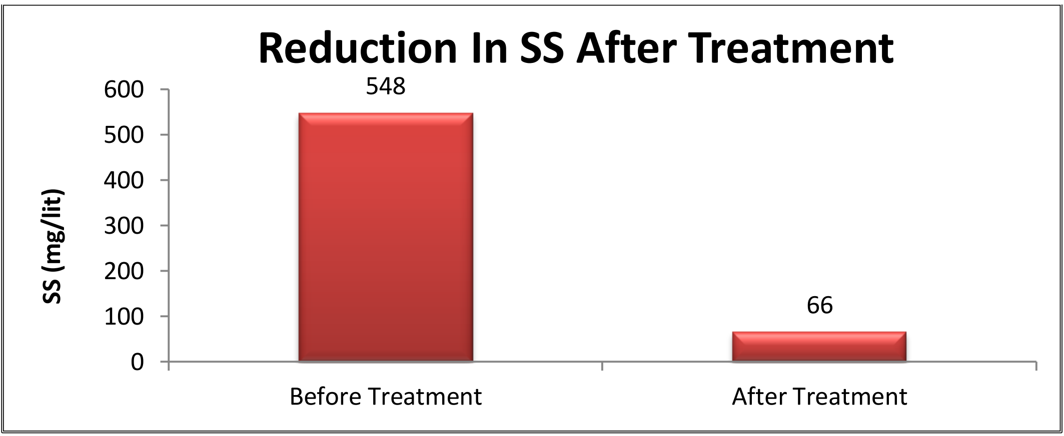
- Turbidity = 5 NTU
- Temperature = 27.6°C
- $P^H$ = 8.4
- SS. = 66 mg/lit
- % Reduction in SS solids = 87 %
- Hardness = 304 mg/lit

**Table 4.17: Treatment Results Before And After Treatment Of Filtration**

| Parameter | Before treatment | After treatment | % Reduction |
|---|---|---|---|
| Turbidity | 26 NTU | 5NTU | 80.76 % |
| SS. | 548 mg/lit | 66 mg/lit | 52 % |




**Graph 4.20: Reduction In Turbidity After Filtration For Sample 3**




**Graph 4.21: Reduction In Suspended Solids After Filtration For Sample 3**

### 4.8.4 Treatment Of Chlorination

A 100 ml sample was taken and chlorine dose was given in different concentrations using NaOCl dozing.

Break Point Chlorination was established for an optimum dose of chlorine

**Table 4.18: Break Point (Optimum) Dose Of Chlorine For Sample 3**

| Bottle No. | Amount Of Sample Taken (ml) | Applied $Cl_2$ mg/lit | Bottle shows blue color | Remaining Chlorine in mg/lit | Chlorine Demand | Chlorine dose (ml) | Exact Dose mg/lit |
|---|---|---|---|---|---|---|---|
| 0 | 100 | 0.00 | - | 0.00141 | - | 0.2 | 0.20 |
| 1 | 100 | 2.50 | | 0.0039 | 2.49290 | 0.2 | 2.69 |
| 2 | 100 | 5.00 | | 0.00177 | 4.98936 | 0.2 | 5.18 |
| 3 | 100 | 7.50 | | 0.01310 | 7.48400 | 0.2 | 7.68 |
| 4 | 100 | 10.0 | | 0.0124 | 9.97520 | 0.2 | 10.17 |
| 5 | 100 | 12.5 | | 0.0100 | 12.4681 | 0.2 | 12.67 |
| **6** | **100** | **15.0** | | **0.0067** | **14.9929** | **0.2** | **15.19** |
| 7 | 100 | 17.5 | | 0.01770 | 17.4823 | 0.2 | 17.68 |
| 8 | 100 | 20.0 | | 0.02660 | 19.9734 | 0.2 | 20.17 |

It can be seen from the above table that optimum dose of Chlorine is 15.2 mg/lit. The results after chlorination treatment are shown as below:

**Table 4.19: Treatment Results Of Chlorination For Sample 3**

| Parameter | Before Treatment | After Treatment |
|---|---|---|
| MPN | > 1600 | <2 |
| TOTAL BACTERIAL COUNT | 26600 | 700 |

### 4.8.5 Softening

The treatment of softening was given using hydrated lime and sodium carbonate.

Amount of hydrated lime required = 224.96 mg/lit

After treatment Hardness = 144 mg/lit

% Reduction = 52.63%

**Table 4.20: Results Of Softening Using Lime Soda For Sample 3**

| Parameter | Before treatment | After treatment | % Reduction |
|---|---|---|---|
| Turbidity | 26 NTU | 5NTU | 80.76 % |
| SS. | 548 mg/lit | 66 mg/lit | 52 % |
| Hardness | 304 mg/lit | 144 mg/lit | 52.63 % |

**ION EXCHANGE Treatment:**

The specifications of the Ion Exchange Column are as used for sample 2.

**Table 4.21: Results of Ion Exchange For Sample3**

| Parameter | Before treatment | After treatment | % Reduction |
|---|---|---|---|
| Turbidity | 26 NTU | 5NTU | 80.76 % |
| SS. | 548 mg/lit | 66 mg/lit | 87 % |
| Hardness | 304 mg/lit | 20 mg/lit | 93.42 % |

A table below shows the overall removal in parameters after each stage of treatment carried out on sample 3:

**Table 4.22: The Reduction In Parameters After Each Stage Of Treatments Carried Out On Third Sampling**

| Parameters | Sample | Characteristics after Coagulation, Flocculation and Sedimentation | Characteristics after Filtration | Characteristics after Chlorination | Characteristics after Chlorination Treatment and softening using Ion exchange |
|---|---|---|---|---|---|
| $P^H$ | 8.4 | 8.25 | 8.2 | 7.9 | 7.8 |
| D.O. | 3.9 | 3.5 | 3.5 | 3.0 | 3.0 |
| Temp. (°C) | 28.75 | 29 | 29 | 29 | 29 |
| Turbidity | 26 NTU | 15 NTU | 5 NTU | 5 NTU | 2 NTU |
| Odour | Objectionable | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable |
| T.S. | 1238 | 955 | 760 | 740 | 550 |
| T.D.S. | 690 | 692 | 694 | 693 | 543 |
| S.S. | 548 | 263 | 66 | - | 7 |
| T.H. | 276 | 270 | 268 | 267 | 20 |
| C.H. | 555 | 550 | 549 | 546 | 10 |
| C.O.D. | 190 | 115 | 94 | 76 | 28 |
| B.O.D. | 120 | 85 | 54 | 25 | 10 |
| Sulphate | 75 | 115 | 120 | 100 | 97 |
| Phosphate | 7.8 | 7.5 | 7.4 | 6.5 | 6.5 |
| Chlorides | 161 | 248 | 255 | 270 | 260 |
| $NH_3$-N | 24.6 | 20 | 18 | 12 | 11 |
| Org. Nitrogen | 11.4 | 11 | 11 | 10 | 9 |
| MPN | >1600 | >1600 | >1600 | >1600 | Nil |
| Total Bacterial Count | 26500 | 26500 | 20000 | Nil | Nil |

(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count)

## 4.9 TREATABILITY STUDIES ON FOURTH SAMPLING

The fourth sample is containing the values of parameters in a very near range for another three samples. So primary and secondary treatment is not tried separately but the tertiary treatment is tried with ozone treatment for disinfection.

**Table 4.23: Characterization Of Sample 4**

| Parameters | Sample collected on | Parameters | Sample collected on |
|---|---|---|---|
| $P^H$ | 8.23 | C.O.D. | 132 |
| D.O. | 3.9 | B.O.D. | 80 |
| Temp. | 29°C | Sulphate | 35 |
| Turbidity | 27 NTU | Phosphate | 3 |
| Odor | Objectionable | Chlorides | 183 |
| T.S. | 842 | $NH_3$-N | 21 |
| T.D.S. | 672 | Org. Nitrogen | 8.1 |
| S.S. | 170 | MPN | >1600 |
| T.H. | 268 | Total Bacterial Count | 32700 |
| C.H. | 492 | | |

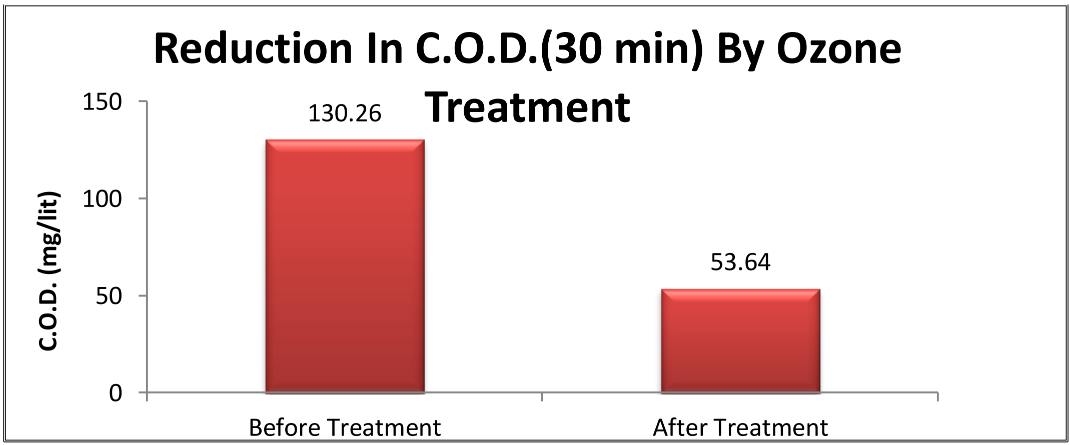
(Note: All Values in mg/lit except $P^H$, MPN and Total Bacterial Count)

From above three sample treatment results, primary and secondary treatment is kept same. For disinfection purpose, after chlorination and ozone, the third treatment option is ozone treatment, which is tried here by varying contact times.

### 4.9.1 Ozone Treatment

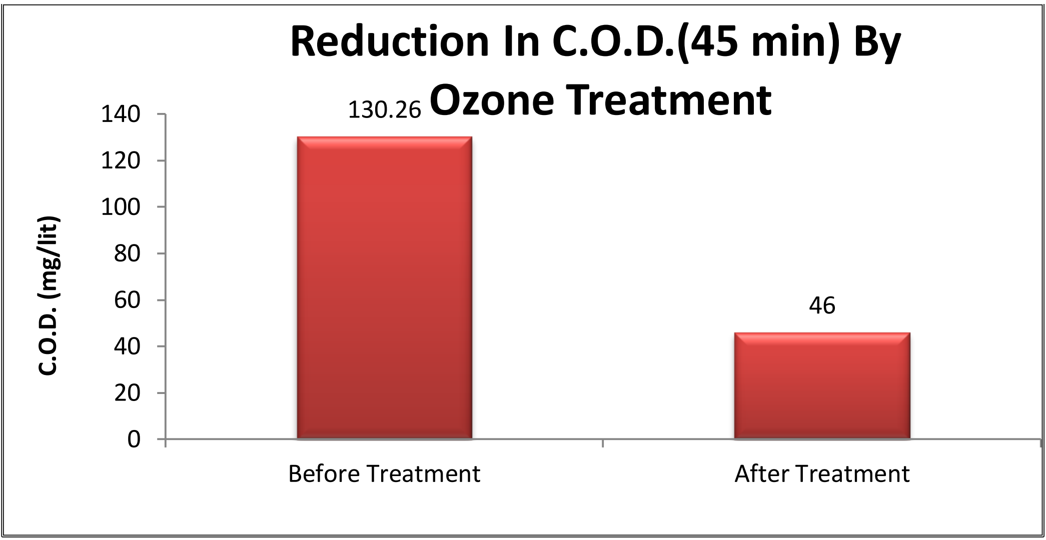
The ozone Treatment was carried out on the above Sample with two different contact times as follows:

- Ozone Dose = 3 gm/hr
- Flow rate = 8.9 Standard cubic ft/hr
- Detention time = 30 min.
- After treatment MPN (48 hr) - >1600
- Total Bacterial Count = 6500
- C.O.D. = 53.65 mg/lit



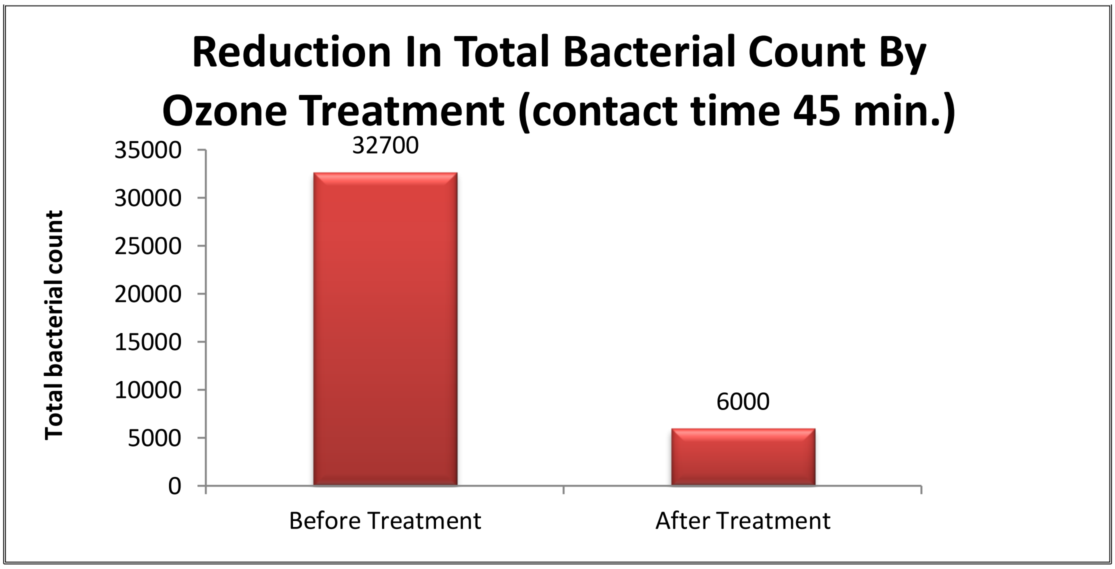

**Graph 4.22: Reduction In COD At Each Stage Of Treatment Of Ozone And Activated Carbon (Contact Time 30 Min)**

- Ozone Dose = 3 gm/hr
- Flow rate = 8.9 Standard cubic ft/hr
- Detention time = 45 min.
- After treatment MPN (48 hr) - <2
- Total Bacterial Count = 6000.
- C.O.D. = 46 mg/lit




**Graph 4.23: Reduction In COD At Each Stage Of Treatment Of Ozone And Activated Carbon (Contact Time 45 Min)**

The overall efficiency of removal of the organics in form of COD is shown and bacterial content by ozone treatment and activated carbon treatment is given below:




**Graph 4.24: Reduction In Total Bacterial Count By Treatment Of Ozone And Activated Carbon (Contact Time 45 Minute)**

**Table 4.24: Results Of The Treatment Of Ozone And Activated Carbon Treatment On Fourth Sampling**

| Description | Parameter: C.O.D. |
|---|---|
| Before Treatment | 130.26 mg/lit |
| After Ozonation (30 min.) | 53.64 mg/lit |
| After Ozonation (45 min.) | 46 mg/lit |
| After Ozonation followed by Activated Carbon (45 min.) | 18 mg/lit |
| % Reduction | 86.19 % overall. |

## 4.10 EXPERIMENTAL WORK FOR CASE STUDY 2: COMMON EFFUENT TREATMENT PLANT

The details of the experimental work carried out on final treated effluent of CETP, is as below.

### 4.10.1 Objectives Of The Case Study

The research work for case study of CETP is done with following objectives

- To assist diagnosing any problem & to help the plant team in optimal management
- To initiate the simple but effective system to check the function of the major components of CETP in that particular plant & to calculate overall performance of the system.
- To use this to create a generic set of guidelines for other CETPs to develop their own monitoring procedure.
- To access the overall performance of CETP
- To review the functioning of all the consistent facilities.
- To review existing operational practices.

**Table 4.25: Characteristics Of Important Parameters At The Initial Stage Of The Plant(inlet)**

| Month | Equalization Tank | | | | Final Outlet | | | |
|---|---|---|---|---|---|---|---|---|
| | COD | BOD | SS | TDS | COD | BOD | SS | TDS |
| Month 1 | 1480 | 390 | 336 | 12620 | 252 | 46 | 89 | 10480 |
| Month 2 | 1375 | 386 | 395 | 10620 | 228 | 36 | 78 | 10360 |
| Month 3 | 1660 | 490 | 412 | 9680 | 238 | 34 | 88 | 9820 |
| Month 4 | 1620 | 512 | 392 | 10326 | 220 | 16 | 68 | 9470 |
| Month 5 | 1428 | 280 | 408 | 9828 | 262 | 78 | 72 | 8628 |
| Month 6 | 1530 | 328 | 510 | 9625 | 222 | 66 | 72 | 9402 |
| Month 7 | 1380 | 3687 | 288 | 12240 | 246 | 64 | 60 | 10220 |

(Note: All Values in mg/lit)

**Table 4.26: Characteristics Of Important Parameters At Equalization Tank**

| Month | Eq.tank | | | | | Final Outlet | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | COD | BOD | BOD/COD | SS | TDS | COD | BOD | BOD/COD | SS | TDS |
| Month 1 | 1688 | 554 | 0.33 | 368 | 12050 | 242 | 36 | 0.15 | 82 | 11084 |
| Month 2 | 1554 | 468 | 0.3 | 244 | 10664 | 218 | 25 | 0.11 | 74 | 10280 |
| Month 3 | 1458 | 362 | 0.25 | 322 | 9864 | 224 | 66 | 0.29 | 98 | 9644 |
| Month 4 | 1248 | 333 | 0.27 | 254 | 10247 | 205 | 16 | 0.08 | 102 | 9832 |
| Month 5 | 1648 | 475 | 0.29 | 316 | 10124 | 246 | 26 | 0.11 | 84 | 10024 |
| Month 6 | 1722 | 514 | 0.3 | 354 | 11224 | 254 | 56 | 0.22 | 64 | 11126 |

(Note: All Values in mg/lit)

## 4.10.2 Treatability Studies

In the initial stage of plant, wastewater has to be provided with specific treatment for the reduction in the high concentration values of certain pollutants and removal of heavy metals and other toxicants. The approach of the treatment is to make the waste water amenable for the biodegradation so suitable pretreatment is required to bring down the pollution load at the inlet of the secondary biological unit.

### 4.10.2.1 Primary treatment

**COAGULATION**:

The waste water was subjected to treatment using 1ml=10mg of Alum solution. The alum dose was optimized by varying alum concentration. The results are tabulated as follows:

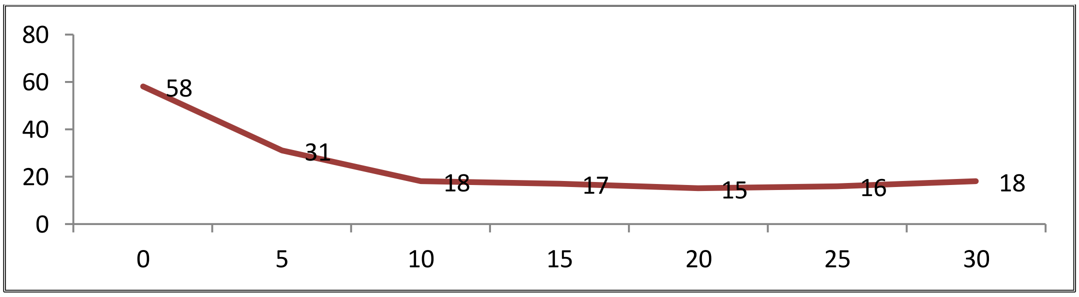
**Table 4.27: Characteristics Of Raw Waste Water**

| Parameter | Raw Waste Water Values | Permissible Value for inlet to CETP | Permissible Discharged Values for the Outlet of CETP |
|---|---|---|---|
| $P^H$ | 7.00 | 6 to 9 | 6 to 9 |
| Total Solids | 20588 | - | - |
| Total Dissolved Solids | 18492 | <9000 | N.A. |
| Total Suspended Solids | 2096 | <200 | 100 |
| Chlorides | 9500 | - | - |
| COD | 1248 | <2000 | 250 |
| BOD | 680 | <800 | 100 |
| Ammonical Nitrogen | Nil | <50 | <50 |
| Organic Nitrogen | Nil | - | - |
| Total Nitrogen | Nil | - | - |
| Phosphate | Nil | - | - |
| Oil & Grease | 19 | <10 | <10 |
| Temperature | 32.9 | Nil | 40 |
| Sulfates | 1800 | - | - |
| BOD / COD | 0.5 | - | - |

(Note: All the Units are mg / l except $P^H$)

**FOR ALUM TREATMENT:**

Initial Turbidity = 101 Units, $P^H$ = 7.00, RPM = 36




## Graph 4.25: Optimum Dose Of Alum For First Sample Of CETP

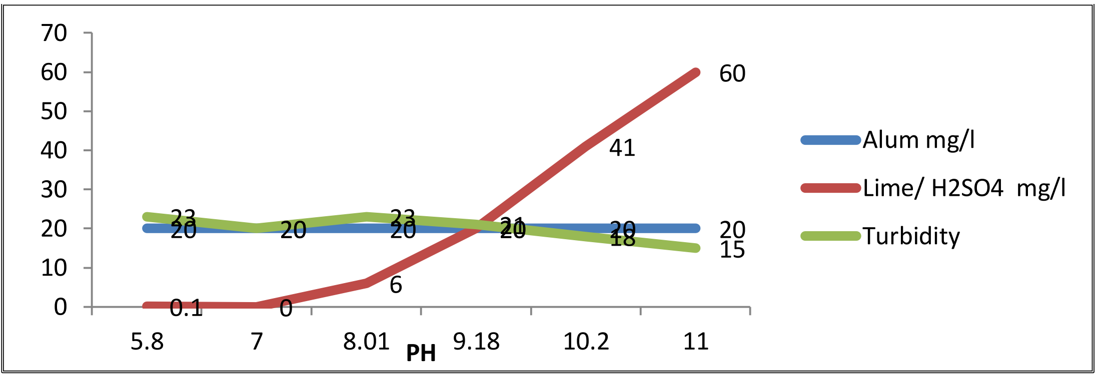
**$P^H$ ADJUSTMENT:**

The $P^H$ of raw composite wastewater was in a range of 8-8.5. $P^H$ adjustment is necessary, prior to chemical treatment, to obtain high percentage of solids settlements. After addition of 10% of lime slurry, having purity of 90%, to the raw waste water with stirring, $P^H$ was adjusted in the range of 5-12 for optimization. The dose of lime slurry of 120 ml/l of wastewater was required to raise the $P^H$ from less than 8.0 to 11.0. The various $P^H$ levels at various lime dose with respective turbidity is shown as follows.

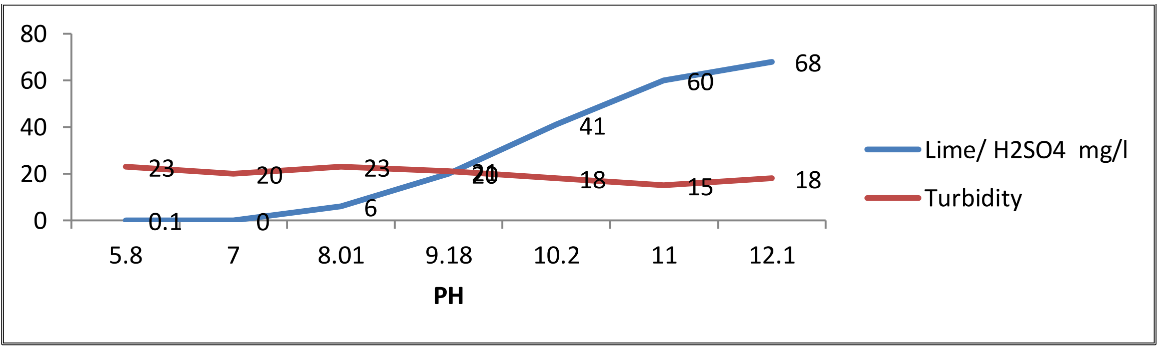
For lime treatment: Initial Turbidity = 101 Units, $P^H$ = 7.00

At different dose of alum at various $P^H$ levels are as below.

Initial Turbidity = 101 Units




**Graph 4.26: Variation In Turbidity At Various Dose Of Alum And Lime**




**Graph 4.27: Turbidity At Different Lime Dose At Predetermined Alum Dose At Variable $P^H$**

When Alum dose of 20 mg/lit was applied at $P^H$ 11.00, the maximum turbidity was removed.

Following table shows characteristics of wastewater after coagulation:

**Table 4.28: Characteristics Of Waste Water After Coagulation**

| Parameter | Values After Coagulation | Permissible Value for inlet to CETP | Permissible Discharged Values for the Outlet of CETP |
|---|---|---|---|
| $p^H$ | 7.90 | 6 to 9 | 6 to 9 |
| Total Solids | 19106 | - | - |
| Total Dissolved Solids | 17432 | <9000 | N.A. |
| Total Suspended Solids | 1674 | <200 | 100 |
| Chlorides | 7248 | - | - |
| COD | 1041 | <2000 | 250 |
| BOD | 530 | <800 | 100 |
| Ammonical Nitrogen | Nil | <50 | <50 |
| Organic Nitrogen | Nil | - | - |
| Total Nitrogen | Nil | - | - |
| Phosphate | Nil | - | - |
| Oil & Grease | 17 | <10 | <10 |
| Temperature | 32.9 | Nil | 40 |
| Sulfates | 1523 | - | - |
| BOD / COD | 0.5 | - | - |

(Note: All the Units are mg / l except $P^H$)

### 4.10.2.2 Biological treatment

The supernatant after coagulation treatment was studied for biological degradability. The $P^H$ was adjusted to 7.9. The system of biological treatment selected was activated sludge process by diffused aeration. For the effluent collected the ratio observed was less and hence it was decided to add nutrient. The BOD of the effluent entering the biological treatment is 580 mg/l and the required nitrogen "N" would be 30mg/l and phosphorus "P" would be 6 mg/l. The deficit was fulfilled by addition of 1 g/l Di-ammonium Phosphate (DAP). To enhance the biomass development 1 g/l of glucose was added.

Aeration was started by compressed air at the rate of 4 lit/min till the wastewater sample was acclimatized. After acclimatization, sample was aerated for 10 hours and continuous sampling at each two hour interval was carried out, results are shown for COD reduction.

**Table 4.29: Results From Aeration System**

| Hour of aeration | PH | Temperature | COD | Dissolved Oxygen |
|---|---|---|---|---|
| 0 hr. | 7.98 | 29.6 | 1032 | 2.4 |
| 2 hr. | 7.96 | 30.1 | 880 | 2.1 |
| 4 hr. | 7.72 | 30.7 | 640 | 2.3 |
| 6 hr. | 7.61 | 30.8 | 557 | 2.3 |
| 8 hr. | 7.58 | 30.7 | 412 | 2.5 |
| 10 hr. | 7.43 | 30.7 | 320 | 2.6 |

**Table 4.30: Characteristics Of Wastewater After Aeration**

| Parameter | Values after Aeration | Permissible Value for inlet to CETP | Permissible Discharged Values for the Outlet of CETP |
|---|---|---|---|
| PH | 7.43 | 6 to 9 | 6 to 9 |
| Total Solids | 17588 | - | - |
| Total Dissolved Solids | 16332 | <9000 | N.A. |
| Total Suspended Solids | 1256 | <200 | 100 |
| Chlorides | 4589 | - | - |
| COD (After 10 hr.) | 320 | <2000 | 250 |
| BOD (After 10 hr.) | 148 | <800 | 100 |
| Ammonical Nitrogen | 10 | <50 | <50 |
| Organic Nitrogen | 7 | - | - |
| Total Nitrogen | 17 | - | - |
| Phosphate | 2 | - | - |
| Oil & Grease | 15 | <10 | <10 |
| Temperature | 30.7 | Nil | 40 |
| Sulfates | 1220 | - | - |
| BOD / COD | 0.5 | - | - |
| MLSS | 3980 | - | - |
| MLVSS | 2984 | - | - |
| MLVSS/MLSS | 0.75 | - | - |

(Note: All the Units are mg/l except PH)

For further removal of pollutant potential tertiary treatment was employed.

### 4.10.2.3 Tertiary treatment

Three treatments were tried for further polishing treatment to the secondary treated effluent.

**a. Treatment With GAC:**

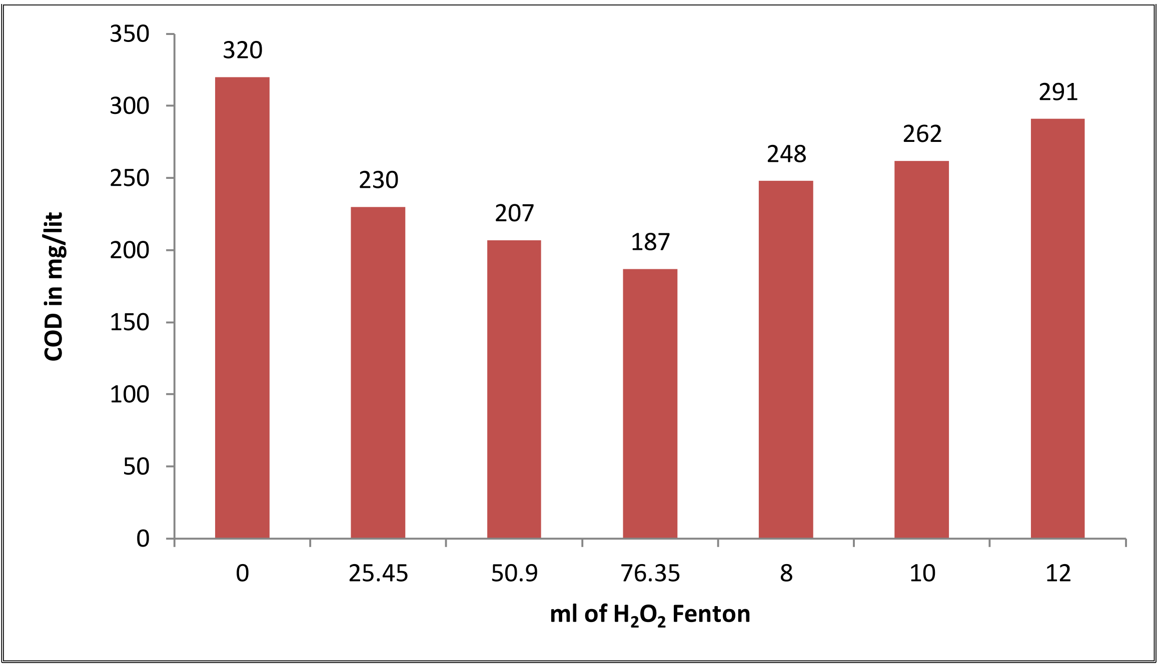
For the removal of residual COD after biological treatment the waste was subjected to treatment with GAC.

**Table 4.31: Filtrate From Activated Carbon Filter**

| Wt. Of AC in mg (M) | Vol. Of Sample in ml (V) | COD from filtrate in mg/l ($C_n$) | Organic matter adsorbed | Wt. Of solids adsorbed | Wt. of solids adsorbed/unit mass in mg. |
|---|---|---|---|---|---|
| 0 | 100 | 320 | - | - | - |
| 50 | 100 | 185 | 135 | 1.35 | 0.42 |
| 100 | 100 | 139 | 46 | 0.46 | 0.248 |
| 200 | 100 | 111 | 28 | 0.28 | 0.203 |

### b. $H_2O_2$+Fe ( Fenton)

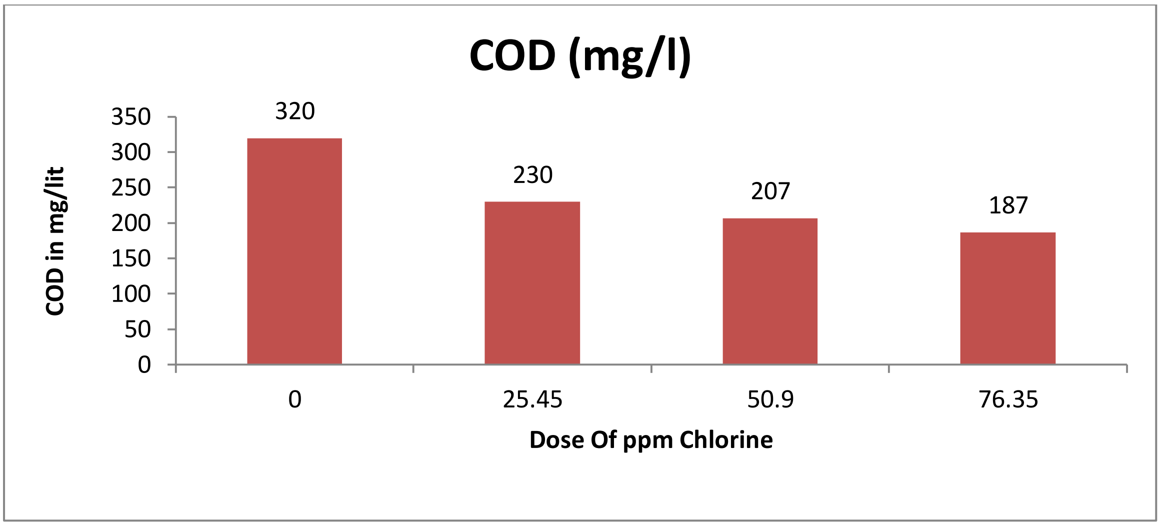
The waste water was subjected to treatment with $H_2O_2$ and reaction time of about ½ hr. was given. After this results were analyzed for COD reduction as under:




**Graph 4.28: COD Reduction At Various $H_2O_2$Doses**

### c. Chlorine Water Treatment

The wastewater was subjected to treatment with chlorine as oxidizing agent for removal of residual COD for a constant time of 30 minutes. The process involves dosing of chlorine water.




**Graph 4.29: COD Reduction At Various Chlorine Doses**

**Table 4.32: Results After Each Stage Of Treatment**

| Parameter | Inlet value (mg/l) | After primary treatment (mg/l) | After Biological process (mg/l) | Quality after tertiary treatment (GAC) |
|---|---|---|---|---|
| $P^H$ | 7.00 | 7.90 | 7.43 | 7.20 |
| COD | 1300 | 1000 | 350 | 150 |
| BOD | 700 | 600 | 200 | 75 |
| TS | 20000 | 19000 | 18000 | 10080 |
| TDS | 19000 | 16000 | 14000 | 10000 |
| Phosphate | Nil | Nil | 2 | 1 |
| Chlorides | 9500 | 7500 | 4500 | - |
| Sulphates | 1900 | 1600 | 1500 | - |
| Ammonical Nitrogen | Nil | Nil | 10 | 6 |
| Organic Nitrogen | Nil | Nil | 7 | 2 |
| Total Nitrogen | Nil | Nil | 17 | 8 |

(Note: All the Units are mg/l except $P^H$)

## 4.10.3 Quality Of The Waste Water After First Trial Of The Treatment

The quality after tertiary treatment is such that it cannot be used for the irrigation purpose or other purposes. Due to high TDS value, one of the solution for making wastewater reusable is to dilute it with treated sewage in appropriate percentage.

The TDS value is about 10000-11000. For irrigation purpose the required TDS value is 2100 as per IS standards. So the TDS concentration will be less than 2100 mg/lit.

### 4.10.3.1 Remarks for initial stage of treatment of wastewater CETP

Following are the results of first stage treatment applied to CETP wastewater:

- The approach to provide treatment at low cost is important factor in common treatment system.

- Due to very low loading only one stage aeration is carried out. However DO level is maintained in aeration tank 1.5 mg/lit.
- Nitrogen, Phosphorus concentration is maintained by addition of di-ammonium phosphate and super phosphate. Cow dung is also added to maintain biomass (MLSS) and partial requirement of nutrient (N:P).
- After secondary clarifier COD and BOD is not within permissible limit, that is 536 mg/lit COD and 258 mg/lit BOD.
- Dual media filter is used for final treatment to get COD 200 mg/lit, BOD 97 mg/lit and Suspended Solids 80 mg/lit
- Activated sludge treatment with 3980 mg/lit MLSS and 2984 mg/lit MLVSS with 10 hrs. Aeration time at $P^H$ 7.9 gave reduction in COD from 1032 mg/lit to 320 mg/lit and BOD from 530 mg/lit to 148 mg/lit.
- Aeration rate was maintained at 4 mg/lit to obtain DO in range of 2.1 to 2.6 mg/lit.
- Nutrient concentration 1 g/lit of di-ammonium phosphate was added to maintain BOD: N:P in 100:5:1 ratio.
- Activated carbon treatment was given to get COD, BOD value within disposal standards as $H_2O_2$ and chlorine oxidation has not reduced organic concentration to required level.
- 50 mg/lit of activated carbon in 100 ml of wastewater gave reduction in COD from 320 mg/lit to 185 mg/lit and with 200 mg/lit of activated carbon dose, it reduces COD to 111 mg/lit and BOD to 80 mg/lit.
- Treated wastewater having BOD and COD is low and can be used for irrigation but TDS is in range of 10000 to 11000 mg/lit. While for irrigation TDS should be less than 2100. Hence dilution with fresh water or with treated sewage will reduce TDS and can be used for irrigation to save fresh water quality.
- Facilities may be provided to treat the higher COD at CETP to reduce COD to 2000 mg/lit. It can save wastewater for which costly treatment needs to be applied that may not be feasible for small scale industries. These can be carried out at CETP by giving $H_2O_2$ treatment at holding tank before putting to inlet of main treatment unit. This can be done by adding cost of treatment for higher COD industries.
- While for reducing cost at CETP the member units should also provide settling and neutralization at higher individual wastewater treatment unit, which will reduce cost of making huge equalization and settling units.

### 4.10.4 $P^H$, Turbidity & COD At Various Alum Dose – A Treatability Study To Reduce Turbidity & COD

Following are the trials done to achieve reduction in turbidity and COD with use of coagulants. For each sample: $P^H$ turbidity, RPM and temperature was measured and it is presented along with the results of treatments applied. The conditions/parameters at the time of testing along with results are as below:

**Optimum Dose**

Sample: Equalization tank

Sampling: Grab Initial $P^H$ = 7.5

$P^H$ set =8 RPM =100

Initial turbidity = 94.9 NTU Temperature: 25°C

**Table 4.33: Optimum Dose of Coagulant For Sample 1**

| Sr. No. | Sample Qty. | Dose Coagulant(ml) | Dose Coagulant(mg/li) | $P^H$ after dosing | Turbidity | COD |
|---|---|---|---|---|---|---|
| | | 1ml=100mg | 1ml=100mg | | | |
| control | 250 | 0 | 0 | 7.5 | 94.9 | 928 |
| 1 | 250 | 1 | 400 | 7.37 | 21.5 | 737 |
| 2 | 250 | 2 | 800 | 7.33 | 15.1 | 716 |
| 3 | 250 | 3 | 1200 | 7.29 | 5.6 | 705 |
| 4 | 250 | 4 | 1600 | 7.27 | 3.8 | 624 |
| 5 | 250 | 5 | 2000 | 7.23 | 4 | 627 |
| 6 | 250 | 6 | 2400 | 7.16 | 5.1 | 689 |

**Optimum $P^H$**

Sampling: grab Sample: equalization tank

Temperature: 25 Initial $P^H$ =7.6

RPM=100 Initial turbidity = 77.5 NTU

**Table 4.34: Optimum $P^H$ For Sample 1**

| Sr. No. | Sample Qty. | Dose (ml) | $P^H$ after dosing | $P^H$ set with lime | Turbidity | COD |
|---|---|---|---|---|---|---|
| | | 1ml=100mg | | | | |
| **Control** | 250 | 0 | 7.63 | 7.63 | 77.5 | 1098 |
| **1** | 250 | 1600 | 6.36 | 6.4 | 13.7 | 972 |
| **2** | 250 | 1600 | 6.36 | 6.6 | 7.6 | 624 |
| **3** | 250 | 1600 | 6.36 | 6.8 | 9.6 | 672 |
| **4** | 250 | 1600 | 6.36 | 7 | 10.5 | 720 |
| **5** | 250 | 1600 | 6.36 | 7.4 | 16.2 | 988 |

**Varying dose with optimum $P^H$**

Sample: equalization tank Sampling: grab

Initial $P^H$ =7.40 Temperature: 25°C

Initial turbidity = 102.1 NTU RPM =100

**Table 4.35: Varying Dose With Optimum $P^H$ For Sample 1**

| Sr. No. | Sample Qty. | Dose coagulant(ml) | Dose coagulant(mg/li) | $P^H$ after dosing | $P^H$ set using lime | Turbidity | COD |
|---|---|---|---|---|---|---|---|
| | | 1ml=100mg | 1ml=100mg | | | | |
| Control | 250 | 0 | 0 | 7.4 | 7.4 | 102.1 | 916 |
| 1 | 250 | 1 | 800 | 6.57 | 6.6 | 15.6 | 887 |
| 2 | 250 | 2 | 1200 | 6.39 | 6.6 | 9.2 | 698 |
| 3 | 250 | 3 | 1600 | 6.24 | 6.6 | 8.1 | 667 |
| 4 | 250 | 4 | 2000 | 6.12 | 6.6 | 9.5 | 714 |
| 5 | 250 | 5 | 2400 | 5.93 | 6.6 | 10.3 | 807 |
| 6 | 250 | 6 | | | | | |

**Optimum flocculation time**

Sample: equalization tank Sampling: grab

Initial $P^H$ = 7.23 Temperature = 25°C

Initial turbidity=103.6 NTU RPM = 40

**Table 4.36: Optimum Flocculation Time For Sample 1**

| Sr. No. | Sample Qty. | Dose coagulant(mg/lit) | $P^H$ set using lime | Flocculation time | Turbidity | COD |
|---|---|---|---|---|---|---|
| Control | 250 | 0 | 7.37 | 0 | 103.6 | 800 |
| 1 | 250 | 1600 | 6.6 | 10 | 8.4 | 544 |
| 2 | 250 | 1600 | 6.6 | 20 | 8.8 | 560 |
| 3 | 250 | 1600 | 6.6 | 30 | 9 | 576 |
| 4 | 250 | 1600 | 6.6 | 40 | 9.2 | 584 |
| 5 | 250 | 1600 | 6.6 | 50 | 10.2 | 608 |
| 6 | 250 | 1600 | 6.6 | 60 | 10.4 | 624 |

**Optimum sedimentation time**

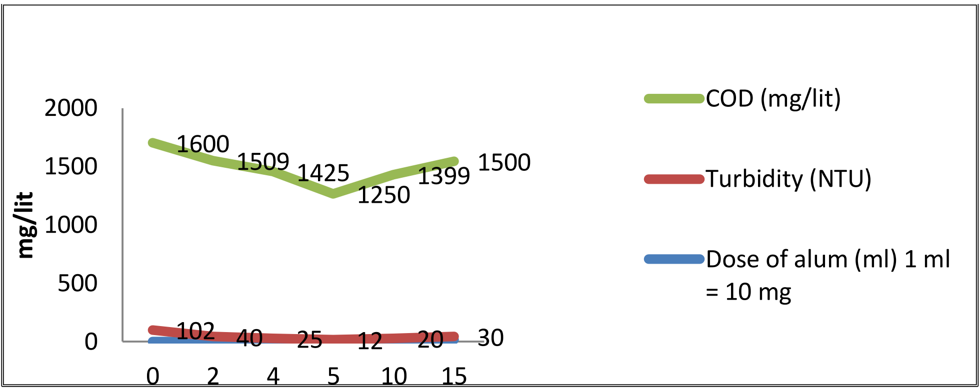
Sample: Equalization tank Sampling: Grab

Initial $P^H$ = 7.23 Temperature = 25°C

Initial turbidity=103.6 NTU RPM = 40

**Table 4.37: Optimum Sedimentation TimeFor Sample 1**

| Sr. No. | Sample Qty. | Dose coagulant(mg/lit) | $P^H$ set using lime | Sedimentation time | Turbidity | COD |
|---|---|---|---|---|---|---|
| Control | 250 | 0 | 7.37 | 0 | 95.5 | 947 |
| 1 | 250 | 1600 | 6.6 | 10 | 11.6 | 714 |
| 2 | 250 | 1600 | 6.6 | 20 | 7.6 | 652 |
| 3 | 250 | 1600 | 6.6 | 30 | 8.2 | 667 |
| 4 | 250 | 1600 | 6.6 | 40 | 8.6 | 698 |

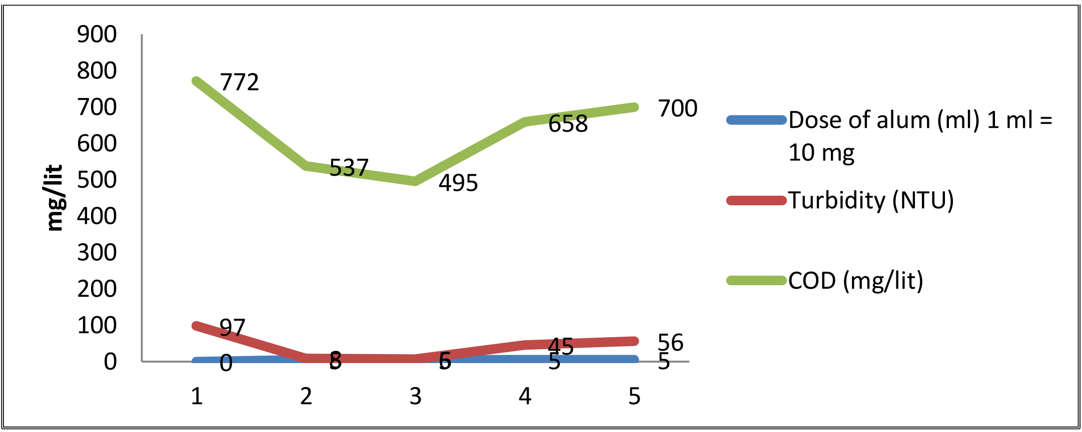



**Graph 4.30: Optimum Dose of Alum For Sample 1**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.5 Temperature = 25°C

Initial turbidity=97 NTU RPM = 30



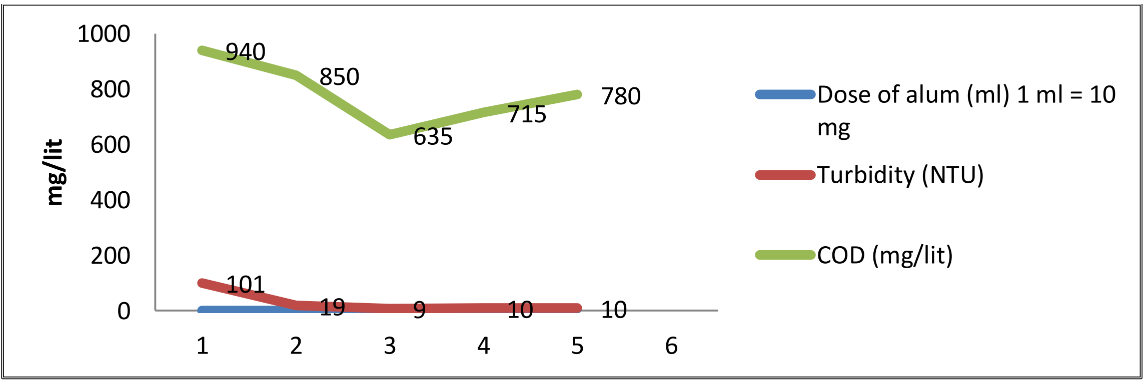

**Graph 4.31: Alum Dose V/S COD & Turbidity For Sample 1**

**Optimum dose of coagulant**

Sample: equalization tank no.2 Sampling: grab

Initial $P^H$ = 8 Temperature = 27°C

Initial turbidity=1017 NTU RPM = 30

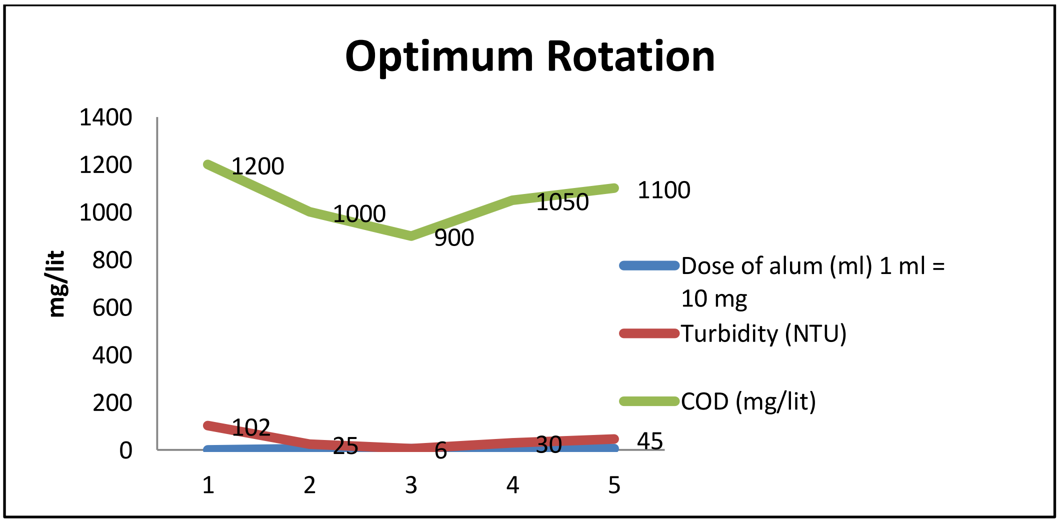



## Graph 4.32: Varying Dose At Optimum $P^H$ Optimum Rotation For Sample 1

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.9 Temperature = 27°C

Initial turbidity=102 NTU RPM = 3



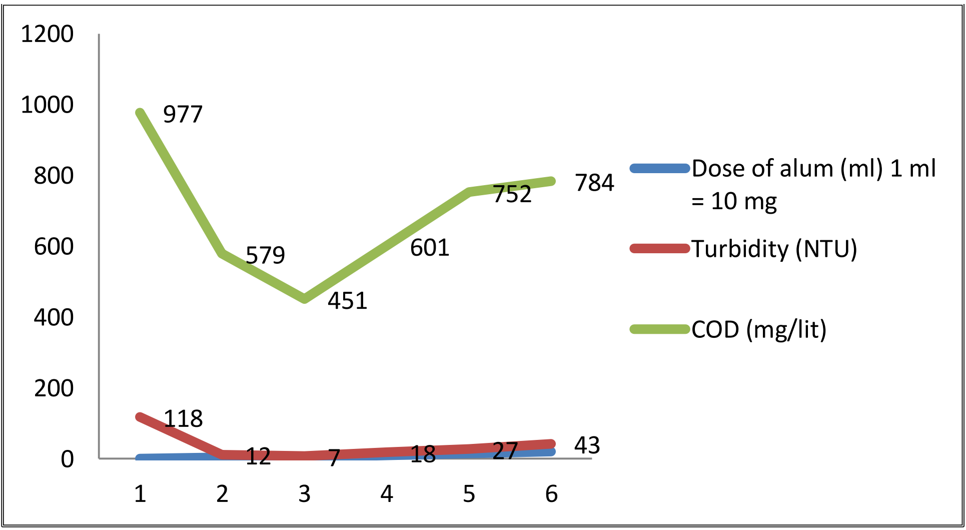

## Graph 4.33: Optimum Rotation For Sample 1

**Optimum dose**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 8 Temperature = 25°C

Initial turbidity=120 NTU RPM = 30



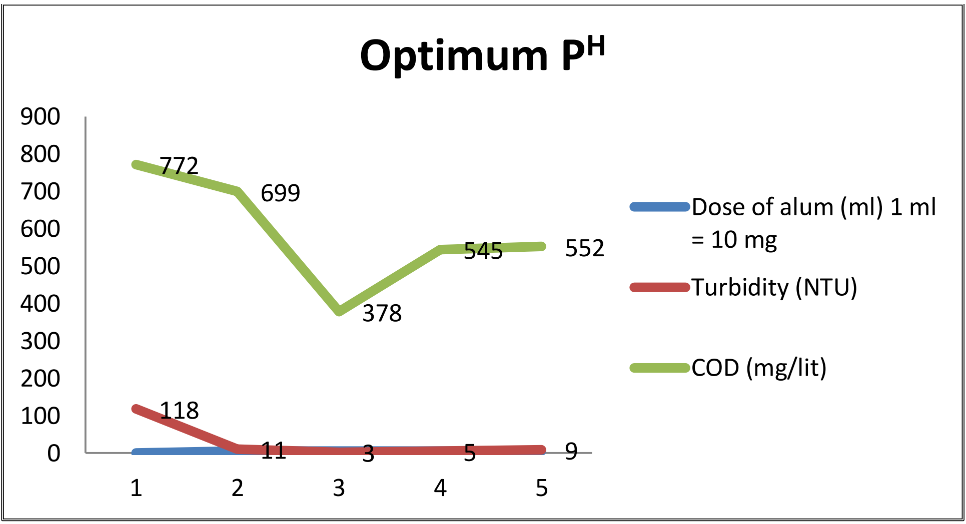

**Graph 4.34: Optimum Dose of Alum For Sample 2**

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.7 Temperature = 25°C

Initial turbidity=118 NTU RPM = 30



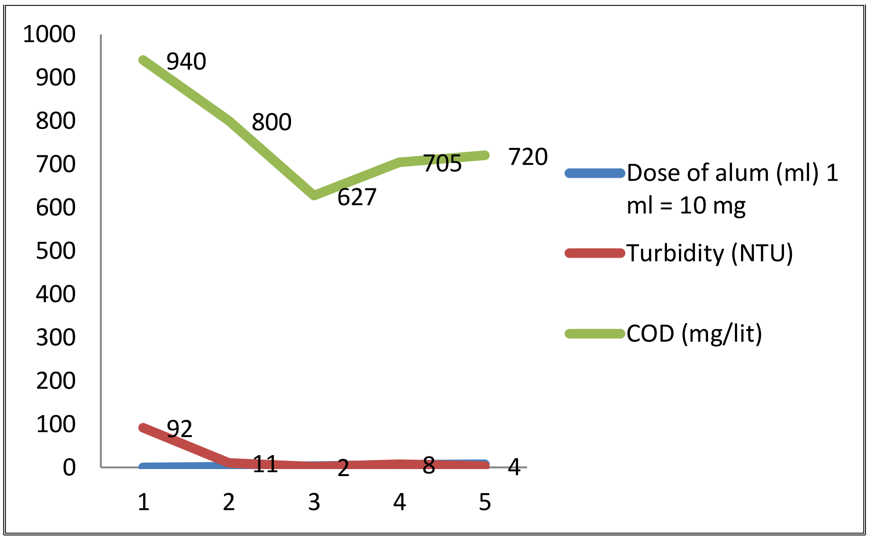

**Graph 4.35: Optimum $P^H$ For Sample 2**

**Optimum $P^H$**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 8 Temperature = 27°C

Initial turbidity=92 NTU RPM = 30



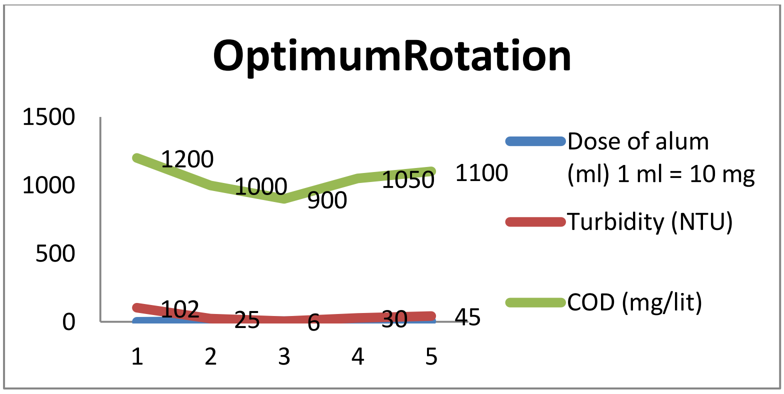

**Graph 4.36: Varying Dose at Optimum $P^H$ For Sample 2**

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.9 Temperature = 25°C

Initial turbidity=102 NTU RPM = 30




**Graph 4.37: Optimum Rotation For Sample 2**

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.5 Temperature = 27°C

Initial turbidity=86 NTU RPM = 30

**Table 4.38: Optimum Dose of $FeSO_4$ For Sample 3**

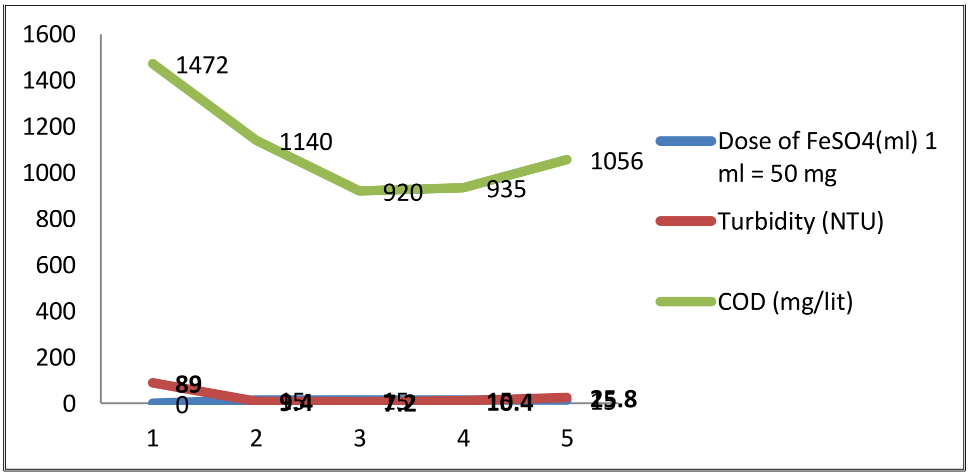
| Sr. No. | Amount of sample (ml) | Dose of FeSO4(ml) 1 ml = 50 mg | Dose of FeSO4 in mg/lit 1 ml = 50 mg | PH after dosing | Turbidity (NTU) | COD (mg/lit) |
|---|---|---|---|---|---|---|
| control | 250 | 0 | 0 | 7.5 | 86 | 1215 |
| 1 | 250 | 5 | 1000 | 6.5 | 26 | 1136 |
| 2 | 250 | 10 | 2000 | 6.1 | 22 | 1059 |
| 3 | 250 | 15 | 3000 | 5.5 | 6 | 823 |
| 4 | 250 | 20 | 4000 | 4.6 | 11 | 940 |

**Optimum $P^H$**

Sample: Equalization tank no.2 Sampling: Grab

Initial PH = 7.4 Temperature = 25°C

Initial turbidity=89 NTU RPM = 30



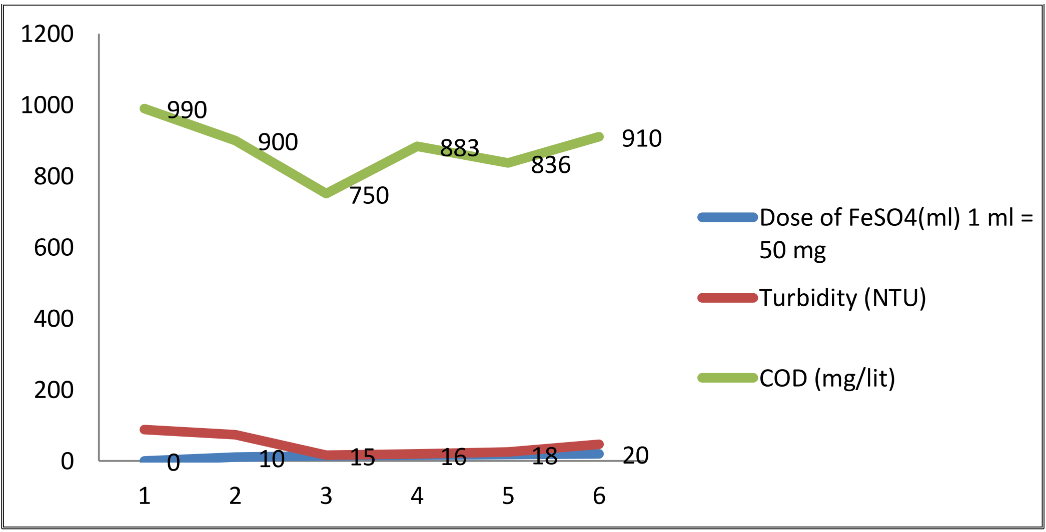

**Graph 4.38: Optimum $P^H$ For Sample 3**

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.7 Temperature = 27°C

Initial turbidity=87 NTU RPM = 30



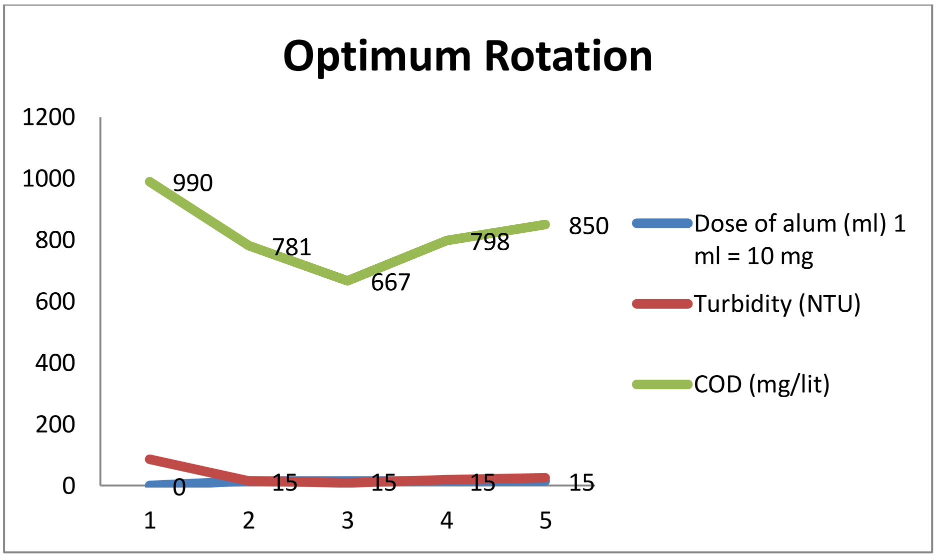

**Graph 4.39: Varying Dose at Optimum $P^H$ For Sample 3**

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.9 Temperature = 25°C

Initial turbidity=87 NTU RPM = 30




**Graph 4.40: Optimum Rotation For Sample 4**

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.8 Temperature = 27°C

Initial turbidity=96 NTU RPM = 35

**Table 4.39: Optimum Dose of $FeCl_3$For Sample 4**

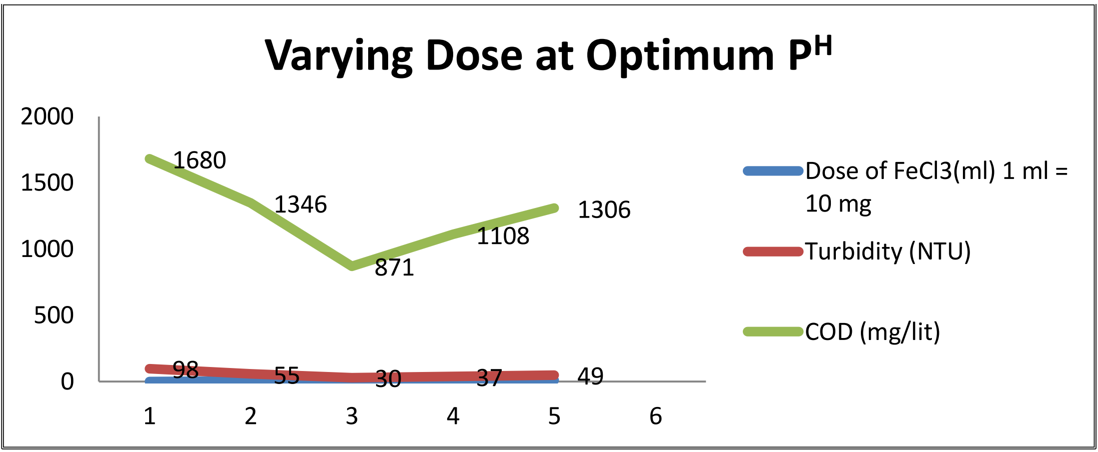
| Sr. No. | Amount of sample (ml) | Dose of FeCl3(ml) 1 ml = 10 mg | Dose of FeCl3 in mg/lit 1 ml = 10 mg | $P^H$ after dosing | Turbidity (NTU) | COD (mg/lit) |
|---|---|---|---|---|---|---|
| control | 250 | 0 | 0 | 7.8 | 96 | 1450 |
| 1 | 250 | 2 | 80 | 7.1 | 54 | 1412 |
| 2 | 250 | 4 | 160 | 6.8 | 16 | 1339 |
| 3 | 250 | 6 | 240 | 6.6 | 4 | 1227 |
| 4 | 250 | 8 | 320 | 6.3 | 15 | 1330 |

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.8 Temperature = 27°C

Initial turbidity=98 NTU RPM = 35



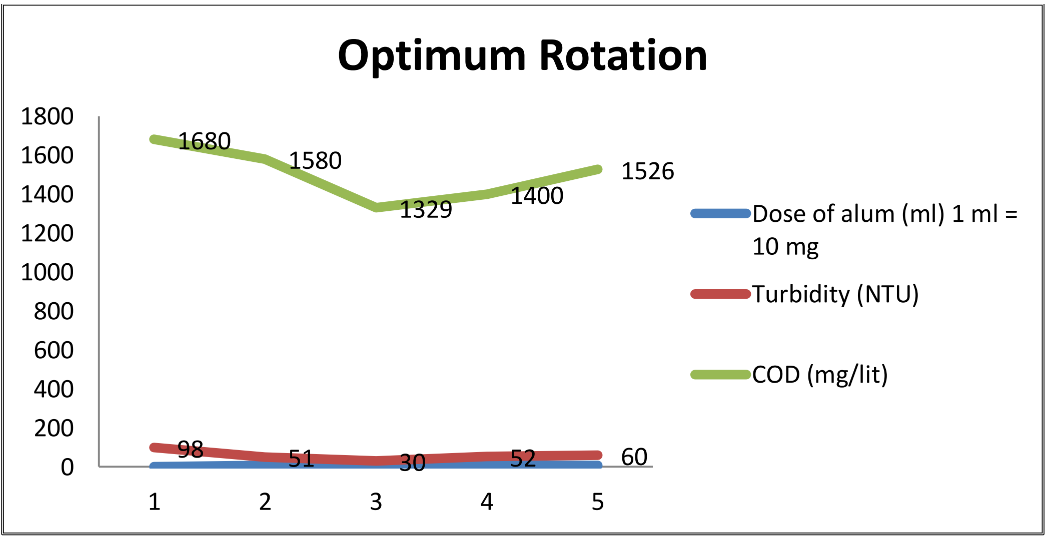

**Graph 4.41: Varying Dose at Optimum $P^H$ For Sample 4**

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 7.9 Temperature = 25°C

Initial turbidity=98 NTU RPM = 30



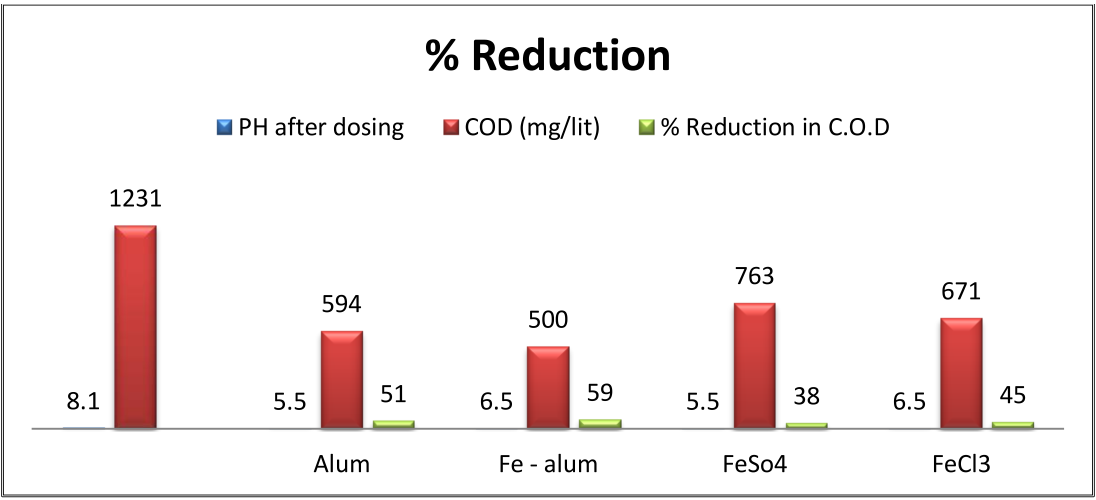

## Graph 4.42: Optimum Rotation For Sample 4

**Optimum Rotation**

Sample: Equalization tank no.2 Sampling: Grab

Initial $P^H$ = 8.1 Temperature = 25°C

Initial turbidity=102 NTU RPM = 30 to 40




## Graph 4.43: % Reduction In Parameters After Primary Treatment

Addition of coagulants is not cost effective, so other option of bio wish was tried.

## 4.11 ADDITION OF BIO WISH

It is necessary for individual units of CETP to set up pretreatment system and also necessary that proper design of the conveyance network with their periodic maintenance like de-sludging should be done to minimize cost. Its effluent quality must be within acceptable norms.

### 4.11.1 Factors To Be Controlled For The Biological Treatment System

To achieve good result in biological treatment, following points are to be considered.

- $P^H$ – between 6.5-8.5
- Temperature – 25 ° C to 40 ° C
- Oil, grease or any floating matter - not more than 10 to 20 ppm. Practically in aerobic system, oil is to be removed as it interferes in oxygen transfer.
- Toxic materials: Toxic and heavy metal should be removed in member industries by biological system, because such toxic and heavy metal completely destroys the micro flora of bacterial culture.
- Supplementation of nutrients: industrial waste water is deficit in primary nutrients elements such as nitrogen & phosphorous. So the waste water is to be analyzed for available nutrients & the required amount can be fed externally.
- Nutrient ratio: for aerobic biological treatment
- BOD:N:P = 100 : 5 : 1

### 4.11.2 Treatability

The treatability factor should also be given due consideration in cost estimation. Efforts should be made by the industry to segregate toxic, highly acidic/highly basic or toxic metals by installing recovery plants, which are feasible for operations of small scale units. The low capital investment and their lower operation and maintenance cost on treatment is important aspect. The mechanical and chemical processes are advantageous over biological treatment process in many cases. The conventional anaerobic processes are not preferred due to huge space requirements and least flexibility. UASB may be feasible treatment with less hydraulic retention time and less space requirement. As CETP is making huge equalization and settling units, the member units should also provide settling and $P^H$ adjustment units in pretreatment system of their individual waste.

At laboratory scale studies with alum coagulation at optimum conditions, the COD reduction was from 1248 mg/lit to 1041 mg/lit, BOD 680 mg/lit to 530 mg/lit and suspended solids 2096 mg/lit to 1674 mg/lit.

At second stage treatment with laboratory scale activated sludge system, the reduction in COD was from 1032 mg/lit to 320 mg/lit, BOD 530 mg/lit to 148 mg/lit and suspended solids 1674 mg/lit to 1256 mg/lit.

After activated sludge treatment COD, BOD and suspended solids were not within disposal limits. Hence third stage treatment was tried with $H_2O_2$, chlorine, but both were not in a position to oxidize addition of organic matter. Hence activated carbon was applied to bring COD, BOD and suspended solids in required limits; after tertiary treatment with granular activated carbon (GAC). After treatment COD was in a range of 100-200 mg/lit, BOD in a range of 50-100 mg/lit. But TDS was higher 12000-13000 mg/lit. This treated wastewater cannot be used for irrigation. Hence this water can be mixed with low TDS water or treated sewage to bring down TDS to less than 2100 mg/lit. so that this can be used for irrigation saving lot of fresh water instead of disposing to sea via effluent channel project.

For solution of this problem bio wish (super catalyze enzyme) was tried at a lab scale and it has been implemented on plant till today. Use of bio wish has saved manpower and resources storage.

### 4.11.3 Brief Of Bio-Wish

In the original design the homogeneous mixture of wastewater from the equalization tank is lifted to the flash mixer for addition of lime and alum and from there by gravity to a clari-flocculator. Flash mixing and clari-flocculation have been totally eliminated after implementing changes recommended by IWA/Environment.

Suspended solids, heavy metals, color, COD and BOD elements that settled out in the clarifier zone were taken to a filter press for sludge dewatering. Since the implementation of new treatment techniques, sludge volume has declined from 84 MT per month to 1.5 MT and the filter press is idle.

The biological segment of the plant follows and uses the complete mix activated sludge process. It consists of two pairs of aeration tanks and clarifiers operated in series. Surface aerators provide dissolved oxygen to Aerator 1 and diffuser system does this for Aerator 2. Nitrogen and phosphorous required for microbial growth are frequently assessed and added into the aeration tank as required (urea- phosphoric acid).

Treated wastewater from Clarifier 2 flows by gravity into an underground collection tank from where it is pumped into the Sand Filter for final polishing of the treated wastewater. This process adsorbs coolers, trace organics, suspended solids and bacteria from wastewater. Treated wastewater from sand filter is collected into the final disposal sump and discharged into the ECP pipeline. In case after treatment the final COD is not within limit, chlorination system is installed for treatment before disposal.

The Issues before the use of Bio Wish are as under:

**a. Ecological Outcomes**

The COD standard for discharge to the ECP pipeline is 250 mg/l. influent volumes and final discharge rates both vary due to factors outside of EICL’s control. These variations alter the residence time at the plant, and made it difficult to meet the discharge standard every day of the month.

**b. Sludge**

The sludge generated at plant is mainly derived from effluents from chemical and pharmaceutical industries. This sludge is designated as hazardous and needed careful attention to achieve compliance to several regulatory controls. The plant was generating 85 metric tonnes a month, and this volume was limiting the plant’s capacity to process additional influent volumes.

**c. Use of Chemicals**

Lime and Alum played a very significant role in reducing COD from the influents received at the plant. EICL consumed 127 metric tonnes of lime and 83 metric tonnes of alum annually. In addition to the direct costs of these materials they increased the TDS measures in the final effluents of the plant. Recently, the bio wish is added in the aeration tank and results are quite good. Bio mass is added and use of chemicals is discultured.

**d. Energy**

EICL’s effluent treatment plant required a substantial energy input for aeration to sustain the microbial population of the system.

**e. Solution**

Two specially designed lab-scale reactors were constructed in the laboratory at EICL's plant and a pilot study was launched. The study was performed on raw effluent output from the equalization tank and was conducted over a 15-day period. Daily incremental differences between a control and treated sample were assessed. The key observation during the trial was that the ratio between BOD and COD changed measurably in the treated sample.

At first glance the implementation design seemed radical: dose the enzyme biotechnology formulation into the equalization tank and at the same time discontinue usage of lime and alum.


## Figure 4.7: Bag Of Bio Wish

### 4.11.3.1 Results Of Bio Wish

Following are the outcomes of the addition of bio wish.

- **Lime and Alum Totally Eliminated:** On the day that the implementation began the project team discontinued dosage of lime and alum. This resulted in an immediate annual saving of Rs. 9.1 lakhs of direct material cost and associated labor costs for materials handling, storage and administration. It also released space in the plant that had been formerly allocated for storage of lime and alum inventories.
- **Sludge Reduced by 98%:** Primary sludge has been totally eliminated, and bio-solid sludge has been dramatically reduced. Before the IWA/Environment implementation the plant produced 85 metric tonnes of sludge each month. Today

the sludge output is about 1.5 metric tonnes a month. This represents an annual saving of Rs. 11 lakhs.

- **Discharge Standards Achieved Every Day:** The plant easily achieves the discharge standard of 250 mg/l COD. It operates stably and is able to accommodate variations in residence time.
- **Influent Volume Doubled:** In the period since the implementation began the volume of fluid being treated at plant has risen from 730 kilo liters per day to 1,500 kilo liters per day.
- **Unit cost of treatment halved:** Cost savings have been significant. The plant has been able to maintain the energy consumption for aeration even though treatment volumes have doubled. Energy cost per litre has been further reduced by the closure of chemical dosage stations and primary clarifier.

**Table 4.40: Energy Cost Per Liter(Base year 2012)**

| Cost Element | Cost Per Liter | |
|---|---|---|
| | Baseline | Post-implementation |
| Aeration | 20.87 | 7.04 |
| Chemicals | 3.41 | - |
| Enzymes | - | 6.27 |
| Sludge Handling | 4.54 | 0.04 |
| Total | 28.84 | 13.35 |

**Bio wish enzymes have increased insoluble into soluble and will attack the insoluble suspended material. Hence they become soluble and bio degradable. Also, BOD/COD ratio is increased from 0.2-0.3 to 0.5-0.6. Still any suspended solids or inert material will finally be removed either in clarifier or pressure sand filter.**

#### 4.11.3.2 The Detailed Implementation Program

The implementation followed a tightly structured methodology with a decision at the end of each phase of work.

- The initial insight phase was performed over 30 days. In this period CETP constructed a pair of 100-litre batch reactors. One reactor was treated with the enzyme biotechnology provided by IWA/Environment and the other was used as a control. Based on results elsewhere in India the preliminary sign hypothesis was that the raw influent could be treated directly, without any $P^H$ adjustment or chemical setting.

- The lab results showed clearly that the treatment reactor generated pollutant removal within a 24-hour period that was equivalent to current plant performance. However, the results were ambiguous, in that the results were not much different from those being recorded in the control reactor. It was however noted that a healthy biomass developed in the treatment tank.
- The enzyme biotechnology supplied by IWA/Environment was dosed into Aeration Tank 1 at 1ppm of plant processing volume. Dosage of lime and alum were discontinued on the same day and all equipment’s used in these components were idled.
- The discharge results were unchanged. Plant inspections were conducted daily as per standard practice and stage-wise pollutant removal performance was recorded. End of pipe results continued to improve and stabilized 20-days after the initial implementation.
- On-site inspection on the $20^{th}$ day resulted in observation of sulphur dioxide and hydrogen sulphide gas in the former primary clarifier. It was then realized that the component had become an aerobic through disuse, and was actually increasing the COD load on the downstream components. Based on the observations and an assessment of the pros and cons, it was decided to bypass the former primary clarifier and shift the enzyme dosage point to the former flash mixer.
- The results were immediate and dramatic. End of pipe outcomes began improving again. As a result of these changes the treatment process of the plant is simplified. Furthermore, the simplified process is achieving discharge compliance at COD of 250 mg/l every day of the month, despite continuing variations in residence time. What make this achievement even more significant is that influent volumes have doubled from the initial 730 KL/day to 1500 KL/day.

### 4.11.4 Results of Bio Wish Addition to EICL

As a result of above success, now member and non-member industries started approaching EICL for treatment of their wastewater. Bio wish is effective at very low dosages, At low dosage, it removes blue green algae as well as it reduces BOD, COD, TDS, Turbidity, SS, TKN, phosphorous, oil & grease, fecal coliform.

#### 4.11.4.1 Waste water treatability at different units at CETP

To carry out the treatability study by newly developed bio mass for CETP with economical aspect by introducing bio wish aqua technologies, so that treatment can be reduced by eliminating some of the traditional unit operations steps.

After addition of bio wish, the parameters were observed and it was found that except TDS, all parameters are within desirable limit.

**Table 4.41: Operational Units COD**

| Sr. No. | Date | Equalization tank | Aeration tank | Secondary clarifier | Final sump |
|---|---|---|---|---|---|
| 1 | Day 1 | 1024 | 454 | 400 | 240 |
| 2 | Day 2 | 800 | 416 | 336 | 312 |
| 3 | Day 3 | 879 | 475 | 372 | 277 |
| 4 | Day 4 | 974 | 432 | 394 | 284 |
| 5 | Day 5 | 816 | 392 | 384 | 320 |
| 6 | Day 6 | 854 | 321 | 297 | 282 |
| 7 | Day 7 | 713 | 360 | 352 | 250 |
| 8 | Day 8 | 720 | 384 | 304 | 280 |
| 9 | Day 9 | 823 | 360 | 345 | 250 |
| 10 | Day 10 | 970 | 438 | 383 | 293 |

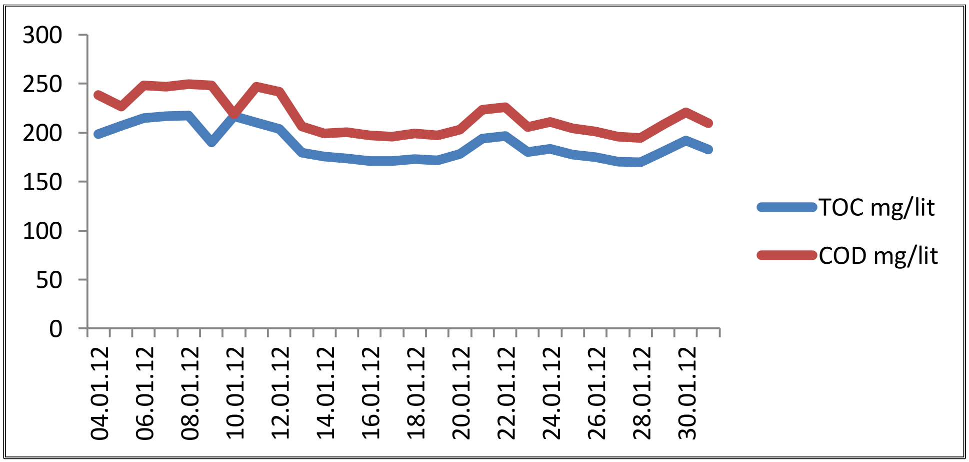
**Table 4.42: Reduction In Turbidity In Operational Units**

| Sr. No. | Date | Equalization Tank | Aeration Tank | Secondary Clarifier | Final Sump |
|---|---|---|---|---|---|
| 1 | Day 1 | 75.7 | 40 | 38 | 11 |
| 2 | Day 2 | 71.7 | 27.9 | 25 | 14.5 |
| 3 | Day 3 | 51 | 25.8 | 25 | 10.3 |
| 4 | Day 4 | 82.6 | 40.3 | 16 | 9.4 |
| 5 | Day 5 | 70 | 29.7 | 25.8 | 7.8 |
| 6 | Day 6 | 98.9 | 26.3 | 25.3 | 9.8 |
| 7 | Day 7 | 56.8 | 22.6 | 19.6 | 12.3 |
| 8 | Day 8 | 74.1 | 27.1 | 22.1 | 13.7 |
| 9 | Day 9 | 72 | 25.7 | 23.8 | 9.9 |
| 10 | Day 10 | 80.7 | 30.8 | 28.1 | 14.6 |

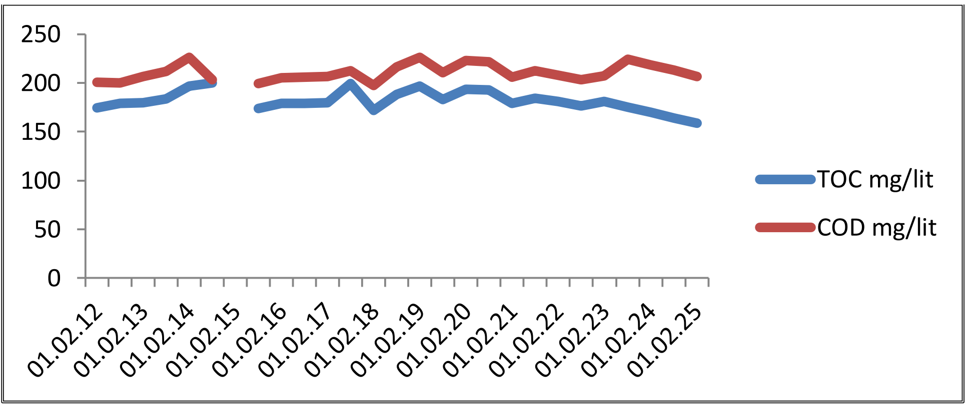
**Table 4.43: Results Of BOD In Different Units**

| Sr. No. | Date | Equalization tank | Aeration tank | Secondary clarifier | Final sump |
|---|---|---|---|---|---|
| 1 | Day 1 | 360 | 140 | 90 | 49 |
| 2 | Day 2 | 296 | 102 | 55 | 30 |
| 3 | Day 3 | 332 | 130 | 72 | 31 |
| 4 | Day 4 | 343 | 120 | 81 | 40 |
| 5 | Day 5 | 325 | 112 | 62 | 32 |
| 6 | Day 6 | 327 | 110 | 70 | 39 |
| 7 | Day 7 | 240 | 90 | 42 | 28 |
| 8 | Day 8 | 280 | 98 | 54 | 27 |
| 9 | Day 9 | 315 | 107 | 57 | 28 |
| 10 | Day 10 | 342 | 121 | 80 | 41 |

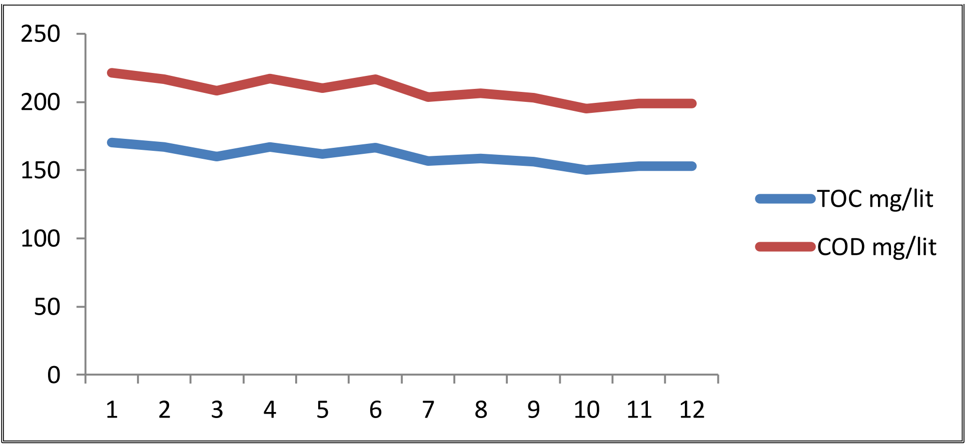
TOC analyzer installed at the plant shows that in the final treated effluent COD, TOC, $P^H$ are within range and now if this water is to be reused, the only problem is of TDS which are quite high and it comes in the range of 7000 to 12500 mg/lit. The sample graphs from TOC analyzer are as below:




**Graph 4.44: TOC & COD FOR JAN, 12**




**Graph 4.45: TOC & COD FOR FEB, 12**




**Graph 4.46: TOC & COD FOR MARCH, 12**

## 4.12 REVERSE OSMOSIS TREATMENT

For removal of TDS the RO plant at lab scale was installed at the plant and continuous readings were taken to decide the type of treatment to be given.

The lab scale RO with a small pretreatment of RO downy membrane filter was installed and the demineralized water was allowed to pass through it.

For number of days, the sample was passed through RO. Such 14 trials are done. The results are as shown in table below. Figure 4.8 shows the lab scale setup of treatment. Height of storage tank was 15 ft. from the RO system. 0.5 HP motor was fitted. The specifications for lab scale RO system are:

- Maximum Flow = 6.75 GPM
- Maximum Pressure = 175 Psi
- Maximum Temperature = 100 °F
- Service Life = 1000 GAL

The sample was given to storage tank and retention time of minimum 2 hours is given. The capacity of tank was 20 lit. The filtrate was collected and the recovery was achieved up to 75 % in the treatment applied. The results of lab scale treatment are as under. It clearly shows that treatment is effective for the removal of TDS from the wastewater and quality output is there which meets the standards for reuse of wastewater.

**Figure 4.8: Pilot Plant for R.O. Treatment**

**Figure 4.9: Aeration tank after addition of bio wish**

**Figure 4.10: Lab Scale Aeration**

**Figure 4.11: $P^H$& TDS Measurement At Laboratory**

**Figure 4.12: BOD Incubator**

**Table 4.44: Characteristics Of Parameters of CETP During Pilot Plant Study**

| Date | Temperature | Initial TDS | Final TDS | PH | Turbidity(NTU) | BOD | TOC | COD | SS | MPN Index(per 100 ml) |
|---|---|---|---|---|---|---|---|---|---|---|
| | ◦C | (mg/lit) | (mg/lit) | | | (mg/lit) | (mg/lit) | (mg/lit) | | |
| Average of trial 1 | 30 | 12000 | 1400 | 6.5 | 4 | 3 | 17 | 25 | 17 | 5.5/10 0ml |
| Average of trial 2 | 30.5 | 8500 | 1050 | 6.6 | 5 | 5 | 18 | 27 | 20 | |
| Average of trial 3 | 29.6 | 8650 | 1560 | 6.5 | 4 | 3 | 20 | 30 | 20 | |
| Average of trial 4 | 29.8 | 8500 | 958 | 6.5 | 5 | 4 | 17 | 35 | 21 | |
| Average of trial 5 | 30.2 | 10000 | 1748 | 6.7 | 8 | 4.5 | 18 | 27 | 18 | |
| Average of trial 6 | 28.5 | 9000 | 1700 | 6.8 | 6 | 5 | 18 | 27 | 19 | 5/100 ml |
| Average of trial 7 | 29.5 | 11000 | 860 | 6.5 | 7 | 3 | 20 | 30 | 20 | |
| Average of trial 8 | 29.6 | 12000 | 1840 | 6.5 | 8 | 4 | 20 | 30 | 17 | |
| Average of trial 9 | 30.8 | 12400 | 1120 | 6.6 | 6 | 5.5 | 19 | 28 | 21 | |
| Average of trial 10 | 31 | 11855 | 1800 | 6.5 | 6.5 | 4.2 | 22 | 32 | 20 | |
| Average of trial 11 | 30.5 | 11000 | 1350 | 6.5 | 5.5 | 4.4 | 21 | 31 | 20 | |
| Average of trial 12 | 44.5 | 4258 | 1500 | 6.8 | 5 | 4.3 | 22 | 33 | 20 | |
| Average of trial 13 | 35 | 3580 | 2000 | 6.8 | 4 | 4.5 | 22 | 32 | 19 | |
| Average of trial 14 | 30.2 | 4950 | 1350 | 6.8 | 6.28 | 4.6 | 25 | 34 | 18 | 5.5/10 0ml |
| Filtered sample | 29 | 8500 | 1800 | 6.5 | 5 | 4.2 | 17 | 35 | 20 | |

(Note: The sample was filtered by simple filter paper before passing it through inlet tank is indicated as filtered sample here)

# 5. DESIGN AND MODELING

## 5.1 DESIGN AND ESTIMATION FOR CASE STUDY 1: DOMESTIC SEWAGE TREATMENT PLANT

The design and cost estimation with all possible options for reuse of treated domestic sewage is stated as under.

### 5.1.1 Options For Basic Design Of Treatment Schemes

Industries may undergo the polishing treatment for reuse of domestic waste water for industrial purpose at the plant premises. For the same the treated waters are required to be transported to the plant premises from the Atladra treatment plant, by means of pumping / gravity system or by tankers.

There are two options for transportation of sewage water.

- By Tanker supply.
- By Pumping / Gravity Pipeline.

#### 5.1.1.1 By tanker supply

This may be a temporary arrangement, as it involves heavy capital investment of purchase of tankers and further operating cost of movement of tankers. However over and above this, it leads to noise problems due to movement of tankers, traffic and their exhausts gases leading to air pollution.

Thus total operating cost per cu. m = 5375 / 600 = 8.96 per cu.m

#### 5.1.1.2 Laying of pipeline

Laying of pipeline will also involve substantial capital investment but the operation is much simpler and costs incurred are much lower. From the Survey Of India Map of the surrounding areas nearby the industry and the treatment plant site the distance and area across which pipeline is to be laid was identified to be about 1.5 Kms.

A study was also undertaken for transportation of the waters by means of pumping main / gravity main. Looking to the terrain of the area, it was found that the treatment plant is at an elevated level than the industry. Hence it is possible to transport the effluent under gravity. Some land would have to be acquired for laying of the pipeline and as the pipeline runs from a locality area, necessary permissions are required to be taken for acquiring of land and the laying of the pipeline.

Various pipeline materials were also studied for cost benefit analysis and the optimization of the head loss arrangements during transportation. The design features and the cost benefit analysis using various pipe materials is discussed below.

In order to overcome the head losses in the pipeline a surge tank is required. Thus a permanent pipeline system with surge tank is considered of required height for covering the pipe loss. A pumping arrangement would be made at the secondary clarifier outlet, which will pump the waters to the surge tank constructed nearby. From the surge tank water will be conveyed to the inlet collection tank of polishing treatment plant within the industry premises, under gravity.

Design of Surge Tank (3.5 m dia. x 2.0 m depth (SWD)) + 0.5 m F.B.+ 3.0 m height from ground). Budgetary Capital Cost of the surge tank is Rs. 1,50,000 /-.

The land for laying the pipeline can be requested for lease to VMC and the rent or purchasing cost with subsidy if corporation permits as it is for the benefit of city only, is considered Rs. 11 /ft. Following table shows the three options along with cost analysis to explore for laying of pipeline.

**Table 5.1: Cost Comparison For Laying Pipeline For Proposed Treatment Plant**

| Option | Basic Cost In Rs. | Operating Cost In Rs. |
|---|---|---|
| Cast iron | 2661385 | 2.5 |
| Mild steel | 1567885 | 2.37 |
| R.C.C. | 1423885 | 2.24 |

Different alternative treatment schemes are developed depending upon the treatability studies carried out. They are as described in below text.

## 5.2 OPTIONS OF TREATMENT SCHEMES DEVELOPED

Following figures shows three alternative options for design and treatment schemes to be developed.

**1.** Coagulation➔ Flocculation ➔ Sedimentation ➔ Sand Filtration ➔ Chlorination ➔ Activated carbon filters ➔ Softening using Ion exchange.

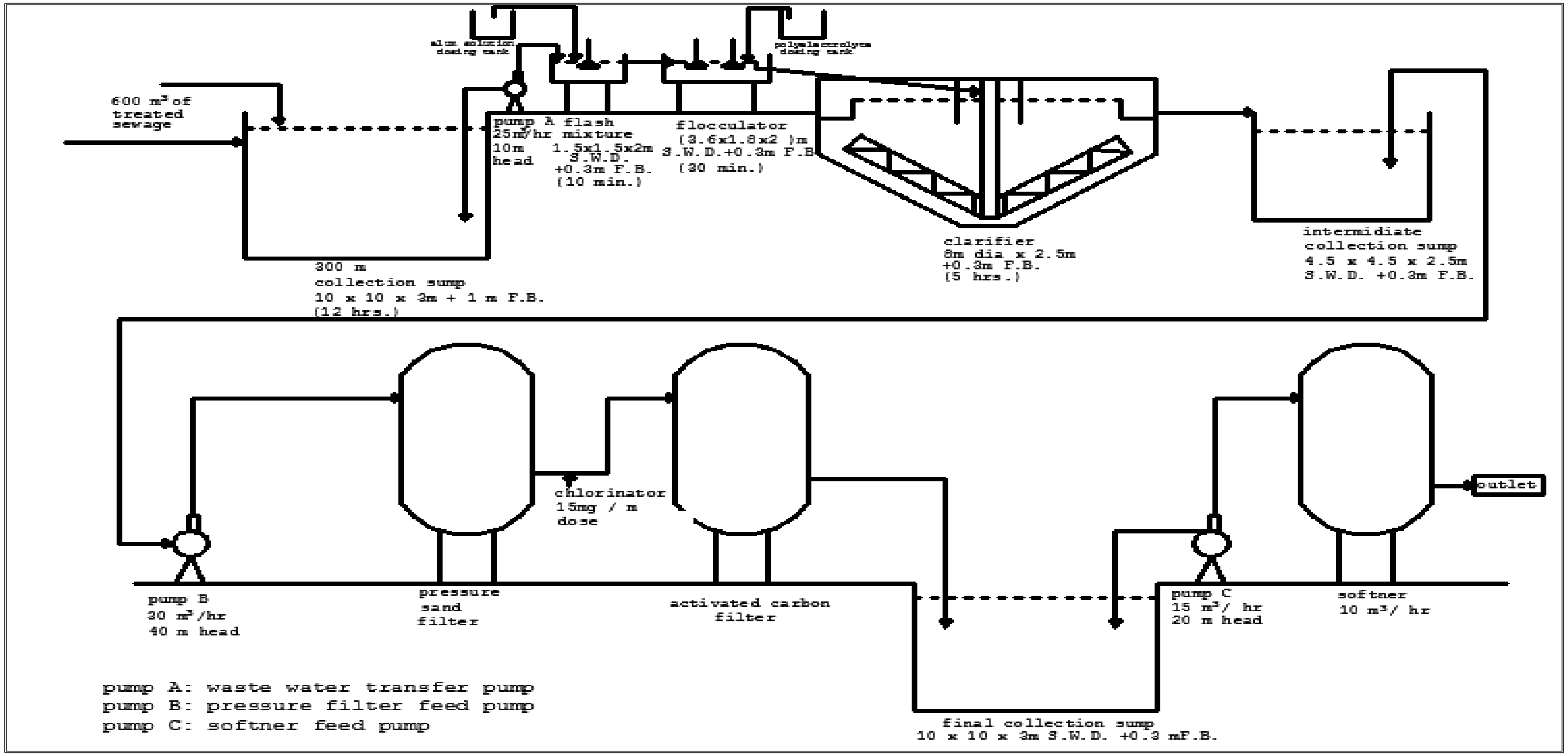



**Figure 5.1 Proposed Flow Diagram With Scheme 1**

**2.** Coagulation ➔Flocculation ➔ Sedimentation ➔ Sand Filtration ➔ Ultra violet radiation ➔ Activated carbon filter➔ Softening using Ion exchange.

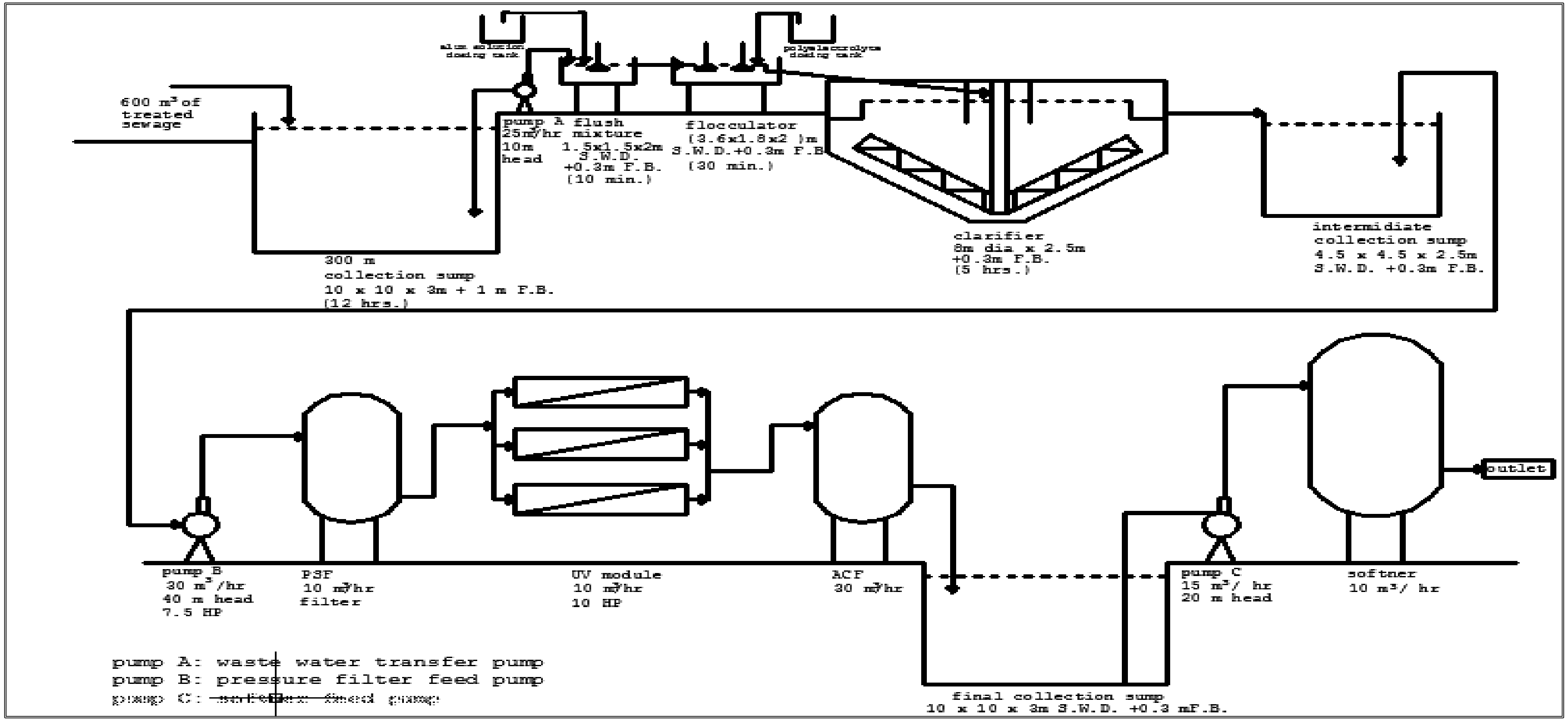



**Figure 5.2 Proposed Flow Diagram With Scheme 2**

3. Coagulation ➔ Flocculation ➔ Sedimentation ➔ Filtration ➔ Ozone treatment ➔ Activated carbon filters ➔ softening using Ion exchange.

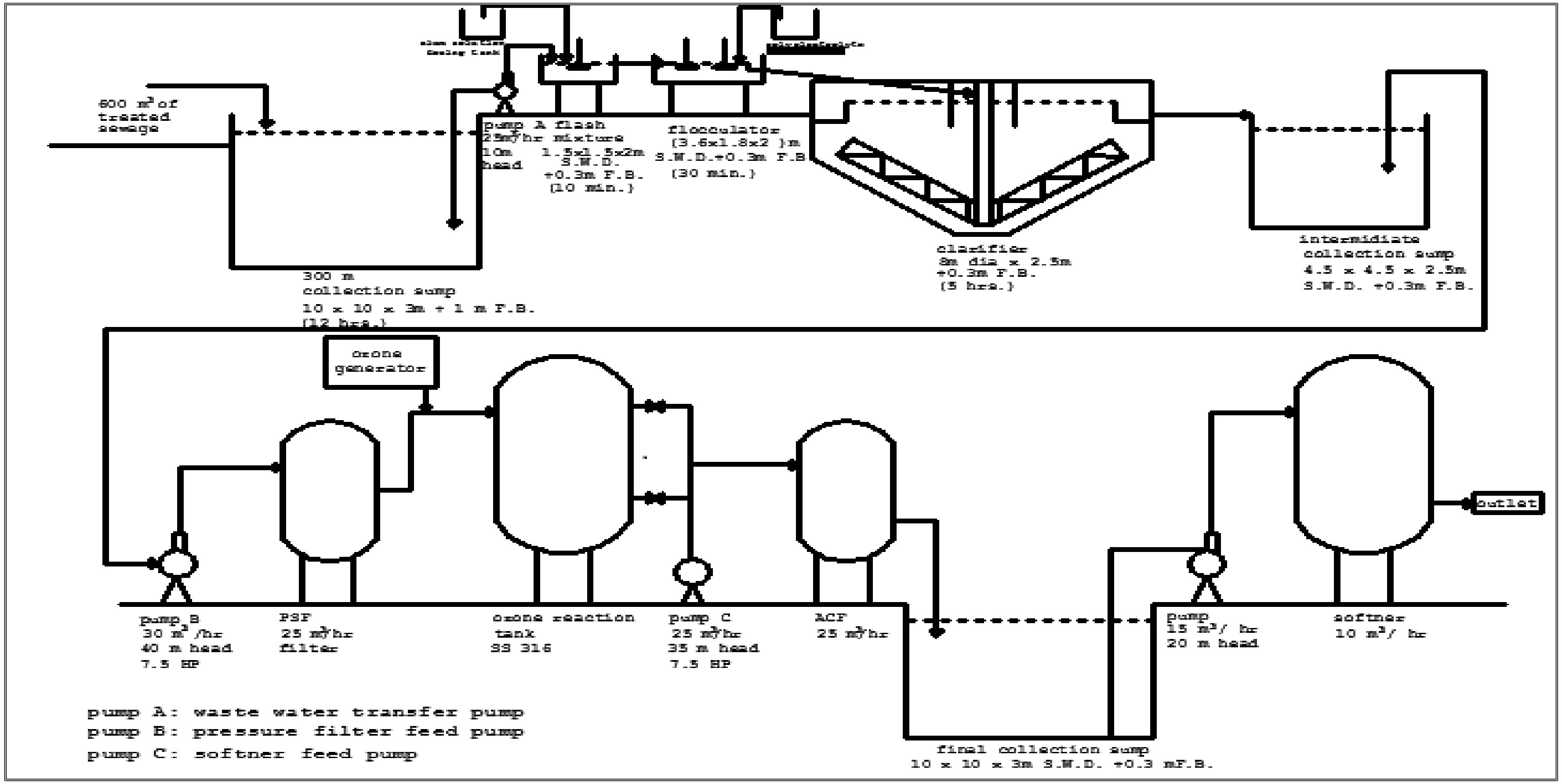



**Figure 5.3 Proposed Flow Diagram With Scheme 3**

**Table 5.2: Budgetary Capital Costs: Coagulation, Flocculation, Sedimentation, Filtration and ACF (Base Year 2012-13)**

| Sr. No. | Description | Size | | Cost calculation | Total cost | Remarks |
|---|---|---|---|---|---|---|
| 1 | Collection sump (R.C.C.) | 10 x 10 x 4.0 450 $m^3$ | @ 1.8 / liter | 450 x 1000 x 1.8 | 810000 | R.C.C. structure |
| 2 | Primary effluent pump | 25 $m^3$/hr10 m head(5 HP) | | Cost of pump+ motor and accessories | 50000 | C.I. Make with semi open impeller |
| 3 | Flash mixer tank | 1.5m x 1.5m x 2.3m 5.175 $m^3$ | @ 4/ liter | 5.175 x 1000 x 4 | 20700 | R.C.C. structure |
| 4 | Flocculator tank | (3.6m x 1.8m x 2.3m depth)14.904 $m^3$ | '@1.8 Rs../liter | 14.904 x 1000 x 1.8 | 268300 | R.C.C. structure |
| 5 | Clarifier | 8.0 m dia. x 2.8 m depth = 140.672 $m^3$ | @ 3.0 Rs../liter | 140.672 x 1000 x 3.0 | 422000 | R.C.C. structure |
| 6 | Flash mixer agitator M.S.structure | Suitable for tank size 1.5m x 1.5m x 2.3m 2 HP | | With gear box and motor mechanism | 28000 | M.S. structure duly Epoxy painted |
| 7 | Flocculater mechanism M.S.structure | Suitable for tank size 3.6 m x 1.8 m x 2.3m 1.5 HP each | | With gear box and motor mechanism | 50,000 | M.S. structure duly Epoxy painted |
| 8 | Intermediate collection tank | (4.5 x 4.5 x 2.8)m 56.7 $m^3$ | @ Rs.2.5/liter | 56.7x1000x2.5 | 142000 | R.C.C. structure |
| 10 | Pressure sand filter | Capacity 25$m^3$/hr. | | M.S. structure | 150000 | Sand and gravel bed in M.S. housing |
| 11 | Activated carbon filter | Capacity 25$m^3$/hr. | | M.S. structure | 175000 | Carbon bed in M.S. housing |
| 12 | Final collection sump | (10 x 10 x 4)m-400$m^3$ | @1.8/liter | 400x1000x1.8 | 720000 | R.C.C. structure |
| 13 | Clarifier mechanism M.S. structure suitable for tank | 8.0 m dia.x 2.8 m depth - 140.762 cu.m | @1.8 Rs./ liter | | 254000 | M.S. structure |
| | | | | | 3090000 | |
| | | Cost of Piping works : 10 % | | | 309000 | |
| | | | | | 3399000 | |

**Table 5.3: Budgetary Capital Costs : Chlorination And Softener System(Base Year 2012-13)**

| Sr. No. | Description | Size | | Cost calculation | Total cost | Remarks |
|---|---|---|---|---|---|---|
| 14. | Chlorination system | Capacity of dosing of | | Inclusive of tank for NaOCl dosing pump | 30000 | NaOCl dosing system |
| 15. | Softener system | 10 $m^3$/hr. capacity | | M S structure inclusive of | 70000 | Softener with ion exchange |
| 16. | Softener feed pump | 15 $m^3$/hr. 20 m head | | Cost of pump and motor+ Accessories | 50000 | C.I. Pump with semi-open impeller |
| | | | | | 150000 | |
| | | Cost of piping works : 10 % | | | 15000 | |
| | | | | Total cost | 165000 | |
| | Total Capital Cost = Rs. | | | | 3564000 | |

**Table 5.4: Budgetary Capital Costs: U.V. and Softener System(Base Year 2012-13)**

| Sr. No. | Description | Size | | Cost Calculation | Total Cost | Remarks |
|---|---|---|---|---|---|---|
| 17 | Ultra violet Radiation modules - 4 Nos.- 10 $m^3$/hr. each | 40 $m^3$/hr. | | The Ultra Violet Lamps with entire assembly | 1800000 | SS 316 L |
| 18. | Softener system | 10 $m^3$/hr. capacity | | M S structure inclusive of | 70000 | Softener with ion exchange |
| 19. | Softener feed pump | 15 $m^3$/hr. 20 m head | | Cost of pump and motor+ Accessories | 50000 | C.I. Pump with semi-open impeller |
| | | Cost Rs. | 1920000 | | | |
| | | Piping Cost : 10% | | | 192000 | |
| | | Total Cost Rs. | | | 2112000 | |
| | | TOTAL CAPITAL COST = Rs. | | | 5482400 | |

**Table 5.5: Budgetary Capital Costs: OzoneSystem And Softener System(Base Year 2012-13)**

| Sr. No. | Description | Size | | Cost Calculation | Total Cost | Remarks |
|---|---|---|---|---|---|---|
| 20. | Transfer pump | 30m$^3$/hr. 40 m head,7.5 HP | | | 80000 | |
| 21. | Ozone system with PSF & ACF system, interconnecting values and piping with Ozone generator system | 100 gms/hr. | | | 3000000 | |
| 22 | Softener system | 10 m$^3$/hr. capacity | | M S structure inclusive of | 70000 | Softener with ion exchange |
| 23 | Softener feed pump | 15 m$^3$/hr. 20 m head | | Cost of pump and motor+ | 50000 | C.I. Pump with semi-open impeller |
| | | Total Cost: | | | 3200000 | |
| | | Piping Cost: 10 % | | | 320000 | |
| | | Total Cost : | | | 3520000 | |
| | | TOTAL CAPITAL COST : Rs. | | | 6890400 | |

**Table 5.6: Budgetary Operating Costs: Coagulation, Flocculation, Sedimentation, Filtration And ACF(Base Year 2012-13)**

| Sr. No. | Description | Size | | Cost calculation | Total operating cost per cum | Remarks |
|---|---|---|---|---|---|---|
| 1 | Primary effluent pump | 25 $m^3$/hr 10 m head 5.0 HP | | 5.0 x 0.746 x 5.5<br>20.515 for 25 cu.m per hr. | 0.8206 | Including Power Cost |
| 2 | Flash mixer | 2.0 HP | | 2.0 x 0.746 x 5.5<br>8.206 for 25 cu.m per hr. | 0.328 | Including Power Cost |
| 3 | Flocculator | 1.5 HP, 2 No. | | 1.5 x 0.746 x 5.5 x 2<br>12.309 for 25 cu.m per hr. | 0.4923 | Including Power Cost |
| 4 | Clarifier mechanism | 2.0 HP | | 2.0 x 0.746 x 5.5 8.<br>206 for 25 cu.m per hr. | 0.328 | Including Power Cost |
| 5 | Pressure filter feed pump | 7.5 HP | | 7.5 x 0.746 x 5.5<br>30.7725 for 25 cu.m per hr | 1.2309 | Including Power Cost |
| 6 | Sand replacement in P.S.F. | 2000 kg | | 219.17 Rs./600$m^3$ | 0.365 | Including Power Cost |
| 7 | ACF Replacement cost | 1500 kg | | 1,05,000/365<br>287.67/600 | 0.959 | Including Power Cost |
| | | | | Total: Rs per cu.m | 4.5238 | |

**Table 5.7: Budgetary Operating Costs for scheme 2(Base Year 2012-13)**

| Sr. No. | Description | Size | | Cost calculation | Total operating cost per cum | Remarks |
|---|---|---|---|---|---|---|
| 1 | Ultra violet module | 400 $m^3$ 4 m head 10 HP | | 40 x 5.7 x 0.746 45.522/40 | 1.063 | SS 316 L Power cost is added |
| 2 | Softener system regeneration | 120 kg NaCl per day x 1 time regeneration per day | | | 1 | |
| 3 | Change of resin bed | Rs.30,000 per change once in a year=30,000/(365x120) | | | 0.685 | Considering replacement of resin bed once in a year |
| 4 | Softener feed pump | 3 HP | | 3.0 x 0.746 x 5.5 12.309/10 cu.m. per hr. | 1.2309 | Power cost is added |
| | | Operating Cost | | | 3.9789 per $m^3$ | |
| | | Total Operating Cost of Plant | | | 8.5027 per $m^3$ | |
| | | Cost of Transportation of the Treated Waters from the Sewage Treatment Plant to the plant site using selected pipe material and pipeline route. | | | 1.95per $m^3$ | |
| | | TOTAL OPERATING COST = Rs. | | | 11.06 per $m^3$ | |

**Table 5.8: Budgetary Operating Costsfor scheme 3(Base Year 2012-13)**

| Sr. No. | Description | Size | | Cost calculation | Total operating cost per cum | Remarks |
|---|---|---|---|---|---|---|
| 1 | Transfer pump | 30 m3/hr,40 m head,7.5 HP | | 5.7x0.946x7.5 31.89/30 | 1.063 | Considering power cost |
| 2 | Ozonator | 100 gm/hr power supply 3.2 kwh | | 5.7x3.2 18.24/30 | 0.608 | Considering power cost |
| 3 | Recirculation pump | 25 m3/hr,35 m head, 7.5 HP | | 5.7x0.746x7.5 31.89/30 | 1.06 | Considering power cost |
| 4 | Softener system regeneration | 120 kg NaCl per day x 1 time regeneration per day | | | 1 | |
| 5 | Change of resin bed | Rs.30,000 per change once in a year=30,000/(365x120) | | | 0.685 | Considering replacement of resin bed once in a year |
| 6 | Softener feed pump | 3 HP | | 3.0 x 0.746 x 5.5 12.309/10 cu.m per hr. | 1.2309 | Considering power cost |
| | | Operating Cost | | | 4.5839 per $m^3$ | |
| | | Total Operating Cost of Plant | | | 9.1077 per $m^3$ | |
| | | Cost of Transportation of the Treated Waters from the Sewage Treatment Plant to the plant site using selected pipe material and piping route. | | | 1.95 per $m^3$ | |
| | | TOTAL OPERATING COST = Rs. | | | 11.06 per $m^3$ | |

## 5.3 CASE STUDY 2: COMMON EFFLUENT TREATMENT PLANT

Following points are to be taken care for design of RO plant with pretreatment units:

### 5.3.1 Design Data

Design criteria for proposed plant are as follows:

- Source of wastewater – treated effluent of CETP = 1400 $m^3$/day
- Design flow of waste water = 58.33 $m^3$/hr.
- Total dissolved solids = 10000 mg/lit
- Recovery factor = 75-85 %
- $P^H$ = 6.5 – 6.8
- COD= 10 mg/lit
- BOD = 3 mg/lit
- MPN = 2.2 /100 ml
- Turbidity = 3 NTU
- Design temperature = 29 °C

### 5.3.2 Design Aspects

Different units of RO treatment system are depicted in diagram below:

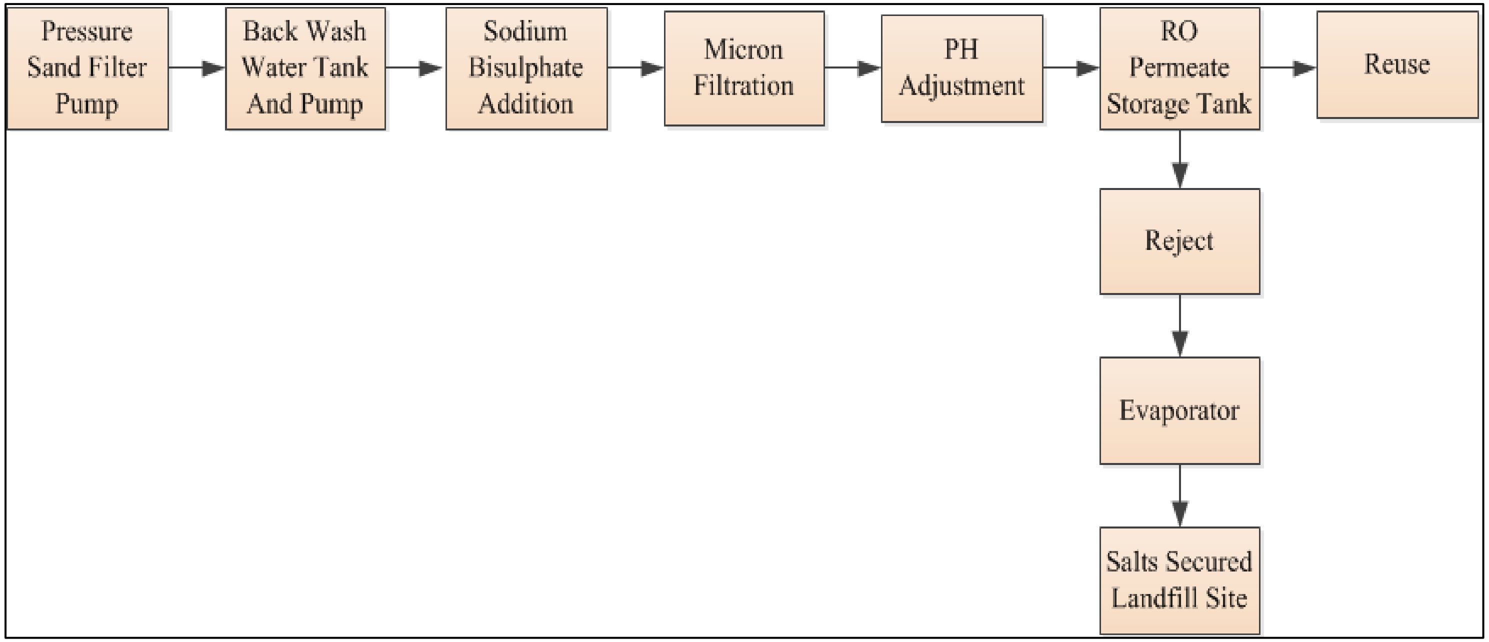



**Figure 5.4 Proposed Flow Diagram For RO Plant**

## 5.4 DESIGN WITH HYDRANAUTICS MEMBRANE SOLUTIONS DESIGN SOFTWARE, v. 2012

This software is based on the principles of reverse osmosis system and has proved a most reliable market product for working in the field.

### 5.4.1 Development Of Reverse Osmosis Technology

Reverse Osmosis (RO) is a modern process technology to purify the water for a wide range of applications, including semiconductors, food processing, biotechnology, pharmaceuticals, power generation, seawater desalting and municipal drinking water. From initial experiments conducted in the 1950's which produced a few drops per hour, the reverse osmosis industry has today resulted in combined world-wide production in excess of 1.7 billion gallons/day. With demand for pure water ever-increasing, the growth of the reverse osmosis industry is poised to continue growing well into the next century.

## 5.5 DESIGN OF REVERSE OSMOSIS TREATMENT

For the case study of CETP waste water treatment, reverse osmosis design is done with design software hydranutics version 2012.

The input parameters are as under.

MPN – 2.2/100 ML

COD – 10 MG/LIT

BOD- 15 MG/LIT

TDS – 8000 MG/LIT

TURBIDITY – 3 NTU

### 5.5.1 Post-Treatment System

Product water from the RO plant requires treatment prior to storage and transmission to consumers. This is necessary as the product water can cause serious corrosion problems in the pipe transmission system (Hanbury, 1993). The product from any type of the membrane usually requires $P^H$ adjustment. This is done by adding a base or by degasification ($H_2S$ and $CO_2$). Since most RO membranes reject calcium in preference to sodium, this necessitates the addition of calcium salts to the product water. The product water requires disinfection to prevent bacterial growth before transferring the product water to the distribution system.

### 5.5.2 Basic Transport Equations in Reverse Osmosis

Once the RO system has been installed, both membranes assembly must be tested for fluxes, salt rejection, recovery under various temperatures, pressures, and feed water salinities.

- **Water Flux**

  The following equation defines the water flux:

  $J1 = K1(\Delta P - \Delta \Pi)$

  $K1 = Kw \times A/\zeta$

  $\Pi = 1.21\ T\ \Sigma Mi$

  Where,

  J1 = Water flux [$m^3/m^2$/sec]

  P = Hydraulic pressure differential across the membrane [atm]

  $\Delta\Pi$ = Osmotic pressure differential across the membrane [atm]

  K1 = Pure water transport coefficient, i.e. the flux of water through the membrane per unit driving force [$m^3/m^2$/sec atm]

  Kw = Membrane permeability coefficient for water

  A = Membrane area [m]

  $\zeta$ = Membrane thickness [m]

  T = Feed water temperature [K]

  Mi = Molality of the $i^{th}$ ionic or nonionic materials.

  K1 is given by the membrane manufacturer or may be found by solving the equation at the standard test conditions. It depends on the membrane properties, temperature of the system and the chemical composition of the salt solution.

- **Salt Flux**

  The salt flux is an indicator for the membrane effectiveness in removing salts from water. The salt flux is a function of the system temperature and the salt composition. Therefore, it is a property of the membrane itself and indirectly related to the feed pressure. It is proportional to the salt concentration difference across the membrane, according to the following equations;

  $J2 = K2x\ \Delta C$

  $\Delta C = Cf - Cp$

  Where,

  J2 =Salt flux [Kg/m2/sec]

K2 =Salt transport coefficient [m/sec]

Cf = Salt concentration in the feed [$Kg/m^3$]

Cp = Salt concentration in the product [$Kg/m^3$]

Since the water flux through the RO membrane is higher than that of salt, there is an accumulation of salt on the membrane surface on the pressurized side of a membrane. This phenomenon is called concentration polarization.

The increase in concentration polarization has two effects:

- Increases the osmotic pressure and reducing the water flux across the membrane.
- Increases the driving force of the concentration difference across the membrane, which reduces the driving potential, increases the salt passage and gives poor product quality. All these effects increase the capital cost and the power requirements per unit of potable water produced.

- **Salt Rejection**

Salt rejection expresses the effectiveness of a membrane to remove salts from the water. It can be calculated from the following equation;

%Salt rejection=(1- Product concentration/ Feed concentration) x 100 %

%Salt rejection = (1- Product TDS/ Feed TDS) x 100 %

%Salt rejection = 1-%Salt passage

The salt passage depends on the feed water temperature and composition, operating pressure, membrane type, material and pretreatment. Salt passage and bundle pressure drop are the two indicators of membrane fouling.

- **Recovery**

The recovery rate for an RO system is: Recovery(R) = (Qp/ Qf) x *100%

Where, Qp = Product flow [$m^3$/day]

Qf = Feed flow [$m^3$/day]

The recovery is specified by the feedwater salinity. Increasing the recovery raises the brine concentration and the osmotic pressure, thus decreasing the permeate flux and increasing the total dissolved solid (TDS) in the product. We can increase the recovery by increasing the number of banks in the system. The above transport equation leads to the following important conclusions:

- J1 is proportional to $\Delta P$

- J2 is proportional to $\Delta C$ and is independent of the applied pressure. The increase in the operating pressure increases the water flow without changing the salt flow.

### 5.5.3 Operational Variables

When a reverse-osmosis system is used on a commercial level, it is important to check its performance periodically. As time passes, the membrane performance deteriorates continuously due to pressure compaction and fouling. This causes its transport parameters to change and the performance of the module to decline. Therefore, data monitoring is an important step in optimizing the performance of an RO plant. The important operating variables of a RO desalination process are as follows:

- **Permeate flux -** At a given feed salinity, the feed flow rate affects the production rate of the plant, water recovery, and the number of modules. A low production rate, below design specifications, could be an indication of membrane fouling. Every stage in an RO plant is designed to operate at a certain recovery, which is the ratio of product flow to the feed flow. If the recovery is above the design specification, then the brine concentration and the osmotic pressure will increase, causing a decrease the permeate flux and an increase in dissolved solid content in the product. Since the feed flow is maintained constant during operation, the product flow must be controlled to maintain a constant recovery during operation.
  - **Permeate conductivity -** The main objective of an RO process is to produce product of low total dissolved solids content. However, since the TDS is not easily measured except under controlled conditions in laboratories, the plant operators use conductivity to estimate the quality of the water produced. Monitoring the product conductivity is necessary to produce good water product. A gradual or rapid increase in the product conductivity is an indication of membrane fouling or mechanical damage in the membrane module, respectively. Both permeate flux and conductivity are affected by : $P^H$, Temperature, Pressure
- **$P^H$** - $P^H$ adjustment is a major step in the pretreatment processes. The $p^H$ of the feed water must be monitored and controlled for the following reasons:
  - To prevent alkaline (calcium carbonate) scale precipitation.

  - To increase the life of a cellular acetate membranes by protecting them from degradation that result from hydrolysis. Hydrolysis is the reaction of cellular acetate with water to produce an alcohol and an acid. Hydrolysis depends on both $P^H$ and temperature. The minimum hydrolysis rate occurs at a $P^H$ of 4.5-5.
  - To optimize the membrane salt rejection.
- **Temperature -** The feed temperature has a significant effect on the membrane performance for the following reasons:
  - The K1 value in equation depends on temperature of the system. An increase in the feed water temperature will cause an increase in water flux.
  - The feed water temperature affects the water flux in another way. If the RO plant is operating under an ideal condition with no fouling or scaling, water flux will decline with time, because of compaction phenomena. The compaction correction factor (CCF) is found from the following equation:

    CCF= $t^m$ where t = Operating time, m = A negative exponent whose value depends on the membrane, operating pressure, and temperature.

    For a membrane under a certain operating pressure, the m value is higher at a higher temperature, which means more compaction loss, and less water flux.
- **Pressure -** The water flux though the membrane is directly proportional to the pressure drop across the membrane. Since the pressure at the product side is constant, it follows that the water flux is directly related to the feed pressure. Additionally, the salt flux is a function of the system temperature and the chemical composition of the salt solution and is indirectly related to the feed pressure. At low operating pressure, less water permeates the membrane while the salt flux stays the same. At higher operating pressures more water permeates the membrane at the same salt flux. High feed pressure may cause a membrane compaction, which reduces the water flux after operating for a certain time

### 5.5.4 Summary Of The Above Parameters

Following points should be taken care for design with Reverse osmosis system.

- Desalination means the removal of fresh water from saline water
- Distillation is the oldest and most commonly-used desalting techniques. In this process, evaporation of the saline water and condensation of the generated vapor occur to obtain fresh water. The major desalting processes are:

  - Multi effect
  - Multistage Flash
  - Vapo compression
  - Reverse Osmosis
  - Electrodialysis
- Reverse osmosis is pressure-driven processes, to allow water, not salt, to diffuse from a salty solution across a semipermeable membrane. The pressure difference across the membrane should be high enough to overcome the osmotic pressure and push reasonable water flux across the membrane. A reverse osmosis system consists of four major components:
  - Pretreatment System
  - High-Pressure Pump
  - Membrane Assembly
  - Post-Treatment System
- The proper pretreatment of water before it reaches the membrane is the key to successful operation of a reverse osmosis plant. A pretreatment steps has the following objectives
  - To remove excess turbidity and suspended solids
  - To inhibit or control scaling and the formation of compounds
  - To disinfect and prevent biofouling
  - To perform chlorination and dechlorination.
  - Product water from the RO plant requires treatment prior to storage and transmission to consumers. This is necessary as the product water can cause serious corrosion and fouling problems in the pipe transmission system.
- Once the RO system has been installed, both membranes assembly must be tested for fluxes, salt rejection, and recovery under various temperatures, pressures, and feed water salinities.

### 5.5.5 Hydranautics Membrane Solutions Design Software, v. 2012

The Hydranautics design software package offers ultrafiltration (UF), RO, and UF+RO design options. It has two inputs RO DESIGN AND DESIGN SOFTWARE 225. Primary input screen shows "calculate" button for Toray DS design program.

The menu bar allows the designer to go to the "Analysis" or "File" screens or to the help screen. The help menu opens up a long list of issues that the designer can find assistance with. Additionally, several of the program inputs allow the designer to double click on the input query and information about that issue will pop up on the screen.

The first input screen is the water analysis screen. This screen is where the designer inputs the water analysis, either as ppm ion or ppm calcium carbonate. The screen also has inputs for iron, SDI, hydrogen sulfide, and turbidity. There is a drop-down menu where the feed water source is input. The bottom of the page lists the scaling indices. Once the "analysis" page has been completed, the "RO Design" input screen can be called up by clicking on the appropriate button. "Help" contents of Hydranautics IMS Design program.

### 5.5.6 Hydranautics Membrane Solutions Design Software, v. 2012

Hydranautics Membrane Solution Design software shows:

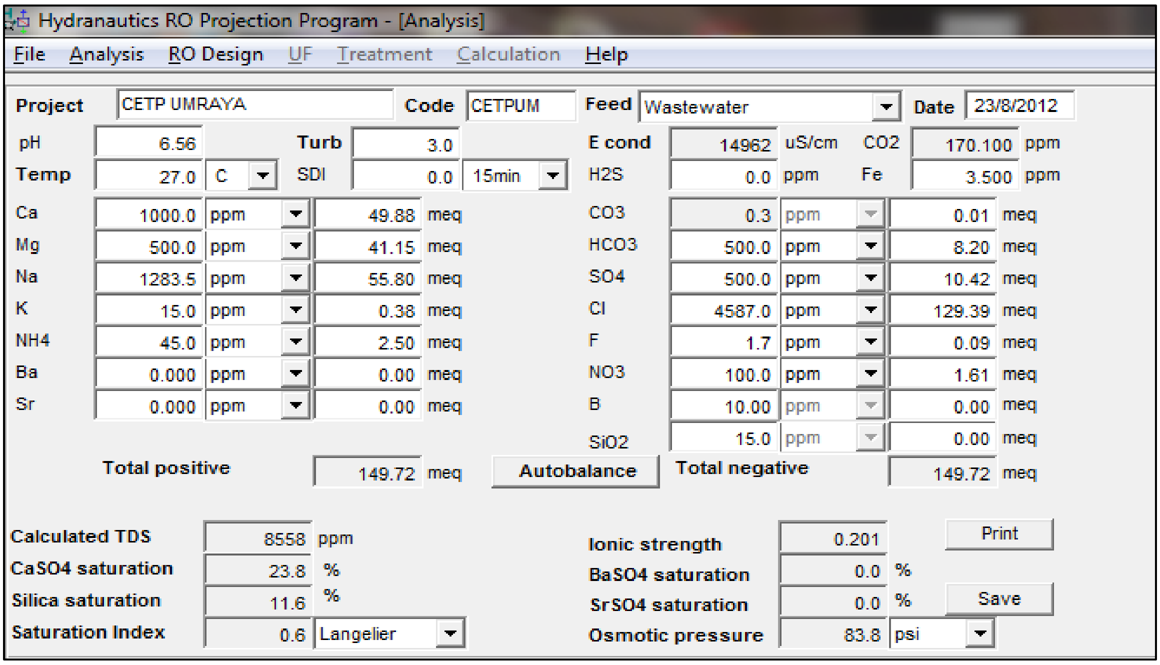
- Water analysis input screen of Hydranautics IMS Design program.
- Primary design input screen of Hydranautics IMS Design program.
- Number of stages per pass: Permeate, Backpressure, Array, Membrane selection and Run, perform the design calculations. $P^H$ and chemical feed are located at the upper right and upper left of the screen, respectively.

The designer can select sulfuric acid or caustic (or none) for chemical feed. Once the chemical feed is selected, the desired $P^H$ is entered. The chemical dosing rate required will appear in the top center of the screen. For general projections, the membrane age is of 3 years should be selected, which assumes a 3 year membrane life. This input works closely with the flux decline and salt passage increase inputs. Selecting performance at end-of-life for the membranes will yield the operating parameters necessary after years of fouling and scaling of the membrane. Flux decline per year input is located in the upper left of the screen. Recommended percentage flux decline per year is a function of feed water quality. The flux decline increases as the water quality gets worse. Salt passage increase is located in the upper left of the screen, just below the flux decline input. Recommended percentage salt passage increase per year is a function of feed water quality.

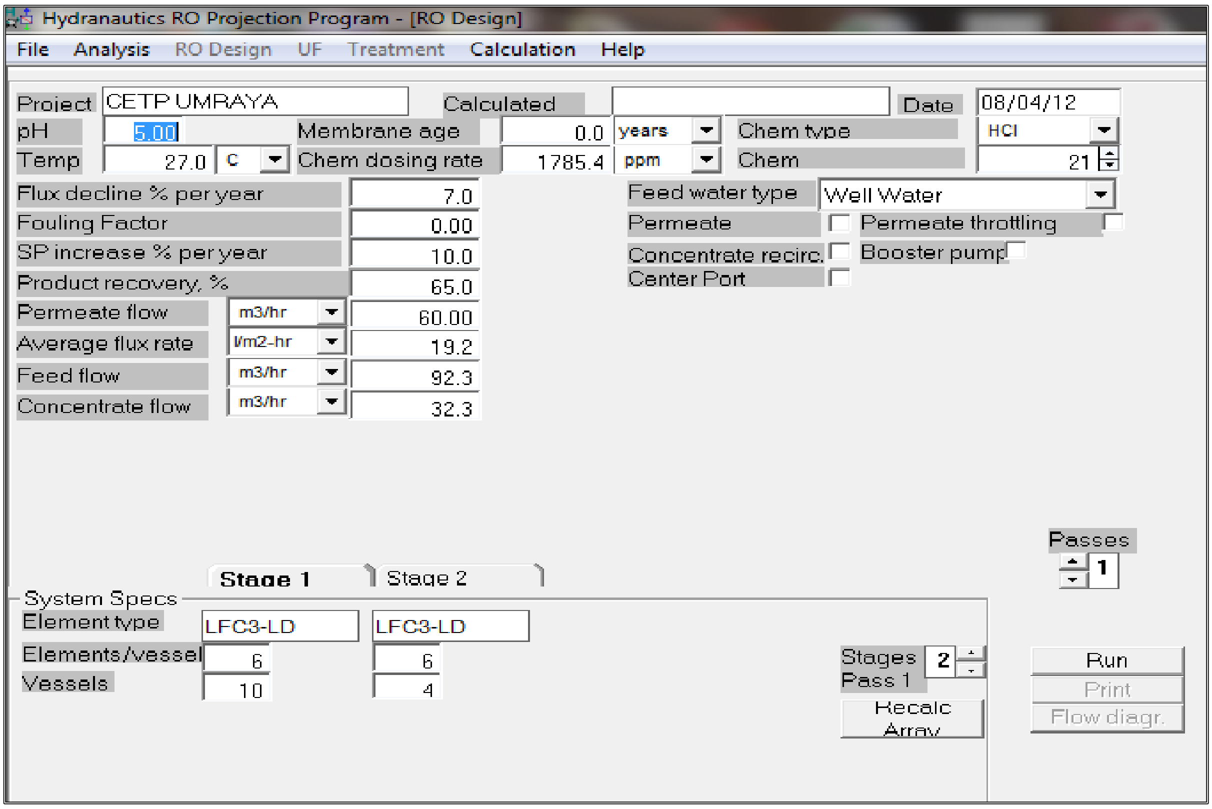
The salt passage increases as the feed water quality goes down. Clicking on the ‘Recalc Array’ button will change the selected array to one that is more appropriate for the conditions entered into the program. ”Auto Display” allows the designer to opt for a full report rather than a summary report of the projection. The full report that comes up on the screen is what the hard copy will look like. The summary report comes up after the calculations are performed by software. The top half of the screen shows the input values, while the bottom half gives a summary of the projected performance. To change any variable and rerun, Summary report output screen of Hydranautics IMS Design program. Hydranautics' recommended salt passage increase percentages per year as a function of feed water quality.

SYSTEMDE SIGN projections, click on "Next". This brings the designer back to the screen. The hard copy output from the Hydranautics design program is two pages. The first page of the hard copy output shows the inputs and project outputs for the design, the projected water quality, and the scaling indices. The second page includes the element-by-element projection data. Here the design is done with the help for the Hydraunautics design software version 2012. The output is showing all the components. For the implementation, following is the front screen of design software.


**Figure 5.5 Front Screen Of Software**




## Figure 5.6 Screen Shot For Analysis




## Figure 5.7 Screen Shot For Second Screen: RO Design

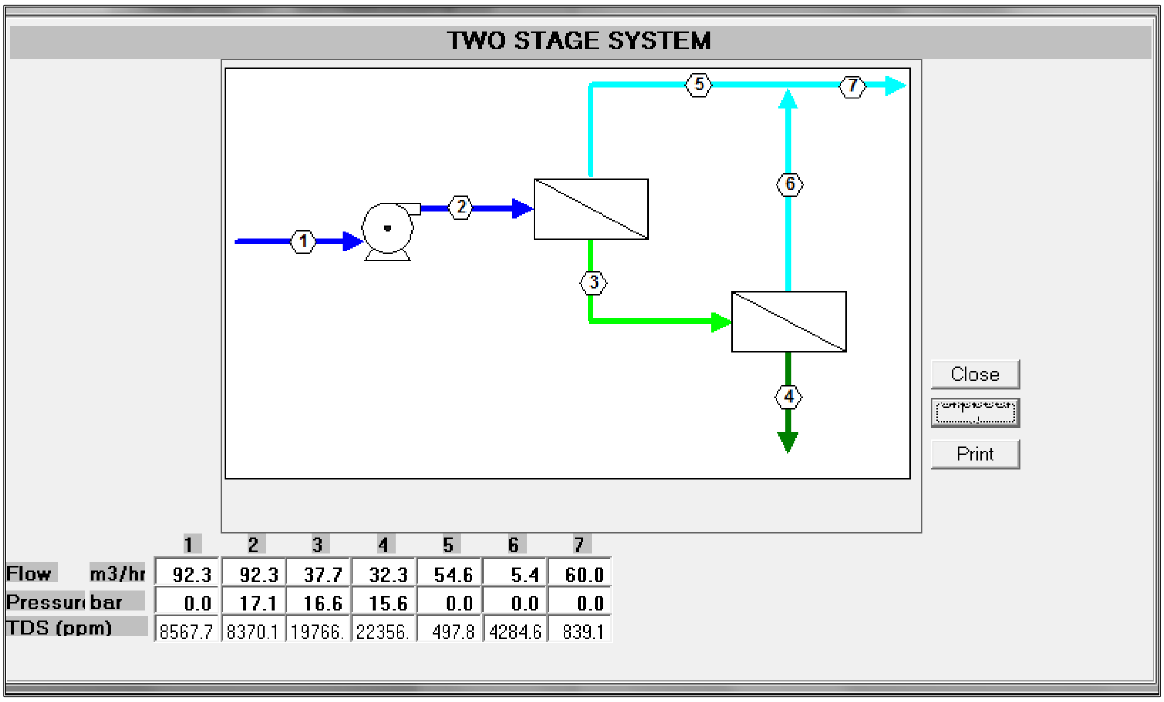



**Figure 5.8 Design Of Two Stage RO System With Hydranautics version 2012**

## 5.6 MODEL MEMBRANE ELEMENT LFC3-LD

Looking to the area available with LFC3-Ld, it is selected from the available options. It has following features:

- Low Fouling Technology is selected as it can treat high TDS waste water
- Performance: Permeate Flow: 11,000 gpd (41.6 $m^3$/d)
- Salt Rejection: 99.7 % (99.5 % minimum)

### 5.6.1 Type Configuration: Low Fouling Spiral Wound

Following are the design configurations for low fouling spiral wound.

- Membrane Polymer: Composite Polyamide
- Neutrally charged
- Membrane Active Area: 400 $ft^2$ (37.1$m^2$)
- Feed Spacer: 34 mil (0.864 mm) with biostatic agent

### 5.6.2 Application Data at Maximum Applied Pressure: 600 psig (4.16 MPa)

Application data for maximum applied pressure is as below.

- Maximum Chlorine Concentration: < 0.1 PPM
- Maximum Operating Temperature: 113 F (45 C)
- $P^H$ Range, Continuous (Cleaning): 2-10 (1-12)*

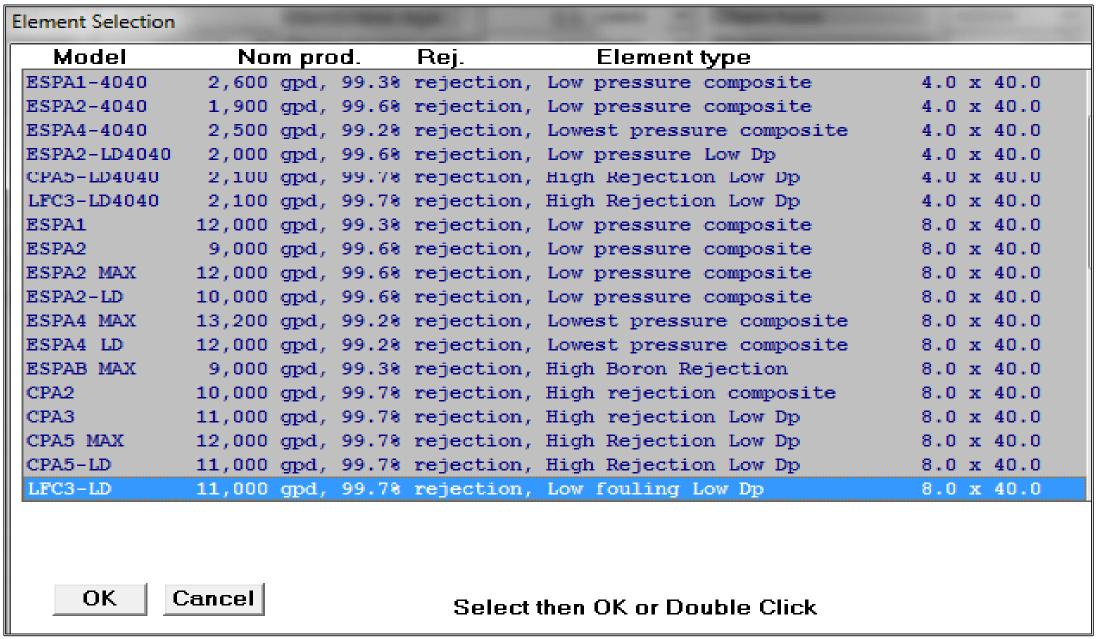
- Maximum Feed water Turbidity: 1.0 NTU
- Maximum Feed water SDI (15 mins): 5.0
- Maximum Feed Flow: 75 GPM (17.0 m3/h)
- Minimum Ratio of Concentrate to Permeate Flow for any Element: 5:1
- Maximum Pressure Drop for Each Element: 10 psi

The limitations shown here are for general use. For specific projects, operating at more conservative values may ensure the best performance and longest life of the membrane.

### 5.6.3 Test Conditions

The specifications for test conditions are as below:

- The stated performance is initial (data taken after 30 minutes of operation), based on the following conditions:
  - 1500 PPM NaCl solution
  - 225 psi (1.55 MPa) Applied Pressure
  - 77 F (25 °C) Operating Temperature
  - 15% Permeate Recovery
  - 6.5 - 7.0 $P^H$ Range



Element Selection

| Model | Nom prod. | Rej. | Element type | |
|---|---|---|---|---|
| ESPA1-4040 | 2,600 gpd, | 99.3% rejection, | Low pressure composite | 4.0 x 40.0 |
| ESPA2-4040 | 1,900 gpd, | 99.6% rejection, | Low pressure composite | 4.0 x 40.0 |
| ESPA4-4040 | 2,500 gpd, | 99.2% rejection, | Lowest pressure composite | 4.0 x 40.0 |
| ESPA2-LD4040 | 2,000 gpd, | 99.6% rejection, | Low pressure Low Dp | 4.0 x 40.0 |
| CPA5-LD4040 | 2,100 gpd, | 99.7% rejection, | High Rejection Low Dp | 4.0 x 40.0 |
| LFC3-LD4040 | 2,100 gpd, | 99.7% rejection, | High Rejection Low Dp | 4.0 x 40.0 |
| ESPA1 | 12,000 gpd, | 99.3% rejection, | Low pressure composite | 8.0 x 40.0 |
| ESPA2 | 9,000 gpd, | 99.6% rejection, | Low pressure composite | 8.0 x 40.0 |
| ESPA2 MAX | 12,000 gpd, | 99.6% rejection, | Low pressure composite | 8.0 x 40.0 |
| ESPA2-LD | 10,000 gpd, | 99.6% rejection, | Low pressure composite | 8.0 x 40.0 |
| ESPA4 MAX | 13,200 gpd, | 99.2% rejection, | Lowest pressure composite | 8.0 x 40.0 |
| ESPA4 LD | 12,000 gpd, | 99.2% rejection, | Lowest pressure composite | 8.0 x 40.0 |
| ESPAB MAX | 9,000 gpd, | 99.3% rejection, | High Boron Rejection | 8.0 x 40.0 |
| CPA2 | 10,000 gpd, | 99.7% rejection, | High rejection composite | 8.0 x 40.0 |
| CPA3 | 11,000 gpd, | 99.7% rejection, | High rejection Low Dp | 8.0 x 40.0 |
| CPA5 MAX | 12,000 gpd, | 99.7% rejection, | High Rejection Low Dp | 8.0 x 40.0 |
| CPA5-LD | 11,000 gpd, | 99.7% rejection, | High Rejection Low Dp | 8.0 x 40.0 |
| LFC3-LD | 11,000 gpd, | 99.7% rejection, | Low fouling Low Dp | 8.0 x 40.0 |

OK Cancel Select then OK or Double Click

**Figure 5.9 Type Of Membranes Available For Selection**

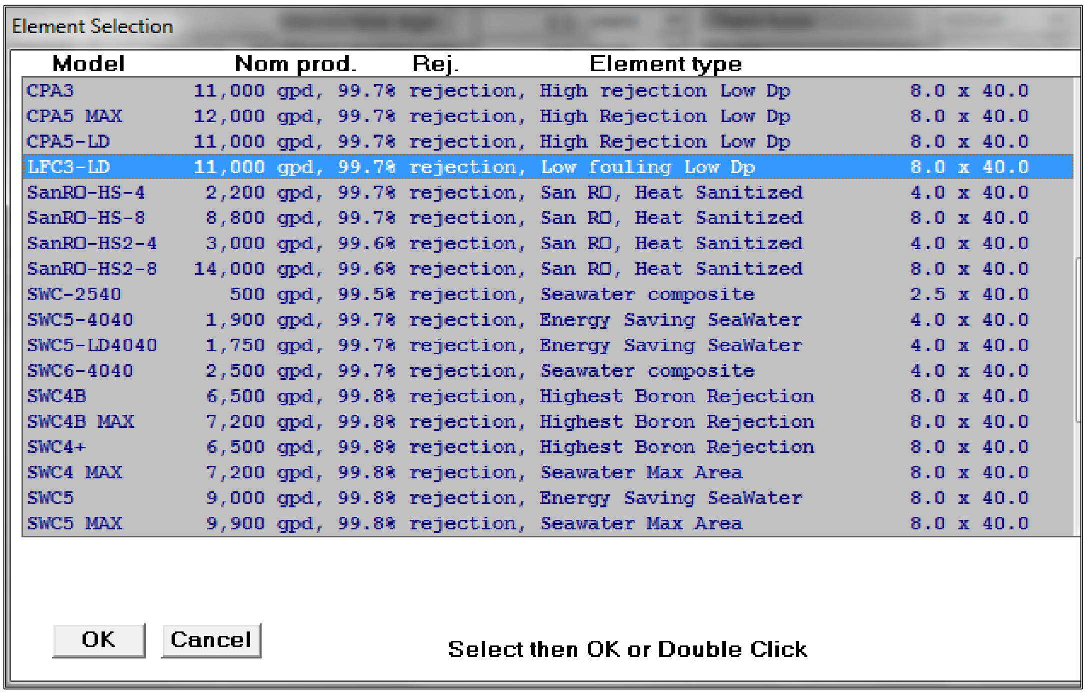



**Figure 5.10 Selection Of Membrane Module**

### 5.6.4 LFC3-LD Membrane

Following figure shows the details and working of LFC3-LD

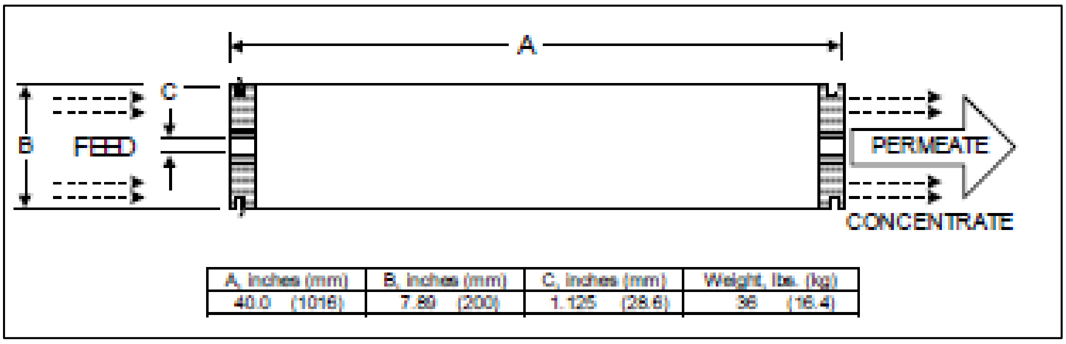



**Figure 5.11 Membrane LFC3-LD**

(Source: Hydraunautics Design Software version 2012)

The screen below shows the summary report of power parameters in software.

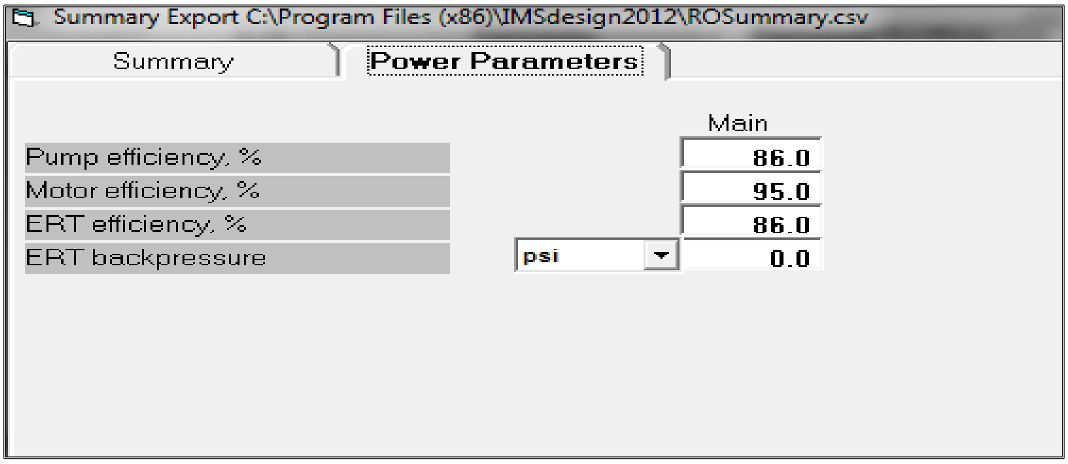



**Figure 5.12 Screen Shot for Power Parameters In Reverse Osmosis Design**

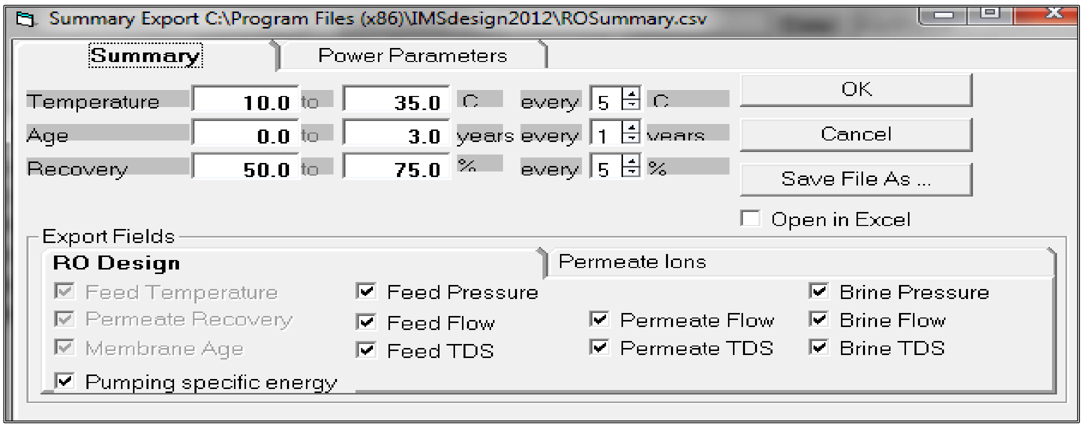



**Figure 5.13 Screen Shot for Summary Of Reverse Osmosis Design**

## 5.7 HYDRANAUTICS DESIGN LIMITS

The following system design limits should be observed when designing a reverse osmosis system.

**Table 5.9: Average Flux Rates And Expected % Decrease In Flux Per Year**

| Water Type | SDI | Flux | % Flux Decline /year |
|---|---|---|---|
| Surface water | 2-4 | 8-14 GFD | 7.3-9.9 |
| Well water | <2 | 14-18 GFD | 4.4-7.3 |
| RO permeate | <1 | 20-30 GFD | 2.3-4.4 |

**Table 5.10: Expected % Salt Decrease Per Year**

| Membrane Type | Abbreviation | % SP Increase /Year |
|---|---|---|
| Cellulose membrane | CAB1,CAB2,CAB3 | 17-33 |
| Composite membrane<br>Brackish low pressure<br>Brackish high pressure<br>Low fouling<br>Seawater<br>Softening, polyvinyl Deriv | ESPA1,ESPA2,ESPA3<br>CPA2,CPA3,CPA4<br>LFC1,LFC2<br>SWC1,SWC2,SWC3<br>PVD1,ESNA1,ESNA2 | 3-17<br>3-17<br>3-17<br>3-17<br>3-17 |

**Table 5.11: Maximum Feed Flow And Minimum Concentrate Flow Rates Per Vessel**

| Membrane Diameter (in) | Max (GPM) | Max ($m^3$/hr) | Min(GPM) | Min($m^3$/hr.) |
|---|---|---|---|---|
| 4 | 16 | 3.6 | 3 | 0.7 |
| 6 | 30 | 8.8 | 7 | 1.6 |
| 8 | 75 | 17 | 12 | 2.7 |
| 8.5 | 85 | 19.3 | 14 | 3.2 |

**Table 5.12: Saturation Limits For Sparingly Soluble Salts In The Concentrate**

| Salt | Saturation % |
|---|---|
| $CaSO_4$ | 230 |
| Sr $SO_4$ | 800 |
| $BaSO_4$ | 6000 |
| $SiO_2$ | 100 |

**Table 5.13: Limits of saturation Indices (Langelier and Stiff & Davis Saturation Indices)**

| Condition | LSI Value |
|---|---|
| LSI and SDSI without scale inhibitor | <= -0.2 |
| LSI and SDSI with SHMP | <= 0.5 |
| LSI and SDSI with organic scale inhibitor | <= 1.8 |

**Table 5.14: Performance Of The Low Fouling Membrane**

| Element type | Min. salt rejection % | Nom salt rejection % | Permeate flow GPD ($m^3$/day) |
|---|---|---|---|
| LFC1 | 99.2 | 99.5 | 11000 (41.63) |
| LFC3 | 99.5 | 99.7 | 9500 (35.96) |
| LFC3-LD | 99.5 | 99.7 | 11000 (41.6) |

## 5.8 LFC PROJECT REFERENCES

Following are case studies in which design by this software has been implemented successfully:

- Kranji, Singapore: 10.5 MGD (40000 $m^3$/day) of industrial water from a waste water source.
- Bedok, Singapore: 8.5 MGD (32000 $m^3$/day) of industrial water from a waste water source

- Lusolana, Spain: 1.3 MGD (48000 $m^3$/day) of industrial water from a surface water source.

Hydranautics, introduces new microfiltration elements based on HYDRAcap MAX technology to treat highly challenging waters. HYDRAcap MAX Microfiltration Technology provides very high membrane surface area, resulting in ultra-low footprint, minimizing capital cost. The crystalline PVDF membrane fiber is extremely strong and durable, resulting in minimal fiber breakage, greatly reducing operating costs while maintaining optimal filtration performance. Additionally, HYDRAcap MAX can operate at high fluxes without the need for backwash and with minimal cleaning, resulting in very high water recovery.

### 5.8.1 Design by Hydranautics Software

Input parameters are added in software and the detail design generated, as end result, is as shown in following pages. ‘Proposed Flow Diagram with Reverse Osmosis Treatment’ is shown after detail design, which may be constructed for reuse of wastewater.

Hydranautics Membrane Solutions Design Software, v. 2012 8/26/2012

BASIC DESIGN

| | | | |
|---|---|---|---|
| RO program licensed to: | | | |
| Calculation created by: | | | |
| Project name: | CETP UMRAYA | Permeate flow: | 60.00 m3/hr |
| HP Pump flow: | 92.3 m3/hr | Raw water flow: | 92.3 m3/hr |
| Feed pressure: | 17.1 bar | Permeate recovery: | 65.0 % |
| Feedwater Temperature: | 27.0 C(81F) | | |
| Feed water pH: | 5.00 | Element age: | 0.0 years |
| Chem dose, ppm (21%): | 1321.2 HCl | Flux decline % per year: | 7.0 |
| | | Fouling Factor | 0.20 |
| | | Salt passage increase, %/yr: | 10.0 |
| Average flux rate: | 19.2 lm2hr | Feed type: | Wastewater |

| Stage | Perm. Flow m3/hr | Flow/Vessel Feed m3/hr | Flow/Vessel Conc m3/hr | Flux l/m2-hr | Beta | Conc.&Throt. Pressures bar | Conc.&Throt. Pressures bar | Element Type | Elem. No. | Array |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-1 | 54.6 | 9.2 | 3.8 | 24.5 | 1.11 | 16.6 | 0.0 | LFC3-LD | 60 | 10x6 |
| 1-2 | 5.4 | 9.4 | 8.1 | 6.1 | 1.01 | 15.6 | 0.0 | LFC3-LD | 24 | 4x6 |

| | Raw water | | Feed water | | Permeate | | Concentrate | |
|---|---|---|---|---|---|---|---|---|
| Ion | mg/l | meq/l | mg/l | meq/l | mg/l | meq/l | mg/l | meq/l |
| Ca | 1000.0 | 49.9 | 1000.0 | 49.9 | 38.539 | 1.9 | 2785.6 | 138.9 |
| Mg | 500.0 | 41.2 | 500.0 | 41.2 | 19.270 | 1.6 | 1392.8 | 114.6 |
| Na | 1283.5 | 55.8 | 1283.5 | 55.8 | 227.450 | 9.9 | 3244.7 | 141.1 |
| K | 15.0 | 0.4 | 15.0 | 0.4 | 3.278 | 0.1 | 36.8 | 0.9 |
| NH4 | 45.0 | 2.5 | 45.0 | 2.5 | 9.835 | 0.5 | 110.3 | 6.1 |
| Ba | 0.000 | 0.0 | 0.000 | 0.0 | 0.000 | 0.0 | 0.0 | 0.0 |
| Sr | 0.000 | 0.0 | 0.000 | 0.0 | 0.000 | 0.0 | 0.0 | 0.0 |
| CO3 | 0.3 | 0.0 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.0 |
| HCO3 | 500.0 | 8.2 | 33.6 | 0.6 | 5.402 | 0.1 | 86.0 | 1.4 |
| SO4 | 500.0 | 10.4 | 500.0 | 10.4 | 11.868 | 0.2 | 1406.5 | 29.3 |
| Cl | 4573.2 | 129.0 | 4842.3 | 136.6 | 446.277 | 12.6 | 13006.4 | 366.9 |
| F | 1.7 | 0.1 | 1.7 | 0.1 | 0.301 | 0.0 | 4.3 | 0.2 |
| NO3 | 124.0 | 2.0 | 124.0 | 2.0 | 67.401 | 1.1 | 229.1 | 3.7 |
| B | 10.00 | | 10.00 | | 8.679 | | 12.45 | |
| SiO2 | 15.0 | | 15.0 | | 0.76 | | 41.45 | |
| CO2 | 170.10 | | 570.01 | | 570.01 | | 570.01 | |
| TDS | 8567.7 | | 8370.1 | | 839.1 | | 22356.4 | |
| pH | 6.56 | | 5.00 | | 4.29 | | 5.23 | |

| | Raw water | Feed water | Concentrate |
|---|---|---|---|
| CaSO4 / Ksp * 100: | 24% | 24% | 88% |
| SrSO4 / Ksp * 100: | 0% | 0% | 0% |
| BaSO4 / Ksp * 100: | 0% | 0% | 0% |
| SiO2 saturation: | 12% | 9% | 27% |
| Langelier Saturation Index | 0.63 | -2.11 | -1.06 |
| Stiff & Davis Saturation Index | 0.15 | -2.58 | -1.96 |
| Ionic strength | 0.20 | 0.20 | 0.54 |
| Osmotic pressure | 5.8 bar | 5.7 bar | 15.2 bar |

Hydranautics Membrane Solutions Design Software, v. 2012 8/26/2012

## BASIC DESIGN

RO program licensed to:
Calculation created by:

| | | | |
|---|---|---|---|
| Project name: | CETP UMRAYA | Permeate flow: | 60.00 m3/hr |
| HP Pump flow: | 92.3 m3/hr | Raw water flow: | 92.3 m3/hr |
| Feed pressure: | 17.1 bar | Permeate recovery: | 65.0 % |
| Feedwater Temperature: | 27.0 C(81F) | | |
| Feed water pH: | 5.00 | Element age: | 0.0 years |
| Chem dose, ppm (21%): | 1321.2 HCl | Flux decline % per year: | 7.0 |
| | | Fouling Factor | 0.20 |
| | | Salt passage increase, %/yr: | 10.0 |
| Average flux rate: | 19.2 lm2hr | Feed type: | Wastewater |

| Stage | Perm. Flow m3/hr | Flow/Vessel Feed m3/hr | Flow/Vessel Conc m3/hr | Flux l/m2-hr | Beta | Conc.&Throt. Pressures bar | Conc.&Throt. Pressures bar | Element Type | Elem. No. | Array |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-1 | 54.6 | 9.2 | 3.8 | 24.5 | 1.11 | 16.6 | 0.0 | LFC3-LD | 60 | 10x6 |
| 1-2 | 5.4 | 9.4 | 8.1 | 6.1 | 1.01 | 15.6 | 0.0 | LFC3-LD | 24 | 4x6 |

| Stg | Elem no. | Feed pres bar | Pres drop bar | Perm flow m3/hr | Perm Flux lm2hr | Beta | Perm sal TDS | Conc osm pres | Ca | Cumulative Perm Ion levels Mg | Cl | B | SiO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-1 | 1 | 17.1 | 0.1 | 1.3 | 35.4 | 1.15 | 168.6 | 6.6 | 5.18 | 2.59 | 100 | 5.43 | 0.13 |
| 1-1 | 2 | 16.9 | 0.1 | 1.2 | 31.6 | 1.10 | 199.2 | 7.8 | 6.34 | 3.17 | 122 | 5.96 | 0.16 |
| 1-1 | 3 | 16.8 | 0.1 | 1.0 | 27.1 | 1.10 | 245.3 | 9.1 | 7.92 | 3.96 | 152 | 6.59 | 0.20 |
| 1-1 | 4 | 16.7 | 0.1 | 0.8 | 22.1 | 1.10 | 309.4 | 10.510.12 | 5.06 | 194 | 7.34 | 0.26 | |
| 1-1 | 5 | 16.7 | 0.1 | 0.6 | 17.1 | 1.13 | 394.5 | 12.013.05 | 6.53 | 249 | 7.98 | 0.34 | |
| 1-1 | 6 | 16.6 | 0.0 | 0.5 | 12.6 | 1.11 | 503.1 | 13.316.84 | 8.42 | 321 | 8.36 | 0.43 | |
| 1-2 | 1 | 16.4 | 0.2 | 0.3 | 9.4 | 1.03 | 550.1 | 14.313.35 | 6.68 | 254 | 6.09 | 0.34 | |
| 1-2 | 2 | 16.2 | 0.1 | 0.2 | 6.4 | 1.02 | 611.6 | 14.615.34 | 7.67 | 294 | 6.51 | 0.39 | |
| 1-2 | 3 | 16.1 | 0.1 | 0.2 | 5.3 | 1.02 | 673.5 | 14.817.70 | 8.85 | 339 | 7.06 | 0.45 | |
| 1-2 | 4 | 15.9 | 0.1 | 0.2 | 4.4 | 1.02 | 736.3 | 15.020.74 | 10.37 | 397 | 7.74 | 0.53 | |
| 1-2 | 5 | 15.8 | 0.1 | 0.1 | 3.7 | 1.01 | 799.7 | 15.224.60 | 12.30 | 471 | 8.33 | 0.63 | |
| 1-2 | 6 | 15.7 | 0.1 | 0.1 | 3.1 | 1.01 | 863.6 | 15.329.41 | 14.71 | 562 | 8.68 | 0.75 | |

| Stage | NDP bar |
|---|---|
| 1-1 | 7.9 |
| 1-2 | 2.6 |

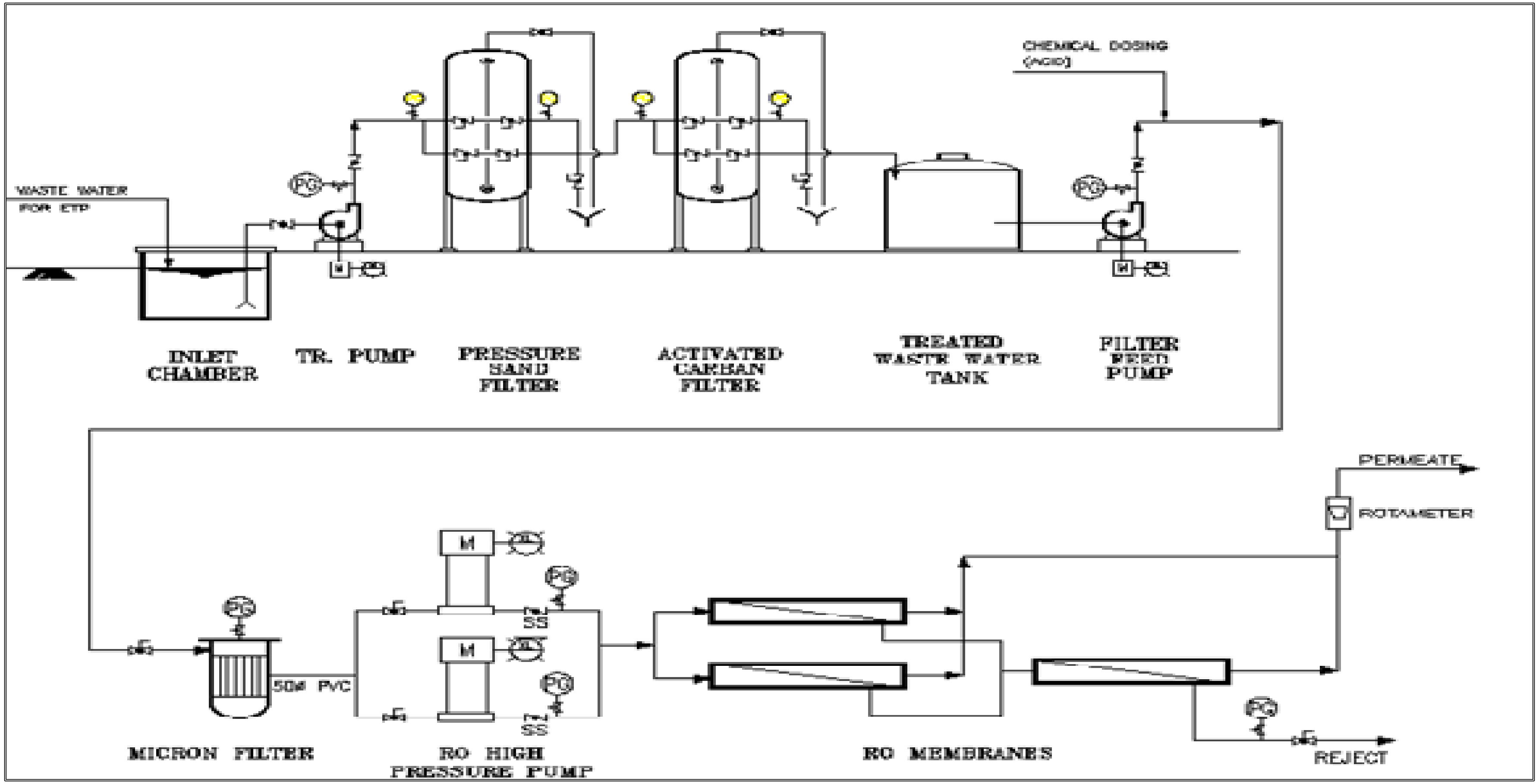



**Figure 5.14 Proposed Flow Diagram With Reverse Osmosis Treatment**

The below table shows, the budgetary capital and operating cost estimation, for proposed RO plant.

**Table 5.15: Budgetary Capital Costs For Units Of Reverse Osmosis Plant(Base Year 2012-13)**

| Sr. No. | Description | Size | Number Of Working & Standby Units | Cost Calculation | Total Cost | Remarks |
|---|---|---|---|---|---|---|
| 1 | Waste water transfer pump<br>Motor | 60 $m^3$/hr @ 1 kg/$cm^2$<br>5 HP | 1+ 1 | 50000 X 2 = 100000<br>25000 X 2 = 50000 | 150000 | Cast iron<br>Standard |
| 2 | Waste water storage tank | 7.75 ML X 7.75 ML X 2 MD + 0.5 F.B. | 1 | 2000000 | 2000000 | R.C.C. Epoxy painted |
| 3 | Sodium bisulphite solution tank<br>Dosing pump | 300 lit capacity<br>50 LPH @ 5 kg/$cm^2$ | 1<br>1 + 1 | 20000 X1 = 20000<br>65000 X 2 = 130000 | 150000 | F.R.P Plastic paint |
| 4 | PSF feed<br>Pump<br>Motor | HOS = 1800 mm<br>Dia = 1450 mm | 2 + 1 | 50000X 2 = 100000<br>45000 X 1 = 45000 | 145000 | Mild steel epoxy painted |
| 5 | Back wash water tank<br>Pump<br>Motor | 2.89ML X 2.89 MB x 2 MLD + 0.5 MFB<br>100 m3/hr @1 kg/$cm^2$<br>10 HP | 1<br>1 +1<br>1+1 | 50000 X 2 = 100000<br>25000 X 2 = 50000 | 150000 | R.C.C. Epoxy painted<br>Cast iron<br>Standard |
| 6 | Micron filter ( 25 cartige) | 450 mm Dia<br>1200 mm height<br>40" length X 2.5" Dia | 2+1 | 120000X 3= 360000 | 360000 | S.S. 304 Polypropylene wound type |
| 7 | High pressure R.O.<br>Pump<br>Motor | 30 $m^3$ /hr. @ 20 kg/$cm^2$<br>20 HP | 2 +1 | 200000X 3 =600000<br>150000X 3 =450000 | 1050000 | S.S. 304 standard |
| 8 | R.O. membrane block ( 2 units producing 46. 875 $m^3$/hr. of permeate each at 75 % recovery) | Two units each of 30 $m^3$/hr. feed water capacity<br>8" dia X 40" length<br>10 nos. of housing ( 6 | 2<br><br>10 housing | 50000X 60= 3000000<br>111000 X 10 =1110000<br>100000<br>1000000 | 5210000 | Thin film composite membrane<br>FRP |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | elements in one housing) | | | | |
| 9 | Membrane cleaning system solution tank Pump Motor Micron filter (Cartage) | 2 $m^3$ capacity<br><br>62.2 $m^3$ /hr. @ 4 kg/cm2<br><br>20 HP<br><br>450 mm dia X 1200 mm length | 1<br>1<br>1<br>1 | 55000 X 1= 550000<br>85000 X1 = 85000<br>28000 X 1 = 28000<br>120000 X 1=120000 | 168000 | FRP/MSRL SS 316<br>Standard SS 304 |
| 10 | Purified water storage tank | 9.49 ML + 9.49 ML + 3 MLD + 0.5 MFB | 1 | | | |
| | | | | | 9383000 | R.C.C. with epoxy painting |

### 5.8.2 Instrumentation And Miscellaneous Items

The list below shows the instruments and miscellaneous items for the proposed treatment plant.

- Pressure gauges- outlet of pumps, pressure sand filter, micron filter, R.O. block
- Temperature indicator alarm - micron filter outlet
- Flow meters - PSF outlet, R.O. permeate, R.O. Reject
- ORP analyzer - PSF outlet
- Conductivity indicator- micron filter outlet, permeate outlet
- Differential pressure indicator - R.O skid, micron filter
- $P^H$ indicator - micron filter outlet, permeate outlet
- Level indicators - waste water tank, lime solution tank, soda ash solution tank, back wash water tank, permeate water tank
- Motor control panel- for operation of meters

## 5.9 MODELLING: CASE STUDY 1: DOMESTIC SEWAGE TREATMENT PLANT

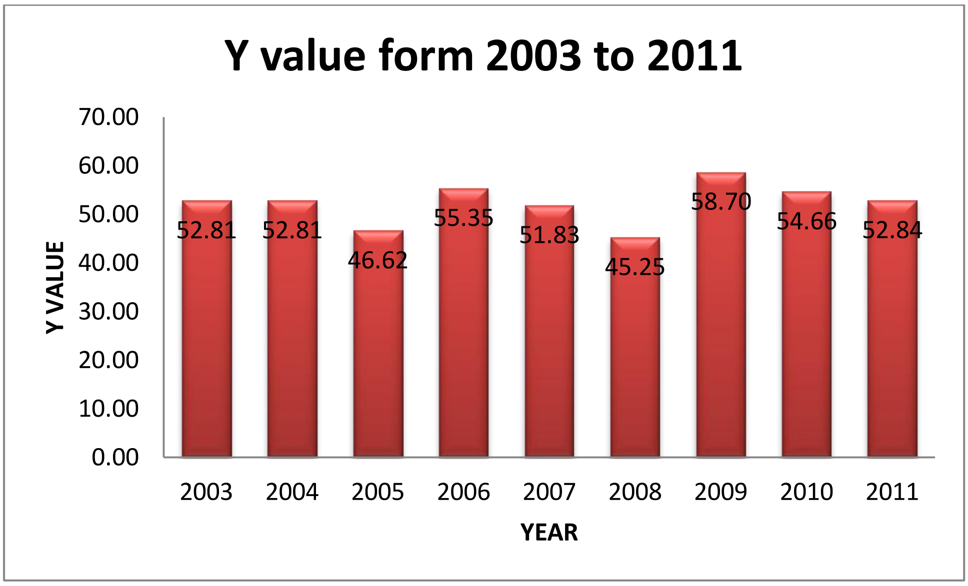
For Atladra sewage treatment plant, data collection is done for 9 years. Alternative treatments were tried and the statistical analysis is done for preparation of mathematical model.

## 5.10 PREAMBLE

To analyses the characteristics of the domestic sewage treatment plant taken for the study, one value is found based on the values of parameters to understand the quality of the waste water. Here, data for all important parameters is available for last 9 years which is difficult to manage. So for feasible proceeding further, from the mathematical relationship, the value Y to represent the quality of the waste water is determined.

## 5.11 AVERAGE VALUE

The characteristic of the wastewater is studied on daily basis after secondary treatment at domestic sewage treatment plant. Considering the main parameters for the reuse purpose, i.e. $P^H$, BOD,COD, TSS, the quality is studied and from average values yearly, the following graph is –plotted. Here Y value indicates the quality of final outlet from sewage treatment plant. It can be seen that the variation is very less, so it can be considered a reliable source of waste water for reuse. The lower the value of Y, better is the quality of waste water for reuse purpose. Also, till the value of Y< /= 154, (Ref: Standards IS and WHO for reuse of waste water) the domestic sewage is recommended for reuse purpose after basic primary treatment.




**Graph 5.1 Y Value Showing Characteristics Of Waste Water For Domestic Sewage Treatment Plant**

## 5.12 MODELING

Models are abstract representation of a specific problems which illustrates significant relationships, they aid in predicting relevant consequences of choosing each alternative.

$$\mathbf{Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4}$$

The four variables which are having impact on the waste water quality are BOD, COD, TSS, $P^H$ represented as $x_1, x_2, x_3, x_4$ here.

$$\mathbf{Y = b_0 + b_{1(BOD)} + b_{2(COD)} + b_{3(TSS)} + b_{4(P^H)}}$$

Compared to disposal standards ( IS ) for domestic sewage, the permissible values for BOD, COD, s, $P^H$ are 30 mg/lit, 150 mg/lit, 20 mg/lit, 6-8 respectively.

$$\mathbf{Y = b_0 + b_{1(30)} + b_{2(150)} + b_{3(20)} + b_{4(7)}}$$

Designating criteria based on which reuse schemes are proposed.

- Water consumption
- Treatment
- Value to be met with guidelines for reuse of waste water

Model-based testing is the application of designing and optimally executing the necessary artifacts to perform testing. Models can be used to represent the desired behavior of the System Under Test (SUT), or to represent the desired testing strategies and testing environment.

## 5.13 NEED OF MODEL PREPARATION

When a huge data is available and on a larger scale if treatments are to be carried out, it is better to have a model to work as prototype and which can be implemented for field work. Need of model preparation is

- To save time and cost by pilot testing for the treatability studies.
- To predict the value of y for deciding if water is reusable or not in which the error in y is minimum.
- To take help of graphical support for the solution of complicated problem.
- To take decision for the quality of water to be used is reusable or not.
- Possible types for the selected options.

### 5.13.1 Various Methods

For a study undertaken, following are the possible types of methods by which models can be prepared.

Here the value of waste water quality after treatability studies carried out is represented as one value P. For the analysis or mathematical model making, the following methods are available:

- **Least square error in cubic relationship**
- **Least square error in quadratic relationship**
- **Least square error in linear relationship**

The method of least squares is a standard approach to the approximate solution of **over determined systems**, i.e., sets of equations in which there are more equations than unknowns. "Least squares" means that the overall solution minimizes the sum of the squares of the errors made in the results of every single equation. The most important application is in **data fitting**. The best fit in the least-squares sense minimizes the sum of squared **residuals**, a residual being the difference between an observed value and the fitted value provided by a model. When the problem has substantial uncertainties in the **independent variable** (the 'x' variable), then simple regression and least squares methods have problems; in such cases, the methodology required for fitting **errors-in-variables models** may be considered instead of that for least squares.

Least squares problems fall into two categories: linear or **ordinary least squares** and **non-linear least squares**, depending on whether or not the residuals are linear in all unknowns. The linear least-squares problem occurs in statistical **regression analysis**; it has a closed-form solution. A closed-form solution (or **closed-form expression**) is any formula that can be evaluated in a finite number of standard operations. The non-linear problem has no closed-form solution and is usually solved by iterative refinement; At each iteration the system is approximated by a linear one, thus the core calculation is similar in both cases.

Least squares correspond to the **maximum likelihood** criterion if the experimental errors have a **normal distribution** and can also be derived as a **method of moment** estimator.

The following discussion is mostly presented in terms of **linear** functions but the use of least-squares is valid and practical for more general families of functions. Also, by iteratively applying local **quadratic approximation** to the likelihood, the least-squares method may be used to fit a **generalized linear model**.

The result of fitting a set of data points with a quadratic function.

The least-squares method is usually credited to Carl Friedrich Gauss (1794), but it was first published by Adrien-Marie Legendre.

### 5.13.2 Curve Fitting, Regression

All control parameters (independent variables) remain constant, the resultant outcomes (dependent variables) vary. A process of quantitatively estimating the trend of the outcomes, also known as regression or curve fitting, therefore becomes necessary.

The curve fitting process fits equations of approximating curves to the raw field data. Nevertheless, for a given set of data, the fitting curves are generally *NOT unique*. Thus, a curve with a minimal deviation from all data points is desired. This *best-fitting curve* can be obtained by the method of least squares.

### 5.13.3 The Method of Least Squares

The method of least squares assumes that the best-fit curve of a given type is the curve that has the minimal sum of the deviations squared (*least square error*) from a given set of data.

Suppose that the data points are ( $x_1,y_1$),($x_2,y_2$),….., ($x_n,y_n$) where $x$ is the independent variable and $y$ is the dependent variable. The fitting curve f(x) has the deviation (error) $d$ from each data point, i.e., $d_1= y_1-f(x_1)$, $d_2= y_2-f(x_2)$,…..,$d_n= y_n-f(x_n)$. According to the method of least squares, the best fitting curve has the property that:

$$\Pi = {d_1}^2 + {d_2}^2 + \ldots + {d_n}^2 = \sum_{i=1}^{n} {d_i}^2 = \sum_{i=1}^{n} [y_i - f(x_i)]^2 = \text{a minimum}$$

## 5.13.4 Polynomials Least-Squares Fitting

Polynomials are one of the most commonly used types of curves in regression. The applications of the method of least squares curve fitting using polynomials are briefly discussed as follows.

**The Least-Squares Line**: The least-squares line method uses a *straight line y= a + bx*to approximate the given set of data, ($X_1,Y_1$), ($X_2,Y_2$),…….(Xn,Yn), where n>=2

**The Least-Squares Parabola**: The least-squares parabola method uses a second degree curve y = a + bx + $cx^2$*to approximate the given set of data,*($X_1,Y_1$), ($X_2,Y_2$),…….(Xn,Yn), where n>=3

**The Least-Squares *m^th^* Degree Polynomials**: The least-squares $m^{th}$ degree Polynomials method uses $m^{th}$ degree polynomialsy = $a_0 + a_1x + a_2x^2 + \ldots\ldots. + a_mx^m$to approximate the given set of data, ($X_1,Y_1$), ($X_2,Y_2$),…….(Xn,Yn), where n>= m + 1.

**Multiple Regression Least-Squares**: Multiple regression estimates the outcomes which may be affected by more than one control parameter or there may be more than one control parameter being changed at the same time, e.g., z= a + bx + cy.

## 5.13.5 Multiple Regression

Multiple regression estimates the outcomes (dependent variables) which may be affected by more than one control parameter (independent variables) or there may be more than one control parameter being changed at the same time.

An example is the two independent variables **x** and **y** and one dependent variable $z$ in the linear relationship case: z= a + bx + cy. For a given data set $(x_1, y_1, z_1)$, $(x_2, y_2, z_2)$, ..., $(x_n, y_n, z_n)$, where $n \geq 3$, the best fitting curve $f(x)$has the least square error, i.e.,

$$\Pi = \sum_{i=1}^{n} [z_i - f(x_i, y_i)]^2 = \sum_{i=1}^{n} [z_i - (a + bx_i + cy_i)]^2 = \min.$$

a, b, c are unknown coefficients. $x_i$, $y_i$, $z_i$ are unknown.

$$\begin{cases} \frac{\partial \Pi}{\partial a} = 2\sum_{i=1}^{n}\left[z_i - (a + bx_i + cy_i)\right] = 0 \\ \frac{\partial \Pi}{\partial b} = 2\sum_{i=1}^{n} x_i\left[z_i - (a + bx_i + cy_i)\right] = 0 \\ \frac{\partial \Pi}{\partial c} = 2\sum_{i=1}^{n} y_i\left[z_i - (a + bx_i + cy_i)\right] = 0 \end{cases}$$

Expanding the above equations, we have

$$\begin{cases} \sum_{i=1}^{n} z_i = a\sum_{i=1}^{n} 1 + b\sum_{i=1}^{n} x_i + c\sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_i z_i = a\sum_{i=1}^{n} x_i + b\sum_{i=1}^{n} x_i^2 + c\sum_{i=1}^{n} x_i y_i \\ \sum_{i=1}^{n} y_i z_i = a\sum_{i=1}^{n} y_i + b\sum_{i=1}^{n} x_i y_i + c\sum_{i=1}^{n} y_i^2 \end{cases}$$

The unknown coefficients a,b and ccan hence be obtained by solving the above linear equations.

## 5.14 MULTIPLE REGRESSION ANALYSIS

**Selection of multiple regression analysis**

- The purpose of multiple regressions is to analyze the relationship between metric or dichotomous independent variables and a metric dependent variable.
- If there is a relationship, using the information in the independent variables will improve our accuracy in predicting values for the dependent variable.

**Types of multiple regressions**

There are three types of multiple regressions, each of which is designed to answer a different question

- Standard multiple regression is used to evaluate the relationships between a set of independent variables and a dependent variable.
- Hierarchical, or sequential, regression is used to examine the relationships between a set of independent variables and a dependent variable, after controlling for the effects of some other independent variables on the dependent variable.
- Stepwise, or statistical, regression is used to identify the subset of independent variables that has the strongest relationship to a dependent variable.

Standard linear regression models with standard estimation techniques make a number of assumptions about the predictor variables, the response variables and their relationship. Numerous extensions have been developed that allow each of these assumptions to be relaxed (i.e. reduced to a weaker form), in some cases eliminated entirely. Some methods are general enough that they can relax multiple assumptions at once, in other cases this can be achieved by combining different extensions.

The following are the major assumptions made by standard linear regression models with standard estimation techniques (e.g. ordinary least squares):

- Weak exogeneity
- Linearity.
- Independence of errors.
- Lack of multi co linearity in the predictors.

### 5.14.1 Use Of A Statistical Regression Model

Building a regression model involves collecting predictor and response values for common samples, then fitting a predefined mathematical relationship to the collected data.

Classical indications for regression as a predictive tool could be the following:

- To use cheap, easy-to-perform measurements as a substitute for more expensive or time-consuming ones
- To build a response surface model from the results of some experimental design, i.e. describe precisely the response levels according to the values of a few controlled factors.

### 5.14.2 Dependent And Independent Variables

In multiple regressions, analysis is done with just one dependent and two or more independent (exploratory) variables. The variable whose value is to be predicted is known as the dependent variable and the ones whose known values are used for prediction are known independent (exploratory) variables.

### 5.14.3 The Multiple Regression Model

In general, the multiple regression equation of Y on $X_1, X_2, \ldots, X_k$ is given by:

$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + b_k X_k$

### 5.14.4 Interpreting Regression Coefficients

Here $b_0$ is the intercept and $b_1, b_2, b_3, \ldots, b_k$ are analogous to the slope in linear regression equation and are also called regression coefficients. They can be interpreted the same way as slope. Thus if bi = 2.5, it would indicates that Y will increase by 2.5 units if Xi increased by 1 unit.

The appropriateness of the multiple regression model as a whole can be tested by the F-test in the ANOVA table. A significant F indicates a linear relationship between P and at least one of the X's.

### 5.14.5 Goodness Of The Regression

Once a multiple regression equation has been constructed, one can check how good it is by examining the coefficient of determination ($R^2$). $R^2$ always lies between 0 and 1.

### 5.14.6 $R^2$ - Coefficient Of Determination

All software provides it whenever regression procedure is run. The closer $R^2$ is to 1, the better is the model and its prediction.

A related question is whether the independent variables individually influence the dependent variable significantly. Statistically, it is equivalent to testing the null hypothesis that the relevant regression coefficient is zero.

This can be done using t-test. If the t-test of a regression coefficient is significant, it indicates that the variable is in question influences Y significantly while controlling for other independent explanatory variables.

### 5.14.7 Assumptions In Multiple Regression

Multiple regression technique does not test whether data are linear. On the contrary, it proceeds by assuming that the relationship between the Y and each of Xi's is linear. Hence as a rule, it is prudent to always look at the scatter plots of (Y, Xi), i= 1, 2,…,k. If any plot suggests non linearity, one may use a suitable transformation to attain linearity.

Another important assumption is non-existence of multi colinearity- the independent variables are not related among themselves. At a very basic level, this can be tested by computing the correlation coefficient between each pair of independent variables. In the case study 1 for domestic sewage treatment plant, the coefficients between each two parameters are found.

Multiple regression analysis is used when one is interested in predicting a continuous dependent variable from a number of independent variables. If dependent variable is dichotomous, then logistic regression should be used.

So assumptions in multiple regression analysis can be summarized as follows.

- Variables are normally distributed.
- Assumption of a linear relationship between the independent and dependent variable(s).
- Variables are measured without error (reliably)
- Reliability and simple regression
- Reliability and multiple regression

A key advantage of multiple regressions, besides being able to use multiple variables, is the ability to use multiple types of variables. For instance, a metric or numerical variable can be regressed on a non-metric or string variable, and vice versa. In addition, combinations of metric and non-metric variables can be regressed on metric and non-metric variables, depending on the specific kind of variable in question, different techniques such as discriminant analysis, logistic regression or SEM (Structured Equation Modeling) can be applied.

### 5.14.8 Selection Of The Model

The multiple linear regression model was selected based on the following advantages compared to other methods:

- Others are complicated to solve
- Correlation between variables.
- Graphical support
- Residual support

If any of the parameter will be zero, we will not take that.

Y <= 154, water quality is reusable

## 5.15 COEFFICIENT OF RELATION BETWEEN VARIOUS PARAMETERS

For both case studies hypothesis is as stated

$H_0$ = Null Hypothesis = Wastewater quality is not reusable after treatment

$H_1$ = Alternate Hypothesis = Wastewater quality is reusable after treatment

Following are the equations for the relation between each two parameters. They are found by statistical analysis also and from selected parameters for study. The figure below is a graph plotted in MATlab software version 2009.

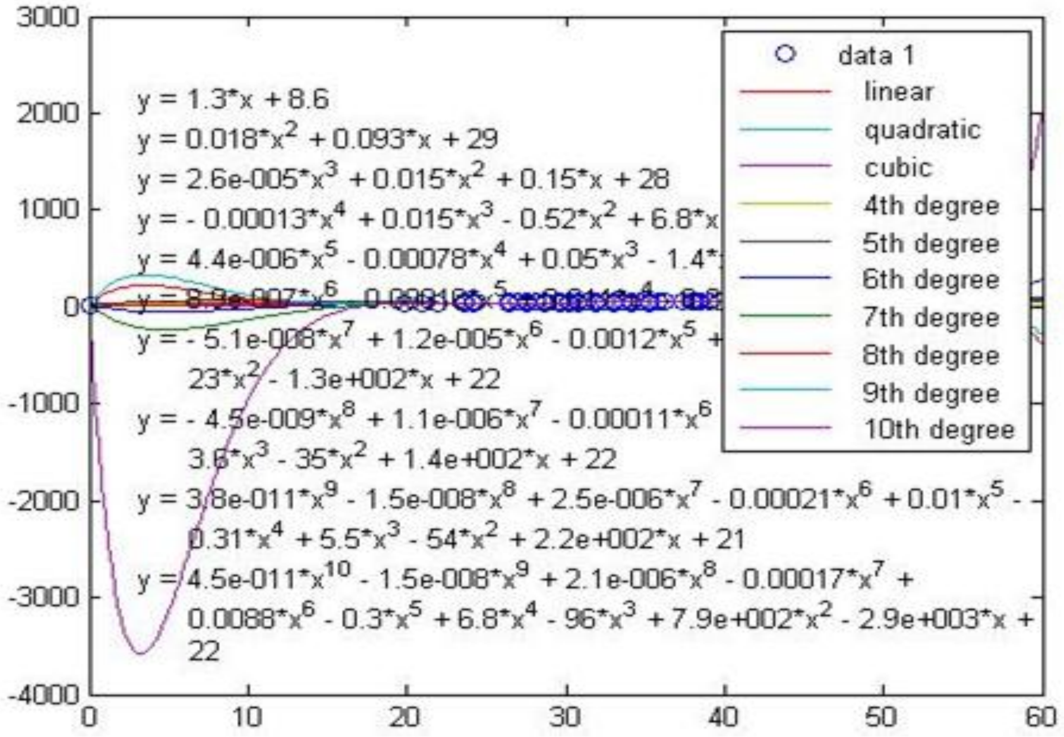



**Figure 5.15 Coefficient of TSS& P Value**

Graph shows equations up to $10^{th}$ degree polynomial. But it is clearly seen that average value is related to TSS linearly.

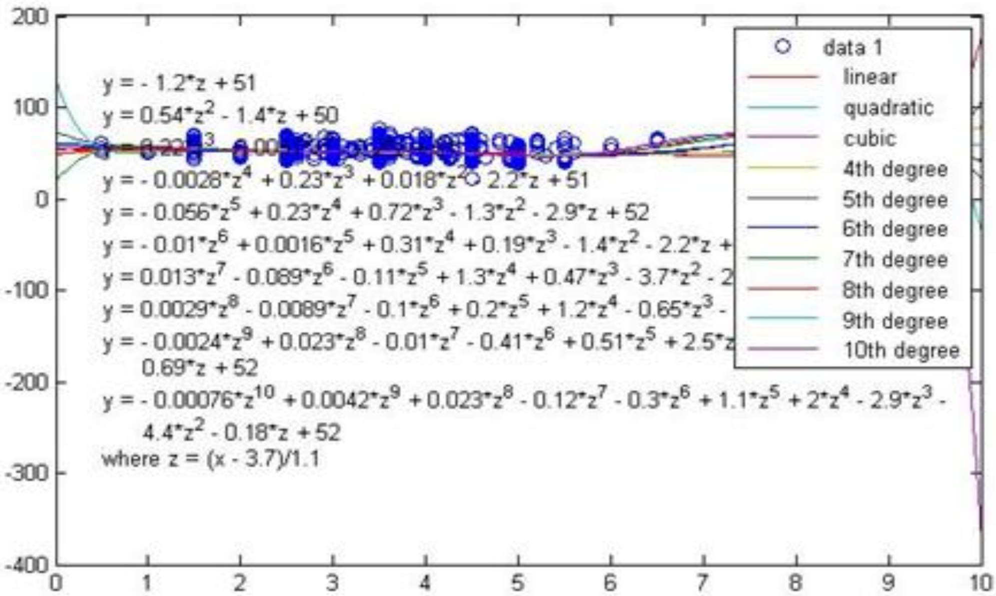



**Figure 5.16 Coefficient Of BOD& P Value**

Figure shows that BOD is highly correlated with average value of waste water

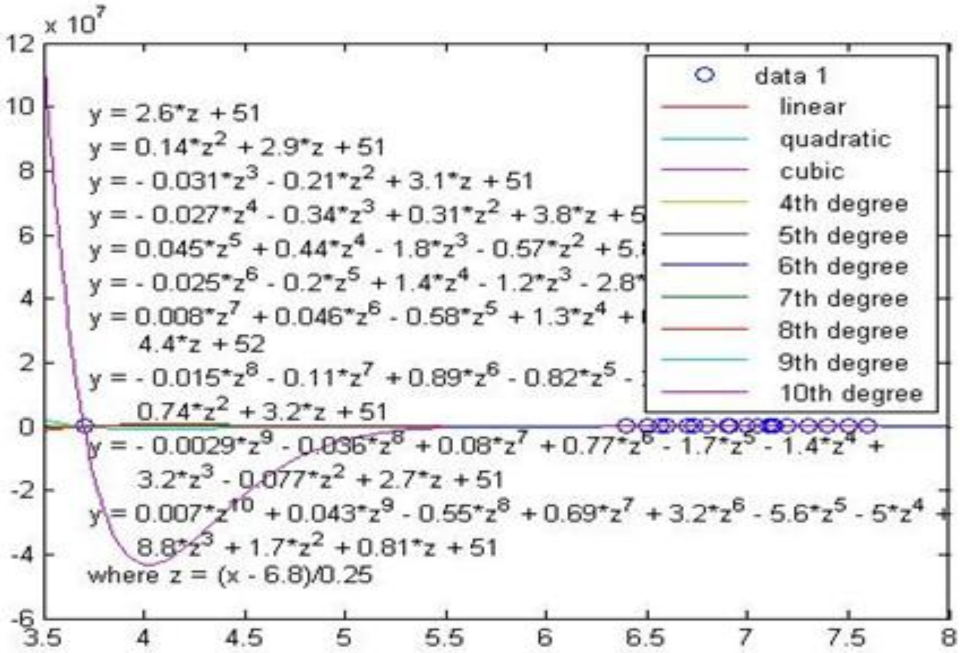



**Figure 5.17 Coefficient Of $P^H$ & P Value**

Variation in $P^H$ is less. Figure shows that average value of waste water is not much affected by $P^H$.

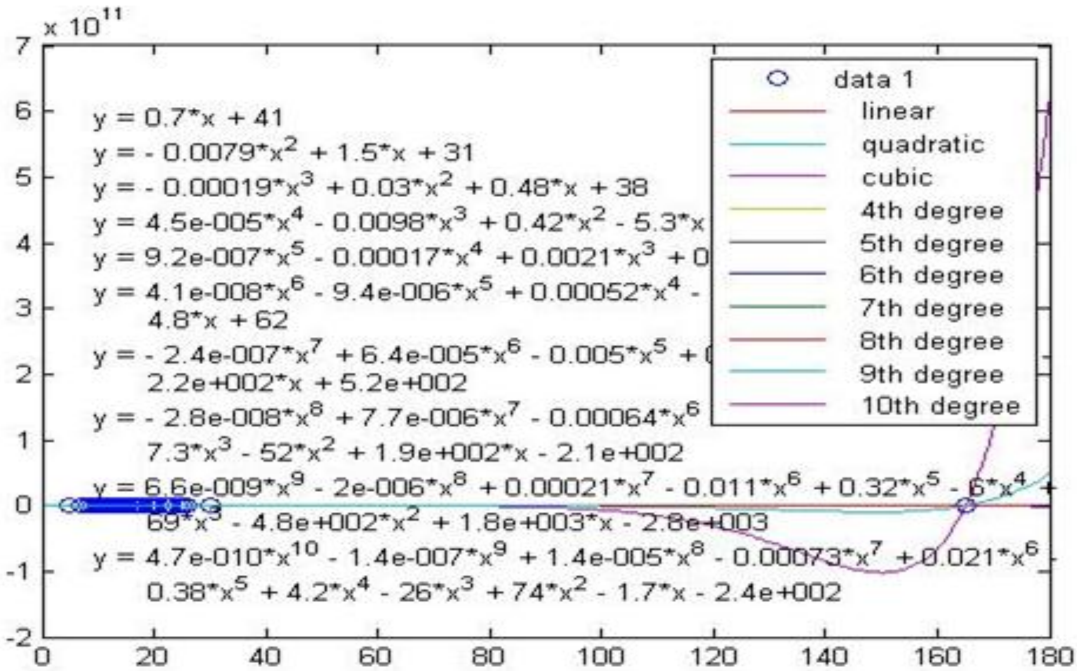



**Figure 5.18 Coefficient Of COD & P Value**

Above figure shows that COD is having impact on average characteristics of waste water.

### 5.15.1 Remarks

From the above mathematical models, it is predicted that BOD and P are having positive relationship, $P^H$ and COD is having some impact. Looking to the curve, it is clearly seen that TSS is not having any effect on the value of Y. So variation in TSS up to some extent will not make any difference to Y. here variation in the waste water quality to a great extent can make a difference to the result of the model.

Model works with assumptions as follows

- The quality of waste water will be maintained considering the plant is running efficiently.
- The parameters $P^H$, BOD, COD, TSS will be maintained in a range at the time of study to achieve efficient results and for reuse of waste water.

From the available data of last nine years, the relation between parameters is found and value of coefficient of correlation between each parameter is mentioned in Table 5.16. From below values, it can be seen that the parameters BOD, COD & $P^H$ are positively correlated. When TSS is considered, the coefficient shows the negative value, so it has negative impact or no effect on the treatments tried for reuse of waste water.

**Table 5.16: Coefficients Between The Parameters**

| Correlation coefficient of | Value |
|---|---|
| BOD & COD | 0.427348 |
| BOD & TSS | -0.2883 |
| BOD & $P^H$ | 0.45164 |
| COD & TSS | -0.836 |
| COD & $P^H$ | 0.38088 |
| TSS & $P^H$ | -0.5633 |

It also matches with the mathematical model that Solids have no impact on the variation of the quality of the waste water as it is domestic sewage; it is having more impact for biological parameters.

## 5.16 STATISTICAL ANALYSIS

For the present study Null Hypothesis is," Waste water is not reusable". Alternative Hypothesis is," Waste water is reusable." From the data available for the domestic sewage treatment plant, the statistical analysis, multiple regression analysis is done to predict the quality of waste water. For domestic sewage treatment plant, the following is the statistical analysis which shows the relation between BOD & COD parameters before treatment.

### 5.16.1 The Relation Between BOD & COD Before Treatment

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.427302 |
| R Square | 0.182587 |
| Adjusted R Square | 0.182335 |
| Standard Error | 3.742204 |
| Observations | 3245 |

ANOVA

| | *Df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 10144.49 | 10144.49 | 724.3951 | 3.5E-144 |
| Residual | 3243 | 45415.26 | 14.00409 | | |
| Total | 3244 | 55559.76 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 12.90868 | 0.108235 | 119.2654 | 0 | 12.69646 | 13.1209 | 12.69646 | 13.1209 |
| X Variable 1 | 0.064673 | 0.002403 | 26.91459 | 3.5E-144 | 0.059962 | 0.069384 | 0.059962 | 0.069384 |

**P= 12.090868 + 0.064 * Q**

### 5.16.2 The Relation Between TSS & BOD Before Treatment

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.001252 |
| R Square | 1.57E-06 |
| Adjusted R Square | -0.00031 |
| Standard Error | 0.330489 |
| Observations | 3220 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 0.000551 | 0.000551 | 0.005045 | 0.943382 |
| Residual | 3218 | 351.4785 | 0.109223 | | |
| Total | 3219 | 351.479 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 6.986449 | 0.020095 | 347.6749 | 0 | 6.947049 | 7.025849 | 6.947049 | 7.025849 |
| 30.25 | 4.4E-05 | 0.000619 | 0.071026 | 0.943382 | -0.00117 | 0.001258 | -0.00117 | 0.001258 |

**$P = 6.98644 + 4.4 \times 10^{-5} Q$**

### 5.16.3 The Relation Between $P^H$& TSS Before Treatment

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.591566 |
| R Square | 0.34995 |
| Adjusted R Square | 0.349748 |
| Standard Error | 21.99141 |
| Observations | 3220 |

ANOVA

| | *Df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 837823.3 | 837823.3 | 1732.392 | 2.6E-303 |
| Residual | 3218 | 1556296 | 483.6222 | | |
| Total | 3219 | 2394120 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -305.098 | 8.205965 | -37.18 | 4.8E-252 | -321.187 | -289.008 | -321.187 | -289.008 |
| 7 | 48.82323 | 1.173015 | 41.62201 | 2.6E-303 | 46.5233 | 51.12316 | 46.5233 | 51.12316 |

**P= -305.098+ 48.8233 Q**

## 5.16.4 The Relation Between TSS & COD Before Treatment

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.315269 |
| R Square | 0.099394 |
| Adjusted R Square | 0.099114 |
| Standard Error | 0.313635 |
| Observations | 3220 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 34.93501 | 34.93501 | 355.1508 | 3.12E-75 |
| Residual | 3218 | 316.544 | 0.098367 | | |
| Total | 3219 | 351.479 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 7.319589 | 0.018452 | 396.678 | 0 | 7.28341 | 7.355768 | 7.28341 | 7.355768 |
| 2.5 | -0.10461 | 0.005551 | -18.8454 | 3.12E-75 | -0.1155 | -0.09373 | -0.1155 | -0.09373 |

**P= 7.319589 – 0.10461*Q**

### 5.16.5 The Relation Between $P^H$ & BOD Before Treatment

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.01894 |
| R Square | 0.000359 |
| Adjusted R Square | 4.81E-05 |
| Standard Error | 27.27106 |
| Observations | 3220 |

ANOVA

| | *Df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 858.828 | 858.828 | 1.154788 | 0.28263 |
| Residual | 3218 | 2393261 | 743.7106 | | |
| Total | 3219 | 2394120 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 34.36444 | 1.658169 | 20.72433 | 1.17E-89 | 31.11327 | 37.61562 | 31.11327 | 37.61562 |
| 30.25 | 0.054907 | 0.051095 | 1.074611 | 0.28263 | -0.04527 | 0.15509 | -0.04527 | 0.15509 |

**P = 34.3644 + 0.054907 * Q**

## 5.16.6 The Relation Between $P^H$ & COD Before Treatment

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.301327 |
| R Square | 0.090798 |
| Adjusted R Square | 0.090515 |
| Standard Error | 26.00819 |
| Observations | 3220 |

ANOVA

| | *Df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 217380.7 | 217380.7 | 321.3666 | 1.42E-68 |
| Residual | 3218 | 2176739 | 676.426 | | |
| Total | 3219 | 2394120 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 62.24096 | 1.530152 | 40.67632 | 3.1E-292 | 59.24079 | 65.2411 | 59.24079 | 65.24113 |
| 2.5 | -8.25223 | 0.460332 | -17.9267 | 1.42E-68 | -9.1548 | 7.34965 | -9.1548 | -7.34965 |

**P= 62.24096 -8.25223* Q**

### 5.16.7 The Relation Between BOD & P

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.938249047 |
| R Square | 0.880311274 |
| Adjusted R Square | 0.880274081 |
| Standard Error | 3.516569229 |
| Observations | 3220 |

ANOVA

| | *Df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 292689.7 | 292689.7 | 23668.41 | 0 |
| Residual | 3218 | 39794.62 | 12.36626 | | |
| Total | 3219 | 332484.3 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 20.30886253 | 0.213819 | 94.98164 | 0 | 19.88963 | 20.7281 | 19.88963 | 20.7281 |
| 30.25 | 1.013635328 | 0.006589 | 153.8454 | 0 | 1.000717 | 1.026554 | 1.000717 | 1.026554 |

**P=20.3088 + 1.0136*Q**

### 5.16.8 The Relation Between TSS & P

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.174275 |
| R Square | 0.030372 |
| Adjusted R square | 0.030071 |
| Standard Error | 10.0091 |
| Observations | 3220 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 10098.16 | 10098.16 | 100.798 | 2.24E-23 |
| Residual | 3218 | 322386.1 | 100.1821 | | |
| Total | 3219 | 332484.3 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 49.44941 | 0.292497 | 169.0597 | 0 | 48.87591 | 50.02291 | 48.87591 | 50.02291 |
| 19 | 0.064945 | 0.006469 | 10.03982 | 2.24E-23 | 0.052262 | 0.077629 | 0.052262 | 0.077629 |

**P= 49.44941 + 0.064945 *Q**

## 5.16.9 The Relation Between $P^H$ & P

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.139271 |
| R Square | 0.019396 |
| Adjusted R Square | 0.019092 |
| Standard Error | 10.06559 |
| Observations | 3220 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 6449.02 | 6449.02 | 63.65245 | 2.04E-15 |
| Residual | 3218 | 326035.3 | 101.3161 | | |
| Total | 3219 | 332484.3 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 21.85978 | 3.755916 | 5.820094 | 6.46E-09 | 14.49555 | 29.22401 | 14.49555 | 29.22401 |
| 7 | 4.283484 | 0.536895 | 7.978249 | 2.04E-15 | 3.230792 | 5.336175 | 3.230792 | 5.336175 |

**P= 21.85978+4.283484Q**

## 5.16.10 The Relation Between COD & P

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.087409 |
| R Square | 0.00764 |
| Adjusted R Square | 0.007332 |
| Standard Error | 10.12575 |
| Observations | 3220 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 2540.293 | 2540.293 | 24.77591 | 6.78E-07 |
| Residual | 3218 | 329944 | 102.5308 | | |
| Total | 3219 | 332484.3 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 54.62111 | 0.595733 | 91.68724 | 0 | 53.45306 | 55.78917 | 53.45306 | 55.78917 |
| 2.5 | -0.89208 | 0.179221 | -4.97754 | 6.78E-07 | -1.24348 | -0.54068 | -1.24348 | -0.54068 |

**P= 54.6211 – 0.89208 * Q**

Final multiple regression analysis for finding quality of waste water is as shown below. By experiments, it is indicated as one value P and predicted P is having very less variation. Highest Residual value is 2.68 which is quite acceptable.

### 5.16.11 The Relation Between $P^H$, BOD, COD, TSS & P

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.348764 |
| R Square | 0.121636 |
| Adjusted R Square | 0.120543 |
| Standard Error | 1.714437 |
| Observations | 3220 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 4 | 1308.617 | 327.1543 | 111.3037 | 5.62E-89 |
| Residual | 3215 | 9449.831 | 2.939294 | | |
| Total | 3219 | 10758.45 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 1.254368 | 0.814362 | 1.540308 | 0.123584 | -0.34235 | 2.851088 | -0.34235 | 2.851088 |
| 19 | 0.018293 | 0.00139 | 13.15815 | 1.49E-38 | 0.015567 | 0.021019 | 0.015567 | 0.021019 |
| 7 | 0.314743 | 0.115287 | 2.730079 | 0.006366 | 0.088699 | 0.540787 | 0.088699 | 0.540787 |
| 30.25 | 0.027175 | 0.003215 | 8.452514 | 4.26E-17 | 0.020871 | 0.033478 | 0.020871 | 0.033478 |
| 2.5 | -0.03626 | 0.032361 | -1.12047 | 0.262597 | -0.09971 | 0.027191 | -0.09971 | 0.027191 |

$$\mathbf{P=1.254368 + 0.018293Q_1 +0.314743Q_2 +0.027175Q_3 - 0.03626\, Q_4}$$

## 5.17 MATHEMATICAL MODELS FOR RELATIONSHIP BETWEEN WASTE WATER PARAMETERS AND VALIDATION

Before treatment, the relationships between parameters are shown in the following mathematical models:

**P= 12.090868 + 0.064 * Q (BOD & COD)**

**Validation of the model:** Following are the five sample readings for confirmation of the mathematical model.

**Table 5.17: Validation Of Relation Between BOD & COD**

| Parameter (actual value)BOD | Parameter COD | Predicted value by model |
|---|---|---|
| 18 | 19 | 13.30687 |
| 18 | 17 | 13.17887 |
| 19 | 8 | 12.60287 |
| 18 | 13 | 12.92287 |
| 17 | 11 | 12.79487 |

The above table shows that values n column 1 & 3 are nearly same or very less difference. SO model is confirmed.

**P=6.98644 – 0.34463* Q (TSS& BOD)**

**Validation of the model**

**Table 5.18: Validation Of Relation Between TSS & BOD**

| Parameter TSS | Parameter (actual value)BOD | Predicted value by model BOD |
|---|---|---|
| 75 | 18 | 16.84 |
| 74 | 18 | 17.7 |
| 56 | 19 | 16.99 |
| 68 | 18 | 16 |
| 56 | 17 | 15.71 |

**P= -305.098 + 48.8223 * Q ($P^H$& TSS)**
**Validation of the model**

**Table 5.19: Validation Of Relation Between $P^H$ &TSS**

| Parameter (actual value) $P^H$ | Parameter TSS | Predicted value by model TSS |
|---|---|---|
| 7.3 | 75 | 36.66475 |
| 7.3 | 74 | 26.90011 |
| 7.1 | 56 | 46.4294 |
| 7.5 | 68 | 51.31172 |
| 7.6 | 56 | 31.78243 |

**P= 7.3195 – 0.1041 *Q (TSS &COD)**
**Variation is high. TSS is having poor relationship.**

**Validation of the model:**

### Table 5.20: Validation Of Relation Between TSS & COD

| Parameter (actual value)TSS | Parameter COD | Predicted value by model |
|---|---|---|
| 75 | 19 | 7.058053 |
| 74 | 17 | 6.953439 |
| 56 | 8 | 7.058053 |
| 68 | 13 | 7.162667 |
| 56 | 11 | 6.953439 |

**P= 34.3644 + 0.0549*Q ($P^H$& BOD)**

**Validation of the model:**

### Table 5.21: Validation Of Relation Between $P^H$ & BOD

| Parameter (actual value)$P^H$ | Parameter BOD | Predicted value by model BOD |
|---|---|---|
| 7.3 | 19 | 20 |
| 7.3 | 17 | 18 |
| 7.1 | 8 | 9.5 |
| 7.5 | 13 | 14.2 |
| 7.6 | 11 | 13 |

**Poor relationship**

**P= 62.24096 – 8.25 *Q ($P^H$& COD)**

### Table 5.22: Validation of the Relation Between $P^H$ & COD

| Parameter (actual value)$P^H$ | Parameter COD | Predicted value by model |
|---|---|---|
| 7.3 | 40 | 41.61039 |
| 7.3 | 30 | 33.35817 |
| 7.1 | 37 | 41.61039 |
| 7.5 | 47 | 49.86262 |
| 7.6 | 34 | 33.35817 |

**After treatment, the relationship between parameters and P value is shown by following mathematical models:**

**P= 21.85978 + 4.283 * Q ($P^H$& P)**

**Validation of the model:**

### Table 5.23: Validation Of Relation Between $P^H$ & P

| $P^H$ experimental | P value experimental | Y value predicted |
|---|---|---|
| 7 | 62.20 | 50.98747 |
| 6.8 | 52.10 | 52.70087 |
| 7.2 | 57.10 | 53.12922 |
| 7.3 | 52.60 | 51.41582 |
| 6.9 | 57.05 | 51.41582 |

**P= 54.6211 -0.89208*Q(BOD & Y)**

**Validation of the model:**

**Table 5.24: Validation Of Relation Between BOD & P**

| BOD experimental | P value experimental | P value predicted |
|---|---|---|
| 2.50 | 62.20 | 51.49884 |
| 3.50 | 52.10 | 52.39092 |
| 2.50 | 57.10 | 53.28299 |
| 1.50 | 52.60 | 51.49884 |
| 3.50 | 57.05 | 46.14638 |

**P= 49.44941 + 0.064945 *Q (TSS &P)**

**Validation of the model:**

**Table 5.25: Validation Of Relation Between TSS & P**

| TSS experimental | P value experimental | P value predicted |
|---|---|---|
| 17 | 62.20 | 49.96897 |
| 8 | 52.10 | 50.2937 |
| 13 | 57.10 | 50.16381 |
| 11 | 52.60 | 50.42359 |
| 15 | 57.05 | 50.68337 |

**P= 20.30886 + 1.01 *Q (COD&P)**

**Validation of the model:**

**Table 5.26: Validation Of Relation Between COD & P**

| COD | P value experimental | P value predicted |
|---|---|---|
| 40.70 | 62.20 | 58.2188 |
| 30.80 | 52.10 | 51.5288 |
| 37.40 | 57.10 | 55.4314 |
| 30.80 | 52.60 | 53.7588 |
| 34.65 | 57.05 | 62.6788 |

**$P=1.254368 + 0.018293Q_1 + 0.314743Q_2 + 0.027175Q_3 - 0.03626Q_4$**

Validations of the model, after treatment for judging the quality of waste water are as follows.

Validation of the model:

**Table 5.27: Validation Of Relation Between BOD & COD**

| COD | $P^H$ | TSS | BOD | P value | Predicted value of P by mathematical model |
|---|---|---|---|---|---|
| | (mg/l) | (mg/l) | (mg/l) | | |
| 19.00 | 7.00 | 30.25 | 2.50 | 7.00 | 4.53653 |
| 17.00 | 7.00 | 40.70 | 2.50 | 5.00 | 4.783923 |
| 8.00 | 6.80 | 30.80 | 3.50 | 4.00 | 4.251044 |
| 13.00 | 7.20 | 37.40 | 2.50 | 3.00 | 4.684022 |
| 11.00 | 7.30 | 30.80 | 1.50 | 6.00 | 4.535815 |
| 15.00 | 6.90 | 34.65 | 3.50 | 5.00 | 4.515193 |
| 19.00 | 6.90 | 33.00 | 9.50 | 7.00 | 4.325967 |
| 17.00 | 7.30 | 41.80 | 7.50 | 7.00 | 4.726938 |
| 18.00 | 7.40 | 38.50 | 4.50 | 6.00 | 4.795808 |
| 17.00 | 7.50 | 35.75 | 3.50 | 7.00 | 4.770518 |
| 16.00 | 6.80 | 37.40 | 2.50 | 6.00 | 4.613003 |
| 17.00 | 6.80 | 38.50 | 1.50 | 7.00 | 4.697449 |
| 16.50 | 7.12 | 45.00 | 4.27 | 6.97 | 4.864546 |

Looking to the mathematical models, it is clear that relation of $P^H$ and TSS before treatment does not exist. Each analysis for each has been done with more than 2500 data. After treatment, all the four parameters have impact on the value of P.BOD is having highest impact on wastewater quality and theoretically also it's true, as this is domestic wastewater.

## 5.18 SIMULATION BY MATLAB

The programming in MATlab version 2009 gives the following relation for parameters for the case study

**P = 0.000000+(-0.505722*$p^h$)+(0.000000*tss)+(0.101997*bod)+(>> 17.00**

From the above equation, it is observed that TSS is having no impact on the treatments carried out for this case study. highest impact is of BOD parameter on the quality of waste water. From multiple regression analysis and MATlab, result is same.

## 5.19 CASE STUDY 2 : COMMON EFFLUENT TREATMENT PLANT

CETP is mainly studied to explore possibility of reuse of waste water for nearby agricultural or industrial area.

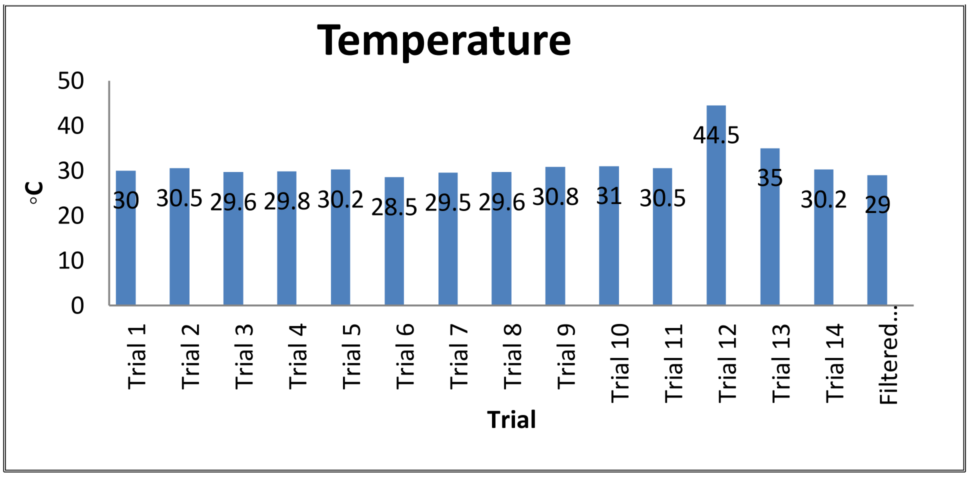
## 5.20 RESULTS OF TREATABILITY STUDIES

The table below shows the characteristics of the parameters after treatability studies which confirms the quality of waste water as reusable.

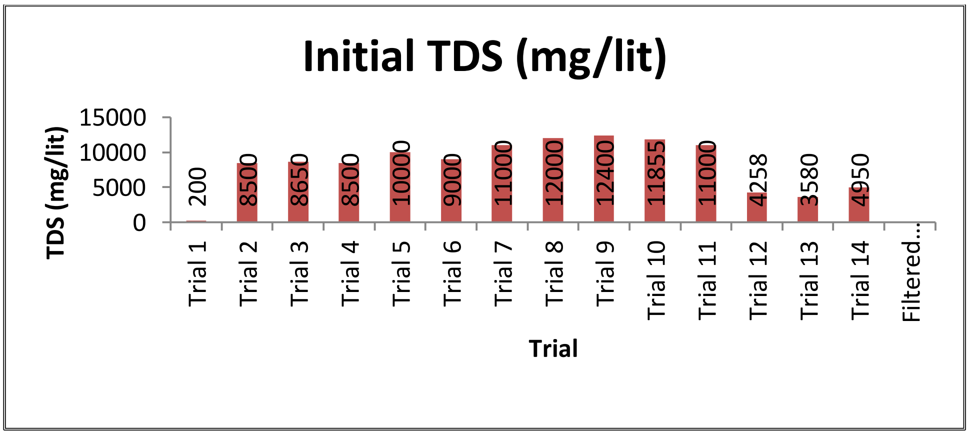
The lab scale RO with a small pretreatment of RO downy filter was installed and the demineralized water was allowed to pass through it. For number of days, the sample was passed through RO. Here, filtered sample means, before RO it was passed through filter paper, but it was not much effective as did not gave satisfactory results, so further trials were avoided. The results are shown in experimental work.

## 5.21 CHARACTERISTICS AT THE TIME OF PILOT SCALE STUDY

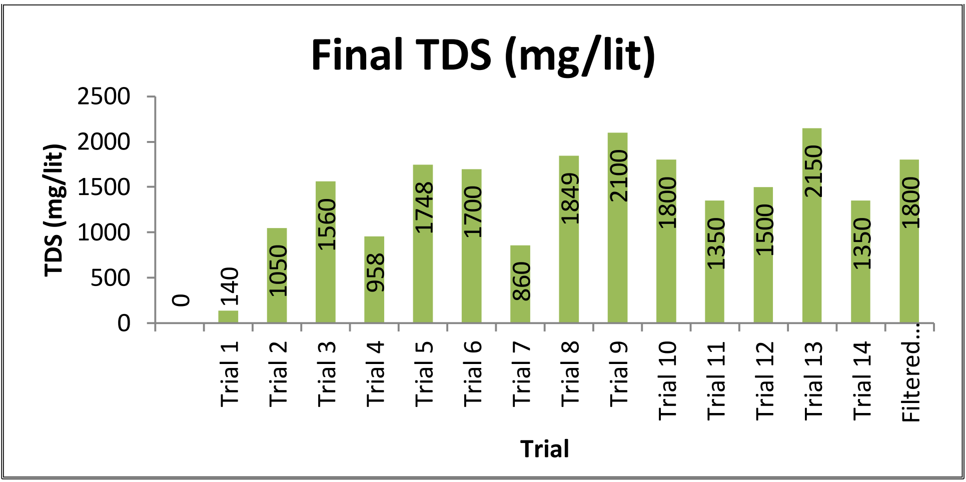
Following graphs shows the results of the parameters of waste waters.



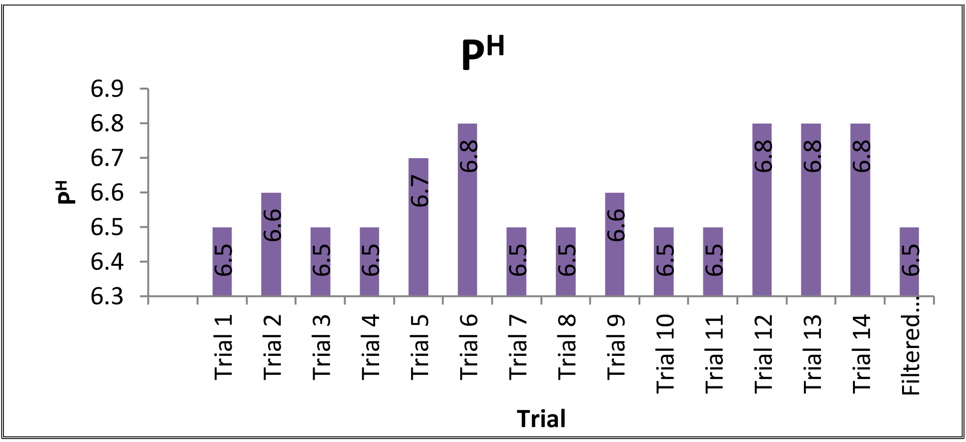

**Graph 5.2 Temperature Of Waste Water**



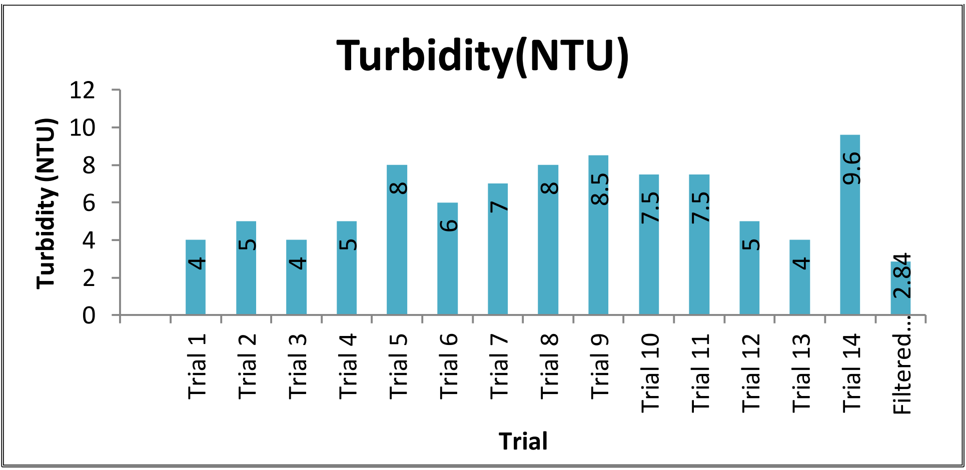

**Graph 5.3 Initial TDS Of Waste Water**



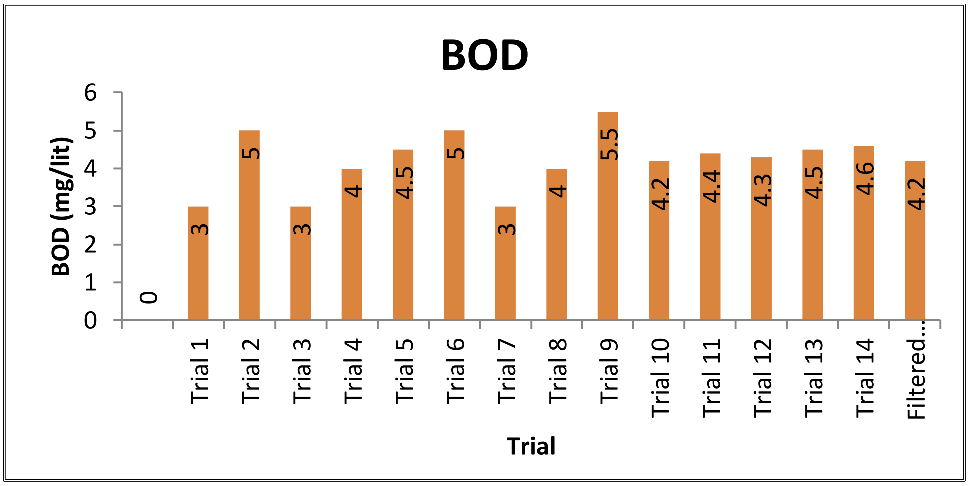

**Graph 5.4 Final TDS Of Waste Water**



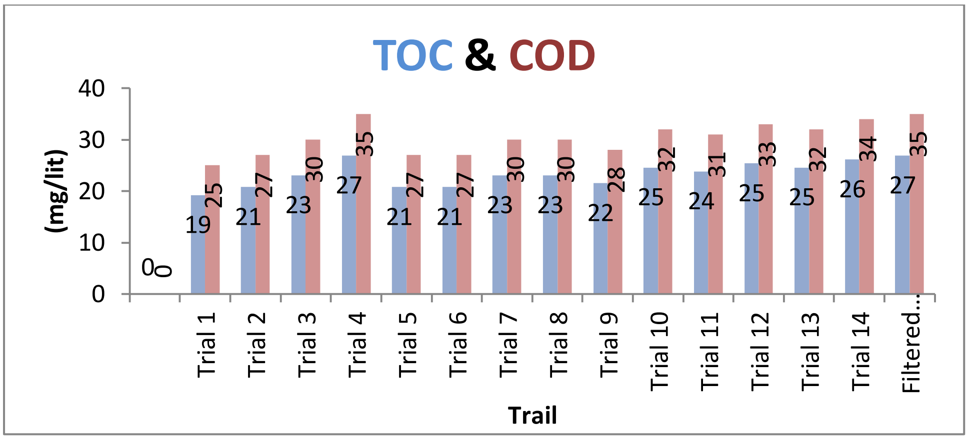

**Graph 5.5 $P^H$ Of Waste Water**



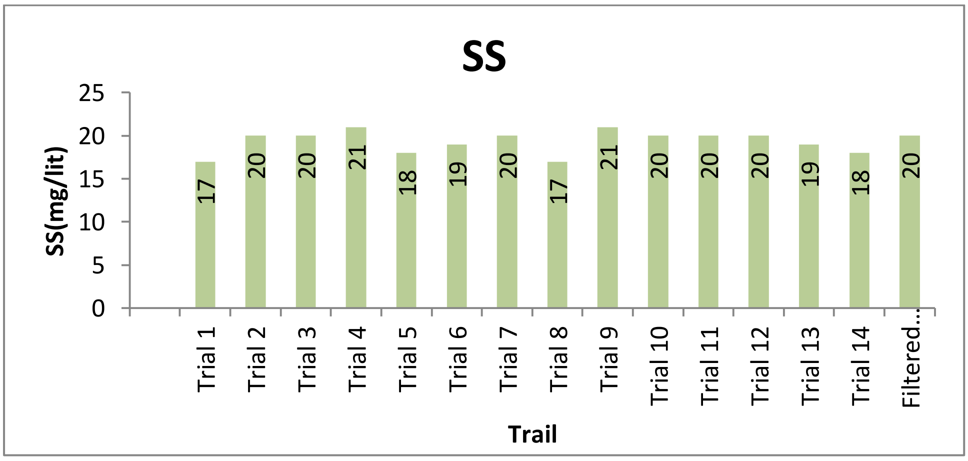

**Graph 5.6 Turbidity Of Waste Water**




Graph 5.7 BOD Of Waste Water




Graph 5.8 TOC & COD Of Waste Water




Graph 5.9 SS Of Waste Water

## 5.22 MATHEMATICAL MODELING

Operating conditions affect the performance of a Reverse osmosis system. Following are the important parameters that affect the performance of a reverse osmosis system:

- Feed water quality and source
- Temperature
- Pressure
- Feed water flow
- Concentrate flow
- Beta
- Recovery
- $P^H$
- Flux

As feed water increases, the driving force of water decreases. Due to increase in osmotic pressure of the feed, there will be a decrease in flux.

### 5.22.1 Assumptions In Model

- There is no ion –ion or ion – membrane interaction in the multicomponent feed water system.
- The feed water is relatively dilute and free of particulates.
- The osmotic pressure in solution is proportional to the sum of the mole fraction of all the ions i.e.
  - $\Pi( \Sigma xi) = BAV \Sigma (xi)$
  - BAV = average proportionality constant representing the slope of mole fraction versus osmotic pressure plots of the single salts.
  - The membrane is uniform with negligible charge density.
  - Fluid properties are essentially constant. Temperature dependence of osmotic pressure and diffusivities of ions is assumed to be negligible.
  - Concentration polarization is absent on the low pressure side of the membrane that on the high pressure side of the membrane evaluated by film theory.
  - For any salt or ion, the ration of diffusivity through the membrane to that of ion water is a constant(Hoffer & Kedem, 1972)i.e.

$$\frac{\text{Dsm}}{\text{Dsw}} = \frac{\text{Dim}}{\text{Di}} = \text{constant}$$

- The complete prediction of performance include

  - Concentration in terms of mole fractions of all the ionic species in the permeate.
  - Ionic fluxes
  - Solvent or water flux
  - Recovery and rejection for all the ions.

- Membrane thickness, material, chemistry is constant
- Membrane area is constant.
- % recovery = (permeate flow / feed flow) * 100
- Beta = concentration polarization factor
- Recovery in RO: as the recovery increases, the water flux decreases slowly until the recovery is so high that the osmotic pressure of the feed water is as high as applied pressure, in which case, the driving force for water through the membrane is lost and flux ceases.
- Flux is proportional to operating pressure water temperature.
- Flux decrease slightly as recovery increases until the osmotic pressure of the feed water equals driving force pressure. Decreases with concentration of dissolved solids.
- Relatively constant over $P^H$
- Developing new design: flux, feed flow rate per pressure vessel, concentrated flow rate per pressure vessel, beta, scaling indexes.
- Numbers of membrane modules are required

  Jw= Fp x 1/MA x 1/N

  Jw = water flux

  Fp = Product flow rate, gallons/Day

  MA = membrane area per module

  N = number of modules.
- Membranes should be cleaned when the normalized permeate flow drops by 10 % - 15 % from initial stabilized performance or when the differential pressure increases by 10 % - 15 %

For the study taken, the reverse osmosis treatment is found most suitable. The softwares available in the market for the design of R.O. are listed in the table.

**Table 5.28: Types Of Design Software Packages**

| Membrane manufacture | Design software package |
|---|---|
| DOW – water solution film Tech | Reverse osmosis system analysis |
| Toray membrane, USA ( Poway, CA) | Torary Design system ( Toray DS) |
| Hydranautics ( Oceanside, CA) | Integrated membrane solution (IMS Design) |
| Koch membrane systems ( Wilminton) | ROPRO |

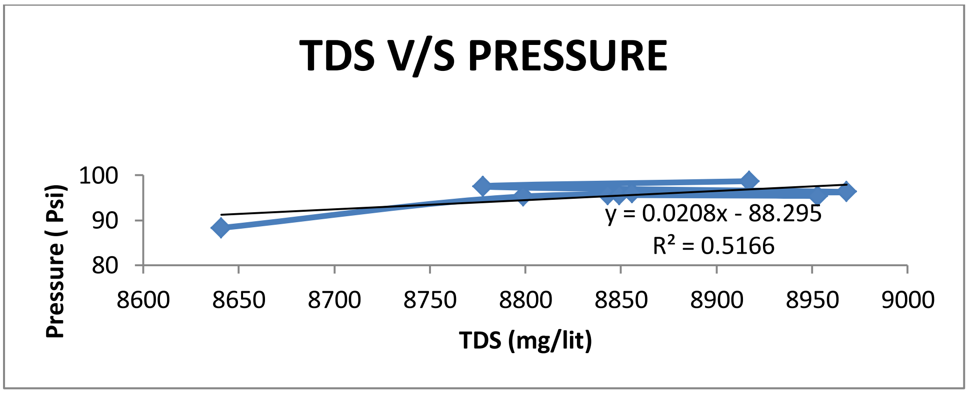
From the above list, it is found that the Integrated membrane solution (IMS Design), hydranautics version 2012 is most accurate. It gives design in depth with least error. The opinion of experts also matches with the selection of the design software.

For the CETP waste water, $P^H$, membrane area, is constant, temperature is in a normal range, flux will be fixed for design, beta will be fixed. The parameters which will vary mainly will be pressure and TDS.

The experiments carried out for reduction of TDS were conducted by varying the pressure (Psi). The equation that gives the required pressure for the value of TDs is:

$Y = 0.0208x – 88.295$

$R^2 = 0.5166$




**Graph 5.10 TDS V/S Pressure For CETP Waste Water**

As TDS increases, pressure required will be more for treatment.

## 5.23 REGRESSION ANALYSIS FOR PRESSURE AND TDS

Following regression analysis shows that the main two parameters which can affect in this case are TDS and pressure. The equation which gives the relation is:

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.180331 |
| R Square | 0.032519 |
| Adjusted R Square | -0.0419 |
| Standard Error | 1.175061 |
| Observations | 15 |

ANOVA

| | *Df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 0.60334 | 0.60334 | 0.436959 | 0.520137 |
| Residual | 13 | 17.94999 | 1.380769 | | |
| Total | 14 | 18.55333 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 67.61435 | 43.29566 | 1.561689 | 0.142368 | -25.9202 | 161.1489 | -25.9202 | 161.1489 |
| 8778 | 0.003224 | 0.004877 | 0.661029 | 0.520137 | -0.00731 | 0.013761 | -0.00731 | 0.013761 |

**P= 67.61435 + 0.003224* Q**

### 5.23.1 Remark - Statistical Analysis

From the above analysis it can be seen that the variation in pressure is not much. Also in a particular range, the variation in TDS or reluctant TDS is not much dependent on pressure.

# 6. FINDINGS & DISCUSSION

## 6.1 RESULTS OF DOMESTIC WASTE WATER TREATMENT

The study shows that null hypothesis is wrong and alternative hypothesis is true. The analysis of treated effluent from the Atladra New sewage Treatment Plant was carried out and various treatments were carried out in the laboratory with reference to the reuse possibilities for the industries on the downstream of the plant.

Following points are the results observed for experimental studies on the sample collected from domestic sewage treatment plant:

- If the effluent from secondary outlet is treated by coagulation and sedimentation using alum 20 mg/lit of optimum dose and 30 min. detention time, the turbidity remains less than the permissible limit and as the $P^H$ of the treated effluent gives the optimum results, here $P^H$ adjustment is not required.
- The treated effluent from clarifier was treated on laboratory scale by preparing a filter column having:

  | | |
  |---|---|
  | Diameter | = 4.8 cm |
  | Gravel size | = 2.36 – 3.25 mm |
  | Coarse sand size | = 1.7 – 2.36 mm |
  | Fine sand size | = 1.18 –1.7 mm |

  With a flow rate of 10 ml/minute, C.O.D. and solids of the effluent are reduced to a maximum limit.
- The process of disinfection by 6 % pure NaOCl with 15-mg/lit doses removes effectively all the major impurities and the treated effluent can be used in large quantity.
- Three treatment sequences are tried to get the results within desirable limit. Industries can directly take water and treat in their own premises or a treatment plant can be installed at the domestic sewage plant premises and treated water can be transferred to industrial area by piping network.
- After coagulation, sedimentation and filtration the disinfection was carried out, as a first option of tertiary treatment (disinfection), with 15 mg/lit dose of 6 % pure NaOCl which reduces MPN <2 and total bacterial count about nil. Disinfection by chlorination after removal of hardness by ion exchange was also carried out which gives the results as MPN <2 and total bacterial count about nil.

- As a second option for tertiary treatment (disinfection), the effluent was given the treatment by passing from UV lamp in the laboratory by the batch wise and continuous condition for 10 min and 12 min duration, at a rate of 10 ml/min at the outlet. The treated effluent was having MPN <2 and total bacterial count nil. This shows that UV treatment is more effective for disinfection. But for more quantity the method may not be economical.
- As a third option for tertiary treatment (disinfection), treated effluent from the treatment plant was given ozone treatment direct to the effluent, by varying the contact time 30 min. and 45 min. MPN and total bacterial count were checked and at the contact time of 45 min. MPN < 2 was observed in a result.
- From three treatment trains, the first option of primary, secondary and tertiary treatment, 'coagulation – flocculation – sedimentation – filtration – chlorination – softening-activated carbon filter' is found as techno economical solution. It is also analyzed that if the treatment plant for reuse of domestic wastewater is constructed for industrial reuse purpose, within a one year time period the cost can be recovered.
- Instead of whole treatment sequence as shown, after filtration, wastewater can be reused for boiler feed purpose. For this purpose, hardness required is < 50 mg/lit and ion exchange treatment gives the hardness below 20 mg/lit. The hardness removal by lime treatment also reduces the hardness by about 50 %.
- The mathematical model shows that the treated waste water is of quite a good quality which is reusable for the nearby industrial area for industrial purpose.

**Y= 32.15257 - 0.34463 * X (BOD & COD)**

**Y=6.98644 – 0.34463 * X (TSS & BOD)**

**Y= -305.098 + 48.8223 * X ($P^H$ & TSS)**

**Y= 7.3195 – 0.1041 * X (TSS & COD)**

**Y= 34.3644 + 0.0549 * X ($P^H$ & BOD)**

**Y= 62.24096 – 8.25 * X ($P^H$ & COD)**

After treatment, the relationship between parameters and P value is shown by following mathematical models:

**P= 21.85978 + 4.283 * Q (TSS& P)**

**P= 54.6211 -0.89208 * Q (COD & P)**

**P= 49.44941 + 0.064945 *Q ($P^H$& P)**

**P= 20.30886 + 1.01 *Q (BOD&P)**

Looking to the mathematical models, it is clear that relation of $P^H$ and TSS before treatment does not exist. After treatment, all the four parameters have impact on the value of P.
Out of four parameters, BOD is having highest impact on quality of domestic wastewater.

With MATlab version 2009, programming is done to find relation between all four parameters and results showed that quality of wastewater is reusable. If equation is having value<=154, wastewater quality is reusable. In this case study, mathematical models show that the quality of wastewater is reusable.

## 6.2 RESULTS OF CETP WASTE WATER TREATMENT

At the initial stage of CETP: the primary, secondary and tertiary treatments were tried and reduction was good in parameters, but not up to the mark as per standards of disposal. The outcome of treatments at initial stage was as below:

- The COD starts from equalization tank itself because of the bio mass in disperse from backwash & leachate and oxygen is available from diffuser aeration tank. Due to bio wish it has capacity to treat with the flocculation changing characteristics due to enzymes.
- The COD of equalization tank was between 1000-1200 mg/lit. It is treated by bio wish in aeration tank. So the COD reduction takes place after filtration.
- Some industrial wastewater was having high COD, but they used leachate for treatment and it reduced COD in equalization tank.
- COD is reduced with BOD & turbidity reduction also took place. Suspended particles remove from wastewater but soluble COD is present & it is responsible for less reduction of COD.
- Because of poor sludge settling, turbidity values are high though COD values are reduced.

Filtration system by filter press can remove further turbidity in a range of 3 – 5 NTU. The COD will be in the range of 150-250 mg/lit & BOD range of 20-30 mg/lit.

After this treatment, the biological enzyme bio wish was added in aeration tank. The results after addition of Bio Wish are as below:

- Lime and Alum Totally Eliminated
- Sludge Reduced by 98%

- Discharge Standards Achieved Every Day
- Influent Volume Doubled
- Unit cost of treatment halved

**Waste water treatability at different units at CETP**

The treatability study was carried out by newly developed bio mass for CETP with economical aspect by introducing bio wish aqua technologies, so that treatment was reduced by eliminating some of the traditional unit operations steps.

After addition of bio wish, the TDS was the only parameter, which was coming more than permissible limit for reuse.

The treatment of reverse osmosis was tried at lab scale for reduction in TDS. Fourteen trials were done and TDS was reduced to less than 2100 mg/lit, which is acceptable for reuse of agricultural or industrial purpose. As of now, farmers are drawing untreated wastewater illegally, instead of which the treated wastewater can be reused for agricultural activity in nearby area of CETP.

Here the design parameters and test conditions are specified, if it has to change, then the lab scale testing is required before implementation.

From the results of lab scale treatment, the IMS design solution Hydranautics Design Software version 2012 is used to design reverse osmosis plant to propose for implementation.

After number of trials, the final design is as suggested and costing is also done, which may be recovered if near-by industries purchase it for industrial purpose. Instead of disposal to ECP canal, treatment by Reverse Osmosis is feasible solution.

For statistical analysis, TDS is considered as variable, because once the plant will be installed, other parameters will be fixed. **The mathematical model that gives the required pressure for the value of TDS is:**

**$Y = 0.0208x – 88.295$, $R^2 = 0.5166$**

With the reverse osmosis treatment at lab scale, the results are within desirable limits for reuse for industrial and agricultural purpose.

## 6.3 DISCUSSION

Following points are to be taken care for implementation of lab scale studies:

### 6.3.1 Case Study 1: Municipal Sewage Treatment Plant

For domestic sewage treatment plant, the findings are applicable with following:

- Considerable variation in characteristics of treated effluent may come. For design, provision needs to be kept for this variation.
- The plant has to run successfully and it must give equally good quality effluent as was the time of sampling.
- The industry, which wants to reuse the treated sewage, should be nearby sewage treatment plant. If somehow, industry shifts to some other location, this analysis will not be useful.
- Industrial requirement should be big enough and continuous to install a plant.
- If variation in the characteristics of sewage changes, e.g. if toxic waste is found, it will create problem to the treatment plant.
- Continuous monitoring is required for efficient and consistent results.
- The necessary permissions from corporation and government are required for legal compliance for purchase of treated effluent from sewage treatment plant.
- The industries on the downstream side should co-operate in the entire process of this type of reuse concept. Individual industry should be ready to give any additional treatment in their individual capacity as per the quality and quantity of treated effluent required for their specific use, if any.
- Proper technical and financial management of the whole system has to be established and to be approved by legal authorities.
- Provision should be made for increasing the capacity of the whole system, if necessity arises.
- Reuse of this plant outlet is considered beneficial, as industries are in downstream side, so conveyance of wastewater is possible by means of gravity only.

### 6.3.2 Case study 2: Common Effluent Treatment Plant

For CETP, the findings are applicable with following:

- If the units are expanded, then according to the quality to be treated, the experiments are to be carried out.
- If the member industries are not following the criteria for giving wastewater to CETP, then it can be challenging to maintain quality of wastewater in CETP.

- If the number of industries which are giving waste water to CETP is not maintained then quality output for disposal to ECP is difficult.
- RO reject has to be handled carefully. Evaporator can be designed instead of disposal to ECP channel or to put in equalization tank. Many industries are mixing reject at equalization tank. If evaporator is to be designed, then solar evaporator is a better option.
- At present 1000-1500 KL water is disposed in ECP canal and it ultimately reaches to sea, instead of which member industries should use this wastewater after giving treatment of RO. Cost of fresh water purchasing as well as quantity of fresh water can be saved.
- Proper maintenance of plant and continuous monitoring is required for quality output.
- Replacement of membrane as per requirement has to be carefully done time to time, for successful operation of plant.

## 6.4 FUTURE SCOPE

The future scope for both the case studies are as described below:

### 6.4.1 Case Study 1: Domestic Sewage Treatment Plant

For the study undertaken following are the possibilities for further work:

- For similar characteristics plant, the same treatments can be tried.
- For domestic sewage treatment plant, other sequences can be tried.
- Industries can directly get wastewater and treat it for reuse or at domestic plant itself, wastewater can be treated and techno economic studies can be tried.
- Possibilities of potable reuse can also be explored.
- Using graph theory, route optimization can be done.

### 6.4.2 Case Study 2: Common Effluent Treatment Plant

For the study undertaken, following are the possibilities for further work:

- For rejected water of RO, the evaporation system can be designed. The cost effectiveness of such evaporator (to evaporate high volume of RO reject water) can be separate study.
- The membrane which is experimented in the study is spiral wound membrane, while the membrane which is under experiment / R & D can also be used for the said work.

- Expansion of CETP units which currently exist can also be studied and proposed for efficient reuse of wastewater. CETP can be expanded keeping in mind the reuse of wastewater.
- Instead of Bio Wish, the homemade or natural organic manure with specific micro floura can be tried in lab.
- Other treatments can also be tried like membrane biological reactor (MBR), titanium dioxide with UV radiation.
- For similar characteristics plant, the same treatments can be tried.
- For reuse of wastewater in specific type of industry, the secondary or tertiary treatments can be tried.
- If pressure, filter stage, filter pass, quantity is varied or different types of membranes are tried, in that case variations may be different. It can be analyzed separately.

Apart from agricultural reuse of CETP water and industrial reuse of domestic wastewater, other possibilities of reuse can also be explored.

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# GLOSSARY

**Activated sludge:** (1) the flocculent mass of microorganisms, mainly bacteria, that develops when sewage or liquid effluent is aerated; (2) a continuous process in which a liquid effluent is aerated in a tank to reduce the BOD and ammonical nitrogen

**Aeration:** the introduction of air into a liquid so that gaseous oxygen dissolves into the liquid

**Aerator:** a mechanical device that transfers oxygen from air into solution

**Aerobic:** (1) microorganisms that require oxygen for their respiratory processes; (2) an environment in which oxygen is available

**Ammonical nitrogen:** nitrogen combined with hydrogen in the form of ammonia (NH3) or the ammonium ion (NH4+); present in sewage, toxic to fish and restricted in discharges to about 5·0-10·0 mg/l

**Anaerobic:** (1) microorganisms that do not require oxygen for their respiratory processes; (2) an environment in which oxygen is not available

**Balancing tank:** provides sufficient storage volume to permit a non-uniform flow of waste water to be collected, mixed and pumped forward to a treatment system at a uniform rate

**Biodegradable:** describes a substance that can be decomposed by microorganisms

**Biofilm, biological film or microbial film:** a thin slimy layer of microorganisms that develops on the surface of the media in trickling filters, biotowers and contactors and oxidizes organic material from effluent

**Biogas:** a mixture of methane (CH4) and carbon dioxide (CO2), produced by the anaerobic digestion of sludges or organic material in landfill sites; can be used to generate heat or power

**Biological filter:** a packaged treatment system that removes BOD and suspended solids from relatively small flows of sewage or industrial wastewater by passing the effluent over plastic media on which aerobic biofilm develops

**Biomass:** the amount of organic material of biological origin in a given area or volume

**Bioremediation**: a treatment that enhances the ability of naturally occurring or cultured microorganisms to degrade organic pollutants in soil

**BOD:** Biochemical Oxygen Demand. Decomposing organics require oxygen. The BOD5 test measures the oxygen consumed by organisms as they decompose organics over a five-day period. BOD is thus an indicator of the concentration of organics in water.

**Cadmium:** a toxic heavy metal to which the most stringent discharge standards apply; a prescribed red list compound with an environmental quality standard (EQS) of 5 -g/l

**Chlorinated hydrocarbons:** organic compounds containing the elements carbon, hydrogen and chlorine, implicated in low level ozone production and high level ozone destruction

**Chromium:** a toxic heavy metal that may contaminate groundwater; stringent environmental discharge limits apply

**Coagulation:** a process that alters the surface charge on dispersed colloidal particles in a liquid so that they are able to agglomerate; the first stage in floc formation

**COD:** Chemical Oxygen Demand. The COD test measures the chemical oxidant required to break down organics. COD is an indicator of the concentration of organics in water. The COD test can be completed in a few hours and is frequently substituted for BOD. COD levels are usually greater than BOD for a given wastewater.

**Cyanides:** toxic inorganic chemical compounds containing cyanide (-CN) groups and classed as special waste

**Detention Time:** (retention time; residence time) The average period of time wastewater stays in a treatment system. Detention times vary for different types of wastewater treatment systems and can range from hours to weeks.

**Digestion:** the enzymatic breakdown of large insoluble organic molecules into small soluble organic molecules which can be absorbed and used by either aerobic and anaerobic microorganisms

**Domestic Sewage:** The liquid and water-borne wastes derived from the ordinary living processes, free from industrial wastes. (Uniform Plumbing Code (UPC) Section 206.0. 1997 edition)

**Effluent:** (1) A flow containing polluting material; (2) liquid waste from sewage treatment, industry, agriculture (3) Water, reused water, recycled water or wastewater exiting a process.

**Electronic Water Disinfection:** a method of sterilizing water by introduction of precise amounts of copper and silver; suitable for cooling towers (Legionella control), potable water, swimming pool and effluents

**Ferric chloride or sulphate:** iron-containing substances used to coagulate and flocculate in effluent treatment processes

**Filter press:** a device that dewaters sludge by compressing it between membranes or cloth-lined plates to produce a cake

**Flocculation:** the agglomeration of coagulated particles to form a floc which can settle or float; may be assisted by biological, chemical or mechanical means

**Heavy metals:** certain metals, used industrially and harmful to living organisms, for which discharge and emission standards are set; including cadmium, chromium, copper, lead, mercury, nickel, zinc

**High performance filter:** a device that separates particles 2-500 µm in size from relatively clean liquid streams

**Industrial Reuse:** The reuse of industrial process wastewater or other previously used water, excluding domestic wastewater, in an industrial process.

**Industrial Waste:** Any and all liquid or waterborne waste from industrial or commercial processes, except domestic sewage (UPC Section 211.0. 1997 edition).

**Influent:** Water, reused water, recycled water or wastewater entering a process.

**Inorganic:** substances such as sand, clay and metals whose molecular structures do not contain carbon-hydrogen (C-H) bonds except as carbonates and similar

**Leachate:** liquid that has percolated through a solid mass; soil leachate may be high in nitrate; landfill leachate may be high in BOD, ammonia, salinity and toxic substances

**Methane (CH4):** highly calorific gas; 60 % of biogas; produced during anaerobic biological processes; may contribute to global warming

**Microfiltration:** the use of microporous filters operating under pressure to remove particles or microorganisms of 0·1-5·0 µm size from process and effluent liquids

**Microorganisms:** microscopic living creatures; bacteria, protozoa, fungi and algae

**Monitoring:** Self-monitoring, sampling, reporting, notification and record-keeping requirements, including an identification of the pollutants to be monitored, sampling location, sampling frequency, and sample type, based on the applicable general pretreatment standards in part 403 of 40 CFR, categorical pretreatment standards, local limits, and State and local law.

**Nitrate (NO3-):** the most oxidized form of nitrogen; formed from the oxidation of ammonia by aerobic bacteria; present in fertilizer; the preferred form of nitrogen in discharges to rivers

**Organic:** substances such as proteins, sugars, wood and plastics with molecular structures containing carbon-hydrogen (C-H) bonds

**Oxidation:** the chemical or biochemical change that occurs when a substance combines with oxygen, for example during combustion and respiration; the release of carbon dioxide and energy from organic compounds

**Ozone (O3):** a naturally occurring unstable form of oxygen; attenuates harmful ultraviolet light in the stratosphere; a pollutant in the atmosphere at ground level; a powerful oxidising agent and disinfectant

**$P^H$:** a logarithmic scale (0-14) that reflects acidity or alkalinity; pH 7 indicates neutrality; acidic solutions have lower pH values; alkaline solutions have higher values

**Pollutant:** a chemical or substance that causes harm in the environment

**Potable water:** water of a quality suitable for drinking

**Pre-treatment:** The reduction of the amount of pollutants, the elimination of pollutants, or the alteration of the nature of pollutant properties in wastewater prior to or in lieu of discharging or otherwise introducing such pollutants into a Publicly Owned Treatment Works (POTW). The reduction or alteration may be obtained by physical, chemical or biological processes, process changes or by other means, except as prohibited by 40 CFR 403.6(d). Appropriate pretreatment technology includes control equipment, such as equalization tanks or facilities, for protection against surges or slug loadings that might interfere with or otherwise be incompatible with the POTW.

**Process Reuse:** Same as Industrial Reuse.

**Recycle:** The beneficial use of municipal wastewater after treatment at a central POTW. The term “recycled water” has the same meaning as “reclaimed water” as defined in Appendix J of the Uniform Plumbing Code (UPC) 1997 edition.

**Reuse:** The use of any wastewater or previously used water not including domestic waste, without discharge to a sewer or treatment at a POTW.

**Reverse osmosis:** a high pressure filtration system that uses selectively permeable membranes with extremely small pores to separate ions and particles

**Sand filter:** separates suspended solids and associated BOD/COD from liquids by passing the liquid through a bed of sand

**Screens:** equipment that separates solid material from liquid by allowing the liquid to pass through constrictions (the screen) of chosen size

**Septic tank:** container that receives untreated sewage, holds back floating scum and retains and digests heavy solids but allows clarified liquor to proceed forward for further treatment or discharge

**Settlement tank:** container that allows sufficient retention time for the separation of organic and inorganic solids from liquid and produces sludge and clarified liquor both of which may receive further treatment

**Sewage:** liquid effluent from domestic and industrial activity

**Sludge:** the wet solids that can be settled from an untreated liquid effluent (primary sludge); or from aerobically treated effluent (secondary sludge)

**Slurry:** mixture of urine, faeces and wash water from cattle or pig rearing

**Sulphur dioxide (SO2) Sulphur dioxide (SO2):** toxic gas produced during the combustion of sulphur compounds in fossil fuels; component of acid rain

**Surface aerator:** equipment in which blades or vanes rotate about a vertical or horizontal shaft and entrain air to mix and aerate wastewater

**Suspended solids:** solids of organic and inorganic origin present in liquid effluents; concentration in (mg/l) measured by filtration followed by drying at 105 -C

**Turbidity:** a measure of the cloudiness of a liquid that is caused by the presence of fine suspended solids

**Ultrafiltration:** the separation from a liquid of particles of 0·005-0·1 µm in size by pumping the liquid through a synthetic membrane at high pressure

**Ultraviolet light system:** a disinfection system in which light of 254 nm, produced by mercury lamps, damages microorganisms by disrupting their genetic material.