PERFORMANCE EVALUATION OF DECENTRALIZED WASTEWATER TREATMENT SYSTEMS IN NORTH INDIA

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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MASTER OF TECHNOLOGY

in

CONSERVATION OF RIVERS AND LAKES

By

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CANDIDATE'S DECLARATION

I hereby declare that the work, which is being presented in the dissertation report, entitled **"PERFORMANCE EVALUATION OF DECENTRALIZED WASTEWATER TREATMENT SYSTEMS IN NORTH INDIA"** in the partial fulfillment of the requirement of the award of the Degree of Masters in Technology in **Conservation of Rivers and Lakes**, submitted in the **Alternate Hydro Energy Center, Indian Institute of Technology, Roorkee,** India is an authentic record of my own work carried out under the supervision of **SH. M.K Singhal,** Senior Scientific Officer, AHEC, Indian Institute of Technology, Roorkee and **Dr. A. A. Kazmi,** Assistant Professor, Department of Civil Engineering, Indian Institute of Technology, Roorkee, during the period of October 2007 to June 2008.

The matter embodied in this report has not been submitted by me for the award of any other degree.

Date: June, 30, 2008

Place: ROORKEE

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Shortage of available water resource is a common problem in many regions of the world. One important measure to solve the problem is to use treated wastewater for non-drinking purposes. Centralized wastewater treatment and reuse often needs large investment and sophisticated management and maintenance systems, which may be unaffordable in less developed countries. In comparison, decentralized systems can offer low cost, easy operation and maintenance, and flexibility for wastewater treatment and reuse.

An investigating study was conducted to evaluate the performance of various decentralized wastewater treatment systems being used at selective wastewater treatment plants in the North India in terms of their economics and treatment potential. Five full-scale decentralized wastewater treatment systems using Aeration cum Constructed Wetlands, Anaerobic filter cum Floating Plants, Fluidized Aerobic Bioreactor (FAB) and Submerged Activated Fixed Film (SAFF) Bioreactor with different process technologies were evaluated. Grab samples for six months from December to May 2008 were collected and analyzed in Environmental Engineering Lab, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee. for physico-chemical and microbiological examination.

Additional information was gathered about facility operations, the types of chemicals used and O & M related problems through review of files and interviews with plant personnel. Time series plots showing effluent parameter concentrations versus sampling frequency were prepared for analyzing the data. Further attempts have been made to establish the relationship between key wastewater constituents & operational parameters such as BOD, TSS and Turbidity with respect to TC & FC. The O & M related problems, observed during visits to STPs, were taken into account and attempts have been made for identification of the cause and rectification. Based on available records, the O & M cost (per year per MLD basis) was calculated for all STPs.

From these studies, it was revealed that SAFF based plant is better than others in removing organic matter and comparable with Constructed Wetlands in removing coliforms. Floating Plants and Constructed Wetlands based plants are having lower O & M cost but land requirement is more. Overall performance of SAFF plant was found to be good.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Shortage of available water resource is a common problem in many regions of the world. One important measure to solve the problem is to use treated wastewater for non-drinking purposes. Centralized wastewater treatment and reuse often needs large investment and sophisticated management and maintenance systems, which may be unaffordable in less developed countries, and even developed countries, need to reduce the cost of wastewater reuse. In comparison, decentralized systems can offer low cost, easy operation and maintenance, and flexibility for wastewater treatment and reuse. Innovative technologies have recently been developed and implemented for decentralized systems. (Xiaochang C Wang, 2006)

Decentralized wastewater treatment has become a topic of interest as a cost effective means to treat and recycle effluent in small communities, unsewered communities, and communities covering a range of elevations. Minnesota Pollution Control Agency (2000) and Otis (2004) investigated and described the need for wastewater treatment system in unsewered areas and the benefits of decentralized wastewater treatment systems. They described a cluster system as a wastewater collection, treatment and disposal system that serves a smaller number of units.

With respect to conventional sewage treatment, decentralized solutions often can yield better environmental benefits as well. By treating the water upstream, neighborhood assets requiring irrigation can receive the treated discharge, which in-turn can percolate underground and help refill aquifers. Large-scale sewage treatment plants are often unable to make use of the treated water and instead of being recycled and returned to the aquifers upstream, much of it is discharged into rivers.

Decentralized wastewater management is not just about the disposal of wastewater and the public health. It has the potential to contribute to the formation of an infrastructure to sustain watershed integrity. Decentralized wastewater treatment is about the "watershed agenda" and the principles of "community preservation" and "sustainable development".

The decentralized approach is a new means of addressing wastewater management needs of sewered and unsewered areas in a comprehensive fashion. The basic idea of that is to treat the wastewater (possibly together with refuses) on-site by means of low-cost treatment systems and make direct use the treatment products (water, compost and biogas). This alternative can meet a sustainable wastewater management requirement and has a promising future, where the water and sanitation issues are becoming a more and more important issue and are under new period of infrastructure development (Nguyen Viet Anh, et al., 2003)

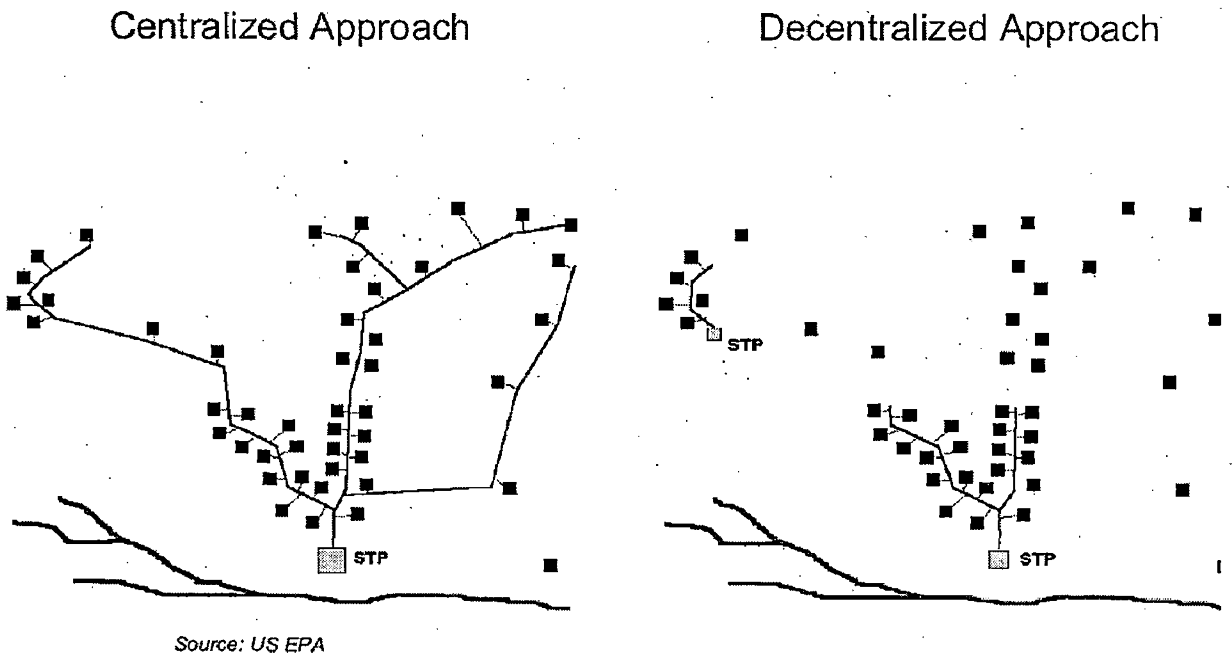


Fig.1.1: Centralized and Decentralized Approach

1.2 IDENTIFICATION OF GAP

However, there is a lot of information available on decentralized systems in developed countries, but the data in Indian context in much scarce. Neverthesee, there is information available on the design, performance of low cost decentralized STPs in Southern India especially in Karnataka, Tamil Nadu & Kerala.

There is almost negligible information available on the performance on small-scale STPs in northern India. Therefore, the performance evaluation of various types of decentralized STP's is considered in this study. Decentralized STPs are generally caters less than 0.5 MLD flow, but in our case maximum capacity of 3 MLD is considered.

1.3 OBJECTIVES OF THE PRESENT STUDY

The objectives of the study are:

1. Performance evaluation of four different types of decentrliazed STPs working in the Northern India in terms of BOD, COD, TSS, TC, FC removal.
2. To study the O & M related problems in these STPs
3. To compare the O & M cost (excluding electricity) per MLD basis of STPs.

1.4 SCOPE OF THE STUDY

The scope of the study is limited to:

1. Only four different process based STPs with capacity varying 0.5 MLD to 3 MLD.
2. The technologies considered for decentrliazed sewage treatment are:
    a. Structured Aerobic Fixed Film (SAFF) system
    b. Fluidized Aerobic Bed (FAB) system
    c. Aeration cum Constructed Wetlands system
    d. Anaerobic Baffled Filter cum Floating Plants system
3. The considered STPs are restricted to Delhi, Haryana & Uttarakhand.

LITERATURE REVIEW

2.1 INTRODUCTION

Only a small percentage of the sewage generated is collected/ treated in small towns and cities as shown in table below. Through the situation in the metropolitan cities is better in terms of collection of sewage, the treatment and disposal requires a lot of improvement. Financial crunch is the main reason for this situation. To get rid of economic constraints, the cost on sewage collection and treatment are required to be reduced on one hand, and the resource value of sewage has to be fully utilized on the other hand.

	Metro cities	Class I including Metro cities	Class II towns
Number	23	299	345
Total Population	7,09,96,726	13,99,66,369	2,26,45,614
Population Density	9,047 per /km^2	--	3695 km^2
Total water supply % population covered by water supply	12,738 MLD 90%	20,607 MLD 88%	2031 MLD 88%
Wastewater generation	9,275 MLD	16,662 MLD	1649 MLD
Average per capita water supply	241 lpcd	183 lpcd	103 lpcd
Volume of sewage collection % population covered	7,471 MLD 78%	11, 938 MLD 70%	1090 MLD 66%
Sewage treatment plant facilities	16 (cities) 4482 MLD 605 of collection	76 (cities) 4037 MLD 33% of collection	17 (cities) 61.5 MLD 6% of collection
Economic value of sewage /annum	Rs. 974 million	Rs. 1828 million	Rs. 160 million

Table- 2.1- : Status of Water Supply and Sewage Collection and Treatment in India

In the decentralized treatment system, a balance between the advantages of large scale treatment in terms of economics of scale and individual responsibility for domestic wastewater treatment can be obtained by providing colony-wise/sector-wise treatment system. Responsibility of construction as well as operation and maintenance may be taken up collectively by the Government authorities, Resident welfare Associations, Builders and Developers. Specific treatment technology should be selected as per the prevailing ground situation like availability of the land, etc.

2.2 PROPERTIES OF DECENTRALIZED WASTEWATER TREATMENT SYSTEMS (DTS)

2.2.1 DTS

- DTS is an approach, rather than just a technical hardware package.
- DTS provides treatment for wastewater flows from 1 -3000m^3 per day, from both domestic and industrial sources.
- DTS is based on a set of treatment principles the selection of which has been determined by their reliability, longevity, tolerance towards inflow fluctuation, and most importantly, because these treatment principles dispense with the need for sophisticated control and maintenance.
- DTS work without technical energy, and thus cannot be switched off intentionally
- DTS guarantees permanent and continuous operation, however, fluctuation in effluent quality may occur temporarily.
- DTS is not everywhere the best solution. However, where skilled and responsible operation and maintenance cannot be guaranteed, DTS technologies are undoubtedly the best choice available.

2.2.2 Treatment Systems

DTS is based on five treatment systems:

- Primary and Secondary treatment in sedimentation ponds, septic tanks or Imhoff tanks.
- Secondary anaerobic treatment in fixed bed filters or baffled septic tanks (baffled reactors).
- Secondary and Tertiary aerobic / anaerobic treatment in constructed wetlands (subsurface flow filters) or floating plants (duckweed, water hyacinth).

- Secondary and Tertiary aerobic / anaerobic treatment in ponds.
- Secondary and Tertiary aerobic treatment in FAB/SAFF reactors.

The above five systems are combined in accordance with the wastewater influent and the required effluent quality. Hybrid systems or a combination of secondary on-site treatment and tertiary co-operative treatment is also possible. The Imhoff tank is slightly more complicated to construct than a septic tank, but provides a fresher effluent when de-sludged at designed intervals. The Imhoff tank is used preferably when post-treatment takes place near residential houses, in open ponds or constructed wetlands of vertical flow type.

Deep anaerobic ponds and shallow polishing ponds are also considered being DTS. Special provisions may have to be made for industrial wastewater before standardized DTS designs can be applied. These for example include an open settler for daily removal of fruit waste from a canning factory, buffer tanks to mix varying flows from milk processing plant, grease traps or neutralization pits to balance the pH of the influent. In these cases, standard DTS are applicable only after such pre-treatment steps have been taken.

Despite their reliability and impressive treatment performance, such well-known and proven systems as UASB, trickling filter, rotating discs, etc. are not considered as being DTS as these systems require careful and skilled attendance. Most of the treatment processes which are used in large-scale treatment plants despite their proven efficiency do not meet the DTS criteria and therefore, cannot be included.

The Fluidized Aerobic Bed Reactor (FAB), Structured Aerobic Fixed Film Bioreactor (SAFF) and aerated or chemical flocculation and all kinds of controlled recirculation of wastewater are part of this category. Regular or continuous re-circulation is partly acceptable under the condition that the pumps that are used cannot be switched off easily, i.e. separately from transportation pumps. Well designed conventional treatment plants may not meet DTS requirements admittedly; this self-imposed restraint over technical choices in DTS could in practice impact upon the quality of the effluent. However, inferior quality need not to be when there is sufficient space for the plant.

There are certain measures at hand to discharge effluent of acceptable quality:

- provision of sufficient space at the source of pollution.

- pre-treatment at source and post treatment where sufficient land is availale.
- pre-treatment at source and post treatment in co-operation with others.
- accepting an effluent with higher pollution load.
- restricting wastewater producing activities at this particular site.
- connection to a central treatment plant via sewage line.

Permanent dilution of wastewater or the installation of a mechanized and highly efficient treatment plant remains theoretical options, because such processes are chronically afflicted by irregular operation.

2.2.3 Advantages and Disadvantages of DTS

Septic tanks are used for wastewater with a high percentage of settle able solids, typically for effluent from domestic sources. Anaerobic filters are used for wastewater with low percentage of suspended solids (e.g. after primary treatment in septic tanks), and narrow COD/BOD ratio; biogas utilization may be considered in case of BOD concentration > 1.000 mg/l. Baffled Septic Tanks are suitable for all kinds of wastewater, however, preferably for such of high percentage of non-settle able suspended solids and narrow COD/BOD ratio.

Constructed wetlands and floating plant systems are used for wastewater with low percentage of suspended solids and COD concentration below 500 mg/l. Wastewater for treatment in aerobic ponds should have a BOD_5 content below 300 mg/l. Facultative and anaerobic ponds may be charged with strong wastewater, however, bad odor cannot be avoided reliably with high loading rates.

Fluidized Aerobic Bed Bioreactor (FAB) and Structured Aerobic Fixed Film Bioreactor (SAFF) are suitable for all kinds of wastewater, however, preferably for such of high percentage of non-settle able suspended solids and COD concentration up to 1000 mg/l.

Type	Kind of treatment	Use for type of wastewater	Advantages	Disadvantages
Septic tank	Sedimentation, sludge stabilization	Wastewater of settle able solids, especially domestic	Simple, durable, little space because of being underground	Low treatment efficiency, effluent not odorless
Imhoff tank	Sedimentation, sludge stabilization	Wastewater of settle able solids, especially domestic	Durble, little space because of being underground, odorless effluent	Less simple than septic tank, needs very regular desludging
Anaerobic filter	Anaerobic degradation of suspended and dissolved solids	Pre-settled domestic wastewater of narrow COD/BOD ratio	Simple and fairly durable if well constructed and wastewater has been properly pre-treated, high treatment efficiency, little permanent space required because of being underground	Costly in construction because of special filter material, blockage of filter possible, effluent smells slightly despite high treatment efficiency
Baffled Septic tank	Anaerobic degradation of suspended and dissolved solids	Pre-settled domestic wastewater of narrow COD/BOD ratio,	Simple and durable, high treatment efficiency, less space required because of being underground, hardly any blockage, relatively cheap compared to anaerobic filter	Less efficient with weak waste water, longer start-up phase than anaerobic filter
Root Zone Treatment System (Constructed Wetlands)	Aerobic facultative – anaerobic degradation of dissolved and fine suspended solids, pathogen removal	Suitable for domestic wastewater where settle able solids and most suspended solids already removed by pre-treatment	High treatment efficiency when properly constructed, pleasant landscaping possible, no wastewater above ground, no nuisance of odor	High space requirement, great knowledge and care required during construction, intensive maintenance and supervision during first 1-2 years
Anaerobic pond	Sedimentation, anaerobic degradation and sludge	Domestic and strong and medium wastewater	Simple in construction, flexible in respect to degree of treatment, little	Wastewater pond occupies open land, there is always some odor, can even be

	stabilization		maintenance	stinky, mosquitoes are difficult to control
Aerobic pond	Aerobic degradation, pathogen removal	Pre-treated domestic wastewater	Simple in construction, reliable in performance if proper dimensioned, high pathogen removal rate, can be used to create an almost natural environment, fish farming possible when large in size and low loaded	Large space requirement, mosquitoes and odor can become a nuisance if undersized, algae can raise effluent BOD
Duck-weed Pond /Water hyacinth	Anaerobic except aerobic at top, Degradation of Suspended and dissolved Solids, Nutrient Removal	Sullage or Pre-treated sewage	Simple in construction, revenue generation through pisciculture, suitable for rural and semi–rural area	High space requirement, possibility of odor can not be ruled out, proper harvesting of duckweed/water hyacinth is must
Fluidized Aerobic Bed reactor (FAB)	Sedimentation, aerobic degradation and sludge stabilization	Suitable for treating the sewage generated from municipalities, hotels, hospitals, IT parks and commercial complexes	No moving parts, total elimination of skilled monitoring, no sludge recycling required, no monitoring of mixed liquor suspended solids (MLSS), lLess space requirement,	Costy, both in capital and O & M cost,Media related problems.
Submerged Aerobic Fixed Film Bioreactor (SAFF)	Sedimentation, aerobic degradation and sludge stabilization	Suitable for treating the sewage generated from municipalities, commercial complexes	No moving parts, total elimination of skilled monitoring, no sludge recycling required, no monitoring of mixed liquor suspended solids (MLSS), less space requirement,	Costy, both in capital and O & M cost, Media related problems.

Table-2.2: Advantages and Disadvantages of Decentralized Treatment Systems (DTS)

2.3 TECHNOLOGY OPTIONS

2.3.1 Septic Tank

This is the most commonly used wastewater ***pretreatment unit*** for decentralized wastewater treatment systems. The tank provides primary treatment by creating quiescent conditions inside a covered, watertight rectangular, oval, or cylindrical vessel, which is typically buried. In addition to primary treatment, the septic tank stores and partially digests settled and floating organic solids in sludge and scum layers. This can reduce the sludge and scum volumes by as much as 40 percent, and it conditions the wastewater by hydrolyzing organic molecules for subsequent treatment in the soil or by other unit processes (Baumann et al., 1978).

Gases generated from digestion of the organics are vented back through the building sewer and out of the house plumbing stack vent. Inlet structures are designed to limit short circuiting of incoming wastewater across the tank to the outlet, while outlet structures (e.g., a sanitary "tee" fitting) retain the sludge and scum layers in the tank and draw effluent only from the clarified zone between the sludge and scum layers. A diagram of a one-compartment tank is shown below in figure-

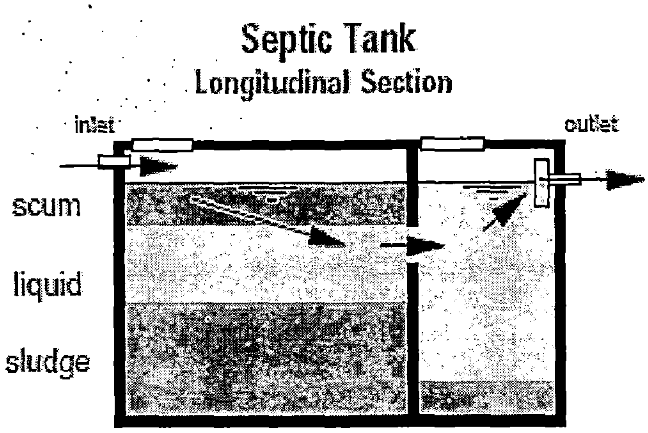


Fig. 2.1: Profile of a single-compartment septic tank with outlet screen

Septic tanks are used as the first or only pretreatment step in nearly all decentralized wastewater treatment systems regardless of daily wastewater flow rate or strength. The tanks passively provide suspended solids removal, solids storage and digestion, and some peak flow attenuation.

A septic tank removes many of the settle able solids, oils, greases, and floating debris in the raw wastewater, achieving 60 to 80 percent removal (Baumann et al., 1978; Boyer and Rock, 1992; University of Wisconsin, 1978). The solids removed are stored in sludge and scum layers, where they undergo liquefaction. Typical septic tank BOD removal efficiencies are 30 to 50 percent (Boyer and Rock, 1992; University of Wisconsin, 1978).

2.3.2 Imhoff or Emscher Tanks

Imhoff or Emscher tanks are typically used for domestic or mixed wastewater flows above 3 m^3/d, where the effluent will be exposed above ground for further treatment, and therefore the effluent should not stink, as it could be the case with a septic tank. The Imhoff tank separates the fresh influent firmly from the bottom sludge.

The tank consists of a settling compartment above the digestion chamber. Funnel-like baffle walls prevent up-flowing foul sludge particles from getting mixed with the effluent and from causing turbulence. The effluent remains fresh and odourless because the suspended and dissolved solids do not have an opportunity to get in contact with the active sludge to become sour and foul. Retention times of much longer than 2 h during peak hours in the flow portion of the tank would jeopardise this effect.

When sludge ferments at the bottom, the sludge particles get attached to foul gas bubbles and start to float upwards, as in the septic tank. The up-flowing sludge particles assemble outside the conical walls and form an accumulating scum layer. This scum grows continuously downwards, until the slots through which settling particles should fall into the lower compartment are closed. The treatment effect is then reduced to that of a too small septic tank. It is for this reason that the sludge and scum must be removed regularly, at the intervals the sludge storage had been designed for. (Imhoff, K and Imhoff,K.R.,1990)

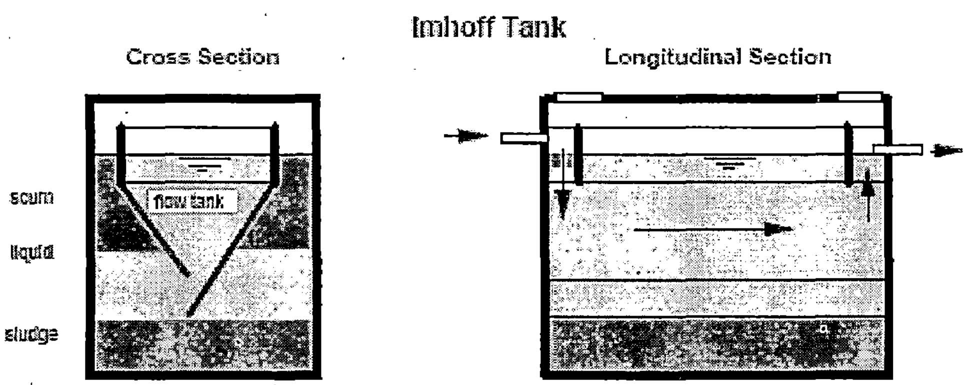


Fig.2.2-: Imhoff Tank

Sustainability of sanitation systems should be related to low cost and low energy consumption and, in some situations, low mechanical technology requirements. Decentralized and low-cost processes are considered to be a better choice for rural areas (Lens et al., 2001). Anaerobic digesters and constructed wetlands are treatment systems with a very small energy input, low operational cost, and low surplus sludge generation ([Sperling, 1996], [Kadlec et al., 2000], [Lens et al., 2001] and [Hoffmann et al., 2002]).

Classical sewage pretreatment technologies include a septic tank and Imhoff tank for small-scale installations. These systems can achieve a TSS removal of 50–70%, up to 50% COD or BOD removal and. generating primary effluent concentrations in the range of 50–90 mgTSS/l when they are operated well (Metcalf and Eddy, 1995).

2.3.3 Baffled Septic Tank/ Anaerobic Baffled Reactor

The baffled septic tank may be considered as the decentralized treatment system (DTS) version of the UASB system. It in fact is a combination of several anaerobic process principles - the septic tank, the fluidized bed reactor and the UASB.

The up-flow velocity of the baffled septic tank, which should never be more than 2 m/h, limits its design. Based on a given hydraulic retention time, the up-flow velocity increases in direct relation to the reactor height. Therefore can the reactor height not serve as a variable parameter to design the reactor for the required HRT. The limited upstream velocity results in large but shallow tanks. It is for this reason that the baffled reactor is not economical for larger plants. It is also for this reason that it is not very well known and poorly researched.

However, the baffled septic tank is ideal for DTS because it is simple to build and simple to operate. Hydraulic and organic shock loads have little effect on treatment efficiency.

The difference with the UASB lies in the fact that it is not necessary for the sludge blanket to float; it may rest at the bottom.3-phase separators are also not necessary since a part of the active sludge that is washed out from one chamber is trapped in the next. The tanks put in series also help to digest difficult degradable substances, predominantly in the rear part, after easily degradable matters have been digested in the front part, already. Consequently, recycling of effluent would have a slightly negative effect on treatment quality. The baffled septic tank consists of at least four chambers in series. The last chamber could have a filter in its upper part in order to retain eventual solid particles. A settler for post-treatment could also be placed after the baffled septic tank.

Equal distribution of inflow, and wide spread contact between new and old substrate are important process features. The fresh influent is mixed as soon as possible with the active sludge present in the reactor in order to get quickly inoculated for digestion. This is contrary to the principle of the Imhoff tank. The wastewater flows from bottom to top with the effect that sludge particles settle against the up-stream of the liquid. This provides the possibility of intensive contact between resident sludge and newly incoming liquid.

The DTS version does not have a grill. It always starts with a settling chamber for larger solids and impurities followed by a series of up-flow chambers. The water stream between chambers is directed by baffle walls that form a down-shaft or by down-pipes that are placed on partition walls. Although with down-pipes the total digester can be shorter (and cheaper), downshifts should have preference because of better distribution of flow.

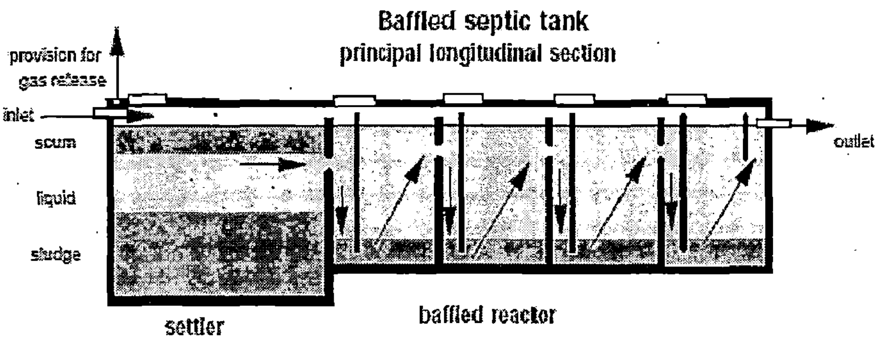


Fig. 2.3: Baffled Septic Tank.

The wastewater that enters a tank should as much as possible be distributed over the entire floor area. This is taken care of by relatively short compartments (length < 50% to 60% of the height). In case, distance between down pipes should not exceed 75 cm. For larger plants, when longer compartments are required, the outlets of down pipes (as well as down shafts) should reach out to the centre of the floor area.

The final outlet as well as the outlets of each tank should be placed slightly below surface in order to retain any possible scum. Baffled septic tanks may be equipped with 3-phase separators in the form of slanting baffles in the upper third of the tank; however, this is done rarely.

The baffled septic tank is suitable for all kind of wastewaters, including domestic. Its efficiency increases with higher organic load. There is relatively little experience with baffled reactors, because the system is only used in smaller units. However, it is the high efficient answer to the low efficient septic tank, because simple and efficient operation goes along with easy construction and low cost. Treatment performance is in the range of 65% - 90% COD and 70% - 95% BOD removal (Grobicki A. et al., 1990). However, three months of maturation should be acknowledged. Sludge must be removed in regular intervals like with a septic tank. Some sludge should always be left for continuous efficiency. It is noticeable that the amount of sludge in the front portion of the digester is more, than in the rear compartments.

2.3.4 Anaerobic Filter

The dominant principle of both the septic tank and Imhoff tank is sedimentation in combination with sludge digestion. The anaerobic filter, also known as fixed bed or fixed film reactor, is different in that it also includes the treatment of non-settle able and dissolved solids by bringing them in close contact with a surplus of active bacterial mass. This surplus together with "hungry" bacteria digests the dispersed or dissolved organic matter within short retention times. Most of the bacteria is immobile. They tend to fix themselves to solid particles or, e.g. at the reactor walls.

Filter material, such as gravel, rocks, cinder or specially formed plastic pieces provide additional surface area for bacteria to settle. Thus, the fresh wastewater is forced to come into contact with active bacteria intensively. The larger the surface for bacterial growth, the quicker is digestion. A good filter material provides 90 to 300 m^2 surface area per m^3 of occupied reactor volume. A rough surface provides a larger area, at least in the starting phase. Later the bacterial "lawn" or "film" that grows on the filter mass quickly closes the smaller groves and holes. The total surface area of the filter seems to be less important for treatment than its physical ability to hold back solid particles.

When the bacterial film becomes too thick it has to be removed. This may be done by back-flash of wastewater or by removing the filter mass for cleaning outside the reactor. Nonetheless, the anaerobic filter is very reliable and robust.

By experience, on an average, 25 - 30% of the total filter mass may be inactive due to clogging. While a cinder or rock filter may not block completely, reduced treatment efficiency is indicative of clogging in some parts. Clogging happens when wastewater finds a channelled way through only some open pores as a result of which the high speed flow washes the bacteria away. Eventually, the lesser used voids in the filter get clogged. The end result is reduced retention time within the few open voids. However, a sand or gravel filter may block completely due to smaller pore size.

The quality of treatment in well-operated anaerobic filters is in the range of 70%-90% BOD removals. It is suitable for domestic wastewater and all industrial wastewater which have a lower content of suspended solids. Pre-treatment in settlers or septic tanks may be necessary to eliminate solids of larger size before they are allowed to enter the filter.

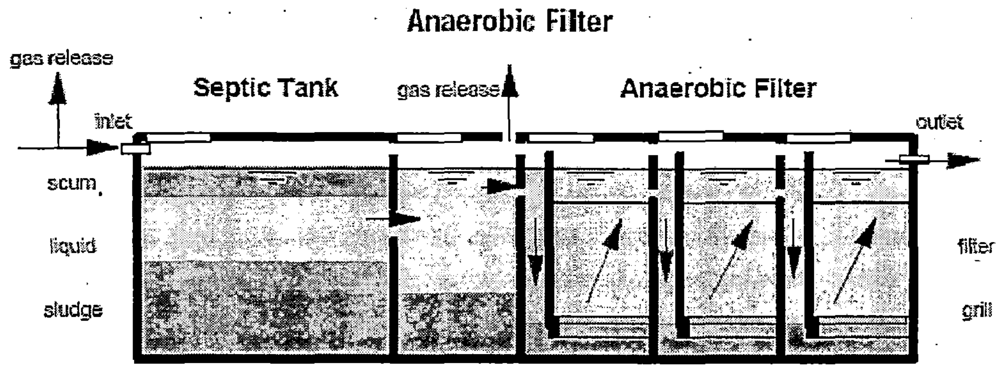


Fig. 2.4: Anaerobic Filter

Anaerobic filters may be operated as down flow or up flow systems. The up flow system is normally preferred as the risk of washing out active bacteria is less in this case. On the other hand, flushing of the filter for the purpose of cleaning is easier with the down flow system. A combination of up-flow and down-flow chambers is also possible. An important design criterion is that of equal distribution of wastewater upon the filter area. The provision of adequate space of free water before the filter and the same before the outlet pipe supports equal distribution. Full-width down flow shafts is preferred to down-flow pipes. The length of the filter chamber should not be greater than the water depth.

For smaller and simple structures, the filter mass consists of cinder (5 to 15 cm in diameter) or rocks (5 to 10 cm in diameter) which are bedded on perforated concrete slabs. The filter starts with a layer of large sized rocks at the bottom. The slabs rest approximately 50 to 60 cm above ground on beams which are parallel to the direction of flow. Pipes of at least 15 cm in diameter or down-shafts over the full width allow desludging at the bottom with the help of pumps from the top. In case the sludge drying beds are placed just beside the filter, sludge may also be drawn via hydraulic pressure pipes. Head losses of 30 to 50 cm have to be counted with.

2.3.5 Submerged Aerobic Fixed Film (SAFF) Reactor

Aerated submerged fixed-film process is a novel attached growth biological treatment system that uses totally submerged fixed media to support biomass growing as a thin biofilm on their surfaces (Hamoda, 1987; Park, 1996; Hamoda, 1998; Hamoda, 1999; Al-Sharekh, 2001). Also, diffusers provide air bubbles for both aeration and turbulence. The turbulence created by this way prevents the excessive biofilm growth (Hamoda, 1999). SAFF process has been successfully applied for treatment of both urban and industrial wastewaters by several researchers (Park, 1996; Hamoda, 1999; Gálvez, 2003; Nabizadeh and Mesdaghinia, 2006).

Aerated submerged fixed-film process is principally designed to enhance the efficiency of conventional activated sludge process. The conventional process tanks occupy larger land area, involve constant monitoring of parameters like MLSS & SVI, require continuous power supply and are susceptible to shock loads. SAFF reactor, whereas, needs, less power, lower volume, no recycling of sludge, less footprint area, besides allowing higher loading to make it an acceptable product. With lower sludge generation plug flow design, the operations of STP's are easier and low monitoring and running costs. The use of structured plastic media with the activated sludge process helped to reduce the volume of the tanks with increased performance. The SAFF systems can easily fit into underground basins because of small foot print area hence the system is most useful for sewage treatment plants in crowded cities where space is a constraint.

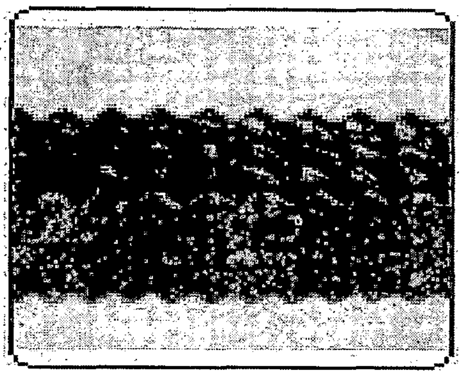
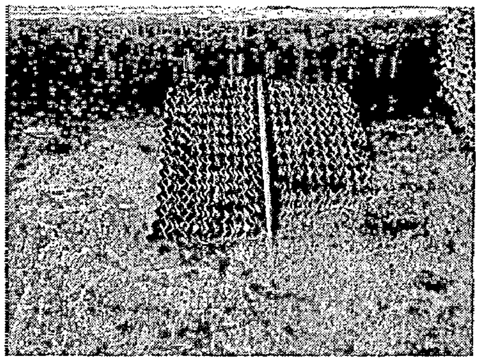
 

Fig. 2.5: Structured Media of SAFF Reactor

The SAFF system can be designed with single stage or two-stage system depending on inlet BOD and COD and other parameters. The system involves attached growth and submerged growth treatment process. Structured media occupies around 50-70% tank volume depending on the type of effluent and rest of the portion is utilized for suspended growth as in the conventional aeration tank

The SAFF can be down flow or up flow system. The structured PVC media is fully submerged in the influent wastewater. The oxygen requirement is met with the help of diffused aeration system, placed at the bottom below the packing media. The fine air bubble passes through the packing assisting microorganisms to degrade the organic constituents and reducing the pollution load of the effluent. The even distribution of air and water facilitates a homogeneous flow across the entire biologically active plant surface area and enables homogeneous suspended solids retention and biomass growth throughout the media without short-circuiting or entrapment of gas bubbles. Additionally since the highest biological activity takes place in the lower half of the filter and treated water remains above the media, odors are eliminated.

The large biomass present in the reactor (as a result of the stable film of bacteria on the media) stabilizes BOD/COD and NH_4-N from influent wastewater flowing past the biofilm. The system includes advantageous of both suspended and attached growth phase at same time in a single reactor.

Also, submerged attached growth systems have high biomass concentrations, leading to short hydraulic residence times (HRTs). Short HRTs cause these systems to be compactly constructed (Leslie Grady et al., 1999).

➢ **Advantages of the SAFF System.**

In comparison to suspended growth biological treatment systems, such as Conventional Activated Sludge process, this system can provide advantages as follows (Park, 1996; Hamoda, 1999; Jianlong et al., 2000; Loukidou, 2001; Jou, 2003; Guimarães et al., 2005; Cooldeck brochure, 2008):

- **Primarily reducing Foot Print Area**: Media provides extra effective surface area available over the basin area, for microorganism to grow and remain in the reactor for longer time. This reduces the foot print area required for SAFF tank by 35-40% compare to activated sludge process. The media can also be stacked up to 3-4 m height, thus reducing the plan area further.
- **Making system stable and efficient**: Higher active surface area, fine corrugation helps in developing quantity of sludge inside the reactor, maintaining the higher MLSS concentration in the tune of 6000-8000 mg/l in the reactor, which is normally not possible in the activated sludge system, leading to short hydraulic resistance time. Efficient BOD removal up to 95-97% can be achieved with single/two stage system.
- **Lower electricity consumption**: Cross corrugation pattern of media ensures that diffused air bubble travels in zigzag fashion increasing the bubble travel path and there by increasing the oxygen transfer rates (oxygen absorption efficiency).This insures efficient use of aeration system. The increased contact time between the wastewater biomass-oxygen due to criss-cross stacking arrangement of media layers helps in achieving the desired results.
- **Low sludge generation:** Attached growth treatment increases MCRT thus reducing the sludge generation. The sludge generated is also stable and denser and can be easily separated in the secondary settling.

Submerged fixed-film reactors are ideal for the pre-treatment of industrial effluents. The advantages lie not only in the investment costs, but also in the operating costs. The pre-treatment plants can be subject to higher loads than are possible with the activated sludge process. Consequently, considerably less space is required. And, it is also possible to treat normally non-degradable industrial effluents, the prerequisites are that system-related general structural requirements are fulfilled and suitable materials are used for the fixed-film reactor.

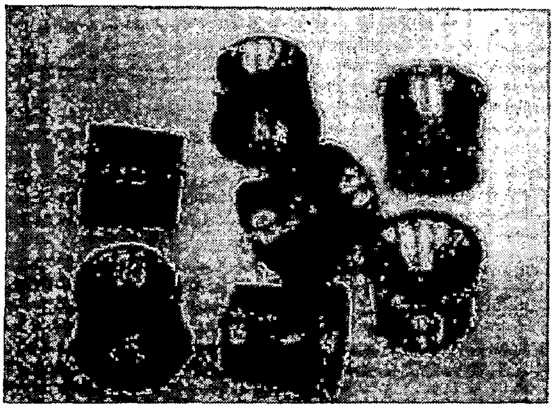
They also offer considerable advantages in terms of operation compared to the activated sludge process, since both a higher oxygen transfer rate and yield are achieved, less sludge is produced and fewer personnel are required. All in all, the upstream submerged fixed-film reactor has proven to be an extremely reliable process, requiring little maintenance that can cope, to a far-reaching degree, with load fluctuations of all types and reduce these. As a result, the operation of downstream treatment stages is also stabilized (Schlegel S. and Teichgräber B.1997).

2.3.6 Fluidized Aerobic Bed (FAB) Bioreactor

During the last few years, a great interest is conceded to the biologic treatment processes, which prove to be economic and efficient. These treatments processes are based on the use of microorganisms, immobilized or not, to eliminate the principal pollutants, generally metals and organic substances, by decomposing the inorganic and organic pollutants in simple products. The existing wastewater treatment processes can use three kinds of microbial aggregates: static biofilms (e.g. in trickling filters), flocs (e.g. in activated sludge processes) and particulate biofilms (in biofilm airlift suspension reactors; biofilm fluidized bed reactors).

Domestic wastewater is difficult to treat using conventional Activated Sludge Process, without having very large tanks and long hydraulic retention time to degrade the waste. Although Activated Sludge Process (ASP) has been a proven alternative, fluidized aerobic bed (FAB) is the alternate to save space and power requirement. (ASP wills need almost 10 times higher space than what is currently available)

Advanced Technology of Fixed Film biological processes having large surface area for bio-mass to grow have been used in past to reduce both the reactor volumes as well as retention time. Further developments in this field have led to development of fluid bed technology in which the fixed film media are made of small plastic materials which are freely moving and non-clogging type.



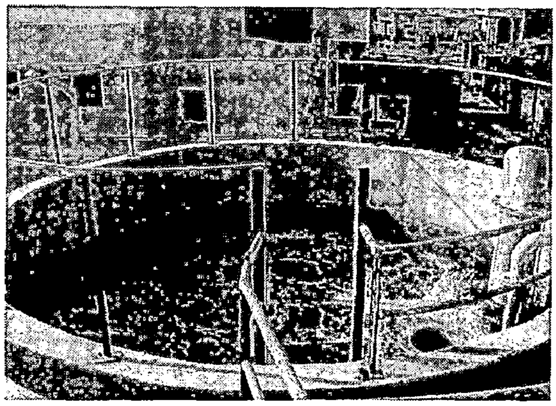


Fig. 2.6: Media of FAB Reactor and FAB Tank

➢ **Advantages of the FAB System.**

The sewage treatment scheme offered has some distinct advantages over conventional activated sludge processes. The scheme is proven, under a variety of operating conditions, and is highly flexible in operation.

- **Small space requirement**

The concept of compact FAB based sewage treatment plant is used so that expensive land requirement is reduced. A conventional treatment requires large space, and large operating force. The FAB based plants individually occupy much less space, making the plants more manageable.

- **Lower operating power requirements**

The system utilizes aeration tanks of much smaller size, thereby reducing the overall power required in aerating the raw sewage. Since the bio-reactor depth is more, efficient transfer of oxygen takes place, thereby reducing the overall power consumed in treatment. Since the plant can be fitted with less foot print area the cost of power required for pumping raw sewage at a site away from city is reduced.

- **Simplicity in operation and maintenance**

The system adopted has much less moving parts (only pumps, blowers, clarisettler mechanism and Filter Press). Further there is no moving part inside the bioreactor. This gives the advantage of continuously running the bioreactor system, under widely fluctuating conditions. All the pumps / blowers, clarisettler and Filter Press are manufactured in India only, and hence there in no problem of availability of spares. All the maintenance on the mechanical systems can be done with normal skilled mechanics available.

- **Uniqueness of system**

The system is unique in operation, such that, only inlet and outlet parameters (i.e. raw sewage BOD / COD/ TSS and treated sewage BOD/COD/TSS) need to be analyzed. Since the bio- reactor is self-sustaining, there is no requirement of recycling the biomass from the secondary clarifier. Hence, analysis such as MLSS/ MLVSS/ SVI (sludge volume index) F/M ratio etc. is not required to be done. This greatly reduces the analytical load on the plant chemist / supervisor, and makes the system very simple to operate and control.

- **Coli form removal**

The outlet BOD of the bio- reactor system being very low (in other words, hardly any food is available to the E-coil), most of the coli form are killed in the reactor itself. There is no need to dose any chlorine to achieve E-coil < 10000 at the outlet of the system.

- **Sludge handing**

The sludge generated in the bio-reactor is totally digested. Since the F/M ratio in the bioreactor is very low; the excess sludge generation is lower than compared to the conventional ASP system. The present system does not envisage any sludge digestion (since the sludge is aerobically stabilized in the bio-reactors itself) making the system more suitable to be installed under such climatic conditions.The excess sludge separated in the clarisettler is thickened in the gravity thickeners. It is then directly pumped to the Filter Press for de-watering.

A lot of development has taken place in understanding the process and in optimizing various parameters with respect to the carrier media size, material, density, shape, area per meter cube volume of the reactor, roughness of surface, fluidizing velocity etc. for a variety of industrial and domestic effluents of varying BOD/ COD levels as also natures of effluents.

Due to fixed film nature these plant can accept shock loads much better than those employed for suspended growth.

➢ Treatment Scheme

The treatment scheme proposed to treat the raw sewage from various locations is split into three distinct parts:

i. Pre-treatment, this comprises of screening and grit removal.

ii. Biological treatment comprising of fluidized aerobic bioreactor followed by clarification.

iii. Sludge treatment comprising of thickening and mechanical de-watering.

Detailed description of each step of treatment is given below:

➢ Pre-Treatment

The raw sewage is collected by gravity in the Receiving Sump and pumped to the downstream units for treatment. The sewage is pumped either half Average/Average/Peak flow rate depending upon the incoming flow. The raw sewage is pumped into the Stilling Chamber and passes through a coarse screen provided in the Bar Screen chamber for removal of floating matter. Removal of such floating/coarse matter is essential because it can otherwise choke pipelines/pumps etc, and hinders the normal operation of the treatment plant. The screens are made of mild steel bars, placed at equal intervals. The raw sewage is made to pass through the screens, wherein the floating matter, any large particles are trapped in the bars. The inclination of bars is kept such that screening becomes easy. The screening trapped is removed manually at fixed interval. The screening is collected and disposed off suitably.

The screened sewage passes through the Grit Chamber where the grit present in the raw sewage representing sand/dirt collected in the sewerage system is separated and keeps the channels/pipes clean. Grit has high settling velocity, and can be easily removed in the grit chamber. The grit removal provided here is a mechanical grit removal system with standby. As the sewage is made to pass through this system the grit settles on the floor. This grit is then removed by a rake mechanism and cleaned with organic return pump. The grit gets dewatered while lifting it to the discharge point. The grit separated is disposed off en by transporting it to suitable location.

- **Biological Treatment**

The bioreactions are carried out in controlled environment in the bioreactor. The bio-reactor comprises of a tank, fitted with aeration grid. The bacterial activity needs dissolved oxygen, to synthesize the organic matter. This is supplied by passing air in the form of small bubbles. The air is passed of the tank, so that complete volume of tank is utilized. Oxygen dissolves in liquid is used by the aerobic bacteria. The bacterial population is present on the media, which forms an integral part of the reactor system. The media is made of small plastic elements. Millions of such pieces are present in the reactor. A very large surface area is made available for the bacterial population to grow. The bacteria grow on the plastic media, by using the organic content in the raw sewage, and the dissolved oxygen available. Due to constant aeration, the media is set in whirling motion, so that cumulous mixing taken place.

The bacterial layer growth on the media surface increases to certain, and then gets sloughed off after a specific period. This phenomenon is called 'sloughing'. This creates new surface for further bacterial growth. Sloughing takes place only after complete growth and subsequent dyeing off of the bacterial layer and hence the sloughed off material is completely digested. Ammonical nitrogen is converted into nitrate nitrogen. The bacterial reaction is carried out in two stages, for maximizing the BOD removal efficiency. Hence, two such reactors are provided in series. Within the reactors, arrangements are made to retain the plastic media in place.

Air supply is done through perforated stainless steel pipes. Use of stainless steel pipes ensures that no maintenance is required. A dose of coagulant i.e. poly aluminum chloride (PAC) is added to the liquor before it enters to Clarisettler to reduced the suspended solids less than 20 mg/l. The sloughed biomass must be removed before the treated sewage can be disposed off hence a Clarisettler is provided. The Clarisettler is a unit in which the sloughed biomass is removed and suspended solids are settled, which are later, scraped mechanically.

The treated sewage, now substantially free from organic contamination is collected in Chlorine Contact Tank where Sodium Hypochlorite / Gas Chlorination is dosed for reducing coli form bacteria within limits prior to suitable disposal. This water can also be re-used for horticulture purpose / toilet flushing or for other secondary applications.

- **Sludge Treatment**

The sludge formed in the process of bio-degradation separated in the Clarisettler is drained periodically in the Sludge Thickener, to increase the consistency. The thickened sludge is pumped into a Manual Filter Press for mechanical dewatering. A hydraulically operated plate and frame type filter press for sludge denaturing has been provided. Polyelectrolyte (PE) is added at the inlet to filter press, which helps in preparation of sludge cakes for its use as a soil conditioner.

The supernatant of Sludge thickener and Filtrate of the Filter Press is collected into the Receiving Sump and pumped back into the System for further treatment and disposal through main stream.

The other principal advantage of the Fluidized Aerobic Reactor is the significant reduction of E-Coil. From an inlet cont of $10^6 - 10^7$ MPN/100 ml the count is reduced to less than 10^3 at the outlet of the CCT.

As per Final Report,Volume 6-Technical Analysis, Section B-Sewerage and Sanitation, TA 4106-IND: *Kerala Sustainable Urban Development Project*, the FAB system can remove 85-90% BOD , 85-90% Suspended Solids and 60-90% of Total coli form (before chlorination).

2.3.7 Constructed Wetlands

Constructed wetlands (CWs) are among the recently proven efficient technologies for wastewater treatment. Compared to conventional treatment systems, constructed wetlands are low cost, are easily operated and maintained, and have a strong potential for application in developing countries, particularly by small rural communities. (Amelia K. Kivaisi, 2001)

Wetlands are characterized by high organic matter accumulation due to a high rate of primary productivity and a reduced rate of decomposition due to anaerobic conditions (Hammer and Bastian, 1989). Incoming nutrients support the growth of vegetation, which converts inorganic chemicals into organic materials, the basis of the wetland food chain. As a result of ample light, water and nutrient supply, the primary productivity of wetland ecosystems is typically high (Brix, 1993a).

CWs for wastewater treatment involve the use of engineered systems that are designed and constructed to utilize natural processes. These systems are designed to mimic natural wetland systems, utilizing wetland plants, soil, and associated microorganisms to remove contaminants from wastewater effluents (EPA, 1993)

The basic types of soil-based constructed wetlands are:

i. Horizontal surface flow systems (with the wastewater level above the soil surface);
ii. Horizontal subsurface flow systems (with the wastewater level below the soil surface);
iii. Vertical flow systems with upstream or downstream characteristics and continuous or intermittent loading.

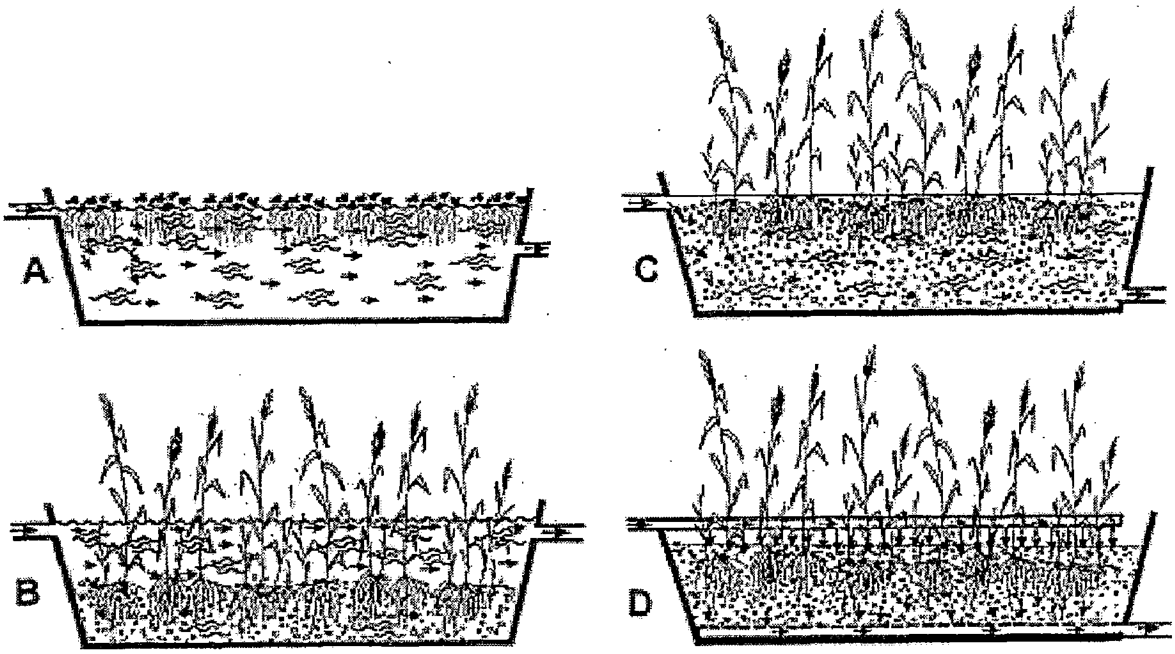


Fig. 2.7: Wetland Systems for Wastewater Treatment (A, pond with free-floating plants; B, horizontal surface flow wetland with emergent water plants; C, horizontal subsurface flow wetland; D, vertical flow wetland).

Although all the plant species listed in Table- 2.3 are suitable, reeds along with types of rushes and cattails are the ones most frequently used. Recently, the suitability of fast-growing trees such as willows has also been examined (Greenway and Bolton, 1996).

Scientific name	English name
Phragmites Australis (cav.)	Common reed
Trinex Steud.	
Juncus Spp.	Rushes
Scirpus Spp.	Bulrushes
Typha Angustifolia L.	Narrow leaved cattail
Typha Lalifolia L.	Broad leaved cattail
Iris Pseudacorus L.	Yellow flag
Axorus Calamus L.	Sweet flag
Glyceria Maxima (Hartm.)	
Holomb.	
Carex Spp.	Sedges

Table-2.3 : Selection of Plant Species Used in Constructed Wetlands

The active reaction zone of constructed wetlands is the root zone (or rhizosphere). This is where physicochemical and biological processes take place that are induced by the interaction of plants, microorganisms, the soil and pollutants.

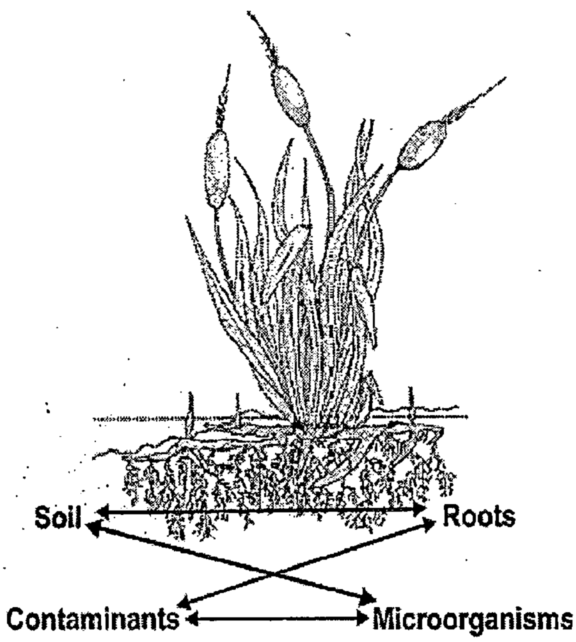


Fig. 2.8: Active Reaction Zone of Constructed Wetlands

Originally coined in 1903 by (Hiltner and Störmer, 1903), the term rhizosphere can be subdivided into the endorhizosphere (the root interior) and the ectorhizosphere (the root's surroundings). The zone in which these two areas meet is known as the rhizoplane (Elliott et al., 1984). This is where the most intensive interaction between the plant and microorganisms is to be expected.

➢ **Processes within constructed wetlands**

Within a CW, the contaminated effluent is treated through various physical, chemical and biological processes involving aquatic plants (predominantly macrophytes), algae, micro-organisms, water, soil and sun (e.g. direct process via photo degradation). The main processes for which detailed examples can be found elsewhere ([Mantovi et al., 2003], [Scholz and Xu, 2002], [Scholz and Lee, 2005], [Scholz, 2006a], [Scholz et al., 2007], [Zedler, 2003]) are as follows:

i. Physical filtration of suspended solids by wetland vegetative biomass acting as a hydrological baffle to incoming flows (optimized by high vegetation density and low flow velocity).
ii. Settling of suspended particulate matter by gravity (optimized by low flow velocity, low wind speed, low disturbance and long residence time).
iii. Uptake, transformation and breakdown of nutrients, hydrocarbons and pesticides by biomass, plants and microbes (increased by a relatively high temperature, long residence time, contact with micro-organisms and plants, high micro-organism and plant density, and a relatively high organic matter content).

➢ **Advantages of Constructed wetlands**

The main benefits of CW as discussed by (Zedler, 2003), (Scholz and Xu, 2002) and (Scholz et al., 2007) and other researchers (see below) are summarized below:

- **High level of treatment and robustness**

  Efficient treatment up to 99% reduction of contaminants can be achieved (Braskerud, 2002).

- **Relative low cost and simplicity of operation**

  CW has minimal equipment needs and little, if any, energy use since water can be transferred by gravity through the system. They are also simple to operate and more cost-effective than alternative methods of disposing of farm runoff (Poe et al., 2003).

- **Odor minimization:**

  Odor can be a serious problem when handling and treating agricultural wastes. Odors are minimized in CW by using a dense plant cover, appropriate and tall plant species, a shallow water level and maintaining surface flow.

- **Aesthetically pleasing:**

  CW enhances the landscape by adding colors, texture, and by increasing the diversity of plants and habitats (Scholz, 2007).

- **Habitat and biodiversity enhancement**

  CW provide habitats for a wide variety of birds, mammals, reptiles, amphibians and invertebrates (e.g. Froneman et al., 2001)

2.4 OPERATION AND MAINTENANCE (O & M) OF STPs

2.4.1 Introduction

The operation and maintenance (O&M) of STPs is most important factor for smooth and efficient working. Inadequate O&M may result in reduced performance of the components and result in premature failure before the period for which they were designed

The maintenance activities are generally related to and include:

- Repair and up-keeping of civil, mechanical and electrical components of the scheme and the conveyance system in order to enable them to function at rated capacity throughout the design period; and also
- Routine repairs/replacements of parts as necessary to prevent malfunctioning of the components.

2.4.2 Basic Requirements for O&M Practices

The improved O & M shall comprise the following essential practices:

- Availability of detailed plans, drawings and O & M manuals for use of the O & M personnel;
- Preparation and following a schedule of inspection of machinery;

- Maintaining records of repairs / replacements of the equipment or spare parts;
- Maintaining and monitoring records of quality of wastewater effluent;
- Maintaining and monitoring records of key activities of O & M;
- Maintaining inventory of stores and procurement of essential chemicals, spares, pipes, valves and specials well in advance; and
- Provision of required staff and their effective day-to-day deployment.

2.4.3 Major O & M Activities for Decentralized STPs

- Operation of STP including sewage pump houses, primary screening, gritting, biological reactors etc., repairs and preventive maintenance of all equipment and machines to achieve their performance to rated capacities;
- Attending to chokage of sewer or manhole chambers by sewer cleaning machines;
- Monitoring quality of effluent from STP discharging to canals/water bodies; and
- The safe / hygienic disposal of sludge.

2.4.4 O & M Cost

The O & M cost for the proposed facilities of sewerage and sanitation mainly consist of O & M staff salaries, energy cost, chemical cost and repair & maintenance cost. The administrative costs depend upon the expanse of STPs to be maintained for effective day to day maintenance. These include cost towards staff salary, repairs, energy, consumables etc.

SAMPLE COLLECTION AND METHODOLOGY

3.1 SAMPLING LOCATION

For the examination of different physico-chemical parameters, total coliform and fecal coliform, samples were collected from different stages of sewage treatment plants. Sampling locations for different STPs are shown in the Fig. 3.1 – Fig. 3.5. Grab samples are collected 8 times from 3 MLD FAB plants and 6 times from SAFF, Aeration cum CW and Anaerobic filter cum FP plants.

In the present study the performances of five decentralized wastewater treatment plants in North India were evaluated. The details of these plants are shown in Table no.

S. No.	Treatment plant/ Process	Location	Type of wastewater being treated	Capacity	No. of sampling points
1.	Fluidized Aerobic Bed (FAB) at Molarbund	20 km. south of Delhi city	Domestic wastewater	3 MLD	3
2	Baffled Anaerobic Bioreactor and Floating Plant (FP) at Vasant Vihar	20 km South-West of Delhi city	Domestic wastewater	0.5 MLD	2
3	Aeration cum Constructed Wetlands at Sector-13	5 km west of Faridabad city (Haryana)	Domestic wastewater	3 MLD	2
4	Submerged Activated Fixed Film (SAFF) at ISBT	Inter State Bus Terminus, Dehradun (Uttrakhand)	Domestic/ Industrial wastewater	1 MLD	3
5	Fluidized Aerobic Bed (FAB) at Bakkarwala	30 km West of Delhi city	Domestic wastewater	3 MLD	3

Table 3.1: Details of STPs with Processes and Capacities

Samples were taken from plants over a period of five months, and the performance of each plant in removing organic matter, coli forms was determined. Samples have been collected from inlet, outlet points, after chlorination and FAB tank of FAB plants, inlet and outlet points of FP plant, inlet, outlet points and from SAFF tank of SAFF plant and inlet, outlet points and aeration tank of CW plant

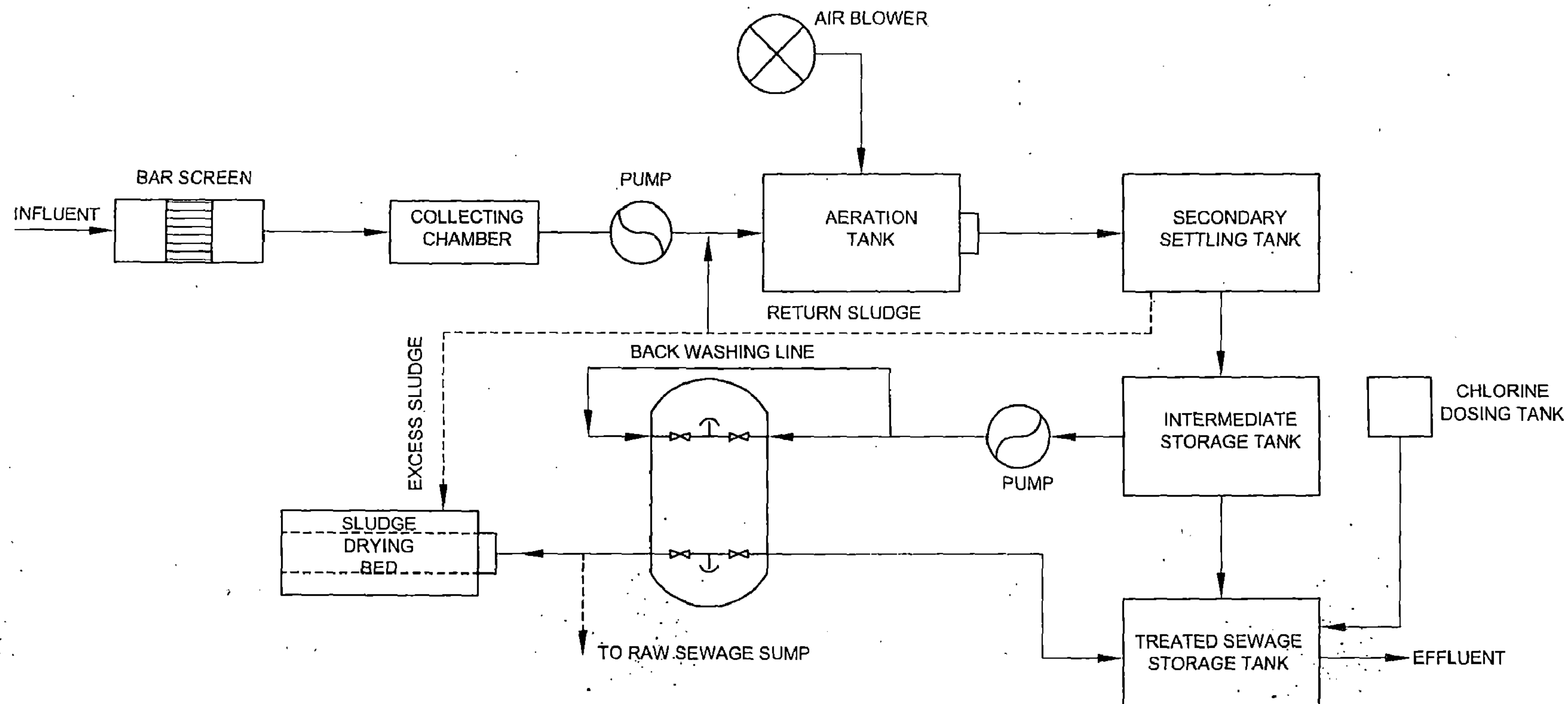
3.2 DESCRIPTION OF THE TREATMENT PLANTS

3.2.1 Submerged Aerobic Fixed Film Bioreactor (SAFF), Dehradun (Uttrakhand)

Submerged Aerobic Fixed Film (SAFF) Process plant has been established in the year 2003. It is used for treating waste water generated from Inter State Bus Terminus (ISBT) complex, Dehradun. The capacity of the Plant is 1 MLD and the plant receives around 0.5-1 MLD flow per day. Plant contains Bar Screens, Sewage Receiving Sump, Aeration Tank, Secondary Settling Tank, Intermediate Storage Tank, Treated Sewage Storage Tank, and Sludge Drying Beds. Most of the final treated effluent is used for washing open area of ISBT and for horticulture purpose.

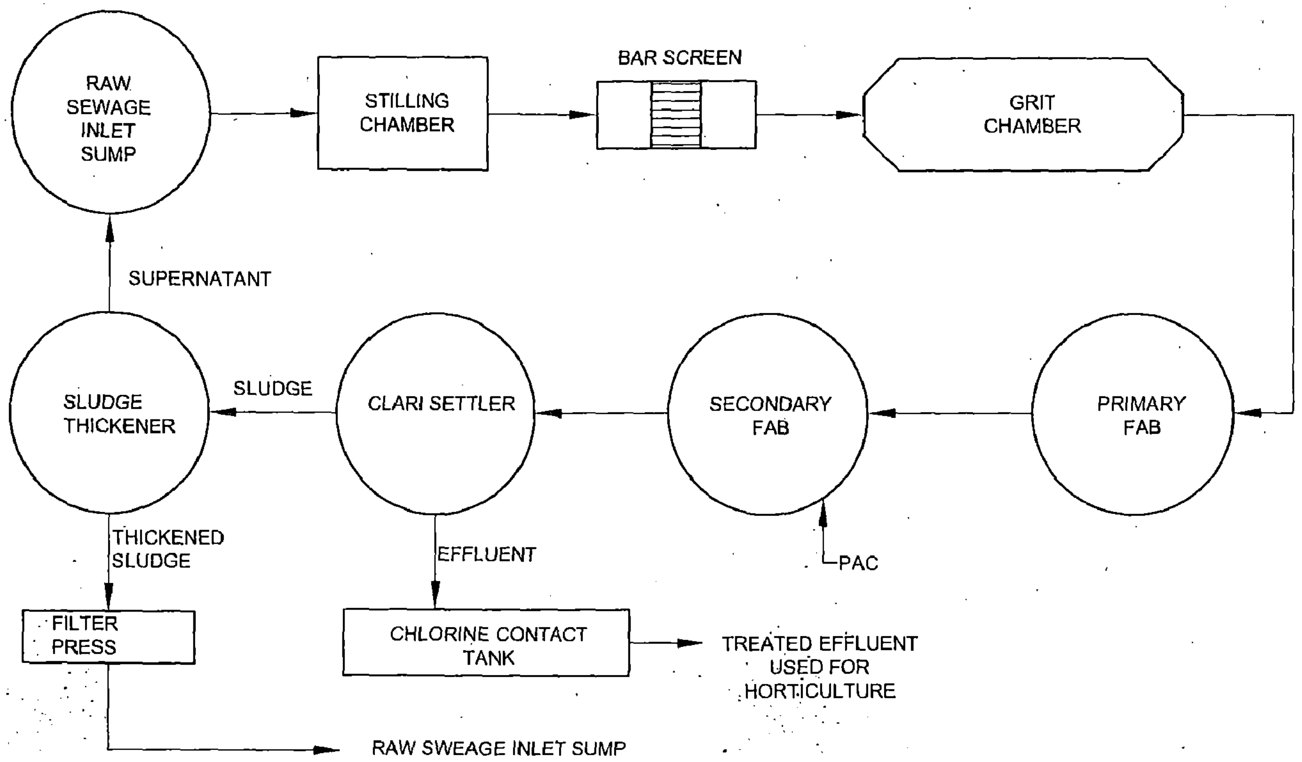
3.2.2 Fluidized Aerobic Bed (FAB) Plant, Molarbund (Delhi)

Fluidized Aerobic Bed Process has been established in the year 2003 under Yamuna Action Plan. It is used for treating domestic waste water generated from nearby resettlement slum colony. The capacity of the Plant is 3 MLD and the plant receives around 1-3 MLD flow per day. Plant contains Sewage Receiving Sump, Stilling Chamber, Bar Screens, Grit Chamber, FAB Tanks (two) in series with Aeration Grid at bottom, Clarisettler, Chlorine Contact Tank, Sludge Thickener and Filter Press. Most of the final treated effluent is used for horticulture purpose.



STRUCTURED AEROBIC FIXED FILM (SAFF) BIOREACTOR

INTER STATE BUS TERMINOUS, DEHRADUN (UTTARAKHAND)



FLUIDIZED AEROBIC BED (FAB) BIOREACTOR, MOLARBUND (DELHI)

3.2.3 Fluidized Aerobic Bed (FAB) Plant, Bakkarwala (Delhi)

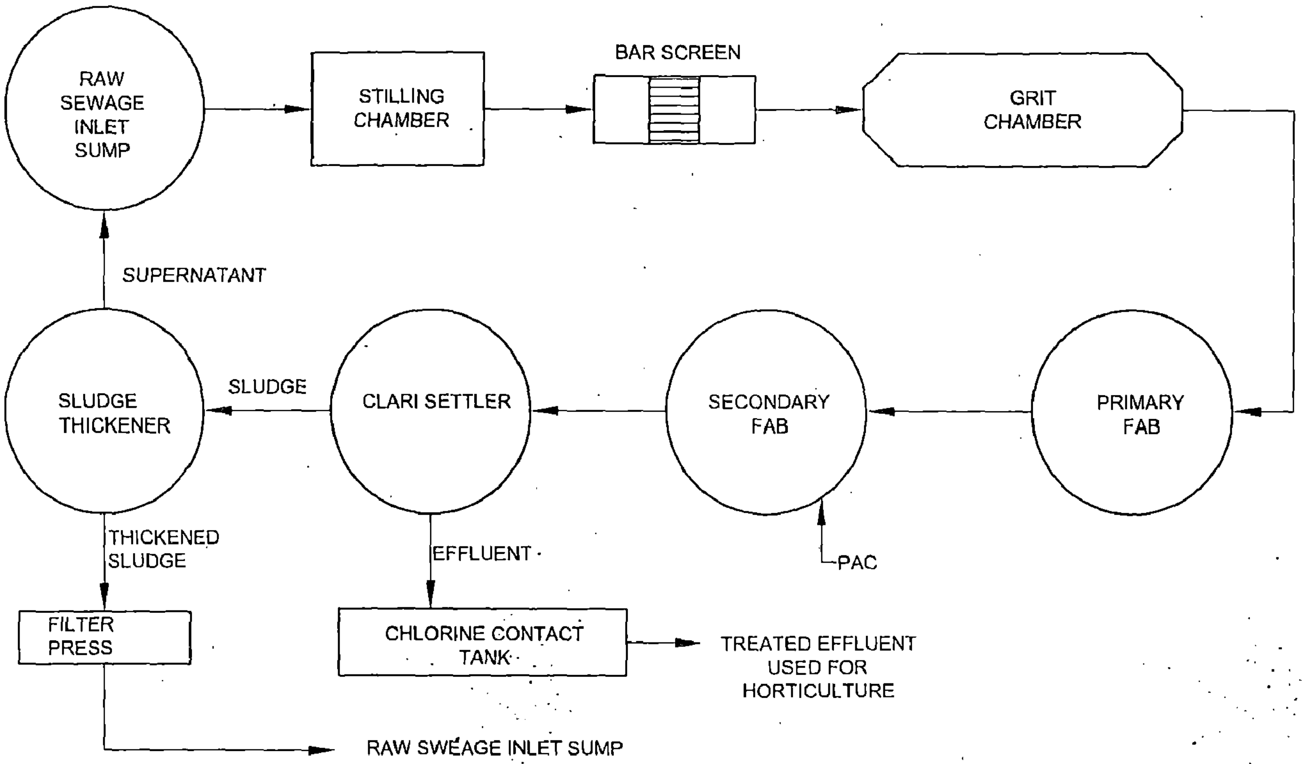
Fluidized Aerobic Bed Process plant has been established in the year 2003 under Yamuna Action Plan. It is used for treating municipal waste water generated from slum colony. The capacity of the Plant is 3 MLD and the plant receives around 1-2 MLD flow per day. Plant contains Sewage Receiving Sump, Stilling Chamber, Bar Screens, Grit Chamber, FAB Tanks (two) in series with Aeration Grid at bottom, Clarisettler, Chlorine Contact Tank, Sludge Thickener, Filter Press, and Sludge Drying Beds. Most of the final treated effluent is used for horticulture purpose.

3.2.4 Anaerobic Baffled Filter and Floating Plants (FP) System, Vasant Vihar (Delhi)

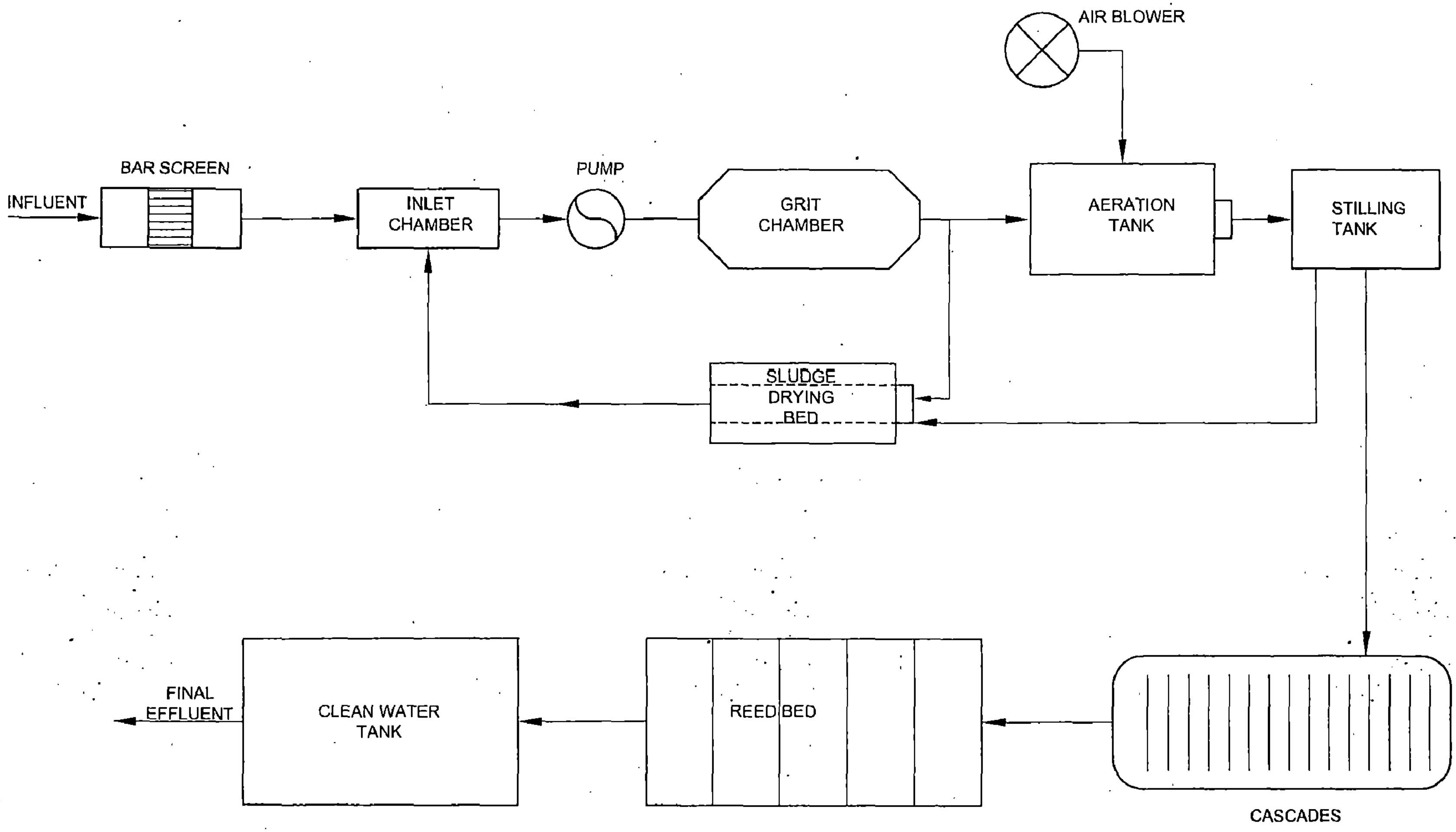
Anaerobic Baffled Filter and Floating Plants System have been established in the year 2002 by Resident Welfare Association (RWA) of Vasant Vihar, Horticulture Department of Municipal Corporation of Delhi (MCD) and supervising NGO, Vigyan Vijay Foundation (VVF). It is used for treating municipal waste water generated from Vasant Vihar Colony. The capacity of the Plant is 0.5 MLD. Plant contains Bar Screens, Sewage Receiving Tank, Anaerobic Baffled Filter, Cascade Steps, Channels with Floating Plants, Channels with Charcoal Filtration, Cyclic Path, Consolidation Tank and Reception Tank. Most of the final treated effluent is used for horticulture purpose in nearby MCD parks.

3.2.5 Wastewater Treatment and Reuse Plant (Constructed Wetlands), Faridabad (Haryana)

Wastewater Treatment and Reuse Plant (Constructed Wetlands) has been established in the year 2007 by Haryana Urban Development Authority (HUDA). It is used for treating municipal waste water generated from nearby sectors. The capacity of the Plant is 3 MLD and the plant receives around 1-3 MLD flow per day. Plant contains Bar Screens, Sewage Receiving Tank, elevated Inlet Chamber, Grit Chamber, Aeration Tank, Settling Tank, Cascade Steps, Root Zone Beds (Constructed Wetlands), Sludge Drying Beds and Treated Sewage Storage Tank. Most of the final treated effluent is used for horticulture purpose at Town Park and washing of roads.



FLUIDIZED AEROBIC BED (FAB) BIOREACTOR, BAKKARWALA (DELHI)



FLOW DIAGRAM FOR WASTE WATER RECYCLING PLANT SECTOR-13 FRIDABAD

3.3 SAMPLE COLLECTION

Grab Samples have been taken for physico-chemical Examination in 1000 ml Plastic bottles. Grab sample were collected from treatment plants in 1000 ml sterilized bottles for microbiological Examination as per the method prescribed in standard methods of water and waste water examination (*APHA-1998), 20th* edition. The sampling bottles were transported to Environmental Engineering Lab, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee. The microbiological examination was carried out on the same day of sample collection. Microscopic analysis for protozoan was performed as soon as possible and always within 6 hrs of sample collection.

For physico-chemical examination, samples had been stored in a deep freezer at the temperature of 4^{0}C and experiments have been carried out within two days of sample collection. All samples were assayed for microbiological parameters (Total Coli forms, Fecal Coli forms, and Protozoa) as well as physico-chemical parameters (COD, BOD, TSS, TDS, Turbidity and pH).

3.4 IDENTIFICATION PROCEDURE FOR MICROBIOLOGICAL PARAMETERS

3.4.1 Total Coli form, Fecal Coli form

The following methods for identification of total coliforms and fecal coli forms are given in standard methods

i. Rapid detection method
ii. Member filter technique
iii. Multiple-tube fermentation technique

The seven hour fecal coliform test (rapid detection method) is similar to the fecal coliform membrane filter procedure but use a different medium and incubation temperature to yield result in 7 h that generally are comparable to those obtained by the standard fecal coliform method.

Due to simplicity of detection in operation and cost effectiveness multiple-tubes fermentation technique was chosen for enumeration of total coliform and fecal coliform.

Total and fecal coliform was selected as indicator organism for monitoring. The method used for enumeration was in accordance with Standard method (APHA, 1998). Three tube fermentation tests were used for identification of total and fecal coliform. In all the test dilution were done. The MPN of fecal coliform in each test was determined by using the MPN table or by Thomas formula.

$$\text{MPN/100ml} = \frac{\text{No. of positive tubes X 100}}{\sqrt{(\text{mL of sample in negative tubes x ml of sample in all tubes})}}$$

The culture media used for bacteriological analysis are given in Table 3.2.

S. No.	Indicator Organisms	Culture Medium	Incubation temperature & period	Expression of result
1.	Total coliform	Lauryl tryptose broth with Bromocresol purple	35±0.5^{0}C 24±2h or 48h.	MPN/100 ml
2.	Fecal coliform	EC-Medium	44.5±0.2^{0}C in water bath for 24±2h.	MPN/100 ml

Table-3.2: Culture Medium and Incubation Temperature and Period for Indicator Organism

The steps for analysis of total coliform and fecal coliform are shown in Fig. 3.8.

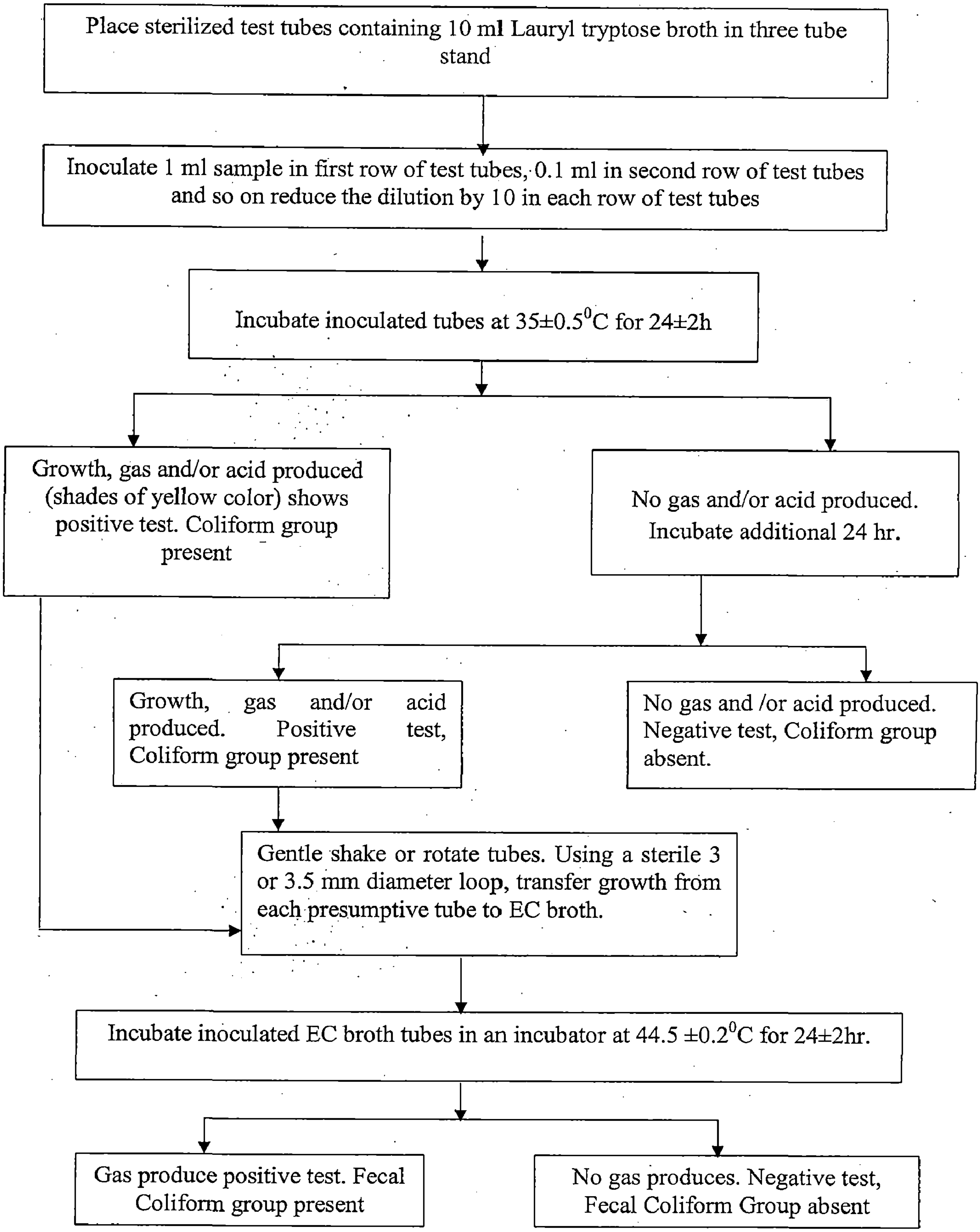
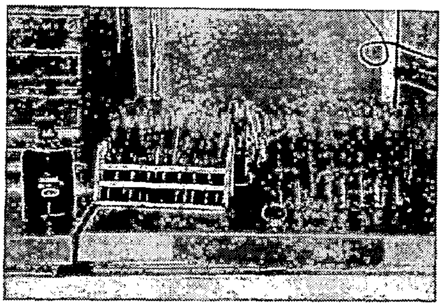


Fig. 3.8: Schematic outline for detection & enumeration of TC and FC (*APHA-1998*)



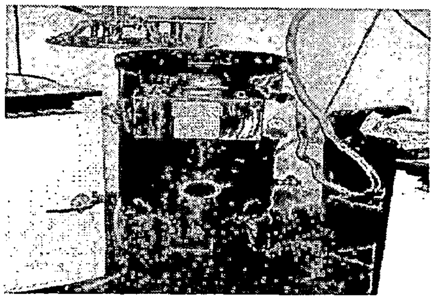
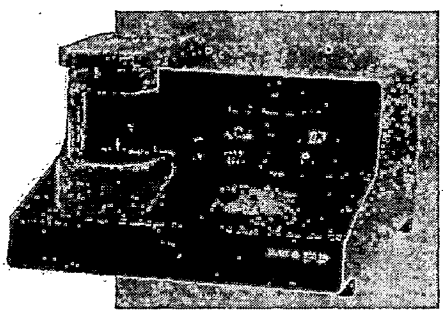


Fig. 3.9: Multiple Tube Technique and Autoclave

3.4.2 Protozoa

The protozoan contents of roots from constructed wetlands were enumerated by Scanning Electron Microscopy (SEM), an imaging technique for getting high resolution images, at 1000x magnification. Sample of root rhizomes was taken from the constructed wetland for microscopic observation through SEM.



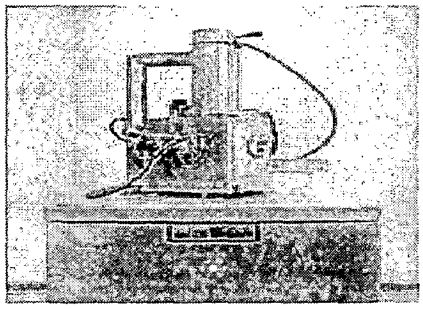


Fig. 3.10: Sputter Coater and Scanning Electron Microscopy (SEM)

The prepared sample is then kept in Sputter Coater, a sputtering device, for providing conductive films of gold on sample for further X-Ray microanalysis. Sputter Coater is a one button push machine providing thin films on samples to be analyzed on SEM.

3.5 ANALYSIS OF PHYSICO-CHEMICAL PARAMETERS

Different physico-chemical are analyzed here are pH, Temperature, DO, BOD, COD, Turbidity, Total solids, Suspended solid and Dissolved solid.

3.5.1 pH

For the measurement of pH a digital pH meter is used and pH is measured at the site by collecting the sample in a beaker at different point of sampling.

3.5.2 Temperature

For the measurement of temperature a digital thermometer meter is used and temperature is measured at the site by collecting the sample in a beaker at different point of sampling.

3.5.3 DO

DO is fixed at site by collecting the sample in 300ml capacity BOD bottles and analyzed at lab. For fixing DO $MnSO_4$ and KI solution is used (1ml each). It is analyzed according to Modified Winkler's Method.

3.5.4 BOD

For analyzing the BOD Winkler's Method is used with incubation period 3 days at 27^0C. Different dilution are made for each sample i.e. inlet and outlet. Here initial and final DO is analyzed and finally BOD calculated as for each sample.

$$\text{BOD3 (mg/L)} = \frac{[\,(DO_i - DO_f)_{sample} - (DO_i - DO_f)_{di}\,]}{F}$$

where, DO_i = Initial DO of diluted sample or dilution water (mg/l)

DO_f = Final DO of diluted sample or dilution water after 3 days (mg/l)

$$F = \text{dilution factor} = \frac{\text{(ml of sample)}}{\text{(ml of dilution water)}}$$

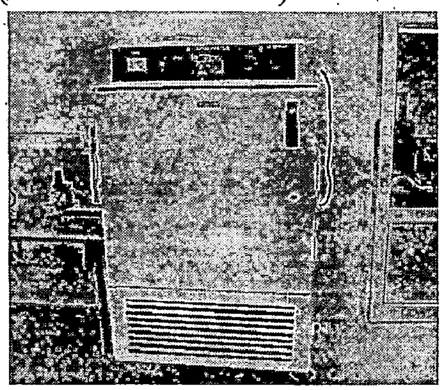


Fig. 3.11: Photographic view of BOD Incubator

3.5.5 COD

Chemical Oxygen Demand (COD) is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions. The quantity of oxidant consumed is expressed in terms of oxygen equivalence. When sample is digested, the dichromate ions oxidized COD material in the sample. During the digestion process the chromium ions changes from the hexavalent (VI) state to the trivalent (III) state. Both of these chromium species are coloured and absorb in the visible region of the spectrum. The chromic ions absorbs strongly in the 600-nm region, where the dicromate has nearly zero absorption. Thus, closed reflux, colorimetric method was used, available in standard methods for COD measurment. Hach COD system (DR/4000U spectrophotometer) set at λ=600 nm was used for COD measuement for this study. The photographic view of COD reactor and Hach COD systemis shown in Fig.3.5.

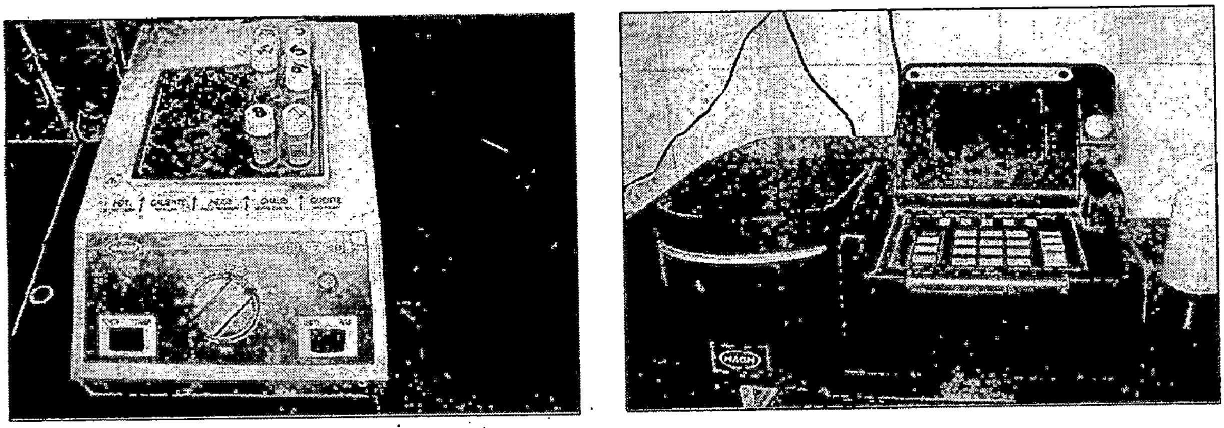


Fig. 3.12: Photographic view of COD reactor (Digester) and Hach COD system (DR/4000U spectrophotometer)

3.5.6 Turbidity

Sewage water is normally turbid; this turbidity can be measured by Turbidity Rod or turbidity meter. For this work HACH 2100AN turbidity meter is used for measuring the turbidity.

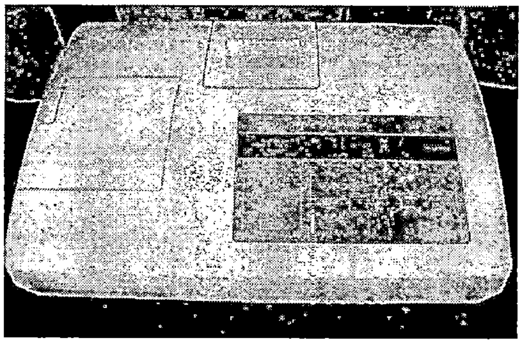


Figure 3.13: Photographic View of HACH 2100AN Turbidity Meter

3.5.7 Total Solids, Suspended Solid and Dissolved Solid

Sewage contains about 0.05% to 0.1% solids, (500 mg/L to 1000 mg/L). In this work Total solids are analyzed in the laboratory by taking 100 ml sample in a pre weighted beaker and putting it in oven at 105 ^{0}C and then again finding weight of beaker with solids.

Total Solids = $W_2 - W_1$

Where W_2 = weight of beaker after vaporization of wastewater sample

W_1 = weight of empty beaker.

Suspended solid are find by taking 100ml sample and filtering it through filter paper. The filter paper used was pre filtered by 100ml distilled water and then dry at 105^{0}C and its weight is noted (W_3). After filtering the sample this paper again dried at 105^{0}C and weight is noted (W_4).

Total Suspended Solids = $W_4 - W_3$

Dissolved solids are find by taking 100ml sample and filtering it through filter paper and filtrate is dried at 180^{0}C in a beaker and its weight is noted (W_6).

Total Dissolved Solids = $W_6 - W_5$

Where W_6 = weight of beaker after drying of wastewater sample

W_5 = weight of empty beaker.

Finally these are expressed in mg/L

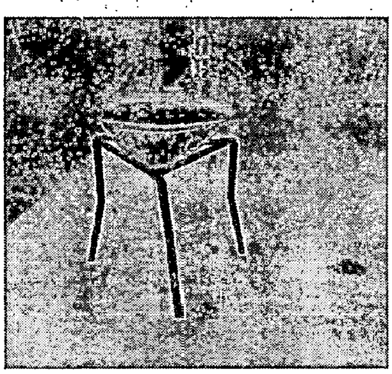


Figure 3.14: Determination of Suspended Solids

RESULTS & DISCUSSION

The grab samples of FAB plants at Molarbund and Bakkarwala in Delhi were collected from the inlet, outlet points, FAB tank and after chlorination and analyzed from January 2008 to May 2008. Grab samples of SAFF plant at Dehradun were collected from the inlet, outlet points and SAFF tank and analyzed from February 2008 to May 2008. Samples from the inlet, outlet points and aeration tank of aeration cum CW plant at Faridabad were collected and analyzed from March 2008 to May 2008 and samples collected from the inlet, outlet and after filtration of Anaerobic baffled filter cum FP plant at Vasant Vihar in Delhi were analyzed from December 2007 to May 2008. Disinfection is applied in FAB plants at Molarbund and Bakkarwala, Delhi. Table 4.1 to Table 4.12 in Appendix -A gives the descriptive data on sampling frequency, Turbidity, pH, TSS, BOD, COD and micro organisms' concentration in influent and effluent of treatment plants.

Variations of Turbidity, TSS, BOD, COD, TC and FC in inlet and outlet points of SAFF plant at Dehradun, for different sampling dates are shown in Fig. 4.1 to Fig 4.6

Variations of Turbidity, TSS, BOD, COD, TC and FC in inlet and outlet points of FAB plants, Bakkarwala and Molarbund, Delhi for different sampling dates are shown in Fig. 4.19 to Fig 4.24 and Fig. 4.37 to Fig 4.42 respectively.

Variations of Turbidity, TSS, BOD, COD, TC, and FC in inlet and outlet points of Anaerobic Baffled Filter cum FP plant at Vasant Vihar, Delhi and Aeration cum CW plant, Faridabad for different sampling dates are shown in Fig.55 to Fig. 60 and Fig.67 to Fig. 72.

The study has brought out following observations and results pertaining to different decentralized STPs.

4.1 SUBMERGED AEROBIC FIXED FILM (SAFF) PLANT, DEHRADUN

On the basis of the analyzed data of SAFF Process following observations have been made:

- In the **Raw sewage** BOD, COD and TSS was found vary from 172 - 380 mg/L (Avg.- 267 mg/L), 441.64 - 880.23 mg/L (Avg.- 624.36 mg/L) and 468 -1104 mg/L (Avg.- 755.16 mg/L) respectively. As per Metcalf & Eddy (1995) typical COD concentration in the Untreated Domestic sewage ranges from 250-1000 mg/L.

- The BOD, COD and TSS concentration in **effluent** ranges from 14 - 64 mg/L (Avg.- 39.66 mg/L), 158.98 – 289.46 mg/L (Avg.- 212.75 mg/L) and 86 -275 mg/L (Avg.- 172.16 mg/L) respectively.

- The **mean removal efficiency** of BOD, COD and TSS has been found to be 85.95, 65.96 and 77.21 respectively. Most of the researchers have mentioned the removal efficiency of BOD for SAFF in the range of 80-95%. Izanloo H. et al.,2006 has reported that the COD removal efficiency could be more than 83%. As per Cooldeck, Brochure on SAFF , the BOD removal efficiency could be more than 95%..Mohamed F. Hamoda et al., has reported high removal efficiencies of up to 98% for BOD and 75% for COD but process appears to be more capable of maintaining a stable and efficient treatment at higher loading rates

- TC and FC concentrations in the system **influent** was varied from $2.8x10^6 – 2.3x 10^7$ MPN/100mL (Avg. – 1.10×10^7 MPN/100mL) and $9.3 x10^5 – 6.5x 10^6$ MPN/100mL (Avg. – 3.42×10^6 MPN/100mL).

- Observations revealed that the **effluent** has concentration of TC and FC ranges from $2.3x10^5$- $4.3x 10^6$ MPN/100mL (Avg. 1.90×10^6 MPN/100mL) and $9.3x 10^4$ - 9.3×10^5 MPN/100 ml (Avg.- 5.38×10^5 MPN /100mL)

- The percentages **mean removal efficiency** of TC and FC has been found 84.80 and 84.58. Livingston, 1991; Sokol, 2001and 2003 has reported that with favorable operating conditions, from hydrodynamic and mass transfer point of view, the pollutant could be biologically degraded up to 90%. Since the mean value of FC in treated effluent (5.38×10^5 MPN /100mL) is more than the permissible limits i.e. 1000 MPN/100mL, as specified by WHO (1989) for unrestricted irrigation, the dose of chlorination should be optimized.

➢ Further attempts have been made to establish the relationship between key wastewater constituents & operational parameters such as BOD, TSS and Turbidity with respect to TC & FC. We found significant correlation between all above mentioned parameters.

- Turbidity and BOD show significant correlation with TC & FC and its correlation coefficient (r^2) of Turbidity with TC and FC is 0.64 and 0.61 respectively and for BOD the correlation coefficient (r^2) with TC and FC is 0.65, 0.60 respectively at the outlet point of the plant. These are shown in Fig. 4.7 to 4.10.

  Haas et. al, 1983 noted that increased values of turbidity were associated with increased concentration of microorganism. Studies have showed a correlation between decreased turbidity and reduced bacterial counts. *Cinque et. al, 2004* stated that high turbidity is currently used as a surrogate of pathogens and harvesting of water is based on its measurement. *Mallin et. al, 2000 & Muirhead et. al, 2004* stated that there was a correlation between turbidity and indicator bacteria concentrations (*Nishida et. al, 2005*)
- A correlation between TSS with TC & FC has been found (r^2 = 0.76 & 0.76 respectively) at the outlet point of the plant. These are shown in Fig. 4.11and 4.12 respectively.
- As suggested by *Fecham et. al, 1981* that removal of bacteria caused by settlement. Because they adsorbed or interrupt within suspended solids. *Drift et. al, 1977* reported that the bacterial removal could be achieved by sorption of bacteria to the sludge flocs. According to *Mahler et. al, 2000* a significant proportion of bacteria were associated with suspended solids.

➢ Above all these things operation parameters like MLSS, SVI and F/M ratio has been related with effluent TC and FC and by controlling those operational parameters it was tested that whether enhanced removal can be attained by controlling these parameters. These operational parameters show the significant correlation with effluent TC & FC.

- Concentration of indicator microorganisms was increased with the increasing value of MLSS in the effluent. The correlation coefficient (r^2) between MLSS and indicator microorganisms (TC & FC) is 0.85 and 0.84 respectively (shown in Fig. 4.13 and 4.14).

- Similarly significant relationship was attained between the concentrations of indicator microorganisms in the effluent with F/M value. A concentration of these organisms was decreased with the decreasing value of F/M. The correlation coefficient (r^2) between F/M and indicator microorganisms (TC and FC) is 0.78 and 0.54 respectively (shown in Fig. 4.15 and 4.16)
- Even Concentration of indicator microorganisms in the effluent was decreased with more settling (lesser SV30). The correlation coefficient (r^2) between SV30 and indicator microorganisms (TC & FC) is 0.78 and 0.89 respectively (shown in Fig. 4.17 and 4.18)

4.2 FLUIDIZED AEROBIC BED (FAB)PROCESS, BAKKARWALA (DELHI)

On the basis of the analyzed data in Fluidized Aerobic Bed Process, Bakkarwala (Delhi) following observations have been made

- In the **Raw sewage** BOD, COD and TSS was found vary from 85 - 174 mg/L (Avg.- 139.25 mg/L), 92.48 - 374.91 mg/L (Avg.- 233.17 mg/L) and 212 -526 mg/L (Avg.- 379.25 mg/L) respectively. As per Metcalf & Eddy (1995) typical COD concentration in the Untreated Domestic sewage ranges from 250-1000 mg/L.

- The BOD, COD and TSS concentration in **effluent** ranges from 16 - 48 mg/L (Avg.- 28.50 mg/L), 46.54 – 105.874 mg/L (Avg.- 66.187 mg/L) and 42 -92 mg/L (Avg.- 65.75 mg/L) respectively.

- The **mean removal efficiency** of BOD, COD and TSS has been found to be 79.50, 73.06 and 82.66 respectively. Most of the researchers have mentioned the removal efficiency of BOD for FAB in the range of 85-93%. As per final report, Volume 6- Technical Analysis, Section B-Sewerage and Sanitation, TA 4106-IND: *Kerala Sustainable Urban Development Project*, the FAB system can remove 85-90% BOD , 85-90% Suspended Solids.

- TC and FC concentrations in the system **influent** was varied from $9.3 \times 10^5 - 6.4 \times 10^6$ MPN/100mL (Avg. – 3.68×10^6 MPN/100mL) and $4.3 \times 10^4 - 7.5 \times 10^5$ MPN/100mL (Avg. – 4.24×10^5 MPN/100mL).

- Observations revealed that the **effluent** has concentration of TC and FC ranges from $2.3x10^5$- 9.3x 10^5 MPN/100mL (Avg. 6.7 x 10^5 MPN/100mL) and 9.3x 10^3 - 9.3 x 10^4 MPN/100 ml (Avg.- 6.24 x 10^4 MPN /100mL)

- The percentages **mean removal efficiency** of TC and FC has been found 80.39 and 82.45. As per final report,Volume 6-Technical Analysis, Section B-Sewerage and Sanitation, TA 4106-IND: *Kerala Sustainable Urban Development Project*, the FAB system can remove 60-90% of Total coli form (before chlorination). Livingston, 1991; Sokol, 2001and 2003 has reported that with favorable operating conditions, from hydrodynamic and mass transfer point of view, the pollutant could be biologically degraded up to 90%. The mean value of FC in treated effluent (5.38 x 10^5 MPN /100mL) is more than the permissible limits i.e. 1000 MPN/100mL, as specified by WHO (1989) for unrestricted irrigation.

- Further attempts have been made to establish the relationship between key wastewater constituents & operational parameters such as BOD, TSS and Turbidity with respect to TC & FC. We found significant correlation between all above mentioned parameters.

    - Turbidity and BOD show significant correlation with TC & FC and its correlation coefficient (r^2) of Turbidity with TC and FC is 0.73 and 0.66 respectively and for BOD the correlation coefficient (r^2) with TC and FC is 0.53, 0.54 respectively at the outlet point of the plant. These are shown in Fig. 4.25 to 4.28.

      Haas et. al, 1983 noted that increased values of turbidity were associated with increased concentration of microorganism. Studies have showed a correlation between decreased turbidity and reduced bacterial counts. *Cinque et. al, 2004* stated that high turbidity is currently used as a surrogate of pathogens and harvesting of water is based on its measurement. *Mallin et. al, 2000, Nagels et. al, 2002 & Muirhead et. al, 2004* stated that there was a correlation between turbidity and indicator bacteria concentrations (*Nishida et. al, 2005*)
    - A correlation between TSS with TC & FC has been found (r^2 = 0.72 & 0.76 respectively) at the outlet point of the plant. These are shown in Fig. 4.29 and 4.30, respectively.

- As suggested by *Fecham et. al, 1981* that removal of bacteria caused by settlement. Because they adsorbed or interrupt within suspended solids. *Drift et. al, 1977* reported that the bacterial removal could be achieved by sorption of bacteria to the sludge flocs. According to *Mahler et. al, 2000* a significant proportion of bacteria were associated with suspended solids.

➢ Above all these things operation parameters like MLSS, SVI and F/M ratio has been related with effluent TC and FC and by controlling those operational parameters it was tested that whether enhanced removal can be attained by controlling these parameters. These operational parameters show the significant correlation with effluent TC & FC.

- Concentration of indicator microorganisms was increased with the increasing value of MLSS in the effluent. The correlation coefficient (r^2) between MLSS and indicator microorganisms (TC & FC) is 0.89 and 0.73 respectively (shown in Fig. 4.31 and 4.32).
- Similarly significant relationship was attained between the concentrations of indicator microorganisms in the effluent with F/M value. A concentration of these organisms was decreased with the decreasing value of F/M. The correlation coefficient (r^2) between F/M and indicator microorganisms (TC and FC) is 0.45 and 0.54 respectively (shown in Fig. 4.33 and 4.34)
- Even Concentration of indicator microorganisms in the effluent was decreased with more settling (lesser SV30). The correlation coefficient (r^2) between SV30 and indicator microorganisms (TC & FC) is 0.57 and 0.62 respectively (shown in Fig. 4.35 and 4.36)

4.3 FLUIDIZED AEROBIC BED (FAB) PROCESS, MOLARBUND (DELHI)

On the basis of the analyzed data in Fluidized Aerobic Bed Process Molarbund, **following** observations have been made

➢ In the **Raw sewage** BOD, COD and TSS was found vary from 60 - 380 mg/L (Avg.- 255.62 mg/L), 151.02 - 963.124 mg/L (Avg.- 629.16 mg/L) and 302 - 1414 mg/L (Avg.- 941.75 mg/L) respectively. As per Metcalf & Eddy (1995) typical COD concentration in the Untreated Domestic sewage ranges from 250-1000 mg/L.

- The BOD, COD and TSS concentration in **effluent** ranges from 16 - 92 mg/L (Avg.- 59 mg/L), 42.93 – 152.36 mg/L (Avg.- 108.20 mg/L) and 58 -214 mg/L (Avg.- 130.50 mg/L) respectively.

- The **mean removal efficiency** of BOD, COD and TSS has been found to be 76.92, 82.80 and 86.20 respectively. Most of the researchers have mentioned the removal efficiency of BOD for FAB in the range of 85-93%.

- TC and FC concentrations in the system **influent** was varied from $2.3 \times 10^6 - 6.5 \times 10^7$ MPN/100mL (Avg. – 2.88×10^7 MPN/100mL) and $2.3 \times 10^5 - 4.3 \times 10^5$ MPN/100mL (Avg. – 3.15×10^5 MPN/100mL).

- Observations revealed that the **effluent** has concentration of TC and FC ranges from $3.9 \times 10^5 - 9.3 \times 10^6$ MPN/100mL (Avg. 4.79×10^5 MPN/100mL) and $2.3 \times 10^4 - 7.5 \times 10^4$ MPN/100 ml (Avg.- 4.9×10^4 MPN /100mL)

- The percentages **mean removal efficiency** of TC and FC has been found 83.40 and 84.44. As per Final Report, Volume 6-Technical Analysis, Section B-Sewerage and Sanitation, TA 4106-IND: *Kerala Sustainable Urban Development Project*, the FAB system can remove 85-90% BOD , 85-90% Suspended Solids and 60-90% of Total coli form (before chlorination). Livingston, 1991; Sokol, 2001and 2003 has reported that with favorable operating conditions, from hydrodynamic and mass transfer point of view, the pollutant could be biologically degraded up to 90%. The mean value of FC in treated effluent (5.38×10^5 MPN /100mL) is more than the permissible limits i.e. 1000 MPN/100mL, as specified by WHO (1989) for unrestricted irrigation.

- Further attempts have been made to establish the relationship between key wastewater constituents & operational parameters such as BOD, TSS and Turbidity with respect to TC & FC. We found significant correlation between all above mentioned parameters.

  - Turbidity and BOD show significant correlation with TC & FC and its correlation coefficient (r^2) of Turbidity with TC and FC is 0.71 and 0.64 respectively and for BOD the correlation coefficient (r^2) with TC and FC is 0.67, 0.67 respectively at the outlet point of the plant. These are shown in Fig. 4.43 to 4.46.

Haas et. al, 1983 noted that increased values of turbidity were associated with increased concentration of microorganism. Studies have showed a correlation between decreased turbidity and reduced bacterial counts. *Cinque et. al, 2004* stated that high turbidity is currently used as a surrogate of pathogens and harvesting of water is based on its measurement. *Mallin et. al, 2000, Nagels et. al, 2002 & Muirhead et. al, 2004* stated that there was a correlation between turbidity and indicator bacteria concentrations (*Nishida et. al, 2005*)

- A correlation between TSS with TC & FC has been found (r^2 = 0.64 and 0.61 respectively) at the outlet point of the plant. These are shown in Fig. 4.47 and 4.48.
- As suggested by *Fecham et. al, 1981* that removal of bacteria caused by settlement. Because they adsorbed or interrupt within suspended solids. *Drift et. al, 1977* reported that the bacterial removal could be achieved by sorption of bacteria to the sludge flocs. According to *Mahler et. al, 2000* a significant proportion of bacteria were associated with suspended solids.

➢ Above all these things operation parameters like MLSS, SVI and F/M ratio has been related with effluent TC and FC and by controlling those operational parameters it was tested that whether enhanced removal can be attained by controlling these parameters. These operational parameters show the significant correlation with effluent TC & FC.

- Concentration of indicator microorganisms was increased with the increasing value of MLSS in the effluent. The correlation coefficient (r^2) between MLSS and indicator microorganisms (TC & FC) is 0.76 and 0.78 respectively (shown in Fig. 4.49 and 4.50).
- Similarly significant relationship was attained between the concentrations of indicator microorganisms in the effluent with F/M value. A concentration of these organisms was decreased with the decreasing value of F/M. The correlation coefficient (r^2) between F/M and indicator microorganisms (TC and FC) is 0.62 and 0.63 respectively (shown in Fig. 4.51 and 4.52)

- Even Concentration of indicator microorganisms in the effluent was decreased with more settling (lesser SV30). The correlation coefficient (r^2) between SV30 and indicator microorganisms (TC & FC) is 0.67 and 0.66 respectively (shown in Fig. 4.53 and 4.54)

4.4 BAFFLED ANAEROBIC BIOREACTOR AND FLOATING PLANT (FP) AT VASANT VIHAR

On the basis of the analyzed data in Fluidized Aerobic Bed Process Vasant Vihar, **following** observations have been made

- In the **Raw sewage** BOD, COD and TSS was found vary from 124 – 288 mg/L (Avg.- 219.83 mg/L), 236.697 - 536.236 mg/L (Avg.- 418.50 mg/L) and 254 - 668 mg/L (Avg.- 476 mg/L) respectively. As per Metcalf & Eddy (1995) typical COD concentration in the untreated domestic sewage ranges from 250-1000 mg/L.

- The BOD, COD and TSS concentration in **effluent** ranges from 26 - 68 mg/L (Avg.- 48 mg/L), 113.54 – 236.354 mg/L (Avg.- 183.88 mg/L) and 114 -274 mg/L (Avg.- 189.33 mg/L) respectively.

- The **mean removal efficiency** of BOD, COD and TSS has been found to be 78.16, 56.22 and 60.22 respectively. Most of the researchers have mentioned the removal efficiency of BOD for FAB in the range of 85-93%.

- TC and FC concentrations in the system **influent** was varied from $9.3 \times 10^5 - 6.4 \times 10^6$ MPN/100mL (Avg. – 3.68×10^6 MPN/100mL) and $4.3 \times 10^4 - 7.5 \times 10^5$ MPN/100mL (Avg. – 4.24×10^5 MPN/100mL).

- Observations revealed that the **effluent** has concentration of TC and FC ranges from $2.3 \times 10^5 - 9.3 \times 10^5$ MPN/100mL (Avg. 6.70×105^4 MPN/100mL) and $9.3 \times 10^3 - 9.3 \times 10^4$ MPN/100 ml (Avg.- 6.24×10^4 MPN /100mL)

- The percentages **mean removal efficiency** of TC and FC has been found 80.39 and 82.45. Livingston, 1991; Sokol, 2001and 2003 has reported that with favorable operating conditions, from hydrodynamic and mass transfer point of view, the pollutant could be biologically degraded up to 90%. The mean value of FC in treated effluent (6.24 x 10^4 MPN /100mL) is more than the permissible limits i.e. 1000 MPN/100mL, as specified by WHO (1989) for unrestricted irrigation.

➢ Further attempts have been made to establish the relationship between key wastewater constituents & operational parameters such as BOD, TSS and Turbidity with respect to TC & FC. We found significant correlation between all above mentioned parameters.

- Turbidity and BOD show significant correlation with TC & FC and its correlation coefficient (r^2) of Turbidity with TC and FC is 0.79 and 0.69 respectively and for BOD the correlation coefficient (r^2) with TC and FC is 0.66, 0.63 respectively at the outlet point of the plant. These are shown in Fig. 4.61 to 4.64.

  Haas et. al, 1983 noted that increased values of turbidity were associated with increased concentration of microorganism. Studies have showed a correlation between decreased turbidity and reduced bacterial counts. *Cinque et. al, 2004* stated that high turbidity is currently used as a surrogate of pathogens and harvesting of water is based on its measurement. *Mallin et. al, 2000*, *Nagels et. al, 2002* & *Muirhead et. al, 2004* stated that there was a correlation between turbidity and indicator bacteria concentrations (*Nishida et. al, 2005*)
- A correlation between TSS with TC & FC has been found (r^2 = 0.64 & 0.65 respectively) at the outlet point of the plant. These are shown in Fig. 4.65 and 4.66.
- As suggested by *Fecham et. al, 1981* that removal of bacteria caused by settlement. Because they adsorbed or interrupt within suspended solids. *Drift et. al, 1977* reported that the bacterial removal could be achieved by sorption of bacteria to the sludge flocs. According to *Mahler et. al, 2000* a significant proportion of bacteria were associated with suspended solids.

4.5 AERATION CUM CONSTRUCTED WETLANDS (CW) AT SECTOR-13

On the basis of the analyzed data in Fluidized Aerobic Bed Process Faridabad, **following** observations have been made

- In the **Raw sewage** BOD, COD and TSS was found vary from 182 - 250 mg/L (Avg.- 210 mg/L), 305.12 – 777.84 mg/L (Avg.- 516.04 mg/L) and 754 - 1430 mg/L (Avg.- 1048.70 mg/L) respectively. As per Metcalf & Eddy (1995) typical COD concentration in the Untreated Domestic sewage ranges from 250-1000 mg/L.

- The BOD, COD and TSS concentration in **effluent** ranges from 32 - 72 mg/L (Avg.- 54 mg/L), 102.95 – 197.20 mg/L (Avg.- 145.44 mg/L) and 126 -236 mg/L (Avg.- 183.17 mg/L) respectively.

- The **mean removal efficiency** of BOD, COD and TSS has been found to be 74.28, 71.89 and 82.53 respectively. Most of the researchers have mentioned the removal efficiency of BOD for CW in the range of 85-93%.

- TC and FC concentrations in the system **influent** was varied from $6.5x10^6$ – $9.3x\ 10^7$ MPN/100mL (Avg. – $4.66\ x\ 10^7$ MPN/100mL) and $7.5\ x10^5$ – $6.5x\ 10^6$ MPN/100mL (Avg. – $3.9\ x\ 10^6$ MPN/100mL).

- Observations revealed that the **effluent** has concentration of TC and FC ranges from $6.4\ x10^5$ – $7.5\ x\ 10^6$ MPN/100mL (Avg. $5.14\ x\ 10^6$ MPN/100mL) and $9.3x\ 10^4$ – $4.3\ x\ 105^4$ MPN/100 ml (Avg.- $3.00\ x\ 10^5$ MPN /100mL)

The percentages **mean removal efficiency** of TC and FC has been found 90.15 and 87.60. Livingston, 1991; Sokol, 2001and 2003 has reported that with favorable operating conditions, from hydrodynamic and mass transfer point of view, the pollutant could be biologically degraded up to 90%. Kadlec and Knight, 1996 has listed the efficiency of the elimination of coliforms in various systems of constructed wetlands more than 90%. The mean value of FC in treated effluent ($5.38\ x\ 10^5$ MPN /100mL) is more than the permissible limits i.e. 1000 MPN/100mL, as specified by WHO (1989) for unrestricted irrigation.

- Further attempts have been made to establish the relationship between key wastewater constituents & operational parameters such as BOD, TSS and Turbidity with respect to TC & FC. We found significant correlation between all above mentioned parameters.
    - Turbidity and BOD show significant correlation with TC & FC and its correlation coefficient (r^2) of Turbidity with TC and FC is 0.70 and 0.81 respectively and for BOD the correlation coefficient (r^2) with TC and FC is 0.74, 0.60 respectively at the outlet point of the plant. These are shown in Fig. 4.73 to 4.76.

      Haas et. al, 1983 noted that increased values of turbidity were associated with increased concentration of microorganism. Studies have showed a correlation between decreased turbidity and reduced bacterial counts. *Cinque et. al, 2004* stated that high turbidity is currently used as a surrogate of pathogens and harvesting of water is based on its measurement. *Mallin et. al, 2000*, *Nagels et. al, 2002* & *Muirhead et. al, 2004* stated that there was a correlation between turbidity and indicator bacteria concentrations (*Nishida et. al, 2005*)
    - A correlation between TSS with TC & FC has been found (r^2 = 0.76 & 0.68 respectively) at the outlet point of the plant. These are shown in Fig. 4.77 to 4.78 respectively.
    - As suggested by *Fecham et. al, 1981* that removal of bacteria caused by settlement. Because they adsorbed or interrupt within suspended solids. *Drift et. al, 1977* reported that the bacterial removal could be achieved by sorption of bacteria to the sludge flocs. According to *Mahler et. al, 2000* a significant proportion of bacteria were associated with suspended solids.

- Above all these things operation parameters like MLSS, SVI and F/M ratio has been related with effluent TC and FC and by controlling those operational parameters it was tested that whether enhanced removal can be attained by controlling these parameters. These operational parameters show the significant correlation with effluent TC & FC.
    - Concentration of indicator microorganisms was increased with the increasing value of MLSS in the effluent. The correlation coefficient (r^2) between MLSS

and indicator microorganisms (TC & FC) is 0.63 and 0.57 respectively (shown in Fig. 4.79 and 4.80).

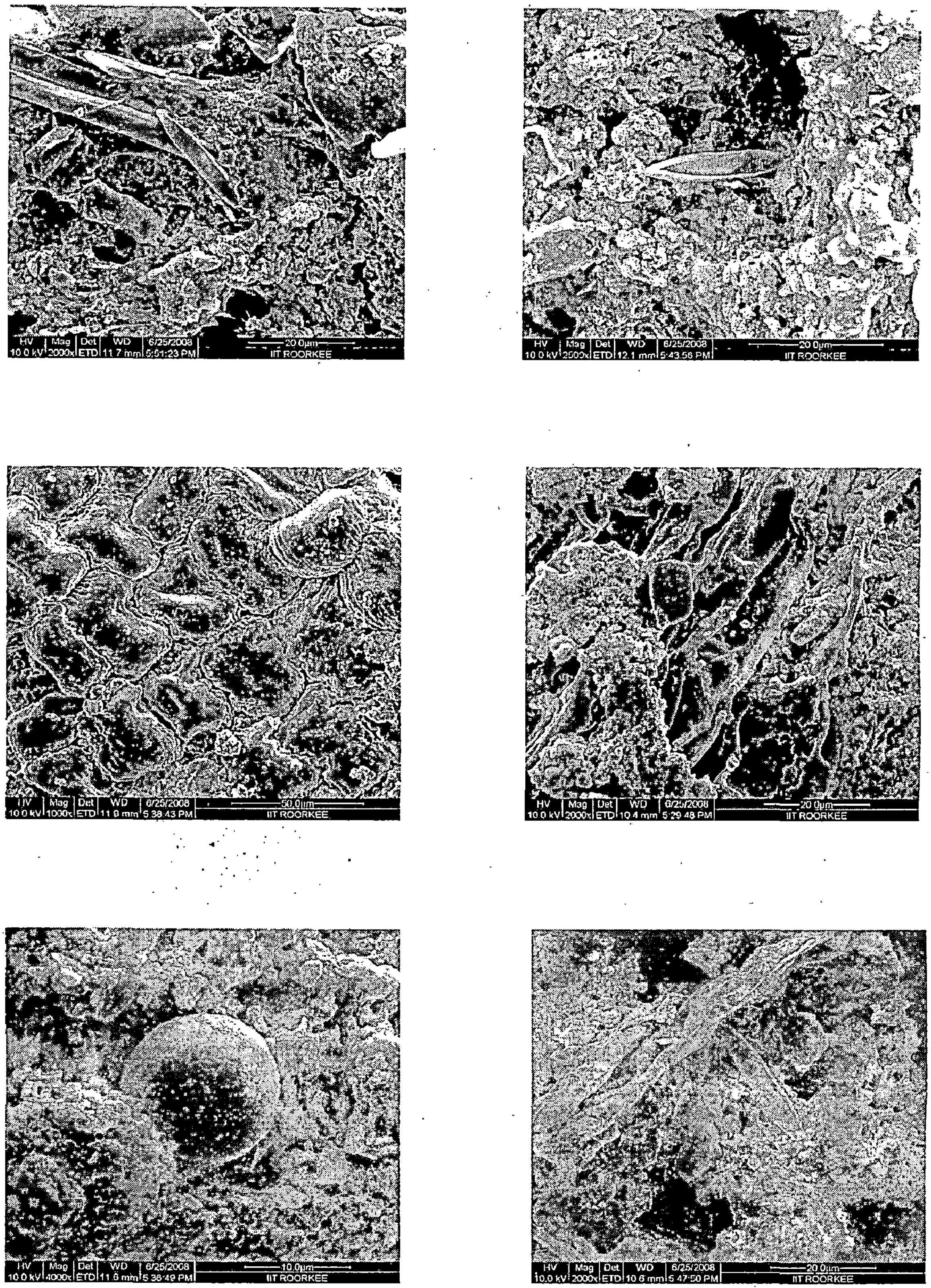
- Similarly significant relationship was attained between the concentrations of indicator microorganisms in the effluent with F/M value. A concentration of these organisms was decreased with the decreasing value of F/M. The correlation coefficient (r^2) between F/M and indicator microorganisms (TC and FC) is 0.58 and 0.57 respectively (shown in Fig. 4.81 and 4.82)

- Even Concentration of indicator microorganisms in the effluent was decreased with more settling (lesser SV30). The correlation coefficient (r^2) between SV30 and indicator microorganisms (TC & FC) is 0.57 and 0.67 respectively (shown in Fig. 4.83 and 4.84)

Further attempts have been made to establish the relationship between various microorganisms and role of Protozoa in removing microorganisms in constructed wetlands.The role of ciliated protozoa in the root zone method of wastewater treatment was assessed by analyzing ciliate community in the root rhizomes sample through Scanning Electron Microscopy (SEM) at 1000x magnification. The presence of protozoa and higher indicator coliform removal efficiency can be correlated. Ciliated protozoa in sewage treatment plants produce clear effluents of good quality (i.e. higher transparency of treated waste waters) because of their ability to feed on dispersed bacteria and suspended particles (*Ratshak et al, 1996; Curds et al, 1968*).

Regardless of bacterial diversity, maximum coliform destruction was correlated with the presence of protozoa. It appears that protozoan predation may exert pressure on bacterial populations in a variety of environments, both aqueous and terrestrial (*Enzinger et al, 1976*). Taking into account the retention time and ciliate abundance, it was calculated that ciliates, by their predatory activities, are capable of removing up to 2.35 x 10^5 and 0.45 x 10^5 E. coli in the first third of the planted gravel bed (Decamp O.; Warren A.; Sanchez R,1999.)

Fig. 4.1A : SEM Magnification of Root Rhizome Sample from CW And Present of Ciliated Protozoa



The presence of ciliate protozoa reflects an improvement in effluent quality with respect to reduced BOD, suspended solids particulates and pathogens and coliform numbers (*Salvado et al, 1995; Al. Shahwani et al, 1991*). *G. Bitton, 2002* signified the importance of protozoan as they feed on pathogenic bacteria and fecal bacteria contributing to their removal efficiency at 95%.

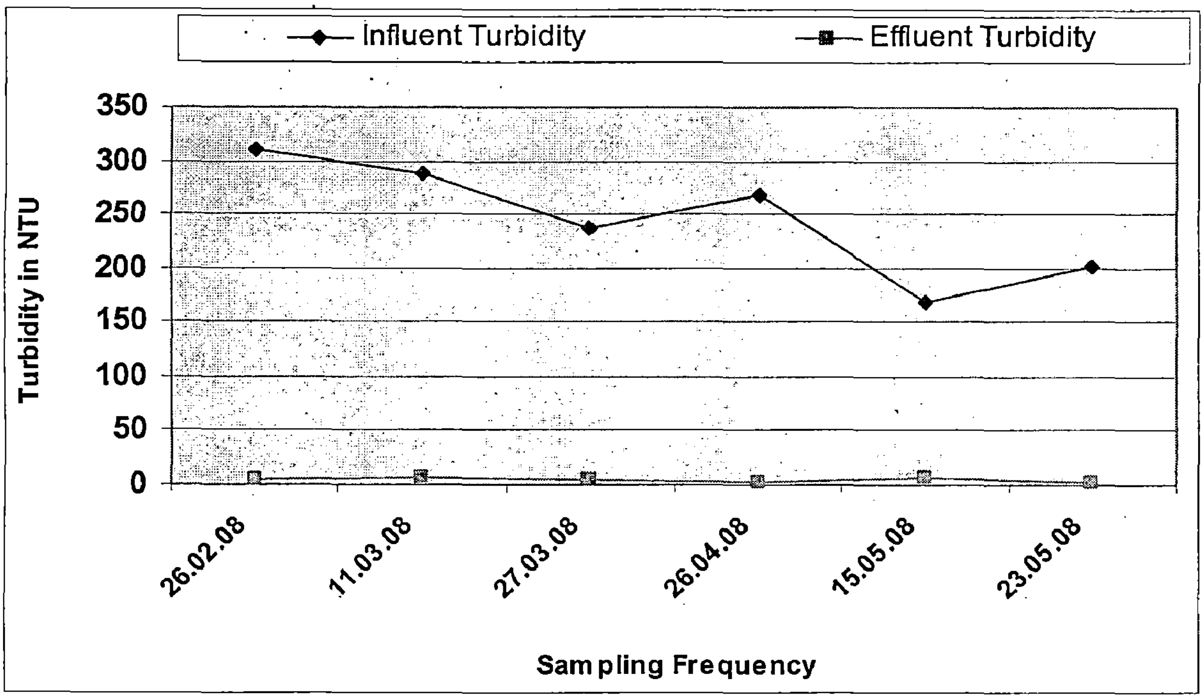


Fig.4.1 :Turbidity variations at Inlet and Outlet of SAFF plant Dehradun (Uttrakhand)

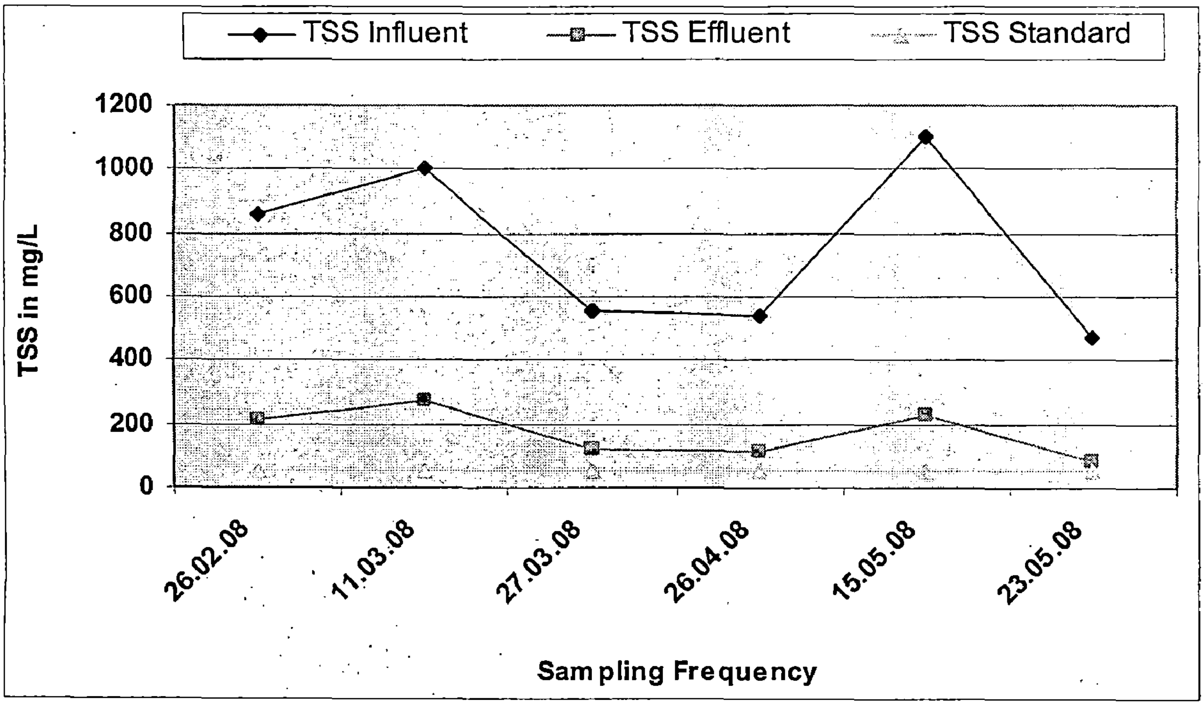


Fig.4.2 : TSS variations at Inlet and Outlet of SAFF plant Dehradun (Uttrakhand)

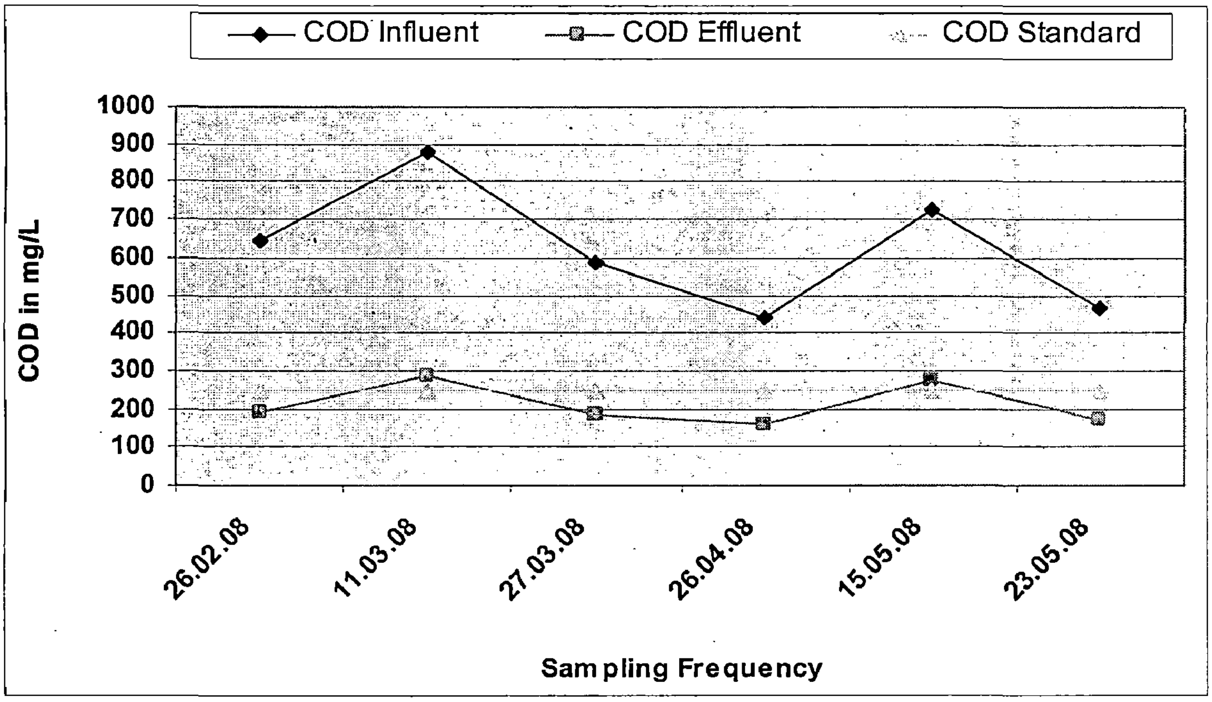


Fig.4.3 : COD variations at Inlet and Outlet of SAFF plant Dehradun (Uttrakhand)

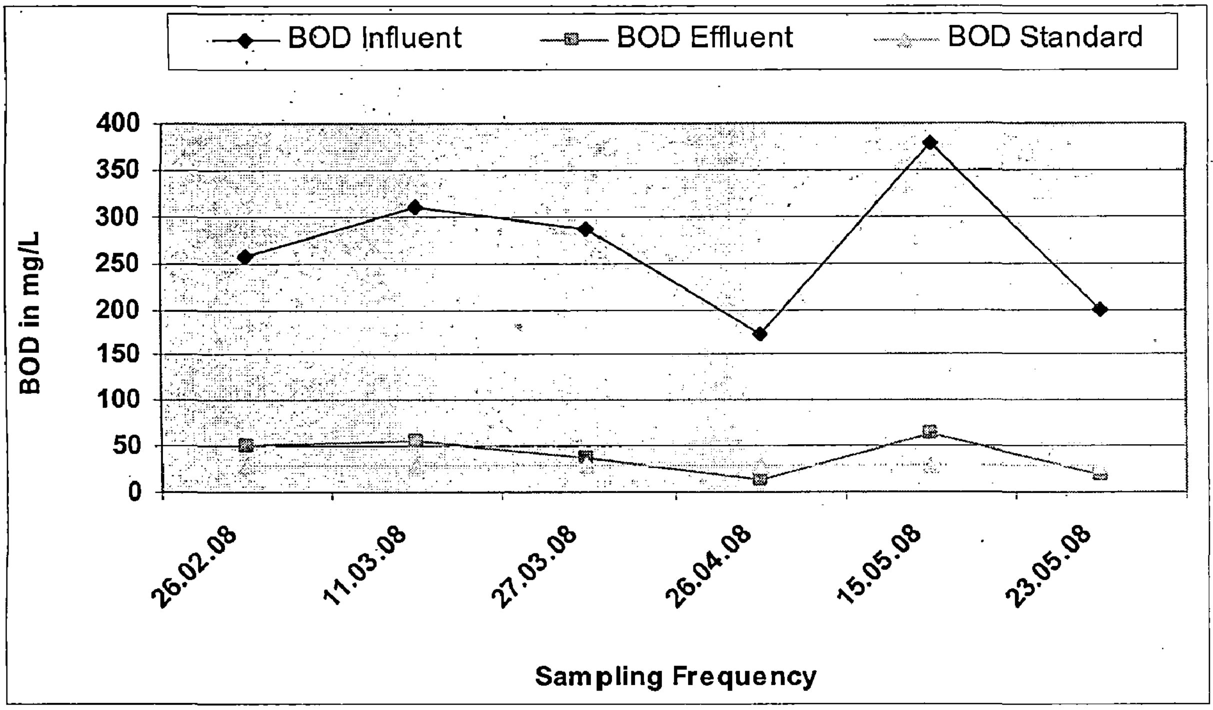


Fig.4.4: BOD variations at Inlet and Outlet of SAFF plant Dehradun (Uttrakhand)

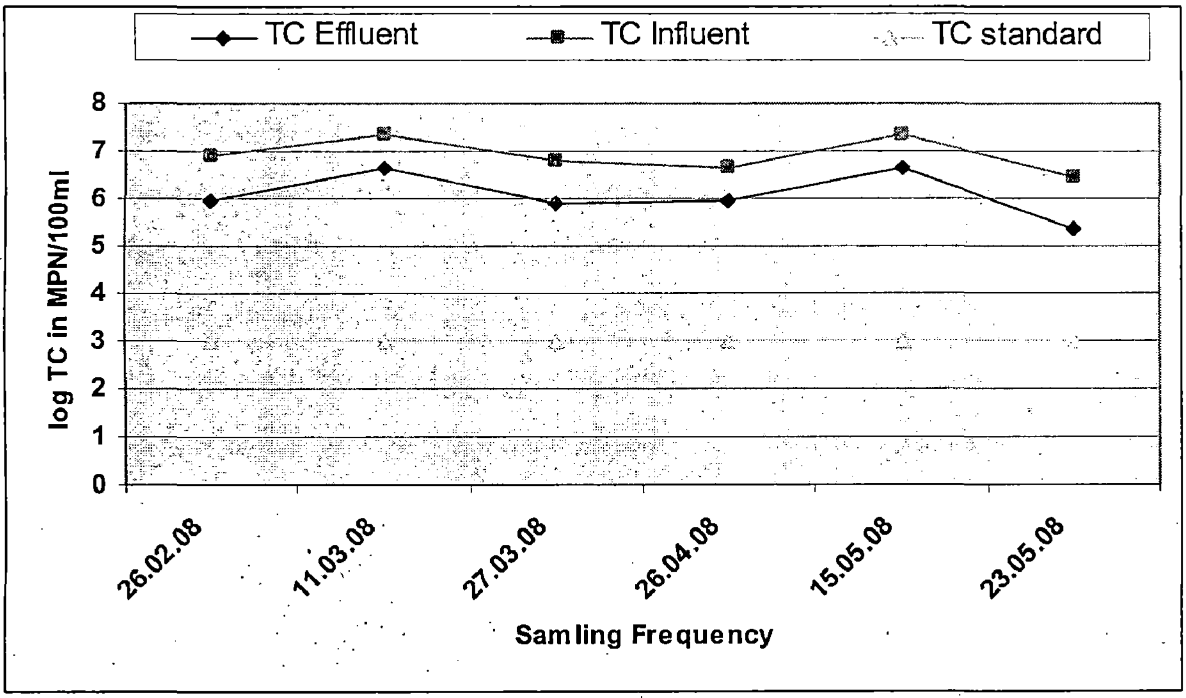


Fig.4.5 :TC variations at Inlet and Outlet of SAFF plant Dehradun (Uttrakhand)

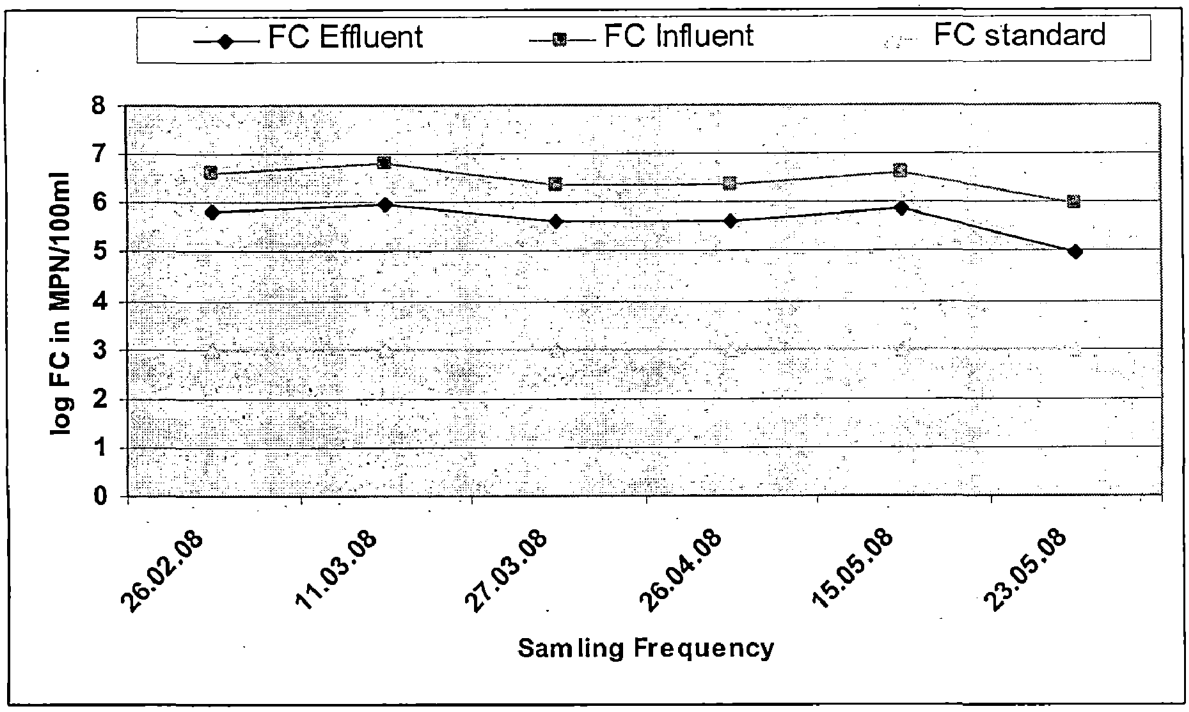


Fig. 4.6:FC variations at Inlet and Outlet of SAFF plant Dehradun (Uttrakhand)

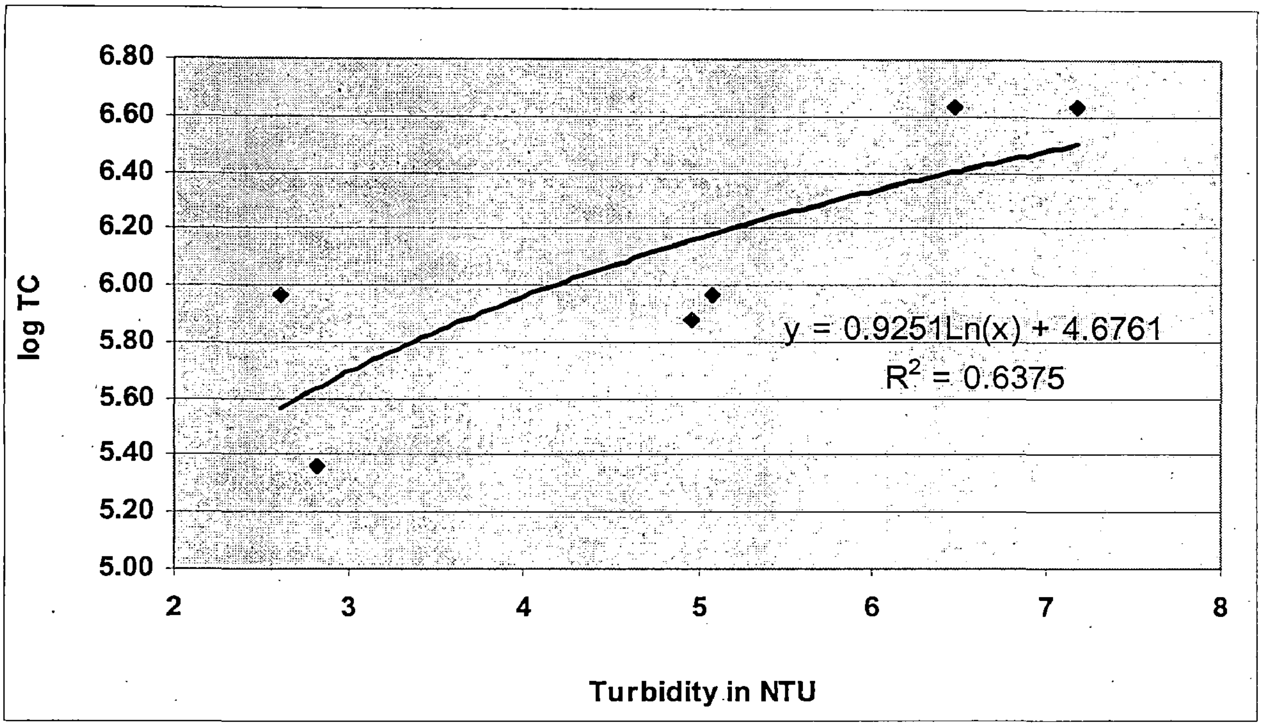


Fig.4.7:Correlation b/w Turbidity and TC at Outlet of SAFF plant Dehradun (Uttrakhand)

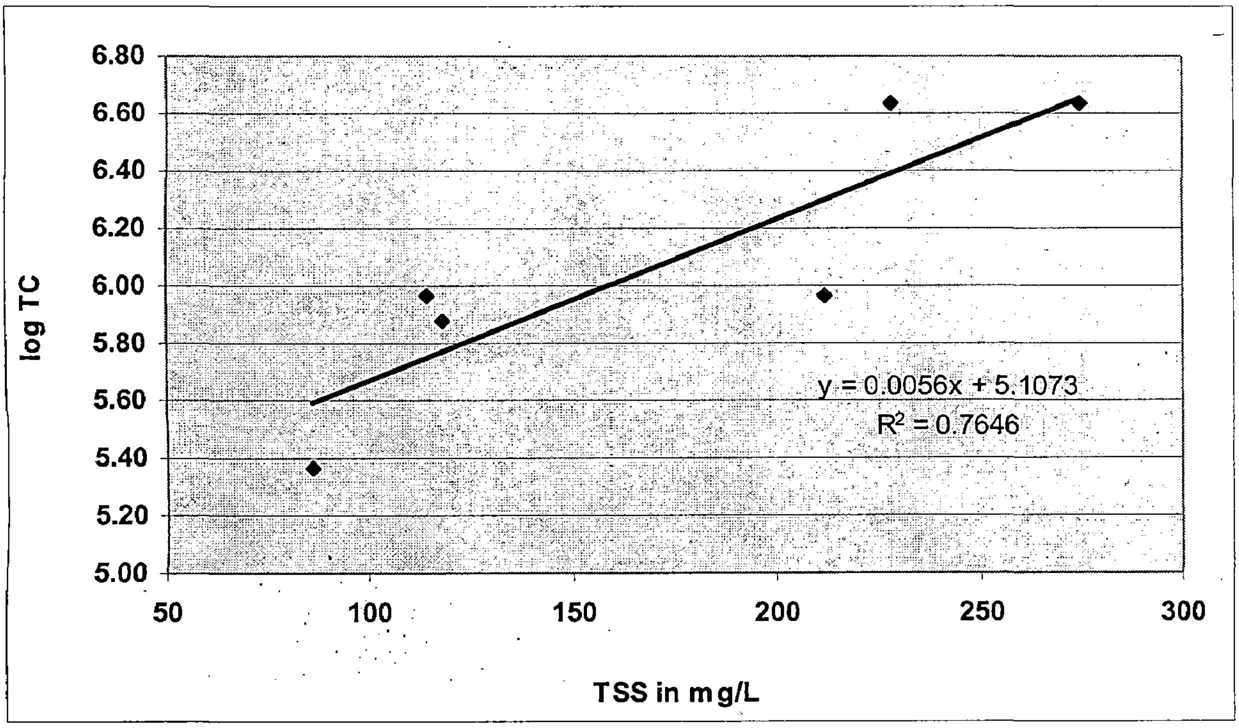


Fig.4.8:Correlation b/w TSS and TC at Outlet of SAFF plant Dehradun (Uttrakhand)

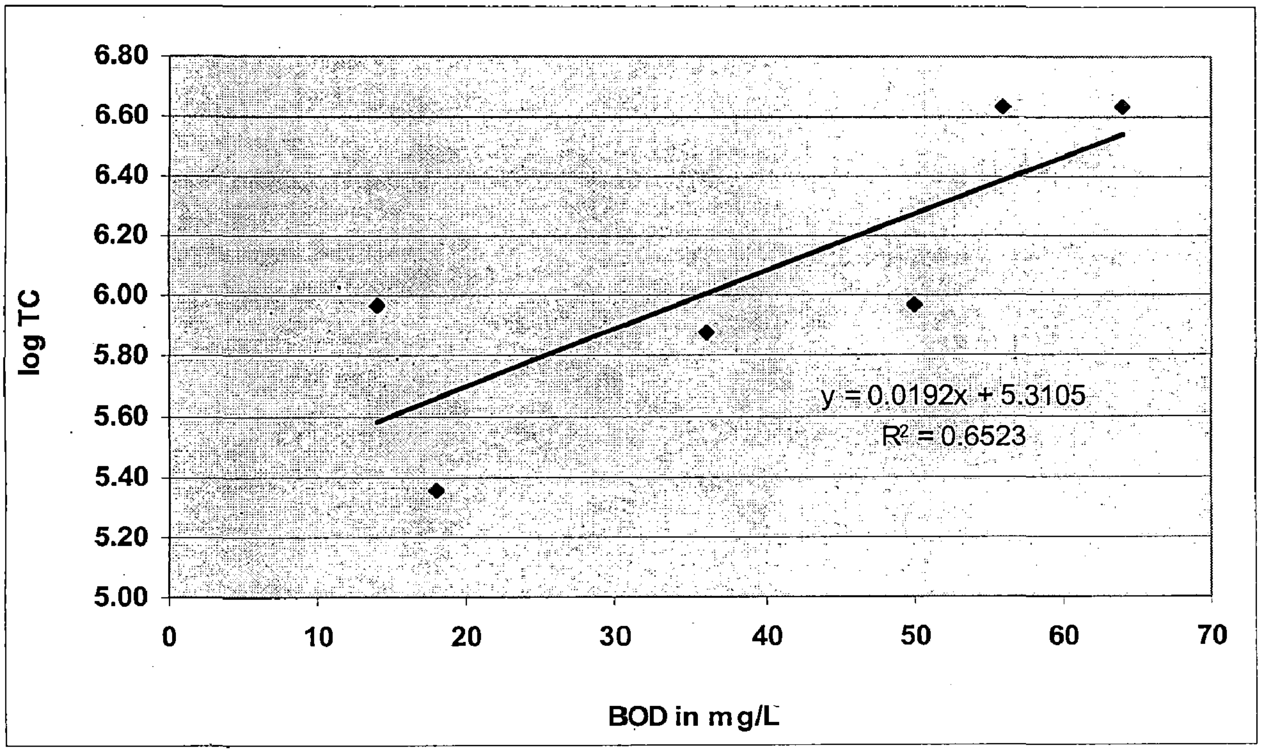


Fig.4.9:Correlation b/w BOD and TC at Outlet of SAFF plant Dehradun (Uttrakhand)

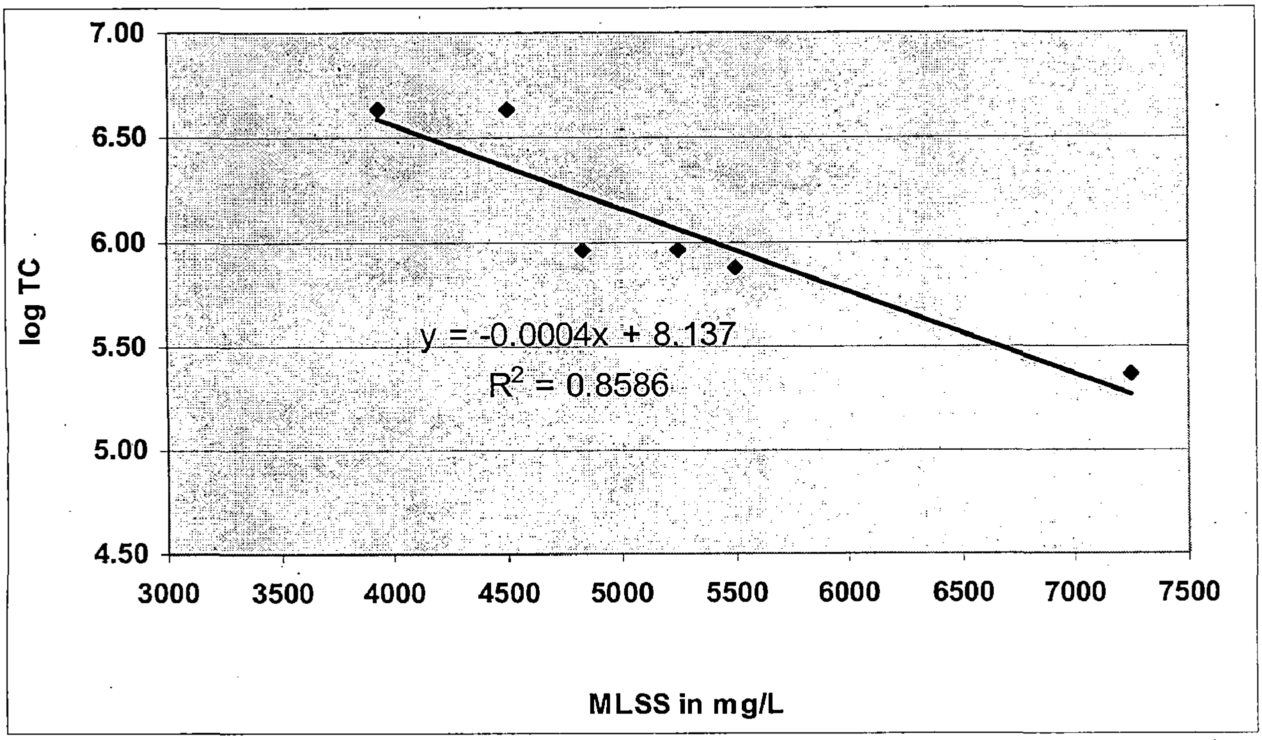


Fig.4.10:Correlation b/w MLSS and TC at Outlet of SAFF plant Dehradun (Uttrakhand)

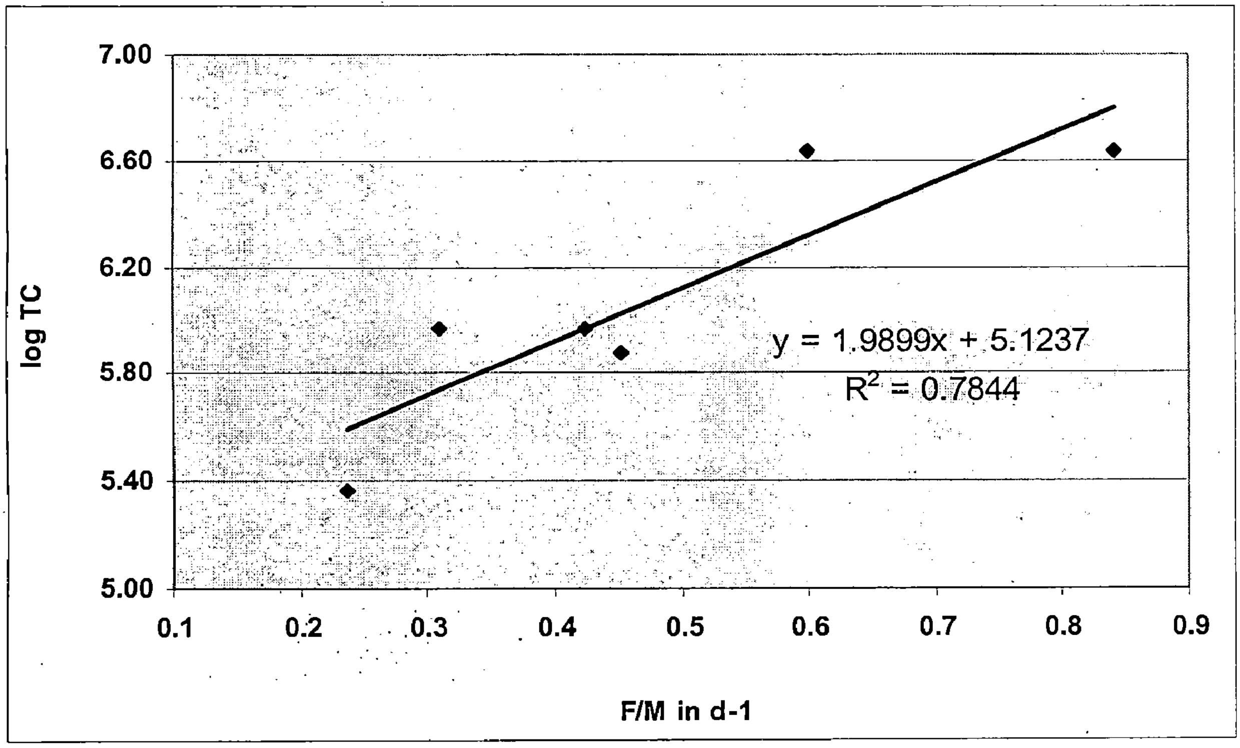


Fig.4.11:Correlation b/w F/M and TC at Outlet of SAFF plant Dehradun (Uttrakhand)

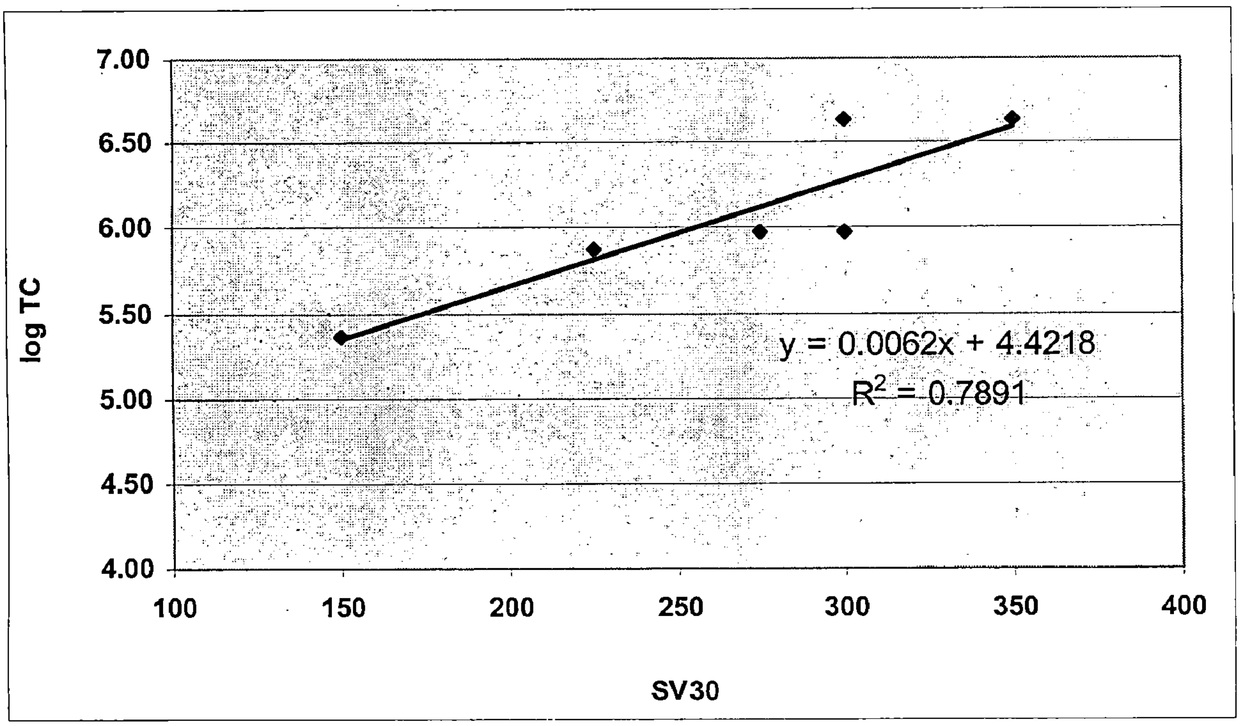


Fig.4.12:Correlation b/w SV30 and TC at Outlet of SAFF plant Dehradun (Uttrakhand)

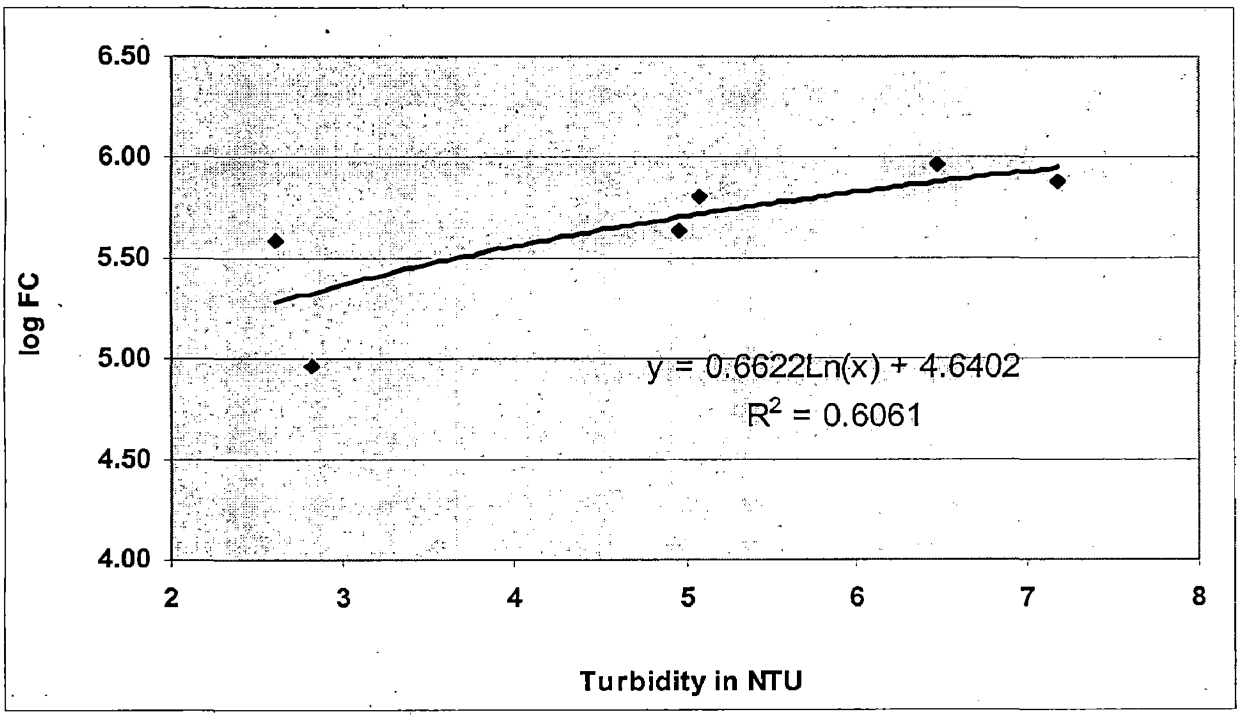


Fig.4.13:Correlation b/w Turbidity and TC at Outlet of SAFF plant Dehradun (Uttrakhand)

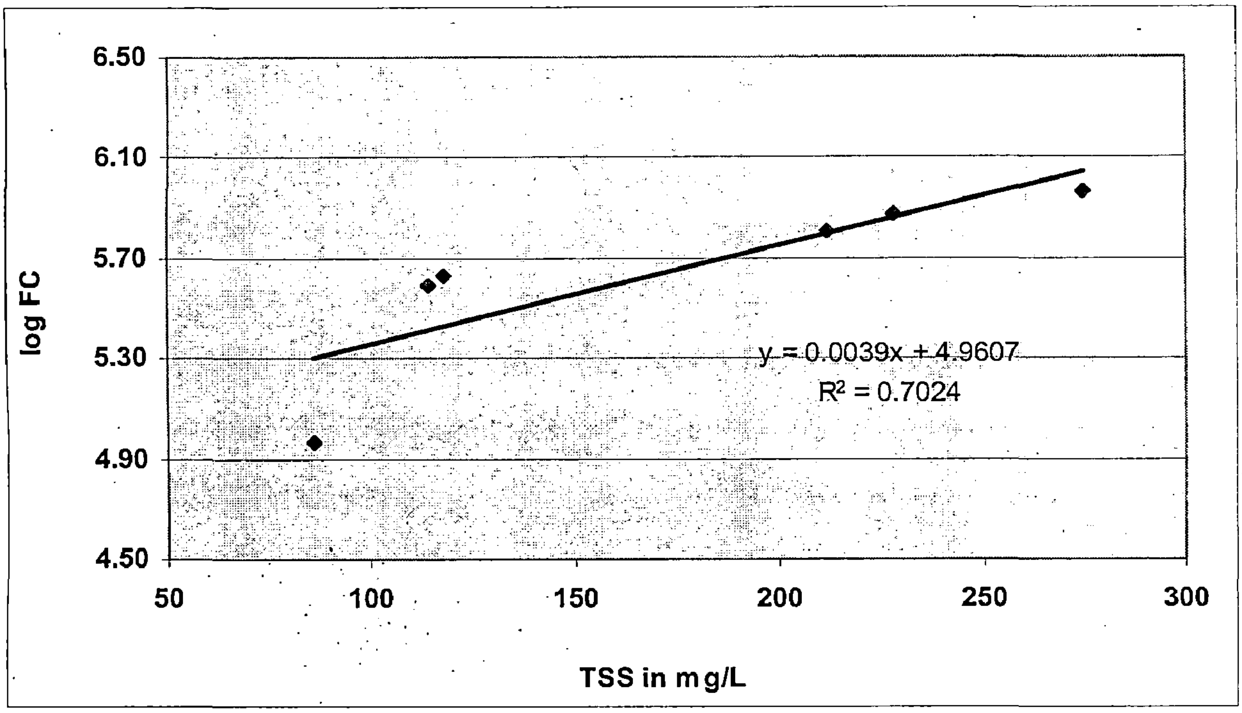


Fig.4.14:Correlation b/w TSS and FC at Outlet of SAFF plant Dehradun (Uttrakhand)

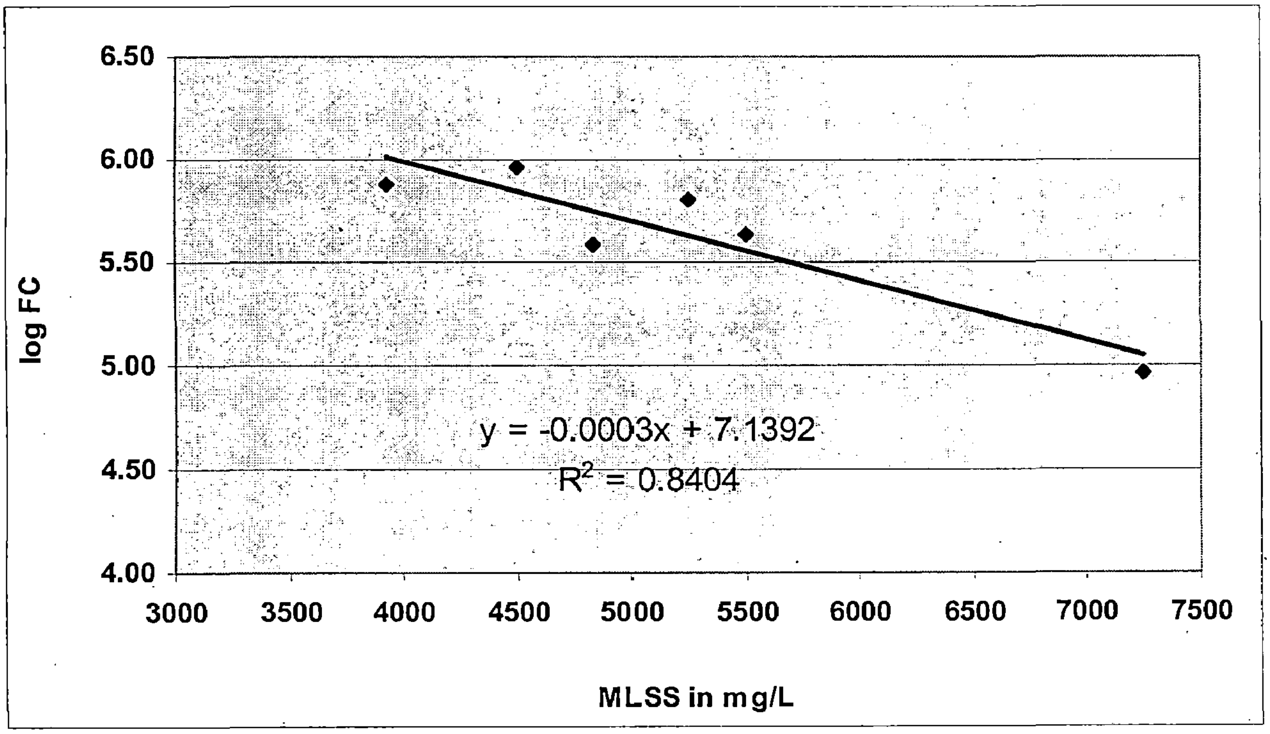


Fig.4.15:Correlation b/w TSS and FC at Outlet of SAFF plant Dehradun (Uttrakhand)

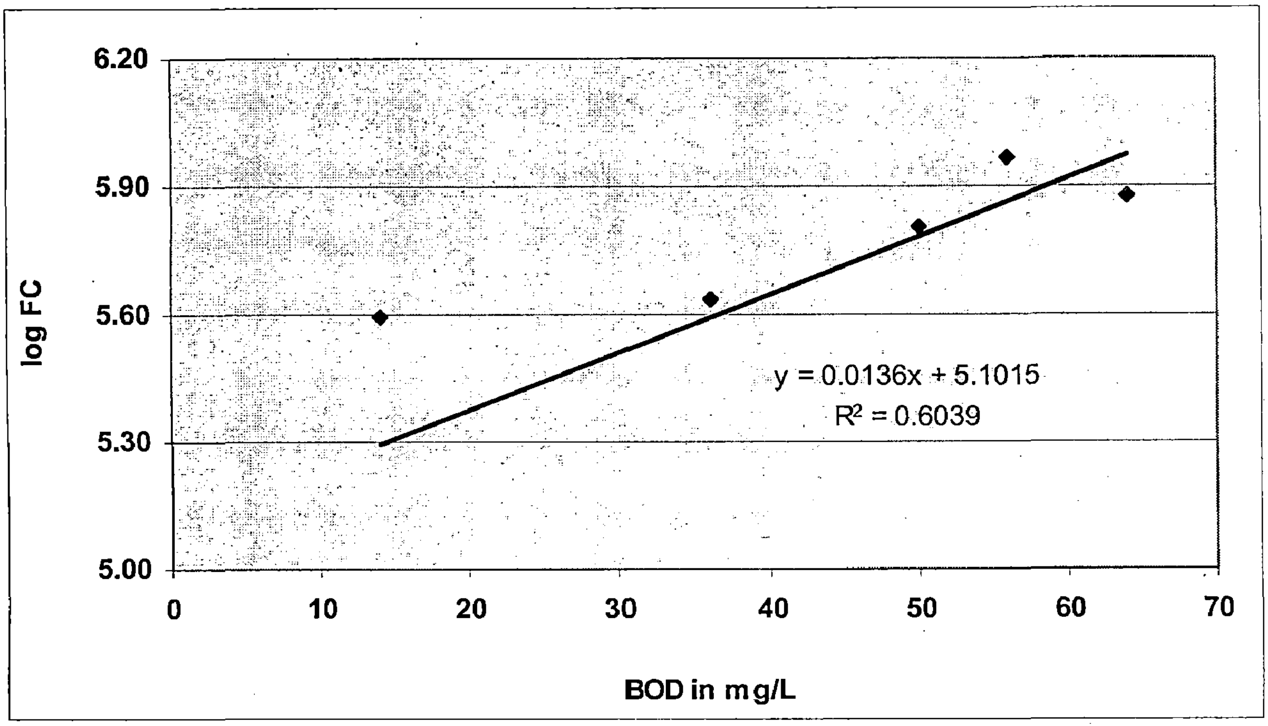


Fig.4.16:Correlation b/w BOD and FC at Outlet of SAFF plant Dehradun (Uttrakhand)

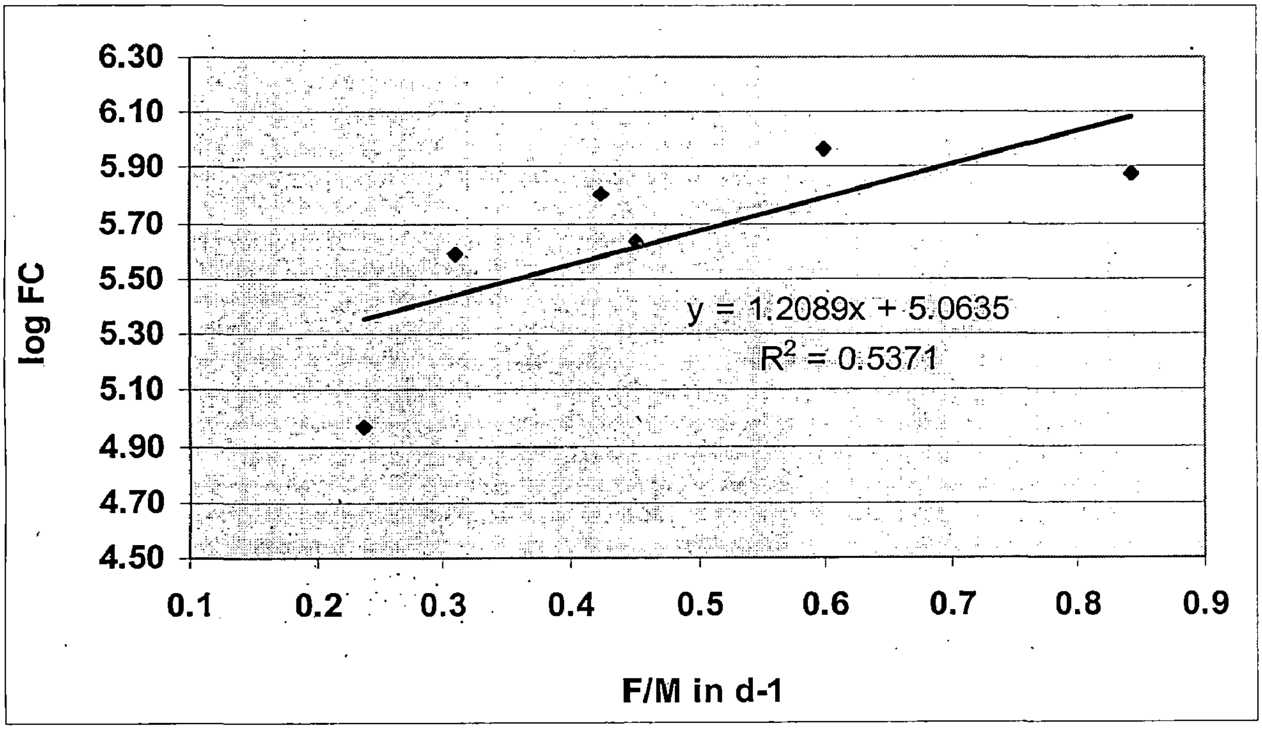


Fig.4.17:Correlation b/w F/M and FC at Outlet of SAFF plant Dehradun (Uttrakhand)

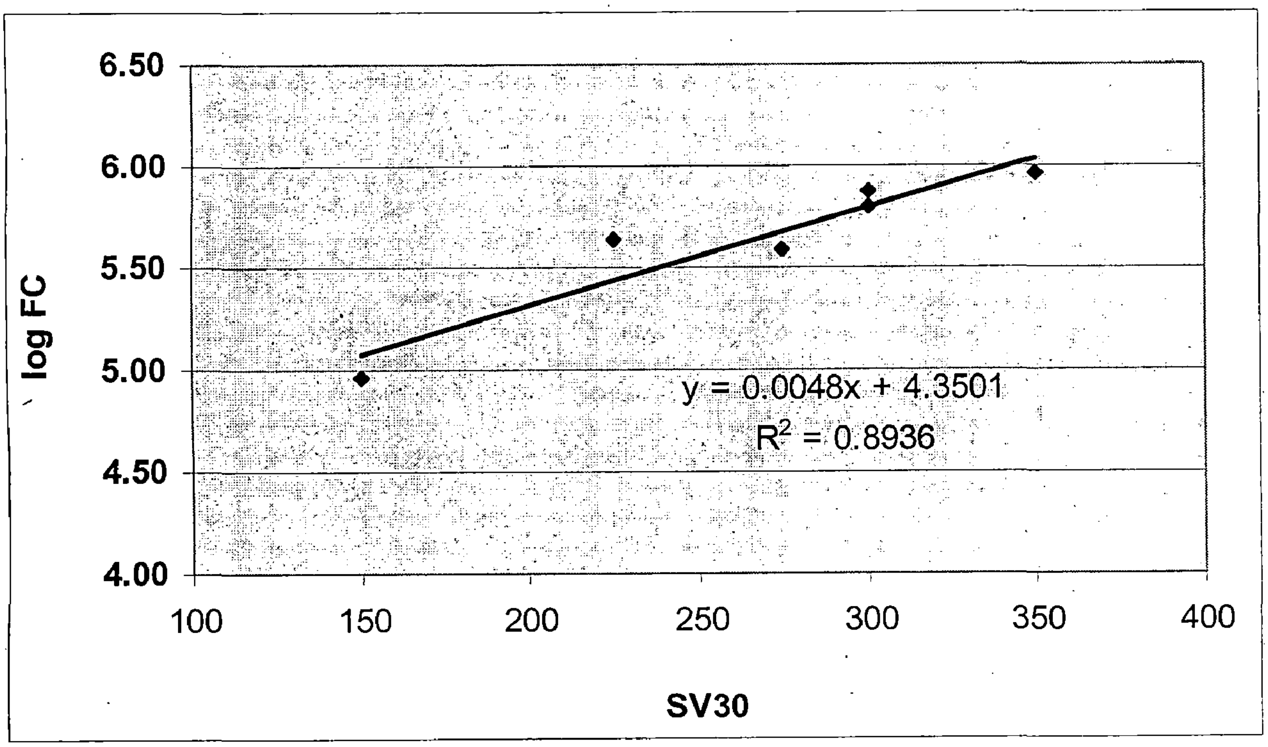


Fig.4.18:Correlation b/w SV30 and FC at Outlet of SAFF plant Dehradun (Uttrakhand)

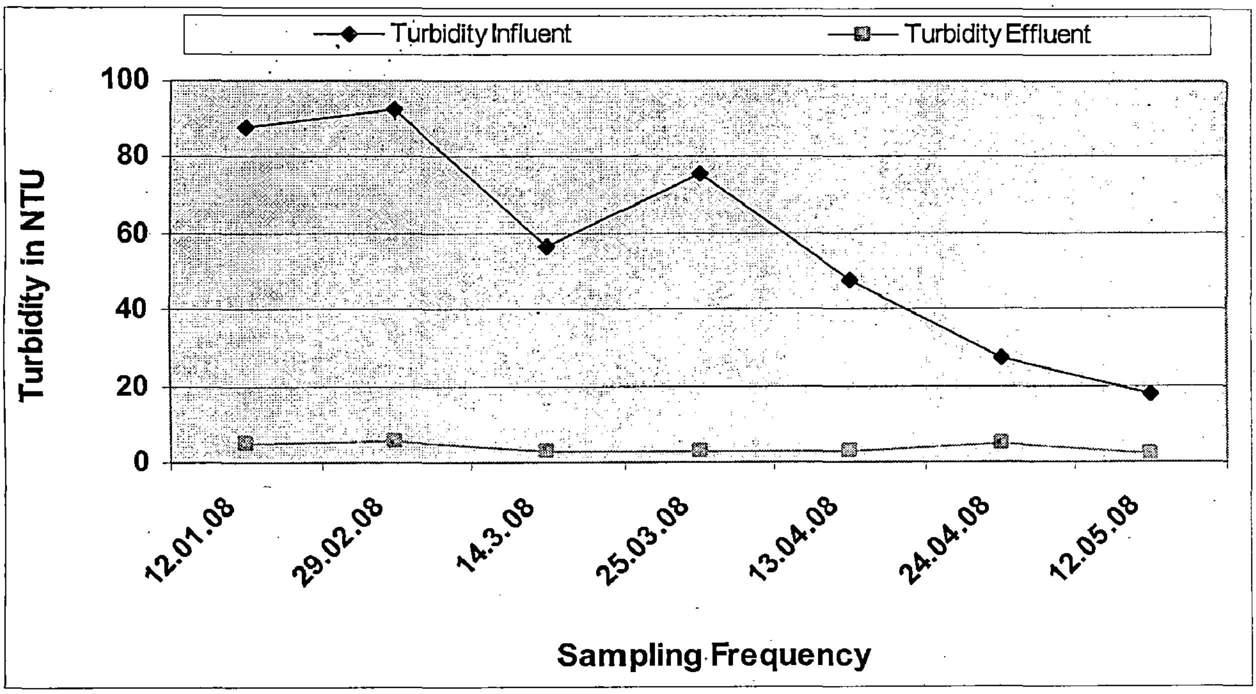


Fig. 4.19:Turbidity variations at Inlet and Outlet of FAB plant Bakkarwala (Delhi)

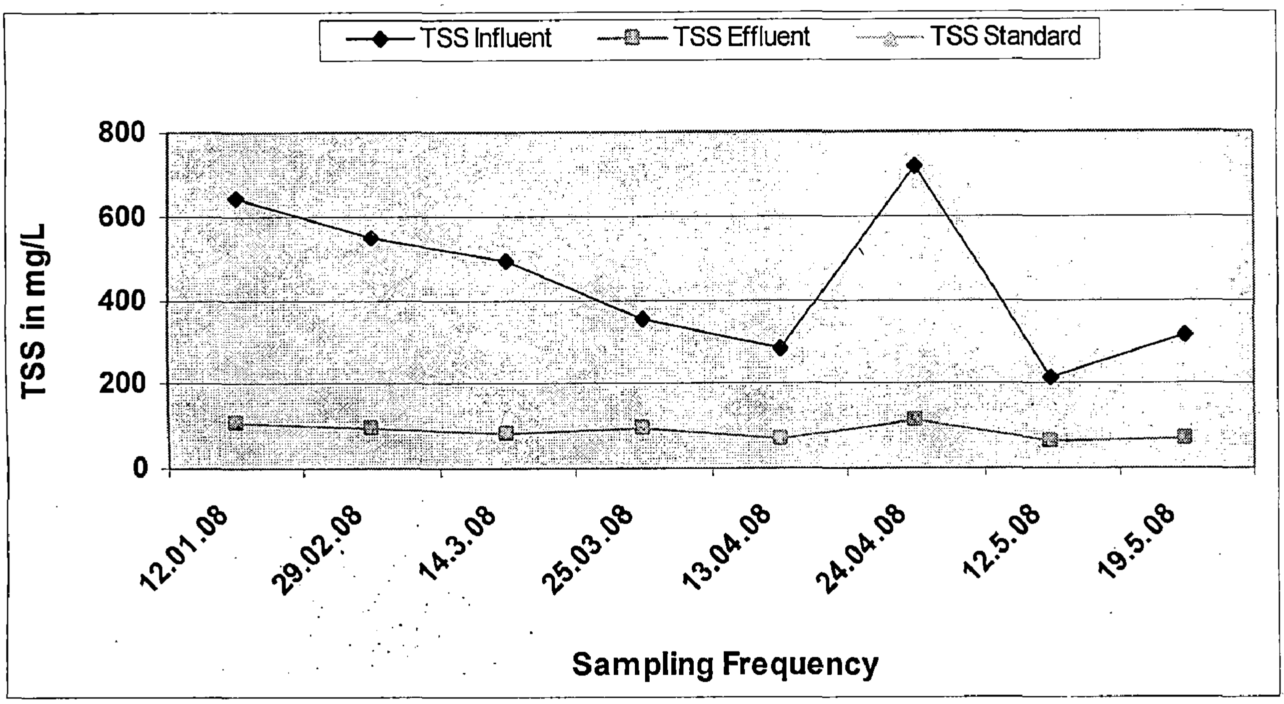


Fig. 4.20: TSS variations at Inlet and Outlet of FAB plant Bakkarwala (Delhi)

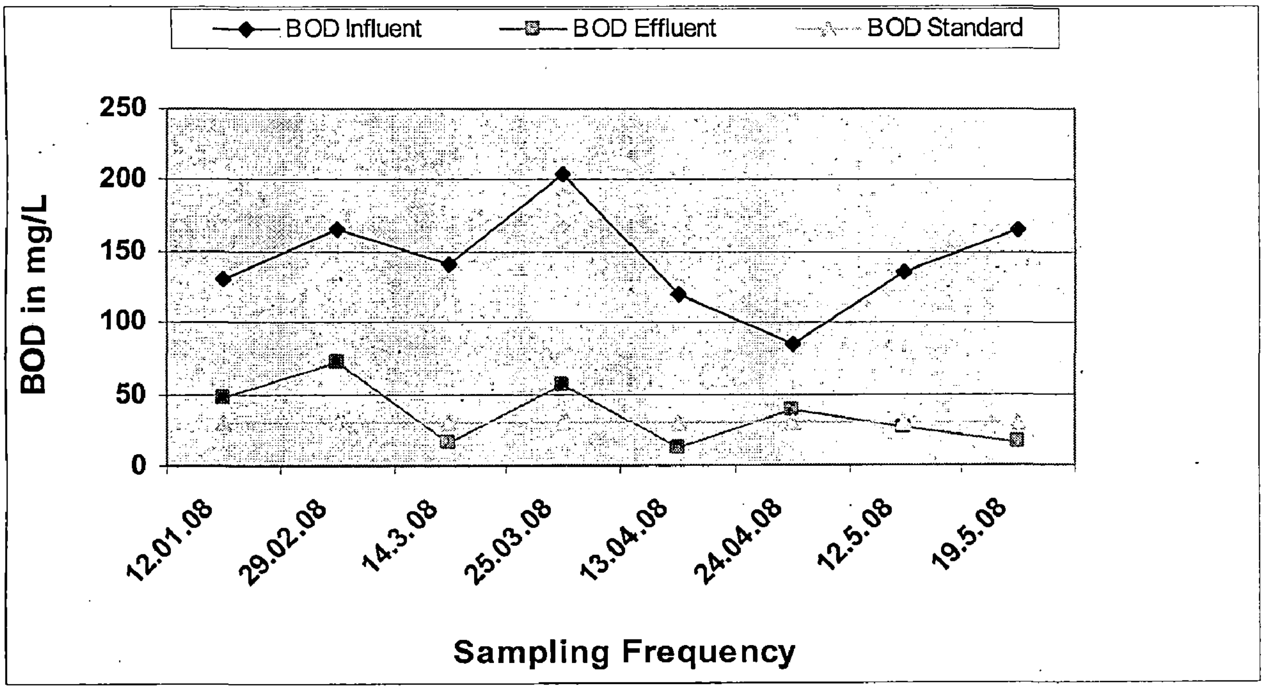


Fig.4.21: BOD variations at Inlet and Outlet of FAB plant Bakkarwala (Delhi)

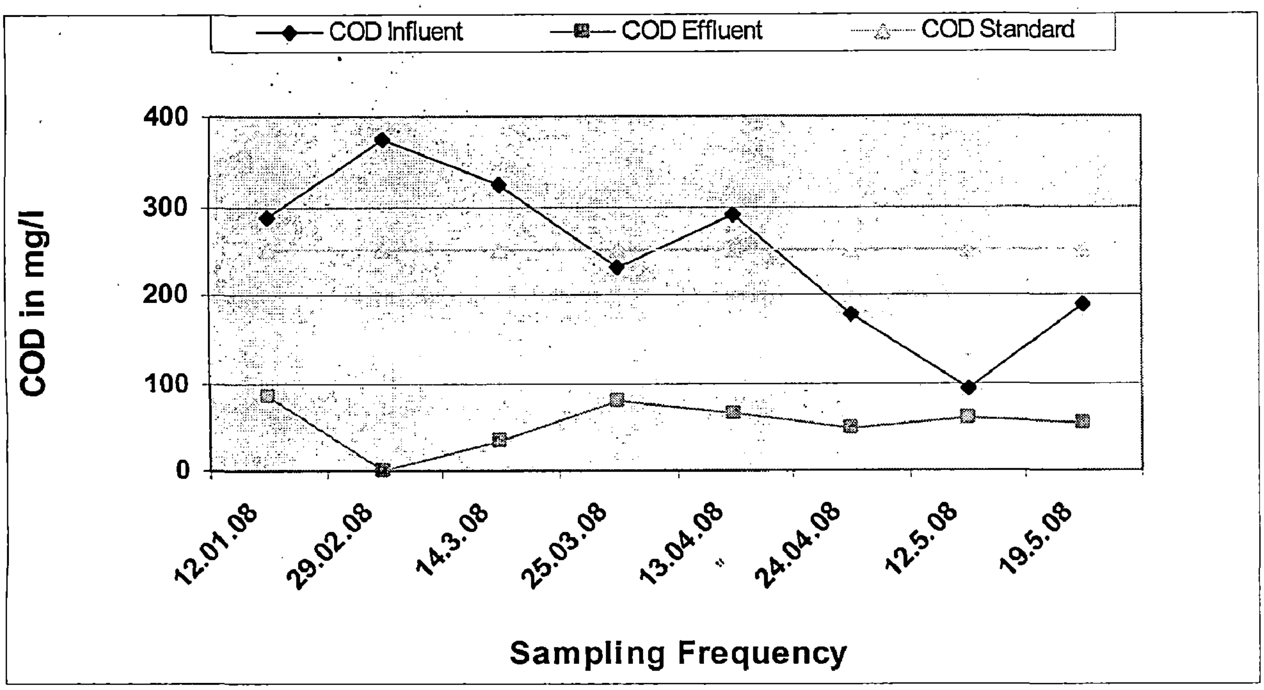


Fig. 4.22: COD variations at Inlet and Outlet of FAB plant Bakkarwala (Delhi)

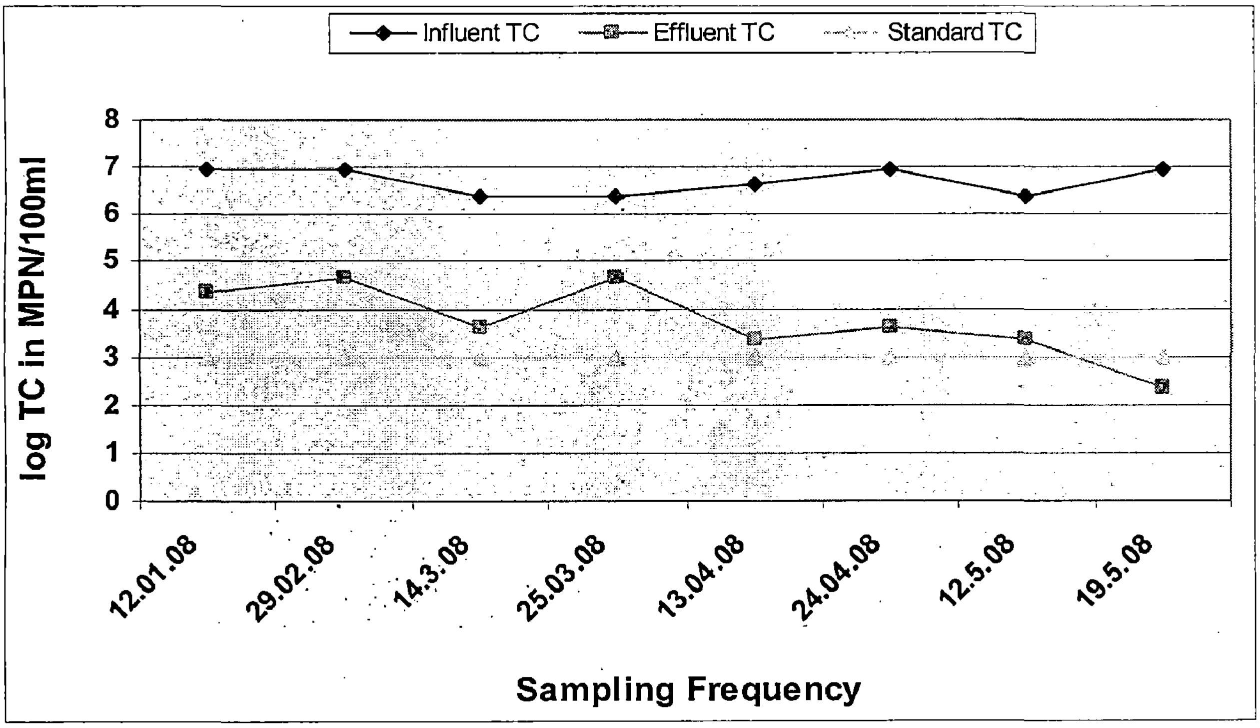


Fig. 4.23:TC variations at Inlet and Outlet of FAB plant Bakkarwala (Delhi)

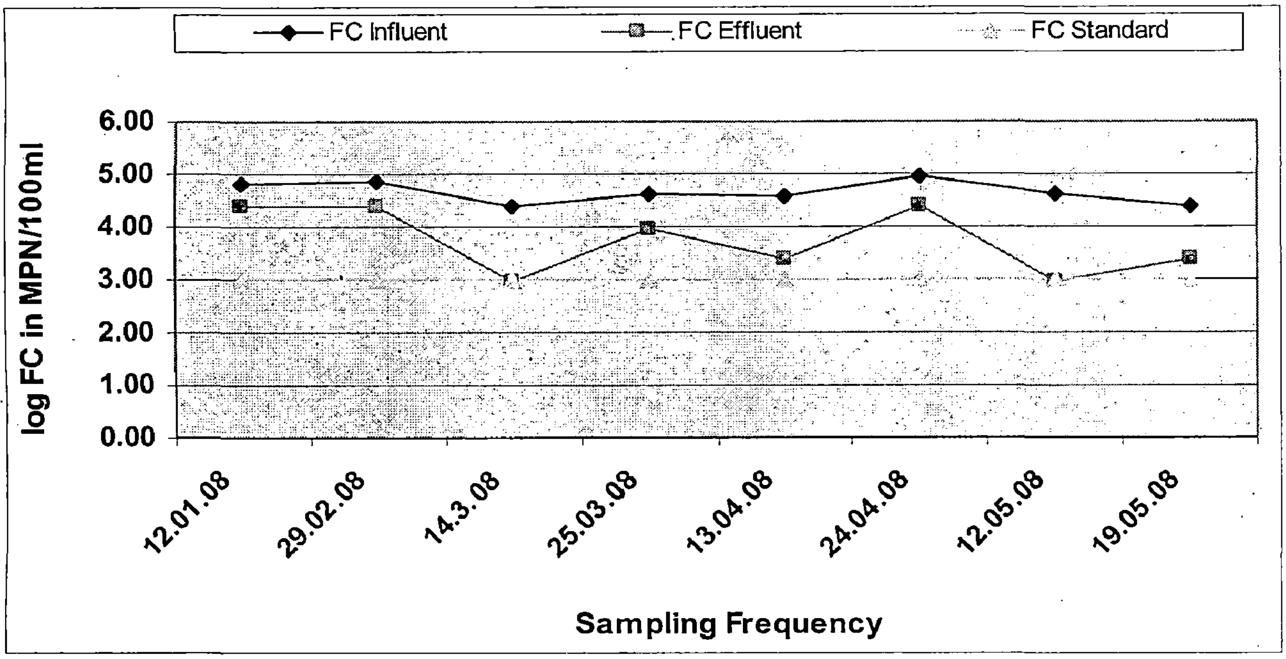


Fig.4.24 :FC variations at Inlet and Outlet of FAB plant Bakkarwala (Delhi)

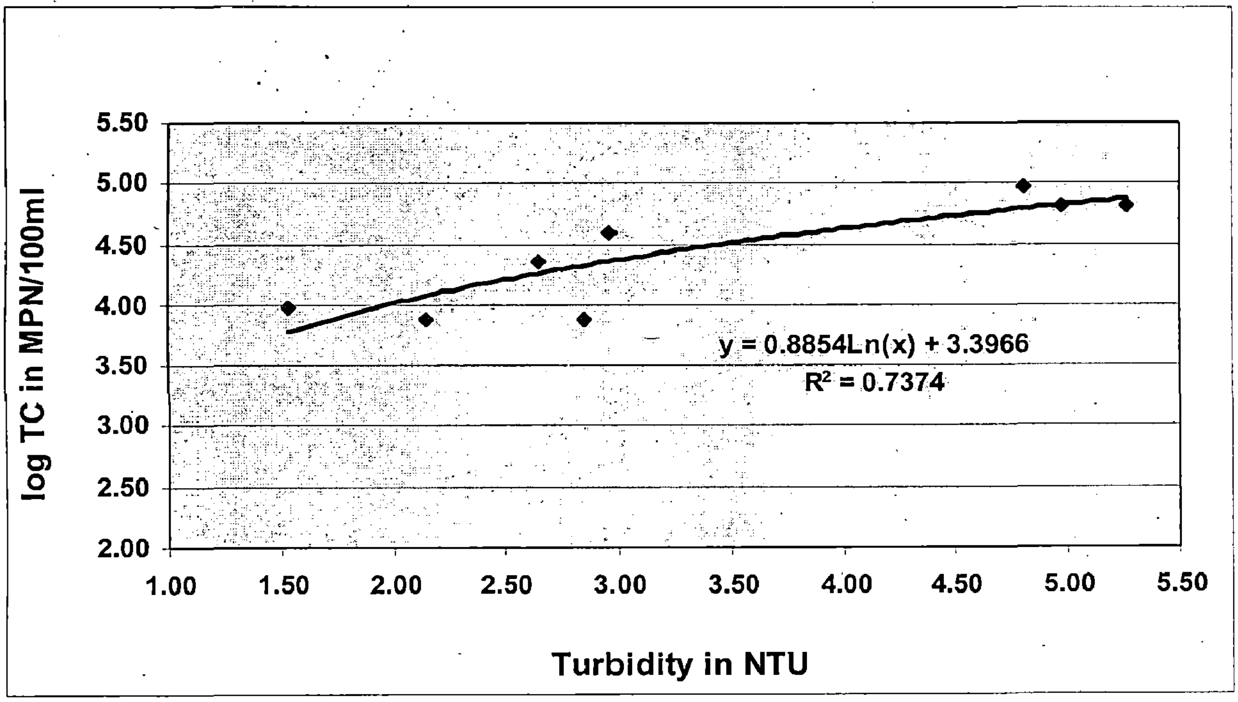


Fig.4.25:Correlation b/w Turbidity and TC at Outlet of FAB plant Bakkarwala (Delhi)

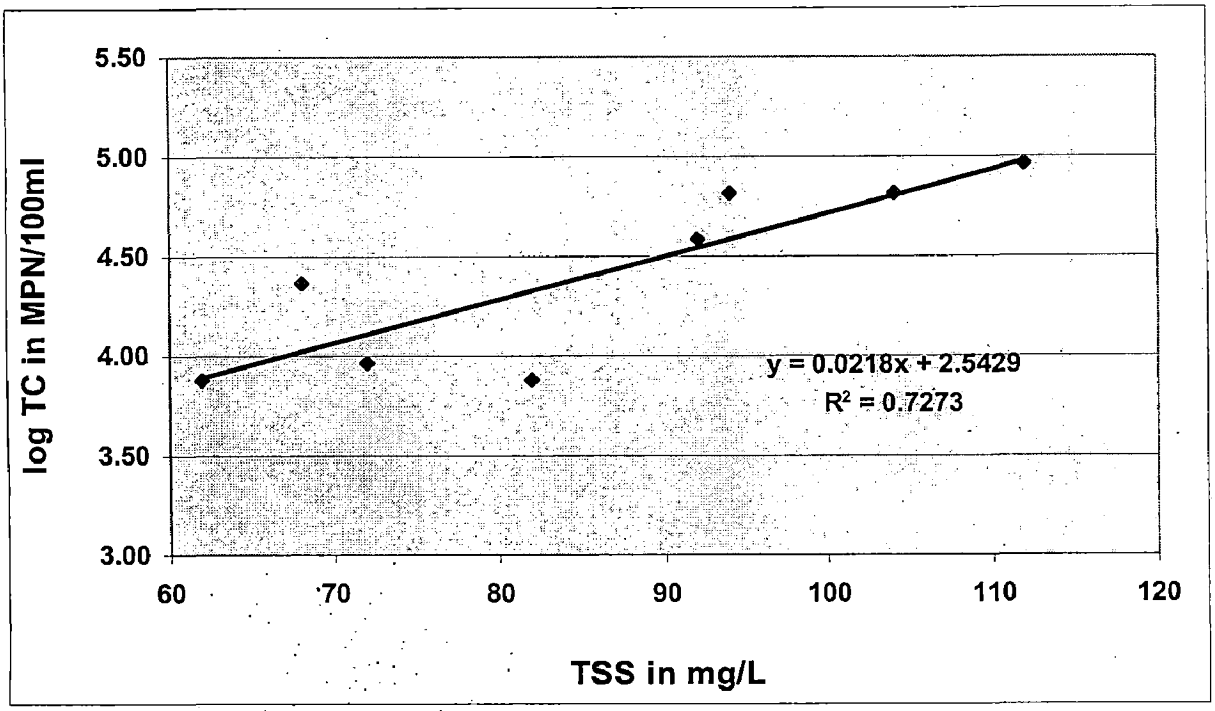


Fig.4.26:Correlation b/w TSS and TC at Outlet of FAB plant Bakkarwala (Delhi)

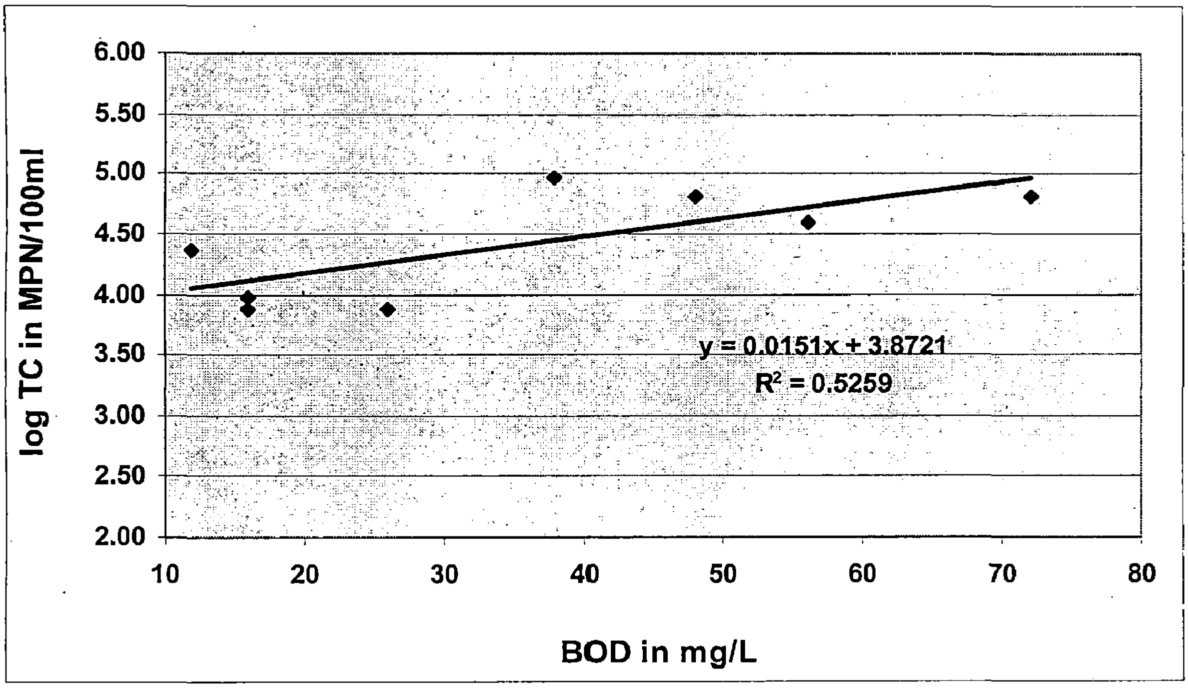


Fig.4.27:Correlation b/w BOD and TC at Outlet of FAB plant Bakkarwala (Delhi)

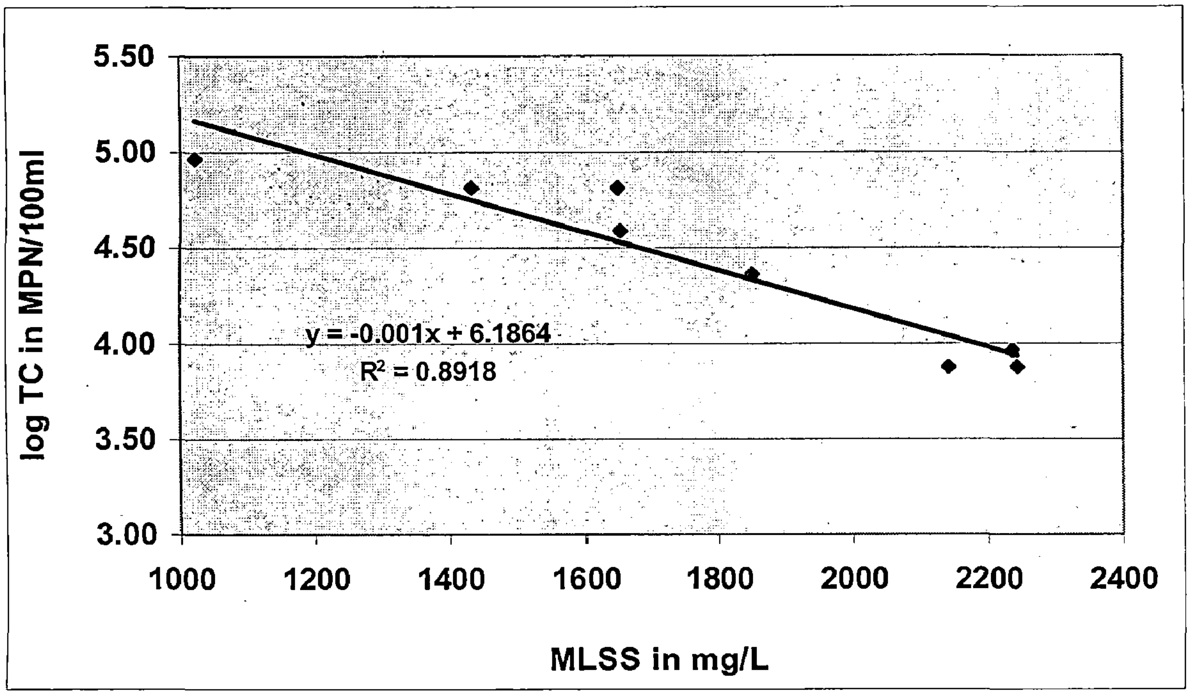


Fig.4.28:Correlation b/w MLSS and TC at Outlet of FAB plant Bakkarwala (Delhi)

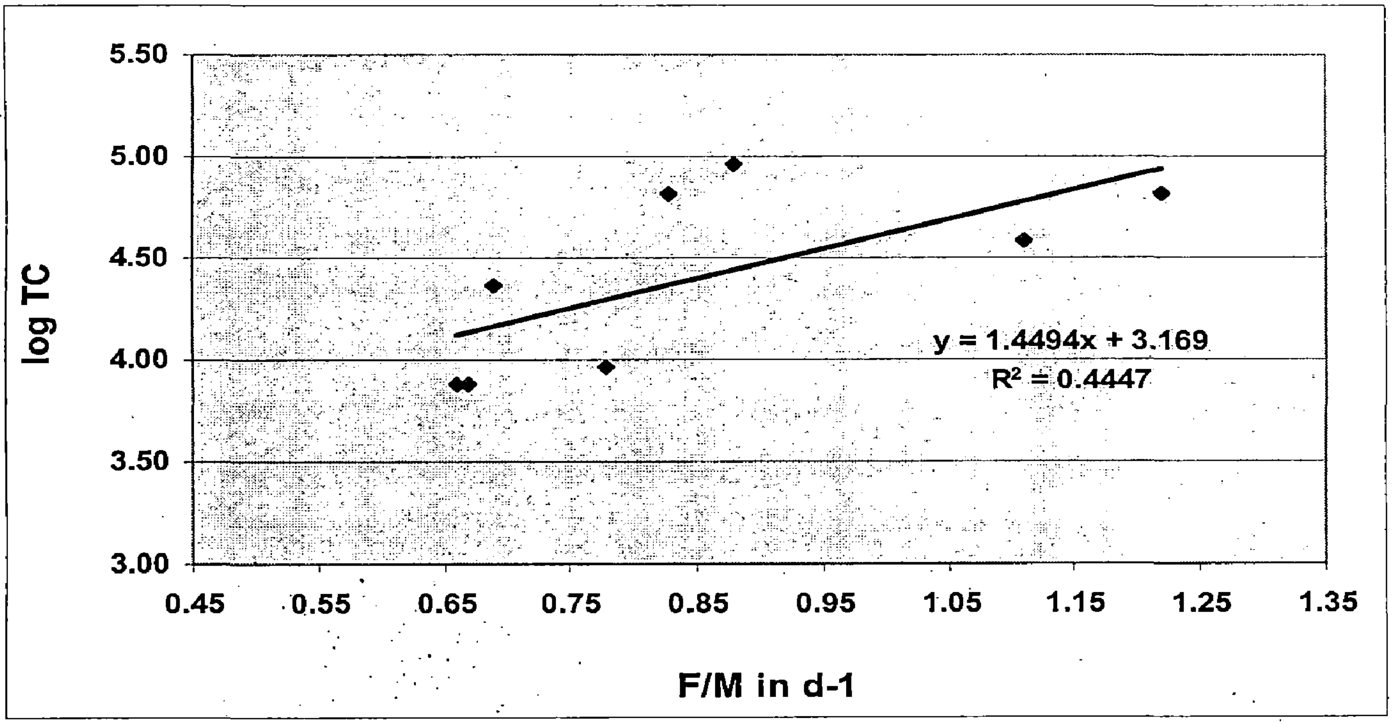


Fig.4.29:Correlation b/w F/M and TC at Outlet of FAB plant Bakkarwala (Delhi)

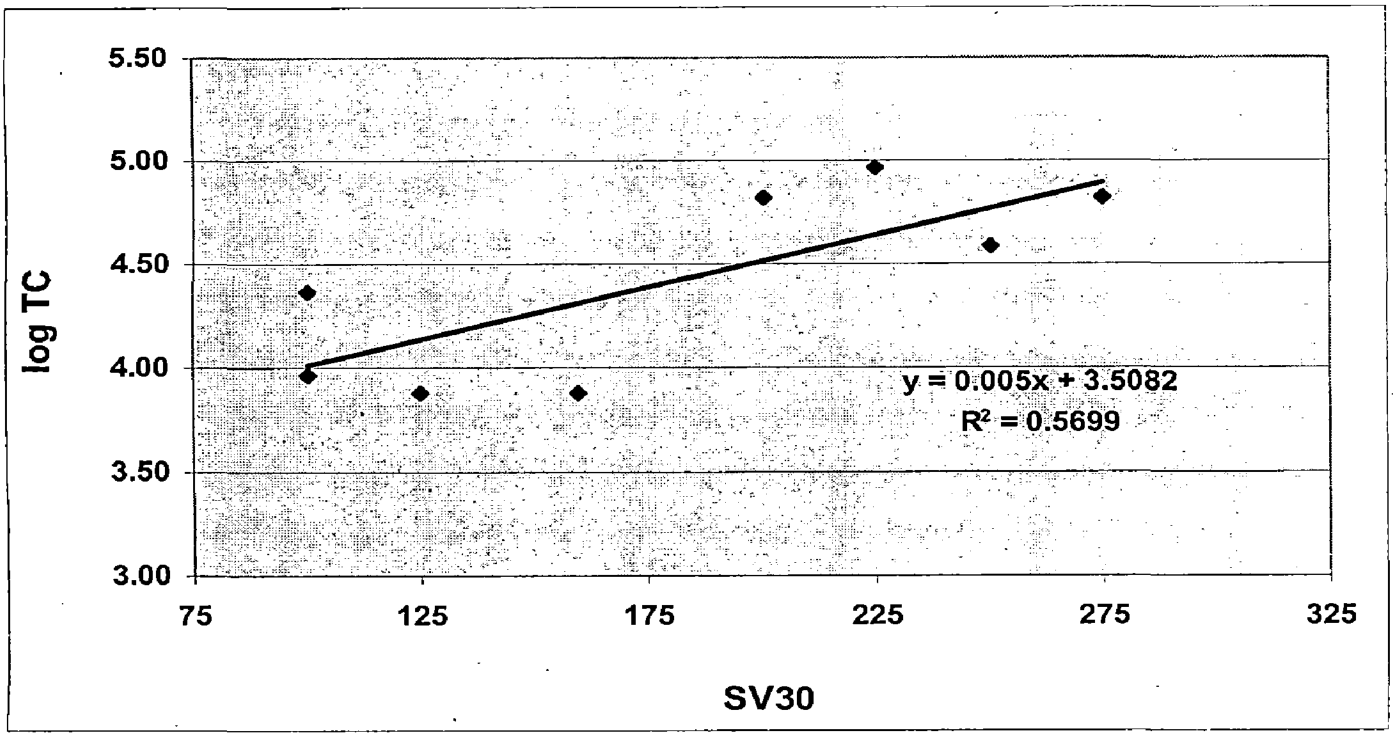


Fig.4.30:Correlation b/w SV30 and TC at Outlet of FAB plant Bakkarwala (Delhi)

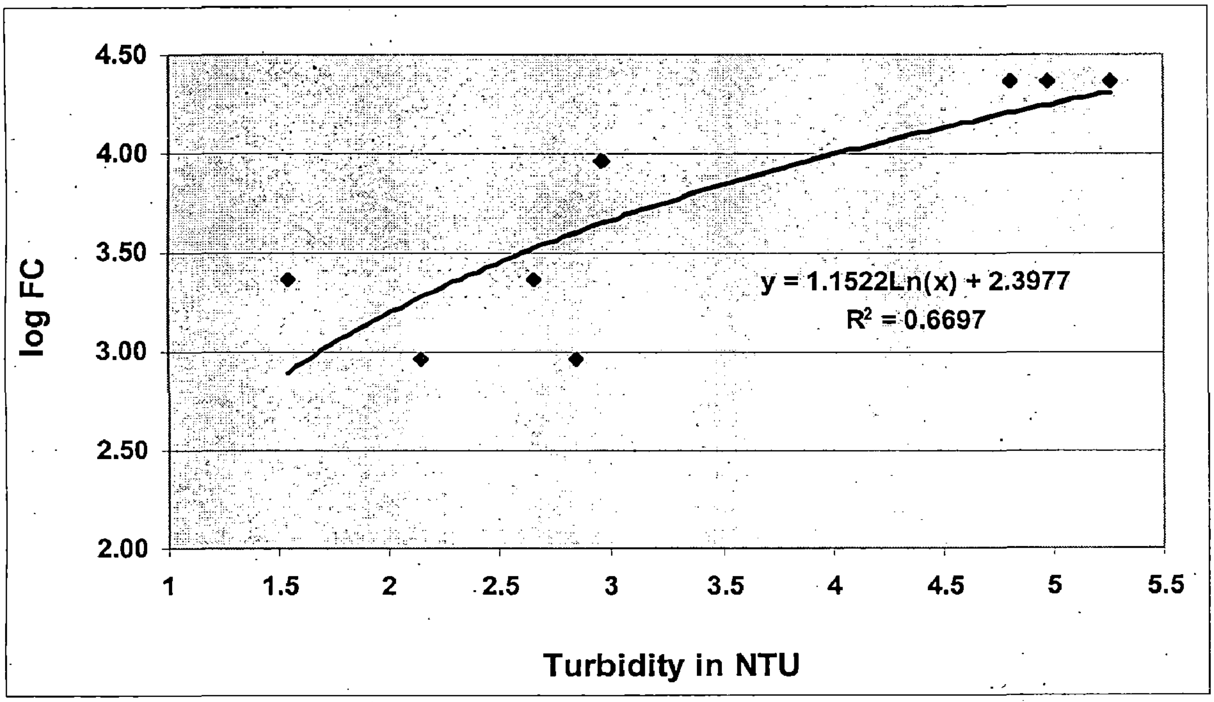


Fig.4.31:Correlation b/w Turbidity and TC at Outlet of FAB plant Bakkarwala (Delhi)

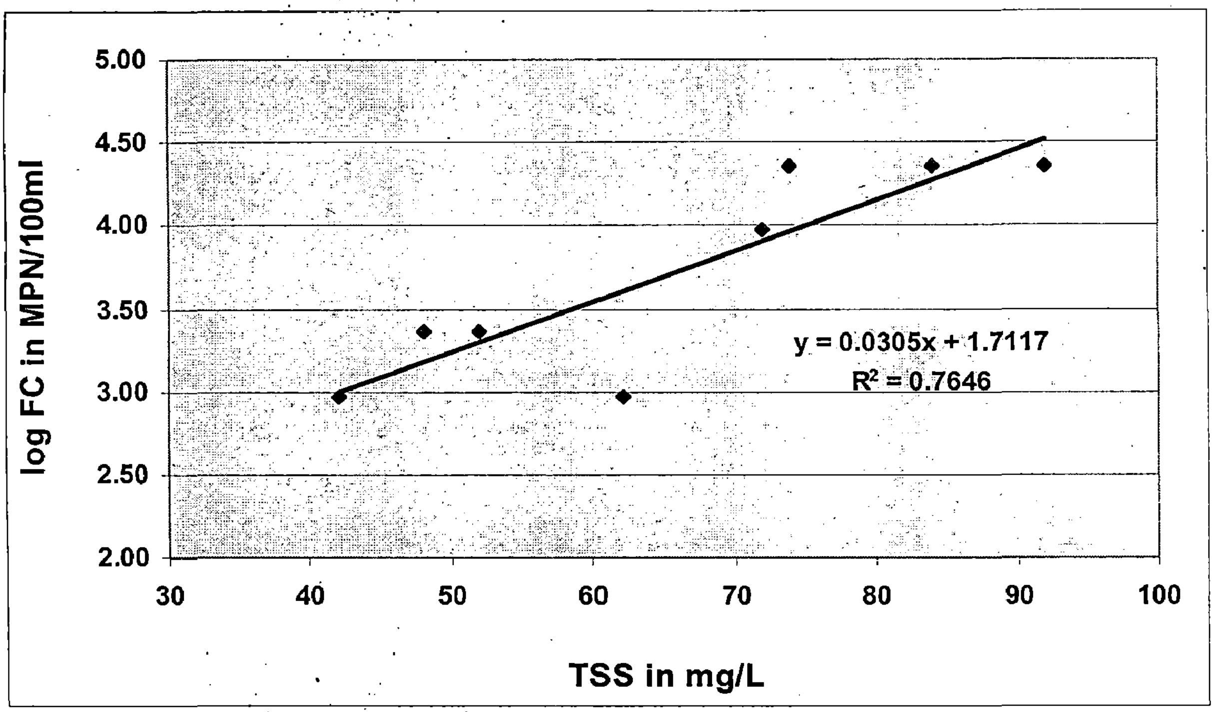


Fig.4.32:Correlation b/w TSS and FC at Outlet of FAB plant Bakkarwala (Delhi)

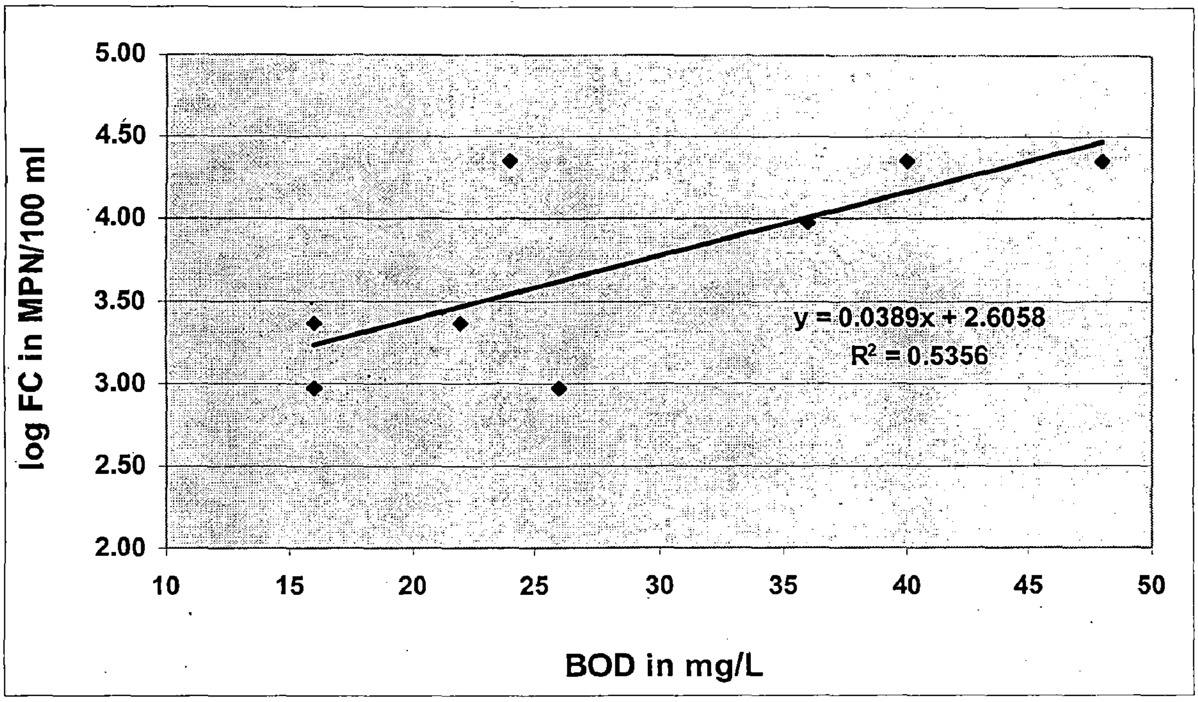


Fig.4.33:Correlation b/w BOD and FC at Outlet of FAB plant Bakkarwala (Delhi)

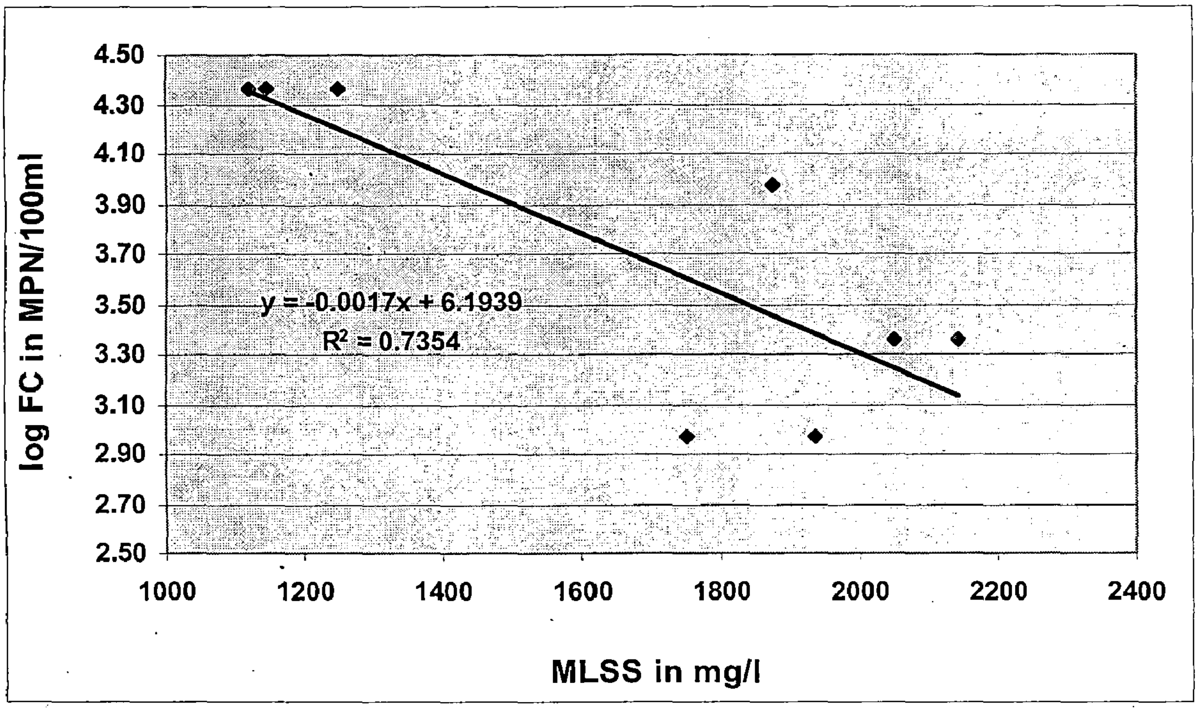


Fig.4.34:Correlation b/w MLSS and FC at Outlet of FAB plant Bakkarwala (Delhi)

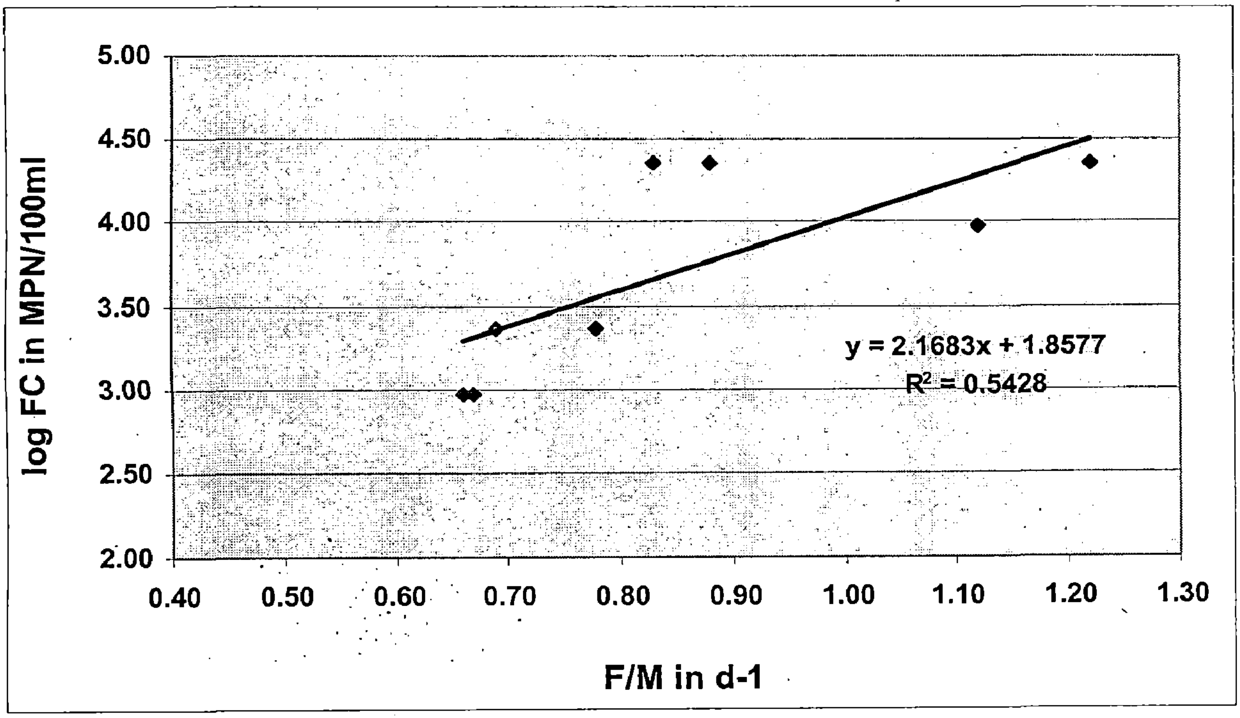


Fig.4.35:Correlation b/w F/M and FC at Outlet of FAB plant Bakkarwala (Delhi)

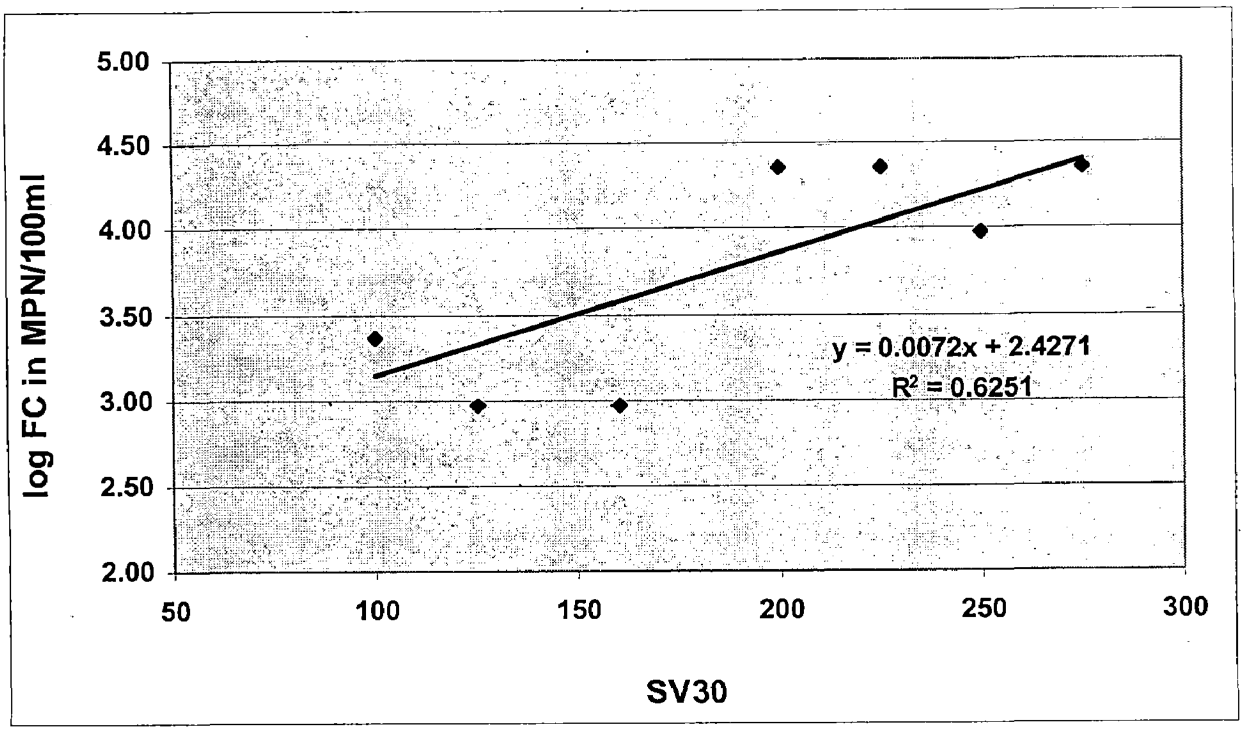


Fig.4.36:Correlation b/w SV30 and FC at Outlet of FAB plant Bakkarwala (Delhi)

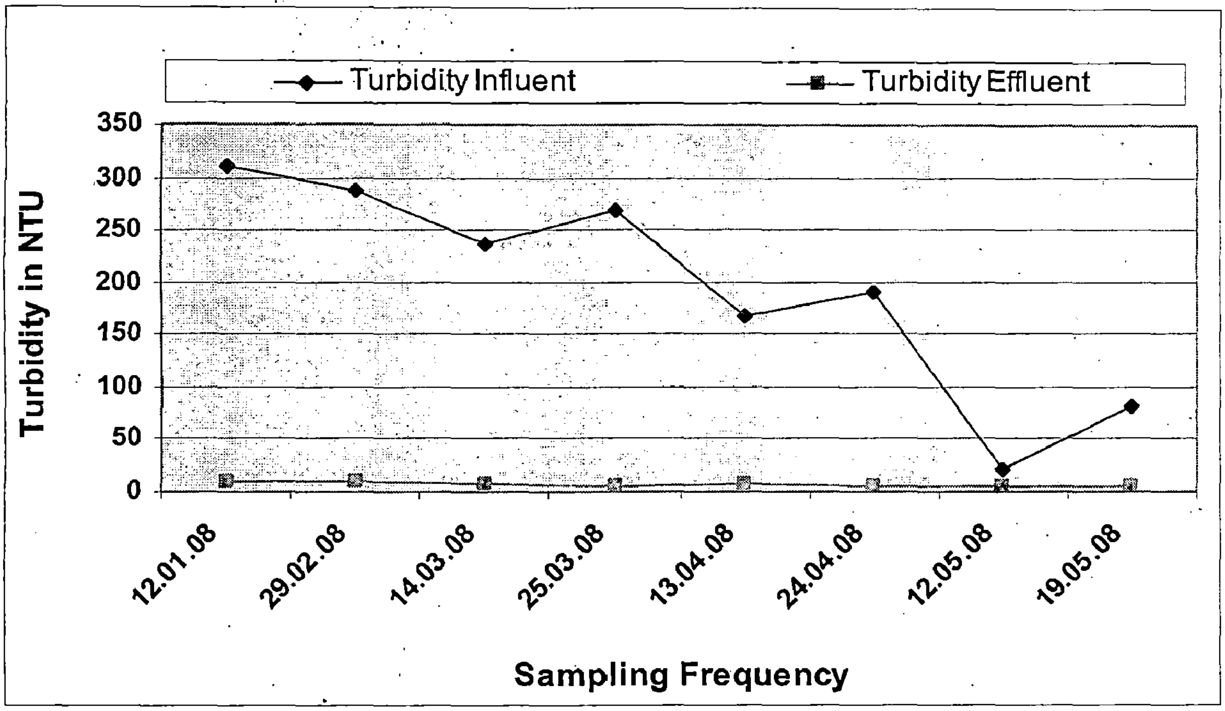


Fig. 4.37:Turbidity variations at Inlet and Outlet of FAB plant Molarbund (Delhi)

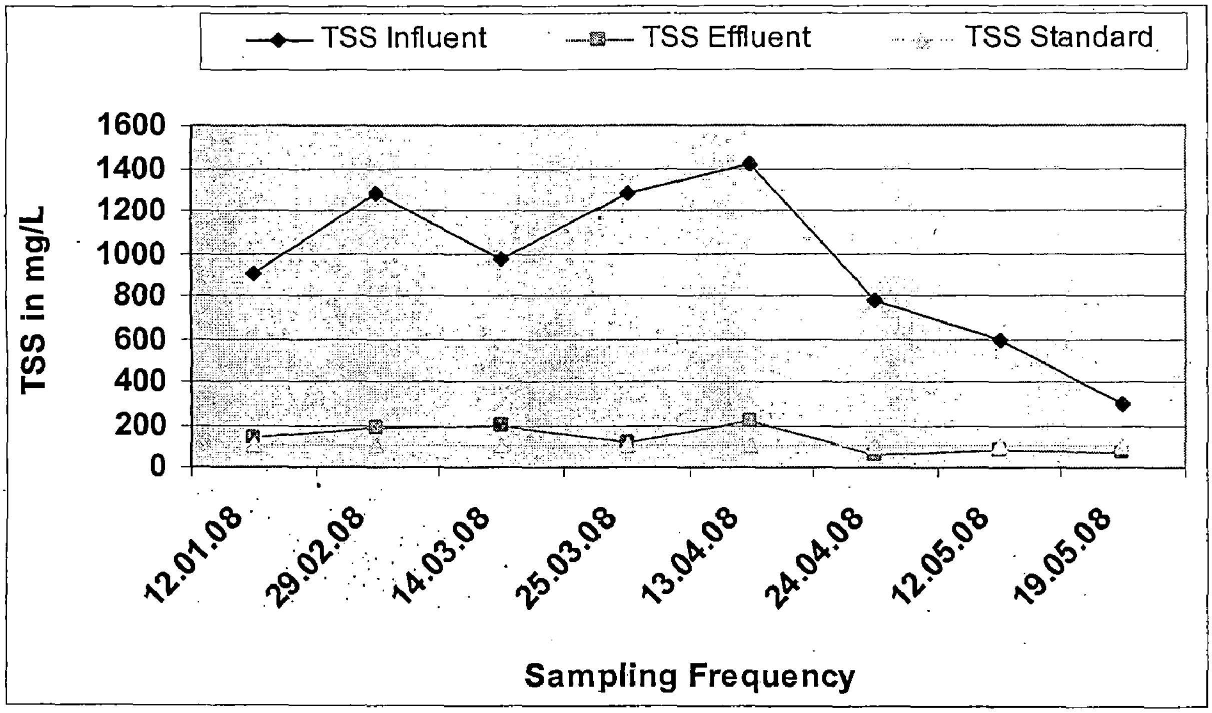


Fig. 4.38: TSS variations at Inlet and Outlet of FAB plant Molarbund (Delhi)

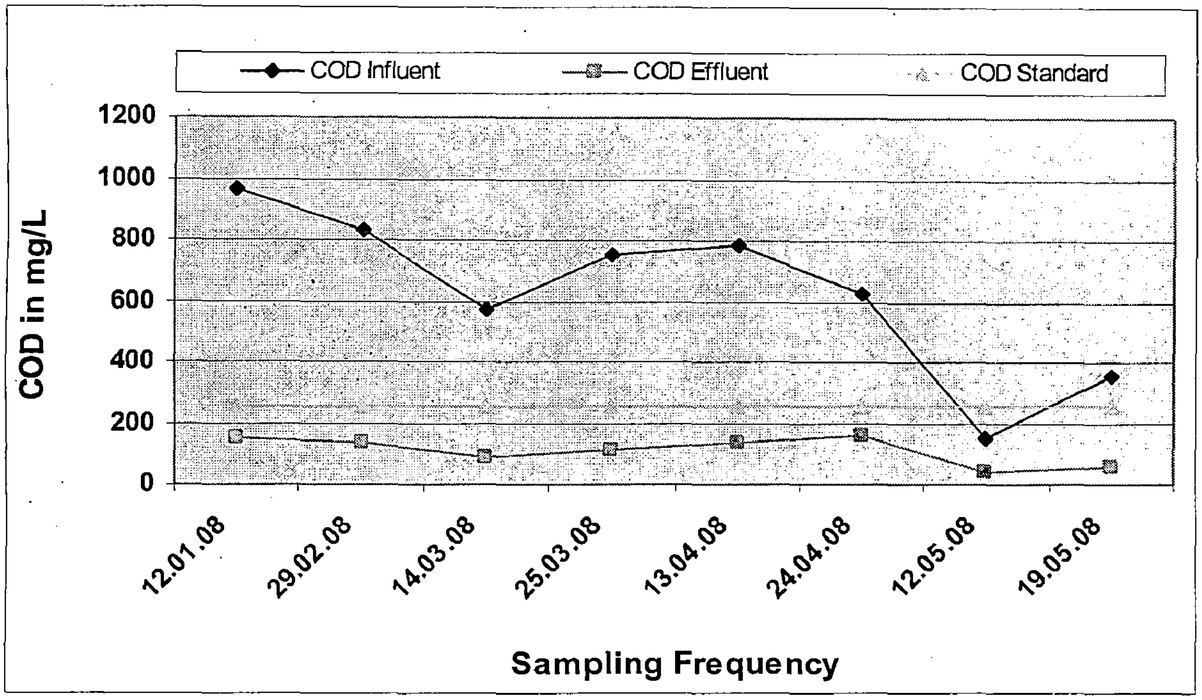


Fig. 4.39: COD variations at Inlet and Outlet of FAB plant Molarbund (Delhi)

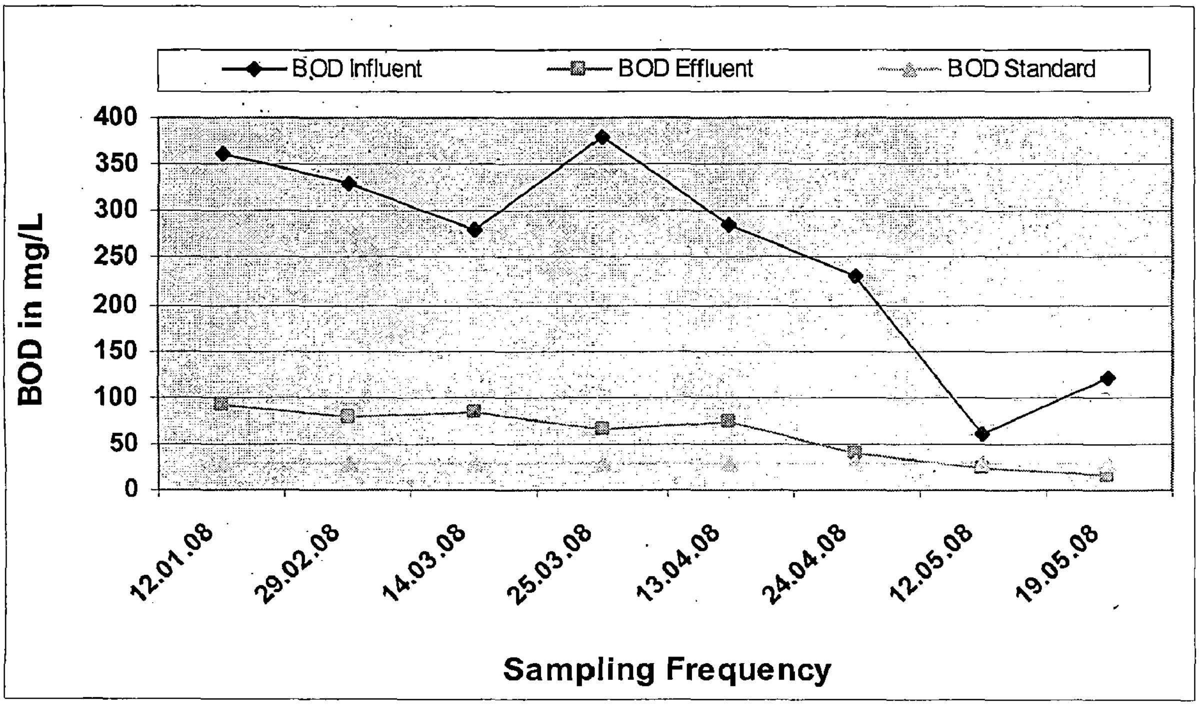


Fig.4.40: BOD variations at Inlet and Outlet of FAB plant Molarbund (Delhi)

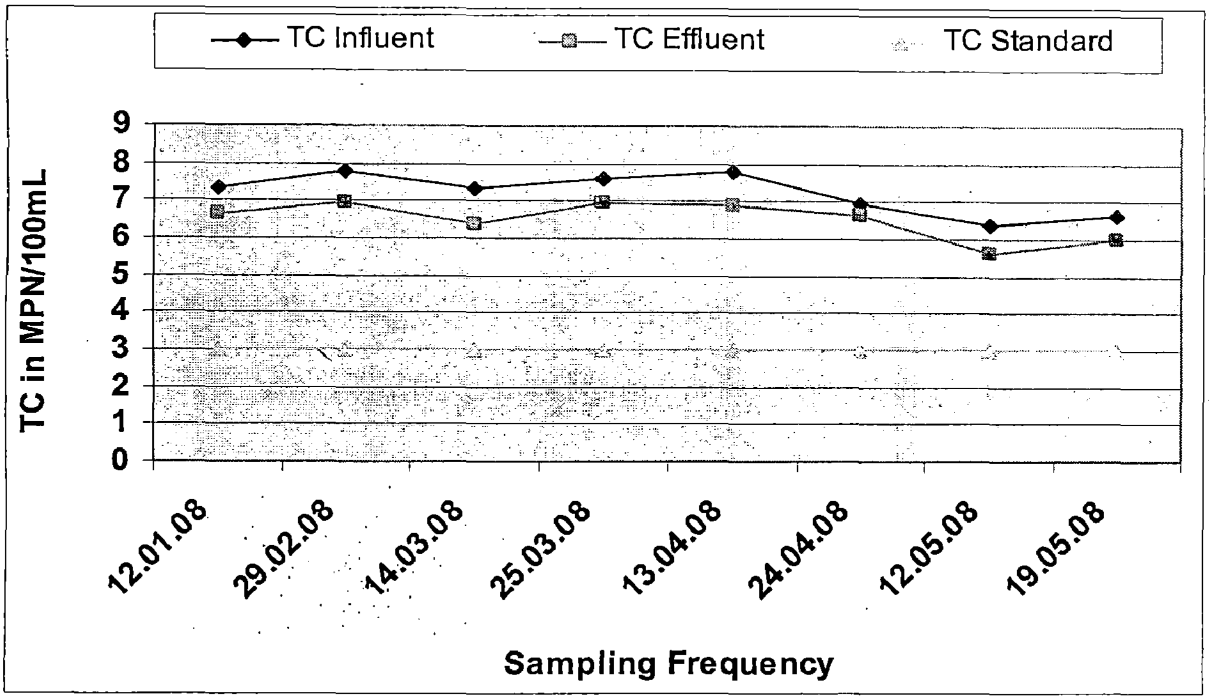


Fig.4.41 :TC variations at Inlet and Outlet of FAB plant Molarbund (Delhi)

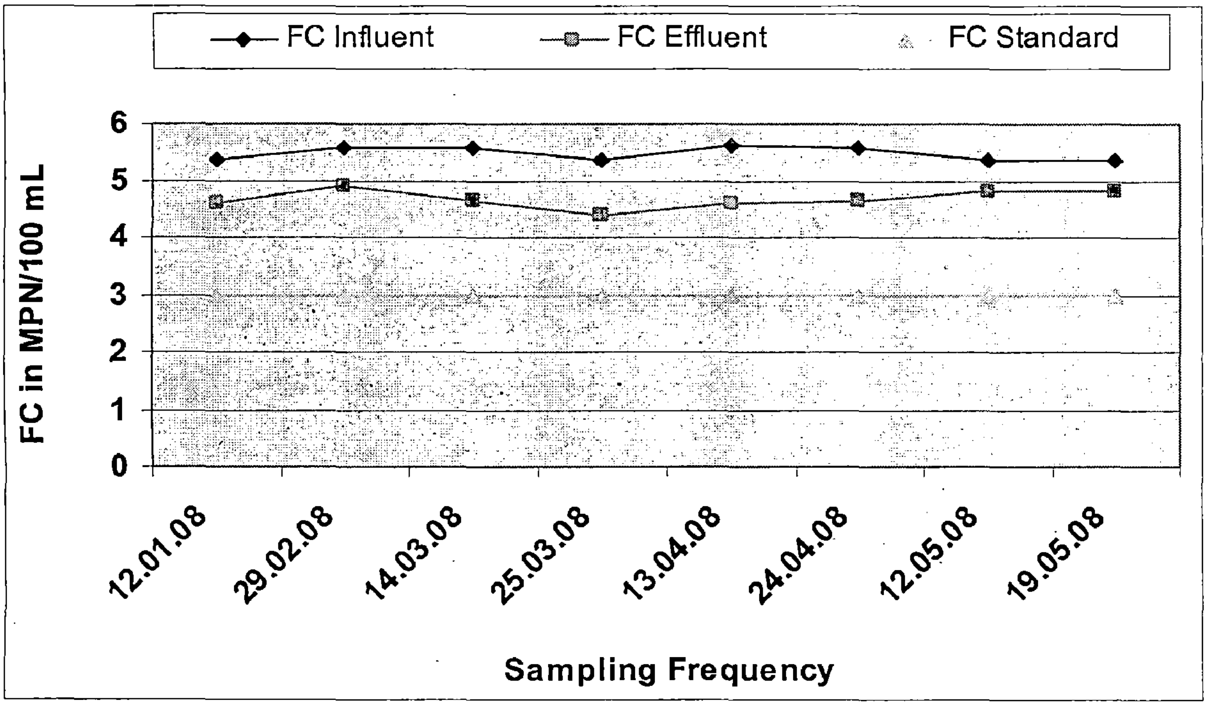


Fig. 4.42:FC variations at Inlet and Outlet of FAB plant Molarbund (Delhi)

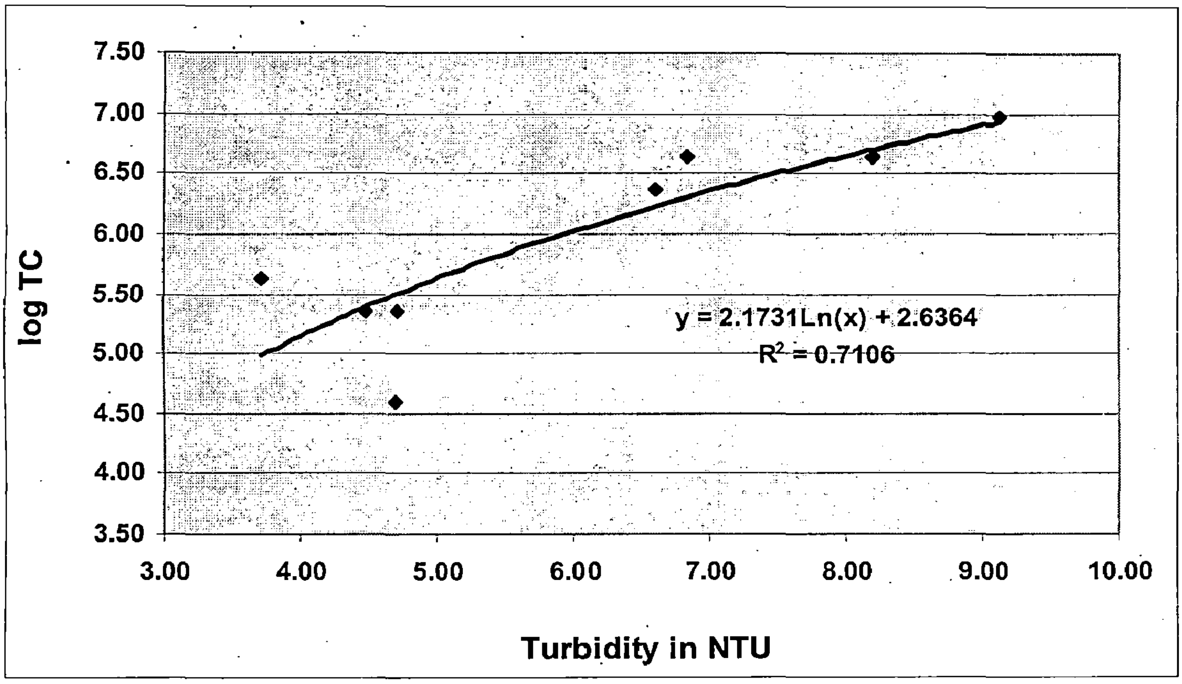


Fig.4.43:Correlation b/w Turbidity and TC at Outlet of FAB plant Molarbund (Delhi)

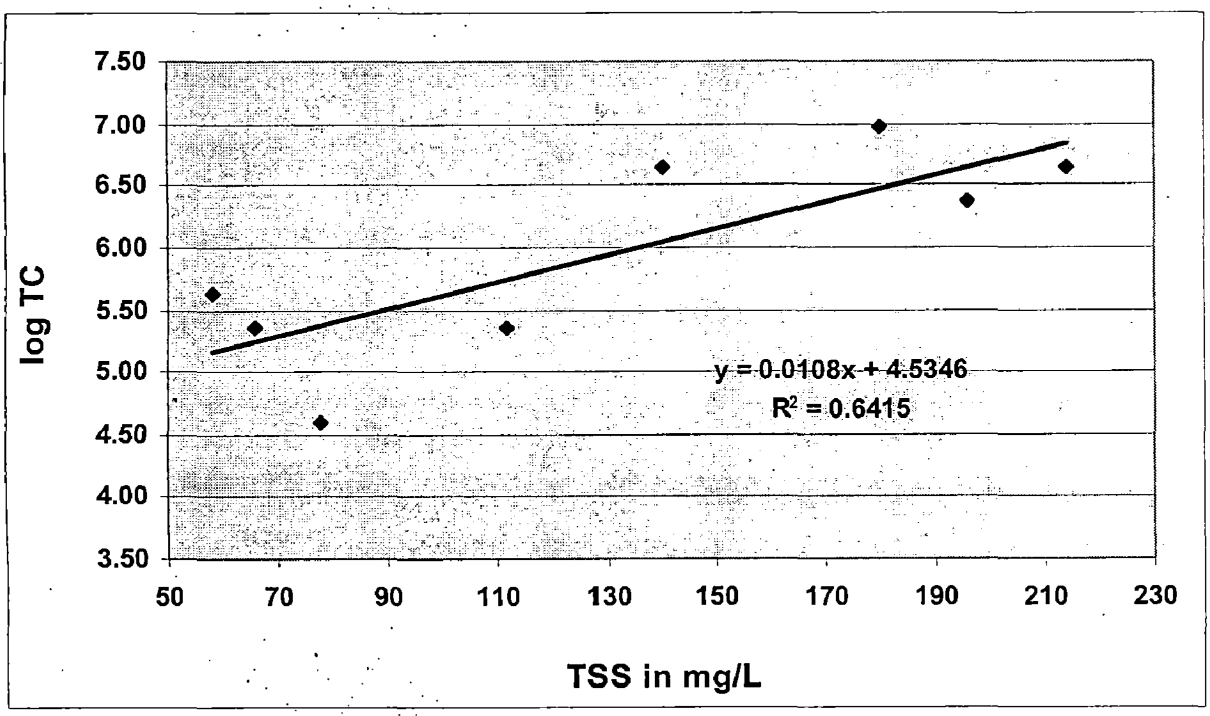


Fig.4.44:Correlation b/w TSS and TC at Outlet of FAB plant Molarbund (Delhi)

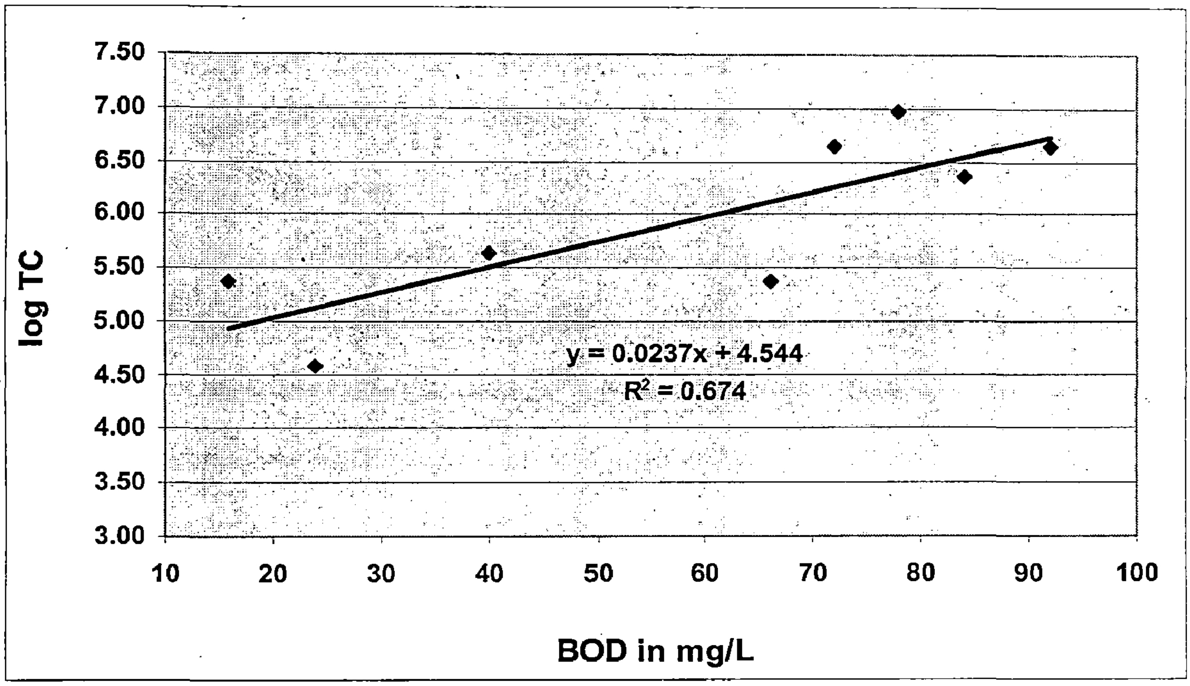


Fig.4.45:Correlation b/w BOD and TC at Outlet of FAB plant Molarbund (Delhi)

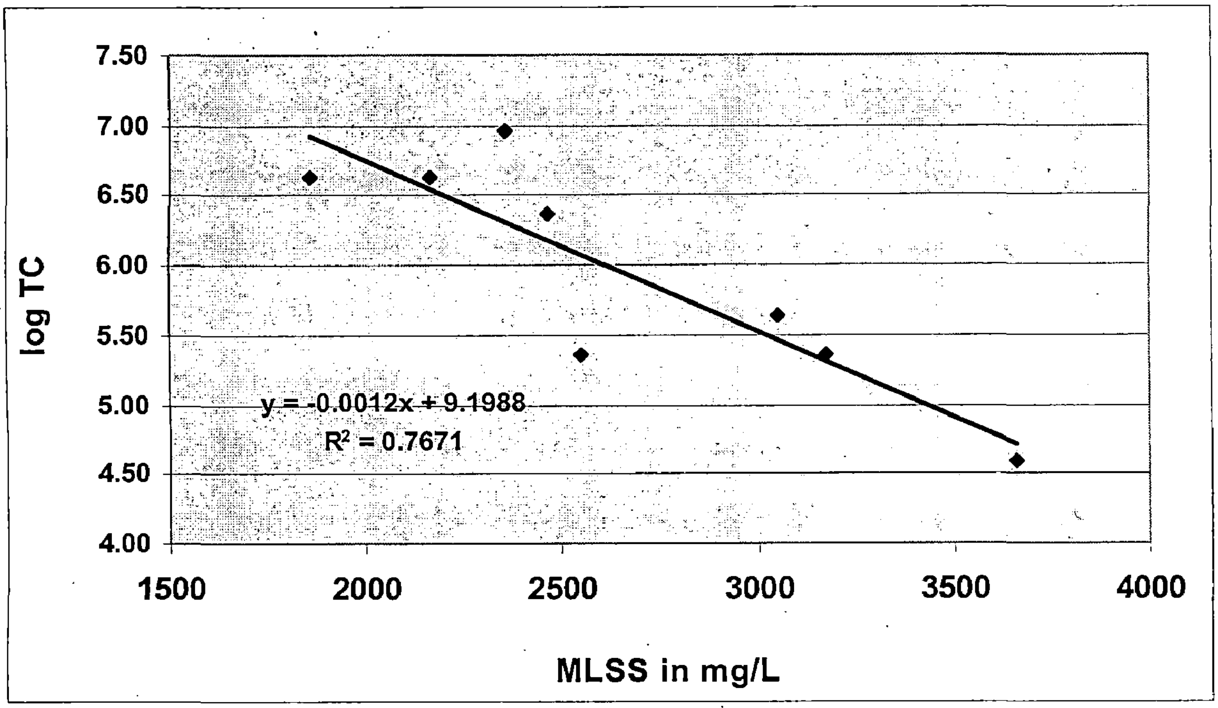


Fig.4.46:Correlation b/w MLSS and TC at Outlet of FAB plant Molarbund (Delhi)

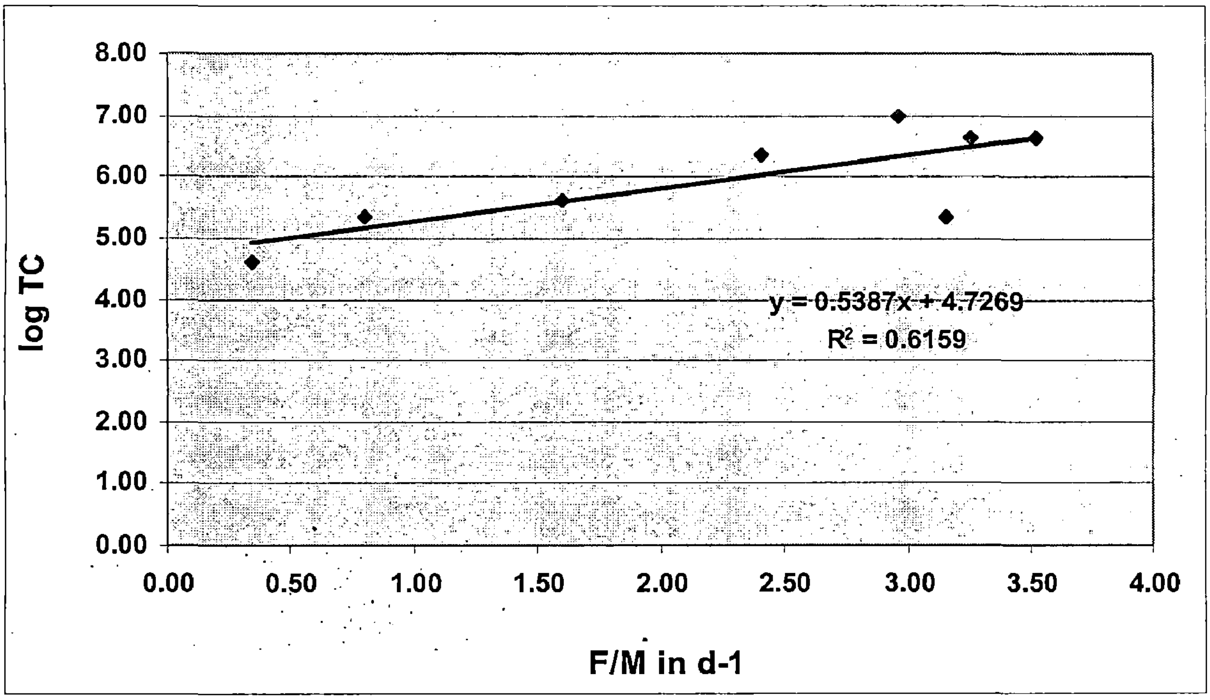


Fig.4.47:Correlation b/w F/M and TC at Outlet of FAB plant Molarbund (Delhi)

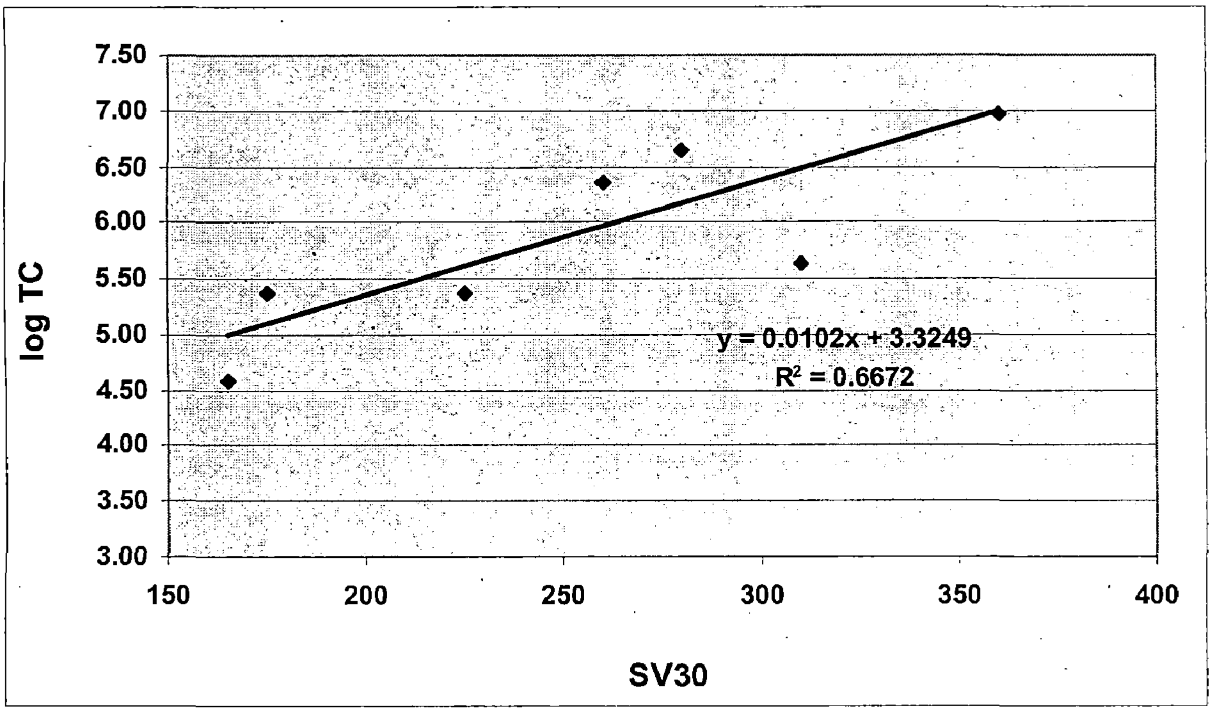


Fig.4.48:Correlation b/w SV30 and TC at Outlet of FAB plant Molarbund (Delhi)

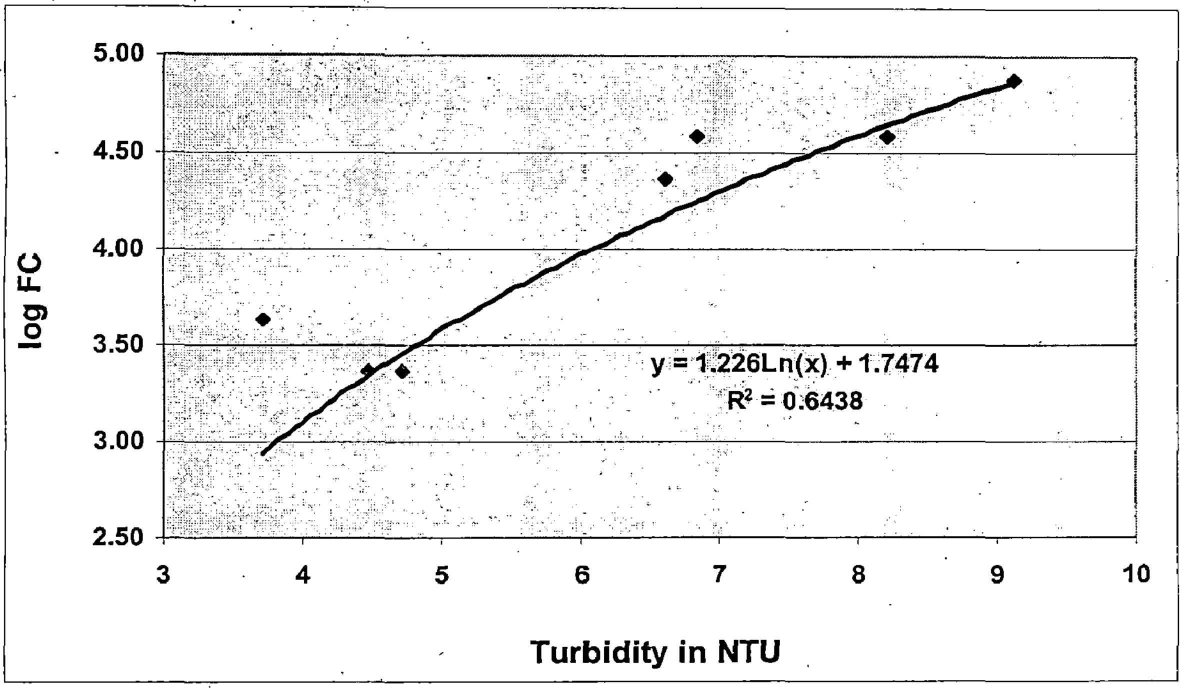


Fig.4.49:Correlation b/w Turbidity and TC at Outlet of FAB plant Molarbund (Delhi)

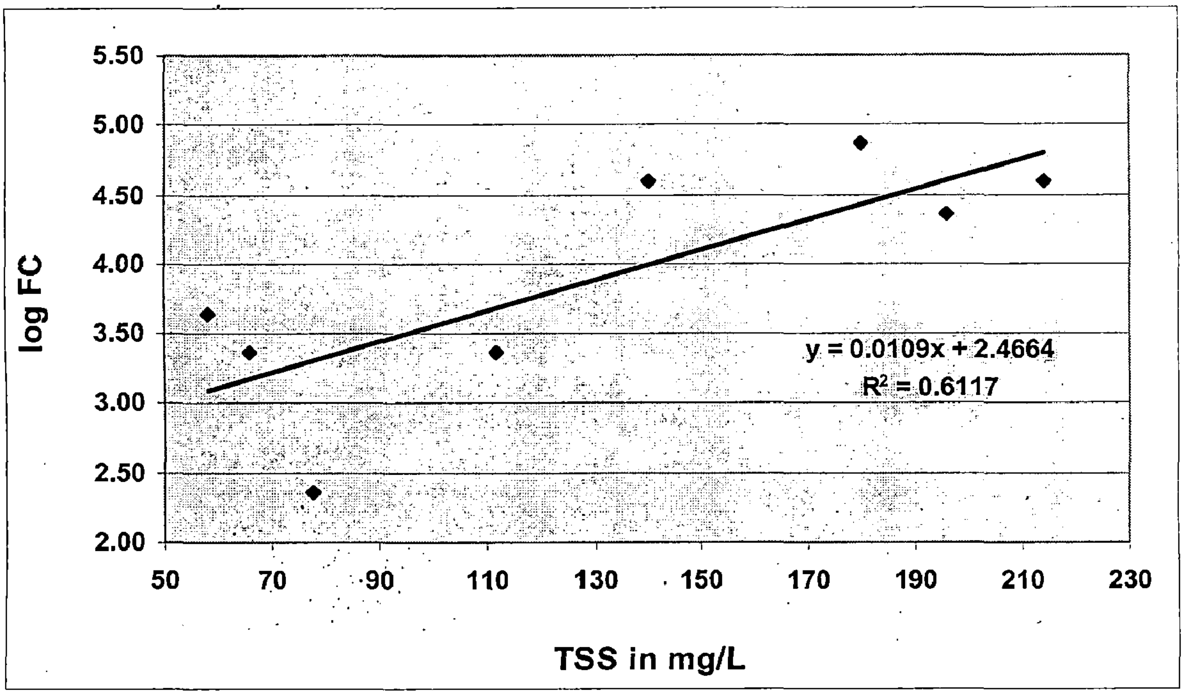


Fig.4.50:Correlation b/w TSS and FC at Outlet of FAB plant Molarbund (Delhi)

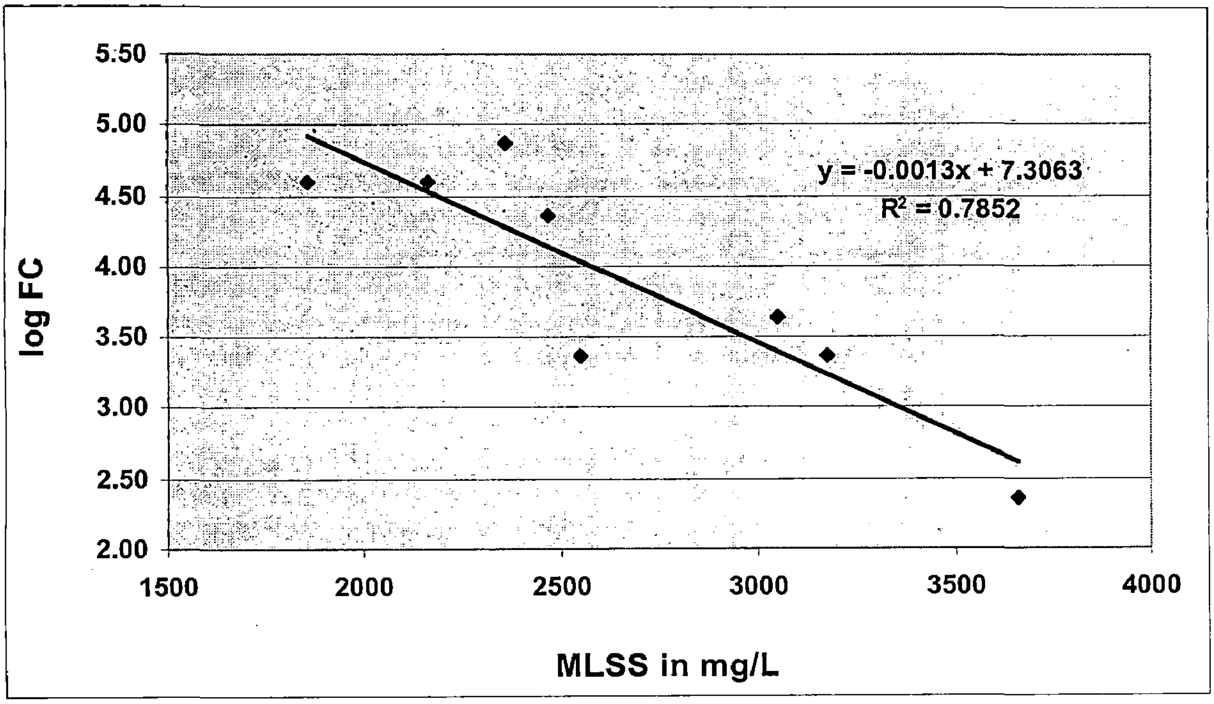


Fig.4.51:Correlation b/w MLSS and FC at Outlet of FAB plant Molarbund (Delhi)

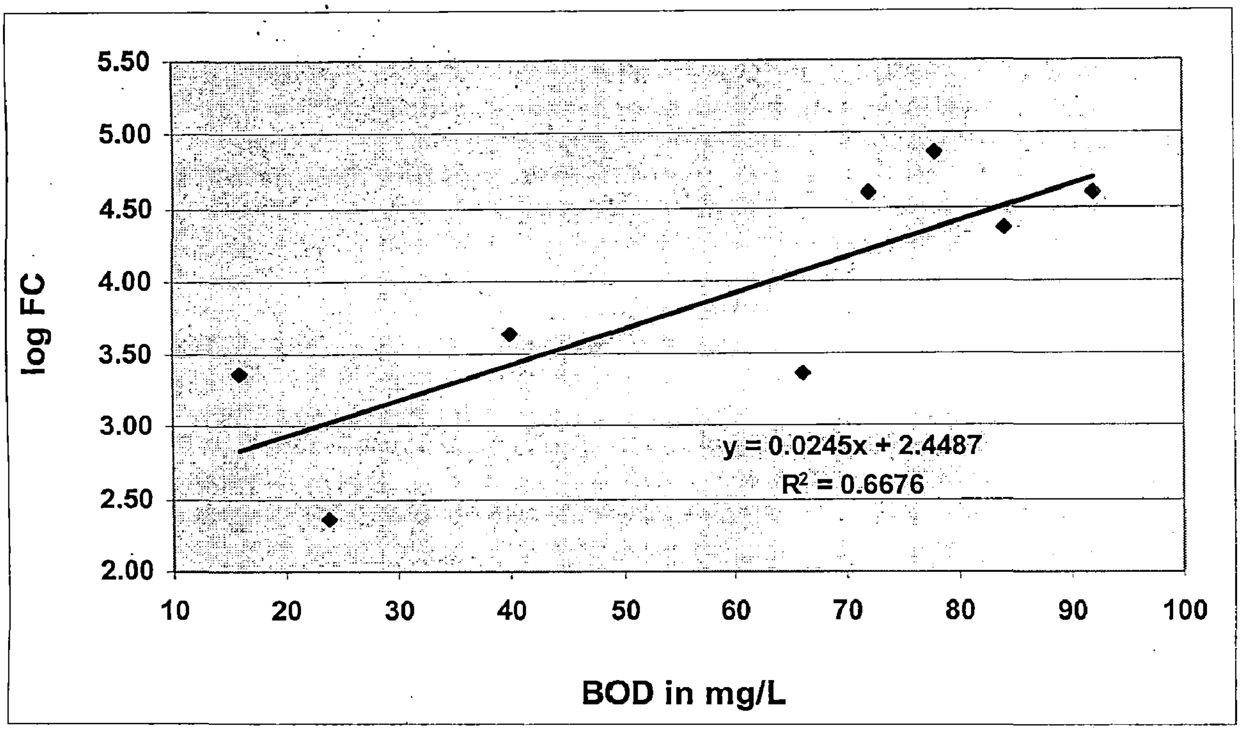


Fig.4.52:Correlation b/w BOD and FC at Outlet of FAB plant Molarbund (Delhi)

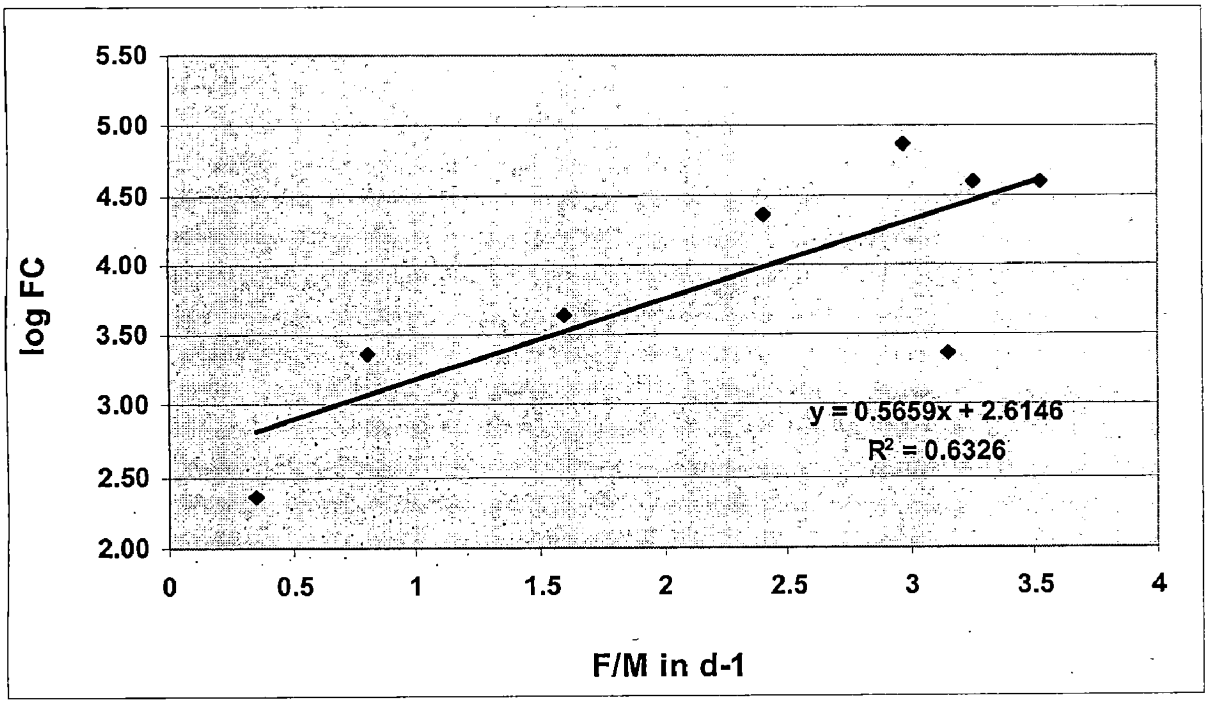


Fig.4.53:Correlation b/w F/M and FC at Outlet of FAB plant Molarbund (Delhi)

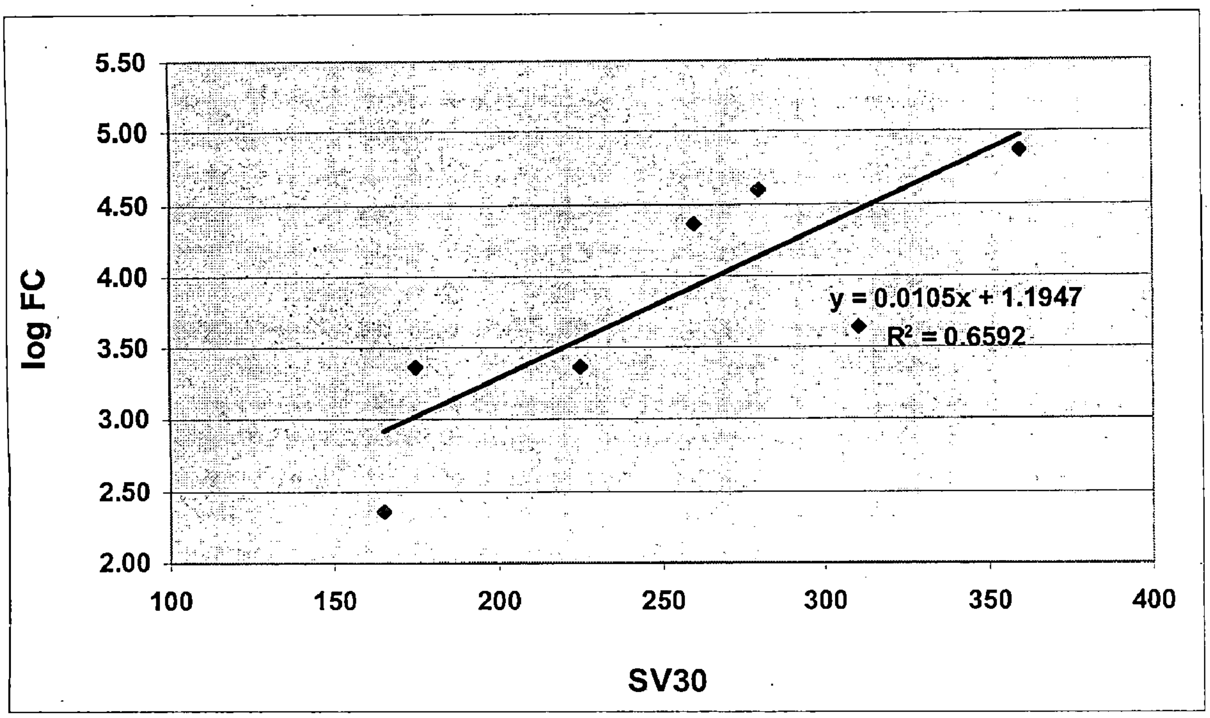


Fig.4.54:Correlation b/w SV30 and FC at Outlet of FAB plant Molarbund (Delhi)

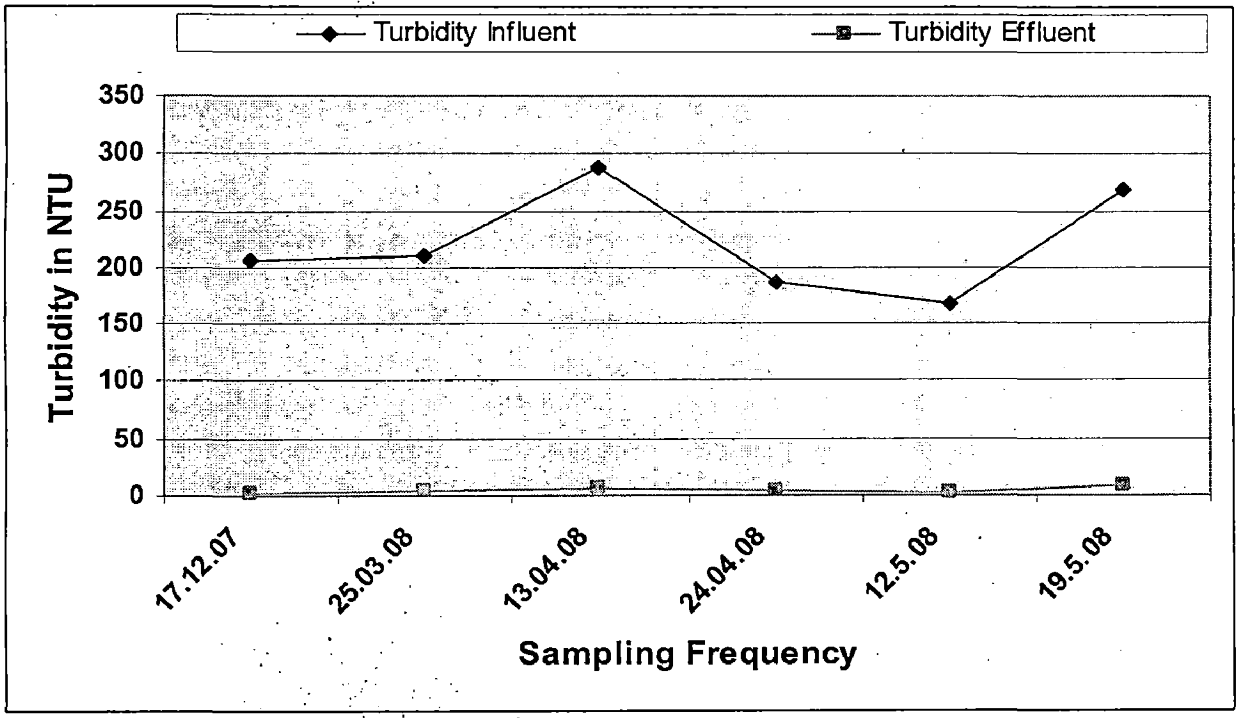


Fig. 4.55:Turbidity variations at Inlet and Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

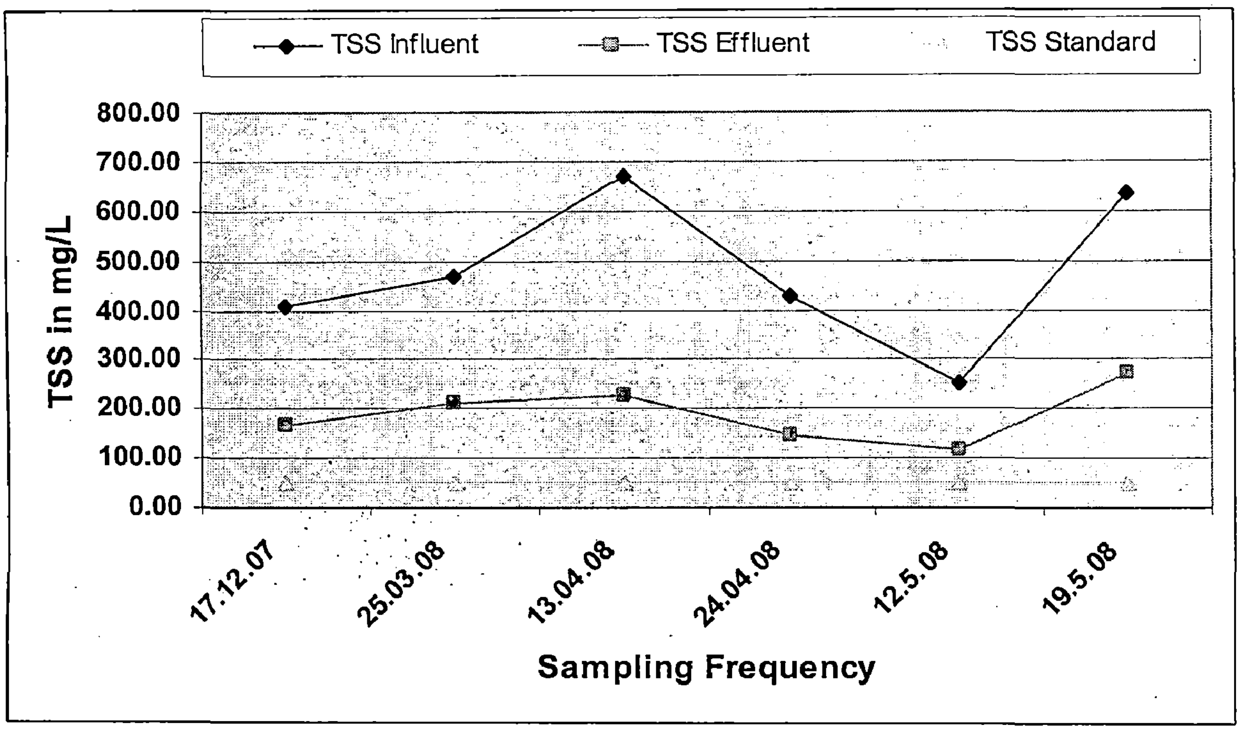


Fig.4.56 : TSS variations at Inlet and Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

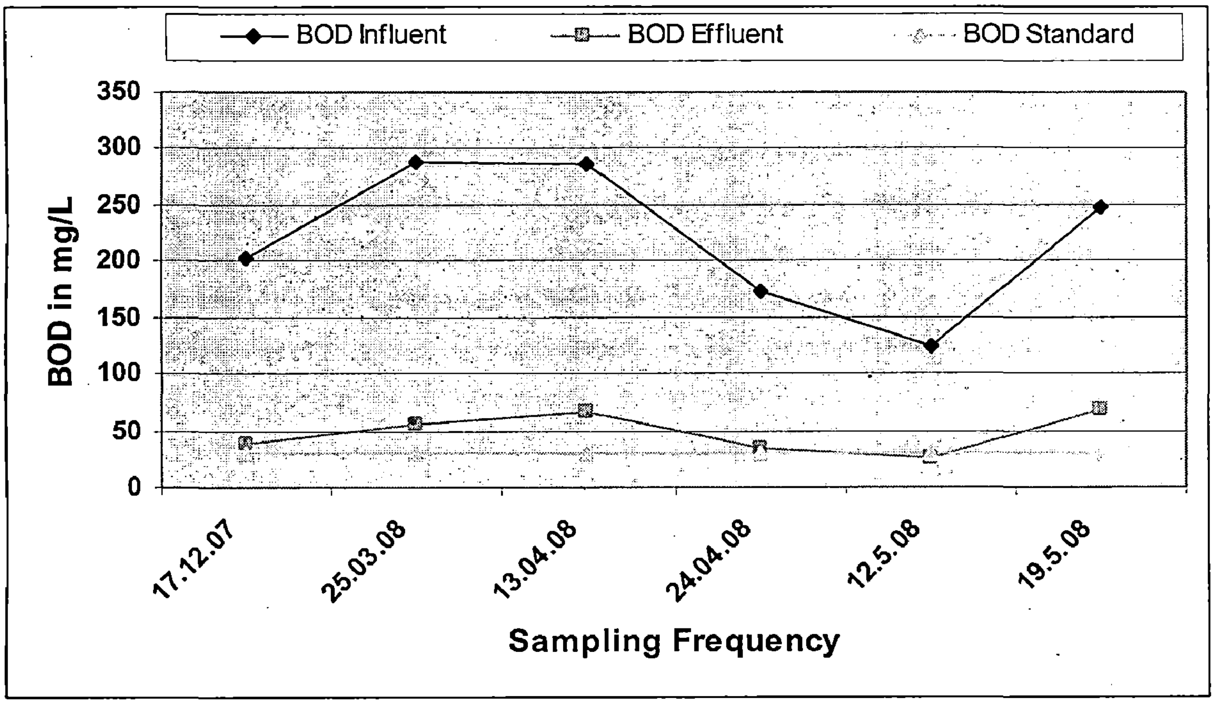


Fig.4.57: BOD variations at Inlet and Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

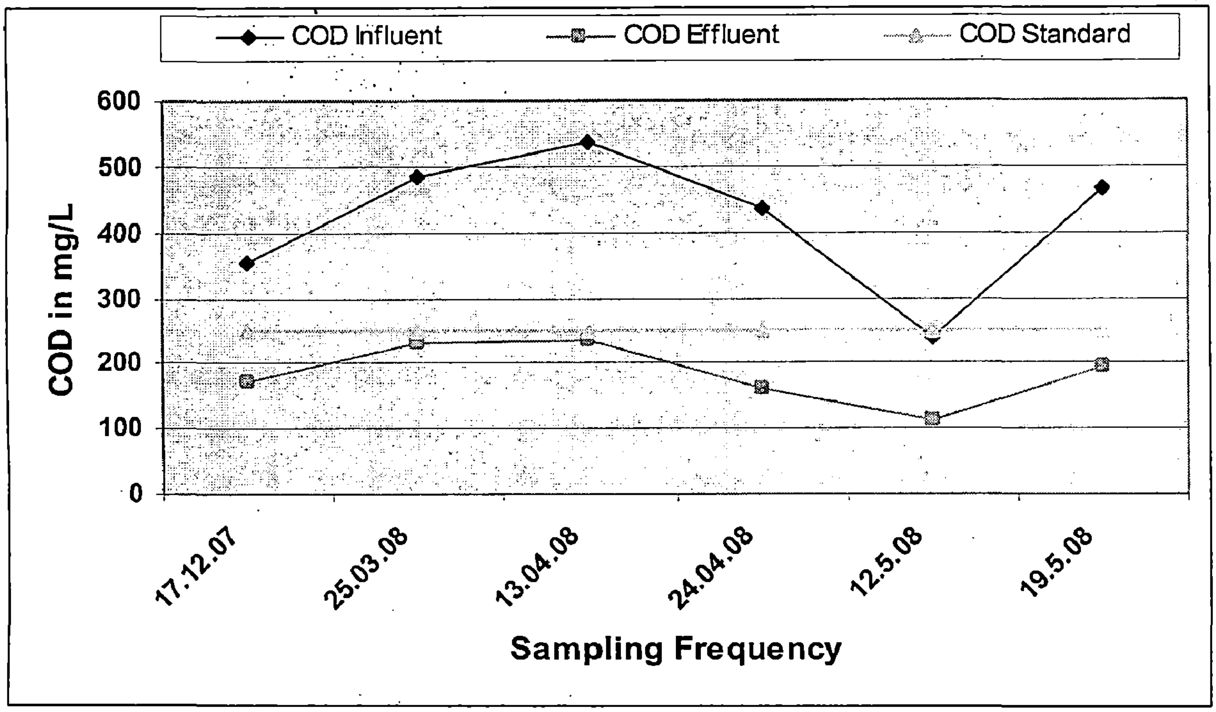


Fig. 4.58: COD variations at Inlet and Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

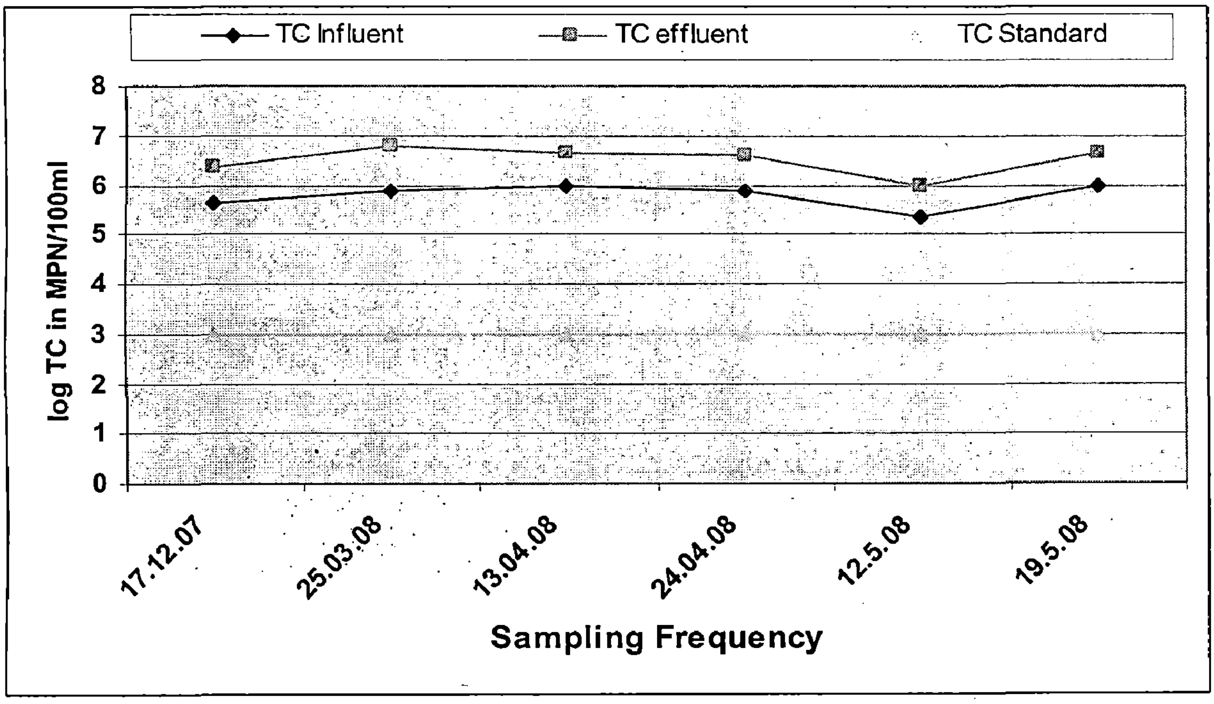


Fig.4.59 :TC variations at Inlet and Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

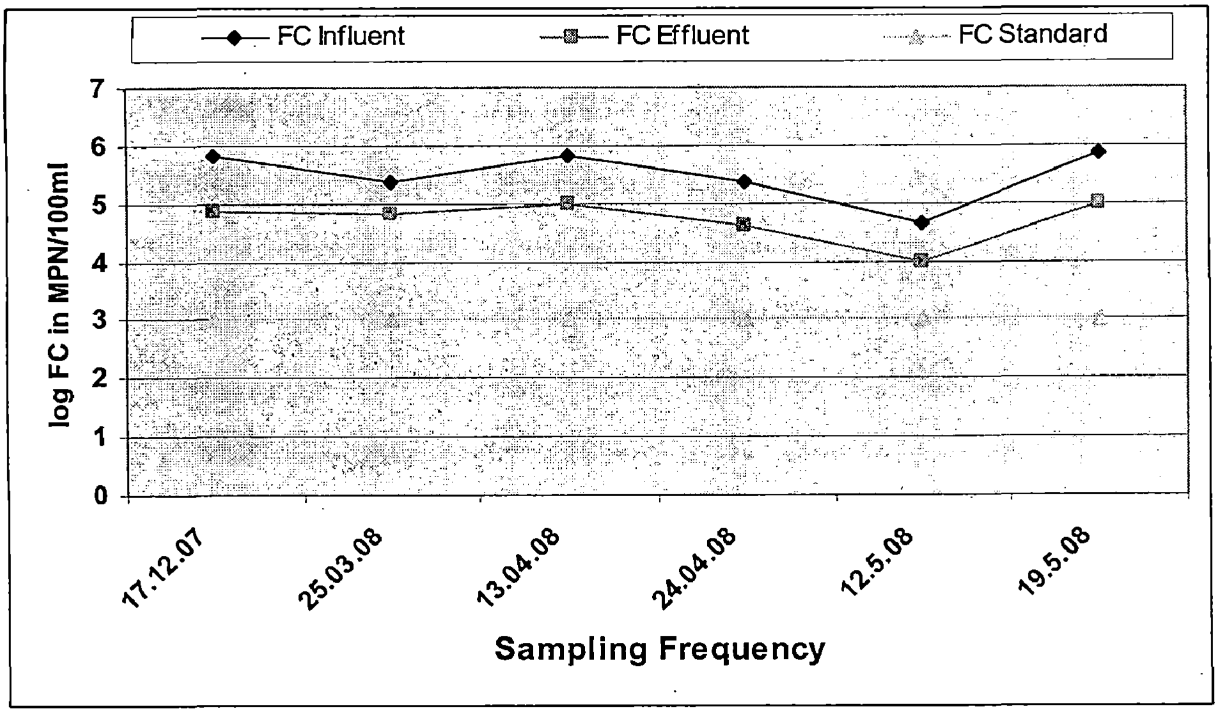


Fig. 4.60:FC variations at Inlet and Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

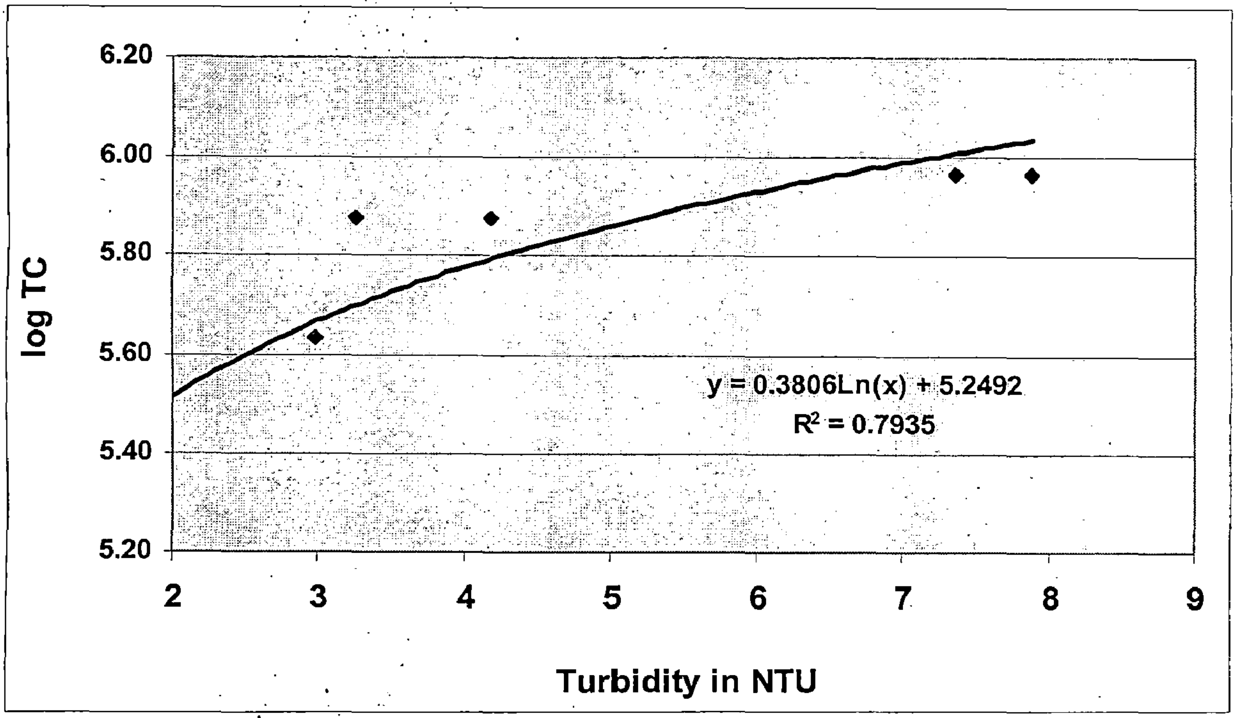


Fig.4.61:Correlation b/w Turbidity and TC at Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

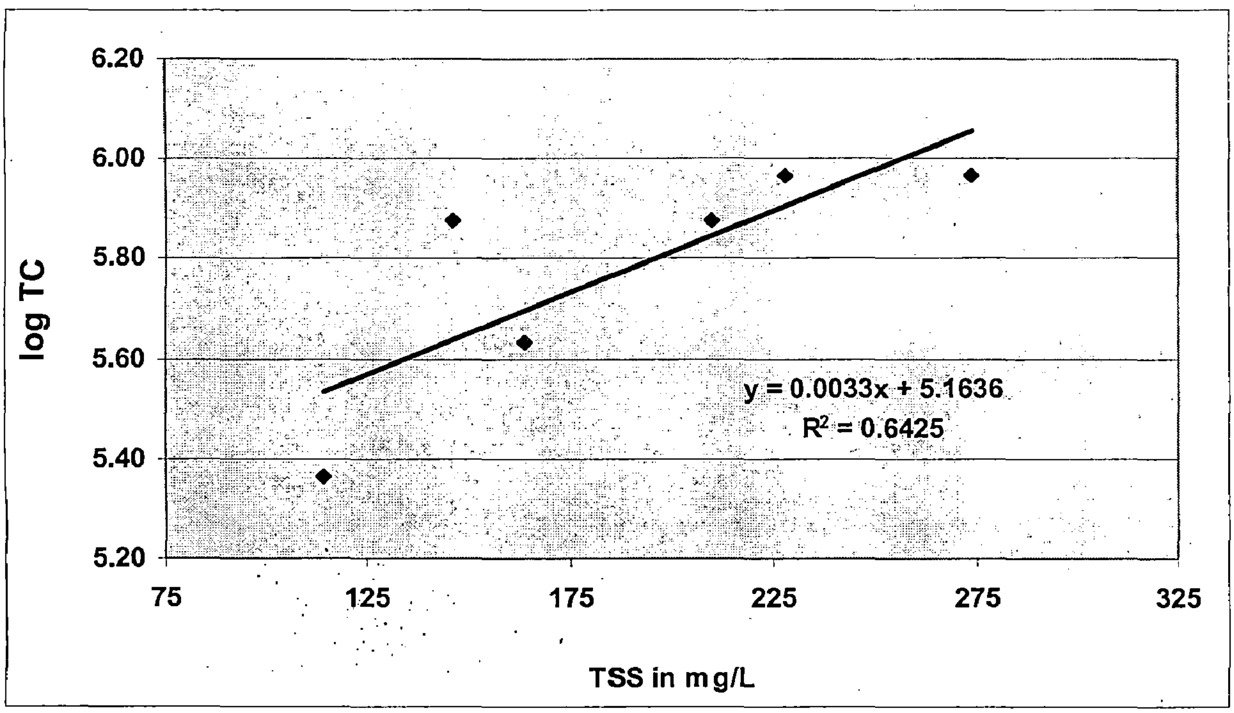


Fig.4.62:Correlation b/w TSS and TC at Outlet of Anaerobic Filter Cum Fp plant Vasant Vihar (Delhi)

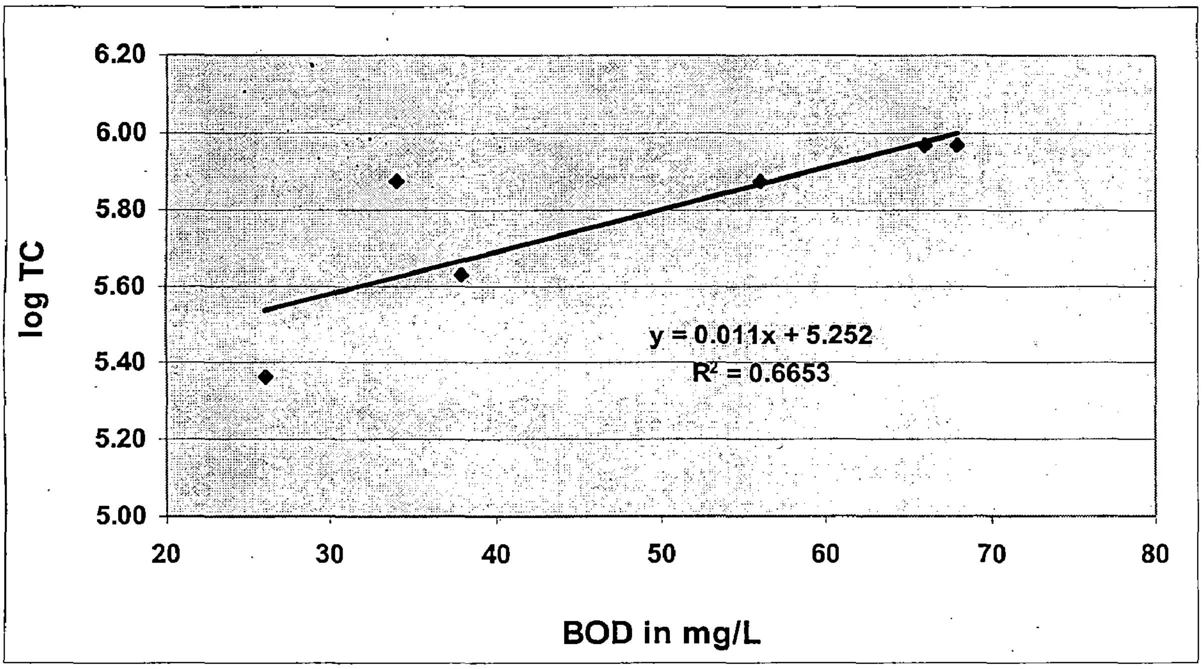


Fig.4.63:Correlation b/w BOD and TC at Outlet of Anaerobic Filter Cum Fp plant Vasant Vihar (Delhi)

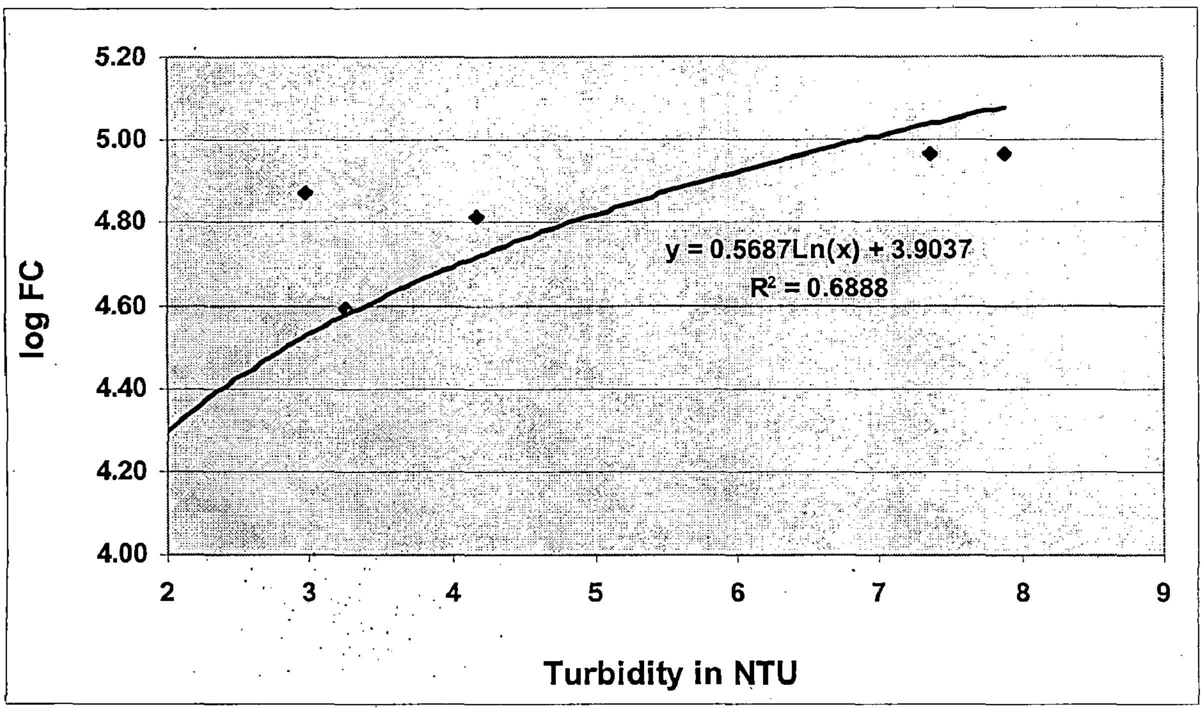


Fig.4.64:Correlation b/w Turbidity and FC at Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

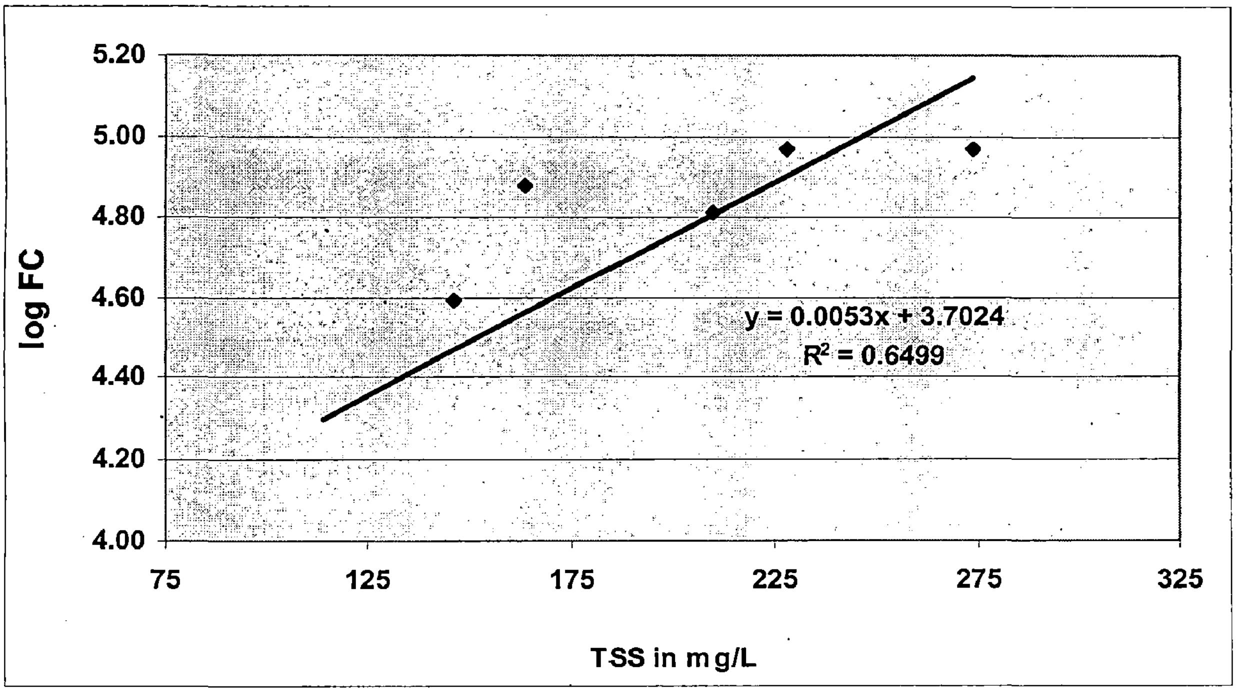


Fig.4.65:Correlation b/w TSS and FC at Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

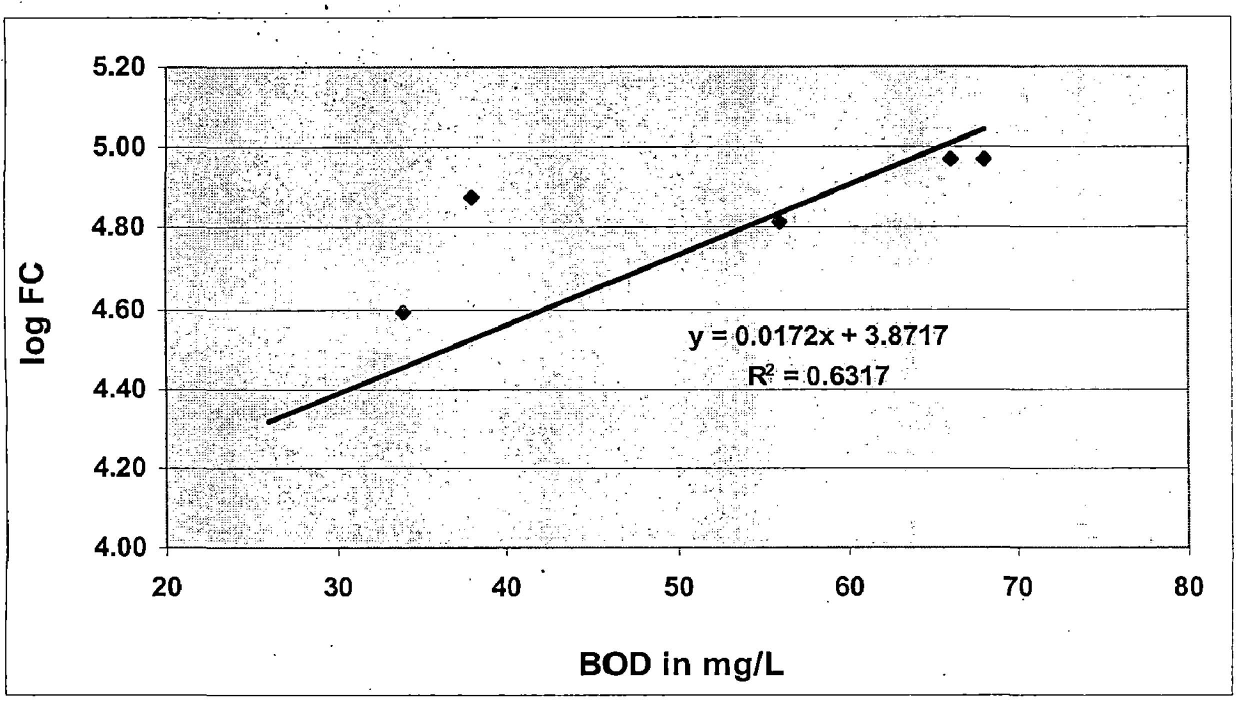


Fig.4.66:Correlation b/w BOD and FC at Outlet of Anaerobic Filter Cum FP plant Vasant Vihar (Delhi)

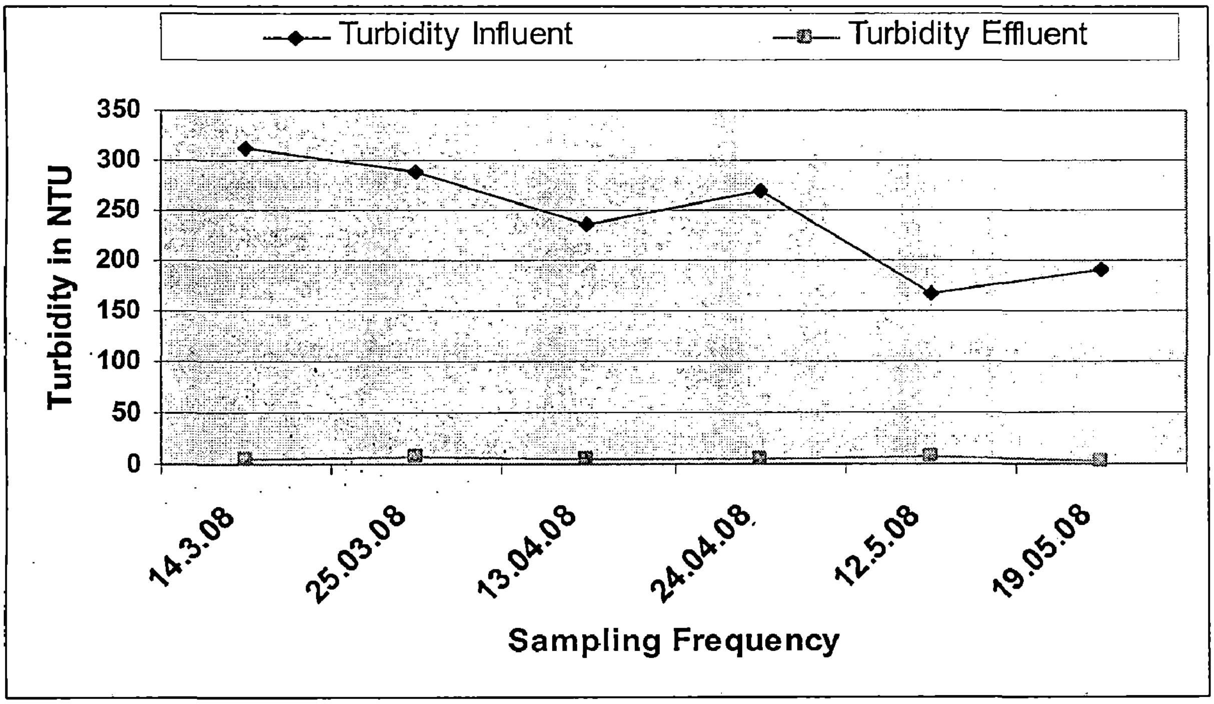


Fig. 4.67:Turbidity variations at Inlet and Outlet of aeration cum CW plant Faridabad (Haryana)

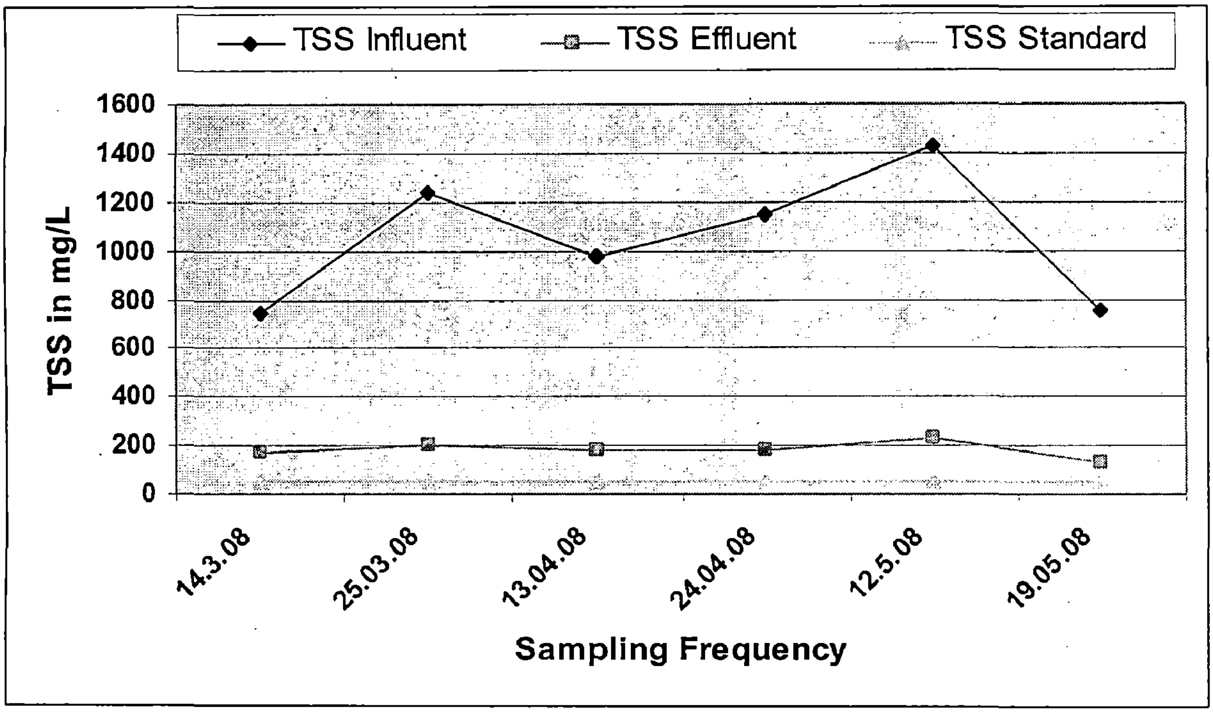


Fig. 4.68: TSS variations at Inlet and Outlet of aeration cum CW plant Faridabad (Haryana)

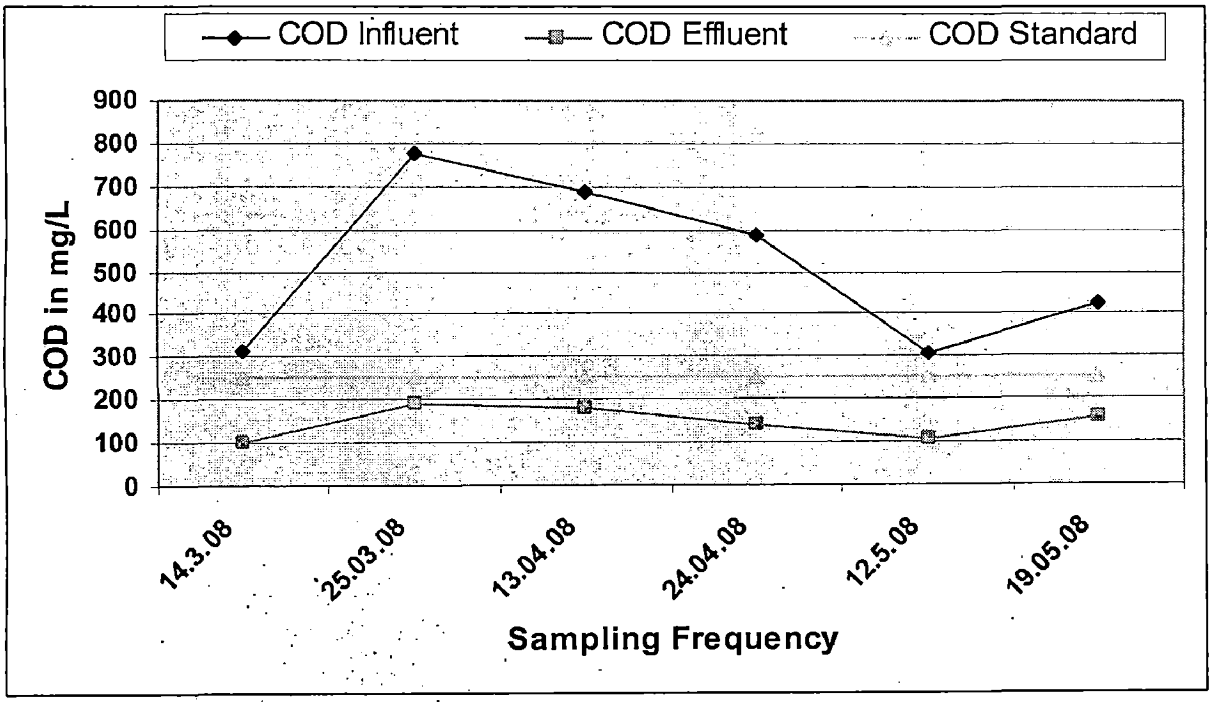


Fig. 4.69: COD variations at Inlet and Outlet of aeration cum CW plant Faridabad (Haryana)

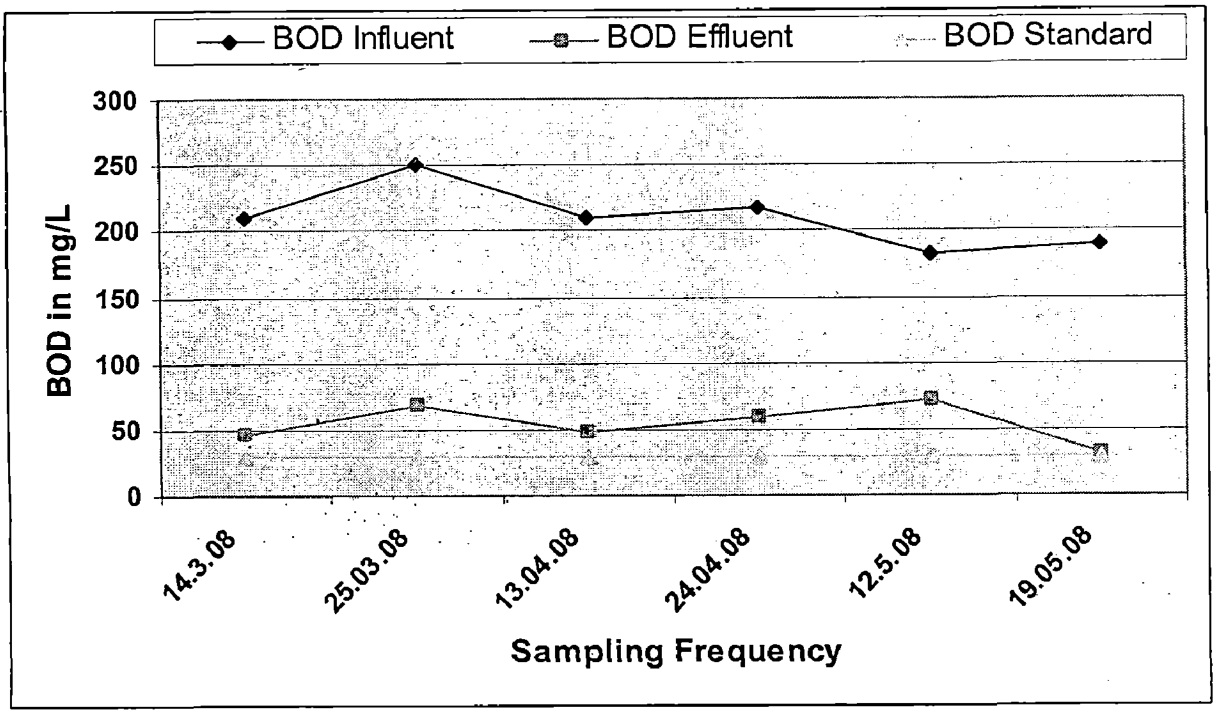


Fig4.70.: BOD variations at Inlet and Outlet of aeration cum CW plant Bakkarwala (Delhi)

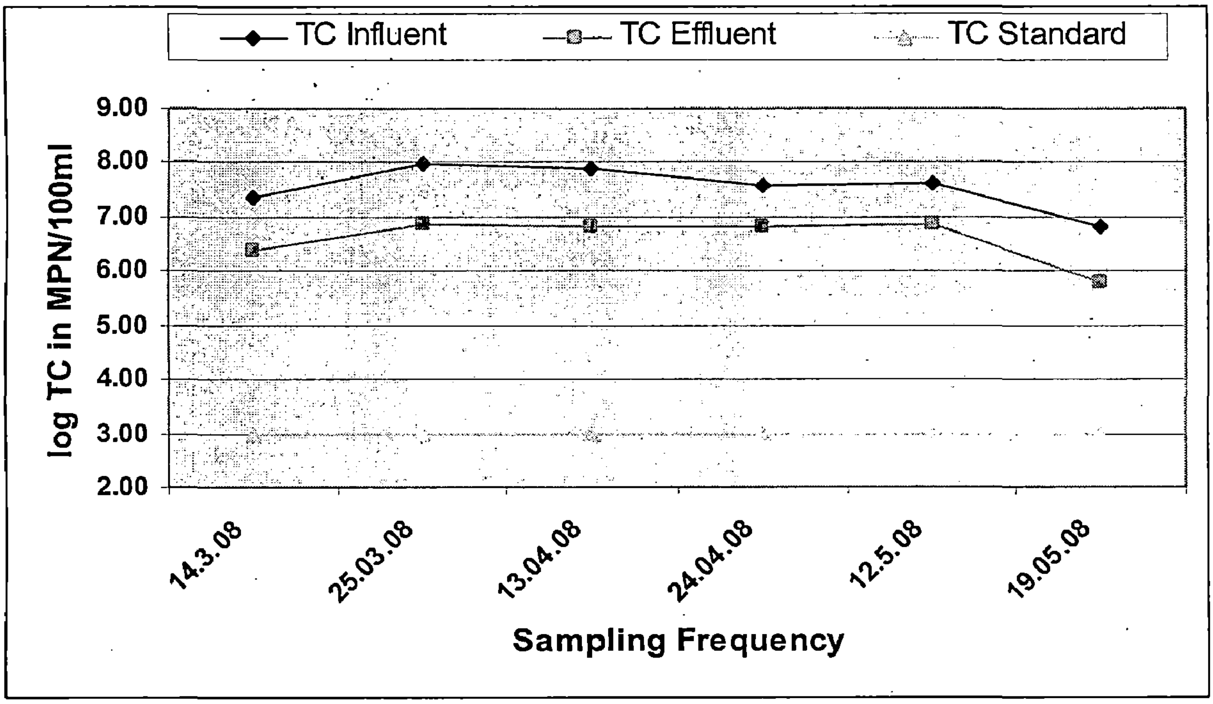


Fig.4.71 :TC variations at Inlet and Outlet of aeration cum CW plant Faridabad (Haryana)

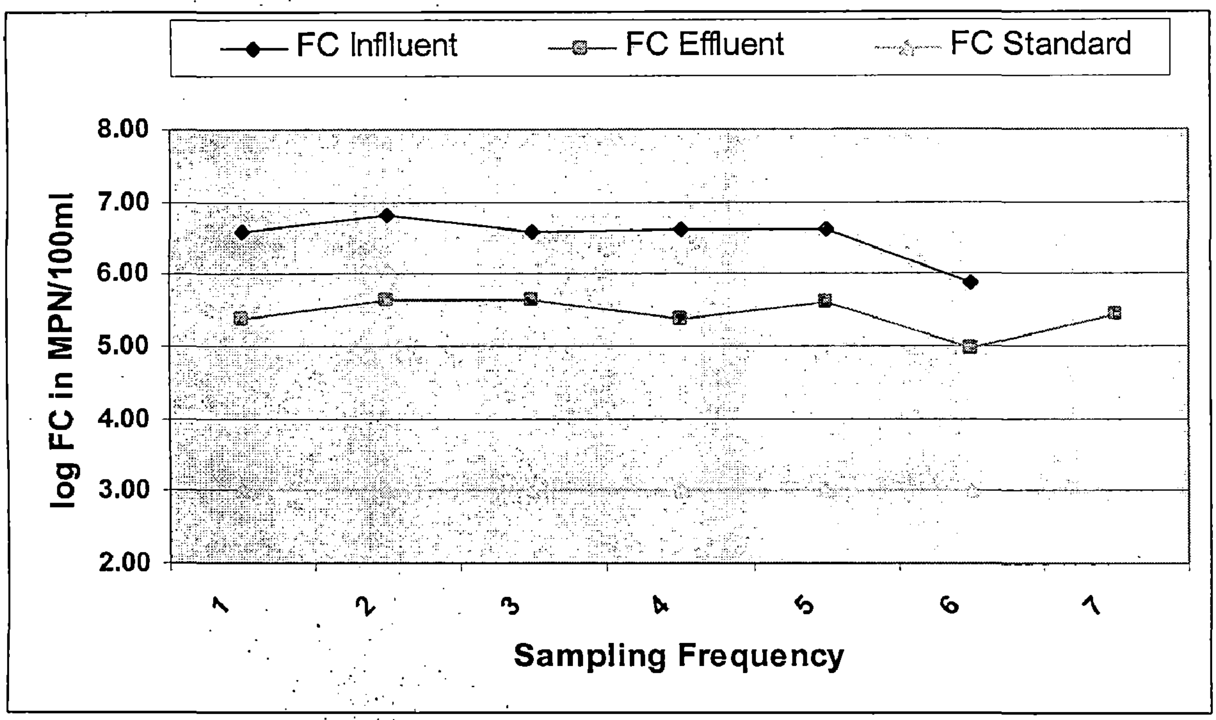


Fig. 4.72:FC variations at Inlet and Outlet of aeration cum CW plant Faridabad (Haryana)

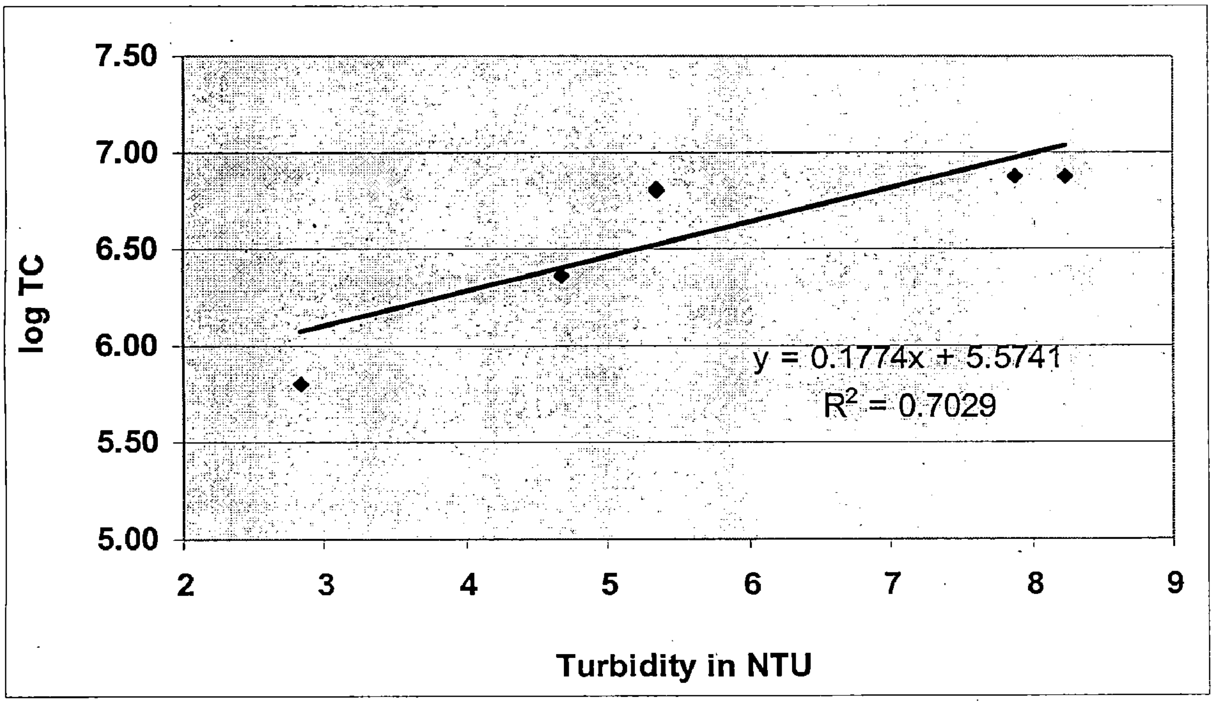


Fig.4.73:Correlation b/w Turbidity and TC at Outlet of aeration cum CW plant Faridabad (Haryana)

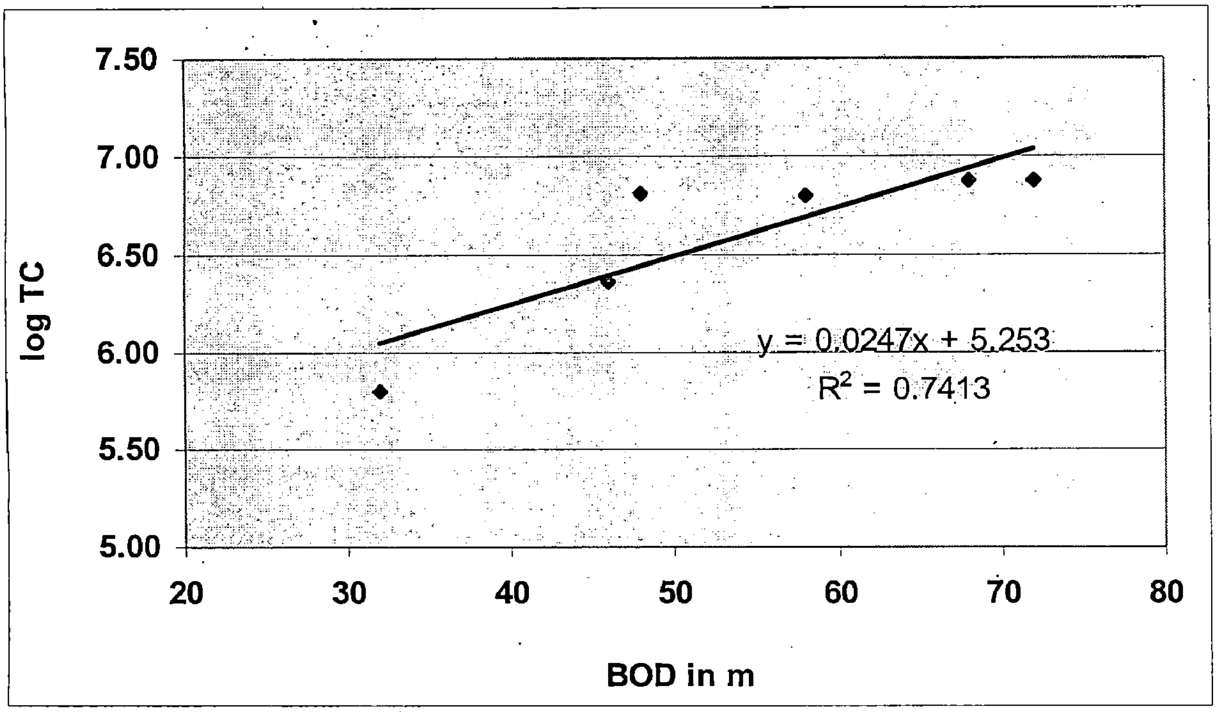


Fig.4.74:Correlation b/w BOD and TC at Outlet of aeration cum CW plant Faridabad (Haryana)

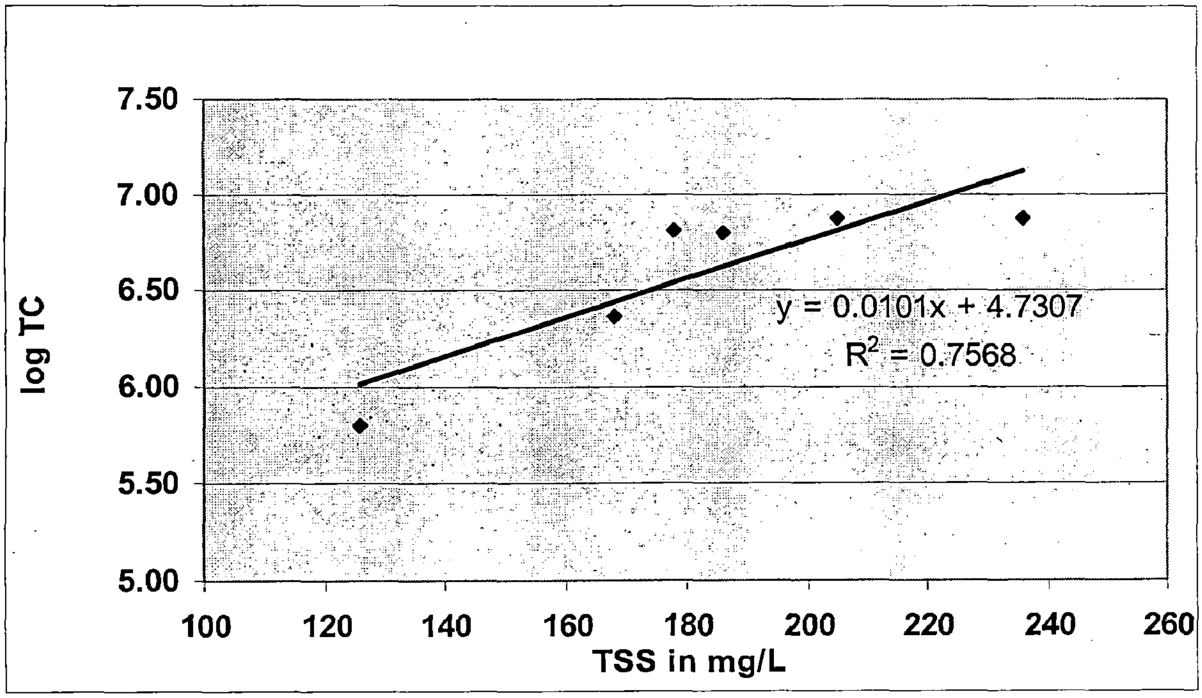


Fig.4.75:Correlation b/w TSS and TC at Outlet of aeration cum CW plant Faridabad (Haryana)

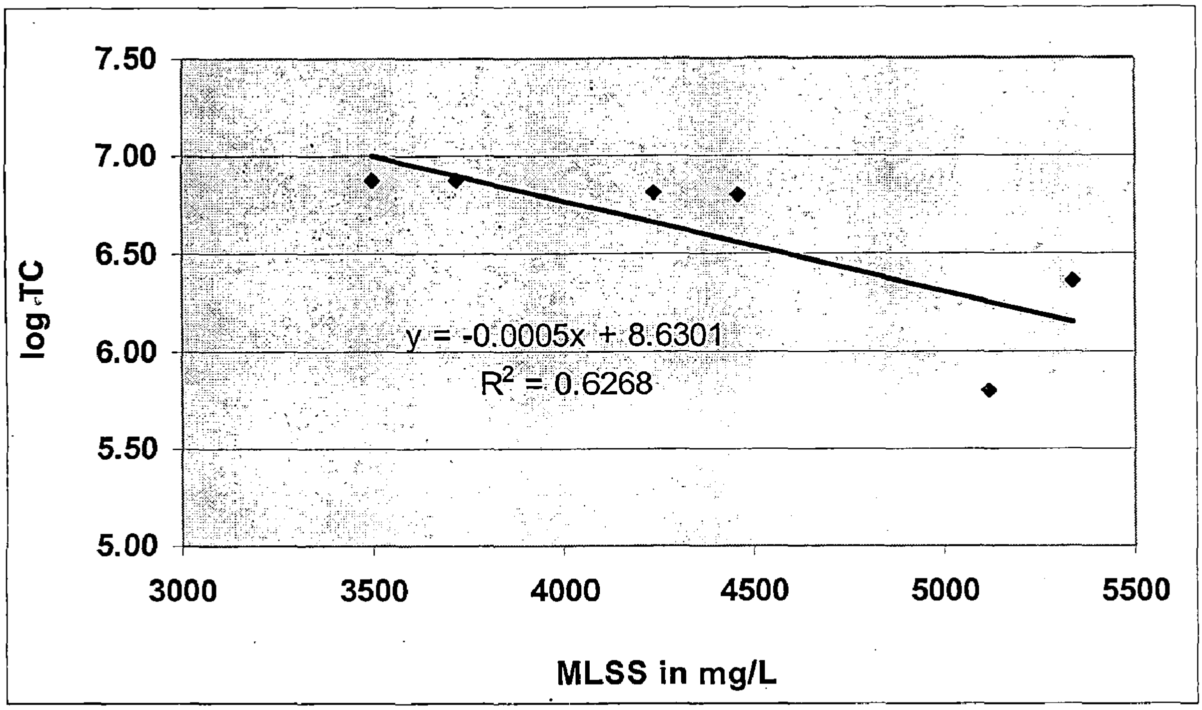


Fig.4.76:Correlation b/w MLSS and TC at Outlet of aeration cum CW plant

Faridabad (Haryana)

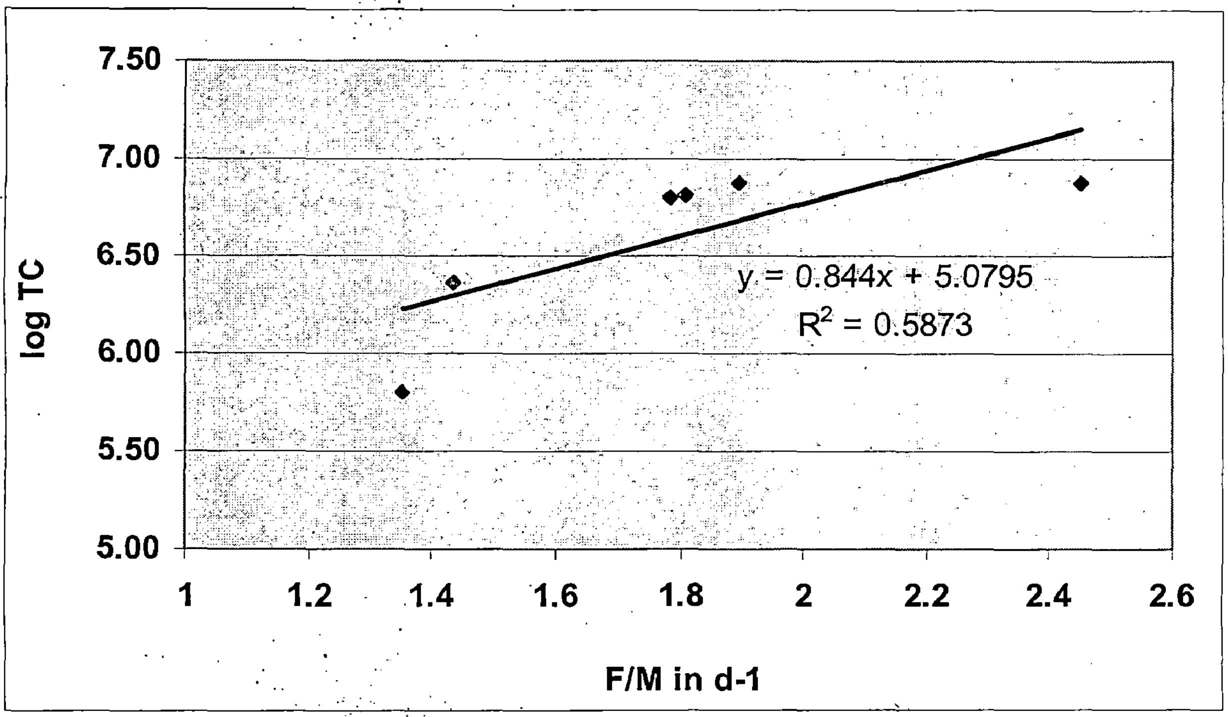


Fig4.77:Correlation b/w F/M and TC at Outlet of aeration cum CW plant Faridabad (Haryana)

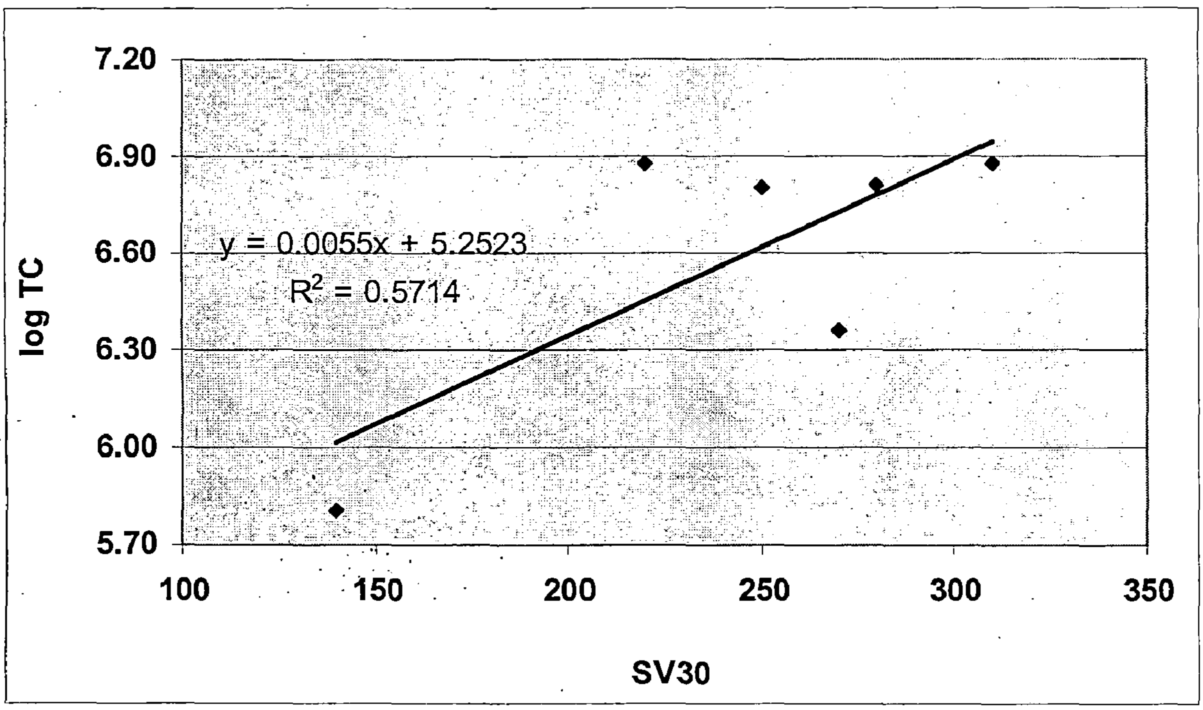


Fig.4.78:Correlation b/w SV30 and TC at Outlet of aeration cum CW plant Faridabad (Haryana)

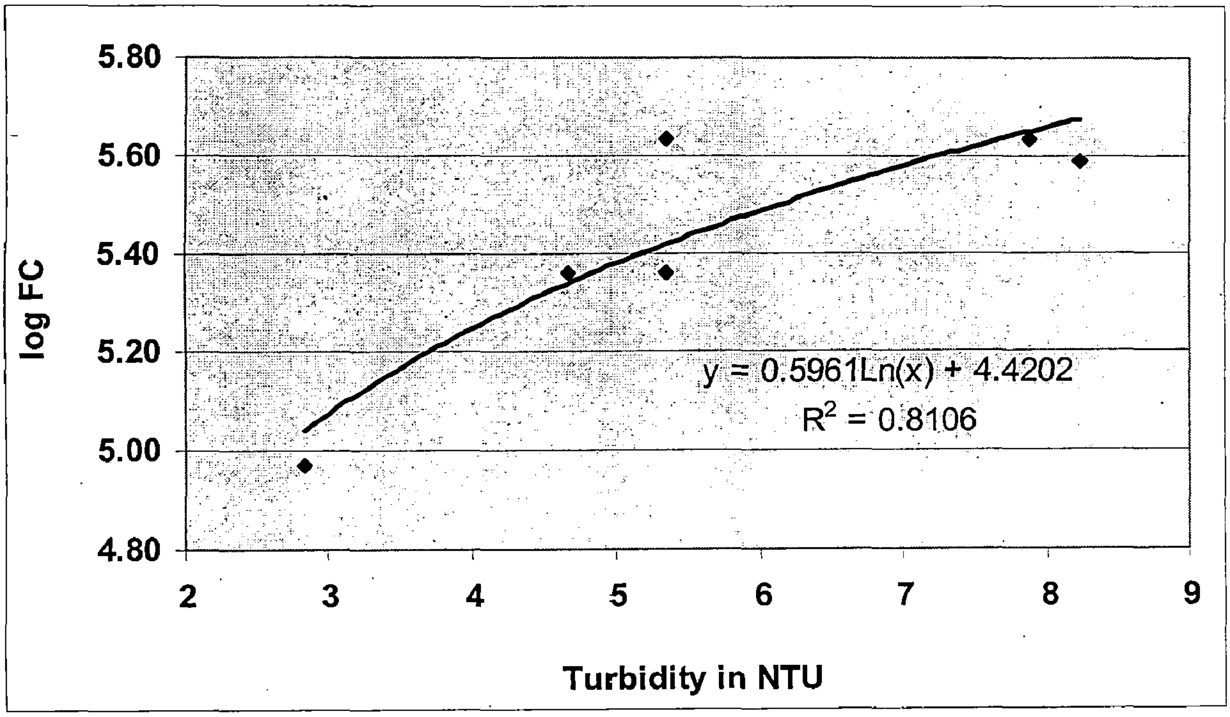


Fig.4.79:Correlation b/w Turbidity and FC at Outlet of aeration cum CW plant Faridabad (Haryana)

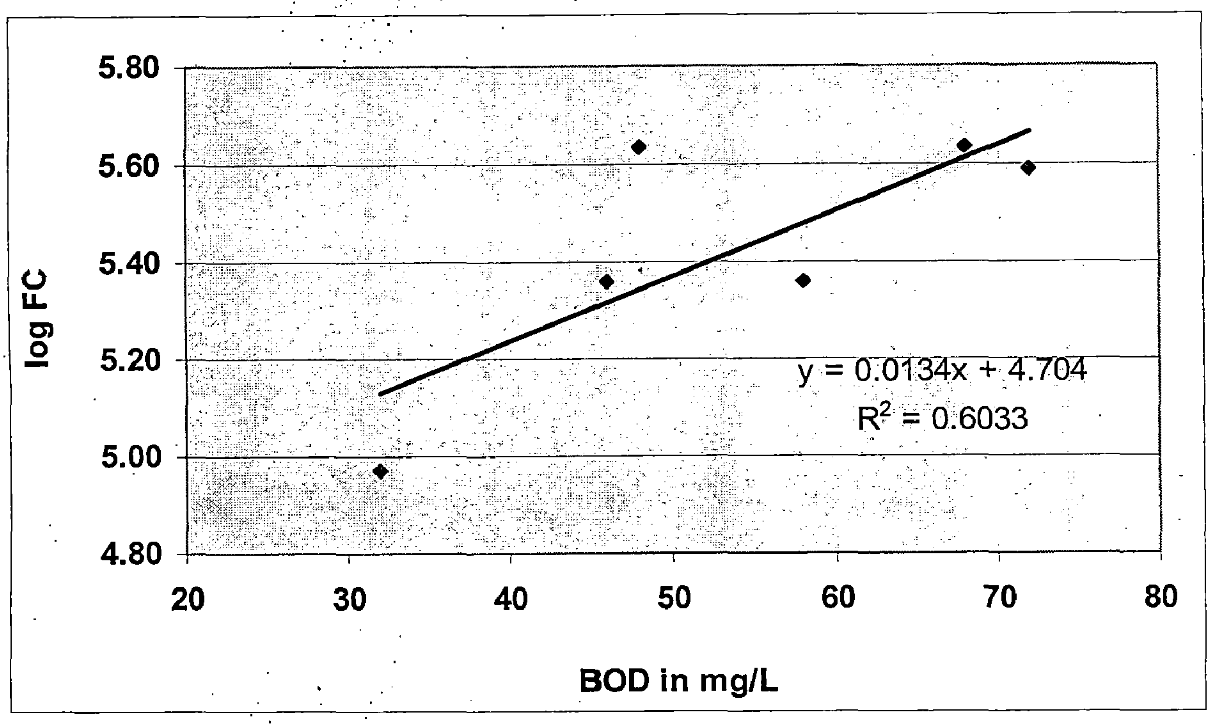


Fig.4.80:Correlation b/w BOD and FC at Outlet of aeration cum CW plant

Faridabad (Haryana)

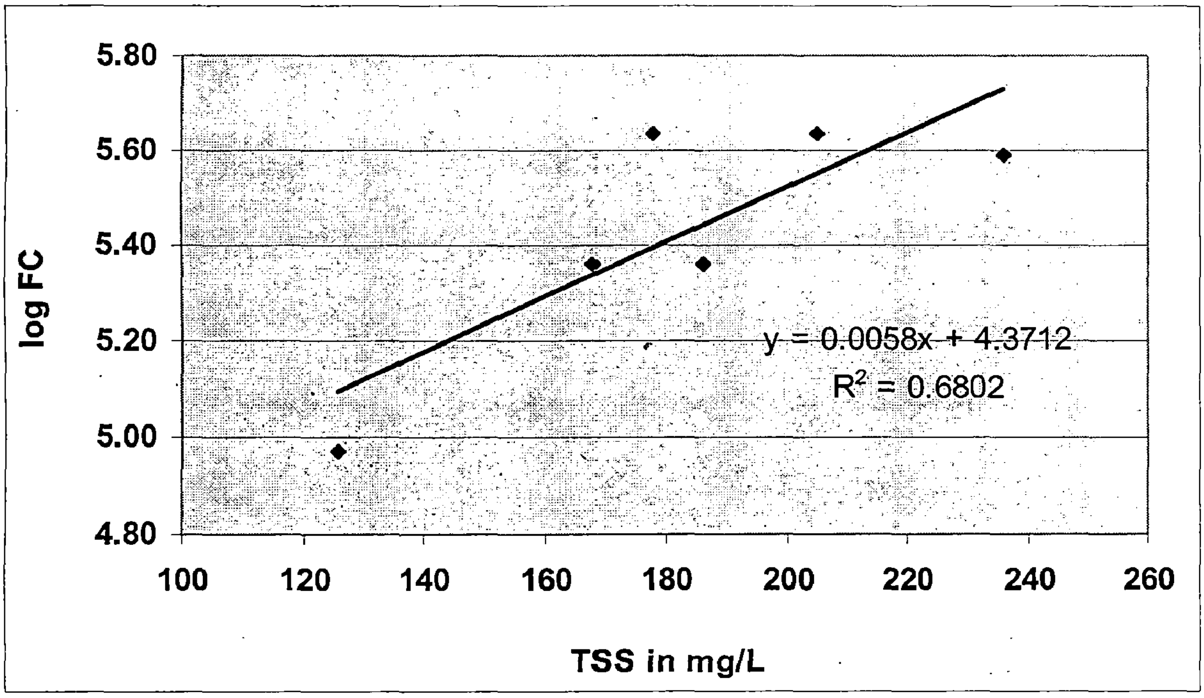


Fig.4.81:Correlation b/w TSS and FC at Outlet of aeration cum CW plant Faridabad (Haryana)

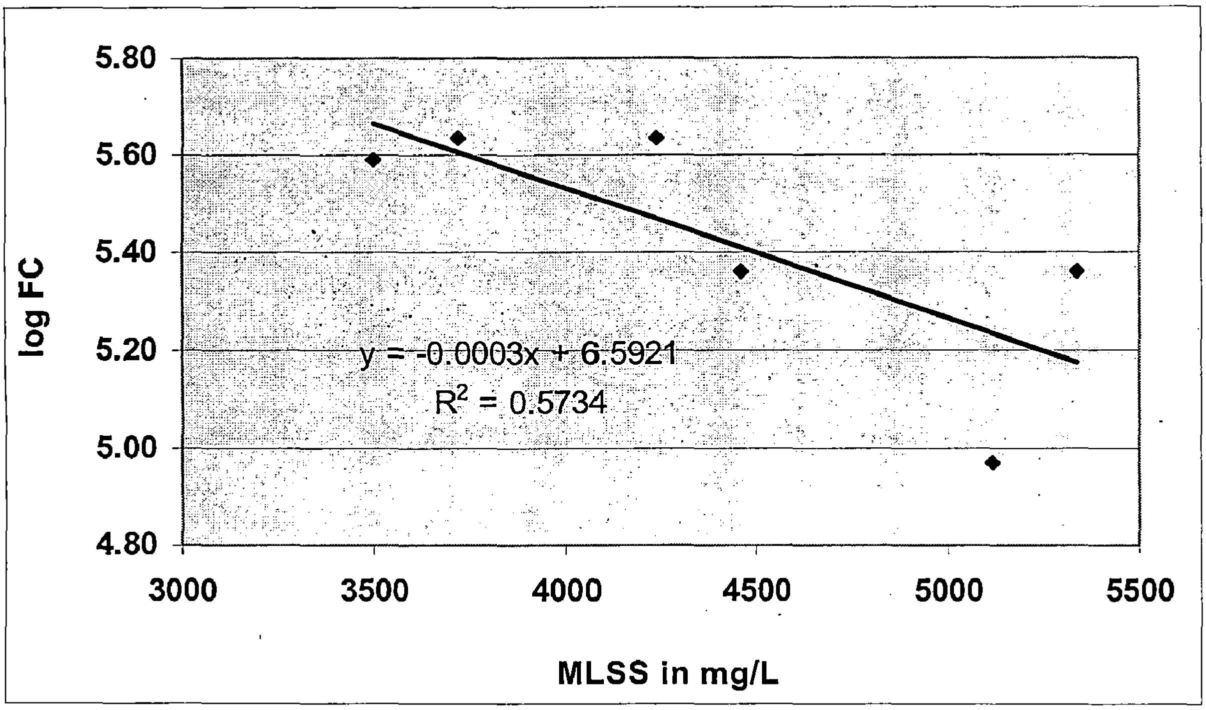


Fig.4.82:Correlation b/w MLSS and FC at Outlet of aeration cum CW plant Faridabad (Haryana)

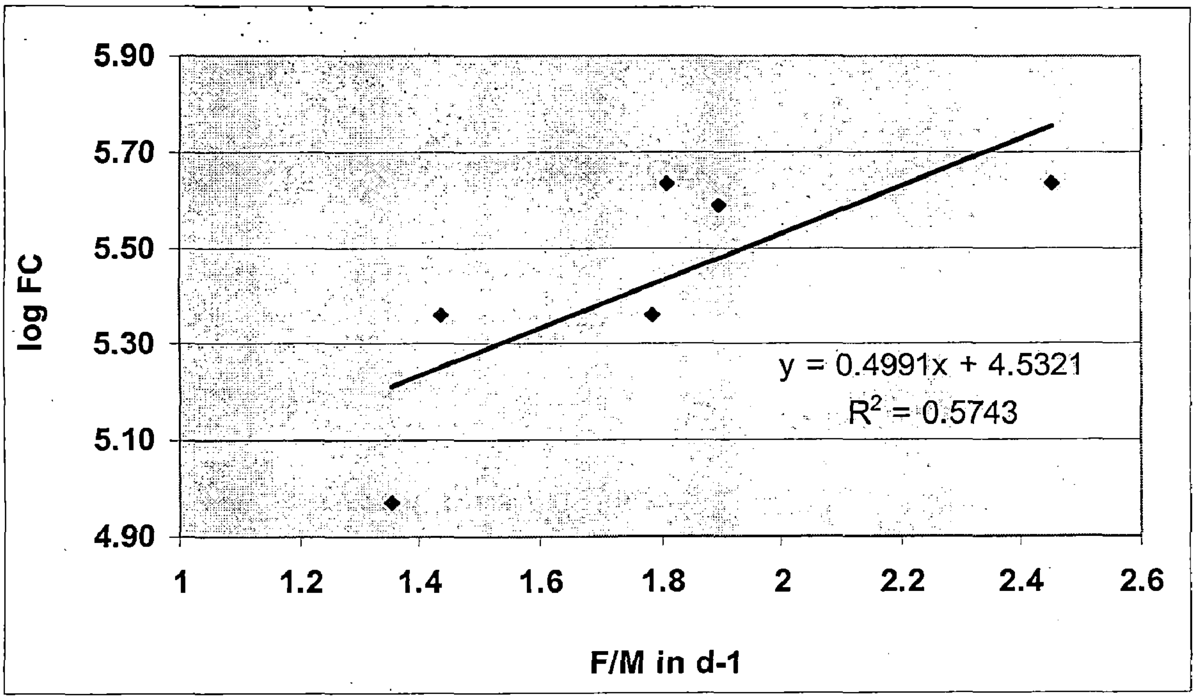


Fig.4.83:Correlation b/w F/M and FC at Outlet of aeration cum CW plant Faridabad (Haryana)

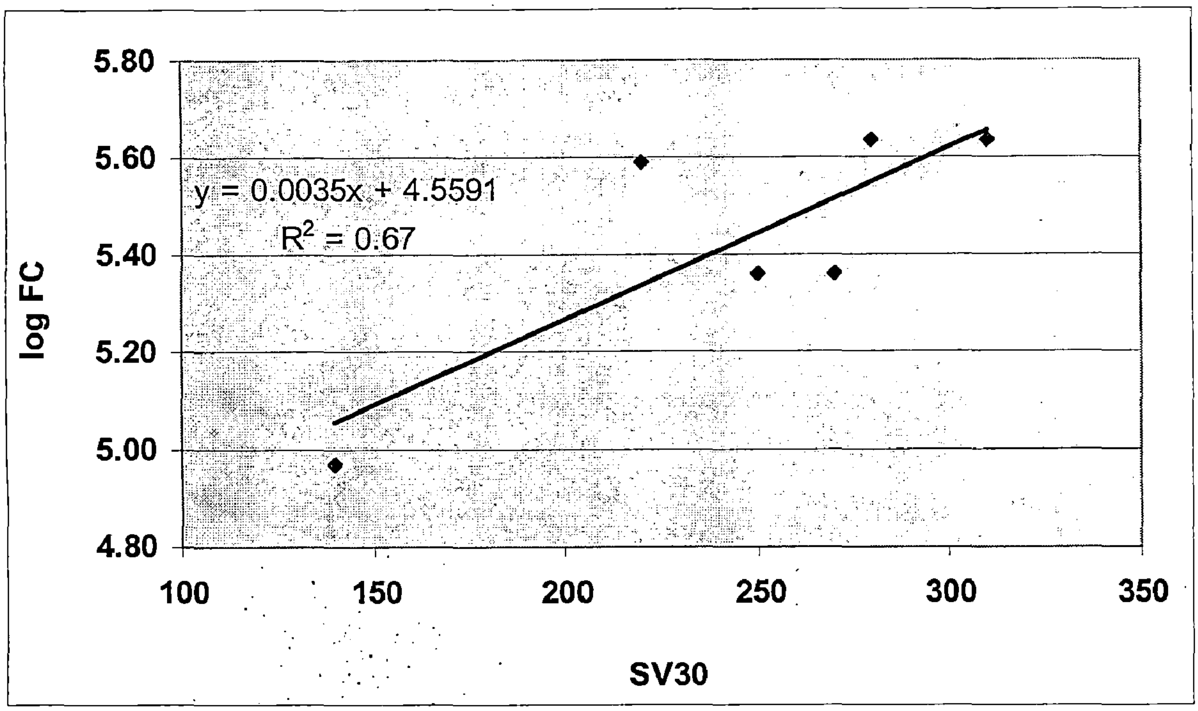


Fig.4.84:Correlation b/w SV30 and FC at Outlet of aeration cum CW plant Faridabad (Haryana)

4.6 OPERATION AND MAINTENANCE (O & M) OF STPs: OBSERVATIONS

4.6.1 SAFF System

- Fixed Media was found worn out on few visits; this is due to improper fastening of fixed media with the bed. The upward buoyancy force of water exerts pressure on media and hence proper fastening arrangements must be made for it. Also media gets damaged/deteriorated if comes out from wastewater, care should be taken to keep media fully submerged.

- Uniform air bubbles on the water surface in aeration tank was not observed on two occasions, this shows non uniform air flow from the diffusers .one of the reason for this is clogging of lower third media, the active zone for biological activities. Hence care should be taken for clogging of media otherwise air flow will not be uniform and this leads to lower performance.

- Raw sewage pumps are very important features of SAFF plants. Chocking of these pumps are quite frequent due to shortcomings in the functioning of bar screens .The floating materials was seen in the sump tanks causing chocking of pumps and these materials if pumped along with wastewater will chocked the media also.

- Sand Filter was found not working at one occasion. The washing out of sand requires immediate refilling. The availability of specific sand should be ensured. Frequent backwashing is also required fo rproper functioning of filter.

- On one occasion the sludge was found floating on the surface of the tank, the reason may be decomposing of sludge in the tank itself or blocking of withdrawal line of sludge.

- Chlorination of treated water is must for bringing the treated effluent within the standard limits. Chlorination was not done at all during the visits.

4.6.2 FAB System

- The elimination of media from the FAB reactor was observed. This may be due to uncontrolled operating conditions in FABs. The liquid flow velocity should not be more than certain threshold fluidization velocity to retain the complete media in FAB reactor and biomas loss from the media surface.

- On examination of media, taken from the reactor, it was observed that the media within the reactor was not completely coated with biofilm. This results in under performance of FAB system.
- Optimum dosage of chemicals is required to be ascertained. There was no controlled system for this.

4.6.3 Aeration cum CW System

- The inlet and outlet structures of reed beds are found partly chocked causing non uniform distribution of water in the reed beds. Frequent cleaning and brushing is required to avoid it.
- The emergent plants of CW system have higher growth rate and hence harvesting of plants is required. Composting, replanting and weeding are also required for efficient performance of system.
- Weeds were found in patches in reed beds, one of the methods to control it by raising and lowering of water level.
- Some patches in reed beds were found without vegetation. The clogging of gravel/sand bed was observed in those patches. The pretreatment of wastewater before CW is most important parameter, the proper functioning of settling tank is needed otherwise the suspended solids will pass through and will clog the sand/gravel bed.
- Stagnation of wastewater was seen on one occasion, causing mosquito breeding.

4.6.4 Anaerobic Baffled Filter cum Floating Plants System

- On most of the times the inadequate growth of floating plants was observed. The plants used in the system are of Cahyana specie. This specie may not be fit for the kind of wastewater coming in the plant and hence selection of specie is very important factor.
- Chocking of sand/gravel filter was seen, resulting in short-circuiting of wastewater and hence poor performance of plant in terms of BOD, COD and TSS removal.
- Bed odor was experienced in the vicinity of plant.

4.7 O & M COST COMPARISON OF THE STPs

The treatment plants considered in this study, are of different capacities, hence comparison of plants have been done on per MLD basis. Since the STPs under consideration have different treatment technologies and located at different parts of Northern India, only O & M cost comparison is done.

In case of FAB and SAFF plants, the cost of chemicals used in the plants at various stages like Sodium Hypochlorite, PAC, PE and other chemicals have been included in their O & M costs respectively likewise in case of constructed wetlands and floating plants system, the cost of plants, seeds have been included. Table-4.16 to 4.19 and Fig.4.86 show the comparison.

As can be seen, the anaerobic baffled filter cum floating plants system is cheaper in comparison to other systems if only O & M cost is considered. The system is comparatively cheaper if cost of electricity during O & M is considered. FAB based systems, because of the sophistication of technology, are costlier as these systems required highly skilled supervision and costly chemicals. However, the overall economics of comparison of plants will includes the cost of land, cost of process and design, cost of civil works, cost of E & M supply and erection, capital cost etc.

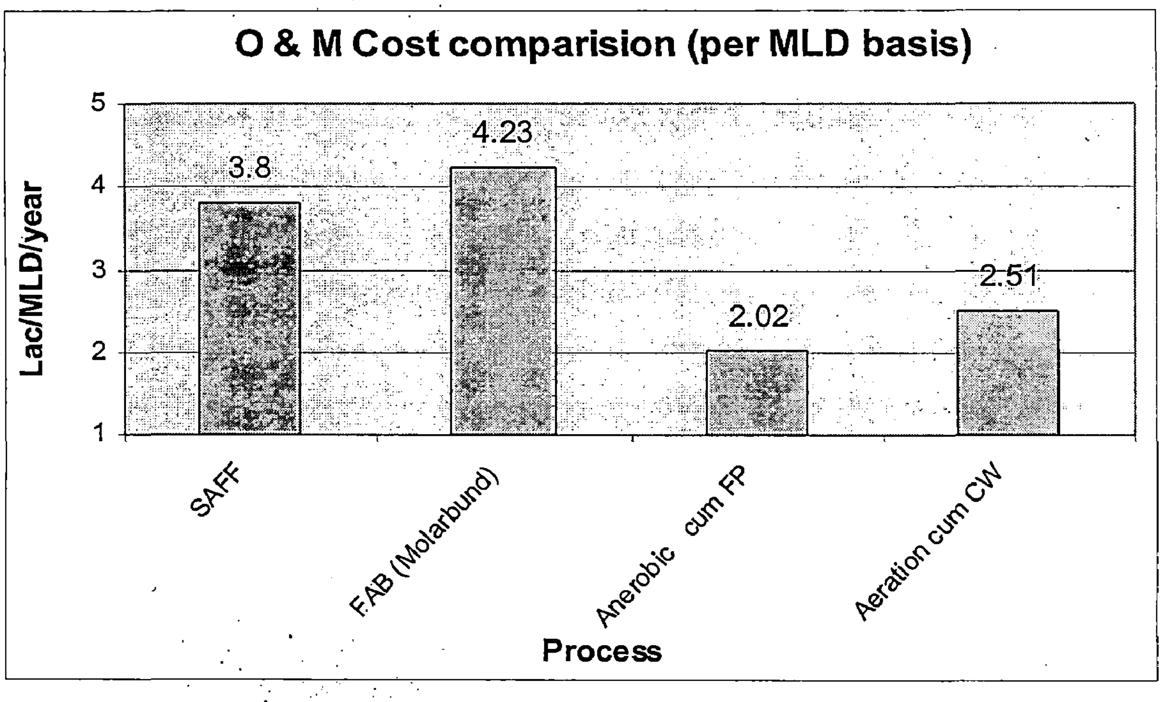


Fig. 4.86: O & M Cost Comparison (per MLD per year basis) of Different Processes

CONCLUSION

This study mainly emphasizes the performance evaluation of four different types of decentralized STPs in terms of BOD, COD, TSS, TC, FC removal. This study also includes O & M related problems in these STPs and there O & M cost (per MLD per year basis).Following conclusions are drawn from this study:

5.1 BASED ON SAFF PROCESS

- Effluent turbidity and TSS has a good correlation with the effluent concentrations of indicator microorganisms. As suggested by *Fecham et. al, 1981* that removal of bacteria caused by settlement because they adsorbed within suspended solids.

- Operational parameters like MLSS, SV30 and F/M have been correlated with the effluent concentrations of micro organisms. This shows that by controlling these operational parameters plant can be operated in an efficient way.

- Lab scale and Full–scale experiments are necessary to understand the dynamics of micro organism in SAFF systems at different loading rate and how to maintain these organisms keeping effluent quality better. Also designing of fixed film media structure requires more attention.

- Over all performance of SAFF system was found good in terms of mean removal percentage of BOD, TC and FC. SAFF system was found better than FAB system in organic matter removal and matches in coliform removal.

5.2 BASED ON FAB PROCESS

- Effluent turbidity and TSS has a moderate correlation with the effluent concentrations of indicator microorganisms. Also BOD correlation coefficient is approximately equal to 0.67 with the indicator micro organisms. The average performance indicates not suitability of FAB systems for treatment of wastewater with insoluble BOD as solids are not retained in the reactor for sufficient time for the solubilization.

- Over all performance of FAB system was found good in terms of mean removal percentage of BOD when strength of influent wastewater is low.

- Operational parameters like MLSS, SV30 and F/M have been correlated with the effluent concentrations of micro organisms. This shows that by controlling these operational parameters plant can be operated in an efficient way. The higher F/M ratio and low HRT was found in FAB systems.

- Some components of FAB systems require redesigning /modifications to make them efficient. The observations shows that these systems are not optimized due to shortage of lands in urban scenario.

5.3 BASED ON ANEROBIC CUM FLOATING PLANTS PROCESS

- The performance of FP plant was poor in BOD and COD removal. Plant shows moderate results in terms of indicator coliform removal. The possible mechanism is predation by protozoa in removal of microorganism. The SEM analysis on root rhizome sample confirms the presence of Protozoa.

- For efficient functioning of FP plant, it was observed that specialized supervision is required.

- Locally available plants having higher growth rate should be used.

- The O & M cost is lowest as compared to other STPs this system can work efficiently, if managed properly.

5.4 BASED ON AERATION CUM CONSTRUCTED WETLANDS

- The overall performance of CW plant was good in coliform removal. Plant shows moderate results in terms of BOD removal. The possible mechanism is predation by protozoa in removal of microorganism. The SEM analysis on root rhizome sample confirms the presence of Protozoa.
- For efficient functioning of CW plant, it was observed that specialized supervision of reed bed is required.

- Locally available vegetation should be used, to facilitate the replanting and attracting fauna and flora.
- The O & M cost is low as compared to FAB and SAFF.

5.6 GENERAL CONCLUSION:

- The main difficulties in the data analysis were heterogeneity of the data, monitoring frequency, monitoring quality and quantity of treatment plants within each technology.

- The treatment plants showed difficulty to achieve most of the standards set by the CPCB/WHO, even the less stringent ones, based only on BOD and TSS removal.

- The small efficiency presented by the treatment plants can be a consequence of design problems or poor operation and maintenance.

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Table 4.1 Physico-Chemical & Microbiological Parameters for Inlet & Outlet points of SAFF plant, Dehradun

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
26.02.08	Inlet	7.25	311	856	645.658	256	7.50E+06	4.30E+06
	Outlet	7.77	5.08	212	191.465	50	9.30E+05	6.40E+05
11.03.08	Inlet	7.34	287.43	1003	880.23	310	2.30E+07	6.40E+05
	Outlet	7.89	6.48	275	289.458	56	4.30E+06	9.30E+05
27.03.08	Inlet	7.54	236.12	558	588.741	286	6.50E+06	2.30E+06
	Outlet	7.95	4.96	118	186.852	36	7.50E+05	4.30E+05

Table 4.2 Physico-Chemical & Microbiological Parameters for Inlet & Outlet points of the SAFF plant, Dehradun

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
26.04.08	**Inlet**	7.27	268.87	542	441.64	172	4.30E+06	2.30E+06
	Outlet	7.66	2.61	114	158.98	14	9.30E+05	4.30E+05
15.05.08	**Inlet**	7.19	167.3	1104	725.369	380	2.30E+07	4.30E+06
	Outlet	7.54	7.18	228	175.967	64	4.30E+06	7.50E+05
23.05.08	**Inlet**	7.12	202.32	468	464.569	198	2.80E+06	9.30E+05
	Outlet	7.43	2.82	86	173.785	18	2.30E+05	9.30E+04

Table 4.3 Physico-Chemical & Microbiological Parameters for Inlet, Outlet & After chlorination points of the FAB plant, Molarbund, Delhi

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
12.01.08	Inlet	7.25	311	906	963.124	360	2.30E+07	2.30E+05
	Outlet	7.34	8.2	140	152.365	92	4.30E+06	3.90E+04
	After Chlorination	-	-	-	-	-	2.30E+03	2.30E+03
29.02.08	Inlet	7.54	287.43	1284	831.532	330	6.50E+07	3.90E+05
	Outlet	7.27	9.12	180	131.071	78	9.30E+06	7.50E+04
	After Chlorination	-	-	-	-	-	2.30E+03	9.30E+02
14.03.08	Inlet	7.19	236.12	976	568.824	280	2.30E+07	3.90E+05
	Outlet	7.28	6.6	196	87.856	84	2.30E+06	4.30E+04
	After Chlorination	7.25	-	-	-	-	3.90E+03	2.30E+03

Table 4.4 Physico-Chemical & Microbiological Parameters for Inlet, Outlet & After Chlorination Points of the FAB Plant, Molarbund, Delhi

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
25.03.08	Inlet	7.36	268.87	1280	756.03	380	3.90E+07	2.30E+05
	Outlet	7.16	4.72	112	108.478	66	9.30E+06	2.30E+04
	After Chlorination	-	-	-	-	-	2.30E+04	4.30E+03
13.04.08	Inlet	7.77	167.3	1414	785.311	285	6.50E+07	4.30E+05
	Outlet	7.89	6.84	214	133.254	72	7.50E+06	3.90E+04
	After Chlorination	-	-	-	-	-	2.30E+04	9.30E+03
24.04.08	Inlet	7.95	189.77	780	625.399	230	9.30E+06	3.90E+05
	Outlet	7.66	3.72	58	155.41	40	4.30E+06	4.30E+04
	After Chlorination	-	-	-	-	-	2.30E+04	6.50E+03

Table 4.5 Physico-Chemical & Microbiological Parameters for Inlet, Outlet & After Chlorination Points of the FAB Plant, Molarbund, Delhi

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
12.05.08	Inlet	7.54	20.7	592	151.021	60	2.30E+06	2.30E+05
	Outlet	7.69	4.7	78	42.93	24	3.90E+05	6.50E+04
	After Chlorination	-	-	-	-	-	6.50E+03	4.30E+02
19.05.08	Inlet	7.77	80.43	302	352.015	120	4.30E+06	2.30E+05
	Outlet	7.35	4.48	66	54.235	16	9.30E+05	6.50E+04
	After Chlorination	-	-	-	-	-	2.80E+04	3.90E+02

Table 4.6 Physico-Chemical & Microbiological Parameters for Inlet, Outlet & After Chlorination Points of the FAB Plant, Bakkarwala, Delhi

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
12.01.08	Inlet	7.25	87.7	484	287.654	130	7.50E+05	6.50E+04
	Outlet	7.87	4.98	84	85.232	48	6.50E+04	2.30E+04
	After Chlorination	-	-	-	-	-	7.50E+02	2.30E+02
29.02.08	Inlet	7.18	92.45	508	374.912	165	6.40E+05	7.50E+04
	Outlet	7.67	5.26	74	105.874	40	6.50E+04	2.30E+04
	After Chlorination	-	-	-	-	-	2.30E+02	2.30E+02
14.03.08	Inlet	7.53	56.13	390	323.235	140	2.30E+05	2.30E+04
	Outlet	7.93	2.85	62	33.545	16	7.50E+03	9.30E+02
	After Chlorination	-	-	-	-	-	2.30E+03	9.30E+02

Table 4.7 **Physico-Chemical & Microbiological Parameters for Inlet, Outlet & After Chlorination Points of the FAB Plant, Bakkarwala, Delhi**

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
25.03.08	Inlet	7.49	75.55	352	231.31	174	4.30E+05	4.30E+04
	Outlet	7.88	2.96	72	78.31	36	3.90E+04	9.30E+03
	After Chlorination	-	-	-	-	-	3.90E +03	2.30E+03
13.04.08	Inlet	7.61	47.63	284	289.45	120	3.90E+05	3.90E+04
	Outlet	7.99	2.65	48	65.984	22	2.30E+04	2.30E+03
	After Chlorination	-	-	-	-	-	4.30E+02	2.30E+02
24.04.08	Inlet	7.32	27.39	526	178.114	85	6.40E+05	9.30E+05
	Outlet	7.78	4.81	92	46.54	24	9.30E+04	2.30E+04
	After Chlorination	-	-	-	-	-	6.50E+03	3.90E+02

Table 4.8 Physico-Chemical & Microbiological Parameters for Inlet, Outlet & After Chlorination Points of the FAB Plant, Bakkarwala, Delhi

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
12.05.08	Inlet	7.49	18.01	212	92.482	135	2.30E+05	4.30E+05
	Outlet	8.06	2.15	42	59.254	26	7.50E+03	9.30E+02
	After Chlorination	-	-	-	-	-	4.30E+02	2.30E+02
19.05.08	Inlet	7.38	23.17	278	188.239	165	2.30E+05	2.30E+05
	Outlet	7.46	1.54	52	54.764	16	9.30E+03	2.30E+02
	After Chlorination	-	-	-	-	-	2.30E+02	NIL

Table 4.9 Physico-Chemical & Microbiological Parameters for Inlet, After filter & Outlet points of the Anaerobic filter cum FP plant, Vasant Vihar, Delhi

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
17.12.07	Inlet	7.25	205.09	406	354.232	202	2.30E+06	6.40E+05
	After Filtration	-	-	-	-	84	9.30E+05	2.30E+05
	Outlet	7.77	2.98	164	171.432	38	4.30E+05	7.50E+04
25.03.08	Inlet	7.34	210.37	468	484.485	288	6.40E+06	2.30E+05
	After Filtration	-	-	-	-	106	2.30E+06	7.50E+04
	Outlet	7.89	4.18	210	229.457	56	7.50E+05	6.50E+04
13.04.08	Inlet	7.54	287.43	668	536.236	285	4.30E+06	6.50E+05
	After Filtration	-	-	-	-	112	2.30E+06	2.30E+05
	Outlet	7.95	7.36	228	236.354	66	9.30E+05	9.30E+04

Table 4.10 Physico-Chemical & Microbiological Parameters for Inlet, After filter & Outlet points of the Anaerobic filter cum FP plant, Vasant Vihar, Delhi

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
24.04.08	Inlet	7.27	187.46	426	434.785	172	3.90E+06	2.30E+04
	After Filteration	7.66	3.26	146	158.98	78	2.30E+06	2.30E+04
	Outlet	-	-	-	-	34	7.50E+05	9.30E+03
12.05.08	Inlet	7.19	167.3	254	236.697	124	3.90E+05	3.90E+04
	After Filteration	7.54	1.84	114	113.54	54	2.30E+05	9.30E+03
	Outlet	-	-	-	-	26	2.30E+04	2.30E+03
19.05.08	Inlet	7.32	268.87	634	464.569	248	4.30E+06	7.50E+05
	After Filteration	7.69	7.83	274	193.549	108	3.90E+06	4.30E+05
	Outlet	-	-	-	-	68	9.30E+05	9.30E+04

Table 4.11 Physico-Chemical & Microbiological Parameters for Inlet, After Aeration & Outlet Points of the Aeration cum CW plant, Sector-13, Faridabad

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
14.03.08	Inlet	7.25	311	748	311.252	210	2.30E+07	3.90E+06
	After Aeration	-	-	-	-	158	9.30E+06	2.30E+06
	Outlet	7.77	4.68	168	102.95	46	2.30E+06	2.30E+05
25.03.08	Inlet	7.34	287.43	1234	777.84	250	9.30E+07	6.50E+06
	After Aeration	-	-	-	-	172	6.40E+07	4.30E+06
	Outlet	7.89	7.88	205	191.2	68	7.50E+06	4.30E+05
13.04.08	Inlet	7.54	236.12	978	688.042	210	7.50E+07	3.90E+06
	After Aeration	-	-	-	-	158	4.30E+07	2.30E+06
	Outlet	7.95	5.35	178	178.45	48	6.50E+06	4.30E+05

Table 4.12 Physico-Chemical & Microbiological Parameters for Inlet, After Aeration & Outlet Points of the Aeration cum CW plant, Sector-13, Faridabad

Date	Sampling Point	pH	Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TC (MPN/ 100mL)	FC (MPN/ 100mL)
24.04.08	Inlet	7.27	268.87	1148	588.56	218	3.90E+07	4.30E+06
	After Chlorination	-	-	-	-	152	2.30E+07	3.90E+06
	Outlet	7.66	5.35	186	138.87	58	6.40E+06	2.30E+05
12.05.08	Inlet	7.19	167.3	1430	305.128	182	4.30E+07	4.30E+06
	After Chlorination	-	-	-	-	134	3.90E+07	2.30E+06
	Outlet	7.54	8.24	236	104.54	72	7.50E+06	3.90E+05
19.05.08	Inlet	7.28	189.77	754	425.399	190	6.50E+06	7.50E+05
	After Chlorination	-	-	-	-	126	4.30E+06	6.50E+05
	Outlet	7.69	2.84	126	156.6	32	6.40E+05	9.30E+04

Table- 4.13: Data Obtained from the Analyzed Samples of Aeration Tank at Different Plants

Sampling Date	Parameters	Process Analyzed			
		SAFF	FAB(Molarbund)	FAB(Bakkarwala)	Aeration + CW
12.01.08	MLSS	5255	2165	1650	-
	SV30	300	280	200	-
26.02.08*	DO (Aeration Tank)	≈ 2mg/L	≈ 3mg/L	≈ 2mg/L	-
	F/M	0.42	3.52	0.83	-
29.02.08	MLSS	4510	2358	1435	-
	SV30	350	360	275	-
11.03.08*	DO (Aeration Tank)	≈ 2mg/L	≈ 2mg/L	≈ 2mg/L	-
	F/M	0.60	2.96	1.22	-
14.03.08	MLSS	5500	2468	2245	5338
	SV30	4834	260	160	270
27.03.08*	DO (Aeration Tank)	≈ 2mg/L	≈ 2mg/L	≈ 2mg/L	≈ 1mg/L
	F/M	0.31	2.40	0.66	1.43

* Sampling date for SAFF - Not analyzed

Table- 4.14: Data Obtained from the Analyzed Samples of Aeration Tank at Different Plants

Sampling Date	Parameters	Process Analyzed			
		SAFF	FAB(Molarbund)	FAB(Bakkarwala)	Aeration + CW
25.03.08	MLSS	3926	2552	1654	3723
	SV30	300	225	250	310
15.5.08*	DO (Aeration Tank)	≈ 2mg/L	≈ 2mg/L	≈ 2mg/L	≈ 2mg/L
	F/M	0.84	3.15	1.11	2.45
13.04.08	MLSS	7250	1856	1850	4236
	SV30	150	280	100	280
23.05.08*	DO (Aeration Tank)	≈ 1mg/L	≈ 3mg/L	≈ 2mg/L	≈ 2mg/L
	F/M	0.24	3.25	0.69	1.81
24.04.08	MLSS	-	3050	1023	4456
	SV30	-	310	225	250
	DO (Aeration Tank)	-	≈ 1mg/L	≈ 2mg/L	≈ 1mg/L
	F/M	-	1.60	0.88	1.78

* Sampling date for SAFF - Not analyzed

Table- 4.15: Data Obtained from the Analyzed Samples of Aeration Tank at Different Plants

Sampling Date	Parameters	Process Analyzed			
		SAFF	FAB(Molarbund)	FAB(Bakkarwala)	Aeration + CW
12.05.08	MLSS	-	3660	2142	3500
	SV30	-	165	125	220
	DO (Aeration Tank)	-	≈ 2mg/L	≈ 2mg/L	≈ 2mg/L
	F/M	-	0.35	0.67	1.89
29.05.08	MLSS	-	3175	2236	5116
	SV30	-	175	100	140
	DO (Aeration Tank)	-	≈ 2mg/L	≈ 2mg/L	≈ mg/L
	F/M	-	0.80	0.78	1.36

APPENDIX-B

Table-4.16: O & M Cost (per year per MLD basis) of FAB plant at Delhi (3 MLD plant)

Sr. No. (1)	Description of Items (2)	No. (3)	Units (4)	Rate /month (5)	Amount in Rs. (Col. 5 x 12)
1.	**Man Power engaged**				
	i. Junior Engineer	1	Man day	12000/-	144000/-
	ii. Supervisor	1	Man day	4500/-	54000/-
	iii. Plumber	2	Man day	4000/-	96000/-
	iv. Beldar/labour	2	Man day	3000/-	72000/-
	v. Safai karamcharis	3	Man day	3000/-	108000/-
	vi. Electricians	1	Man day	5000/-	60000/-
	vii. Asst. Chemist	1	Man day	5000/-	60000/-
	viii. Driver	1	Man day	3500/-	42000/-
2.	**Chemicals consumption** (Plant record)				
	i. Poly Aluminium Chloride (PAC)	@	8 l/day	Rs.15/litre	43200/-
	ii. Poly Electrolyte (PE)	@	7 kg/day	Rs.50/kg	4200/-
	iii. Sodium Hypochlorite	@	25 l/day =270X750/35	Rs.270/ 35litre	69428/-
3.	**Spare parts/Consumables** (Oil for pumps, Bushes for couplings, Valves, Spare parts for pumps, Grease, glen dori for leakage repairs, nut-bolts, bleaching powder, soaps, clothes etc)		Plant record		50000/-

4.	**Media repair/replacement** (taking life of media 3 years)		Lump sum		40000/-
5.	**Pumps repair/ replacement** (taking life of pumps 5 years)		Plant record		50000/-
6.	**Cost of lab analysis** (chemicals, apparatus etc.)		Lump sum		50000/-
7.	**Laboratory and Vehicle maintenance**		Lump sum		10000/-
8.	**Cost of Conveyance**		Plant record		100000/-
9.	**Miscellaneous civil works**		Lump sum		50000/-
10.	**Miscellaneous E & M works**		Lump sum		50000/-
				Sub cost	1152828/-
	Establishment Charges (Staff salaries, Office /Record keeping)	@	10% of	Sub cost	115280/-
			Total	Cost	1268108/-
			Cost	**/MLD**	**422700/-**

Table-4.17: O & M Cost (per year per MLD basis) of SAFF Plant at Dehradun (1 MLD plant)

Sr. No. (1)	Description of Items (2)	No. (3)	Units (4)	Rate /month (5)	Amount in Rs. (Col. 5 x 12)
1.	**Man Power engaged**				
	i. Junior Engineer	1/12	Man day	12000/-	12000/-
	ii. Supervisor	1	Man day	4500/-	54000/-
	iii. Plumber	1/5	Man day	4000/-	30000/-
	iv. Beldar/labour	2	Man day	3000/-	72000/-
	v. Safai karamcharis	1/2	Man day	3000/-	18000/-
	vi. Electricians	1/4	Man day	5000/-	15000/-
	vii. Asst. Chemist	1/4	Man day	5000/-	15000/-
2.	**Chemicals consumption**				
	i. Sodium Hypochlorite/chlorine		Plant record		15000/-
3.	**Spare parts/Consumables** (Oil for pumps, Bushes for couplings, Valves, Spare parts for pumps, Grease, glen dori for leakage repairs, nut-bolts, bleaching powder, soaps, clothes etc)		Plant record		15000/-
4.	**Media repair/replacement** (taking life of media 3 years)		Lump sum		20000/-

5.	**Pumps repair/ replacement** (taking life of pumps 5 years)		Plant record		15000/-
6.	**Cost of lab analysis** (chemicals, apparatus etc.)		Lump sum		20000/-
7.	**Laboratory and Vehicle maintenance**		Lump sum		5000/-
8.	**Cost of Conveyance**		Plant record		25000/-
9.	**Miscellaneous civil works**		Lump sum		5000/-
10.	**Miscellaneous E & M works**		Lump sum		10000/-
				Sub cost	346000/-
	Establishment charges (Staff salaries, Office /Record keeping)	@	10% of	Sub cost	34600/-
			Total	Cost	**380600/-**

Table-4.18: O & M Cost (per year per MLD basis) of Anaerobic cum Floating Plants at Delhi (0.5 MLD plant)

Sr. No. (1)	Description of Items (2)	No. (3)	Units (4)	Rate /month (5)	Amount in Rs. (Col. 5 x 12)
1.	**Man Power engaged**				
	i. Trained Supervisor	1/4	Man day	4500/-	13500/-
	ii. Beldar/labour	1/2	Man day	3000/-	18000/-
	iii. Safai karamcharis	1/4	Man day	3000/-	9000/-
	iv. Asst. Chemist	1/4	Man day	3500/-	10500/-
	v. Gardener (mali)	1/4	Man day	3000/-	9000/-
2.	**Spare parts/Consumables** (Oil for pumps, Bushes for couplings, Valves, Spare parts for pumps, Grease, glen dori for leakage repairs, nut-bolts, bleaching powder, soaps, clothes etc)		Plant record		3000/-
3.	**Pumps repair/ replacement** (taking life of pumps 5 years)		Lump sum		5000/-
4.	**Cost of lab analysis** (chemicals, apparatus etc.)		Lump sum		4000/-
5.	**Laboratory and Vehicle maintenance**		Plant record		2000/-

6.	**Cost of Conveyance**		Plant record		3000/-
7.	**Miscellaneous civil works**		Lump sum		8000/-
8.	**Miscellaneous E & M works**		Lump sum		5000/-
9.	**Miscellaneous horticulture works** (plants, seeds)		Lump sum		2000/-
				Sub cost	92000/-
10.	**Establishment Charges** (Staff salaries, Office /Record keeping)	@	10%	Sub cost	9200/-
			Total	Cost	101200/-
			Cost	**/MLD**	**202400/-**

Table-4.19: O & M Cost (per year per MLD basis) of Aeration cum CW Plant at Faridabad (3 MLD plant)

Sr. No. (1)	Description of Items (2)	No. (3)	Units (4)	Rate /month (5)	Amount in Rs. (Col. 5 x 12)
1.	**Man Power engaged**				
	i. Trained Supervisor	1	Man day	4500/-	54000/-
	ii. Beldar/labour	1	Man day	3000/-	36000/-
	iii. Safai karamcharis	1	Man day	3000/-	36000/-
	iv. Asst. Chemist	1/2	Man day	3500/-	21000/-
	v. Gardener (mali)	1/2	Man day	3000/-/-	18000/-
	vi. Junior Engineer (Hort.)	1/2	Man day	12000/-	72000/-
2.	**Spare parts/Consumables** (Oil for pumps, Bushes for couplings, Valves, Spare parts for pumps, Grease, glen dori for leakage repairs, nut-bolts, bleaching powder, soaps, clothes etc)		Plant record		25000/-
3.	**Pumps repair/ replacement** (taking life of pumps 5 years)		Lump sum		25000/-
4.	**Cost of lab analysis** (chemicals, apparatus etc.)		Lump sum		25000/-
5.	**Laboratory and Vehicle maintenance**		Plant record		15000/-

6.	**Cost of Conveyance**		Plant record		15000/-
7.	**Miscellaneous civil works**		Lump sum		40000/-
8.	**Miscellaneous E & M works**		Lump sum		25000/-
9.	**Miscellaneous horticulture works** (plants, seeds)		Lump sum		5000/-
				Sub cost	412000/-
	Establishment charges (Staff salaries, Office /Record keeping)	@	10% of	Sub cost	41200/-
			Total	Cost	453200/-
		Total	**Cost**	**/MLD**	**151066/-**