Performance of Slow Sand Filters In Treating Secondary Effluent Using Different Sizes of Local Sand

by

Ali Khamis Al-Yousef

A Thesis Presented to the

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This thesis, written by **ALI KHAMIS MANSOUR AL-YOUSEF** under the direction of his Thesis Advisor, and approved by his Thesis Committee, has been presented to and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements for the degree of

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بسم الله الرحمن الرحيم

This Thesis is Dedicated to

My Parents

My Wife

My Children

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THESIS ABSTRACT

NAME OF STUDENT : ALI KHAMIS AL-YOUSEF

TITLE OF STUDY : PERFORMANCE OF SLOW SAND FILTERS IN TREATING SECONDARY EFFLUENTS USING DIFFERENT SIZES OF LOCAL SAND

MAJOR FIELD : CIVIL ENGINEERING

DATE OF DEGREE : JUNE, 1990

This study is aimed to evaluate slow sand filtration as tertiary treatment of secondary wastewater effluents at pilot scale using different sizes of local sands. The wastewater was taken from extended aeration Treatment Plant of North Aramco. Two different sizes of local sand with effective sizes of 0.31 mm and 0.56 mm were used. In both cases, three different depths of sand bed, e.g., 135, 105 and 55 cm were investigated. This investigation was carried out over a period of about one year in order to include the seasonal variations in wastewater influent quality to the filter. It was found that the percent removal for all the parameters analyzed were decreasing by decreasing the sand depth and/or by increasing the sand size.

The pilot scale filter was successfully able to achieve consistent results. The average percent removals of turbidity, BOD, COD, standard plate counts, and total coliform bacteria were 95, 89, 67, 93 and over 99%, respectively. In view of the results, it was found that efficiency of the filter at all sand depths and sizes with respect to the percent removal of bacterial contaminants were exceptional to an extent that the effluent would easily qualify for unrestricted irrigation according to the standards employed in the Kingdom. Also, it was found that the filter could be operated until the sand depth is reduced to 55 cm due to cleaning purposes without any problem. The starting depth of the filter sand was 145 cm. The average percent removals of turbidity, BOD, COD, Standard Plate Counts, and total coliform bacteria were 91, 83, 50, 88 and over 93%, respectively, in a sand bed of 55 cm. The effect of the sand size on percent removal was marginal. It may be suggested to use coarse sand with deeper bed compared to fine sand of shallow bed to get the desired efficiency.

It was also found that the presence of algal blooms are critical for the performance of the slow sand filter as they resulted in decreasing the operational cycle about three folds. It was observed that the coarse sand resulted in longer duration of filter operation as compared to the fine sand, i.e., 84 days against 26 days for almost similar quality of the influent.

MASTER OF SCIENCE DEGREE

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ملخص الرسالـــــة

اسم الطالـــــب: علي خميس ال يوسف

عنوان الرسالـــة: فعالية المرشحات البطيئة لمعالجة مياه المجاري باستخدام مقاسات مختلفة من الرمال المحلية

التخصص الرئيسي: هندسة مدنيـــــة

تاريخ الحصول على الدرجة : ذو القعدة ١٤١٠هـ

تهدف هذه الدراسة الى تقييم الترشيح البطيء كوسيلة للمعالجة الثالثة لمياه مجاري محطة شمال الظهران بارامكو بعد المعالجة البيولوجيه بواسطة مرشح بقياس تجريبي باستخدام عدة مقاسات من الرمال المحلية . لقد تم دراسة مقاسين من الرمال ، ٣١ر. ، ٥٦ر. مم . وقد تم دراسة ثلاث ارتفاعات من الرمل كوسط ، ١٣٥ ، ١٠٥ ، ٥٥سم لكلا الحالتين . لقد استغرقت الدراسة اكثر من سنة لدراسة مدى تاثير فصول السنة على نوعية المياه المتدفقة للمرشح . لقد اظهرت الدراسة ان جميع العناصر التي حللت تقل نسبة ازالتها من المياه المرشحة كلما نقص ارتفاع طبقة الرمل او زاد مقاس الرمل المستخدم .

ان الترشيح البطيء هو حقا فعال بشكل منتظم حيث ان معدل نسبة ازالة الغشاوة ، المواد العضوية القابلة للتحلل بيولوجيا ، المواد القابلة للتحلل كيميائيا ، العدد الكلي للبكتيريا ، بكتيريا الكوليفورم كانت ٩٥، ٨٩، ٦٧ ، ٩٣ ، واكثر من ٩٩٪ بالمماثلة بالنظر الى النتائج . لقد استنتج ان المرشح فعال لكل المقاسات والارتفاعات من الرمال التي تم دراستها لازالة ملوثات البكتيريا والذي كان رائعا لدرجة ان المياه المرشحة قد تصلح بسهولة للاستخدام في الري بشكل غير مقيد حسب المواصفات المتبعة في المملكة ، كذلك اظهرت الدراسة ان المرشح قادر على ان يعمل بصورة جيدة حتى بارتفاع ٥٥سم من الرمل حيث ان معدل نسبة ازالة الغشاوة ، المواد العضوية القابلة للتحلل بيولوجيا ، المواد القابلة للتحلل كيميائيا ، العدد الكلي للبكتيريا ، بكتيريا الكوليفورم كانت ٩١، ٨٣، ٥٠ ، ٨٨ ، واكثر من ٩٣٪ ، بالمماثلة بارتفاع ٥٥سم من الرمل .

ان تأثير مقاس الرمل في نسبة ازالة الملوثات كانت هامشية .. حيث انه من الممكن اقتراح استخدام رمل بمقاس كبير بطبقة اعمق نسبة الى مقاس صغير بطبقة ضحلة من الرمل للحصول على نفس الكفاءة للمرشح .

كما أظهرت الدراسة ان وجود الطحالب مسألة هامة لانها تؤثر في تقصير مدة عمل المرشح حوالي ثلاث مرات . كذلك استنتج ان باستطاعة المرشح العمل فترة اطول بالمقاس الاكبر مقارنة بالمقاس الاصغر مثلا ٨٤ يوم نسبة الى ٢٦ يوم باستخدام نفس النوعية من المياه نسبيا .

درجة ماجستير في العلوم

جامعة الملك فهد للبترول والمعادن

الظهران ـ المملكة العربية السعودية

ذو القعدة ١٤١٠هـ

CHAPTER 1

INTRODUCTION

The rapid growth of industries along with huge growth of population all over the world has resulted in a large demand for water. This has led to acute water shortage since the natural sources of water can only meet the demands to a very limited extent. In fact, projections of water demand and supplies show that the situation in the Kingdom of Saudi Arabia is critical in many areas (57). This leads us to conserve water by reuse of wastewater effluents.

The reuse of wastewater has a valuable economical sources of water for agriculture and livestock production as well as industrial use (8,18,57). Literature (58) showed that 60% of wastewater is reused for agricultural irrigation, 30% for industrial cooling and process waters and about 10% for fish and wildlife, recreation, and groundwater recharge.

In the Kingdom, the reuse of wastewater is in its early stages of development, and requires extensive treatment and control with strict water quality standards (18). The health authorities of the Kingdom have adopted the criteria of 23 MPN/100 ml on a 30 day average basis for unrestricted agricultural reuse of wastewater (51). According to the Third Five Year Development Plan, the Kingdom of Saudi Arabia will recycle 335 million cubic meters per year of wastewater by the year 1990 and this quantity will reach to 730 million cubic meters by the year 2000 (57). Since direct reuse of secondary effluents is not justified mainly because of potential health hazards, in this aspect tertiary treatment is selected to improve the quality to such an extent that it may be directly reused.

Tertiary wastewater treatment technology is designed to remove pollutants, which cannot adequately be removed by conventional secondary treatment processes. These pollutants may include soluble inorganic compounds, organic materials, bacteria, viruses, turbidity, or soluble minerals which may interfere with reuse of the wastewater. So, the purpose of tertiary treatment of wastewater is to provide a water quality adequate for reuse (10).

Generally, the techniques of tertiary wastewater consist of : microstrainers, lagoons, sand filtration (slow, rapid, upward flow filtration), upward flow clarifiers and nitrifying filters (12). One of the attractive techniques adopted in this study is "Slow Sand Filtration". The reason behind this choice is summarized as follows :

Slow sand filters are widely used for purification of potable water due to their ability to produce a high quality filtrate. As the name implies, the key to the performance of a slow sand filter is the very low filtration rate. Rates listed in the literature range from 0.04 to 0.4 m/h with 0.12 m/h being a common value (21). This rate is approximately 100 times slower than a rapid sand filter and thus a comparable capacity slow sand filter will require 100 times the area of a rapid filter. Other disadvantages are their poor performance at low temperature and poor workability at high turbid waters. It should be realized however that the first two disadvantages are not a problem for Saudi Arabia while the third is of a little concern in view of the characteristics of the secondary effluents. The advantages of slow sand filters are (50) :

- Stable and effective SS and bacterial removal.
- Can be built with local materials using local skills and labour.
- Avoid much of the complex mechanical and electrical equipment.
- No chemicals are necessary

Slow sand filtration is widely used for water treatment, but it is very limited for wastewater treatment. The literature on slow sand filtration as a tertiary treatment process is very limited. Most of the results obtained based on experimental observations depended on laboratory scale models. However, satisfactory results were obtained in these studies .

It is proposed in this study to evaluate the performance of slow sand filters in treating secondary effluents. Two sizes of local sand have been investigated for different depths of sand bed (135,105, 55 cm) using the same hydraulic loading $\frac{Q}{A}$ = 0.16 m/hr. Furthermore, this study also investigated the effects of summer and winter seasons on the operational parameters. This study is, as it is believed, a continuation to the study conducted by Al-Adham (1) in order to investigate the design criteria ranges for slow sand filtration in the Kingdom as an alternative of tertiary treatment of wastewater effluent.

CHAPTER 2

LITERATURE REVIEW

2.1 Need for Wastewater Reuse

2.1.1 Water Resources in the Kingdom

The Kingdom is an arid country extending over an area of 2,125,000 sq. km. and current population of about 15 million. This vast country has wide variations in climate as annual rainfall varies from 500 mm in the mountainous southwest region to near zero in the Rub'al Khali region. There are no rivers or fresh water lakes. However, it has large reservoirs of geologically trapped groundwater , which is the primary source of water supplies in the Kingdom . Available water resources may be divided into two categories : Conventional resources such as aquifers and saline water conversion and non-conventional through water conservation and reuse. By far, the largest source of groundwater comes from the deep aquifer system in the Eastern, Northern and Central regions, and to a less extent from the shallow aquifers in the Western region. The best current estimates of water availability to the Kingdom are shown in Table 2.1 (57).

The heavy down draw in the aquifers, the traditional source of water with little or no recharge, there exists a danger that these aquifers will totally dry up. The high costs associated with current desalination production technology and the long distances for conveyance, desalinated sea water cannot presently be regarded as a viable long-term substitute for groundwater in meeting domestic users' need completely (18,26). Therefore, it is imperative to look into the feasibility of reusing municipal wastewater as water source.

Table 2.1 : Estimates of Water Availability and Its Utilization From 1980-2000 in the Kingdom in Million Cubic Meters Per Year (57)

Water Resources	1980	1985	1990	2000	Water Utilization	1980	1985	1990	2000
Non-Renewable	3,450	3,450	3,450	3,450	Urban & Industrial	502	823	1,211	2,279
Renewable	1,145	1,145	1,145	1,145	Rural & livestock watering	27	28	31	38
Desalination	63	605	794	1,198	Irrigated agriculture	1,832	1,873	2,345	3,220
Reclaimed from Urban Wastewater	-	140	335	730	Surplus (Deficit)	2,247	2,616	2,137	986
TOTAL RESOURCES	4,658	5,340	5,724	6,523	TOTAL UTILIZATION	4,658	5,340	5,724	6,523

o

2.1.2 Wastewater Reuse

Most wastewater treatment schemes cover conventional secondary treatment which can be characterized in terms of three main parameters : biochemical oxygen demand (BOD), total suspended solids (TSS), and fecal coliform (FC) concentrations. In general, the 30-consecutive day arithmetic means for BOD and TSS should be less than 30 mg/l; while for the fecal coliforms, the limit is 200 FC/100 ml (58). The major concern of wastewater reuse is related to health aspects. The bacteriological standards set for unrestricted irrigation in the State of California are 7-day maximum coliform concentration not in excess of 2.2 MPN/100 ml and a 30-day maximum coliform concentration not in excess of 23 MPN/100 ml (26,45,55). The quality criteria for wastewater reused for industrial cooling system in a large refinery and petrochemical complex, etc., were related to scale formers, corrosion, and biogrowth (41). There can be many applications for reclaimed wastewater in different categories of reuse such as irrigation, industry, groundwater recharge, etc.

2.1.3 Wastewater Reuse Criteria in the Kingdom

Actually, reclamation of wastewater is in its early stages of development in the Kingdom, and requires extensive treatment and control in accordance with strict water quality standards. Advances in treatment technology and the improvement of sewerage networks have resulted in the ability to utilize this resource for irrigated landscaping and industrial uses (18).

The concept of wastewater reuse given impetus by a legal ruling given by religious scholars of Islamic Council of Research and Consultation in April 1979. The ruling declared that treated wastewater can be used for all religious rituals, etc., and was considered clean for human use if it meets the health standards (15,16,17,26). Jeddah Municipality allowed reuse of untreated sewage for urban landscaping along highways, since 1984. However, this practice has been replaced by secondary treated water. In 1981, the Riyadh Region Water and Sewage Authority and Ministry of Agriculture and Water established standards of unrestricted irrigation as shown in Table 2.2 (26,51). However, the criteria for reuse of wastewater for irrigation now under discussion is likely to be much more stringent, and most of the existing treatment plants in the Kingdom may not meet the requirements without an advanced tertiary treatment unit (26).

TABLE 2.2 : STANDARDS FOR UNRESTRICTED IRRIGATION (26,51)

PARAMETER	STANDARDS
BOD	10 mg/l
Nitrate	10 mg/l
TSS	10 mg/l
Fecal Coliforms	
7 day average value	2.2 MPN/100 ml
30 day average value	23 MPN/100 ml

2.2 Filtration for Wastewater Reuse

Filtration is defined as physical, chemical and to some extent biological process for removing suspended impurities from water or wastewater by passing it through porous media (46). The filtration treatment has been introduced in the early 19th century, but its application to wastewater has not been well-established. Strict standards for quality have increased practice in wastewater filtration dramatically in the last twenty years. Wastewater filtration is considered among the well-established processes for the tertiary treatment of secondary effluents (12, 14, 31, 33, 43, 56, 58).

Filters used for treating wastewater are essentially similar to those employed for the treatment of drinking water; the processes , however, have significant differences mainly due to the fact that (7) :

- more removal of impurities on the surface of the sand due to particle size
- compressibility criteria of wastewater plays a role on filtration limiting the pressure applied and plugging the bed surface
- large variations exist in the grain size distribution of the wastewater
- filter media particles may be coated by slim growth formed by bacteria, reducing the bed capacity.

Variety of methods are established for filtration, including microstrainers, lagoons, and precoat filters; however, granular media filters are well recommended method of filtration (30, 31, 33, 56).

Slow sand filters are different from the rapid sand filters in terms of several aspects. Table 2.3 shows a comparison of the general features of both slow and rapid filters (14).

2.3 Rapid Sand Filtration

De Leon *et al.* (11) conducted research on microorganism removal from wastewater by rapid mixed filtration. They concluded that removal of naturally occurring coliphage and coliphage f2 were similar upon alum and polymer addition and averaged about 38%. Considering the simian rotavirus SA-11

Table 2.3 : GENERAL FEATURES OF CONVENTIONAL SLOW AND RAPID SAND FILTERS (14)

	Slow Sand Filters	**Rapid Sand Filters**
Rate of filtration	0.1 to 0.4 m/hr	4 to 21 m/hr
Area of the filter	Large, 2000 m^2	Small, 40-400 m^2
Depth of bed	30 cm of gravel, 90 to 110 cm of sand	30 to 45 cm of gravel, 60 to 70 cm of sand
Size of sand	ES 0.15-0.35 mm UC 3 or less sand	ES 0.35 mm or more UC 1.5 or less
Grain size distribution of sand	Unstratified	Stratified
Head loss	6 cm initial to 120 cm final	30 cm initial to 275 cm final
Length of run between cleanings	20 to 60 days	12 to 72 hours
Method of cleaning	Scraping off surface layer	Backwashing
Amount of water used in cleaning	0.2 to 0.6% of water filtered	1 to 6% of water filtered
Cost of construction	Relatively low	Relatively high
Cost of operation	Relatively low	Relatively high

and coliphage f2 as worst possible situation as far as animal viruses are concerned can probably be expected by mixed media filtration after the addition of 1.5 mg/l of alum and 0.25 mg/l of polymer averaged 21-38%. As expected, detection of human enteric viruses in the chlorinated sewage discharge was erratic. They further concluded that filtration was effective in reducing the fecal coliform bacteria.

Pomona virus study was a major research project that investigated the efficiency of virus removal by a conventional municipal water processing scheme of coagulation, sedimentation, filtration, and disinfection and direct filtration scheme without prior flocculation and sedimentation. The influent wastewater was seeded with a sufficient polio virus concentration to produce measurable effluent virus counts in order to evaluate process removal efficiency. It was reported that the two schemes performed equivalent (22).

Al-Sawaf (45) investigated the treatability of secondary effluent of North Aramco Wastewater Treatment Plant (NAWTP) by tertiary treatment using a direct filtration system. Two kinds of wastewater effluent (chlorinated and unchlorinated) were investigated. He concluded that direct filtration with dual medium was an effective tertiary process for Aramco secondary effluents in terms of effluent quality, head loss. The average turbidity removal ranged from 75 to 90% using various chemical dosages. He also studied the removal of turbidity without chemical addition. He concluded that the effluent turbidity exceeded 1.0 NTU with percent removal averaging from 28 to 39%. Eventually, he reported that 90% of the coliform bacteria were removed in the filtration process at alum dosages 5 mg/l and 95% when the alum dosage was 10 mg/l. The recommended nominal filtration rate is 4 gpm/sq.ft (9.8 m/hr.).

Suhail (55) investigated on a bench-scle study the tertiary treatment of

North Aramco Wastewater Treatment Plant (NAWTP) in order to be utilized for unrestricted reuse of landscape irrigation. The process employed for this study was coagulation, flocculation, sedimentation, filtration and chlorination. Two kinds of wastewater effluent (chlorinated and unchlorinated) were investigated. He reported that the overall percentage of turbidity removal for chlorinated secondary effluent ranged from 16 to 61% after sedimentation, while it ranged from 77 to 92% after the filtration process at various chemical dosages. The coliform count in the unchlorinated wastewater was reduced by 98%. The system was able to successfully satisfy the standards for coliform as it was reduced to 2.2 MPN/100 ml.

Hammer *et al.* (22) reported that all of the results from the above two studies showed that the performance of direct filtration (45) was equal or superior to the conventional system (55). Therefore, direct filtration is preferred because it significantly lowered the cost of construction and operation.

2.4 Slow Sand Filtration

Conventional slow sand filters have been used in the treatment of drinking water; however, their application in advanced treatment of secondary effluent is a new phenomenon due to their simplicity and effectiveness.

Slow sand filtration is considered the cheapest, simplest and most efficient for water treatment. Slow sand filters are the first modern treatment techniques used for the purification of clean water. They are still extensively employed in potable water industry for their well-known consistency of producing highly purified filtrate. Slow sand filters are widely used in treating potable water even in highly modernized regions. For example, they cover 72 hectares of land area for the treatment of London's potable water (46). A survey of 27 slow sand filtration plants in the United States indicated that most of these plants are currently serving communities of fewer than 10,000 people, are more than 50 years old, and are effective and inexpensive to operate (54). Basically speaking, Slow sand filters are more convenient for developing countries since local skills and materials can be used. Moreover, they are more efficient than rapid filters in removing microbial contaminants (6, 13, 20, 24, 49, 50).

The applications of slow sand filtration for wastewater treatment are very limited. Most of the results available in the literature are obtained based on experimental observations which depended on laboratory scale models. Slow sand filters required large land areas, besides their poor performance at low temperatures and poor workability at high turbid waters. It should be realized that the first two disadvantages are not a problem for the Kingdom, while the third disadvantage is dependent on the characteristics of the wastewater . Coupling those with the following advantages of slow sand filters :

- it is very stable and effective in removing suspended solids (SS) and bacterial contaminants.
- can be built with local materials using local skills and labor;
- avoid much of the complexity in mechanical and electrical equipment as compared with other treatment methods; and
- no chemicals will be used, so avoiding the hazards along transporting and storing of those chemicals. From the previous discussion, it is concluded that slow snd filtration would be an appropriate tertiary treatment process for the Kingdom.

2.4.1 Construction Features of Slow Sand Filter

Filter Box: The filter box is usually rectangular or cylindrical in shape and has vertical walls over 3 m in height. The most common materials used for construction are reinforced concrete or steel with concrete floor . Filter boxes should be watertight to prevent loss of water. The filter box essentially serves as the housing for three sections, viz., under drainage, gravel, and sand of which only the sand has direct role to play in the purification. The water reservoir above the sand bed can be considered for improving the water quality (13).

Underdrainage: The underdrainage system plays an important role in providing an unobstructed passage way for the treated water to leave the underside of the filter. The drainage system should be carefully designed so that it can be inspected, cleaned or repaired without the complete removal of the filter bed material. The underdrains take various forms such as (20) :

- Bricks carefully laid to form channels
- perforated pipes
- porous concrete covering drains.

One layer of 10-20 cm thickness would be sufficient for bricks with 10 mm openings between adjacent bricks (50). Bellamy ***et al.*** (5) stated that drain tiles are placed at the bottom of the gravel support to collect the filtered water.

Gravel: Used to prevent the filter material from entering and blocking the underdrainage system, a series of graded gravel layers can be used. The under layer of coarse size should be large enough to keep the openings in the filter bottom free; and the upper layer so fine that the overlying filter sand will not sink into its pores. Four layers will be required , i. e., 0.4-0.6 mm, 1.5-2.00

mm, 5-8 mm, and 15-25 mm size each layer about 10 cm thick (50). Gravel ensures a uniform abstraction of filtered water when a limited number of drains are provided. It was suggested that a thickness of 10-30 cm of graded gravel (20). Bellamy ***et al.*** (5) suggested a depth of 30 to 50 cm of graded gravel. Seelaus ***et al.*** (48) suggested size and depth of 5 layers of gravel as follows :

Size (mm)	**Depth (cm)**
3.0- 6.0	5
6.0-12.5	10
12.5-19.0	10
19.0-37.5	13
37.5-62.5	23

Paramasivam ***et al.*** (38) suggested 5 layers of gravel to make 40 cm of depth as follows :

Size (mm)	**Depth (cm)**
0.7- 1.4	6
2.0- 4.0	6
6.0-12.0	6
18.0-38.0	12
50.0	10

Fair *et al.* (14), Gumerman *et al.* (21), Paramasivam *et al.* (39), and Salvato (44) suggested depth of 30 cm. Montgomery (36) suggested a depth of 50 cm. Poynter and Slade (40) suggested a depth of 15 cm. Steel (53) suggested 3 layers of gravel as follows :

Size (mm)	Depth (cm)
4.5- 9.0	5
9.0-18.75	5
18.75-50.0	17.5

Stezak and Sims (54) suggested 3 layers of gravel as follows :

Size (mm)	Depth (cm)
3.0-10.0	10.1
6.0-18.0	10.1
18.0-50.0	10.3

Barnes and Wilson (4) suggested depth of gravel between 8 and 60 cm.

Filter Bed: Although various materials have been introduced as a filter bed in slow sand filters, sand is the most pronounced. The sand is characterized by its effective size (ES), which is defined as the diameter for which 10% of the sand is finer by weight (D_{10}), and its uniformity coefficient (UC), which is defined as the ratio of (D_{60})/(D_{10}). So, the literature of sand is discussed hereon.

Sand Size: The filter sand through which the water is passed should be free from clay, loam and organic matter; if necessary, the sand should be washed. Some degree of uniformity is desirable in order to ensure reasonable pore sizes and a sufficient porosity, by sieving out the particles which are too small or too large (20). Sand with an effective size (D_{10}) about 0.2 mm and a coefficient of uniformity (UC) less than 3 is normally slected . When such sand is not available a coefficient of uniformity up to 5 may be accepted, and an effective size of the sand ranging from 0.15 to 0.35 mm. Builder's grade sand often satisfies these requirements (50). Removals of total coliform bacteria declined from 99.4 percent for 0.128 mm sand to 96.0 percent for 0.615 mm sand (6). Bellamy ***et al.*** (5) suggested effective sand sizes ranging from 0.15 to 0.35 mm with UC less than 2. Ellis (12) used in his study two different sizes of sand (D_{10}) = 0.30 mm UC = 2.0; (D_{10}) = 0.60 mm UC = 1.2. Fair ***et al.*** (14) suggested (D_{10}) = 0.25-0.35 mm, UC between 2-3. Fox ***et al.*** (19) suggested (D_{10}) = 0.17 mm, UC = 2.1. Huisman and Hood (24) reported that UC of less than 3 should always be chosen; UC of less than 2 is preferable, but there is little advantage, in terms of porosity and permeability, in sand having UC below 1.5 if additional cost is thereby incurred. (D_{10}) having 0.15 to 0.35 mm was recommended. Montgomery (36) and Barnes and Wilson (4) suggested sand size (D_{10}) = 0.25-0.35 mm. Salvato (44) stated that sand with (D_{10}) = 0.25-0.35 mm and UC = 2-3 was recommended. Seelaus ***et al.*** (48) suggested sand size (D_{10}) = 0.28 mm and UC value of 1.4. Steel (53) suggested sand size (D_{10}) = 0.25-0.35 mm and UC less than 3. Stezak and Sims (54) suggested (D_{10}) = 0.1-0.5 mm.

Sand Depth: In practice, it has been found that the full bacterial activity extends over a depth of about 60 cm of filter bed so that the effective bed thickness should not be less than 70 cm ; so the initial bed thickness should be 30-50 cm more, in order to allow for a number of filter scrapings before resanding. The filter bed is normally 100-120 cm thick (50). Bellamy ***et al.*** (5), Salvato (44), and Steel (53) reported that the depth of sand bed ranges from 60 to 120 cm. Bacterial removal is not overly sensitive to sand bed depth in excess of 48 cm (6). Culp ***et al.*** (10) suggested a depth of 30 to 75 cm. Ellis (12) suggested 95 cm as a sand bed. Fair ***et al.*** (14) suggested sand bed of 60 to 105 cm. Fox ***et al.*** (19) suggested sand bed of 76 cm. Gumerman ***et al.*** (21) recommended sand bed depth ranging from 60 to 140 cm with 107 to 122 cm being the most popular. Montgomery (36) and Paramasivam ***et al.*** (39) suggested sand depth of 100 cm. Poynter and Slade (40) suggested sand depth of 60 cm. Stezak ***et al.*** (54) suggested sand depth ranging from 38 to 183 cm. Barnes and Wilson (4) suggested depth of sand 90 cm (UK) to 120 cm (USA).

The Water Reservoir: The depth of water over the filter bed is usually kept at about 100 to 150 cm. It provides a pressure or head of water, to drive the water through the fine spaces in the sand and to overcome resistance in other parts of the system; it also provides a storage period since each drop of water entering the filter stays several hours in the supernatant water layer before it reaches the sand surface (20,24). Fox ***et al.*** (19) suggested water above sand bed 125 cm. Gumerman ***et al.*** (21) recommended water depth ranging from 100 to 125 cm. The water to be treated stands to a depth ranges from 100 to 150 cm above the filter bed (24,49,50). Montgomery (36) suggested depth of 120 to 150 cm. Paramasivam ***et al.*** (38) suggested depth of 113 cm.

Paramasivam *et al.* (39) suggested depth of water above sand bed of 100 cm, Poynter and Slade (40) suggested depth of 150 cm. Weber (61) suggested water depth ranging from 90 to 150 cm.

2.4.2 Hydraulic Loading

Hydraulic loading rates range from 0.04 to 0.4 m/h (5). Bellamy *et al.* (6) and Fox *et al.* (19) suggested flowrates of 0.12 m/h. Ellis (12) suggested flowrate between 0.15 and 0.30 m/hr. It was stated that the usual rate lies between 0.1 and 0.2 m/h (20). Montgomery (36) suggested flowrate between 0.125 and 0.625 m/h. Flowrate of 0.1 to 0.3 m/h was chosen (39,50). Seelaus *et al.* (48) suggested flowrate of 0.26 m/h. Stezak and Sims (54) suggested flowrate range between 0.1 to 0.4 m/h. Barnes and Wilson (4) suggested flow rate range between 0.1 and 0.23 m/h.

Mode of Flowrate: The slow sand filters are commonly operated at constant rate filtration; however, in some instances, they are operated at declining rate filtration. This is normally done by closing the inlet valve but keeping the outlet valve open during overnight shutdown.

Constant-Rate-Filtration: The flowrate in a constant-rate filter is controlled by an effluent valve. In the first stages of filter run, the filter bed is relatively clean and provides little resistance to the flow ; thus at the start of a filter run, the effluent valve is open a little. As a filter run progresses, the surface of the sand bed is blocked and head loss across the bed increases. The valve gradually open to counteract head loss, thereby maintaining a constant-filtration rate (9).

Declining-Rate-Filtration: In declining rate filtration, the resistance of clean bed is low at first, and the flowrate is high. As the filter clogs with solids, resistance through the filter bed increases, which causes the flow rate to decrease. Declining rate filter includes such benefits as economy and ease of operation (9,20). If both inlet and outlet valves are closed for overnight shutdown, intermittent operation, the water above the sand bed surface becomes stagnant.

Intermittent Operation: Intermittent operation of slow sand filters is not advisable. This causes lower levels of water in contact with a highly biological active layer of sand (i.e. Schmutzdecke). This may lead to anaerobic condition when the dissolved oxygen is depleted (13,20,24). Investigations were carried out on pilot slow sand filters to study the effect of intermittent operation on the quality of filtrate. It has been observed that the bacteriological quality of filtrate is adversely affected (38).

2.4.3 Aerobic and Anaerobic Activity

Since biological activity is an important effect parameter in filtration, it is wise to emphasize the aerobic nature of the biological activity in slow sand filter. The biological processes will only continue to operate without harmful effects while enough dissolved oxygen is present in the influent. Huisman and Wood (24) suggested that aerobic biological activity will only continue if the influent to the filter contains a minimum of about 3 mg/l of dissolved oxygen and even at this level, the filtrate will probably be anoxic, charged with CO_2. A number of undesirable results, including taste and odor and more importantly the percentage removal of intestinal bacteria will be more lower than under aerobic conditions.

2.4.4 The Purification Mechanisms

The purification process introduced by slow sand filtration is so complex, although it is the oldest known method of treatment, it is not fully understood. The following two distinguished mechanisms are expected to take place after commissioning of the filter which lead to effective removal of suspended contaminants. (1) Sedimentation and straining, (2) chemical and bacteriological. Huisman and Wood (24) suggested mechanical straining, sedimentation, adsorption and chemical and biological activity as the important processes of slow sand filtration .

Sedimentation and Straining: Sedimentation and straining are taking place during the first few days of operation. The supernatant water above the sand bed is about 100-150 cm deep, and the average time that the sample will remain above the sand is from 3 to 12 hours, depending on the filtration rate. The heavier particles of suspended matter start to settle while the lighter particles are drawn into the pores between the sand grains and removed by straining on the top few millimeters. During the filtration process, a layer of inert deposits and biological matter forms on the top layer of the sand bed. This layer is referred to as Schmutzdecke. Moreover, biological growth also occurs within the sand bed and within the gravel support. Both the schmutzdecke and the biological growth have significant effect in the purification mechanism (5,6,13,20,24,30,50).

Chemical and Bacteriological: On the surface of the sand, there is a thin layer of material, schmutzdecke, which consists of thread like algae and numerous other forms of life including plankton, diatoms, protozoa rotiferes, fungi, bacteria, and actinomycetes, some of which may also live several centimeters below the sand surface. When the water passes through this layer, nearly all suspended matter and bacteria are removed. Some of the coloring matter and organic matter are also removed through this layer. The impurities stick to the bacterial slim and are subsequently broken down by biochemical action. The bacteria which were present in the sample are caught up in the schmutzdecke, since the amount of organic matter will not be sufficient to support the bacteria which will, in turn, slowly die out or may be eaten up by protozoa. Accordingly, some of the living organisms feeding upon bacteria will also be affected. As a result, some additional organic matter will be available from the dead organisms which will be feeding for bacteria at lower depths of the sand. This feeding will be depleted at deeper depth. In other words, the original degradable organic matter present in the sample will be gradually broken down and discharged with the effluent as inorganic compounds such as nitrates, sulfates, phosphates and carbon dioxide (13,20,24).

2.4.5 Effects of Algae

Algae are photosynthetic eucaryotes. They may be unicellular or Multicellular. Algae are found in all natural waters where light penetrates; moreover, algal blooms can develop whenever there is standing or slow-flowing body of water. They are classified by morphology and life cycle (34). There are several forms of algae and that can be present in water in a very high concentrations as high as 35,000 forms/ml or even 45,000 forms/ml. Some forms of algae have significant effects on the working of a biological filter. These effects may be beneficial or harmful depending on a variety of conditions. The algae may enter the filter along with the influent drawn from the reservoir or develop directly in the filter as a result of certain nutrients, (particularly nitrates and phosphates) and under the influence of sunlight.

The major adverse effects of algae on the operation and efficiency of a slow sand filtration are :

- early blocking of the filter
- increase difficulties associated with filter cleaning
- increase in concentration of soluble and biodegradable organics.

Other changes would also occur as a result of the presence of algae. For example, during the photosynthetic activity of algae, inorganic carbon sources as dissolved CO_2, bicarbonate and carbonate are used for anabolic processes. This both reduces the natural buffering capacity and produces hydroxyl ions. As a result of this, the pH would increase (up to PH 10, or even higher). As a consequence, magnesium hydroxide and calcium hydroxide are precipitated onto the sand grains. Algae are able to produce oxygen in relatively large quantities as a result of photosynthesis (13,20,24,50).

$$CO_2 + 2H_20 + \text{sunlight.........} CH_2O + O_2 + H_2O$$

The dissolved oxygen content would rise to as much as three times the theoretical saturation level during the day time (24). However, the reverse reaction will occur during the night time . The rate at which algae consume oxygen from the water may only be 10 to 15% of the rate of their production during the day. The presence of high concentration of algae may cause anaerobic biological activity and in turn produces tastes and odors (13).

Algal growth in filters is not totally disadvantageous. At moderate concentrations, they help in building up the filter skin. They also perform a useful service in providing the water with oxygen. The algae themselves, according to some investigations, produce substances harmful to bacteria, thus reducing their chances of survival. At high concentrations, however, they should be controlled by using one or more of a number of possible techniques. Both chemical and physical methods may be employed. Physical controls include harvesting the algal blooms from water surface periodically. Centrifugation is the most rapid and simple means of harvesting; however, it is costly. A more realistic approach is autoflocculation, which occurs in shallow ponds when the pH becomes above 9.5. The flocs settle out and can be recovered in the same method used for sludge collection (34). Covering both the filter and the feed reservoir is another means to control algal blooms. Chemical controls include prechlorination, preozonation, or addition of copper sulfate to the water (13). Chlorination of the supernatant water has been attempted, usually employing low chlorine concentrations 0.2 to 1.0 mg/l, but studies showed that even prechlorination resulting in total chlorine residuals of 8.8 mg/l, prolonged the filter run without affecting the treatment process. This is probably due to the prevention of algal growth in the supernatant reservoir (27,61).

2.4.6 Head Loss Through Filter Media

Generally the head loss through a clean media is very small. As the filtration operation in progress, clogging of the sand bed is increasing due to accumulation of impurities on the surface of the sand. As a result, the porosity changes with different degrees of clogging. So, mathematical expressions of head loss are very complex to be calculated if not impossible. In fact, several expressions have been proposed for computing the clean bed head loss such as Carman-Kozeny, Fair and Hatch, Rose and Hazen equations (33,58). As an example, the Fair and Hatch proposed the following equation :

$$h/L = \frac{36\,Kv(1-n)^2\,V}{g\,n^3\,W^2}\;\Sigma\;\frac{P_i}{d_i^2}$$

Where:

h/l = Headloss per unit depth of filter bed, m/m

K = Empirical constant equal to 5.0, dimensionless

v = Kinematic Viscosity, m^2/s

n = Porosity, dimensionless

V = Filtration velocity, m/s

g = Gravitational acceleration, m/s^2

w = Sphericity of grains (0.7 for angular and 0.8 for rounded)

P_i = Fraction of total weight of filter grains in layer i, dimensionless

d_i = Geometric mean diameter of grains in layer i, m.

The initial head loss through a filter depends on the size and depth of media, the rate of flow through the filter, type of underdrains and general filter piping arrangement.

Monk (35) stated that the total head losses cannot exceed the available head i.e., the difference between the water level over the filter bed and the water level over the weir. He further stated that, in order to avoid negative pressures it is not necessary to locate the weir chamber above the filter bed or to have an excessive depth of water over the filter bed .

Cleaning the Filter Bed: Cleaning should be conducted immediately following termination of the filtration cycle, otherwise if the filter is kept for a few days without cleaning, the overall effectiveness of the filter regarding contaminant removal will be adversely affected. In particular, significant deterioration of the bacteriological quality of the filtered water due to sloughing of these bacteria with the filter effluent could occur.

Cleaning of the filter bed is done when the head loss exceeds the designed value or the required flow rate becomes less than the designed value and in most cases because the filtrate quality is deteriorated. The interval between scrapings depends on the contaminants present in the influent, the hydraulic loading rate, the size, uniformity of the sand bed and particularly on climatic conditions which greatly influence the development of algal blooms.

The filter will be drained to a level, 10-20 cm, below the sand bed so that the filter skin and the top layer become relatively dry and easy to handle. The upper 2 cm has to be removed. The filter will be refilled from the bottom valve with clean water to a level of about 20 cm above the sand bed. This is done to drive out air bubbles from the filter bed. Then the inflow pump will be resumed again .The desired filtration rate will be adjusted by the outlet valve and the filter will be operated as before.

Resanding: Sand replacement is necessary after repetitive scrapings which will reduce the sand bed to its lowest acceptable depth. The resanding is usually done as shown in Figure 2.1. Approximately, the top 20-30 cm of the sand bed will be removed and kept at one side. After that, the filter will be refilled with new sand to a level 20-30 cm below the maximum sand bed depth. After that, the sand kept at one side will be added on the top of the new sand. This method is expected to reduce the time of schmutzdecke formation since it contains all the organisms needed for proper biochemical functioning (24,50). At this stage, the filter will be ready for the next operation.

2.4.7 Performance

Generally, the literature published on slow sand filtration is limited. Moreover, most of the literature available is related to filtration of potable water. Studies on experimental and pilot plant models as well as full-scale

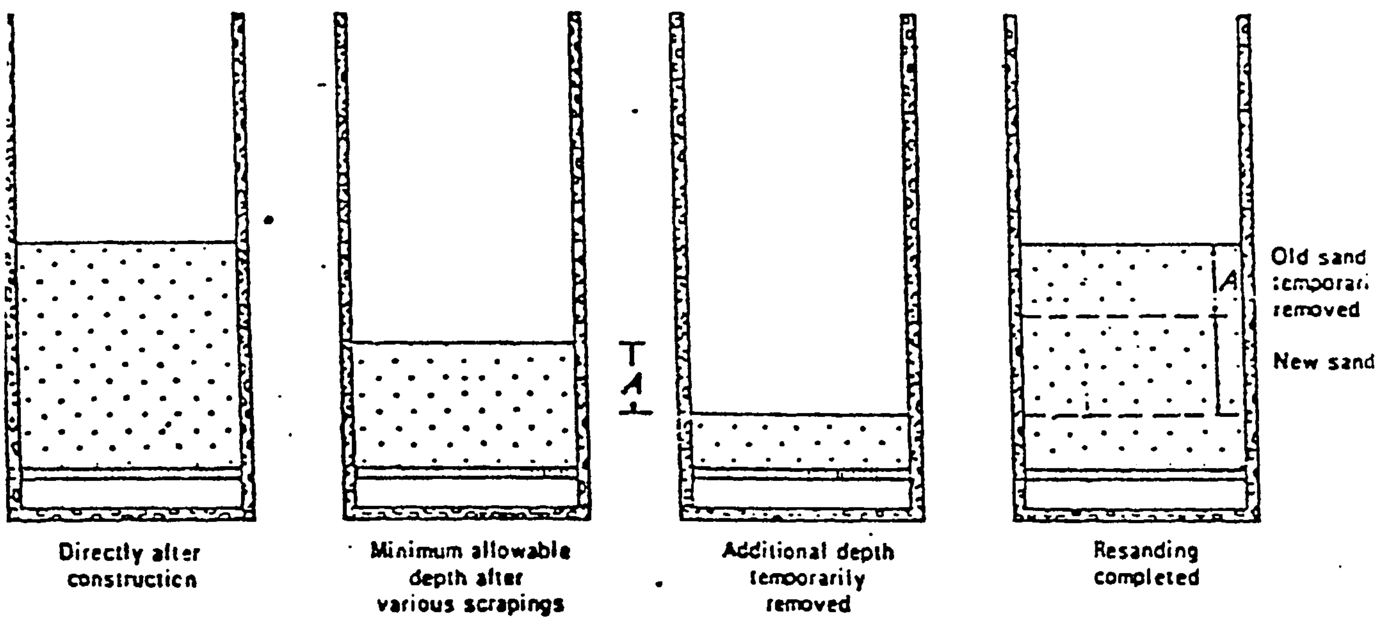

Figure 2.1: Resanding of a Slow Sand Filter (50)

water treatment plants showed excellent performance, especially in terms of SS and microbial contamination. The reported performance of slow sand filters regarding virus removal, as shown in Table 2.4 is worth noting (23). Poynter and Slade (40) concluded that polio viruses were removed with an efficiency similar to but slightly greater than that of bacteria. This similarity implies that normal bacteriological methods can be indicative of virus removal. This conclusion, in fact, showed that assessment of viral quality of waters is an expensive process, requiring highly specialized personnel.

TABLE 2.4 : PERCENT REMOVAL OF VIRUSES AND GIARDIA LAMBLIA BY DIFFERENT FILTRATION PROCESSES IN WATER (23, 40)

UNIT PROCESS	Viruses	Giradia Lamblia
Rapid Filtration with Coagulation, Sedimentation	99	98.8-99.9
Direct Filtration with	90-99	
- Coagulation		95.9-99.9
- No Coagulation		10 - 70
Diatomaceous Earth		
Filtration	> 99.95	> 99.9
Slow Sand Filtration	99.8-99.9999	100

Bellamy *et al.* (5) conducted pilot plant studies to determine the efficiency of slow sand filters in removing Giardia cysts in particular and other substances. They reported that Giardia cyst removal exceeded 98 percent for all operating conditions tested. Once the sand bed matures biologically will be virtually 100 percent. Coliform removal exceeded 99 percent, averaged over all operating conditions. For new sand, coliform removal reached 85 percent. Removal of standard plate count bacteria and particles ranged from 88 to 91 percent and 96 to 98 percent, respectively. Their findings were confirmed by Hansen (23) who observed the removal efficiencies of Giardia Lamblia by several filtration methods as shown in Table 2.4. Bellamy ***et al.*** (6) conducted a research to determine the influences of selected process variables on the treatment efficiency of slow sand filtration . Their findings are summarized below.

Temperature: The slow sand filters removal efficiency decreased with declining the ambient temperature in terms of coliform and standard plate counts bacteria. However, Giardia removal efficiency was insensitive to temperature variations.

Sand bed Depth: The results showed that the bed depth can be reduced to 48 cm without significant effect on the bacteriological quality of the filtrate.

Sand Size: When the effective sand size of the sandbed was increased, insignificant decrease in removal efficiency was reported on both coliform and standard plate counts . Giardia removal was again insensitive to sand size variations.

Hydraulic Loading Rate: Basically speaking, there was an apparent decrease in removal efficiencies of total coliform , standard plate counts bacteria , and turbidity with an increase in the hydraulic loading. However, it was reported that within the range studied the difference was not substantial.

The literature on the application of slow sand filter to wastewaters as a tertiary treatment is very limited. Results from earlier studies (29) were below the expected in view of the excellent performance of slow sand filters with potable water. Ellis (12) investigated the viability, or otherwise, of slow sand filtration as a means of tertiary treatment of secondary effluent derived from conventional aerobic, biological activated sludge plant and from a percolating filtration plant. The basic slow sand filtration unit used consisted of 14 cm (in diameter) and 265 cm (in height) filter unit containing 95 cm depth of fine sand. Treatment rates either 0.14 m/hr or 0.29 m/hr and the sand used was of an effective size of 0.3 mm and 0.6 mm. This work was carried out in different stages. The principle objectives of these stages to investigate efficiencies of two different sizes of sand; and to determine whether or not coarse sand (0.6 mm) could be operated at a higher rate of flow; further, to study the effect of the influent source on the filtrate quality. The investigation has demonstrated that consistent removals of at least 90% of SS, more than 65% of BOD, 54% of COD and over 95% of coliform were observed from secondary effluent from an operational percolating filter plant. Slightly less removal were achieved when the secondary effluent was taken from an operational activated sludge treatment plant.

Ellis concluded that no nitrification was taking place during filtration even when the dissolved oxygen content of the secondary effluent, influent to the filter, was increased by aeration. As a comment to that, Scutt (47) raised an interesting point in this regard. He pointed out that because Ellis's conclusion is based on a reduction in nitrate concentration during filtration, the possibility of nitrification taking place in the upper aerobic layers of the filter and followed by denitrification due to absence of oxygen in the lower layers should not be eliminated.

Al-Adham (1) evaluated slow sand filtration at pilot scale as a tertiary treatment process to the secondary effluent of the North Aramco Wastewater Treatment Plant. In this study, a pilot scale consisted of 100 cm (in diameter) and 340 cm (in height) filter unit containing 105 cm (initial depth) of local sand with effective size of 0.23 mm. Treatment rates used were 0.08, 0.16, 0.24 m/hr. He concluded that slow sand filtration is very effective in removing contaminants from secondary effluents to an extent that the filtrate would easily qualify for unrestricted irrigation. In view of the experimental results, 0.16 m/hr is suggested a suitable hydraulic loading for the design of similar systems in the Kingdom. At this hydraulic loading, the observed average removals of BOD, SS, turbidity, and total coliform bacteria were 86, 69, 88 and over 99% respectively and the length of the filtration run was about 20 days. He also confirmed that most of the purification is occurring at the top layers of the filter such that even a sand bed depth of 35 cm yielded significant levels of contaminants removal. Table 2.5 shows percent removal efficiency of slow sand filter at different hydraulic loading (1).

Al-Adham (1) in his research also pointed out that nitrification is probably taking place at the upper layers of the sand bed, when he observed that the average $NO_2^- + NO_3^-$ concentration at the bottom sampling port is higher than that in the influent. This observation may be reasonable since adequate oxygen is present at the upper layers of the filter bed. He also pointed out that denitrification is taking place, when he observed that the concentration of $NO_2^- + NO_3^-$ in the filtrate is lower than that in the sampling port. This is probably true, since the dissolved oxygen concentration in deeper layer is decreasing, thus denitrification is more likely to occur.

Finally, it should be emphasized that the information and results presented in this chapter summarize the nature of slow sand filtration process, there is no generalized approach for the design of full-scale filters. This is mainly because of the variation of the influent characteristics which in turn affect the filter performance. In that way, the best thing to ensure appropriate performance of a filtration unit is to conduct pilot plant studies.

Table 2.5 Percent Removal Efficiency of Slow Sand Filter (1)

Parameter	Hydraulic Loading		
	0.08 m/hr	0.16 m/hr	0.24 m/hr
BOD, mg/l	83.3	86	88.5
SS, mg/l	69.9	69	57
Turbidity, NTU	88.8	88	73.9
COD, mg/l	18.5	35.4	50.8
Total coliform bacteria MPN/100 ml	*	> 99	*

Remarks:

* Not specified

2.5 Need for the Study

Saudi Arabia is an arid country that lacks natural resources of water for different purposes. Water demand is increasing day-by-day due to rapid population growth, industrialization and agricultural activities. Thus, the reuse of treated wastewater is worthwhile idea, since the cost of other alternative sources are very expensive.

Eventually, the North Aramco Wastewater Treatment Plant is designed to treat 30,000 m^3/day. This plant utilizes the extended aeration process to produce a high quality secondary effluent. The treated wastewater after the chlorination is pumped to a spray field located 5 KM away where the effluent is percolated into the soil in a series of percolation ponds. Because of the limited permeability of the soil, this operation requires continuing management. Moreover, this huge quantity of such high quality secondary effluent is being disposed off without regard to its value. Reuse of this treated wastewater after tertiary treatment is both environmentally beneficial and economical.

Slow sand filters can, not only be the simplest and cheapest, but also be the most efficient process for the tertiary treatment. In addition to that, their poor performance at low temperatures and their large land area requirement are not a problem in the Kingdom.

Study conducted by Al-Adham (1) evaluated pilot scale slow sand filter as a tertiary process for the North Aramco Wastewater Treatment Plant Secondary effluent using one size of local sand with an effective size of 0.23 mm. It is possible that this size of sand may not be the optimum. In order to determine an appropriate size of local sand which can meet the requirements of the wastewater filters in Saudi Arabia and, at the same time, meet the optimum operation (long filtration run and high filtrate quality) which will satisfy the criteria and meet the health standards for reuse. Two different sizes of local sand would be studied along with optimizing of different design parameters. Furthermore, this study will also investigate the effects of summer and winter seasons on the operational parameters.

2.6 Objectives of the Study

The main objective of this study is to evaluate slow sand filtration as tertiary treatment of secondary wastewater effluents at pilot level for reuse purposes.

The specific objectives can be summarized as follows :

1. Study of the effects of sand sizes: Two different sizes of local sand with (ES = 0.31 mm, UC = 2.0; and ES = 0.56 mm, UC = 1.64) would be studied regarding removal efficiencies of various pollution parameters such as total coliform bacteria, standard plate counts, turbidity, BOD, COD, nutrients, heavy metals, etc. Also, to investigate the effect of sand size on the length of operation run at a specified hydraulic loading and the head loss build up throughout the operational run.

2. Study of the Effect of Sand Depth on Removal Efficiencies: Three different depths of sand bed listed as 135, 105 and 55 cm would be studied to investigate the optimum depth which can satisfy the criteria and meet the health standards for reuse purposes.

3. Study the Seasonal Effects: To investigate the effect of summer and winter seasons on the operational parameters, because the algal growth in the influent would be tremendous during summer, which may have an adverse effect on the length of the operational run and quality of the filtrate.

CHAPTER 3

EXPERIMENTAL WORK

3.1 Experimental Set-up

The pilot-scale filter unit is located within the boundaries of the KFUPM Agricultural Research Farm . There is an operational pipeline conveying secondary effluent from North Aramco Wastewater Treatment Plant (NAWTP). The NAWTP has a design capacity of 30,000 cubic meters/day and is currently serving Aramco community in addition to KFUPM. It is an extended aeration plant yielding a high quality secondary effluent (plant records show that an average BOD and SS removals exceeded 97% (2)). The effluent is stored in a holding pond (135x65x4 m) from which it is pumped, following chlorination, to a spray field located 5 KM away. At present, limited reuse of the effluent is being practiced in the form of landscape irrigation in a very limited area.

3.1.1 Filter Unit

The filter unit was fabricated at the Central Research Workshop at KFUPM. It was fabricated using three 2 mm galvanized iron sheets. Each sheet was welded to form a hollow cylinder with an inside diameter of 100 cm. The cylinders were connected to each other with angles using bolts and nuts. A rubber gasket ring was placed between the angles to avoid leakage. Manometer and sampling ports were provided on the middle cylinder. An overflow wier was mounted to the top cylinder to have a uniform and steady inflow. A float switch was also fixed at the top cylinder to start and stop the inlet pump so as to keep a constant water level above the sand bed. Outlet and drain valves were provided to the filter. Figure 3.1 shows the description of the filter unit and its auxiliaries.

3.1.2 Installation

A reinforced concrete slab of 15 cm thickness was made to give a levelled and rigid base for the filter. Then the first cylinder, 100 cm in height, was installed using a portable crane. The second cylinder, 120 cm in height, was then mounted on top of the first cylinder and fixed with bolts and nuts. Then, the top cylinder, 120 cm in height, was mounted on top of the second cylinder. Finally, the float switch was connected to control the inflow. A summary of the depth of filter unit elements is shown in Table 3.1.

Underdrain: Underdrain system consisting of open joint standard bricks were washed and laid in a grid with 1 cm openings between adjacent blocks.

Gravel: The supporting gravel was washed out and placed in four layers. The depth and size distribution of each layer is given in Table 3.2.a (when sand with ES = 0.31 mm) was used and Table 3.2.b (when sand with ES = 0.56 mm) was used.

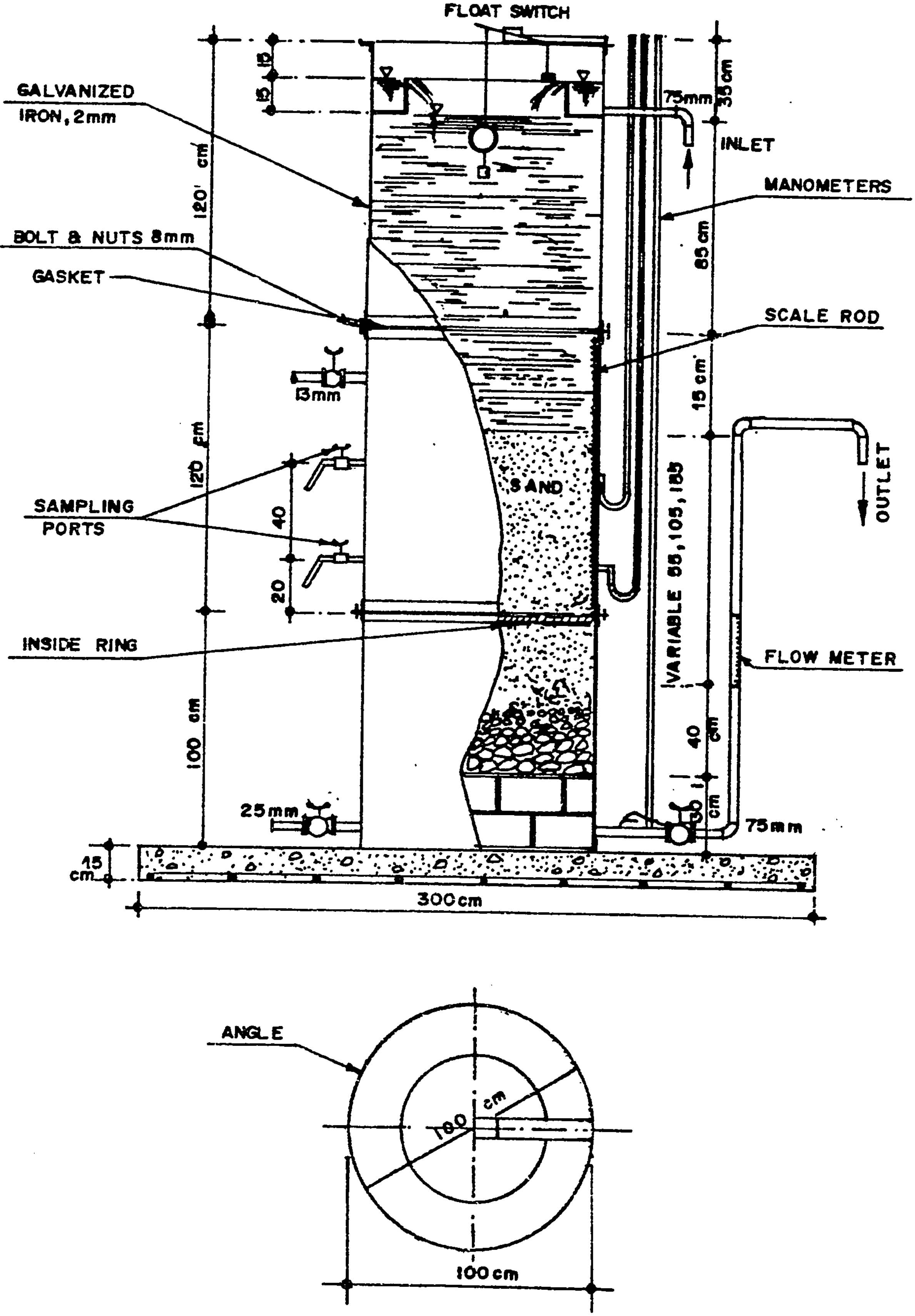

FIGURE 3.1 PILOT FILTER UNIT

Table 3.1 : DEPTH OF FILTER UNIT ELEMENTS (23,46,54)

ELEMENT	SELECTED,cm	RECOMMENDED,cm
Freeboard	20	20
Superntant Water	115	100-150
Sand (Initial)	135 *	38-183
Supporting Gravel	40	10-50
Underdrains	30	20-30
Total	340	-------

Remark:

* initial depth of sand when routine runs started

Table 3.2.a: Depth and Size of Gravel Layers With the Fine Sand

Layer	Depth (cm)	Size (mm)
Top	5	0.425-2.0
Second	5	2.0-4.0
Third	10	5.0-12.5
Bottom	20	12.5-25.0

Table 3.2 b: Depth and Size of Gravel Layers With the Coarse Sand

Layer	Depth (cm)	Size (mm)
Top	5	0.85-2.0
Second	5	2.0-4.0
Third	10	5.0-12.5
Bottom	20	12.5-25.0

Sand: Sand which serves as filter material was properly washed and cleaned before it was put in the filter. The sand used was obtained locally and it was sieved to obtain a media with sand size as follows:

Sand	Effective Size (mm)	Uniformity Coefficient
1	0.31	2.00
2	0.56	1.64

The gradation curve for the sand used is given in Figure 3.2.a (for sand ES = 0.31 mm) and Figure 3.2.b (for sand ES = 0.56 mm). The filter unit was operated at three different depths of sand bed listed as **135, 105, and 55 cm.**

To study the effect of sand size, it is preferable to have two filters working at the same time to be able to control all other parameters (i.e. temperature, hydraulic loading, sand depth, etc.). However, one filter was available for this study . When effect of sand size was studied , the other parameters (i.e. hydraulic loading, sand depth, water above sand bed, etc.) were kept the same and the size of sand was changed. It may be realized that the temperature was not necessarily the same but the comparison between the two cases should be made when the temperature nearly the same.

3.2 Experimental Procedure

3.2.1 Characterization of Secondary Effluent

The secondary effluent of North Aramco Wastewater Treatment Plant (NAWTP) can be characterized as an excellent effluent of municipal sewage introduced by extended aeration processes. A summary of the basic parameters of the effluent before and after chlorination are given in Table 3.3.(1) . Clearly, the effluent satisfies the secondary effluent standards stated in literature. However, for reuse of this effluent, tertiary treatment is still more pronounced from bacteriological point of view.

3.2.2 Initial Commissioning of the Filter

First, with all outlet valves closed, the filter was charged with clean

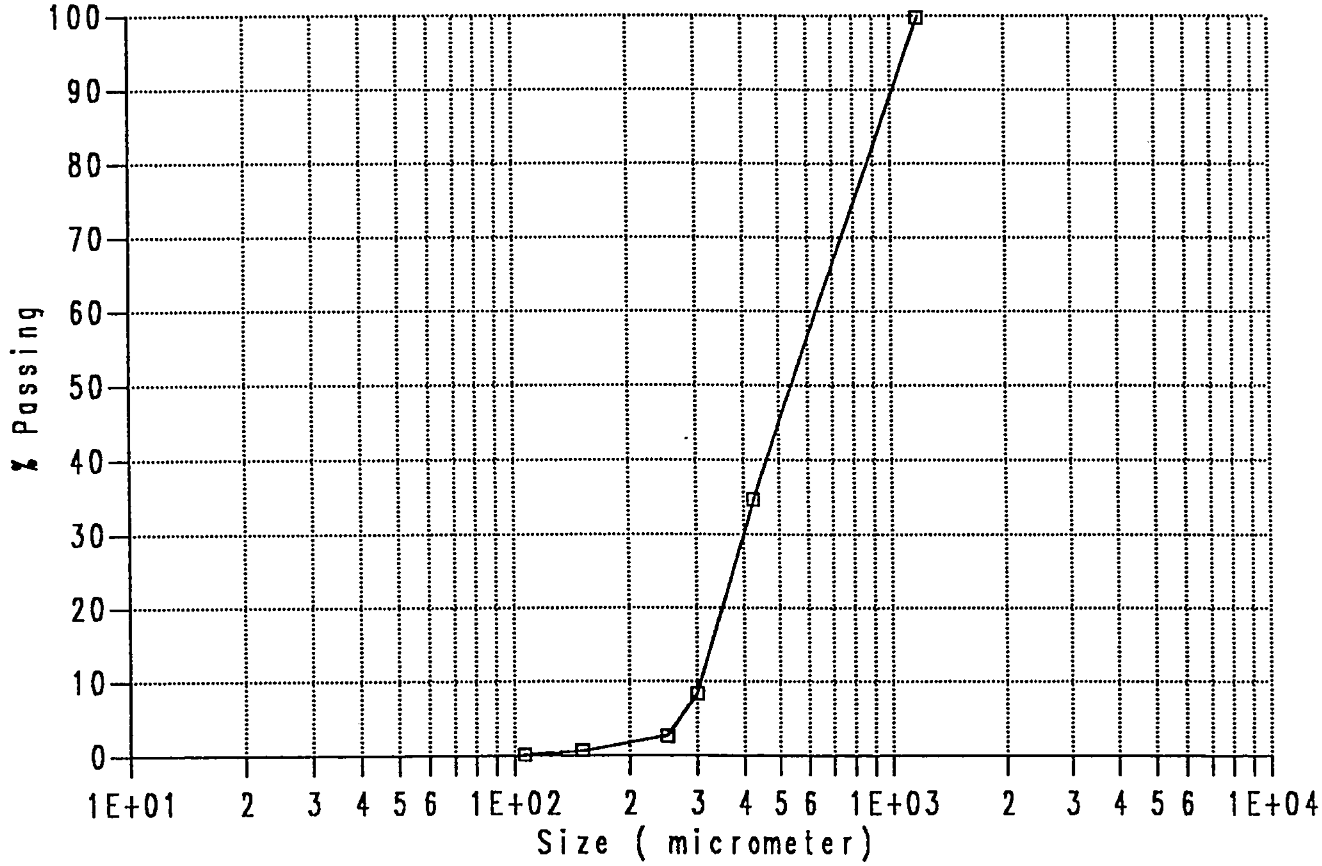

Figure 3.2.a : Gradation Curve for Sand # 1 (ES=0.31 mm)

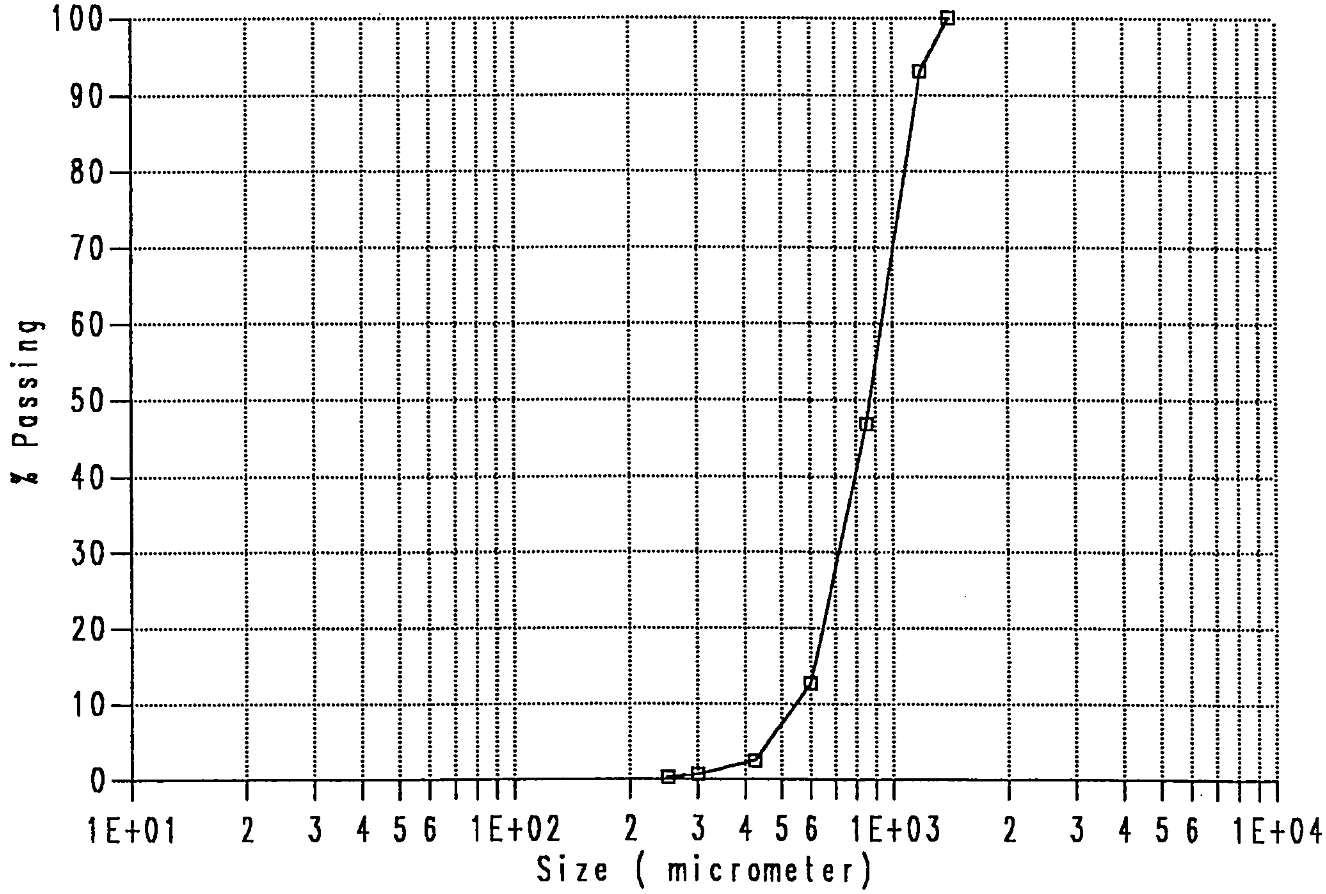

Figure 3.2.b : Gradation Curve for Sand # 2 (ES=0.56 mm)

Table 3.3 : CHARACTERISTICS OF THE NAWTP EFFLUENT (1)

PARAMETER	NUMBER OF SAMPLES	UNCHLORINATED	CHLORINATED
pH	10	8.2	8.0
BOD ,mg/l	10	< 5.0	< 5.0
SS ,mg/l	10	5.0-16.0 (12.0)*	6.0-14.0 (11.5)*
Residual chlorine mg/l	5	----	0.3-0.8 (0.6)*
Total Coliform Bacteria,MPN/100ml	10	$35x10^3$ -$160x10^3$	< 2 - 240

Remarks:

* Indicates average value

water, introduced from the bottom to a level of about 60 cm above the sand bed. This was done to drive out air bubbles from the filter bed; then the inflow pump was started . After that , the outlet valve was opened slowly at first but at an increasing rate . The filter was run continuously and without interruption. The rate of flow was gradually increased during this period until it reached the desired filtration rate.

3.2.3 Filter Ripening - Preliminary Runs

The filter was operated for the whole study at a flow rate of 2 L/min corresponding to a hydraulic loading (Q/A) of 0.16 m/hr. The depth of sand (sand with ES = 0.31 mm) at starting of the filtration was 145 cm followed by Run No. 2 with a sand depth of 142 cm followed by Run No. 3 with a sand depth of 139 cm. On the other hand, one run was conducted for the sand (sand with ES = 0.56 mm); the depth of sand at starting of the filtration was 140 cm. These runs, which will be referred to as Preliminary runs from hereon, were conducted mainly for ripening of the sand filter (i.e. maturation of the sand bed). As reported in the literature (12,13.20,24,50), a stable filtrate quality can be achieved only after the filter bed has biologically matured. Through the preliminary runs, samples were taken from the inlet, outlet and sometimes from the sampling ports and tested for selected parameters. In addition, the clean bed head loss and head loss build-up were recorded .

3.2.4 Routine Runs

Following all last preparatory steps, experiments were started in order to evaluate the system performance. The filter was operated continuously with constant-rate, constant-head mode for the whole study at Q/A = 0.16 m/hr. Samples were collected daily from the inlet, and outlet . In addition , manometer readings were recorded to observe the head loss build-up. All procedures, sample preparation and analysis were conducted in accordance with stipulations in the 15th Edition of the Standard Methods for Examination of Water and Wastewater (52).

3.2.5 Regulation of the Filtration Rate

The desired filtration rate was achieved initially by manual adjustment of the effluent valve. As the operation progressed, the resistance to flow or head loss was increasing due to clogging. Accordingly, the filtration rate was decreased because the available head above the sand surface was fixed. At this point, the effluent valve was open further until the desired flowrate was reached. This operation was continued until the outlet valve was widely open. In this case, the run was terminated by stopping the inflow and cleaning of the filter bed was conducted.

Cleaning the Filter Bed: The filter was drained to a level, 10-20 cm, below the sand bed so that the filter skin and the top layer became relatively dry and easy to handle; then the upper 2 cm was removed. After that The filter was refilled from the bottom valve with clean water to a level of about 60 cm above the sand bed. This was done to drive out air bubbles from the filter bed. Then the inflow pump was resumed again. The desired filtration rate was adjusted by the outlet valve and the filter was operated as before.

3.2.6 Changing the Depth of the Filter Bed

The filter was operated at 3 different sand depths as mentioned before. The operation was started as follows :

Initially, (when system reached steady state), the depth of sand was at

135 cm and when the depth of sand wanted to be decreased to (i.e. 105 cm), the top 2 cm was scrapped and discarded, then another 30 cm was removed and kept at one side in a container. After that the desired sand wanted to be removed (until 30 cm below the required depth) was removed and discarded. Then, the sand which was kept at one side added on the top to have the desired 105 cm depth of sand. This method was expected to reduce the time of schmutzdecke formation since it contained all the organisms needed for proper biochemical functioning. At that stage, the filter was ready for the next operation.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Preliminary Runs for the Maturation of Filter

Since slow sand filter is a highly biologically active unit, it is not possible to consider operating a filter freshly filled with a clean sand with the expectancy of achieving a highly purified filtrate immediately (13). The biological conditions governing the effectiveness of the filter are (1) the degree of schmutzdecke formation and (2) the microbiological maturity of the sand bed (5). To some extent, the process of maturation will involve the development of the correct balance of electrostatic charges on the individual grains of sand (13).

At the start of the operation of the filter, the sand has a negative charge and is, therefore, only positive-charged particles are adsorbed, such as floc carbonates, iron and aluminium hydroxide and cations of iron and manganese. Particles such as bacteria, colloidal matter of organic origin, etc., have a negative charge and are consequently repelled; this is one of the reasons why such impurities are not removed when a filter with clean sand is taken into service. However, during the initial ripening process positively charged particles may accumulate on some of the filler grains to such an extent that over-saturation occurs. The overall charge of the filter bed grain coatings then reverses and becomes positive, after which negative-charged particles will be attracted and retained. After the initial ripening period, the filter bed will exhibit a varied and continuously varying series of negative and positive charged grain coatings that are able to adsorb most impurities from the influent (24,50).

The biological maturity of the sand bed indicates the degree of microbiological development throughout its depth. This condition is not measurable, but is a function of the number of weeks of undisturbed filter operation (5). The period of maturation may require a time of up to 40 days or even more. Bellamy *et al.* (6) has reported that the column had operated for more than 100 days to mature the bed, and was operated for 40 more days to develop and mature the schmutzdecke. The most pertinent conditions that affect the length of time required to bring the bed to maturity are nutrient availability and temperature (5).

In order to build up the biological content of the filter bed, i.e., a build-up of a film on the grain of the filter until the purifying bacteria becomes well established and play an important part in the treatment process; three sets of experiments have been conducted using a sand of ES = 0.31 mm, UC = 2.0, and one experiment using sand of ES = 0.56 mm, UC = 1.64, to determine the maturation of the slow sand filter. Several investigations have established the need for the maturation of the filter prior to regular operation for any given set of conditions (12, 13, 20, 24, 50).

Run No. 1

The sand depth in this run has been 145 cm and hydraulic loading (HL) = 0.16 m/hr which corresponds to a flow rate of 2 l/min. The influent of this run is taken from the feed reservoir, having a heavy algae growth. This heavy algae growth is a result of impondent of secondary effluent even for 2 days in summer. Clearly, the high temperature during this run (about 35°C) has been the main reason for the high growth rate of algae. The length of operation of this run has lasted only 11 days when the valve gate is fully open , could not give the required hydraulic loading of 0.16 m/hr. It should be pointed out that during this run, several trials have been made to dilute the high concentration of algae (i.e. flooding the feed reservoir). But those trails have been unsuccessful. Therfore, it has been decided to empty the feed reservoir and fill it again with fresh effluents. No water quality data have been collected in this run due to preliminary nature of the work. The eleven days of operation was not sufficient to mature the filter as recommended in the literature review; therefore, it was decided to conduct another run.

Run No. 2

Upon termination of Run No. 1, the feed reservoir has been emptied and refilled with fresh effluent from North Aramco Wastewater Treatment Plant. It has been thought that this would contribute in solving the problem to a certain extent, but unfortunately, a considerable algal growth has been formed by the second day. Consequently, the filter has been cleaned and flushed up for one day with clean water; this has been followed by initiating Run No. 2. This run has been operated at hydraulic loading of 0.16 m/hr. and the depth of sand has been 142 cm. The influent of this run has been taken again from the feed reservoir. Incidentally, the operational cycle has been terminated after 11 days when the hydraulic loading dropped below 0.16 m/hr. upon full opening of the outlet valve. In this run, samples have been collected daily from the influent and the effluent for analysis of different parameters. The results of this analysis are summarized in Table 4.1.

Turbidity, one of the most important parameters to monitor the performance of filter, has ranged from 3.7 to 7.1 NTU with an average of 5.1 NTU in the influent, whereas, the effluent-turbidity has ranged from 0.22 to

Table 4.1 : FILTER PERFORMANCE (RUN # 2 , ES = 0.31mm)

Date: 24.6.1989 to 4.7.1989

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	11	35.0-35.5	35	36.5-37.5	37
pH	11	8.3- 9.2	-	7.8- 8.9	-
DO, mg/l	11	9.3-10.2	9.9	4.9- 7.5	6.5
Turbidity, NTU	11	3.7- 7.1	5.1	0.22-0.7	0.37
Residual chlorine, mg/l	11	0.15-0.30	0.21	0.1- 0.2	0.16

Remarks:

Bed depth : 142 cm

Length of operation : 11 days

Influent from the reservoir.

0.7 NTU with an average of 0.37 NTU. The daily variation of the influent, the effluent, and percent removal are illustrated in Figure 4.1. The percent removal of turbidity is 92.7%. The turbidity has been removed sufficiently even in the first stage of filtration (20).

The dissolved oxygen (DO) levels in the influent have ranged from 9.3 to 10.2 mg/l with an average of 9.9 mg/l, whereas, the dissolved oxygen levels in the effluent have ranged from 4.9 to 7.5 mg/l with an average of 6.5 mg/l. The percent depletion of DO is 34.3% on the average. The depletion in DO content in the filtrate is most probably due to biological decomposition of the organic matter as a result of aerobic biological activity occurring within the filter bed.

The value of pH in the influent have ranged from 8.3-9.2, whereas, the effluent levels have ranged from 7.8 to 8.9. It is found that there is a small decrease in the pH in the filtrate. This is probably due to the dissolution of carbon dioxide as a result of biological activity, in the top layer (Schmutzdecke).

Samples analyzed for the total coliform bacteria have been collected routinely from the influent and the effluent of the filter. The influent total coliform bacteria has ranged from 6 to 13 MPN/100 ml, whereas, the effluent has ranged from 0 to 14 MPN/100 ml. One might observe that the total coliform bacteria in the effluent is higher than that in the influent in one observation. This might be a reason of particles, such as bacteria, growing within the filter during normal operation, making it impossible to differentiate between those particles that have passed through the filter and those that are produced and sloughed from the filter. The total coliform bacteria in the influent, the effluent, and percent removal are illustrated in Figure 4.2. The percent

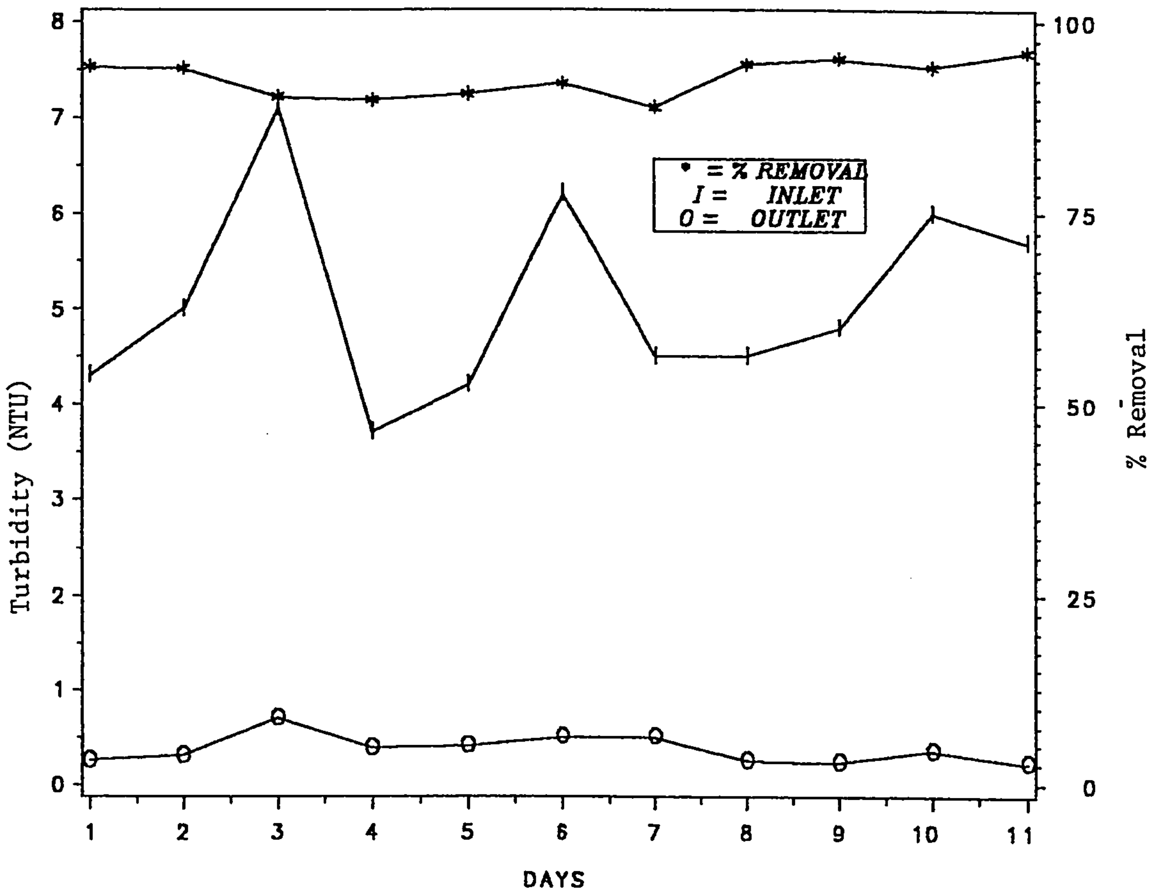

FIGURE 4.1:REMOVAL OF TURBIDITY THROUGH SAND BED OF 142CM AND EFFECTIVE SIZE OF 0.31MM

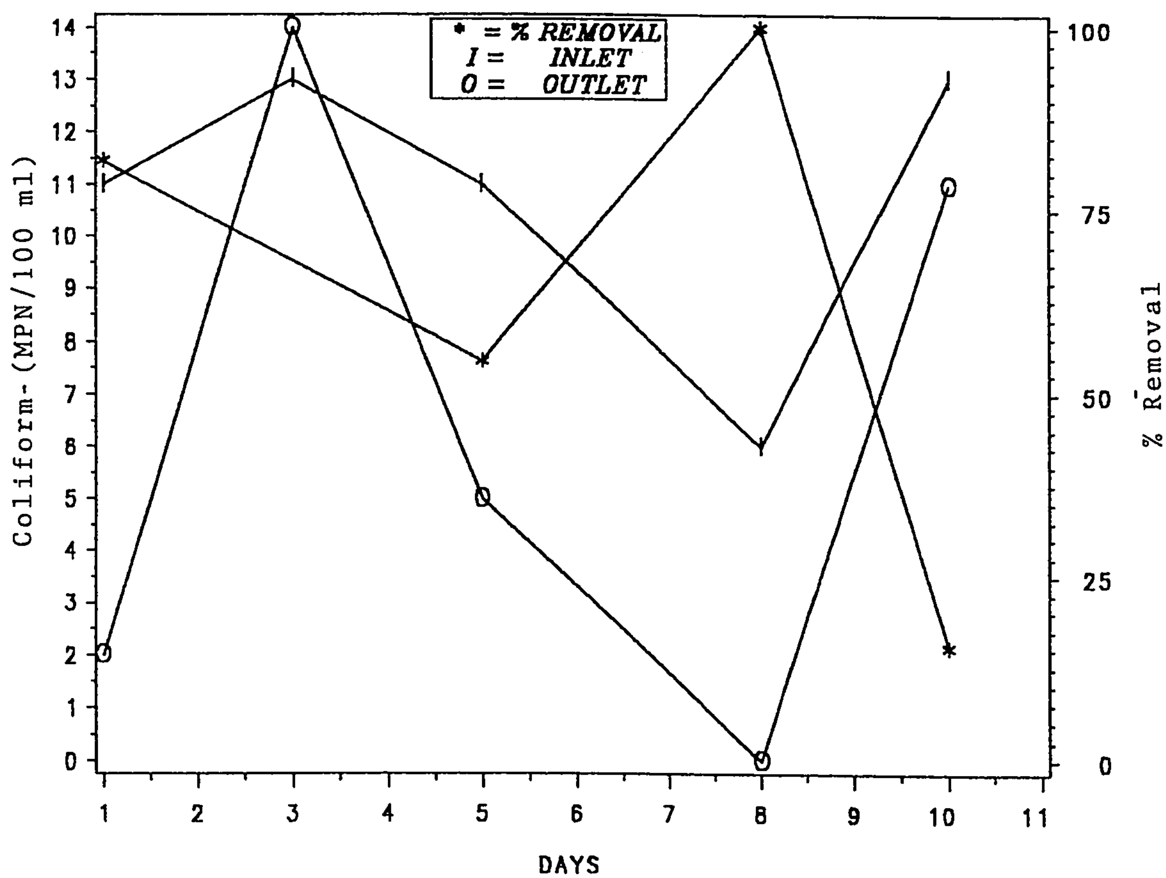

FIGURE 4.2:REMOVAL OF COLIFORM THROUGH SAND BED OF 142CM AND EFFECTIVE SIZE OF 0.31MM

removal of total coliform bacteria is 40.74%. The bacteriological removal level in this run have been not as expected.

One might be tempted to think that the filter is not performing well since the usual removal efficiencies of bacteriological pollutants by slow sand filters exceed 90%. This could be primarily due to immature nature of the filter because the maturity of a filter has been known to have a significant bearing on the efficiency with which bacteria are removed.

Samples analyzed for standard plate counts have been collected routinely from the influent and the effluent of the filter. The standard plate counts levels in the influent have ranged from 145 x 10 to 105 x 10^2 colonies/ml, whereas, the effluent levels have ranged from 70 x 10 to 90 x 10^2 colonies/ml. Standard plate counts influent, effluent and percent removal are illustrated in Figure 4.3. The percent removal of standard plate counts is 19.02% only.

It is observed in the second run that the data about the turbidity removal is excellent; however, the removal of total coliform and total bacterial counts are highly erratic, indicating that the filter has not reached the steady state condition. This has necessitated further preliminary operation of the filter.

Run No. 3

At the end of Run No. 2, the filter has been cleaned and operated at the same hydraulic loading (0.16 m/hr) and the sand depth of 139 cm. The influent in this run has been fed directly from the line, without passing through the reservoir. It has been done to avoid the excessive algal growth problem in reservoir due to summer conditions, which subsequently is reducing the

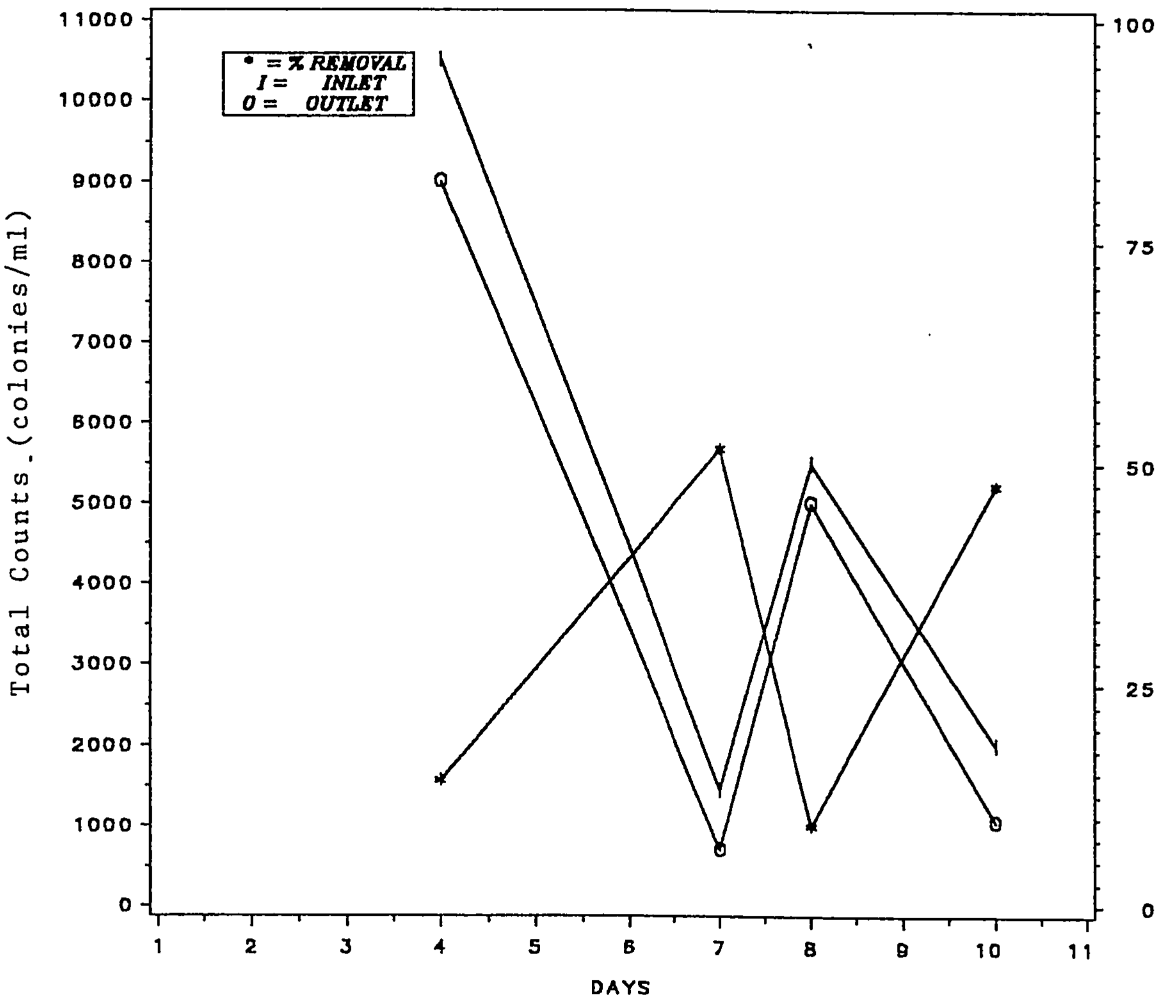

FIGURE 4.3:REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 142CM AND EFFECTIVE SIZE OF 0.31MM

effective run of the filter. The operational cycle in this run has continued for 26 days without any problem which is much longer than 11 days compared to the influent from the reservoir in the past two runs. In this run, samples have also been collected from the sampling ports for a period of 8 days prior to the termination of the filter run to investigate the removal of pollution parameters at different depths and to verify if the system has been matured.

The head loss build-up as recorded at the three manometers throughout this run is illustrated in Figure 4.4. The available head in this run is 116 cm, whereas the total head loss build-up is 115 cm. This agrees with the statement of Monk (35) who has stated that the total head loss can not exceed the available head. The initial clean bed head loss of 10.8 cm has been observed at the outlet manometer which quite agrees with the value of 11.1 cm calculated by Fair and Hatch equation (58) given in Section 2.4.6 as follows:

$$h/l = \frac{36\ Kv\ (1-n)^2\ V}{gn^3\ W^2}\ \Sigma\ \frac{P_i}{d_i^2}$$

$$h/139 = \frac{36x5x0.729x10^{-6}x(1-0.31)^2x4.244x10^{-5}}{9.81x0.31^3x0.75^2}\ x4.964x10^{-6} = 11.1\ cm$$

With K = 5.0, v = 0.729 x 10^{-6} m^2/S (for water at 35°C)

V = 4.244 x 10^{-5} m/s, L = 1.39 m, g = 9.81 m/S^2.

In addition, the sphericity of grains has been assumed to be 0.75 and the porosity has been determined as 0.31. The porosity has been determined according to the procedure stated by O'Conner (37). Finally, the term $\Sigma\ \frac{P_i}{d_i^2}$

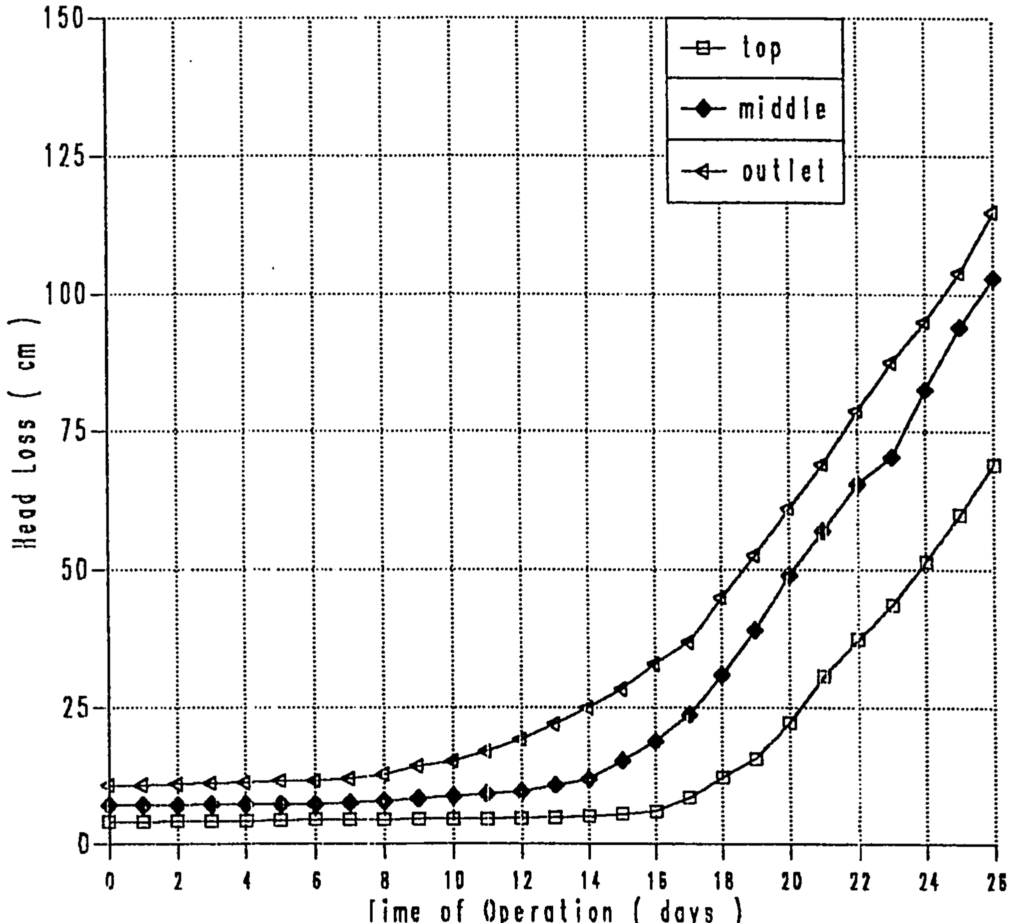

Figure 4.4:Head Loss Development Pattern at Sand Depth of 139cm and Effective Sand Size of 0.31mm

has been calculated as 4.964 x 10^{-6} m^2 using Figure 3.2.a. As can be observed from Figure 4.4, most of the head loss is due to the top layer (Schmutzdecke) since the head loss between the top manometer and the outlet manometer is almost small compared to the total head loss.

The results of this run are summarized in Table 4.2. Observations have shown that samples from the outlet, i.e., bottom of the filter (sand depth of 139 cm) are slightly better in quality than that at the sand depths of 89 and 49 cm respectively from the surface of the sand.

During night times and on the week-ends, the influent has been fed from the reservoir. This influent is containing high concentration of algal blooms. Apparently, the algae have deteriorated the quality of the influent (i.e. turbidity of 12 NTU has been recorded).

Turbidity levels in the influent have ranged from 1.0 to 12.0 NTU with an average of 2.6 NTU, whereas, the effluent turbidity values have ranged from 0.08 to 0.70 NTU with an average of 0.19 NTU. The turbidity levels in the top sampling port have ranged from 0.15 to 0.20 NTU with an average of 0.17 NTU, whereas, the turbidity levels in the middle sampling port have ranged from 0.10 to 0.15 NTU with an average of 0.13 NTU. The average value of the turbidity in the top and middle sampling ports are 0.17 and 0.13 NTU, respectively. The average effluent turbidity over the entire operational cycle (26 days) is 0.19 NTU, however, the value over the last 8 days ranges from 0.08 to 0.12 NTU with an average of 0.10 NTU. The daily variation of the influent, the effluent and the percent removal are illustrated in Figure 4.5. It might be emphasized here that no breakthrough of turbidity has occurred during the filter run although filter flow has been reduced significantly due to

Table 4.2 : FILTER PERFORMANCE (RUN # 3 , ES = 0.31mm)

Date: 5.7.1989 to 31.7.1989

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	27	34.0-39.0	35.7	34.5-40.0	37.8
pH	27	7.4- 9.2	-	7.4- 7.8	-
DO, mg/l	26	7.4-13.3	10.1	3.8- 7.9	5.3
	8			4.1- 5.1	4.7*
	8			3.9- 4.6	4.4**
COD, mg/l	2	35 -37	36	25.0-26	25.5
Turbidity, NTU	27	1.0-12.0	2.6	0.08-0.70	0.19
	8			0.15-0.20	0.17*
	8			0.10-0.15	0.13**
Residual chlorine, mg/l	25	0.05-0.30	0.13	0.04-0.2	0.08
Ammonia, mg/l	1	0	0	0	0

Remarks:

Bed depth : 139 cm

Length of operation : 26 days

Influent direct from the pipe.

* Effluent at the depth of 49 cm from surface

** Effluent at the depth of 89 cm from surface

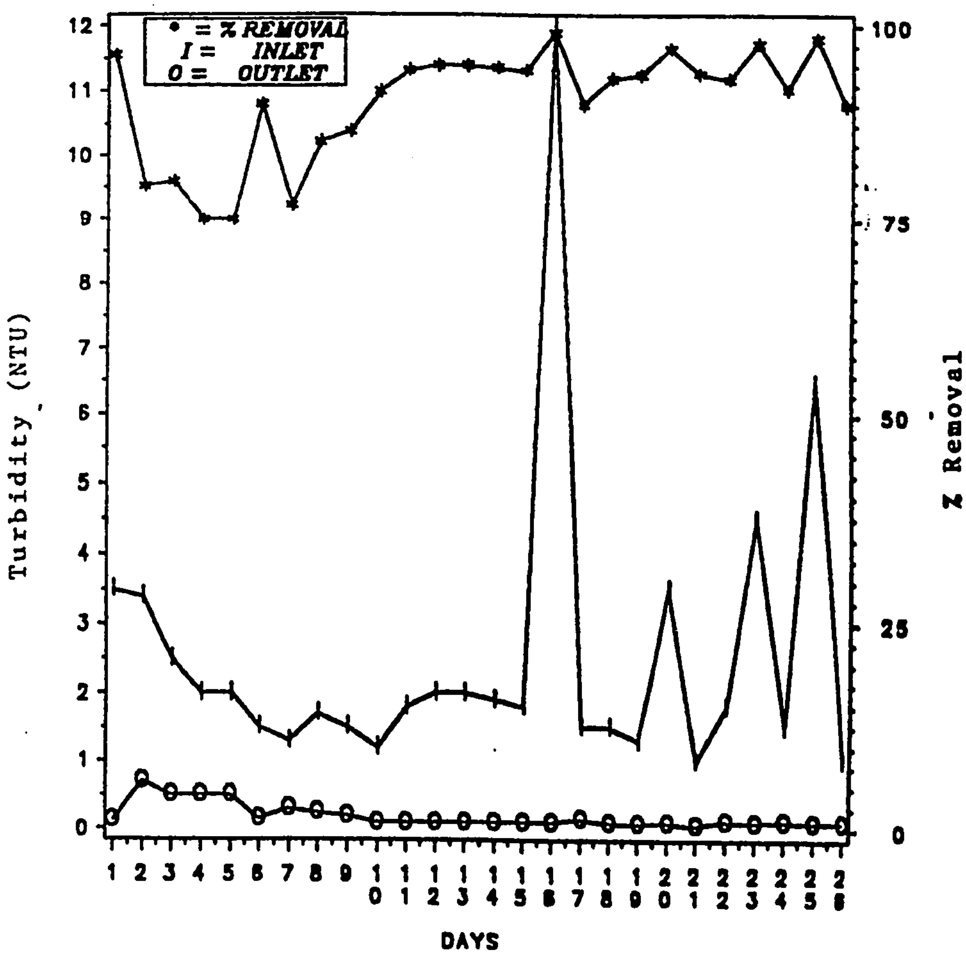

FIGURE 4.5:REMOVAL OF TURBIDITY THROUGH SAND BED OF 139CM AND EFFECTIVE SIZE OF 0.31MM

excessive drop in head loss. Furthermore, scraping the top layer (Schmutzdecke) has not affected the effluent turbidity. The percent removal of turbidity is 92.7% on the average.

The dissolved oxygen levels in the influent have ranged from 7.4 to 13.3 mg/l with an average of 10.1 mg/l, whereas, the effluent levels have ranged from 3.8 to 7.9 mg/l with an average of 5.3 mg/l. The dissolved oxygen levels in the top sampling port (49 cm below surface of the sand) have ranged from 4.1 to 5.1 mg/l with an average of 4.7 mg/l, whereas the dissolved oxygen levels in the middle sampling port (89 cm below surface of the sand) have ranged from 3.9 to 4.6 mg/l with an average of 4.4 mg/l. The average values of DO in the top and middle sampling ports are 4.7 and 4.4 mg/l respectively. These are the average values during 8 days, whereas the value of 5.1 mg/l is the average value for the effluent during the whole operational cycle of this run (26 days).

It is worth noting that a good removal of turbidity has been achieved at the top sampling port. This observation is in confirmation with the widely quoted statement in the literature the "purification is occurring at the top layer of the sand bed (i.e., Schmutzdecke)" (24). Also, most of the dissolved oxygen depletion has been occurring at the top layer.

The organisms attached to the media at the top layer grow rapidly, feeding on the abundant food supply. As the wastewater penetrate through the media, the organic content decreases to the point where the microorganisms at the bottom of the media are in state of starvation. This is why most of the pollutants are removed at the top layer.

The analysis for COD has been conducted twice during this run. COD levels in the influent have ranged from 35 to 37 mg/l with an average of 36 mg/l, whereas, the effluent COD levels have ranged from 25 to 26 mg/l with an average of 25.5 mg/l. The percent removal of COD in this run is 29.2%.

Samples analyzed for total coliform bacteria have been collected routinely from the influent and the effluent of the filter. The influent total coliform bacteria levels have ranged from 5 to 240 MPN/100 ml, whereas, the total coliform bacteria levels in the effluent have ranged from 2 to 49 MPN/100 ml.

Total coliform bacteria in the influent, the effluent and the percent removal are illustrated in Figure 4.6. The average removal of total coliform bacteria obtained in this run is 82.04%. This agrees with what has been reported by Bellamy *et al.* (5). He has reported that a new sand bed removed 85% of the coliform bacteria.

Samples analyzed for standard plate counts have been collected routinely from the influent and the effluent of the filter. The standard plate counts levels in the influent have ranged from 40×10^2 to 270×10^2 colonies/ml, whereas, the standard plate counts levels in the effluent have ranged from 30×10 to 130×10^2 colonies/ml. Standard plate counts influent, effluent and percent removal are illustrated in Figure 4.7. The average percent removal of standard plate counts obtained in this run is 69.66%.

During this run, the total coliform bacteria and standard plate counts are much higher than the previous run (Run No. 2). This has given a better picture of slow sand filtration capabilities with respect to bacteriological removal. In this run, the average bacteriological removal is better than the previous run. This has assured the progress in the maturity of the filter bed. By the last days of this run, the results have been almost stable.

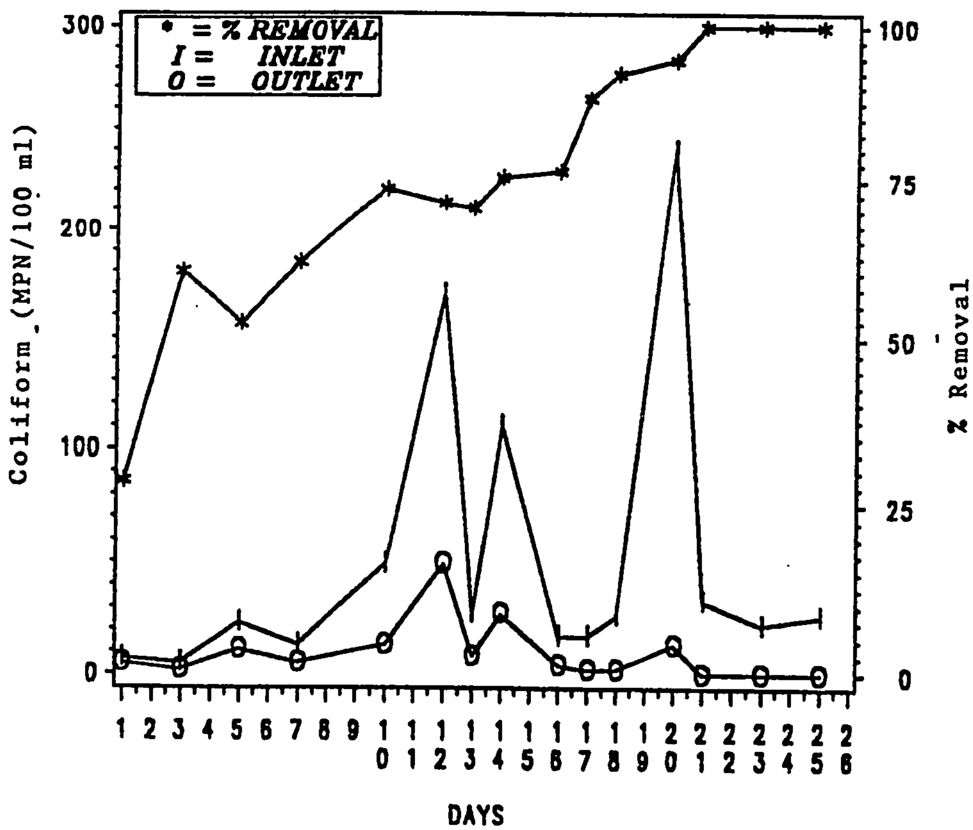

FIGURE 4.6:REMOVAL OF COLIFORM THROUGH SAND BED OF 139CM AND EFFECTIVE SIZE OF 0.31MM

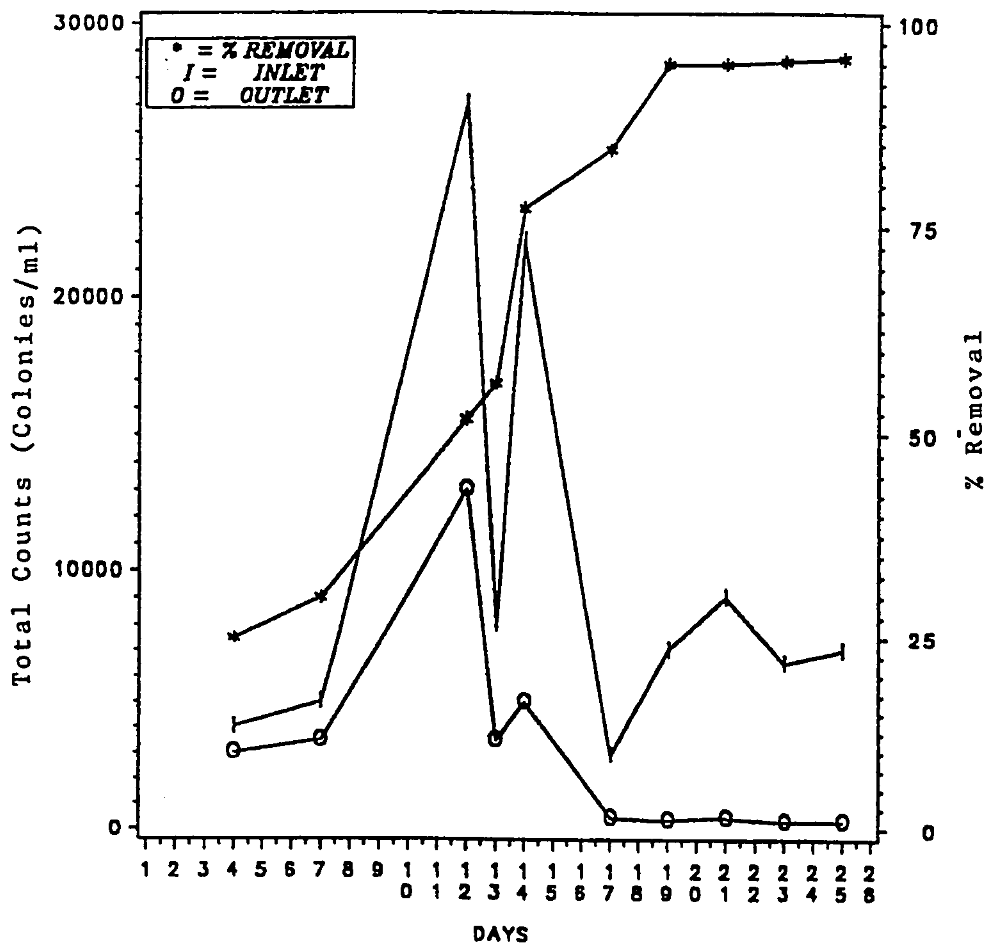

FIGURE 4.7:REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 139CM AND EFFECTIVE SIZE OF 0.31MM

Coupling the stability of the results with the fact that the system has been operated for about 7 weeks in such high ambient temperature (about 38°C) has definitely contributed in accelerating the ripening process. Therefore, it is assumed that the filter has reached steady state.

Upon maturation of the filter, the routine experiments were conducted for the sand size (ES = 0.31 mm) at sand depths of 135, 105 and 55 cm. The results of these experiments are given under next section of Routine Runs. After completing these experiments, the sand was replaced by new sand of ES = 0.56 mm and the filler was operated again for several days in preliminary mode to reach the maturation stage. The results of these experiments are discussed under Run No. 4.

Run No. 4

Upon terminating the last routine run (sand depth of 53 cm) of the fine sand, the whole sand in the filter has been removed. In addition, the top 5 cm layer of the gravel (0.425 - 2.0 mm) has been removed and replaced by a new 5 cm layer (0.85 - 2.0 mm). The inside walls of the filter have been well swabbed down. A new sand width (ES = 0.56 mm, UC = 1.64) has been washed and put in the filter. The filter has been operated as normal. The filter at first has been operated for 56 days to enable the sand bed to mature. After the filter has matured (judged by the improvement in both physical and bacteriological quality of the filtrate), the routine runs have been started.

The sand depth in this run has been 140 cm and hydraulic loading of 0.16 m/hr. The influent of this run has been taken direct from the operational line. This run has been operated for 56 days (until the sand bed is assumed reaching complete maturation), then the run has been terminated.

The head loss build up recorded at the three manometers throughout this run has been insignificant as illustrated in Figure 4.8. The available head in this run has been 115 cm, whereas the total head loss build-up has been around 10.5 cm. The clean bed head loss of 1.9 cm is observed at the outlet manometer which quite agrees with the value of 2.0 cm calculated by Fair and Hatch equation (58) given in Section 2.4.6, with :

$K = 5.0$, $v = 0.8558 \times 10^{-6}\ m^2/s$ (for water at 27°C).

$V = 4.244 \times 10^{-5}\ m/s$, $L = 1.40\ m$, $g = 9.81\ m/S^2$.

In addition, the sphericity of grains was assumed to be 0.75 and the porosity was determined as 0.38. The porosity is determined according to the procedure stated by O'Conner (37). Finally, the term

$\Sigma = \frac{P_i}{d_i^2}$ is calculated as $1.75 \times 10^{-6}\ m^2$ using Figure 3.2.b.

Table 4.3 summarizes the filter influent and effluent characteristics during this run. Turbidity levels in the influent have ranged from 0.90 to 3.3 NTU with an average of 1.24 NTU,whereas, the effluent turbidity levels have ranged from 0.14 NTU to 0.37 NTU with an average of 0.18 NTU. The variation of the influent, effluent, and percent removed are illustrated in Figure 4.9. The average percent turbidity removal is 85.5%. The dissolved oxygen levels in the influent have ranged from 7.3 to 14.8 mg/l with an average of 8.6 mg/l, whereas the effluent levels have ranged from 5.1 to 8.5 mg/l with an average of 6.5 mg/l. The percent depletion of dissolved oxygen is 24.4% on the average.

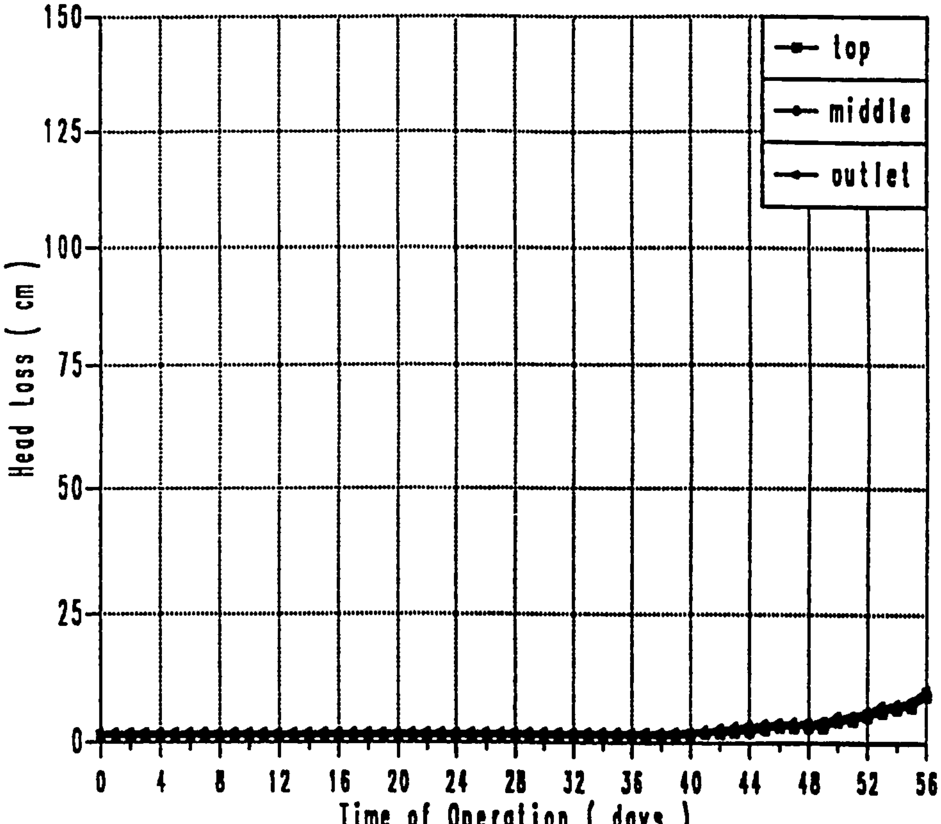

Figure 4.8:Head Loss Development Pattern at Sand Depth of 140cm and Effective Sand Size of 0.56mm

Table 4.3 : FILTER PERFORMANCE (RUN # 4 , ES=0.56mm)

Date: 30.10.1989 to 25.12.1989

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	57	15.0-30.5	24.7	16.5-30.5	25.4
pH	32	7.1- 8.6	-	7.1-8.4	-
BOD,mg/l	13	0.2-3.25	0.90	0.1-0.40	0.20
DO,mg/l	33	7.3-14.8	8.6	5.1- 8.5	6.5
Turbidity, NTU	32	0.9-3.30	1.24	0.14-0.37	0.18
Residual chlorine,mg/l	20	0.05-0.15	0.07	0.03-0.10	0.05
Sulfate, mg/l	3	707-773	741	749-827	783
Nitrite + Nitrate , mg/l	18	4.52-12.88	6.67	2.81-9.36	4.69
Ammonia, mg/l	7	0	0	0	0
TOC, mg/l	3	3.0-4.0	3.67	1.0-2.5	1.83
COD, mg/l	11	20.0-44.0	30.55	16.0-29.0	21.46

Remarks:

Bed depth : 140 cm

The filter was terminated after 56 days of operation (the system reached steady state)

Influent direct from the pipe.

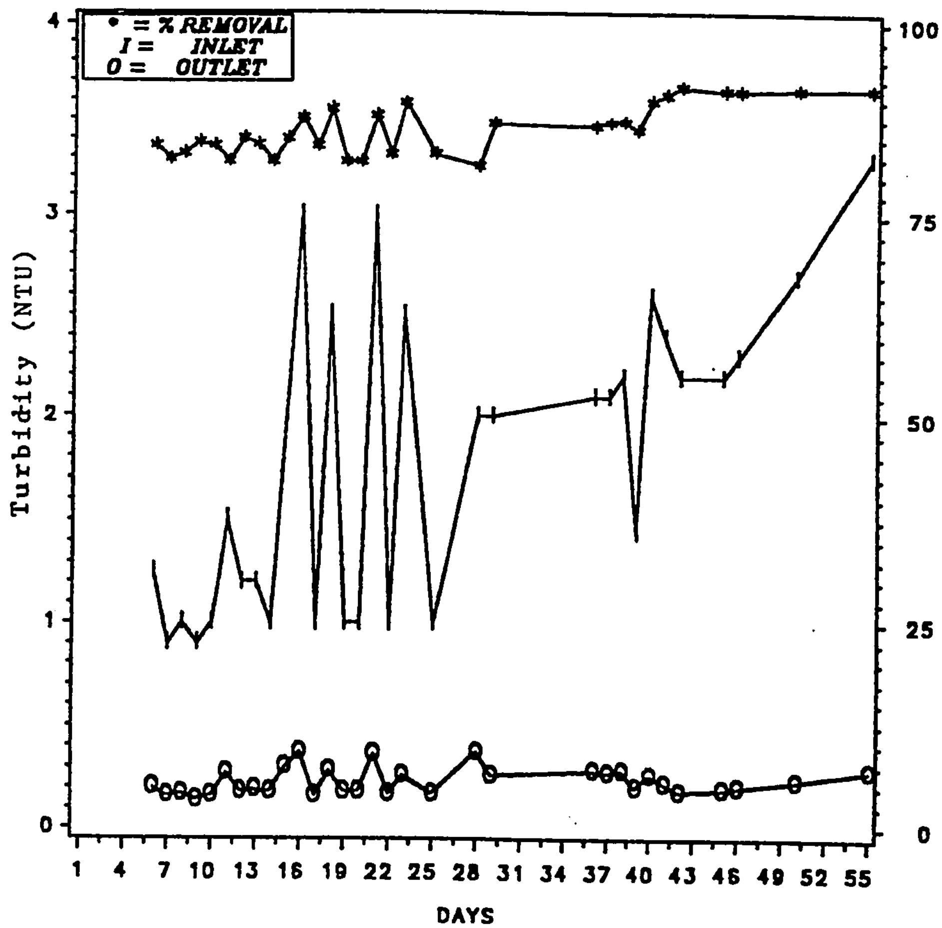

FIGURE 4.9:REMOVAL OF TURBIDITY THROUGH SAND BED OF 140CM AND EFFECTIVE SIZE OF 0.56MM

Samples of the filter influent and effluent have been monitored routinely for biological oxygen demand (BOD). The BOD levels in the influent have ranged from 0.2 to 3.25 mg/l with an average of 0.90 mg/l, whereas, the effluent levels have ranged from 0.10 to 0.40 mg/l with an average of 0.20 mg/l. The variation of the influent, effluent, and percent removal are illustrated in Figure 4.10. The average percent removal is 77.8%. The low percent removal at the first weeks of the start up of the filter operation for this sand is due to the fact that the filter has not reached steady state condition. The filter was successfully able to give consistent and high percent removal by the end of this run.

COD influent levels ranged from 20.0 to 44.0 mg/l with an average of 30.55 mg/l, whereas, the effluent levels ranged from 16.0 to 29.0 mg/l with an average of 21.46 mg/l. Variation of the influent, effluent, and percent removal are illustrated in Figure 4.11. The average percent removal is 29.8%. This value is relatively low compared with the value reported in the literature, mainly because the filter performance with new sand, as expected, is very poor. But it has given better results at the end of this run showing the progress in maturity of the sand bed.

Samples analyzed for total coliform bacteria have been collected routinely from the influent and effluent of the filter. The influent levels of total coliform bacteria have ranged from 34 to 220 MPN/100 ml, whereas, the effluent levels have ranged from 2 to 49 MPN/100 ml. The variation of the influent, effluent and percent removal are illustrated in Figure 4.12. The average percent removal is 80.25%. This agrees with what has been reported by Bellamy *et al.* (5). They have reported that a new sand bed has removed 85% of the total coliform bacteria. The slightly less value of percent removal of this

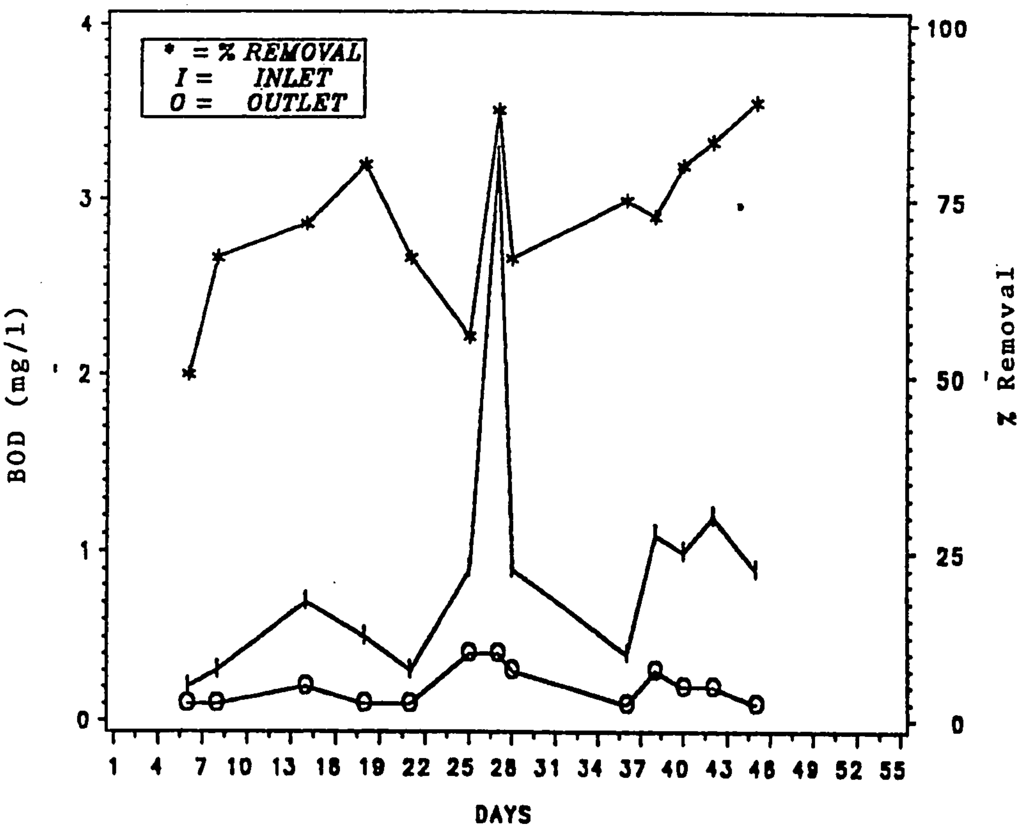

FIGURE 4.10:REMOVAL OF BOD THROUGH SAND BED OF 140CM AND EFFECTIVE SIZE OF 0.56MM

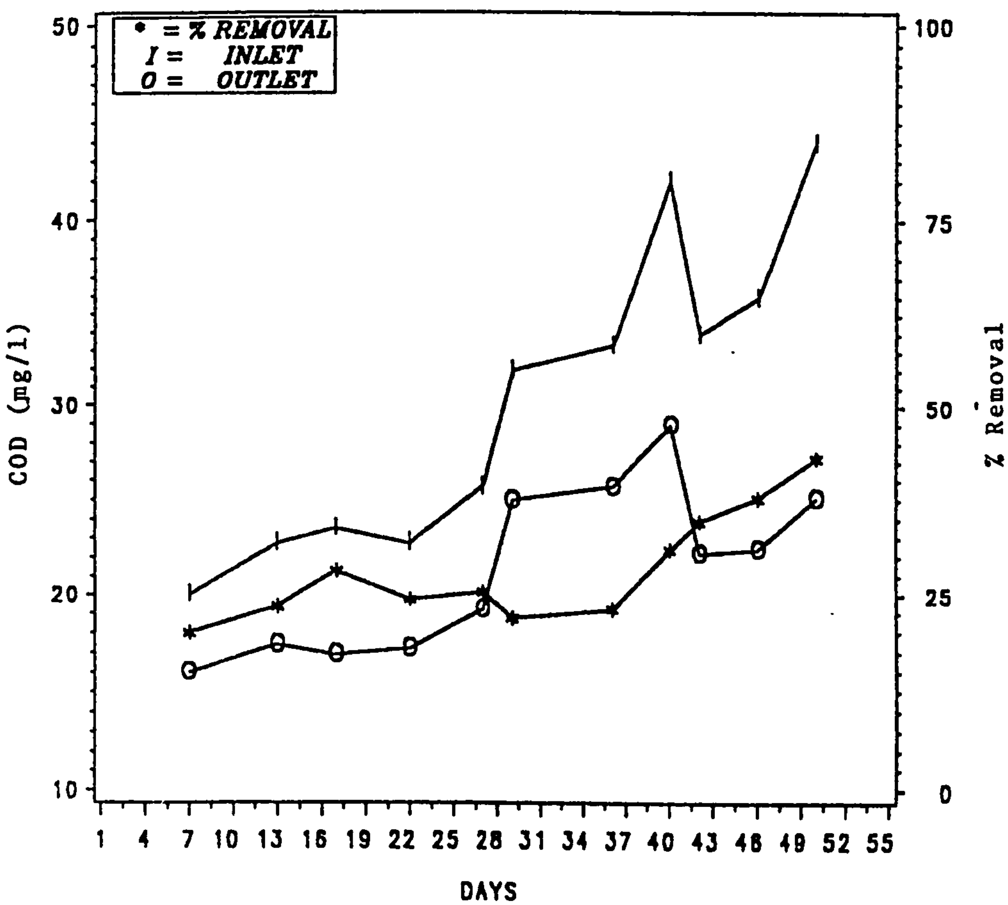

FIGURE 4.11:REMOVAL OF COD THROUGH SAND BED OF 140CM AND EFFECTIVE SIZE OF 0.56MM

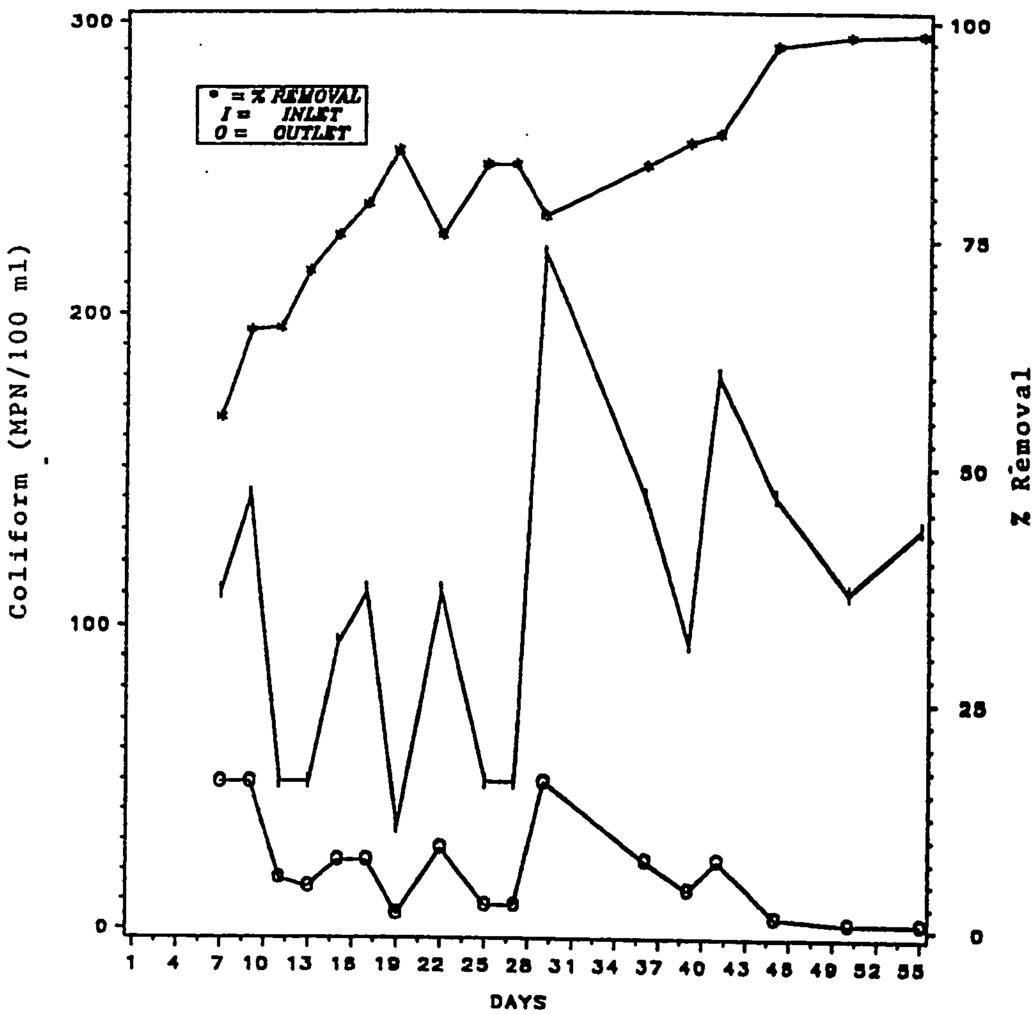

FIGURE 4.12: REMOVAL OF COLIFORM THROUGH SAND BED OF 140CM AND EFFECTIVE SIZE OF 0.56MM

run is mainly a reason of the low concentration of coliform bacteria compared to 1 x 10^9 coliform/100 ml reported in Bellamy *et al.* (5) study. The performance of the filter in removing total coliform bacteria at the last days of the run has been much better regarding the efficiency and the consistency.

Samples analyzed for standard plate counts have been collected routinely from both the influent and effluent of the filter. The influent levels of standard plate counts have ranged from 35x10^2 to 225x10^2 colonies/ml, whereas, the effluent levels have ranged from 60x10^2 to 65x10^2 colonies/ml.

The variation in the influent, effluent and percent removal are illustrated in Figure 4.13. The average percent removal is 78.92%. This value is low due to the low percent removal obtained at the first weeks of the start up of the filter operation for this new sand. The filter has successfully able to obtain consistent and high percent removal by the last days of this run.

The analysis for total organic carbon (TOC) has been conducted three times throughout this run. TOC levels in the influent have ranged from 3.0 to 4.0 mg/l with an average of 3.67 mg/l, whereas, the effluent levels have ranged from 1.0 to 2.5 mg/l with an average of 1.83 mg/l. The average percent removal is calculated as 50.1%. This value is remarkably superior to 15 and 19% reported by Fox *et al.* (19) using sand size with (ES = 0.29 and 0.17 mm respectively) in treating surface water.

The analysis for ammonia has been conducted continuously for seven days starting from the 7th day from start up of the filter operation. No ammonia has been detected either in the influent or in the effluent. This disagrees with the findings of Ellis (13) when he states that absence of ammonia in the filter effluent would indicate a mature filter. The analysis for

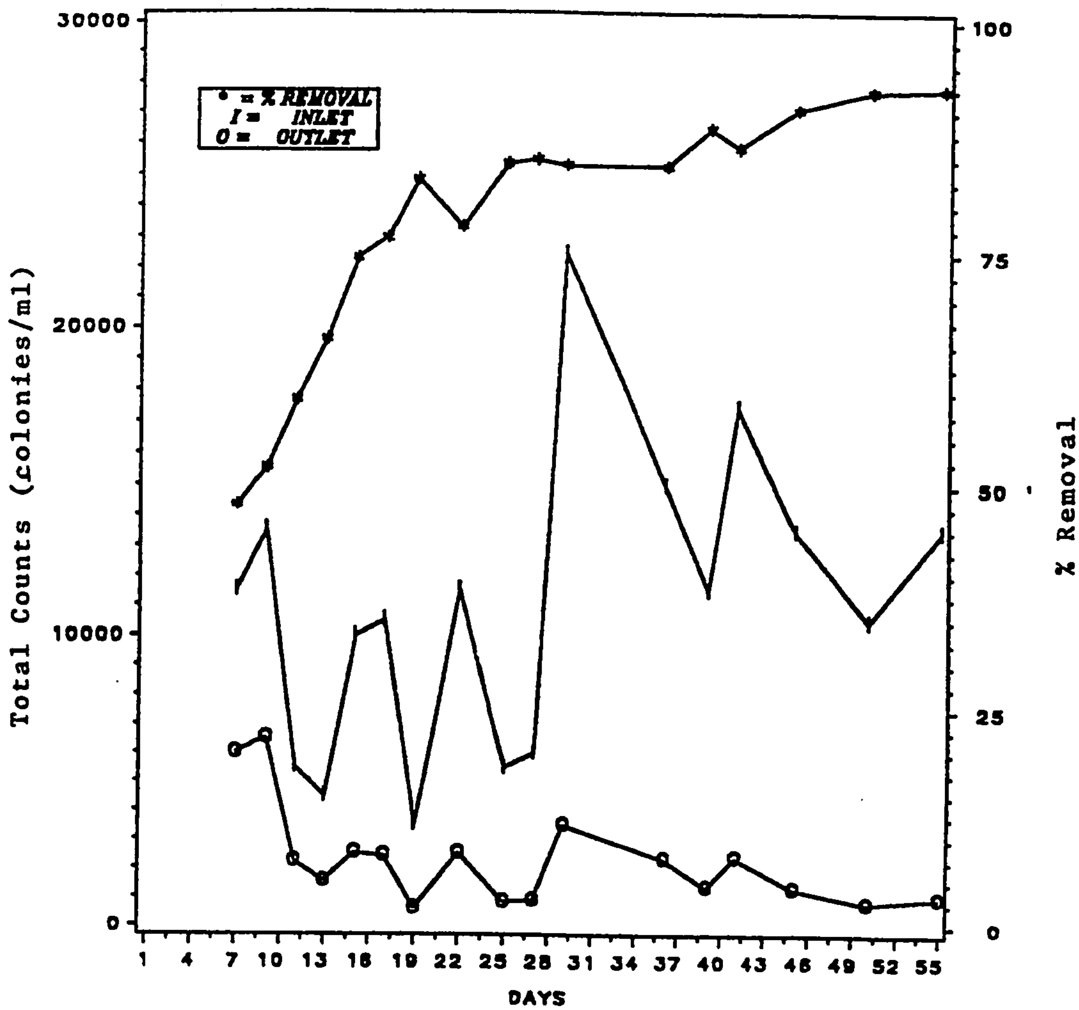

FIGURE 4.13: REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 140CM AND EFFECTIVE SIZE OF 0.56MM

NO_2^- + NO_3^- has been conducted routinely throughout this run. The influent levels have ranged from 4.52 to 12.88 mg/l with an average of 6.67 mg/l, whereas the effluent levels have ranged from 2.81 to 9.36 mg/l with an average of 4.69 mg/l. It is obvious that there is decrease of NO_2^- + NO_3^- in the effluent. This effect must be indicative of the intensity of biological activity on and within the sand (12). The decrease of nitrate in the effluent agrees with the findings of Ellis (12). This observation could not be verified as denitrification because it is based only on decrease in NO_2^- + NO_3^- concentration, the possibility of nitrification taking place should not be eliminated. The average percent reduction in NO_2^- + NO_3^- concentration during this run is 29.7%. In summary,the preliminary runs are found to be very useful as they have led to :

- the confirmation of high performance of slow sand filters in removing contaminants, especially bacteriological removals are exceptional;
- an estimate for the expected duration of a filtration run whether using the influent from the feed reservoir or direct from the line; and
- the observation and solution of operational problems.

4.2 Routine Runs

Upon concluding that the filter has reached steady state following the preliminary runs for the same sizes of 0.31 mm and 0.56 mm, the proceeding runs have been conducted for evaluating the system performance. Six runs have been conducted covering different sand depths and sizes and operated at the same hydraulic loading of 0.16 m/hr. First, the filter has been operated at sand depth of 135 cm and the influent is taken from the feed reservoir. After that, the filter has been operated at sand depth of 105 cm and the influent is taken directly from the line. Then, based on the results of these two runs, particularly the bacteriological removal efficiency, another run with sand depth of 55 cm has been selected for evaluation. The influent of this run is also taken directly from the line. This last run for the fine sand has been duplicated using sand depth of 53 cm to verify the efficiency of slow sand filters and to establish the adequacy of the experimental data under repeated conditions. The influent of this run is taken again directly from the line. Similarly, three depths of sand have been investigated listed as 135, 105 and 55 cm using sand of effective size of 0.56 mm. The influent of these three runs is taken from the feed reservoir.

4.2.1 Head Loss

The influent throughout the study has been taken from two feeds, either from the reservoir or directly from the operational line. Although the two feeds have been taken from North Aramco Treatment Plant, the quality of wastewater in the reservoir is deteriorated because of the presence of algae. To avoid the excessive algal growth problem in the reservoir, the influent has been taken directly from the operational line. However, at night time when the line has not been operational, the feed has been taken from the reservoir.

Two different sizes of local sand (ES = 0.31 mm and ES = 0.56 mm) have been investigated. The system has been evaluated at three different depths of sand bed as 135, 105 and 55 cm for each size of the sand. Moreover, the hydraulic loading has been 0.16 m/hr (corresponding to a flow rate of 2 l/min). This hydraulic loading has been selected according to Al-Adham (1) study. He has suggested that (0.16 m/hr) is a suitable hydraulic loading for the design of slow sand filtration in Saudi Arabia after investigating three hydraulic loadings, i.e., 0.08, 0.16 and 0.24 m/hr.

As the filter run has progressed, the head loss in the medium has increased because of the build-up of suspended material in the pores of the medium. Therefore, the outlet valve is open proportionally to compensate for the head loss. This process is done until the valve is widely open. When the full opening of the outlet valve could not give the required hydraulic loading, the filter runs have been terminated, since the hydraulic loading has been fixed (0.16 mm/hr) throughout the study. The duration of the runs have been dependent mainly upon the influent quality and the size of the sand.

The head loss build up as recorded at the three manometers for various sand depths and sand sizes investigated throughout the study are illustrated in Figures 4.14 to 4.20. The head loss is equal to the the vertical distance between the surface of the water on the filter and the water level in the manometer (35). Figures 4.16 , 4.17 and 4.20 show the head loss build up at the outlet and the middle manometer only. This is due to decreasing of the sand depth to 55 cm at which level the top manometer port extrude from the sand bed. The development of head loss has always followed an exponential pattern. This agrees with what has been stated in the literature (Cleasby *et al.* (8)) that the development of head loss in slow sand filters always followed an exponential pattern. Also, most of the head loss has been due to the top layer (Schmutzdecke). Since the head loss between the top manometer and the outlet manometer is almost small compared to the total head loss. Moreover, it has been observed that the total head loss never exceeded the available head. This agrees with Monk (35). The available head is the vertical distance between the top of the water level in the filter and the level of the surface of

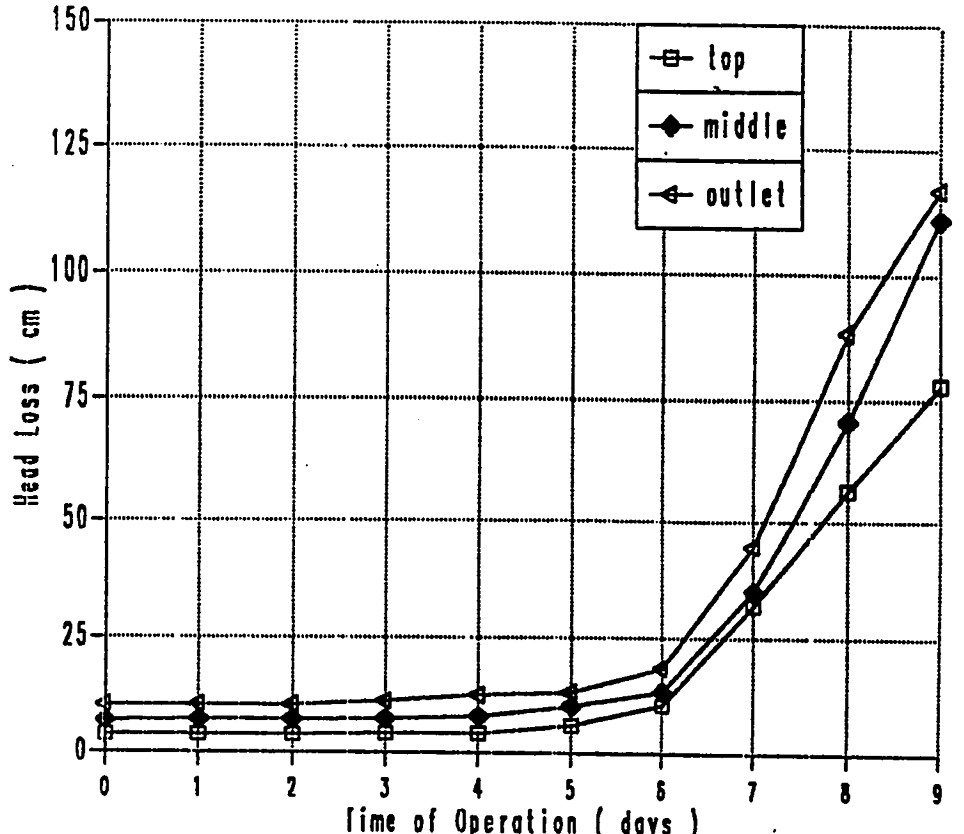

Figure 4.14:Head Loss Development pattern at Sand Depth of 135cm and Effective Sand Size of 0.31mm

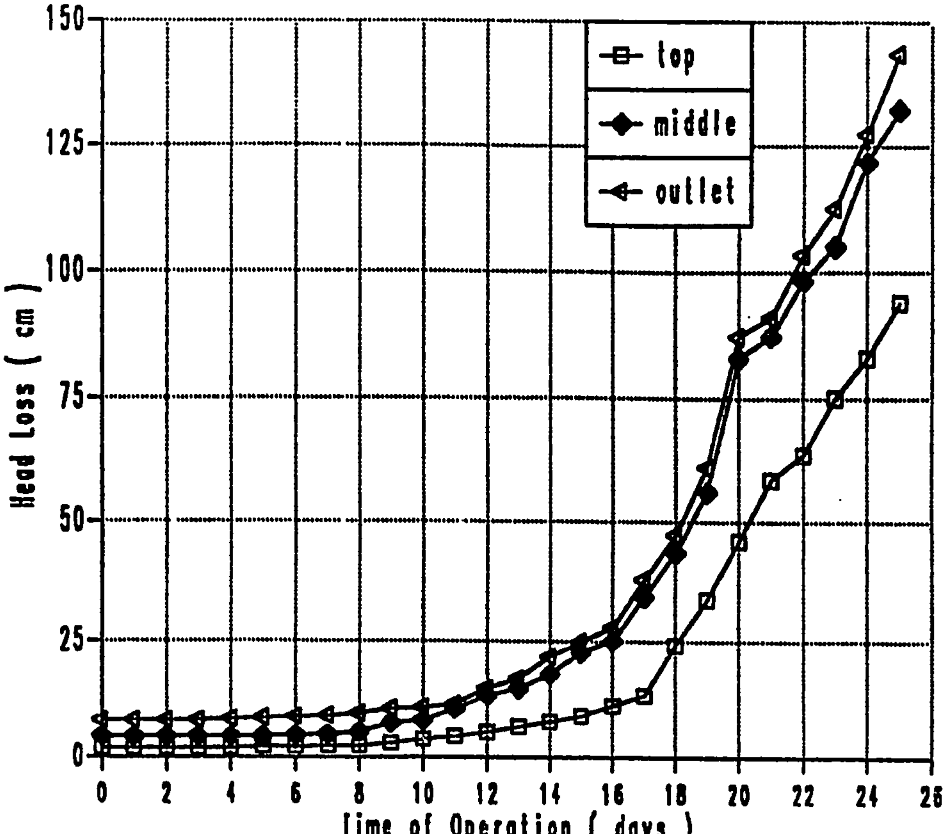

Figure 4.15:Head Loss Development Pattern at Sand Depth of 105cm and Effective Sand Size of 0.31mm

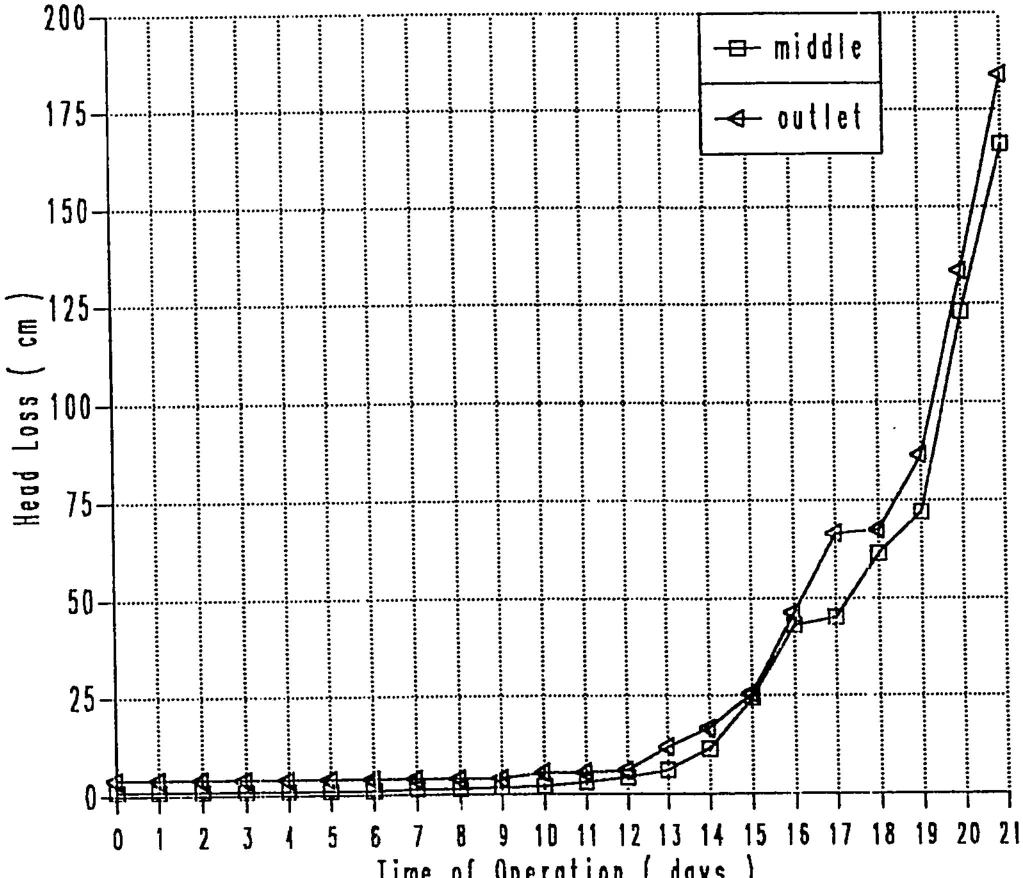

Figure 4.16:Head Loss Development Pattern at Sand Depth of 55cm and Effective Sand Size of 0.31mm

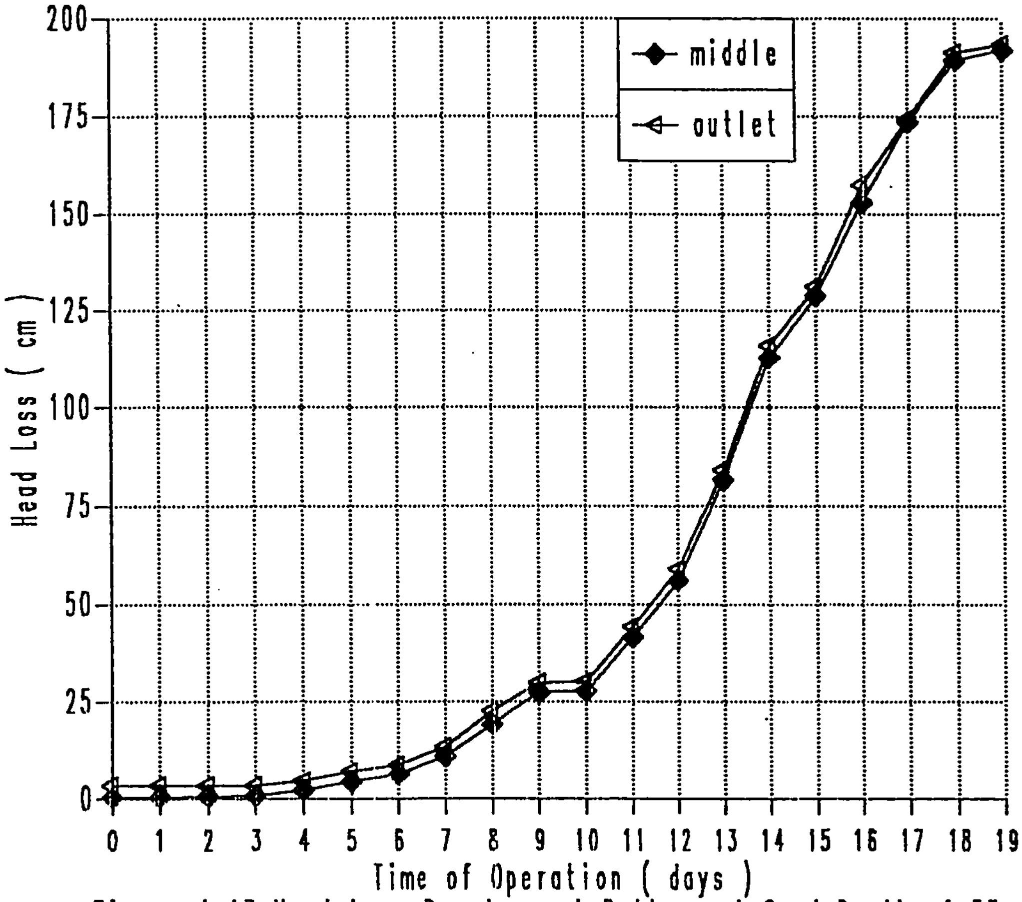

Figure 4.17:Head Loss Development Pattern at Sand Depth of 53cm and Effective Sand Size of 0.31mm

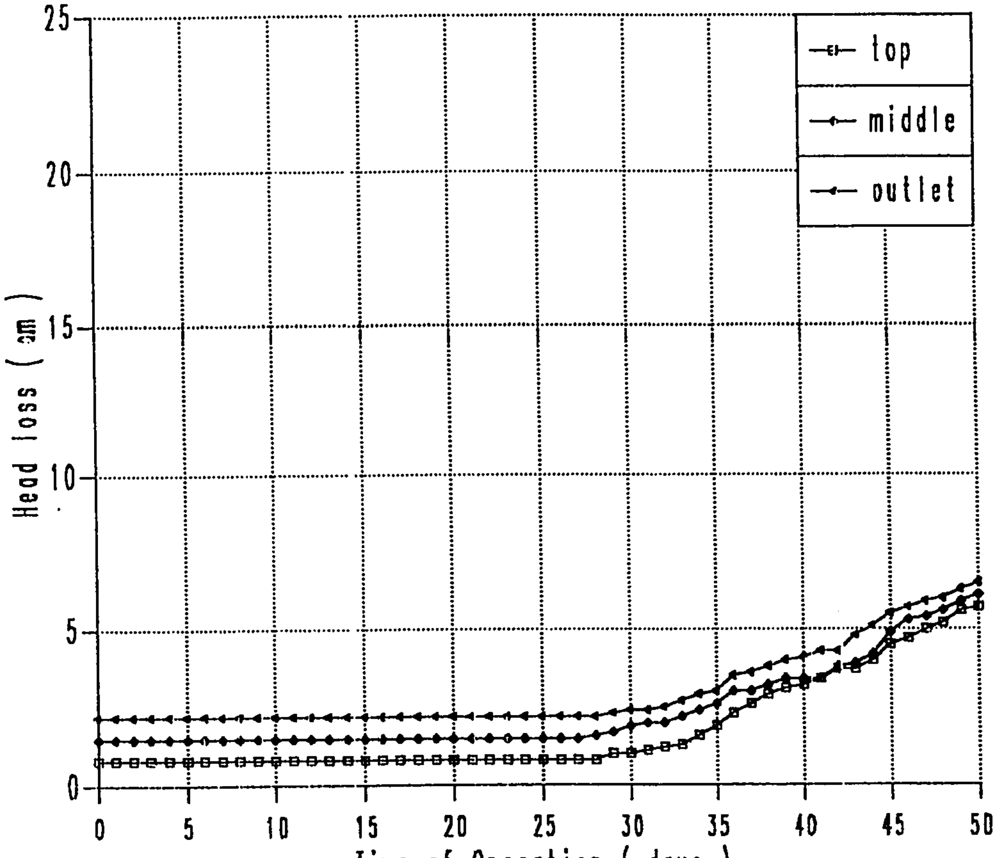

Figure 4.18:Head Loss Development pattern at Sand Depth of 135cm and Effective Sand Size of 0.56mm

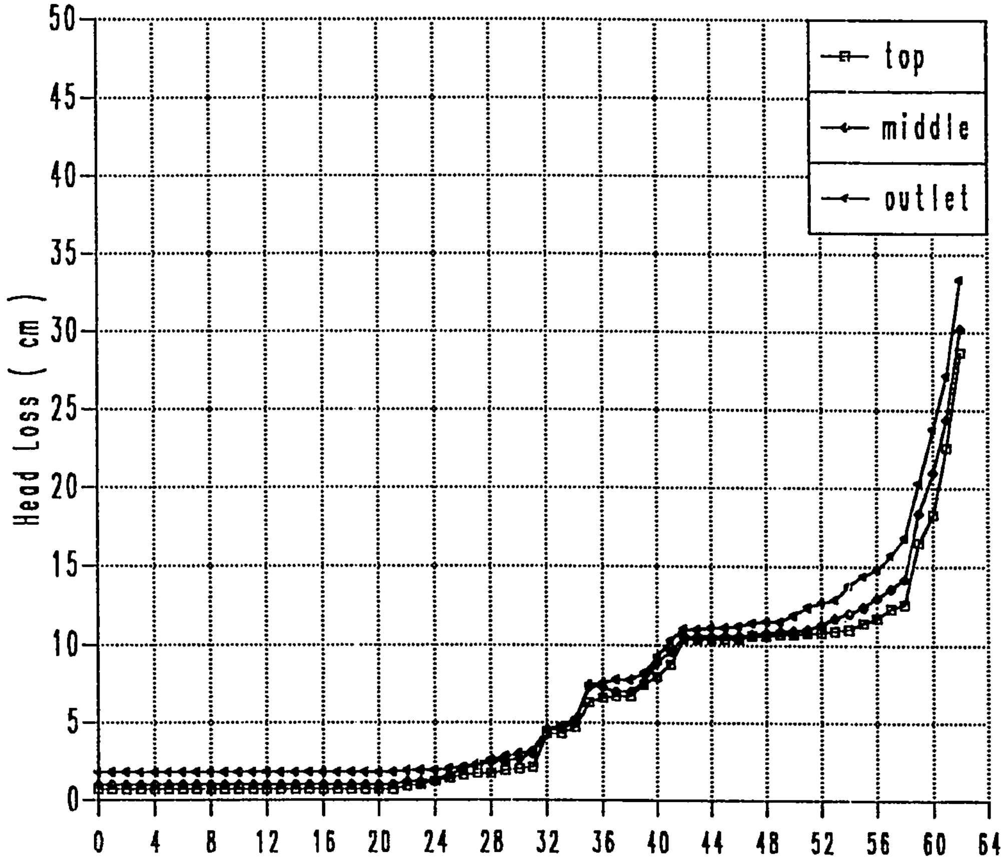

Figure 4.19:Head Loss Development Pattern at Sand Depth of 105cm and Effective Sand Size of 0.56mm

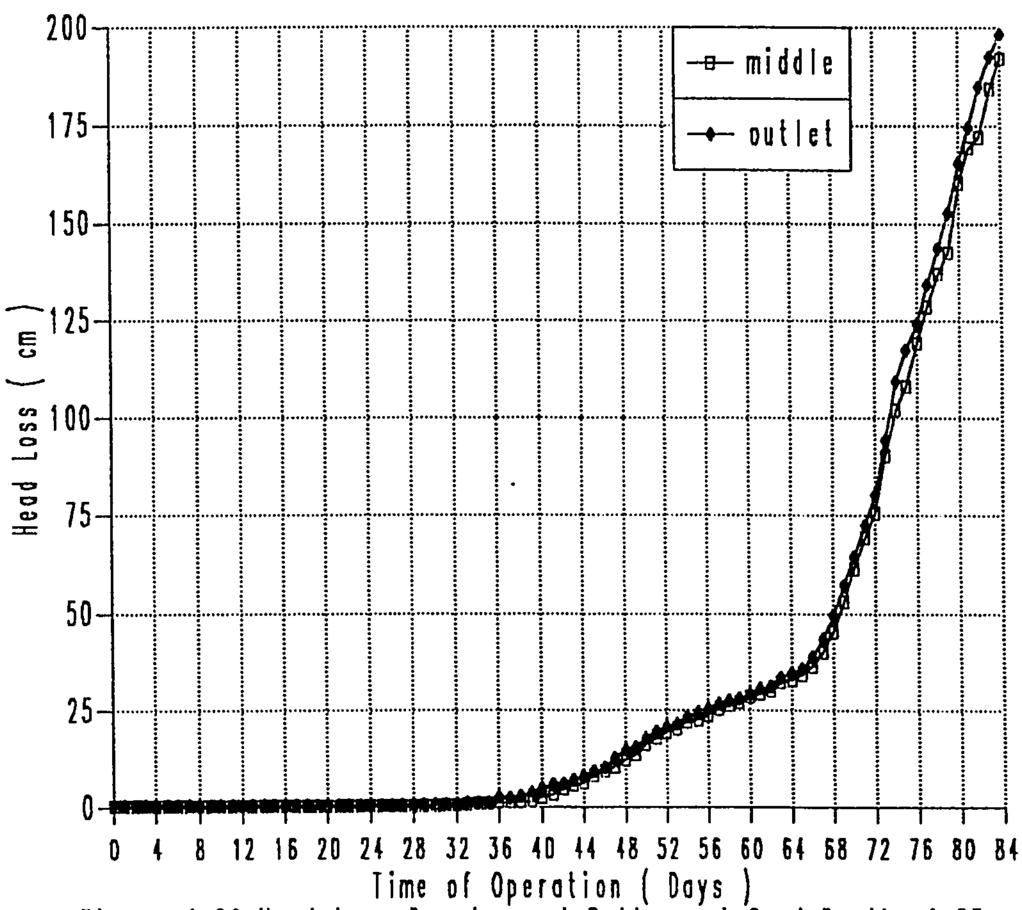

Figure 4.20:Head Loss Development Pattern at Sand Depth of 55 cm and Effective Sand Size of 0.56mm

the sand. Table 4.4 illustrates the available head and the actual total head loss as recorded at the manometers throughout the study. In this study, the available head has been increased as the depth of the sand bed decreased. When the sand with (ES = 0.56 mm) has been used, the head loss is found very small (6.5 and 34.4 cm) compared to the available head of 120 to 150 cm (Figures 4.18 and 4.19).

The clean bed head loss recorded at the outlet manometer almost agrees with the value calculated by Fair and Hatch equation (58) in all the runs. The clean bed head loss has been experimentally determined as the difference between the water level in the outlet manometer before the opening of the outlet valve and immediately after its opening to the specific hydraulic loading of 0.16 m/hr. Table 4.5 shows the clean bed head loss as calculated by the equation and as experimentally determined at the outlet manometer throughout the routine runs.

The shortest duration cycle observed throughout the study is 9 days during summer. The influent turbidity in that run has varied from 1.7 to 6.0 NTU with an average of 3.0 NTU. Unexpectedly, the operational cycle for the run with sand depth of 105 cm is longer than that at sand depth of 55 cm. Although the influent turbidity in the first run is slightly higher than that in the second run. Moreover, the available head in the first run is less than that in the second run. It is known that more available head permits greater head loss and a proportionately longer filter run. This is due to small pieces of leaves and sticks coming with the influent. This has accelerated clogging of the top layer of the filter.

The duration of operation is found almost three times when the influent has been taken directly from the operational line as compared to the feed

Table 4.4:TOTAL AVAILABLE HEAD AND ACTUAL HEAD LOSS AT THE TERMINATION OF THE FILTER

Depth of sand (cm)	Total Available Head (cm)	Total Actual Head Loss (cm)		
		Outlet	Middle	Top
Sand Size (ES = 0.31mm)				
135	120	117.0	110.0	78.0
105	150	143.5	132.3	94.0
55	200	184.0	166.0	*
53	202	193.4	191.9	*
Sand Size (ES = 0.56mm)				
135	120	6.5	6.1	5.7
105	150	33.4	30.2	28.7
55	200	198.2	192.1	*

Remarks:

Middle and Top manometer ports are 120 and 160 cm above the outlet respectively.

* This port becomes non-functional when sand depth reduces below 90 cm.

Table 4.5:CLEAN BED HEAD LOSS

Depth of sand (cm)	Clean bed head loss by Fair and Hatch equation (cm)	Clean bed head loss as recorded in the outlet manometer (cm)
Sand Size (ES=0.31mm)		
135	10.7	10.5
105	8.4	8.0
55	4.4	4.9
53	4.5	3.5
Sand Size (ES=0.56mm)		
135	2.3	2.2
105	1.8	1.8
55	0.7	0.5

reservoir (Figures 4.14 and 4.15). This has concluded that algal blooms are critical parameters which have affected the filter performance. Another observation that, when the sand with (ES = 0.56 mm) has been used as a filter media, the operational cycle has continued for 84 days as illustrated in Figure 4.20 . This is much longer than the operational cycle resulted by using sand size with (ES = 0.31 mm).

In general, the length of operations throughout the study are superior to what has been reported by Ellis (12) i.e., 7 and 20 days for secondary effluent using effective sand sizes of 0.30 and 0.60 mm, respectively, and with hydraulic loading of 0.14 m/hr. However, the duration cycle is comparable with what has been reported by Al-Adham (1) of 12 days, using sand size of ES = 0.23 mm and hydraulic loading of 0.16 m/hr. The influent turbidity in Al-Adham (1) study has ranged from 1.2 to 1.8 NTU with an average of 1.5 NTU.

Figures 4.21 and 4.22 illustrate the head loss build up as recorded at the outlet manometers throughout the operational runs at sand depths of 135, 105 and 55 cm, respectively for sands of ES = 0.31 and 0.56 mm , respectively. It is clear from Figure 4.21 that the head loss in the case of 55 cm sand depth is lower than that of 105 cm and 135 cm depths respectively as expected. However, head loss increases significantly in case of 55 cm depth of sand bed after 15 days and the filter run has to be terminated after 21 days as compared to 25 days in the case of 105 cm sand depth. This excessive head loss has been primarily due to the presence of small pieces of sticks and the leaves in the influent to the filter. Theoretically, the filter duration for 55 cm sand depth should have been longer than 105 cm depth because of the availability of more head, i.e., 200 cm as against 150 cm.

Figure 4.23 illustrates the head loss build up as recorded at the outlet

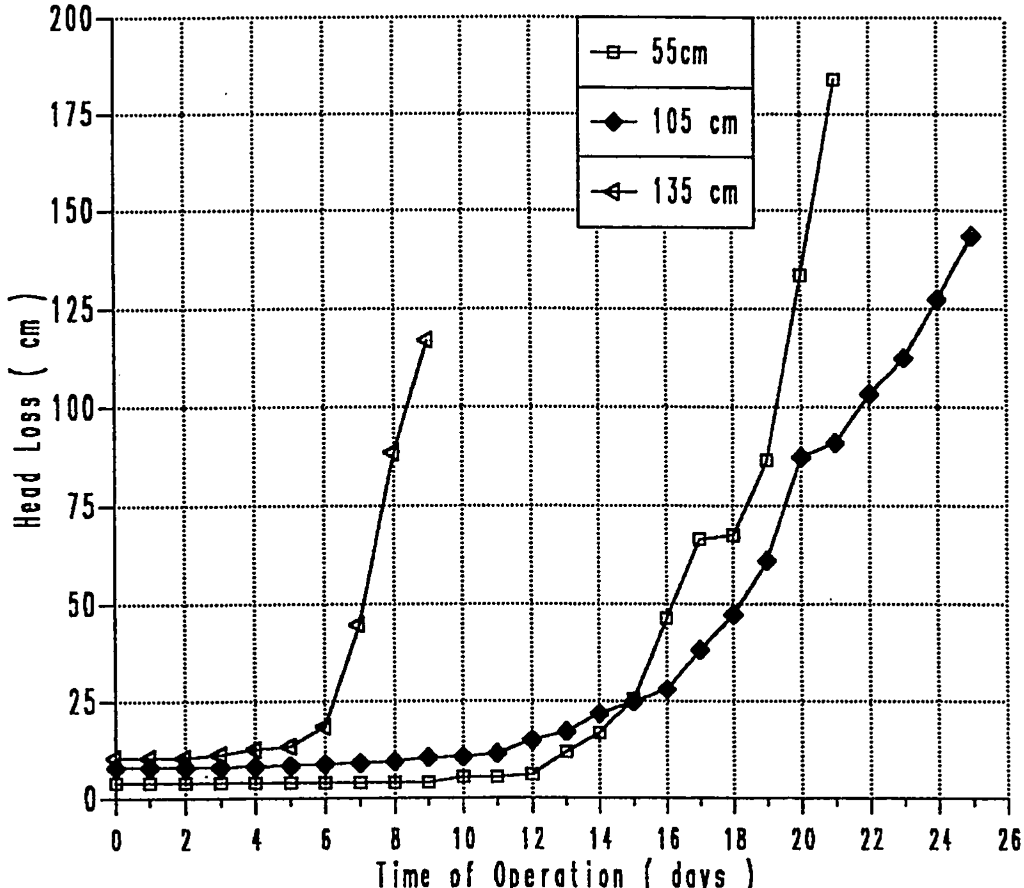

Figure 4.21:Head Loss Development Pattern at Various Sand Depths for Effective Sand Size of 0.31mm

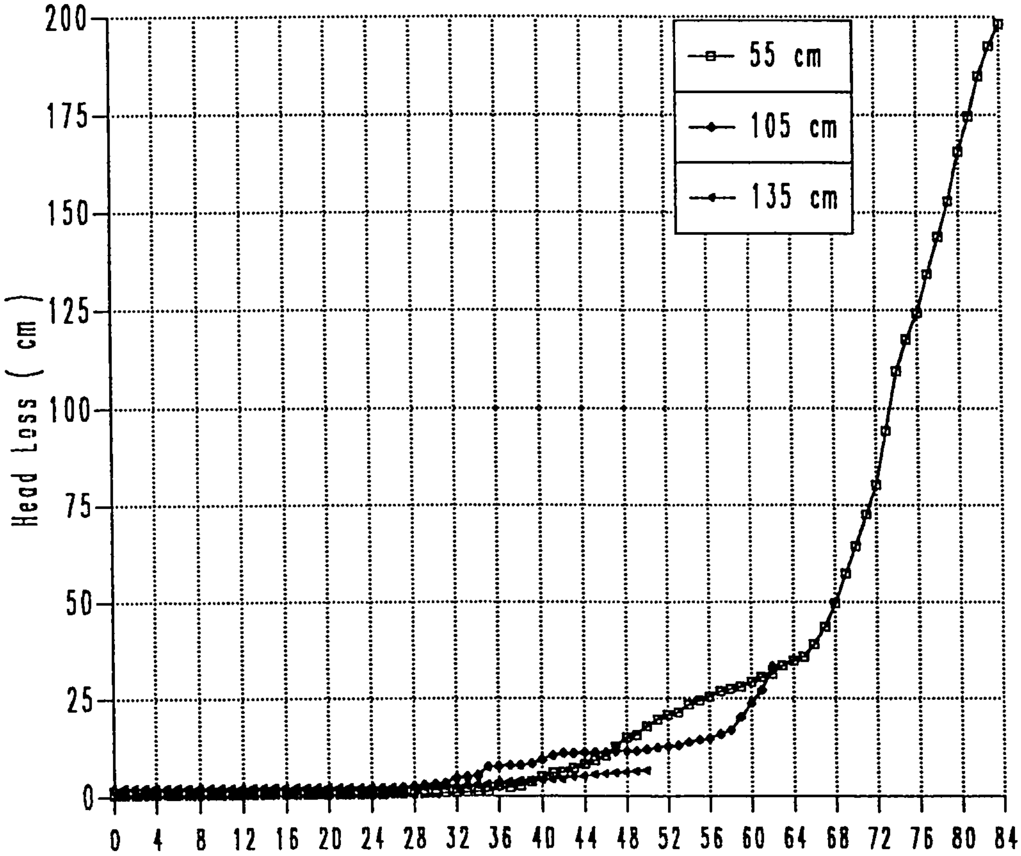

Figure 4.22:Head Loss Development Pattern at various Sand Depths for Effective Sand Size of 0.56mm

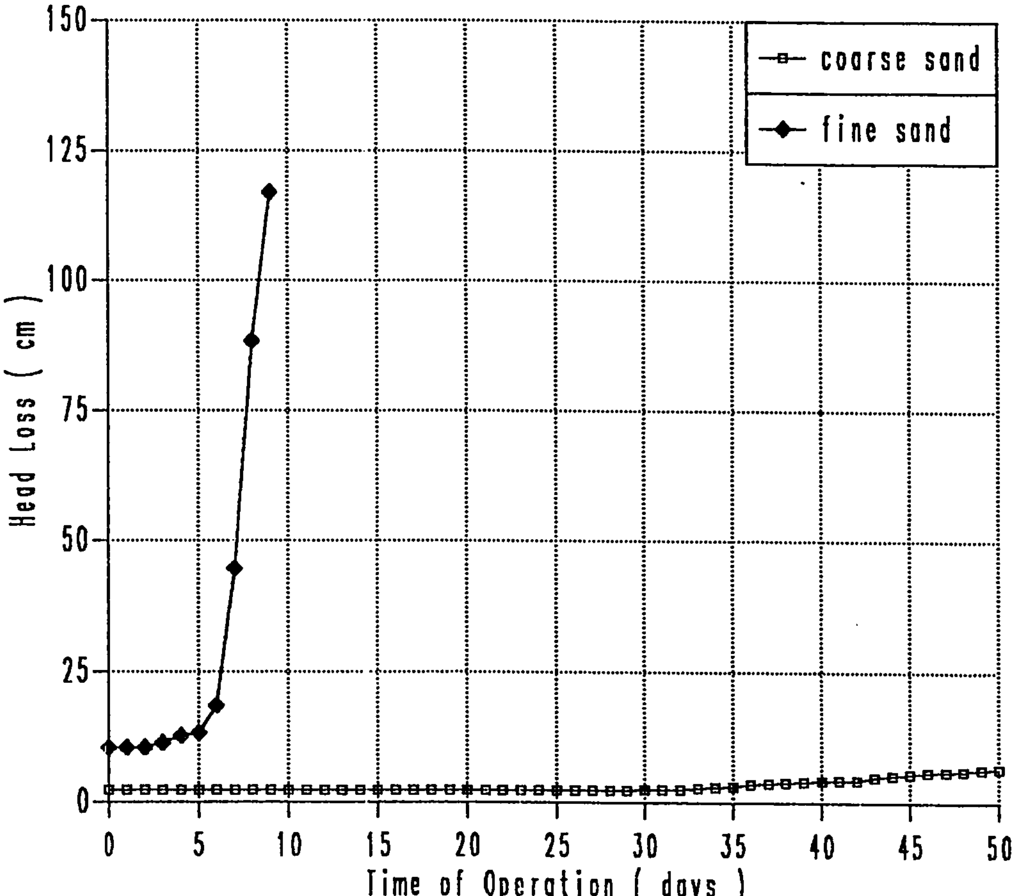

Figure 4.23:Head Loss Development Pattern at Various Types of Sand at Sand Depth of 135cm

manometers throughout the operational runs at sand depth of 135 cm for both the fine and the coarse sands. Although the influent turbidity is almost similar in both the runs, yet the total head loss developed with the fine sand is tremendously greater than that of coarse sand. The run has to be terminated after 9 days of operation in the case of fine sand due to the development of excessive head loss. On the other hand, the total head loss developed with the coarse sand is very small even after 50 days. However, the filter run has been terminated after 50 days of operation without any problem due to shortage of time for the operation of the filter to reach the breakthrough. Similar results have been found at the sand depth of 105 cm for two different sizes of sand as can be seen from Figure 4.24. On the other hand , the head loss developed with the coarse sand was tremendous after 84 days of filter operation as illustrated in Figure 4.25 .

4.2.2 Turbidity

Turbidity is one of the most important parameters to monitor the performance of the filter. It is believed that turbidity serves as a carrier for nutrients that can result in biological activity. The analysis for turbidity has been conducted daily throughout the study. Turbidity levels in the influent throughout the study have ranged from 0.9 to 12 NTU, whereas, the effluent levels have ranged from 0.05 to 0.70 NTU. The wide range of turbidity values has resulted from the influent feed, i.e., direct from the operational line or from the reservoir. The range of the influent, and the effluent are reported in Table 4.6. The average percent removals have ranged from 88.6 to 95% using different sizes and depths of sand. This degree of clarity of the filtered secondary effluent is superior to the quality required of drinking water, which is 1.0 NTU. The low turbidity in the filtered effluent of this study is attributed in

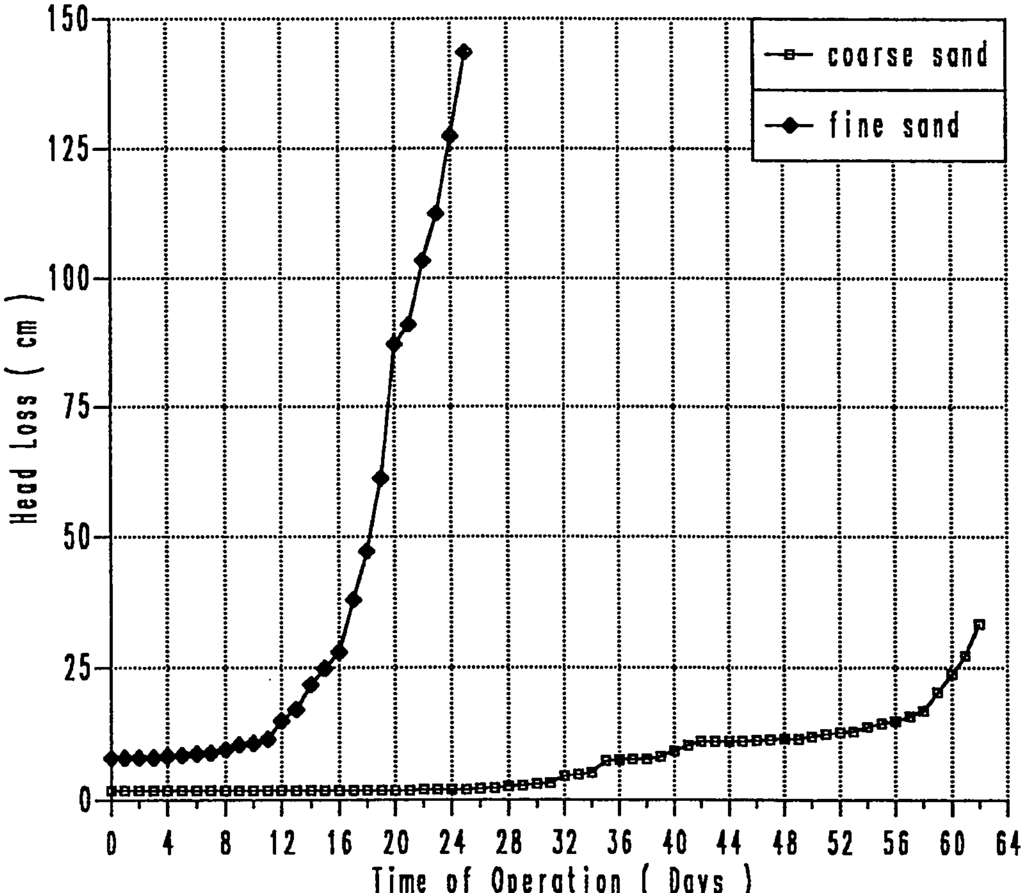

Figure 4.24:Head Loss Development Pattern at Various Types of Sand at Sand Depth of 105 cm

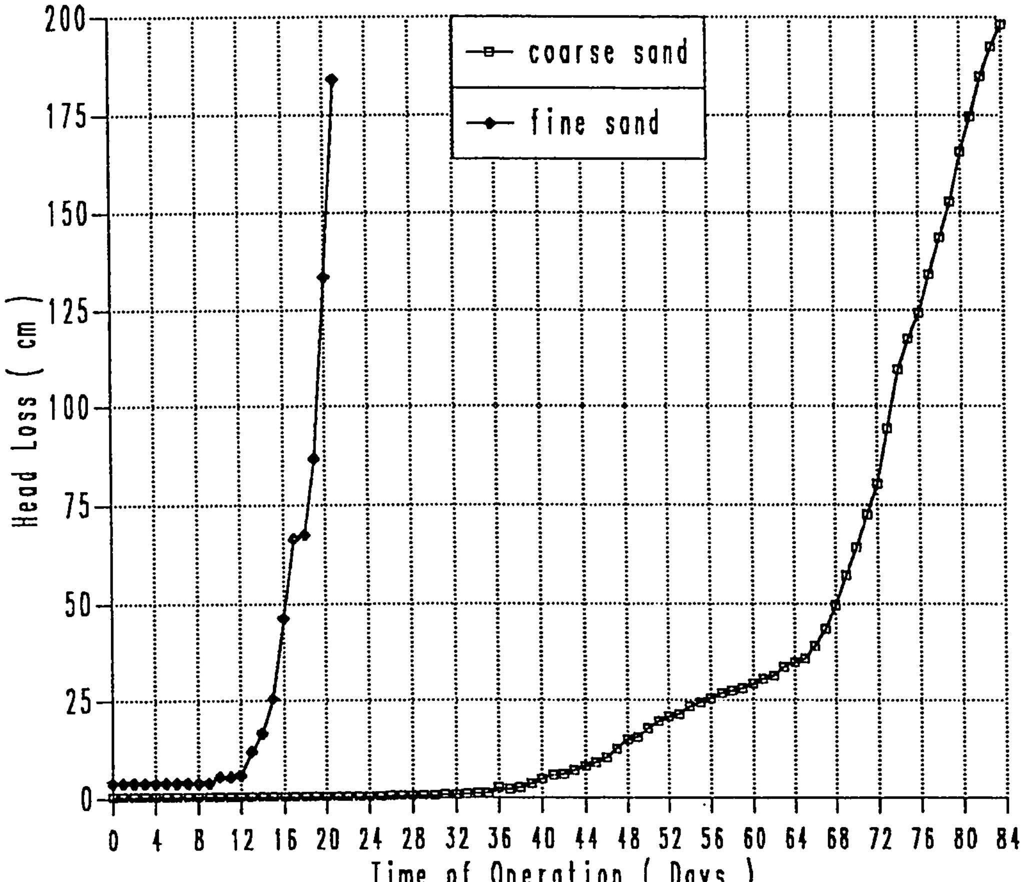

Figure 4.25:Head Loss Development Pattern at Various Types of Sand at Sand Depth of 55 cm

Table 4.6:AVERAGE REMOVAL OF TURBIDITY UNDER VARIOUS EXPERIMENTAL CONDTIONS

Depth of sand (cm)	No. of Samples Analyzed	INFLUENT		EFFLUENT		Percent Removal
		Range	Mean	Range	Mean	
Sand Size (ES=0.31mm)						
135	9	1.7-6.0	3.0	0.05-0.40	0.15	95.0
105	25	1.0-2.5	1.5	0.05-0.30	0.12	92.0
55	20	1.0-3.25	1.46	0.10-0.18	0.13	91.0
53	19	1.10-1.75	1.33	0.09-0.20	0.12	91.0
Sand Size (ES=0.56mm)						
135	43	1.0-3.0	1.71	0.10-0.26	0.14	91.8
105	53	1.2-3.7	1.94	0.13-0.40	0.21	89.1
55	39	1.2-3.7	2.09	0.13-0.43	0.24	88.6

part to the high quality of the biologically treated wastewater from the North Aramco Wastewater Treatment Plant. The variation of the influent, the effluent and the percent removal at various depths and sizes of the sand are illustrated in Figures 4.26 to 4.32 . In spite of the variation in the influent quality associated with changing the feed, i.e., from the reservoir with huge algal blooms, or direct from the operational line, the turbidity removal has been consistently high.

The average percent removal at sand depth of 105 cm and ES = 0.31 mm (92%) is slightly superior to that reported by Al-Adham (1). He has reported that the turbidity percent removal is 88%, using smaller size of sand with (ES = 0.23 mm) and sand depth of 84 cm. The hydraulic loading has been 0.16 m/hr. But this is slightly inferior to the value reported by Cleasby *et al.* (8) of 97.8% or better, treating surface water having turbidity values ranging from 0.35 to 18.1 NTU. The other filter parameters were ES = 0.32 mm, sand depth = 94 cm, and the hydraulic loading = 0.12 m/hr.

In general, the performance of slow sand filter is superior to the other techniques reported in the literature treating low to moderate turbid water or wastewater . Study has been conducted by Suhail (55) using conventional treatment (coagulation, sedimentation, and rapid filtration), treating secondary effluent from North Aramco Wastewater Treatment Plant. He has reported that the overall percentage turbidity removal for chlorinated secondary effluent has ranged from 77 to 92% after the filtration process at various chemical dosages 5 to 20 mg/l of commercial grade alum (molecular weight = 600 g) with 0.10 to 0.30 mg/l of Magnafloc 155 anionic polymer (Allied colloids). Al-Sawaf (45) has conducted a study using direct filtration treating the same wastewater . He has reported that the average turbidity removal ranged from 75 to

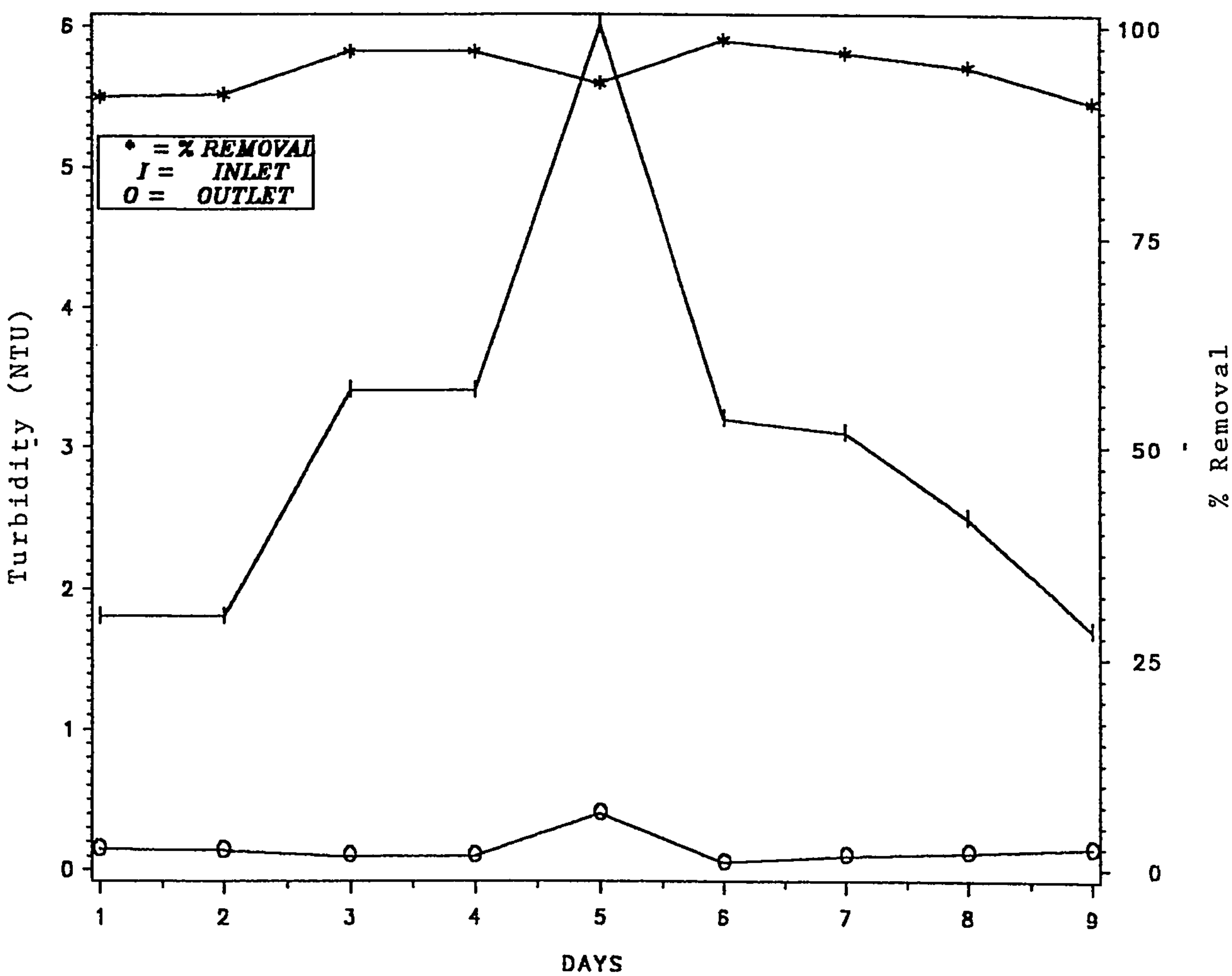

FIGURE4.26:REMOVAL OF TURBIDITY THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.31MM

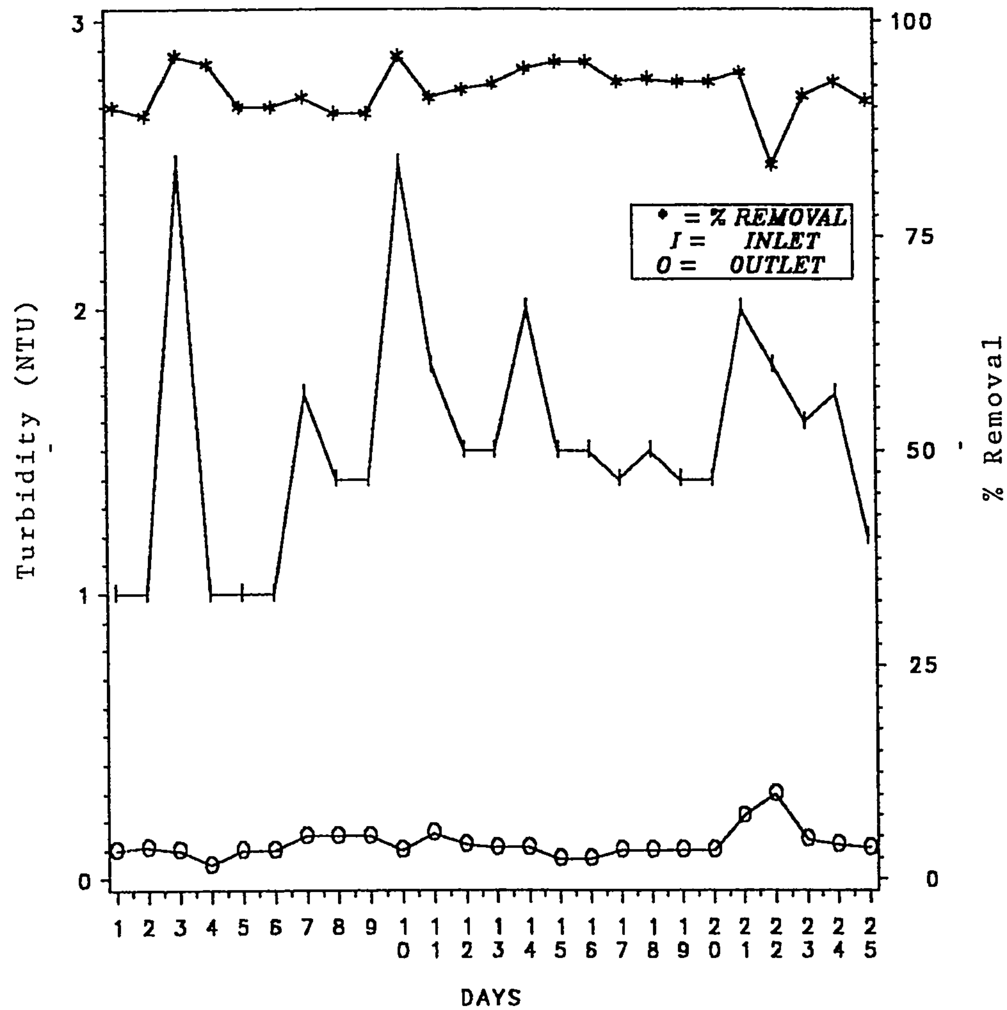

FIGURE 4.27: REMOVAL OF TURBIDITY THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.31MM

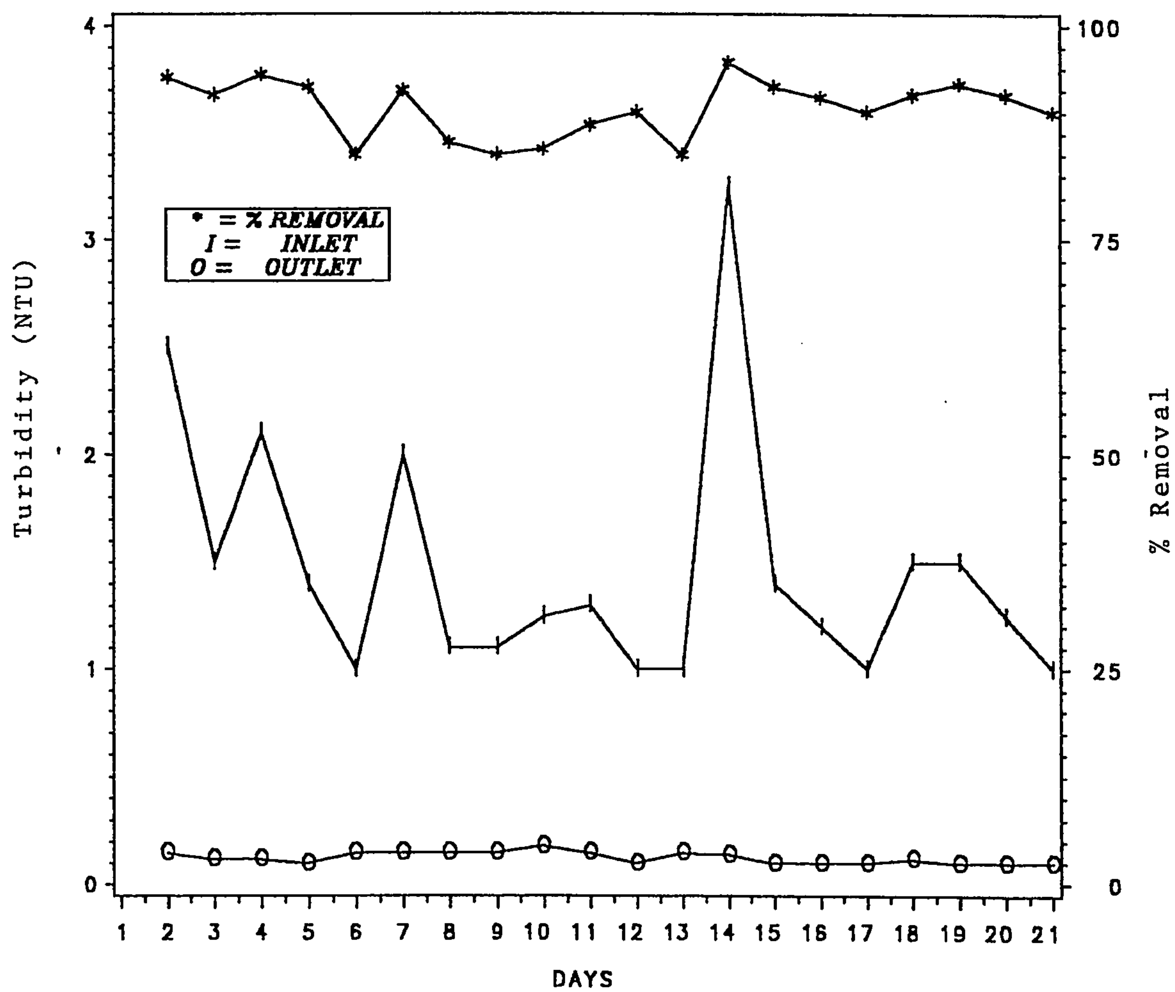

FIGURE 4.28: REMOVAL OF TURBIDITY THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.31MM

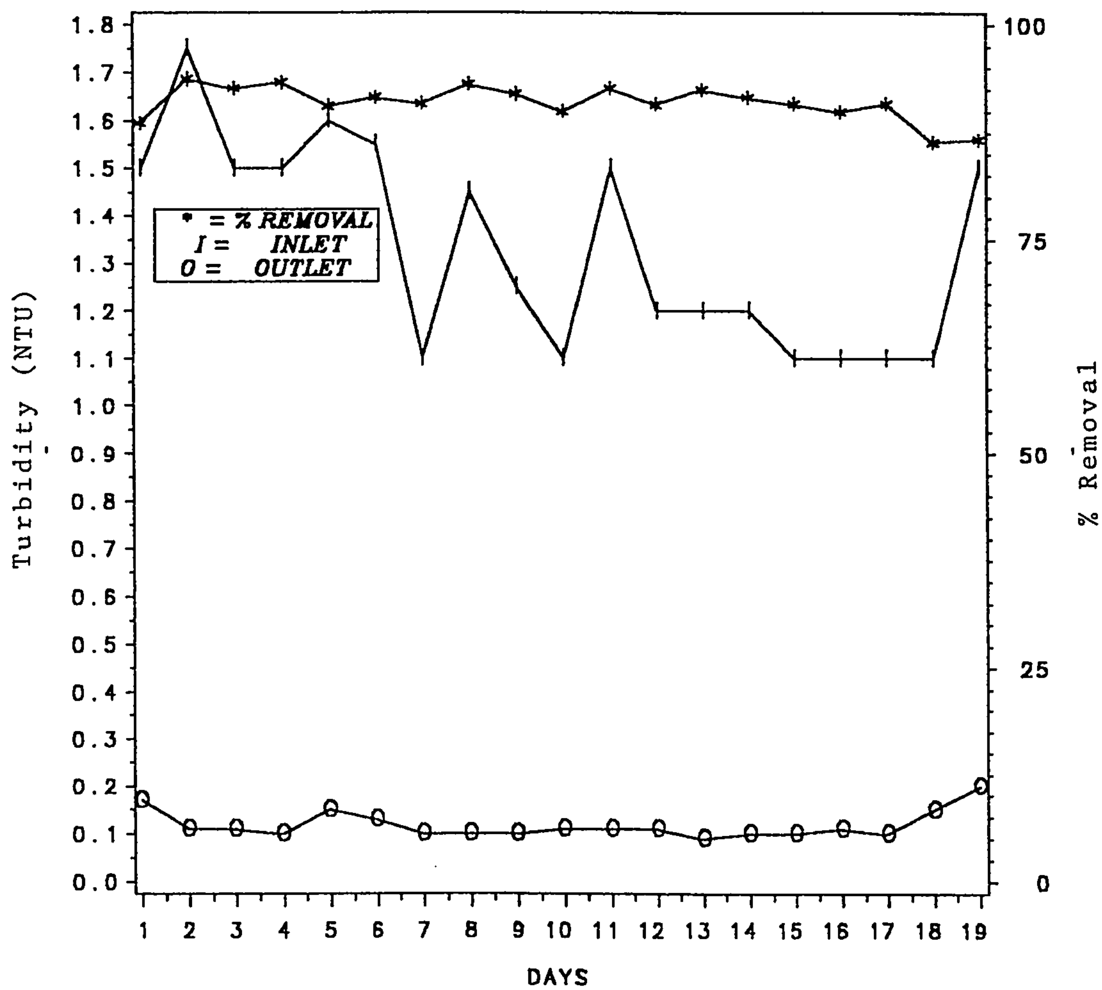

FIGURE 4.29: REMOVAL OF TURBIDITY THROUGH SAND BED OF 53CM AND EFFECTIVE SIZE OF 0.31MM

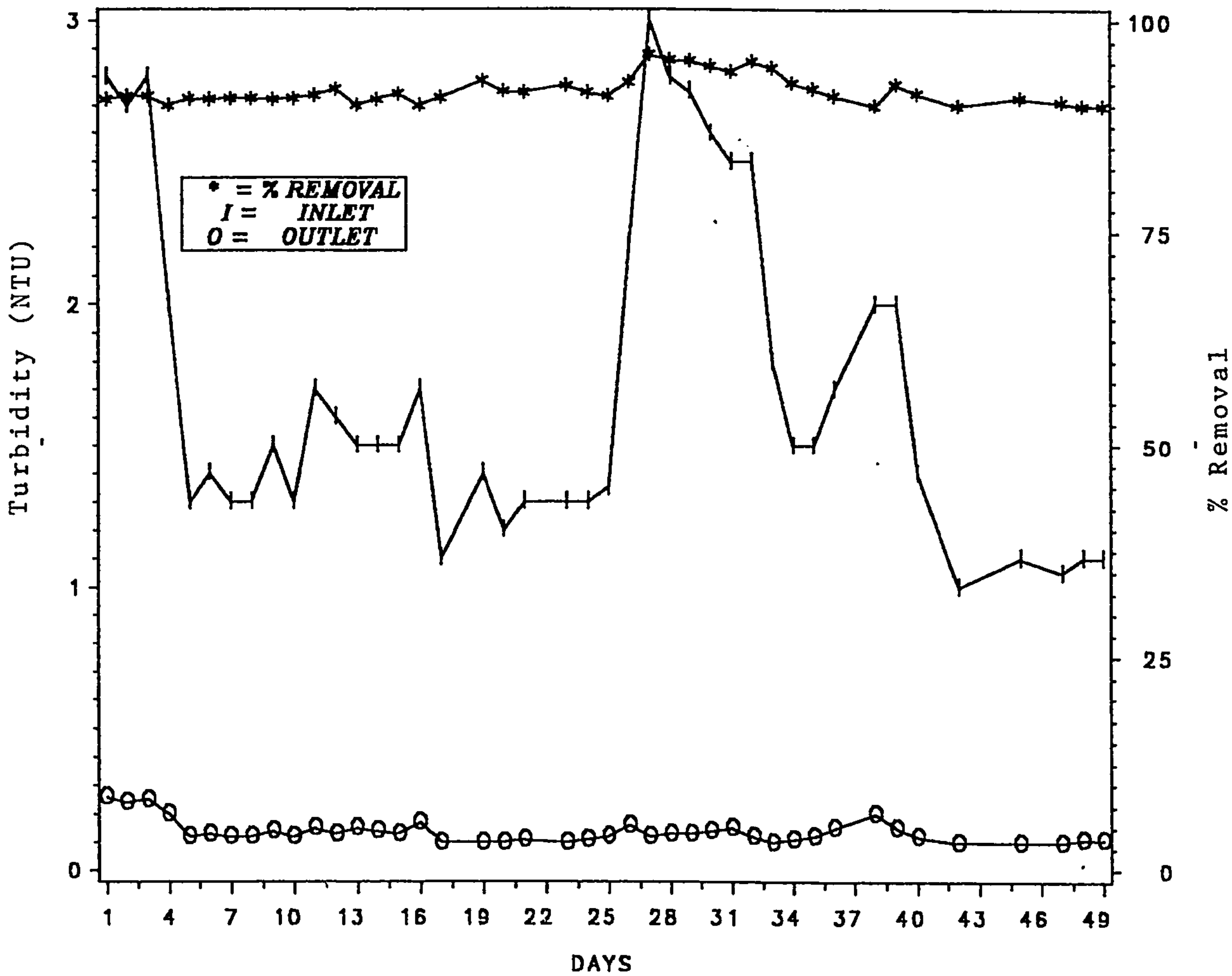

FIGURE 4.30: REMOVAL OF TURBIDITY THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

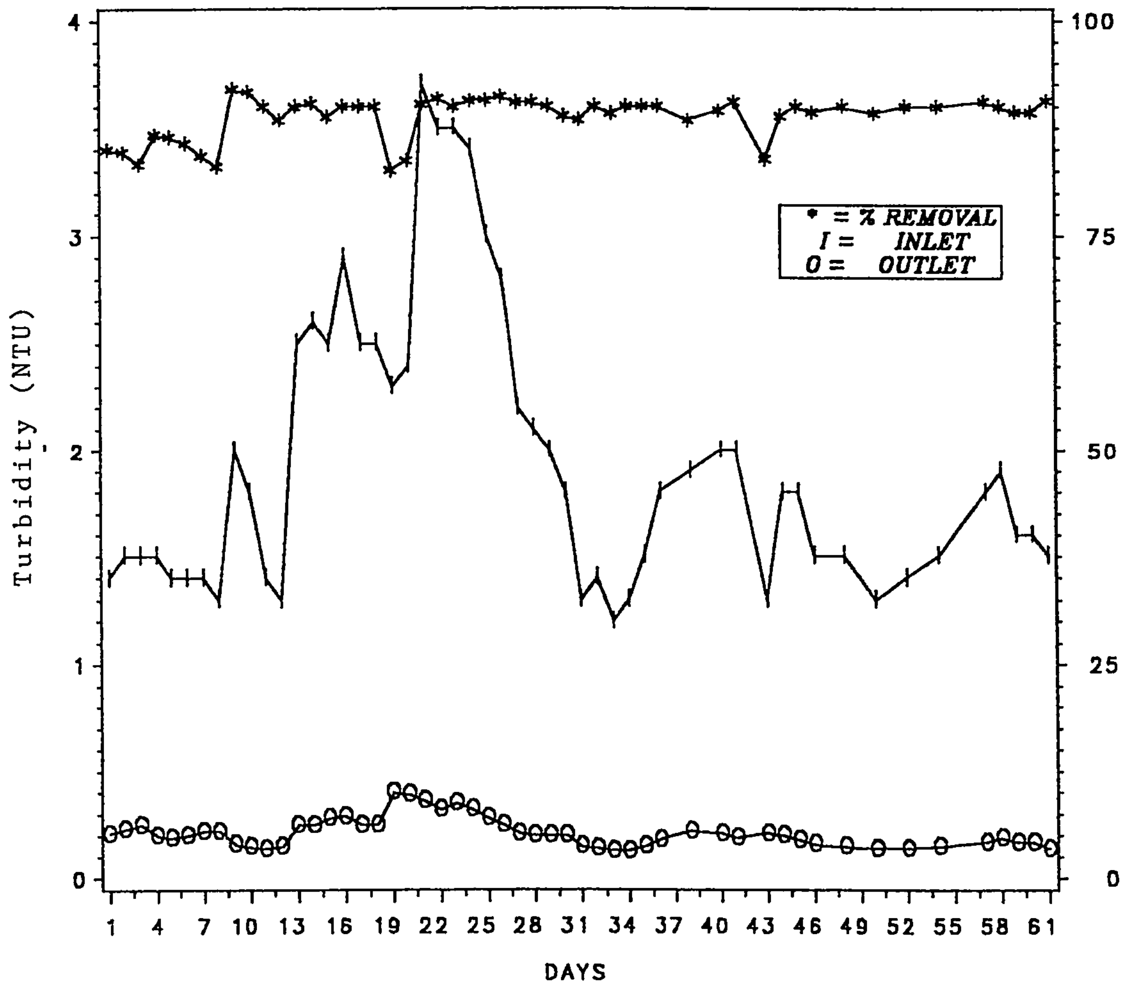

FIGURE 4.31: REMOVAL OF TURBIDITY THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.56MM

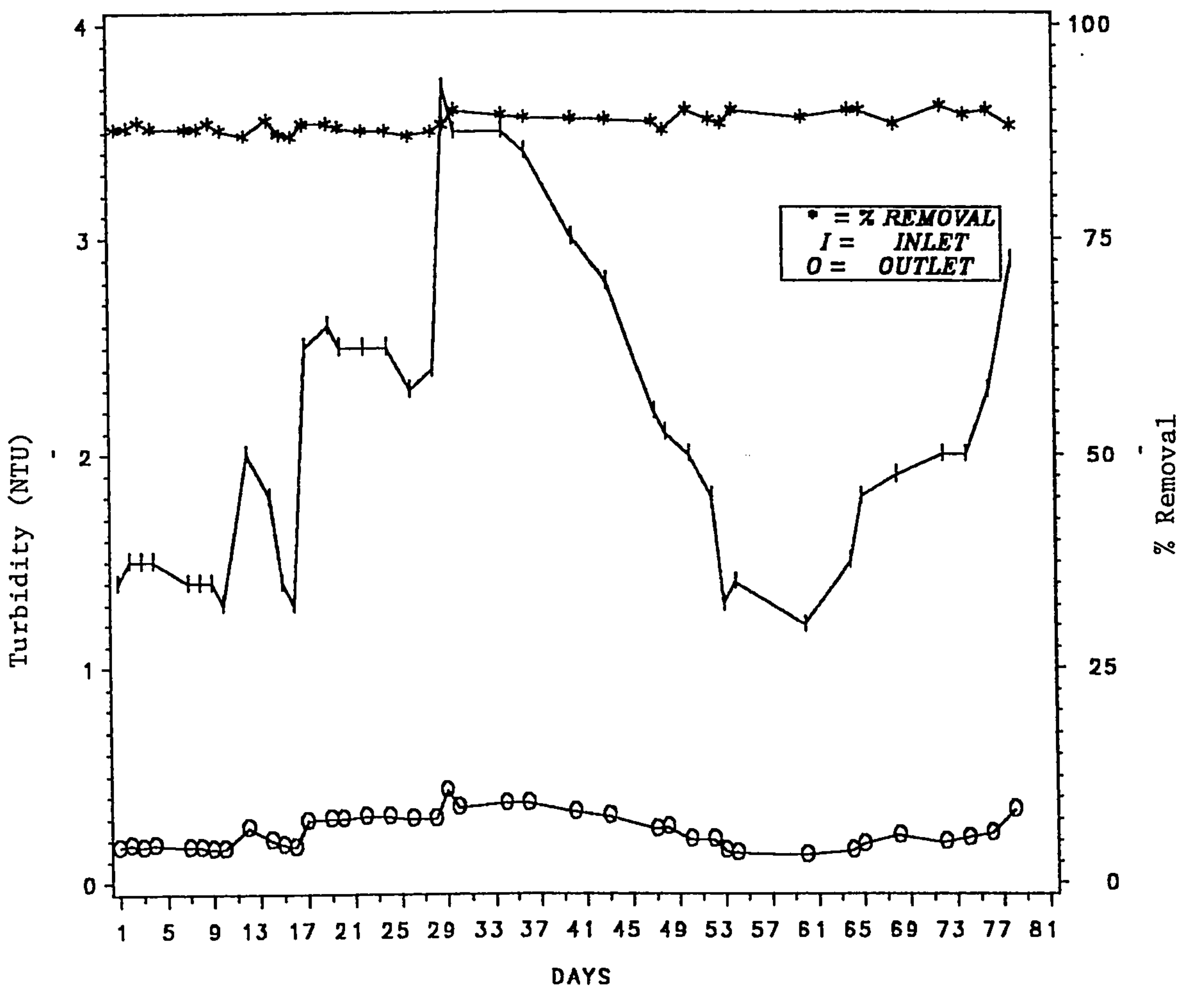

FIGURE 4.32: REMOVAL OF TURBIDITY THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.56MM

90% using the same chemicals and dosages as Suhail (55) . He also studied the removal of turbidity without chemical addition. The effluent turbidity has exceeded 1.0 NTU with percent removal averaging from 28 to 39%.

The percent removals of turbidity for the fine sand at sand depths of 135, 105 and 55 cm are 95, 92 and 91% respectively as shown in Figure 4.33 The trend for percent removal is upward with increasing depth of sand bed. This indicates that the larger depth of sand bed is better for the removal of turbidity for a given quality of the influent. On the other hand, the percent removals of turbidity with the coarse sand at sand depths of 135 , 105 , and 55 cm are 91.8 , 89.1 and 88.6% , respectively as shown in Figure 4.34

Figures 4.35 , 4.36 and 4.37 illustrate the variation of the percent turbidity removal through fine and coarse sand at bed depths of 135 , 105 and 55 cm, respectively. It is found that as the sand size decreases, the percent removal improves slightly. Figure 4.38 shows the averages of the percent removal of turbidity for the three depths investigated for the fine and the coarse sands. It is observed that the percent removal is decreasing by decreasing the sand depth and/or by increasing the sand size. The effect of sand size on percent removal is marginal. Therefore, it may be suggested to use the sand of larger size with deeper bed compared to finer sand of shallow bed to get the desired efficiency .Although the coarse sand has resulted in almost similar percent removal as the fine sand, yet the coarse sand has resulted in longer duration of the filter runs.

4.2.3 Total Coliform Bacteria

Samples analyzed for total coliform bacteria have been collected routinely from the influent and the effluent of the filter. The influent total coli-

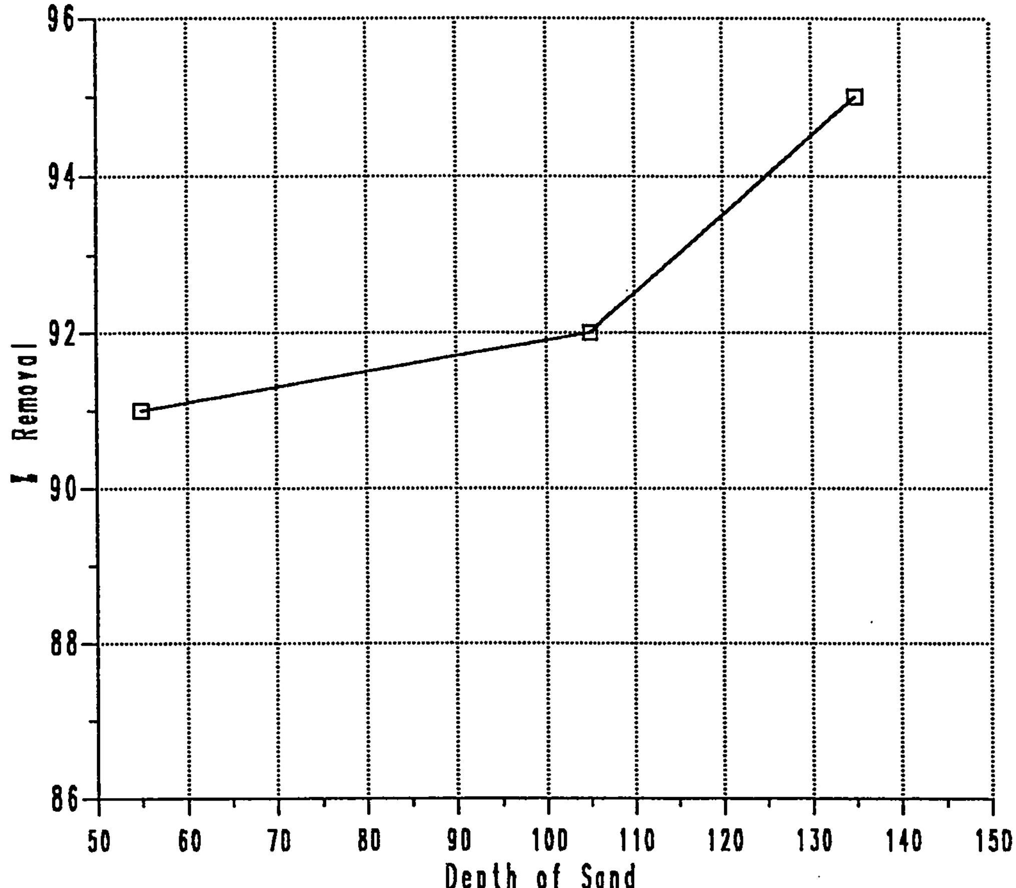

Figure 4.33:Turbidity Removal at Various Sand Depths
for Effective Sand Size of 0.31mm

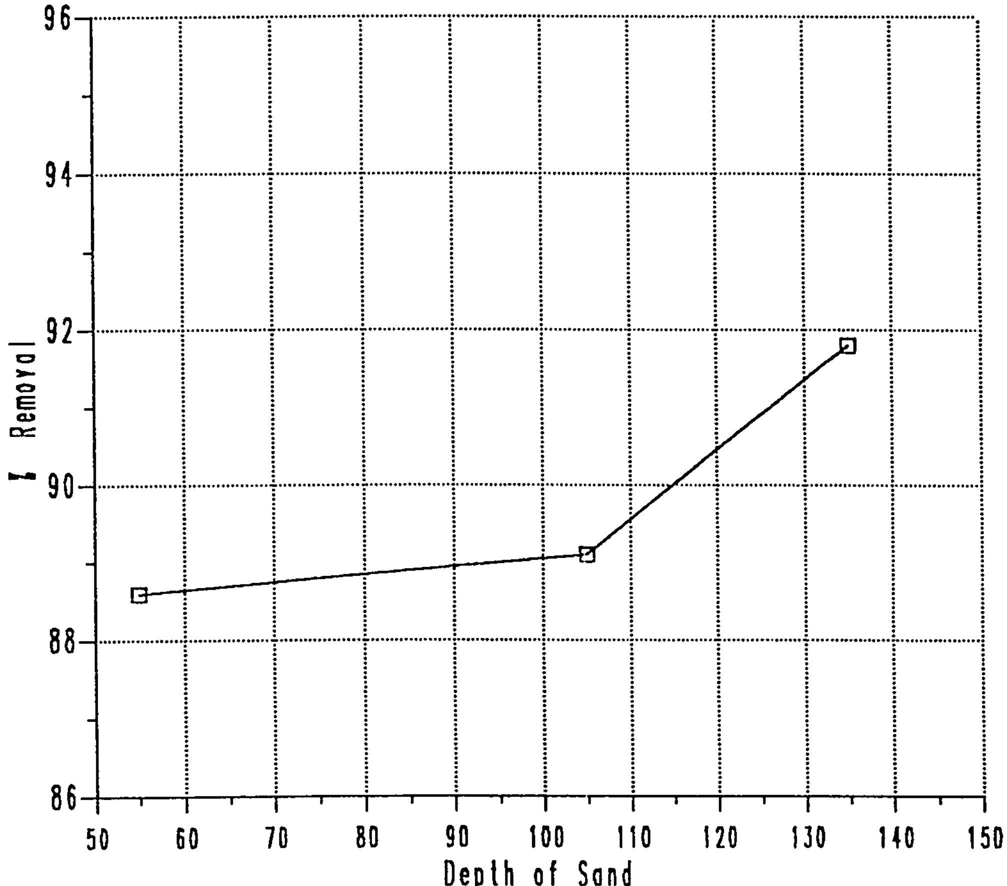

Figure 4.34: Turbidity Removal at Various Sand Depths for Effective Sand Size of 0.56mm

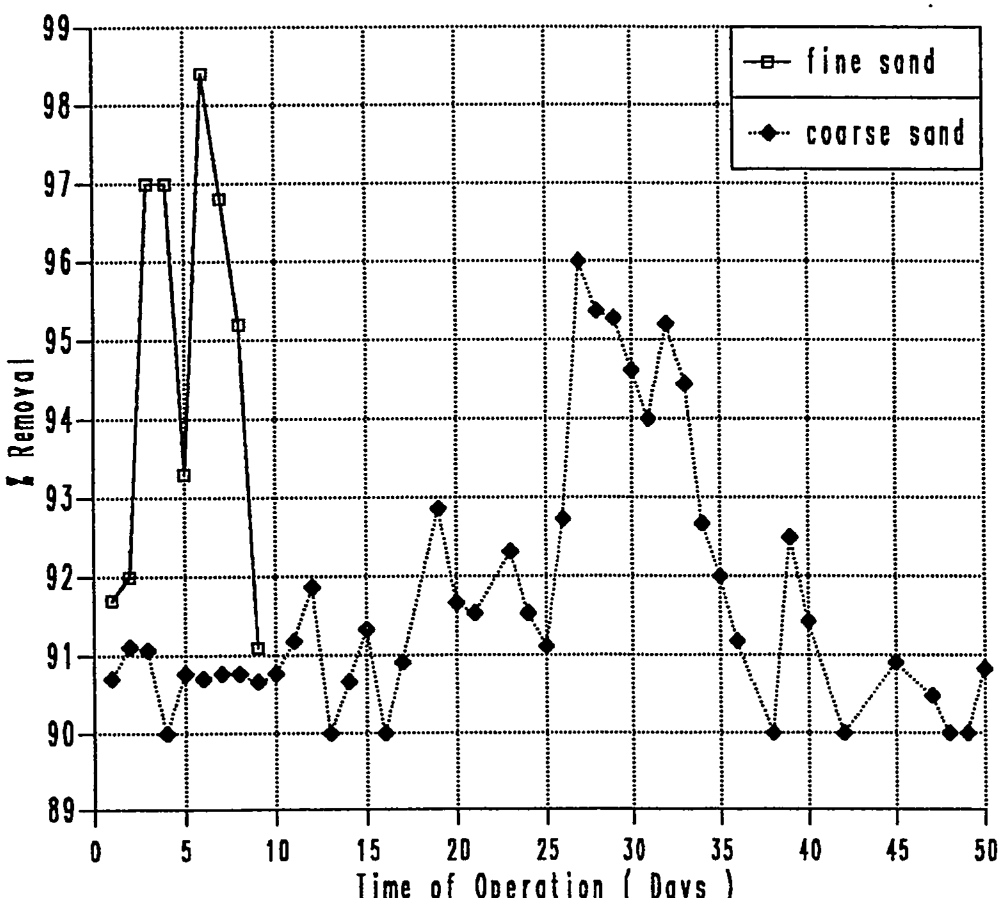

Figure 4.35:Removal of Turbidity Through Various Types of Sand at a Sand Depth of 135cm

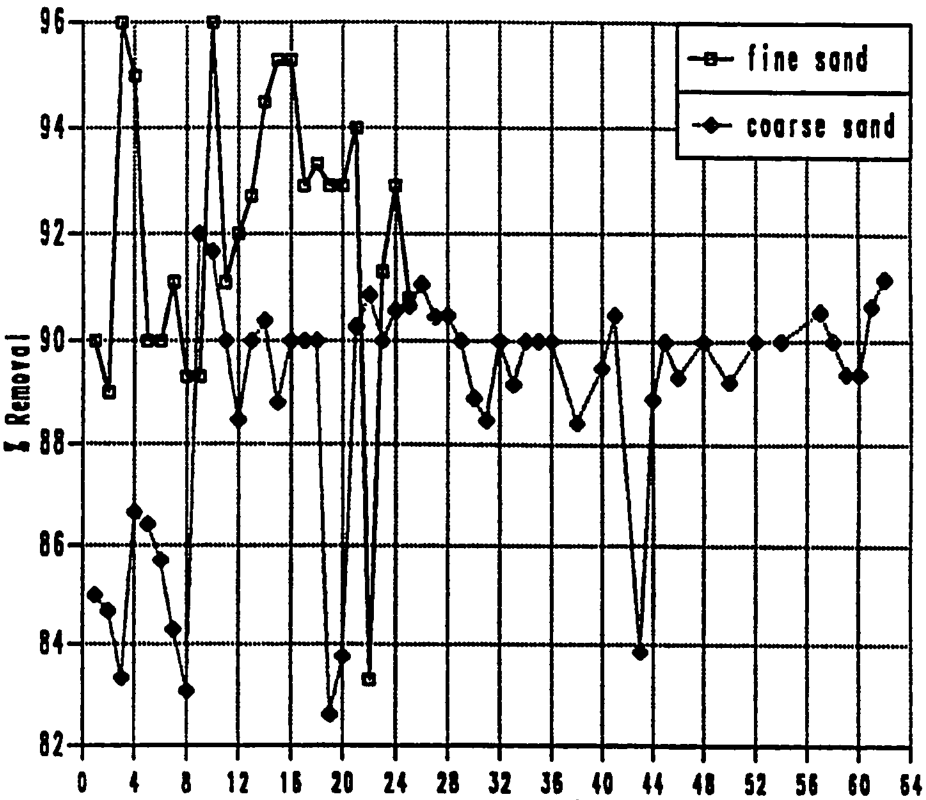

Figure 4.36:Removal of Turbidity Through Various Types of sand at a Sand Depth of 105cm

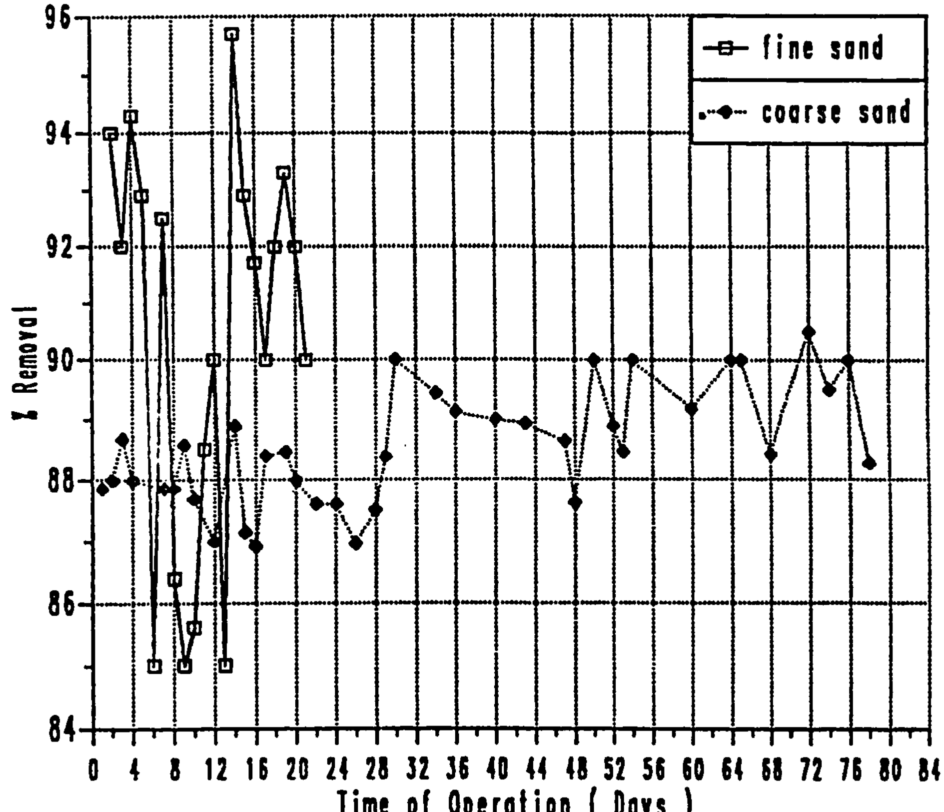

Figure 4.37:Removal of Turbidity Through Various Types of Sand at a Sand Depth of 55cm

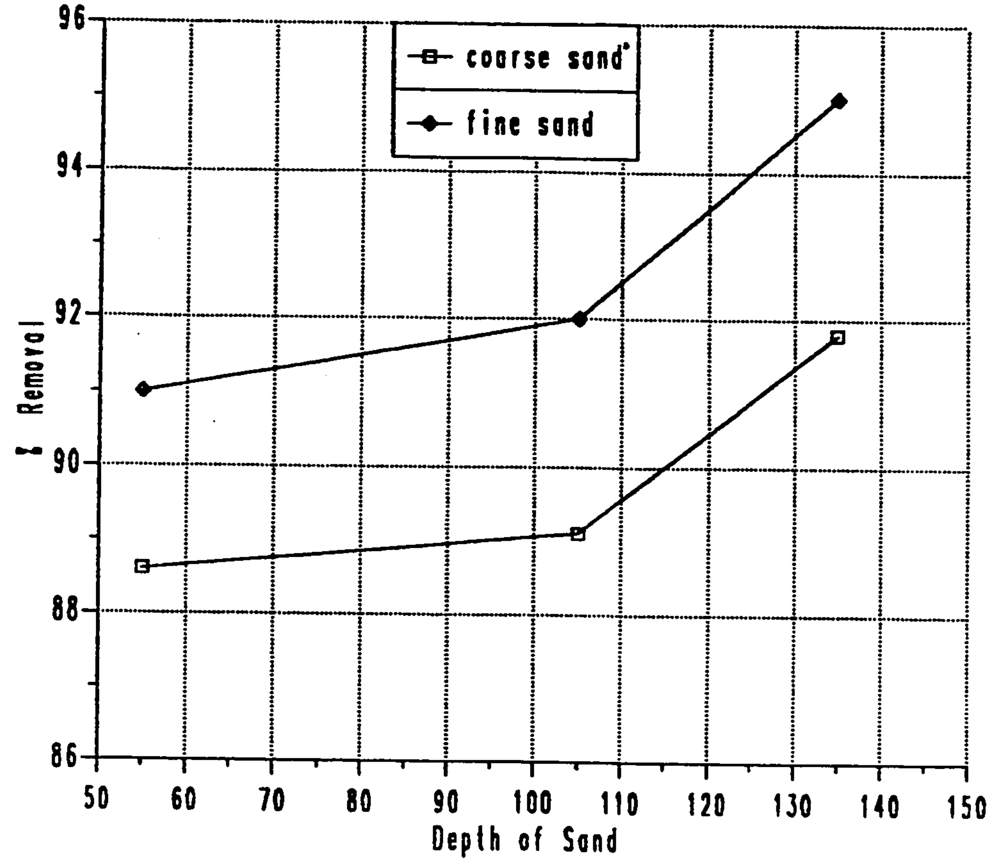

Figure 4.38:Removal of Turbidity at Various Sand Depths and Sizes

form bacteria levels throughout the routine runs have ranged from 8 to 240 MPN/100 ml, whereas, the effluent levels have ranged from 0 to 12 MPN/100 ml. The range of total coliform bacteria in the influent and the effluent, and the average percent removal are illustrated in Table 4.7. Moreover, the variation of the influent, the effluent, and the percent removal on daily basis during the duration of filter cycle are illustrated in Figures 4.39 to 4.45 . Figure 4.39 shows that the removal efficiency is much higher i.e., over 90 percent as compared to preliminary runs, where removal ranged from 40 to 82 percent. This means that the filter bed has been fully matured. This observation is a confirmation of the widely quoted statement "biological activity within the sand bed has the strongest influence on removal efficiency of total coliform bacteria by slow sand filtration" (6).

The average percent removal at this run, at a sand depth of 135 cm using sand size of ES = 0.31 mm is 99.76%. Figure 4.40 illustrates the variation variation of the total coliform bacteria percent removal at sand depth of 105 cm and sand size with ES = 0.31 mm. The average percent removal is 97.82%. This is slightly inferior to the value reported by Al-Adham (1). He has reported that the average percent removal of total coliform bacteria is over 99%. This may have resulted from the smaller size (ES = 0.23 mm) which has been used by Al-Adham (1). This is also slightly inferior to the findings of Cleasby *et al.* (8). They have reported that the average percent removal is over 99%, using sand size of ES = 0.32 mm, and sand depth of 94 cm. This is expected because the influent concentration of the total coliform bacteria in Cleasby *et al.* (8) study is much higher. Bellamy *et al.* (5) have reported that the percent removal increases as the influent concentration increases. On the other hand, the results of the present study agree with the findings of Ellis (12). He has reported that the average percent removal of total coliform

Table 4.7:AVERAGE REMOVAL OF TOTAL COLIFORM BACTERIA UNDER VARIOUS EXPERIMENTAL CONDTIONS

Sand Depth (cm)	No. of Samples Analyzed	Influent range MPN/100 ml	Effluent range MPN/100 ml	% Removal
Sand Size (ES=0.31mm)				
135	6	79-240	0-2	99.76
105	10	23-94	0-2	97.82
55	8	23-180	2-12	93.46
53	8	79-140	2-12	93.00
Sand Size (ES=0.56mm)				
135	23	8-110	0-2	99.39
105	29	8-130	0-4	97.26
55	20	22- 94	2-9	93.03

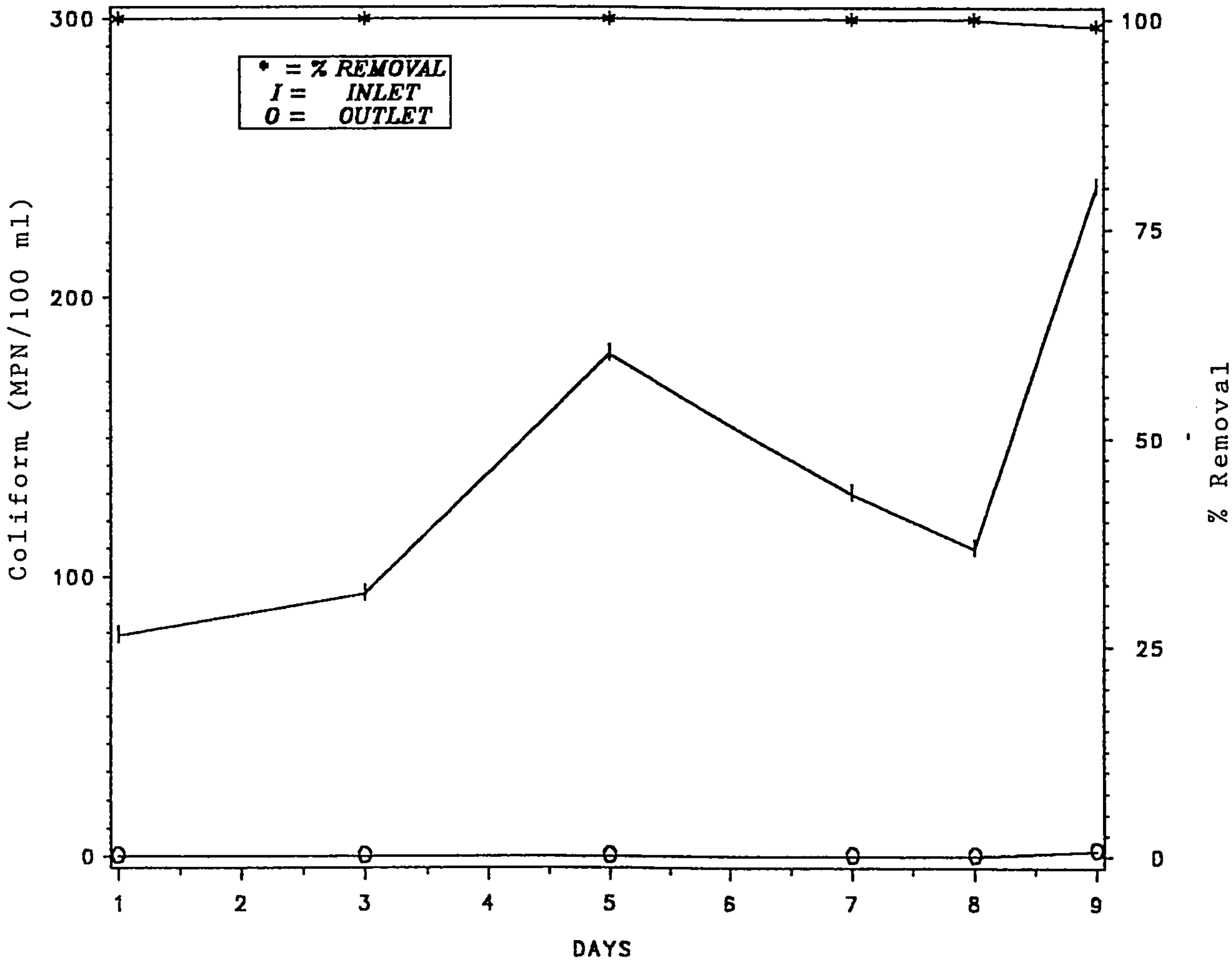

FIGURE 4.39: REMOVAL OF COLIFORM THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.31MM

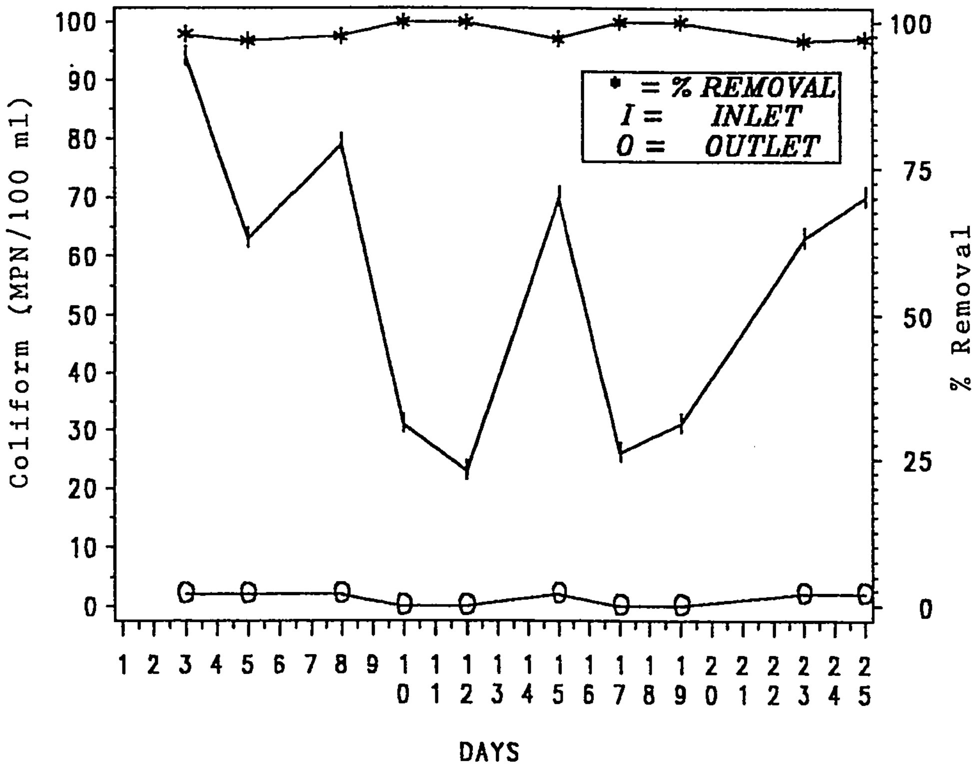

FIGURE 4.40 REMOVAL OF COLIFORM THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.31MM

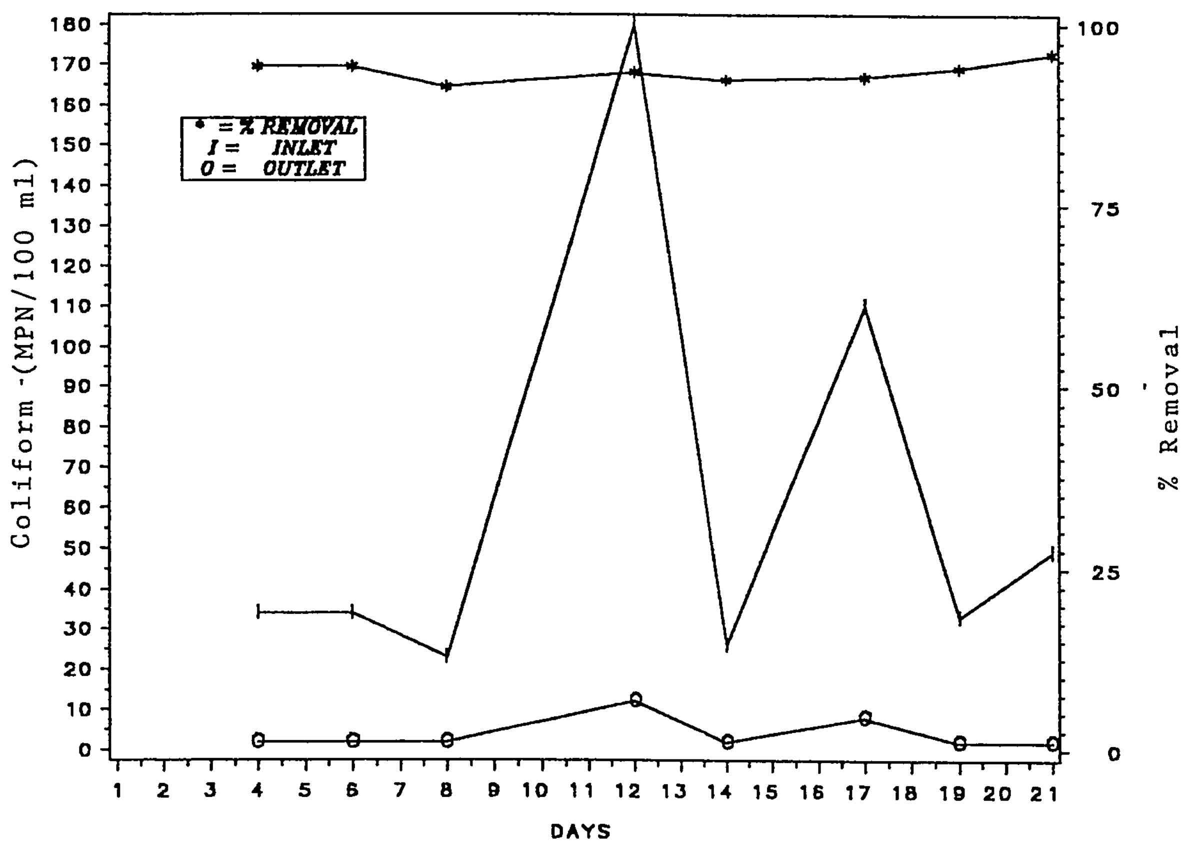

FIGURE 4.41: REMOVAL OF COLIFORM THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.31MM

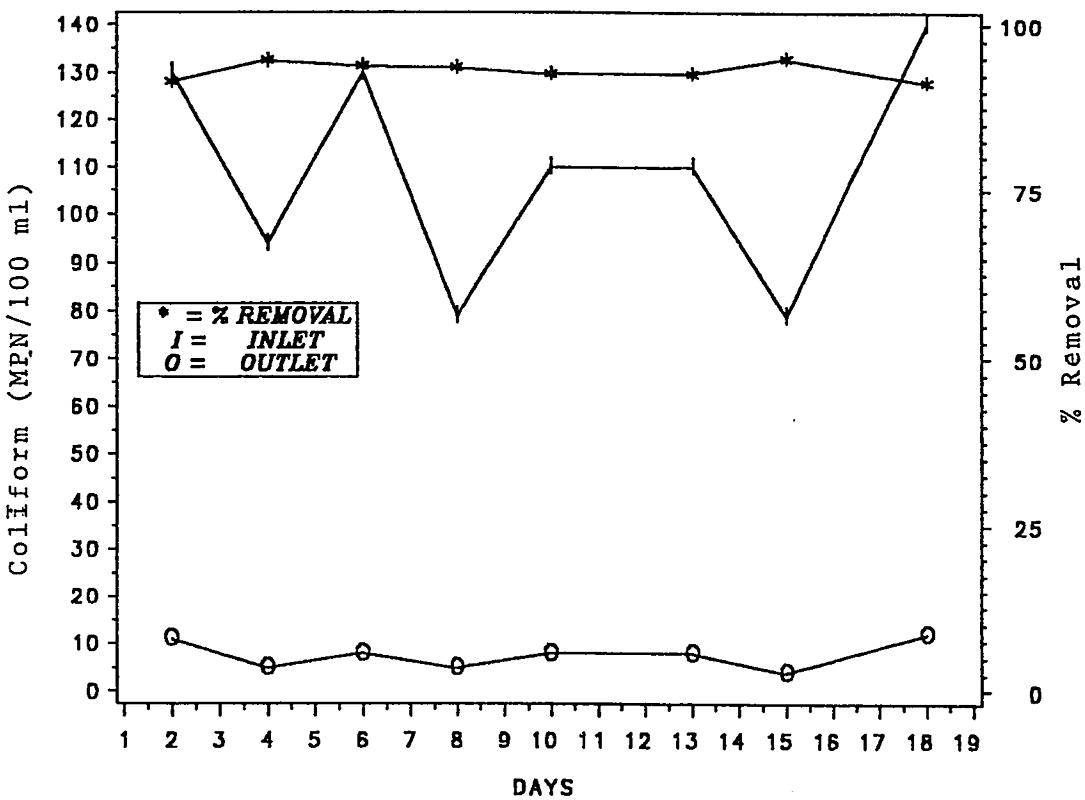

FIGURE 4.42: REMOVAL OF COLIFORM THROUGH SAND BED OF 53CM AND EFFECTIVE SIZE OF 0.31MM

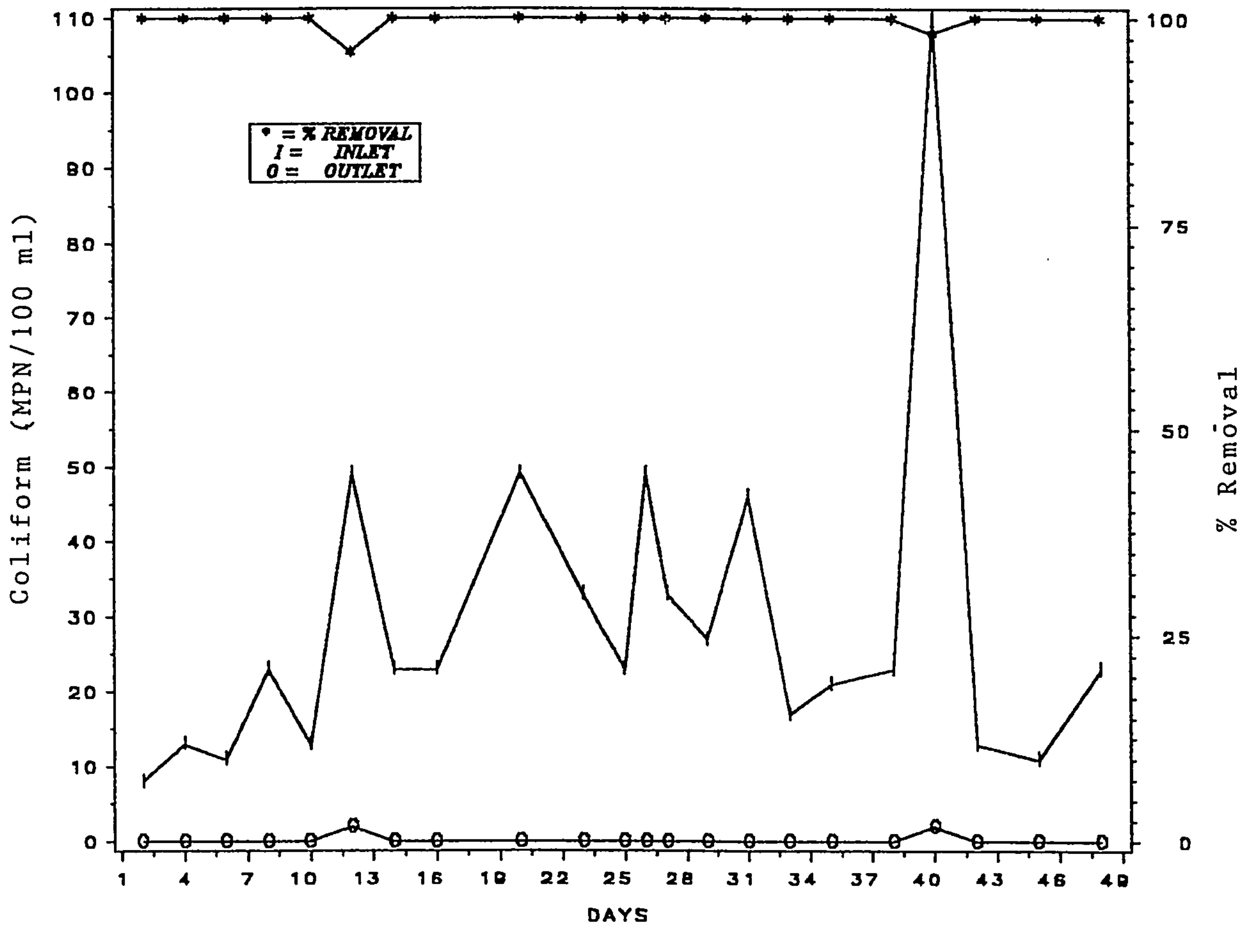

FIGURE 4.43 : REMOVAL OF COLIFORM THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

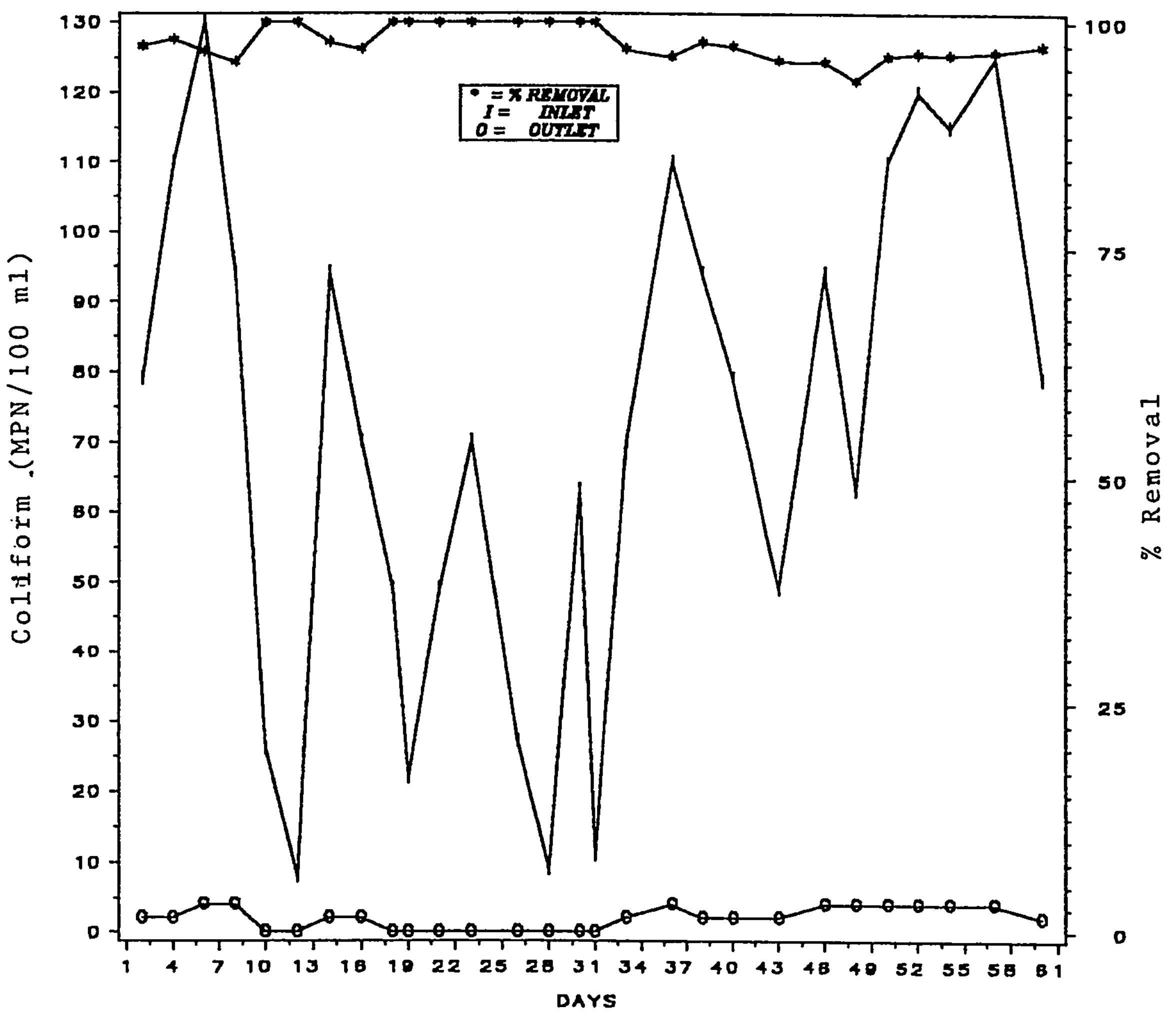

FIGURE 4.44 : REMOVAL OF COLIFORM THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.56MM

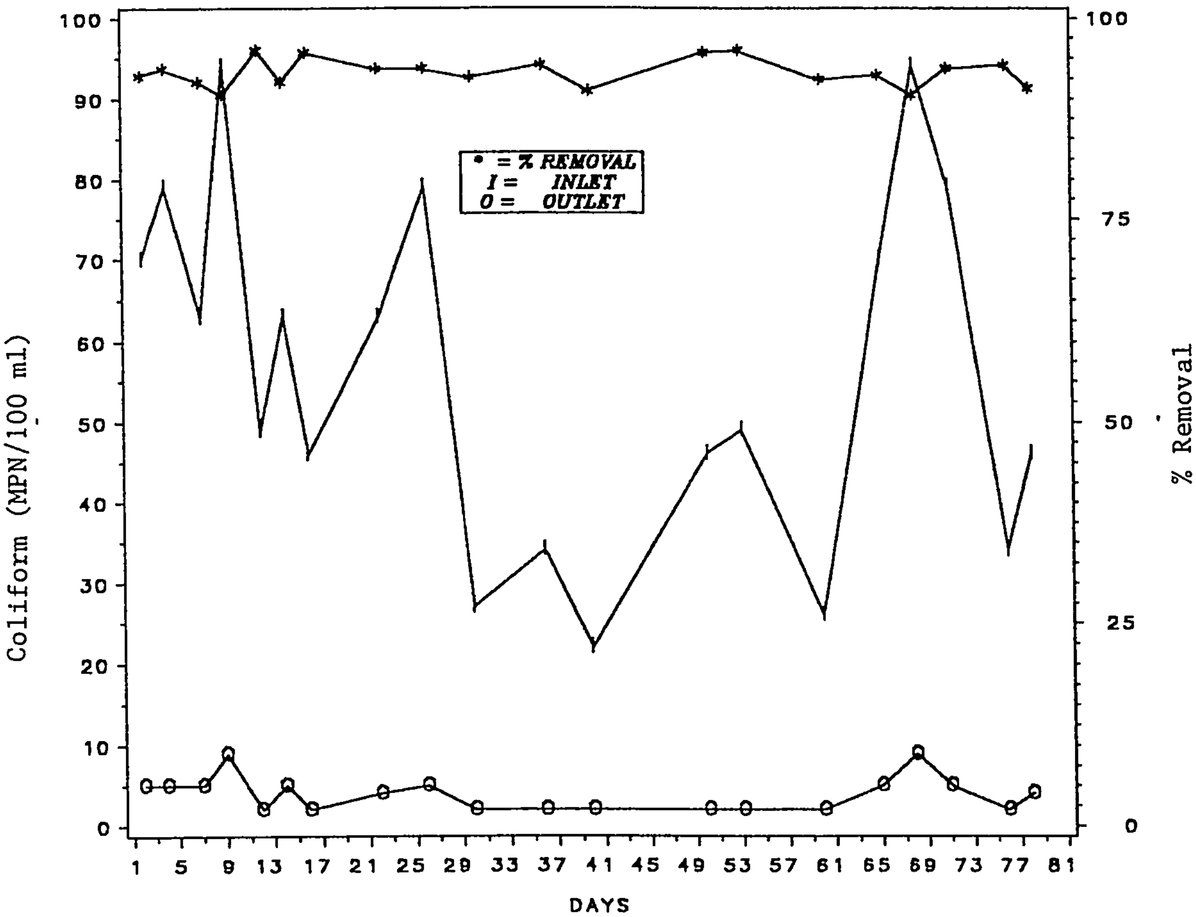

FIGURE 4.45:REMOVAL OF COLIFORM THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.56MM

bacteria is 97%, using effluent from a percolating filter plant and sand size of ES = 0.30 mm. This also agrees with the findings of Bellamy ***et al.*** (6). They have reported that the average percent removal is 97% using sand size of ES = 0.29 mm and sand depth of 97 cm. Furthermore, the percent removal (98%) in the present study is superior to the value of 90% reported by Al-Sawaf (45) using direct filtration.

The results of other sand depths and sizes with respect to the removal of coliforms are given in Figures 4.41 to 4.45 . The maximum removal varies from 93 to 98 to 99.8% at sand depths of 55, 105 and 135 cm, respectively for sand effective size of 0.31 mm. Similarly, for the sand size of 0.56 mm, the percent removal varies from 93 to 97 to 99.4% at sand depths of 55 , 105 and 135 cm respectively. The removal data at bed depth of 55 cm for fine sand is similar to that of 48 cm as reported by Bellamy ***et al.*** (6). They found 95% removal with sand of ES = 0.29 mm. Similarly, the results of coarser sand agree with the data reported by Ellis (12) i.e., percent removal of 97% for sand of ES = 0.6 mm.

Figure 4.46 shows the average percent removal of total coliform for the fine sand at sand depths of 135, 105 and 55 cm. The average percent removal has decreased from 99.76 to 97.82 to 93.46% by decreasing the sand bed from 135 to 105 to 55 cm, respectively. On the other hand, the average percent removals of total coliform bacteria with the coarse sand at sand depths of 135 , 105 and 55 cm are 99.39 , 97.26 and 93.03% , respectively as shown in Figure 4.47 . Figures 4.48 , 4.49 and 4.50 illustrate the variation of the percent total coliform bacteria removal for different sizes of sand at sand depths of 135 , 105 and 55 cm, respectively. It is clear that both the sands result in similar percent removal of coliform for a given quality of influent.

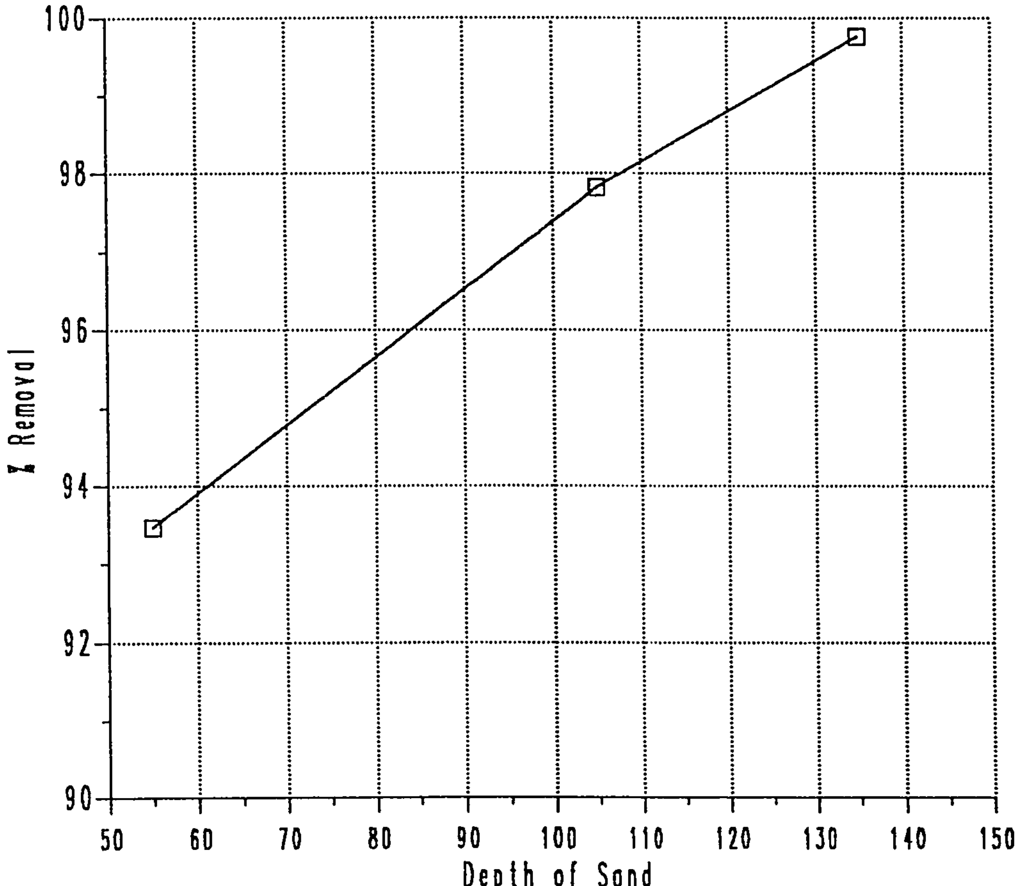

Figure 4.46:Removal of Coliform at Various Sand Depths for Effective Sand Size of 0.31mm

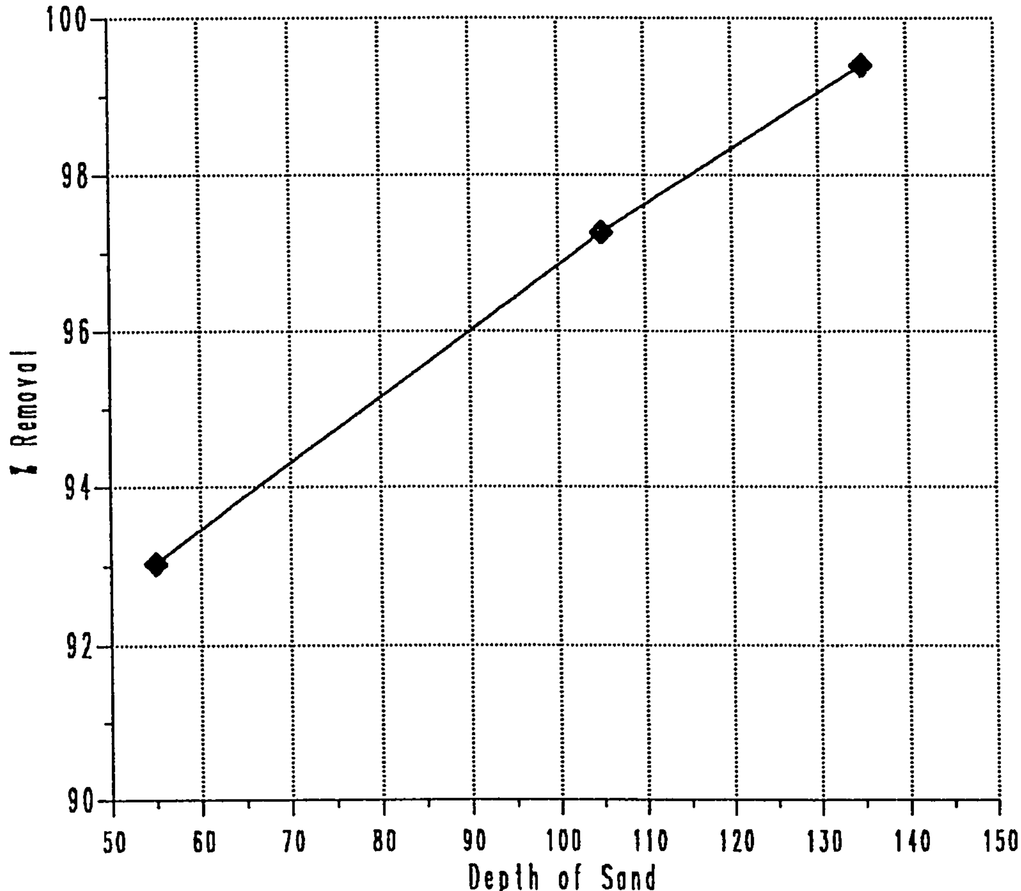

Figure 4.47: Removal of Coliform at Various Sand Depths for Effective Sand Size of 0.56mm

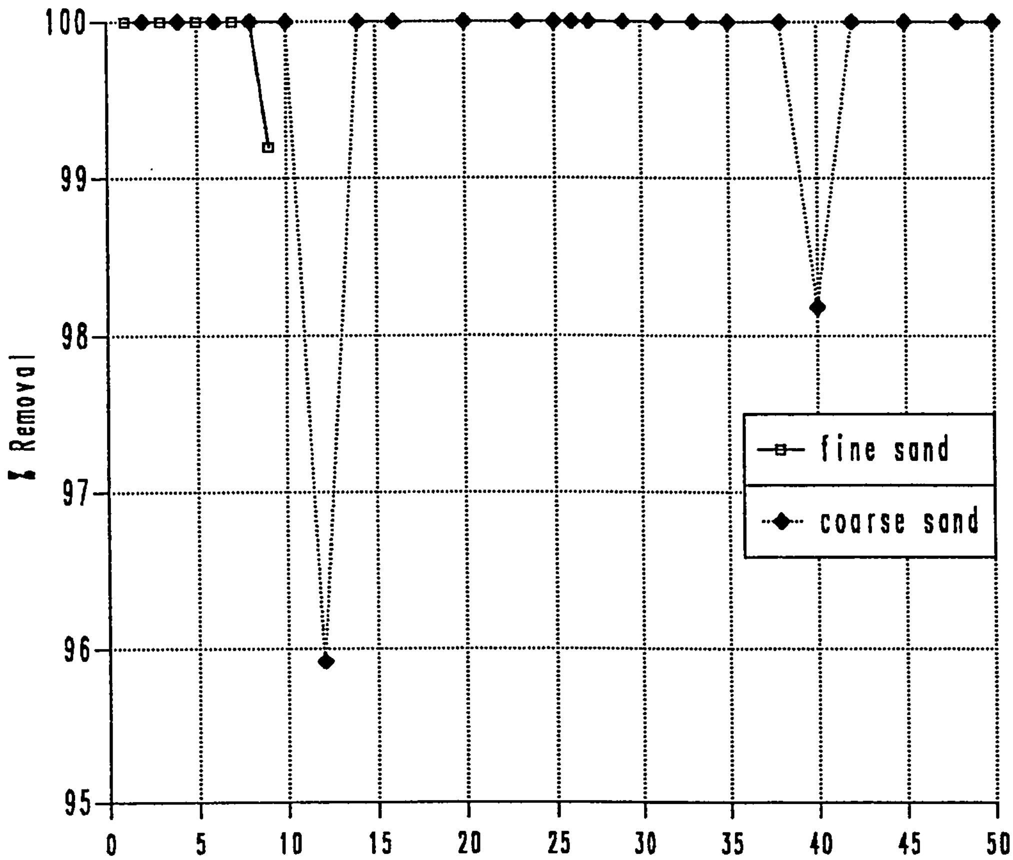

Figure 4.48:Removal of Coliform Through Various Types of Sand at a Sand Depth of 135cm

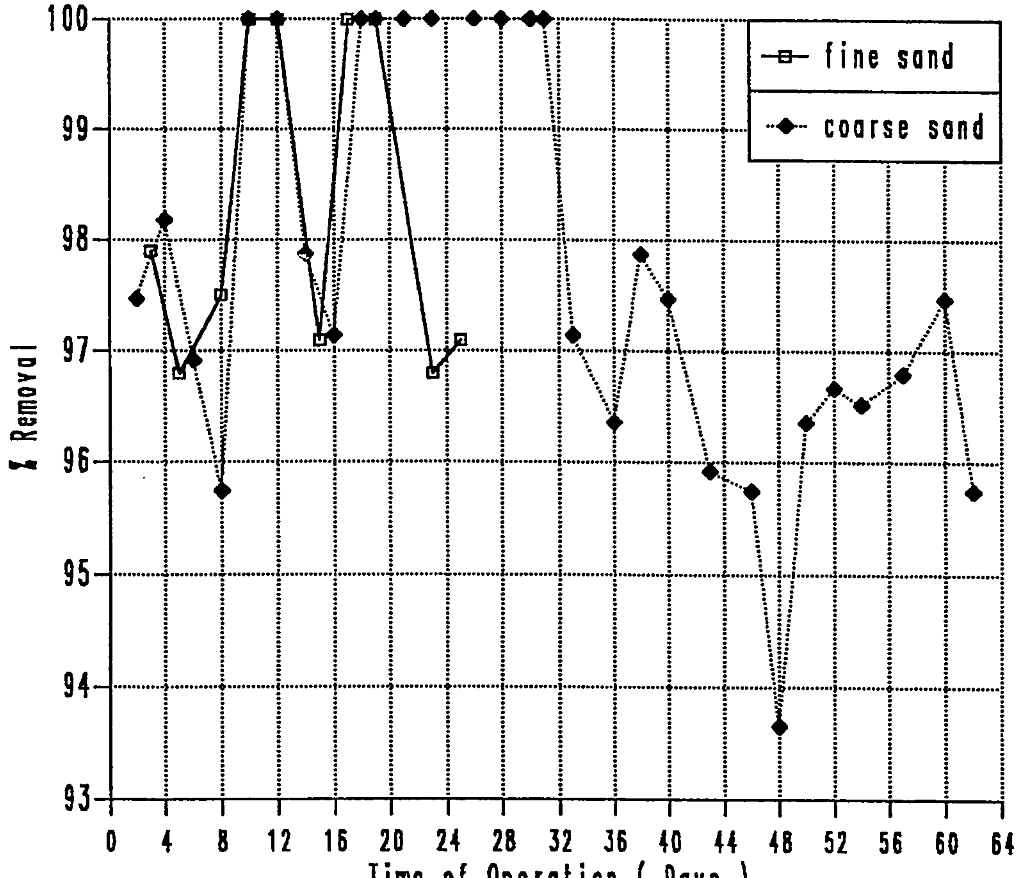

Figure 4.49:Removal of Coliform Through Various Types of Sand at a Sand Depth of 105cm

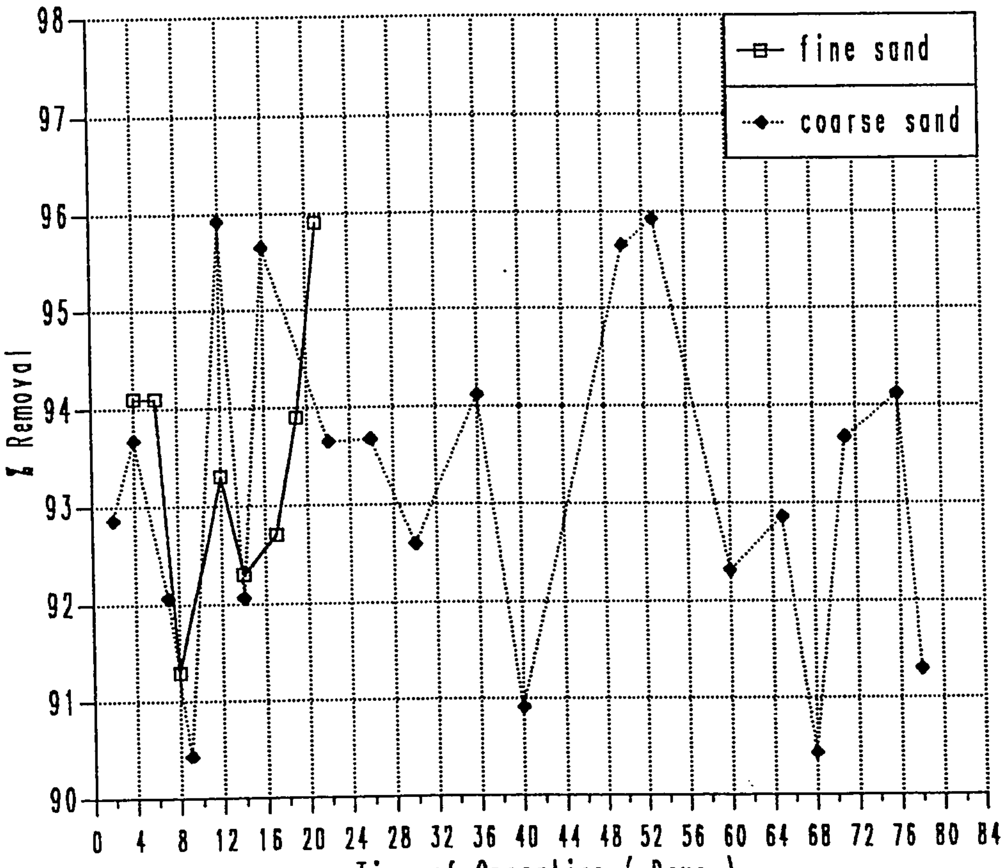

Figure 4.50:Removal of Coliform Through Various Types of Sand at a Sand Depth of 55cm

Figure 4.51 illustrates the trends of the average percent total coliform bacteria removal for the three depths investigated for the fine and the coarse sands. It is found that the percent removal is decreasing by decreasing the depths of the sand and/or by increasing the size of the sand. These results are similar to that of the removal of turbidity. Furthermore, it appears that the effect of the sand size on percent removal is very small for the sizes of the sand investigated.

In general, the percent removal of coliform bacteria has been exceptional to an extent that the effluent would easily qualify for unrestricted irrigation according to the standards employed in the Kingdom (2.2 MPN/100 ml and 23 MPN/100 ml).

4.2.4 Standard Plate Counts

Samples analyzed for the standard plate counts have been collected routinely from the influent and the effluent of the filter. The influent standard plate counts levels throughout the routine runs have ranged from 30 x 10^2 to 295 x 10^2 colonies/ml, whereas, the effluent levels have ranged from 30 x 10 to 260 x 10 colonies/ml. The range of standard plate counts in the influent and the effluent, and the average percent removal are illustrated in Table 4.8. Furthermore, the variation of the influent, the effluent and the percent removal on daily basis during the duration of filter cycle are illustrated in Figures 4.52 to 4.58 . In spite of the wide variation of standard plate counts in the influent, the filter was successfully able to achieve consistent percent removal.

Figure 4.52 shows that the percent removal is much better, i.e., over 90% as compared to preliminary runs, where removal only varied from 19 to 70%. The average percent removal at this run, at a sand depth of 135 cm

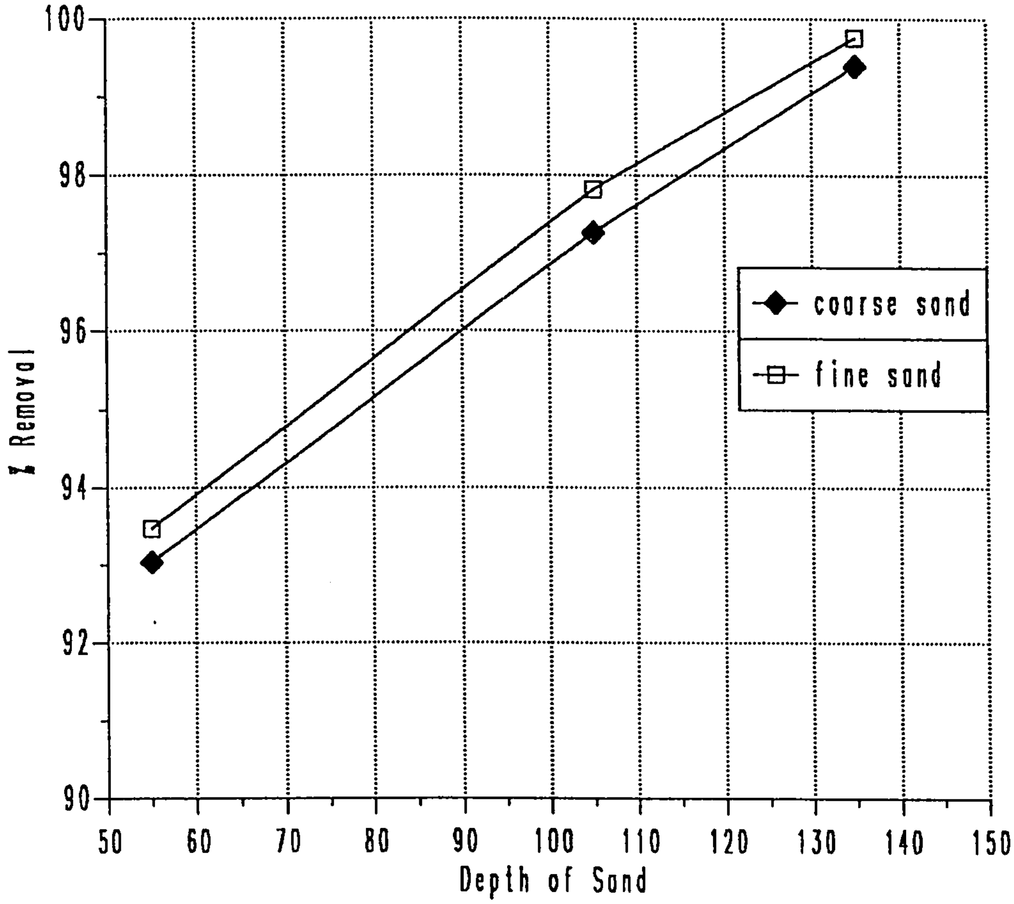

Figure 4.51:Removal of Coliform at Various Sand Depths and Sizes

Table 4.8:AVERAGE REMOVAL OF STANDARD PLATE COUNTS UNDER VARIOUS EXPERIMENTAL CONDTIONS

Sand Depth (cm)	No. of Samples Analyzed	Influent Range Colonies/ml	Effluent Range Colonies/ml	% Removal
Sand Size (ES=0.31mm)				
135	6	$35x10^2$-$295x10^2$	30x10-205x10	92.99
105	10	$50x10^2$-$290x10^2$	45x10-260x10	90.94
55	8	$45x10^2$-$205x10^2$	55x10-230x10	88.07
53	8	$90x10^2$-$180x10^2$	115x10-230x10	87.50
Sand Size (ES=0.56mm)				
135	23	$35x10^2$-$225x10^2$	30x10-160x10	92.13
105	29	$30x10^2$-$240x10^2$	30x10-255x10	89.87
55	20	$30x10^2$- $95x10^2$	40x10-120x10	87.46

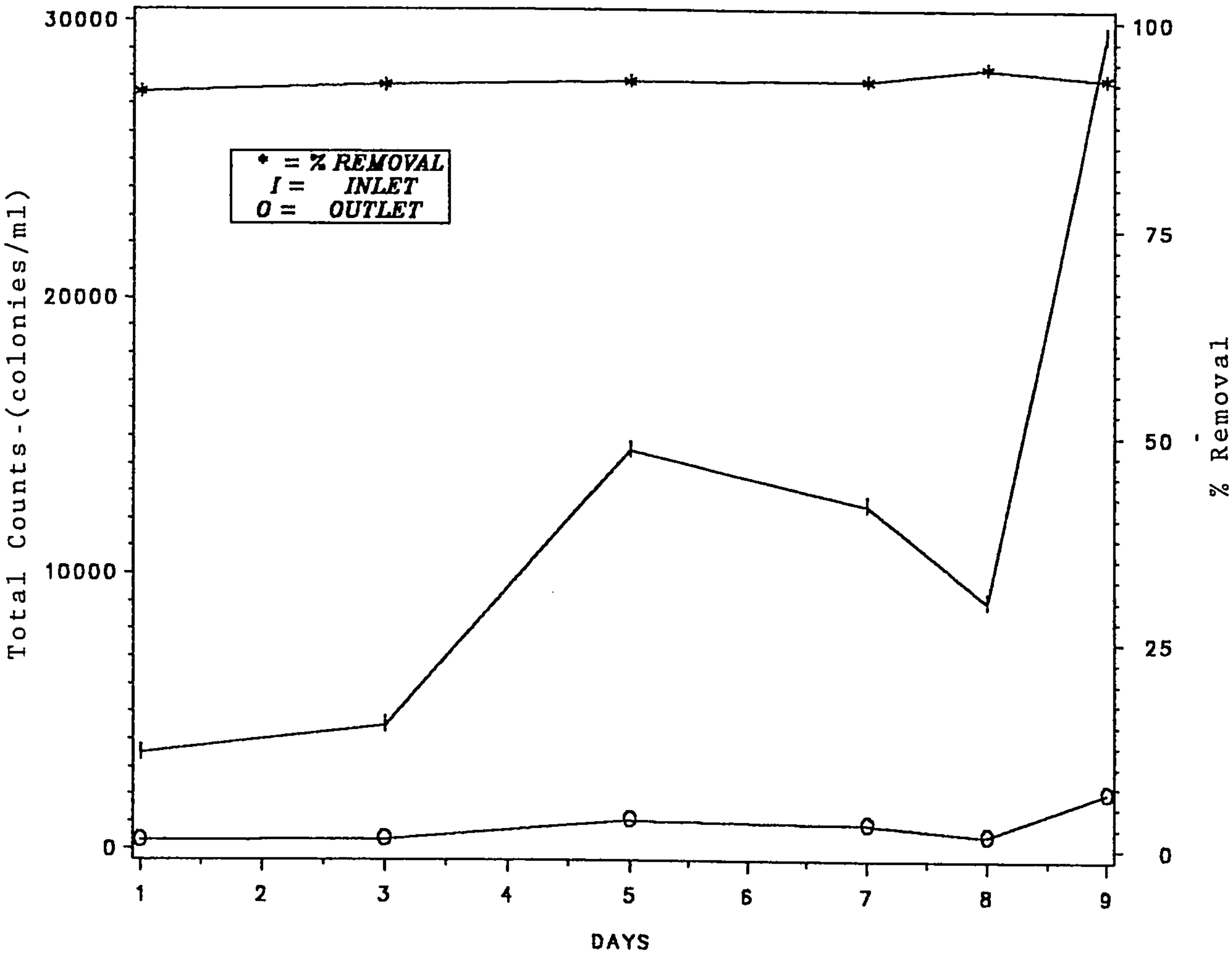

FIGURE4.52:REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.31MM

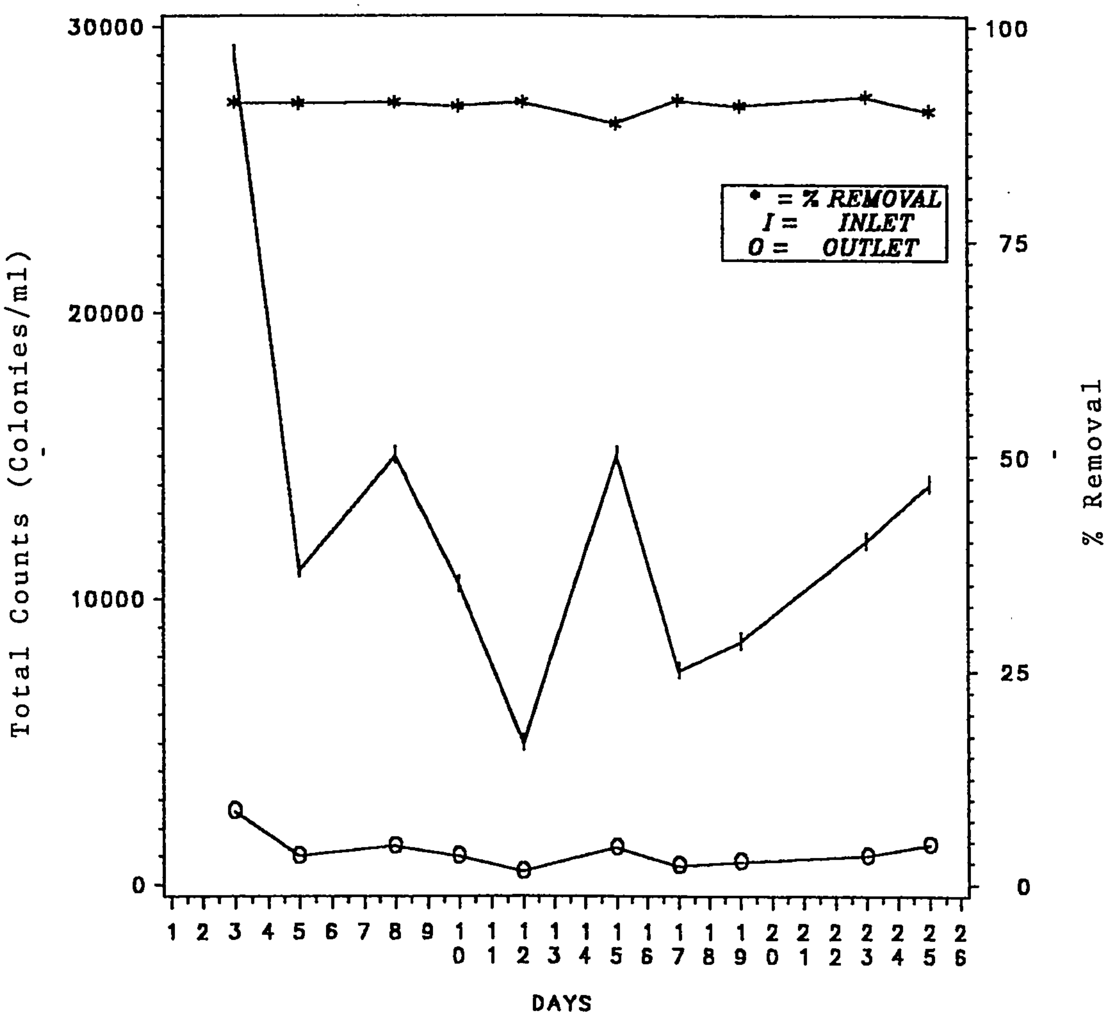

FIGURE 4.53: REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.31MM

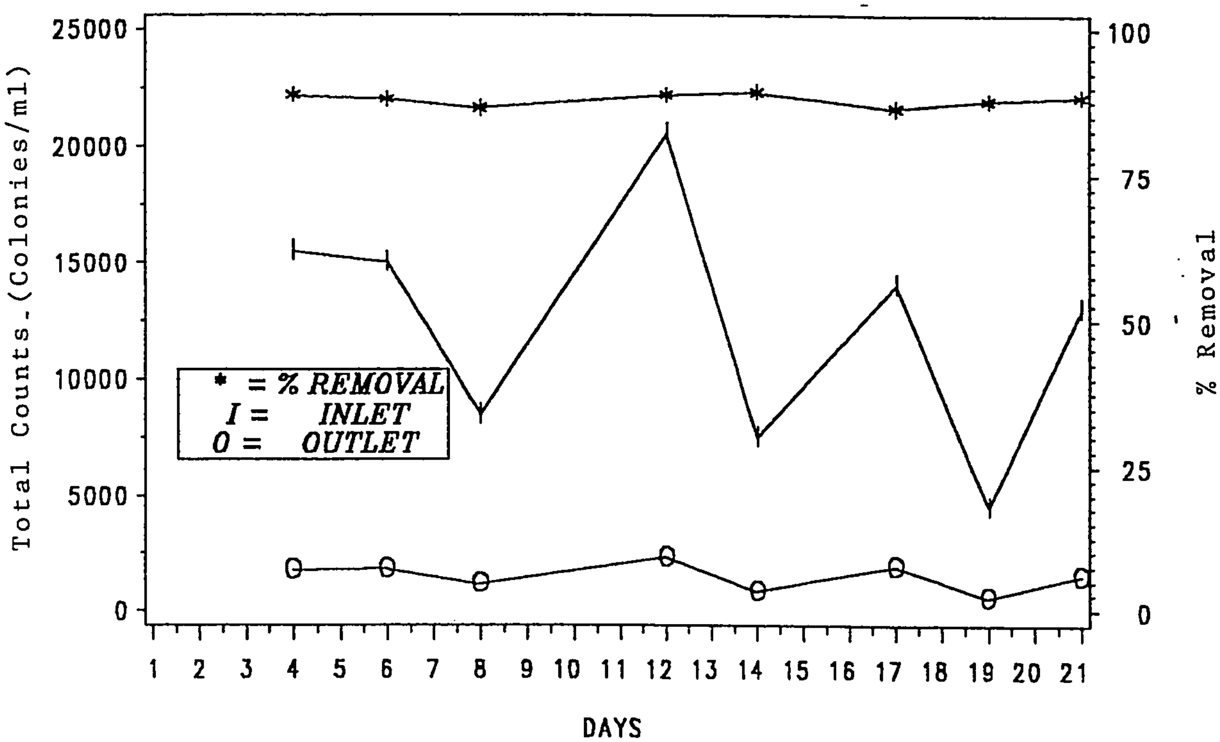

FIGURE 4.54 REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.31MM

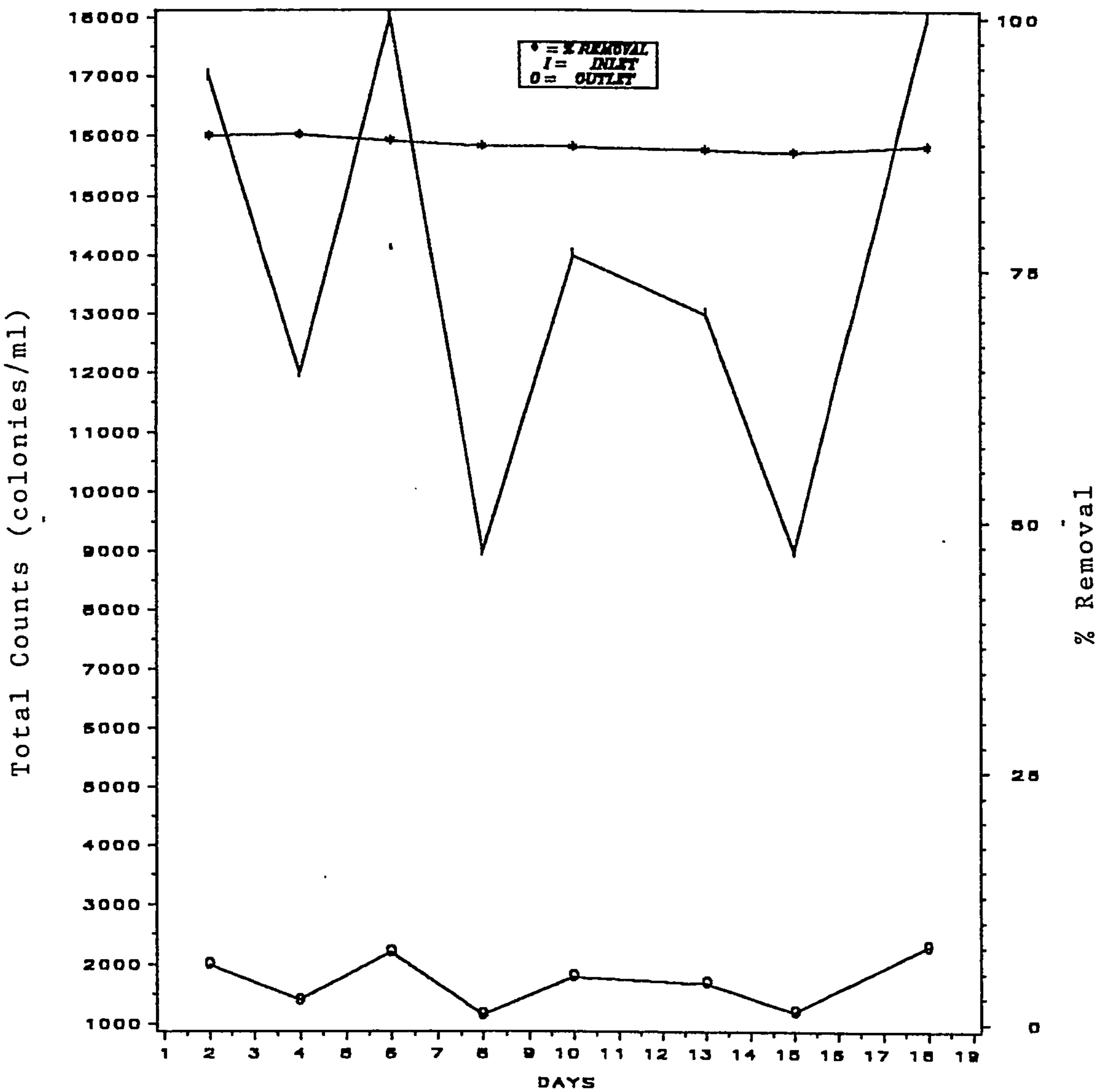

FIGURE 4.55: REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 53CM AND EFFECTIVE SIZE OF 0.31MM

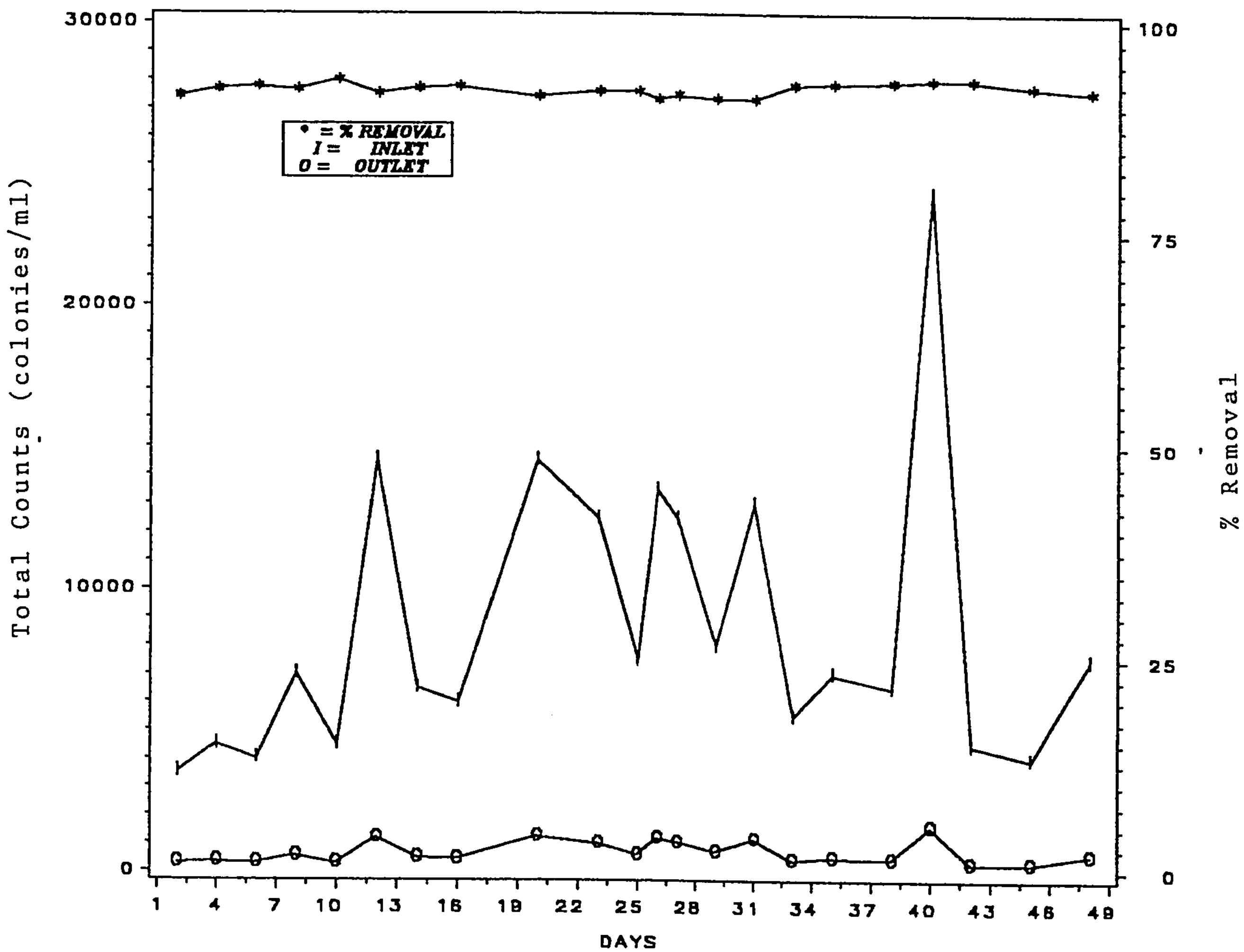

FIGURE 4.56 : REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

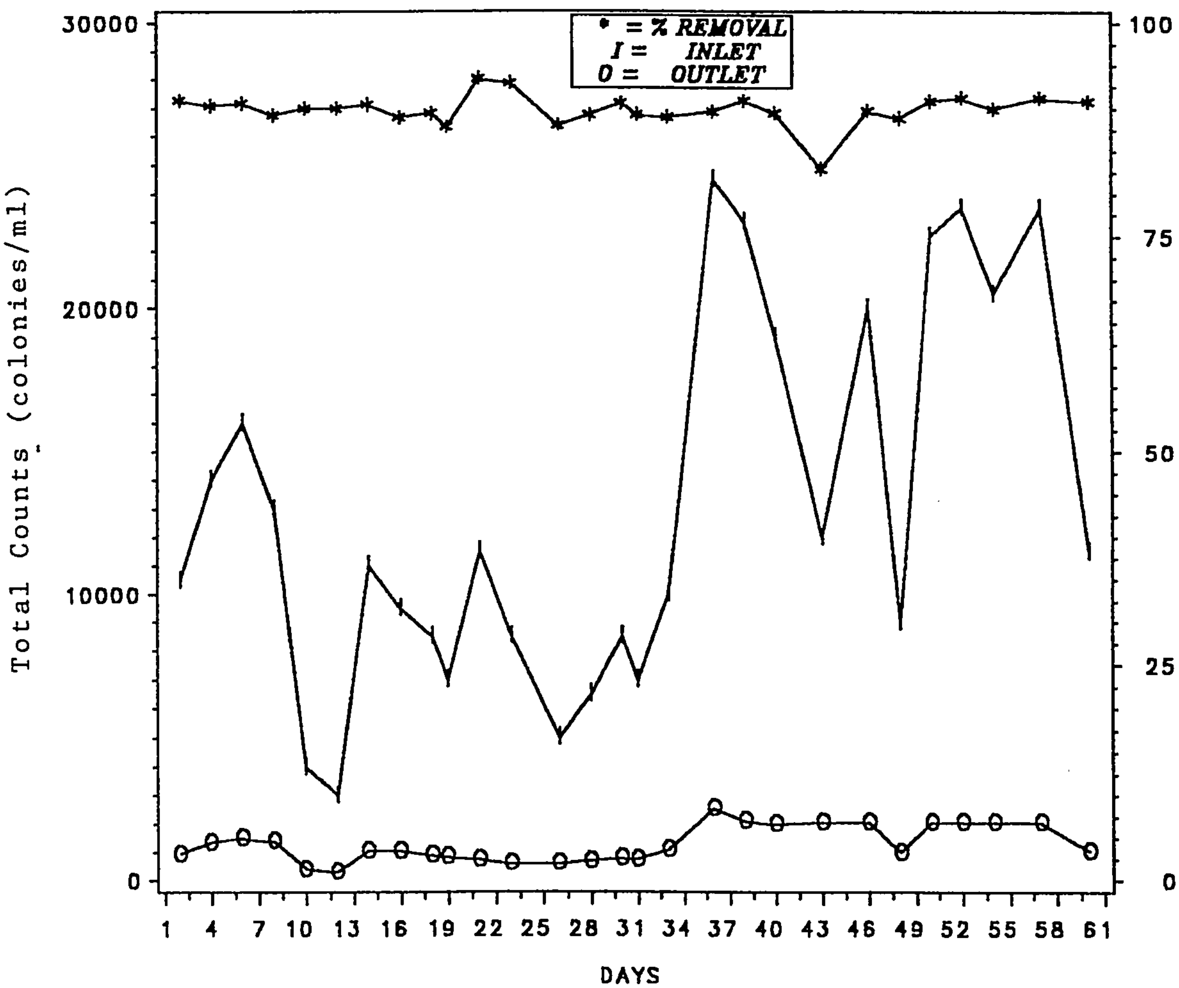

FIGURE 4.57:REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.56MM

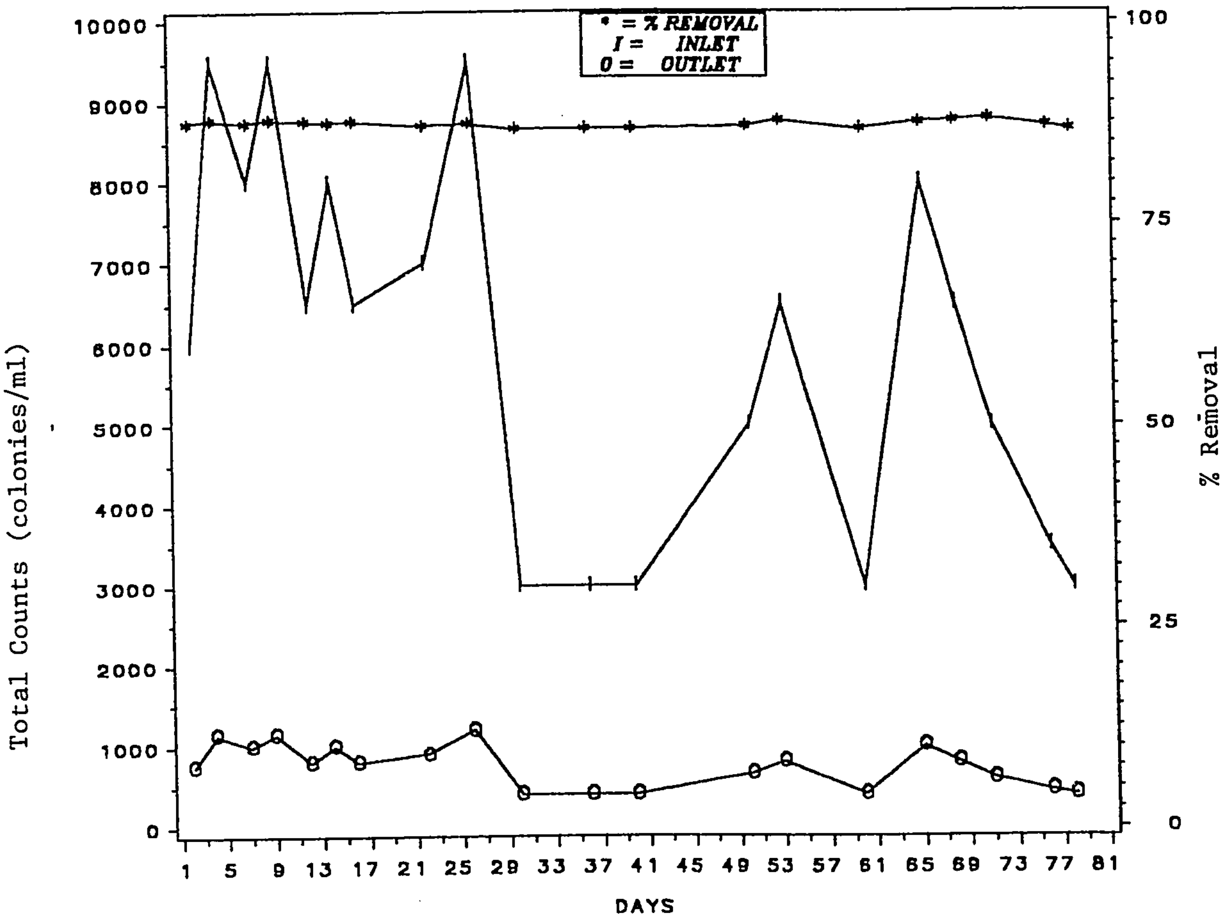

FIGURE 4.58:REMOVAL OF TOTAL COUNTS THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.56MM

using sand size of ES = 0.31 mm is 92.99%. Figure 4.53 illustrates the percent removal of standard plate counts at depth of 105 cm. The average percent removal is 90.94%. This agrees with the value reported by Bellamy ***et al.*** (5), who used sand with ES = 0.28 mm and depth of 96 cm for treating potable water. They have reported that the removal of standard plate counts ranged from 88 to 91%. On the other hand, it is slightly inferior compared to what is reported by Bellamy *et al.* (6), in a follow up study, using similar sand (ES = 0.28 mm). They reported the percent removal of 99.9%.

The results of other depths and sizes with respect to the removal of standard plate counts are given in Figures 4.54 to 4.58 . The maximum removal vary from 88 to 91 to 93 percent at sand depths of 55, 105 and 135 cm, respectively, for the sand effective size of 0.31 mm. Similarly, the percent removal for the sand effective size of 0.56 mm vary from 87.5 to 89.9 to 92.1 percent at sand depths of 55 to 105 to 135 cm respectively.

Figure 4.59 illustrates the average percent removal of standard plate counts for the fine sand at sand depths of 135, 105 and 55 cm. The average percent removal has decreased from 92.99 to 90.94, to 88.07% by decreasing the sand bed from 135, 105 and 55 cm, respectively. On the other hand, the average percent removals of standard plate counts with the coarse sand at sand depths of 135 , 105 and 55 cm are 92.13 , 89.87 and 87.46%, respectively, as illustrated in Figure 4.60 .

Figures 4.61 , 4.62 and 4.63 illustrate the variation of the percent standard plate counts removal for different sizes of sand at sand depths of 135 , 105 cm and 55 cm , respectively. There appears to be no significant difference in the removal of total counts for the two sizes of the sand studied.

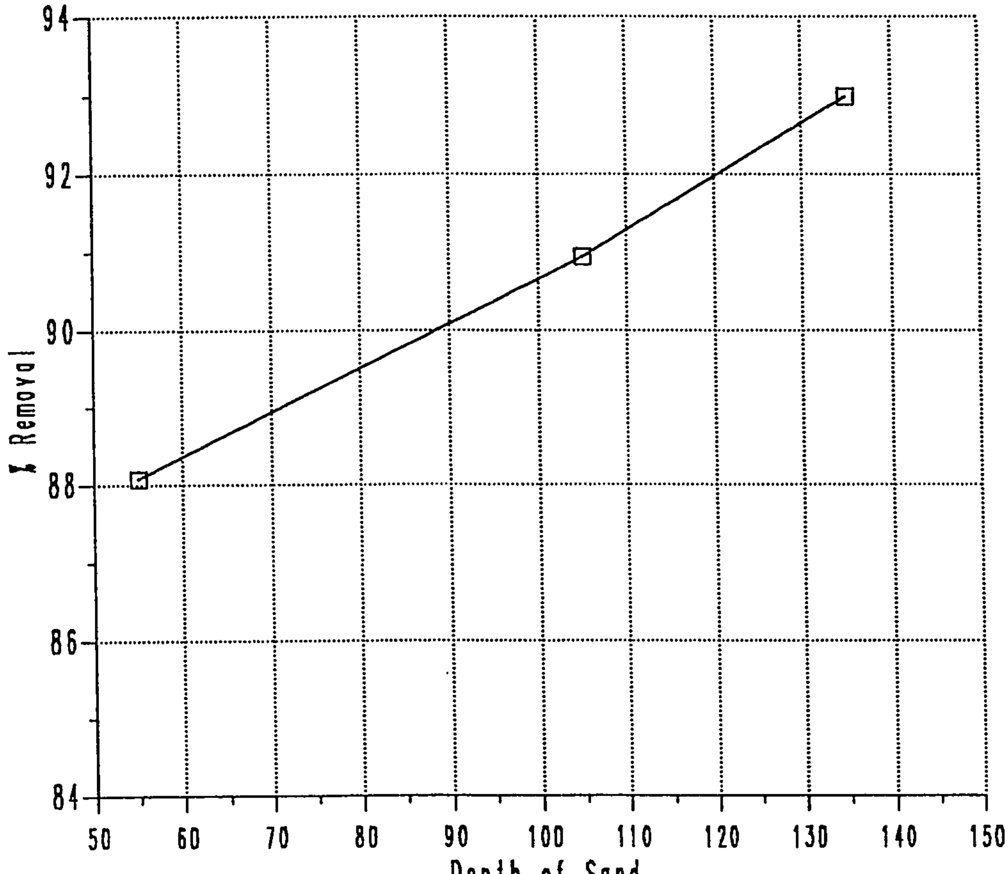

Figure 4.59:Removal of Total Counts at Various Sand Depths for Effective Sand Size of 0.31mm

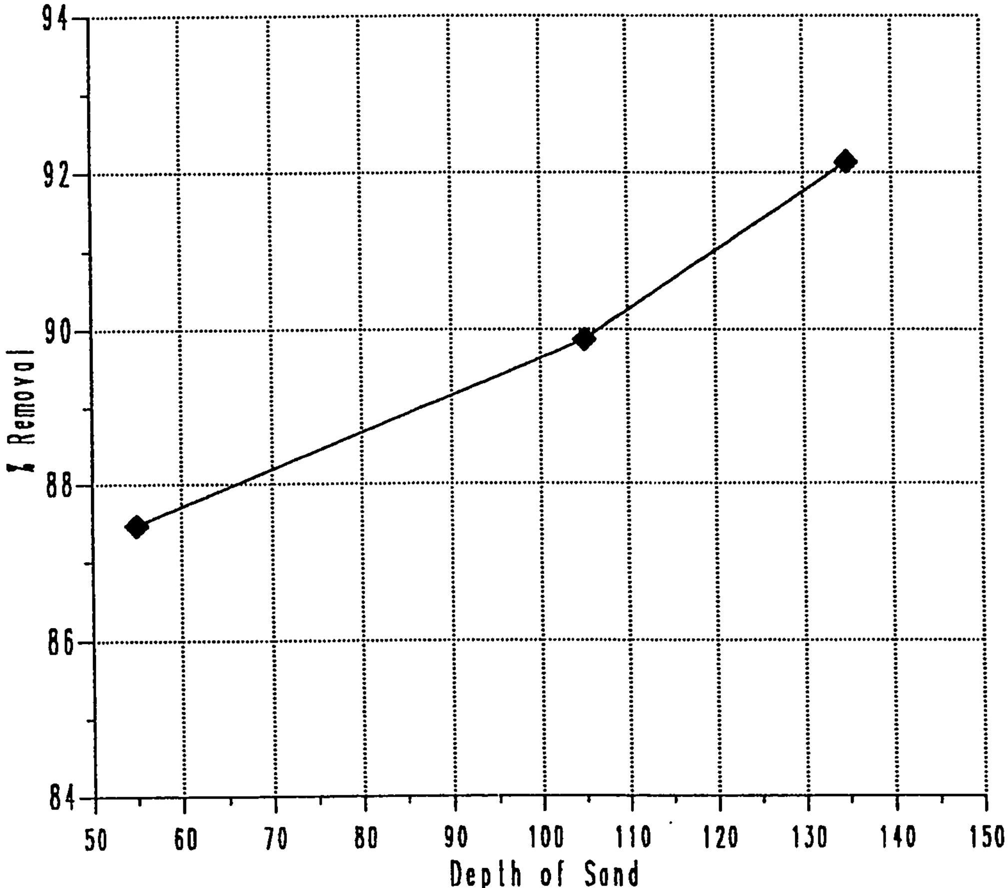

Figure 4.60:Removal of Total Counts at Various Sand Depths for Effective Sand Size of 0.56mm

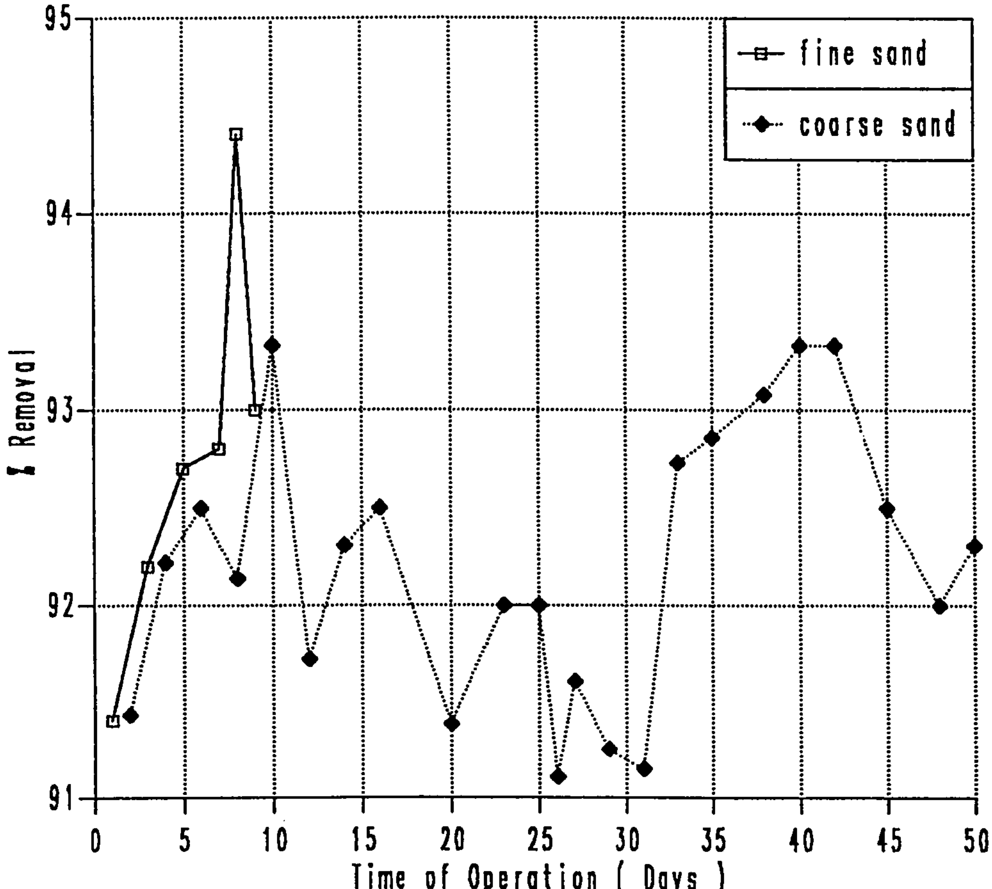

Figure 4.61:Removal of Total Counts Through Various Types of Sand at a Sand Depth of 135cm

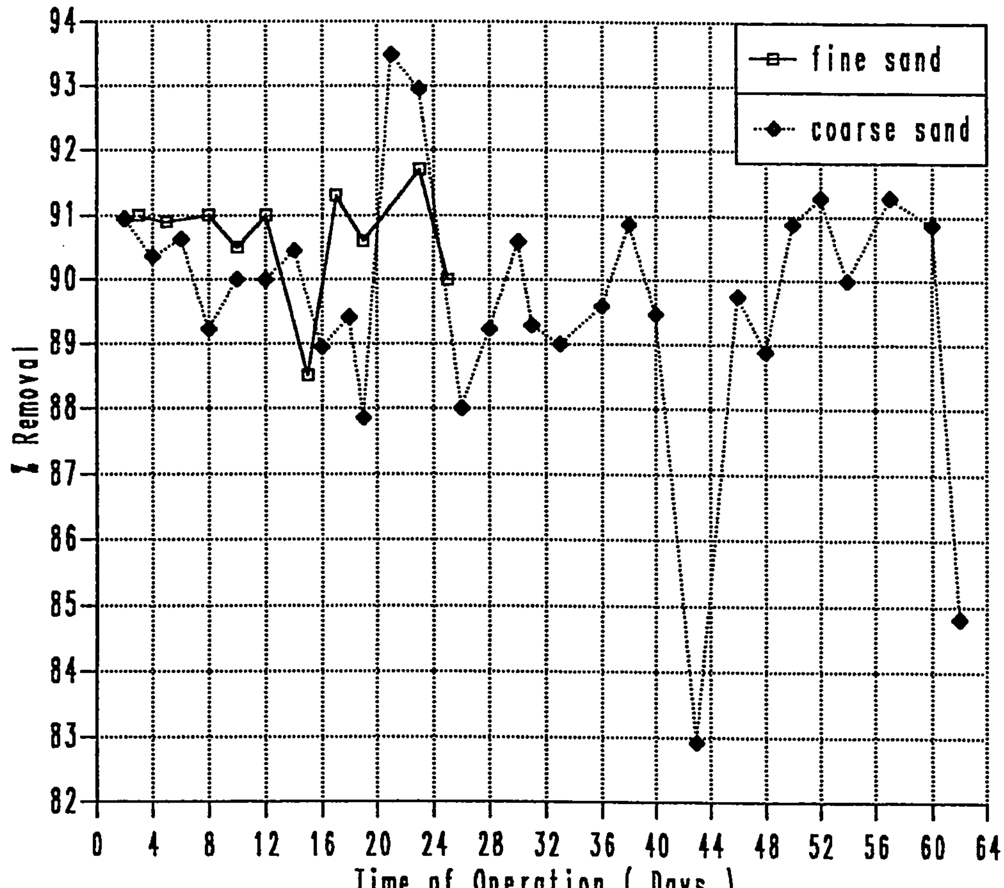

Figure 4.62:Removal of Total Counts Through Various Types of Sand at a Sand Dpth of 105cm

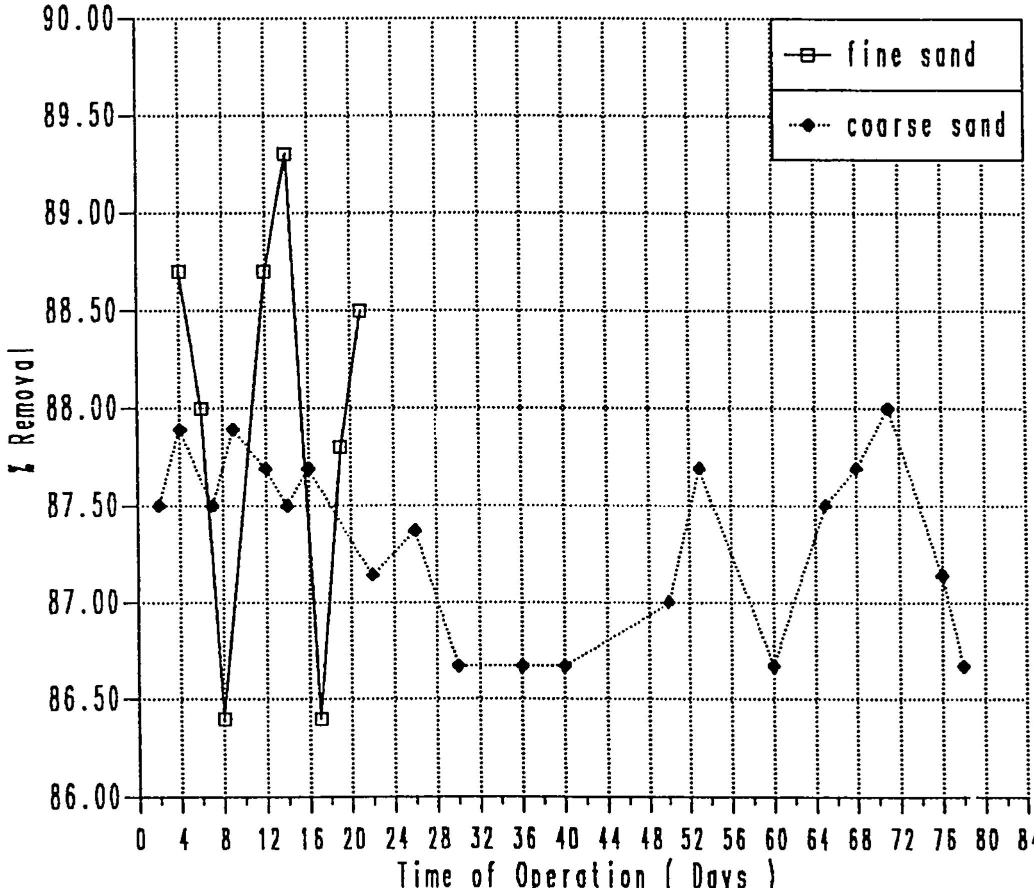

Figure 4.63: Removal of Total Counts Through Various Types of Sand at a Sand Depth of 55cm

Figure 4.64 illustrates the trends of the average percent removal of standard plate counts for the three depths investigated for the fine and the coarse sands. It is found that the percent removal is decreasing by decreasing the depth of the sand and/or by increasing the size of the sand. However, there is a small decrease in the removal of total counts for coarse sand as compared to the fine sand for the respective depth of the filter beds.

4.2.5 Organic Matter

(a) BOD

The analysis for BOD has been conducted routinely throughout the routine runs when the coarse sand has been investigated. The data are not available for finer sand. The influent levels have ranged from 1.6 to 4.9 mg/l, whereas the effluent levels have ranged from 0.2 to 0.9 mg/l. The variation of the influent, the effluent and the percent removal are illustrated in Figures 4.65 , 4.66 and 4.67.

Figure 4.65 illustrates the percent removal at sand depth of 135 cm. The removal efficiency in this run is much higher i.e., 88.8% as compared to the preliminary run, where the removal was 77.8%. Figures 4.66 and 4.67 illustrate the percent removal at sand depth of 105 and 55 cm , respectively . The average percent removal is 84.7 and 82.6% , respectively . These values are superior to that reported by Ellis (12) of 76% for sand size of ES = 0.60 mm and sand depth of 95 cm. But it is almost comparable to the value of 86% reported by Al-Adham (1). Ellis (12) has discussed in his study that the purification achieved has not been purely the result of a straining action at the surface of the filter. The higher ratios of BOD removal to suspended solids removal obtained in his study from the operations of a slow sand filter to those

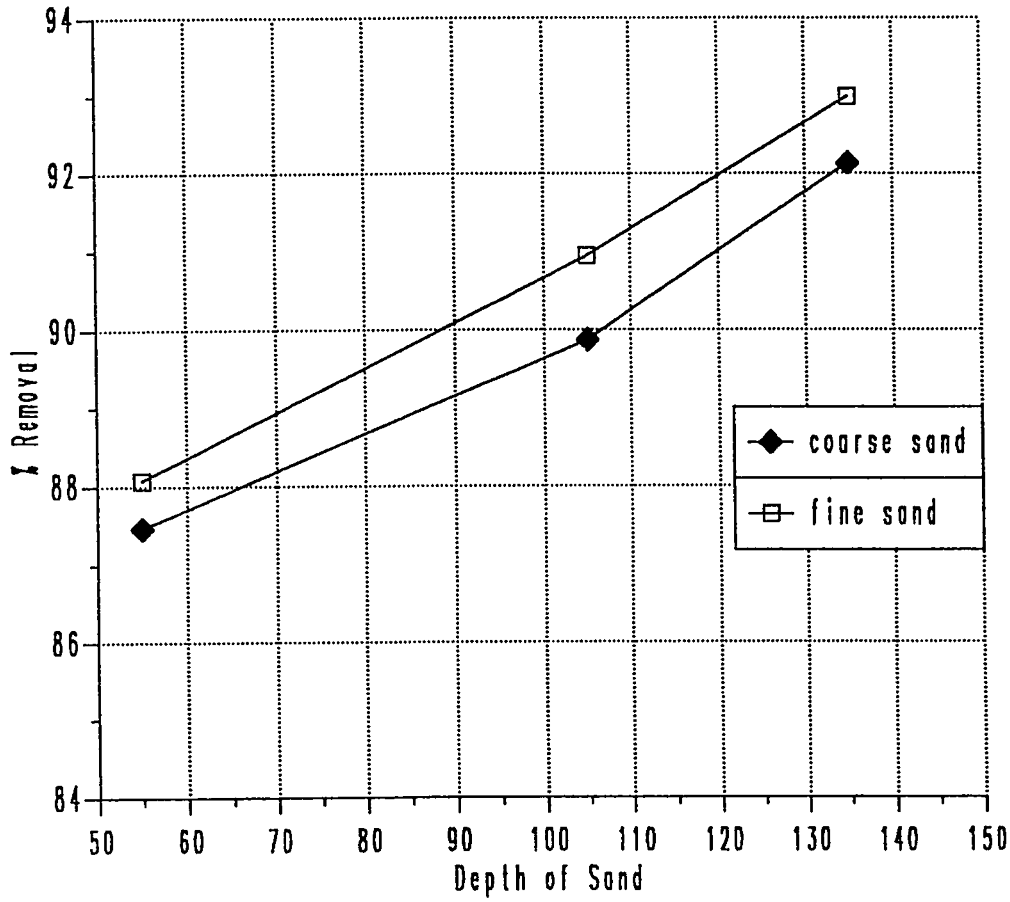

Figure 4.64:Removal of Total Counts at Various Sand Depths and Sizes

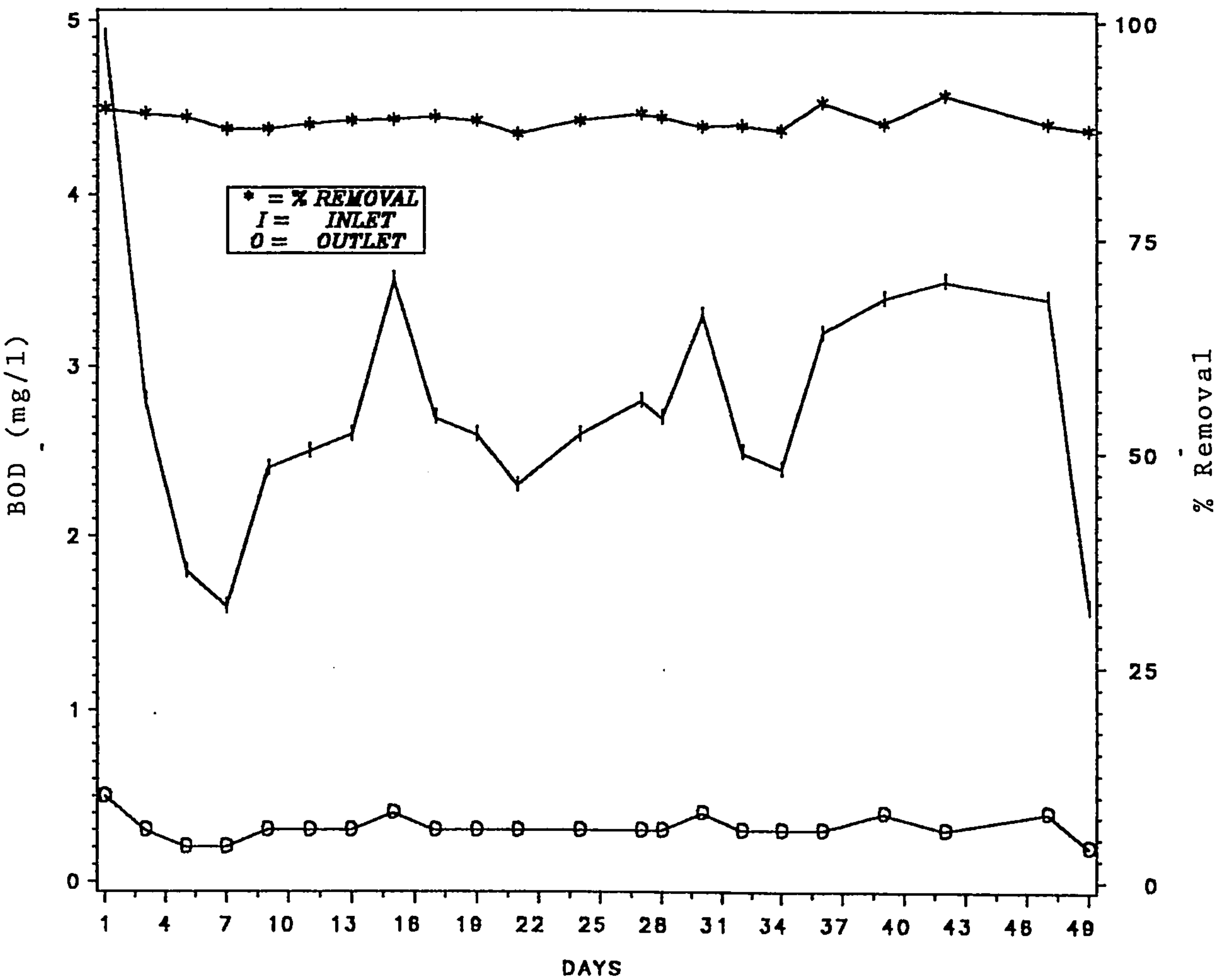

FIGURE 4.65: REMOVAL OF BOD THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

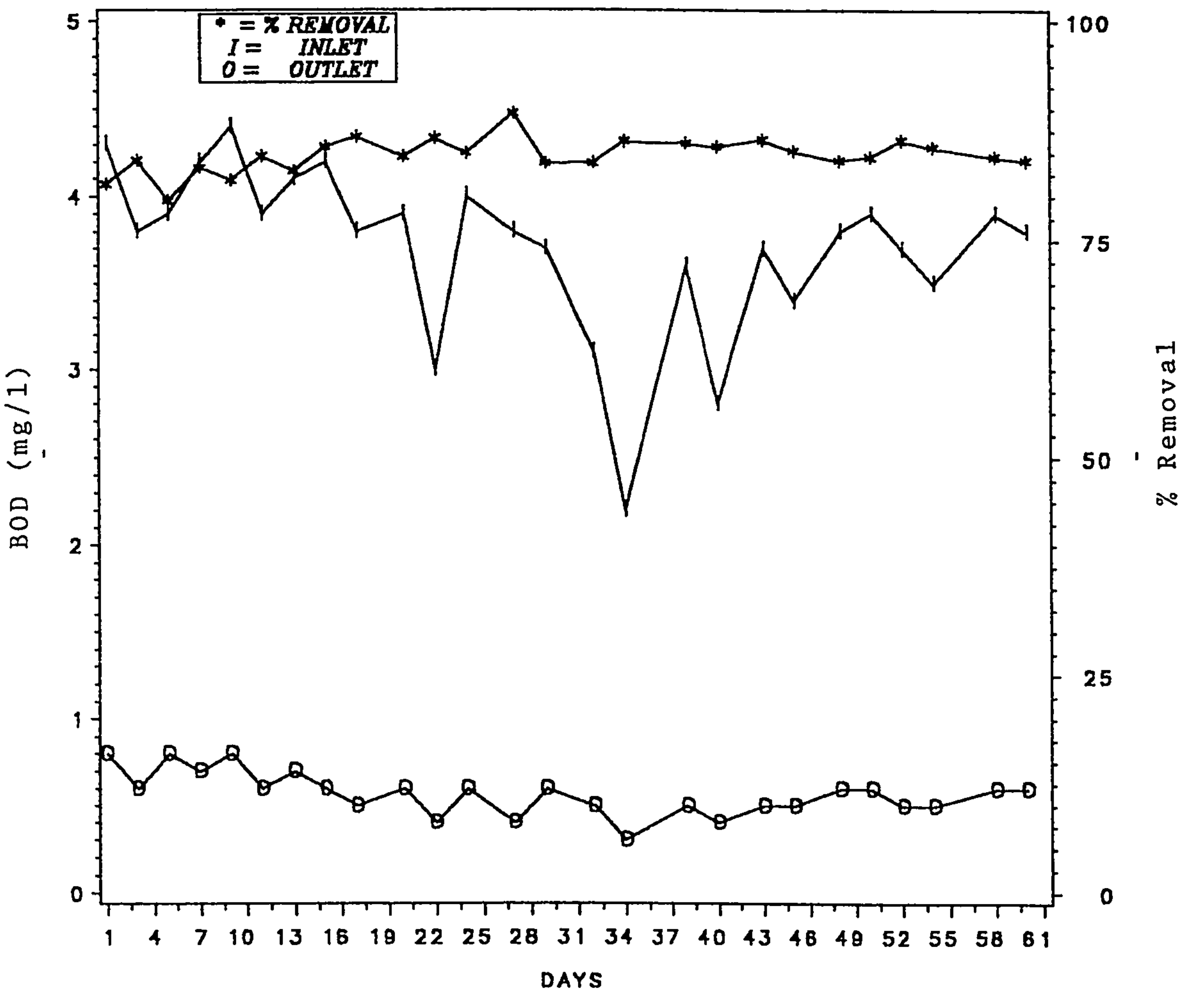

FIGURE 4.66: REMOVAL OF BOD THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.56MM

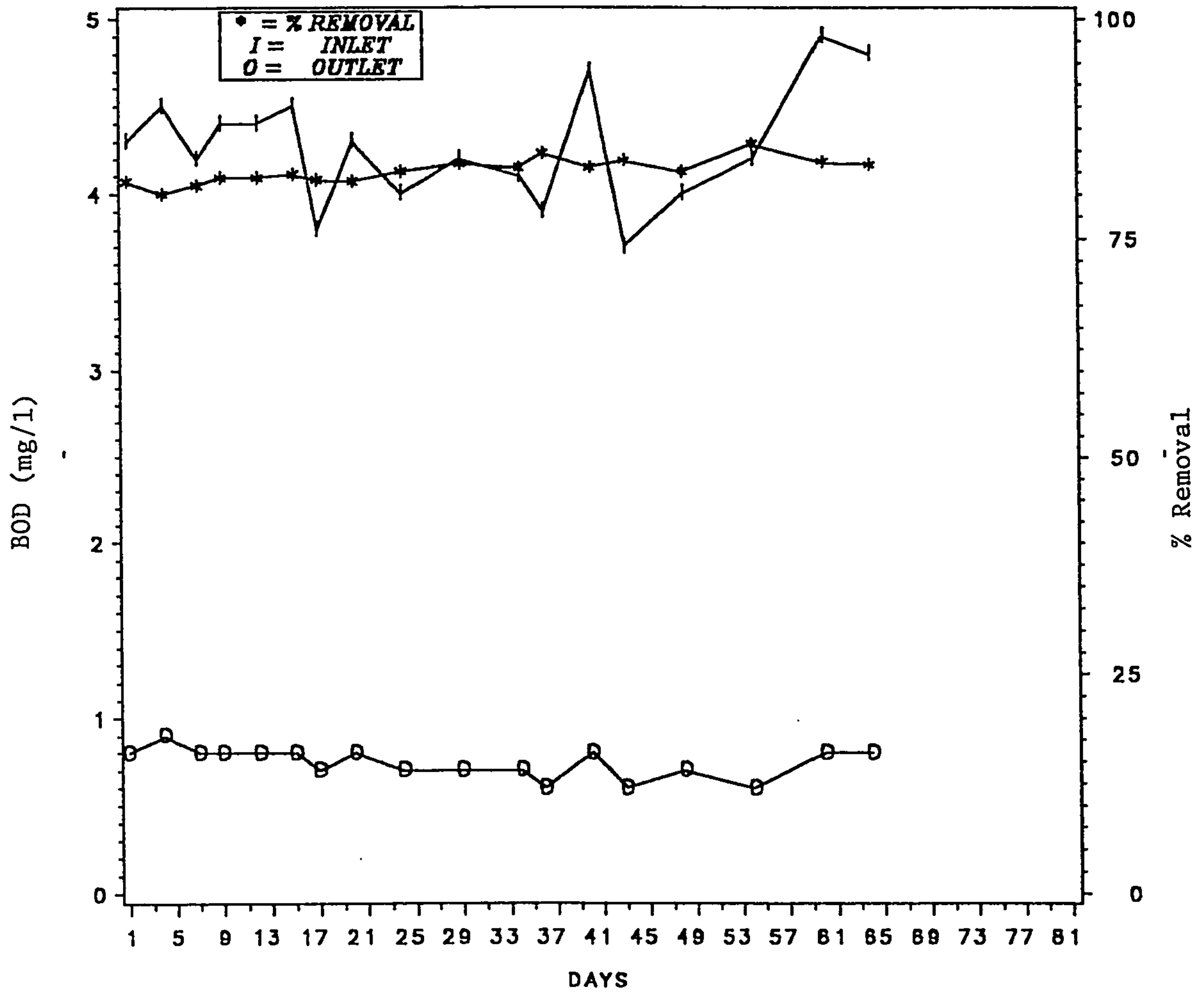

FIGURE 4.67:REMOVAL OF BOD THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.56MM

obtained from the operations of microstrainers must have been the result of appreciable biological activity within the sand bed.

(*b*) *COD*

The analysis for COD has been conducted routinely throughout the study for fine and coarse sands. COD levels in the influent throughout the routine runs have ranged from 23 to 120 mg/l, whereas, the effluent levels have ranged from 9 to 49.7 mg/l. The high concentration of COD in the influent, i.e., 120 mg/l is primarily due to the presence of high concentration of algae. The variation of the influent, the effluent, and percent removal are illustrated in Figures 4.68 to 4.71. The average percent removal at sand size with ES = 0.31 mm and sand depth of 135 cm is 66.6%. Figure 4.68 illustrates the percent removal at sand depth of 105 cm. The average percent removal is 57.7%. This is comparable to the value reported by Ellis (12) as 54%. But this is superior to the range reported by Al-Adham (1) (35.4 to 37.8%). This value is slightly inferior to the value reported by Paramasivam *et al.* (38), treating raw water having COD ranged from 4.5 to 10.5 mg/l. They have reported that the percent removal of COD uses 67.1% with sand size of ES = 0.21 mm and hydraulic loading of 0.10 m/hr.

Figure 4.69 illustrates the variation of the percent removal at sand depth of 135 cm using sand size with ES = 0.56 mm. The average percent removal is 48.2%. This value is much higher than that obtained in the preliminary run (29.8%). Figure 4.70 illustrates the variation of the percent removal at sand depth of 105 cm. The average percent removal is 43.9%. This is slightly less than that reported by Ellis (12) as 50% using sand size of ES = 0.6 mm and sand depth of 95 cm. Figure 4.71 illustrates the variation of the

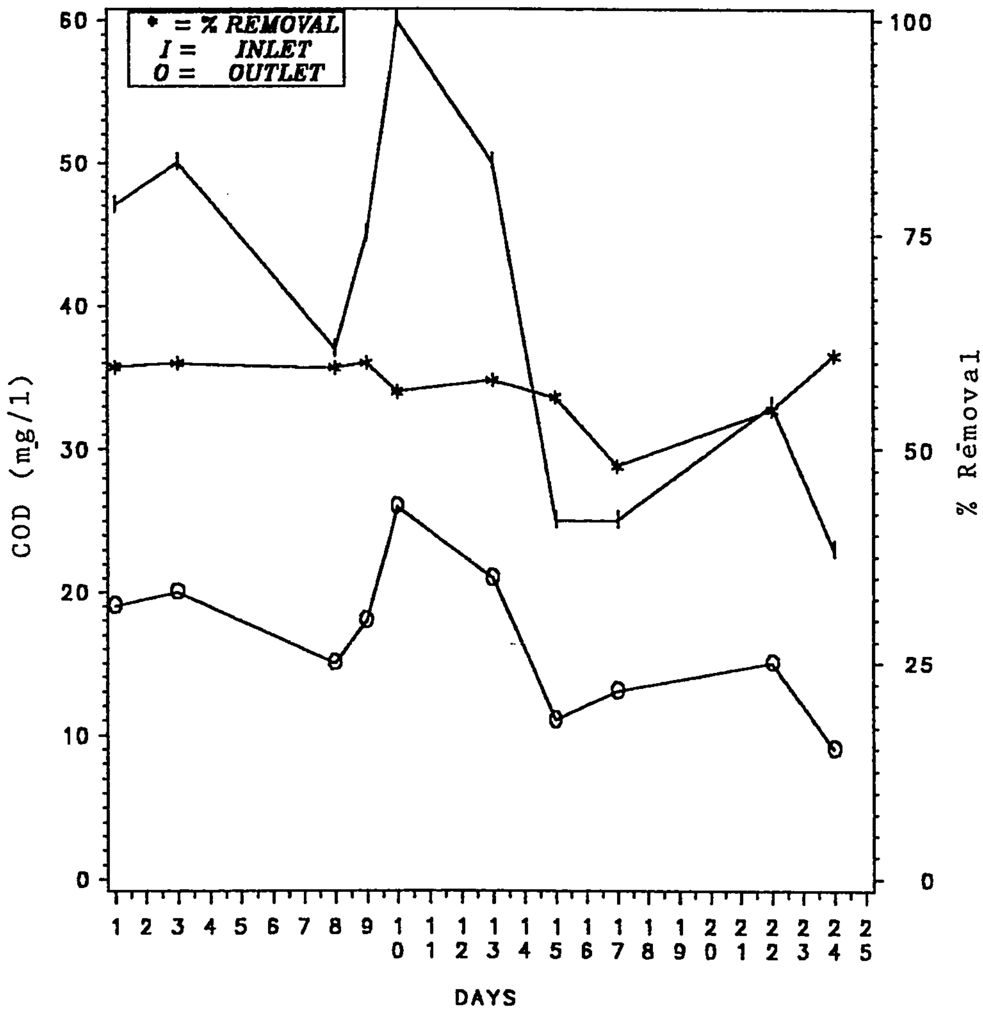

FIGURE 4.68:REMOVAL OF COD THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.31MM

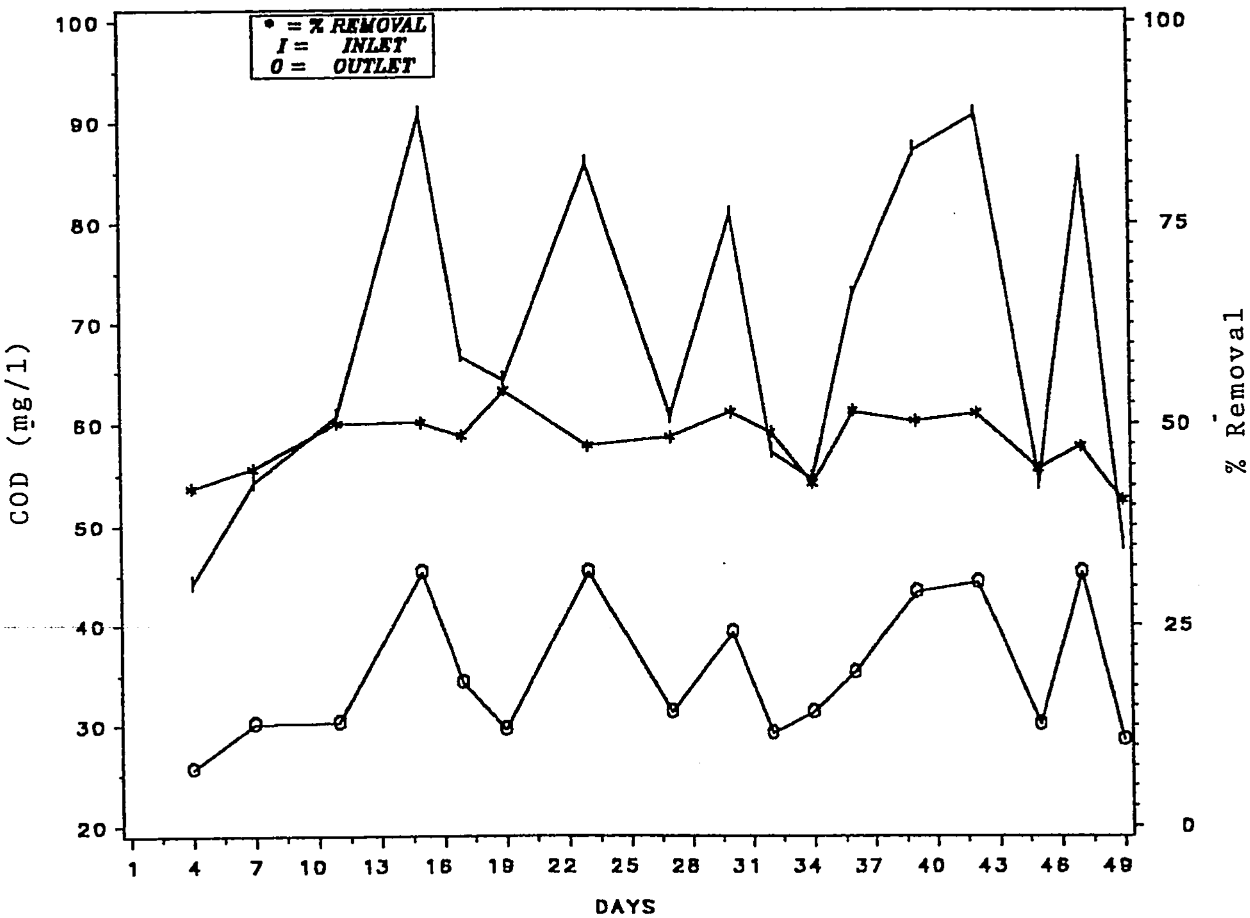

FIGURE 4.69 : REMOVAL OF COD THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

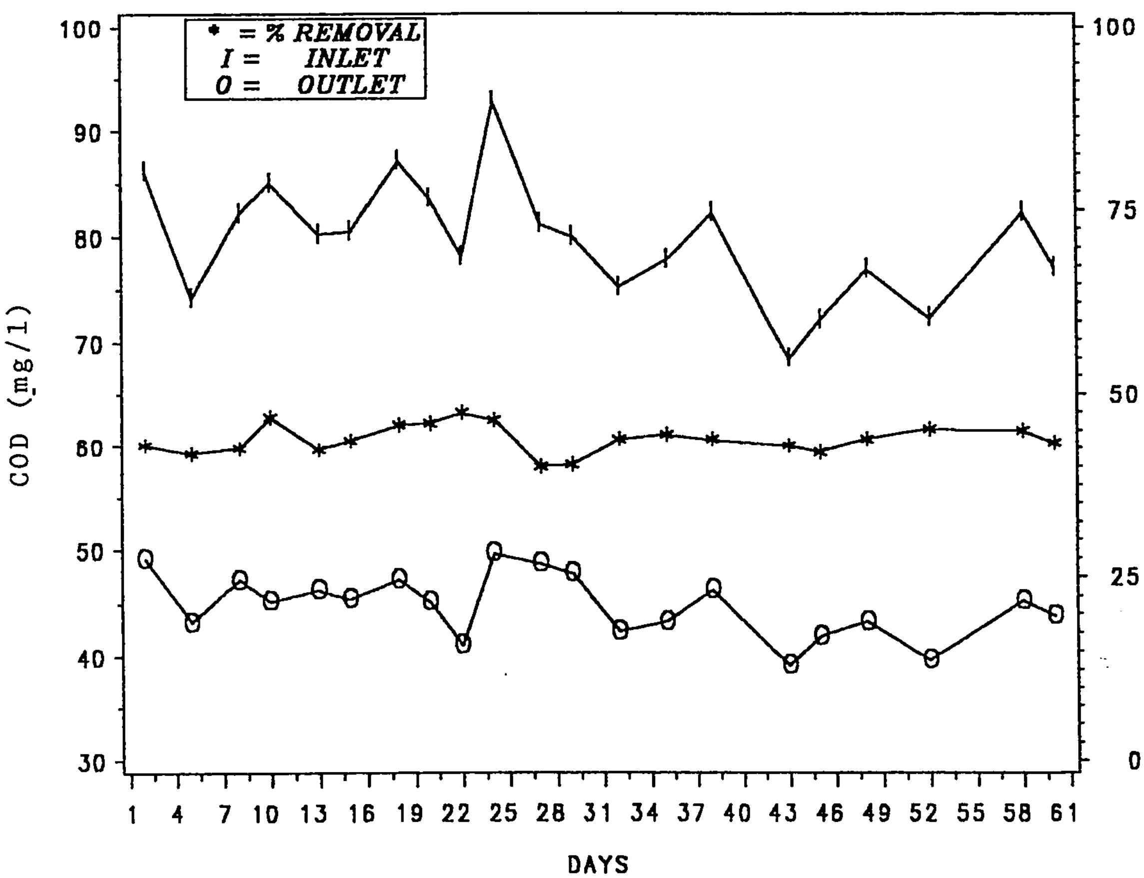

FIGURE4.70REMOVAL OF COD THROUGH SAND BED OF 105CM
AND EFFECTIVE SIZE OF 0.56MM

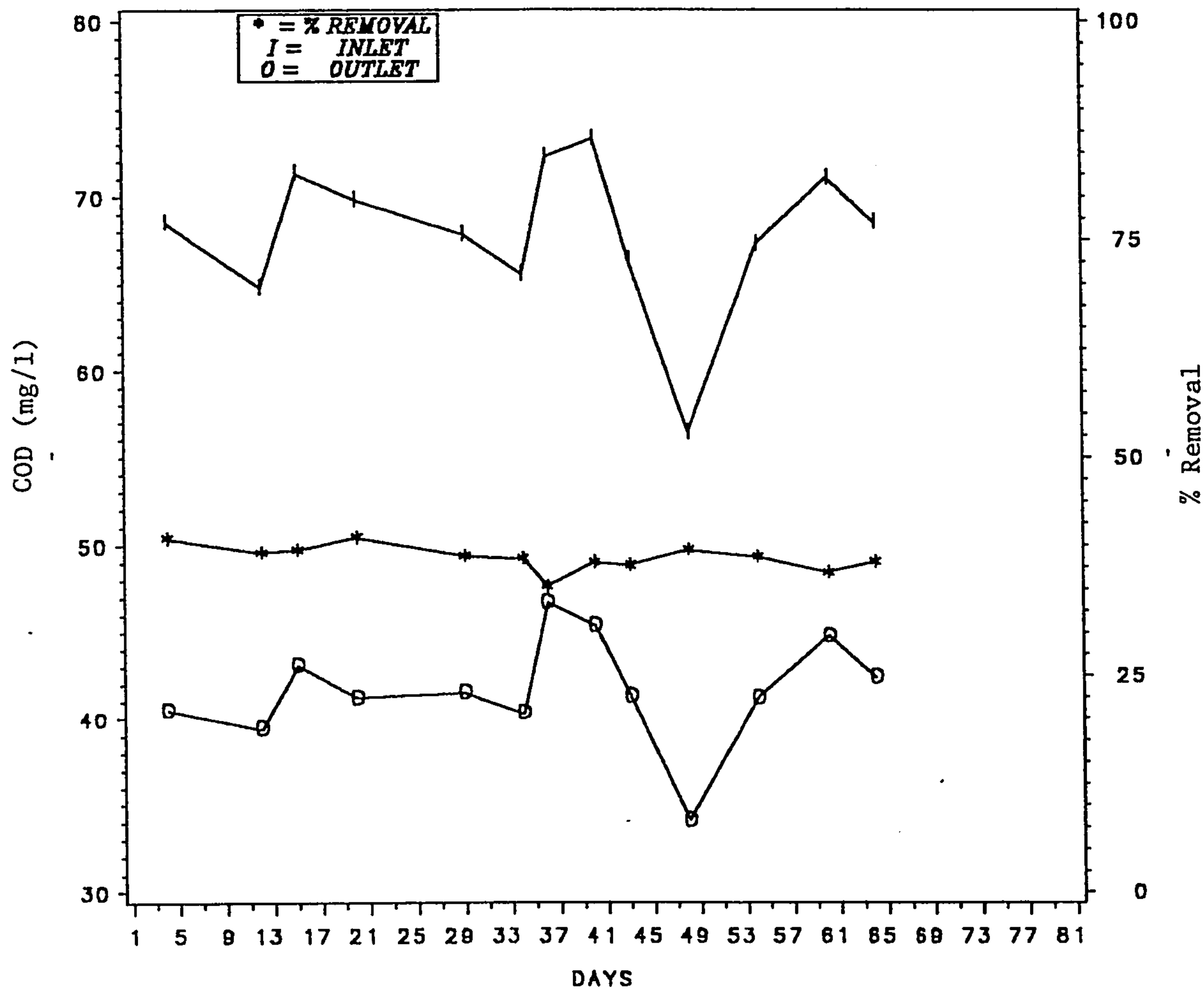

FIGURE 4.71:REMOVAL OF COD THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.56MM

percent removal at sand depth of 55 cm. The average percent removal is 38.6%.

Figure 4.72 illustrates the average percent removal trend for the fine sand at sand depths of 135, 105 and 55 cm. The average percent removals are 66.6, 57.7 and 50% at sand depths of 135, 105 and 55 cm, respectively, indicating increase in removal with increase in sand depth. Another reason of higher removal at the sand depth of 135 cm could be the high concentration of COD (120 mg/l) in the influent of that set of experiment. It is known that higher removals will be achieved in the case of higher concentrations of organic matter in the influent. On the other hand, the percent removals of COD with the coarse sand at sand depths of 135 , 105 and 55 cm are 48.2 , 43.9 and 38.6% , respectively as shown in Figure 4.73.

Figure 4.74 illustrates the variation of the percent COD removal at sand depth of 105 cm. The two variation trends represent the fine and the coarse sands. It is found that as the sand size increases, the percent removal decreases. Figure 4.75 depicts the trends of the average percent COD removal for the three depths investigated for the fine and the coarse sands. It is found that the percent removal is decreasing by decreasing the sand depth and/or by increasing the sand size. There is only a marginal difference in the removal efficiency resulted with the coarse sand compared to the fine sand.

4.2.6 Nitrification and Denitrification

The analysis for $NO_2^- + NO_3^-$ have been conducted routinely throughout the routine runs. The influent levels have ranged from 4.0 to 6.3 mg/l, whereas, the effluent levels have ranged from 3.1 to 6.6 mg/l. These values are resulted from two runs (sand depths of 55 and 53 cm, ES = 0.31 mm). The

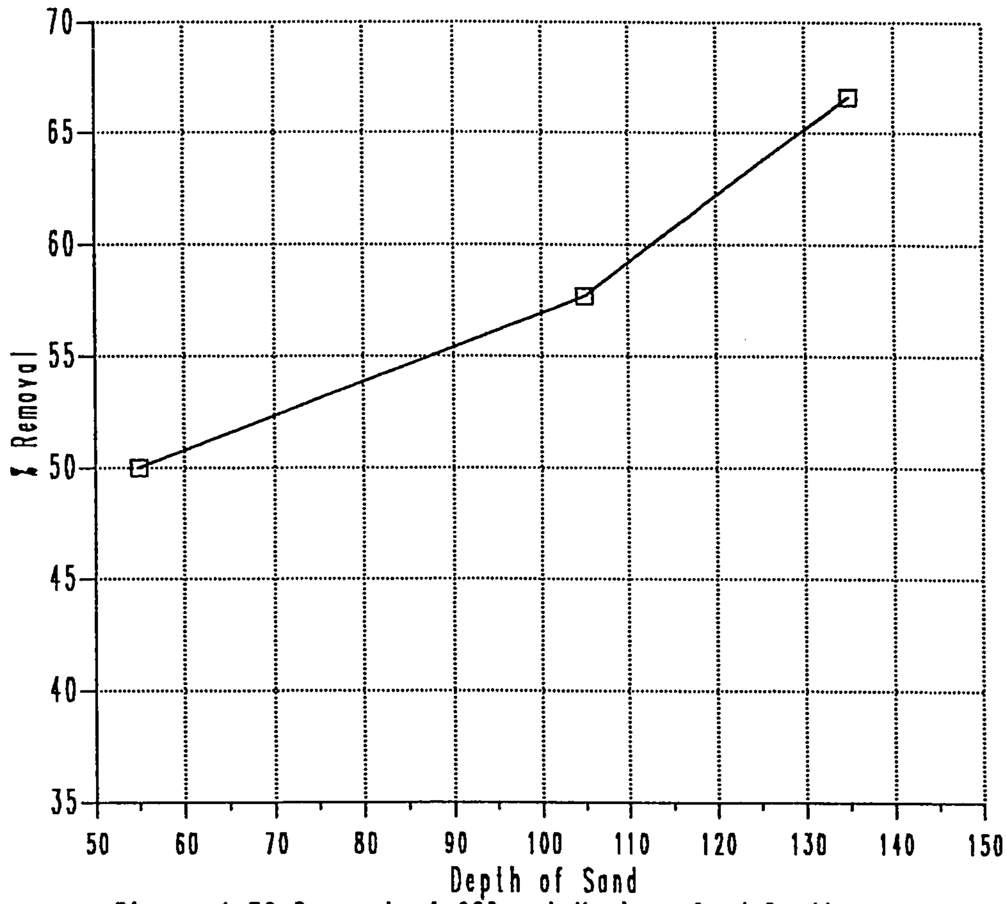

Figure 4.72:Removal of COD at Various Sand Depths
for Effective Sand Size of 0.31mm

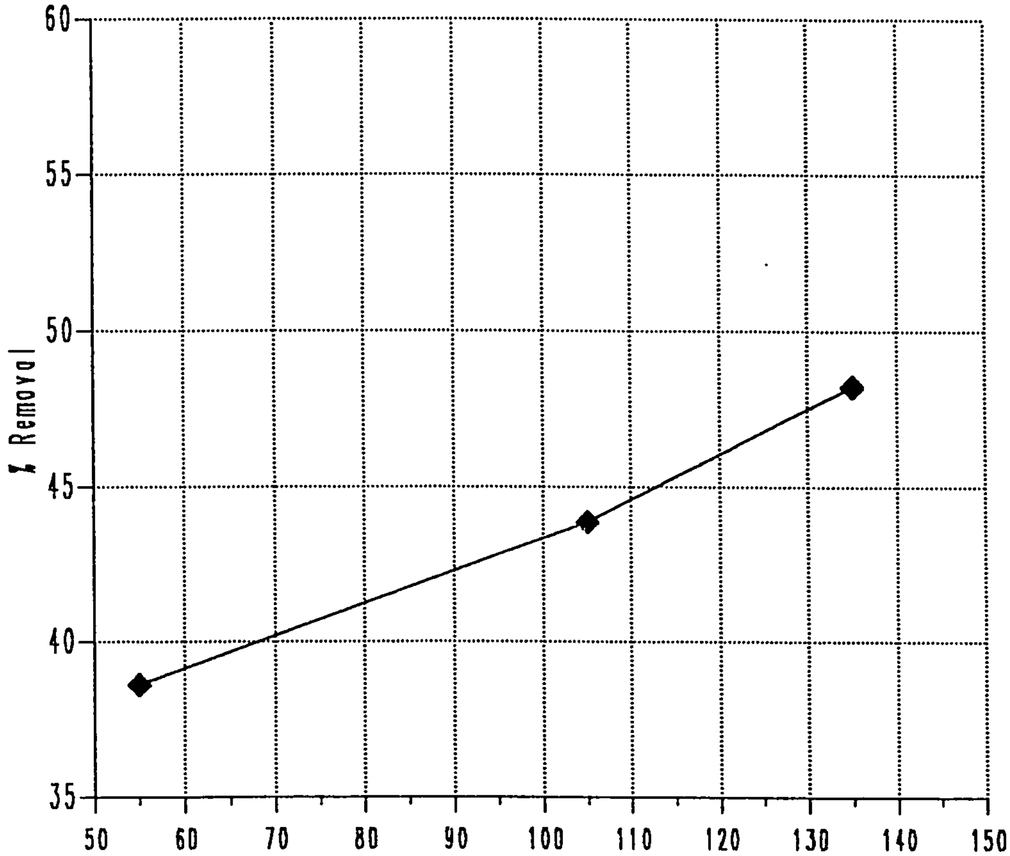

Figure 4.73:Removal of COD at Various Sand Depths for Effective Sand Size of 0.56mm

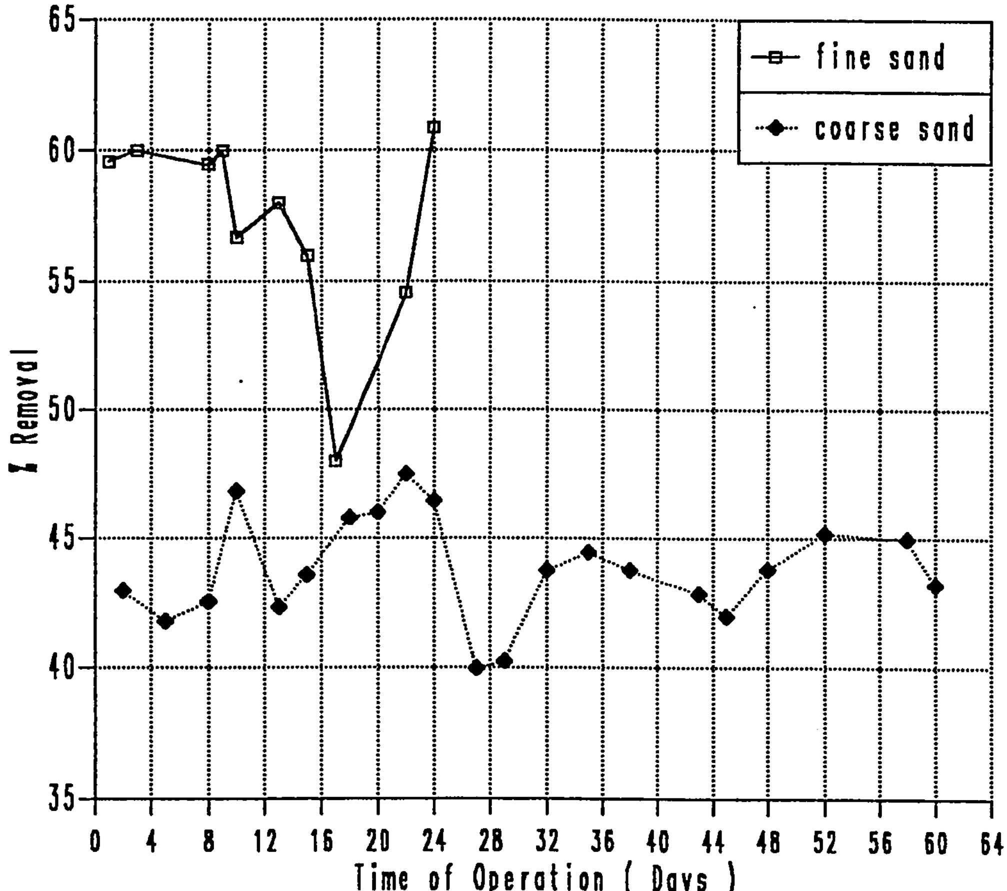

Figure 4.74:Removal of COD Through Various Types of Sand at a Sand Depth of 105cm

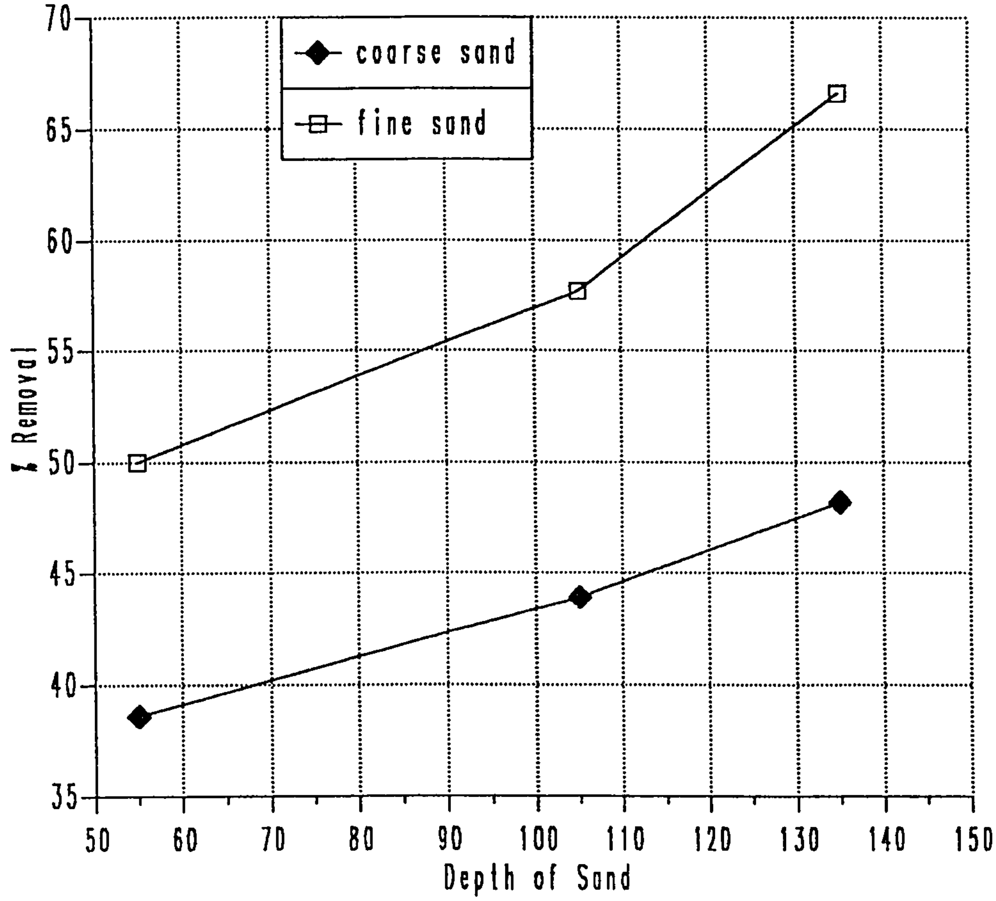

Figure 4.75:Removal of COD at Various Sand Depths and Sizes

average dissolved oxygen in the effluent has been 4.7 mg/l at (depth of sand 55 mm) which is quite adequate for nitrification to take place. Viessman and Hammer (58) have reported that the laboratory studies have shown that there is no detectable inhibition of nitrification at DO levels exceeding 1.0 mg/l. Metcalf and Eddy (33) have reported that the dissolved oxygen level has been found to affect the maximum specific growth rate of nitrifying organisms.

The influent temperature levels have been reported throughout this run (i.e. sand depth 55 cm, ES = 0.31 mm) have ranged from 33 to 37°C with an average of 34.6°C. Even these high temperatures along with adequate DO levels have not shown any significant increase in the concentration of NO_2^- + NO_3^- as can be seen in Tables 4.11 and 4.12. This indicates that no nitrification is taking place in the filter bed. This is also confirmed due to the absence of ammonia in the influent and the effluent. However, Viessman and Hammer (58) have reported that increased temperatures have significant effect in establishing and maintaining healthy nitrifier populations. Similarly, Metcalf and Eddy (33) have reported that the temperature has a significant effect on nitrification rate.

The influent pH levels have ranged from 7.3 to 7.8, whereas the effluent levels have ranged from 7.3 to 7.6. It has been observed that the maximum rate of nitrification occurs with pH ranging from 7.2 to 9.0 (33). Viessman and Hammer (58) have reported that the optimum pH for nitrification is ranging from 8.2 to 8.6, with 90% of the maximum occurring at pH 7.8 and 8.9.

The coarse sand (ES = 0.56 mm) also has been investigated for NO_2^- + NO_3^-. The influent levels have ranged from 5.1 to 8.7 mg/l, whereas, the effluent levels have ranged from 3.1 to 6.8 mg/l. These values are resulted from three runs (sand depths of 135 , 105 and 55 cm, ES = 0.56 mm). It is obvious that there is decrease of $NO_2^- + NO_3^-$ in the effluent (Figures 4.76 to 4.78). The decrease of $NO_2^- + NO_3^-$ in the effluent agrees with the findings of Ellis (12). He has reported that this effect must be indicative of the intensity of biological activity on and within the sand. This observation could not be verified as denitrification because it is based only on decrease in $NO_2 + NO_3^-$ concentration. The average percent reduction in $NO_2^- + NO_3^-$ concentration is about 30 , 16.7 and 6.9% ,respectively.

4.2.7 Other Parameters

The analysis for DO, alkalinity, sulfate and phosphate have been conducted routinely throughout the routine runs. The influent and the effluent ranges and means are summarized in Tables 4.9 to 4.15.

The influent DO levels have ranged from 5.8 to 16.7 mg/l whereas, the effluent levels have ranged from 2.9 to 11.7 mg/l. DO has been monitored daily to observe the progressive effects of biological activity in the filter. It is found throughout the study that oxygen level is sufficient to support any aerobic biological activity within the bed. This is confirmed as the DO level decreased from 7.1-14.6 mg/l to 3.9-10.4 mg/l in the effluent. It has been observed that the depletion rate of DO is decreasing with decreasing sand depth and/or increasing the sand size. Figure 4.79 illustrates the variation of the influent, the effluent, and percent depletion of DO at sand depth of 135 cm for the coarse sand. The average percent depletion is 49.6% .

The influent alkalinity levels have ranged from 94 to 148 mg/l, whereas, the effluent levels have ranged from 91 to 143 mg/l. The variation of the infl-

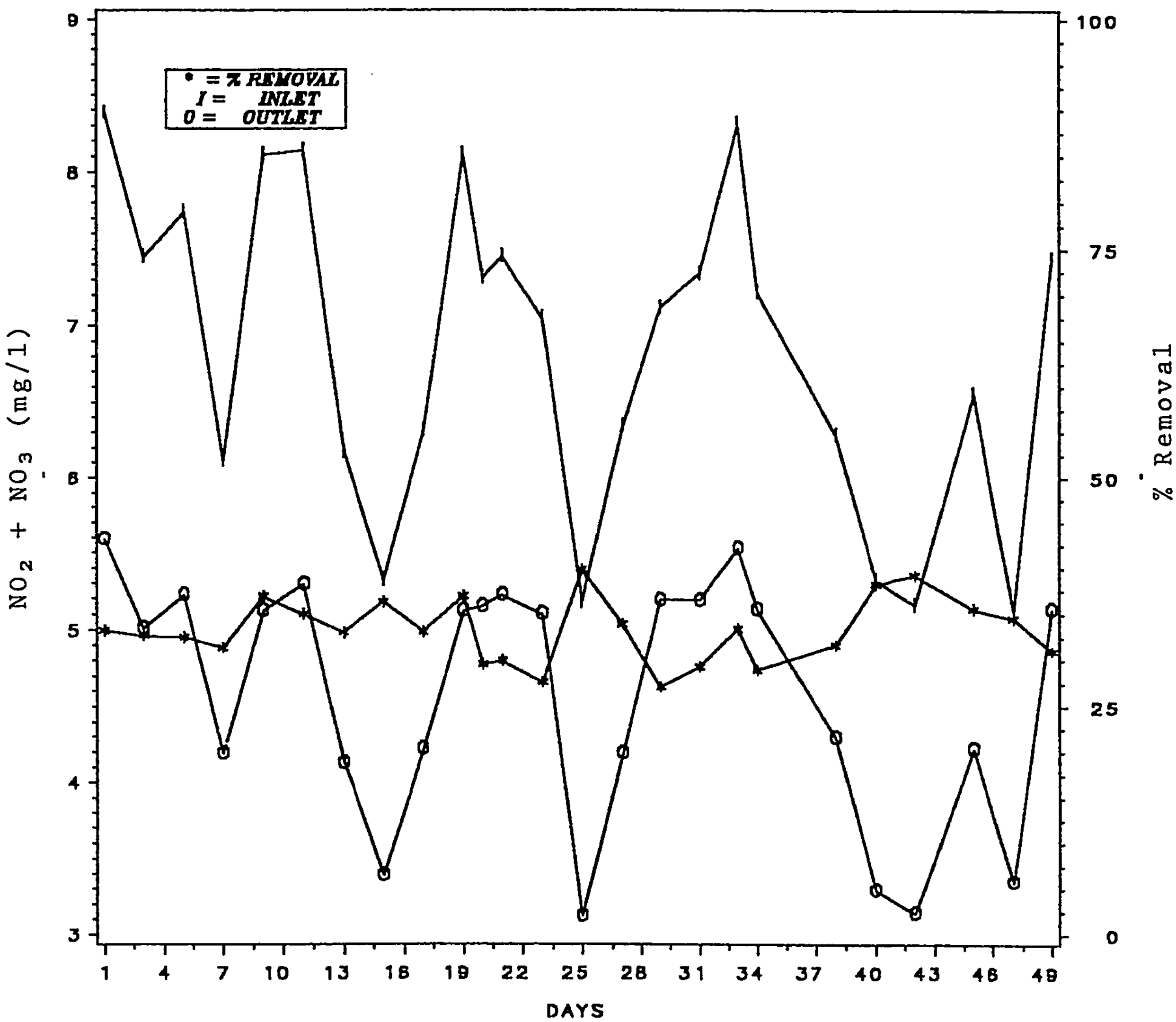

FIGURE 4.76 REMOVAL OF NITRITE + NITRATE THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

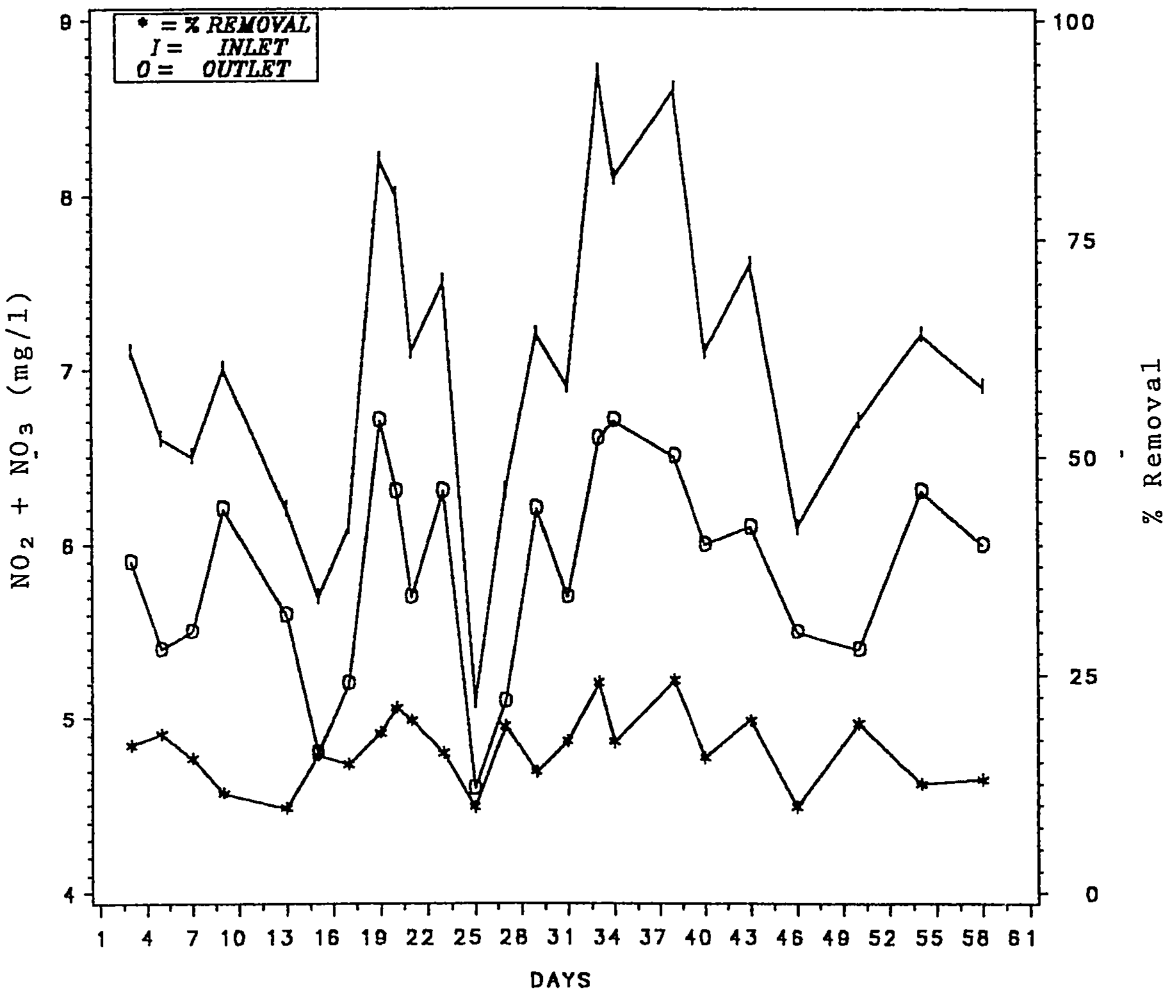

FIGURE 4.77: REMOVAL OF NITRITE + NITRATE THROUGH SAND BED OF 105CM AND EFFECTIVE SIZE OF 0.56MM

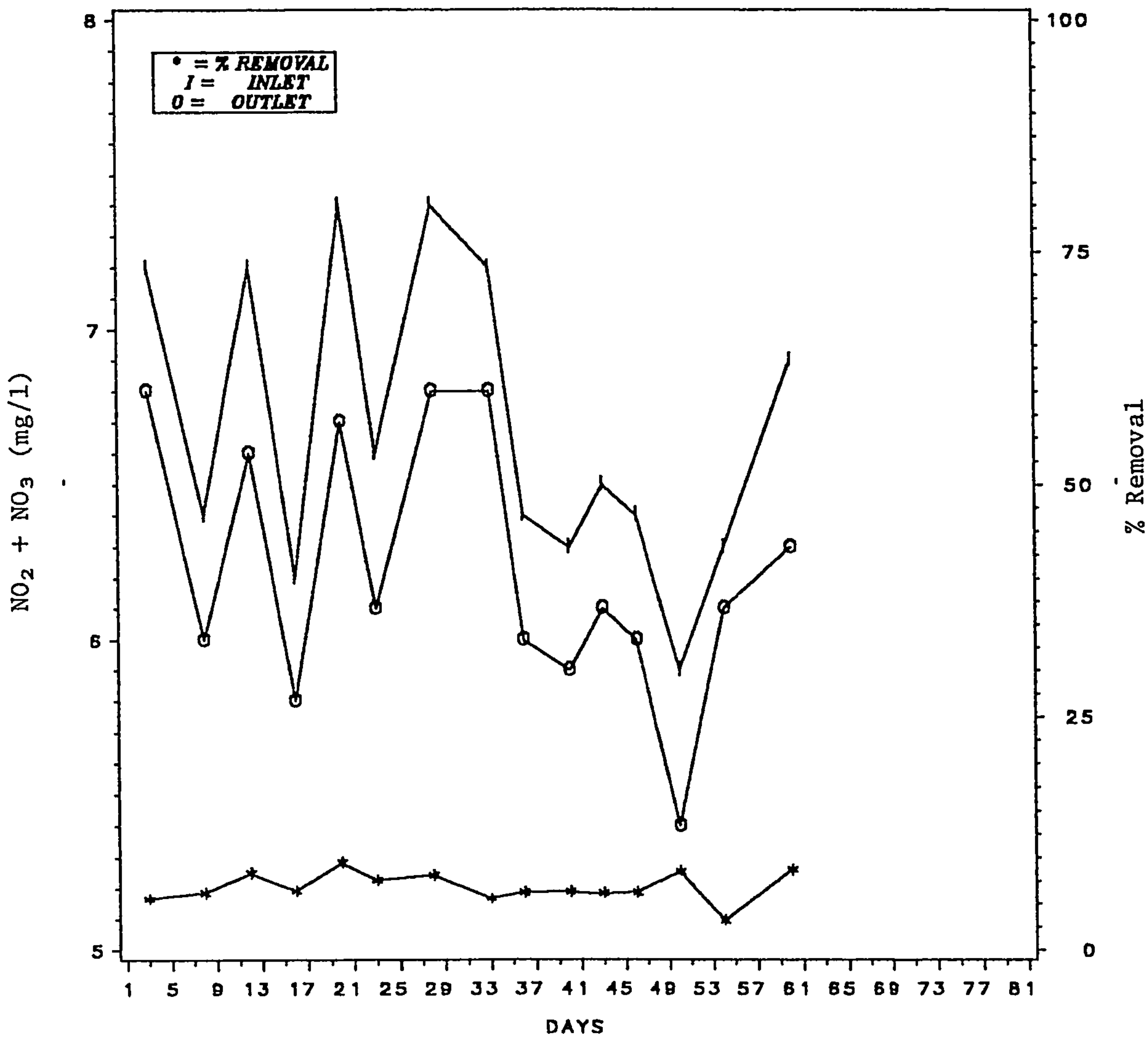

FIGURE 4.78: REMOVAL OF NITRITE + NITRATE THROUGH SAND BED OF 55CM AND EFFECTIVE SIZE OF 0.58MM

Table 4.9 : FILTER PERFORMANCE (SAND DEPTH = 135cm , ES = 0.31mm)

Date: 1.8.1989 to 10.8.1989

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	9	33-36.5	35	36-39.5	37
pH	9	7.9- 9.3	-	7.5- 8.3	-
DO,mg/l	9	9.6-15.1	11.3	4.0- 5.2	4.7
COD,mg/l	2	80-120	100	26.7-40.0	33.4
Turbidity, NTU	9	1.7- 6.0	3.0	0.05-0.40	0.15
Alkalinity, mg/l	1	147	147	135	135
Sulfate, mg/l	2	680-707	693.5	720-746	733
Residual chlorine,mg/l	8	0.04-0.12	0.08	0.02-0.05	0.04
Conductivity, micromhos/cm	2	5500-6800	6150	5500-6800	6150
TON, mg/l	2	2.24	2.24	0.84-1.12	0.98
Ammonia, mg/l	1	0	0	0	0

Remarks:

Length of operation : 9 days

Influent from the reservoir.

Table 4.10 : FILTER PERFORMANCE (SAND DEPTH =105cm , ES=0.31mm)

Date: 11.8.1989 to 5.9.1989

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	25	31.0-36.0	34.5	35.5-38	36.7
pH	25	7.4- 8.1	-	7.2- 7.6	-
DO,mg/l	25	6.1-10.3	7.7	2.9- 5.0	3.9
COD,mg/l	10	23.0-60.0	39.5	9.0-26.0	16.7
Turbidity, NTU	25	1.0- 2.5	1.5	0.05-0.30	0.12
Alkalinity, mg/l	10	129-148	142	122-140	133
Sulfate, mg/l	7	680-760	722	693-800	748
Phosphate, mg/l	7	1.71-1.91	1.8	0.26-0.33	0.29
Residual chlorine,mg/l	19	0.03-0.14	0.09	0.03-0.07	0.05
Conductivity, micromhos/cm	11	4500-6200	5360	4500-6200	5360
TON, mg/l	6	0.0-2.24	1.02	0.0-0.84	0.23
Ammonia, mg/l	3	0	0	0	0

Remarks:

Length of operation : 25 days

Influent direct from the pipe.

Table 4.11 : FILTER PERFORMANCE (SAND DEPTH = 55cm , ES = 0.31mm)

Date: 6.9.1989 to 26.9.1989

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	21	30.0-35.5	32.8	33-37	34.6
pH	20	7.3- 7.8	-	7.3-7.6	-
BOD,mg/l	3	0.3-0.70	0.50	0.1-0.20	0.13
DO,mg/l	20	6.0- 9.1	7.1	4.0- 5.7	4.7
Alkalinity, mg/l	8	136-144	140	130-139	135
Turbidity, NTU	20	1.0-3.25	1.46	0.10-0.18	0.13
Residual chlorine,mg/l	14	0.07-0.14	0.09	0.04-0.09	0.06
Sulfate, mg/l	6	707-733	720	733-760	749
Phosphate, mg/l	3	1.79-2.71	2.21	0.81-1.29	0.97
Nitrite + Nitrate , mg/l	2	4.10-4.20	4.15	4.30-4.43	4.36
Ammonia, mg/l	1	0	0	0	0
TON, mg/l	2	0	0	0	0
COD, mg/l	3	60	60	30	30
Conductivity, micromhos/cm	5	5200-5700	5340	5200-5700	5340

Remarks:

Length of operation : 21 days

Influent direct from the pipe.

Table 4.12 : FILTER PERFORMANCE (SAND DEPTH = 53cm , ES = 0.31mm)

Date: 27.9.1989 to 16.10.1989

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	19	30.0-32.0	31.2	30-35	33
pH	19	7.1- 7.6	-	7.1-7.4	-
DO,mg/l	19	5.8- 9.2	7.3	4.0- 6.0	4.9
Alkalinity, mg/l	9	136-148	141	131-143	136
Turbidity, NTU	19	1.10-1.75	1.33	0.09-0.20	0.12
Residual chlorine,mg/l	13	0.06-0.14	0.09	0.04-0.10	0.06
Sulfate, mg/l	7	620-760	723	629-787	737
Phosphate, mg/l	4	1.82-1.97	1.90	0.82-0.86	0.84
Nitrite + Nitrate , mg/l	7	3.04-6.29	5.28	3.09-6.56	5.52
Ammonia, mg/l	3	0	0	0	0
TON, mg/l	2	0	0	0	0
COD, mg/l	2	40-89	64.5	30-36	33
Conductivity, micromhos/cm	6	5200-6200	5650	5200-6200	5650

Remarks:

Length of operation : 19 days

Influent direct from the pipe.

Table 4.13 : FILTER PERFORMANCE (SAND DEPTH = 135cm , ES = 0.56mm)

Date: 27.12.1989 to 15.2.1990

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	45	13.0-23.0	18.2	13.0-23.0	18.4
pH	43	7.5- 9.0	-	7.5-8.7	-
BOD,mg/l	22	1.6-4.90	2.78	0.2-0.50	0.31
DO,mg/l	43	7.6-16.6	12.1	3.8- 8.7	6.1
Alkalinity, mg/l	16	94 - 112	102	91 - 108	98
Turbidity, NTU	43	1.0- 3.0	1.71	0.10-0.26	0.14
Sulfate, mg/l	17	680-813	726	720-840	762
Phosphate, mg/l	14	0.97-1.85	1.33	0.91-1.77	1.22
Nitrite + Nitrate , mg/l	25	5.12-8.38	6.84	3.12-5.59	4.58
COD, mg/l	17	31.3-90.7	63.9	18.6-45.3	33.1
Conductivity, micromhos/cm	10	4600-5200	4865	4600-5200	4865

Remarks:

The filter was terminated after 50 days of operation

Influent from the reservoir.

Table 4.14 : FILTER PERFORMANCE (SAND DEPTH = 105cm , ES = 0.56mm)

Date: 16. 2.1990 to 19.4.1990

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	56	16.5-31.5	23.5	17.5-32.0	24.0
pH	45	7.7- 9.2	-	7.5-8.9	-
BOD,mg/l	26	2.2-4.40	3.71	0.3-0.80	0.57
DO,mg/l	53	6.3-16.7	11.6	3.8- 9.1	6.4
Alkalinity, mg/l	18	99 - 117	107	96 - 115	103
Turbidity, NTU	53	1.2- 3.7	1.94	0.13-0.40	0.21
Sulfate, mg/l	10	645-887	720	650-892	730
Phosphate, mg/l	7	0.32-1.81	0.67	0.31-1.72	0.63
Nitrite + Nitrate , mg/l	24	5.1 -8.7	7.02	4.6 -6.7	5.85
COD, mg/l	21	72.1-92.8	79.8	39.1-49.7	44.8
Conductivity, micromhos/cm	5	5200-5900	5560	5200-5900	5560

Remarks:

The filter was terminated after 62 days of operation

Influent from the reservoir.

Table 4.15 : FILTER PERFORMANCE (SAND DEPTH = 55cm , ES = 0.56mm)

Date: 20. 4.1990 to 13.7.1990

PARAMETER	Number of Samples	INFLUENT		EFFLUENT	
		Range	Mean	Range	Mean
Temperature, C	75	28.0-38.0	33.8	28.5-39.0	34.4
pH	39	8.5- 9.3	-	8.3-9.1	-
BOD,mg/l	18	3.7-4.90	4.27	0.6-0.90	0.74
DO,mg/l	39	11.5-15.9	14.6	8.1-11.7	10.4
Alkalinity, mg/l	17	101 - 127	111	98 - 124	108
Turbidity, NTU	39	1.2- 3.7	2.09	0.13-0.43	0.24
Sulfate, mg/l	12	623-765	677	639-785	695
Phosphate, mg/l	9	0.95-1.35	1.21	0.90-1.30	1.16
Nitrite + Nitrate , mg/l	15	5.9 -7.4	6.69	5.4 -6.8	6.23
COD, mg/l	13	56.4-73.3	67.9	34.1-46.7	41.7
Conductivity, micromhos/cm	7	5300-5850	5550	5300-5850	5550

Remarks:

The filter was terminated after 84 days of operation

Influent from the reservoir.

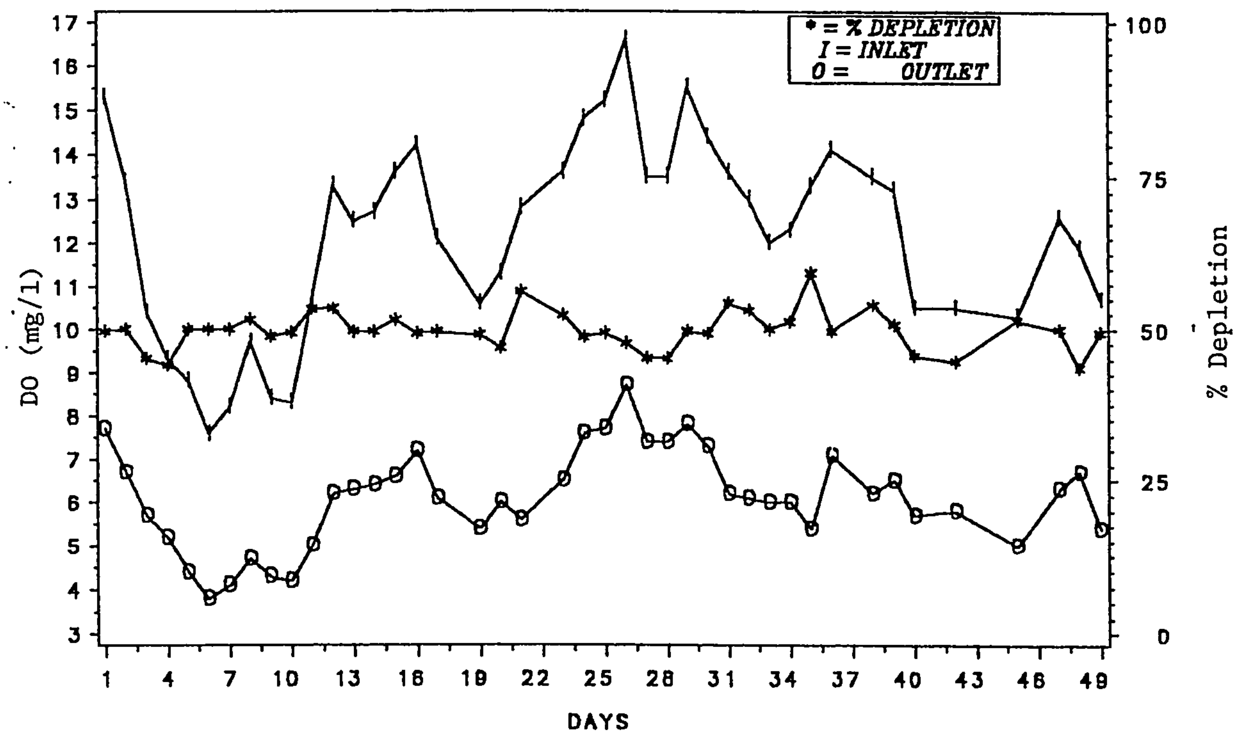

FIGURE 4.79:DEPLETION OF DO THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

uent, the effluent, and percent removal are illustrated in Figure 4.80 The average percent removal obtained is 3.5 to 8%. These values are slightly more than the value reported by Al-Adham (1) of 1.9%.

The sulfate influent levels have ranged from 620 to 887 mg/l, whereas, the effluent levels have ranged from 629 to 892 mg/l. The sulfate concentration has increased in the filtrate. This means biochemical oxidation of the organic matter is probably taking place in the filter bed. This agrees with what has been reported by Al-Adham (1). He has reported that the sulfate concentration is more in the filtrate. The variation of the influent, the effluent, and percent increase are illustrated in Figure 4.81. The percent increase at sand size of ES = 0.56 mm and sand depth of 135 cm is 5% on the average.

The phosphate influent levels have ranged from 0.32 to 2.71 mg/l, whereas, the effluent levels have ranged from 0.26 to 1.77 mg/l. The phosphate concentration is found less in the filtrate. This is probably due to the removal of surface active agents during filtration which is possible due to their adsorption onto the media. The phosphate variation in the influent, the effluent, and the percent removal are illustrated in Figure 4.82. The percent removal of the phosphate is 83.9% during summer with average ambient turbidity of 36.7°C. The average percent removal has dropped dramatically during winter with average ambient temperature of 18°C to 8.3%. This value is comparable to what has been reported by Al-Adham (1) of 7.5%. Eventually, because of the lack of accuracy of these tests at the extremely low values that existed make it very difficult to make the reasonable judgement.

The analysis of heavy metals (Cd, Cr, Cu, Fe, Pb, Mn, and Zn) have been conducted twice during the study. However, no metals were detected in the influent and the effluent.

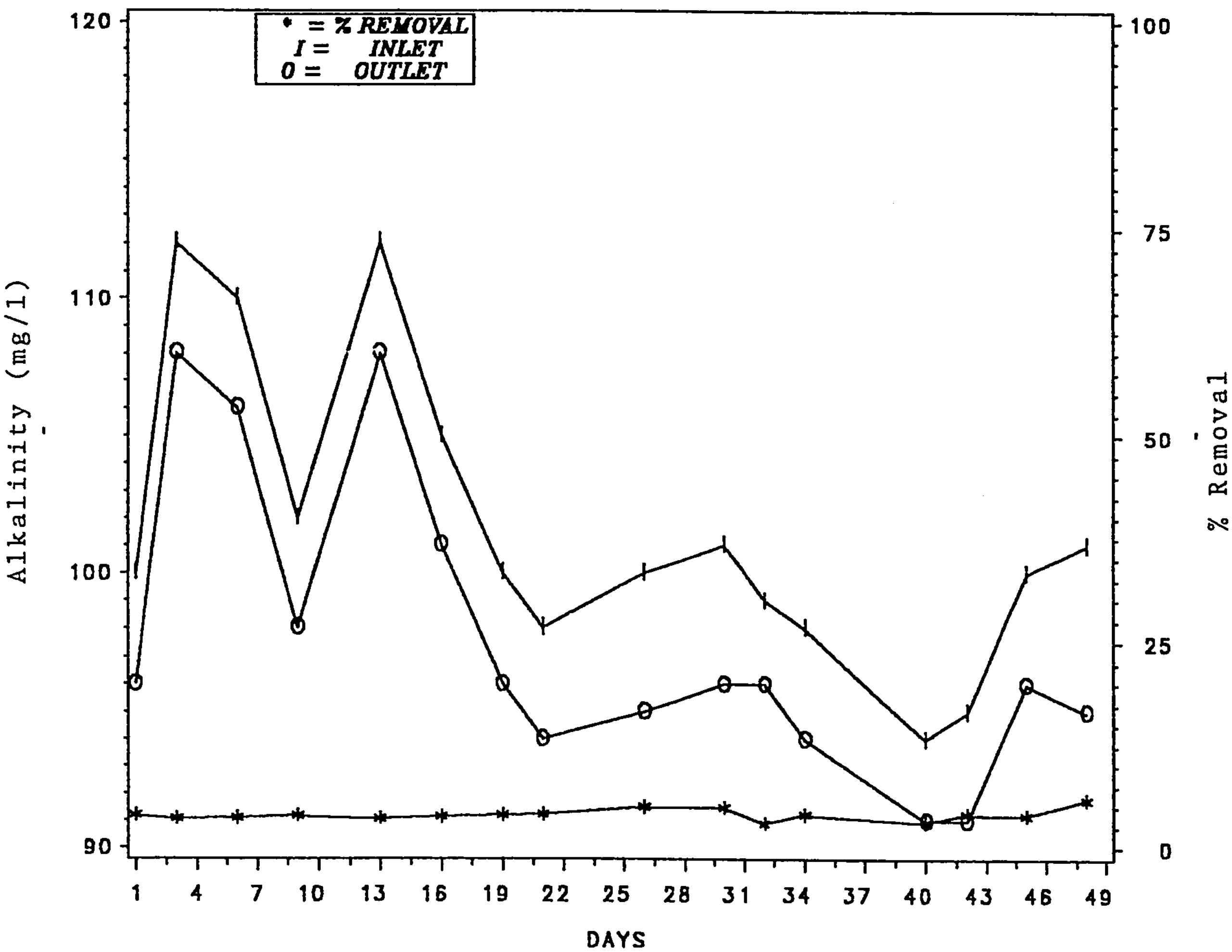

FIGURE 4.80 :REMOVAL OF ALKALINITY THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

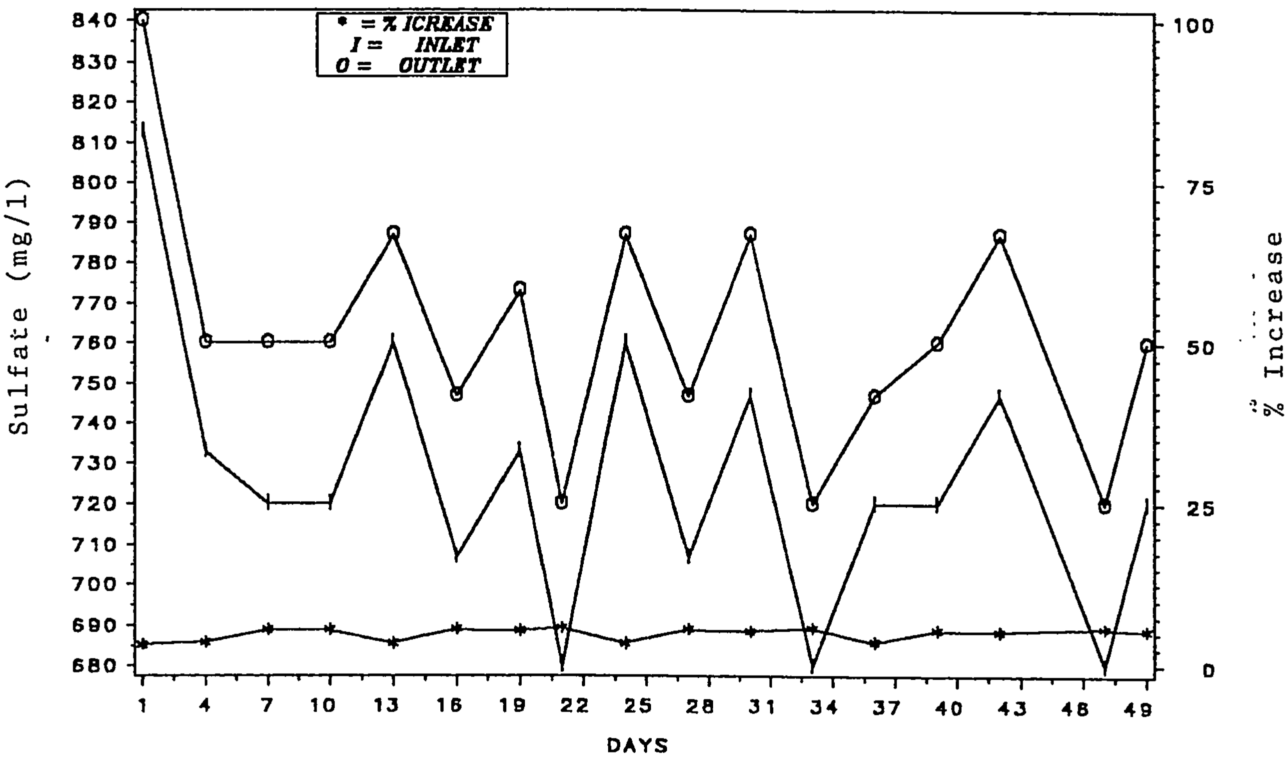

FIGURE 4.81: INCREASE OF SULFATE THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

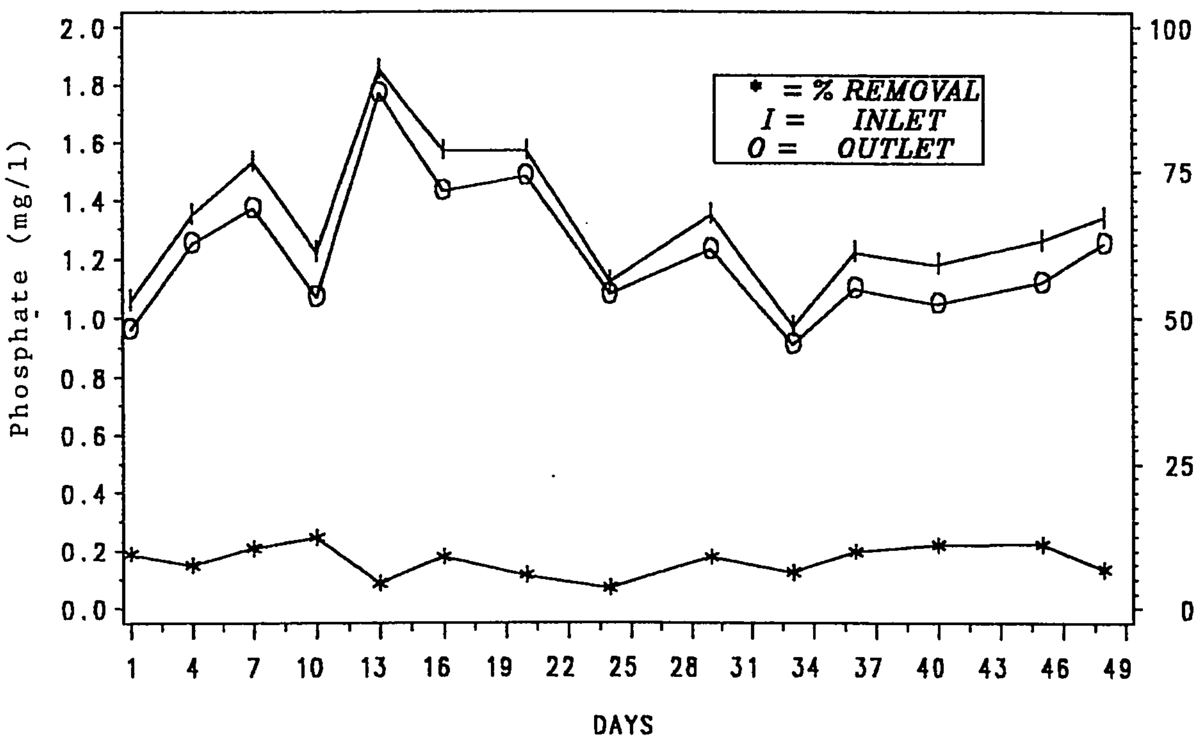

FIGURE 4.82: REMOVAL OF PHOSPHATE THROUGH SAND BED OF 135CM AND EFFECTIVE SIZE OF 0.56MM

4.2.8 *Seasonal Variation of the Quality of Influent*

In order to determine the effect of seasonal variation on the water quality, statistical correlations between various parameters have been determined. The influent water quality data from the feed reservoir for both summer and winter have been collected. Consequently, statistical evaluation for correlation data have been made. Three categories of relationships have been selected as follows:

0.50 - 0.70	Correlation
0.70 - 0.90	Strong correlation
0.90 - 1.00	Excellent correlation

Summer Season: It is found that the temperature and turbidity have a positive correlation (Table 4.16). Temperature also has a strong positive correlation with DO. This can be explained as the temperature is increasing the rate growth of algal blooms is increasing tremendously. This has resulted in high turbidity and DO values. The value of pH also has a reasonable positive correlation with temperature for the same reason. Total coliform bacteria and standard plate counts have a weak negative correlation with the temperature . This means, as the ambient temperature is increasing, the bacteria are dying off.

Winter Season: It is found that the temperature has a weak positive correlation with turbidity (Table 4.17). The algae during this period are minimal which have resulted in small increase in turbidity. Temperature has a weak negative correlation with both pH and DO. Clearly, as the temperature goes up, the solubility of dissolved oxygen is decreasing. Total coliform bacteria

TABLE 4.16:CORRELATION AMONG VARIOUS CONVENTIONAL PARMETERS(1.8.1989 to 10.8.1989)

PARAMETER	TEMP	PH	DO	TURB	COLF	TCount
Temp	1.00000	0.42845	0.71626	0.68834	-0.22343	-0.39539
	0.0000	0.3967	0.1093	0.1306	0.6704	0.4378
pH	0.42845	1.00000	0.34381	0.69884	0.43188	0.33587
	0.3967	0.0000	0.5046	0.1224	0.3925	0.5151
DO	0.71626	0.34381	1.00000	0.87373	0.09688	-0.13686
	0.1093	0.5046	0.0000	0.0229	0.8551	0.7960
Turb	0.68834	0.69884	0.87373	1.00000	0.12368	-0.08832
	0.1306	0.1224	0.0229	0.0000	0.8154	0.8679
Colf	-0.22343	0.43188	0.09688	0.12368	1.00000	0.97253
	0.6704	0.3925	0.8551	0.8154	0.0000	0.0011
TCOUNT	-0.39539	0.33587	-0.13686	-0.08832	0.9725	1.00000
	0.4378	0.5151	0.7960	0.8679	0.0011	0.0000

TABLE 4.17:CORRELATION AMONG VARIOUS CONVENTIONAL PARAMETERS(27.12.1989 to 15.2.1990)

PARAMETER	TEMP	PH	DO	TURB	COLF	TCOUNT
Temp	1.00000	-0.10590	-0.09603	0.08487	0.71026	0.74426
	0.0000	0.6306	0.6629	0.7002	0.0001	0.0001
pH	-0.10590	1.00000	0.62813	0.39115	0.27086	0.29236
	0.6306	0.0000	0.0014	0.0649	0.2113	0.1758
DO	-0.09603	0.62813	1.00000	0.47074	0.13909	0.20913
	0.6629	0.0014	0.0000	0.0234	0.5268	0.3382
Turb	0.08487	0.39115	0.47074	1.00000	0.03796	0.08762
	0.7002	0.0649	0.0234	0.0000	0.8635	0.6910
Colf	0.71026	0.27086	0.13909	0.03796	1.00000	0.96706
	0.0001	0.2113	0.5268	0.8635	0.0000	0.0001
TCOUNT	0.74426	0.29236	0.20913	0.08762	0.96706	1.00000
	0.0001	0.1758	0.3382	0.6910	0.0001	0.0000

and standard plate counts have a strong positive correlation with temperature . As the temperature is increasing, the bacteria are surviving to a limit, then they started to die off at high ambient temperature , i.e., during summer. Eventually, during the two seasons of study, i.e., summer and winter, it is found that there is an excellent positive correlation between total coliform bacteria and standard plate counts.

CHAPTER 5

CONCLUSIONS

This study is aimed to evaluate slow sand filtration as tertiary treatment of secondary wastewater effluents at pilot scale. The influent through the study has been taken from feeds, either from the reservoir or directly from the operational line from the treatment plant. In both the cases, the wastewater have been taken from extended aeration Treatment Plant of North Aramco. When the secondary effluent was stored in the reservoir, its quality deteriorated due to the excessive growth of algae particularly during summer. Two different sizes of local sand with effective sizes of 0.31 mm and 0.56 mm have been used. In both the cases, three different depths of sand bed, e.g., 135 cm, 105 cm and 55 cm were investigated. This investigation has been carried out over a period of about one year in order to include the variations in the wastewater influent quality to the filter. The filter is operated continuously at constant head, constant rate mode. The hydraulic loading throughout the study has been maintained around 0.16 m/hr. This is achieved by manual adjustment of the outlet valve. The overall operational schedule for the filter is summarized in Table 5.1, and the specific conclusions drawn from the study are given as follows:

1. The operational cycle is found increase about three folds when the influent has been taken directly from the operational line (26 days) as compared to the feed reservoir (9 days). This has shown that algal blooms as a result of storage in the feed reservoir are critical for the performance of the slow sand filter.

Table 5.1 : Summary of Experimental Results of 398 Days Operation of the Slow Sand Filtration

Dates	Experimental Description	Remark
11.6.1989 to 31.7.1989 (48 days)	ES = 0.31 mm Sand depth = 145 cm Influent: Reservoir line (last 26 days)	Preliminary runs to mature the filter, the filter matured after 48 days which was determined by good removal of turbidity and bacteria.
1.8.1989 to 10.8.1989 (9 days)	ES = 0.31 mm Sand depth = 135 cm Influent: Reservoir	Removals of turbidity, organic matter, and bacteria have been excellent. The filter was terminated due to excessive head loss
11.8.1989 to 5.9.1989 (25 days)	ES = 0.31 mm Sand depth = 105 cm Influent: Line	Removals of turbidity, organic matter, and bacteria have been excellent. The filter was terminated due to excessive head loss.
(1st run) 6.9.1989 to 26.9.1989 (21 days) (2nd run) 27.9.1989 16.10.1989 (19 days)	(1st run) ES = 0.31 mm Sand depth = 55 cm (2nd run) Sand depth = 53 cm. Influent: Line (both cases)	The experiment was repeated twice to establish the repeatability of the data. Removal of turbidity, organic matter and bacteria have been excellent in both runs. The filter was terminated due to excessive head loss.
30.10.89 to 25.12.1989 (56 days)	ES = 0.56 mm Sand depth = 140 cm Influent: Line	Preliminary run to mature the filter, the filter matured after 56 days which was determined by good removal of turbidity and bacteria. Filter never reached the breakthrough.
27.12.89 to 15.2.1990 (50 days)	ES = 0.56 mm Sand depth = 135 cm Influent: Reservoir	Removal of turbidity, organic matter, and bacteria have been excellent. The filter was terminated after 50 days due to lack of time. Filter never reached the breakthrough.
16.3.1990 to 19.4.1990 (62 days)	ES = 0.56 mm Sand depth = 105 cm Influent: Reservoir	Removal of turbidity, organic matter, and bacteria have been excellent. The filter was terminated after 62 days due to lack of time. Filter never reached the breakthrough.
20.4.1990 to 13.7.1990 (84 days)	ES = 0.56 mm Sand depth = 55 cm Influent: Reservoir	Removal of turbidity, organic matter, and bacteria have been excellent. The filter was terminated after 84 days due to excessive head loss.

2. The coarse sand of ES = 0.56 mm has resulted in long duration of filter operation as compared to the fine sand, i. e., 84 days against 26 days.

3. The development of the head loss has followed an exponential pattern. Also, most of the head loss has been due to the top layer (Schmutzdecke) since the head loss between the top manometer and the outlet manometer is small compared to the total head loss. Moreover, it has been observed that the total head loss always remained within the available head.

4. The initial clean bed head loss recorded at the outlet manometer agrees very closely with the value calculated by Fair and Hatch equation.

5. The turbidity of the filtrate throughout the study is found less than 1.0 NTU with influent turbidity in the range of 0.9 to 12 NTU. The turbidity percent removal has ranged from 89 to 95% for all sand depths and sizes investigated. Moreover, the schmutzdecke layer appears to have essentially no influence on the removal of turbidity because filter scraping has no deterioration effect on the effluent quality.

6. Most of the purification has been observed to occur in the top layers of the sand bed, i.e., most of the dissolved oxygen reduction occurred at the top layers which means most of the biological activity occurred at the top layers. However, the removal of biodegradable organic material continued to be achieved to a substantial extent down the whole depth of the filter.

7. It is found that the percent removal for all the parameters analyzed are decreasing by decreasing the sand depth and/or by increasing the sand size. The effect of the sand size on percent removal is marginal. Therefore, it may be suggested to use the sand of coarser size with deeper bed

compared to finer sand of shallow bed to get the desired efficiency. Although the coarse sand has produced in similar results as the fine sand, the coarse sand has resulted in longer duration of the filter runs.

8. Very good removal of coliform was found as the percent removal of coliform dropped from 99.76 to 97.82 to 93.46% as the filter bed decreased from 135 to 105 to 55 cm, respectively, using the fine sand. On the other hand, the percent removal dropped from 99.39 to 97.26 to 93.03% as the filter bed decreased from 135 to 105 to 55 cm , respectively, using the coarse sand.

9. Similarly, the good removal of total bacterial counts have been observed, because the percent removal of standard plate counts dropped from 92.99 to 90.94 to 88.07% as the filter bed decreased from 135 to 105 to 55 cm, respectively, using the fine sand. Whereas the percent removal dropped from 92.13 to 89.87 to 87.46% as the filter bed decreased from 135 to 105 to 55 cm, respectively, using the coarse sand.

10. The percent removal of COD dropped from 66.6 to 57.7 to 50% as the filter bed decreased from 135 to 105 to 55 cm respectively, using the fine sand. On the other hand, the percent removal dropped from 48.2 to 43.9 to 38.6% as the filter bed decreased from 135 to 105 to 55 cm. respectively, using the coarse sand.

11. $NO_2^- + NO_3^-$ concentration essentially remained the same or slightly increased in the filtrate for the fine sand at sand bed of 55 cm. On the other hand, $NO_2^- + NO_3^-$ concentration has slightly decreased in the filtrate in case of the coarse sand. These results could not be verified as nitrification or denitrification due to lack of significant trends.

12. Temperature has a positive correlation with turbidity, DO, and a weak negative correlation with total coliform bacteria and standard plate counts during summer which means as the temperature is increasing, algal activity is increasing resulting in the increase of turbidity and DO level. On the other hand, the growth of coliform and total counts is decreasing with increasing temperature. However, during winter, the turbidity increased slightly due to increase in temperature while the DO level decreased. Whereas the total counts and coliform level increased with increase in temperature during winter.

13. The slow sand filter can be operated up to a sand bed level of 55 cm without any problem. The average percent removals of turbidity, BOD, COD, standard plate counts and coliform at sand depth of 55 cm were 91, 83, 50, 88 and over 93% respectively.

In view of the above results, it can be concluded that efficiency of the filter at all sand depths and sand sizes with respect to the percent removal of bacterial contaminants were exceptional to an extent that the effluent would easily be qualified for unrestricted irrigation. In spite of the wide variation of standard plate counts in the influent, the filter successfully was able to achieve consistent percent removal.

CHAPTER 6

RECOMMENDATIONS

The following recommendations are addressed for future research in this field :

1. Study the nitrification-denitrification phenomenon by introducing sufficient nitrate in the system to produce measurable values in the effluent.

2. Conduct seeding experiments by introducing sufficient pathogenic organisms to produce measurable effluent organisms concentrations to determine the removal efficiency of bacterial contaminants at high concentrations.

3. Study the removal of viruses through sand filter.

CHAPTER 7

APPLICATIONS

Saudi Arabia is an arid country that lacks natural resources of water for different purposes. Thus, the reuse of treated wastewater is worthwhile idea, since the cost of other alternative sources are very expensive. The reuse of wastewater has a valuable additional and economical sources of water for agriculture and livestock production as well as industrial use. The Kingdom is currently planning to use all wastewater for reuse. According to the Third Five Year Development Plan, the Kingdom will recycle 335 million cubic meters per year of wastewater by the year 1990, and this quantity will reach to 730 million cubic meters by the year 2000.

The major concern of wastewater reuse is related with health aspects. Along these lines, the standards set for unrestricted irrigation according to the Riyadh Region Water and Sewage Authority and Ministry of Agriculture and Water as follows :

BOD = 10 mg/l, TSS = 10 mg/l, NO_3 = 10 mg/l, and Fecal coliforms 7 day average values of 2.2 MPN/100 ml, no value above 23 MPN/100 ml in 30 days period. However, the criteria for reuse of wastewater for irrigation now under discussion is likely to be much more stringent, and most of the existing treatment plants in the Kingdom may not meet the requirements without an advanced tertiary treatment unit.

Slow sand filters can not only be the simplest and cheapest, but also be the most efficient process for the tertiary treatment. In addition to that, their poor performance in temperate climate and their large land area requirements are not a problem in the Kingdom.

Study has been carried out to evaluate slow sand filtration at pilot-scale as a means of tertiary treatment for secondary wastewater effluents for reuse purposes. The pilot-scale filter operated over a period of one year was successfully able to achieve consistent removal. The average percent removals achieved of turbidity, BOD, COD, standard plate counts, and total coliform bacteria were 95, 89, 67, 93 and over 99% respectively. In view of the results, the effluent resulted by the pilot-scale filter would easily qualify for unrestricted irrigation according to the standards employed in the Kingdom.

As a result of that, the Kingdom should undertake pilot plant studies of tertiary treatment by slow sand filtration at a larger scale. The recommended procedure is to build a portable pilot plant of sufficient capacity to simulate full scale condition. In addition to the necessary facilities to conduct routine chemical and bacteriological analysis. The pilot plant and supporting laboratory can then be set up in various wastewater treatment plants throughout the Kingdom.

According to the findings, if the slow sand filter will be constructed to treat similar secondary effluent for reuse purposes, the following design recommendations can be incorporated to produce the most efficient slow sand filtration system :

* Use local sand with effective size of 0.31 mm or 0.56 mm and uniformity coefficient of 2 or less. The expected operation periods of the filter without cleaning would be 26 and 84 days, respectively.

* Operate the filter at hydraulic loading of 0.16 m/hr.

* Start the filter at a sand depth of 135 cm, which can be terminated when it reaches depth of 55 cm due to scrapping. At this time, new sand can be added to raise its depth to 135 cm again.

* Slow sand filtration should be applied after secondary treatment.

* Control the excessive growth of algae in the influent for successful operation of the system such as prevention of exposure of the influent to sunlight by covering the feed reservoir.

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