International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:4, No:2, 2010

Effect of a Gravel Bed Flocculator on the Efficiency of a Low Cost Water Treatment Plants

Alaa Hussein Wadi

Abstract**—**The principal objective of a water treatment plant is to produce water that satisfies a set of drinking water quality standards at a reasonable price to the consumers. The gravel-bed flocculator provide a simple and inexpensive design for flocculation in small water treatment plants (less than 5000 m^3/day capacity). The packed bed of gravel provides ideal conditions for the formation of compact settleable flocs because of continuous recontact provided by the sinuous flow of water through the interstices formed by the gravel.

The field data which were obtained from the operation of the water supply treatment unit cover the physical, chemical and biological water qualities of the raw and settled water as obtained by the operation of the treatment unit. The experiments were carried out with the aim of assessing the efficiency of the gravel filter in removing the turbidity, pathogenic bacteria, from the raw water. The water treatment plant, which was constructed for the treatment of river water, was in principle a rapid sand filter.

The results show that the average value of the turbidity level of the settled water was 4.83 NTU with a standard deviation of turbidity 2.893 NTU. This indicated that the removal efficiency of the sedimentation tank (gravel filter) was about 67.8 %. for pH values fluctuated between 7.75 and 8.15, indicating the alkaline nature of the raw water of the river Shatt Al-Hilla, as expected. Raw water pH is depressed slightly following alum coagulation. The pH of the settled water ranged from 7.75 to a maximum of 8.05.

The bacteriological tests which were carried out on the water samples were: total coliform test, E-coli test, and the plate count test. In each test the procedure used was as outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, and WPCF, 1985). The gravel filter exhibit a low performance in removing bacterial load. The percentage bacterial removal, which is maximum for total plate count (19%) and minimum for total coliform (16.82%).

Keywords**—**Gravel bed flocculator, turbidity, total coliform.

I. Introduction

THE principal objective of a water treatment plant is to produce water that satisfies a set of drinking water quality standards at a reasonable price to the consumers. A water treatment plant utilizes many treatment processes to produce water of desired quality. These processes generally fall into two broad divisions: unit operations and unit processes, the removal of contaminants is brought about by the physical forces, in the unit processes; however, the treatment is achieved by chemical and biological reactions. Often the terms unit operation and unit process are used interchangeably, because many processes are integrated combinations of operations serving a single primary purpose. As an example, turbidity removed by coagulation combines chemical addition, mixing and dispersion, flocculation, and settling.

The selection of plant capacity, which is dependent upon many factors including population, design period, storage facilities, the distance between source and plant, and financial resources. Selection of the design period alone is no simple matter, depending as it does on rate of population growth, interest rates (which are a function of financial resources), ease of expansion of facilities, and the useful life of component structures and equipment [1].

II. Objectives

The main objectives of the present work are:

1. To determine the feasibility of using “gravel bed flocculator” as sedimentation media to treat surface waters, for producing water with turbidity less than 5 NTU.
2. To determine the contribution of gravel bed flocculator as a pretreatment process for raw water. Through the removal efficiency of turbidity.
3. To determine the bacterial percentage removals for the gravel bed flocculator.

III. Small Treatment Unit

A small developed compacted Model HH-4 treats water from pressurized water sources and re-pressurizes it for distribution. Water enters the system under pressure and flows through 5- micron and activated carbon filters and the disinfection unit. Clean water is discharged to a 56-gallon storage tank. Water is than pumped into a pressure tank, from which it is fed into the house under pressure, providing 4-5 gpm (15-19 lpm) at 45 psi.

Model HH-4 includes the UV water works disinfection unit, one 5-micron and one activated carbon filter, one pressure tank and pump, and controls to automate pump functions and system operation. The system can be installed outdoors or indoors. Each model includes an extra UV lamp and fuse and one set of replacement filter cartridges, which should last for one year under normal usage.

Author is with University of Babylon, College of Engineering, Civil Engineering Department, Iraq.

IV. Flocculation

The coagulation process chemically modifies the colloidal particles so that the stability forces are reduced. To insure that a maximum amount of turbidity is removed, mixing condition and energy input must be properly provided after rapid mixing, to allow the aggregation destabilized particles. The coagulated water must be gently stirred to promote the growth of the floc. This process is known as flocculation. The precipitate initially forms into small particles that cannot readily be settled or filtered. In the flocculation process, the mixture is gently stirred to promote the growth of the floc to a size that can be removed by sedimentation and filtration. The typical floc size is in the range from 0.1 to 2.0 mm.

The terms parakinetic and orthokinetic are often used in describing the coagulation flocculation process. Parakinetic refers to the growth of particles as a result of interparticle contacts due to Brownian motion. Orthokinetic refers to particle growth as a result of interparticle contacts due to fluid motion. Parakinetic coagulation alone is typically inefficient for turbidity removal. Only in extremely high solids concentrations will a sufficient number of particle collisions occur due to Brownian motion. In most water treatment processes, orthokinetic flocculation predominates as a mechanism to promote particle growth.

A. Types of Flocculators

Flocculation units are often divided into two general groups: (1) hydraulic flocculators, and (2) mechanical flocculators. The hydraulic flocculators simply utilize cross-flow baffles or 180^0 turns to produce the required turbulence. The critical design objective in hydraulic flocuulators is to achieve gentle, uniform mixing that will not shear the floc. These types of flocculators are effective only if the flow rate is relatively constant. They are rarely used in medium- and large-sized water treatment plants, because of their sensitivity to flow changes. In mechanical flocculators, any of the mixes can also be used (at a reduced speed) for flocculation. The mixes typically used in flocculation basins are horizontal-shaft *paddle wheel* flocculatrs. The turbine types are axial-and radial-flow vertical and horizontal flocculators. In addition to mixer types, other common flocculators are the *walking beam* type and the *oscillating* type.

B. Gravel-bed Flocculators

The gravel-bed flocculator provide a simple and inexpensive design for flocculation in small water treatment plants (less than 5000 m^3/day capacity).it has tested experimentally and employed successfully in several upflow-downflow plants in India [2](*Kardile*, 1981) and in package plants in Parana, Brazil [3](*Wagner*, 1982). The packed bed of gravel provides ideal conditions for the formation of compact settleable flocs because of continuous recontact provided by the sinuous flow of water through the interstices formed by the gravel. The velocity gradients that are introduced into the bed area are a function of: (1) the size of the gravel, (2) rate of flow, (3) cross-sectional area of the bed, and (4) the head loss across the bed. The direction of the flow can be either upward or downward, and is usually determined from the design and hydraulic requirements of other process units in the plants.

A unique characteristic of this type of hydraulic flocculator is its ability to store agglomerated flocs within the interstices or to settle flocs on top of or below the gravel bed (depending on the direction of flow) due to the sudden drop in velocity as the flow of water emerges from the bed. Moreover, the sludge storage capabilities of gravel-bed flocculators make them ideal pretreatment units prior to filtration in small plants, often eliminating the need for a separate sedimentation step.

Assuming laminar flow across the gravel bed, velocity gradient, and head losses in gravel bed flocculators can be estimated from the following equations [1]:

$$G = [(h\,\rho\,g\,Q)/\,(V)]^{1/2} \quad (1)$$

$$h = (f/\theta)\,((1\text{-}\alpha)/\alpha^3)\,(Lv^2/dg) \quad \textit{(Karmin-kozeny equation)} \quad (2)$$

$$f = 150\,((1\text{-}\alpha)/N_R) + 1.75 \quad (3)$$

$$N_R = dv\,\rho/\mu \quad (4)$$

Where G = velocity gradient (sec^{-1}).

h = head loss (m).

ρ = specific gravity of water (kg/m^3).

g = gravity constant (9.8 m/sec^2).

Q = flow rate (m^3/sec).

μ = dynamic viscosity (kg/m.s).

α = porosity (~0.4).

V = volume of gravel bed (m).

f = friction factor.

L = depth of gravel bed (m).

θ = shape factor (~0.8).

N_R = Reynolds number.

d = average size of gravel (m).

v = face velocity (m/s).

When greater accuracy is desired, G-values may be determined from bench-scale experiments. Plastic cylinders are filled with the desired gravel medium at the same depth as the full-scale gravel-bed flocculator, and arrangements are made for measuring head loss at several points along the length of the cylinder. After sufficient head loss data are collected for a range of flows, the corresponding velocity gradients can be calculated from Eq. 1.

Tapered velocity gradients are achieved in gravel-bed flocculators by changing the cross-sectional area of the bed and/or by grading the bed with different-sized layers of gravel. The downward flow unit in Fig. 1 is comprised of a graded gravel bed ranging in size from 20 to 60 mm from top to bottom inside a concrete masonry chamber, and supported on mild steel grating. The hopper bottom in the chamber has 45^0 slopes, and is used to drain sludge under hydrostatic pressure.

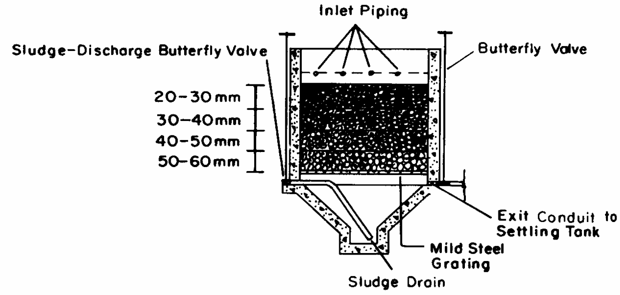

Fig. 1 Down-flow gravel bed flocculator, [2]

The upward flow unit, shown schematically in Fig. 2, combines two sizes of layered gravel (5 to 10 mm and 10 to 20 mm) with sections of increasing cross-sectional area to produce the desired tapering. The velocity gradients range from 1230 s at the inlet (where rapid mixing occurs), to 35 s in the uppermost and largest section for a flow rate of 270 m^3/day. The traced shape of the flocculator is formed from mild steel and is protected by corrosion-proof paint and supported by horizontal rods attached to an outer concrete chamber. This design has been used in package plants in India.

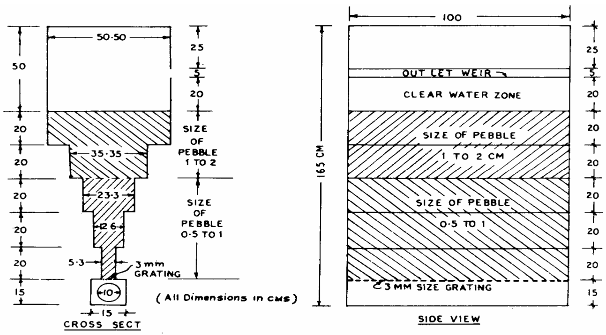

Fig. 2 Upward flow gravel bed flocculator, [4]

Flocculation time can be reduced considerably by using gravel beds, because the entire bed is effective in the formation of sizable flocs and there is very little short-circuiting. Three to 5 min flocculation in the gravel bed is equivalent to 15 min in jars under laboratory conditions, and to 25 min in noncompartmented plant flocculaton basins as revealed in Fig. 3 [5]. Depth of gravel bed generally varies from 1.5 to 3 m. Flocculated water may be conveyed from the flocculation chamber to the settling tanks via submerged perforated pipes or channels. The sedimentation step is often omitted in small plants, and the flocculated water is applied directly to the filter, as in filtration.

The main problem with gravel-bed flocculators is likely to be one of fouling, either by intercepted flocs or biological growth in the gravel. Therefore, sludge collection and removal is an important consideration in the design of such units. For downward flow units, hopper bottoms, such as that depicted in Fig. 1, drain the sludge by hydrostatic pressure. Upward flow units often rely on a perforated drainage pipe grid, located just above the top of the bed, for removing the sludge that is deposited on the surface of the gravel. Both types of flocculator units should include arrangements for draining the water from the flocculator chamber to waste, and backwashing capabilities to remove sludge settled within the bed.

Gravel-bed flocculator have proven to be simple, low cost, and an effective method of flocculation for several small water treatment plants in India [2], and they have been used recently in modular plants in Latin America [6]. They have also been installed in low-cost package water treatment plants designed and manufactured in India [4].

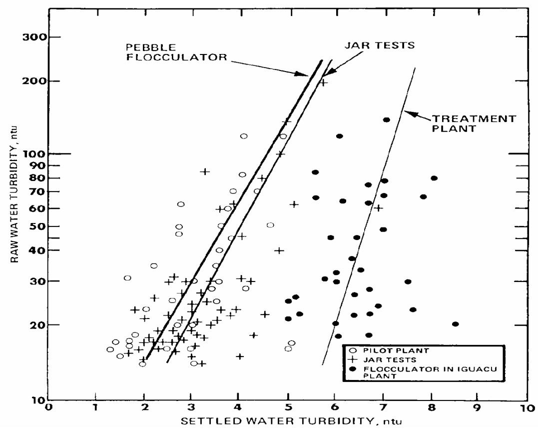

Fig. 3 Comparison of results of gravel bed (pebble) flocculation in the pilot plant with results of jar tests with the full scale plant flocculator at the Iguaçu plant in Curitiba, Brazil, [7]

C. Detention Time in Flocculation Basin

The detention time in flocculation basins is much higher than that in rapid-mix basins. Detention times from 20 to 60 minutes are common. The key design factor in a flocculation basin is the value of Gt (velocity gradient × detention time), because the number of particle collisions within the basin is directly proportional to the value of Gt. Typical Gt values range from 10,000 to 150,000. As with rapid mixing, the deign parameters for a flocculation facility are best determined experimentally or from experience at water treatment plants treating similar water.

V. Water Examinations

A. Turbidity

Turbidity measurements were carried out using (HACH) turbidmeter model 2100 A. the turbidity of the raw water, and the filter effluent were measured.

B. PH Measurements

pH measurements were carried out using pH-meter (PW 9418 pH-meter). APHA 1985, reported that the measurement of pH is one of the most important and frequently used test in water and wastewater treatment e.g., acid-base neutralization, water softening, precipitation, coagulation, disinfection and corrosion control is ph dependent.

C. Bacteriological Measurements

1. Standard Plate Count

Standard plate count is the total colonies of bacteria developing from measured portions (two 1- ml and two 0.1 - ml) of the water being tested, which have been planted in Petri dishes with a suitable culture media (agar) and included for 48 hrs at 37 ^{0}C and 72 hr at 20 to 22 ^{0}C [8]. The standard plate counts are made by counting the number of the colonies of bacteria which develop and are visible under magnifying glass [9].

2. Total Coliform Test (Presumptive Test)

The study adopted the multiple fermentation technique [10]. The coliform bacteria is capable of fermenting lactose with production of an abundance of gas at 37 ^{0}C. to enumerate the number of gas producing organisms in a sample from raw water, a series of three diction tube (0.1, 0.01, 0.001) ml with five tubes for each dilution are made and a 1-ml sample from each dilution transferred to each of five test tubes which contain the culture medium (MacConkey broth) with single strength and gas collection tubes (Durham tubes). The accumulation of gas in the invert Durham tubes after 24-48 hrs is considered to be a positive reaction [11].

3. Most Probable Number Technique

The MPN is not actual enumeration of coliform bacteria in any given volume of sample. It is however, a valuable tool for appraising the sanitary state of water and the effectiveness of water treatment processes [10]. For simplicity, tables were prepared to approximate quickly the results, as shown in table 1 [11].

TABLE I
MOST PROBABLE NUMBER OF COLIFORM BACTERIA PRESENT IN THE SAMPLE FOR DRINKING WATER STANDARD, U.S., PUBLIC HEALTH SERVICE [11]

No. of portions		M.P.N of coliform bacterial/100 ml	
Negative	Positive	When 5-10 ml portions are examined	When 5-100 ml portions are examined
5	0	Less than 2.2	Less than 0.22
4	1	2.2	0.22
3	2	5.1	0.51
2	3	9.2	0.92
1	4	16.0	1.6
0	5	More than 16.0	More than 1.6

VI. RESULTS AND DISCUSSIONS

The field data which were obtained from the operation of the water supply treatment unit are analyzed and discussed here. The data cover the physical, chemical and biological water qualities of the raw and settled water as obtained by the operation of the treatment unit. The experiments were carried out with the aim of assessing the efficiency of the gravel filter in removing the turbidity, pathogenic bacteria, from the raw water. The water treatment plant, which was constructed for the treatment of river water, was in principle a rapid sand filter.

A. Turbidity Data Analysis

Figs. 4 shows the water turbidity profiles of the raw, and settled water streams for the period from 17th April to 25th May of 2005. It is interesting to note the little variation in the level turbidity of the raw water throughout this period. From this figure it can be seen that the turbidity levels of the settled water resembled that of the raw water. However it has a lower mean value and a smooth shape. This is expected since such settling tank acts as low-pass filter, i.e.; smoothing short time, like spikes [12].

The average value of the turbidity level of the settled water was 4.83 NTU with a standard deviation of turbidity 2.893 NTU. This indicated that the removal efficiency of the sedimentation tank (gravel filter) was about 67.8 %.

It can be seen from Fig. 5 which shows the cumulative percentage removal of turbidity of the water through the different units of the filter plant for the water of the River of Shatt Al-Hilaa. It can be seen that the gravel filter achieved about 67.8 % removal.

TABLE II
STATISTICAL DESCRIPTION OF DAILY TURBIDITY SUPPLIES WATER OF TREATMENT PLANT

	Settled water turbidity, NTU	Raw water turbidity, NTU
Average	4.83	15
Standard dev.	2.893	3.733
Minimum	2.6	7
Maximum	10	20

B. Water pH

Fig. 6, show plots of pH variation of the settled water and the influent stream into the water purification unit. It is observed that the pH values fluctuated between 7.75 and 8.15, indicating the alkaline nature of the raw water of the river Shatt Al-Hilla, as expected. Raw water pH is depressed slightly following alum coagulation. The pH of the settled water ranged from 7.75 to a maximum of 8.05.

C. Biological Water Quality

Bacteriological analysis was carried out on raw water and settled water. The bacteriological tests which were carried out on the water samples were: total coliform test, E-coli test, and the plate count test. In each test the procedure used was as outlined in the Standard Methods for the Examination of Water and Wastewater [13].

Fig. 7 through 9 shows the results of the bacteriological test using plate count technique at 37 ^{0}C on the water of the River Shatt Al-Hilla and on the settled water from the gravel filter. Here again, these figs. indicates that the gravel filter exhibit a low performance in removing bacterial load. Fig. 10 shows the percentage bacterial removal, which is maximum for total plate count (19%) and minimum for total coliform (16.82%).

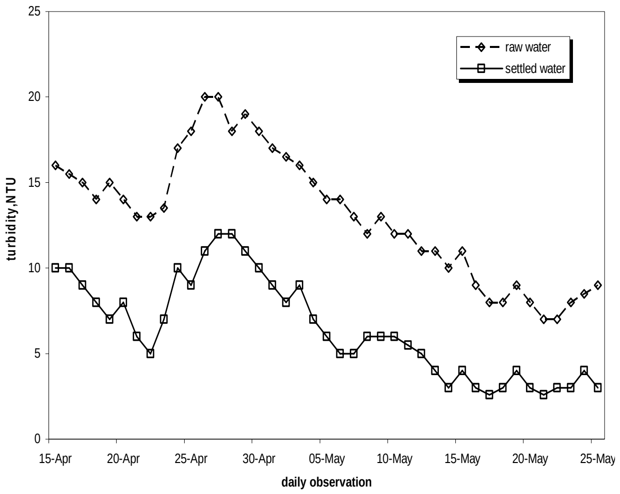

Fig. 4 Raw and settled water turbidity profile

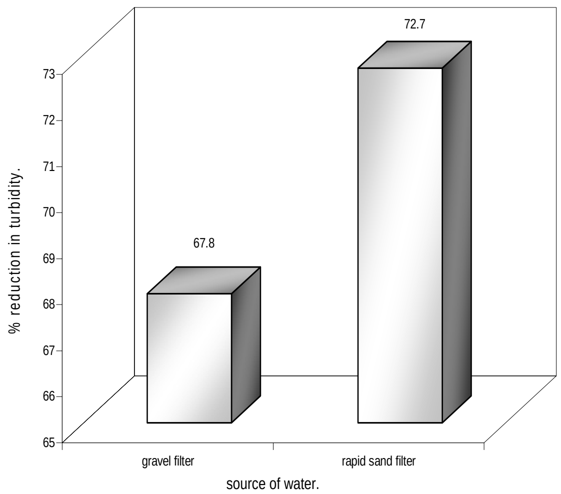

Fig. 5 Comulative Improvement in Water Quality (Turbidity Removal) in Water Treatment System

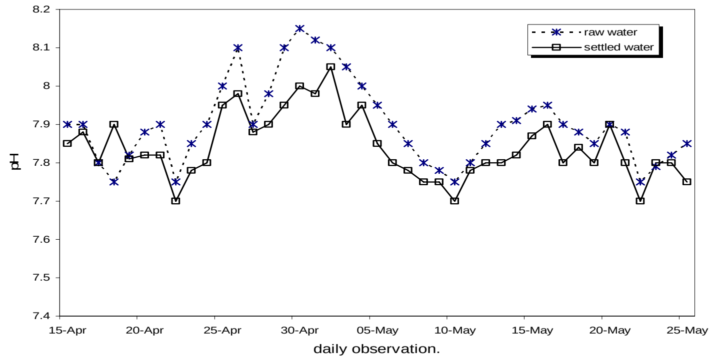

Fig. 6 Raw and Settled Water pH Profile

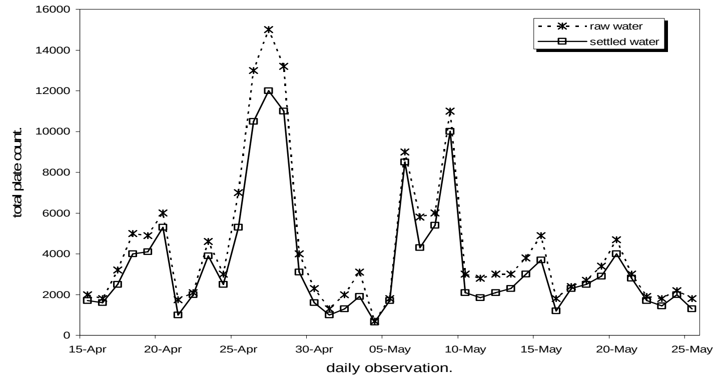

Fig. 7 Raw and Settled Water Total Plate Count Concentration Profile

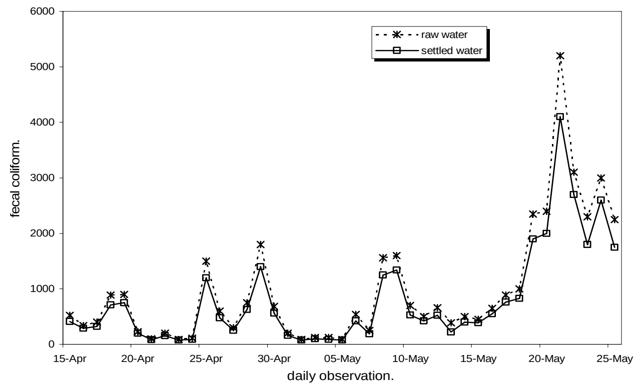

Fig. 8 Raw and settled water fecal coliform concentration profile

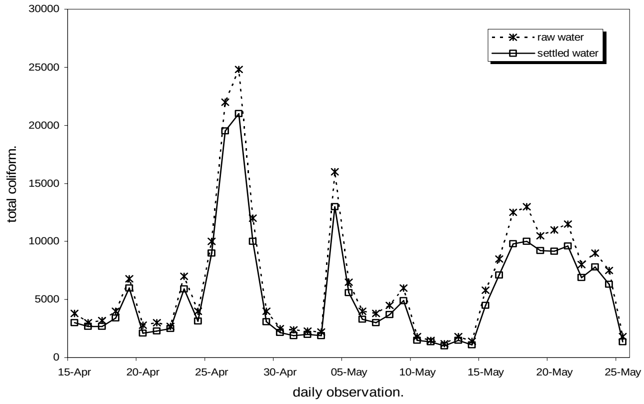

Fig. 9 Raw and settled water total coliform concentration profile

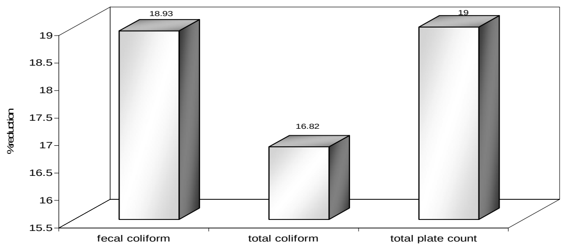

Fig. 10 Comulative improvement in water quality (bacteria removal)

REFERENCES

[1] Fair, G.M., J.G. Geyer, and D.A. Okun, 1971, “Element of Water Supply and Wastewater Disposal,” Wiley, New York.

[2] Kardile, J.N., 1972, “Crushed Coconut Shell as a New Filter Media for Dual and Multi-Layer Filters,” Jour. Indian water works assoc., vol. 1, no. 1.

[3] Wagner, G., 1982, “The Latin America Approach to Improving Water Supply,” Jour. AWWA, Vol. 74, No. 4.

[4] Bhole, A.G., 1981, “Design and Fabrication of a Low Cost Package Water Treatment Plant for Rural Areas in India,” AQUA, No. 5.

[5] Wagner, G., 1982, “The Latin America Approach to Improving Water Supply,” Jour. AWWA, Vol. 74, No. 4.

[6] CEPIS 1982, “Modular Plants for Water Treatment,” Vol. 1 and Vol. 2, Technical Document No. 8, Pan American Health Organization, Lima, Peru.

[7] Richards, P.A., 1996, “Unit Operations and Processes in Environmental Engineering,” 2nd ed., PWS Publishing Co., Boston, MA.

[8] Salvato, J.A., 1982, “Environmental Engineering And Sanitation”, 3rd Ed., ,” John Wiley & Sons Inc., New York.

[9] AWWA, 1999, “Water Quality and Treatment,” 5th ed., McGraw-Hill Book Co., New York.

[10] AWWA, 1990, “Water Quality and Treatment: A Handbook of Public Water Supply,” 4th ed., McGraw-Hill, Inc., New York.

[11] Tchobanoglous, D. and Schroeder, E., 1985, “Water Quality”, Addison Wesley Publishing Co., Reading, Mass.

[12] Al-Samawi, Adnan, 1979, “Time Series Analysis of Rectangular Sedimentation Tank”, Ph.D thesis, University of Strathclyde, U.K.

[13] APHA, AWWA and WPCF, 1985, “Standard Methods for the Examination of Water and Wastewater”, 16th ed., American Public Health Association, Washington, U.S.A.