THE EFFECT OF SAND FILTER CHARACTERISTICS ON REMOVAL EFFICIENCY OF ORGANIC MATTER FROM GREY WATER

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ABSTRACT

The specific goals of this study are to determine the optimum inflow to the filters (hydraulic loading rates) and media characteristic such as the effective size, the particle size distributions within the bed media. In addition to modify the traditional slow sand filter to gain better flow control to treat grey water of high turbidity. Three set of experiments were carried out during nine months from April to December in Mustansiryiah University, college of engineering, environmental hydraulic laboratory.

The first set of experiments were achieved by using (1m height) sand of effective diameter 0.35 mm, uniformity coefficient, UC=2.2 and porosity (39%), the second set of experiments were carried out by using sand of 0.75mm diameter, UC= 2.9 and porosity (43%) to study the effect of grain size of sand on water head over sand surface and removal efficiency. While the other set of experiments were done by using (0.7m height) sand of effective diameter 0.35 mm, UC=2.2 and porosity (39%) to study the effect of filter height of sand on removal efficiency.

Measurements of chemical, physical and bacterial parameters were achieved during nine months from April to December. These parameters include turbidity, pH, PO_4^{-2}, BOD_5, COD, TDS, TSS, and coliform removal for treated grey water.

Results show that filter loading rate has been determined to be not more than 680 L/hr/m^2 which removal efficiency of BOD_5 was (51%) and minimum filter loading rate has been tested to be 212 L/hr/m^2 which removal efficiency of BOD_5 was (83%).

Key words: Slow Sand Biofilter, Grey Water, BOD, COD, Effective Diameter.

تاتير خصائص المرشح الرملي على كفاء ازاله المواد العضويه من المياه الرماديه

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المستخلص:

الاهداف الرئيسية لهذه الدراسة هي تحديد التصريف الامثل الداخل للمرشحات (معدلات التحميل الهيدروليكي) وتحديد مواصفات وسط المرشح مثل الحجم الفعال وتوزيع احجام وسط المرشح بالنسبة الى طبقات المرشح، اضافة الى التعديل على مرشحات الرمل البطئية للحصول على افضل تحكم في التصاريف في معالجة المياه الرمادية عالية العكورة.

ثلاث مجاميع من التجارب اجريت خلال فترة الدراسة التي استمرت تسعة اشهر (من نيسان الى كانون الاول). المجموعة الاولى تمت باستخدام مرشح رملي بارتفاع (١ م) وقطر فعال (٠.٣٥ ملم) ومعامل التماثل (UC=2.2) ونفاذية مقدارها (٣٩%). المجموعة الثانية من التجارب تمت باستخدام مرشح رملي بحجم فعال (٠.٧٥ ملم) ومعامل تماثل (UC=2.9) ونفاذية مقدارها (٤٣%)وارتفاع (١ م)، اما المجموعة الاخيرة من التجارب فقد تمت باستخدام مرشح رملي بارتفاع (٠.٧ م) وحجم فعال (٠.٣٥ ملم) ومعامل تماثل (UC=2.2) ونفاذية (٣٩%).

شملت الدراسة اجراء فحوصات العناصر الفيزياوية والكيمياوية والبكترولوجية خلال فترة، هذه العناصر هي: العكورة، الدالة الحامضية، الفسفور، الطلب الحيوي على الاوكسجين، الطلب الكيمياوي على الاوكسجين، المواد العالقة الكلية، الاملاح الذائبة الكلية، وبكتريا الكوليفورم.

اظهرت النتائج بان اقصى حمل هيدروليكي هو (٦٨٠ لتر/ساعة/م٢) والذي اعطى كفاءة ازالة لـ BOD مقدارها (٥١%) فيما كان اقل حمل هيدروليكي (٢١٢ لتر/ساعة/م٢) والذي اعطى كفاءة ازالة لـ BOD مقدارها (٨٣%).

INTRODUCTION

The process Slow Sand Filtration (SSF) percolates untreated water slowly through a bed of porous sand, with the influent water introduced over the surface of the filter, and then drained from the bottom.

Biosand filter was designed and constructed for removing suspended organic, inorganic matter and pathogenic organisms. The treatment technology must be economical to build, and simple to operate and maintain given the adverse economic and environmental conditions. For these reasons, slow sand filtration has been selected as a potential water treatment technology. The resulting recommendations are planned around and sized appropriately for use by the many small community for water treatment in Baghdad.

The major benefits of slow sand filtration are due to the microbiology of the filter. The microbiological community must be kept alive for the filter to be effective. In a conventional slow sand filter, oxygen is supplied to the organisms through dissolved oxygen in the water. Consequently, they are designed to be operated continuously. In addition, because the water moves through at a slow rate, the filter beds tend to be very large.

A bucket of water is poured into the top of the filter as necessary. The water simply flows through the sand media and is collected in another bucket or gravel container at the base of the spout. It normally takes a few minutes for the entire bucket to make its way through the filter. There are no valves or moving parts and the design of the outlet system ensures that a minimum water depth of five centimeters is maintained over the sand when the filter is not in use. When the water is flowing through the filter, oxygen is supplied to the biologic layer at the top of the sand by the dissolved oxygen in the water. When water sand levels is too shallow (less than 50mm) biolayer dries out especially in hot days during periods from May to September causing major problem for restarting after back washing and pause period. An other problems may be occurred when water sand level is too deep (more than 500mm during continuous run and 100mm during pause period) because of insufficient oxygen for biolayer.

LITERATURES SURVEY

Originating in Europe, slow sand filtration is classified as the first, modern water treatment technology (Ellis, 1985). This filtration process removes particles and microorganisms by the slow percolation of water through a porous sand media. Unlike other water treatment technology (i.e. rapid sand filtration), conventional slow sand technology does not involve chemical or physical pre-treatment applications (Collins etal, 1992).

Problems associated with highly turbid waters made conventional slow sand treatment impractical for communities plagued with such source water. Conventional slow sand filters clogged under such conditions, and the technology of choice became rapid sand filtration, due to its ability to produce large quantities of acceptable finished water from highly turbid source water

(Ellis, 1985). An additional factor influencing the move to rapid sand filtration was public support for the newest technology available, regardless of community size (Logsdon, 1991).

Recently, however, slow sand filtration technology has received a resurgence of interest in the United States (Logsdon, 1991). Increased concerns regarding the persistence of *Giardia* cysts in many municipal water systems has led to a greater interest in slow sand technology (Lange, Bellamy, Hendricks and Logsdon, 1986; Fogel, Isaac-Renton, Guasparini, Moorehead and Ongerth, 1993). With the 1989 passage of the Surface Water Treatment Rule (SWTR) in the United States, many previously unfiltered surface water sources now require filtration (Logsdon, 1991; Brink and Parks 1996). The United States Environmental Protection Agency (EPA) has set a turbidity standard < 1 nephelometric turbidity unit (NTU) 95 percent of the time, never to exceed 5 NTU's. Furthermore, the removal or inactivation of *Giardia* cysts is to be > 3-logarithmic (log) and virus removals are to be > 4-log removal. Removals of microorganisms in slow sand filters have proven to be 2 – log to 4 – log in effluent of slow sand filters (Hendricks and Bellamy, 1991). The effectiveness of slow sand filtration in removing *Giardia* cysts is well documented (Fogel et al., 1993; Bellamy, Hendricks and Logsdon, 1985; Ellis, 1985). Research in the United States and Great Britain has shown the effectiveness of slow sand filtration in removing viruses and bacteria (Wheeler and Lloyd, 1988; Poynter and Slade 1977 as cited by Hendricks and Bellamy, 1991).

The effectiveness, affordability and ease of operation available with slow sand filtration systems is appealing to small communities (those under 10,000 people) that lack significant capital for constructing, operating and maintaining rapid sand filtration facilities (Riesenberg, Walters, Steele, and Ryder, 1995; Li, Ma and Du, 1996). As of 1984, a survey by Simms and Slezak identified 71 slow sand filtration facilities in operation in the United States. Brink and Parks (1996) stated that a preliminary report compiled for the American Slow Sand Association indicated that 225 such facilities were in use in the United States. It is anticipated that additional facilities will be built by small communities needing affordable, effective water treatment technology to comply with the surface water requirements established in 1989 (Logsdon, 1991; Brink and Parks, 1996).

Based on slow sand filter research, the biosand filter may also remove some heavy metals (Muhammad, 1997; Collins, 1998). There is also a design modification known as the Kanchan^{TM} Arsenic Filter that is effective in removing both pathogens and 85-90% of arsenic from source waters (Ngai, 2007).

Preliminary health impact studies estimate a 30-40% reduction in diarrhea among all age groups, including children under the age of five, an especially vulnerable population (Liang, 2007; Sobsey, 2007).

EXPERIMENTAL WORK

Grey water is pumped to the slow sand biofilter made from PVR of 1800mm height and 300mm diameter (1) to remove suspended organic matter, algae etc. Overflow outlet (4) back to holding tank (2) maintains constant depth to water layer as shown in **Figure (1)**. The slow sand biofilter consists of: a water storage layer (5), a bed of fine sand or media filter bed (6) (**Plates (1 and 2)**), diffuser plate (7) and gravel layers (9) (**Plate (3)**)to support filter bed. The outflow (10) may be fitted with a flow regulator valve to control the filtration rate, flow meter (8) is used for measured treated water flow, and a piezometers (open tube) (11) to measure filter head loss. A small collection tank (12) collects filtered water for distribution by pump (13). The thermometer (3) is put in the middle of water storage zone to measure water temperature.

The first set of experiments were achieved by using sand of effective diameter 0.35 mm, UC=2.2 and porosity (39%) (**Plate (2)**), while the other set of experiments were carried out by using sand of 0.75mm UC= 2.9 and porosity (43%) (**Plate (3)**) to study the effect of grain size of sand on water head over sand surface and removal efficiency.

The effective size ES or d10 is defined as the sieve size in mm that permits passage of 10% by weight of the sand. The uniformity coefficient (UC) of a sand is defined as d60/d10, uniform (the UC is 2.6), and be washed free of loam, clay, and organic matter. Fine particles will quickly clog the filters and frequent cleaning will be required. A sand that is not uniform will also settle in volume, reducing the porosity and slowing the passage of water.

Measurements of chemical, physical and bacterial parameters were achieved during six months from April to December. These parameters include turbidity, pH, PO_4^{-2}, BOD_5, COD, TDS, TSS, and coliform removal for treated grey water.

RESULTS

The efficiency of SSF depends on the particle size distribution of the sand, the ratio of surface area of the filter to depth and the flow rate of water through the filter.

FLOW RATES

The biosand filter has been designed to allow for a filter loading rate (flow rate per square meter of filter area) which has proven to be effective in laboratory and field tests. This filter loading rate has been determined to be not more than 680 liters/hour/square meter (Q=48L/h) which removal efficiency of BOD_5 was (51%) and the minimum filter loading rate has been tested to be 212 liters/hour/square meter (Q=15L/h) which removal efficiency of BOD_5 was (83%) (**Figure(2)**).

The percentage removal of contaminants is inversely proportional to the flow rate through the filter because the biologic reduction of contaminants takes time. The amount of water that flows through the biosand filter is controlled by the size of sand media contained within the filter. If the rate is too fast, the efficiency of bacterial removal may be reduced. If the flow rate is too slow, there will be an insufficient amount of treated water, the users will become impatient and may use contaminated sources of water.

The micro-organisms are more closely confined near the surface of the sand bed in a continuously operated slow sand filter because the oxygen supply is limited by diffusion from the surface. Because of the thin biologic zone, there is a shorter contact time between the bio film and water during filter runs. Slower filtration rates are therefore required in a biosand filter to produce water of similar bacteriological quality as a continuously operated filter.

WATER DEPTHS

Changes in the water depth will change the depth of the bio zone and removal efficiency of biofilteration. A greater water depth (500 mm) results in lower oxygen diffusion and consequently a thinner bio zone and reduce the removal efficiency. With increasing water depth (more than 500 mm), the bio-layer moves upwards in the sand bed and thus oxidation and metabolism decrease. Eventually, the filter becomes a non living system. Changes in the water depth above the sand surface will cause a change in the biological zone disrupting the removal efficiency of the filter. Results of analysis measured such as turbidity and BOD_5 show that the removal efficiency of turbidity and BOD_5 in the first biosand filter (sand of effective diameter 0.35 mm and porosity (39%) and 500mm water depth was 89% and 43% respectively, while the removal efficiency of turbidity and BOD_5 in the second biosand filter (sand of effective diameter 0.75 mm and porosity (43%) and 500mm supernatant water depth) was 81% and 64% respectively. The removal efficiencies of different depth on BOD_5 and turbidity values is shown in **Figures (3 to 5)**.

A water depth of greater than 500 mm results in lower oxygen diffusion and consequently a thinner biological zone. A high water level can be caused by a blocked outlet spout or by an insufficient amount of sand media. As the water depth increases, the oxidation and metabolism of the microorganisms within the biological zone decrease. Eventually the layer dies off and the filter becomes ineffective.

The water passes through the sand from top to bottom. Any larger suspended particles are left behind in the top layers of sand. Smaller particles of organic sediment left in the sand filter are eaten by microscopic organisms including bacteria and protozoans which ’stick’ in the layers of slime that form around the sand particles and the clean water which passes through the filter is safe to drink. Provided that the grain size is around 0.1mm in diameter, a sand filter can remove all fecal coliforms (bacteria that originate from feces) and virtually all viruses.

WATER QUALITY

Biosand filters have been shown to remove most pathogens found in raw water. If the grey water is highly contaminated, the outlet water may still have some contaminants. The same source of water should be used consistently because the biolayer cannot quickly adapt to different water quality. Over time, the micro-organisms in the biologic layer become adapted to conditions where a certain amount of food is available.

The turbidity of the source water is also a key factor in the operation of the filter. If the turbidity is greater than 50 NTU, the raw water should be settled or strained before it goes though the biosand filter.

In a slow sand filter, the filter bed is constructed of a medium with high surface area which can be colonized by suppressive micro-organisms. This fine media also presents a physical barrier to the passage of spores of plant pathogens.

In a SSF, plant pathogens recirculation in the irrigation water are captured in the filter media, and at slow rates of water filtration (100-200 $l/hr/m^2$ surface area of the first filter), are acted upon by the antagonistic micro organisms that colonized the filter bed. The maximum water level may be automated by using a float and a control valve or by periodically adjusting the valve manually to maintain the water lever near the overflow line. The depth of the filter bed has a strong influence on the effectiveness of the filtration and should be at least 0.75 - 1.0 meters.

High turbidity levels in the raw water will prematurely block the slow sand biofilter, leading to a much shortened time span between cleanings and an overall deterioration of the water quality. High turbidity in the raw water may shorten the filter life from several months to a matter of days. Other means of turbidity reduction include holding ponds and sedimentation tanks.

The processes that occur in the schmutzdecke are enormously complex and varied, but the principal one is the mechanical straining of most of the suspended matter in a thin dense layer in which the pores may be very much less than a micron. The thickness of this layer increases with time from the initial installation to the point where the flow rates become unacceptably small, when it is usually about 25 mm. The greatest benefit of the SSF lies in its ability to trap bacteria and viruses in this schmutzdecke. Bacterial and biological activity maximizes in there but will continue at a decreasing level down into the sand of the filter bed. A certain minimum level of dissolved oxygen should be present to support the aerobic actions that occur in the bed. After the initial installation of the SSF, the formation of the schmutzdecke and bacterial/biological activity in the bed may take days or weeks depending strongly on the ambient temperature. The comparsion between biosand filters (1 &2) and previous works is shown in **Table (1)**.

Slow sand filters consistently demonstrate their effectiveness in removing suspended particles with effluent turbidities below 1.0 nephelometric turbidity units (NTU), achieving 90 to 99 + percent reductions in bacteria and viruses, and providing virtually complete *Giardia lamblia* cyst and *Cryptosporidium* oocyst removal. The parameters limitations are shown in **Table (2)**.

Chlorination processes are most widely used for water disinfestations. The effectiveness of such chemical treatments in controlling plant pathogen depends on correct dosages and treatment times, control of suspended particulate matter in the recycled water, and foolproof monitoring systems. Chemical treatments have proven effective when used properly, however they are relatively expensive and present safety issues to the handlers and the environment.

Sand filters cannot cope with heavy metals or other excessive pollutants. Their prime purpose is to remove bacteria and particles. It is not appropriate to use the technology to clean up water contaminated by chemicals. If water source does have a high level of contamination, ideally you should locate a new one. If this isn't possible other methods of filtration may be used, depending on the level of contamination. If the water contains sediment, it should be passed through an initial settling tank before it gets to the sand filter.

TIME AND TEMPERATURE

It normally takes a period of three weeks for the biologic layer to develop to maturity in a new filter. During that time, both the removal efficiency and the oxygen demand of the filter increase as the biologic layer grows and increase the pressure head drop **Figure (6)**. The filters are cleaned by stirring up the thin layer of sand at the surface and scooping out the resulting dirty water. After cleaning, the removal efficiency declines somewhat, but increases very quickly to its previous level as the bio-layer is re-established. Over time, the pore opening between the sand grains will become clogged with sediment. As a result, the water flow rate through the filter will slow down.

To clean the filter, the surface of the sand must be agitated to re-suspend the sediment in the standing water. The dirty water can be removed using a small container. The process can be repeated as many times as necessary to regain the desired flow rate. After cleaning, it will take the biolayer up to a week to re-establish itself and return the removal efficiency to its previous level.

The diffuser plastic plate of 10 mm mesh diameter was designed and laid on the free sand surface to damp the strong shock of turbid grey water on sand bed and to prevent the disturbance of the sand layer when water is poured into the filter.

Different experiments were conducted to study the water temperature affects. Water temperatures ranged from 16 ^oC to 32 ^oC were experimented for biosand filter of (0.35 mm dia.) and 1 m depth as shown in **Figure (7)**.

The removal efficiency for biological treatment also depends upon empty bed contact time (EBCT), results show that efficiency of COD and BOD_5 increases when EBCT increases (**Figure(8)**).

CONCLUSIONS:

Three sets of experiments were achieved to evaluate the optimum hydraulic loading rate for two different grain sizes of sand media and two different depths of sands filter, all these experiments were achieved on grey water.

1. The removal efficiency of BOD5 increases from 51% at hydraulic loading 680 L/hr/m^2 to 83% when filter loading rate be tested at 212 L/hr/m^2.
2. The removal efficiency of turbidity for the first biosand filter (sand effective diameter d10=0.35 mm, porosity = 39%) was 89%, while the removal efficiency of the second biosand filter (d10 = 0.75mm and porosity = 43%) was 81%.
3. The removal efficiency of COD increases when empty bed contact time (EBCT) increase. The COD removal efficiency mesursed from 41% at EBCT = 48 min to 76% at EBCT = 9 min.
4. The increasing in water temperature increases the removal efficiency of BOD_5 and COD. The BOD_5 removal efficiency measured from 64% at T = 18 ^oC to 78% T = 32^oC.

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Table (1) Shows The Comparison Between
Biosand Filters (1 & 2) and Previous Works

Parameter	Biosand Filter (R1) Removal Efficiency	Biosand Filter (R2) Removal Efficiency	Previous Works
E. Coli - An Indicator of Fecal Contamination	> 91%	> 81%	> 97% (Duke, 2006; Stauber, 2006)
Protozoa and Helminthes	> 93%	90%	> 99% (Palmateer, 1999)
Viruses	Could not be tested	Could not be tested	80-90% (Stauber, 2005)
Organic and Inorganic Toxicants	56-81%	42-86%	50-90% (Palmateer, 1999)
Iron			90-95% (Ngai, 2007)
Most Suspended Sediments	98%	95%	--------

Table (2) Shows The Parameters Limitations

Parameter	Limitations
Turbidity	<1.0 NTU
Coliforms	1-3 log units
Enteric Viruses	2-4 log units
Giardia Cysts	2-4+log units
Cryptosporidium Oocysts	>4 log units
Dissolved Organic Carbon	<15-25%
Biodegradable Dissolved Organic Carbon	<50%
Trihalomethane Precursors	<20-30%
Heavy Metals	
Zn, Cu, Cd, Pb	>95-99%
Fe, Mn	>67%
As	<47%

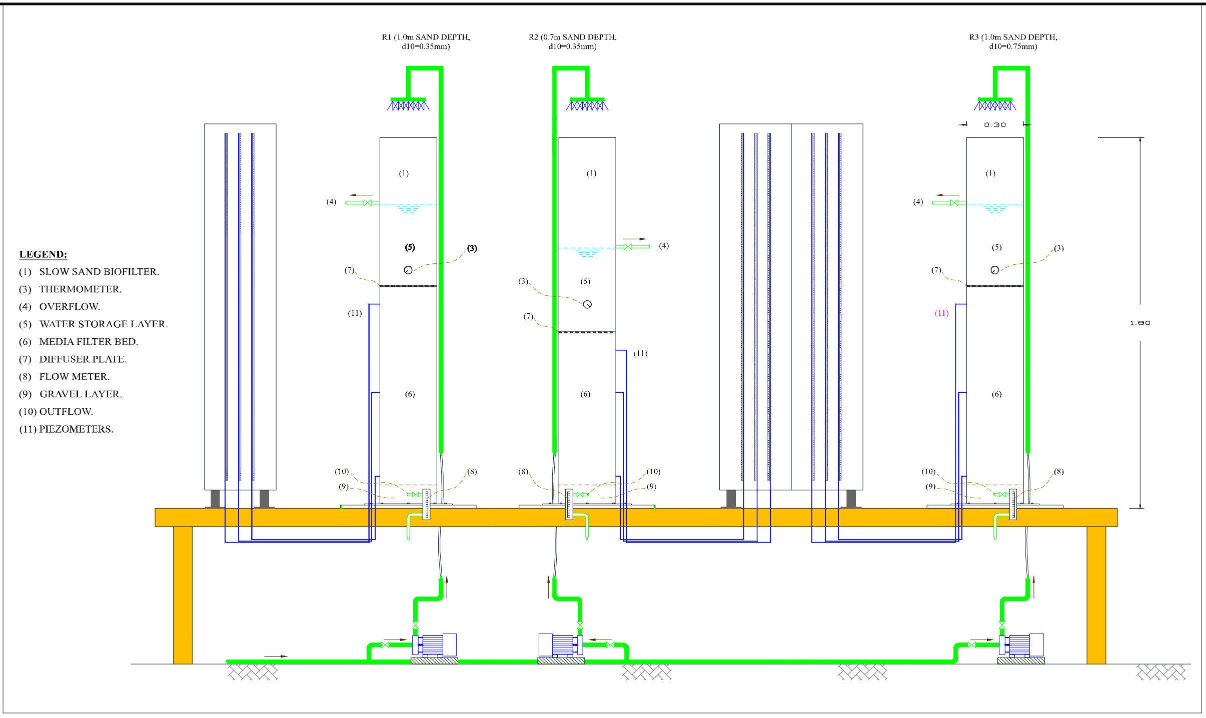

Figure (1) Filtering Systems

Plate (1) Sand Of
Effective Diameter 0.35mm

Plate (2) Sand Of
Effective Diameter 0.75mm

Plate (3) Gravel
Layer Material

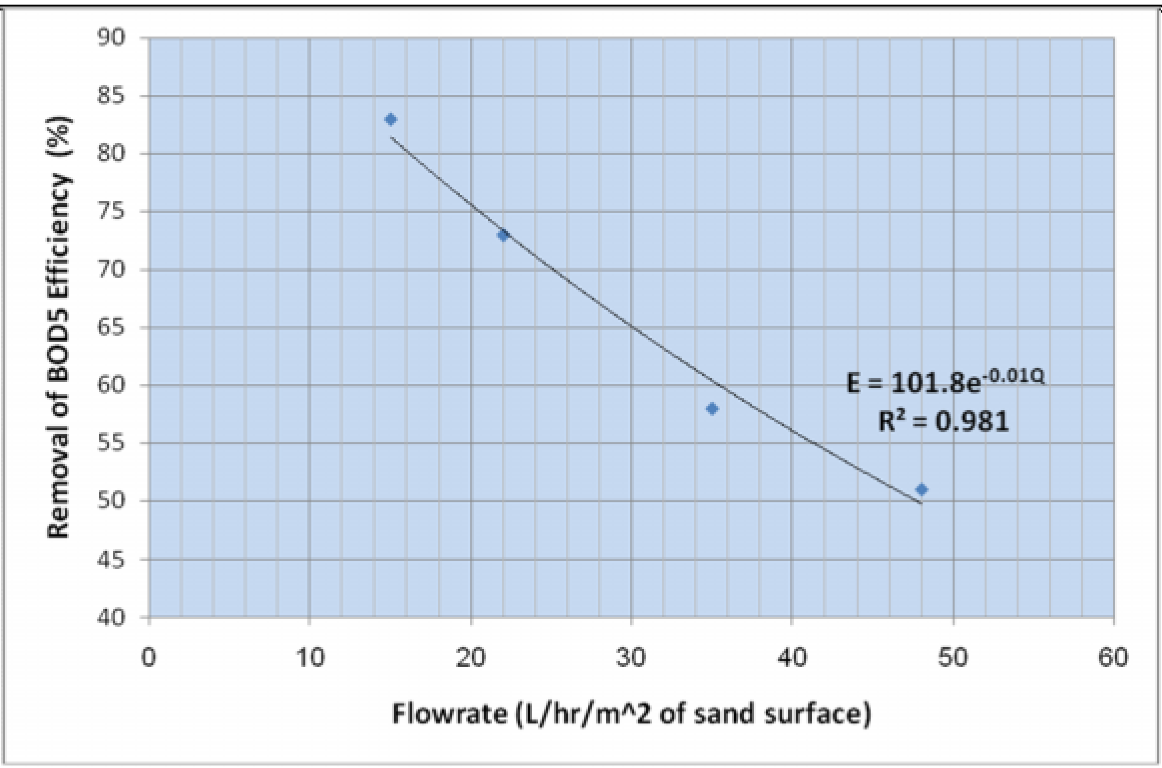

Figure (2) Effect Of Flow Rate On Removal Of BOD5 Efficiency

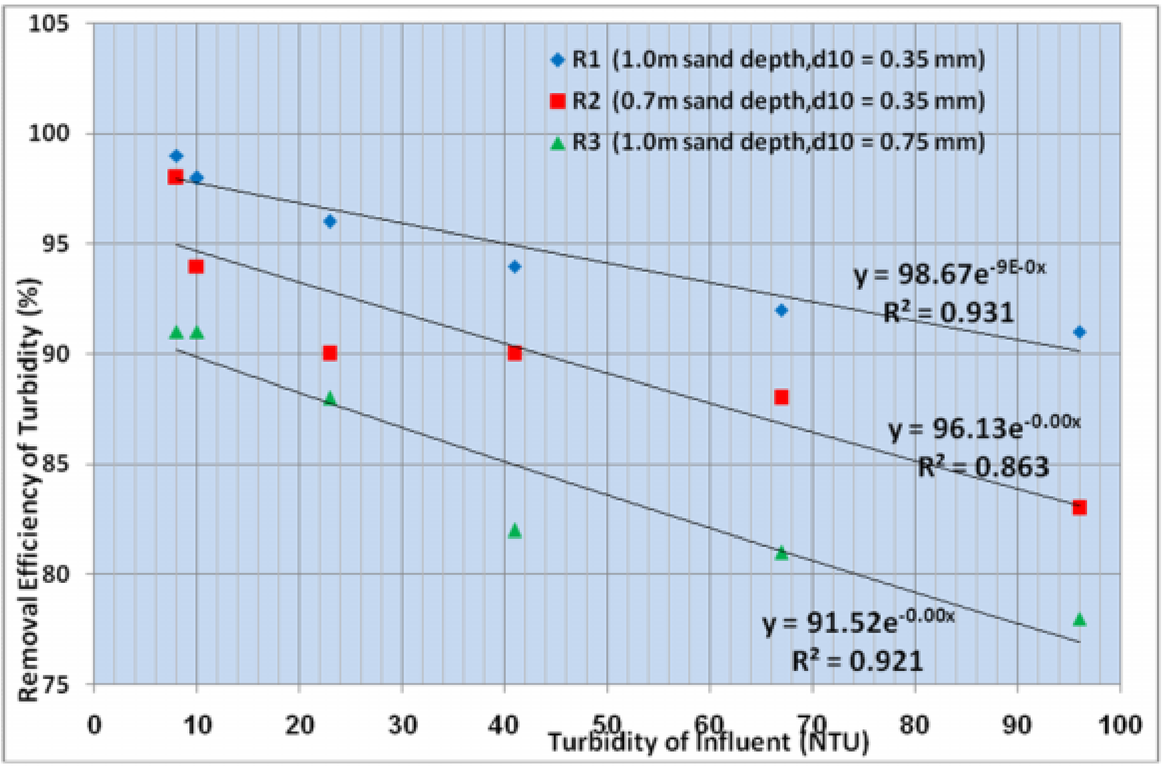

Figure (3) Relationship Between Turbidity Of Influent Water (NTU) And Removal Efficiency Of Trubidity

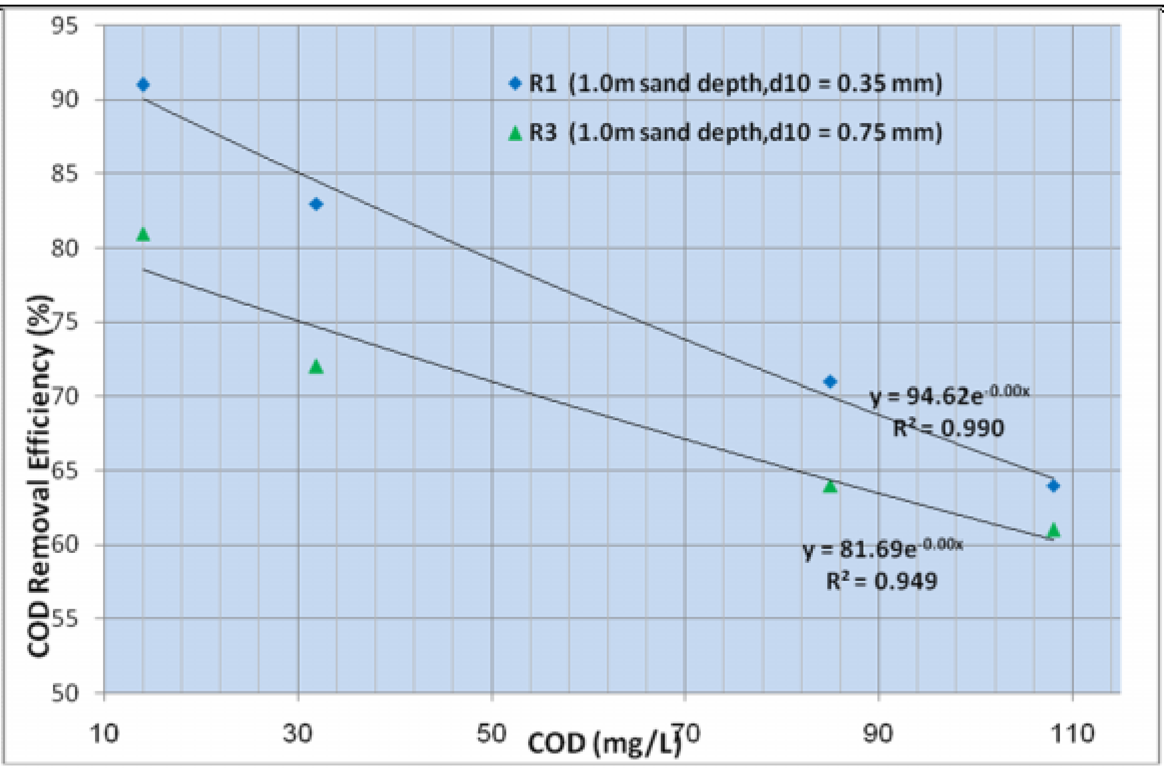

Figure (4) Relationship Between COD (Mg/L) Of Influent Water And COD Removal Efficiency For Filters (R1 And R3)

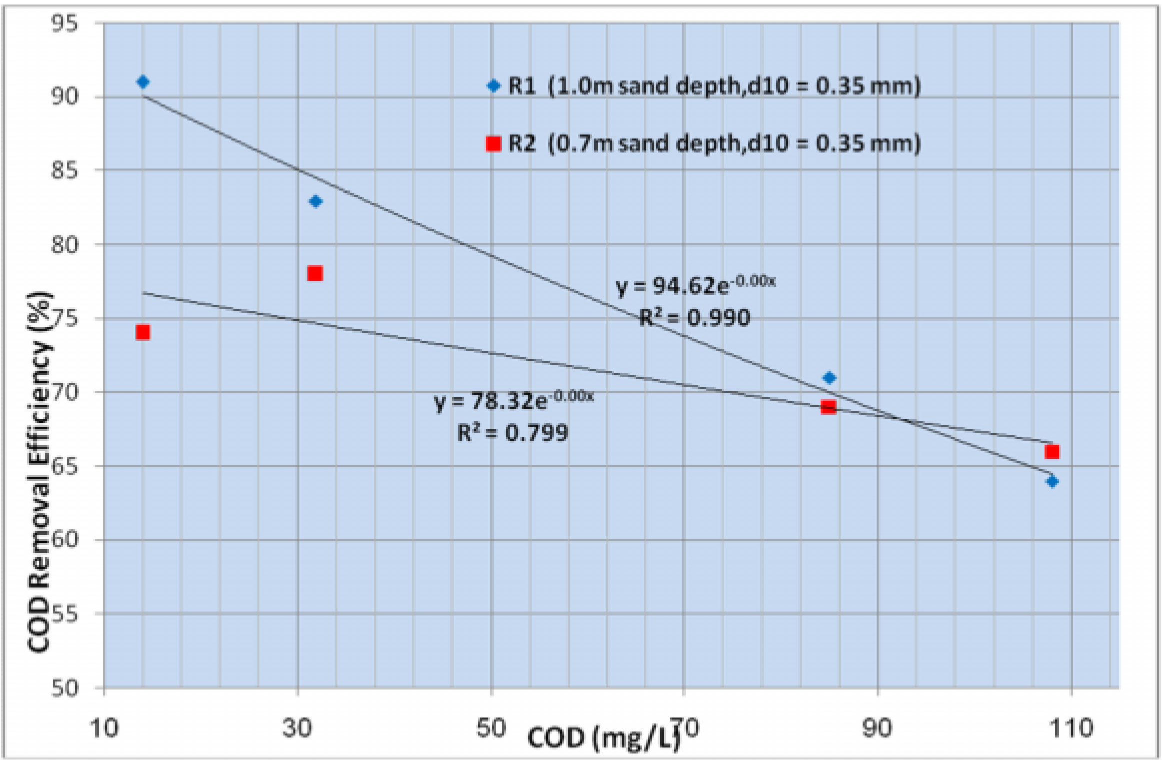

Figure (5) Relationship Between COD (Mg/L) Of Influent Water And COD Removal Efficiency For Filters (R1 And R2)

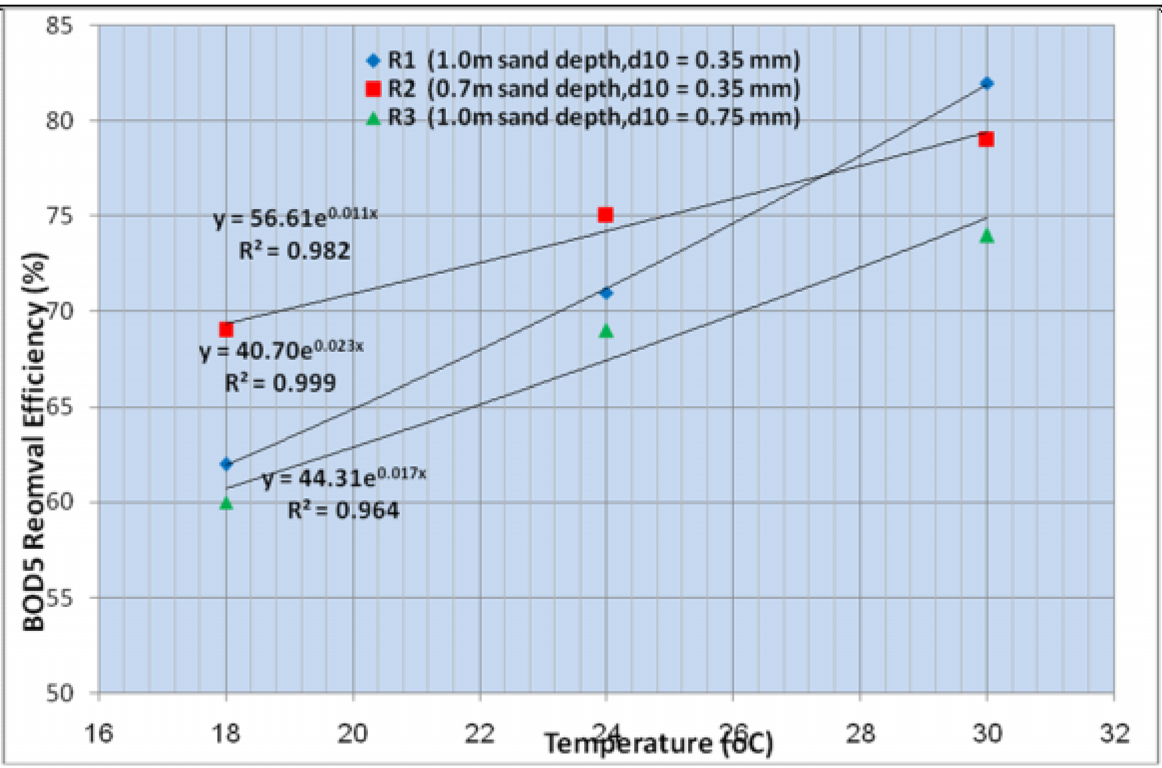

Figure (6) Effect Of Grey Water Temperature On BOD$_5$ Removal Efficieny

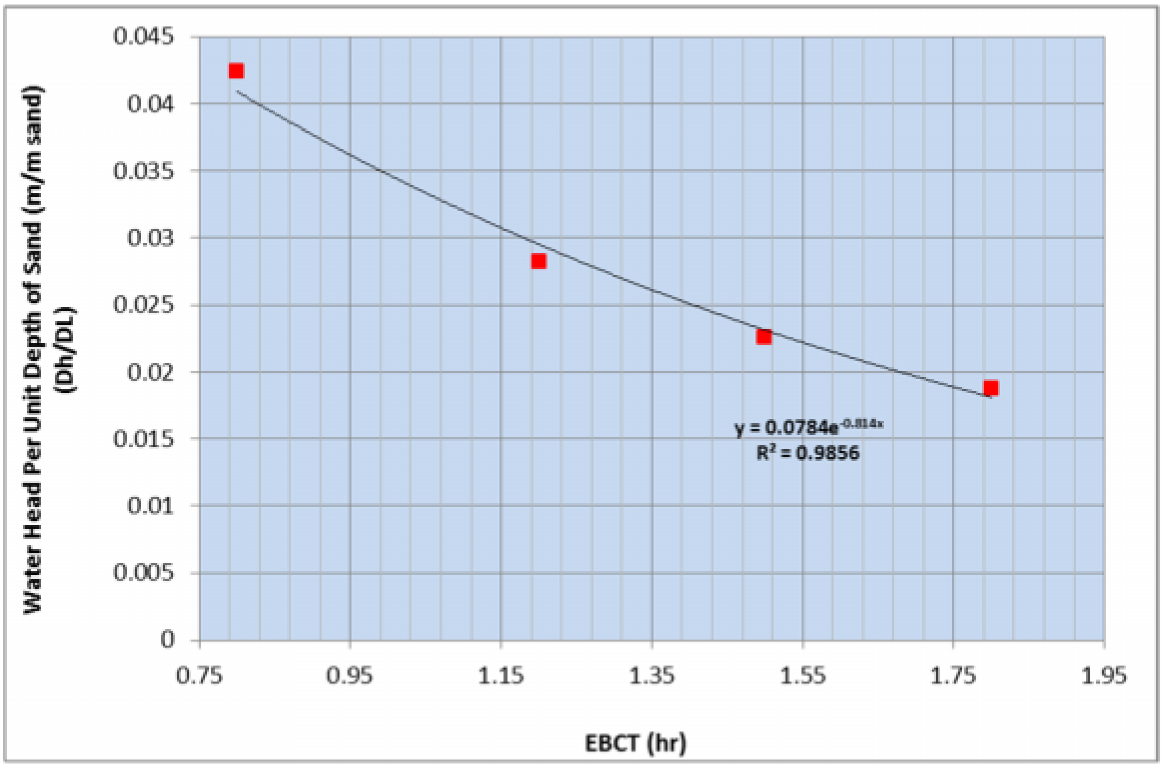

Figure (7) Relationship Empty Bed Contact Time (EBCT) And Water Head Per Unit Depth Of Sand (M/M Sand $\Delta H/\Delta L$)

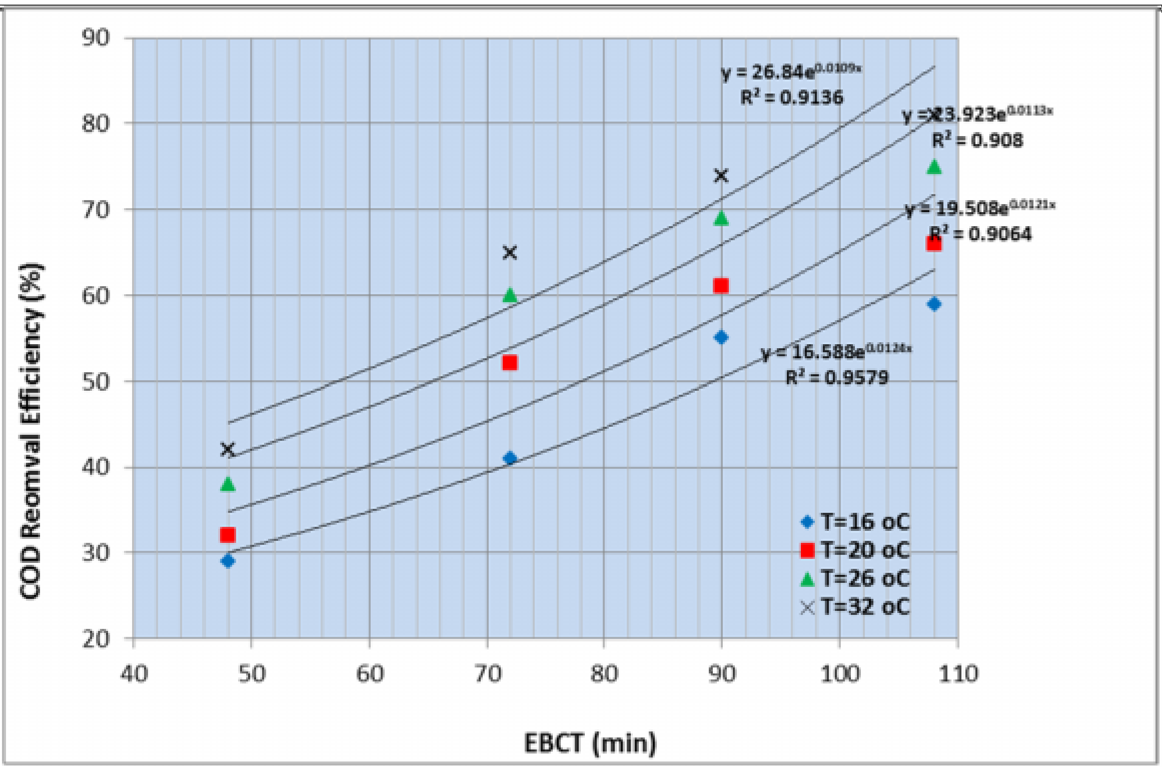

Figure (8) Effect Of Grey Water Temperature On Relationship Empty Bed Contact Time (EBCT) And COD Removal Efficiency