Improvement of Domestic Wastewater Treated Effluent from Sequencing Batch Reactor Using Slow Sand Filtration

Dr. Basim Hussein Khudair
Assistant professor
Engineering College
University of Baghdad
basim22003@yahoo.com

Shatha Abdulrazzak Jasim
M.Sc. Student
Engineering College
University of Baghdad
shathaabdulrazzak@gmail.com

Abstract:-

The effluent quality improvement being discharged from wastewater treatment plants is essential to maintain an environment and healthy water resources. This study was carried out to evaluate the possibility of intermittent slow sand filtration as a promising tertiary treatment method for the sequencing batch reactor (SBR) effluent. Laboratory scale slow sand filter (SSF) of 1.5 UC and 0.1 m/h filtration rate, was used to study the process performance. It was found that SSF IS very efficient in oxidizing organic matter with COD removal efficiency up to 95%, also it is capable of removing considerable amounts of phosphate with 76% and turbidity with 87% removal efficiencies. Slow sand filter efficiently reduced the mass of suspended and dissolved material to a very high TSS and conductivity removal efficiency of about 99% for both of them. Therefore, it can be said that slow sand filtration would be a promising technology as a tertiary treatment of SBR reactor effluent, and economically achievable as a mean of upgrading wastewater effluents to meet more stringent water quality standards, where treated effluent can be reused for various recreational purposes i.e. gardening and irrigation, as well as for safe discharge.

Keywords: **Slow sand filtration, tertiary wastewater treatment, physicochemical parameters, SBR, Laboratory scale.**

1. Introduction

Nowadays wastewater's management is facing a huge challenge in providing a sustainable and energy efficient an effluent's supply that met the standards and would be safe to the receiving environment [**3**]. Wastewater treatment plants generally are intending to decrease the pollutant load on the receiving environment, however, they often have effluents that are high in concentrations of pollution indicators such as: total suspended solids (TSS), Biochemical Oxygen Demand (BOD_5), bacterial load and nutrients (N and P) [**29**]. Thus, they threaten the receiving environment by posing health problems and diseases, fish kills, algal blooms and overall scarcity of fresh water [**2**].

Slow sand filtration (SSFs) or biological sand filtration is a system technology that could be used for the reduction of loads of wastewater's pollutant, feasibly and efficiently **[18]**. Recently, attention has been fixated on the application of SSFs as tertiary treatment [**30**]. SSFs filter water at very slow rates through a granular media, so, a large land area is required for the filtration basins. SSF is simple in design, construction and operation [**25]**, and it does not need a high degree of skill or attention, no electricity needed for operation, no chemicals addition is required and relatively of low cost [**9**].

Particles removal is achieved by various physical and biological processes that complement each other to improve delivered water quality. Generally, physical filtration could be consisted of three categories: straining, sedimentation and absorption **[22]**. Straining occurs at the sand surface for particles which are too large to pass through the sand bed. Sedimentation takes place inside the pore space between the sand grains and removes smaller particles than the pore space by settling down on the sand grains. Absorption preferred dissolved and colloidal substances by a physicochemical removal process [**11**].

The most significant purifying mechanism is the biological filter which is characterized by formation of a slimy matting layer called “schmutzdecke”, or filter skin, on top of the filter bed, through which the water passes before the filter bed is reached [**23**]. This layer consists of algae and various forms of life like diatoms, fungi, protozoa, rotifer and bacteria. These microorganisms interrupt, digest and brake down organic and nitrogenous compounds [**13, 15**]. As the water passes downward, some color is removed and considerable portion of inert suspended particles is removed by the mechanical straining mechanism, in addition to the removal of the smallest particles by the adsorption mechanism **[20].**

The SSF literature shows high removal efficiency of various physicochemical parameters, which is effected by hydraulic loading rate, media characteristics and environmental condition. COD removal found to be enhanced with temperature increase, it would be decreased with increasing filter loading rate [**1**]. Sand particles size, and the uniformity coefficient (UC) of the sand particles are very effective factors on the SSF performance. UC is the ratio of the size at which 60 percent (by weight) of a sand sample passes through a sieve, divided by the size at which 10 percent of the same sample (by weight) passes through a sieve. UC illustrates that all of the grains are of similar size. As the number increases, the differences become greater and the sand quality becomes less suitable for SSF application **[33]**. Sand grain size also has substantial importance effect on the filtration rate, filter maintenance, and the overall efficiency. Bigger sand grain sizes are more preferable, since water can be percolated faster, while, finer sand particles would have smaller spaces in between with a provision of further efficient filtration, but would considerably have slower water filtration rate and more chance of clogging the filter **[32]**. Researches have proven that maximum efficiency would be gotten if slow sand filtration grain size was between 0.4 mm and 0.15 mm **[34]**, with best operation if the UC is less than 2 **[31]**. Nevertheless, grain size normally, does not apply to the gravel layer at the filter bottom, which acts as support layer, and is usually had a depth of few inches.

Intermittent SSF seems to offer an effective and reliable treatment process for the removal of organic matter from high-strength wastewater, and for complete ammonium nitrification **[24].** In addition to its ability as tertiary treatment for suspended solids, turbidity, color, bacteria and nutrient with significant removal efficiency **[8; 10].** A “ripening” period is necessary for the organisms to be matured in a new filter. SSF should be cleaned periodically by scraping or harrowed when head loss becomes significant across the filter bed [**26**]. In this study, the SSFs acted as tertiary treatment for sequencing batch reactor's effluent (SBR). The objective of this study was to evaluate the efficiency of SSFs as tertiary treatment by testing its ability to improve the physical and chemical qualities of wastewaters and studying its ability to produce effluent suitable for agriculture as wastewater reuse application.

2. Slow Sand Filter Concept and Mechanisms.

Various physicochemical and biological mechanisms are responsible for the removal or elimination of microorganisms, nutrient, organic matter and other substances in SSFs. In general, physical filtration could be comprised of three categories: straining, sedimentation or precipitation and absorption. Straining occurs at the sand surface at which particles which are too large to pass through the sand bed would be retained. Sedimentation takes place within pores of the SSF. Particles that are smaller than the pore space would be removed by settling on the sand grains **[12].** Absorption is a physicochemical removal process at which dissolved matters and colloidal holdups. The achievement of absorption is a result of surface forces like electrostatic interactions and Van der Waals forces between the constituent and the sand grains (e.g. metals which are positively charged in solution are easily absorbed by quartz sand because of their negative charge) **[28].**

These mechanisms are essential in the purification process. The long hydraulic retention time of the water above the sand bed, permits organic material and particles to be placed on top of the bed, which in turn permitting the growth of a significant biological community (biofilm) to create, mainly an algal mat identified as the schmutzdecke layer **[7]**, where, some microbiologically purification mechanisms like predation, adsorption, scavenging, and bio-oxidation assume to happen within the biofilm formation in the filter **[14].** The first purification mechanisms are thought to occur in the supernatant, where the sunlight and nutrients allow algae to multiply, absorbing nitrates, carbon dioxide, phosphates, and freeing oxygen. The released oxygen reacts with organic substances forming inorganic salts like phosphates, nitrates, and sulphate. In addition to nitrogenized compounds that are oxidized creating nitrates that are assimilated by algae **[16].** As mentioned, the biofilm is very active at the various organisms entrapping, assimilating and the breakdown of organic material contained within the water **[5].** When designed, and operated appropriately, slow sand filters are very successful at eliminating pathogens such as Escherichia coli **[21; 27],** in addition to viruses, cysts and parasites efficiently **[17]**.

3. Experimental Work

3.1 Laboratory Scale Description

In this study, a laboratory bench scale sequencing batch reactor (SBR) followed by slow sand filtration system was set up to treat domestic wastewater. The effluent from SBR flows to an equalization tank which is used as the influent of the SSFs at filtration rate of (0.1) m/h. The filter container was made from galvanized steel with (0.3) m diameter and (0.6) m height as shown in **Fig. 1**. The filter media consisted of three sand layers with UC equal to 1.5. The first top layer was the finest with an effective size of (0.25) mm and (5) cm in depth, the second layer of sand with an effective size of (0.3) mm and (6) cm depth, and the third layer had an effective size of (0.4) mm and (19) cm in depth. These sand layers were placed over two layers of gravel support of about (0.15) m. The first gravel layer was the finest with an effective size of (6.7) mm, supported by a coarse layer with an effective size of (9.5) mm. The gravel support was laid on the top of a perforated pan to save under-drainage pipe against possible clogging by the filters media contents. The filtered water percolate through the porous of the pan and then collected by a central drain. The drain was connected with an out-let arrangement that finally discharged the filtered water in the collector container, as shown in **Fig. 1**.

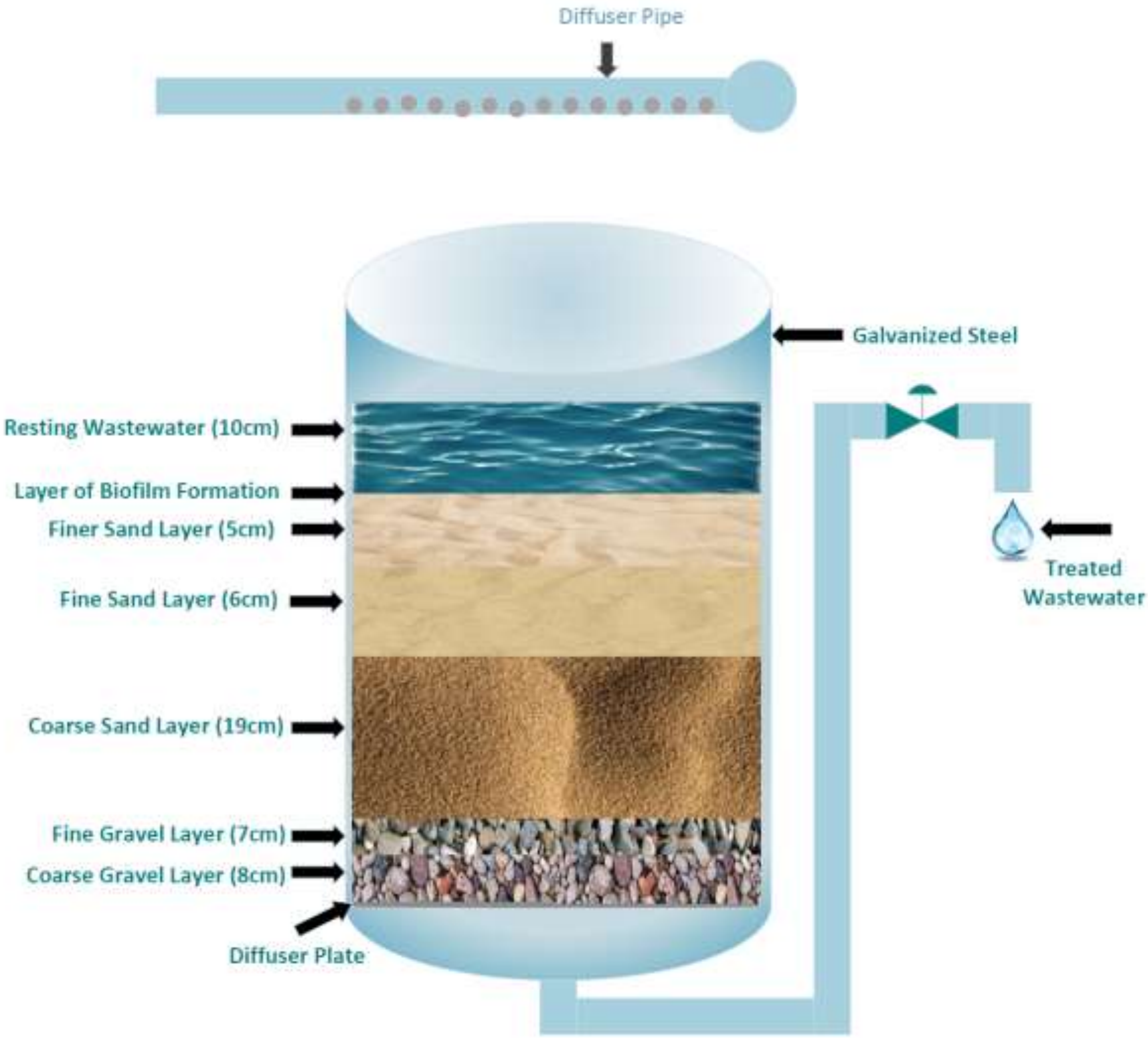

Fig. 1 Cross-sectional diagram of the laboratory scale SSF.

3.2 Data Collection and Analytical Methods

This study was carried out at the Sanitary Laboratory of Civil Department-Engineering College /University of Baghdad, over fifty days of operation. Samples of filtered and unfiltered effluents were collected and analyzed for physicochemical parameters at the laboratory. Samples were withdrawn about three times a week at different times of experimental period.

SSF was cleaned by wet-harrowing method when the flow rate through the filter slows (as indicated by head loss) that may be initiated for its clogging.

Analyses of Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Turbidity and Phosphate (PO_4) all these tests were performed to assess the evaluation. In addition to Electrical Conductivity (EC) that was established to provide a measurement of total dissolved solids, which gives an indication of salinity (the dissolved salt content). COD was measured by the use of a Lovibond (Check it Direct/COD VARIO and EC by the use of Orion 4 Star/Thermo Electron Corporation /pH. Conductivity, Benchtop Meters. While, a Lovibond / Multi Direct, Benchtop Photometer, was used for TSS and PO_4 measurements).

4. Results and Discussion

4.1 Influent and Effluent Characteristics

Rarely process can result in such development in the physical and chemical quality of wastewater as that achieved by slow sand filtration with simple design, operation and without chemical addition. The characteristics of the SBR effluent parameters which acted as a feeding wastewater to the filter are shown in **Table.1** Throughout the experimental period, the average influent TSS concentrations was (109.8 mg/L) and average effluent TSS concentrations (0.91 mg/L) as shown in **Table.1**. Removal percentage of TSS varied from (98.9 % to 100 %) with average TSS reduction (99.17 %) as shown in **Fig.2** along the operational period.

Table. 1 Experimental SBR effluent (Filter's feeding water) and SSF effluent.

Parameter	Influent Range	Average	Effluent Range	Average	Removal efficiency %
TSS mg/L	53-173	109.8	0-1.73	0.91	99.17
Turbidity NTU	44-208	93.4	6.1-31.1	13.2	87.2
EC µs/cm	1294-1761	1514.6	3-2354	266.3	99.8
COD mg/L	61-415	191.3	4-41.3	14.5	95
PO_4 mg/L	3.1-10.9	8.5	0.84-2.71	2.3	76
pH	7.21-7.99	7.67	7.1-7.38	7.24	6

Fig. 2 shows highly removal efficiency of TSS concentration due to the straining mechanism. As the treated wastewater entered the filter, combined with the water resting above the filter bed (supernatant) and subsequently heavier suspended particles start to settle and the bigger ones are arrested in the voids of the filter. Thus, by this mechanical straining mechanism, the wastewater will be free from such particles [**12**].

In addition adsorption mechanism which results from electrical forces, mass attraction and chemical bonding, adsorption could occur at every surface where there is a contact between water and sand grain, causing a slowdown of particles and finally settle in mini sedimentation basins formed by these forces. Here, the water would be free from these small particles before continuing its path downward [**6**].

The average influent Turbidity was (93.4 NTU) and in the effluent, was (13.2 NTU) as shown in **Table. 1**, Removal percentage of Turbidity along the operational period varied from (83.9 % to 87.2%) with average turbidity reduction of (87%) as shown in **Fig. 3**.

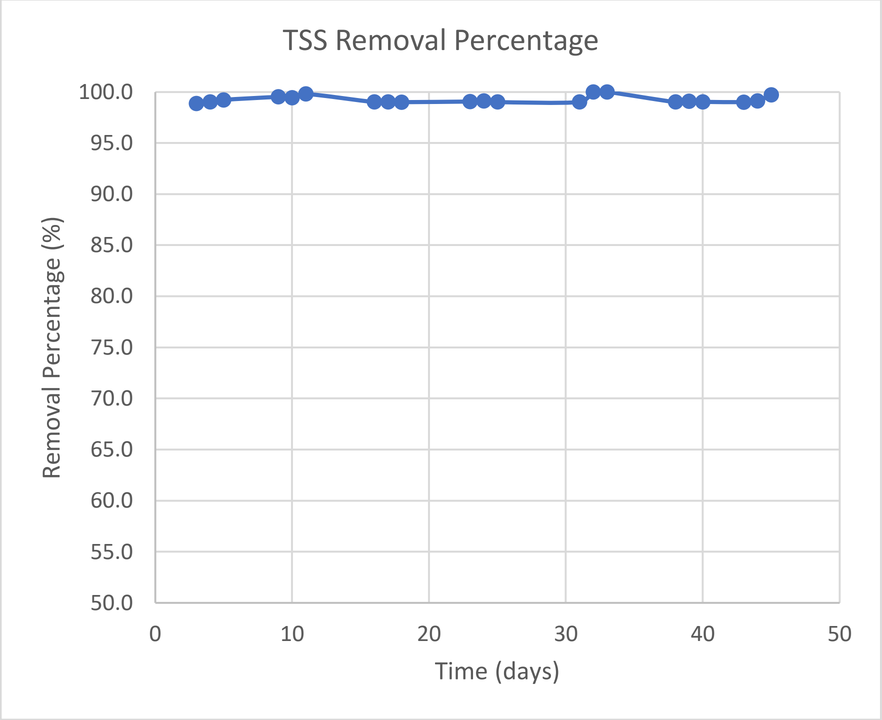

Fig. 2 Total suspended solids (TSS) removal percentage evaluation

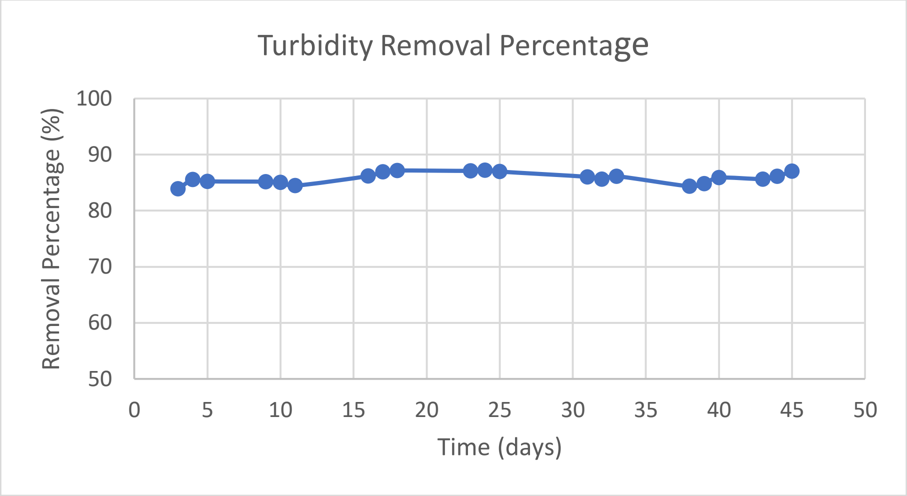

Fig. 3 Turbidity removal percentage evaluation

The average influent EC was (1514.6 µs/cm) and average effluent (266.3 µs/cm) as shown in **Table. 1**. Removal percentage of EC along the operational period varied from (64.8 % to 99.8 %) with average EC reduction (99.8 %).

Table. 1 shows removal percentage of COD along the operational period varied from (73.1% to 95%) with average COD reduction (95%) as shown in **Fig.4**. At the beginning of the experiment, the removal percentage was lower than 95% since there was not enough developing biofilm “schmutzdecke”, as shown in **Fig. 4.** From this about 10 days was required to build up the biofilm so the removal efficiency increased up to 95% [**19**]**.** A filter depth of 30 cm found to be suitable for maintaining a stable dissolved oxygen in the filter that may help in better COD removal, where in higher depths shortage of dissolved oxygen and nutrients may be observed **[35]**. In addition to that, present overly higher COD removal is possibly related to the higher levels of dissolved and suspended solids reduction **[37]**.

On the other hand, PO_4 concentration of SSF influent varied within the range illustrated in **Table. 1**, the reduction of phosphate was about 76% resulted from biological and adsorption mechanisms as shown in **Fig. 5**. Whereas, removal of phosphate through sand beds was mainly achieved by adsorption onto sand grain and the reactions of precipitation/fixation **[4]**. SSF produced effluent with PO_4 concentration lower than 3 mg/L through the experimental time. In addition to that, increasing the length of the filter run by a low flow rate of 0.1 m/h (in this study) also might be contributed in improving overall filter effluent's quality **[36].**

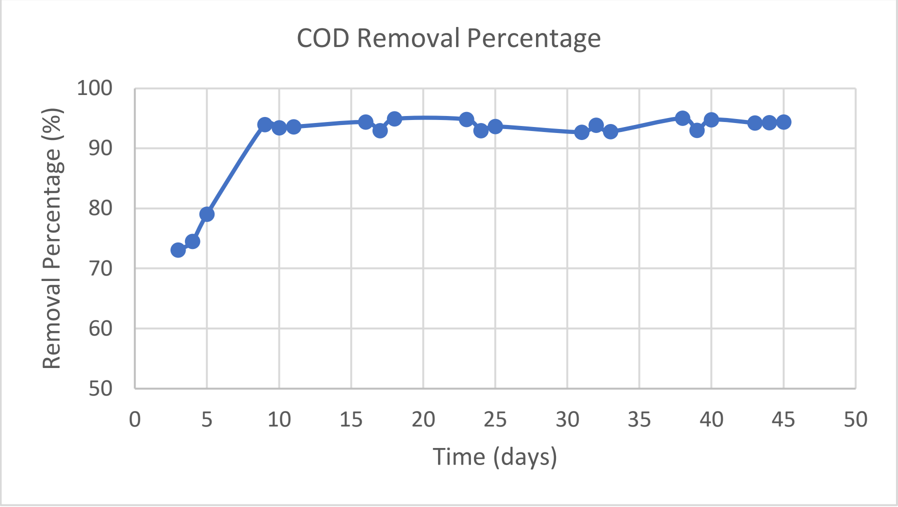

Fig. 4 Chemical oxygen demand (COD) removal percentage evaluation

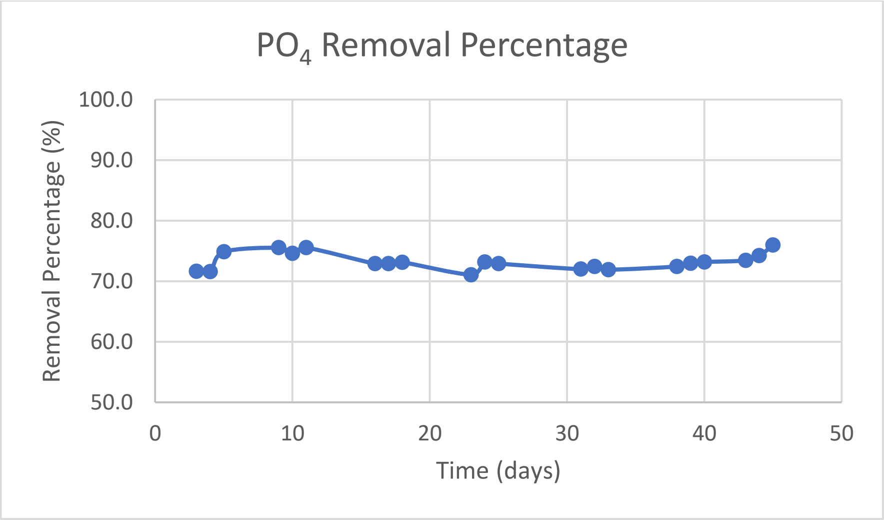

Fig. 5 Phosphate (PO₄) removal percentage evaluation

4.2 The Use SSF Treated Effluent for Agricultural Wastewater Reuse

Climate changes and the subsequent change in agricultural conditions increase the susceptibility of agricultural water use. Wastewater reuse as an alternative water resource has been practiced commonly in a varying agricultural environment around the world. Wastewater reuse had an increase application owing to the growth exposure. A comparison between characteristics of SSF treated effluent and limitations of agricultural wastewater reuse for the selected parameters is shown in **Table. 2**. The characteristics of treated effluent approached to the values listed by the different specifications considered in this table.

5. CONCLUSION

Based on experimental results of this study, the overall performance of the laboratory scale SSF was worthy producing a significantly improved wastewater quality. Where, best removal efficiencies were gotten for all of selected physicochemical parameters. The removal percentage reached up to 99% for both of TSS and EC and COD which had about 95% removal percentage. In addition to turbidity and PO_4 which had 87% and 76% removal percentage respectively. In addition to its provision as safe and sustainable practices of wastewater reuse for irrigation application. So, if SSF was operated and designed appropriately, all existing wastewater treatment plants could be upgraded by the use of it to meet the regulatory standards or their water quality goals.

Table. 2 SSF treated effluent parameters and the standards for agricultural wastewater reuse

Parameter	Treated Effluent Range	FAO	USEPA	Iraqi Standards
TSS mg/L	0 - 1.73	-	≤ 30	60
Turbidity NTU	6.1 - 31.1	-	≤ 2	-
EC µs/cm	3 – 3.29	0.7 - 3	-	-
COD mg/L	4 - 41.3	-	-	≤ 100
PO_4 mg/L	0.84 -2.71	-	-	3
pH	7.1 – 7.38	6.5 – 8.4	6 - 9	6 – 9.5

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تحسين المطروحات المعالجة من مفاعل العمليات المتعاقبة باستخدام المرشح الرملي البطيء

د.باسم حسين خضير
استاذ مساعد
كلية الهندسة-جامعة بغداد
basim22003@yahoo.com

شذى عبدالرزاق جاسم
طالبة ماجستير
كلية الهندسة-جامعة بغداد
shathaabdulrazzak@gmail.com

الخلاصة:

إن تحسين نوعية المياه السائلة التي يتم تصريفها من محطات معالجة مياه الصرف الصحي أمر ضروري للحفاظ على البيئة وصحة الموارد المائية. وقد أجريت هذه الدراسة لتقييم إمكانية الترشيح الرملية البطيء كطريقة معالجة ثالثية للمفاعلات العمليات المتعاقبة. تم استخدام مقياس مختبري كمرشح رملي بطي ذو معامل انتظام 1.5 ومعدل سرعة الترشيح 0.1 م/ساعة لدراسة اداء العملية. وقد وجدت الدراسة بان المرشح الرملي البطيء ذو كفاءة عالية بأكسدة المواد العضوية مع كفاءة ازالة لمتطلب الاوكسجين الكيميائي تصل إلى 95٪، وقادرة على إزالة كميات كبيرة من الفوسفات وبكفاءة ازالة 76٪ وبكفاءة ازالة للعكورة 87٪. وكفاءة المرشح الرملي البطيء يقلل كتلة المواد العالقة والذائبة وبكفاءة ازالة عالية للمواد العالقة الكلية التوصيلية الكهربائية تصل حوالي 99٪. لذلك يمكن القول بأن الترشيح الرملي البطيء ستكون تكنولوجيا واعدة كعلاج ثالثي من للنفايات السائلة من المفاعل العمليات المتعاقبة ويمكن تحقيقه اقتصاديا كوسيلة لتحديث مياه الفضلات السائلة لتلبية معايير أكثر صرامة لنوعية المياه، حيث يمكن إعادة استخدام النفايات المعالجة لأغراض ترفيهية مختلفة مثل البستنة والري، وكذلك للتفريغ الآمن.

الكلمات المفتاحية: المرشح الرملي البطيء، معالجة الثالثية لمياه الصرف، المعلمات الفيزيائية والكيميائية، مفاعل العمليات المتعاقبة، مقياس المختبر.