Advanced Engineering Science
http://publish.mersin.edu.tr/index.php/ades
e-ISSN 2791-8580

Design parameters of sand filtration systems in wastewater treatment process

Ece Kalay *1, **Hasan Sarıoğlu** 1, **İskender Özkul** 2

1 Ergil Group and Aager GMBH, Research and Development Department, Mersin, Türkiye, eecekalay@gmail.com; hasan.sarioglu@aager.de
2 Mersin University, Engineering Faculty, Mechanical Engineering Department, Mersin, Türkiye, iskender@mersin.edu.tr

Cite this study: Kalay, E., Sarıoglu, H., & Özkul, İ. (2021). Design parameters of sand filtration systems in wastewater treatment process. Advanced Engineering Science, 1, 34-42.

Keywords
Sand filtration
Backwashing
Wastewater treatment
Filtration hydraulics

Research Article
Received:06.05.2021
Revised: 02.07.2021
Accepted:07.07.2021
Published:15.08.2021

Abstract

In parallel with the increasing population of the world, natural water resources are also decreasing day by day. Technologies need to be improved due to the official regulations for the protection of the environment and the increased need for water in enterprises. It is important to minimize the amount of waste water and recover valuable particles. Sand filtration is a system that has been frequently used in waste water recovery processes for years. It is effective in removing large particles, suspended solids and particles such as clay and silt that cause turbidity in water from water. In this study, the basic mechanism and design criteria of the system to obtain the best treatment efficiency in sand filtering systems are examined. However, more research is needed to focus on the composition and properties at the molecular level.

1. Introduction

Water scarcity is one of the major problems of many countries in the 21st century. This will be one of the most critical environmental issues in ten years. Southern states of the USA, Southern Europe, North Africa, the Middle East and Australia are already struggling with this problem [1].

The water in the world is 1 billion 400 million km^3 (1 km^3 = 1 billion m^3). 97.5% of this water consists of salty water in the seas and oceans. The remaining 2.5% is fresh water. A very small part of this ratio is used for various purposes. The percentage of the total amount of water in the world is presented in Table 1 [2]. We should consume these extremely limited natural water resources consciously.

Wastewater has an important water resource potential in places with a high population, in arid regions and in cases where quality water is limited. With water recovery systems, energy consumption and water supply costs can be reduced. In addition, the deterioration of the quality of surface waters can be prevented. As a result, treated water can be reused in various areas. Usage and application areas of treated wastewater are shown in Table 2 [3].

Table 1. Percentage of total water in the world

Percentage	%
The amount of salt water in the seas and oceans	97.5
Amount of fresh water	2.5
The amount of water evaporating per year	0.036
The amount of water falling with rainfall per year	0.007
Amount of water flowing with rivers	0.003
Technical and economical amount of water available	0.00064

Water must be brought to certain standards in the reuse of wastewater process. The recovery of water is theoretically possible at any time under suitable conditions. This depends on economic possibilities. The technology to be selected for the reuse of treated water; The properties of treated wastewater should be determined by considering quality criteria for reuse purposes, reliability, ease of operation and economic possibilities [4].

Table 2. Usage area and applications of treated wastewater [2]

Reuse	Applications
Environmental applications	bogs and wetlands, parks, lakes, fishing and aquaculture, stream flow regulation
Agriculture and garden irrigation	feed and seed products, feed water, grass and forests, nursery garden
Underground water discharge	Providing control for salt water inlet
Urban applications	Fire protection, Street / car washing, air conditioning, toilet flushing
Industrial applications	Cooling, boiler feeding, Construction, Flue gas cleaning
For drinking purposes	Direct drinking, indirect drinking

Reverse osmosis (RO) has effective results in desalination processes. Oron et al. [5] initially treated 81% of wastewater with an electrical conductivity of 2020 µS/cm. In their other study, they increased the $Na+$ concentration of 208 mg/L by 83%. In addition, they were able to remove the initial Cl concentration of 48 mg / L by 80% reverse osmosis. Reverse osmosis can remove sodium ions and divalent cations. Therefore, it is very effective in reducing sodium adsorption rate [5].

Yim et al. [6], have achieved virus removal from wastewater at a rate of 99% using ultrafiltration technology.

Hyun et al. [7], results provided a 95% removal efficiency for heavy metals such as Fe, Mn, Cu, Cr and Pb under optimal operating conditions after a series of biofiltration and membranes. It is concluded that treated water is suitable for use in agricultural areas. Agricultural irrigation and ultraviolet system (FTS) are also suitable for reuse of wastewater. The results of the research showed that it can remove 76% of As, 80% of Cd and Cu, 88% of Cr and Pb, 97% of Zn.

Nakada et al. [8] examined the removal of endocrine disrupting chemicals with 24 drugs and personal care products in the secondary wastewater of the sewage treatment plant with sand filtration and ozonation and found that the removal of most pollutants was more than 80%.

In this study, the basic mechanism and design criteria to achieve the best treatment efficiency in sand filtration systems varying according to operating conditions were examined.

2. Filtration mechanism

The waters that are subjected to the filtration process are high quality exit waters. During this process, the quality of water increases with the retention of suspended and colloid materials, removal of microorganisms and changes in chemical compounds [9]. The media used in the filtration process can be granular sand beds, pebbles, anthracite, glass, small coal particles, or any stable material. The most common filter material is silica sand. The fact that sand is cheap compared to other filter materials, easy to find and effective results have caused it to be widely used. Anthracite or other filter materials are generally used with sand material in the construction of double or multi-layer (multi-media) filter beds that provide higher capacity [10, 11].

Filters consist of three groups as single media, dual media and multi media according to the filter media used. Single media filters are one type of filters and generally the filter media is sand or compressed anthracite. If the size of the filter material in the bed is the same, it is called homogeneous single media filters, if it is different, it is called heterogeneous single media filters. In dual media filters, there are two types of filter material in the filter bed. Multimedia filters contain more than two filter materials [12].

Filters consist of two groups, gravity operated and pressurized, depending on the operating conditions. Gravity operated filters are the process of filtering water from the filter media by gravity effect. Outlet water pressure in these filters is equal to atmospheric pressure. Gravity operated filters are divided into two as slow sand filters and rapid sand filters according to their working speed [13].

Treatment technology with granular activated carbon is the ideal solution for removing chlorinated-hydrocarbons and trihalomethanes, disinfection by-products, volatile organics, pesticides and micro-contaminants that cause taste and odour in drinking water.

Pressure filters are generally made in the form of tanks. The force that moves the water in these filters is the pressure difference at the filter inlet and outlet. The most important properties of these filters is that they do not come into contact with the atmosphere. Pressure filters are made in the form of vertical pressure filters and horizontal pressure filters [13].

2.1. Slow sand filtration

In this system, the filter speed changes between 0.1-0.5 $m^3/m^2.h$ In slow sand filters, fine-grained sand material with an effective diameter of 0.15-0.35 mm is used for the filter media. In slow sand filters, the thickness of the filter media (sand layer) should be between 0.6-1.2 m. Since the grain diameter of the sand is small, suspended and colloid substances in the inlet water cannot arrive at the bed depth of the filter. Therefore, clogging occurs in the upper layer of the filter media [14].

2.2. Rapid sand filtration

In rapid sand filters, filter speed is between 5—15 m/s. The grain diameter of the sand to be selected should be between 0.5—2 mm and the bed thickness should be between 0.5—2 m. It should be noted here that the grain size is uniform. Due to the high speed of the filter and the large flow rate passing through the filter area, rapid sand filters clog faster than slow sand filters. Clogged rapid sand filters are cleaned by backwashing. Backwash time is calculated according to the head loss [15].

The backwashing process takes place by reversing the water flow direction. The filter bed expands during backwashing. The pollutants kept in the pores of the particles are cleaned by rubbing them against each other. The important point is to reduce the particle size and increase the densities in order to prevent displacement during backwashing. For example, sand is used as the middle layer, anthracite which is a lighter material on top of it, and magnetite, which is a heavy material at the bottom layer [16].

2.3. Granular activated carbon

They filter synthetic and organic chemicals depending on the pollutant type and concentration [17]. Granular activated carbon filters can be used in place of or combined with slow sand filters. Thus, the need for excessive filtration is reduced. Therefore, they are often used in situations where space is a limiting factor [18]. Activated carbons are frequently used as filter media with their high de-chlorination kinetics and hydrocarbon adsorption capacity. Coconut-based activated carbons are generally preferred in drinking water treatment processes, while coal-based activated carbons are preferred in wastewater treatment applications.

2.4. Pressurized multi-media filtration

In the multi-layer pressure filtering process, the waste water coming into the system is sprayed to the filtering tank from above through nozzles. As the wastewater moves down through the filter media, it passes through the media of different pore diameters. During this transition, suspended solids and contaminants such as clay and silt that cause turbidity are retained. The treated water passing through the nozzles placed on the bottom of the tank is sent to the storage tank. The pressure of the system increases as contaminants accumulate in the media during filtration. In this case, it is necessary to perform a backwashing process in order to remove the contaminants accumulated between the media. In the backwash process, the flow of water is reversed and the system is supplied with water at high speeds from the bottom. Thus, the particles between the media are cleaned by reverse flow. In the backwash mode, there are enlargements in the media environments. This is an important parameter to be considered in the multi-layer filtering system to be designed [19]. The components of the multimedia system are shown in Figure 1.

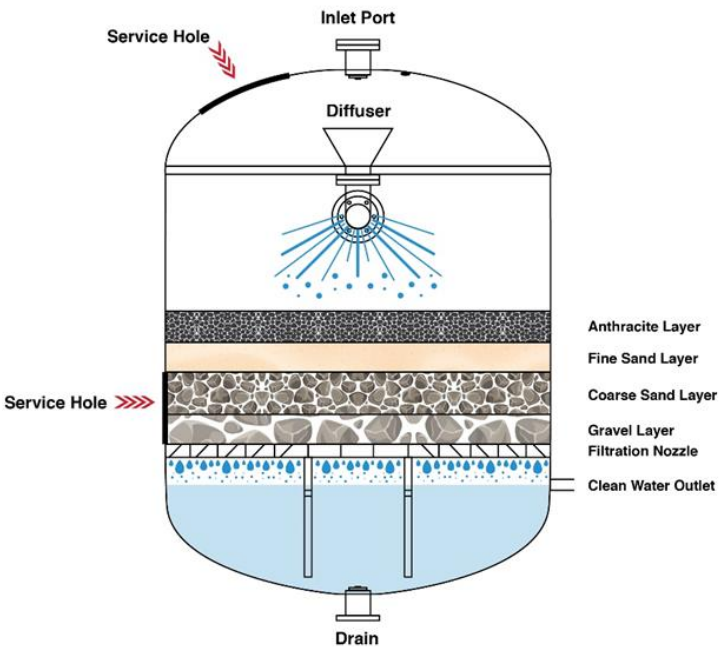

Figure 1. The components of the multimedia system.

3. Design parameters of filtration system

Some parameters are determined by engineers in the design of filtration systems. The main design parameters to be determined are the type and physical properties of the filter material, filtration rate control method, pressure losses, and backwashing process.

3.1 Filter materials

Various filtering media can be used in multi-media filtration [20, 21]. Silica sand is most commonly used in the world and in Turkey. A coarser but less dense material (usually anthracite) is placed on silica sand. Anthracite is a natural mineral used as a top layer filtration mineral. The use of multi-layer filter materials has become commonly in developed countries. Media with different characteristics are used according to the diversity of pollutants from water [9].

Quartz sand is used as filtration media or substrate depending on the suspended solid particle size and application. It increases filtration efficiency by reducing retention time and pressure loss with high flow rates. Garnet media is a high-density filter media. It is generally used as base media. Increases productivity with sand, gravel and anthracite. It should have the necessary hardness properties for maximum efficiency and should be rounded rather than angular. Calcite media is a calcium carbonate compound. It is used to neutralize acid. Manganese green sand is a siliceous media treated for the treatment of water containing iron, manganese and hydrogen sulphide. Dolomite is a granular calcium carbonate filtration media with a particle size of 1 to 2 mm. This media is used for adjusting the pH level of drinking water and for the remineralization of desalinated water [22, 23].

3.2 Filtration hydraulics

The law that best explains the flow of fluid in a porous environment is Darcy's Law. According to Darcy's Law, the filter speed (V_f) is directly proportional to the permeability coefficient of the filter medium and the hydraulic gradient. Accordingly, the filter speed is expressed by Equation 1 [24].

$$V_f = k \; x \; l \tag{1}$$

Here, V_f is the filter speed *(m/s)*, k is the permeability coefficient, l is the hydraulic slope. Hydraulic slope is the ratio of the distance between the water surfaces to the bed thickness in filters and it is expressed as *l= H L.H (m)* is the distance between water surfaces, that is, the load container, L (m) is the thickness of the bed. If this formula is substituted in Equation 1, the expression giving the filtration rate will be as in Equation 2.

$$V_f = k \;\; x \; \frac{H}{L} \tag{2}$$

Carmen-Kozeny or Sabri Ergün equations are used to calculate head losses of filtration units. The expression that gives the permeability coefficient in a filter bed with a continuous flow of diameter d according to the Carman-Kozeny equation is given in Equation 3.

$$k = \frac{\rho}{180 \; x \; \vartheta} \; x \; \frac{\varphi^3}{(1-\varphi)^2} \; x \; d^2 \tag{3}$$

Here; ρ is the density, ϑ the kinematic viscosity, φ the porosity and d (m) the grain diameter. The porosity value varies according to the type of filter material. Kinematic viscosity is a temperature dependent parameter and is calculated using Equation 4. T refers to temperature in °C.

$$\vartheta = \frac{(1.31) x \; 10^{-6}}{(0.72)+(0.028 \; x \; T)} \tag{4}$$

The diameter d of the filter material is found depending on the shape coefficient θ and the specific grain diameter d_s. Accordingly, d is calculated using the formula in Equation 5.

$$d = \; d_s \; x \; \theta \tag{5}$$

The shape coefficient varies according to the shape of the material used in the filter medium. It changes by taking a value of 1 if the material is spherical, 0.7 if the broken material is close to the sphere geometry, 0.95 if it is close to the sphere geometry, and 0.7-0.95 in other shapes [24].

When the value of k given in Equation 3 is replaced in Equation 2, the load loss is calculated as in Equation 6 according to the Carmen-Kozeny equation. The Carmen - Kozeny equation is often used for laminar flows.

$$H = \frac{V_f \, x \, L}{d^2} \, x \, \frac{1800 \, x \, \vartheta}{\rho} \, x \, \frac{(1-\varphi)^2}{\varphi^3} \tag{6}$$

In addition, the Sabri Ergün equation, which is a broader equation that includes laminar flow, transition region and turbulent flow, is used [24].

$$\frac{H}{L} = \frac{150\,\mu}{g.p} \, x \, \frac{(1-\varphi)^2}{\varphi^3} \, x \, (S/6)^2 \, x \, V_f + 1.75 \frac{(1-\varphi)}{\varphi^2} \frac{S}{6} \frac{V_f^2}{g} \tag{7}$$

Here:
H = head loss
L = Mattress thickness
g = acceleration of gravity
p = density
φ = porosity
S = specific surface
μ = dynamic viscosity
V_f = filter speed

Specific surface S in Equation 7 refers to the area of grain surface per unit volume. The first term of the Sabri Ergün equation is similar to the Carmen-Kozeny equation. The second part expresses the energy losses [24].

3.3 Backwashing

Backwashing is the removal of contaminants accumulated on the material in the filter bed by washing the filter upwards. There should be no material loss during backwashing. In this process, the filter bed is made fluid. When the bed is fluid, the upward force (pressure drop) and the downward force and the weight of the bed under water are equal. This is mathematically represented in Equation 8 [24].

$$\rho \, . \, g \, . Z . A = (1\text{-}\,\varphi). \mathrm{L}. (\rho_S - \rho). \mathrm{g}. \mathrm{A} \tag{8}$$

Here:
ρ: density of water (kg/m^3)
ρ_s: density of the material (kg/m^3)
L: bed thickness (m)
φ: Porosity of the bed
g: acceleration of gravity
Z: head loss in the filter bed during backwashing
A: Filter bed surface area (m^2)
Another parameter in backwash is the expansion percentage *(E)*. This percentage can be calculated using Equation 9.

$$E = 100 \, \frac{L_e - L}{L} = 100 \, \frac{\varphi_e - \varphi}{1 - \varphi_e} \tag{9}$$

Here L_e and φ_e show the expanded bed thickness and porosity, respectively.
The total head loss is calculated using Equation 10.

$$H = H_{base} + H_{bed} + H_{pipe} \tag{10}$$

3.4 Physical and chemical parameters

3.4.1 Turbidity (Appearance) and Colour

Drinking and potable water should be clear. Turbidity in water is caused by the presence of silt, clay, degraded organic matter, plankton and bacteria. Turbid water can be pathogenic (may contain disease-causing bacteria).

Pathogenic bacteria can settle in the pores of solid particles that create turbidity. Colour is a very important property for drinking water. Clean waters are colourless. Organic substances are found in yellow or brown waters, and iron and manganese in reddish or dark brown waters. It gives colour to water in substances that are dissolved in water and in colloidal form.

3.4.2 Smell and Taste

Drinking and potable water should be odourless and tasteless. In general, the smell and taste of the waters come from organic substances, living and non-living vegetable organisms (algae), metals (iron, manganese, etc.), phenol, chlorine and chlorine compounds. Humus, acidic, ferrous and manganese waters give the water a taste of ink and sulphurous hydrogen water with a stinky egg smell. Waters with large amounts of chloride will have a salty taste.

3.4.2 pH value

The pH value indicates that the water is acidic or alkaline in character. Pure water has a pH of 7. A low pH value indicates that the water has an acid character and a high pH value indicates a basic character. The pH value is of great importance in cleaning the waters. Treatment of iron, manganese compounds in water, taste, odour and corrosion control are directly related to the pH of the water. The optimum limits of pH, which is an important factor in biological and chemical systems of natural waters, for aquatic life are between 8.5 - 9.0. The high pH value also changes the toxicity of other pollutants.

3.4.3 Hardness

The hardness of the water; It is the property of polyvalent metal ions in water to form insoluble compounds with soaps (organic salts formed by high fatty acids of potassium and sodium). The most important salts that create hardness in water are calcium and magnesium ions. Soap is precipitated especially by calcium and magnesium ions that are always present in water. Water hardness is also used as a contamination indicator.

3.4.5 Sulphate

Sulphate in water resources is generally caused by the soil structure containing sulphate, sulphate fertilizers used in agricultural lands, waste paper, H_2SO_4, pharmaceutical industry, sugar factory and dairy industry wastes reaching the receiving water environment. Sulphate is one of the parameters that should be examined especially in terms of aquatic life. Since the sulphate ion is essential for plant nutrition, it should be present in all irrigation water. Sulphated waters cause the destruction of concrete and iron pipes to lose their durability.

3.4.6 Chloride

Chloride, which is present in almost all natural waters, is present in high amounts in waters that are filtered from mineral salt deposits and under the influence of sea water. Because more than half of the dissolved NaCl ion concentration in sea water forms chloride. The amounts of chloride ions are an indicator for healthy water. The amount of chloride in many drinking waters does not exceed 30 mg/lt. This chloride concentration rises in waters close to sea and rock salt deposits. Excessive amount of chloride in water spoils the taste of the water. Therefore, the chloride concentration should not be more than 250 mg/lt. If this amount is exceeded, water becomes undrinkable in terms of taste, even if there is no health hazard.

3.4.7 Nitrite

Source of nitrite in water; organic substances, nitrogenous fertilizers and some minerals in nature do not constitute. Nitrite occurs from the oxidation of nitrogen by means of ammonia. Therefore, the formation of nitrite is a factor that reduces the oxygen in the water. Another negative effect of nitrogen and therefore nitrite is that it causes eutrophication with water due to nitrification. This event is a factor that increases the pollution in the water. The presence of nitrite in water is very important for human and living health. Because; nitrite forms nitrosamines and nitroamides in an acidic environment.

3.4.8 Nitrate

Nitrate is one of the important water quality parameters that affect efficiency in water. Nitrate ions in water are caused by the oxidation of ammonia resulting from protein decomposition of animal and vegetable wastes, nitrate fertilizers used in agricultural fields, direct oxidation of nitrogen-to-nitrogen oxides as a result of electrical discharges in the atmosphere and the reactions of these oxides in water. The amount of nitrate in water varies widely in nature. The amount of precipitation may increase significantly after the dry periods. While the amount of chlorinated water is low, the amount of chlorine increases in non-chlorinated water. Nitrates can also be an indicator of water pollution.

3.4.9 Ammonia

Ammonia concentrations in drinking water are indicative of organic contamination. The toxic effect of ammonia on living beings increases with the lack of oxygen, increase in temperature and the presence of other toxic substances. It is known that some of the nitrogen combined with the organics in the clay and soil is converted into ammonia by the bacteria in the soil. The level of this transformation is; Although it varies depending on the soil type, climate and the type of plant grown at that soil level, it is at most 3%.

4. Results

The factors to be considered in order to obtain an effective result in the selection of the filtration system can be listed as follows.

- Maximum flow rate required
- System operating temperature
- Flow
- Nature of suspended solids or turbidity
- Water analysis of feed water
- Quality of the water to be treated
- Availability of sufficient water source for backwashing

The filter base should be made in a way that it does not clog and prevents the material in the filter bed from mixing with the filtered water. There is a sand and gravel layer under the filter bed at the filter base, and nozzles and manifold under it. The sand-gravel layer under the filter bed must be arranged very well. There is a fine-grained layer at the top of this layer.

The biggest head loss in filters depends on filter bed thickness and material density. Taking this issue into consideration in filtration designs, large bed thickness is preferred in order to keep the filtration time long.

Sometimes water and sometimes air are used in backwashing processes. In systems where water is used, backwash rate changes between 37-70 m^3/m^2.h, while compressed air velocity varies between 1-1.5 m^3/m^2.min.

Fast sand filters require low construction costs and high operating costs. These filters should be cleaned within 1-3 days.

For slow sand filters, there are high construction costs and low operating costs. These systems should be cleaned after 90-120 days.

5. Discussion

Sand Filtration Systems is a technology recommended by the World Health Organization as a wastewater treatment technique. Large-scale technologies such as nano filtration, reverse osmosis, ultraviolet filtration, membrane bioreactors are available, but they are not cost effective. Sand Filtration Systems are more cost-effective systems where raw materials can be obtained in cheap ways. They are used to treat all types of waste, drinking or rainwater. The basic mechanism of this system lies primarily in the development of media mediums responsible for the removal of bacteria and viruses.

Hydrophobic interactions, hydration and Van der Waals forces, surface roughness and bridging at the macromolecular level are mechanical factors responsible for bacterial adhesion and make their removal from water difficult [25].

Studies have shown that aluminium hydroxide or iron oxide coated sand gives more effective results than uncoated sand [26]. However, whether placing it on the sand or at another depth will yield the same results is an important research that needs to be done yet.

In the future, the focus should be on researching the effects of metal coating of filtering sands on productivity and human health.

6. Conclusion

Parameters such as flow rate, filter size, contaminant rate and types in water, filter depth, head loss change the design of filtration systems significantly. The proposed in this study can be used to optimize the design of sand filtration systems. Alternatives can be designed with media of different specific gravities and sizes. The results obtained by examining various facility designs are as follows.

- Methods developed for single media can also be used for multimedia filters.
- Polyacrylamides, suspended solids, sulphate, nitrite, water hardness, ammonium greatly alter the performance of all filtration systems and must be considered in filter design.
- Filter design should not be limited to general standards. It should be designed according to the source of the water. The operating results of many facilities have shown that the specific design is suitable for specific situations.

Funding

This research received no external funding.

Author contributions

Ece Kalay: Conceptualization, Methodology, Software **Hasan Sarıoğlu:** Data curation, Writing-Original draft preparation, Software, Validation. **İskender Özkul:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Pintilie, L., Torres, C. M., Teodosiu, C., & Castells, F. (2016). Urban wastewater reclamation for industrial reuse: An LCA case study. *139*, 1-14.
2. Başkan, T. (2006). *Arıtılmış Evsel Atıksuların Tarımda Sulama Amaçlı Yeniden Kullanılması.* (Yüksek Lisans), İstanbul Teknik Üniversitesi,
3. Asan, C. (2013). *Gri suların yeniden kullanımında membran biyoreaktör (MBR) uygulamaları.* (Yüksek Lisans Tezi), Ondokuz Mayıs Üniversitesi,
4. Büyükkamacı, N. (2009). *Su yönetiminin etkin bileşeni: yeniden kullanım.* Paper presented at the İzmir Kent Sorunları Sempozyumu.
5. Oron, G., Gillerman, L., Buriakovsky, N., Bick, A., Gargir, M., Dolan, Y., . . . Hagin, J. J. D. (2008). Membrane technology for advanced wastewater reclamation for sustainable agriculture production. *218*(1-3), 170-180.
6. Yim, S.-K., Ahn, W.-Y., Kim, G.-T., Koh, G.-W., Cho, J., & Kim, S.-H. J. D. (2007). Pilot-scale evaluation of an integrated membrane system for domestic wastewater reuse on islands. *208*(1-3), 113-124
7. Hyun, K.-S., Lee, S.-J. J. W. S., & Technology. (2009). Biofilm/membrane filtration for reclamation and reuse of rural wastewaters. *59*(11), 2145-2152.
8. Nakada, N., Shinohara, H., Murata, A., Kiri, K., Managaki, S., Sato, N., & Takada, H. J. W. r. (2007). Removal of selected pharmaceuticals and personal care products (PPCPs) and endocrine-disrupting chemicals (EDCs) during sand filtration and ozonation at a municipal sewage treatment plant. *41*(19), 4373-4382.
9. Muhammad, N., Parr, J., Smith, M. D., & Wheatley, A. D. (1997). Removal of heavy metals by slow sand filtration.
10. Bruni, M., & Spuhler, D. J. S. i. (2012). Slow Sand Filtration.
11. Bland, L. (2008). Final Report: Sustainable Community Development–Water Slow-Sand Filtration. US EPA Grant Number SU833544. In.
12. D'Alessio, M., Yoneyama, B., Kirs, M., Kisand, V., & Ray, C. J. S. o. t. T. E. (2015). Pharmaceutically active compounds: Their removal during slow sand filtration and their impact on slow sand filtration bacterial removal. *524*, 124-135.
13. Sánchez, L., Marin, L., Visscher, J., Rietveld, L. J. D. W. E., & Science. (2012). Low-cost multi-stage filtration enhanced by coagulation-flocculation in upflow gravel filtration. *5*(1), 73-85.
14. Khengaoui, K., Mahammed, M. H., Touil, Y., & Amrane, A. J. E. P. (2015). Influence of secondary salinity wastewater on the efficiency of biological treatment of sand filter. *74*, 398-403.
15. Vries, D., Bertelkamp, C., Kegel, F. S., Hofs, B., Dusseldorp, J., Bruins, J., . . . Van den Akker, B. J. W. R. (2017). Iron and manganese removal: Recent advances in modelling treatment efficiency by rapid sand filtration. *109*, 35-45.
16. Han, S., Fitzpatrick, C. S., & Wetherill, A. J. W. r. (2009). The impact of flow surges on rapid gravity filtration. *43*(5), 1171-1178.
17. Arena, N., Lee, J., & Clift, R. J. J. o. C. P. (2016). Life Cycle Assessment of activated carbon production from coconut shells. *125*, 68-77.

18. McCleaf, P., Englund, S., Östlund, A., Lindegren, K., Wiberg, K., & Ahrens, L. J. W. r. (2017). Removal efficiency of multiple poly-and perfluoroalkyl substances (PFASs) in drinking water using granular activated carbon (GAC) and anion exchange (AE) column tests. *120*, 77-87.
19. Smith, K., Li, Z., Chen, B., Liang, H., Zhang, X., Xu, R., . . . Liu, S. J. C. (2017). Comparison of sand-based water filters for point-of-use arsenic removal in China. *168*, 155-162.
20. Soyer, E., Akgiray, Ö., Eldem, N. Ö., & Saatcı, A. M. J. C. S., Air, Water. (2010). Crushed recycled glass as a filter medium and comparison with silica sand. *38*(10), 927-935.
21. Evans, G., Dennis, P., Cousins, M., Campbell, R. J. W. S., & supply, t. W. (2002). Use of recycled crushed glass as a filtration medium in municipal potable water treatment plants. *2*(5-6), 9-16.
22. Rutledge, S. O., Fahie, C., & Gagnon, G. A. (2002). Assessment of crushed-recycled glass as filter media for drinking water treatment.
23. WATER, A. H. O. D. (2010). Water quality and treatment.
24. Eroğlu, V. J. İ. T. Ü. K. (1991). Su Tasfiyesi (3. Baskı). (1439), 175-248.
25. Kim, S.-B., Park, S.-J., Lee, C.-G., Choi, N.-C., Kim, D.-J. J. C., & Biointerfaces, S. B. (2008). Bacteria transport through goethite-coated sand: Effects of solution pH and coated sand content. *63*(2), 236-242.
26. Scholl, M. A., Harvey, R. W. J. E. S., & Technology. (1992). Laboratory investigations on the role of sediment surface and groundwater chemistry in transport of bacteria through a contaminated sandy aquifer. *26*(7), 1410-1417.