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Abstract- About 297,900 Palestinian who lives in 532 residential areas in Area c of Palestine (Jarrar, 2019). Many of them rely on rain harvesting into cisterns during winter to fulfill their needs of drinking water. For instance, in Massafer Yatta, results of water quality from cisterns showed contamination levels that are ranging from 20-100 CFU/100ml. The Bio-sand filter (BSF) has been prompted extensively for water treatment in households in developing countries. In the present study, we investigated the influence of 9 operating parameters on BSF efficiency for Thermo tolerant coliform (TTC). Results analysis showed that five h residence time and media age more than one month were significant with P-values of 0.0439 and 0.0089, respectively. Although the fiveh residence time was insufficient to minimize TTC below the drinking water permissible level of 10 CFU/100ml when influent water had 500 CFU/100ml TTC. In addition, the use of five h residence time may have reduced the filter age and efficiency in removing TTC. Charge volume, turbidity, and using different cistern to fill BSF had no significant influence.

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Optimizing Bio-Sand Filter (BSF) for Maximum Thermotolerant Coliform (TTC) Removal from Drinking Water in West Bank

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Abstract- About 297,900 Palestinian who lives in 532 residential areas in Area c of Palestine (Jarrar, 2019). Many of them rely on rain harvesting into cisterns during winter to fulfill their needs of drinking water. For instance, in Massafer Yatta, results of water quality from cisterns showed contamination levels that are ranging from 20-100 CFU/100ml. The Bio-sand filter (BSF) has been prompted extensively for water treatment in households in developing countries. In the present study, we investigated the influence of 9 operating parameters on BSF efficiency for Thermo tolerant coliform (TTC). Results analysis showed that five h residence time and media age more than one month were significant with P-values of 0.0439 and 0.0089, respectively. Although the fiveh residence time was insufficient to minimize TTC below the drinking water permissible level of 10 CFU/100ml when influent water had 500 CFU/100ml TTC. In addition, the use of five h residence time may have reduced the filter age and efficiency in removing TTC. Charge volume, turbidity, and using different cistern to fill BSF had no significant influence. The use of sand of 0.18 mm effective size was significant with a P-value of 0.0016. While the temperature itself and inflow rate had no significant influence, the interaction of temperature and size was significant with a P-value of 0.0459. We found that temperature up to 33 °C negatively interfering with BSF's ability to remove TTC when the BSF has sand size of 0.23mm. The influent TTC count had a significant effect on the effluent BSF TTC with a P-value of 0.0004. The use of 23h residence time was the most influential among all operation parameters with a P-value <0.0001. The study concluded that the most crucial operation parameters for BSF to remove 99.8% TTC are 23h residence time and 0.18mm sand size. The study recommended designing a BSF that produces more than 20L to be used once every 23h and to replace the BSF sand top every four years at maximum.

I. Introduction

There are around 1.1 billion people worldwide who lack access to safe drinking water. This lack of access, combined with insufficient water supplies, is responsible for the occurrence of 4 billion cases of global diarrheal diseases (Sobsey et al., 2008). More than half a million children die from diarrhea each year (Kumar et al., 2020).In the occupied Palestinian territories, about 12.3% population isoff access to public water supply(Mahmoud et al., 2018). Diarrhea in the territoriesis a major cause of outpatient visits and hospitalizations (Elamreen et al., 2007). According to the Vulnerability Profile Project (VPP), there are about 297,900 Palestinians in 532 residential areas in area c lives without access to public water grid (Jarrar, 2019). Residents of these areas subsist on herding and non-mechanized agriculture; they rely on rain harvesting into cisterns during winter to fulfill their needs of water that is contaminated with domestic animal's organic wastes. The available database from Comet-Me(Community Energy Technology-Middle East) has shown Thermotolerant Coliform (TTC)water contamination levels, ranging from 20-100 CFU/100ml in drinking water cisterns.

The Bio-sand filter (BSF) is prompted extensively for water treatment in households in developing countries. It has been introduced in at least 36 countries worldwide, with more than half a million people using this technology (Elliott et al., 2008).This filter is easy to operate, maintain, affordable, durable, manufactured using local materials, zero energy consumption, and sustainable (Kubare & Haarhoff, 2010).BSF seems to be an appropriate technology for biological water treatment in residential areas of Palestinian territories. In this paper, BSF operation conditions were characterized and optimized based on the design of the experiment (DOE) provided by Design-Expert software. We investigated the influence of 9 operating parameters on BSF efficiency for Thermotolerant coliform (TTC) removal. These parameters were residence time, charge volume, media age, turbidity, changing water source, temperature, sand size, influent TTC counts, and inflow rate.

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II. Methodology

As per the Center for Affordable Water and Sanitation Technology (CAWST) specifications, the following (Fig.1) show the BSF design. The filter is a cylinder pipe of 90cm height and 25 cm. diameter. At the bottom, 10cm layer of small gravel is installed, followed by another 10cm larger gravel layer and a 40cm layer of sieved and treated sand.

a) *Residence time, charge volume, media age, water source, and turbidity characterization experiment*

In this experiment, we used Regular Two Levels factorial design 25-1 with four center points to characterize the influence of residence time, charge volume, media age, water source, and turbidity. We assigned the residence time low level as 1h,the high level 5h, and the center as 3h.We selected the charge volume low, center point, and high levels as 4, 6, and 8L. Media age levels were 1, 37, and 73 months. Turbidity levels were 1, 10, and 20 NTU. Two different cisterns of harvest one and harvest two were included to characterize changing water sources influence on BSF treatment efficiency.

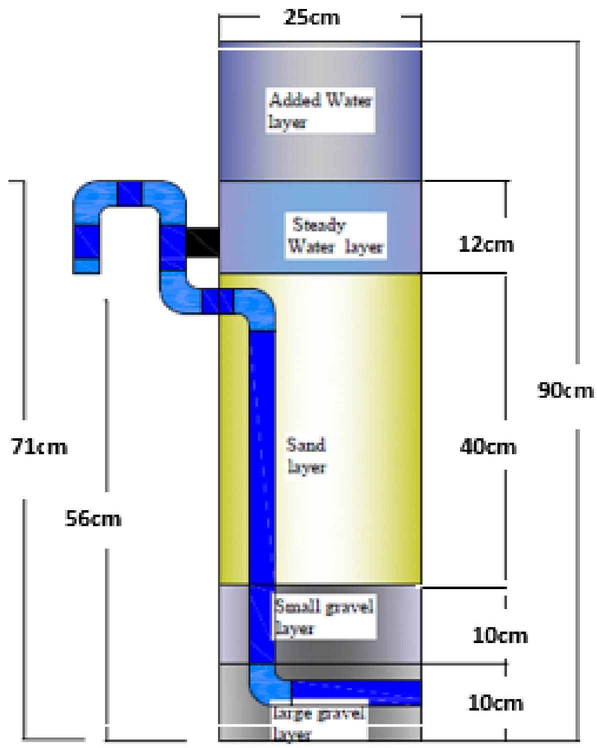

Fig. 1: BSF design

b) *Temperature, residence time, charge volume, effective size, and inflow rate characterization experiment*

In this experiment, we used a replicated Regular Two Levels factorial design 25-1 without center points. For temperature, we have chosen a constant low level of 25 °C inside the cave and a fluctuating high level of average 33°C outside the cave. The low and high levels of sand size were 0.18 and 0.23mm. Inflow rate levels were irrigation meter as low and manual charge as high levels. The residence time low level was 2h while the high level was 4h. The charge volume low and high levels were six and 8L.

c) *Residence time optimization with influent count and media age*

We used Response Surface Method (RSM) and Behnken Box Design (BBD) in this experiment to obtain a mathematical equation that can be used to inform farmers how many times they should fill the filter per day and how long they should wait before complete water treatment is ensured based on TTC concentration in their cistern. Residence time had three levels of 1, 12, and 24h. Media age levels were 4, 40, and 77 months. Influent TTC counts were 10, 500, and 1000 CFU/100ml.

III. Analytical Methods

TTC analysis was performed using the Del Agua kit (manual version 5.0). This analysis is based on the membrane filtration method of TTC specified by the WHO in annex 6 of guidelines for drinking water quality. Turbidity was measured by nephelometric tube method provided with the Del Agua kit.

Porosity, pore volume of the filter sand, and sand size and uniformity coefficient (UC) were measured based on CAWST guidelines.

IV. Results and Discussion

a) *Residence time, charge volume, media age, water source and, turbidity characterization experiment*

The analysis of results using design expert software (Analysis of Variance ANOVA) showed that only residence time and media age were significant with P-values of 0.0439 and 0.0089, respectively. Charge volume, turbidity, and changing water source had no significant influence (Fig.2).

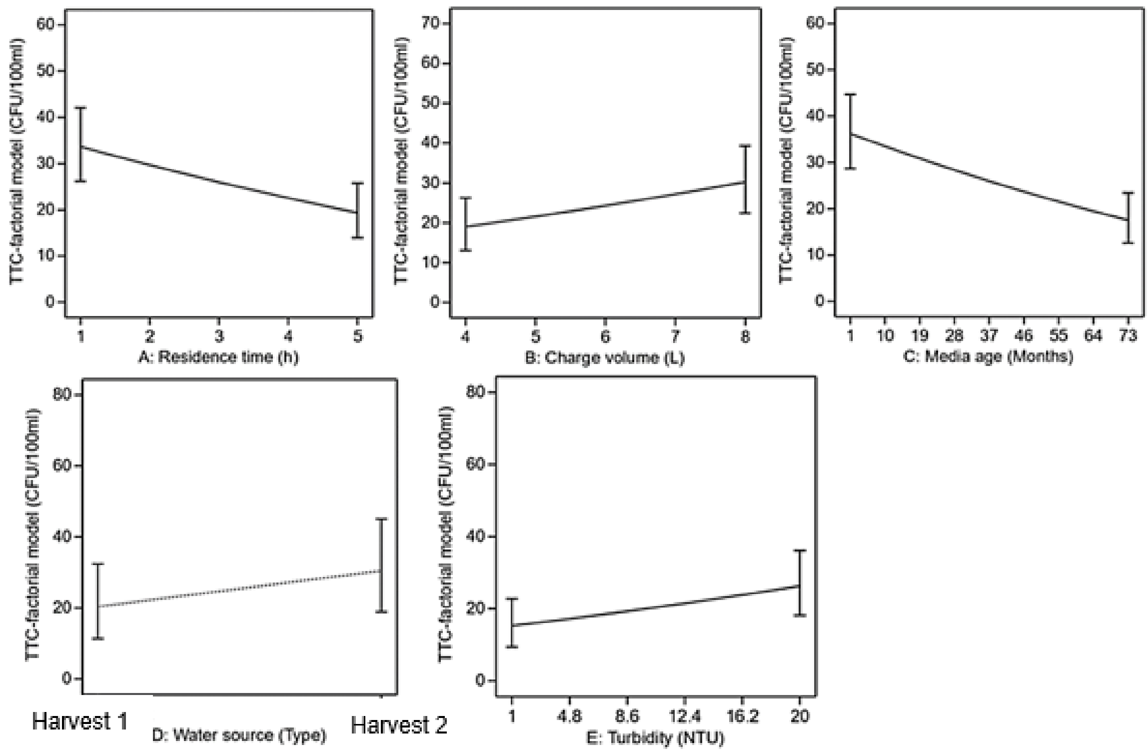

Fig. 2: Residence time, charge volume, media age, water source and turbidity influence on TTC removal from BSF

In this experiment, residence time was compared for the levels of 1, 3, and 5 h. CAWST recommends BSF operation with a minimum of 5 h after each fill. The BSF elimination of pathogens is based on their contact time with sand particles. The longer water retention in sand media increases the opportunity to adsorb or trap more pathogens. Despite that, when the water source had TTC concentration up to 500 CFU/100ml, the 5h residence time operation format was not completely effective. In this experiment, the results of TTC after BSF were higher than the reasonable water quality limits of 0-10 CFU/100ml. The average TTC in effluent samples was 22.62 ± 4.3 CFU/100ml.

Although increasing charge volume did not show a significant change in TTC removal, this was not a contradiction to its significant role in the filtration process that have been described by previous studies. On the contrary, referring to the current BSF design in the methods, the total sand volume in BSF can be approximately 19.6L. At the completion of all experiments, sand porosity for each filter was measured after completely drying sand samples. The average filter porosity in this experiment was 0.43; this is about 8.5L water that can be retained in 19.6 L of sand. This explains the insignificance of charge volume in this study. When the filter is filled 4, 6 or 8L, the whole charged volume was, approximately speaking, contained in the BSF sand layer.

The media age was also significant with a P-value of 0.0089. Most previous studies investigated this factor in the range of 1 to few months. This study has compared the media age up to 6 years. The findings here were consistent with most previous works, which emphasized an increased BSF efficiency after one month of operation. BSF is assumed to remain effective up to many years. In the current study we found that BSF of 28–46-months as the most effective to reduce TTC by 96% and produce reasonable water quality. However, further investigation is required to ensure the efficiency of BSF beyond this age when it is being operated in intervals of 1-5 h residence time (Fig.3).

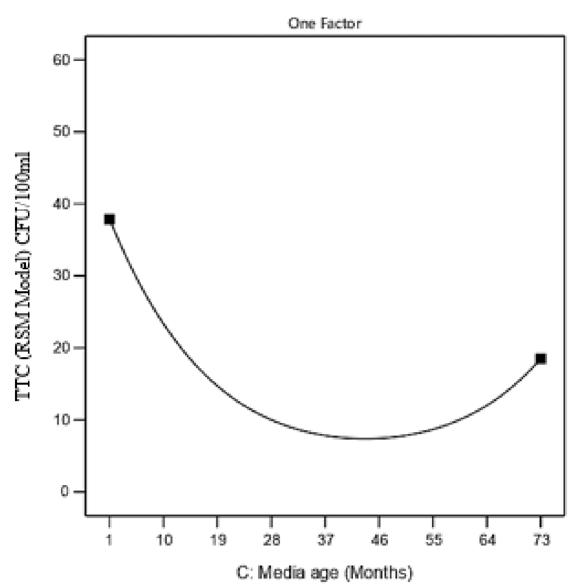

Fig. 3: Influence of media age on TTC Removal when residence time is 1-5h

There were no significant effects that resulted from changing the water source to a different cistern as long they have relative TTC concentration (about 500 CFU/100ml in this case). This factor was included because farmers in area c usually have few cisterns to fill during the rainy season. The main cistern near the household is filled with other cisterns when it is empty.

There was no significant influence for turbidity in the range of 1-20 NTU on BSF removal efficiency. However, turbidity reduction to acceptable limits (< 5 NTU) by BSF is important to ensure water is safe to drink.

The Design-Expert software helps to predict optimal values of factors based on the regression model generated from results analysis. By using this feature, the most optimum solution was suggested as 5h residence time, 7.77 L charge volume, and 53.3 months media age.

b) Temperature, residence time, charge volume, effective size, and inflow rate characterization experiment

The analysis of variance ANOVA showed that effective size and residence time had a significant influence on BSF TTC removal with P-value of 0.0016 and 0.0238, respectively. While temperature, inflow rate, and charge volume were insignificant factors (Fig.4).

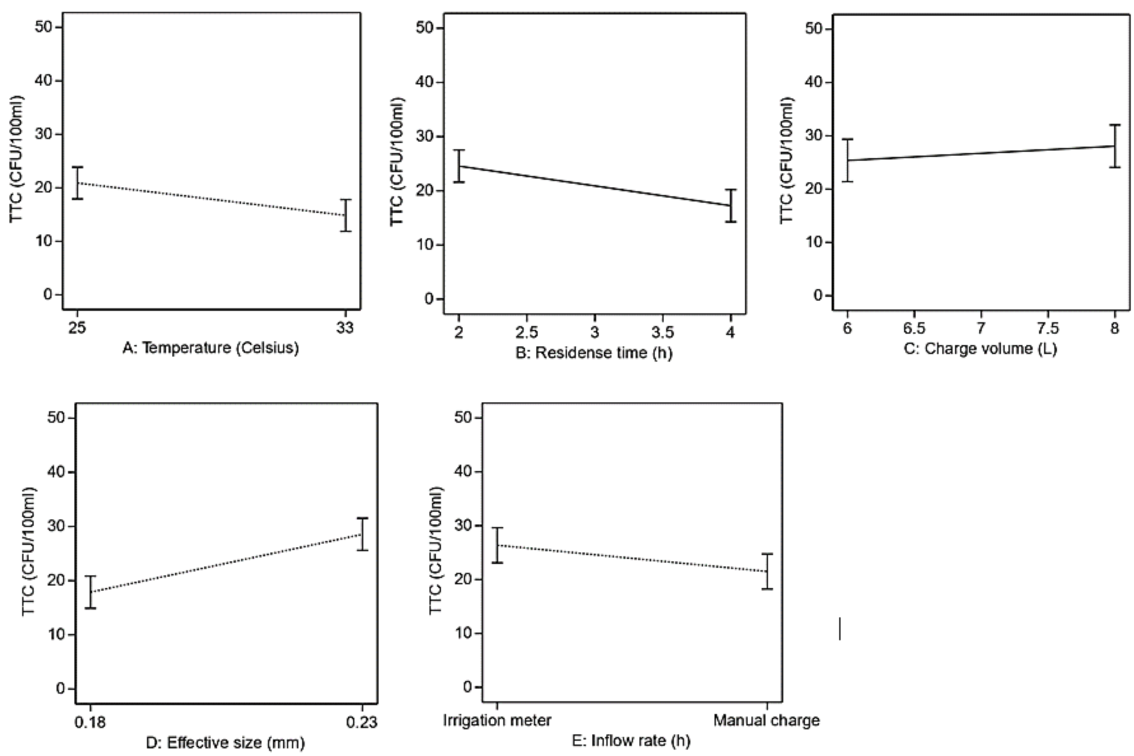

Fig. 4: Temperature, residence time, charge volume, effective size and inflow rate influence on BSF TTC removal

Temperature influence on BSF was investigated as constant and fluctuating in this experiment. Whether filters were operated at a constant temperature of 25 °C or a fluctuating average 33°C, there was no variation on BSF TTC removal. While the temperature itself was not significant, it showed an interaction with effective size (Fig.5). At 25 °C, both 0.18 and 0.23mm had the same influence on TTC removal. On the other hand, at 33 °C, 0.18mm was significantly more effective to remove TTC. (Bai et al., 2016) investigated the effect of temperature on the transport of suspended particles in the pore space of material. They found that when temperature increases, it accelerates the irregular movement of suspended particles and reduces their migration velocity; this can be attributed to the narrower pores in 0.18mm than 0.23mm.

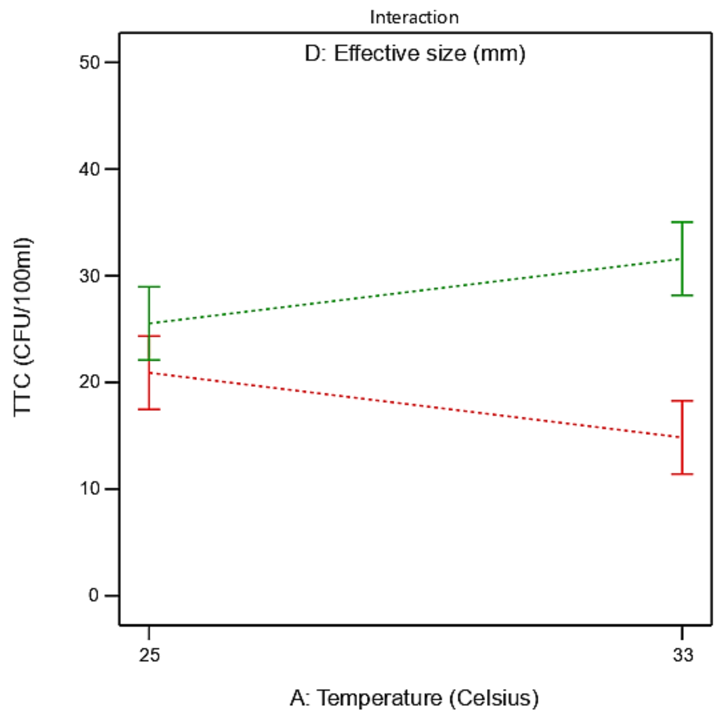

Fig. 5: Temperature and effective size interaction

The residence time was a gain significant when it was increased from 2 to 4h. The reason behind using these two levels in this experiment was that 1 to 5h is considered long for a nonlinear factor without a middle point. Charge volume significance did not appear as well; this is due to the sufficient sand pore space that can contain six and 8L.

Finally, changing the inflow rate of water into the BSF from manual charge to automatic irrigation meter did not produce any significance. This is probably due to the mechanical action of diffuser placed above the standing water layer, which maintains regular water flow on the BSF top layer.

c) *Residence time optimization with influent count and media age*

In the first experiment, it was concluded that residence time of 5 hours and media age over one month has a significant influence on BSF TTC removal (minimized TTC by 50 Δy). The significant model calculated desired charge volume as 7.77 L. It was also concluded in the second experiment that finer sand of 0.18mm effective size improves TTC removal. In this experiment, the previous significant findings were taken into consideration. The charge volume was adjusted at 7 L, the 0.18 mm effective sand size was selected, and media age was upgraded to four, 40, and 77 months.

Seventeen runs were designed in this experiment to mathematically model the influence of influent TTC count, media age, and residence time on BSF efficiency. In this case, residence time, Influent TTC count, Residence time-influent count interaction were significant model terms with P-value 0.0006, 0.0004, 0.0006, respectively. The influence of media age was insignificant with a P-value of 0.4295; this is due to including filters older than four months. The RSM graphical presentation (Fig.6) shows the interaction of residence time and influent count. The graph surface slice shows that increasing residence time to 24h was necessary to keep high BSF efficiency to remove the TTC count of 1000 CFU/100ml. The color of the surface slice changed from blue to green at that point to visualize the difference. Fig.7 presents the interaction of media age and influent count; there was no clear variation on the slice surface or color. Fig.7 is also driving the conclusion that media age more than one moth will have same efficiency of TTC removal when selected residence time is up to 24h.

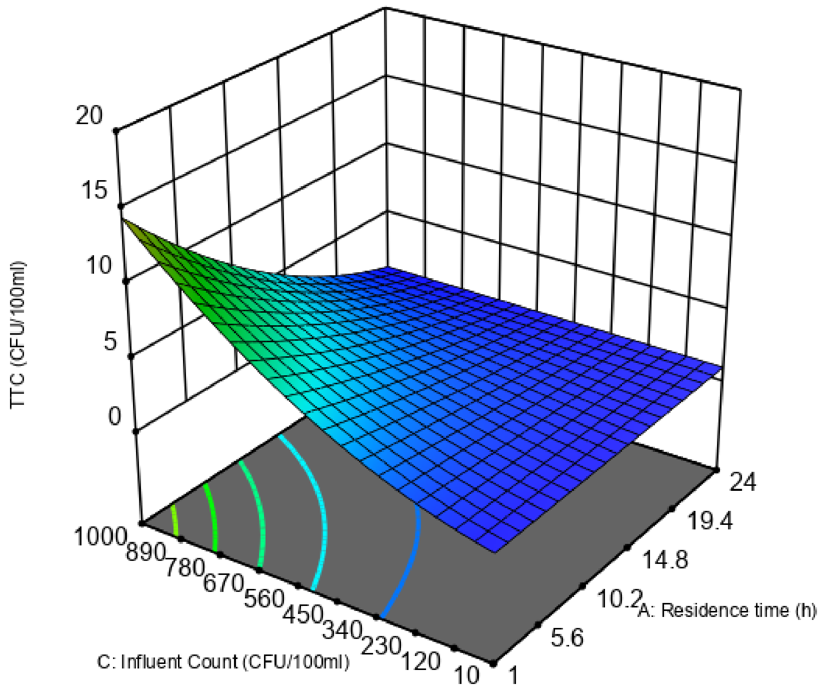

Fig. 6: Interaction of Influent count and Residence time

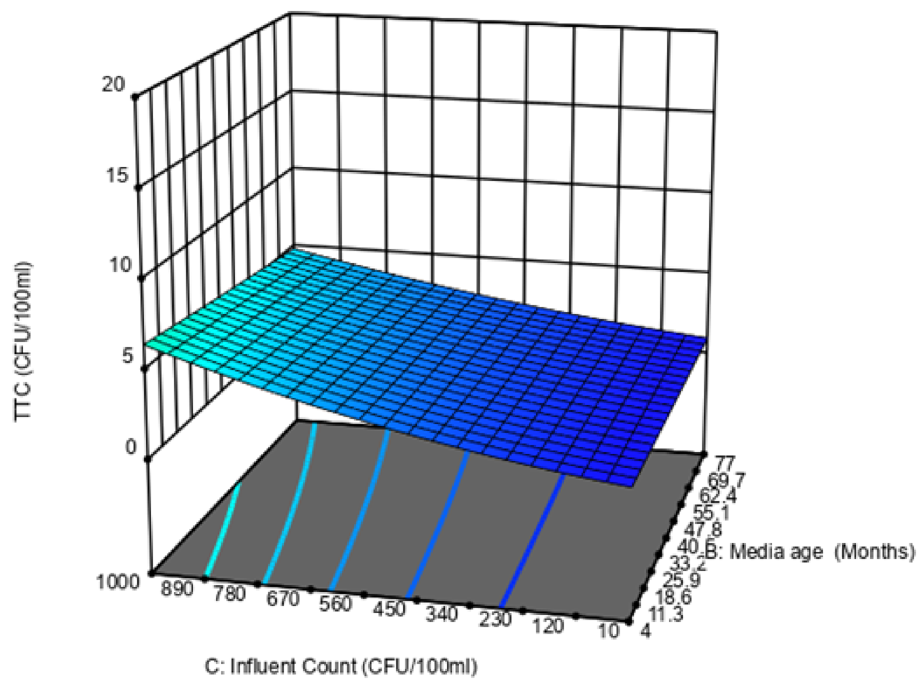

Fig. 7: Interaction of influent count and media age

The review of fit statistics and diagnostics of this experiment showed an R2 value of 0.9224; this means that the RSM model is well explaining the data. Adjusted and Predicted R2 were in reasonable agreement of 0.8758 and 0.7652. Their difference was less than 0.2. The RSM model of this experiment specified optimum conditions to maximize TTC removal by BSF as the following: residence time of 23 hours, media age 29.9 months, and influent count of 475.9 CFU. The result is 99.8% TTC removal as the response TTC result under these conditions is 0.953 CFU/100ml.

V. Conclusions

1. The five-h residence time was enough to produce Δy change of 50 CFU/100ml. Despite that, when the water source had TTC concentration up to 500

CFU/100ml, the five-h residence time was not completely effective. In this case, the results of TTC after BSF were higher than the reasonable water quality limits of 0-10 CFU/100ml. The average TTC in effluent samples was 22.62 ± 4.3 CFU/100ml.

2. BSF media age is more efficient for TTC removal after one month of filter setup. The BSF operation format of once every 1-5 hours residence time may result in filter age reduction to less than 4-6 years. On the contrary, the BSF operation format of 12-24 h extends filter age to more than six years. This is due to the operation of the BSF less frequently (1-2 times per day).
3. There is no significant effect on BSF TTC removal when it is filled from a different water source as long they both have relatively equal TTC concentration.
4. BSF is excellent for turbidity removal in the range up to 50 NTU. Turbidity of 1-20 NTU is within filter capability for this purpose.
5. The optimum charge volume of BSF is the volume of sand pore space. BSF media should be designed to contain approximately all charged water volume to ensure complete water treatment.
6. Smaller effective sand size has expressed a significant effect on TTC removal from BSF. Together with uniformity coefficient should be considered among critical factors to improve BSF efficiency.
7. Whether BSF is filled manually or using an irrigation meter, this should not be of great concern when operating the filter in rural areas that lack electricity or water grid infrastructure.
8. Sand effective size of about 0.18mm is necessary to maintain high BSF efficiency when temperature rises to 33 °C. Filters of larger sand effective size cannot produce reasonable water quality (TTC <10 CFU/100ml) in warm climates.
9. The optimum BSF operation residence time should be 23h when raw water has TTC up to 1000 CFU/100ml.

Recommendations

The BSF can be an effective, sustainable solution for water treatment in area c of the West Bank. The filter installation materials are cheap and available from local materials. It requires a minimum periodic maintenance. The present research recommends BSF design and operation as the following:

1. The size of BSF should be related to the family size and number of users. BSF should be ideally operated once per day. If it is still insufficient to meet family needs, the filter can be used twice a day with a residence time of 12 hours. For this reason, a bigger filter which can produce more than 20L per charge is more desirable.
2. Since BSF media efficiency to remove TTC reduces with time, particularly after four years, it is recommended to replace the top 10-20cm of the sand column after this period.
3. The average temperature in West Bank may reach 33°C during summer. It is recommended to install BSF with sand of 0.18 mm effective size to minimize the adverse effects of temperature on BSF efficiency for TTC removal.

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