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Performance of Modified Slow Sand Filter to Reduce Turbidity, Total Suspended Solids, and Iron in River Water as Water Treatment in Disaster Areas

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ABSTRACT

This study aimed to determine the ability to modify slow sand filter (SSF) media with silica sand or *Anadara granosa* shells on the efficiency of removal of turbidity, total suspended solids (TSS), and iron in the water of Kali Jagir Surabaya as an effort to achieve clean water in disaster areas, to obtain the influence of variables, and to optimize the obtained results. The research data was processed using Design Expert 11 Software which factors consisted of media type, filtering speed, and running time, for the responses of removal efficiencies for each parameter. The reactor was operated continuously for 6 days, and samples were analyzed for turbidity parameters based on Indonesian standard (SNI 06-6989.25-2005); TSS and Iron Standard Method 23rd 3500A. In addition, the results of the parameters were processed using the Analysis of Variance (ANOVA) to show the significant effect of the variables on the efficiency of the elimination of all parameters. Optimal research was achieved in the SSF reactor unit with silica sand media type and filtering speed of 0.1 m/hour turbidity removal efficiency of 82.07%; TSS 89.5%; and 50.14% iron. However, the reactor that was chosen was the filtering speed of 0.1 m/hour with a flow rate of 22.8 L/day, while the SSF was suitable to be applied in disaster areas, which had a large discharge. Hence, the reactor is suitable for use in water sanitation in disaster areas, namely with a filtering speed of 0.3 m/hour which produces a discharge of 68.4 L/day with variations of sand, geotextile, and silica sand media.

Keywords: *Anadara granosa*, environmental pollution, filtration, iron, silica.

INTRODUCTION

Indonesia is categorized as a country that has a high disaster risk. This is because Indonesia is located on four plates, namely Eurasia, Indo Australia, the Philippines, and the Pacific which makes Indonesia prone to earthquakes, tsunamis, and volcanic eruptions (BNBP, 2020). In addition, 75% of industrial infrastructure and basic connectivity in Indonesia are in disaster-prone areas; this causes high exposure and vulnerability to disasters (UNDRR, 2020). When a disaster occurs, the availability of water becomes very crucial. The problem of clean water in disaster conditions can occur due to disruption of water sources causing cloudy water quality, damage to processing installations, disruption of distribution systems, and water scarcity in refugee areas (Hindiyeh et al., 2021).

Clean water is one of the 17 goals of the new global agenda, known as the Sustainable Development Goals (SDGs) (Kurniawan et al., 2021, 2020a). The SDGs are a long-term world program to optimize all the potential and resources of each country (van Leeuwen et al., 2018). The goal of clean water in the SDGs is in point six, namely ensuring the availability of clean water and sustainable sanitation for everyone. However, the SDGs, i.e., clean water and sanitation, are still far away from the 100% target by 2030 (Sianes et al., 2022). One of the efforts to fulfill SDG number six is to provide access to clean water in disaster areas.

Priority for water supply is given to the areas that are highly affected. The US Agency for International Development (USAID) 2007, states that the water needs of victims after the flood disaster are between 12–15 liters per person per day. Clean water treatment installations in remote and difficult to reach areas can use a simpler and easier to operate system, one of these systems is to use the principle of filtration which is directed to meet the minimum need for clean water for disaster victims, both for drinking, cooking, and drinking purposes, as well as personal hygiene (Dwiratna et al., 2018). The raw water that can be used in disaster locations is generally river water that is processed into clean water using a treatment that is simple, portable, easy to operate, and inexpensive in terms of operational and maintenance costs. One of the clean water treatment plants that meet these criteria is a slow sand filter unit (Fitriani et al., 2020). Slow sand filter has the advantage of not requiring chemicals in its processing.

The slow sand filter unit will treat raw water from rivers because it is easy to obtain and can be used to meet the clean water needs of disaster victims (Ni'matuzahroh et al., 2022). However, the quality of river water after a disaster, especially a flood disaster, is worse because there is sediment carried into the water source. According to Paramita et al. (2021), the rivers in Serang Regency that were affected by floods have turbidity that tends to increase towards the downstream of the river, which indicates that additional sedimentary material is transported downstream. In addition, the high suspended solids in the river are also caused by waste from domestic activities. In response to this, the water from Kali Jagir Surabaya was used in the study, because it has the water quality that resembles river water in disaster areas. Kali Jagir Surabaya is one of the tributaries of Kali Surabaya, while Kali Surabaya is a tributary of the Brantas River. The high pollutant substances in Kali Jagir Surabaya are because they are located downstream of the river (Wasesa and Irianto, 2016).

On the basis of the test results of the water quality characteristics of Kali Jagir Surabaya on the parameters of turbidity and iron, the turbidity concentration was 32 NTU and iron was 1.31 mg /L. The high iron parameter in Kali Jagir Surabaya water is caused by the industrial activities that produce iron, namely paint factories, ceramic factories, and steel factories along the Brantas River. Iron is a component that contributes to color pigments in the paint industry, the basic material for ceramics comes from clay while in steel factories there is an accumulation process that has occurred for years (Galvão et al., 2018).

On the basis of the background described above, this research will test the ability of the slow sand filter modification unit in treating the water of Kali Jagir Surabaya to reduce the parameters of turbidity, total suspended solids (TSS), and iron with various media variations of sand with silica sand and geotextile and sand with *Anadara granosa* shell and geotextile. The data obtained from the results of laboratory analysis will be analyzed using software response surface methodology (RSM) on the Design Expert 11 application to obtain the optimum results of the research design. In addition, the results of the test of each parameter were compared to the Indonesian Ministry of Health quality standard Number 32 of 2017 concerning Hygiene and Sanitation Quality Standards. If the results of the quality of the treated water using the unit Slow Sand Filter have met the quality standard, it is hoped that the reactor can not only be used for hygienic water but also for drinking water which is implemented in disaster areas.

MATERIAL AND METHODS

Place and time of research

The research was conducted out from December 2022 to April 2022. This research includes several processes, namely raw water quality testing, reactor preparation and design, reactor operation, data analysis and discussion and thesis preparation. The research was carried out at the Faculty of Science and Technology, Airlangga University, in two locations, namely the Environmental Engineering Study Program Workshop and the Ecology and Environment Laboratory. The modified Slow Sand Filter reactor was placed in the Environmental Engineering Study Program Workshop. Turbidity and TSS analysis carried out at the Ecology and Environment Laboratory, Faculty of Science and Technology, Airlangga University and iron analysis conducted at the Environmental Quality Management Laboratory of the Sepuluh Nopember Institute of Technology.

Tools and materials

The equipment used includes 1 unit of HDPE 1100 L tank profile, 1 unit of roughing filter reactor, and 2 units of slow sand filter reactor. The equipment used when sampling water from Kali Jagir Surabaya is a water pump with a tensile capacity of 3 meters; 2” diameter hoses; 2 long roll cables; 20 jerry cans of 25 L. The 20 jerry cans are used to collect raw water before it is placed into the profile of a 1100 L HDPE tank at the Environmental Engineering Study Program Workshop.

The equipment used in the turbidity analysis is the Thermo Scientific Eutech TN-100 turbidimeter. The equipment used in the TSS analysis is an oven with a temperature of 103 °C to 105 °C; desiccator; analytical balance with a readability of 0.1 mg; petri dish; 100 mL measuring cup; tweezers; Whatman filter paper 934AH; and a glass vacuum filtration system. The equipment used in the analysis of iron is a 250 mL Erlenmeyer flask; 100 mL measuring cup; watch glass; 10mL volume pipette; heating; 50 mL volumetric flask; and atomic absorption spectrophotometer.

The materials used during the operation of the reactor included water from Kali Jagir Surabaya, tile fragments measuring 1 cm; pumice stone diameter 1 cm; gravel 2 cm in diameter; silica sand stuck to mesh 45, shells of *Anadara granosa* stuck to mesh 45, geotextile fabric, fine sands stuck to mesh 60 with a diameter of 0.15–0.25 mm; PVC pipe; 4” pipe 1.2 meters long and 5” pipe 0.65 meters long; 4” and 5” diameter pipe caps.

The materials used in the analysis of turbidity are distilled water. The materials used in the TSS analysis were distilled water and Whatman 934AH filter paper. The materials used in the iron analysis were distilled water, HCl solution, NH_2OH solution, buffer solution, phenanthroline molybdate solution.

Statistical analysis of response

Experimental responses were analyzed by Analysis of Variance (ANOVA) test. The recommended ANOVA model is the *2FI* model which has significance in the ANOVA and non-significance to the lack of fit test. A final equation in terms of actual factors is released as a mathematical function of the research model that can be applied in the field to predict and calculate response values. The interaction between single or multiple independent factors on the response is visualized in contour graphs and 3D surface graphs.

RESULT AND DISCUSSION

Effectiveness of SSF on test parameter allowance

The study used two slow sand filter (SSF) reactors using several modifications. The modifications made are the filter media and the filtering speed of the SSF which is divided into two, namely SSF1 using a combination of sand, geotextile, and silica sand with a speed of 0.1 m/hour and 0.3 m/hour and SSF2 with a combination of sand, geotextile, and shells of *Anadara granosa* with a filtering speed of 0.1 m/hour and 0.3 m/hour.

Effectiveness of SSF on turbidity parameter removal

The research data are shown by the percentage removal of turbidity parameters by SSF1 with a filtering speed of 0.1 m/hour (SSF1 0.1) and 0.3 m/hour (SSF1 0.3) and SSF2 at a filtration speed variation of 0.1 m /hour (SSF2 0.1) and 0.3 m/hour (SSF1 0.3) which can be seen in Table 1 while the graph of the percentage of turbidity removal efficiency can be seen in Figure 1.

Figure 1 shows that SSF1 with a filtering speed of 0.1 m/hour has the highest efficiency value on day 2, reaching 96.17; the lowest efficiency on day 1 is 77.72% and the average efficiency is 84.34%. SSF2 with a filtering speed of 0.1 m/hour has the highest efficiency value on day 3 of 90.73%; the lowest efficiency on day 1 of 67.09%; and the average efficiency is 79.37%; SSF1 with a filtering speed of 0.3 m/hour has the highest efficiency value on day 5, namely 94.34%; the lowest efficiency on day 1 of 58.01%; and the average efficiency is 70.91%. SSF2 with a filtering speed of 0.3 m/hour has the highest efficiency value on day 5, namely 84.78%; the lowest efficiency on the 1st day of 46.81%; and the average efficiency is 63.39%. The results of the

Table 1. Data on average percentage of turbidity removal efficiency by SSF1 0.1; SSF2 0.1; SSF1 0.3; and SSF2 0.3

Running time	SSF1 0.1 (%)	SSF2 0.1 (%)	SSF1 0.3 (%)	SSF2 0.3(%)
1	77.72 ± 4.37	67.09 ± 5.45	58.01 ± 2.35	46.81 ± 3.35
2	96.17 ± 1.22	86.55 ± 7.62	69.13 ± 0.90	58.72 ± 4.12
3	91.30 ± 2.03	90.73 ± 3.22	60.01 ± 0.29	52.10 ± 2.64
4	81.89 ± 2.53	75.15 ± 4.96	67.73 ± 4.42	66.01 ± 5.75
5	82.88 ± 0.23	78.70 ± 0.15	94.34 ± 1.13	84.78 ± 3.57
6	79.77 ± 4.61	77.98 ± 1.13	76.24 ± 1.50	71.89 ± 4.64

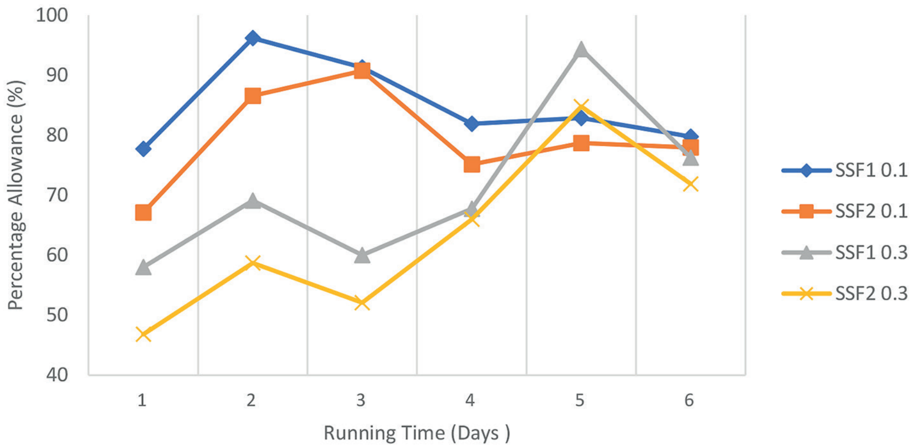

Figure 1. Graph of mean percentage of turbidity removal by SSF1 0.1; SSF2 0.1; SSF1 0.3; SSF2 0.3

percentage of removal of turbidity show results that are not much different from the research of Mirza (2019), namely the percentage of removal of the Slow Sand Filter can reach 79%.

The percentage efficiency of the turbidity parameter at the filtering speed of 0.1 m/hour and 0.3 m/hour has a different trend. The filtering speed of 0.3 m/h has an increasing trend on days 1 to 6, but the efficiency is lower than the filtering speed of 0.1 m/h. This is because faster the flow of water through the cavities between the media causes a reduced contact time between the surface of the media and the water to be treated, so that the percentage of decrease is low (Andini and Purnomo, 2014). While the filtering speed of 0.1 m/hour has a low trend at the beginning, namely 77.72% and 4.37%, the efficiency in the middle is becoming better because of the length of contact time and the percentage of constant removal.

This is influenced by the turbidity removal mechanism in SSF, namely the process of straining or large particles passing through the media grains and being trapped. In addition, there is a sedimentation process, if in the straining process there are particles that escape, these particles can settle on the sand media. Both of these processes result in the longer running time, the cavity in the media will be filled with polluting particles thereby reducing the space in the filter media.

Effectiveness of SSF on TSS parameter removal

The percentage of parameter removal efficiency is calculated using the efficiency formula data from the research shown by the percentage

Table 2. The percentage data of TSS removal efficiency by SSF1 0.1; SSF1 0.3; SSF2 0.1; and SSF2 0.3

Running time	SSF1 0.1 (%)	SSF2 0.1 (%)	SSF1 0.3 (%)	SSF2 0.3 (%)
1	77.55 ± 2.82	76.43 ± 4.39	31.26 ± 0.22	25.71 ± 20.20
2	96.60 ± 1.34	96.60 ± 1.34	32.63 ± 9.88	34.10 ± 26.47
3	87.56 ± 10.69	93.87 ± 5.13	51.47 ± 16.88	58.50 ± 10.38
4	92.30 ± 7.73	92.30 ± 7.73	49.10 ± 12.87	59.55 ± 27.65
5	78.80 ± 5.38	80.65 ± 15.06	65.94 ± 2.90	53 ± 4.24
6	89.35 ± 0.32	88.31 ± 1.15	66.93 ± 7.63	60.96 ± 10.06

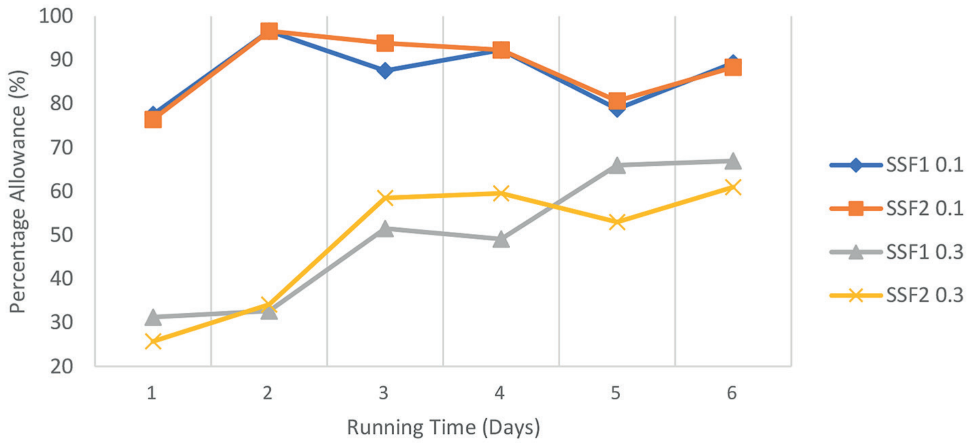

Figure 2. Graph of the average percentage of TSS removal by SSF1 0.1; SSF2 0.1; SSF1 0.3; SSF2 0.3

removal of TSS parameters by SSF1 and SSF2 at variations in filtration speed of 0.1 m/hour and 0.3 m/hour, which can be seen in Table 2, while the graph of the percentage of turbidity removal efficiency can be seen in Figure 2.

Figure 2 shows that SSF1 with a filtering speed of 0.1 m/hour has the highest efficiency value on day 2 of 96.6%; the lowest efficiency on day 1 of 77.55%; and the average efficiency is 87.03%. SSF2 with a filtering speed of 0.1 m/hour has the highest efficiency value on day 2 of 96.60%; the lowest efficiency on day 1 was 76.43%; and the average efficiency is 88.03%. SSF1 with a filtering speed of 0.3 m/hour has the highest efficiency value on day 6, namely 66.93%; the lowest efficiency on day 1 of 31.26%; and the average efficiency is 49.56%. SSF2 with a filtering speed of 0.3 m/hour has the highest efficiency value on the 6th day, namely 60.96%; the lowest efficiency on day 1 of 25.71%; and the average efficiency is 48.64%. The results of the TSS removal percentage show results that are not much different from Mirza's (2019) research, namely the slow sand filter removal percentage can reach 96%.

Comparison of the results of increasing the percentage of TSS removal at filtering speeds of 0.1 m/hour and 0.3 m/hour is different. The increase in efficiency at a filtering speed of 0.1 m/hour occurred on the 1st to 2nd day, while the increase in efficiency at a filtering speed of 0.3 m/hour occurred on 4th to 6th day. These results are in accordance with Mirza's research (2019), namely if the filtering speed is large, the efficiency of parameter removal is slow, compared to the small filtering speed. This is because there are microorganisms that grow on the granules of the media, playing a role in reducing suspended particles in water quality.

The graphs in Figures 1 and 2 show the results of turbidity values that are not proportional to the TSS value. The results of the study are in accordance with the research conducted by O'Marga (2020), namely the TSS value is not always linearly proportional to the turbidity value. This is because the turbidity material consists of various materials that have different shapes and specific gravity.

The above has been proven by the research by Aziz (2014) which showed that the highest TSS removal efficiency was obtained on a fine filter media of 0.21 – 0.42 mm and it was stated that the size of the filter media had an effect on TSS in the water, the smaller size of the sand particle, the higher removal efficiency of the TSS. In addition, the high efficiency of TSS reduction is due to the transportation mechanism, namely the movement of chocolate and the sedimentation process in the Slow Sand Filter. Brownian motion is a circular flow through the filter media layer, causing the suspended particles to collide with each other than the suspended particles will experience aggregation, when the suspended particles have agglomerated to become large enough to be retained by the filter media, the suspended particles were then experiencing settlement (Kurniawan et al., 2020b, 2022b, 2022a).

Effectiveness of SSF on iron removal

The iron parameter test on the results of Slow Sand Filter processing was carried out at the beginning, middle, and end. This is supported by the results of Hidayatullah and M.H. (2019), namely the percentage of iron parameters has an even distribution of values and a decrease in concentration

Table 3. Data on percentage of iron removal efficiency by SSF1 0.1; SSF1 0.3; SSF2 0.1; and SSF2 0.3

Running time	SSF1 0.1 (%)	SSF2 0.1 (%)	SSF1 0.3 (%)	SSF2 0.3 (%)
1	57.14	42.85	22.22	22.22
2	-	-	-	-
3	45.45	36.36	36.36	45.45
4	-	-	-	-
5	-	-	-	-
6	50	50	50	40

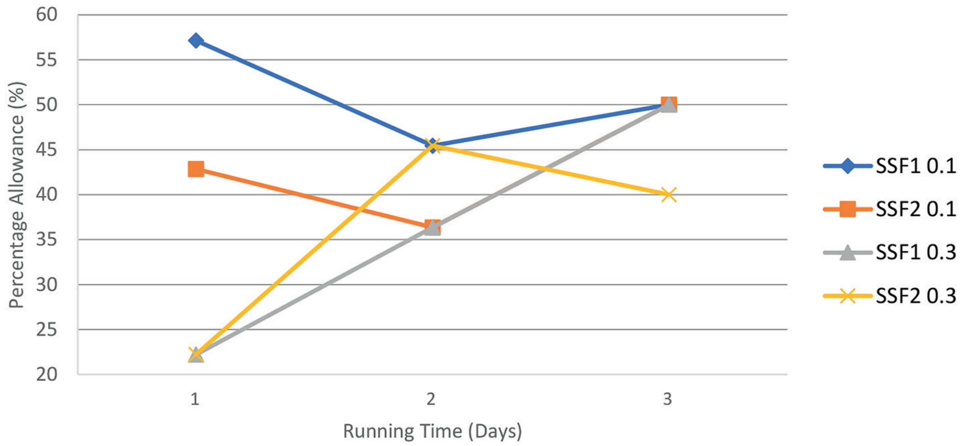

Figure 3. Graph of the average percentage of iron removal by SSF1 0.1; SSF2 0.1; SSF1 0.3; SSF2 0.3

that is not much different every day from 66–84.19%. Therefore, the sampling in this study was carried out three times, because it was considered representative of the processing in SSF of iron parameters and could save research costs.

The research data are shown by the percentage removal of iron parameters by SSF1 and SSF2 at variations in filtration speed of 0.1 m/hour and 0.3 m/hour, which can be seen in Table 3 while the graph of the percentage of iron removal efficiency can be seen in Figure 3.

Figure 3 shows that SSF1 with a filtering speed of 0.1 m/hour has the highest efficiency value on day 1 of 57.14%; the lowest efficiency on the 2nd day of 45.45%; and the average efficiency is 50.86%. SSF2 with a filtering speed of 0.1 m/hour has the highest efficiency value on day 6 of 50%; the lowest efficiency on the 3rd day of 36.36%; and the average efficiency is 43.07 %. SSF1 with a filtering speed of 0.1 m/hour has the highest efficiency value on day 1 of 57.14%; the lowest efficiency on the 2nd day of 45.45%; and the average efficiency is 50.86%. SSF1 with a filtering speed of 0.3 m/hour has the highest efficiency value on day 6, namely 50%; the lowest efficiency on day 1 is 22.22%; and the average efficiency is 36.16%. SSF2 with a filtering speed of 0.3 m/hour has the highest efficiency value on the 3rd day, namely 45.45%; the lowest efficiency on day 1 is 22.22%; and the average efficiency is 35.89%. The results of the percentage removal of iron show results that are in accordance with Hidayatullah and M.H., (2019), namely the percentage of iron removal in the Slow Sand Filter every day which is stagnant or not much different.

Comparison of the results of increasing the percentage of iron removal at filtering speeds of 0.1 m/hour and 0.3 m/hour is different. The increase in efficiency at a filtering speed of 0.1 m/hour occurred on days 1 to 3, while an increase in efficiency at a filtering speed of 0.3 m/hour occurred on days 3 to 6. This is because the surface contact time of the media with water is longer, so that it provides an opportunity to react, bind, and settle between the treated water and the filter media (Andini and Purnomo, 2014).

The high or low efficiency of iron removal was caused by the filter media that can work with ion exchange processes to reduce iron in water. Ion exchange process occurs because of two things, namely there are natural particles such as shells and there are synthetic particles, i.e., organic resins. In research, the ion exchange process occurs because there are natural particles. According to

Table 4. ANOVA model 2FI turbidity

Source	Sum of squares	df	Mean Square	F-value	p-value	Significance
Model	19.69	6	328.17	6.18	0.0061	Significant
A-Time Running	682.92	1	682.92	12.87	0.0050	
B-Filtration Rate	1235.96	1	1235.96	23.28	0.0007	
C-Variation Media	139.93	1	139.93	2.64	0.1355	
AB	201.53	1	201.53	3.80	0.0799	
Air conditioning	69.95	1	69.95	1.32	0.2777	
BC	18.53	1	18.53	0.3492	0.5677	
Residual	530.8	10	53.08			Not significant
Lack of Fit	437.02	5	87.40	4.66	0.0583	
Pure Error	93.78	5	18.76			
Cor Total	2499.8	16				

Kurnyawaty et al. (2020), the absorption mechanism of the Fe metal can occur if it interacts with CaCO3. This was supported because the ionic radii of Fe and Ca atoms are similar so that they were able to replace the position of the ions. The cycles that occur in the process are as follows:

$$CaCO_3 \rightarrow CO_3^{2-} + Ca^{2+} \quad (1)$$

$$CaCO_3(s) + Fe_{2+} + CO_3^{2-} \rightarrow FeCO_3 + Ca^{2+} \quad (2)$$

$$Fe_{2+} + CO_3^{2-} \rightarrow FeCO_3(s) \quad (3)$$

The insoluble Fe metal will be retained in the pores of the filter media when water passes through the media, so that it can reduce the Fe content in the water that comes out at the outlet (Hidayatullah and M.H., 2019). In addition, iron removal was influenced by the transport mechanism so that an adsorption process occurs in the SSF unit. The adsorption process occurs because there is a diffusion process so that the adsorbate is adsorbed. In addition, there is an attachment mechanism caused by the van der Walls force (Wang et al., 2020). Silica sand and shells of *Anadara granosa* have a negative (-) charge, so they can attract positively (+) charged particles such as cations from iron molecules (Fitriani et al., 2022).

Optimal media variation for each parameter

The removal efficiency value of each parameter is expressed as the actual response value. The number of actual response value data obtained is 17 data and is completed in Table 7 on Design Expert 11 software for statistical analysis. Statistical analysis was carried out using the Analysis of Variance (ANOVA) to determine whether there was an effect of the variables used in SSF to answer the hypothesis and to determine the selected research model (suggested). The suggested model obtained has significance on ANOVA with p-value < 0.05 and non-significant to the lack of fit test with p-value > 0.05 for each parameter tested (Oyekanmi et al., 2019). The results of statistical analysis from RSM include analysis of variance (ANOVA), contour graphs and 3D surfaces.

Statistical analysis of the effect of running time, filtering speed, and media variation on turbidity parameters

The percentage of data allowance that has been evaluated statistically using Design-Expert 11 software, with statistical test results including analysis of variance (ANOVA), and 3D surface graphs. The ANOVA test used is a two-factor interaction (*2FI*) model with the results shown in Table 4.

On the basis of Table 4 ANOVA model *2FI* turbidity, the results showed that the F-value of 6.18 with a p-value of 0.0061. The result of p-value which is less than 0.05 proves that the three factors, namely running time, filtering speed, and media variation, have an effect on the efficiency of removing turbidity parameters. This indicates that the research hypothesis H_1 is accepted so that there is a significant influence between the three factors used in the study. In turn, the results of lack of fit or lack of suitability are p-values of 4.66. The p-value of more than 0.05 proves that the lack of fit is relatively insignificant to pure error. Lack of fit shows a strong interaction between data and factors, so that a non- significant lack of fit is a good result, because a model should ideally be fit, and the model can be used to predict response values with different factors.

Table 5. Fit statistics ANOVA turbidity

Std. Dev.	7.29	R^2	0.7877
Mean	71.96	Adjusted R^2	0.6603
C.V. %	10.12	Predicted R^2	0.4611
		Adeq precision	8.4458

On the basis of Table 5 Fit statistics, the turbidity ANOVA shows that the correlation coefficient (R^2) is 0.79. These results indicate that the relationship between variables and data is strong according to Davarnejad and Nasiri (2017), namely the good (R^2) value is close to one. This was reinforced by the results of Adeq precision, which describes the effect of signal to noise ratio as predicted by the model. The model results are desired if the signal to noise ratio is > 4 (Oyekanmi et al., 2019). Adeq precision of the turbidity parameter shows a ratio of 8.44 which indicates the suitability of the model for parameter analysis.

All data on the response value of the turbidity parameter that has been entered in the software yielded a comparison of the actual response value with the predicted response value along with the normal probability plot test. The two results that were read on the software function to measure the accuracy value of the research results. The data on the comparison of the actual and predicted response values can be seen in Table 6 and the normal probability graph can be seen in Figure 4.

On the basis of Figure 4, there are points which are 17 actual response values with stated data results normally distributed because the scatter plot follows a straight-line colored red. In addition, the software also represents the shape of the contour graph and three-dimensional surface (3D surface) to facilitate the illustration of the influence of independent factors on the response in the *2FI* model which can be seen in Figure 5–8.

On the basis of the two pairs of contour graphs and 3D surface graphs above, it shows that the longer the running time and the smaller the filtering speed, the better the trend of turbidity removal efficiency. However, from the two modifications

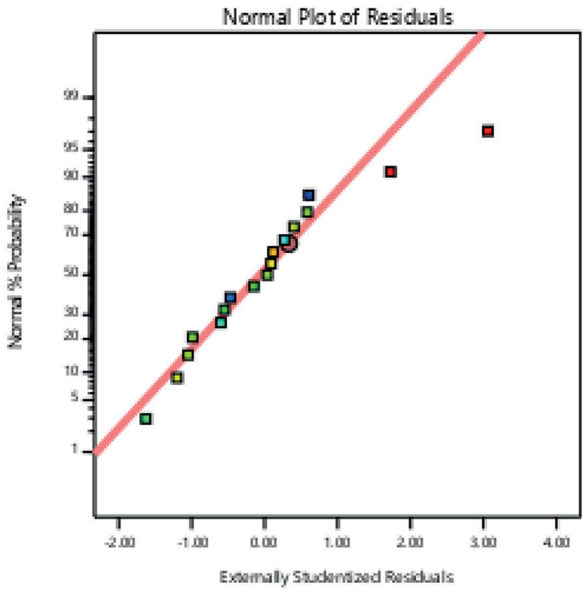

Figure 4. Normal turbidity probability

Table 6. Comparison of actual and predicted response turbidity values

Run	Day	m/hour	SSF	Actual value	Predicted value
1	6	0.1	P+PS	83.00	82.31
2	1	0.3	P+KR	46.81	43.98
3	1	0.1	P+KR	70.95	71.87
4	6	0.3	P+PS	75.18	74.97
5	6	0.1	P+KR	78.80	83.47
6	3	0.1	P+PS	91.33	81.10
7	1	0.1	P+KR	63.23	71.87
8	1	0.1	P+PS	80.82	80.29
9	6	0.3	P+KR	68.61	71.80
10	3	0.3	P+PS	60.22	64.03
11	3	0.1	P+KR	90.73	76.51
12	1	0.3	P+PS	58.00	56.73
13	6	0.3	P+PS	77.30	74.97
14	3	0.3	P+KR	52.10	55.11
15	6	0.1	P+PS	76.51	82.31
16	1	0.1	P+PS	74.63	80.29
17	6	0.3	P+KR	75.17	71.80

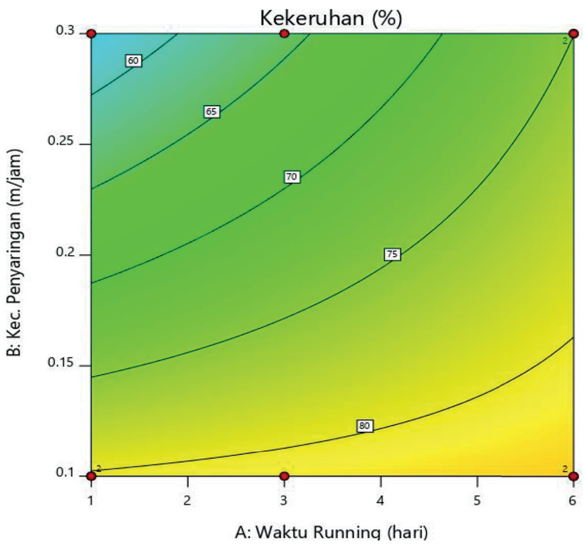

Figure 5. SSF1 turbidity contour

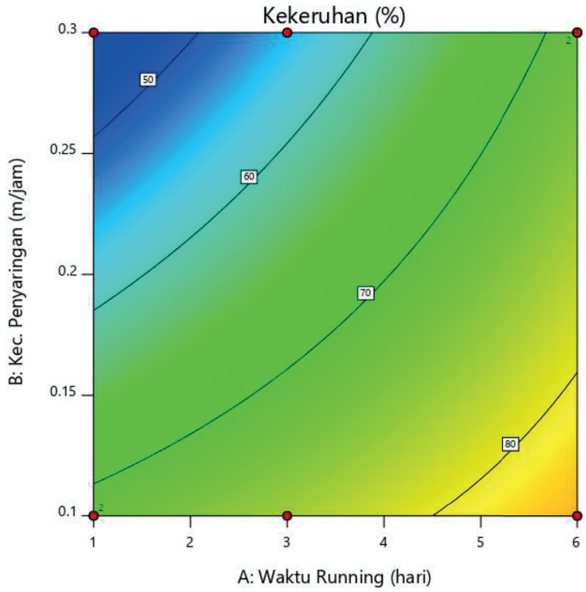

Figure 7. SSF2 turbidity contour

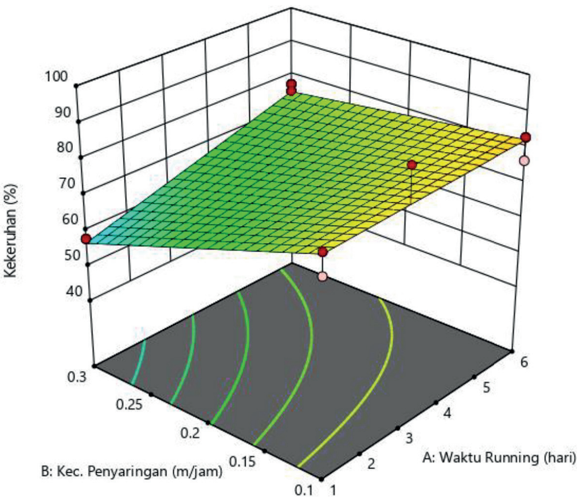

Figure 6. 3D graph of the surface turbidity of SSF1

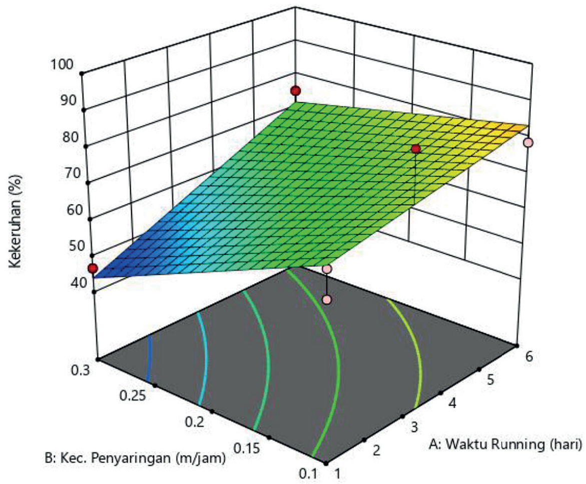

Figure 8. 3D graph of SSF2 turbidity surface

of SSF, the one that is superior in removing turbidity is SSF1 with silica sand filter media with an effectiveness of 74.63–83%. These results were supported by previous research from Kandra et al. (2015), where SSF with silica sand filter media can achieve the removal of the turbidity parameter of 62%. In addition, the turbidity removal efficiency can be high, if the filter media still considers the presence of high SiO_2 compounds. The SiO2 compounds found in silica sand are 55.3 – 99.8% (Selintung and Syahrir, 2019).

Statistical analysis of the effect of running time, filtering speed, and media variation on parameter

The percentage of allowance data that has been obtained was statistically tested using Design-Expert 11 software, with statistical test results including analysis of variance (ANOVA), and 3D surface graphs. The ANOVA test used is a two-factor interaction (*2FI*) model with results that can be seen in Table 7.

On the basis of Table 7 ANOVA model *2FI* TSS, the results showed that the F-value of 17.83 with a *p*-value of 0.0001. The result of *p*-value less than 0.05 proves that the three factors, namely running time, filtering speed, and media variation had an effect on the efficiency of removing TSS parameters. This indicates that the research hypothesis H1 was accepted, so that there is a significant influence between the three factors used in the study. While the results of lack of fit or lack of conformity with the *p*-value of 1.81. The result of *p*-value which is more than 0.05 proves that the lack of fit is relatively insignificant to pure error.

Table 7. ANOVA model 2FI TSS

Source	Sum of squares	df	Mean square	F-value	p-value	Significance
Model	5749.29	6	958.21	17.83	0.0001	Significant
A-Time Running	1460.75	1	1460.75	27.18	0.0004	
B-Filtration Rate	4826.61	1	4826.61	89.82	0.0001	
C-Variation Media	11.50	1	11.50	0.2140	0.6536	
AB	321.73	1	321.73	5.99	0.0344	
AC	1.33	1	1.33	0.0247	0.8783	
BC	2.53	1	2.53	0.0470	0.8327	
Residual	537.34	10	53.73			Not significant
Lack of Fit	350.90	5	70.18	1.88	0.2522	
Pure Error	186.44	5	37.29			
Cor Total	6286.61	16				

Lack of fit shows a strong interaction between data and factors, so that a non-significant lack of fit is a good result, because a model should ideally be fit, and the model can be used to predict response values with different factors.

On the basis of Table 8 Fit statistics ANOVA TSS shows that the correlation coefficient (R^2) was 0.91; these results indicate that the relationship between variables and data is classified as strong according to Davarnejad and Nasiri's (2019) research, namely the good (R^2) value is close to one. This was reinforced by the results of Adeq precision which describes the effect of signal to noise ratio as predicted by the model. The model results are desired, if the signal to noise ratio is > 4 (Oyekanmi et al., 2019). Adeq precision parameter TSS shows a ratio of 12.39 which indicates the suitability of the model for parameter analysis.

Table 8. Fit statistics ANOVA TSS

Std. Dev.	7.3	R^2	0.9145
Mean	69.09	Adjusted R^2	0.8632
C.V. %	10.61	Predicted R^2	0.7540
		Adeq Precision	12.39

All TSS parameter response value data that has been entered in the software also releases a comparison of the actual response value with the predicted response value along with the normal probability plot test. The two results that were read on the software were used to measure the accuracy value of the research results. The data

Table 9. Comparison of actual and predicted response TSS values

Run	Day	m/hour	SSF	Actual value	Predicted value
1	6	0.1	P+PS	89.50	90.94
2	1	0.3	P+KR	25.70	32.66
3	1	0.1	P+KR	79.50	78.50
4	6	0.3	P+PS	61.50	67.18
5	6	0.1	P+KR	88.30	89.42
6	3	0.1	P+PS	89.30	83.60
7	1	0.1	P+KR	73.30	78.50
8	1	0.1	P+PS	79.50	78.71
9	6	0.3	P+KR	53.80	64.06
10	3	0.3	P+PS	51.47	47.55
11	3	0.1	P+KR	88.20	82.87
12	1	0.3	P+PS	31.10	34.46
13	6	0.3	P+PS	72.30	67.18
14	3	0.3	P+KR	58.50	45.22
15	6	0.1	P+PS	89.10	90.94
16	1	0.1	P+PS	75.50	78.71
17	6	0.3	P+KR	68.00	64.06

on the comparison of the actual and predicted response values can be seen in Table 9 and the normal probability graph can be seen in Figure 9.

Figure 9 shows that there are points which are 17 actual response values with stated data results normally distributed because the scatterplot follows a straight red line. In addition, the software also represents the shape of the contour graph and three-dimensional surface (3D surface) to simplify the illustration of the influence of independent factors on the response in the *2FI* model which can be seen in Figures 10–13.

On the basis of the two pairs of contour graphs and 3D surface graphs above, it shows that the longer the running time and the smaller the filtering speed, the better the trend of turbidity removal efficiency. However, of the two modifications of SSF, the one that is superior in removing TSS is SSF1 with silica sand filter media with an effectiveness of 79.5–89.1%. These results are supported by previous research from Hidayatullah and M.H. (2019), where SSF with modified silica sand filter media can achieve a TSS parameter removal of 84.19%. The size of silica sand which is smaller than the shell of *A. granosa* has an effect on removing TSS in water because the smaller the particle size of the filter media used, the greater the surface area of the filter media so that the filtering power of TSS will increase (Aziz, 2014).

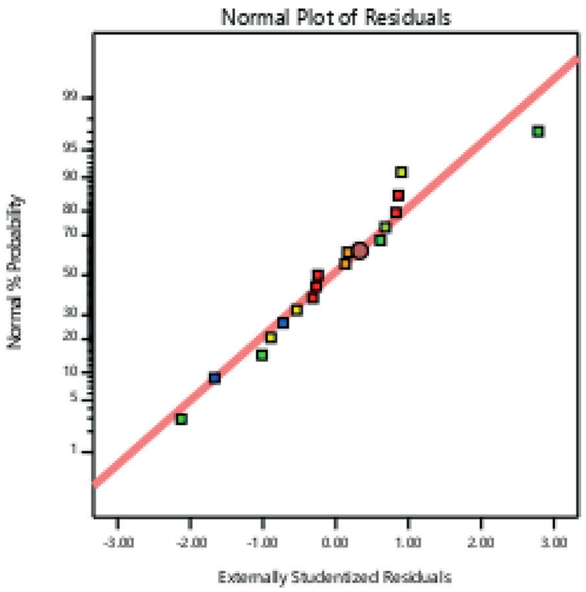

Figure 9. Normal probability of TSS

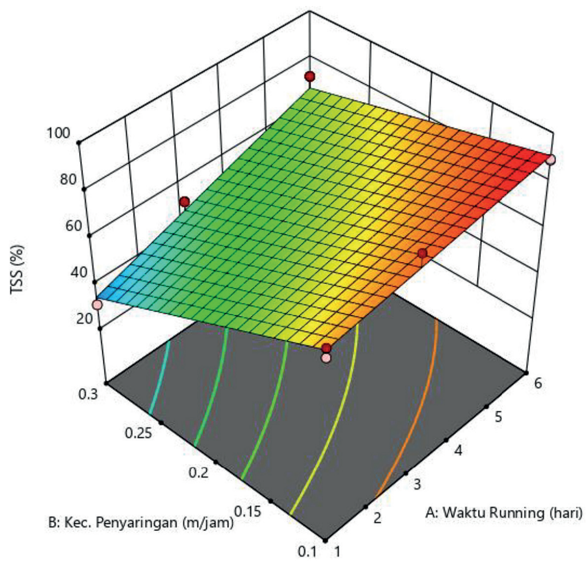

Figure 11. 3D graph of TSS SSF1 surface

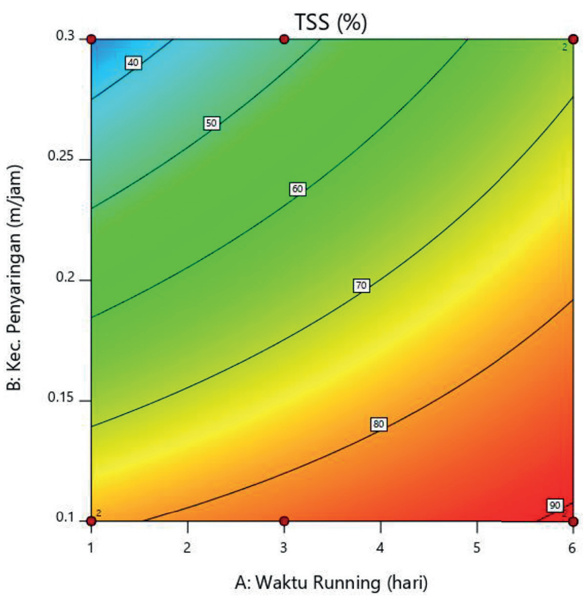

Figure 10. TSS SSF1 contour

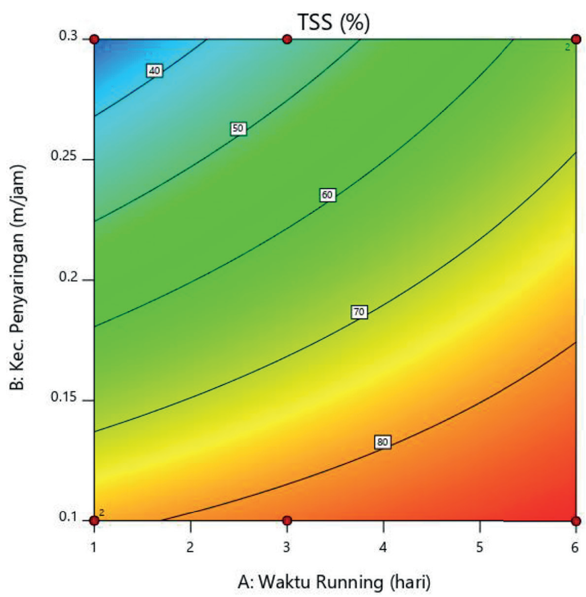

Figure 12. TSS SSF2 contour

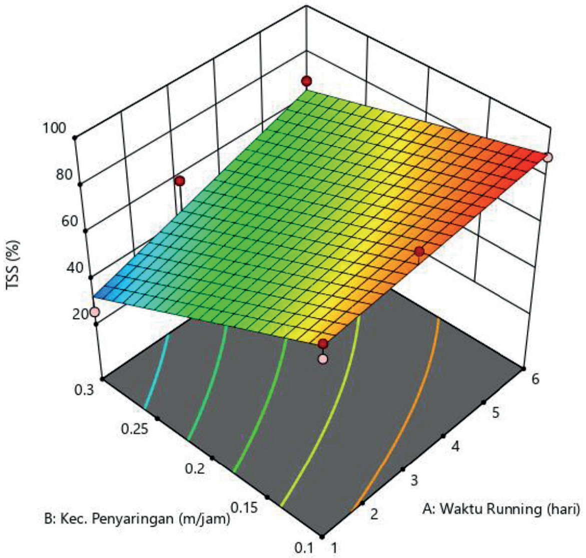

Figure 13. 3D graph of the TSS SSF2 surface

Statistical analysis of the effect of running time, filtering speed, and media variation on iron parameters

The percentage of allowance data that has been obtained was statistically evaluated using Design-Expert 11 software, with statistical test results including analysis of variance (ANOVA), and 3D surface graphs. The ANOVA test used is a two-factor interaction (*2FI*) model with the results shown in Table 10.

On the basis of Table 10 ANOVA of the iron *2FI* model, the results showed that the F-value was 5.07 with a *p*-value of 0.0123. The result of *p*-value less than 0.05 proves that the three factors, namely running time, filtering speed, and media variation affect the efficiency of iron parameter removal. This indicates that the research hypothesis H1 is accepted, so that it can be concluded that there is a significant effect between the three factors used in the study. The results of lack of fit or lack of conformity have the *p*-value of 3.02. The result of *p*-value which is more than 0.05 proves that the lack of fit is relatively insignificant to pure error. Lack of fit shows a strong interaction between data and factors, so that a non-significant lack of fit is a good result, because a model should ideally be fit, and the model can be used to predict response values with different factors.

Table 11. ANOVA fit statistics for iron

Std. Dev.	6.34	R^2	0.7526
Mean	43.40	Adjusted R^2	0.6042
C.V. %	14.61	Predicted R^2	0.1611
		Adeq Precision	7.73

On the basis of Table 11 showing ANOVA fit statistics for iron shows that the correlation coefficient (R^2) was 0.75. These results indicate that the relationship between variables and data is quite strong according to Davarnejad and Nasiri's research (2019), namely the good (R^2) value is close to one. This was reinforced by the results of Adeq precision, which describes the effect of signal to noise ratio as predicted by the model. The model results are desired if the signal to noise ratio is > 4 (Oyekanmi et al., 2019). Adeq precision iron parameter shows a ratio of 7.73 which indicates the suitability of the model for parameter analysis.

All data on the response value of the iron parameter that has been entered in the software also releases a comparison of the actual response value with the predicted response value along with the normal probability plot test. The two results that were read on the software function to measure the accuracy value of the research results. The data on the comparison of the actual

Table 10. ANOVA model 2FI iron

Source	Sum of squares	df	Mean square	F-value	p-value	Significance
Model	1222.43	6	203.74	5.07	0.0123	Significant
A-Time Running	297.12	1	297.12	7.39	0.0216	
B-Filtration Rate	521.55	1	521.55	12.98	0.0048	
C-Variation Media	135.27	1	135.27	3.37	0.0964	
AB	325.74	1	325.74	8.11	0.0173	
AC	48.92	1	48.92	1.22	0.2957	
BC	27.08	1	27.08	0.6739	0.4308	
Residual	401.83	10	40.18			Not Significant
Lack of Fit	301.83	5	60.37	3.02	0.1253	
Pure Error	100.00	5	20.00			
Cor Total	1624.27	16				

Table 12. Comparison of actual and predicted response iron values

Run	Day	m/hour	SSF	Actual Value	Predicted Value
1	6	0.1	P+PS	50.00	49.61
2	1	0.3	P+KR	22.20	22.64
3	1	0.1	P+KR	42.80	41.76
4	6	0.3	P+PS	50.00	45.86
5	6	0.1	P+KR	50.00	45.30
6	3	0.1	P+PS	45.40	52.30
7	1	0.1	P+KR	42.85	41.76
8	1	0.1	P+PS	57.10	54.08
9	6	0.3	P+KR	40.00	46.78
10	3	0.3	P+PS	45.40	36.18
11	3	0.1	P+KR	36.36	43.18
12	1	0.3	P+PS	22.22	29.72
13	6	0.3	P+PS	50.00	45.86
14	3	0.3	P+KR	36.36	32.30
15	6	0.1	P+PS	50.00	49.61
16	1	0.1	P+PS	57.14	54.08
17	6	0.3	P+KR	46.78	46.78

and predicted response values can be seen in Table 12 and the normal probability graph can be seen in Figure 14.

On the basis of Figure 14, there are points which are 17 actual response values with stated data results normally distributed, because the scatter plot follows a red line. In addition, the software also represents the shape of the contour graph and three-dimensional surface (3D surface) to facilitate the illustration of the influence of independent factors on the response in the *2FI* model which can be seen in Figures 15–18.

On the basis of the two pairs of contour graphs and 3D surface graphs above, it shows that the longer the running time and the smaller the filtering speed, the better the trend of turbidity removal efficiency. However, of the two modifications of SSF, the one that is superior in removing iron is SSF1 with silica sand filter media with an effectiveness of 45.4–50%. The low efficiency of iron removal is due to the diameter of the reactor used is 10 cm and the height of silica sand is 15 cm. These results are supported by the previous research from Hidayatullah and M.H. (2019),

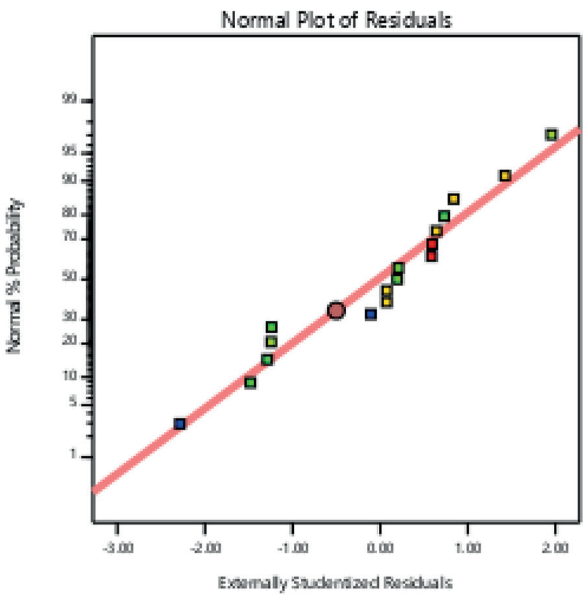

Figure 14. Normal probability of iron

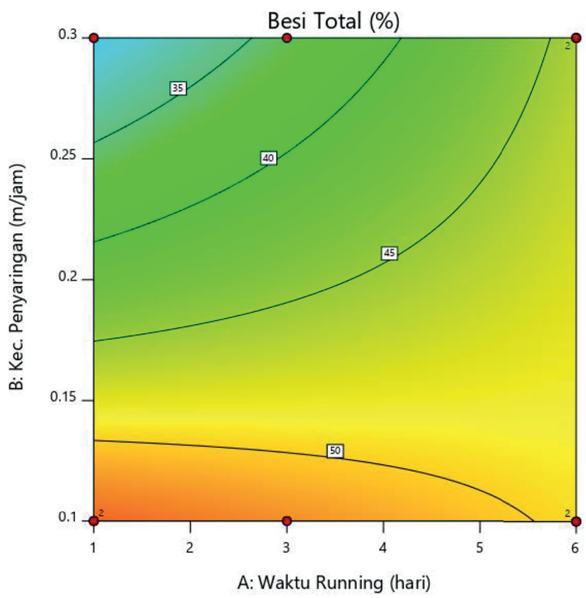

Figure 15. SSF1 iron contour graph

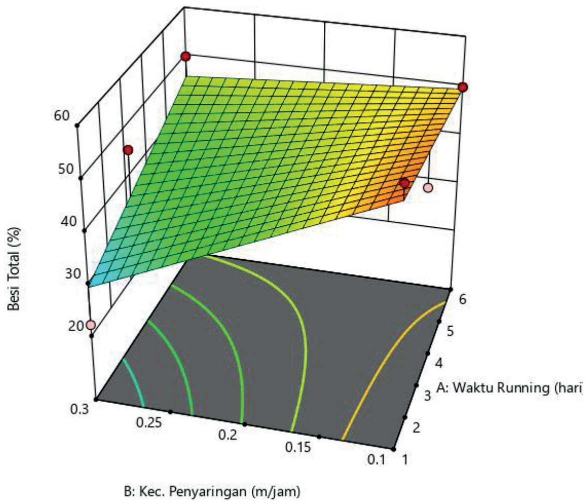

Figure 16. 3D graph of SSF1 iron surface

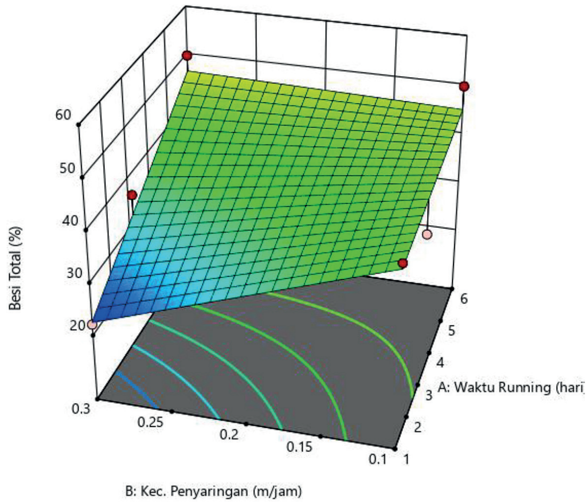

Figure 18. 3D graph of SSF2 iron surface

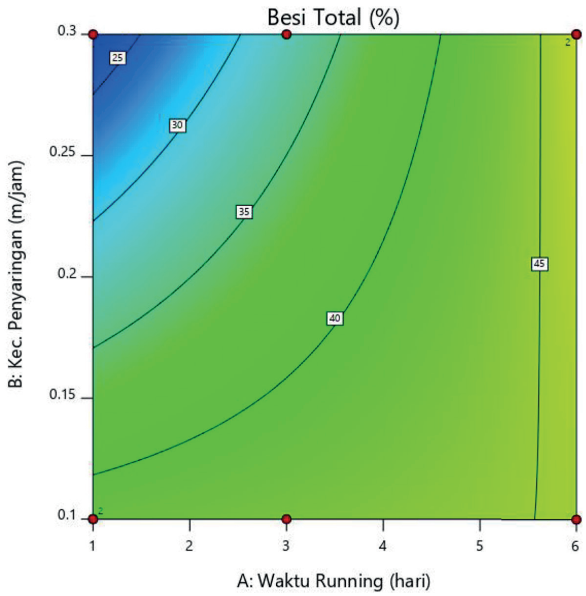

Figure 17. SSF2 iron contour graph

namely SSF with a height of 75 cm high silica sand can achieve an iron parameter removal of 72.96%. According to Hidayatullah and M.H. (2019), the silica sand in the Slow Sand Filter functions as an adsorbent and oxidizing agent for water pollutants. Silica sand has a (-) charge, so that it can attract positively charged particles such as cations from the trapped iron molecules.

Optimal research application of response surface methodology

Optimal research results are carried out using optimization techniques on the RSM application. The desired goal is in the research model response, namely maximizing the actual response value. The final result of the numerical point optimization technique shows there are 17 alternative solutions that can be chosen to achieve the target removal efficiency response, which can be seen in Appendix 6. The most optimal variation of SSF in processing all parameters is SSF1, namely SSF with silica sand filter media and filtering speed of 0.1 m/hour with the results of the desirability value in the study being 0.859.

In addition, these results can be observed visually with a 3D desirability graph that is used to find the accuracy of the research results with respect to the predicted value and an overlay plot graph that is used to map the surface area of the independent factor that produces the highest average value of removal effectiveness for each test parameter. The results of the 3D desirability graph and the overlay plot can be seen in Figures 19 and 20, respectively.

On the basis of Figures 19 and 20, research validation was carried out to confirm whether the predicted value calculated from the RSM was in accordance with the actual results in the field (actual value) and resulted in an efficiency response to the maximum test parameter allowance. The results of the selected optimum parameter validation research can be seen in Table 13.

On the basis of Table 13, the most optimal variation of SSF in processing all parameters is SSF1, namely SSF with a running time of day 6, silica sand filter media, and filtering speed of 0.1 m/hour. The running time was chosen on day 6, because the turbidity and TSS parameters had a stable removal percentage. The filtering speed of 0.1 m/hour was chosen because the slower the flow of water through the cavities between the media, it causes an increase in contact time between the surface of the media and the water and fine particles are retained so that the process of removing polluted parameters is good (Andini et al., 2014). According to Jannah (2019), silica sand media is widely used in water treatment plants in the filtration process to reduce turbidity caused by dissolved organic and inorganic compounds. In addition, the silica sand used has a very small diameter in accordance with the research of Nurmalia et al. (2019), namely the smaller the diameter of the media used, the greater the retention of Jagir River water particles so as to increase the effectiveness of the filtering process on the Slow Sand Filter.

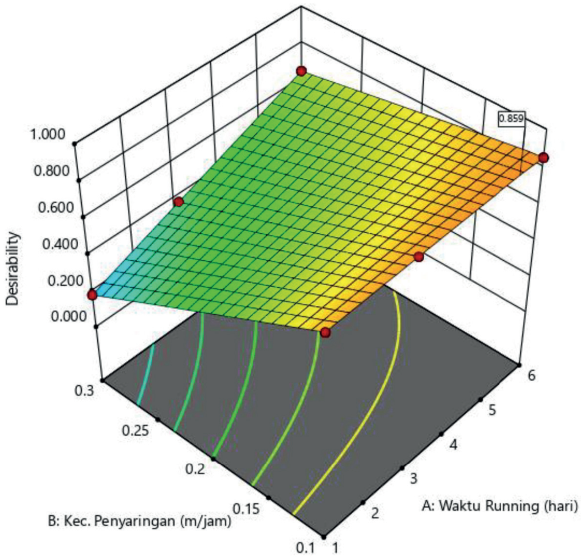

Figure 19. 3D desirability graph optimum model solution

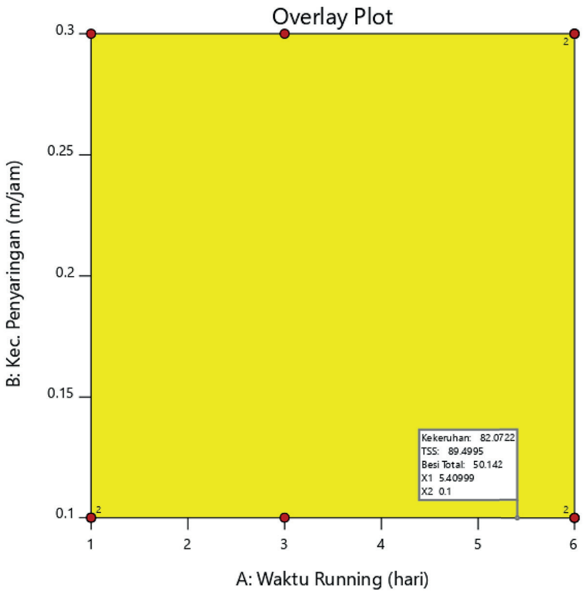

Figure 20. Overlay plot graph of the optimal solution model

Actual yield (% Allowance) if converted to units according to quality standards (NTU and mg/L) it will produce turbidity of 0.32 NTU; TSS 5 mg/L; and 0.02 mg/L iron. The actual result of turbidity efficiency, iron TSS is lower than the predicted result. The lower result is within the standard deviation range so that it remains in optimal data conditions. The actual result was not significantly different from the predicted data obtained previously, which was 0.28 NTU turbidity; TSS 4.93 mg/L; and 0.019 mg/L iron. The optimal result of this research is related to the desirability value in the study, which is 0.859. Therefore, SSF using silica sand media, filtering speed of 0.1 m/hour and running time on the 6th day will result in the percentage removal of turbidity, TSS, and iron parameters in accordance with the optimization target of 85.9%.

Optimal SSF quality and quantity comparison

The results of the optimal research on the Response Surface Methodology software in the Design expert 11 application are using a filtering speed of 0.1 m/hour. According to Dwiratna et al. (2018) the need for clean water in disaster areas is high. For this reason, an analysis of the quality and quantity of water produced by the Slow Sand Filter was carried out. The quality of the output of water treatment using a slow sand filter reactor is compared with the water quality standard for sanitation hygiene based on the Regulation of the Minister of Health of the Republic of Indonesia No. 32 of 2017 concerning Environmental Health Quality Standards and Water Health Requirements

Table 13. Optimal SSF variation

Solution 1 of 18 responses	Predicted (%)	Actual (%)	Std dev	A (day)	B (fliting speed)	C (media variation)
Turbidity	82.07	79.61	7.28	6	0.1 m/hour	P+ PS
TSS	89.5	89.36	7.33			
Iron	50.14	50	6.33			

Table 14. SSF output results against the quality standard of each parameter

Run	SSF1 0.1	SSF2 0.1	SSF1 0.3	SSF2 0.3	Quality Standard
Turbidity (NTU)					
1	0.62	0.89	0.52	0.66	25 NTU
2	0.34	0.34	0.42	0.56	
3	0.31	0.31	0.77	0.92	
4	0.39	0.54	0.38	0.4	
5	0.41	0.51	0.14	0.39	
6	0.31	0.34	0.33	0.39	
TSS (mg/L)					
1	10	10.5	27.5	29.0	40 mg/L
2	1.5	1.5	30.5	29.0	
3	5.0	2.5	20.5	17.5	
4	3.0	3.0	29.0	22.0	
5	9.0	8.0	9.5	20.0	
6	5.0	5.5	14.0	16.5	
Iron (mg/L)					
1	0.03	0.04	0.07	0.07	1 mg/L
3	0.06	0.07	0.07	0.06	
6	0.02	0.02	0.05	0.06	

for Sanitary Hygiene Needs. Parameters that are not listed in the previous regulation was then referred to the Indonesian Minister of Health's regulation on Regulation No. 22 of 2021 Appendix VI about river water standard class II. One of the research objectives is to determine the suitability of reactor quality and quantity that can be applied in disaster areas for sanitation hygiene which includes cleaning, sanitation, and washing clothes. The results of the output of all SSFs compared with the quality standards can be seen in Table 14.

On the basis of Table 14 the output parameters of turbidity and iron in all SSF have met the quality standards of sanitation and hygiene in accordance with the Regulation of the Minister of Health of the Republic of Indonesia No. 32 of 2017. Meanwhile, the TSS parameter has complied with Appendix VI of RI Government Regulation No. 22 of 2021 which refers to the second-class water quality standards for rivers and the like. As shown by the results of the comparison, the reactors that use speeds of 0.1 m/hour and 0.3 m/hour have met the quality standards so that at speeds of 0.1 m/hour and 0.3 m/hour can be used as sanitary hygiene water.

According to U.S. Agency for International Development (USAID) 2007, the water needs needed by refugees are 15 L/person/day which includes drinking water needs 3 L/person/day, cleaning needs 2 L/person/day, sanitation needs 6 L/person/day, and the need to wash clothes 4 L/person/day. However, in this study the treated water is intended for sanitation hygiene purposes, which is 12 L/person/day, so that the quantity of treated water is obtained according to the calculation of the service for 1 reactor in Chapter III with the result that one SSF reactor with a filtration speed of 0.1 m/hour can produces clean water of 22.8 L/day and can meet the needs of clean water for 2 people/day. The SSF reactor unit with a filtering speed of 0.3 m/hour can produce clean water in the amount of 68.4 L/day and can meet the needs of 6 people/day of clean water.

According to Dwiratna et al. (2018), SSF that is suitable for use in disaster locations is SSF which has a large quantity due to the urgent need for clean water. Therefore, based on the results of the service calculation above, SSF with a speed of 0.3 m/hour is suitable to be applied in disaster areas because the flow rate is greater than 0.1 m/hour. The scrapping process carried out as an effort to clean suspended particles stuck in the media does not depend on the speed of filtration because the SSF period for the scrapping process is 1–2 years (Huisman and Wood, 2013). This is in accordance with the research of Kem (1996), which states that SSF with turbidity >5 NTU can be scraped after 2 years of operation.

On the basis of the comparison of quality and quantity above, the results of the optimal research of the Point Optimization technique on Software Design Expert 11 are in accordance with quality standards and produce a discharge of 22.8 L/day to meet the needs of clean water for 2 people/day but the maximum filtering speed to be applied in disaster areas is 0.3 m/hour. Therefore, the reactor with a filtering speed of 0.3 m/hour and a variety of silica sand, geotextile, and sand media is suitable for use as water for sanitation hygiene and raw water for drinking water in disaster areas.

CONCLUSIONS

The results of Design Expert 11 with the optimal custom design method show that the most optimal variation of the slow sand filter in removing turbidity, TSS, and iron in the Jagir Surabaya water is to use a combination of sand, geotextile, and silica sand media, filtering speed 0.1 m/hour, and running time 6th day. The results showed that the actual values of turbidity, TSS, and iron were 79.61%; 89.36%; and 50% close to the predicted value of 82.07%; 89.5%; and 50.14%. Meanwhile, the reactor which is suitable for use in disaster areas is SSF which has a large discharge using a filtering speed of 0.3 m/hour. Sampling and analysis of water from slow sand filter processing for each parameter being tested should be carried out more than once so that the results obtained are more accurate. Pipe accessories in the slow sand filter reactor must be checked periodically for potential leaks, if small cracks or seepage is seen in the reactor, it is immediately covered with silicone rubber sealant, while the leak point on the pipe is closed with PVC pipe glue.

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