Rotating Ceramic Water Filter Discs System for Water Filtration

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ABSTRACT

This work aimed to design, construct and operate a new laboratory scale water filtration system. This system was used to examine the efficiency of two ceramic filter discs as a medium for water filtration. These filters were made from two different ceramic mixtures of local red clay, sawdust, and water. The filtration system was designed with two rotating interfered modules of these filters. Rotating these modules generates shear force between water and the surfaces of filter discs of the filtration modules that works to reduce thickness of layer of rejected materials on the filters surfaces. Each module consists of seven filtration units and each unit consists of two ceramic filter discs.

The average measured hydraulic conductivity of the first module was 13.7mm/day and that for the second module was 50mm/day. Results showed that the water filtration system can be operated continuously with a constant flow rate and the filtration process was controlled by a skin thin layer of rejected materials. The ceramic water filters of both filtration modules have high removal efficiency of total suspended solids up to 100% and of turbidity up to 99.94%.

Key words: ceramic filters, filtration system, water filtration, water purification.

منظومة اقراص مرشحات الماء الخزفية الدوارة لترشيح المياه

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الخلاصة

هدف هذا العمل هو تصميم وانشاء وتشغيل منظومة جديدة بمقياس مختبري لترشيح المياه. استخدمت هذه المنظومة لفحص كفاءة اثنين من المرشحات الخزفية كوسط لترشيح المياه. تم تصنيع هذه المرشحات الخزفية من اثنين من الخلطات الخزفية من الطين الاحمر المحلي مع نشارة الخشب والماء. صممت منظومة الترشيح باثنين من وحدات ترشيح متداخلة ودوارة من هذه المرشحات. يعمل تدوير هذه الوحدات على توليد قوة قص بين الماء وسطوح اقراص الترشيح التي تعمل على تقليل سمك طبقة المواد المرفوضة على سطوح المرشحات. تتألف كل وحدة من سبعة مفردات من المرشحات، وكل مفردة تتألف من اثنين من اقراص المرشحات الخزفية.

كان معدل الايصالية الهيدروليكية المقاسة للوحدة الاولى 13.7 ملم/اليوم وللوحدة الثانية 50 ملم/اليوم. بينت النتائج ان منظومة ترشيح المياه لها القابلية على العمل باستمرار بمعدل تصريف ثابت وان عملية الترشيح محكومة بطبقة رقيقة من المواد المرفوضة المتراكمة على اسطح المرشحات. تمتلك مرشحات الماء الخزفية لكل من وحدتي الترشيح كفاءة عالية في ازالة المواد العالقة الكلية تصل الى 100% وفي ازالة العكورة تصل الى 99.94%.

1. INTRODUCTION

Availability of fresh and safe water for human consumptions is becoming scarce due to the increasing population, deficit in water sources, and contaminations being released into these sources. Governments, several civilian community organizations, universities, scientific research centers, and other institutions are working to get rid of these problems by supporting studies, researches, and activities in the fields of improving the water quality and increasing the water uses efficiencies. One of the fields of concerns is to supply safe water with low cost systems.

Ceramic is one of the common materials that had been used to produce water filters for a safe drinking water. The ceramic filters offer many advantages over other filters made of other materials. The ceramic filters are efficient in raw water filtration, of low cost, environmentally friendly, and a simple technology is needed to produce them.

Many studies and researches were performed on ceramic filters to improve the water quality by using and developing different mixtures and techniques to increase the efficiency of removing the suspended materials. **Jassim, 2010**, studied the evolution of water purifier cartridge made from Iraqi local ceramic materials. The main conclusion of this study was that all of the tested ceramic filters produced using four types of additives have excellent removal efficiencies of suspended materials and have good efficiencies in adsorption of some cations and anions. **Musa, 2010**, studied the performance of ceramic water filters made from selected two types of clays, sawdust and water for point-of-use. A linear relation between filters porosity and the percentage of the added sawdust was obtained. A quadratic relation was found between the percolation rate of water and the filters porosity. Moreover, a nonlinear polynomial relation of third degree was obtained between the percolation rate and the filters thickness. The results of the study showed that the filters made of both clay types have good removal efficiency of turbidity and total coliform. **Plappally, et. al, 2011**, conducted a field study on the use of ceramic water filters of frustum shaped and influences on the general health. These filters were made from different percent of local clay and sawdust. The results showed that the filters made from the mix ratio of clay: sawdust of 50:50 by volume has better efficiency in microbial filtration and better field service than the other ratios. In laboratory part of a study on the hydraulic performance ceramic pot water filters, **Peabody, 2012**, tested the comparison of hydraulic properties of the Filter Pure (FP) and Potters for Peace (PFP) ceramic pot filters. The FP filters was made from a mixture of clay, sawdust, water, and colloidal Silver. The PEP filter was made from the same mixture of the filter FP except of colloidal silver which was used as coated layer on the surface of PEP filter. The results showed that the filter FP has hydraulic performance better than the PEP filter. In the study of **Sharhan, 2013,** ceramic filter discs were produced from different Iraqi local materials to test their hydraulic performance. A laboratory scale bioreactor for municipal wastewater treatment with rotating ceramic discs was designed and constructed in order to examine the quality of water filtrated by using these ceramic discs. The obtained results showed that the mixture of red clay soil and sawdust as an additive has a maximum hydraulic conductivity over other additives. The results indicated that the bioreactor system can be used efficiently to treat municipal wastewater. The removal efficiency of the bioreactor system was related inversely to the hydraulic conductivity of the ceramic filters and was proportionally related to the hydraulic detention time. **Subriyer, 2013**, studied the treatment of domestic water using ceramic filter made from natural clay, fly-ash, and iron powder. In this study, the content of heavy metal in water was minimized by using a simple method of filtration technology. The analysis showed that the filtration system has good ability to decrease dissolved solids in permeates. It was found that the flow rate has no significant influence on the reduction of dissolved solids. The study showed that these filters have high efficiency in producing good quality of permeate due to removing the iron and zinc by more than 99% and 96% respectively. **Yakub, et. al, 2013**, conducted the research on the filtration characteristics of frustum-shaped ceramic water filters. These filters were made from red clay and sawdust in three different proportions by volume. It was found that filters produced with 50% of sawdust have an optimum flow rate and high efficiency of E. coli removal. The study concluded that the filtration efficiency did not change significantly with volume fraction of sawdust. Moreover, the removal of E. coli was referred in general to the geometrical clogging resulted by micro-pores and totally may be by a high adsorption due to the increasing of tortuosity. **Zair, 2013**, carried out a research on development of the performance of ceramic candle filters for water purification using mixing of different percent of Iraqi locally materials. It was found that the filters made from a mixture by weight of 25% activated kaolin clay, 35% coal, and 40% porcelanite have good performance of water purification. **Abiriga**, and **Kinyera, 2014**, studied the purification of water by ceramic filters in double filtration system. The ceramic filters were made from different mixes of ball clay, hardwood sawdust and grog. This filtration system has two ceramic disc fixed one over other with a specified distance between them. The results showed that the double filtration discs produced from mix ratios 5:1:2 and 4:2:1 by volume of clay, sawdust, and grog respectively for each have best efficiency of E. coli removal.

The above mentioned studies are some examples and there are many other studies that encourage efforts for more studies to develop new ceramic filter having different geometric shapes with high performance in purifying of water and to apply new design of water filtration systems that use this type of filtration material.

Generally, this study aims to produce two different ceramic filters with a disc shape manufactured from local materials. These disc filters are assembled to form two different filtration modules that are used in a designed and constructed laboratory scale water filtration system. The modules filters are rotated within the system to reduce accumulation of rejected materials on the surfaces of the filters.

2. CERAMIC FILTERS MODULES

Two different ceramic filters modules were prepared, FM1 and FM2. Each module consists of fourteen ceramic disc filters. Ceramic filter discs in each module have approximately the same properties. The filters used in these two modules were produced from two mixtures of local raw materials. These mixtures have different ratios of red clay, and sawdust as an additive. The ratios of the raw materials in addition to the pressure used to form these discs and the firing temperature are the key parameters that affect the filtration properties of the filters. **Table.1** presents the ratios of raw materials used in each mixture, in which all the presented ratios are by weight. The percentage of water added to the mixtures was 10% by weight. Semi dry pressing method was used to form the disc shape of these filters. Details of this method can be found in **Hammer, 1975**. A special steel mold was used and press pressures of 40, and 20MPa were applied to prepare the ceramic filters of FM1 and FM2, respectively. The mold was designed to produce ceramic filters of 12cm in diameter and a thickness of 2.5mm. The ceramic filters were fired inside a programmable electrical kiln according to a time schedule program of firing. The final firing temperature of 1070˚C was used to produce both filters discs. This firing temperature was found suitable to give efficient filter disc, **Sharhan, 2013**. **Fig. 1** shows samples of the produced ceramic filters discs. Each of the filtration module, **Fig. 2**, consists of seven ceramic filter units. The filter unit is constructed from two discs separated by PVC ring of 3mm width as shown in **Fig. 3**. A pipe with holes at each filter unit is used to fix these units and to collect the filtered water from each unit. This pipe is of 20mm outer diameter and 12mm inner diameter.

The produced ceramic filters of the two modules were tested for their hydraulic conductivity and are presented in **Table 2**. The measured hydraulic conductivity of the filters of FM1 ranged between 10 and 17mm/day with an average of 13.7mm/day. The hydraulic conductivity of FM2 ranged between 46 and 55mm/day with an average of 50mm/day.

3. WATER FILTRATION SYSTEM

A laboratory scale water filtration system was prepared by using the ceramic filter modules. **Fig. 4** shows a schematic diagram of this system and **Fig. 5** shows the filtration system installed in the laboratory. The system consists of a storage tanks, filtration tank, two ceramic filtration modules, backwash tank, two treated water storage tanks, peristaltic pump, and an electrical control board. All units are fixed on a steel frame of three floors. The dimensions of the storage tank were 34cm width, 66cm length, and 34cm depth with 60l net volume. The tank is supplied by raw water through a pipe of 12mm inner diameter located at the left hand side at a distance 2cm from the top edge of the tank. This pipe is controlled by an electrical float valve used to preserve 30cm of raw water depth. This tank supplies raw water to the filtration tank. The filtration tank is the main unit of filtration system that consists of the filtration modules. The tank has the outer dimensions of 32cm width, 81cm length, and 52cm depth with 96l net volume. A mechanical float valve was used to control the inflow to the filtration tank. Four submersible water pumps were used to circulate raw water in order to prevent settling of the suspended materials. A drain pipe of 50mm fixed at the bottom of filtration tank was controlled by a mechanical valve to wash or empty the filtration tank and also used for taking samples. The two ceramic filtration modules were installed inside the filtration tank in a way shown by **Fig. 2.** The distance between the two filter modules is 75mm center to center with an interference of about 20% between the surface areas of each of the filtration units of the two modules. A motor is used to rotate these modules at rate of 15rpm. The reason behind rotating the ceramic filtration modules is to provide a shear force between these discs by water filling the gap between the filters. This force provides unsuitable environment for micro-organism growth and reduces the thickness of the accumulated rejected materials by the filters. Backwashing with clear water is necessary to remove the rejected material within and over the ceramic filter during operation. The backwash tank has a square base of 32×32cm and a depth of 28cm with 20l net capacity. Fresh water is supplied to this tank through an inlet pipe of 12mm diameter controlled by a mechanical float valve. The backwash process is carried out by a pump that operates at a maximum rate of 20l/min and a minimum rate of 8l/min. The filtration system was supplied by two treated water storage tanks of 17.5cm width, 21cm length, and 16cm depth. The capacity of each tank is 4l. Each tank receives treated water from one filtration modules. Each tank has a tap of 12mm diameter that is used for water sampling. A peristaltic pump with two heads was used to pump water from each filtration modules to the treated water storage tanks. The rotating speed of this peristaltic pump is ranged between 60 and 600rpm. Four sizes of silicon tubes can be used to pump water with a range vary between 6 and 180l/hr. Two pressure gauges were installed at the section side of each head of the peristaltic pump.

3.1 Design of Experiment Runs

A total of twenty experiment runs was carried out by using raw water with five different total suspended solids, TSS, concentrations. These experiments were grouped in five sets. Each set consists of four experiments that were carried out with a specific concentration of TSS of the water to be filtered by using the filtration system. The concentrations of TSS were 500, 1000, 3000, 5000, 7000 mg/l. These concentrations were achieved by adding red clay as weight percentage to the volume inside the filtration tank. Properties of raw water that was used in the experiments are summarized in **Table 3**. The first experiment run of each set was conducted without using peristaltic pump and without using backwash. In this case, the water flows through the ceramic filters to the treated water storage tank by gravity. Other three experiments were conducted by using peristaltic pump and backwash with different discharge and backwash time.

The discharge of the peristaltic pump in the second to the fourth experiments of each set is selected to be one and half, three and six times the higher value of the steady state flow rate obtained from the two modules.

A total of thirty tests of temperature, pH, electrical conductivity, turbidity, total dissolved solids and total suspended solids of raw water were carried out before starting each set of experiment run. Four hundred and eighty physical tests were carried out on the effluent of the filtration system including turbidity and total suspended solids. One hundred and eighty negative suction pressure readings of the two pressure gauges were recorded during all runs when using the peristaltic pump. Sixty water flow rate measurements of treated effluent discharge were carried out during experiment runs without using the peristaltic pump.

3.2 Water Filtration System Operation Procedure

Each set of experiments is executed according to the following procedure:

1. Tap water is filtrated before it was added to the storage tank by one-micron cotton filter. Then, the filtration tank is filled with the filtered potable water via the storage tank.
2. The water filtration system is operated without using peristaltic pump and backwash pump. The flow rate of treated filtrating water from each of the two filtration modules is measured by volumetric test using graded vessel with time watch. The flow rate is measured every one hour until reaching the steady state of flowing for each module. This run is too important in order to be sure that all trapped air and probable residue of ceramic incineration have been removed from filter pores.
3. The required concentration of TSS for raw water is prepared by adding a calculated amount of red clay slurry to the filtered tap water inside the filtration tank. The slurry of the red clay is prepared by adding amount of clay to about 15l of water in a container and is mixed well. This slurry is then gradually added with a good mixing to the filtration tank.
4. The samples of raw water are collected by using clean plastic bottles. These samples are to be tested for pH, EC, TSS, TDS, and turbidity.
5. The first experiment is carried out without using peristaltic pump and backwash pump. At the beginning, the flow rate from each filtration module is measured volumetrically as water flow by gravity. Then the flow rate is measured each hour of five hours running.
6. Samples of water filtered by each filtration module are collected from the treated water storage tanks. These samples are to be tested for TSS and turbidity only. The temperature of water is measured each time of the water samples collection.
7. All filtrated water during the experiment is continuously returned back to the storage tank in order to maintain the concentration of raw water and the constant head in the filtration tank.
8. At the end of operation, the filtration tank is drained out and the accumulated rejected materials on the filters are removed during the backwashing by using distilled water for a duration of twelve seconds on and off for a period of half hour. Moreover, tap water is poured gently on the outer faces of filters. Finally, the filtration tank is well cleaned by potable water and is then completely drained.
9. The filtration tank is filled with tap water in the same way as in the first step mentioned above. The water filtration system is then kept running without peristaltic pump by using tap water. The effluent of filtration water from the modules was monitored until it reached the steady state flow rate.

10. The filtration system is operated with the use of peristaltic pump and backwash pump. The flow rate of peristaltic pump is selected to be one and half of the maximum steady state flow rate resulted from step number 9 mentioned above. The backwash pump is operated when the negative suction pressure gauge reading being less than about -0.4bars and stop when the reading of pressure becomes higher than -0.4bars. The system is kept running for five continuous hours. Samples of filtrated water are collected from each of filtration modules to be tested for TSS and turbidity t the starting time and at each hour of operation.
11. Steps 7 to 10 are then repeated two times. These represent experiment number three and four. But in step number 10, the flow rate of the peristaltic pump is selected to be three and six times the maximum steady state flow rate for experiment number three and four, respectively.

4. RESULTS ANALYSIS

Tests results of the five sets of experiments are presented in **Table 4 to Table 8** under different concentration of TSS of 500, 1000, 3000, 5000, and 7000mg/l, respectively. The calculated removal efficiencies during these experiments are presented in **Table 9**. **Figs. 7** and **8** show the time variation of effluent of FM1 and FM2 during the first experiment of each set, respectively. The relation between the steady state effluent of filtration modules and the used TSS concentration during the first experiment of each set are presented in **Fig. 9**. The time variation of suction pressure gauge readings of the two modules for all TSS of raw water that were recorded during the experiments is presented in **Figs. 10** to **15**.

The steady state potable water flow rate of FM1 and FM2 when the filters are virgin was 125ml/min and 175ml/min, respectively. All other examined flow rates with potable water of FM1 and FM2 during other experiments reach a steady state flow rate of 100ml/min and 150ml/min, respectively. These steady flow rates are achieved after approximately three hours of the test start. This change in steady state flow rate is probably due to clogging of some pores inside the body of the filter discs. The steady flow rate of FM1 is less than that of FM2 by about 29%. This is due to the use of less percentage of sawdust and high pressing pressure in the production of FM1 compared to that of FM2.

In general, in all experiment with raw water of different concentrations of TSS, a thin layer of rejected materials was formed on the surfaces of ceramic filters. This layer increased with time until they reached a steady state thickness. This thickness is a function of the concentration of TSS and the shear resulted between the filters units due to their rotation. This layer is controlling the filtration process instead of the ceramic filters medium.

In the first experiment of all sets, the results showed that the effluent water from modules FM1 and FM2 is decreasing gradually until it reached a steady state effluent rate. The rate of this decrease and the value of the steady state depend on the concentration of the TSS of the water being treated. The overall percentage of decrease in the effluent of modules FM1 and FM2 is 20% and 14%, respectively. The maximum percentage of this decrease is 28% and 19% for FM1 and FM2, respectively, that was recorded during experiment with 7000mg/l TSS concentration of raw water. While, its minimum value of 12% and 9% for FM1 and FM2, respectively, which was recorded during the experiment with TSS concentration of 1000mg/l. It is expected that the minimum decrease to be recorded when the concentration of TSS is 500mg/l, which is during the first experiment of the first set. But in this experiment, the filter has never been subjected to raw water before and the initial effluent rate was 125 and 175ml/min for FM1 and FM2, respectively. While in all other experiment, the initial effluent rate was 100 and 150ml/min for FM1 and FM2, respectively. This may explain why the minimum reduction in the effluent rate was not in the first experiment of the first set. At the end of the first run of experiment of the first set, some of the pores of the filter media were clogged by the suspended particles that cannot removed by backwashing and this clogging being permanent. In these experiments, the steady state effluent rate is reached after approximately three hours. The values of steady state effluent of FM1 were 100, 88, 83, 77, and 72ml/min that was recorded during the first experiment of the five sets, respectively, and that for FM2 were 150, 136, 133, 128, and 122ml/min. The variation in values of the steady state effluent with the variation in the concentration of TSS may be referred to the nature of formation of the thin layer of the rejected materials on the filters surfaces. This formation depends on the concentration of the TSS and the shear between the filter surfaces due to the rotation of filtration modules. As the concentration of the TSS increased, the rate of accumulation of this layer is increased also, but the shear at the filter surface attempts to reduce the thickness of this layer until a steady state relation between the thickness formation and the shear is reached so that a specific thickness is achieved. This specific thickness of the rejected material is proportionally related to the concentration of the TSS.

In all experiments, the results showed that the values of TSS concentration and turbidity of the effluent for both FM1 and FM2 start to decrease during all runs and then reach a constant value. This may be referred to formation of the thin layer of rejected material on the surface of the filters. The particles of this layer have smaller pores than that of the filter and are forming a skin filter on the original filter media.

The overall average of TSS concentration of the effluent of FM1 is 1.3mg/l, while that for FM2 is 1.2mg/l. This difference in TSS concentration between both modules FM1and FM2 is referred to the smaller pores of module FM1 compared to that of Module FM2 as a result of using less percentage of sawdust and high press pressure in the production of FM1 compared to that of FM2.

The maximum recorded value of the TSS concentration of the effluent of the both modules FM1 and FM2 was 4mg/l that was recorded at the beginning of test number two of set number one. This was expected during the first run of using the peristaltic pump with TSS concentration of 500mg/l that forces fine particles to penetrate inside the filters pores at the beginning of this run and cannot be removed by the subsequent backwash. No TSS concentration in the effluent of FM1 and FM2 was recorded after three hour of test number four of set number one. This may be due to temporarily clogging of more filter pores during the second and third runs and accumulation of more fine partials on the surface of the filters.

The behavior of turbidity of effluent water is completely like that of TSS concentration for all runs of all experiments sets because turbidity reflects the same index of total suspended solids in the water. The turbidity of effluent water for both modules FM1 and FM2 is generally less than 5NTU. This turbidity is within the requirements of the Iraqi water quality and the world health organization standard of turbidity in drinking water, **WHO, 2004; Iraqi Central Organization for Standardization and Quality Control, 2001**.

The results of experiments showed that the ceramic water filters discs of both filtration modules FM1 and FM2 have high removable efficiency of the TSS and turbidity. The range of removal efficiency of TSS varies from 99.20% to 100% for filtration module FM1 and from 99.40% to 100% for filtration module FM2. The range of removal efficiency of turbidity was from 97.12% to 99.94% for filtration module FM1 and from 97.70% to 99.94% for filtration module FM2. These results indicated that the removal efficiencies of the two filtration modules are approximately the same.

The negative gauge pressure measured at the suction side of the peristaltic pump was recorded during each run of the experiment sets that were carried out with the peristaltic pump. The results of these runs showed that the negative suction gauge pressure for modules FM1 and FM2 is decreased with time until it reaches a steady state value at about the third hour of running. Moreover, the results showed that the suction pressure for both modules FM1 and FM2 decreased when increasing the discharge of peristaltic pump. The negative suction pressure for both modules FM1 and FM2 was decreased with the increasing of TSS concentration of influent raw water. The minimum value of negative suction gauge pressure was -0.52bar for FM1 and -0.50bar for FM2 that were recorded during the second hour of run number four of experiments set number five. The decreasing in the pressure with time is due to clogging of filter pores during time with suspended solids of raw water and reaching the steady state suction pressure is due to effect of the thin layer of the rejected materials on the filters surfaces that was kept at a final constant thickness due to the action of the shear force.

Therefore, filters of module FM2 is better than of module FM1 because filters of module FM2 have hydraulic conductivity about three times greater than that of module FM1.

5. CONCLUSIONS

The salient issues obtained from this study to test the filtration efficiency of ceramic filter discs by using the laboratory scale water filtration system are as follows:

1. The water filtration system showed excellent performance in water purification.
2. The water filtration system can be continuously operated with a constant flow rate.
3. A thin layer of rejected materials was formed on the surfaces of ceramic filters during all runs. This thickness is a function of the concentration of TSS and the shear resulted between the filters units due to their rotation.
4. The filtration by using water filtration system is controlled by a skin thin layer of rejected materials which was formed during system operation.
5. When the FM1 and FM2 are virgin and when using potable water, the steady state effluent was 125ml/min and 175ml/min, respectively. In all other experiments with potable water, the examined effluent of flow of FM1 and FM2 reach a steady state of 100ml/min and 150ml/min, respectively.
6. The effluent water from modules FM1 and FM2 during the first experiment of all sets is decreased gradually until it reached a steady state effluent rate. The rate of this decrease and the value of the steady state depend on the concentration of the TSS of the water being treated. The overall percentage of decrease in the effluent of modules FM1 and FM2 is 20% and 14%, respectively.
7. The maximum decreasing percentages in the effluent of the modules FM1 and FM2 was 28% and 19%, respectively, occurred at the first run of experiments set using 7000mg/l TSS concentration of raw water.
8. The minimum percentages of decreasing the effluent of the modules FM1 and FM2 was 12% and 9%, respectively, occurred at the first run of experiments set using 1000mg/l TSS concentration of raw water.
9. The overall average TSS concentration of the effluent of FM1 is 1.3mg/l, while that for FM2 is 1.2mg/l.
10. The turbidity of effluent water for both modules FM1 and FM2 is within the requirements of the WHO and Iraqi standards of turbidity in drinking water which is 5NTU.
11. There is no significance difference of removal efficiencies of TSS and turbidity between ceramic filter discs of both filtration modules. Therefore, from the hydraulic conductivity point of view, the FM2 is better than FM1 because filters of module FM2 have hydraulic conductivity about three times greater than that of module FM1.
12. The removal efficiencies of TSS and turbidity were increased with time during the operation of water filtration system for both of filtration modules FM1 and FM2.

13. The negative suction gauge pressure for both modules FM1 and FM2 was decreased with increasing of the discharge of the peristaltic pump. As well as, the negative pressure for both modules FM1 and FM2 was decreased by increasing of TSS concentration of the raw water. The lower value of suction pressure was -0.52bar for FM1 and -0.50bar for FM2 occurred at the second hour of run number four of experiments set number five.

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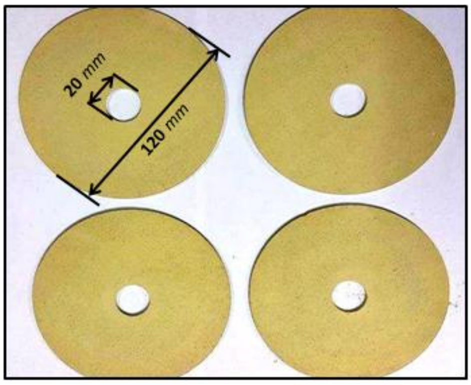

Figure 1. Samples of the produced ceramic filter discs.

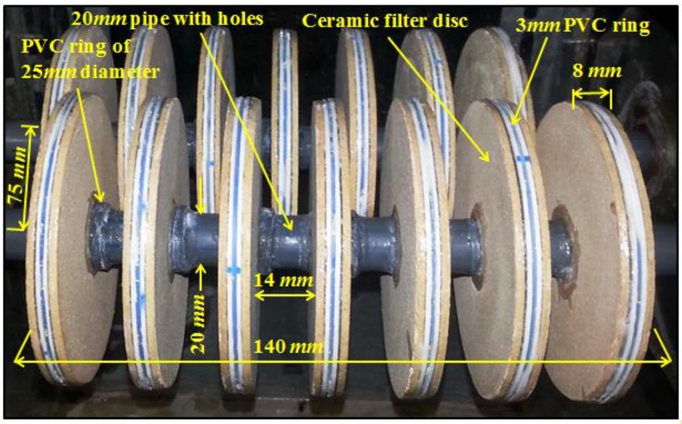

Figure 2. The filtration modules.

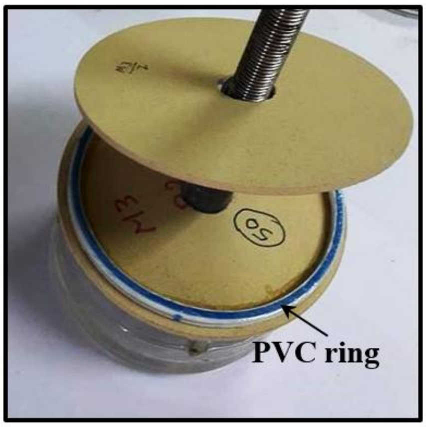

Figure 3. The filter unit.

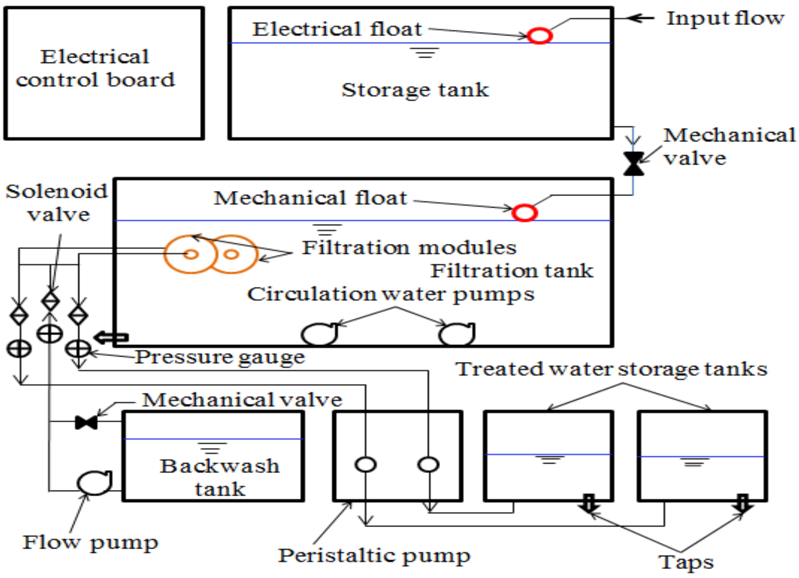

Figure 4. A schematic diagram of the water filtration system.

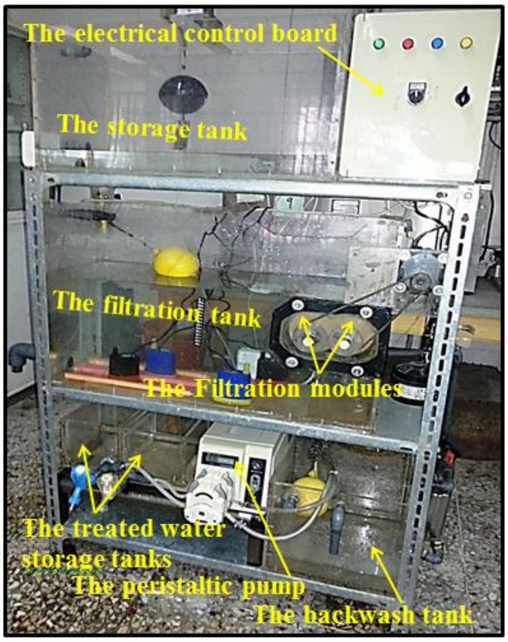

Figure 5. The water filtration system installed in the laboratory.

Table 1. Different mixtures of red clay and sawdust.

Filters Set	**Red Clay**, %	**Sawdust**, %	**Particle size of sawdust,** μm
S1	95	5	75 - 425
S2	92.5	7.5	

Table 2. Measured hydraulic conductivity of the filtration modules

Filtration module FM1				**Filtration module FM2**			
Filter unit no.	**Ceramic filter disc no.**	**Hydraulic conductivity** mm/day		**Filter unit no.**	**Ceramic filter disc no.**	**Hydraulic conductivity** mm/day	
		Ceramic disc	**Filter unit**			**Ceramic disc**	**Filter unit**
1	1	13	13.5	1	1	52	50
	2	14			2	48	
2	3	15	14	2	3	52	50
	4	13			4	48	
3	5	17	13.5	3	5	53	49.5
	6	10			6	46	
4	7	14	14	4	7	55	50.5
	8	14			8	46	
5	9	14	14	5	9	50	50
	10	14			10	50	
6	11	14	13.5	6	11	50	50
	12	13			12	50	

7	13	16	13.5	7	13	50	50
	14	11			14	50	
Mean hydraulic conductivity			13.7	Mean hydraulic conductivity			50

Table 3. Physical properties of raw water used for water filtration system tests.

Run set no.	**TSS** mg/l	**TDS** mg/l	**Turbidity** NTU	**EC** µs/cm	**pH**	**Temperature** ˚C
1	500	524	174	874	8.42	20
2	1000	554	326	924	8.30	16
3	3000	562	1235	936	8.27	16
4	5000	610	1751	1017	8.12	15
5	7000	652	3194	1086	7.85	15

Table 4. The results of water filtration system tests with TSS concentration of 500mg/l.

Raw water		**Run case**	**Run no.**	**Time** hr	**Effluent water**						**Suction pressure** bar	
Turbidity NTU	**TSS** mg/l				**Turbidity** NTU		**TSS** mg/l		**discharge** ml/min			
					FM1	**FM2**	**FM1**	**FM2**	**FM1**	**FM2**	**FM1**	**FM2**
174	500	Without using peristaltic pump	1	0	4	4	3	3	125	175		
				1	4	3	3	2	122	171		
				2	3	2	2	1	118	165		
				3	2	2	1	1	112	159		
				4	2	2	1	1	100	150		
				5	2	2	1	1	100	150		
		With using peristaltic pump	2	0	5	5	4	4	263		0	0
				1	3	3	2	2			-0.04	-0.01
				2	2	2	1	1			-0.07	-0.01
				3	2	2	1	1			-0.08	-0.02
				4	2	2	1	1			-0.08	-0.02
				5	2	2	1	1			-0.08	-0.02
			3	0	3	3	2	2	450		0	0
				1	3	3	2	2			-0.11	-0.05
				2	2	2	1	1			-0.12	-0.06
				3	2	2	1	1			-0.13	-0.07
				4	2	2	1	1			-0.13	-0.07
				5	2	2	1	1			-0.13	-0.07
			4	0	2	2	1	1	900		0	0
				1	2	2	1	1			-0.2	-0.15
				2	2	2	1	1			-0.23	-0.18
				3	1	1	0	0			-0.25	-0.2
				4	1	1	0	0			-0.25	-0.2
				5	1	1	0	0			-0.25	-0.2

Table 5. The results of water filtration system tests with TSS concentration of 1000mg/l.

Raw water		**Run case**	**Run no.**	**Time** hr	**Effluent water**						**Suction pressure** bar	
Turbidity NTU	**TSS** mg/l				**Turbidity** NTU		**TSS** mg/**l**		**Discharge** ml/min			
					FM1	**FM2**	**FM1**	**FM2**	**FM1**	**FM2**	**FM1**	**FM2**
326	1000	Without using peristaltic pump	1	0	2	2	1	1	100	150		
				1	2	2	1	1	98	147		
				2	2	2	1	1	94	142		
				3	2	2	1	1	88	136		
				4	2	2	1	1	88	136		
				5	2	2	1	1	88	136		
		With using peristaltic pump	2	0	2	2	1	1	225		0	0
				1	2	2	1	1			-0.06	-0.01
				2	2	2	1	1			-0.08	-0.03
				3	2	2	1	1			-0.10	-0.05
				4	2	2	1	1			-0.10	-0.05
				5	2	2	1	1			-0.10	-0.05
			3	0	3	3	2	2	450		0	0
				1	3	3	2	2			-0.14	-0.1
				2	3	2	2	1			-0.16	-0.13
				3	2	2	1	1			-0.18	-0.16
				4	2	2	1	1			-0.18	-0.16
				5	2	2	1	1			-0.18	-0.16
			4	0	4	3	3	2	900		0	0
				1	4	3	3	2			-0.22	-0.17
				2	3	3	2	2			-0.27	-0.22
				3	3	2	2	1			-0.28	-0.26
				4	2	2	1	1			-0.28	-0.26
				5	2	2	1	1			-0.28	-0.26

Table 6. The results of water filtration system tests with TSS concentration of 3000mg/l.

Raw water Turbidity NTU	Raw water TSS mg/l	Run case	Run no.	Time hr	Effluent Turbidity NTU FM1	Effluent Turbidity NTU FM2	Effluent TSS mg/l FM1	Effluent TSS mg/l FM2	Discharge ml/min FM1	Discharge ml/min FM2	Suction pressure bar FM1	Suction pressure bar FM2
1235	3000	Without using peristaltic pump	1	0	3	3	2	2	100	150		
				1	3	3	2	2	96	145		
				2	2	2	1	1	90	139		
				3	2	2	1	1	83	133		
				4	2	2	1	1	83	133		
				5	2	2	1	1	83	133		
		With using peristaltic pump	2	0	2	2	1	1	225		0	0
				1	2	2	1	1			-0.07	-0.03
				2	2	2	1	1			-0.09	-0.04
				3	2	2	1	1			-0.11	-0.06
				4	2	2	1	1			-0.11	-0.06
				5	2	2	1	1			-0.11	-0.06
			3	0	2	2	1	1	450		0	0
				1	2	2	1	1			-0.17	-0.14
				2	2	2	1	1			-0.18	-0.15
				3	2	2	1	1			-0.19	-0.17
				4	2	2	1	1			-0.19	-0.17
				5	2	2	1	1			-0.19	-0.17
			4	0	2	2	1	1	900		0	0
				1	2	2	1	1			-0.31	-0.29
				2	2	2	1	1			-0.35	-0.32
				3	2	2	1	1			-0.35	-0.32
				4	2	2	1	1			-0.35	-0.32
				5	2	2	1	1			-0.35	-0.32

Table 7. The results of water filtration system tests with TSS concentration of 5000mg/l.

Raw water Turbidity NTU	Raw water TSS mg/l	Run case	Run no.	Time hr	Effluent Turbidity NTU FM1	Effluent Turbidity NTU FM2	Effluent TSS mg/l FM1	Effluent TSS mg/l FM2	Discharge ml/min FM1	Discharge ml/min FM2	Suction pressure bar FM1	Suction pressure bar FM2
1751	5000	Without using peristaltic pump	1	0	4	3	3	2	100	150		
				1	2	2	1	1	89	139		
				2	2	2	1	1	83	133		
				3	2	2	1	1	77	128		
				4	2	2	1	1	77	128		
				5	2	2	1	1	77	128		
		With using peristaltic pump	2	0	4	4	3	3	225		0	0
				1	3	3	2	2			-0.1	-0.07
				2	2	2	1	1			-0.12	-0.08
				3	2	2	1	1			-0.14	-0.11
				4	2	2	1	1			-0.14	-0.11
				5	2	2	1	1			-0.14	-0.11
			3	0	3	3	2	2	450		0	0
				1	2	2	1	1			-0.20	-0.18
				2	2	2	1	1			-0.21	-0.19
				3	2	2	1	1			-0.22	-0.20
				4	2	2	1	1			-0.22	-0.20
				5	2	2	1	1			-0.22	-0.20
			4	0	3	2	2	1	900		0	0
				1	3	2	2	1			-0.34	-0.32
				2	2	2	1	1			-0.36	-0.34
				3	2	2	1	1			-0.36	-0.34
				4	2	2	1	1			-0.36	-0.34
				5	2	2	1	1			-0.36	-0.34

Table 8. The results of water filtration system tests with TSS concentration of 7000mg/l.

Raw water Turbidity NTU	Raw water TSS mg/l	Run case	Run no.	Time hr	Effluent Turbidity NTU FM1	Effluent Turbidity NTU FM2	Effluent TSS mg/l FM1	Effluent TSS mg/l FM2	Effluent discharge ml/min FM1	Effluent discharge ml/min FM2	Suction pressure bar FM1	Suction pressure bar FM2
3194	7000	Without using peristaltic pump	1	0	4	3	3	2	100	150		
				1	3	3	2	2	83	133		
				2	3	2	2	1	77	128		
				3	2	2	1	1	72	122		
				4	2	2	1	1	72	122		
				5	2	2	1	1	72	122		
		With using peristaltic pump	2	0	3	3	2	2	225		0	0
				1	3	3	2	2			-0.2	-0.17
				2	2	2	1	1			-0.24	-0.21
				3	2	2	1	1			-0.25	-0.22
				4	2	2	1	1			-0.25	-0.22
				5	2	2	1	1			-0.25	-0.22
			3	0	3	3	2	2	450		0	0
				1	3	2	2	1			-0.30	-0.28
				2	3	2	2	1			-0.32	-0.30
				3	2	2	1	1			-0.32	-0.30
				4	2	2	1	1			-0.32	-0.30
				5	2	2	1	1			-0.32	-0.30
			4	0	3	2	2	1	900		0	0
				1	3	2	2	1			-0.47	-0.45
				2	2	2	1	1			-0.52	-0.5
				3	2	2	1	1			-0.52	-0.5
				4	2	2	1	1			-0.52	-0.5
				5	2	2	1	1			-0.52	-0.5

Table 9. Removal efficiency of TSS and Turbidity from raw water by using filtration modules FM1 and FM2.

Raw water		Run no.	Filtration module code	Removal efficiency% of TSS			Removal efficiency% of Turbidity		
TSS mg/l	Turbidity NTU			Max.	Min.	Ave.	Max.	Min.	Ave.
500	174	1	FM1	99.80	99.40	99.60	98.85	97.70	98.28
			FM2	99.80	99.40	99.60	98.85	97.70	98.28
		2	FM1	99.80	99.20	99.50	98.85	97.12	97.99
			FM2	99.80	99.60	99.70	98.85	98.28	98.57
		3	FM1	99.80	99.60	99.70	98.85	98.28	98.57
			FM2	99.80	99.60	99.70	98.85	98.28	98.57
		4	FM1	100	99.80	99.90	99.43	98.85	99.14
			FM2	100	99.80	99.90	99.43	98.85	99.14
1000	326	1	FM1	99.90	99.90	99.90	99.39	99.39	99.39
			FM2	99.90	99.90	99.90	99.39	99.39	99.39
		2	FM1	99.90	99.90	99.90	99.39	99.39	99.39
			FM2	99.90	99.90	99.90	99.39	99.39	99.39
		3	FM1	99.90	99.80	99.70	99.39	99.10	99.25
			FM2	99.90	99.80	99.70	99.39	99.10	99.25
		4	FM1	99.90	99.70	99.80	99.39	98.77	99.08
			FM2	99.90	99.80	99.70	99.39	99.10	99.25
3000	1235	1	FM1	99.97	99.93	99.95	99.84	99.76	99.80
			FM2	99.97	99.93	99.95	99.84	99.76	99.80
		2	FM1	99.97	99.97	99.97	99.84	99.84	99.84
			FM2	99.97	99.97	99.97	99.84	99.84	99.84
		3	FM1	99.97	99.97	99.97	99.84	99.84	99.84
			FM2	99.97	99.97	99.97	99.84	99.84	99.84
		4	FM1	99.97	99.97	99.97	99.84	99.84	99.84
			FM2	99.97	99.97	99.97	99.84	99.84	99.84
5000	1751	1	FM1	99.98	99.94	99.96	99.90	99.80	99.85
			FM2	99,98	99.96	99.97	99.90	99.83	99.87
		2	FM1	99.98	99.94	99.96	99.90	99.80	99.85
			FM2	99.98	99.94	99.96	99.90	99.80	99.85
		3	FM1	99.98	99.96	99.97	99.90	99.83	99.87
			FM2	99.98	99.96	99.97	99.90	99.83	99.87
		4	FM1	99.98	99.96	99.97	99.90	99.83	99.87
			FM2	99.98	99.98	99.98	99.90	99.90	99.90
7000	3194	1	FM1	99.99	99.96	99.98	99.94	99.87	99.91
			FM2	99.99	99.97	99.98	99.94	99.91	99.93
		2	FM1	99.99	99.97	99.98	99.94	99.91	99.93
			FM2	99.99	99.97	99.98	99.94	99.91	99.93
		3	FM1	99.99	99.97	99.98	99.94	99.91	99.93
			FM2	99.99	99.97	99.98	99.94	99.91	99.93
		4	FM1	99.99	99.97	99.98	99.94	99.91	99.93
			FM2	99.99	99.99	99.99	99.94	99.94	99.94

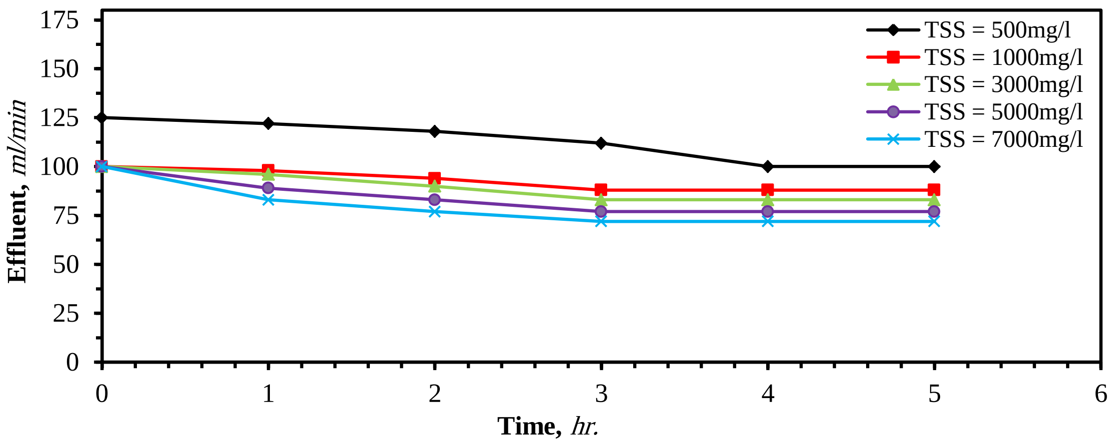

Figure 7. The time variation of effluent of FM1during runs without using peristaltic pump.

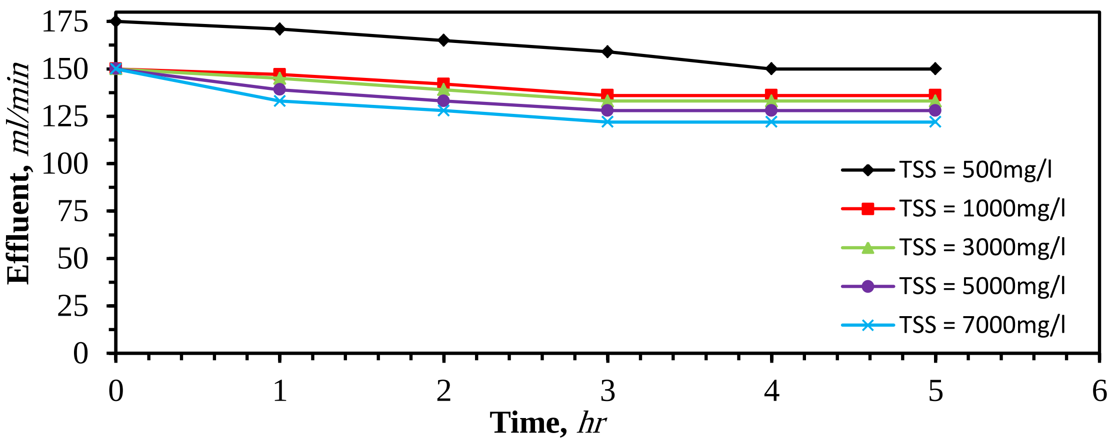

Figure 8. The time variation of effluent of FM2 during runs without using peristaltic pump.

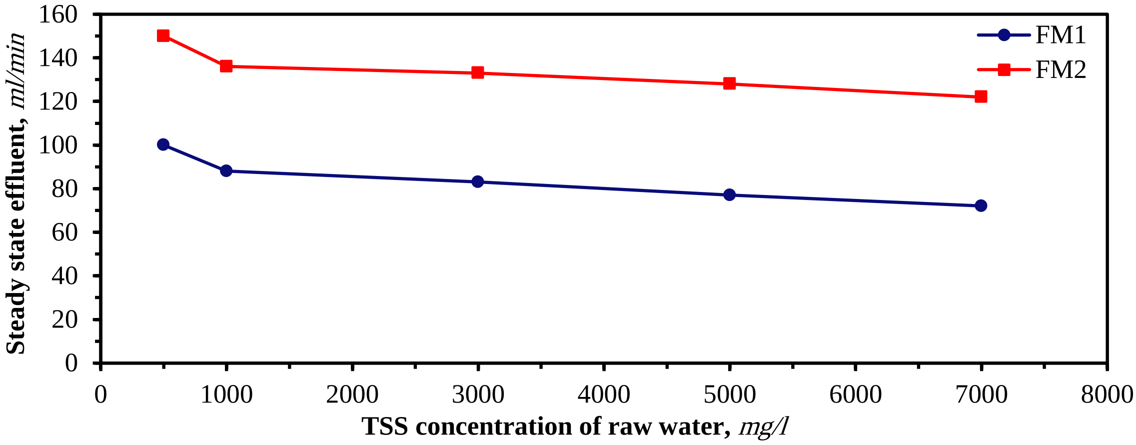

Figure 9. Relation between the steady state effluent of modules and the TSS concentration of raw water without using peristaltic pump.

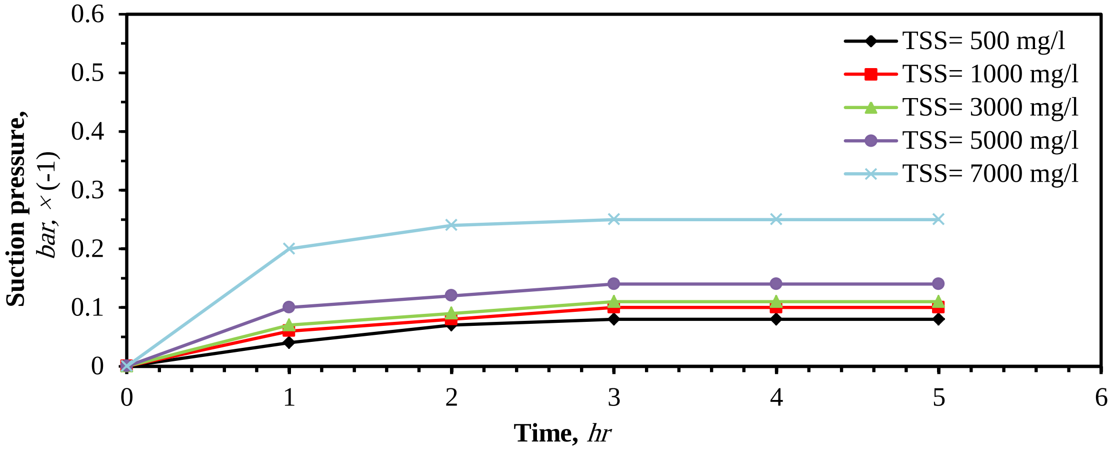

Figure 10. Comparison of time variation of the suction pressure gauge reading of FM1, discharge of peristaltic pump= 225ml/min except for TSS= 500mg/l was = 263ml/min.

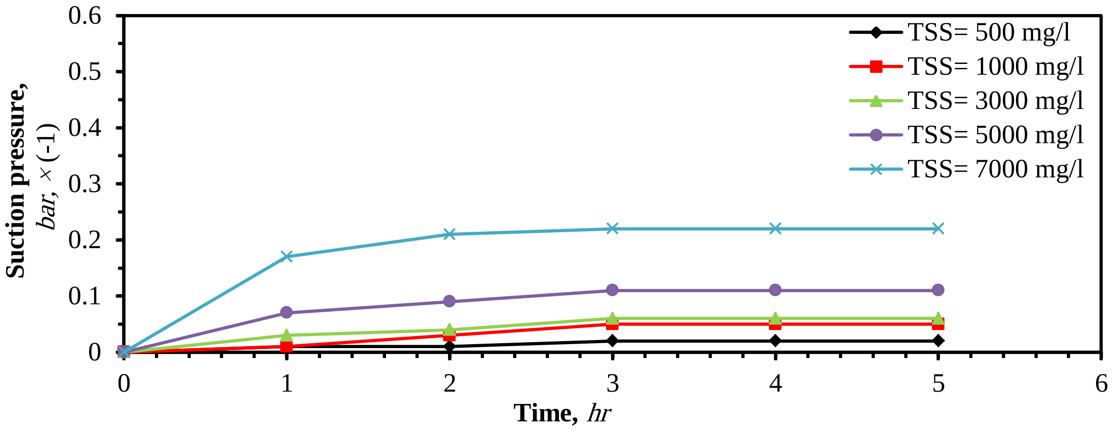

Figure 11. Comparison of time variation of the suction pressure gauge reading of FM2, discharge of peristaltic pump= 225ml/min except for TSS= 500mg/l was = 263ml/min.

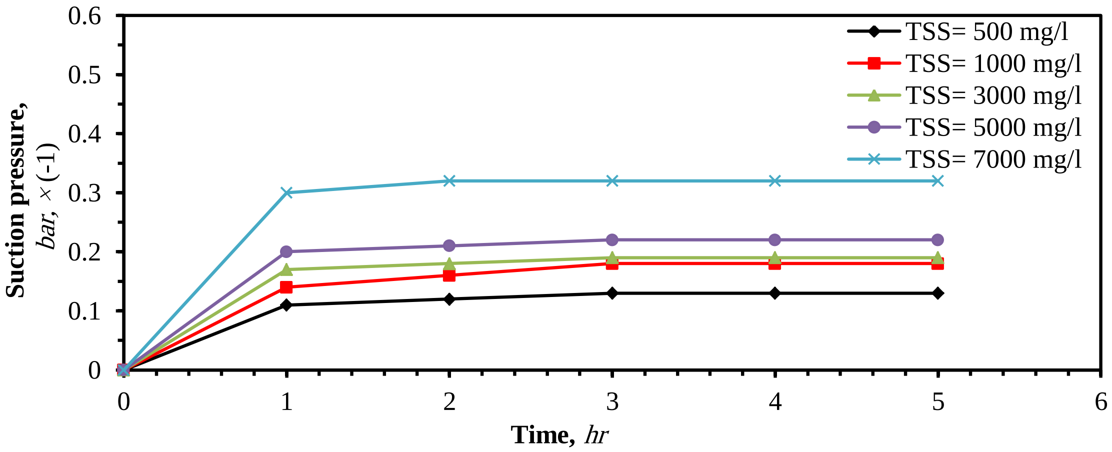

Figure 12. Comparison of time variation of the suction pressure gauge reading of FM1, discharge of peristaltic pump= 450ml/min.

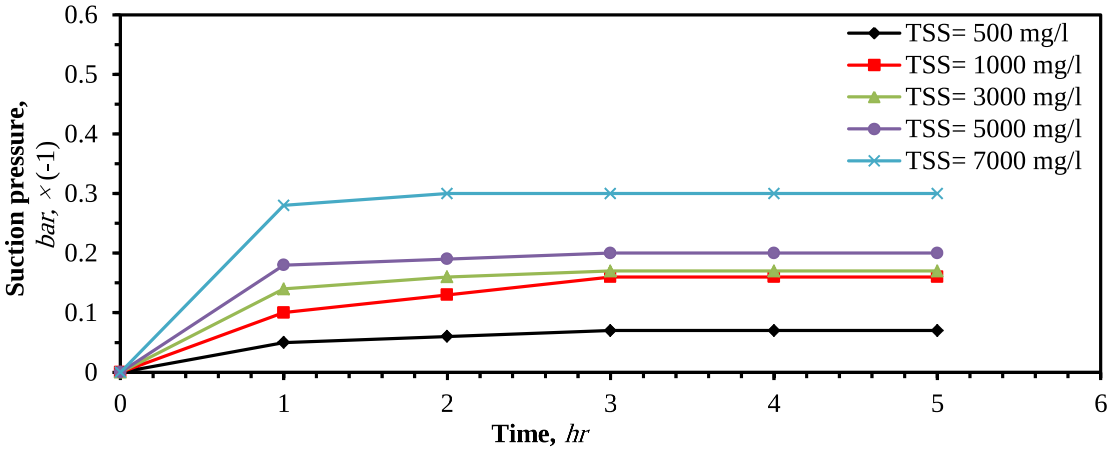

Figure 13. Comparison of time variation of suction pressure gauge reading of FM2, discharge of peristaltic pump= 450ml/min.

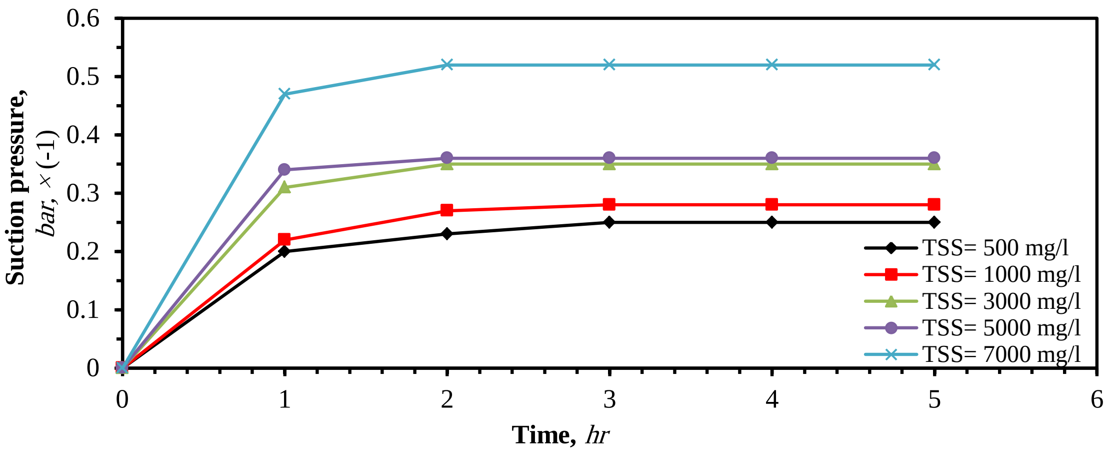

Figure 14. Comparison of time variation of suction pressure gauge reading of FM1, discharge of peristaltic pump = 900ml/min.

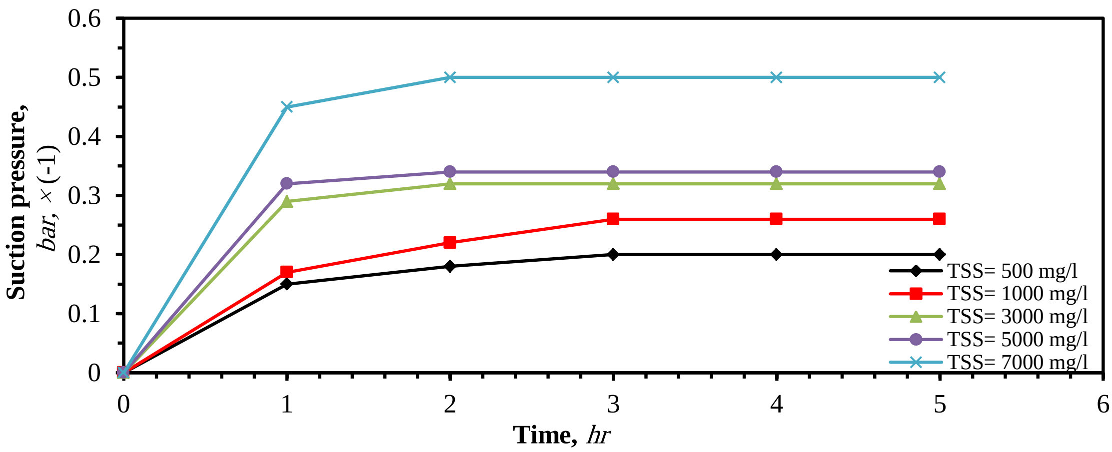

Figure 15. Comparison of time variation of suction pressure gauge reading of FM2, discharge of peristaltic pump = 900ml/min.