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Iron and manganese removal on a household scale by physical methods

Helsinki Metropolia University of Applied Sciences

Bachelor of Engineering

Degree Programme in Environmental Engineering

Bachelor's Thesis

10.10.2018

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Title	Iron and manganese removal on a household scale by physical methods
Number of Pages	30 pages
Date	10 th October 2018
Degree	Bachelor of Engineering
Degree Programme	Environmental Engineering
Specialisation option	Water Treatment Technology
Instructor(s)	Esa Toukoniity, Senior Lecturer
<p>Nowadays, not only in rural areas but also in suburbs of some large cities, people are still struggling with heavy metal polluted water sources. Iron and manganese are two main metals that pollute the water. Along with the development of mining activities, the high metals content and the microbes available in the soil have been increasing the iron and manganese contents in groundwater exceeding the allowed limits.</p> <p>There is a demand for domestic water filtering system that can treat Fe and Mn impurities. The system should be simple, easy to build and effective in operation. In this thesis, the formation mechanisms of iron and manganese in water and their treatment methods were studied and a proper design of a treatment system on a household scale was created. This design could be realized in Vietnam where many ores are located along the country.</p> <p>The system has two main stages. The first step is aeration, which provides oxygen for metals in the water in order to oxidize Fe and Mn to be precipitative hydroxides, which are physically removable. The second stage is using slow sand filter and activated charcoal to purify the water.</p>	

Keywords	contamination, iron, manganese, water, water treatment, design

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Abbreviations

L	litre
p	person
d	day
g/p/d	gallons/person/day
%	percent
Fe	Iron
Mn	Manganese
H	Hydro
O	Oxygen
min	minute
g	gram
mg	milligram
m	metre
mm	millimetre
cm	centimetre
m ²	metre square
m ³	metre cubic
SSF	slow sand filter
GAC	granular activated carbon
SG	separating gravel
UG	underdrain gravel
HLR	hydraulic loading rate
RO	reverse osmosis
EU	European Union
WHO	World Health Organization

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1 Introduction

Water is essential for all living beings on the earth. Without water, life no longer exists. Humans may survive without eating for 21 days but only one week without drinking water [1].

In some rural areas and suburbs of underdeveloped or developing countries, the groundwater sources are highly polluted with iron and manganese due to natural geodetical soil even after being treated. The water has chemical scum and is very yellow or black in colour; sometimes there appears some coloured, concentrated flocculation. People in these areas are still suffering from that water quality and even have to go far away to buy clean water or keep using it for cooking or drinking after boiling and eventually still get diseased.

Regarding the preparation of daily meals and beverages, a person needs only 2.7-3.7 L a day [2]. However, in addition people consume water for different purposes such as personal hygiene, laundry and house cleaning. The water-consuming requirement in large cities is somewhere around 80-100 g/p/d equals to 300-380 L/p/d (≈ 340 L/p/d) according to U.S Geological Survey [3]. Therefore, in order to supply enough water for a family of four members, the total demand is 1360 L a day. The target capacity for the treatment plant design in this thesis was approximately enough for more than a day's use in one batch, which is roughly 2000 L. In the rest idle time, people could consume water for cleaning and maintaining the system.

2 Iron and manganese formation in groundwater and their damaging effects

2.1 Iron and manganese occur in groundwater

Iron and manganese occur naturally in soils and minerals in nature, and groundwater is in contact with them when it flows through the soil. The groundwater hence dissolves microbes and minerals, altogether with the anaerobic condition, bacteria with some organic compounds start decomposing

and lowering the pH. Acidic environment dissolves the minerals and along with lacking oxygen, the ferric and manganese (4⁺) atoms are reduced to Fe²⁺ and Mn²⁺ and released into the water body. [4]

Manganese ions are dissolved in water from different layers of rock and soil that contains manganese oxide. The reaction happens under anaerobic condition with the impact of microorganisms [5]:



2.2 Iron and manganese water damaging effects

In the seriously contaminated samples, the water has large amount of rust, metallic taste, fishy odour, yellow or black colour, and clothes washed in this water become yellow/black stained. On the other hand, in some places, the water might be very limpid right after being obtained from its source, but after settling for a few days, the scum will rise to the surface (Figure 1).



Figure 1: Iron contaminated water

If iron contaminated water is used for cooking, drinking and personal activities, kitchen tools will be all eroded, the bodily skin will be itchy and peel due to alkaline

substances. Iron water containing a considerable amount of ferrous matter has an opaque yellow colour, which does not look very attractive or safe to use. Drinking and eating sources that contain too high iron levels will cause iron overload phenomenon, which will mutate the gene that digests iron. Iron overload will also damage liver, heart and pancreas as well as diabetes. The manifestation of excessive iron in the human body is stomachache, nausea and vomiting [6].

The water contaminated with manganese has a milky colour and a fishy smell (Figure 2). When in contact with the air, Mn^{2+} ions will become manganese dioxide (MnO_2) and leave a layer of black residue (MnO_2) on the furnishings as well as on clothes after laundry. Manganese affects the respiration and the brains. Additionally, manganese may cause Parkinson's disease, hallucinations, forgetfulness or impotency. [7]



Figure 2: Manganese contaminated water

According to the World Health Organization Guidelines (WHO) for Drinking-water Quality Standard 2011, the concentration of iron in water should not exceed 0.1

mg/L, and the concentration of manganese in water should not be over 0.05 mg/L. [8]

3 Treating method

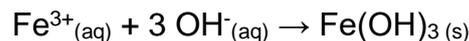
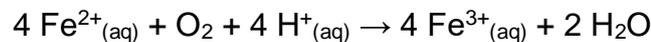
3.1 Aeration

The aeration process utilizes the oxygen in the air to oxidize iron and manganese ions dissolved in water. In addition, this process will also reduce the content of carbon dioxide and raise water's pH to intensify the oxidizing and hydrolysing process of iron and manganese ions.

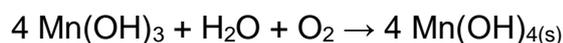
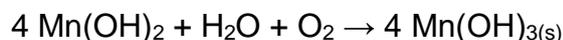
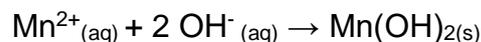
The ferrous ions will be oxidized to be ferric ions; afterwards, ferric ions will continuously hydrolyse to be $\text{Fe}(\text{OH})_3$ – an insoluble and removable substance. Similarly to ferrous ions, Mn^{2+} ions will be oxidized to be Mn^{3+} and Mn^{4+} , and then hydrolysed to be precipitative hydroxides.

The chemical reactions of this process happen as follows:

With iron:



With manganese:



People can use an air compressor to blow the air into the water body to get the best efficiency as the amount of air contact with molecular water is greatest, this aeration technique is called *fine bubble aeration*. An air compressor will pump the air through a hose, this hose is connected to an aeration unit under the bottom of the aeration tank. There is a number of diffusers connected to the unit. The

diffusers have various shapes such as plate, tube or disc and are made from, for example, porous ceramic plastic, polyvinyl chloride (PVC) or perforated membranes made from ethylene propylene diene Monomer (EPDM) rubber [16]. The air pumped in is released to water through the diffusers as small bubbles, which are called *fine bubbles*. Fine bubbles generally are smaller than 1 mm in radius [16]; thus, the contact area between the air and water molecule is much greater than in other techniques. This aeration technique normally can transfer approximately 9.1 kilograms of O₂/kilowatt/hour into water body at maximum [16]. The range of air volume released into the water body can differ from 56.6-113.3 L/min [16]. In order to oxidize completely the ferrous and manganese ions in a water volume unit, it is required to have at least the same volume of air aerated into the aeration tank. Figure 3 shows an example of the use of fine bubbles aerator.



Figure 3: An example of fine bubbles aerator

However, at prolonged time of operation, the hydroxide ions may clog the membranes of ceramic diffusers; therefore, it needs to be cleaned or replaced by a new one to keep the best optimum efficiency.

3.2 Filtration

The filtration stage uses some filter materials to clarify particles or chemicals that are unable to either scum or precipitate completely by making water flow through two tanks that contains some different filter layers. There are many different water filter materials in the market, but the most essential and popular ones are sand, activated charcoal and gravel, which are recommended to use in small-scale system due to their effectiveness and prevalence.

Three main types of sand filter are used in water filtering industries: *rapid sand*, *upward flow sand*, and *slow sand*. The rapid sand and upward flow sand are generally used after using flocculant chemicals in the water and mainly for producing potable water only [9]; therefore, they are not required in this system as the initial purpose is to treat water for non-potable demands only.

3.2.1 Slow sand filter specifications

A typical *Slow sand filter* (SSF) has four basic components that are a tank, a fine sand bed, one or several layers of gravel to support the sand, an under-drains system to collect filtered water and finally a regulating valve to control the filtration rate. SSF does not require any chemical or electrical system to operate. According to Collins, M. R [25], the SSF can remove up to 95-99% of Zn, Cu, Cd and Pb content and more than 67% content of iron and manganese in water. The particle size of fine sand varies from 0.15 to 0.20 mm [13]. Unlike the rapid sand and upward flow sand, the water flow through SSF has quite slow rate as indicated by the name. But on the contrary, SSF provides a better filter quality than other filter sand types. Table 1 shows some advantages and disadvantages of SSF in comparison with rapid sand filtration.

Table 1: SSF and rapid sand filtration comparison [20]

	Rapid sand filtration	SSF
Removal ability	<ul style="list-style-type: none"> • 90% coliforms • 50-90% Cryptosporidium and Giardia cysts • 10% colour • 5% organic content 	<ul style="list-style-type: none"> • 95% coliforms • 99% Cryptosporidium and Giardia cysts • 75% colour • 10% organic content
Flow rate	04 - 21 m/h	0.1 - 0.3 m/h
Effective size of removal	> 0.55 mm	0.15 – 0.35 mm
Filtering mechanism	Physical	Physical and biological

The SSFs use both physical and biological mechanisms to remove turbidity, bacteria, viruses and organic compounds that have diameter greater than 0.15 mm in slow rate [9]. The biological mechanism plays an important role in the purification capability of SSF. The SSFs use slow flowing rate to filter water, hence most of the solid particles are trapped in the topmost 0.5-02 cm of the sand. This thin layer is developing a biologically active area which is called *schmutzdecke* (means “dirty layer” in German). The *schmutzdecke* is sticky and has brown colour, containing some decomposing organic compounds, iron, manganese and silica [20]. This layer removes fine colloidal particles and microorganisms in the raw water. Any pathogen or organism that can escape this layer will eventually be either trapped or killed in between the fine sand below altogether with the larger dirty particles. However, it normally takes at least 15 days to form up the *schmutzdecke*. Once this layer has shaped up, it should be remained undisturbed until the whole filter bed needs to be cleaned by removing 1 cm top of the sand layer and doing backwashing for the whole bed.

There are two quantities need to take into account when choosing an SSF for use:

- Effective size (D_{10}): this is the particle diameter that 10% by weight of grain sample are smaller and 90% of the sample are larger than it.
- Uniformity coefficient: the ratio of the sizes between the largest grain and the smallest grain in the sand sample. The uniformity coefficient is generally illustrated as D_{60}/D_{10} , where D_{60} is the particle size that 60% of grain samples fall below and the remaining 40% exceed.

The recommendation type of SSF is the one that has effective size between 0.15 – 0.35 mm and uniformity coefficient smaller than 2 [20].

There is one recommendation on filtration sand bed depth that its length should not be less than 50 cm to ensure the efficiency of sand filtration step [13]. The height of sand layer is also a parameter affects the hydraulic loading rate (HLR, also called *filtration rate*) of the system, the thicker of the depth of sand will provide the better water quality outcome but also decrease the hydraulic loading rate due to it will create more friction of water movement. Therefore, the thickness of the slow sand layer in this design is chosen to be 50 cm to maintain the hydraulic loading rate not from becoming too low [13]. The filtration rate of SSF normally varies from 0.08 - 0.25 [$\text{m}^3/(\text{m}^2 \times \text{h})$] (or m/h), but it is recommended to assume the filtration rate is 0.2 m/h [12], therefore, in this thesis, the filtration rate of SSF will be assumed to be 0.2 m/h.

Please note that the trapped particles will build up on the top surface of the SSF layer after several times of operation and may stop the down-flow of water, thus, it is needed to scrap the dirty layer away and replace the top few centimetres of sand after every couple operation [10].

3.2.2 Activated carbon filtration specification

The activated carbon is used to disinfect the water by eliminating natural organic matters, taste and odour compounds. According to Aji [26], activated carbon can

give 88% removal of iron and 99% removal of manganese from water. It works by both physical mechanism to trap the dirt and chemical processes to adsorb organic substances at the carbon surface and prevent them from going back into the water. However, the chemical process takes a while to make the organic matters adsorb to the carbon, this is called *contact time*. The longer the contact time, the more contaminants would be adsorbed to the carbon surface. In general, the contact time range would be 30 – 60 minutes [13]. The contact time is adjusted by increasing or decreasing either the carbon bed volume (total volume of carbon used) or the water flow rate through the filter.

There are many types of activated carbon in the market, but *granular activated carbon* (GAC) is the one that is mainly used in water treatment industry [14]. The GAC is classified by sizes, some common sizes of GACs used in water treatment are 12×40 mesh, 20×40 mesh or 20×51 mesh. The finer mesh gives the better removal ratio and shorter contact time but also has larger risk of clogging the filter. For example, *FILTRASORB 400 12×40* mesh is a type of GAC applied widely in down-flow activated carbon bed operation using gravity or pressure systems. Also, *FILTRASORB 400 12×40* mesh GAC is the most popular one to apply in water treatment plant due to its balance size, surface area and its effective particle trapping size [14] (0.55 mm at minimum [19]), hence, it is the chosen type of GAC filter in this thesis design. The properties of *FILTRASORB 400* are given in Table 2.

Table 2: Properties of FILTRASORB 400 [15,19]

Specifications	Value
Iodine Number, min., mg/g	1000
Methylene Blue Number, min.	260
Abrasion Number, min	75
Moisture Content, as packed, max., %w/w	2
Effective Size, mm	0.55-0.75
Uniformity coefficient, max	1.9
Mesh Size, US Sieve Series	12x40
> 8 mesh (2.36mm), max.%	-
> 12 mesh (1.70mm) max.%	5
< 30 mesh (0.60mm), max.%	-
< 40 mesh(0.425mm), max.%	4

3.2.3 Gravel filtration specification

The gravel layers are usually placed at the bottom of the tank and right under the SSF and GAC layers. There will be two types of gravel used in the filtration tank. The first one is *separating gravel* (SG), which has smaller size (from 0.7 mm to 6.0 mm). the main purpose of separating gravel is to keep the slow sand and GAC from slipping through their positions and then clogging the hydraulic drainage or even going inside the drainage pipe. The second layer is *underdrain gravel* (UG), this layer has larger size (from 6 mm to 12 mm) and will be placed at the bottommost tank with the drainage pipe to create aperture for water flowing into the pipe and also to prevent the separating gravel to go inside the pipe. Both gravel layers also support for the SSF layer and GAC layer in filtering the very last particles that can have gone through all the filter layers above. The

recommended thicknesses of SG layer and UG layer are 6 cm and 12 cm respectively [13].

4 Design of iron and manganese removal treatment on a single household-scale

As mentioned earlier, in an average family which has 4 members, the consuming water demand is roughly 1360 L per day. Hence, this thesis focussed on designing a treatment and distribution storage system that can treat and produce an approximate amount that is enough for use in more than a day (2000 L) in each operation. In the pause period, users can clean and maintain the system. People who are suffering from the input water quality (especially in rural areas where the water is not treated in a treatment plant) can refer to this design, then estimate their demand by themselves and build for their own a treatment system with different dimension parameters.

On the basis of the components and properties of iron and manganese contaminated water and on the treatment methods used in industry that have been researched and summarized, the basic model of treatment designed during this thesis project is presented in Figure 4.

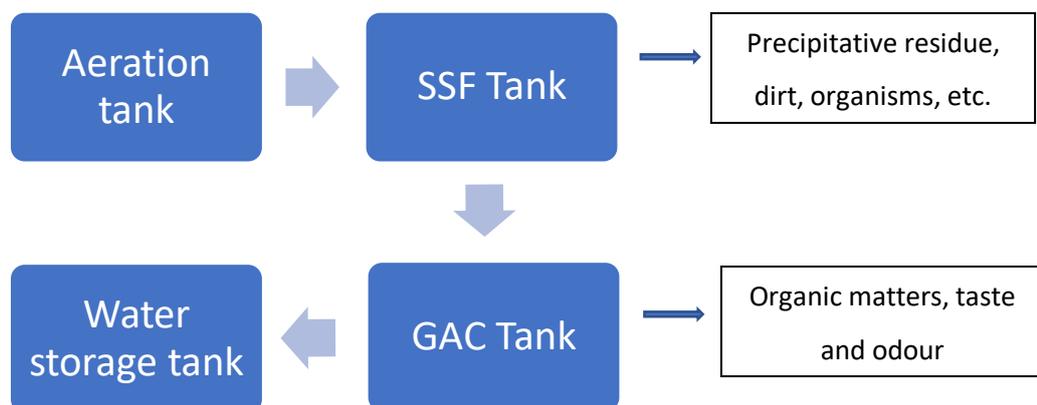


Figure 4: Water treatment system process

4.1 Aeration tank

The aeration is the very first step of the water-filtering process, therefore, the aeration tank should be large enough and provided a decent power as well as capacity to supply saturated-oxygen water for the whole stage. Considering the targeted water volume needs to be produced in an operation (2000 L), the tank's dimension should have the same volume. The recommended shape of the tank would be rectangular parallel piped with a square bottom in order to easily install the aerator system as the air supplied to all diffusers will be the same from the hose placed at the centre of the tank.

4.1.1 Aeration tank specifications and functioning

The capacity volume of the tank is 2000 L, equally to 2.0 m³. The larger the bottom area, the more diffusers need to be provided. Hence, with the volume of 2.0 m³, the recommended height for the tank is 1.3 m, slightly lower than the average height of a human so that people can look inside and get in to carry out replacement or maintenance. Hence, the bottom square area of the tank would be the following:

$$\frac{2.0 \text{ m}^3}{1.3 \text{ m}} = 1.55 \text{ m}^2$$

Thus, the dimension of the side of the tank could be calculated as follows:

$$\sqrt{1.55 \text{ m}^2} = 1.25 \text{ m}$$

Therefore, the tank's dimensions would be the following:

- Length = Width = 1.25 m
- Height = 1.30 m

Figure 5 shows the transection of the basic design for the aeration tank.

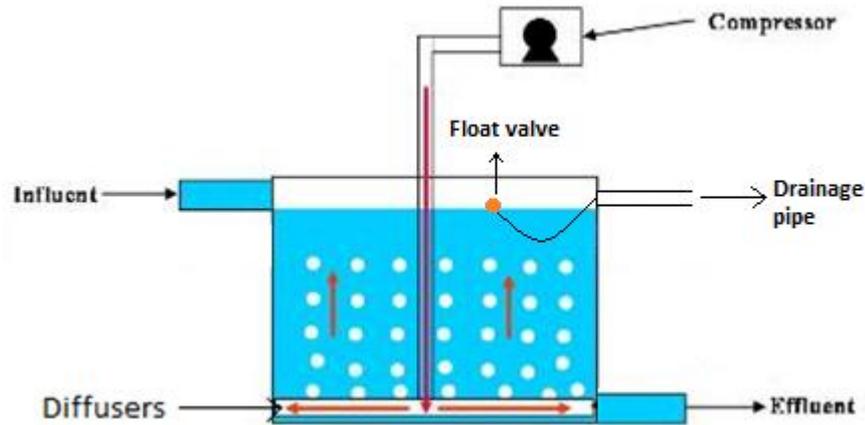


Figure 5: Aeration-tank with air compressor design in cross-section

There are in total three pipes connected to the tank's body. The first one is the water supply pipe, where one end connects to the pump and one end connects to the top of a tank's wall to supply water. The second one is the effluent pipe where water has been aerated will be transferred to the SFF tank. There is a valve on the effluent pipe for people to manually open or close it once the aeration step has been completed. Finally, there is a float valve of the tank connected to the drainage pipe at the same height point with the supply pipe but in opposite wall to avoid overflow. The float valve has a sensor that connected to the pump in order to make the pump notices when the tank is empty to start pumping and when it is full to stop functioning. Besides, the drainage pipe lets the overflow water to flow into sewer.

The diffuser type chosen is the membrane tube diffuser, with the unit placed in the centre of the bottom. The unit has 4 outputs and connected to 4 tubes using EPDM membrane as cross figure. The chosen tube is BLOWTAC membrane tube-65-580 with dimensions are $580 \times 65\Phi$ mm [17]. The average air volume that one tube can release in one minute is 55L [17], thus, with 4 tubes, it takes roughly $2000 \text{ L} / (4 \times 55 \text{ L/min}) \approx 9$ minutes to saturate the water with the air. According to Wikipedia [18], there is only 20.95% (roughly 1/5) volume of the atmosphere is oxygen, therefore, the needed time for having 2000 L of water saturated with oxygen is

$$9 \text{ min} \times 5 = 45 \text{ minutes}$$

Therefore, the minimum required time for aeration step is 45 minutes.

It should be noted that the aeration tank must be placed at the highest position in the whole system so that water can flow down to other stages based on gravity. The outlet point of the aeration tank must be higher than the inlet position of SFF tank at least 10 cm hence that the pressure of flow downstream is high enough. The drainage pipe connected to the SFF tank should be determined and installed carefully to fit the flow rate inside the SFF tank.

4.1.2 Cleaning of the tank

After long time functioning, the membrane of the diffusers might get clogged due to the precipitative particles settle on its surface. Therefore, the membranes need to be changed once the air on the water surface emerging inconstantly. It is recommended to change the diffuser membrane every month to get the best efficiency of aeration stage.

4.2 Filtration stage

In the filtration stage, filtration materials are usually divided into separate different tanks for easy movement and installation. In the filter layers, dirt removal is a combination of various processes such as deposition, adsorption, filtration and biochemical activity. The depths of separating gravel layer and underdrain gravel layer have been assumed to be 6 cm and 12 cm from the section 3.2.3, as their purposes are only to support the filtration steps from SSF layer and GAC layer and also to prevent the grains and charcoal particles clogging the water flow downstream, hence, their thicknesses do not really matter to the whole filtration process and can be adjusted as wishes.

Inversely, the depths of SSF layer and GAC layer play an important role in the whole process, therefore, the influencing factors and determination of each layer will be explained in the following sections.

It should be noted that in this design, the SSF tank and the GAC filter tank are decided to have cylindrical shape, as all the theoretical information of their design focus only on this shape.

4.2.1 SSF tank design

The SSF tank contains three layers which are fine sand, SG and UG, where SG and UG play supporting role for the SFF layer in the bottom of the tank. The tank is assumed and planned to have cylindrical shape, 1200L of volume and should be made from stainless steel or PVC to avoid being moss-grown. The dimensions of the desired tank would be as follows:

- Volume (V) = 1200 L = 1.2 m³
- Area (A) = 1.2 m²
- Height (h) = 1 m
- Diameter (d) = 1.23 m

4.2.1.1 Sand bed, separating gravel and underdrain gravel heights

The depths of SG and UG are 6 cm and 12 cm respectively as mentioned in the section 3.2.3. Hence, the total height of gravel layers is $h_g = 18$ cm. The water input drain connects the tank at the highest point in the wall. When it comes to determine the fine sand depth, there are two parameters that need to be taken into account, which are *standing water height*, *reservoir height*.

- The standing water is the water layer right above of the sand, this layer becomes stable after the raw water above stops flowing. And provides oxygen for the biological film of SSF, when the biolayer becomes too thin, it will disappear. The recommended height of this layer is $h_{sw} = 5$ cm [21]. The standing water can be adjusted by controlling the constant head by using float valve.
- The reservoir volume decides the hydraulic head to the SSF. The reservoir volume should be controlled carefully to maintain a constant HLR.

Generally, one float will be attached with input valve to control the closing and opening of the valve automatically to maintain a constant reservoir volume inside the tank. In order to reach the constant HLR of 0.2 m/h as mentioned in the section 3.2.1, the depth of sand bed must be roughly 6 times of the height of reservoir [12]:

$$h_s = h_r \times 6,$$

where h_s is the height of sand bed and h_r is the height of reservoir.

The height of the tank is the total working length of the tank, the inside of the tank consists of gravel layers, sand bed layers, a standing water layer and the reservoir. Hence, the height of the tank equals to the total height of each layers:

$$h = h_r + h_{sw} + h_s + h_g$$

$$1 \text{ m} = h_r + 5 \text{ cm} + h_r \times 6 + 18 \text{ cm}$$

$$100 \text{ cm} = 7 \times h_r + 23 \text{ cm}$$

$$h_r = 11 \text{ cm}$$

After calculation, the height of reservoir in this tank would be 11 cm; hence, the height of sand bed would be 66 cm for this design.

4.2.1.2 Water filtration flow-rate

The flow-rate of the water through the sand bed is proportional to the surface area of the sand bed and the HLR of water [22]. The formula of flow rate is calculated as below:

$$Q = HLR \times A,$$

Where Q is the flow-rate of water through the filter bed [m^3/h], HLR is the filtration rate [m/h], was assumed to be 0.2 m/h in the section 3.2.1., and A is the area of the filter bed, in this case it equals to the area of the tank is 1.2 m^2 .

Therefore, the value of Q after inserting all the values in the formula is calculated as follows:

$$Q = 0.2 \text{ m/h} \times 1.2 \text{ m}^2 = 0.24 \text{ m}^3/\text{h}$$

4.2.1.3 Under-drain pipe specifications

The underdrain pipe is located among the UG layer to collect filtered water and transmit to the drainage pipe. It is important to use the non-corrosive and non-mossy material; otherwise the water will be polluted again. It is best to use stainless steel, otherwise PVC is a good choice and used widely today. The underdrain pipe is recommended to have several sections if the filter diameter is larger than 0.3 m [22]. Hahn [13] suggests using the 60 mm diameter pipe with 10-20 holes of 6 mm diameter each hole for small scale design.

The chosen pipe type in this design is the PVC perforated pipe with 60 mm diameter with 3 pipes section in one end, connected in the middle of the tank's bottom. Each section is capped the end and the length approximately equals to the radius of the tank by 60 cm. Users should drill holes into the pipe and sections along the whole body, each hole should be away from each other for at least 1 cm. Due to the size of UG is 6-12 mm, hence, the diameter of the drilled-holes should be smaller to avoid the gravel from blocking the water flow, 5 mm is an appropriate diameter. A sketch of the under-drain pipe design is illustrated in Figure 6 below:

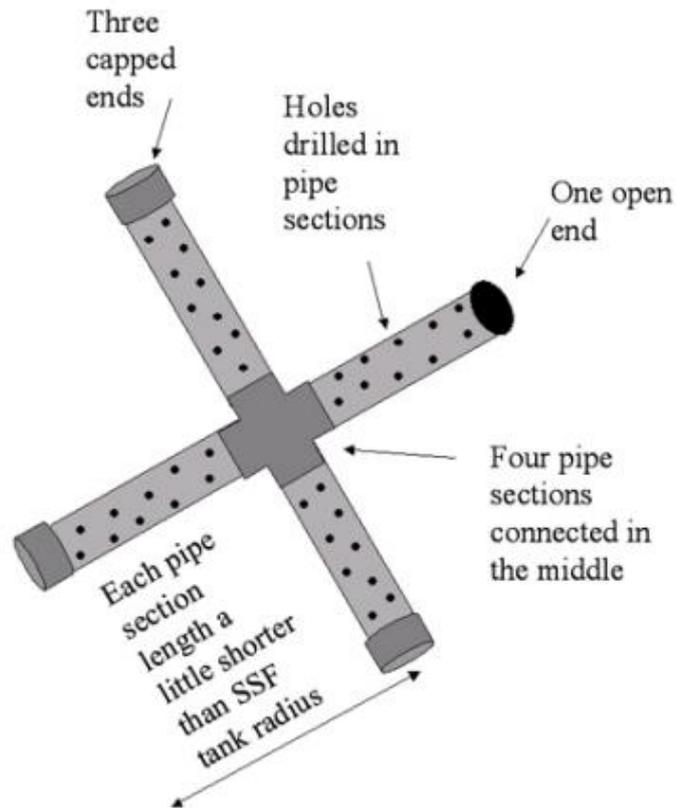


Figure 6: Underdrain for a tank [23]

There is a cleanout valve connected to the tank in the same height where the standing water locates. This valve can be used whenever people want to do a regular cleaning of the tank. The residue is drained, and dirt stays on top of the fine sand layer.

A sketch of the SSF tank design is shown in Figure 7 below:

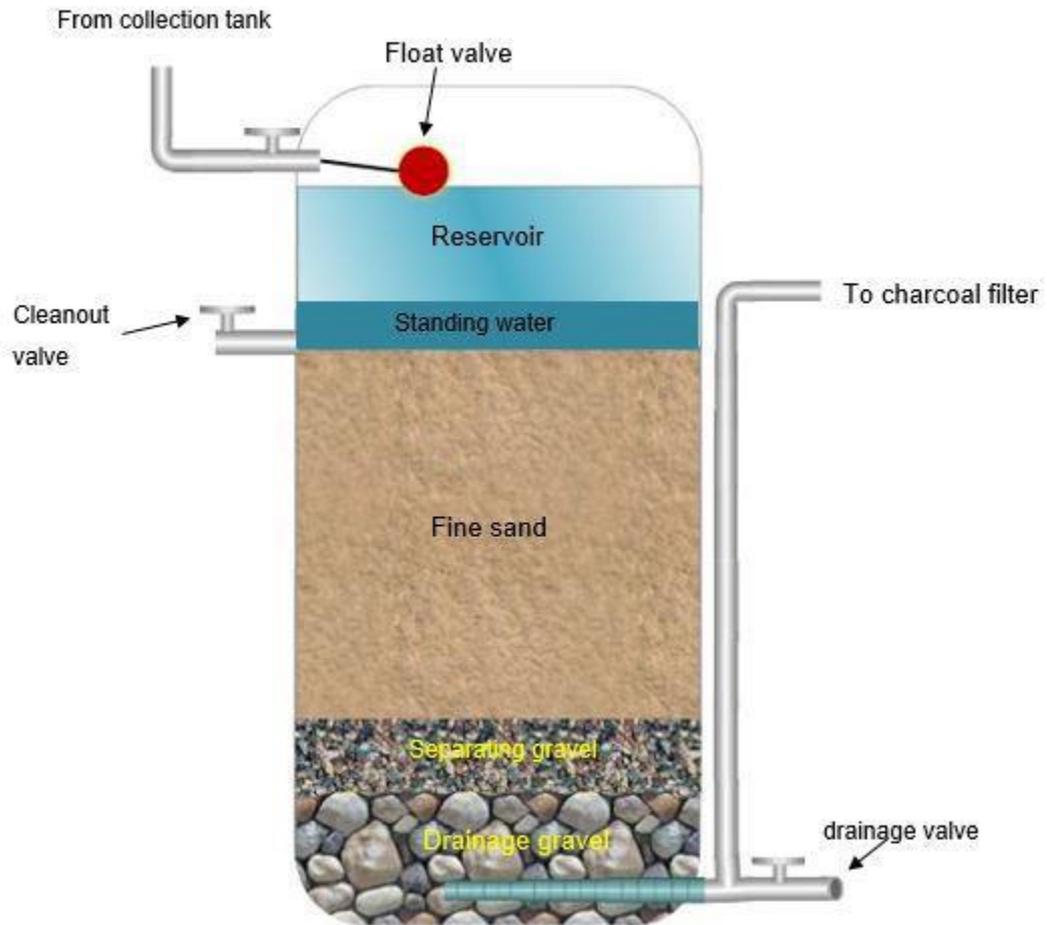


Figure 7: SSF tank design in cross-section [29]

4.2.2 GAC filter tank design

Similarly to the SFF tank, the GAC filter tank has cylindrical shape and under the GAC bed, there are SG and UG layers which have the heights 6 cm and 12 cm respectively. The SG and UG layers support the GAC bed in the filtration step and in collecting water for the underdrain pipes.

4.2.2.1 GAC bed specifications

In general, the GAC beds are designed to have a depth between 1 – 10 m and 0.3 – 0.5 m in diameter [27]. The FILTRASORB 400 has the effective size of 0.55 – 0.75 mm (from table 1), hence, its average effective size is 0.65 mm. Oscar [27] also recommends the minimum diameter of GAC column should be at least 50 times of the GAC's effective size to avoid channelling. Therefore, the chosen

diameter for the GAC column would be 0.60 m and the height of the GAC bed is 0.7 m. The area of the GAC column would be approximately 0.28 m².

There are two parameters need to be taken into account when designing GAC filter tank is the *HLR* inside the GAC column and the *contact time* as mentioned in the section 3.2.2. Their formulas are demonstrated below:

$$HLR \left(\frac{m}{h}\right) = \frac{Flow\ rate \left(\frac{m^3}{h}\right)}{Surface\ area \left(m^2\right)} \quad (1)$$

$$Contact\ time \ (min) = \frac{charcoal\ volume \ (m^3) \times 60 \left(\frac{min}{h}\right)}{Flowrate \left(\frac{m^3}{h}\right)} \quad (2)$$

The HLR for the down-flow of charcoal column varies from 8 – 12 m/h [28]. However, Oscar [27] recommends assuming the HLR of 10 m/h, therefore, in this design calculations, the HRL of GAC is assumed to be 10 m/h. The flow rate of equation (1) is calculated by the following formula:

$$Q = HLR \times A$$

Where Q is the flow rate of water through the GAC column (m³/h) and *HLR* is the HLR (m/h) of water in the GAC material and *A* is the area of the GAC bed (m²). Inserting the values of HLR and A will give the value of Q as below:

$$Q = 10 \ (m/h) \times 0.28 \ m^2 = 2.8 \ m^3/h$$

Thus, the water is flowing through the GAC column with the linear velocity is 2.8 m³/h. However, the water source that goes to the GAC filter tank is from the SSF tank, where the water flow-rate was calculated to be 0.24 m³/h, therefore, 0.24 m³/h will be the flow-rate of water inside the GAC bed.

Due to the tank is cylindrical, thus, the GAC bed inside the tank is also have cylinder, hence, the total volume of the GAC is calculated using the following formula:

$$V_c = A \times h_c$$

Where V_c is the GAC volume (m^3), A is the surface area of the GAC column, equally to the area of the tank is $0.28 m^2$ and h_c is the height of the GAC column, which was assumed to be $0.70 m$. Thus, the total volume of GAC would be:

$$V_c = 0.28 m^2 \times 0.70 m = 0.196 m^3$$

Therefore, the total required carbon volume for the GAC layer is $0.196 m^3$. Thus, inserting the known values into the formula (2) will give the total contact time number is:

$$\text{Contact time} = \frac{0.196 m^3 \times 60 \left(\frac{\text{min}}{h}\right)}{0.24 \left(\frac{m^3}{h}\right)} = 49 \text{ min}$$

Therefore, the contact time between the water and the GAC layer is calculated to be 49 minutes, which fits the minimum contact range [13].

4.2.2.2 GAC filter tank dimensions

As mention above, the GAC filter tank contains G16AC layer, SG and UG layers and a space for reservoir. The GAC bed has the height of $0.70 m$, the total height for SG and UG layers is $18 cm$ equally $0,18 m$. The diameter of the tank would equal to the diameter of the GAC column by $0.60 m$. The reservoir volume is adjusted to be $0.30m$. Therefore, the total height of the tank would be $1.18 m$ and its volume would be $0.33 m^3$.

The material used to build the tank can be concrete as well as PVC or stainless steel. However, stainless steel is recommended as it can prevent algae or mosses growth.

The underdrain system of GAC tank would be the same type with the SSF tank about properties and design, except for the length of each section should be the same as the radius of GAC tank by $0.30 m$ only. The drainage pipe is connected to the underdrain system and has two outlets, one is connected to the water

storage tank and one is connected to the drainage system to use in cleaning times.

The sketch of the GAC filter tank design would be as below:

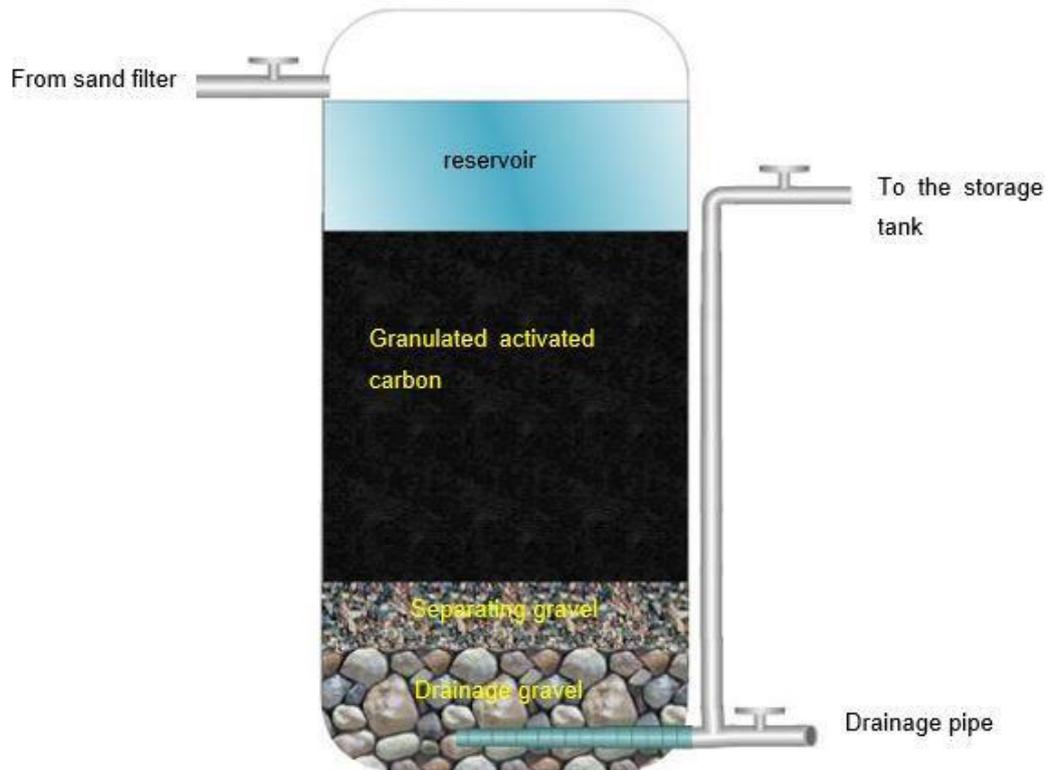


Figure 8: GAC filter tank design in cross-section [29]

4.2.3 Regular cleaning filter system

The filter layers need to be cleaned manually. With respect to the SSF filter, after every 1-2 months, the microbial membrane agglomerated on the surface of the SSF layer becomes too dirty and thick, clogging the water flow. The membrane needs to be removed by stirring the standing water on top (adjust 2-3 cm of thickness). This should be done until the water becomes cloudy; after that, the cleanout valve is opened to discharge all the water containing sediments. This step is repeated one or two times until the water is completely clean. Then, a few centimetres of the topmost sand should be removed and replaced by a new sand. After every 9-12 months, the whole sand bed should be changed by a new one.

Unlike the SSF, the GAC filter can be cleaned by the backwashing technique, which uses air scour and water to remove the trapped particles and decaying microorganisms from carbon filters. However, backwashing technique cannot remove the compounds that are adsorbed to carbon already, GAC filter needs to be replaced by a new one to have the best use in adsorbing mechanism. It is recommended to change the GAC layer every six months along with doing backwashing after every week [10].

The gravels layers, the pipes and valves also need to be checked and cleaned every six-months to ensure the water flowrate and prevent the algae or mosses from growing.

4.3 Water storage tank

With regards to singular household scale, it is common to place water storage tank (WST) on the rooftop. The tank's volume should be approximately tantamount to the initial phase water production volume and could be slightly smaller with maximum disparity is 5%. Therefore, the total volume of the tank would be 2000 L as that is the target water volume the system should produce daily.

The tank's shape can be cubic, rectangular parallelepiped or cylinder. The recommended material for WST stainless steel (INOX) to avoid rusty and mosses growth (Figure 8). In this design, the chosen shape of the tank would be cylindrical, the dimensions of the tank would be as follows:

- Height = 1.8 m
- Diameter = 1.2 m
- Area = 1.13 m²
- Total volume = 2 m³

Figure 9 shows an example of an INOX tank that has been widely used in market.



Figure 9: an Inox water- tank

The water storage tank is basically provided by these types of tube: input drain, output drain and a ventilation drain. The input drain is the drainage water pipe from the GAC filter tank and connected to the tank from the top. The output drain is connected to the tank at the bottom at one end, the other end will connect to the water distribution system of the house. The bottom of storage water tank should be placed above the roof at least 0.5 m to take precaution for repair and maintenance in the future.

5 Discussion

In European nations and other developed countries, the water sources after treatment that are supplied to singular households are of high quality and suitable for drinking directly from the taps. However, in Vietnam and other Asian countries, tap water is not clean enough to drink and can only be used for minor demands such as laundry, shower and cleaning. The system above is designed to meet those purposes only.

In case people want to have a reliable water source that is potable, they need to boil the water up to kill bacteria and clear the gas and evaporative compounds in

the water. Otherwise, the best preparation to have a totally clean water for cooking and drinking is to install an extra *Reverse Osmosis* (RO) water filtration system for the kitchen. Figure 10 shows a photo of a common RO water filtration model that is commonly used in Vietnam.



Figure 10: A RO water filtration system

These systems in the market generally have 5-9 different filter layers and apply RO technology. Therefore, it guarantees the purest water quality with added healthy minerals, which are definitely good for the health of the users.

It should be noted that this system is very limited in the power and capacity (around 2L per hour) and able to filter only half of the input water amount, therefore, it is only appropriate with cooking and drinking purpose only

6 Conclusion

Iron and manganese contaminated water has a great impact on human life, construction works and loss of aesthetic sense. Furthermore, it also causes many diseases to humans and affects dialysis function of the kidneys. Therefore, finding the solutions and tools to remove poisonous components in iron and manganese contaminated water is very necessary. The filtration designed method mentioned above is easy to apply and have lower cost than buying imported advanced water filtering systems from EU or Japan, it can reduce the amount of iron and manganese in water simply. Especially, this approach changes the iron and manganese compounds only, makes them become heavy and easy to settle down. The water after sedimentation step will stratify clearly. After treatment, the quality of the water is suitable for cooking and human daily activities. The treatment process does not use any chemical at all, therefore, it is not harmful and toxic to human health. Furthermore, its components are very common and cheap in the market; hence, it is easy to apply and to find replacements for normal households. To conclude, this filter system will lower the costs of buying fresh water and can be widely applicable.

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