Science on Natural Resources and Environment
Journal homepage: tapchikhtnmt.hunre.edu.vn

COMPARISON OF THE FEASIBILITY OF ULTRAFILRATION AND NANOFILTRAITON MEMBRANE IN DRINKING WATER TREATMENT AT HOUSEHOLD SCALE

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Received 05 October 2019; Accepted 16 December 2020

Abstract

The paper is aimed to build a water treatment model in the laboratory using nanofiltration (NF) and ultrafiltration (UF) membranes at a household scale. The filtration efficiency of both models will be assessed and compared, from which the paper will give the conclusion on the feasibility of each model in the application for drinking water treatment at household scale. The models were designed and tested in the laboratory of Hanoi University of Natural Resources and Environment. After that, the typical models were installed and tested at households in Truong Son Ward, Sam Son City, Thanh Hoa Province. Assessment is based on parameters of TDS, Hardness, Ammonium. The quality of the treated water meets QCVN 01/2009/BYT for drinking water.

Keywords: Nanofiltration membrane; Ultrafiltration membrane; Rainwater

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1. Introduction

Sam Son City is 16 km away from Thanh Hoa City. Current drinking water is supplied from treated water system of Thanh Hoa City, the water source is from Chu River, the raw water is treated in water treatment plant and then the treated water is distributed on the water supply network of the city, it is supplied through Quang Hung booster pumping station to Sam Son City by ductile iron pipes of DN400. The capacity of the booster pumping station is 6,000 m^3/day. However, the water network has covered approximately 45% of the area. Therefore, people in Sam Son City still use groundwater and rainwater for drinking and living. Because it is a coastal city with a long-established tourism industry, the tourist season is the peak season for water use [1].

In recent years, the cut off water supply in Sam Son City has occurred regularly, especially in the peak months of the summer, making many households plunged into misery because of lack of domestic water.

In addition to the treated water supplied by Thanh Hoa Water Supply Company, people here, especially coastal households, also use another water source, it is rainwater. Most households which use rainwater always build tanks, and during the rainy season they will collect water in the tank and use it gradually throughout the year.

Current methods for drinking water treatment focus on three main processes: pre-filtration, disinfection and fine filtration.

Membrane operations in the last years have shown their potentialities in the rationalization of production systems. Their intrinsic characteristics of efficiency, operational simplicity and flexibility, relatively high selectivity and permeability for the transport of specific components, low energy requirements, good stability under wide spectrum of operating conditions, environment compatibility, easy control and scale-up have been confirmed in a large variety of applications and operations, as molecular separation, fractionation, concentrations, purifications, clarifications, emulsifications, crystallizations, etc., in both liquid and gas phases and in wide spectrum of operating parameters such as pH, temperature, pressure, etc. Therefore, today, membrane science and technology are considered to consist of the basic aspects that satisfy the requirements of process intensification, which is the most interesting strategy for realizing sustainable growth [2, 3].

Membrane technologies, compared to conventional technologies, respond more efficiently to the requirements of process intensification strategy because they permit drastic improvements in industrial production, substantially decreasing the equipment-size/ production-capacity ratio, energy consumption, and/or waste production so resulting in cheaper, sustainable technical solutions [2]

Especially, Ultrafiltration (UF) and Nanofiltration (NF) membranes are two modern and effective technologies for drinking water treatment. Their size vary from 0.1 ~ 0.001 micron (µm), Ultra-filtration membrane can retain impurities such as bacteria, oil, grease, metal hydroxides, colloids, emulsions, suspended particles, and the largest molecules from water and other solutions (pollen, algae, parasites, viruses, and pathogenic bacteria, etc.) and especially can kill bacteria up to 99.9 %. Large molecules such as impurities, viruses, and bacteria will be retained and discharged. Nanofiltration membrane can remove sugar molecules, bacteria, viruses, proteins, suspended substances, etc. and keep mineral components, which are good for the human. The Nanofiltration membrane with a pore size of 0.5 - 10 nm can retain ions and low molecular weight organic substances [4].

In this paper, we present some research results on the water treatment model, treatment efficiency and assess the feasibility of Ultrafiltration (UF) and Nanofiltration (NF) membranes for rainwater treatment in Truong Son Ward, Sam Son City, Thanh Hoa province.

2. Subjects and methods of the research

2.1. Location, time and subjects of the research

- *Research location:* Truong Son Ward, Sam Son City, Thanh Hoa Province.

- *Research duration:* September 2018 - November 2019.

- *Subject of the research:* Rainwater stored in a cement storage tank which is built at the household.

2.2. Determination of the research capacity

- According to TCVN 33: 2006/ BXD, the standard for domestic water is 60 - 200 l/cap.day. Considering the demand for drinking water: q_{au} = 2.5 l/cap.day. For a household with 4 people, the amount of drinking water is estimated as q = 10 l/day. Then the designed capacity is Q = 10 l/ day.

2.3. Research methods

- *Sampling method:* Water sampling is implemented according to TCVN 6663-1:2011 - National standard on water quality - Sampling - Part 1: Guidance on the establishment of the sampling program and sampling technique and samples are preserved according to TCVN 6663-3: 2008 - National standard Part 3: Guidance on preservation and handling of samples.

- *Calculation and design of model method:* The treatment capacity of the model is calculated according to TCVN 33: 2006/ BXD, based on the results of the analysis of input water quality (rainwater stored in cement storage tank), the model is designed with the objective of treating water to meet the National technical regulation on drinking water quality QCVN 01: 2009/ BYT.

- *Laboratory analysis method:* Water samples are analyzed before and after being treated with the water treatment model, samples are taken and preserved and then analyzed at the laboratory of Hanoi University of Natural Resources and Environment and Thai Duong Environmental Treatment and Monitoring Joint Stock Company.

- *Application of AutoCAD software in drawing and design models:* Applying 2D AutoCAD software to design the models with calculated data using actual design calculation method.

- *Modeling method:* From the drawings designed by AutoCAD software, materials are prepared, and water treatment models are built.

- *Data processing method*.

3. Building the experimental model

3.1. Assessment of input parameters

Water in the tank was stirred, and then it was stored in a clean container, tightly closed to avoid contamination during transportation. The sample was stored at a normal temperature of 20 - 22.5ºC, the sample was taken for analysis at the laboratory of Hanoi University of Natural Resources and Environment and Thai Duong Environmental Treatment and Monitoring Joint Stock Company. The analysis results of the water samples in the laboratory shows that some parameters such as TDS, NH_4^+ and hardness ($CaCO_3^-$) are needed to be treated.

3.2. Establishment of water filtration model

3.2.1. Model 1: Water treatment technology using UF membrane

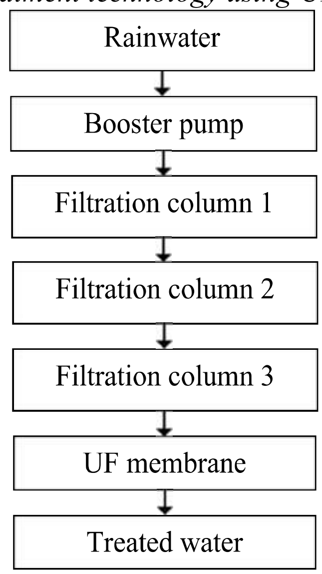

Figure 1: Diagram of water treatment technology using UF membrane

a. The design parameters of the model:

The water pipe is chosen with the diameter of D = 10 mm. Filtration column No. 1: *Choosing the filtration core of 5 Micrometer. Material: PP(Polypropylen) 5 Micrometers*. Filtration column No. 2: *Activated carbon.* Technical parameters: Size of activated carbon particle: D = 3 mm; H = 10 mm; Thickness of upper cotton padding layer: 20 mm; Total height of filter material layer: 220 mm; Thickness of supporting cotton padding layer: 10 mm. Replacing cycle: 3 - 6 months depending on water quality. Filtration column No.3: *Choosing the filtration core of 1 Micrometer. Material*: *PP(Polypropylen) 1 Micrometer.* Technical parameters: Average pore diameter: 1 Micrometer; Filter capacity: 36000L; Replacing cycle: 6 - 9 months; Outside diameter: 60 mm; Internal diameter: 30 mm; Thickness of filter layer: 15 mm; Height of filter column: 10 inches = 254 mm. Filtration column 4: *Choosing UF membrane type U.* Technical parameters: To be used at maximum temperature: 45°C; To be used at maximum pressure: 120 PSI; Replacing cycle: 24 months; Meet NSF Standard; Active filter length: 100 mm; Total diameter of filtration thread: 38 mm. Pump: *Choosing booster pump AP - 50 with the following parameters*: Voltage to be used: 24V; Pump flow: 1.6 LPM; Pressure: 80 PSI; Maximum pressure: 130 PSI; Electric current: 1.2 A; Origin: Thailand.

b. Experimental process

Water is pushed by a suction pump from the water storage tank through filtration column No. 1. In filtration column No. 1, suspended particles with the size bigger than 5 Micrometers (mud, sand, algae, etc.) are removed. Then under the pressure, the water is passed through filtration column 2. In filtration column 2, organic substances, heavy metals, toxins in the water will be adsorbed by activated carbon. After the filtration column 2, the water continues to be passed through filtration column 3 under the pressure of the pump. In filtration column 3, the remaining impurities that are larger than 1 Micrometer in size are completely removed by the filtration membrane. The water is then passed through the filtration column No. 4. Here, UF membrane type U helps to remove impurities smaller than bacteria, oil, grease, metal hydroxides, colloids, emulsions, suspended solids, and especially can kill bacteria up to 99.9%. These impurities will be discharged through the drain valve. Water is penetrated through capillaries with the size of 0.1 ~ 0.001 micrometer (µm) with the treated water meeting TCVN 01: 2009 /BYT.

3.2.2. Model 2: Water treatment technology using NF membrane

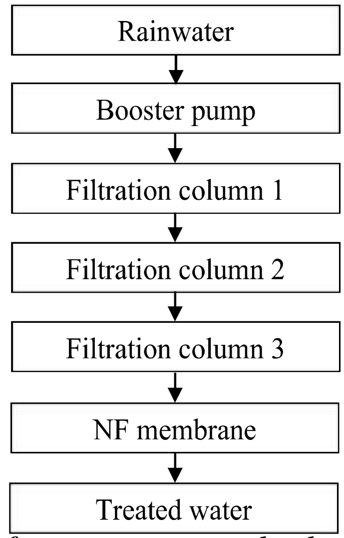

Figure 2: Diagram of water treatment technology using NF membrane

a. The design parameters of the model

Choosing water pipe with diameter D of 10 mm. Filtration column 1, filtration column 2, filtration column 3 and booster pump are selected as same as in the water treatment technology using UF membrane. Filtration number 4: NF membrane: Choosing Nano Ultrafiter manufactured by Rising Sun Membrane Technology (Beijing) with the following parameters: Polyamide thin film composite with the average pore size of 1 nm. The membrane has the ability to prevent 99.9% of bacteria from the air, and prevent re-infection during the water filtration.

b. Experimental process

The experimental process of this model is similar to the one of model 1. Only in filtration number 4, NF is used instead of UF. NF can remove up to 99% of all dissolved solids, bacteria, small particles and organic compounds with a molecular weight greater than 300 or particles about 0.001 micrometer in size. After the filtration column 4, purified water can be collected. Wastewater of the system will be discharged through the discharged valve.

4. Results and discussion

4.1. Determination of parameters of input water

The sample of treated water was taken for analysis at the laboratory of Hanoi University of Natural Resources and Environment and Thai Duong Environmental Treatment and Monitoring Joint Stock Company. The analysis results of the water sample showed that almost the parameters meet the QCVN 01/2009/ BYT, only some parameters such as TDS, NH_4^+ and hardness ($CaCO_3^-$) need treating to meet the standard.

Several analysis results of the input water sample are presented in the following table

Table 1. Test results of parameters in input water

No.	Parameters	Unit	Value	QCVN 01:2009/BYT	Note
1	Total dissolved solids (TDS)	mg/l	2000	1000	To be treated
2	Ammonium (NH_4^+)	mg/l	4.12	3	To be treated
3	Hardness ($CaCO_3^-$)	mg/l	350	300	To be treated

4	Nitrite	mg/l	0.025	-	
5	Nitrate	mg/l	0.7	-	
7	Hydrogen sulfide	mg/l	<0.05		
8	Total iron	mg/l	<0.07	0.3	
9	Exceeded Chloride	mg/l	NA	0.3 - 0.5	
10	Total copper	mg/l	0.16	1	
11	Nickel	mg/l	<0.01	0.02	
12	Total Chromium	mg/l	<0.01	0.05	
13	Lead	mg/l	NA	0.01	
14	Total Coliform	MPN/100ml	NA	0	
15	E.coli	MPN/100ml	NA	0	
16	Temperature	ºC	18		
17	pH		7.1	6.5 - 8.5	
18	Turbidity	NTU	1.2	2	
19	Odor		No strange taste and odor	No strange taste and odor	

NA: Not available

After being treated with two models using UF and NF membranes, the test results of parameters in treated water can be shown in Table 2 as follows:

Table 2. Test results of parameters in treated water with two types of membranes.

No	Parameters	Unit	Before being treated	After being treated with NF membrane	After being treated with UF membrane	QCVN 01:2009/BYT
1	TDS	mg/l	2000	350	600	1000
2	NH_4^+	mg/l	4.12	0.17	0.32	3
3	Hardness ($CaCO_3^-$)	mg/l	350	210	210	300

The treatment efficiency of the two models was highest with NH_4^+ (95.8% for NF membrane model and 92.23% for UF membrane model). Besides, there was also high TDS treatment ability, reaching 82.5% for NF membrane model and 70% for UF membrane model. The ability to remove Hardness ($CaCO_3^-$) of NF membrane model and 92.23% for UF membrane model was the same with an efficiency of 40%. After the process of treating rainwater with two types of UF and NF membrane, it can be seen that the quality of treated water meets QCVN 01/2009 / BYT for direct drinking water. However, treatment using NF membrane will be more efficient with two parameters of TDS and NH_4^+. For the hardness, the treatment efficiency of two models is the same. The treatment efficiency of hardness ($CaCO_3^-$) seems to be different compared to the result of Amir Abbas Izadpanah and Asghar Javidnia. Their research showed that the nanofiltration membrane is capable of retaining 96 - 98% of the total hardness [5]. This difference can be explained by the fouling and scaling by calcium ions on the surface of membrane, calcium carbonate is one of major causes of fouling on process equipment surfaces which can lead to the drawback of reducing the removal efficiency of the membrane [6].

4.2. Economic benefits of using membrane compared to conventional boiling method

Considering the amount of drinking water of q_{au} = 2.5 l/ cap.day, the cost estimation showed that during one year, a household with 4 persons will save about VND 0.5 million of electricity bill to boil drinking water. At the same time, the treated water with NF and UF membrane will have better quality, contributing to improving the health of the people in the area.

4.3. Economic comparison between UF model and NF model

The total cost estimate of manufacturing UF model is: VND 1,889,000

The total cost estimate of manufacturing NF model is: VND 2,596,500.

4.4. Comparison of water use efficiency

From the research results above, it can be concluded that using the UF and NF membrane technology for filtration of drinking water at household scale is suitable. However, using UF model will be more economical because the price for manufacturing its model is more affordable compared to the NF model. Therefore, rainwater treatment with UF model is recommended to be used in households in Truong Son Ward, Sam Son City, Thanh Hoa Province.

4.5. Solutions to overcome the drawback of fouling and scaling of membranes

To overcome the drawback of fouling and scaling UF and NF which reduces the filtration efficiency of the membrane. It is recommended the users to change the filtration membrane according to the instruction of the manufacturer.

5. Conclusion

The use of UF and NF membranes for treatment of rainwater to drinking water brings the hygienic drinking water, eliminates toxic substances for humans but retains useful minerals. Besides scientific and technical benefits, the water treatment by membranes will save more money and energy resources, meeting the requirements of the sustainable development strategy.

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