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STUDY ON ADVANCED TREATMENT OF WASTEWATER BY ULTRA FILTRATION FOR REUSING PURPOSE-ON-SITE PILOTS

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Abstract. Reclaimed water has been greatly applied worldwide recently to augment water supply for non-potable domestic purpose. The present study put an effect on assessing the application of ultra-filtration (UF) on advanced treatment following conventional domestic wastewater treatment and coal mining wastewater for reusing purpose. On-site advanced treatment pilots using UF membrane with the capacity of 1 - 1.5 m^3/h were built to treat decentralized domestic wastewater which has a low concentration of organic matters and coal mining wastewater which is abated by chemical-physical process and advanced treatment train. Dissolved oxygen (DO), pH, Chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), volatile suspended solids (VSS), Total Nitrogen (TN) and ammonium-nitrogen (NH_4-N) in domestic wastewater and TSS, iron (Fe), manganese (Mn), and hardness of coal mining wastewater were analyzed. The pollutants in domestic wastewater were reduced significantly as of 82 % TSS, 86 % BOD_5, 82 % COD, and 96 % NH_4-N. The removal efficiency in coal mining wastewater reached 93.5 % TSS, 67 % iron, 68 % manganese, and 52 % hardness. The analyzed parameters in permeate of both pilots met legislation thresholds of Vietnam technical regulation on domestic water quality, proving that reclaimed water treated by UF can be used for non-potable domestic purposes.

Keywords: decentralized domestic wastewater, coal mining wastewater, ultra- filtration, reclaimed water.

Classification numbers: 3.3.3., 3.6.2, 3.7.1.

1. INTRODUCTION

On account of severe drought and adverse weather patterns, there is an imminent water scarcity worldwide, especially in remote areas. Reclaimed water is increasingly important to ensure adequate usable water resource. It is also noted that water reclamation minimizes the untreated wastewater collected to urban centralized wastewater treatment plants [1]. For industrial purposes, there is a great demand of non-potable water for manufacturing process and domestic uses of workers, which is mainly distributed by centralized water supply facilities. In fact, a high number of mining points are located in remote or mountainous areas, where is a limitation in water supply [2]. Coal mining is a particular example which requires a great volume of clean water for bathing of workers. It is suggested that reclaimed water reuse derived from underground mining activities can be recycled for this purpose. Coal mining wastewater refers to un-wanted water generated from mining activities, which derives from groundwater source, penetrates to the geological layers, and eventually appears in the mines. Typically, it is polluted by inorganic constitutes as a high level of suspended solids and heavy metal ions. Reclaimed water after sole ultra-filtration (UF) or UF integrated with physical-chemical treatment steps is able to meet recycled water criteria [3]. In Germany, 150 million of cubic of coal mining wastewater are further degraded by membrane to utilize for industrial and domestic purposes [4]. Color of coal mining wastewater can be effectively removed by spiral wound polymeric UF membranes [5]. The advantages of membrane technique for advanced wastewater treatment has been widely known. Membrane filtration can be employed as a physical barrier to lessen concentration of undissolved compounds and pathogens in wastewater. Before that, wastewater has been treated by the conventional treatment train including physical, chemical, and biological processes to remove organic matters, nutrients, heavy metal ions and suspended solids [6]. Particularly, Micro-Filtration (MF) and Ultra-Filtration (UF) can be placed in membrane bio-reactor (MBR) technique to treat domestic wastewater or to remove undissolved substance in coal mining wastewater. With the pore size ranging from 2 - 200 nm, ultrafilter has shown a great performance to remove heavy metal ions in coal mining wastewater or pathogen risks in domestic wastewater [7].

The study introduces feasible applications of UF for on-site pilots to treat domestic wastewater and provide an advanced treatment for coal mining wastewater to guarantee a sustainable water supply in remote areas.

2. MATERIALS AND METHODS

2.1. UF on-site pilot for domestic water reuse

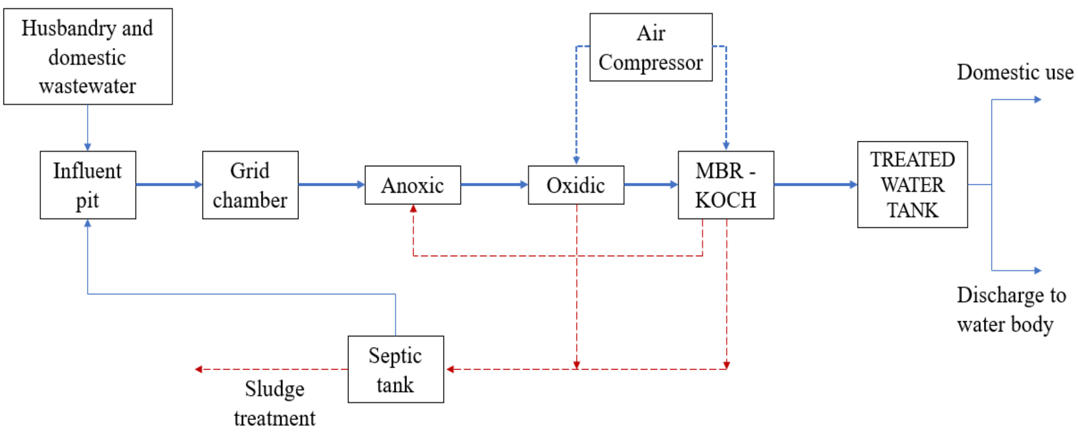

Figure 1. Treatment process of domestic wastewater in Thanh Liet dam.

A small unit of Ha Noi Sewerage and Drainage Company, which is located in Thanh Liet dam and considered as a decentralized discharging point, generates 20 - 25 m^3/day of domestic wastewater. After being pretreated in household septic tanks, domestic wastewater consists of

TSS (48 - 125 mg/L), BOD_5 (65 - 148 mg/L), COD (110 - 240 mg/L) and NH_4-N (7.4 - 24.8 mg/L). While treated wastewater was directly discharged into To Lich river, there was a high demand of water supply in the unit. To reuse reclaimed water, the treatment process was designed based on the Anoxic and Oxidic condition as shown in Figure 1 [4].

The on-site pilot included the inlet tank, fine screening, biological treatment unit equipped with anoxic (A) and oxidic (O) chambers, MBR and effluent tank. Ultrafiltration spiral membrane with the pore size of 0.03 µm and surface area of 41 m^2 was made from Polyvinylidene Fluoride (PVDF) produced by Koch company (USA). Operation time was 150 days with various retention time and return activated sludge rate (Q_{RAS}) to assess the removal rate of organic matters and nitrogen compounds. The operation indexes were shown in Table 1.

Table 1. Operation indexes.

Period	Day	Influent Q_v (L/h)	Return activated sludge Q_{RAS} (L/h)	Retention time HR (hour)	Hydraulics load HL ($m^3/m^2/d$)	COD of influent (mg/L)
1	001 - 300	1000	1000	4.5	0.6	200
2	031 - 600	950	950	9.0	0.56	180
3	061 - 120	900	1800	9.0	0.52	192
4	121 - 150	850	2550	5.1	0.49	220

2.2. UF on-site treatment for coal mining wastewater

The effluent of coal mining wastewater of Mao Khe Company, which was treated by coagulation, flocculation and filtration, met the requirement of surface water quality as regulated in Column B of QCVN 40:2011/BTNMT [8]. After that, wastewater was pumped to the inlet tank of UF pilot which was operated with the capacity of 25 - 30 m^3/d. The process was illustrated in Figure 2.

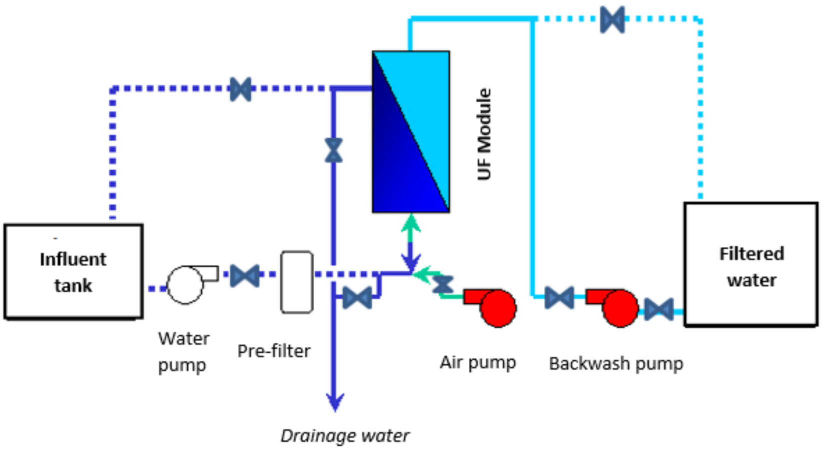

Figure 2. UF on-site treatment for coal mining wastewater.

The influent was pumped through a pre-filter (filament filter, pore size of 100 µm), which was then evenly distributed over the inlet into the ultrafiltration membrane module (UF). The membrane used in the pilot was the fiber-optic UF membrane, which was operated on the principle of blocking with the following characteristics: a hydrophobic polyacrylonitrile (PAN) with the pore size of 0.01 - 0.1 µm, nominal filtration area: 48 m^2, membrane filtration capacity (throughput): 11 - 72 L/m^2 (at 25 °C), maximum inlet pressure: 241 kPa, maximum filtration pressure: 55 kPa. The other major equipment of the model was the water pump for Ebara membrane, type 3S65-125/4.0, backwash water pump Ebara type 3S65-125/7.5 and Tohin air blower. There was also a flow control valve that allowed the system to maintain a steady feed flux.

Water was filtered through the UF membrane. The membrane was automatically operated according to the instruction of supplier Mann-Hummel. Each filtration cycle lasted in 10 minutes. After 10 minutes, the surface of the filters was dirty and the valve opened automatically. The membrane was washed with compressed air at 13 kPa in 30 seconds. After that, it was flushed with permeate water with flow rate 90 L/m^2/h. Therefore, in each 11.5-minute cycle, the volume of filtered water and circulated feed water was appropriate 410 and 72 liters, respectively. This circulating water limited the amount of dirt concentrated on the membrane surface. Similarly, the regulating valve maintained a constant circulating water flow.

In order to remove all adhering dirt on the surface, the filters were backwashed each five minute by a combination of aeration and the use of filtered water. The backwash system was connected to a filtered water tank and a backwash pump, designed to suit the number of filters and backwash frequency. The pump was attached to an inverter to maintain the backwash speed according to the preset parameters. Backwash water from the top combined with compressed air from the bottom made the filter vibrate strongly to remove dirt from the fiber surface. The dirty water was discarded after that.

2.3. Analysis methods

Regarding domestic wastewater, DO, pH and temperature of influent were measured on-site, while other indexes such as COD, BOD, TSS, VSS, Total nitrogen and NH_4-N were sampled and analyzed three times per week. The analysis was conducted by Spectrophotometer HACH DR2100 based on methods regulated in Vietnam National Standard TCVN, APPHA 2003.

In terms of coal mining wastewater, the quality of water was analyzed by methods described in TCVN 6492:2011 (ISO 10523:2008) Water quality – Determination of pH [9]; TCVN 6625:2000 (ISO 11923:1997) Water quality - Determination suspended solids by filtration through glass-fiber filters [10]; TCVN 6177:1996 Water quality - Determination of iron- Spectrometric method using 1.10- phenantrolin [11]; TCVN 6002:1995 Water quality - Determination of manganese - Formaldoxime spectrometric method [12]; TCVN 6224: 1996 Water quality - Determination of the sum of calcium and magnesium - EDTA titrimetric method [13] and TCVN 6200: 1996 Water quality - Determination of sulfate - Gravimetric method using barium chloride [14].

3. RESULT AND DISCUSSION

3.1. Recycled water treatment for reusing by MBR

In the first phase of 30-day operation, the pilot was operated with the influent of 1000 L/h, hydraulics load of 0.6 m^3/m^2/d, while the initial mixed-liquor suspended solids (MLSS) of aeration tank was 2000 mg/L and it was unstable over the period given. After 60 days, the increasing volume of return activated sludge resulted in the rise of MLSS, and it remained stable at the range of 3000 - 4000 mg/L in the third phase (day 120th). The increase of MLSS was due to the higher volume of influent and returned activated sludge. The peak value of MLSS reached 5600 mg/L.

While the MLSS in aeration tank fluctuated due to the variation of HRT and Q_{RAS}, MLSS in aeration tank maintained stable in the range of 2000 – 3000 mg/L throughout the operation period.

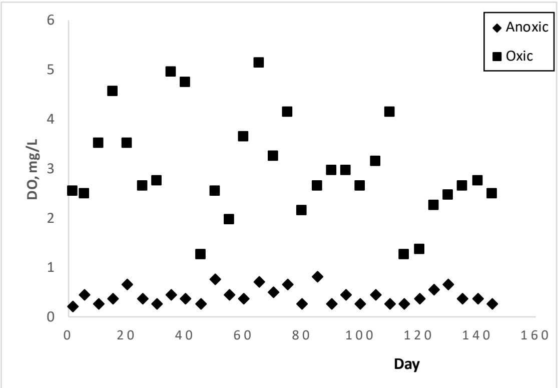

Figure 3. The variation of DO in reaction tank (aeration and anoxic tank).

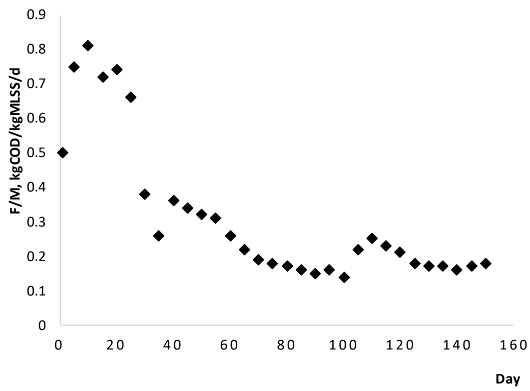

Figure 4. The change of F/M in aeration tank.

Figure 3 shows the change of DO concentration in aeration tank and anoxic tank over time. DO concentration ranged around 3.0 mg/L and 0.5 mg/L in aeration and anoxic tank, respectively. It is noted that even when Q_{RAS} rose to 300 %, the concentration of DO in aeration and anoxic tanks were higher than 2 mg/L and less than 0.5 mg/L, respectively.

In the first phase (day 1 - 30), the rate of F/M (F and M refers to Food and Microorganisms) was relatively low and stable. In the second phase, while there was a decline of influent (50 %) and the amount of Q_{RAS} rises to 300 %, F/M continuously decreased and bottomed as shown in Figure 4. The average value of F/M was 0.1 - 0.15 kg COD/kg MLVSS/d, which was similar to other studies [15, 16].

According to Figure 5, COD of the feed ranged from 110 to 240 mg/L, which might suggest a low level of COD in Hanoi domestic wastewater compared to other sources. There was a stability in COD removal. It is worth to note that COD of the effluent was less than 50 mg/L, which satisfied Vietnam national technical regulation QCVN 08-MT:2015/BTNMT for water resources of irrigation or other purposes.

Ammonia in the feed ranged from 7.4 to 24.8 mg/L as shown in Figure 6. On the first 30 days, the level of ammonia was relatively high, which suggested that there was a low efficiency of the conversion from ammonia into nitrate in the aeration tank. The low efficiency was due to the insufficient hydraulic retention time and the oxidizing capacity of bacteria in the start-up phase. However, in the second phase, the removal rate of ammonia considerably increases (> 96 %). Also, the nitrogen rate rose while there was an increase of returned activated sludge.

Alkalinity in the feed ranged from 200 to 250 mg $CaCO_3$/L and in the permeate was greater than 80 mg/L, suggesting that the alkalinity concentration afforded the conversation of ammonia into nitrate. When MLSS exceeded 5000 mg/L, the activated sludge was drained and raw wastewater was added to reach the level of MLSS of 3500 mg/L. The quality of the permeate remained stable and met the legislation thresholds of supplementation of surface water as in column B1 (QCVN 08-MT:2015/BTNMT) [17].

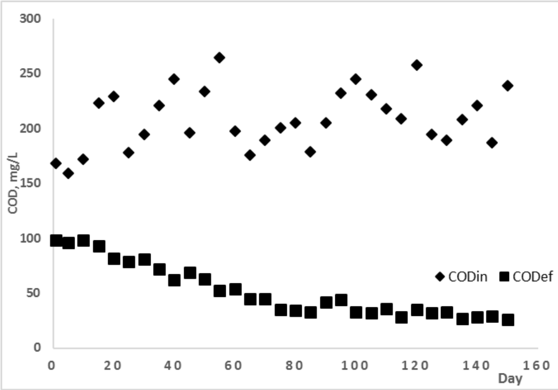

Figure 5. COD in the feed and permeate.

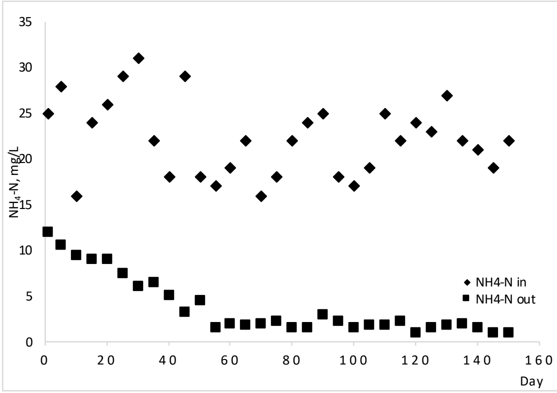

Figure 6. NH_4-N in the feed and permeate.

The results from Table 2 showed that anoxic oxidic- membrane bioreactor system (AO-MBR) had a better performance than other domestic wastewater treatment systems being applied such as Sequencing Batch Reactor (SBR) or Oxidation Ditch. Research on domestic wastewater treatment in a pilot model at Kim Lien wastewater treatment plant in Ha Noi also achieved the same treatment efficiency as the pilot built in this study [19]. Another advantage of AO-MBR system is that there is no need for additional chemicals such as alkalinity adjustment, flocculants, thus, reducing the operating costs of treatment technique [20, 21].

Table 2. Removal efficiency of AO-MBR pilot in Thanh Liet dam.

No.	Index	Feed water	Permeate	Regulated value (1)
1	pH	7.2 (6.7-7.8)	6.95-7.75	5.5 -9
2	TSS, mg/L	102 (48-125)	18	50
3	BOD_5, mg/L	102 (65-148)	14	15
4	COD, mg/L	180 (110-240)	32	30
5	NH_4-N, mg/L	17.5 (7.4-24.8)	0.7	0.9
6	NO_3-N, mg/L	1.5 (0.5-9.5)	9	10
7	Alkalinity, mg $CaCO_3$/L	220 (200-250)	85	
8	Coliform, MPN/100mL	12000	500	5000

Note: (1) - equivalent to column B1 of QCVN 08-MT:2015/BTNMT for surface water resources used for irrigation or other purposes.

3.2. On-site pilot of coal mining wastewater treatment

After being treated by the flocculation – coagulation – filtration process, Mao Khe coal mining wastewater satisfied Column B of QCVN 40:2011/BTNMT. Coal mining wastewater was pumped to UF membrane system to be continuously treated.

Figure 7 shows the TSS removal efficiency in UF membrane over time. The TSS concentration ranged from 16 to 45 mg/L, depending on operation modes and the quality of influent. After going through UF membrane, TSS reached 2 mg/L (ranged from 0.2 to 5.8

mg/L). The average TSS removal rate was 93.5 %. The permeate quality satisfied National technical regulation on domestic water quality QCVN 02:2009/BYT (If the turbidity is less than 5 NTU, TSS is 5 mg/L) [22].

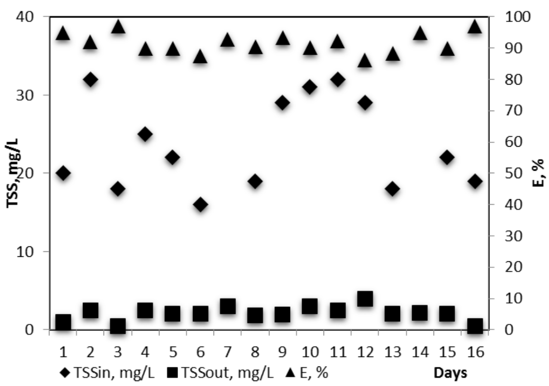

Figure 7. TSS removal by UF membrane.

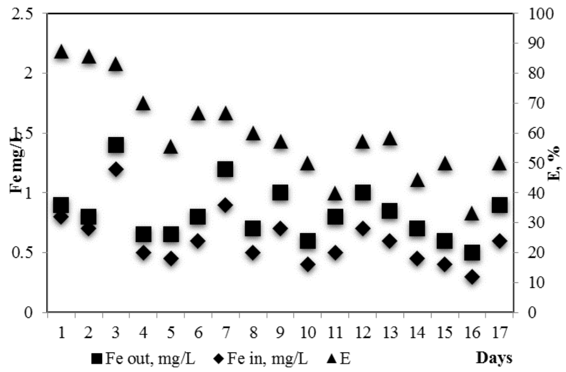

Figure 8. Iron removal by UF membrane.

According to Figure 8, with the total iron concentration of the feed ranged from 0.3 to 1.2 mg/L including Fe(II) occupied of 25 - 30 %, iron concentration in permeate declined to 0.1 to 0.3 mg/L, below the required value regulated in QCVN 02:2009/BYT. After UF system, iron removal reached 67 % (ranged from 60 - 70 %).

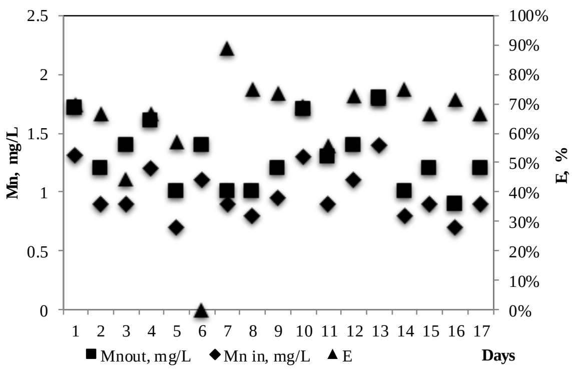

Figure 9. Manganese removal by UF membrane.

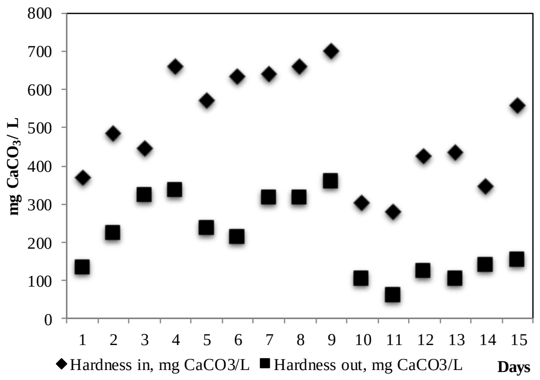

Figure 10. Hardness removal by UF membrane.

In Figure 9, manganese appeared in undissolved form as of $Mn(OH)_2$ in the feed water, ranging from 0.7 - 1.4 mg/L, and decreases to 0.5 mg/L after UF system. There are 12 of seventeen samples had the concentration of manganese less than 0.3 mg/L, which satisfied the requirement of national technical regulation on drinking water quality QCVN 01:2009/BYT [23]. The average removal rate was 68 %.

Hardness measured by $CaCO_3$ concentration over time was shown in Figure 10. Coal mining wastewater refers to un-wanted water generated from mining activities, which derives from groundwater source, penetrates to the geological layers, and eventually appears in the mines. Typically, it is polluted by inorganic constitutes as a high level of suspended solids and heavy metal ions. In this study, hardness in the feed water was quite high, ranging from 280 to 700 mg $CaCO_3$/L. After the UF membrane filtration process, the hardness decreased significantly, ranging from 60 to 360 mg/L. Those values were within the permissible range regulated in National technical regulation on domestic water quality QCVN 02:2009/BYT [22].

After flocculation - coagulation - filtration process of Mao Khe coal mining wastewater treatment plant, there was an inadequate amount of oxygen for oxidation of iron and manganese; thus, the concentration of those metals were still high. Thanks to the UF membrane, the average value of iron and manganese in the permeate reached 0.2 and 0.3 mg/L, which met the recommendation of World Health Organization for potable use [24]. In addition, UF system removed dispersed solid particles, leading to small turbidity of permeate, ensuring the requirement for domestic water quality. The removal efficiency of insoluble particles (TSS, Fe, Mn, …) were higher than those of dissolved salts.

Table 3. The removal rate of pollutants by UF membrane for Mao Khe coal mining wastewater.

No.	Index	Concentration in feed water, mg/L	Average removal rate, %	Average concentration, mg/L	
				Permeate	QCVN 02:2009/BYT
1	TSS	16 - 45	93.5	2	5
2	Fe	0.3 - 1.2	67	0.2	0.5
3	Mn	0.7 - 1.4	68	< 0.3	-
4	Hardness (mg $CaCO_3$/L)	280 - 700	52	200	350
5	Coliform (MPN/100mL)	-	-	3	50

The research results of Mao Khe coal mining wastewater were illustrated in Table 3. The analysis results showed that most of the indexes, except manganese, satisfied the requirement of water quality for domestic purposes regulated in QCVN 02:2009/BYT. However, coliform still maintained in the permeate with low concentration.

Wastewater from coal mining pit can be further treated by membrane filtration methods for reuse. In the Federal Republic of Germany, some brown coal mines with a capacity of 110 million tons/year have treated up to 140 million m^3/year of mining water for industrial and domestic water [4]. According to Sivakumar *et al*. [25], the hollow fiber MF membrane can remove 99.9 % of solid mineral particles in coal mining wastewater. The effluent discharge from a local coal mine containing 2332 mg/L of TDS (Total Dissolved Solids), 14.4 mg/L of Ca, 2.72 mg/L of Mg, 1.92 mg/L of Fe and 3.38 mg/L of Al was treated by a vacuum membrane distillation system. In addition, Longyu Coal Company in Henan Province - China applied the UF line and reverse osmosis filter RO to recycle coal mine wastewater to provide 5277.6 m^3 of water/day for the boiler in a power production plant, and for domestic water reuse [26].

4. CONCLUSIONS

For industrial purposes, there is a great demand of non-potable water for manufacturing process and domestic uses of workers, which is mainly distributed by centralized water supply facilities. In fact, a high number of mining pits are located in remote or mountainous areas, where there is a limitation in water supply. Due to the scattered location, those mining pits are also the decentralized wastewater discharge points. The application of membrane technology for advanced treatment in on-site wastewater treatment plant in those mining pits for domestic purpose, namely watering plants, stamping dust, and supplementing for surface water resources is, therefore, reasonable.

By installing two onsite pilots, this study proved that UF membrane with numerous outstanding technical characteristics can be applied into treatment line of domestic wastewater or several types of industrial wastewater. For domestic wastewater with low organic and nutrient concentration, the first pilot was built with the capacity of 20 - 25 m^3/day. Operating result from the first pilot showed that low strength domestic wastewater can be recycled for washing vehicles, watering plants, creating landscapes and replenishing water sources in rivers and lakes in the area since water quality of the permeate meet the National Standard of QCVN 08-MT: 2015/BTNMT [17]. For coal mining wastewater, the second pilot was built with the capacity of 20-25 m^3/day and physical-chemical process combining with UF system. Treated wastewater after physical and chemical treatment reached B level of QCVN 40: 2011 [8]. The UF membrane removes elements such as suspended solid, iron, manganese, hardness, coliform, etc. Therefore. Treated wastewater satisfied the National Standard of QCVN 02: 2009/BYT. According to the results from those pilot, UF can be applied for reclaimed water in mining pits, such as laundry activities of the workers or spraying dust in the pit.

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