

## Wastewater Analysis Using Kubota Membrane Bioreactor System

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### Abstract

Wastewater treatment plays a crucial role in daily life, serving as a process that addresses and eliminates multiple environmental and health issues through proper testing and control. Its primary goal is to ensure that wastewater can be disposed of safely, without threatening public health and with little to no impact on natural water bodies. Effective treatment helps minimize or eliminate pollutants, which not only supports industrial activities economically but also reduces toxic elements, solid waste, and raw material losses. This leads to lower purchase and management costs, improved efficiency, higher profits, better community relations, and enhanced environmental performance. The purpose of this study was to expand knowledge of wastewater treatment, including its chemical and biological characteristics, as well as overall water quality. It also provided hands-on experience in designing, building, and operating a lab-scale wastewater treatment plant. A key focus was on optimizing techniques - such as scouring - to reduce membrane fouling. The project involved setting up a pilot-scale treatment plant modeled after the Kubota MBR system, which uses flat-plate thin-film composite membranes, and running it with synthetic wastewater prepared from a standard recipe. Over a six-week period, treatment parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), pH, temperature, turbidity, and nutrients were monitored. Consistent flux outputs were obtained across different membrane conditions. Findings showed that Dissolved Oxygen (DO) and nitrate levels are inversely proportional to Mixed Liquor Suspended Solids (MLSS), while COD and turbidity are directly proportional to MLSS. All measured parameters were consistent with the results reported by previous studies and experts in the field of wastewater treatment.

**Keywords:** Wastewater treatment, MBR system, Kubota MBR system, pollutants.

### 1.0 Introduction

Water being the most important world resources, without which life would not have existed and industries would not have been able to operate. Even if these industries do exist, they will be polluting the environment and deposit a lot of concentrated sludge [1]. Been important to life is how human beings can exist without food for many days even though the food also needs water to grow, but barely resist or survive in the absence of water. Instable community, a safe and reliable water source is required, as safe drinking water is a right not a privilege [2]. Most developing nations depending on untreated water as their source of water (river, lakes, etc.), With a lot of rural dwellers depending on running surface water for their drinking water and this is usually polluted by the direct discharge of waste coming out from both domestic and industrial activities and other runoffs from agricultural lands [1].

Many water related conflicts have occurred for centuries due to protective of guarded water bodies by communities especially in developing countries, such as disputes over access to water which lead to border conflicts, conflicts between land owners and settlers which affect and delay agricultural developments, outputs and also affecting the economy of a nation. Others are conflicts between industries and environmental protective agencies, legislative laws and the environment and many more. All the above mentioned means are significant for managing and conserving a natural resources such as water, which is of paramount importance and must be acknowledged worldwide [3].

With the apparent increase in population, urbanization, industrialization as well as the demand to increase food production, and the issues related to climate change and global warming. All the aforementioned problems are putting our water sources at risk of getting contaminated. This and many more is making researchers all over the world to focus in finding a solution regarding water and wastewater treatment alternatives and reuse of wastewater from other sources. This idea could possibly control the release of clean water for use in sectors that actually need fresh water rather than providing it to the sectors that can utilize treated wastewater such as in irrigation and other related services [4].

All water that enters into the drains or into the sewage collection system is termed wastewater. This is categorized into municipal and domestic wastewaters, and all this type of wastewater needs to be treated to the highest quality of effluent discharge within the set standard. This can be done by many processes.

Wastewater treatment is based on the reduction or removal of nuisance either in solids form either through the action of filtration or settling (physical processes) and through biological processes when the compounds are soluble (biodegradable) or by chemical oxidation, ion exchange, desorption (non-biodegradable compounds) [5]. Membrane Bioreactor (MBR) system is a combination of the conventional biological wastewater treatment and a membrane filtration system put together. There only difference to the traditional wastewater treatment plant (WWTP) is the separation of the activated sludge and the treated wastewater, but they are quite similar in terms of configuration [6]. The MBR system having high retention ability holds the potential of becoming one of the most used and new generation process in wastewater treatment. This system uses either micro-filters (MF) or ultrafilters (UF) of different molecular weights to separate solids from liquids in wastewater treatment systems [6,7]. Another advantage of using MBR is its ability of retaining higher molecular weight compounds which normally escapes when settling is operated as the final separation step in wastewater treatment. This also depends on the molecular weight of the membrane used as higher molecular weights membranes have higher retaining capacity and vice versa [8]. This study focusses on the analysis of both influent wastewater entering the reactor as well as the effluent coming through the membrane for chemical and biological tests.

## 2.0 Materials and Methods

### 2.1 Experimental rationale and configuration

The experimental plan was to develop and test samples of a wastewater treatment system using a flat sheet membrane that would yield a good permeate free from pollutants. The pilot system configuration set up of the unit was followed accordingly to a standard activated sludge treatment plant. It consisted of three large plastic buckets/tanks, one of them is a black 20L tank and the other two were clear 30L tanks. The black tank was for the synthetic wastewater; however, the clear tanks were both membrane units with a Kubota cartridge installed in each of them. One of these clear tanks was a membrane unit as well as it was acting as a bioreactor tank where the reaction between synthetic wastewater (food) and sludge (microorganisms) took place by aeration (using an aerator) and mixing (using a mixing paddle drill). Furthermore, the other clear tank was only a membrane unit with wastewater being drain into it from the bioreactor after the sludge is settled and no reaction is happening here since there is no sludge. Eventually, a peristaltic pump was linked to both membrane unit tanks sucking treated water from each tank to a 1 L permeate tank where the flux is measure then the water is taken for further chemical and biological tests to measure other parameters.

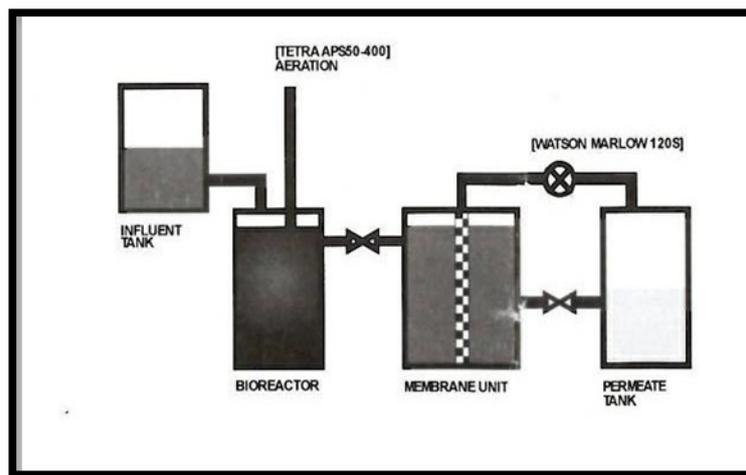


Figure 1: Shows the initial configuration of the pilot unit

### 2.2 Experimental location and setting up

Sludge properties change drastically throughout treatment; raw sludge is an organic-rich, wet semi-solid containing pollutants, while stabilized sludge after treatment is a less watery, more manageable material, but still contains nutrients and solids. Properties before treatment (primary and secondary sludge) are characterized by high moisture, organic content, and potential pathogens. During treatment, sludge becomes thicker, and organic matter is reduced through thickening, digestion, and dewatering, resulting in a denser, more stable product with reduced volume and pathogens. This study was conducted in the lab as the whole system is a pilot study. The sample used for the whole system are synthetic wastewater made from concentrated solutions which was diluted using a distilled water at the ratio of 1:60 and a sludge which was picked from Hogsmill and Beddington sewage treatment works located in Beddington and Lower Marsh Lane, London-United Kingdom. After the whole system

set up was completed, the sludge collected was fed with the synthetic wastewater and was left for 72 hours Hydraulic Retention Time (HRT).

### 2.3 Experimental cycle using the initial configuration

After 72 hours of HRT, the experiment cycle starts the peristaltic pump should run from both tanks to the permeate containers for 15 minutes in order to withdraw treated samples and measure their parameters, then compare them together such as, Flux, MLSS, DO, COD, and Nitrate. The volume of permeate and the running time are used to measure the volume flow rate which is vital to calculate the permeate flux. After that both the aerator and the mixing paddle in the bioreactor tank are turned off for 3-5 minutes to allow the sludge to settle, then only 3 litres of the liquid on top is drained to the membrane unit after draining 3 litres from it as well to waste. The bioreactor tank is then topped up with 3 litres of synthetic wastewater to keep the Food-to-Microorganism (F:M) ratio balanced. Finally, the aerator and the mixing paddle are turned on again and the unit is left for running another 48 hours as HRT, then the cycle is repeated.



Figure 2: experimental set-out of the submerged membrane reactor system and how the system works

### 2.4 Experimental cycle using the modified configuration.

A simple modification has been applied to enhance the efficiency of the configuration of this unit by removing membrane unit tank and avoiding the settling stage, which consumed time and space. The main reason behind this modification is that after comparing between both tanks in the initial protocol it was noticed that the results of permeates for both tanks were almost the same for the first 10 days. This goes with a research conducted by Li et al. (2023) that concludes that in many MBR-like systems, early-stage performance over the first ~10 days was found to be unstable or similar across variants before longer-term differences emerged.

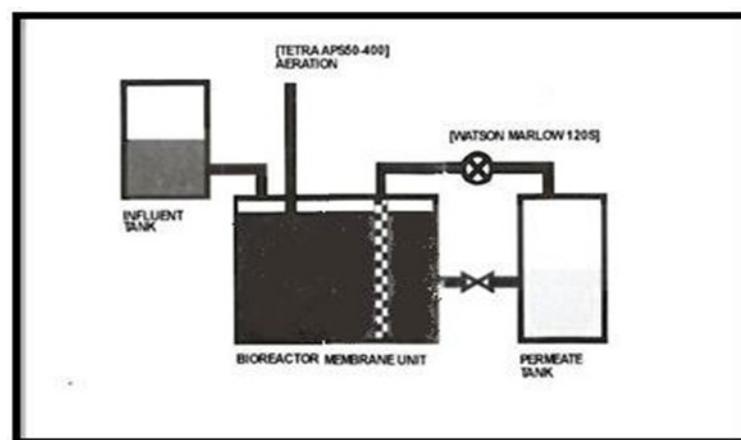


Figure 3: shows the modified configuration of the pilot unit

Another study conducted by Nguyen et al. 2013 for municipal wastewater treatment observed that removing the membrane unit tank and settling stage gave almost the same permeate results as the original setup for the first 10 days. The experiment cycle in this configuration also starts by running the peristaltic pump from the bioreactor tank to the permeate container for 15 minutes in order to withdraw treated samples and measure its parameters. After that three liters (3) of the bioreactor tank is drained to waste, then it is topped up with 3 liters of synthetic wastewater to keep the F:M ratio balanced. Finally, the unit is left for running another 48 hours as HRT, and then the cycle is repeated.

**2.5 Analytical Measurements**

Effluents collected from both the initial configuration and the modified configuration of the pilot units were tested. The parameters measured include; flux, MLSS, DO, COD, Nitrate, temperature, pH, turbidity, microbiological activities and phosphate. All these are measured in order to compare or to determine the changes in parameters between the water in the activated sludge, membrane unit tank and permeate. Measurements were performed as defined in standard methods [17]. COD as now recognized as the most important parameter to measure in both natural and engineered systems, is given more consideration in this study. In the COD test, the organic matter in the sample is oxidized to CO<sub>2</sub> and H<sub>2</sub>O by potassium dichromate in boiling concentrated sulphuric acid (150°C) and in the presence of a silver catalyst. In this study, COD measurements were performed as described by ISO 6060 [19,20]. The microbiological test were conducted using an Oxfam DelAgua (Marlborough, United State) water testing kit and manual, to test the presence of coliforms in the permeate water as it indicated water pollution [1].

**3.0 Results and Discussion**

**3.1 Flux Measurement**

Measuring the flux in this system is of paramount importance in order to determine the performance of the membrane. Reduction in flux is usually caused by the action of fouling of the membrane and sometimes due to technicality problem in the system. To bring this problem to an end, air scouring which is one of the best methods of reducing fouling problem in membrane treatments was used with the aid of some aeration stones installed below the membrane.

Table 1: shows different flux output between membrane

Test	Permeate 1 (L/h/m <sup>2</sup> )	Permeate 2 (L/h/m <sup>2</sup> )
1	9.82	9.82
2	9.82	9.82
3	9.82	9.82
4	9.82	9.82
5	9.82	9.82
6	9.82	9.82
7	9.82	9.82
8	9.82	9.82
9	9.82	9.82
10	9.82	9.82
11	9.82	9.82
12	9.82	9.82
13	9.82	9.82
14	9.82	9.82
15	9.82	9.82
16	9.82	9.82
17	9.82	9.60
18	9.82	9.60
19	9.82	9.60
20	9.82	9.60

The result from this study shows how the flux is being constant (9.82 L/h/m<sup>2</sup>) in all of the 16 cycles of the experiment which lasted for a month time. While the small reduction seen towards the last 4 number of tests in the second permeate was caused by the effect of fouling in the membrane. The result shows an effective scouring system used in the study as a result of excellent positioning of the aeration system. However, a small reduction was noticed towards the end of the experiment, which is caused by a minor fouling activity.

### 3.2 pH

To ensure the safety of the treatment system and that of the operators, the pH of the wastewater had to be tested as one of the main parameters. This is because water with extremely high or low pH values can be deadly to humans and corrosive to membranes and several other infrastructures in water treatment systems. In this study, the tank used, permeate container and membrane were all made of durable materials that can handle moderately high and low pH's values.

Table 2: showing the result of the pH stability throughout the process

Test	Activated sludge	Permeate 1	Permeate 2	Membrane unit
1	7.2	7.0	7.0	7.0
2	7.4	7.2	7.5	7.0
3	7.0	7.0	7.3	7.5
4	7.5	7.5	7.0	7.4
5	7.3	7.0	7.3	7.2
6	7.4	7.1	7.0	7.0
7	7.1	7.3	7.1	7.1
8	7.5	7.0	7.1	7.1

The result shown in table 2 above, level of the pH throughout the process was in the neutral zone of the scale (7.0-7.5). This observation confirms that the pH was reasonably stable throughout the process.

### 3.2 Turbidity is Proportional to MLSS

Turbidity is measured using Hach2100Q turbidity meter. This is use to determine the quality of water and wastewater as well as the efficiency of the membrane when it is used in a study. Turbidity also serve as a measure to ensure the absence of suspended solids, algae, microbes, and other substances that cannot be seen by the naked eye in the final permeate. In this study, the turbidity of the activated sludge was not measured due to high MLSS content in the tank, and when measured it exceed the maximum limit of the turbidity meter (>1000NTU).

Table 3: shows how turbidity is proportional to MLSS in over the study period.

Test	Membrane Unit (NTU)	Permeate1 (NTU)	Permeate 2 (NTU)
1	44	3.2	5.3
2	56	4.0	4.6
3	70	5.0	3.5
4	38	3.0	2.1
5	64	4.1	2.5
6	35	3.3	3.0
7	40	4.2	2.6
8	62	2.4	2.4

From Table 3, the result shows how low the turbidity in the membrane tank is ranging from 38 to 70NTU. Comparing this result with that of the activated sludge, it can be seen that there exists a separation of most of the solids when the sludge is settled before it is drained to the membrane unit tank. Moreover, pumping out the water through the membrane resulted in a significant reduction in the turbidity (up to 99.9% reduction). This is also as a result membrane action in the system as well as coagulation and sedimentation processes. Some results from the permeates (2.4 - 5.3NTU) were much lower than the target turbidity of 5.0NTU, which is the standard value set by WHO for drinking water [11].

### 3.3 Dissolved Oxygen (DO) is Inversely Proportional to MLSS

Dissolved oxygen (DO) is a measure of the amount of available oxygen in any water or wastewater. In water or wastewater, nothing is more important than oxygen amount for organic communities and microorganisms. DO in water bodies are usually temperature dependent, with colder water having much more oxygen. However, in wastewater treatment plants, this depends on the actions of microorganisms present in water. In activated sludge treatment plants, air or pure oxygen are usually pumped into the system (aeration tank) and mixed with the sludge to suspend microorganisms present in the wastewater. This is done to ensure microorganisms are receiving enough oxygen and to maintain 2 mg/L or more of DO level in the system.

Table 4: shows how DO values increased when MLSS values decreased during the study period

Test	Activated sludge(mg/L)	Membrane unit(mg/L)	Permeate 1(mg/L)	Permeate 2 (mg/L)
1	0.2	5.0	8.0	8.0
2	1.3	5.3	8.1	8.4
3	1.9	6.0	8.5	8.5
4	2.4	6.0	8.6	8.5
5	3.0	6.1	8.4	8.5
6	3.7	6.4	8.7	8.6
7	3.9	6.8	8.9	8.8
8	4.0	7.0	9.0	9.0

The table above, shows the result of how DO level in the activated sludge was low ranging from 0.2 - 4.0 mg/L, due to high concentration of microorganisms in the activated sludge tank. Increase in the DO level was achieved as a result of a continuous aeration system installed in the tank as well as the change in F:M by increasing the feed of the synthetic wastewater. Moreover, the result from the table above clearly shows decrease in the DO level in the membrane unit (5.0 - 7.0 mg/L) as well as that of the permeate (8.0 - 9.0 mg/L). This result explained the separation action of most solids when sludge is settled before it is drained to the membrane unit tank, meaning that fewer microorganisms are consuming the DO in the water. The DO level of all permeates were moderately high and compatible with the WHO standards.

### 3.4 COD is Proportional to MLSS

The Chemical Oxygen Demand (COD) is one of the indexes used in finding out the organic concentrations in water and wastewater (Diaz et.al, 2011). This was tested to indirectly measure the amount of oxygen required by chemical agents to degrade both the organic and inorganic matter present in the activated sludge in order to ensure the absence of organic and inorganic pollutants in the permeate. Different kits were used for the measurement of the COD, LCK014 1000 – 10,000 mg/L (activated sludge), LCK514 100 – 2000 mg/L (membrane unit tank) and LCI500 0-150 mg/L (permeates). An aeration tank was also use in order to reduce the COD concentration in the activated sludge.

Table 5: shows how the reduction in COD levels is affected by the change in F:M ratio

Test	Activated sludge(mg/L)	Membrane unit(mg/L)	Permeate1(mg/L)	Permeate 2(mg/L)
1	11976	234	92	84
2	9486	211	81	69
3	8016	189	76	52
4	7940	184	52	41
5	6580	179	49	29
6	5190	174	31	21
7	4970	172	23	14
8	4627	170	11	9

From Table 5, the result shows an extreme reduction in COD in the activated sludge from 11976 mg/L to 4627 mg/L. this reduction occurs due to reliance of the system on the aerators and DO provided to the tank. Moreover, it is clear from table 2 above how low is the DO in the membrane unit tank (ranging 170 - 234 mg/L) in comparison to the activated sludge which can simply be explained by the separation of most of the solids when the sludge is settled before it is drained to the membrane unit tank meaning that less microorganisms are demanding the DO and other chemicals in the water. On the other hand, that of the permeate 1 and 2 were in the range between 9 – 92 mg/L showing 99 % reduction in COD.

### 3.5 Nitrate Inversely Proportional to MLSS

The nitrate concentration was tested in both the influent and effluent wastewater samples; this is done in order to prevent the system from excessive algal growth. These microorganisms deplete oxygen, which result in harmful unhealthy water with a disturbing smell. In this study, two different nitrate testing kits were used; LCK339 5-35mg/L for activated sludge and membrane unit and LCK339 0.23-13.5mg/L for permeates (effluents). The results of the testing were shown in the table below;

Table 6: shows how nitrate is inversely proportional to MLSS.

Test	Activated sludge	Membrane unit	Permeate 1	Permeate 2
1	28	20	10	12
2	33	25	12	10
3	38	30	14	13
4	44	35	15	15
5	41	37	13	14
6	42	35	12	10
7	39	34	10	12
8	36	34	11	11

### 3.6 Monitoring the F:M Ratio

Monitoring the F:M ratio was used in order to ensure that there is a balance between the food (COD) entering into the system and the microorganisms in the aeration basin of the system. In this research, a modified equation by Geilvoet, 2009 was used [8]:

$$\frac{F}{M} = \frac{\text{Food}}{\text{microorganisms}} \quad (1)$$

$$= \frac{[\text{COD}(\frac{\text{mg}}{\text{L}})] \times [Q(\frac{\text{mg}}{\text{L}})]}{[\text{MLSS}(\frac{\text{mg}}{\text{L}})] \times [V(L)]} \quad (2)$$

The F:M ratio results were being calculated using the above formula on daily basis, and was modified accordingly. The F:M ratio standard is given in the range between 0.15 - 0.70 for an activated sludge.

Table 7: showing the variations in F:M values in the AS Tank over the study period.

Test	COD (mg/L)	Water flow(L/hr)	MLSS (mg/L)	AS Tank volume(m <sup>3</sup> )	F:M Ratio
1	11976	1.09	4098	24	0.133
2	9521	1.09	3059	25	0.136
3	8125	1.09	2373	26	0.144
4	7937	1.9	2026	26	0.174
5	7641	1.09	1768	26	0.191
6	7254	1.09	1653	26	0.194
7	6896	1.09	1618	26	0.189
8	6614	1.09	1567	26	0.187
9	6412	1.09	1524	26	0.186
10	6269	1.09	1583	26	0.176
11	6083	1.09	1524	26	0.177
12	5842	1.09	1398	26	0.185
13	5628	1.09	1334	26	0.187
14	5475	1.09	1282	26	0.189
15	5297	1.09	1243	26	0.189
16	5136	1.09	1197	26	0.190
17	4983	1.06	1137	26	0.189
18	4761	1.06	1102	26	0.186
19	4643	1.06	1073	26	0.186
20	4572	1.06	1046	26	0.188

For the first cycle, the F:M ratio was seen to be lower than the recommended minimum value for an activated sludge (0.133). Additional volume of synthetic wastewater was added to the feeding batch in the second and third cycle (1 Liter and 2 liters respectively) until the F:M ratio pass the minimum required value of 0.15. This in turn changes the final volume of the wastewater in the aeration tank to 26 liters, while the F:M ratio remained in the adequate range throughout the research.

### 3.7 Comparing the Quality of Kubota Flat Sheet with the Jordan Standards

After completing all the tests and collection of all data and results, a comparison was made in order to compare the quality of the Kubota flat sheet permeate to the Jordan standards. As shown in the summary table below, all results were adequate and met the required standards (for agricultural reuse) except for the TSS where the results are higher than the required. This could be due to a fault of the analyzer sensor.

Table 8: shows a comparison produced between the quality of Kubota flat sheet permeate to the Jordan Standards (JS: 893/2002) for discharge to streams

Test	Jordanian standards	Kuwait	Activated sludge	Membrane unit	Permeate1	Permeate 2
Flux (L/h/m <sup>2</sup> )	-	-	-	-	9.77	9.91
pH	6.0-9.0	6.5-8.5	7.24	7.26	7.24	7.25
Turbidity (NTU)	5	-	-	51.16	3.54	3.58
DO(mg/L)	>2	>2	2.27	8.69	6.07	8.61
TSS (mg/L)	50	15	1685.25	321.38	149.65	243.5
Nitrate (mg/L)	30	-	39.88	31.31	13.75	12.70
COD (mg/L)	100	100	6621.00	187.25	35.50	36.50
Coliform per 100ml	1000		>1000	75	0	0

### 4.0 Conclusion

The importance of wastewater treatment for public health and environmental safety necessitates investigating the practicality and the effectiveness of the modified water treatment plants. In this study as a pilot case, KOBUTA membrane system which is one step intensified treatment and infiltration system was used. This system uses a flat thin-film composite membrane to accomplish the study aim. The result of the study how both influent and effluent wastewater going in and coming out of the system are chemically and biologically good and free from pollutants. The system monitors all parameters and concentrations in influent and effluent water quality like COD, BOD, TSS and asses flux of the performing membrane. The experimental result also satisfies the critical issues of wastewater discharges and reuse and also comply with both Jordanian and Kuwait standard as shown in table 8 above. This study also gives the internal experience of designing, fabricating and operating a wastewater treatment plant.

### References

- [1] H. Gökçekuş, M. Nuhu, P. Paul, D. Orhon. (2019), Experimental basis of an emergency filtration system treating river flood water for rural areas in developing countries, 152 133–138. <https://doi.org/10.5004/dwt.2019.23982>.
- [2] SDG, S. Report, Sustainable Development Goal 6 Synthesis Report on Water and Sanitation 2018, 2018.
- [3] D. Chapman, Water Quality Assessments. (2013) - A Guide to Use of Biota , Sediments and Water in Environmental Monitoring - Second Edition Chapter 1 \* - AN INTRODUCTION TO WATER QUALITY, <https://doi.org/10.4324/9780203476710>.
- [4] A. Said, D.K. Stevens. (2004) An Innovative Index for Evaluating Water Quality in Streams, 34 406–414. <https://doi.org/10.1007/s00267-004-0210-y>.
- [5] Wastewater treatment: an overview. (2018) Green Adsorbents for Pollutant Removal, 18, Springer Nature, pp.1-22, , Environmental Chemistry for a Sustainable World, 978-3-319-92111-2. [ff10.1007/978-3-319-92111-2\\_1](https://doi.org/10.1007/978-3-319-92111-2_1)
- [6] C. Wisniewski, Membrane bioreactor for water reuse, (2017). <https://doi.org/10.1016/j.desal.2006.05.002>.
- [7] J.H.Tay. O. T. Iorhemen, R. A. Hamza, (2016). Membrane bioreactor (Mbr) technology for wastewater treatment and reclamation: Membrane fouling, Membr. (Basel),. 6(2) 13–16.
- [8] J. Hoinkis, S.A. Deowan, V. Panten, A. Figoli, R. Rong, (2012). Procedia Engineering Membrane Bioreactor (MBR) Technology – a Promising Approach for Industrial Water Reuse, 00 1–8. <https://doi.org/10.1016/j.proeng.2012.01.1199>.
- [9] V. Der Graaf, The European MBR tour of the Delft Filtration Characterization method The European MBR tour of the Delft Filtration Characterisation method, (2009).
- [10] Nguyen, T. T., Ngo, H. H., Guo, W., Chang, S. W., Nguyen, D. D., & Bui, X. T. (2013). *Pilot scale study on a new membrane bioreactor hybrid for municipal wastewater treatment*. Bioresource Technology, 141, 8–12. DOI: 10.1016/j.biortech.2013.02.025

- [11] WHO (2006). *Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture.* World Health Organization, Geneva.
- [12] WHO (2018). *Guidelines for drinking-water quality, 4th edition incorporating the 1st addendum.* World Health Organization, Geneva. ISBN: 9789241549950