

Membrane Bioreactors Used for Treatment of Food Industry Effluents

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Abstract. Effluents from the food industry determine pollution problems due to high COD and BOD concentrations. Compared to other industrial divisions, food industry requires large amounts of water. In this study, MBR was based on submerged hollow fibers membranes functioning by low vacuum. Two phases of bioreactor treatment were carried out with different HRTs (2-8) and (2-24) hours. Sixteen water samples collected from the influent and the effluent of the bioreactor during the two phases. NaOCl compound was added during the backwashing process for all tests, and the same compound was added with mixed liquid for the second test at period 24 hour of aeration. The samples were tested for twelve water quality tests: temperature, Dissolved Oxygen, pH, Turbidity, Total Suspended Solids, Mixed Liquor Suspended Solids, Chemical Oxygen Demand, Biochemical Oxygen Demand, Nitrate Nitrogen, Ammonium Nitrogen, Total Phosphate, and Ortho Phosphate. The results indicated that the bioreactor system can be used efficiently to treat industrial wastewater from the food industry. The efficiency of the technology was evaluated with sodium hypochlorite addition to removing the adherent bacteria on the surface area of hollow fibers. The results showed that the bioreactor under the conditions of the second phase was excellent in removing Turbidity, TSS, COD, and BOD₅ with a removal efficiency 99.96%, 89.52%, 93.56%, and 99.36% respectively, when added 82 ml of NaOCl in the bioreactor tank, and was a good removing of TP, and Ortho-P with removal efficiency 60.76% and 48.95% respectively. Otherwise, a negative effect of NaOCl on both of NO₃-N and NH₄-N was obtained in term of removal where the minimum removal efficiency was observed when adding 82 ml of NaOCl under the conditions of the second phase.

Keywords: MBR, Food Industry, NaOCl, Activated sludge.

1. Introduction

Most countries suffer from water shortage and poor quality due to population growth, climate variability, and human activity, which leads to a food gap and decreasing of water resources. The situation is worsening by the pollution of freshwater resources, due to the discharge of untreated industrial and municipal wastewater into freshwater sources, thus constituting the main source of water pollution [1]. Industrial wastewater varies in the flow and pollution strength. The industrial wastewaters contain suspended, colloidal and dissolved (mineral and organic) solids. The wastewater may contain inert, organic or toxic materials and possibly pathogenic bacteria. The wastes may be drained to the sewer system provided if not have a noxious effect on treatment efficiency on the sewer system. Full treatment is necessary when the waste is discharged directly into surface or groundwater [2]. The membrane bioreactor, MBR is one of the leading technologies currently used in countries around the world for water reuse. Because of advances in technology and declining costs, MBR technology application for water reuse has increased

sharply over the past few years [3]. MBR systems have been used to treat wastewater as a potential technique, especially for industrial wastewater treatment. MBR is an alternative biological treatment method associated with the conventional activated sludge process with its smaller footprint, less sludge production, and ability to operate under the production of high-quality effluent, [4]. The basic parameters for industrial wastewater characteristics include chemical oxygen demand, COD, biochemical oxygen demand BOD₅, suspended solids, SS, ammonium nitrogen, NH₄-N, pH, turbidity, and Dissolved Oxygen, DO. Food industry wastewater is considered industrial wastewater which contains residues that consume the oxygen in receiving streams. Oxygen demand and nitrogenous pollutants in wastewater are a potential threat to the aquatic environment and hence to public health. The oxygen demand and ammonium nitrogen NH₄-N can result in dissolved oxygen DO consumption of the received water body [5]. The most important criteria used for food industry wastewater to determine the quality of water are chemical oxygen demand, COD, and biochemical oxygen demand, BOD₅. These parameters are important to evaluate the efficiency of wastewater treatment. Hollow fiber ultrafiltration UF membranes are

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flexibility during water treatment and can be used in a number of configuration processes to meet advanced effluent treatment objectives. These membranes used for removal of particular and colloidal contaminants. Also, can be combined with biological or chemical treatment to dispose of dissolved pollutants. In this paper, the analytical results obtained during the experimental tests for wastewater treatment of the food industries in a meat processing plant in Romania will be presented using the activated sludge method with MBR system type ZW-10 producing from Zenon® (General Electric) Company.

2. Materials and Methods

Figure 1, shows the schematic diagram of a hollow fiber MBR system used in this study. The membrane module ZW-10 is a polyethylene hollow fiber manufactured by Zenon-General Electric with an OCP chemistry, with a pore size of 0.036 μm and total active area is 0.93 m². The pilot plant used during the experiments was made available by the company Zenon KFT Hungary. This pilot plant is located in the hydraulic laboratory of the Technical University of Civil Engineering in Bucharest UTCB, Romania. This membrane module is a unique outside-in hollow fiber module that operates under a low vacuum instead of high pressure [6]. The membrane is installed in 26 liters volume of bioreactor plastic tank with dimensions of 18×18×80 cm. The aeration of the activated sludge was performed by fine air bubble diffusers.

A Verder gear pump located in the center of the MBR system was used to create a negative suction head at the membrane module to sustain the permeate stream flow rate. This pump permits for the reversal of the flow in the

pump according to the power requirements, to ensure reverse supply role in the backwashing process of the membranes. The bioreactor was operated in two phases, (RI, RII), with different hydraulic retention times “HRT”. Industrial wastewater provided by food industry factory of meat processing was used as a sample of wastewater in this study. The conventional aeration method for activated sludge was used by two phases. The first phase, RI was conducted in 09-Nov.-2017, while the second phase, RII, was conducted in 29-Nov.-2017. The HRTs were selected to be 2, 4, and 8 hours for RI, and 2, 4, 8, and 24 hours for RII respectively with the adding 6 ml of NaOCl compound during backwashing process, also, 82 ml of NaOCl at HRT 24 hours in RII was added in the bioreactor tank with mixed liquor.

The sludge activation process is the first step that was implemented before the operation of the bioreactor system to treat the wastewater samples. In the first phase, 550 liters of industrial wastewater sample was pumped into the storage tank with 20 liters of the mixed liquid of activated sludge at concentration 3.542 gr/l. While 1000 liters of the raw wastewater taken from the same source was pumped into the storage tank with 40 liters of the mixed liquid of activated sludge at concentration 3.234 gr/l to sludge activation purpose in the second phase as a pre-treatment process. 13 l/h of the air flow rate was pumped continuously by using 4 air dispensers during the aeration process of the experiment. The recycling pump was operated in the storage tank to ensure the mixing between the sludge and the wastewater sample and activate all aerobic bacteria.

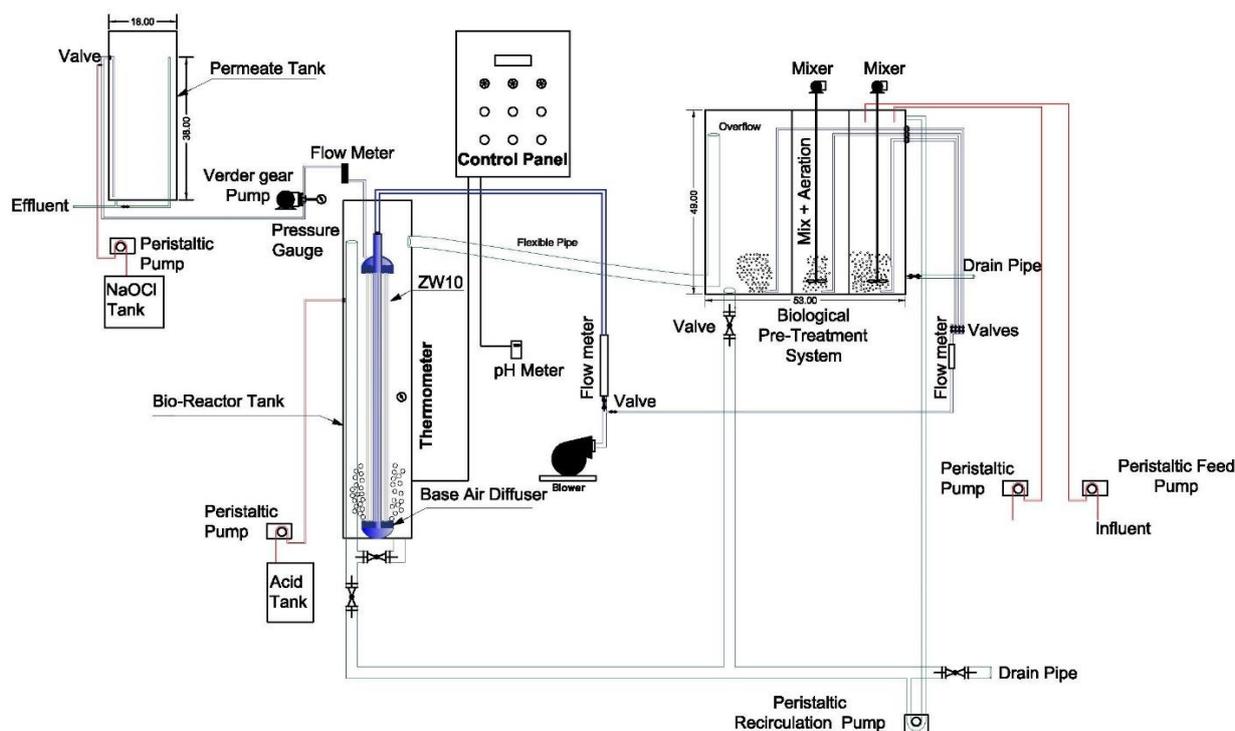


Fig. 1. Schematic diagram of pilot plant for MBR system used in this study.

During the aeration process, the liquid mixture was pumped from the storage tank to the activated sludge tank of the pilot plant by using two peristaltic pumps with flow rate 32.31 and 28.31 l/h, then to the bioreactor tank by overflow pipe fixed inside the activated sludge tank. The aeration process was carried out in the activated sludge tank using 3 diffusers at air flow rate 6 l/min, whereas, the air in the bioreactor was pumped from the base of the membrane at flow rate 50 l/min to prevent the adhesion of sludge around the surface area of the membrane. Six milliliters of the sodium hypochlorite "NaOCl" was added during the backwashing process by used a peristaltic pump with flow rate 6 ml/min distributed by 3 ml per 30 seconds, while 82 ml of NaOCl was added by another peristaltic pump to the bioreactor tank with the mixed liquid at HRT 24 hours during RII at a flow rate of 4.1 ml/min. The treatment process and backwash process were programmed at time 600 sec, and 30 sec respectively.

3. Water Quality Parameters and Sampling Tests

During each run in the bioreactor system, a number of water quality parameters were tested to examine the influent and effluent physical, and biochemical properties.

These parameters are DO, pH, Temperature, Turbidity, TSS, MLSS, BOD₅, COD, NO₃-N, NH₄-N, TP, and OP. Sixteen samples were collected to analyze physical and biochemical tests. The samples were taken from the storage tank, activated sludge tank, and effluent tank. Regarding the first phase "RI", seven samples were taken with 2, 4, and 8 hours of aeration time, the first sample was taken from the raw wastewater at reached to the laboratory in 09-Nov.-2017, at 9:45 am. While, nine samples were taken on the second phase" RII" with 2, 4, 8, and 24 hours of aeration time and the first sample was taken from the raw wastewater at reached to the laboratory in 29-Nov.-2017, at 10:45 am. These times were selected in the treatment process to determine the BOD removal efficiency, COD removal efficiency, and suspended solids removal efficiency, as well as determine the effect of the chemical compound represented by NaOCl on the treatment efficiency. The DO, pH, and temperature were measured on-site before sampling.

4. Results and Discussions

The collected samples were tested for twelve of physical and biochemical tests. The biochemical tests were analyzed in the chemical laboratory of UTCB, which consists of mixed liquor suspended solids, MLSS, total suspended solids, TSS, biochemical oxygen demand, BOD₅ chemical oxygen demand, COD, nitrate nitrogen, NO₃-N ammonium nitrogen, NH₄-N, total phosphate, TP, and orthophosphate, Ortho-P, whereas, the physical tests were carried out on the site which consists of dissolved oxygen DO, pH, and temperature.

The codes of influent and effluent samples were I1, E1, I2, and E2 during RI and RII runs respectively. Analysis of these results is presented in the following subsections.

4.1. Temperature

The temperature of the wastewater samples for RI varied between 19 and 20.5°C with gradual increasing during the operating time as shown in figure 2. The maximum and minimum temperature of I1 was found, 20.3°C and 19.7°C, respectively, whereas, the maximum and the minimum of E1 was found 20.5°C and 19.9°C respectively. Regarding RII, the temperature of the wastewater samples varied between 16.8 and 18.3°C with gradual increasing during the operating time except at time 24 h, where it was decreased as shown in figure 3. The maximum and minimum temperature of I2 was found, 17.4°C and 17°C, respectively, whereas, the maximum and the minimum of E2 was found 18.3°C and 17.5°C respectively. The temperature during RI was slightly higher than RII, this may have been due to the variation of weather conditions. The effluent temperatures were in general higher than the influent, due to the biochemical processes of microorganisms in the bioreactor.

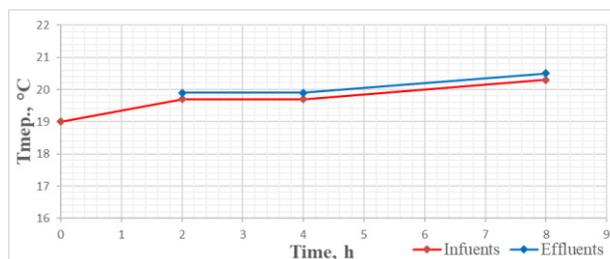


Fig. 2. Variations of the temperature in RI.

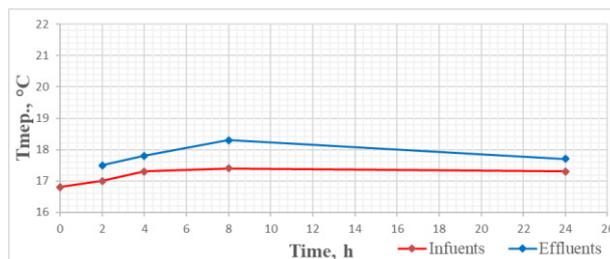


Fig. 3. Variations of the temperature in RII.

4.2. Dissolved Oxygen, DO

The dissolved oxygen concentrations of the wastewater samples during RI varied between 0.04 and 4.98 mg/l as shown in figure 4.

The maximum and minimum DO of I1 was 1.48 and 0.45 mg/l respectively, whereas, the maximum and minimum of E1 were found 4.98 and 2.14 mg/l respectively. All DO concentrations in influents during RII run were found to be close to zero. Generally, the DO concentrations during RII run varied between 0.09 and 8.4 mg/l with low concentrations in the influents, as shown in

figure 5. The maximum and minimum of E2 were found 8.4 and 5.64 mg/l respectively.

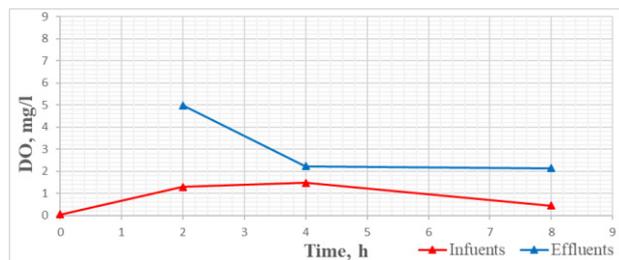


Fig. 4. Variations of the DO in the RI.

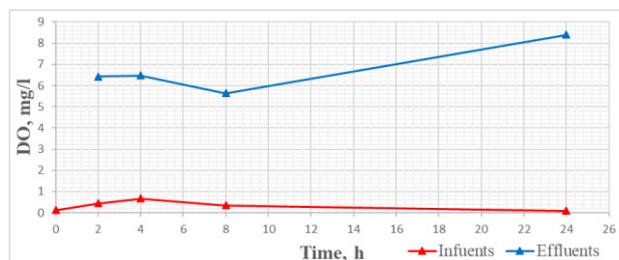


Fig. 5. Variations of the DO in the RII.

The low value of DO at I2 may refer to the Oxygen depletion in the pretreatment process represented (during sludge activation) by the microorganisms for growth and organic biodegradation comparing with short to long HRTs.

4.3. pH

The variation values of pH during RI and RII runs are shown in figures 6 and 7 respectively. All the influent values of pH were higher than 7 except the raw wastewater, where was less than 7.

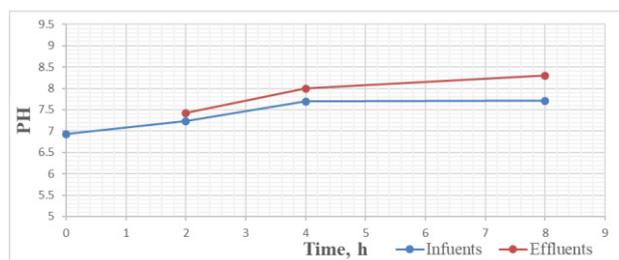


Fig. 6. Variations of the pH in the RI.

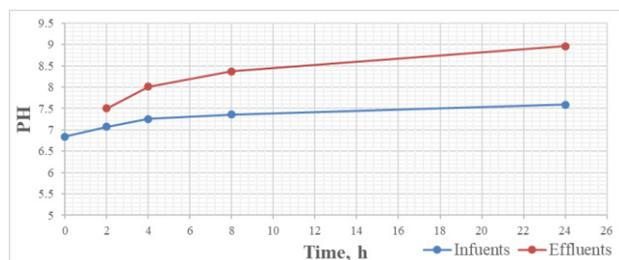


Fig. 7. Variations of the pH in the RII.

The average, maximum, and minimum pH value of I1 was 7.54, 7.71, and 7.23, respectively, while the average, maximum, and minimum pH value of I2 was 7.32, 7.59, and 7.07, respectively. The pH values of the effluents

during the tests RI and RII were higher than that of the influents, because of NaOCl effect in the bioreactor and indicate an alkaline solution. The average pH values of E1 and E2 were found 7.91 and 8.21 respectively.

4.4. Turbidity

The tested values of the turbidity during RI runs are shown in figure 8. The turbidity concentration of raw wastewater was 205 NTU and, the average, maximum, and minimum value of I1 was 271, 305, and 217 NTU respectively, whereas the average, maximum, and minimum value of E1 was 1.11, 1.51, and 0.37 NTU respectively.

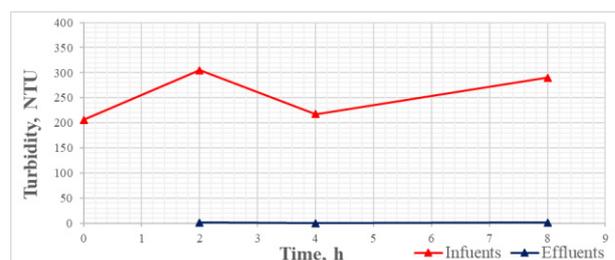


Fig. 8. Variations of the turbidity in the RI.

Figure 9 shows the values tested of turbidity concentration during RII runs. The turbidity value of raw wastewater was 250 NTU and the average, maximum, and minimum value of I2 was 310, 346, and 292 NTU respectively, whereas the average, maximum, and minimum value of E2 was 2.28, 4.35, and 0.1 NTU respectively. The membrane filter showed an excellent turbidity removal, where the removal of turbidity during all tests carried out varied between 99.27% and 99.82% for RI runs and 99.02% and 99.96% for RII runs. In general, all the turbidity of effluents during RI and RII runs were much less than that of the influents, this indicates that the membrane filter was very efficient in retaining solids.

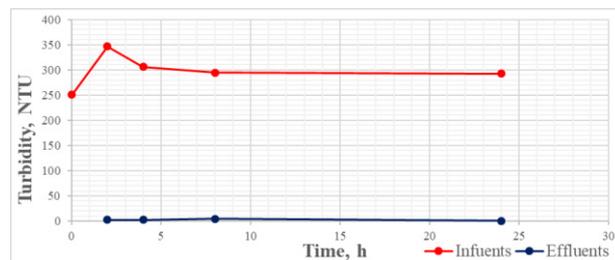


Fig. 9. Variations of the turbidity in the RII.

4.5. Total Suspended Solids, TSS

The results of tested values for total suspended solids during the RI and RII runs was shown in figures 10 and 11. The results obtained from these tests are the raw wastewater and effluents. On the first test, the TSS value of raw wastewater sample was 522 mg/l, and the average, maximum, and minimum value during E1 runs was 121, 132, and 112 mg/l respectively. The removal of TSS during all tests performed in RI runs varied between

74.71% and 78.54%. The results of tested values for TSS during the RII runs are shown in figure 11. The TSS value of raw wastewater sample was 744 mg/l, and the average, maximum, and minimum value during E2 runs was 164, 242, and 78 mg/l respectively. The removal of TSS during all of RII runs varied between 67.47% and 89.52%.

Total suspended solids are greatly related to the turbidity. Generally, the results obtained showed, the highest removal efficiency of TSS achieved when adding of NaOCl amount, where it reached 89.52%.

4.6. Mixed Liquor Suspended Solids

The results of mixed liquor suspended solids "MLSS" tested that were taken from influents during the RI and RII runs were shown in figures 10 and 11. The average, maximum, and minimum value of MLSS during the I1 was 586, 672, and 452 mg/l respectively, whereas, the average, maximum, and minimum value during the I2 was 932, 1046, 868 mg/l respectively. The results obtained are shown that decreased of MLSS concentrations with the time during aeration process, that means the decline of the number of microorganisms represented by sludge due to the consumption of organic matter in the wastewater.

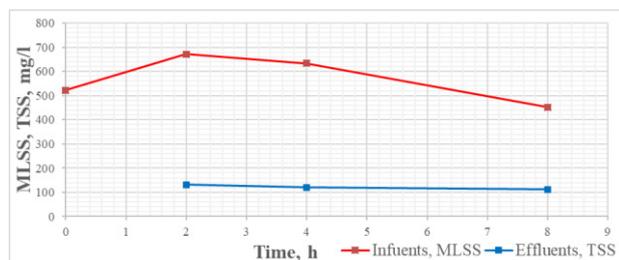


Fig.10. Variations of the MLSS and TSS in RI run.

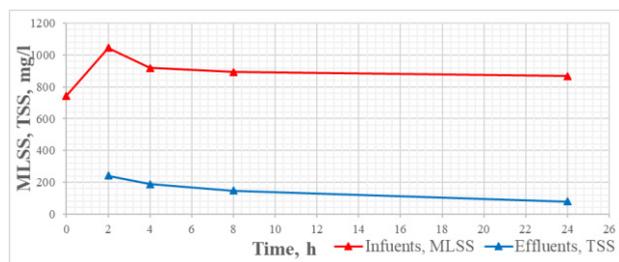


Fig.11. Variations of the MLSS and TSS in RII run.

4.7. Biochemical Oxygen Demand, BOD₅

The tested values of BOD₅ during RI and RII runs are shown in figures 12 and 13, respectively. The tested values of BOD₅ of both influents, I1 and I2, depended on the incoming organic load in the sample of raw wastewater, where in the RI was found 1442 mg/l, and in the RII was 1864 mg/l. The BOD₅ values of influents fluctuated between 1398 and 946 mg/l during RI runs, and between 1808 and 1483 mg/l during RII runs respectively. Also, the BOD₅ values of the effluent during RI runs decreased gradually and reached to 340 mg/l. Whereas for RII runs, the BOD₅ of the effluents has been significantly decreased and reached to 12 mg/l after 24 hours of aeration due to the effect of NaOCl compound. The

removal efficiency of BOD₅ during the RI runs varied between 70.87% to 76.42%, whereas, the removal efficiency during RII runs varied between 69.96% to 99.36% respectively. The fourth test during RII showed the highest removal efficiency, due to the addition 82 ml of NaOCl into the bioreactor tank with the mixed liquor during bioreactor process. The difference in removal between RI and RII runs due to the temperature, organic load, and NaOCl addition. The temperature represents an effective factor in the solute extraction because it has a strong influence on the bioreactor reaction rate, [7].

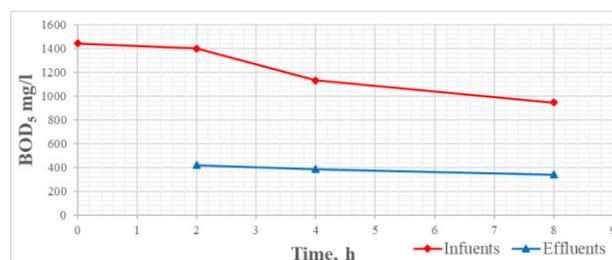


Fig. 12. Variations of the BOD₅ in RI run.

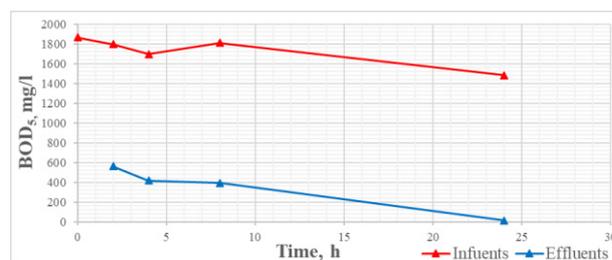


Fig. 13. Variations of the BOD₅ in RII run.

4.8. Chemical Oxygen Demand, COD

The tested values of the COD during RI and RII runs are shown in figures 14 and 15 respectively. The COD tested values of both raw wastewater samples in RI and RII runs were found 2458 and 2534 mg/l respectively. The average, maximum, and minimum COD concentration of I1 were 1830, 2227, and 1421 mg/l respectively, whereas, the average, maximum, and minimum COD concentration of I2 were 2256, 2458, and 2112 mg/l, respectively.

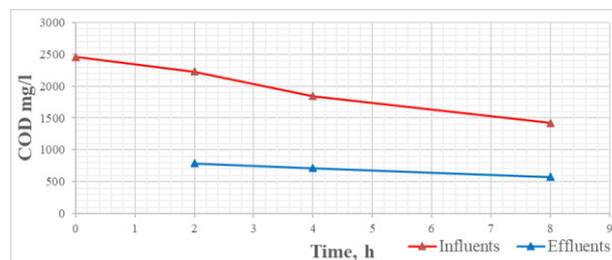


Fig. 14. Variations of the COD in the RI run.

Regarding effluents test, the values of COD during RI runs was decrease gradually to reached 576 mg/l with the average concentration 691 mg/l, whereas, the COD of the effluent E2 during RII runs has been significantly decreased to reached 163 mg/l at HRT 24 hours due to the effect of NaOCl, with the average concentration 598 mg/l. Most of removed COD was due to BOD removal and most

of the remained part is for the biologically was degradable of organic matter. The removal efficiency of COD during RI runs varied between 67.97% and 76.56%, while the removal efficiency during RII runs varied between 65.53% and 93.56%, respectively.

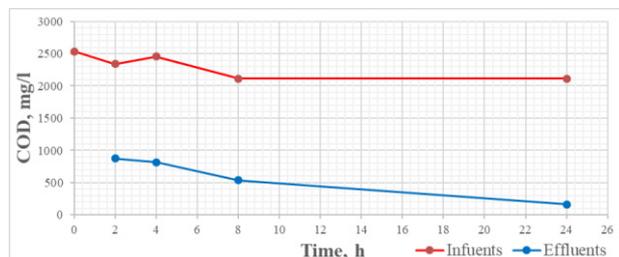


Fig. 15. Variations of the COD in RII run.

The results show a reduction in COD values when 82 ml of NaOCl was added in the fourth test during RII runs, thus achieving the highest removal efficiency.

4.9. Nitrate Nitrogen NO₃-N

The tested values of the NO₃-N during RI and RII runs are shown in figures 16 and 17, respectively. In these tests, the NO₃-N values of both raw wastewater in RI and RII runs were found 3.87 and 3.92 mg/l respectively.

Regarding influents, the average, maximum, and minimum of NO₃-N concentration during RI runs was 2.76, 2.89, and 2.53 mg/l, respectively, while the average, maximum, and minimum of NO₃-N concentration during RII runs were 3.35, 3.73, and 3.14 mg/l, respectively. For effluents, the average, maximum, and minimum concentration during RI runs was 2.47, 2.62, and 2.2 mg/l respectively, and the average, maximum, and minimum concentration during RII runs was 2.74, 3.11, and 2.36 mg/l respectively.

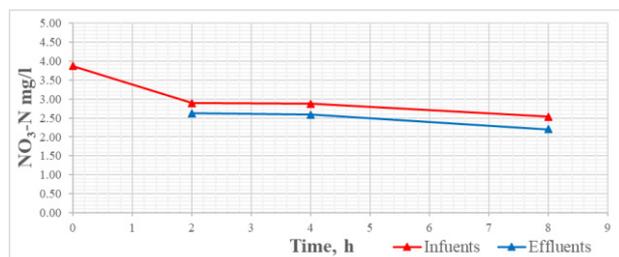


Fig. 16. Variations of the NO₃-N in RI run.

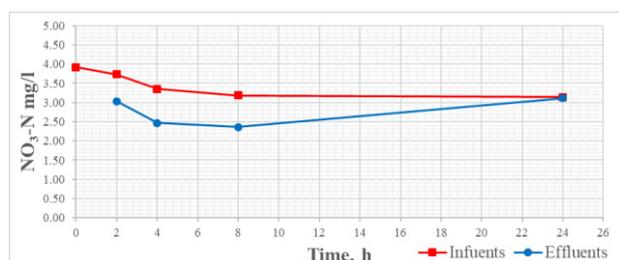


Fig. 17. Variations of the NO₃-N in RII run.

In these tests, there was no significant effect on the NO₃-N removal efficiency of effluents, as well as, the negative effect of sodium hypochlorite NaOCl on the

effluents in terms of removal was observed, where the values of the nitrate concentrations in effluents were very close to the influent thus achieving a minimum removal efficiency. Generally, the removal efficiency of NO₃-N during the RI runs varied between 32.3% and 43.15%, while, the removal efficiency during RII runs varied between 20.66% and 39.8%, respectively.

4.10. Ammonium Nitrogen NH₄-N

The tested values of the NH₄-N during RI and RII runs are shown in figures 18 and 19, respectively. The NH₄-N values of raw wastewater samples for both phases were found 19.5 and 16.5 mg/l, respectively. During RI runs, the NH₄-N removal within the effluents varied between 41.01% and 67.33%, while, in RII runs, sodium hypochlorite NaOCl had a negative effect in term of removal, where the negative removal efficiency was obtained when 82 ml of NaOCl added with the mixed liquor in the bioreactor tank, where reached to (-39.4%), otherwise, the removal efficiency during RII runs varied between 35.27% and 78.42%. The average, maximum, and minimum value of influent I1 during RI runs were 15.16, 16.5, and 13.42 mg/l respectively, whereas, the average, maximum, and minimum value of effluent E1 were 8.44, 11.5, and 6.37 mg/l, respectively. While, the average, maximum, and minimum value of influent I2 during RII runs were 11.98, 12.5, and 11.62 mg/l respectively, whereas, the average, maximum, and minimum value of effluent E2 were 11.56, 23, and 3.56 mg/l, respectively.

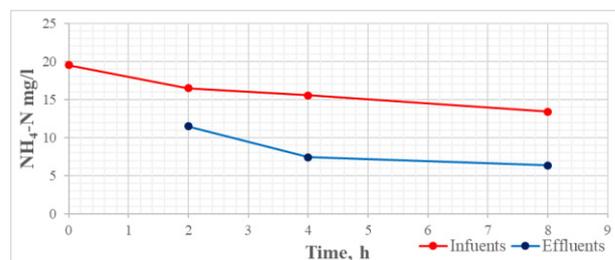


Fig. 18. Variations of the NH₄-N in RI run.

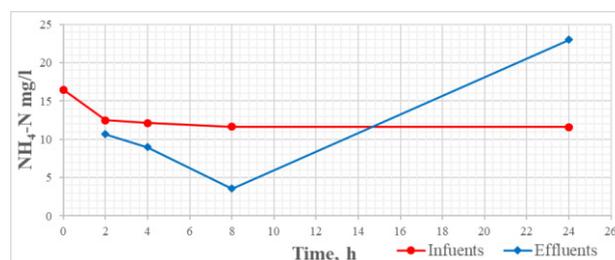


Fig. 19. Variations of the NH₄-N in RII run.

4.11. Total Phosphate PO₄-P

The variations of TP concentration during RI runs are shown in figure 20, while, the variations of TP concentration during RII runs are shown in figure 21. The concentration of TP of raw wastewater samples in RI and RII was 55 mg/l and 57.6 mg/l respectively, and the

concentration of TP for I1 during RI runs fluctuated between 54.4 and 60.4 mg/l, while, for I2 during RII runs fluctuated between 57.2 and 67 mg/l with gradual increase in both of RI and RII runs. For bioreactor process, the concentration of TP for E1 runs fluctuated between 34.4 and 40.2 mg/l, while, for E2 runs fluctuated between 22.6 and 50 mg/l, with the gradual decrease has been observed in both of RI and RII runs after 4 hours of aeration time. The removal efficiency of E2 higher than that in E1. The highest TP removal was obtained because of the NaOCl effect, where it has the effect on the decreasing of total phosphate concentration and obtaining the highest removal efficiency, where reached 61%. In general, the removal efficiency of TP during RI and RII runs varied between (26.91%-37.45%) and (13%-61%), respectively. The low removal efficiency of TP refers to the system works aerobically.

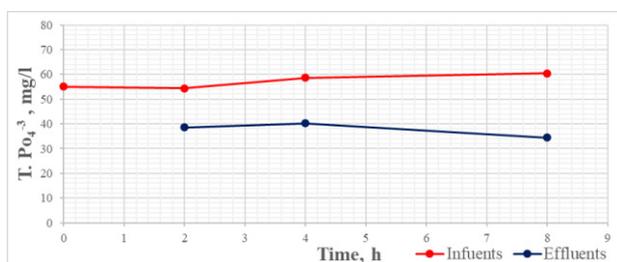


Fig. 20. Variations of the TP in RI run.

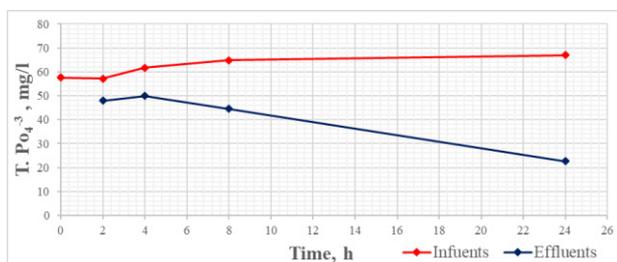


Fig. 21. Variations of the TP in RII run.

4.12. Orthophosphate PO₄-P

The orthophosphate, Orth-P is the form of phosphate that can be used and consumed by the microorganisms. The organic phosphate can be converted to orthophosphate after decomposition. The tested values of the orthophosphate during RI and RII runs are shown in figures 22 and 23, respectively. The concentration of Orth-P of raw wastewater samples in RI and RII was 38.2 mg/l and 38 mg/l respectively, and the concentration of Orth-P in I1 during RI runs fluctuated between 38.4 and 47.2 mg/l, while the concentration of Orth-P in I2 during RII runs fluctuated between 38.8 and 46.4 mg/l depending on the concentrations of Orth-P within the influent. The difference between the influent of Orth-P and TP represents the polyphosphate. The effluents generally have lower Orth-P concentration values than that of the influents and follow the same trend of fluctuation as in the TP. The removal efficiency of E2 was higher than that of E1. Also, the highest removal of Orth-P recorded was in the RII runs due to the NaOCl effect, where this

compound had an effect on decreasing the orthophosphate concentrations and thus obtaining the highest removal efficiency, where reached 49%. In general, the removal efficiency of Orth-P during RI and RII runs varied between (4.19%-14.14%) and (13%-49%), respectively. The low removal efficiency of Orth-P refers that the system works aerobically.

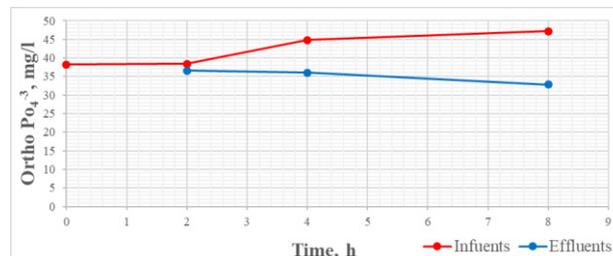


Fig. 22. Variations of the OP in RI run.

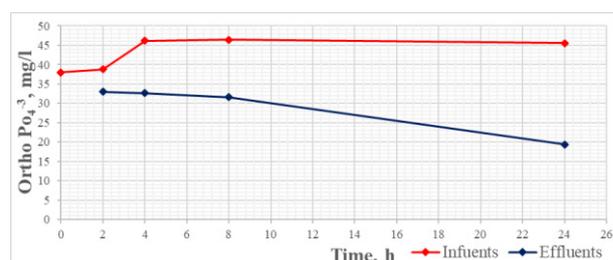


Fig. 23. Variations of the OP in RII run.

5. Conclusions:

The two phases of experimental trials using MBR system were carried out with HRTs of 2-8 h and 2-24 h showed that the bioreactor can be used efficiently to treat industrial wastewater. The wastewater was treated by using ZW10 hollow fibers membrane. On the first phase "RI", sodium hypochlorite "NaOCl" has been added during the backwashing process as a sterilizer in water as well as to prevent clogging in the pores of the membranes. On the second phase "RII", NaOCl has been added during the backwashing process at HRT 2-24 h, but, at 24 h of aeration, 82 ml of NaOCl was added with mixed liquor in the bioreactor tank to study its effect on the treatment process. The results obtained can be summarized as follows:

1. The pH value had gradually increased with HRT during the aeration process for both phases, where the pH value during RI increased from 6.9. to 7.71, while during RII, the pH value increased from 6.84 to 7.59. The reason for this increase is the disintegration and oxidation of the organic matter during the aeration process, which leads to the formation of CO₂. Some part of the CO₂ released as a gas from the aeration tank, that resulting in a decreasing of acidity in the water thus increasing the pH value. Generally, the pH value for the effluents was higher than that of influents, due to the effect of the NaOCl on the treatment process, which indicates that it is an alkaline solution.

2. For the treatment process, the membrane filter showed an excellent turbidity removal for both phases, thus indicates that the membranes filter was very efficient in retaining solids. the highest removal efficiency observed when adding 82 ml of NaOCl in the bioreactor tank in RII runs.
 3. For TSS, BOD and COD removal during the treatment process, a very good removal has obtained for COD, BOD₅ and TSS concentrations during RI runs where ranged between (67.97%-76.56%) and (70.87%-76.42%) and (74.71%-78.54%) respectively, while the effect of NaOCl compound on effluent during RII was observed., whereas, the best results were obtained after 24 hours of aeration when added 82 ml of NaOCl to the bioreactor tank with mixed liquor, where the treatment process was excellent in removing of COD, BOD₅, and TSS with removal efficiency 93.56%, 99.36%, and 89.52% respectively.
 4. The addition of the NaOCl compound during the RII runs had a negative effect on the nitrogen removal represented by nitrates and ammonium, where the minimum removal efficiency of NO₃-N was observed when adding 82 ml of NaOCl in the fourth run where it was 20.66%, whereas, a negative removal efficiency of ammonium was observed when adding 82 ml of NaOCl in the fourth run where it was (-39.39%). Generally, the variation of removal efficiency for the NO₃-N except for the fourth run in RII ranged between (32.3%-43.15%) in RI and (22.7%-39.8%) in RII, whereas, the variation of removal efficiency for the NH₄-N except for the fourth run in RII ranged between (41.03%-67.33%) in RI and (35.27% -78.42%) in RII.
 5. The addition of the NaOCl compound during the RII runs had a positive effect on the phosphor removal represented by total phosphate and ortho-phosphate, where the highest removal efficiency of total phosphate and ortho-phosphate was observed when adding 82 ml of NaOCl in the fourth run where it was 60.76% and 48.95% respectively. In general, the variation of removal efficiency for the TP except for the fourth run in RII ranged between (29.82%-37.45%) in RI and (16.67%-22.57%) in RII, whereas, the variation of removal efficiency for the Ortho-P except for the fourth run in RII ranged between (4.19%-14.14%) in RI and (13.16%- 16.84%) in RII.
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