Studying the Effects of Organic and Hydraulic Shock Loads on the Membrane Bioreactor (MBR) By Using GPS-X Mathematical Model

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Abstract: Membrane-based systems (MBR) used in wastewater treatment have many advantages over conventional activated sludge processes. They have proven to be very effective in removing organic and inorganic contaminants as well as biological entities from water. The objective of this work is to propose an optimal operation of the bioreactor after having detailed in the relationships between the nature of the sludge, its conditions is obtaining the performance of the membrane using a simulation software (GPS-X). The effects of organic and hydraulic shock loads on the MBR system were also studied. The GPS-X simulation program was used in this study to simulate the membrane bioreactor setup. The BOD removal system we used was 78%. In addition, the MBR system has a significant capacity due to the hydraulic shock load of the operation and the process efficiency for the MBR installation due to this shock load based on BOD removal was reduced up to 65%. The MBR system has a good ability to handle the organic shock loads of the operation with no significant loss in treatment efficiency. The treatment efficiency of the MBR system, due to organic shock loads based on BOD removal, decreased slightly to 80%, however, it is shown how their properties determine the extent of sludge fouling in the membrane. Based on these results, operational conditions favoring a reduction of fouling are proposed.

Keywords: Wastewater, Membrane Bioreactor (MBR), GPS-X Model, Shock Loads, Simulation.

1. INTRODUCTION

The World Health Organization (WHO) estimates that almost 80% of diseases affecting the world's population are directly caused by water. Moreover, despite appearances, disease transmission from polluted water is not limited to developing countries [1, 2]. Urban wastewater should not be discharged into the natural environment, because without treatment it can cause major environmental and public health problems. It must therefore be directed to wastewater treatment plants, whose role is to concentrate the pollution present in the wastewater in the form of residues, and to discharge the treated water, through physical-chemical and biological processes [3-5].

Urban wastewater treatment is in most cases carried out by a conventional activated sludge system. The management of the process is the most simple and the installation and operation costs are the lower. However, the quality of the water treated and the control of stable systems are very sensitive to variations in the flow rate and composition of the effluent to be treated [6, 7].

As water treatment has become obligatory and regulated, biological processes are constantly reviewed and improved. At present, they continue to be the most economical, the most expensive and the most competitive. Two main objectives are considered in the development of new products, a quality objective and a cost objective, with a general concern of process efficiency and reliability. Activated sludge systems coupled with a process known as membrane bioreactor respond to these expectations. Research on membrane bioreactors started about 30 years ago [8].

Membrane bioreactor technology has been developed rapidly for large applications subsequently [9]. From a scientific point of view, the objectives are to the main axes of research will tend to favor the operation of the reactor in periods of high demand as long as possible. The limitation in this respect is the fouling and cleaning of the membrane, the comprehension of which is then the main focus of the work. of investigation in the field. Thus, strategies to minimize fouling can be obtained by studying membrane filtration and understanding the biology involved in these conditions [10].

The methodology is carried out to determine, at time zero, the characteristics of the following parameters: BOD5, COD.... From the general volume, a quantity of 5 Liters is taken under evacuation after agitating and is decanted into a receptor with a volume of 6L. This is the gross reactor. This filtration is carried out under vacuum and the excess volume is left to rest for 10

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minutes. The supernatant is filtered until a quantity of 6 liters is received and placed in a new container [11-15]. This forms the filtered reaction vessel. This filter process is carried out using first large pore glass fiber filters of approximately 2 µm and then fiber filters. All filters are pre-flushed with ultra-filtered water and then with the samples to be filtered to minimise the risk of sampling contamination by COD release, in accordance with the protocol [16-17].

Many studies have focused on the measurement of membrane fouling, using monitoring of fouling resistance during reactor operation, or in parallel [18]. The study authors also often relate the filtration behavior of the sludge to its biochemical composition and in particular to the amount of extracellular polymers present in the flocs and in the surface supernatant [19-24]. They conclude by giving a hypothesis on the possible fouling mechanisms involved in the decrease of the filtration characteristics of the membranes. In the continuity of the identification of fouling mechanisms, the work developed is based mainly on the time on model solutions. The objective of this research is the multipurpose modeling for the simulation of industrial municipal wastewater treatment plants under the GPS-X software. This is an advanced computer tool useful for dynamic modeling and simulation of wastewater treatment plants to assist and facilitate the improvement of the operational part.

2. MATERIALS AND METHODS

The work done on urban wastewater. We continued this study by increasing the number of splits. Under these conditions, the verification of the reliability and the robustness of the protocol are better established. Samples are taken at regular intervals in the sampler positioned before the pretreatment, some data of the self-monitoring (output flow) completed these samples [25-26]. The protocol of fractionation of the parameters previously proposed is referenced on two campaigns of 24 hours in the same station.

2.1. Operating Conditions of MBR

Membrane filtration allows working at higher sludge concentrations. However, in order not to have too much impact on the good filterability of the water/sludge mixture, operators generally maintain sludge rates lower than those indicated by the manufacturers. Consequently, with the MBR process, the biomass concentration can be maintained at a level about 2 to 4 times higher than in a conventional BA tank, which is generally limited to a maximum value of 5g/L [27]. This ensures a higher biomass age (60 to 100 days) which favors a decrease in the sludge produced, the development of nitrifying bacteria and the degradation of organic complexes that are difficult to biodegrade. In fact, the very low mass load (Cm) in the process directs the metabolism towards processes other than biosynthesis and thus ensures a lower production of biomass (or sludge) [28]. The concentration is nevertheless limited by the need to maintain the viscosity of the medium and the oxygen transfer coefficients at acceptable values that are not detrimental to the system. In fact, the vast majority of urban MBRs on the market operate with a mass load between 8 to 15g/L to optimize oxygen transfer conditions and thus limit the associated energy consumption. In the majority of cases, at the outlet of an urban MBR, the effluent contains almost no suspended solids. BOD5 and COD values are generally less than 5mg/L and 50mg/L, respectively [30-33]. The MBR not only allows higher purification performances than the conventional BA, but above all performances that vary less according to the operating conditions.

2.2. Modeling and Simulation Software

To perform the simulation and because of the ease of collection and processing of results, two types of wastewater collection systems with specific design schemes were created using GPS-X software . The advantages of the GPS-X (Global Purpose System) software are that it is very powerful and very user-friendly, provided that the various possibilities of its operation are mastered. However, it is constantly evolving according to the needs of the market. Moreover, its efficiency is linked to the use of a large amount of data. Simulations can be carried out in both steady state and dynamic mode. For example, Mabrouki J *et al*. 2020 carried out steady-state simulations of a set of urban wastewater fractionations from the Moroccan city and the coefficients acquired were validated in dynamic regime [18, 34]. In each regime, it is possible to make calibrations, adjustments, sensitivity analyses and process customization. Nitrification and denitrification efficiencies are obtained for different stations. The software programming language used is Fortran and ACSL, Advance Control Simulation (java interface), which is available at ENGEES and is used for research simulations and can of course be applied to fractionation studies based on the samples collected at the purification plant. Its network operation allows a concerted use on the development and adjustment of the models [35].

3. RESULTS AND DISCUSSION

3.1. Proposed System Configuration

The evolution of the technology is not difficult to imagine and will lead to the advancement of more cost effective modules with longer lifetimes and higher energy yields. In this research the MBR system can be known as the immersed MBR system because the membranes of the hide are immerged in the aeration tank. The moving force accross the membrane is obtained by producing a negative pressure on the permeate side. The membrane is flushed by frequent pulses of permeate in countercurrent and by occasional chemical cleaning. Place the diffuser directly under the membrane module to assist in filter surface scrubbing. The unit also provides aeration and mixing [36]. Module producers as well as research centers, universities, and private laboratory are developing the design of the modules and the nature of the membranes to have higher chemical and mechanical resistance at the lowest possible cost. The objectives of the processing technology are to reduce the cost of construction and production of manufactured membranes. Indeed, membrane suppliers rely heavily on the surface area of the sold membranes to reduce their fabrication costs and to recover their research and development expenses. This may eventually lead to a future type/module standardization of the membrane to some configuration or other [37]. The first part is the effluent settlement by a clarifier and the second part is the aeration tank unit for biological decomposition of waste compounds and the membrane module unit for effluent separation from the aeration tank. The arrangement of the proposed wastewater plant is illustrated in the next setup.

3.2. Results of the Wastewater Characterization

The average pH value measured is 8.1 the pH found is between 5.5 and 8.5 according to the standard of waste water discharges in Morocco [38-41], knowing that if the values found are lower than 5.5 or higher than 8.5, they may have a negative impact on the growth and survival of the microorganisms. The variation in pH is illustrated in Table **1**. The temperature value measured at the sampling site is approximately constant at 20.5 °C.

Table 1: Wastewater Parameters Before and After MBR Treatment

Parameter	Wastewater	MBR input
pH	8.1	7.8
Temperature (°C)	25	26
Dissolved oxygen (mg/L)	0.5	0.4
BOD5 (mg/L)	350	224
COD (mg/L)	764	435
Total SS (mg/L)	312	265
Volatile SS (mg/L)	184	145
TKN (mg/L)	19.5	17.2
$NH4^+$ (mg/L)	13	9.8

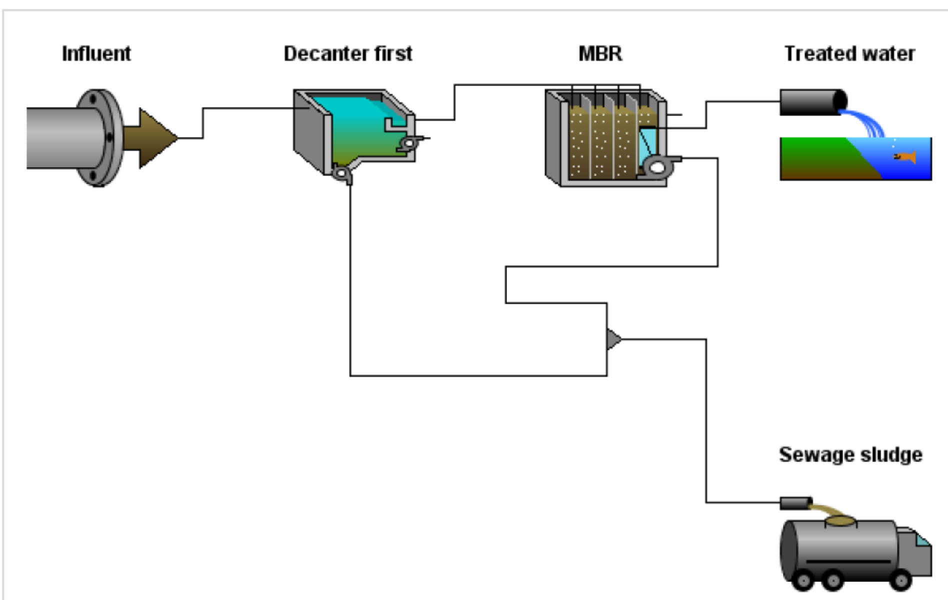

Figure 1: Diagram of the water system plant in GPS-X.

The total suspended solids include settleable matter expressed in cm^3/l and the colloidal matter, their effects on the physico-chemical characteristics of the water are very detrimental (modification of the turbidity of the water and reduction of light penetration). The TSS concentration measured during the sampling was 312 mg/L. These concentrations are quite high and far exceed the value accepted by the Moroccan standard, making it necessary to treat the analyzed effluents.

The COD and BOD5 values are above the acceptable standards for this particular industry. This may be due to the raw material used in the formulation of the product. It also indicated that the effluent is biodegradable, so the discharge is not readily biodegradable. As shown in Table **1**, the discharge is high in organic content. The resulting values are very high compared to the tolerance. The presence of organic matter results in high COD and possibly high BOD due to starch [42]. In this work, we have referred to the general limit values prescribed for direct discharges by the Committee on Norms and Standards of the Commission for the Prevention and Control of Pollution and Nuisance.

3.3. Result of Hydraulic Shock Loads Normal Operation

The performance of the MBR process was monitored during the MBR reactor operation period (10 weeks). Measurements of carbonaceous and nitrogenous pollution were carried out at the input and output, during the periods from the fifth to the eighth week. Modeling by the GPS-X model for the normal operating mode of the MBR plant was carried out during 90 days of operation with an average daily flow of 1500 m3/d and 300 mg/l respectively. Figure **2** shows the relationships between effluent BOD5 concentrations and operating time under normal operation of the MBR plant. Figure **2**(**b**) shows the correlation between effluent TKN and operating time for normal operation.

Table **2** presents a summary of the MBR model results for the normal operating scenario. It is clear from the above results that the 78% BOD5 removal can be achieved after 26 days of operation without adding to the MBR system. It can therefore be inferred that the start-up period of the plant is 26 days of operation. After this period, the BOD removal efficiency of the MBR plant ranges from 76 to 78%. The average TKN removal efficiency for the MBR model has been 80.2%.

Table 2: Summary of Results for the MBR Model for Normal Operation

Parameter	MBR output	Removal (%)
pH	7.5	-
Temperature (°C)	22	-
Dissolved oxygen (mg/L)	3.4	-
BOD5 (mg/L)	48	78
COD (mg/L)	92	79
Total SS (mg/L)	68	74.3
Volatile SS (mg/L)	54	67
TKN (mg/L)	3.4	80.2
NH_{4^-} (mg/L)	1.5	84.7

The results of the treatment of nitrogen pollution (by MBR of public wastewater give values in conformity with the most demanding standards such as the Moroccan standards (NH4+ < 15 mg/ l). According to the results presented in Table **2**, the ammonium concentration at the MBR inlet of 13 mg/l decreases to 1.5 mg/l. The abatement rate increases with increasing sludge age and reaches its maximum value of 84.7% when the sludge age varies between 20 and 30 days. The decrease in the concentration of ammonium ions after MBR treatment could be explained by the phenomenon of nitrosation where ammonium ions are oxidized to nitrite [43]. Also for total nitrogen, the MBR input concentration of 17.2 mg/L decreases to 3.4 mg/L and the removal rate increases with increasing sludge age and reaches its maximum value of 80.2% at 25-day sludge age. The reduction in nitrite levels is due to the aerobic nitrification process, which reduces nitrite to N2O or molecular nitrogen. As for SS removal, the MBR input concentration of 265 mg/L, decreases to 68 mg/L and the removal rate increases with increasing sludge age and reaches a maximum value of 54% at 26-day sludge age. This could be due to the denitrification phenomenon that takes place in the bioreactor during the biological treatment wastewater effluent under aerobic conditions, which is advantageous on a large scale. During this study, we found a reduction in the concentration of BOD5 ions at the exit of the bioreactor, which could be explained by aerobic denitrification. As a result, the denitrification can take place in the activated sludge flocs, despite the high oxygen levels in the bioreactor [44]. In addition, the presence of oxygen in wastewater does not inhibit denitrification at the microenvironmental level [45].

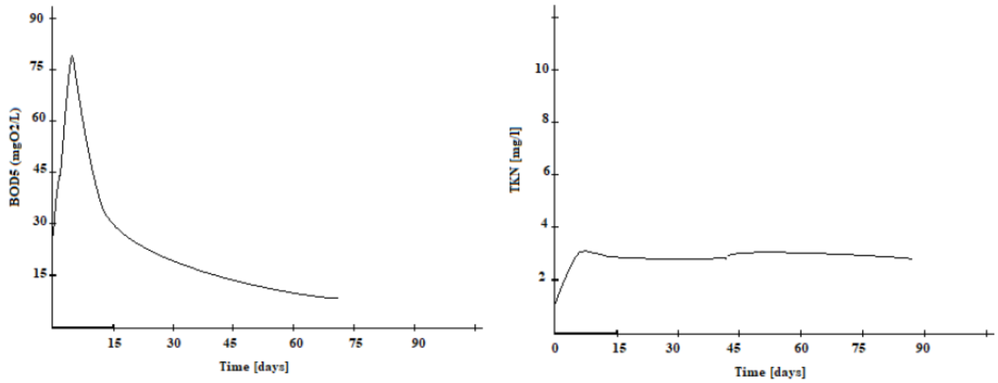

Figure 2: Variation of BOD5 and TKN of the effluent as a function of time for normal operation.

The results of the MBR model for the hydraulic shock load simulation scenario. As in the case of normal operation, the starting period to achieve 78% BOD removal for the MBR plant was 28 days of operation. After this, steady-state operation commenced and the MBR plant efficiency during the steady state period for BOD removal and TKN removal was approximately 80% and 860% respectively. Treatment efficiency suddenly decreased due to the hydraulic shock loading period. Afterwards, as shown in Figure **2**, a shutdown period was maintained for approximately 12 days of operation. The effectiveness of the MBR plant during the outage period for the removal of BOD and TKN decreased to 70% and 80%, respectively. After that, a new stable operating state was established and the treatment efficiency returned to the same values as in normal operation. It can be concluded from these results that MBR is very sensitive to hydraulic shocks and that the treatment efficiency of the MBR plant decreased up to 75% of the BOD removal [43].

3.4. Result of Organic Shock Load

The organic shock operating mode of the system for the MBR WWTP in the GPS-X model was used for 80 days of operation with an average daily flow and BOD5

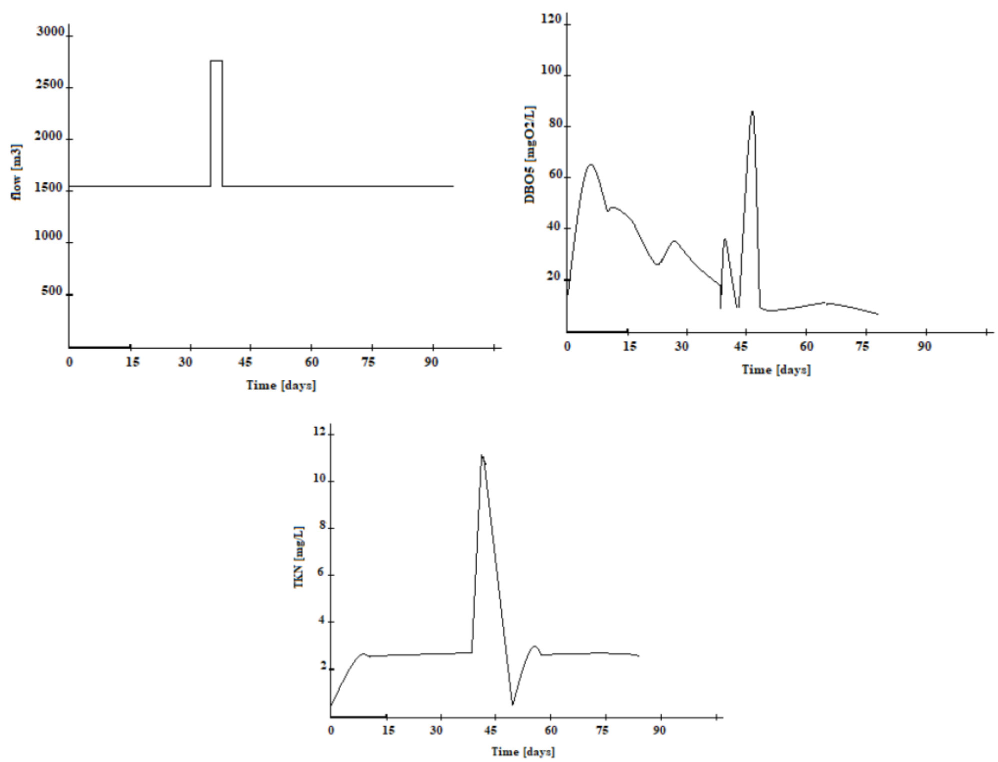

Figure 3: Relationship between flow rate, BOD5 and TKN of the influent and time for hydraulic shock loading.

of 1500 m3/d and 300 mg/l, respectively. Sudden organic shock loads on the MBR WWTP model were obtained by duplicating the influent BOD5 in the middle of the operating period. The influent BOD5 during the organic shock loads was 350 mg/l. Figure **4** shows the distribution of the relationship between influent BOD5 and operational time during the hydraulic shock load case. Figure **4** shows the relationship between effluent BOD5 concentrations and operating time. It shows the relationship between effluent TKN concentrations and operating time during the organic shock loading. The figures present a summary of the MBR model results for the organic shock Loading scenario. Similar to the normal operation case, the start-up period was 28 days of operation to reach 78% BOD removal for the MBR plant. After that, steady-state operation began and the efficiency of the MBR plant during steady-state period for BOD and TKN removal was about 80.2% and 72% respectively. The treatment efficiency decreased slightly due to the organic shock loading period. The short shutdown period was maintained for 28 days of operation. The efficiency of the MBR plant during the downtime period for BOD and TKN removal decreased slightly to 80% and 75% respectfully. After that, a new steady state of operation was established and the treatment efficiency returned to the same values as during normal operation. It can be concluded from these results that the MBR has a good ability to receive the operation's organic shock loads without a significant reduction in treatment effectiveness. In addition, the organic shock load caused a short period of one-day operation interruption with a slight reduction in treatment efficiency [46].

The results show the COD decay during the first week of operation of the MBR reactor, which is comparable to the results obtained by Reif *et al* [45]. This increase in COD during the first week could be due to the increase in microorganisms due to the stresses experienced during the acclimatization phase of the activated sludge. However, the second decrease in COD during the third week could be explained by the presence of organic and mineral micro pollutants that have a bactericidal effect. The BOD5 abatement rate of 78% is less important than the COD abatement rate. The average output values of MBR are 48 mg/l and 92 mg/l respectively (Table **2**), and are much lower than those of the indirect discharge standards (100 mg/l and 100mg/l). The high BOD5 removal rate can be explained by the performance of the sludge used in the MBR, which degrades the biodegradable organic matter present in the wastewater, and also by the presence of a purifying biomass. According to our results, the MBR process we applied gave very good results in terms of organic load reduction (79% COD and 78% BOD5 reduction) compared to the work reported by Mohan and his collaborators [47]. The reduction of COD and BOD5 is mainly due to the duration of the aerobic phase, which is in line with the results obtained in other research [26]. On the other hand, other studies attribute the reduction of COD and BOD5 to the anaerobic phase in aerobic systems [46-29.]. Based on our results, we confirm that the efficiency of the MBR process, in terms of purification efficiency in public wastewater treatment, is satisfactory, as it meets Moroccan legislative requirements [38]. Each change in sequential operation leads to significant changes in the reactor output variables. These variations can be attributed to variations in stress related to the activated sludge used and can be more or less significant depending on aeration phases (short cycle or long cycle). These modifications undoubtedly have consequences on the operating behaviour of the reactor and its performance (modification of the bacterial metabolism) [50].

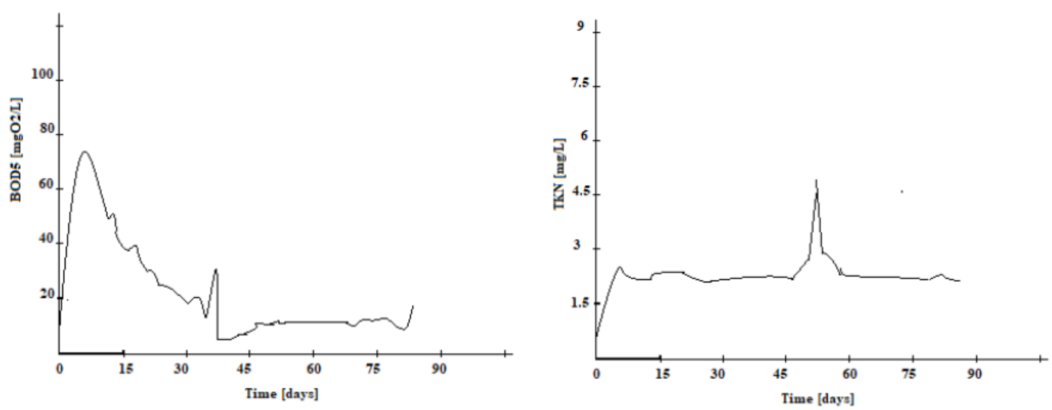

Figure 4: Relationship between BOD5 and TKN of the influent and time for organic shock loading.

4. CONCLUSION

MBRs now seem to be recognized as a high-performance technology for wastewater treatment plants subject to specific requirements: advanced purification, limited space or absence of the required sanitary nuisances. For wastewater treatment plants in areas with no environmental or economic stakes, it seems that without a change in discharge regulations, more conventional technologies are always a small step ahead. The obtained results in this study, worded as The treatment efficiency of the MBR system for BOD removal was about 80% in steady state, while the TKN removal for the MBR system was about 85%. Our chosen system has a sensitive capacity due to the sudden hydraulic shock load of the operation. The factors that hinder further MBR development are mainly the costs due to membrane replacement and higher energy consumption compared to conventional BA systems. The processing efficiency of the MBR plant due to these shock loads based on the removal of BOD and TKN has decreased and the good capacity to receive a sudden organic shock load without significant loss of MBR system treatment efficiency. The good performance of the MBR system in absorbing sudden organic shock loads without significant loss of MBR system treatment efficiency, but the organic shock loads caused a short period of interruption in the operation of the MBR system, and the costs decrease in proportion to the increase in knowledge and control of the MBR process, especially in the area of fouling and the impact of this fouling on the life of the membranes. As far as oxygen transfer in the mixed liqueur is concerned, it seems that this point remains to be optimized in order to reduce energy consumption without losing the advantages inherent to a high sludge age.

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