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# Membrane bioreactor for the treatment of municipal blackwater in Egypt

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**ABSTRACT**

Membrane bioreactor (MBR) technology has become a key component in water reclamation schemes for nearly 30 years due to the possibility of providing high quality water. The objective of the present study is to investigate the efficiency of MBR for the treatment of municipal blackwater. A pilot-scale MBR unit was installed and operated in the NRC, Egypt. Blackwater was primary treated through three chambers baffled sedimentation tanks. The effluent was then directed to the MBR. The reduction in the MBR permeates for COD and BOD ranged from 90 to 94% and from 90 to 97%, successively. The corresponding level of COD ranged from 34 to 76 mg/l, and BOD ranged from 6 to 18 mg/l. The average removal rate of ammonia and TKN was 97% and 94%, respectively. The averages values of some parameters in permeate were as follow: TSS, 0.6 mg/l; COD, 42 mg/l; BOD, 10 mg/l; $NH_3$-N, 5.8 mg/l. This indicates the advantages of membrane filtration over the activated sludge processes. Therefore, MBR process was found to be efficient for improving effluent quality. Such performance will guide the decision maker on the potential of MBR application and advantages of efficient wastewater treatment for irrigation purpose in Egypt.

*Keywords*: Membrane bioreactor (MBR); Municipal separation; Wastewater; Treatment; Blackwater

## 1. Introduction

The Mediterranean basin is one of the poorest regions in the world in terms of water resources. An increased water consumption rate along with a high population growth, have an adverse effect on water resources. Meanwhile, water scarcity is a problem faced by the Southern Mediterranean countries. This region, with a very young and still fast-growing population, is the highest water stress in the world, the lowest per capita availability of water and the highest use of all potential freshwater resources. Most water produced in urban areas of the region is inefficiently treated due to poor maintenance of the equipment, high electricity cost and lack of recent technologies [1,2]. Therefore, the reuse of inefficiently treated wastewater or even directly without treatment for irrigation or sanitary purposes is serving as a carrier for diseases or causing water pollution when discharged to water bodies.

In the last decade, several water treatment technologies have been used in the region, but with little success in relation to pathogen removal. This significantly reduces the opportunity of using the treated effluent for unrestricted irrigation of higher value crops such as vegetables and medicinal plants [3,4].

Membrane bioreactor (MBR) technology has become a key component in water reclamation schemes due to the possibility to provide high quality water, e.g. as particle-

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free permeate, removal of microbiological contamination and the cost-effective of reclaimed effluents that are needed to boost water recycling applications in target area but also in other regions of the world [5]. It has been used for various specialty treatment applications for nearly 30 years [6,7]. Membrane costs have declined by an order of magnitude over the past decade [6]. The MBR process was demonstrated to be cost-effective over conventional water reclamation systems for urban irrigation [8].

There are a number of benefits associated with MBRs compared to conventional wastewater treatment processes. Therefore, excellent effluent quality can be obtained generally suitable for reuse as membranes provide high removals of pathogens including bacteria, protozoa and viruses resulting in excellent physical disinfection. Moreover, suspended solids and the large particles such as colloids are also retained within the bioreactor device. This enhances the adsorption surface and therefore, the micropollutants will be more likely adsorbed onto the retained suspended solids [9]. In addition, the organic load is biodegraded, hens, decreased significantly as indicated by the BOD and COD. It has been documented also that the other pollutant parameters such as nitrogenous compounds (ammonium, nitrates and nitrites) phosphates and heavy metals decreased down to variable degrees [10,11].

In addition, MBR allows exceptional versatility in the design of new modules into existing aeration tanks [6,7,12–15]. Therefore, applications of the increasingly diverse range of commercial technologies available have tended to be restricted to the range between 10 and 50,000 $m^3$/d of installed capacity, although larger MBRs are being built year-on-year [16]. On the other hand, increasing water scarcity coupled with stringent regulations have meant a single-household MBR (<5 $m^3$/d), with the effluent being recycled for non-human contact applications such as irrigation, washing and toilet flushing, is potentially economically viable. However, a single-household MBR is believed costly compared with established freshwater supply and effluent discharge [17]. However, membrane fouling, which reduces productivity and increases maintenance and operating costs, is one of the major drawbacks of MBR processes [18,19].

The objective of the present study is to investigate the efficiency of MBR for the treatment of municipal separated black water. The seasonal variable characteristics of the influent and effluent were considered. The characteristics of the treated effluent were evaluated according to permissible level of water reuse for irrigation purposes.

## 2. Materials and methods

A pilot-scale submerged continuously operated MBR unit was installed and fully operated for the treatment of municipal blackwater within the premises of National Research Center (NRC), Cairo, Egypt. Municipal wastewater from a residential house was separated into black and grey waters through two piping lines system and was connected to the pilot plant in the premises of (NRC). The blackwater was first treated through three chambers baffled sedimentation tanks as a primary treatment. Each tank is 1 $m^3$. The outlet was then directed to the MBR for further treatment. Fig. 1 illustrates the schematic diagram of the treatment train.

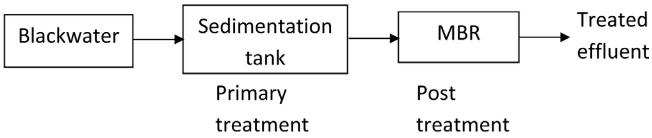

Fig. 1. Schematic diagram of the treatment train.

### 2.1. MBR pilot unit

The MBR unit is especially designed in 2009 that implies a down-scaled version for treatment domestic wastewater. It combines the activated sludge process with membrane filtration for separation of activated sludge. Membranes in the microfiltration range with nominal pore sizes of 0.387 μm guarantee a reliable separation of bacteria and all particulate material. Fouling on the surface of the plate and frame module (KUBOTA) is controlled through tangential flow along the membrane surface. The necessary trans-membrane pressure difference is applied by the water head above the membrane (gravity flow) [19]. The specification of the MBR is given in Table 1 and is shown in Fig. 2.


Fig. 2. MBR unit.

Table 1
Specification of MBR units

| Item | Specification |
|---|---|
| Membrane material | PEC |
| Membrane surface, $m^2$ | 5 |
| Number of membranes | 12 |
| Resistance/pH range | 1.5–10 |
| Resistance/$H_2O_2$ (NaOCl), ppm | 3000–5000 (normal 500) |
| Resistance/temperature, °C | < 50 |
| Resistance/pressure, mWS | Max. 1–3 (1.02 mWS = 10 kPa) |

The small pore sizes of 0.387 μm of the membrane guarantee retaining the nitrifiers bacteria and other microorganisms in the reactor. Furthermore, the separation by membranes allows mixed liquor suspended solids (MLSS) concentrations that by far exceed the usual 2–4 g/L in conventional treatment systems. The purpose is to obtain an effluent free of particles and germs.

### 2.2. Sampling and analytical methods

The present study was carried out continuously for 12 months to investigate the efficiency of MBR for the treatment of blackwater. Composite samples of raw blackwater, sedimentation tank effluent and final effluent of the MBR treatment unit were collected and analyzed for the physical and chemical parameters namely; pH, chemical oxygen demand (COD), biological oxygen demand (BOD), total Kjeldahl nitrogen (TKN), ammonia, phosphorus, total dissolved salts (TDS) and TSS. These parameters were carried out according to Standard Methods for Examination of Water and Wastewater [19].

## 3. Results and discussion

During the entire operation period, the characteristics of the raw blackwater exhibited both diurnal and seasonal variation. This is mainly due to the variation in water consumption during the different seasons especially the fasting month of Ramadan as well the relatively diet habits in winter, summer and the holidays. Wastewater temperature slightly dropped in the winter to as low as 10°C an increased in the summer to 32°C.

### 3.1. Physico-chemical characteristics of blackwater

The organic load (as measured by BOD and COD) exhibited wide variations. Similar significant variation was also observed for TSS (Fig. 3). The level of COD, BOD and TSS ranged from 452 to 954, 255 to 574 and 122 to 632 mg/l with an average of 694, 441 and 244 mg/l, respectively (Fig. 3). The BOD/COD ratio varied from 0.6 to 0.7 and the average value was 0.65 as indication of organic nature that can be biodegraded. The level of total phosphates (TP) and TKN ranged from 0.25 to 0.39 and 254 to 352 mg/l with an average value of 0, 32 and 282 mg/l, respectively (Fig. 4). These results confirmed that there is wide variation in the wastewater characteristics with relatively moderate organic load as shown in the level of BOD, COD and TKN.

### 3.2. Effluent of the sedimentation tank

The levels of COD, BOD and TSS in the effluent of sedimentation tank (ST) ranged greatly from 301 to 803, from 180 to 450 and from 68 to 199 mg/l (Fig. 5). The corresponding average values were 423, 256 and 84 mg/l for the COD, BOD and TSS, respectively (Fig. 5). The maximum removal rate of these parameters is 51, 67 and 79%, successively. The removal of the nutrients ranged from 1 to 33% with the average of 11.4% for TKN, and

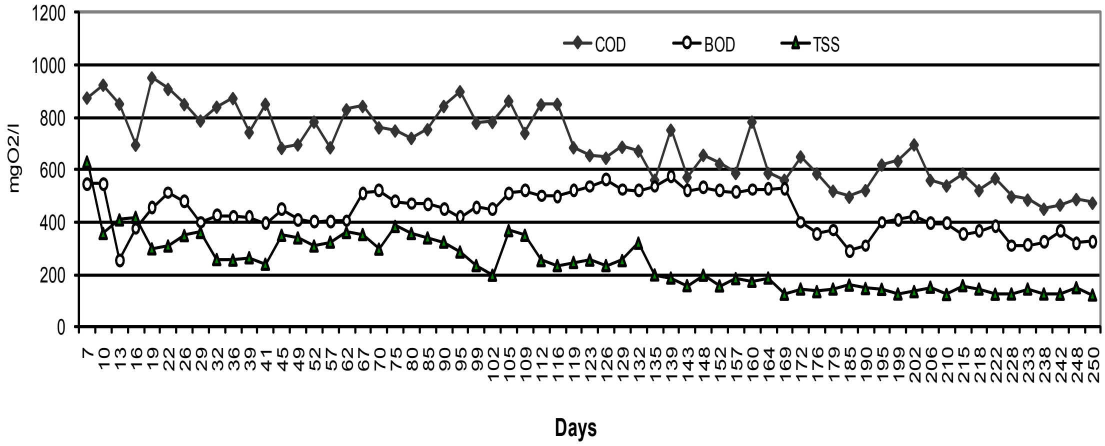


Fig. 3. Variations in COD, BOD and TSS of the raw blackwater.

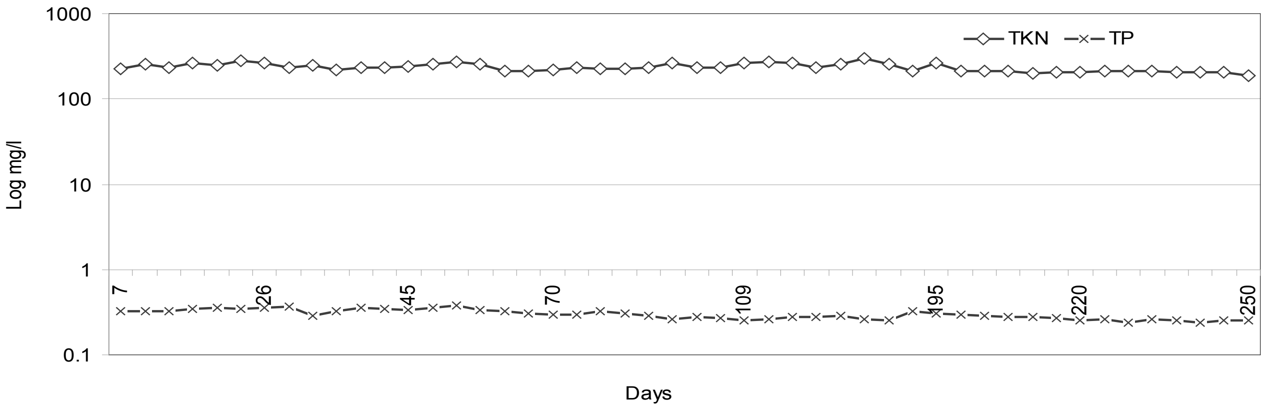


Fig. 4. Variations in TKN and TP of the raw blackwater.

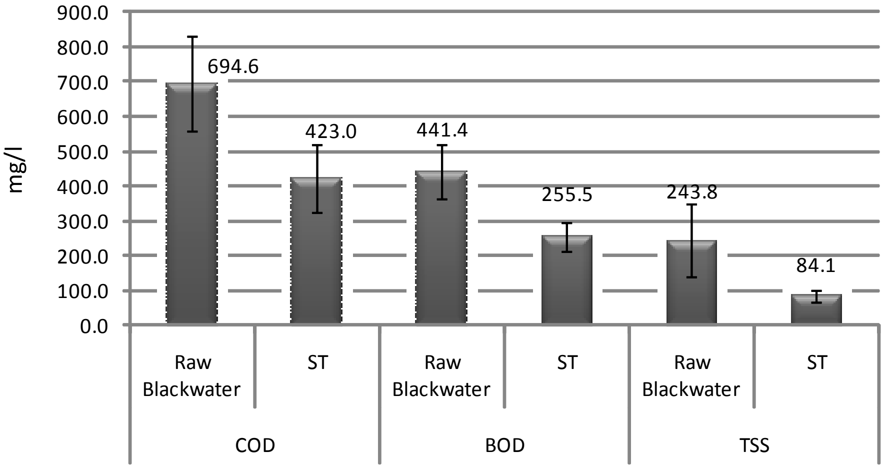


Fig. 5. Variations of COD, BOD and TSS in raw blackwater and the septic tank effluent.

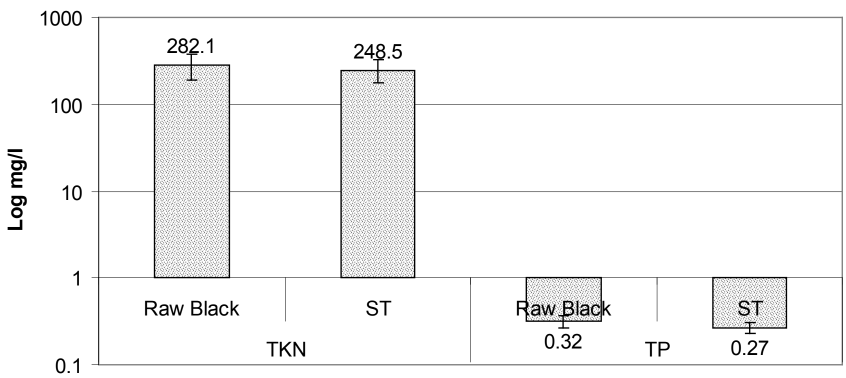


Fig. 6. Variations of TKN and TP in raw blackwater and the effluent of sedimentation tank.

from 2.6 to 20.0% with average value of 15.6 %, for TP (Fig. 6). These results indicate that a great variation in the characteristics of the ST effluent due to the variations of influent (Fig. 5). However, efficient removal was achieved in terms of COD, BOD and TSS. On the other hand, low removal was reached for both TKN and TP (Fig. 6).

It is clear from the above obtained results that the treated effluent should be further treated to meet the requirements for water reuse in agriculture purpose.

### 3.3. Removal efficiency of MBR

#### 3.3.1. Removal of COD, BOD and TSS

The hydraulic residential time (HRT) of MBR operation was kept constant during the study at 2.4 d. Figs. 7a and 7b exhibit the level of COD and BOD in the feed and MBR permeate during the study period. The recorded reduction in the MBR permeate was 423–256 and 42–10 mg/l for the COD and BOD, respectively. Most of the time, COD and BOD reduction were in the range of 86–94% and 90–97%, successively. The TSS in the MBR effluent was completely removed and could not be detected as indication of efficient membrane filtration. Meanwhile, the level of COD ranged from 34 to 76 mg/l, and BOD ranged from 6 to 18 mg/l during the present study period. These results (Figs. 7a and b) indicate that efficient removal was achieved by MBR as exhibited by the reduction in BOD and COD as well as a complete retention of TSS. The applied flux in this study was 0.167 l/m$^2$/d which is very low compared with other reported works [22–25]. The corresponding reported investigations were dealing with much diluted or regular municipal wastewater compared with the present blackwater.

#### 3.3.2. Nutrient removal: ammonia, total Kjeldahl nitrogen (TKN) and total phosphorus (TP)

The variations in ammonia and TKN in the feed and permeate of the MBR unit are illustrated in Figs. 8a and 8b. The levels of ammonia and TKN were reduced from 224 to 5.8 and from 248 to 12 mg/l as average values, respectively. The nitrogen removal ranged from 270 to 335 mgN/l with an average value of 302 mg N/l. These results (Figs. 8a and b) indicate an efficient reduction of

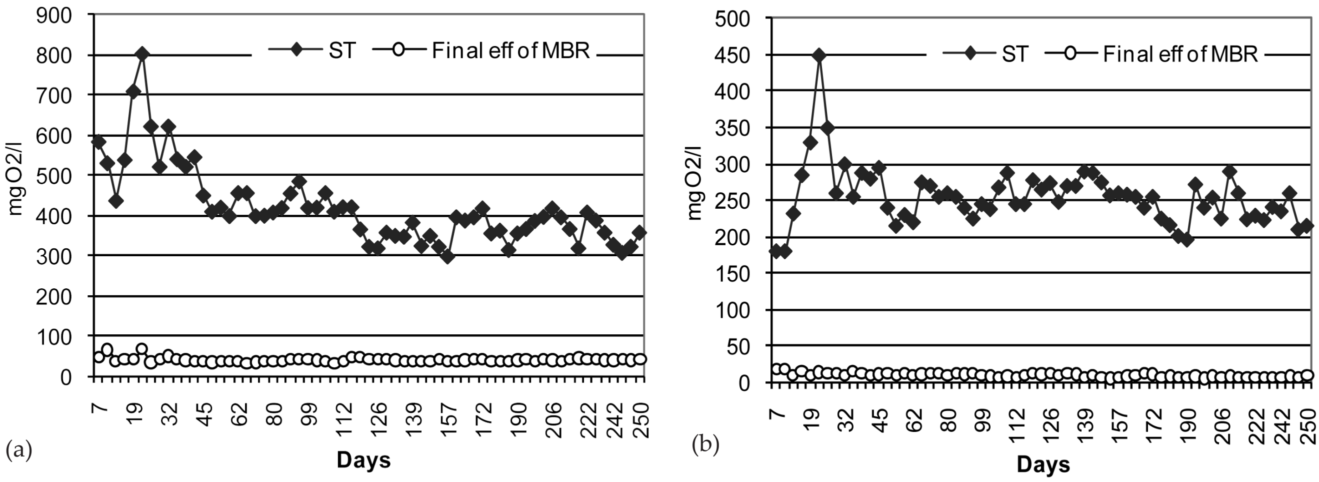


Fig. 7. Variations in the (a) COD and (b) BOD of ST effluent as well as permeate of MBR.

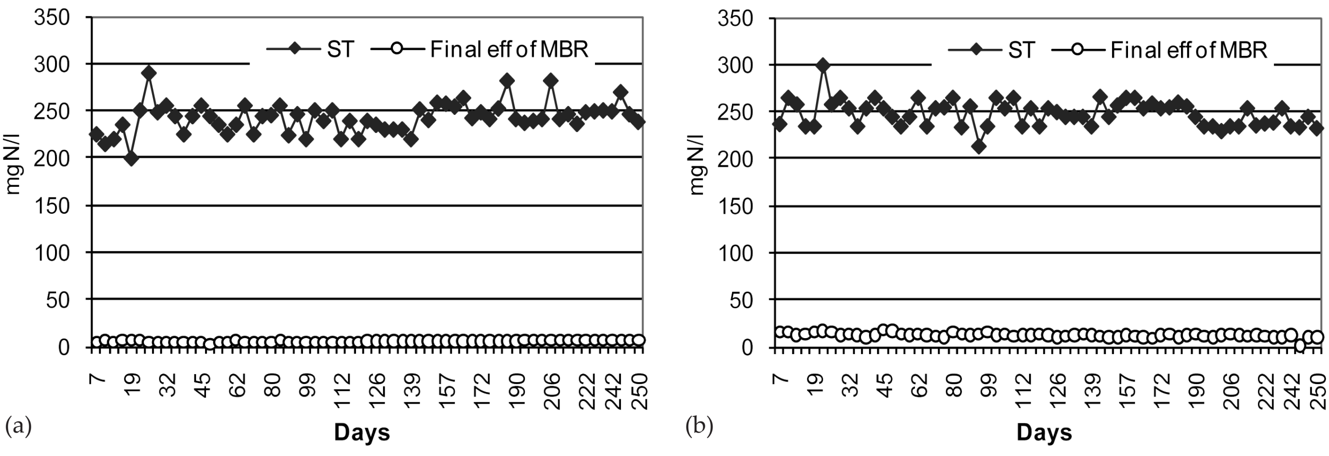


Fig. 8. Variations of (a) ammonia and (b) TKN of MBR permeate.

ammonia and TKN corresponding to the removal rate of 97.4% and 95.2% respectively via the MBR treatment.

It is worth mentioning that the reactor is regulated to receive wastewater five times a day. At moment of receiving such influent, vigorous aeration for 15 min occurs, followed by a great decrease in the aeration. The purpose is to enhance the nitrification and denitrification process as well as increasing the bacterial growth that consume the nutrient elements. At the meantime, the ammonia and any gases that could be possible formed through the aeration and/or nitrification/denitrification process can be released from the MBR unit mainly because the top the system is not completely sealed. The results achieved in terms of ammonia and TKN elimination are in good agreement with that found by Li and Chu [21].

Fig. 9 illustrates the level of total phosphorus (TP) in the MBR permeate. It ranged from 0.15 to 0.37 mg/l with average of 0.23 mg/l. The TP elimination rate ranged from 2.6 to 25 % with an average of 14.8 %.

## 4. Conclusions

The treated effluent is free of particles and organic load thus can be directly reused, e.g. for irrigation. Membrane bioreactors offer the possibility of very low sludge production rates when operated with very low food to mass ratios (F/M) [25].

The characteristics of the raw blackwater exhibited both diurnal and seasonal variation during the MBR operation. Although the influent characteristics were highly variable, the MBR system performed well throughout the one year study period. The treatment performance was not negatively affected by variation in operational parameters including organic loading rate and specific substrate removal efficiency. The level of TSS in the MBR effluent is not detected indicating the advantages of membrane filtration over the activated sludge processes. Hydraulic residential time (HRT) of 2.4 d in MBR was found to be sufficient for treating the blackwater. The average values of some parameters in permeate samples during all operation period were as following: COD, 42 mg $O_2$/l; BOD, 10 mg $O_2$/l; NH3-N, 5.8 mgN/l. High sludge ages are one of the main advantages of MBR, considering that in conventional treatment processes long SRTs are impossible because of bad settling ability of sludge at high concentration and withdrawal of suspended solids with the effluent [27]. The obtained results suggest that the MBR process can be technically feasible for blackwater treatment, not only for nitrification–denitrification and organic degradation, but also for the possible replacement of the conventional treatment process. Therefore, MBR process demonstrated the improved product quality in terms of physico-chemical parameters. Such performance of the MBR pilot system treating a highly variable and strong blackwater will guide the decision on a potential full-scale MBR application and reuse of treated wastewater for irrigation purpose in Egypt. It is worth mentioning that the total phosphates exhibited the lowest removal rate which is an advantage for the water reuse in irrigation on the desert sandy soil of Egypt.

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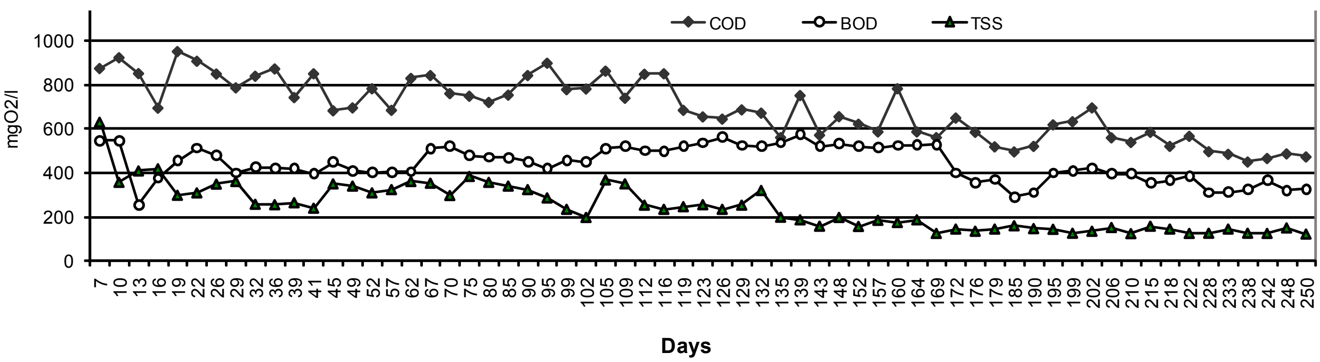


Fig. 9. Variations in the level of TP of MBR permeate.

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