TREATMENT OF POTATO PROCESSING WASTEWATER USING A MEMBRANE BIOREACTOR

S.K.I. Sayed [a], K.H. El-Ezaby [b], L.Groendijk [c]

[a] Department of Process Technology, Vitens Watercompany, P.O. Box 400, 8901 BE Leeuwarden, The Netherlands.
E-mail address: sameh.sayed@vitens.nl
[b] Environmental Sciences Department, Faculty of Science at Damietta, Mansoura University, P.O. Box 34517, New Damietta City, Egypt.
[c] Department of Environmental Technology, Van Hall Institute, P.O. Box 1528, 8901 BV, Leeuwarden, The Netherlands.

ABSTRACT

The present study was carried out to assess the feasibility of using a pilot scale aerobic side stream membrane bioreactor (MBR) for treatment of potato-processing wastewater. The MBR dealt with a continuous feeding with a constant organic load for 24 h a day. Volumetric organic loading rate up to 26.3 Kg COD m^{-3} d^{-1} was satisfactory accommodated, with a hydraulic retention time (HRT) varied from 24 h at the beginning to 8 h at the end of the study. The mean mixed liquor suspended solids (MLSS) concentration was 11.8 g/l and air flush – water flow ratios of 1-1 and 2-1 were applied to the membrane during the experiments. The mean value of the permeability of the side stream MBR during the whole period of the treatment of the potato-processing wastewater was 67.7 l/m^2/h/bar.

The biodegradability of the potato-processing wastewater was tested and the results revealed that 94.4 % of that water was biodegradable. The obtained value of the BOD_5^{20}/COD quotient for the potato-processing wastewater, which was 0.57, indicated also a good biodegradability of that wastewater. The achieved removal efficiency of the COD and BOD_5^{20} by using the aerobic side stream MBR was excellent regardless how high the COD or the BOD_5^{20} concentration of the studied wastewater. The MBR system was able to treat a high strength (potato-processing) wastewater with a COD of 17686 mg/l and gave a removal efficiency of 98.2 %. The mean removal efficiencies of the COD, BOD_5^{20}, TKN, NH_4^+-N and PO_4-P that achieved by the MBR system were reached up to 99.08, 99.85, 98.78, 98,70 and 77.67 %, respectively. The obtained results revealed also that increasing the applied air flush – water flow ratio from 1-1 to 2-1 made a reasonable improvement in the percent removal efficiency of the TKN, NH_4^+-N and PO_4-P during the treatment of the potato-processing wastewater. However increasing the air flush – water flow ratio showed no effect on the COD removal efficiency.

Keywords: Potato-processing wastewater; MBR; Biodegradability; COD; Removal efficiency

INTRODUCTION

Wastewaters discharged by industrial operations are in some cases among the worst sources of water resource pollution. Although the nature of the pollutants associated with these wastewaters differs greatly from one industry to another, in almost all cases the problems are caused by one or a combination of the following conditions in the wastewater: high Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD), high concentration of suspended solids and / or presence of toxic substances. Indeed the BOD and suspended solids in some industrial wastewaters may be a factor of 10 or more than the BOD and suspended solids in raw sewage. It is not hard to imagine that severe oxygen depletion and/or turbidity and sedimentation problems could result from the discharge of such wastewater [1].

Future applications of new wastewater treatment systems are inevitable in order to ensure the best possible elimination of pollutants from highly contaminated effluents. Not only it is essential to protect the aquatic environment against the discharge of high Chemical Oxygen Demand (COD) pollutants but it is also important to safeguard against the discharge of nitrogen, phosphorous, suspended solids and other potential contaminants. Nowadays, it is supposed that Membrane Bioreactor (MBR) wastewater treatment procedures represent an excellent solution to meeting the requirements for future wastewater treatment demands [2].

Membrane bioreactors, are the amalgamation of a suspended growth biological reactor and membrane filtration device into a single unit process. The membrane unit can be configured external to, as in side stream operation or immersed in the bioreactor. The coupling of a membrane to a bioreactor has attracted increasing interest both academically and commercially because of the inherent advantages the process offers over conventional biological wastewater treatment systems [3]. The primary driver for using a membrane bioreactor technology is to achieve a high degree of treatment while reducing footprint, treatment complexity and operational requirements [4]. The combination of high biomass concentrations and the complete retention of solids allow the process to be operated at low organic loading rates [5]. The lower loading rates also reduce excess sludge production down to below half that commonly occur in activated sludge. Moreover, permeate from the membrane is free from solids and macro-colloidal material [3].

The objective of this study is to assess the feasibility of using a laboratory scale aerobic side stream membrane bioreactor (MBR) for treatment of potato-processing wastewater. Potato-processing manufactures produce deep-frozen chipped potatoes, potato crisps, French fries, puree, starch and starch products. The wastewaters from these industries contain high concentrations of organic materials like starch and proteins, and are therefore very prone to fermentation and frothing. They have also significant concentrations of organic and inorganic nitrogenous compounds and phosphates. Therefore, the potato-processing wastewater is considered as a very good material for the study.

MATERIALS AND METHODS

A. Assessment of biodegradability of the potato-processing wastewater [6-9]

In the first part of this study, the biodegradability of the potato-processing wastewater was examined and assessed. The aim of these tests was to investigate the applicability of using the MBR treatment technique for treating the potato-processing wastewater. The tests were carried out generally by monitoring and measuring the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) for the wastewater for 28 days. These long-time degradability tests of wastewater samples involved the following aspects and procedures:

I. The degradability tests were performed at a constant temperature of 20°C.
II. Each type of wastewater was monitored daily via measuring the BOD by using of the OxiTop® Control system. At the same time, the COD was also measured via the open reflux method [10] but at interval times which required at least four separate tests during the 28 days, in addition to the test before dosing of 1 ml of activated sludge, which was supplied to the potato-processing wastewater samples.
III. The nutrient ratio in the beginning of the tests was kept in the optimum range for the biological growth (C : N : P = 100 : 23 : 3).
IV. The test was supplied with a certain drops of N-Allylthiourea (ATH) for the inhibition of the nitrification.

In addition to the pervious tests, the relation between the BOD_5^{20} and the COD was also investigated as an indication of a good or poor biodegradability [11],[12].

B. Treatment of potato-processing wastewater by using of aerobic side stream membrane bioreactor

1. Materials

a) Potato-processing wastewater

The source of the studied industrial wastewater was a wastewater from the potato-processing factory (VRISO) at Oosterbierum, the Netherlands. The characteristics of the studied wastewater are shown in Table (1).

Table (1): Characteristics of the potato-processing wastewater

Parameter	Concentration (mg/l)
COD	4100 – 18000
BOD_5^{20}	2700 – 7500
TKN	150- 500
NH_4^+-N	60 – 240
PO_4-P	35 – 170
COD : BOD_5^{20}	2.1 : 1
C : N : P	110 : 4 : 1

b) Aerobic activated sludge

The aerobic activated sludge used in this study was brought from an activated sludge system at the wastewater treatment plant of Leeuwarden, the Netherlands.

c) Ultrafiltration membrane module

The membrane used in this study was a product of the X-Flow Company, the Netherlands. The specifications of this Ultrafiltration membrane module are shown in Table (2).

Table (2): Specifications of the ultrafiltration membrane module

Parameter	Specification
Configuration	tubular
Material	Polyvinylidene fluoride
Membrane type	F 5385
Type of filtration	ultrafiltration
Mean pore size	30 nm
Hydraulic membrane diameter	8.0 mm
Membrane area	0.15 m^2
Module Length	100 cm

2. Procedures

The experimental setup, operational conditions, membrane cleaning, sampling and methods of analyses were as the following:

a) Setup of the Side Stream Membrane Bioreactor (MBR) System

The process scheme diagram of the side stream MBR system used for the treatment of the potato-processing wastewater is shown in Figure (A).

The aerobic side stream MBR system was setup in a laboratory scale in order to treat the potato-processing wastewater. The system was principally composed of:

1) 6 m^3 wastewater buffer tank,
2) screen of 1.0 mm for rejecting the large solid particles of the wastewater,
3) wastewater buffer tank of 600 L capacity,
4) influent feeding pump connected to a level control for keeping the volume constant inside the reactor.
5) aerobic reactor of 400 L capacity, surrounded by an external cooler to overcome the rising in the temperature inside the reactor.
6) oxygen meter: Microprocessor Oximeter OXI 196, WTW, Germany for the continuous monitoring of the oxygen concentration inside the reactor.

7) sludge-withdrawing pump to withdraw the excess of the sludge yield continuously from the reactor.
8) ultrafiltration membrane module working in a cross flow mode of operation which implied a feed, retentate and permeate.
9) permeate buffer tank including a backwash pump to backwash the membrane in intervals by the permeate itself.

Air was entrained continuously at the feed side of the membrane module, parallel to the flow of the influent wastewater. The ratios of 1-1, 2-1 and 3-1 of Air Flush-Water Flow were respectively applied to the membrane during the experiments.

The system was controlled by a Quick Scan, X-Flow, The Netherlands and monitored by a Data Logger, 1000 Series SQUIRREL METER / LOGGER, Made by Grant Instruments Ltd. Barrington Cambridge, England.

At the beginning of the experiment, the aerobic activated sludge, obtained from the municipal wastewater treatment plant, was adapted to the potato-processing wastewater for about 10 days until the mixed liquor suspended solids (MLSS) of about 8.0 g/l was obtained. Then the experiment was started to treat the potato-processing wastewater at a HRT of 24 hours, which was the highest HRT applied.

b) Operational Conditions

The operational conditions of the MBR system in case of treating the potato-processing wastewater was as shown in Table (3).

c) Cleaning regime of the membranes

The cleaning regime of the membranes during the treatment of the potato processing wastewater was in three forms:

i) Air Flush process, in which the air was entrained continuously at the feed side of the membrane, removing deposits from the membrane surface.
ii) The membrane was cleaned by the backwash, with the permeate for 1 minute every 10 minutes of production.
iii) The membrane was disconnected and cleaned chemically once a week, in the two following steps:

Step 1: Using of 500 p.p.m. sodium hypochlorite solution for 2 hours with a turbulence mixing.

Step 2: Using an enzymatic cleaning via a mixture of two enzymatic solutions, UltraSil 60 A and UltraSil 62 with a mixed ratio of 0.5 % and 0.25 % respectively, at a temperature of 35°C for 24 hours.

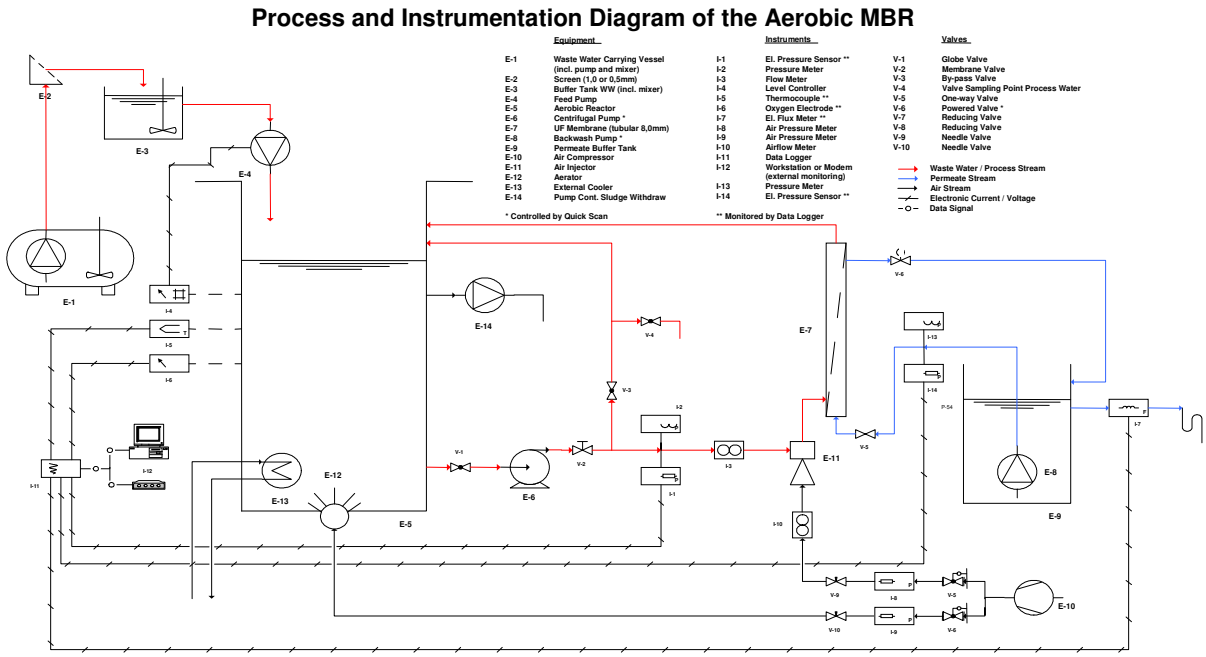

Figure (A): Process scheme diagram of the aerobic side stream MBR system

Table (3): The operational conditions of the MBR, used for treating of the potato-processing wastewater

Parameter	Operational Condition
Min. and Max. volume in the reactor	70- 300 Liter
Mode of operation	Inside to outside, cross flow
Trans Membrane Pressure (TMP)	0.5 bar
Backwash pressure	0.35 bar
Production – Backwash time	10 min.- 1 min.
Hydraulic Retention Time (HRT)	24, 18, 15, 12 and 8 hours
Average Volumetric Organic Loading Rate	6.1 – 26.3 Kg COD/m^3/day
Average Sludge Loading Rate	0.52 – 2.23 kg COD. kg^{-1} MLSS . d^{-1}
Mixed Liquor Suspended Solids (MLSS)	11.8 g/l
Mean sludge age	43 days
Air flush – Water flow ratio	1-1 and 2-1
Oxygen concentration inside the reactor	1.5 – 6 mg/l
Temperature in the bioreactor	20 – 28 C^o
pH in the bioreactor	5.5 – 6.5

d) Sampling

The influent samples and the samples for the dry matter content analyses were collected via a grab sampling method while the permeate samples were collected via a composite sampling method.

e) Methods of analyses

The following characteristics were monitored during the study:

1- Chemical Oxygen Demand (COD).
2- Biochemical Oxygen Demand (BOD_5^{20}).
3- Total Kjeldahl Nitrogen (TKN).
4- Ammonia Nitrogen (NH_4^+-N).
5- Total Phosphate (PO_4-P).
6- Dry matter content
   i) Mixed Liquor Suspended Solids (MLSS).
   ii) Mixed Liquor Volatile Suspended Solids (MLVSS).

The mentioned characteristics were determined according to the Standard Methods for the Examination of Water and Wastewater [10], except for the PO_4-P and $BOD_5^{20.}$ The PO_4-P was determined by using of DR LANGE Test Kit; (Sensor Array Photometer "LASA® 20" with its chemical kits); Germany; method LCK 350 with measuring range 2-20 mg/l PO_4-P. The highly concentrated samples were diluted before the analyses. The BOD_5^{20} was determined by using of a manometric BOD measuring system: OxiTop® Control systems, WTW, Germany.

The samples for all the mentioned characteristics were collected from both of the influent and permeate except the MLSS and MLVSS, which were collected from the bioreactor.

In addition to monitoring of the mentioned characteristics, the permeability of the side stream MBR was also daily monitored and calculated in $l/m^2/h/bar$.

RESULTS AND DISCUSSION

A. Biodegradability of the Potato-Processing Wastewater

The obtained results of the 28 days BOD biodegradability experiment of the potato-processing wastewater are shown in Figure (1). At the first few days of studying the BOD biodegradability of the potato-processing wastewater, there was a rapid increase in the BOD values as shown in Figure (1). After that, the values started to be in a slight increase. The plateau formation of the values was reached after about 12 days and the values were mostly stable till the end of the study after 28 days. On the other hand, the COD biodegradability of the potato-processing wastewater was also studied at the same time of the BOD biodegradability study. At the first two days of the study, there was a steep decrease in the COD values followed by a temporary stability of the values during the next eight days, then decreasing again in the COD values till they became mostly stable after about 13 days from the beginning. The behavior of both of the BOD and COD biodegradability of the potato-processing wastewater revealed that the compounds of the studied wastewater are biodegradable after about 12-13 days. This indicates that the potato-

processing wastewater is medium biodegradable [13], with respect to the time needed to reach the maximum percent of biodegradation.

The biodegradable part of the potato-processing wastewater during the biodegradability experiment was about 94.4%. A value of the BOD_5^{20}/COD quotient of 0.57 was obtained for the studied potato-processing wastewater indicates also a good biodegradability of that wastewater.

B. Treatment of the potato-processing wastewater

The assessment of the efficiency of the aerobic side stream MBR for removing some organic and inorganic substances from the potato-processing wastewater was performed by evaluating the quality of the permeate, produced from the system, in comparison to the influent. The evaluation was done by monitoring some influent and permeate characteristics; COD, BOD_5^{20}, TKN, NH_4^+-N and PO_4-P, at different HRT; 24, 18, 15, 12 and 8 hours in succession.

The HRT 24 hours was applied using the air flush – water flow ratios 1-1, 2-1 and 3-1 successively. The efficiency of removing of the all studied characteristics was the best among the whole study when the air flush – water ratio 3-1 was applied. However, the system was operated under this ratio 3-1 for only 4 days because the experience with this ratio was not encouraging. The system did not work properly because of a dramatic drop in the trans membrane pressure, which could not be controlled. Therefore, it was obvious that the air flush – water ratio 3-1 is impractical.

On the other hand, the HRT 18, 15, 12 and 8 hours were applied using the air flush – water flow ratio 2-1. The percent removal efficiencies could also be calculated depending on the obtained results.

COD removal efficiency

The values of COD of the treated water samples (permeate) were always less than that of the potato-processing wastewater (influent). COD values for the permeate were ranged from 32.8 to 315.3 mg/l during the treatment of the potato-processing wastewater, whereas the corresponding values for the influent were found to be from 4095 to 17686 mg/l.

The obtained COD results for the influent and the permeate at HRT 24 hr and air flush – water flow ratios of 1-1 and 2-1 respectively are shown in Table (4), even as the obtained COD results for the influent and the permeate at HRT 8 hr and air flush – water ratios of 2-1.

The mean removal efficiency of COD at air flush – water flow ratio 1-1 and HRT 24 hr was 98.32% while it was 98.97, 99.08, 98.53, 98.91 and 98.90% at air flush –

water flow ratio 2-1 and HRT 24, 18, 15, 12 and 8 hr respectively. These percent removal efficiencies of COD indicate an excellent removal efficiency of the COD of the potato-processing wastewater by using the aerobic side stream MBR system. The MBR system was able to treat a high strength (potato-processing) wastewater with a COD of 17686 mg/l and gave a removal efficiency of 98.2%.
There was almost no difference in the percent removal efficiency on using different HRT, which indicates that the MBR system was capable to give mostly the same percent removal efficiency with the lowest HRT used (8 hr).

BOD_5^{20} removal efficiency

The results of the BOD_5^{20} during the different stages of the experiment showed that the BOD_5^{20} of the potato-processing wastewater was almost removed completely. The permeate values of the BOD_5^{20} were ranged from zero to 39.4 mg/l, whereas the corresponding values for the influent were ranged from 2750 to 7540 mg/l. The obtained BOD_5^{20} results for the influent and permeate at HRT 24 hr and air flush – water ratios of 1-1 and 2-1 respectively are shown in the Figures (2) and (3), while the obtained BOD_5^{20} results for the influent and the permeate at HRT 8 hr and air flush – water ratios of 2-1, are shown in Table (4).

The mean removal efficiency of BOD_5^{20} at air flush – water flow ratio 1-1 and HRT 24 hr was 99.44% while it was 99.85, 99.50, 99.56, 99.68 and 99.69% at air flush – water flow ratio 2-1 and HRT 24, 18, 15, 12 and 8 hr respectively.

The values of the BOD_5^{20} of the permeates of the treated potato-processing wastewater were almost within the LAWA (German) discharge standards for the potato-processing wastewater, in which the maximum permissible level of the BOD_5^{20} is 30 mg/l [14].

TKN removal efficiency

The results of the TKN during the different stages of the experiment showed that there was a great reduction in the TKN concentrations of permeate compared with the influent of the potato-processing wastewater. The values of TKN of permeate were ranged from 1.3 to 54.2 mg/l, whereas the corresponding values for the influent were ranged from 148 to 493 mg/l. The obtained TKN results for the influent and the permeate at HRT 24 hr and air flush – water ratios of 1-1 and 2-1 respectively are shown in the Figures (4) and (5), while the obtained TKN results for the influent and the permeate at HRT 8 hr and air flush – water ratios of 2-1, are shown in Table (4). The mean removal efficiency of the TKN at air flush – water flow ratio 1-1 and HRT 24 hr was 96.20% while it was 97.64, 94.74, 98.78, 95.77 and 98.21% at air flush – water flow ratio 2-1 and HRT 24, 18, 15, 12 and 8 hr respectively.

The obtained high percent removal efficiency of the TKN might be attributed to the completion of the nitrification process in the bioreactor.

NH_4^+-N removal efficiency of the potato-processing wastewater

The values of NH_4^+-N of permeate were ranged from zero to 49.7 mg/l, whereas the corresponding values for the influent were ranged from 61 to 241 mg/l. The obtained NH_4^+-N results for the influent and the permeate at HRT 24 hr and air flush – water ratios of 1-1 and 2-1 respectively are all shown in Table (4), even as the obtained NH_4^+-N results for the influent and the permeate at HRT 8 hr and air flush – water ratios of 2-1. The mean removal efficiency of the NH_4^+-N at air flush – water flow ratio 1-1 and HRT 24 hr was 92.83% while it was 98.17, 95.28, 98.70, 92.95 and 97.89% at air flush – water flow ratio 2-1 and HRT 24, 18, 15, 12 and 8 hr respectively.

The obtained results showed that the percent removal efficiencies of the NH_4^+-N of the potato-processing wastewater were relatively high, which might also be attributed to the completion of the nitrification process in the bioreactor.

PO_4-P removal efficiency

The values of PO_4-P of permeate were ranged from 3.3 to 53.7 mg/l, whereas the corresponding values for the influent were ranged from 36 to 170 mg/l. The obtained PO_4-P results for the influent and the permeate at HRT 24 hr and air flush – water ratios of 1-1 and 2-1 respectively are all shown in Table (4), even as the obtained NH_4^+-N results for the influent and the permeate at HRT 8 hr and air flush – water ratios of 2-1. The mean removal efficiency of the PO_4-P at air flush – water flow ratio 1-1 and HRT 24 hr was 67.3%, while it was 74.43, 70.95, 77.45, 74.57 and 77.67% at air flush – water flow ratio 2-1 and HRT 24, 18, 15, 12 and 8 hr respectively.

The relatively low percent removal of PO_4-P of the potato-processing wastewater indicates that the MBR system was unable to remove the PO_4-P efficiently from the potato-processing wastewater. This would be attributed to the relatively less volume of excess sludge wasted, which reduced the amount of phosphorous removed from the aerobic bioreactor with the excess sludge.

The range of the influent values, permeate values and the mean values of the % removal efficiencies of the all studied parameters at the different HRT, during the treatment of the potato-processing wastewater using the side stream MBR are summarized in Table (4).

Table (4): The influent values, permeate values and mean values of the % removal efficiencies of the studied parameters during the treatment of the potato-processing wastewater

Para meter	HRT (hr.)	Air flush - Water flow Ratio	Influent (mg/l)	Permeate (mg/l)	Mean % Removal efficiency
COD	24	1 - 1	4360 – 8540	50 - 235	98.3
	24	2 - 1	4100 – 13600	33 - 121	99.0
	18		4400 - 12600	33 – 125	99.1
	15		6300 – 17700	62 – 315	98.5
	12		5556 - 12210	48 – 385	98.9
	8		5328 - 13493	45 – 170	98.9
BOD_5^{20}	24	1 - 1	2750 - 4170	6 – 23	99.4
	24	2 - 1	4420 - 7210	2 – 23	99.9
	18		3720 - 5400	8 – 28	99.5
	15		5744 - 7100	23 – 34	99.6
	12		4960 - 5740	12 – 23	99.7
	8		2290 - 7540	0 – 40	99.7
TKN	24	1 - 1	410 – 500	12 – 21	96.2
	24	2 - 1	150 – 390	1 – 11	97.6
	18		210 –325	3 - 42	94.7
	15		230 – 360	3 – 5	98.8
	12		240 – 410	3 – 55	95.8
	8		220 – 465	3 – 13	98.2
NH_4^+-N	24	1 - 1	150 – 225	4 - 21	92.8
	24	2 - 1	60 – 165	0 – 6	98.2
	18		145 – 240	2 – 30	95.3
	15		110 – 220	1 – 4	98.7
	12		75 – 230	2 – 50	93.0
	8		70 – 230	1 – 10	97.9
PO_4-P	24	1 - 1	40- 105	13 – 30	67.3
	24	2 - 1	38 – 90	3 – 22	74.4
	18		110 – 125	30 – 41	71.0
	15		105 – 170	25 – 32	77.5
	12		80 – 110	16 – 30	74.6
	8		35 -155	5 – 54	77.7

MLSS and MLVSS concentrations, Volumetric Organic Loading Rate and Permeability

The mean concentration of the mixed liquor suspended solids (MLSS) during the study was 11.8 g/l, while the mean concentration of the mixed liquor volatile suspended solids (MLVSS) was 8.3 g/l. The mean % MLVSS / MLSS during the

whole experiment was 73.5%. The obtained results of the analyses of both of MLSS and MLVSS during the study are shown in Figure (6).

The high removal efficiency of COD, BOD_5^{20}, TKN and NH_4^+-N during the treatment of the potato-processing wastewater showed that the mean value of the MLSS (11.8 g/l) was good enough for an efficient biodegradation process and for getting a relatively high sludge age of 43 days. Accordingly, the disposed sludge was low.

The mean % MLVSS / MLSS throughout the experiment, which was found to be about 73.5%, indicating that the organic matter content in the bioreactor was high and there was no accumulation of inorganic materials occurred. This in turn led to a good condition for the biodegradability of the potato-processing wastewater.

The mean applied volumetric organic loading rate of the MBR system during the treatment of the potato-processing wastewater, at HRT 24 h and air flush – water flow ratio 1- 1 was 6.1 Kg COD/m^3/day. At air flush water flow ratio 2 – 1, it was ranging from 7 Kg COD/m^3/day at HRT 24 h to 26.3 Kg COD/m^3/day at HRT 8 h. The mean volumetric organic loading rates during all stages of the treatment at air flush - water flow ratio 2 – 1 are shown in Figure (7). The study revealed that the MBR was able to accommodate significantly high volumetric organic loading rates during the all stages of the potato-processing wastewater treatment, which reached to 26.3 Kg COD/m^3/day at HRT 8h and air flush – water flow ratio 2-1.

The values of the permeability of the side stream MBR during the whole period of the treatment of the potato-processing wastewater were ranged from 206.8 to 10.7 l/m^2/h/bar with a mean value of 67.7 l/m^2/h/bar. The recorded results of the permeability during the whole experiment are shown in Figure (8).

The effect of air flush – water flow ratio, on the removal efficiency and permeability of the side stream MBR

The results revealed that increasing the air flush – water flow ratio from 1 – 1 to 2 – 1 made a reasonable improvement in the percent removal efficiency of the TKN, NH_4^+-N and PO_4-P during the treatment of the potato-processing wastewater as shown in Table (4). The improvement in the removal efficiency of the TKN and NH_4^+-N by increasing the air flush – water flow ratio might be due to the increase of the dissolved oxygen level inside the bioreactor and in turn providing more oxygen supply for the Nitrosomonas sp. and Nitrobacter sp. to convert NH_4^+ to NO_3^- during the nitrification process. In the same manner, the obligate aerobic genus Acinetobacter sp. which present in the activated sludge inside the bioreactor might use the excess oxygen available in the bioreactor to uptake more phosphate. However, increasing the air flush – water flow ratio to 2 – 1 showed no significant effect on the COD removal efficiency. This would be attributed to the sufficiency of the dissolved oxygen that supplied to the bioreactor at air – water ratio 1 – 1 for achieving the complete biodegradation of the biodegradable part of the COD, as appeared by the achieved percent removal efficiency. The remaining part of the

COD (non-biodegradable part) can not be removed biologically under any circumstances. Accordingly, supplying more dissolved oxygen to the bioreactor; as in case of applying the air – water ratio 2-1 can not enhance the removal efficiency of the COD. At the same time, increasing the air flush – water flow ratio to 2 – 1 had no obvious effect on the permeability.

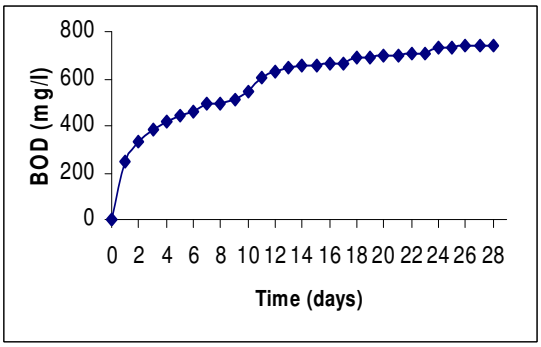

Fig 1: BOD biodegradability of the potato processing wastewater

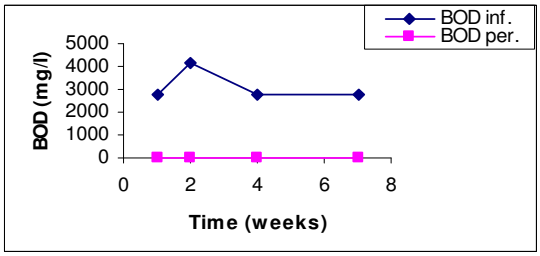

Fig 2: BOD values for potato-processing wastewater at HRT 24 hr and air flush: water ratio = 1:1.

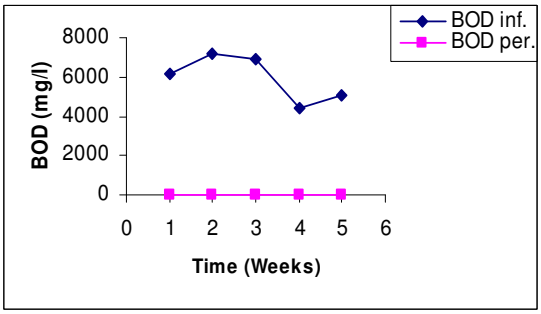

Fig 3: BOD values for potato-processing wastewater at HRT 24 hr and air flush: water ratio = 2:1.

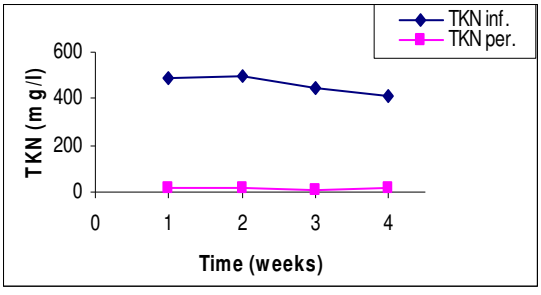

Fig 4: TKN values for potato-processing wastewater at HRT 24 hr and air flush: water ratio = 1:1.

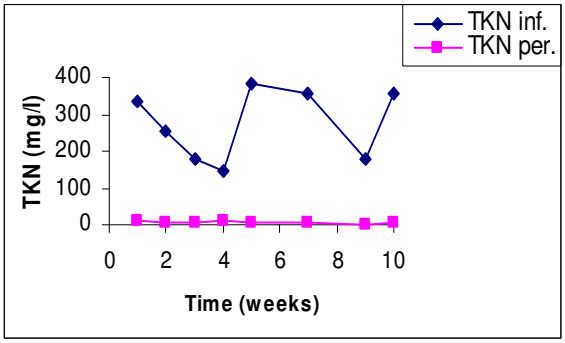

Fig 5: TKN values for potato-processing wastewater at HRT 24 hr and air flush: water ratio = 2:1.

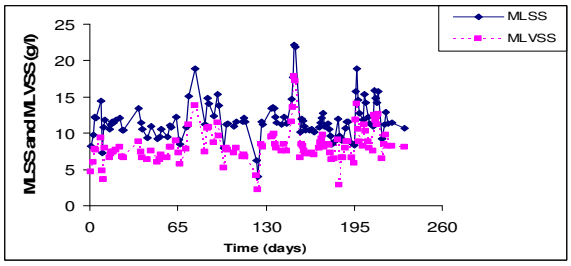

Fig 6: MLSS and MLVSS (g/l) of the side stream MBR during the treatment of potato processing wastewater

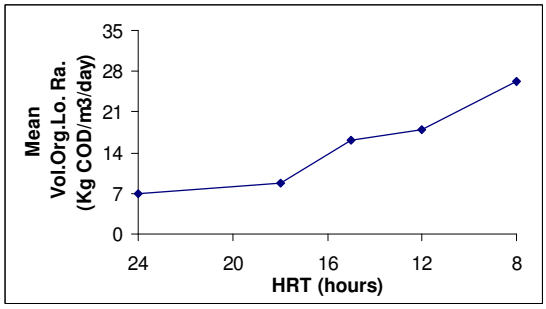

Fig 7: Mean Volumetric Organic Loading Rates at air flush: water ratio = 2:1 during the treatment of the potato-processing wastewater

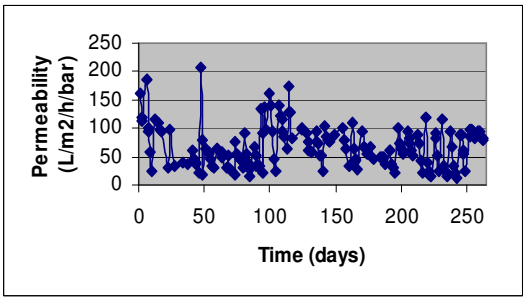

Fig 8: Permeability of the side stream MBR during the treatment of the potato-processing wastewater

CONCLUSIONS

1- The biodegradability of the potato-processing wastewater was generally good.
2- The aerobic side stream MBR was highly efficient for removing the COD, BOD_5^{20}, TKN and NH_4^+-N from the potato-processing wastewater.
3- High removal efficiency of the COD and BOD_5^{20} was achieved by using the aerobic side stream MBR regardless how high the COD or the BOD_5^{20} concentration in the studied wastewater. The MBR system was able to treat a high strength (potato-processing) wastewater with a COD of 17686 mg/l and gave a removal efficiency of 98.2 %.
4- The water produced from the treatment of the potato-processing wastewater by using of the aerobic side stream MBR was almost complying with the international standards for the effluent discharge to the surface water especially with respect to the BOD_5^{20} and TKN.
5- The aerobic side stream MBR was capable to achieve high removal efficiency at the lowest applied HRT, which was 8 hours.
6- The removal efficiency of the PO_4-P during the treatment of the potato-processing wastewater using the aerobic side stream MBR was relatively low.
7- The applied MLSS, which was around 10–12 g/l during the treatment of the potato-processing wastewater, was good enough for an efficient biodegradation process in the bioreactor and for a stable operation condition of the MBR system.
8- The aerobic side stream MBR was capable to operate at high sludge ages, which were 43 days during the treatment of the potato-processing wastewater. Because of working at high sludge age, the sludge production was low, which is one of the advantages of using the MBR's.
9- The studied MBR revealed high volumetric organic loading rate capability, which reached to 26.3 Kg COD/m^3/day at HRT 8 hours, during the treatment of the potato-processing wastewater.
10- Changing the air flush – water flow ratio from 1 – 1 to 2 – 1 improved the removal efficiency of the TKN, NH_4^+-N and PO_4-P during the treatment of the potato-processing wastewater by using of the aerobic side stream MBR. However, it didn't improve the COD removal efficiency.

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