*Environ Res Tec, Vol. 5, Issue. 3, pp. 197–201, September 2022*

Environmental Research and Technology
https://ert.yildiz.edu.tr - https://dergipark.org.tr/tr/pub/ert
DOI: https://doi.org/10.35208/ert.1102829

**Research Article**

# Treatment of slaughterhouse industry wastewater with ultrafiltration membrane and evaluation with life cycle analysis

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## ARTICLE INFO

*Article history*
Received: 13 April 2022
Revised: 03 June 2022
Accepted: 15 July 2022

**Key words:**
Irrigation water; Life cycle assessment; Membrane system; Slaughterhouse wastewater

## ABSTRACT

Slaughterhouse wastewater is one of the most produced industrial wastewater in the world and has a high pollution potential, and this wastewater can cause a high level of polluting effect when it is given directly to river beds or sewage systems. Wastewater contains proteins, fats, carbohydrates in the treatment of blood, skin and feathers, which results in much higher biological oxygen demand (BOD) and chemical oxygen content (COD). The possibility of using ultrafiltration for slaughterhouse wastewater treatment was investigated. The results showed that ultrafiltration can be an efficient purification method. COD and $BOD_5$ removal efficiency is around 96% and 95%. In addition to these results, the Life Cycle Analysis (LCA) of the ultrafiltration system was also carried out. Accordingly, the effects of ultrafiltration system on human health, ecosystem quality, climate change and resources were calculated as 0,00000046 Disability-Adjusted Life Years (DALY), 0,134 PDFxm$^2$yr, 0,336 kg $CO_2$ eq and 6,937 MJ respectively. As a result of the study, it is thought that slaughterhouse wastewater can be used as irrigation water after passing through the ultrafiltration membrane due to the high content of N and P.

**Cite this article as:** Çetinkaya AY, Bilgili L. Treatment of slaughterhouse industry wastewater with ultrafiltration membrane and evaluation with life cycle analysis. Environ Res Tec 2022;5:3:197–201.

## INTRODUCTION

Global meat production has doubled in the last thirty years, and it is thought that this consumption will continue to increase rapidly with the increase in the income and quality of life of people in underdeveloped countries [1–3]. Slaughterhouse wastewater (SWW) is one of the most produced industrial wastewater worldwide. It is assumed that the European SWW industry produces 145 million m$^3$ of wastewater per year that must be treated for discharge into rivers or municipal wastewater networks. SWW industries use approximately 29% of the fresh water consumed by the agricultural sector worldwide [4]. In 2004, the United States Environmental Protection Agency (USEPA) listed SWW as one of the most harmful industrial wastes in the agriculture and food category. SWW is characterized by a complex mixture of mostly oil, protein and fiber [5]. These wastewaters cause a highly polluting effect when they are discharged into river beds or sewer systems without any treatment. Due to the high organic, nitrogen (N) and phosphorus (P)

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Published by Yıldız Technical University Press, İstanbul, Türkiye

content of these wastewaters, they cause eutrophication in surface water and pollution of groundwater [6]. Wastewater from the SWW industry needs to be treated and stabilized before it is discharged into the soil to prevent environmental pollution, removing the contents such as blood, manure, hair, oil, feathers and bones [7].

Due to the rapid population growth of developed Asian countries such as Saudi Arabia, Japan and South Korea, the need for more and quality water has increased. Developed Asian countries such as Singapore, Japan, and South Korea have adopted large-scale Ultrafiltration membranes (UF) membrane water purification systems to partially fulfill their drinking water requirements and through distribution networks. UF have made their way into wastewater treatment methods quickly, thanks to their environmental friendliness and easy installation of advanced devices [8]. It has been reported that membrane technologies fulfill multiple sustainability criteria in terms of flexibility, adaptability, minimal footprint and environmental impacts [9, 10]. UF membrane systems have received a lot of notice in the water treatment industry as they can provide stable filtrate quality by removing colloids, particles and microorganisms. Compared to conventional treatment methods, UF membrane provides better quality purified water. Compared to conventional treatment methods, UF membrane provides better quality purified water. Removal of pathogens and particles can be achieved with a UF membrane, which significantly increases the biological safety of drinking water. Particles and macromolecules in the range of 0.001–0.1 µm are usually removed in these systems [11]. Dissolved salts and small molecules in water pass through the membrane. Substances removed include colloids, proteins, microbiological contaminants and large organic molecules. In UF membrane systems, molecules with molecular weight greater than 1000–100000 Da are removed. The application pressure in the membrane is in the range of 1–7 bar on average [12].

Life Cycle Analysis (LCA), in the simplest terms, is an innovative and holistic approach that aims to reduce the energy, waste and emissions that any product, system or service consumes during the process from the raw material and preliminary design stage to the recycling and disposal stage. LCA is a scientific and comparative analysis and evaluation process of the environmental effects of a product, system or service. LCA differs from traditional methods with the terms "cradle to grave" and "functional unit" [13]. There are four concepts in the concept of LCA, namely target and scope definition (ISO 14040), inventory analysis (ISO 14041), impact assessment (ISO 14042) and interpretation (ISO 14043), and these four concepts should be combined with others for the healthy execution and implementation of the LCA method [14]. In this study, the treatment performance of SWW with UF membrane was evaluated. In addition, the reuse potential of treated water was investigated according to current water quality standards. These treatment performance values were analyzed with LCA and their effects on the ecosystem were examined.

**Table 1.** Chemical analysis results

| Parameter | Raw wastewater (mg/L) | UF membrane removal efficiency (%) |
|---|---|---|
| COD | 4150 | 96 |
| $BOD_5$ | 3120 | 95 |
| TDS | 2320 | 94 |

## MATERIALS AND METHODS

The raw wastewater used in this study was taken from the integrated meat plant in Aksaray, which produces approximately 5 tons of wastewater per day. The effluent samples obtained were characterized based on the pollutant concentration. Samples were preserved by storing them in a cold room at 4°C and brought to room temperature only 2 hours before the start of the experiment. COD was performed using the closed reflux method (5220-D) and $BOD_5$ was determined according to the 5-day BOD test method (5210-B). The Chemical Oxygen Demand (COD) of the raw wastewater was measured as 4150 mg/L, and the Biological Oxygen Demand ($BOD_5$) was measured as 3120 mg/L.

### Membrane System

Details of membrane system design the study have been summarized in earlier study [15]. UP150 (Microdyn-Nadir, Germany) was used in this study. The membrane assembly was operated under a pressure of 3 bar. The experimental setup of the membrane module consists of a nitrogen gas system for constant pressure filtration. The filtered water was weighed and collected using a personal computer to calculate the data flow. All experimental sets were repeated 2 times.

### LCA System

In this study, SimaPro 8.2.3.0 package program and Ecoinvent 3 library in this program and IMPACT 2002+ method were used for LCA calculations. IMPACT 2002+ was developed by the Swiss Federal Institute of Technology in 2002 and was designed to link 14 intermediate categories with 4 damage categories. Damage categories, on the other hand, make it possible to qualitatively understand the damage of the product, system or service to human health and the environment.

## RESULTS AND DISCUSSIONS

Most of the wastewater from the SWW is of organic origin and contains high amounts of COD and $BOD_5$. The results in Table 1 reveal that there is significant removal of certain pollution indices (ie $BOD_5$, COD) after ultrafiltration of SWW. $BOD_5$, COD, TDS (Total Dissolved Matter) removal was 94%, 96% and 94%, respectively. In the microfiltration membrane, the removal of $BOD_5$, COD and TDS is 66%, 64% and 71%, respectively.

SWW cause pollution of water resources and emerge as a large pollutant load in the treatment plant. Bohdziewicz and Sroka (2005) analyzed SWW with RO membrane and showed a removal efficiency of 85.8%, 50.0%, 97.5% and 90.0% for COD, $BOD_5$, Total Phosphorus (TP) and TN, respectively [16]. Gürel and Büyükgüngör (2011) investigated the performance of membrane bioreactors (MBRs) for the treatment of SWW. It achieved 44%, 65%, 96% and 97% removals for Total Kjeldahl Nitrogen (TKN), TP, Total Organic Carbon (TOC) and COD, respectively [17]. Although organic matter was successfully removed, a high nitrate concentration remained in the treated wastewater. Also, membrane processes may face major fouling problems when processing high concentration feed streams such as the abattoir industry, which can greatly limit the rate of permeability across membranes due to the formation of thick biofouling layers on thick surfaces [18, 19].

### Flux Graphs of Membranes

Membrane fouling is stated as the main disadvantage of membrane technology in the face of widespread application. Contamination reduces the permeability because of the deposition of colloids, particles, macromolecules and salts on the surface of the membranes, thus reducing the flux, shortening the membrane life and increasing the cost due to frequent chemical and physical cleaning. Operating at higher membrane flows results in increased system costs. On the other hand, higher flux treatment can increase surface contamination by increasing the convective force towards the membrane, since flux is also directly related to the driving force and the total hydraulic resistance offered by the membrane. Flux graph of UF membrane was given in Figure 1.

When Figure 1 was examined, it was observed that the flux in UF membrane decreased over time.

### LCA Results

In this study, the analysis of the environmental effects of the system was completed by performing the LCA analysis of the parts of the UF membrane system. Table 2 presents the damage category values obtained as a result of the LCA analysis of the ultrafiltration membrane system.

DALY is defined as the healthy life span lost as a result of various processes [20]. In DALY calculations, each individual has a healthy life span, which is assumed to be in his hands at birth. This period may decrease over time due to various factors. DALY is an expression of this loss of healthy life expectancy [20]. PDF x $m^2$ x yr unit is an expression of the species that are expected to disappear in 1 $m^2$ of soil over a year. While the Kg $CO_2$ eq value is a unit in which the climate change effects of various gases are measured in terms of $CO_2$, the MJ unit is the expression of the energy spent while extracting or processing resources [21].

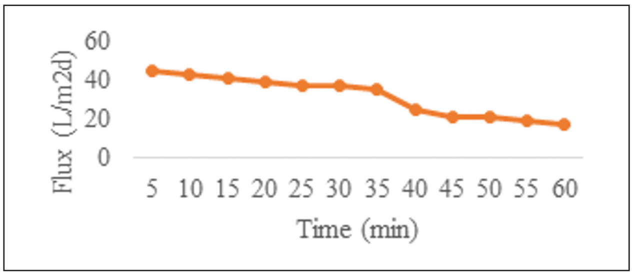

**Figure 1**. Flux graph of UF Membrane.

**Table 2.** LCA analysis results

| Damage category | Value | Unit |
|---|---|---|
| Human health | 0,00000046 | DALY |
| Ecosystem quality | 0,134 | PDF x $m^2$ x yr |
| Climate change | 0,336 | kg $CO_2$ eq |
| Resources | 6,937 | MJ |

At these values, it seems that the ultrafiltration membrane system steals 0.00000046 years from the healthy life of a person. The same system causes the extinction of a total of 0.134 species in one $m^2$ of soil in a year and produces 0.336 kg of $CO_2$ equivalent greenhouse gas. The total energy spent for the creation of the membrane system, including the extraction and processing of raw materials, was calculated as 6,937 MJ.

In addition, the production of the ultrafiltration membrane system releases 320.097 g of $CO_2$, 1.16 g of methane ($CH_4$) and 1.44 g of sulfur dioxide ($SO_2$) into the air. The same system deposits various types of petroleum-derived products and 12.76 g of calcium waste onto the land. Similarly, 13.62 g silicon and 7.69 g Sulphate ($SO_4^{2-}$) lead the way in wastes to water. These values belong to the waste products that are released the most, and in fact, much more waste products are released into the environment. The total effects of all these wastes and emissions are already presented in Table 2.

## CONCLUSIONS

Agricultural water is defined as water used to grow fresh produce and sustain livestock. Due to the effects of urbanization, industrialization and climate change, there will be more competition among agricultural water resources. For these reasons, countries have started to use pre-treated waste water as irrigation water in agriculture. Wastewater contains rich nutrient material and fertilizer consumption can be less than 50% when this wastewater is applied to the soil after a pre-treatment. SWW contain a high percentage of nutrients. With this study, it is thought that SWW can be used as irrigation water after passing through ultrafiltration membrane, since it contains high amounts of N and P. In addition to the environmental benefits of SWW, the environmental damage caused by the processing of these waters was also examined, and the product life cycle was completed and a full environmental performance review was carried out. The LCA technique can be used to integrate environmental considerations holistically into the water recycling technology selection. Accordingly, while the environmental damage of membrane systems occurs in very small amounts, it is estimated that the benefits of the treated wastewater will be much more than the damage to the environment.

## ACKNOWLEDGMENT

The authors express their special thanks to Metsims Sustainability Consulting for their support in using the SimaPro program.

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## ETHICS

There are no ethical issues with the publication of this manuscript.

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