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Environmental impact assessment for a meat processing industry in Turkey: wastewater treatment plant

Pelin Soyertaş Yapıcıoğlu

Engineering Faculty, Environmental Engineering Department, Harran University, Şanlıurfa 63000, Turkey
E-mail: pyapicioglu@harran.edu.tr

Abstract

The meat processing industry has many unfavorable impacts to the environment in Turkey. One of these impacts is wastewater treatment. Meat processing wastewater contains large amounts of proteins, fats, nutrients such as nitrogen, and pathogenic and non-pathogenic microorganisms and viruses. The high organic and hazardous content of wastewater causes environmental challenges for the flora and fauna in receiving water bodies unless it is treated adequately. Due to these reasons, the treatment process to be implemented should be the least damaging to the environment. In this study, three treatment scenarios that include a UASB (upflow anaerobic sludge bed) reactor (Scenario-1), an advanced oxidation process that includes UV/H_2O_2 treatment (Scenario-2) and a membrane bioreactor (Scenario-3) have been studied for a meat processor's wastewater treatment plant. For these three scenarios, an environmental impact assessment was undertaken using the Fine-Kinney method. The evaluation results revealed that Scenario-2 has the smallest environmental impact value with 475. Scenario-1 has the highest total environmental impact value as 765. Scenario-3's environmental impact value is 637. According to the evaluation results, the UV/H_2O_2 process is the most applicable technology for wastewater treatment in Turkey's meat industry.

Key words: advanced oxidation, environmental impact, meat processing wastewater, membrane bioreactor, UASB reactor

INTRODUCTION

The meat processing industry generates large volumes of wastewater in many countries, which is in need of considerable treatment if its release to the environment is to be sustainable (Johns 1995). Turkey is one of these countries that has a significant number of these types of facilities. Meat processing has many unfavorable environmental impacts, with wastewater disposal from this industry being the most significant. The meat industry has been classified as generating one of the most harmful wastewaters for the environment by the United States Environmental Protection Agency (EPA 2004).

The effluent discharge from meat industries causes deoxygenation of rivers and contamination of groundwater (Masse & Masse 2000; Lecompte & Mehrvar 2014). The organic matter and total suspended solids concentration is very high and has a highly contaminating effect (Ruiz *et al.* 1997). The wastewater mainly contains organics, pathogenic and non-pathogenic viruses and bacteria, and detergents and disinfectants used for cleaning activities (Debik & Coskun 2009; Lecompte & Mehrvar 2014). For effective treatment and a reduced impact of meat processing wastewater, the organic and microbial content should be decreased. There are many treatment methods such as biological, biochemical and chemical processes that could be used by the meat industry. There are several methods for the treatment of meat processing wastewater, with most focusing on biological processes such as activated sludge, stabilization ponds and aerobic reactors (Davarnejad & Nasiri

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2017). Although these systems are effective and economic, they also usually require a long retention time, have a large footprint, have a high energy demand due to aeration, and generate high volumes of sludge (Daneshvar *et al.* 2007; Bayar *et al.* 2014; Davarnejad & Nasiri 2017). At the same time, anaerobic digestion could be implemented in general due to the high chemical oxygen demand (COD) (>5,000 mg/l). Energy use, area requirement and waste sludge amounts are lower when compared with aerobic methods (Speece 1996; Metcalf & Eddy 2014). In addition to biological methods, physicochemical treatment is preferred for wastewater treatment. Different physicochemical treatment technologies include dissolved air flotation (DAF), coagulation, and electrochemical methods (Lecompte 2015). Chemical coagulation is a common process. Along with these classic methods, advanced treatment methods such as advanced oxidation process (AOP), membrane configurations, electrocoagulation, adsorption, microfiltration, reverse osmosis, ultrafiltration and UV (ultraviolet light) and their combinations can be implemented to treat meat processing wastewater (Lecompte & Mehrvar 2014). More importantly, before deciding the treatment process to be implemented, the environmental impact has to be considered. An Environmental Impact Assessment (EIA) is a methodology that helps to determine the levels of impacts and to categorize the hazard levels. With this methodology, the damage to the environment can be detected and minimized using prevention methods.

In this study, the aim was to determine which treatment process has the lowest environmental impact for a meat industry wastewater treatment plant in Turkey, by implementing EIA methodology. The evaluation was carried out using the Fine-Kinney method.

METHODS

Description of the meat industry

The meat industry is located in an organized industrial zone in Turkey. The main products being processed are sujuk, sausage, salami, meatball, raw meat, döner and jambon. All products are made from beef, so there is no chicken processing on site. The main wastewater generating points of the industry are the slaughterhouse, rendering unit, and intestinal washing process. The other sources are residential activities (dining hall, toilet, etc.), cleaning and irrigation of the lawns in the factory garden. The wastewater characteristics of this meat industry are given in Table 1. The wastewater analysis results were obtained using Standard Methods (APHA 1998).

Figure 1 indicates the available wastewater treatment process flow scheme in the plant. Biological treatment method is implemented as extended aeration activated sludge system to remove organic and suspended materials from the wastewater. In the DAF tank, oil, grease and other organic material is removed. Disinfection is undertaken for pathogens and microorganism removal from effluent. The wastewater is then discharged to the Organized Industrial Zone Central Wastewater Treatment Plant. Because of the high environmental impacts such as high energy demand, inefficient and inadequate

Table 1 | Influent wastewater characteristics of the meat industry

Parameter	Value
COD (mg/l)	5,293
BOD (mg/l)	2,554
TSS (mg/l)	2,122
Oil and grease (mg/l)	329
pH	7.29

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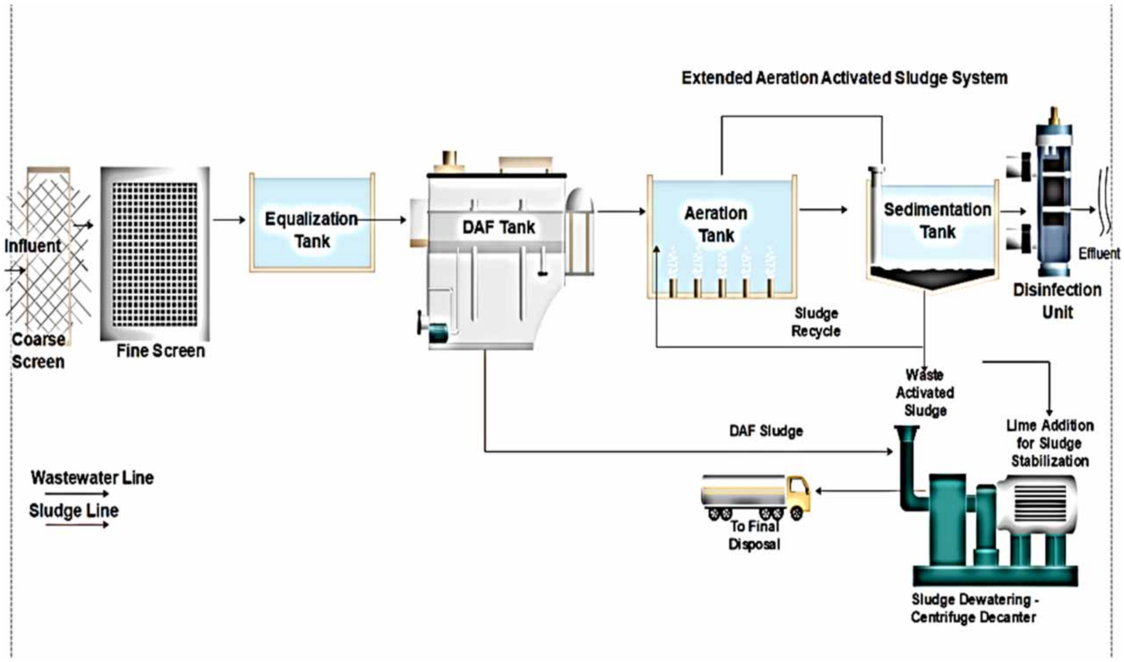

Figure 1 | Available wastewater treatment process flow diagram.

wastewater treatment and excess sludge production of the available treatment system, the decision was made to elect a new, innovative and environmentally-friendly wastewater treatment process in the meat industry.

Environmental impact assessment methods

EIA is a process in which an analysis and assessment is undertaken to study the impact of a particular human activity on the environment. The protection of the ecosystem aims to form a sustainable environment, and an EIA is one of the most effective tools in environmental planning and environmental management (Çakmak 2014; Bilgin 2015). An EIA enhances our ability to describe, estimate and understand the consequences of an action. The evaluation should enable the description of aspects of soil, water, atmosphere, flora, fauna and natural sources. Today, there are many different methods used for assessing environmental dimensions. The most frequently used method, which has the simplest calculation of mathematical values and question list-based data is the L type 5×5 matrix method. The main EIA approaches used are the 5×5 matrix, uncertainty analysis, multi-criteria assessment, Delphi method, 3×3 matrixes, Fine-Kinney method, fault mode and effect analysis (FMEA), and fault tree analysis (FTA) (Çakmak 2014). In this study, the environmental evaluation was carried out by the Fine-Kinney method. The reason why the Fine-Kinney method is preferred is its ability to use multiple variables and real values.

Fine-Kinney method

Developed by G.F. Kinney and A.D Wiruth in 1976, the Fine-Kinney method is a simple-to-use and wide-spread method employed to mathematically evaluate risks and impacts values (Kinney & Wiruth 1976). This method is commonly used in the construction and cement industries, and in the literature it is stated that it is also one of the most simple methods to use, and therefore is the most feasible for small and medium-sized industries. In this method, which frequently uses statistical analysis of previous data, individuals conducting the analysis are required to be familiar with related theorems, otherwise the method cannot be used effectively and could result in time

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being wasted (Oturakçı *et al.* 2015). In the Fine-Kinney risk and impact assessment method, the probability, frequency and severity parameters and scale tables of each parameter are included. Impact value is calculated with severity, probability and frequency multiplication. It is shown in Equation (1).

$$\text{Impact (I)} = \text{Probability (P)} \times \text{Frequency (F)} \times \text{Severity (S)} \quad (1)$$

In developing these scale tables, reference points have been determined in scoring and according to the reference points, other scores have been determined based on experience. Probability, frequency and severity parameter scales recommended for use in the Fine-Kinney method are shown in Tables 2–4 respectively (Kinney & Wiruth 1976).

First of all, these values should be detected by considering industrial and operational conditions. For example, in Table 4, one level of severity is environmental block, which means an action has been prohibited according to the legislation, such as the discharge of untreated wastewater. Then, if they are multiplied with each other, you can ensure the risk score where defined, as in Table 5.

Table 2 | Probability scale of the Fine-Kinney method (Kinney & Wiruth 1976)

Probability	Value
Might well be expected	10
Quite possible	6
Unusual but possible	3
Only remotely possible	1
Conceivable but very unlikely	0.5
Practically impossible	0.2
Virtually impossible	0.1

Table 3 | Frequency scale of the Fine-Kinney method (Kinney & Wiruth 1976)

Frequency	Value
Continuous	10
Frequent (daily)	6
Occasional (weekly)	3
Unusual (monthly)	2
Rare (a few per year)	1
Very rare (yearly)	0.5

Table 4 | Severity scale of the Fine-Kinney method (Kinney & Wiruth 1976)

Severity	Value
Catastrophe (environmental disaster or damage)	100
Disaster (very serious damage)	40
Very serious (environmental block)	15
Serious (serious environmental damage)	7
Important (environmental damage)	3
Noticeable (minor or no environmental damage)	1

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Table 5 | Impact (I) score scale of the Fine-Kinney method (Kinney & Wiruth 1976)

Score	Value
$I < 20$	Perhaps acceptable
$20 < I < 70$	Possible impact, attention indicated
$70 < I < 200$	Substantial impact, correction needed
$200 < I < 400$	High impact, immediate correction required
$I > 400$	Very high impact, consider discontinuing operation

Depending on the determined impact, probability, frequency and severity values are derived from the table and these three factors are multiplied with each other, and the impact score is calculated. The obtained risk scores are classified according to Table 5 and risk avoidance activities are planned according to the risk priority order of each impact.

To determine which scale to choose, for example, if a chemical leakage occurred in the past, you should select '10'. If an accident did not occur in the near past, considering the available precautions, you can choose '0.2', etc. To determine frequency value, routine activities implemented in the plant or facility should be considered and how often these occur in a day or a year. For example, if sewage sludge is sent to a disposal plant once a week, you should select '3' as frequency value. For a UASB reactor, anaerobic sludge is picked up once a year, so you should elect '0.5'.

Description of the case study

There are three treatment scenarios that have been created to evaluate the environmental dimensions and impact, using the Fine-Kinney method. In this case study, the main aim was to determine which wastewater treatment method has the lowest impact on the environment. Before investment, and using the EIA, the most environmentally-friendly wastewater treatment method can then be chosen. Scenario-1 is anaerobic wastewater treatment using a UASB reactor, Scenario-2 uses AOP, and Scenario-3 uses a membrane bioreactor (MBR).

Scenario-1

Anaerobic treatment is one of the oldest used wastewater treatment techniques all over the world (Speece 1996). In ancient history, anaerobic digestion was utilized for sludge stabilization (Metcalf & Eddy 2014). Subsequently it was proved that the high organic content of wastewater could be treated with anaerobic biotechnology, with industrial wastewater in particular being a specific research area in which anaerobic treatment can be implemented (Speece 1996). Anaerobic biotechnology has been widely used to treat many industrial wastewaters (Speece 1996). Anaerobic technology contains different reactor configuration such as UASB, expanded granular sludge bed (EGSB), anaerobic contact (AC) process and anaerobic filters (AFs) (Metcalf & Eddy 2014). The testing of high-rate anaerobic systems has been one of the most active areas of investigation concerning meat processing wastewater treatment. The most common systems installed at large-scale plants are the AC, UASB and AF processes (Johns 1995). The UASB reactor demonstrated an optimum COD removal efficiency of up to 90% at a hydraulic retention time of 10 hours. Moreover, results indicate that by reducing the hydraulic retention time to less than 10 hours in the UASB, sludge wash out occurs and lower COD removal efficiencies of below 70% occur (Rajakumar *et al.* 2011; Lecompte 2015). The UASB process utilizes granules to capture bacteria,

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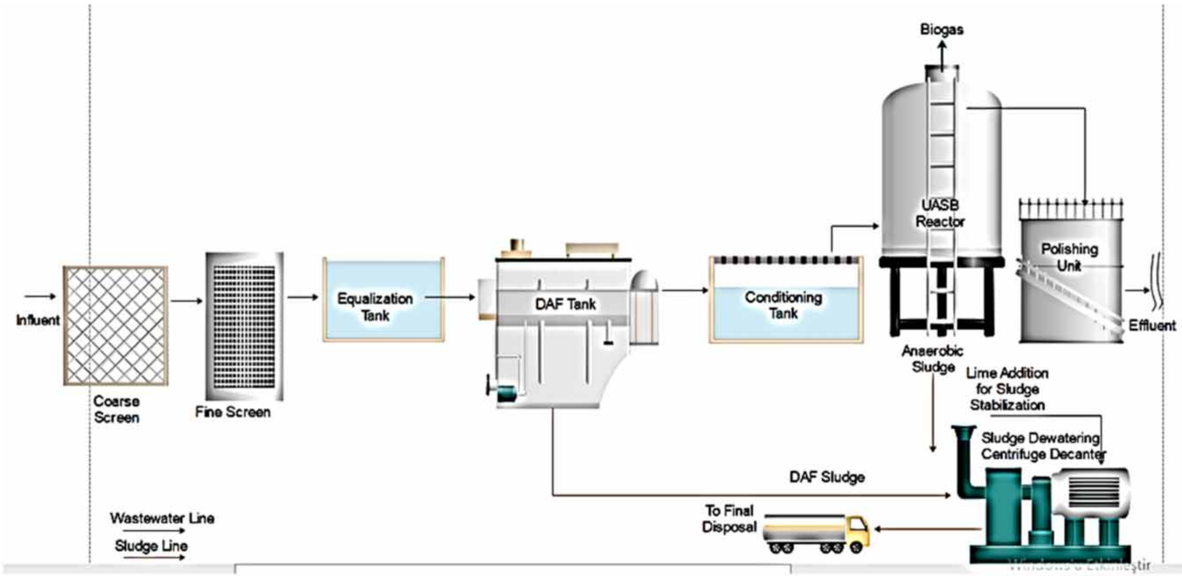

Figure 2 | Scenario-1.

with wastewater flowing from an inlet at the bottom of the reactor, upwards through the sludge blanket and the biomass film, before exiting at the top of the reactor. Essentially, UASB reactors consist of three stages: liquid as wastewater, solid as biomass, and gas as biogas that contains CO_2 and CH_4 produced during digestion (Lecompte 2015).

Scenario-1 is the use of a UASB reactor to treat meat processing wastewater. To determine the cost of investment for the wastewater treatment plant and the environmental impact of the UASB reactor, an EIA was undertaken. Scenario-1 is based on the wastewater treatment flow diagram in Figure 2.

Scenario-2

Advanced wastewater treatment technologies have gained in importance and popularity in recent years. One of them is AOPs. Furthermore, AOPs may inactivate microorganisms without adding additional chemicals to the wastewater in comparison to other techniques such as chlorination that are commonly implemented for water disinfection, thus avoiding the possible formation of hazardous by-products (Sena *et al.* 2009; Lecompte 2015). Therefore, AOPs have been used for the degradation of all organic substances in wastewater, water reuse and pollution control (Sena *et al.* 2009; Lecompte 2015). AOPs produce hydroxyl radicals with a high oxidation potential and these radicals react with the organic components in the wastewater. As a result of this reaction, many organic components, including final and stable products, as well as water and carbon dioxide oxidation, is possible. Therefore, the treatment efficiency is higher than other processes. There are many advanced oxidation processes such as ozonation (O_3), UV/H_2O_2, UV/O_3, vacuum-ultraviolet (VUV), Fenton, photo-Fenton and their combinations (Kılıç & Kestioğlu 2008). The UV/H_2O_2 process is one of the most widely implemented AOP. The UV/H_2O_2 process has been found to be effective for meat processing wastewater treatment. Oxidation and degradation of pollutants by UV/H_2O_2 rely on hydroxyl radicals (*OH), a highly reactive species generated from the reaction of H_2O_2 with UV light (Sena *et al.* 2009; Lecompte 2015). Scenario-2 is based on meat processing wastewater treatment using UV/H_2O_2. The schematic diagram of Scenario-2 is given in Figure 3.

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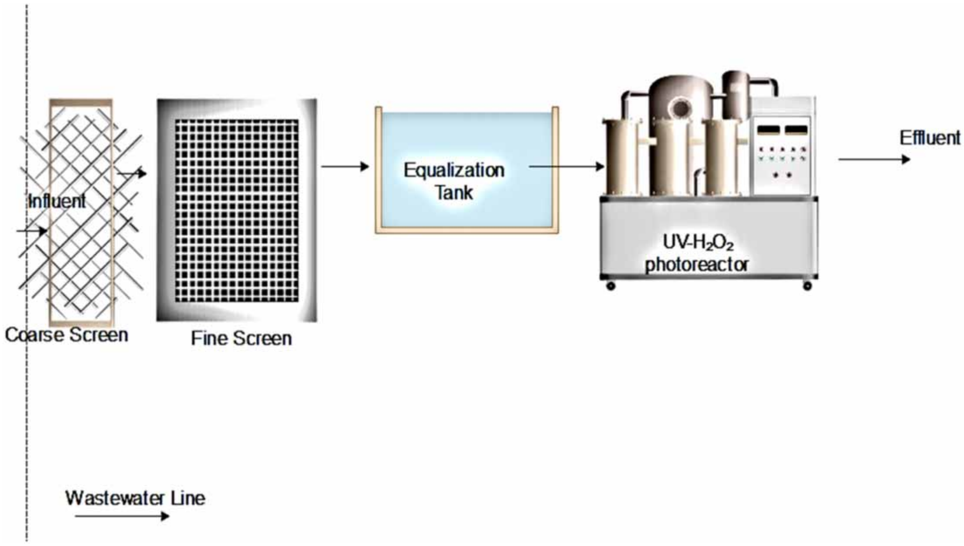

Figure 3 | Scenario-2.

Scenario-3

Membrane technology is an alternative method for meat processing wastewater treatment. Reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) processes are able to remove particles, colloids, and macromolecules depending on the pore size (Lecompte 2015). Membrane treatment is a separation process that has been implemented for water and wastewater treatment worldwide. MBRs are a common type of this technology used in wastewater treatment. MBRs are a compact technology that combines an activated sludge process and membrane filtration for wastewater treatment and recycling. MBRs can achieve high nutrient removal efficiency and complete biomass retention without a secondary clarifier (Meng *et al.* 2017). MBRs therefore can produce a very good effluent quality, with water reuse being possible. As all microorganisms are removed, additional disinfection is not required. However, membrane fouling is a crucial disadvantage. To prevent and decrease fouling, optimization and enhancement of aeration scouring, chemical cleaning and back washing with huge volumes of water are needed (Meng *et al.* 2017). In recent years, anaerobic membrane bioreactor (AnMBR) technology is being considered as a very appealing alternative for wastewater treatment due to the significant advantages over conventional anaerobic treatment and aerobic MBR technology (Lin *et al.* 2013). Gürel & Büyükgüngör (2011) investigated the performance of MBRs for nutrient and organic material removal from meat processing wastewater. The initial COD, total phosphorus (TP) and total nitrogen (TN) concentrations were 571, 16, and 102 mg/L, respectively. A UF membrane was utilized in the MBR. Up to 44, 65, 96, and 97% removals were achieved for TN, TP, TOC, and COD, respectively. Although organic substances were successfully removed, a high nitrate concentration in the treated effluent remained. Thus, denitrification is needed to further treat this effluent (Gürel & Büyükgüngör 2011; Lecompte 2015). Scenario-3 is composed of meat processing wastewater treatment using the MBR process. The schematic diagram of Scenario-3 is given in Figure 4.

RESULTS AND DISCUSSION

Considering legal requirements for a meat processing industry operating in Turkey, by implementing the Fine-Kinney method, environmental dimensions were determined and environmental impacts were assessed for Scenarios 1–3, which were created for new plant investment. In this evaluation,

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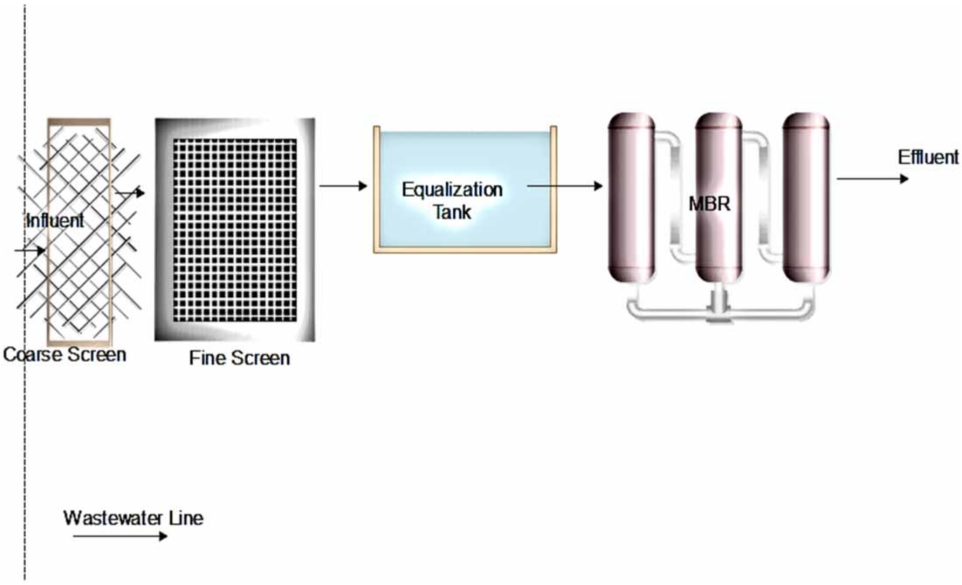

Figure 4 | Scenario-3.

the environmental dimensions of each process in the factory were defined and risk assessments were carried out, together with the existing measures applied, by determining the possible environmental impacts. The results of these evaluations are given in Table 6 for Scenario-1, Table 7 for Scenario-2 and Table 8 for Scenario-3. The process requirements, by-products and end products, operational frequency, preventions to be taken, sludge occurrence, chemical substances use, air emissions, water consumption and energy consumption have been considered for each treatment processes.

Table 6 | Environmental impact assessment of Scenario-1 (UASB reactor)

Environmental dimension	Environmental impact	Assessment	Probability	Frequency	Severity	Impact value	Result
Wastewater treatment	Air pollution, greenhouse effect	UASB reactor will be used. Volatile fatty acid analysis and biogas measurement will have been implemented. CO_2 and CH_4 gas concentrations will be measured but have a greenhouse gas impact.	6	6	7	252	High impact
Sludge treatment	Soil pollution	The produced sludge will be a stabilized for anaerobic digestion. There is no need for a stabilization process. Only DAF sludge should be stabilized.	3	1	3	9	Perhaps acceptable
Energy consumption	Natural resource consumption	There is high electricity consumption because of pumping and conditioning. Reactor effluent will be aerated before discharge. Additional aeration is required.	6	6	7	252	High impact
Disinfection by-products	Soil pollution and water pollution	Additional removal of pathogens from effluent is needed before discharge. Chemical usage.	6	6	7	252	High impact

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Table 7 | Environmental impact assessment of Scenario-2 (advanced oxidation process)

Environmental dimension	Environmental impact	Assessment	Probability	Frequency	Severity	Impact value	Result
Wastewater treatment	Radiation emission	UV radiation and H_2O_2 are implemented together as advanced oxidation. UV has a radiation impact on environment. Closed reactor system will be used.	1	6	15	90	Substantial impact
Chemical usage	Soil and water pollution	Chemical consumption and a leakage chemical collection system will be implemented.	3	6	7	126	Possible impact
Sludge treatment	Soil pollution	This system is a nearly zero sludge system.	1	1	7	7	Perhaps acceptable
Energy consumption	Natural resource consumption	Electricity consumption is high for reactor operation.	6	6	7	252	High impact

Assessment results of Scenario-1

Anaerobic treatment has some challenges for wastewater treatment besides its advantages. The EIA for the anaerobic UASB reactor system has been given in Table 6.

According to the results of Table 6, air pollution, greenhouse effects, water pollution, soil pollution and natural resource consumption are the main environmental impacts for UASB technology. The total impact value is 765.

Assessment results of Scenario-2

AOP has some advantages as there is no need for disinfection and CO_2 oxidation. The EIA results have been defined in Table 7.

According to Table 7, natural resource consumption, radiation emission, and soil and water pollution are the major environmental impacts of advanced oxidation for meat processing wastewater treatment. The total impact value is 475.

Table 8 | Environmental impact assessment of Scenario-3 (MBR)

Environmental dimension	Environmental impact	Assessment	Probability	Frequency	Severity	Impact value	Result
Wastewater treatment	Greenhouse effect	In aerobic membrane bioreactor, CO_2 emissions occur, which causes greenhouse effects.	3	6	7	126	Possible impact
Water consumption	Natural resource consumption	Water consumption. Back washing is implemented for prevention of fouling.	6	6	7	252	High impact
Sludge treatment	Soil pollution	This system is a nearly zero sludge system.	1	1	7	7	Perhaps acceptable
Energy consumption	Natural resources consumption	Electricity consumption is high for reactor operation and aeration.	6	6	7	252	High impact

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Assessment results of Scenario-3

MBR technology has some advantages such as no requirement for disinfection, but for cleaning the membranes, water is consumed in huge amounts and electricity consumption is also high. The results have been described in Table 8.

In the results of the EIA for Scenario-3, the fundamental environmental impacts are natural resource consumption, greenhouse effect and soil pollution. The total value of EIA is 637.

Comparison of wastewater treatment scenarios

An EIA was carried out using the Fine-Kinney method for the three scenarios. The results from the EIAs of Scenario-1, Scenario-2 and Scenario-3 has been demonstrated in Figures 5–7, respectively. Figure 8 shows the comparison of the three scenarios.

If this study is compared with others in the literature, the Fine-Kinney Method is rarely used to study the environmental impacts of a wastewater treatment plant. Yapıcıoğlu (2018) undertook a study on investigation of investigating environmentally-friendly technology for a paint industry

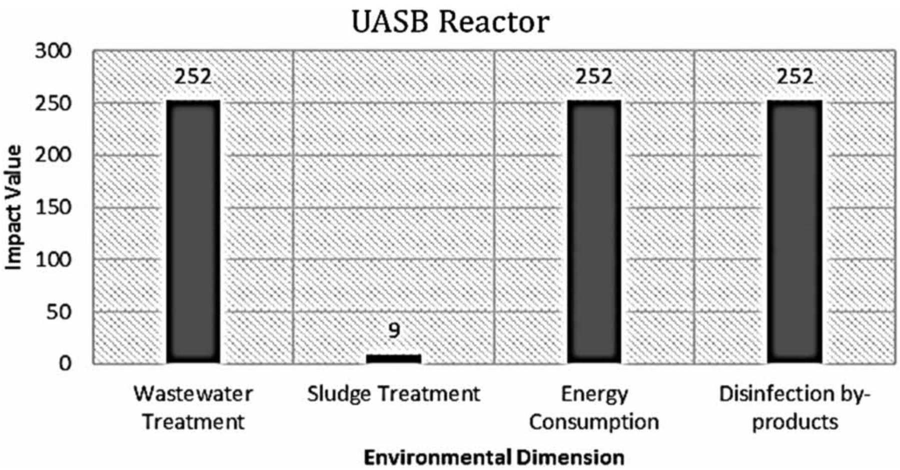

Figure 5 | EIA of Scenario-1.

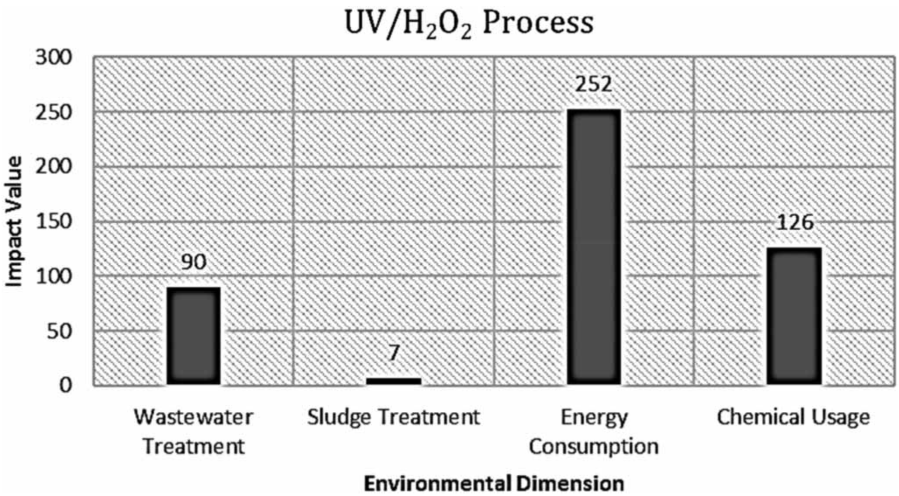

Figure 6 | EIA of Scenario-2.

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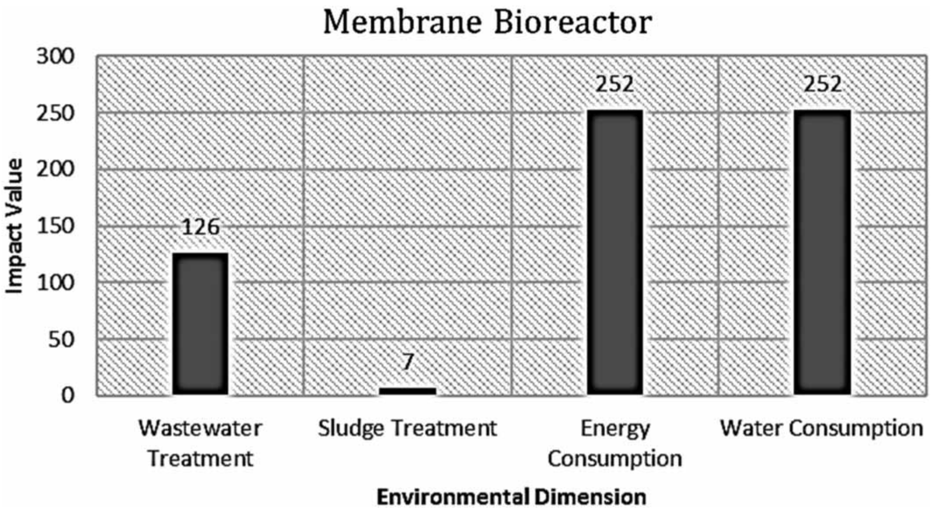

Figure 7 | EIA of Scenario-3.

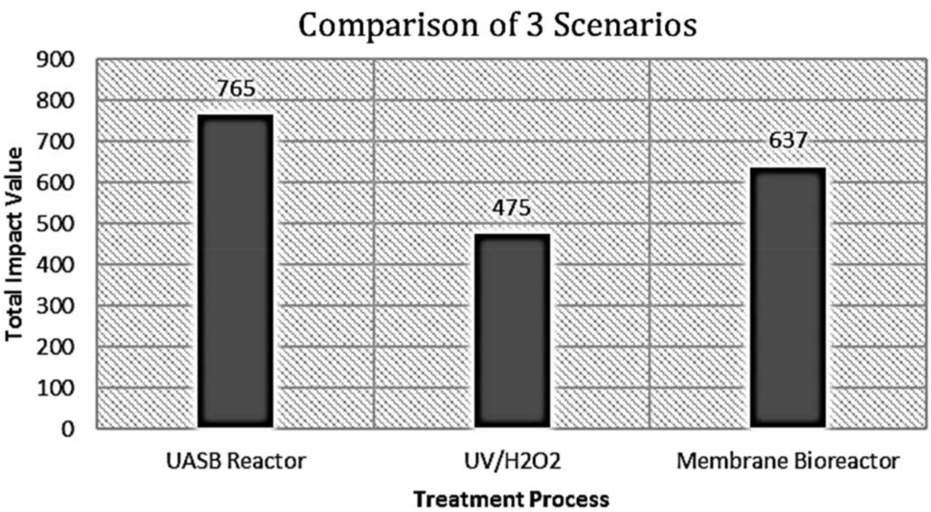

Figure 8 | Comparison of the three scenarios.

plant. She implemented the Fine-Kinney method to detect the environmental impacts of a wastewater treatment plant in order to determine the best available treatment technology (Yapıcıoğlu 2018).

CONCLUSION

An EIA for a meat processing industry located in Turkey has been implemented by carrying out the Fine-Kinney Method for three scenarios using UASB technology, AOP (UV/H_2O_2) and MBR, respectively. EIA is a tool for determining environmentally-friendly treatment technology before investment. The Fine-Kinney method can be used as an EIA methodology for wastewater treatment plants. This use of the Fine-Kinney method for an EIA can be considered as a contribution to the literature. It is a simple, inexpensive benchmarking EIA method. It is based on a simple equation and no software is required, in comparison to other EIA methods.

For Scenario-1, wastewater treatment, disinfection by-products and energy consumption have the same environmental impact value at 252, and are the largest environmental impacts of UASB technology. Sludge has a minimal environmental impact value with 9. Anaerobic sludge has no need for

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stabilization and is produced in very small amounts. The major environmental impacts are air pollution, greenhouse effects (because of biogas), water pollution, soil pollution and natural resource consumption. This technology has several environmental impacts compared with other scenarios. Disinfection and additional aeration should be implemented and these applications also have significant environmental impacts.

The environmental impact value of wastewater treatment is 90 for Scenario-2 because of radiation emissions related to the UV/H_2O_2 process. The highest value is 252 related to energy consumption. The impact value of chemical substances usage is 126 because of hydrogen peroxide utilization, whilst sludge impact is minimal with a value of 7. There is no need for disinfection, but consumption is significant for this treatment technology. Natural resource consumption is the main environmental impact.

In Scenario-3, wastewater treatment has the environmental impact value of 126 because of CO_2 emissions. Due to the nearly zero-sludge process, the impact value of sludge treatment is only 7. Disinfection is not implemented as all pathogens and microorganisms are removed from wastewater, but water consumption and electricity consumption are the main environmental impacts with an equal value of 252.

For determining which process is the best to be implemented, the total environmental value of the three wastewater treatment scenarios was considered. The total value for UASB technology is 765, which was the highest value. The total environmental impact value related to MBR technology is 637 and the UV/H_2O_2 process is 475. According to the EIA results, the UV/H_2O_2 process could be proposed for treating the meat processing wastewater.

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