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Reuse of effluents from cattle slaughterhouses: multicriteria evaluation

Reaproveitamento de efluentes de frigoríficos bovinos: avaliação multicritério

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ABSTRACT

Cattle slaughterhouses generate a large amount of effluent with a high concentration of organic and inorganic compounds. However, the choice of appropriate technologies can produce effluents with sufficient quality for the practice of reuse as a strategy for saving water. This study aimed to determine the efficiency of effluent treatment systems from cattle slaughterhouses to promote the reuse of effluents, specifically for fertigation. The multicriteria analysis was employed, adopting the ELECTRE I method. The effluent treatment alternatives, the definition of the degree of importance, and the weights of each established criterion were considered. The estimated volume of effluents generated in slaughterhouses in Brazil was 85.374 million m^3/year, with a high concentration of biochemical/chemical oxygen demand, nutrients, oils, and greases, solids, and *E. coli*. The treatment technologies that showed the best performance were UASB reactor + ultrafiltration and activated sludge + ultrafiltration, producing effluents with compatible quality for agricultural reuse under Brazilian legislation.

Keywords: agricultural reuse; ELECTRE I method; effluent quality; treatment technologies; environmental sustainability.

RESUMO

Os abatedouros de bovinos geram grande quantidade de efluentes com alta concentração de compostos orgânicos e inorgânicos. Entretanto, a escolha de tecnologias adequadas pode produzir efluentes com qualidade suficiente para a prática do reúso como estratégia de economia de água. Este estudo teve como objetivo determinar a eficiência de sistemas de tratamento de efluentes de frigoríficos bovinos para promover o reaproveitamento de efluentes, especificamente para a fertirrigação. A análise multicritério foi empregada, adotando-se o método ELECTRE I. Foram consideradas as alternativas de tratamento de efluentes, a definição do grau de importância e os pesos de cada critério estabelecido. O volume estimado de efluentes gerados em frigoríficos no Brasil foi de 85,374 milhões de m^3/ano, com alta concentração de demanda bioquímica/química de oxigênio, nutrientes, óleos e graxas, sólidos e E. coli. As tecnologias de tratamento que apresentaram melhor desempenho foram reator *upflow anaerobic sludge blanket* — UASB + ultrafiltração e lodo ativado + ultrafiltração, produzindo efluentes com qualidade compatível para reúso agrícola pela legislação brasileira.

Palavras-chave: reúso agrícola; método ELECTRE I; qualidade de efluentes; tecnologias de tratamento e sustentabilidade ambiental.

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Introduction

The main producing countries of meat are the United States, with 21.70% of world meat production, followed by Brazil with 17.42% and China with 11.99% (USDA, 2023). For 2023, Brazil has an estimated beef production of 10,570 million tons, and remains the second largest producer in the world (USDA, 2023). Countries such as the United States, Brazil and China are consolidating themselves in the market as the largest bovine meat producers in the world, with growth prospects due to market demands which will result in an increase in world production of around 6 million equivalent tons of carcass (TEC) until 2029 (OECD/FAO, 2020).

Water consumption in these facilities varies between 1 and 8.3 m^3 per animal, of which between 0.4 and 3.1 m^3 are discarded as wastewater, depending on the type of animal slaughtered and the processing operation (Gürel and Büyükgüngör, 2011; Farzadkia et al., 2016), which can reach up to 80% of the total water consumed (Metcalf et al., 2004). Due to high production in Europe, bovine meat processing involves water consumption that can vary between 2,500 and 40,000 L/t of product, due to strict sanitary rules. In the United States, water consumption is approximately 3,000 L/t of dead animals (Valta et al., 2015).

Water consumption generates effluents; however, by adopting appropriate technologies, treatment can be optimized, leading to the possibility of reuse. What it represents for the sector is savings in water consumption and/or the destination of the effluent generated for use in another productive sector, as long as it meets the standards established by legislation (Wilcox et al., 2016).

As for the reuse of effluents, directing them to sectors that need a high volume of water, such as agriculture, is an option and a practice already established in several countries (Chen et al., 2017; Libutti et al., 2018; Michetti et al., 2019; Takeuchi and Tanaka, 2020; Habip et al., 2020; Craddock et al., 2021).

In Brazil, the practice of direct reuse for agriculture and forestry is established by Resolution nº 121/2010 (Brasil, 2010). In the specific case of agriculture, Resolution nº 503/2021 is the legal instrument that defines the criteria and procedures for the practice of reuse in fertigation systems, using effluents from the food, beverage, dairy, slaughterhouse, and grease industries (Brasil, 2021). The referred resolution specifies that reuse must be practiced with the stabilized effluent, recommending that analyzes be carried out before the first application and monitored annually (Brasil, 2021).

Adopting appropriate treatment systems and legislation, the practice of reuse, in this case for fertigation, commonly used to irrigate and fertilize crops simultaneously (Pérez-Castro et al., 2017; Senthilkumar et al., 2017; Mainardis et al., 2022), will be more efficient in terms of water use.

The selection of efficient treatment systems for these effluents is generally complex due to the need to define priority criteria and objectives such as environmental, economic, and social ones (De Melo Ribeiro and Naval, 2019). Mathematical models have been developed to help this selection, minimizing errors and maximizing the efficiency of the systems.

Among the typologies of mathematical models, multicriteria analysis has been adopted because it allows the selection of alternatives based on predefined criteria. Among these programs, J ELECTRE v 3.0 was adopted in this study to evaluate, through multicriteria analysis, systems for the treatment of effluents from livestock slaughterhouses and determine the most efficient ones, including those that allow reuse in fertigation systems as a strategy for water economy.

Methodology

Estimation of volume and characterization of effluents generated in cattle slaughterhouses in Brazil.

To determine the volume of effluent generated in cattle slaughterhouses, considering each slaughtered animal, theoretical values of 0.4 to 3.1 m^3 were adopted (Gürel and Büyükgüngör, 2011; Farzadkia et al., 2016). To estimate the volume of effluents generated in cattle slaughterhouses in Brazil, the value of 3.1 m^3 per animal (greater volume) was adopted for safety purposes (Equation 1).

$$VEGS = 3{,}1 * NAS \quad (1)$$

Where:
VEGS: volume of effluent generated at the slaughterhouse, in m^3;
NAS: number of animals slaughtered.

As for the characteristics of the effluents, theoretical values were used, obtaining the average of the concentration of physical, chemical, and microbiological parameters. The parameters employed are those adopted by current Brazilian legislation (Brasil, 2021) and other parameters commonly used for the characterization of this type of effluent, such as: calcium, lead, total organic carbon, biochemical oxygen demand — $BOD_{5,20}$, chemical oxygen demand — COD, total nitrogen, oils and mineral greases, vegetable oils and greases, pH, sodium, total phosphorus, potassium, total suspended solids, total solids, total fixed solids and *Escherichia coli* (*E. coli*) (Table 1).

Reuse of effluents from cattle slaughterhouses in agriculture.

A comparison was made between the characteristics of the effluents generated in slaughterhouses with the legislation for the reuse of effluents in fertigation systems in force in Brazil through Resolution Nº 503/2021 (Brasil, 2021), to verify the possibility of the reuse of effluents from bovine slaughterhouses in agriculture (Table 2). It is reported that Resolution Nº 503/2021 does not establish values for COD or BOD, but only advocates the need for the concentration of the parameter to be reduced (Brasil, 2021).

Table 1 – Physical-chemical and microbiological characteristics of effluents from cattle slaughterhouses.

Parameters	Red Line Average	References
Calcium (mg/L)	57.5	Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
Lead (mg/L)	4.0	Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
BOD (mg/L)	5.746	Mittal (2006); McCabe et al. (2014); Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
COD (mg/L)	19.690	Mittal (2006); McCabe et al. (2014); Bustillo-Lecompte and Mehrvar (2015); Brooms et al. (2020); Ziara et al. (2018)
TN (mg/L)	965.33	Gürel and Büyükgüngör (2011); Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
MOG	209.29	Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
VOG	209.29	Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
pH	7.28	Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
Potassium (mg/L)	138.5	Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
TP (mg/L)	86.0	Gürel and Büyükgüngör (2011); Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
Sodium (mg/L)	1.473	Bustillo-Lecompte and Mehrvar (2015); Ziara et al. (2018)
TSS (mg/L)	1.164	Mittal (2006); Yordano (2010); McCabe et al. (2014); Bustillo-Lecompte and Mehrvar (2015)
TS (mg/L)	10.333	Ziara et al. (2018)
TFS (mg/L)	1.458	Ziara et al. (2018)
E. coli 1000 (MLN/100mL)	344.688	Pereira et al. (2016); Um et al. (2016); Elsaidy et al. (2022)

BOD: biochemical oxygen demand; COD: chemical oxygen demand; TN: total nitrogen; MOG: mineral oils and greases; VOG: vegetable oils and greases; TP: total phosphorus; TSS: total suspended solids; TS: total solids; TFS: total fixed solids.

Table 2 – Characteristics of treated effluents for reuse in fertigation systems, recommended by Resolution Nº 503/2021 (Brasil, 2021).

Parameter	Allowed Value
pH	between 5 and 9
Mineral Oils and Greases	up to 20 mg/L
Vegetable Oils and Greases	up to 50 mg/L
Sodium (Na), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Aluminum (Al).	Parameters with no established maximum value, but mandatory characterization for agronomic purposes.
E. coli (Food eaten raw with an edible part in contact with the ground)	1,000
E. coli (Other crops and pastures)	10,000

Source: Adapted from Brasil (2021).

Determination of treatment systems that allow the reuse of effluents from bovine slaughterhouses

The multicriteria analysis was adopted to determine the most efficient systems for treating effluents from cattle slaughterhouses, which generate effluents that can be reused in compliance with the requirements of the legislation, using the Analytic Hierarchy Process (AHP) method by Saaty (1980) and *Elimination et Choix Traduisant la Realité* (ELECTRE I), proposed by Roy (1968). For this study, ten different technological alternatives for the treatment of effluents were selected (Table 3).

As a criterion for selecting alternatives, the mandatory physical-chemical and microbiological parameters were adopted with reference values established by Brazil's Environment Council (CONAMA) Resolution Nº 503/2021 to determine the efficiency of the treatment alternatives, namely: oils and greases, BOD and/or COD and *E. coli* (Table 3). Other criteria also defined were implementation cost and area occupied by the treatment system (Table 4).

Table 3 – Effluent treatment alternatives are considered in applying the multicriteria analysis, adopting the *Elimination et Choix Traduisant la Realité* (ELECTRE I) method.

Identification	Alternatives
a1	Coagulation and Flocculation + Ultrafiltration
a2	Coagulation and Flocculation + Ozonation
a3	Membrane Bioreactors + Ultrafiltration
a4	Membrane Bioreactors + Ozonation
a5	Anaerobic Lagoon + Ultrafiltration
a6	Anaerobic Lagoon + Ozonation
a7	UASB Reactor + Ultrafiltration
a8	UASB Reactor + Ozonation
a9	Activated Sludge + Ultrafiltration
a10	Activated Sludge + Ozonation

Table 4 – Identification and definition of the criteria adopted for the use of the *Elimination et Choix Traduisant la Realité* (ELECTRE I) method.

Identification	Criterion	Definition
g1	*Escherichia coli* removal	Percentage of removal of *Escherichia coli*
g2	Removal of BOD and/or COD	BOD and/or COD removal percentage
g3	Oil and Grease Removal	Oil and Grease Removal Percentage
g4	Implementation Cost	Cost of implementing the treatment system
g5	Occupied zone	Area occupied by the treatment system

Definition of the degree of importance and weights of each criterion

The AHP method, developed by Saaty (1980), was used to define the degree of importance and weight of each criterion in relation to the others. This method performs a paired comparison between criteria with the aid of the Saaty scale, determining the importance of the standard arranged in lines concerning the criterion arranged in columns, and vice versa (Saaty, 1980).

In defining the degree of importance of the criteria, consideration was given to greater efficiency in removing *E. coli*, BOD (or COD), and oils and greases, lower cost of implementation, and smaller area occupied by the treatment system, in that order of importance.

Each degree of importance was determined using the Saaty scale, which generated a judgment matrix whose importance is translated numerically: 1 represents equality of importance between the criteria; 3 is moderate importance; 5 is high importance; 7 is high importance; and 9 is extreme importance. Values 2, 4, 6, and 8 represent an intermediate degree of importance between the mentioned classes.

The average values of each line of the normalized judgment matrix are calculated to obtain the relative weight (w) for each criterion used in the ELECTRE I method. Based on these data, the consistency ratio (CR) was calculated, which verifies the consistency of the values attributed by judgment, being acceptable when RC ≤ 0.10 (Saaty, 1980).

Once the priority vector is computed, we get the principal eigenvalue from the pairwise comparison matrix. Based on the principal own value, the consistency index metric is calculated. By adopting the consistency index metric, the consistency index is calculated (Equation 2). For the calculation of the consistency index, Equation 3 is adopted. The principal eigenvalue is obtained from the sum of the products between each element of the eigenvector and the sum of the columns of the reciprocal matrix.

$$\text{Consistency Ratio} = \text{Consistency Index} / \text{Random Index} \quad (2)$$

$$\text{Consistency Index} = (\text{principal eigenvalue} - n)/(n-1) \quad (3)$$

Where: n = the dimension of the matrix

Application of the Elimination et Choix Traduisant la Realité (ELECTRE I) Method

Scores from 1 to 10 were defined for each criterion, with 10 being the most efficient value for implementation cost and occupied area. In the case of the criterion removal of BOD/COD, oils and greases and *E. coli*, the removal percentages of each treatment system, normally adopted, were used. The J Electre I v 3.0 software was used to assist in applying the ELECTRE I method considering the agreement and disagreement indexes of 0.7 and 0.3, respectively.

Results and Discussion

Definition of the degree of importance and weights of each criterion

Using the AHP method and Saaty's scale (1980), degrees of importance were obtained for each criterion, generating the judgment matrix and the normalized equivalent matrix. In the case of the chosen criteria, the matrix presents the removal of *E. coli* with greater importance, followed by the removal of BOD/COD, removal of oils and greases, implementation cost, and occupied area, in that order (Table 5). The judgment matrix was normalized to apply the AHP method, resulting in values that were used to calculate the relative weight for each criterion (Table 5). Despite having defined the order of priority, this step of the method was necessary to quantify how much each criterion is a priority for choosing the best treatment system.

Among the effluent treatment systems commonly used in cattle slaughterhouses, high percentages of organic matter (BOD and COD) can be achieved when specific treatment systems are adopted, such as membrane bioreactors, with the removal of about 97% of COD; the anaerobic lagoons that reach 97% of BOD removal; UASB reactors with 90% COD removal; and activated sludge with 97.4% COD removal efficiency (Mittal, 2006; Gürel and Büyükgüngör, 2011; Nacheva et al., 2011; McCabe et al., 2014; Adou et al., 2020; Svierzoski et al., 2021; Ng et al., 2022). As for oil and grease removal, the combinations that stand out are, once again, those linked to ultrafiltration, all with a score above 9.9, due to the 99% removal percentage of this technology. For removing *E. coli*, the technologies of ozonation stand out with 99% removal and ultrafiltration with 99.98% removal (Bertolossi et al., 2021). The combined process of ultrafiltration with ozonation for wastewater treatment is effective in reducing the microbial load (Graça et al., 2020).

The definitive weights of each criterion were calculated, aiming at the application of the ELECTRE I method. The criterion weights were defined as follows: 51.1% for removal of *E. coli*, 23.93% for removal of BOD/COD, 13.28% for oil and grease removal, 7.37% for the implementation cost, and 5.57% for the occupied area (Table 6). The consistency index, which validates the criterion weight calculations, was 0.029 (less than 0.10), showing that the values attributed to the criterion were consistent and could be used in the model.

Table 5 – Judgment matrix for determining the degree of importance of one criterion concerning the others, for selecting the effluent treatment system in cattle slaughterhouses.

Criterion	*E. coli* Removal	BOD/COD Removal	Removal Oil and Grease	Implementation Cost	Occupied Area
E. coli removal	1	3	5	6	8
DBO/COD removal	0.33	1	2	4	6
Oil and grease Removal	0.20	0.5	1	2	4
Implementation Cost	0.17	0.25	0.50	1	2
Occupied zone	0.13	0.17	0.25	0.50	1
Sum	1.83	4.92	8.75	13.50	21.00
Normalized matrix					
E. coli removal	0.55	0.61	0.57	0.44	0.38
BOD/COD removal	0.18	0.20	0.23	0.30	0.29
Oil and grease Removal	0.11	0.10	0.11	0.15	0.19
Implementation Cost	0.09	0.05	0.06	0.07	0.10
Occupied zone	0.07	0.03	0.03	0.04	0.05
Sum	1.00	1.00	1.00	1.00	1.00

Table 6 – Weights of the criteria used in choosing the most efficient treatment system for the reuse of effluents in slaughterhouses, using the *Elimination et Choix Traduisant la Realité* (ELECTRE I) method.

Nº	Criterion	Weights (w)	Weights (%)	Consistency Ratio (RC)
g1	*E. coli* removal	0.5110	51.10	0.029
g2	DBO/COD removal	0.2393	23.93	
g3	Oil and grease removal	0.1328	13.28	
g4	Implementation cost	0.0737	7.37	
g5	Occupied zone	0.0431	4.31	
	Sum	1.00	100	-

Treatment alternatives with the best performance for removing microorganisms (*E. coli*) were prioritized, with the weight representing more than half of the final grade (51.10%). Adding to this percentage the weight for removing organic matter (23.93%), the two criteria correspond to 75.03% of the final grade. That is, combinations of systems that remove high levels of organic matter and *E. coli* are those pointed out by the model.

Application of the Elimination et Choix Traduisant la Realité (ELECTRE I) Method

The scores from 0 to 10 were assigned in the ELECTRE I method to each criterion of each treatment alternative to enable application. For the removal of microorganisms and BOD/COD removal, the grades were defined based on the percentage of reduction of each combined system, also considering the scale from 0 to 10.

The effluent treatment alternatives with the lowest cost and smallest implantation area received the highest scores. The combinations with lagoons, anaerobic lagoon + ultrafiltration and anaerobic lagoon + ozonation received the highest scores, respectively, 10 and 9. In the case of the occupied area, the two best options were given to the combinations with UASB Reactor (UASB reactor + ultrafiltration and UASB reactor + ozonation, both with 10) (Table 7), as they are compact systems.

Regarding the removal of BOD/COD, despite being similar, the combinations of ultrafiltration with activated sludge systems (9.99), membrane bioreactors (9.99), anaerobic lagoon (9.99) and UASB reactor (9.97) received the highest scores (Table 7). For the removal of microorganisms (*E. coli*), the highlight was the use of ultrafiltration, since it gave all alternatives combined with ultrafiltration a score of 9.99 (Table 7).

As for oil and grease removal, the combinations that stand out are, once again, those linked to ultrafiltration, all with scores above 9.9, because of the 99% removal percentage of this technology (Table 7).

Based on the treatment alternatives, the criterion, the scores, and the weight of each criterion, the ELECTRE I model was applied using the J Electre I v3.0 software. The model determined that the most efficient combinations for the treatment of effluents from slaughterhouses to reuse were, respectively, UASB reactor + ultrafiltration (a7) and activated sludge + ultrafiltration (a9) (Table 8).

Table 7 – The efficiency of alternatives for treating effluents from cattle slaughterhouses according to the point scale counted from 0 to 10, with 10 being the optimal value.

	Alternative	Implem. Cost	Occupied Area	BOD/COD	*E. coli*	Oil and Grease
a1	Coagulation and Flocculation + Ultrafiltration	3	7	9.925	9.998	9.981
a2	Coagulation and Flocculation + Ozonation	4	7	8.090	9.900	9.617
a3	Membrane Bioreactors + Ultrafiltration	2	9	9.991	9.998	9.941
a4	Membrane Bioreactors + Ozonation	1	9	9.771	9.900	8.809
a5	Anaerobic Lagoon + Ultrafiltration	10	6	9.991	9.998	9.900
a6	Anaerobic Lagoon + Ozonation	9	6	9.771	9.900	7.952
a7	UASB Reactor + Ultrafiltration	8	10	9.970	9.998	9.987
a8	UASB Reactor + Ozonation	7	10	9.236	9.900	9.744
a9	Activated Sludge + Ultrafiltration	6	8	9.992	9.998	9.976
a10	Activated Sludge + Ozonation	5	8	9.801	9.900	9.524
	Sum	55	80	96.54	98.59	95.43

Table 8 – Selection of treatment alternatives for effluents from cattle slaughterhouses for reuse in agriculture based on the dominance matrix generated by the J Electre I v3.0 software.

Alternatives	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	SUM
a1	-	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	4.00
a2	0.00	-	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
a3	1.00	1.00	-	1.0	0.00	0.00	0.00	0.00	0.00	0.00	3.00
a4	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
a5	1.00	1.00	0.00	0.00	-	1.00	0.00	0.00	0.00	1.00	4.00
a6	0.00	1.00	0.00	0.00	0.00	-	0.00	0.00	0.00	1.00	2.00
a7	1.00	1.00	1.00	1.00	0.00	0.00	-	1.00	1.00	1.00	7.00
a8	0.00	1.00	0.00	1.00	0.00	0.00	0.00	-	0.00	1.00	3.00
a9	1.00	1.00	1.0	1.00	0.00	0.00	1.00	1.00	-	1.00	7.00
a10	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	-	3.00

The dominance matrix of the alternatives defined the best combinations for the treatment. In this matrix, number 1 (one) means that the alternative listed in the line is more indicated than the alternative listed in the column, and zero represents the opposite. According to the model, the alternatives arranged in rows with the highest sum are the best choices. The ideal alternatives are a7 and a9, since the sums were equal to 7 (seven), surpassing the other alternatives (Table 8).

Simulation of the application of the selected alternatives to the raw effluent

Considering each treatment technology and the removal percentage of the COD, *E. coli*, and oils and greases parameters, a simulation was carried out of what would be the characteristics of the effluents after treatment with the selected alternatives (UASB reactor + ultrafiltration [a7] and activated sludge + ultrafiltration [a9]). Data from the red line were used because this is the line with the highest concentrations of pollutants. That is, in theory, the worst scenario for reuse. Notably, the percentage of COD removal presented by ultrafiltration (94%) was considered in the calculation, as the systems act in combination. The final concentrations were obtained by applying the theoretical removal rates (Table 7) and the characteristics of raw effluents from bovine slaughterhouses, which are mandatory for reuse of effluents (Table 2).

It was verified that, after treating the effluents with the combinations UASB reactor + ultrafiltration or activated sludge + ultrafiltration, the effluents from bovine slaughterhouses could be reused in fertigation systems, as they meet the values recommended by current legislation in Brazil (Brasil, 2021). For the data presented, there would only be a need to measure the concentrations of aluminum and magnesium, as they are of agronomic interest, despite not having a reference value in the legislation (Brasil, 2021).

In the simulation carried out, after treatment with the UASB reactor + ultrafiltration, the effluent had a COD of 118.14 mg/L compared to 19,690 mg/L of the raw effluent (Table 9). Regarding oils and greases, the effluent had a concentration of 0.341 mg/L compared to 209.29 mg/L of the raw effluent (Table 9), being within the limit range allowed by law, which is 20 mg/L for oils and mineral greases and 50 mg/L for vegetable oils and greases (Brasil, 2021).

Table 9 – Characteristics of effluents from bovine slaughterhouses after treatment with the combination of UASB reactor + ultrafiltration and activated sludge + ultrafiltration.

Parameters	Effluent	Effluent treated with UASB Reactor + Ultrafiltration	Effluent treated Activated Sludge + Ultrafiltration	Standard for Reuse in Fertigation (Resolution Nº 503/2021)
Calcium (mg/L)	57.5	57.5	57.5	*
COD (mg/L)	19,690	118.14	30.72	7,876.00**
Total Phosphorus (mg/L)	86	86	86	*
Total Nitrogen (mg/L)	965.33	965.33	965.33	-
Mineral Oils and Greases (mg/L)	209.29	0.341	0.494	20
Vegetable Oils and Greases (mg/L)	209.29	0.341	0.494	50
pH	7.28	7.28	7.28	5-9
Potassium (mg/L)	138.5	138.5	138.5	*
Sodium (mg/L)	1,473	1,473	1,473	*
Suspended Solids (mg/L)	1,164	NA	NA	-
Total Solids (mg/L)	10,333.50	NA	NA	-
Total Fixed Solids (mg/L)	1,458	NA	NA	-
E. coli[1] (CFU or NMP/100mL)	344,688	68.93	68.93	1,000
E. coli[2] (CFU or NMP/100mL)	344,688	68.93	68.93	10,000

*Parameters in which characterization is mandatory, even without having recommended a maximum value by legislation; **removal of 60% of DBO, according to Resolution Nº 430/2011 (Brasil, 2011); [1]food consumed raw and whose edible part has contact with the ground; [2]other crops and pastures; NA: parameters not evaluated for removal rate.

Concerning microorganisms, the concentration of *E. coli* became 68.93 MPN/100 mL (Table 9), below what is allowed by Brazilian legislation and allowing fertigation, both for foods consumed raw, with an edible part in contact with the soil (limit of 1,000 CFU or NMP/ 100 mL) and for irrigation of other crops and pastures (limit of 10,000 CFU or NMP/ 100 mL).

As for the simulation carried out with the combination of activated sludge + ultrafiltration, a COD of 30.72 mg/L was obtained, compared to 19,690 mg/L of the raw effluent (Table 9), being even more efficient than the previous alternative (118.14 mg/L), also reaching a value higher than the 60% removal. For oils and greases, the system obtained a final concentration of 0.494 mg/L compared to 209.29 mg/L of the raw effluent, slightly above the alternative with UASB reactor (0.341mg/L), but meeting the requirements of the legislation (Table 9). With regard to the presence of *E. coli*, by using ultrafiltration as an alternative with activated sludge, the treated effluent had a concentration of 68.93 NMP/100 mL compared to 344,688 NMP/100 mL of the raw effluent (Table 9), showing that with the adoption of the defined alternatives it is possible to use the effluents of bovine slaughterhouses in fertigation systems.

Studies that used evaluation methodologies for the use of technology for the treatment of effluents, with a view to reuse, define some systems as more effective, including combined biological systems (De Melo Ribeiro and Naval, 2019). Studies that used methodologies to evaluate the use of technology for the treatment of effluents, with a view to reuse, define some systems as more effective, including combined bilogical systems (De Melo Ribeiro and Naval, 2019), but consider that some criteria are more relevant, depending on the location, especially the economic one, which can influence decision-making to select the treatment system to be used, especially in low-income countries (Ling et al., 2021).

Using multicriteria analysis to define the best technological alternative for the treatment of industrial effluents, treatment systems that combine bioreactor; coagulation/ flocculation/ sedimentation; microfiltration by membranes (Queiroz et al., 2013), sedimentation/ flotation; coagulation/ flocculation; biological treatment by activated sludge process; filtration; reverse osmosis and UV disinfection (Cristovão et al., 2015) have been identified as adequate, when evaluating the criteria construction cost; cost of operation & maintenance; removal of pollutants; system complexity; skilled labor; power consumption; odor and even the possibility of achieving potability (De Melo Ribeiro and Naval, 2019). The fact is that there are different possibilities of technologies to produce reused water, which must be evaluated according to the user's interest criteria.

Ultrafiltration combined with other technologies to produce reuse water has been shown to be among the tertiary treatment alternatives, one of the most appropriate in relation to the criterion related to the cost of the life cycle, making it the most suitable alternative for reuse in industries (Akhoundi and Nazif, 2018).

Based on these analyses, it is observed that cattle slaughterhouses have the potential to allocate the effluents generated for reuse in agriculture due to the volume generated and the nutritional characteristics. Treated effluents have a clear potential to be reused for irrigation, as long as they undergo adequate treatment. This practice is an effective option, especially in regions with intensive agriculture, allowing water savings.

Multicriteria decision-making methods regarding the reuse of treated wastewater can be tools to determine solutions under uncertainties, as they prioritize reuse applications, as well as treatment technologies to be adopted (Akhoundi and Nazif, 2018).

Conclusion

For the defined evaluation criterion, the judgment matrix for determining the degree of importance of a criterion concerning the others indicated the *E. coli* parameter, with a greater degree of importance, followed by removal of BOD/COD, removal of oils and greases, implantation cost and occupied area.

The effluent treatment alternatives with the best performance for the removal of microorganisms (*E. coli*) were prioritized, since the weight represented more than half of the final grade (51.10%), as well as those technologies that best remove the organic matter (23.93%), placing the two parameters as the ones that most influenced the choice of technologies to be adopted.

The combinations of treatment systems "UASB reactor + ultrafiltration" and "activated sludge + ultrafiltration" were the most efficient to enable reuse in fertigation systems since the generated effluents meet the requirements of Brazilian legislation.

Contribution of the authors:

OLIVEIRA, T. D.: Data curation; Formal Analysis; Investigation; Methodology; Software; Validation; Visualization; Writing – original draft. Nepomuceno Faria, C. D.: Data curation; Formal Analysis; Visualization; Writing – original draft. Naval, L. P.: Conceptualization; Methodology; Supervision; Writing – review & editing; Funding; acquisition; Project administration; Resources.

References

Adou, K.E.; Alle, O.E.; Kouakou, A.R.; Adouby, K.; Drogui, P.; Tyagi, R.D., 2020. Anaerobic mono-digestion of wastewater from the main slaughterhouse in Yamoussoukro (Côte d'Ivoire): Evaluation of biogas potential and removal of organic pollution. Journal of Environmental Chemical Engineering, v. 8, (3), 103770. https://doi.org/10.1016/j.jece.2020.103770.

Akhoundi, A.; Nazif, S., 2018. Sustainability assessment of wastewater reuse alternatives using the evidential reasoning approach. Journal of Cleaner Production, 195, 1350-1376. https://doi.org/10.1016/j.jclepro.2018.05.220.

Bertolossi, V.M., Neder, T.F.; Brandão, C.C.S., 2021. Avaliação de ultrafiltração como alternativa à flotação por ar dissolvido no pós-tratamento do efluente de lodos ativados-estudo em escala piloto na estação de tratamento de esgoto Brasília Norte. Engenharia Sanitaria e Ambiental, v. 26, (6), 1003-1014. https://doi.org/10.1590/S1413-415220190210.

Brasil, 2010. Ministério do Meio Ambiente. Conselho Nacional de Recursos Hídricos. Resolução nº 121 de 16/12/2010. Estabelece diretrizes e critérios para a prática de reúso direto não potável de água na modalidade agrícola e florestal, definida na Resolução CNRH nº 54, de 28 de novembro de 2005 (Accessed December 5, 2022) at:. https://www.ceivap.org.br/ligislacao/Resolucoes-CNRH/Resolucao-CNRH%20121.pdf.

Brasil, 2011. Conselho Nacional do Meio Ambiente. Resolução Nº 430, de 13/05/2011. Dispõe sobre as condições e padrões de lançamento de efluentes, complementa e altera a Resolução Nº 357, de 17 de março de 2005, do Conselho Nacional do Meio Ambiente (Accessed December 5, 2022) at:. https://www.gov.br/mma/pt-br.

Brasil, 2021. Conselho Nacional do Meio Ambiente. Define critérios e procedimentos para o reúso em sistemas de fertirrigação de efluentes provenientes de indústrias de alimentos, bebidas, laticínios, frigoríficos e graxarias. Resolução nº 503, de 12 de dezembro de 2021. (Accessed December 5, 2022) at:. https://www.in.gov.br/en/web/dou/-/resolucao-conama-n-503-de-14-de-dezembro-de-2021-367783680.

Brooms, T.; Apollo, S.; Otieno, B.; Onyango, M. S.; Kabuba, J.; Ochieng, A., 2020. Integrated anaerobic digestion and photodegradation of slaughterhouse wastewater: Energy analysis and degradation of aromatic compounds. Journal of Material Cycles and Waste Management, v. 22, 1227-1236. https://doi.org/10.1007/s10163-020-01019-0.

Bustillo-Lecompte, C.F.; Mehrvar, M., 2015. Slaughterhouse wastewater characteristics, treatment, and management in the meat processing industry: A review on trends and advances. Journal of Environmental Management, v. 161, 287-302. https://doi.org/10.1016/j.jenvman.2015.07.008.

Chen, Z.; Wu, Q.; Wu, G.; Hu, H.Y., 2017. Centralized water reuse system with multiple applications in urban areas: Lessons from China's experience. Resources, Conservation and Recycling, v. 117, (part B), 125-136. https://doi.org/10.1016/j.resconrec.2016.11.008.

Craddock, H.A.; Rjoub, Y.; Jones, K.; Lipchin, C.; Sapkota, A.R., 2021. Perceptions on the use of recycled water for produce irrigation and household tasks: A comparison between Israeli and Palestinian consumers. Journal of Environmental Management, v. 297, 113234. https://doi.org/10.1016/j.jenvman.2021.113234.

Cristovão, R.O.; Botelho, C.; Martins, R.; Loureiro, J.; Boaventura, R., 2015. Fish canning industry wastewater treatment for water reuse e a case study. Journal of Cleaner Production, v. 87, 603-612. https://doi.org/10.1016/j.jclepro.2014.10.076.

De Melo Ribeiro, F.R.; Naval, L.P., 2019. Reuse Alternatives for Effluents from the Fish Processing Industry through Multi-Criterion Analysis. Journal of Cleaner Production, v. 227, 336-345. https://doi.org/10.1016/j.jclepro.2019.04.110.

Elsaidy, N.R.; Elleboudy, N.S.; Alkhedaide, A.; Abouelenien, F.A.; Abdelrahman, M.H.; Soliman, M.M.; Shukry, M., 2022. Enhancement Effects of Water Magnetization and/or Disinfection by Sodium Hypochlorite on Secondary Slaughterhouse Wastewater Effluent Quality and Disinfection By-Products. Processes, v. 10, (8), 1589. https://doi.org/10.3390/pr10081589.

Farzadkia, M.; Vanani, A.F.; Golbaz, S.; Sajadi, H.S.; Bazrafshan, E., 2016. Characterization and evaluation of treatability of wastewater generated in Khuzestan livestock slaughterhouses and assessing of their wastewater treatment systems. Global Nest Journal, v. 18, (1), 108-118.

Graça, C.A.L.; Ribeirinho-Soares, S.; Abreu-Silva, J.; Ramos, I.I.; Ribeiro, A.R.; Castro-Silva, S.M.; Segundo, M.A.; Manaia, C.M.; Nunes, O.C.; Silva, A.M.T., 2020. A Pilot Study Combining Ultrafiltration with Ozonation for the Treatment of Secondary Urban Wastewater: Organic Micropollutants, Microbial Load and Biological Effects. Water, v. 12, (12), 3458. https://doi.org/10.3390/w12123458.

Gürel, L.; Büyükgüngör, H., 2011. Treatment of slaughterhouse plant wastewater by using a membrane bioreactor. Water Science and Technology, v. 64, (1), 214-219. https://doi.org/10.2166/wst.2011.677.

Habip, N.; Başaran, Y.; Özüdoğru, A.; Özdemir, O.; Altun, O.; Karaaslan, Y.; Dikmen, B., 2020. Evaluation of Reuse of Wastewater in Agriculture in Turkey: Outbreak Perspective of Covid-19. Turkish Journal of Water Science and Management, v. 4, (2), 178-192. https://doi.org/10.31807/tjwsm.748590.

Libutti, A.; Gatta, G.; Gagliardi, A.; Vergine, P.; Pollice, A.; Beneduce, L.; Tarantino, E., 2018. Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions. Agricultural Water Management, v. 196, 1-14. https://doi.org/10.1016/j.agwat.2017.10.015.

Ling, J.; Germain, E.; Murphy, R.; Saroj, D., 2021. Designing a sustainability assessment framework for selecting sustainable wastewater treatment technologies in corporate asset decisions. Sustainability, v. 13, (7), 3831. https://doi.org/10.3390/su13073831.

Mainardis, M.; Cecconet, D.; Moretti, A.; Callegari, A.; Goi, D.; Freguia, S.; Capodaglio, A.G., 2022. Wastewater fertigation in agriculture: Issues and opportunities for improved water management and circular economy. Environmental Pollution, v. 296, 118755. https://doi.org/10.1016/j.envpol.2021.118755.

McCabe, B.K.; Hamawand, I.; Harris, P.; Baillie, C.; Yusaf, T., 2014. A case study for biogas generation from covered anaerobic ponds treating abattoir wastewater: Investigation of pond performance and potential biogas production. Applied Energy, v. 114, 798-808. https://doi.org/10.1016/j.apenergy.2013.10.020.

Metcalf, L.; Eddy, H.P.; Tchobanoglous, G., 2004. Wastewater Engineering Treatment Disposal Reuse. 4. ed. New York, McGraw - Hill Book, 1815 p.

Michetti, M.; Raggi, M.; Guerra, E.; Viaggi, D., 2019. Interpreting farmers' perceptions of risks and benefits concerning wastewater reuse for irrigation: a case study in Emilia-Romagna (Italy). Water, v. 11, (1), 108. https://doi.org/10.3390/w11010108.

Mittal, G.S., 2006. Treatment of wastewater from abattoirs before land application—a review. Bioresource Technology, v. 97, (9), 1119-1135. https://doi.org/10.1016/j.biortech.2004.11.021.

Nacheva, P.M.; Pantoja, M.R.; Serrano, E.L., 2011. Treatment of slaughterhouse wastewater in upflow anaerobic sludge blanket reactor. Water Science and Technology, v. 63, (5), 877-884. https://doi.org/10.2166/wst.2011.265.

Ng, M.; Dalhatou, S.; Wilson, J.; Kamdem, B.P.; Temitope, M.B.; Paumo, H.K.; Djelal, H.; Assadi, A.A.; Nguyen-Tri, P.; Kane, A., 2022. Characterization of Slaughterhouse Wastewater and Development of Treatment Techniques: A Review. Processes, v. 10, (7), 1300. https://doi.org/10.3390/pr10071300.

Organisation for Economic Co-operation and Development/Food and Agriculture Organization (OECD/FAO). Agricultural Outlook 2020-2029. Paris: OECD Publishing, https://doi.org/10.1787/1112c23b-en.

Pereira, E.L.; Paiva, T.C.B.; Silva, F.T., 2016. Physico-chemical and Ecotoxicological Characterization of Slaughterhouse Wastewater Resulting from Green Line Slaughter. Water Air Soil Pollution, v. 227, 199. https://doi.org/10.1007/s11270-016-2873-4.

Pérez-Castro, A.; Sánchez-Molina, J.A.; Castilla, M.; Sánchez-Moreno, J.; Moreno-Úbeda, J.C.; Magán, J.J., 2017. cFertigUAL: A fertigation management app for greenhouse vegetable crops. Agricultural Water Management, v. 183, 186-193. https://doi.org/10.1016/j.agwat.2016.09.013.

Queiroz, M.I.; Hornes, M.; Manetti, A.; Zepka, L.; Jacob-Lopes, L., 2013. Fish processing wastewater as a platform of the microalgal biorefineries. Biosystems Engineering, v. 115, (2), 195-202. https://doi.org/10.1016/j.biosystemseng.2012.12.013.

Roy, B., 1968. Classement et choix en présence de points de vue multiples. Revue Française D'informatique et de Recherche Opérationnelle, v. 2, (8), 57-75 (Accessed 23 December 2022) at:. http://www.numdam.org/item/RO_1968__2_1_57_0/.

Saaty, T.L., 1980. The Analytic Hierarchy Process. New York: McGraw-Hill International.

Senthilkumar, M.; Ganesh, S.; Srinivas, K.; Panneerselvam, P.; Nagaraja, A.; Kasinath, B.L., 2017. Fertigation for effective nutrition and higher productivity in banana-a review. International Journal of Current Microbiology and Applied Sciences, v. 6, (7), 2104-2122. https://doi.org/10.20546/ijcmas.2017.607.248.

Svierzoski, N.D.S.; Matheus, M.C.; Bassin, J.P.; Brito, Y.D.; Mahler, C.F.; Webler, A.D., 2021. Treatment of a slaughterhouse wastewater by anoxic-aerobic biological reactors followed by UV-C disinfection and microalgae bioremediation. Water Environment Research, v. 93, (3), 409-420. https://doi.org/10.1002/wer.1435.

Takeuchi, H.; Tanaka, H., 2020. Water reuse and recycling in Japan History, current situation, and future perspectives. Water Cycle, v. 1, 1-12. https://doi.org/10.1016/j.watcyc.2020.05.001.

Um, M.M.; Barraud, O.; Kérourédan, M.; Gaschet, M.; Stalder, T.; Oswald, E.; Bibbal, D., 2016. Comparison of the incidence of pathogenic and antibiotic-resistant Escherichia coli strains in adult cattle and veal calf slaughterhouse effluents highlighted different risks for public health. Water Research, v. 88, 30-38. https://doi.org/10.1016/j.watres.2015.09.029.

U.S. Department of Agriculture (USDA), 2023. U.S. Department of Agriculture. Ranking of Countries that Produce the most Beef (USDA (Accessed in July 2023) at:. https://beef2live.com/story-world-beef-production-ranking-countries-0-106885.

Valta, K.; Kosanovic, T.; Malamis, D.; Moustakas, K.; Loizidou, M., 2015. Overview of water usage and wastewater management in the food and beverage industry. Desalination and Water Treatment, v. 53, (12), 3335-3347. https://doi.org/10.1080/19443994.2014.934100.

Wilcox, J.; Nasiri, F.; Bell, S.; Rahaman, M., 2016. Urban water reuse: a triple bottom line assessment framework and review. Sustainable Cities and Society, v. 27, 448-456. https://doi.org.10.1016/j.scs.2016.06.021.

Yordanov, D., 2010. Preliminary study of the efficiency of ultrafiltration treatment of poultry slaughterhouse wastewater. Bulgarian Journal of Agricultural Science, v. 16, (6), 700-704. http://www.agrojournal.org/16/06-06-10.pdf.

Ziara, R.M.; Li, S.; Subbiah, J.; Dvorak, B.I., 2018. Characterization of wastewater in two US cattle slaughterhouses. Water Environment Research, v. 90, (9), 851-863. https://doi.org/10.2175/106143017x15131012187971.