Some practical approaches of the poultry slaughter wastewater treatment by apply physico-chemical treatment

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Abstract. As a result of slaughtering processes, large volumes of effluents with high concentrations of organic, inorganic and microbiological pollutants are generated. The pollutants composition must be reduced by apply simultaneous processes in order, to obtain an proper effluent before discharge. In this paper, the efficiency of the physico-chemical treatment process was determined, in which a rotary sieve and the Dissolved Air Flotation (DAF) system were used. The efficiency of the DAF process was determined by comparing the quality indicators of effluents from a poultry slaughterhouse, analyzed both before and after treatment. To carry out the analysis, the samples were taken in October and November 2023, and they were determined by using certified laboratory procedures. After setting the DAF process to an optimal operating regime and chemicals dosages, the quality indicators were significantly reduced, reaching a maximum of 99%, 98%, 93%, 92%, 85%, 84%, for TSS, PO4, NO3, TKN, BOD5 and COD.

1 Introduction

According to statistics data from the Organisation for Economic Co-operation Development (OECD), annual poultry meat production is expected to increase from 137 million tons in 2020 to 156 million tons in 2023, an increase of 1.3% [1, 2]. This increase is due to the high demand for chicken meat products, which is necessary to feed the growing population [3-5].

The volume of freshwater, and therefore of wastewater resulting from the processing of chicken meat products, is increasing in direct proportion to the production increase [6, 7]. Thus, the production of one ton of chicken meat requires about 4000 m^3 of water, much less than the average water requirement for beef production of about 15,500 m^3, followed by 6100 m^3 for one ton of goose meat and 4800 m^3 for one ton of pork [8-10].

A large volume of water is required to process meat products and especially chicken products. Water consumption varies depending on the stage of the process and the processing technology used [10, 11]. The production of a chicken requires 26.5 L/bird, of which 80% is

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used for the actual processing (stunning, skinning, evisceration, washing) and 20% for cleaning and washing of process equipment [12, 13].

The effluents resulting from the processing of poultry meat products have a high load of organic (meat and feather scraps, blood, fat, protein, fiber, hormones, antibiotics), inorganic (heavy metals, nitrites and nitrates, phosphates and mineral salts) and biological (Salmonella, Escherichia, Vibrio cholerae, viruses, parasite eggs, etc.) pollutants [14-16]. In most cases, these pollutants are characterised by the following quality indicators: turbidity, pH, TSS, oil and fat, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Phosphorus (TP), Total Nitrogen (TN), Total Organic Carbon (TOC), etc. [16-18].

The discharge of untreated or partially treated wastewater from the poultry processing industry into the natural outfall represents a real danger both for aquatic ecosystems through eutrophication and deoxygenation of water bodies and for human health. For this reason, it is necessary to comply with the required legislative quality standards and regulations by applying efficient treatment technologies and methods before discharge into the natural outfall or, where appropriate, for reuse [15, 19, 20].

Coagulation - Flocculation and sedimentation, electrocoagulation, dissolved air flotation (DAF) systems, sand filtration systems, anaerobic reactors, stabilisation tanks, etc. are physico-chemical and biochemical processes and techniques found in the vast majority of industrial wastewater treatment plants, with the role of reducing and neutralising pollutants in effluents from poultry slaughterhouses [2, 19, 21].

In common practice, DAF is applied in primary treatment processes and is used to reduce Suspended Solids (SS) as well as to remove oils and fats from effluents [22-24]. The DAF process consists of immersing air in the effluent mass at a certain pressure (4-6 bar) until the maximum saturation level is reached. Once the air injection pressure decreases, the air dissolves into the effluent and small air bubbles are created, which in turn bind to the particles forming aerated conglomerates. These being lighter than water, tend to float to the surface of the water eventually forming a flotation charge (foam) which is removed by means of collection scrapers [23- 25].

The DAF process can be improved by adding chemical additives either to accelerate flocculation using different anionic or cationic polymers and coagulation by injecting a concentration of aluminum sulphate or ferric chloride, or to adjust the pH using NaOH or H_2SO_4 and antifoaming agents (non-ionic surfactants, silicone, etc.). At the same time, it can be effective when operating at optimal operating parameters taking into account both the air injection pressure, the dose of chemical additives, the air/solids (A/S) ratio required to optimize the flotation process, the load and the effluent characteristics, etc. [21, 24, 26].

The efficiency of the DAF treatment process accompanied by rotating screens, equalization tank and two anaerobic sludge reactors were studied for the treatment of effluent from a poultry slaughterhouse of Céu Azul Alimentos Ltda. The maximum neutralization efficiency of the DAF process was similar for BOD_5, SS, Volatile Suspended Solids (VSS) with 64%, 64% and 65%, and for COD and oils and fats it was 58% and 60%. Also, the best yield of the DAF process was when the coagulant dose of 24 mg/L polyaluminum chloride and 1.5 mg/L anionic polymer was applied and by setting the saturation pressure at 300kPa with a volume of 4.8m3 air with A/S ratio of 0.030 mL air/mg SS) [26].

In contrast to chemical additives, bioflocculants (Bacillus sp. BF-2 and Comamonas aquatica (BF-3) proved to be much more effective in the DAF system for treating effluent from a poultry slaughterhouse, managing to reduce Total Suspended Solids by 91%, lipids by 93% and proteins by 79% [27].

The aim of this work was to determine the degree of pollution of effluent from a poultry slaughterhouse and to determine the efficiency of DAF treatment by comparing quality indicators. Also, it was evaluated the need for integration of a tertiary treatment process using membrane technology in order to meet the water reuse standards.

2 Materials and methods

2.1 Description of slaughter capacity and process

The present study focused on the determination of the quality of effluent from a treatment plant in a poultry slaughterhouse located in the region of Moldova, Romania. The maximum processing capacity of the poultry slaughterhouse is 160 t/day chicken carcasses. The water requirement for the whole slaughtering process is obtained from two supply sources, namely from the public drinking water network (30%) and from the own underground source (70%). The distribution of water consumption and therefore of the total volume of effluent generated is shown in Figure 1. for each stage of the slaughtering technological process.

Both in the diagram described in Fig. 1, and in the literature, it appears that the washing and evisceration stages generate the largest volume of effluent with significant concentrations of toxic pollutants (blood, protein, feathers, fat, oil, faeces, chemical disinfectants, solids).

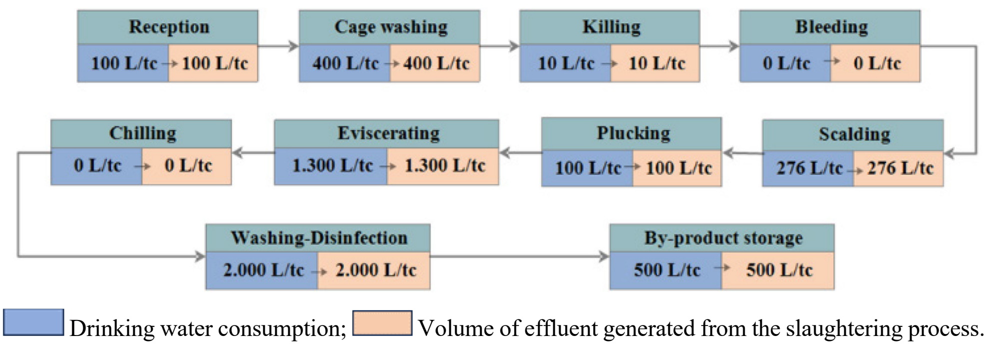

Fig. 1. Diagram of the technological process of slaughtering with the water consumption of each stage and the volume of effluent generated.

Looking at the overall level, approximately 6,510 L/tc are consumed for the processing of one tonne of carcass. According to the literature, the average water consumption for processing a 2.3 kg chicken carcass is 26.5 L, not much higher than the 15 L/c described in the process [19, 23, 28].

2.2 Treatment process of effluent from poultry slaughterhousesing the Integrity of the Specification

The poultry slaughterhouse has an industrial wastewater treatment plant that provides physico-chemical treatment of the effluent from the slaughtering process. The treatment plant consists of a rotary filter, an equalisation tank, a flocculation system and a DAF plant, as shown in Fig. 2.

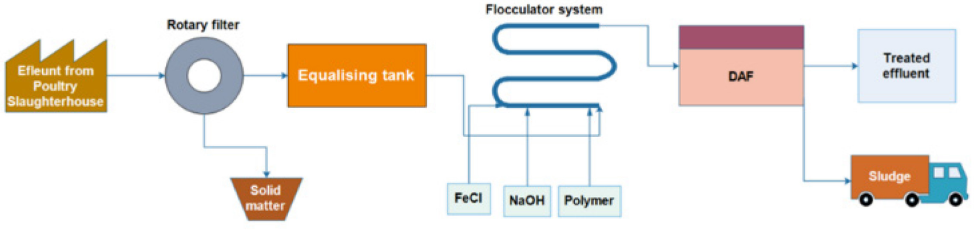

Fig. 2. Treatment process of effluent from poultry slaughterhouse.

The rotary filter consists of a drum that ensures the retention of coarse materials and solid particles in the effluent taken by means of an electropump in a buffer tank with a volume of 40 m3. The coarse matter is separated by the size of the sieve orifices which is 0.75 mm, and cleaning is done by scraping with a scraper, the solid part is collected through a chute into a collection container. The filtered effluent is conveyed via two pumps into the equalisation basin, which is equipped with a homogenising system with mixer. From this basin the effluent is subjected to an injection and homogenisation plant with flocculant chemicals and pH regulators with NaOH.

The mechanically pre-treated effluent is fed into a DAF system, where compressed air under pressure of up to 5.5 bar is dissolved in the water. When the water is saturated with air, the pressure is suddenly released forming small air bubbles. Through the expansion nozzles, the air bubbles are distributed evenly throughout the effluent mass, joining the impurities in the effluent, forcing them to float to the surface. The DAF system is fitted with a trough to remove the layer of impurities formed on the surface of the vessel. Gravity settling sediment is transported by a helical conveyor at the bottom of the DAF system. The resulting sludge is discharged into a sludge buffer tank and the effluent is recirculated within the DAF system

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2.3 DAF system *parameters*

The DAF system operates approximately 9h/day at a capacity of approximately 1200m^3/day. In Table 1. The operating parameters and chemical additives used in the flocculation process are shown.

Table 1. DAF System Operating Parameters

Parameters set	Value
Chemical additives	
Floculant Polimer - 0,05%	2.5 kg/day
FeCl – 42%	25 L/h
NaOH – 25%	18 L/h
Operating parameters	
pH	6.4
Saturation pressure	5,2 bari

Parameters set	Value
Chemical additives	
Compressed air	30 L/min
Volume of the tank	110 m3/h
Dimensions of the basin (l x w x h)	11,8 x 2,9 x 2,4 m

2.4 Determination of quality indicators

The study was carried out on the effluents from the slaughtering processes which were collected twice in October and November 2023 (4 sampling days) to determine the degree of pollution. Sampling was carried out after the DAF system was set to an optimal working regime both in terms of operating parameters and the addition of chemicals required for coagulation and flocculation. Analyses of physical, chemical and biological quality indicators were determined in an authorised laboratory following the standardised working procedures shown in Table 2.

Table 2. Standard methods for determining quality indicators.

Indicator de calitate	U.M.	Metoda standard	Limitele maxime admise conform NTPA 002
pH	-	pH-metru	-
TSS	mg/L	SR EN 872.2009	350
COD	mg/L	KIT KCK 614	500
BOD_5	mg/L	Metoda BOD Trak	300
TKN	mg/l	-	-
NH_3/NH^{4+}	mg/l	KIT LCK 303	30
NO_3	mg/l	KIT LCK 339	-
Cl	mg/l	KIT LCK 311	-
TN	mg/l	KIT LCK 238	-
TP	mg/l	KIT LCK 348	5
PO_4	mg/l	KIT LCK 348	-
SO_4	mg/l	KIT LCK 353	600
NTG	UFC/mL 37oC	SR EN ISO 6222:2004	-

In order to determine the efficiency of the DAF treatment process the effluent sampling was done both before and after and can be determined using (1).

$$RET = \frac{1-E_f}{E_i} x100 \quad (1)$$

Where: RET - Retention rate in %; Ef - Final effluent and Ei - Initial effluent.

3 Results and discussions

The characterization of the sampled effluents was carried out in four days, so in October the sampling and determinations were done on 05 and 19, and in November on 09 and 23, in 2023. In order to give an overview, Table 3 shows the average, minimum and maximum values of the quality indicators determined on the four sampling days.

Table 3. Standard Effluent characteristics determined both before and after the DAF treatment process

Quality indicators	U.M.	Effluent calibration before DAF			Effluent quality by DAF		
		Average	Min.	Max	Average	Min	Max
pH	-	7.02	6.89	7.25	7.39	7.22	7.56
TSS	mg/l	1,326.75	1,210.00	1,457.00	32.23	35.72	35.74
COD	mg/l	1,837.75	1,344.00	2,542.00	365.71	324.33	412.00
BOD_5	mg/l	738.00	512.00	1,077.00	197.06	81.67	335.50
TKN	mg/l	238.29	234.10	242.15	32.23	18.25	45.50
NH_3/NH^{4+}	mg/l	120.00	101.00	139.00	62.57	50.90	76.20
NO_3	mg/l	27.62	23.10	31.21	2.03	1.62	2.35
Cl	mg/l	95.80	94.49	97.63	252.56	201.90	309.04
TN	mg/l	193.10	168.50	216.50	90.54	81.70	102.52
TP	mg/l	27.89	11.10	40.55	1.77	1.07	2.45
PO_4	mg/l	86.20	36.30	124.50	3.68	1.59	6.15
SO_4	mg/l	617.50	605.00	635.00	135.06	117.46	170.09
NTG	UFC/mL 37°C	$1x10^7$	$0.92 x10^7$	$1.06 x10^7$	4002.5x10^2	3897x10^2	4105x10^2

For a comprehensive analysis of the effluent characteristics, 14 quality indicators were determined, both physical (pH and TSS) and chemical (COD, BOD, NO3, TP, TN, TKN, etc.) and biological (Total Count and Total Coliform). As shown in Table 2, the quality indicator values determined before treatment with DAF are very high. The most representative values are given by COD, TSS, BOD_5 and SO_2^{-4} with an average of 1,837.75 mg/L, 1,326.75 mg/L, 738.00 mg/L and 617.50 mg/L.

This is normal since by the nature of the slaughtering process pollutants are generated which are mainly characterised by these quality indicators. The analysed indicators were significantly reduced after the DAF process, so that COD, TSS, BOD5 and SO_2^{-4} were reduced on average up to 365.71 mg/L, 32.23 mg/L, 197.06 mg/L and 135.06 mg/L. Also a significant reduction was found for Total Count (NTG) considering the initial average values 1x107 MPN/100mL.

3.1 Change in effluent quality indicators at the initial time

In the most common case, the effluent from the slaughtering process contains different concentrations of pollutants, the degree of pollution being influenced by the processing capacity of the poultry, the technologies and methods used in the slaughtering process and the management of the resulting by-products [26].
Therefore, the graph in Fig. 3, shows the variations of the quality indicators determined before the effluent treatment, during the hours and days when the slaughterhouse was operating at full capacity, thus providing a clear picture of its quality level.

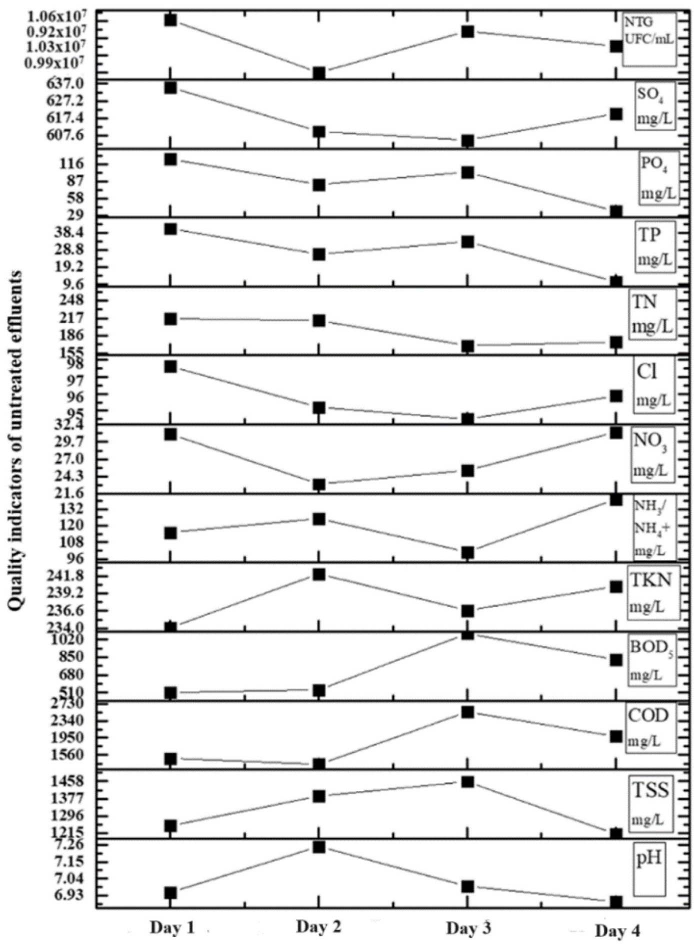

Fig. 3. Variation of effluent quality indicators taken before the treatment process.

The variation of indicators defining effluent quality differs according to the concentration and characteristics of the pollutants. In the case of physical indicators, pH was determined, which tends towards neutral, reaching 7.25 on day 2, and TSS, which shows significant variations, reaching a maximum of 1457 mg/L on day 3.

The most relevant chemical quality indicators for this effluent time are COD, BOD_5, TN, TP and SO4. Thus COD had the highest values fluctuating from 1344 mg/L on day 2 to 2542 on day 3. A similar variation was found for BOD_5 with a maximum of 1077 mg/L. The maximum COD and BOD values found on day 3 can be explained by the higher presence of organic compounds in the effluent due to the intensification of the slaughtering process and also from the washing and sanitation waters. NH_3 ranged from 101 to 139 mg/L, the maximum value being close to that determined by another study characterizing effluent from a poultry slaughterhouse in Croatia, which was 156 mg/L. The TKN value determined in the same study was 340 mg/L, 29% higher than the maximum value determined in the study which was 242 mg/L [29].

In the case of microbiological indicators, the total number of germs (NTG) varied from day to day and was generally maintained between 0.92x107 and 1.06x107 CFU/mL. The variation in these values depended on pH and temperature as well as the organic content of the effluent.

COD, BOD_5, TP, SO_4, TKN, NTG and TSS had higher values compared to the other indicators and the difference in their concentration from day to day is due to the intensity of the washing, evisceration and plucking processes of the chickens and the sanitizing substances used in the slaughtering process.

3.2 Variation of effluent quality indicators at baseline

These operating parameters were set after several tests taking into account the flow rate into the plant, the operating time of the poultry slaughterhouse and the load of organic and microbiological compounds in the effluent. Therefore, the reduction of the pollution level is due to the optimal operating conditions set and the additions of chemicals in the DAF process. The graph in Fig. 4, shows the variations of the quality indicators determined after the DAF process.

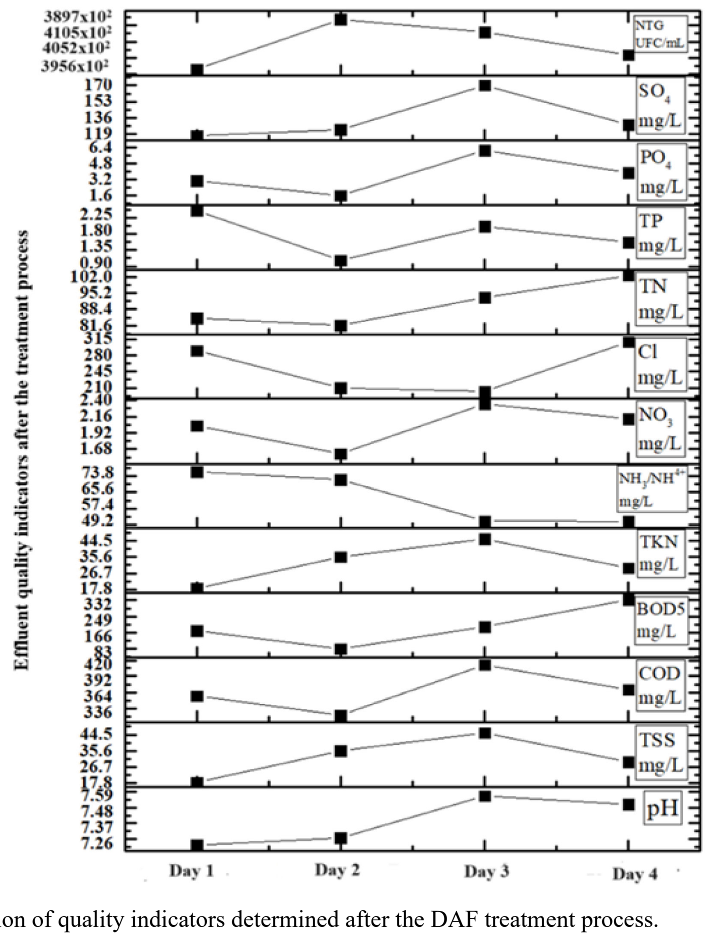

Fig. 4. Variation of quality indicators determined after the DAF treatment process.

As can be seen in the graph shown in figure 3. the pH varied according to the effluent load and the amount of NaOH caustic soda and FeCl injected into the homogenizing flocculant system. In the flocculation system the pH fluctuated between 6.3 and 6.5, being stabilized by increasing or decreasing NaOH and FeCl. After the DAF system, the pH ranged between 7.22 and 7.56 on days 1 and 4 of sampling. The TSS values in the effluent decreased compared to the initial ones, on the first day of sampling identifying the lowest value of 18.35 mg/L.

The concentration of TSS had a slight increase until the third day reaching 45.5 mg/L and on the fourth day it decreased to the value of 29.5 mg/L. Compared to the NTPA 002 limit value of 350 mg/L, the TSS values determined after the DAF process are lower, which means they are compliant for discharge into the municipal sewer system. Compliance was also found in the case of COD and BOD5 values, the limit being 500 mg/L and 300 mg/L. COD was reduced by 324.33 mg/L on the second day of sampling, and on the third day its value increased to 412 mg/L. In the case of BOD5, the maximum value being found on the fourth day of sampling with 335.5 mg/L, having a slight deviation from the technical discharge standard. The persistence of BOD5 and COD in the treated effluent can be explained by the high concentration of organic substances from the slaughter process, the DAF system not having the capacity to completely reduce these compounds.

A significant reduction was also found in the case of SO2-4 with values recorded below the maximum allowed level of 600 mg/L, ranging from 117.46 mg/L on the first day of sampling to 170.09 mg/L on the third day sampling.

In general, concentrations of TN and TP indicate the level of microbial contamination of effluents, so that at their representative concentration it leads to a more intense pathogenic activity. Maximum concentrations of TN and TP were identified on the fourth day with 102.52 mg/L respectively on the first day with 2.45 mg/L, these values are much lower compared to the values determined before the treatment process [19, 30]. NH3/NH4+, more precisely ammonia and ammonium ions, exceeded the maximum value imposed by the technical regulations for discharge in the municipal sewage system by almost half of its value, fluctuating between 50.9 mg/L - 76.2 mg/L. In what he found this total number of germs decreased significantly compared to the initial values, ranging from 3897x102 on the first day to a maximum of 4105x102 on the second day of sampling, the difference between them being reduced.

The chlorine concentration increased in contrast to the initial values, reaching a maximum of 309 mg/L on the fourth day of sampling. This increase can be explained by the fact that during the DAF process FeCl and NaOH are injected as a neutralizer to maintain the pH at a neutral environment. Their concentration changes simultaneously as they influence each other to keep the process at an optimal level of operation.

After passing the effluents through the DAF system, the pollutants were significantly reduced by complying with the technical regulations for discharge into the municipal sewage system, with the exception of NH3/NH4+.

3.3 Efficiency of the DAF treatment process

The retention rate was determined taking into account the input and output data from the treatment system to highlight the efficiency of the treatment process using DAF. Fig. 5, shows the retention rate of the indicators determined after DAF treatment.

The DAF treatment accompanied by the dosing flocculant system was the most effective in reducing TSS and PO4 with a maximum of 99% and 98% on the first day of sampling. Increased retention values were also found in the case of TKN, NO3, TP and SO2-4, with an average of 86%, 93%, 92% and 78%, which denotes that the parameters and concentrations of chemical substances involved in the process are the most optimal for treating effluents.

The retention rate of COD and BOD5 indicators varied between 76% and 84% and 59% and 85%, respectively. In another study that used the DAF system in the treatment of effluents from a poultry slaughterhouse in Sorocaba, SP, Brazil, it obtained a maximum retention rate of 58% as opposed to 84% obtained in the study. Lower efficiency was obtained for NH3/NH4+ and TN with an average retention rate of 47% and 52%.

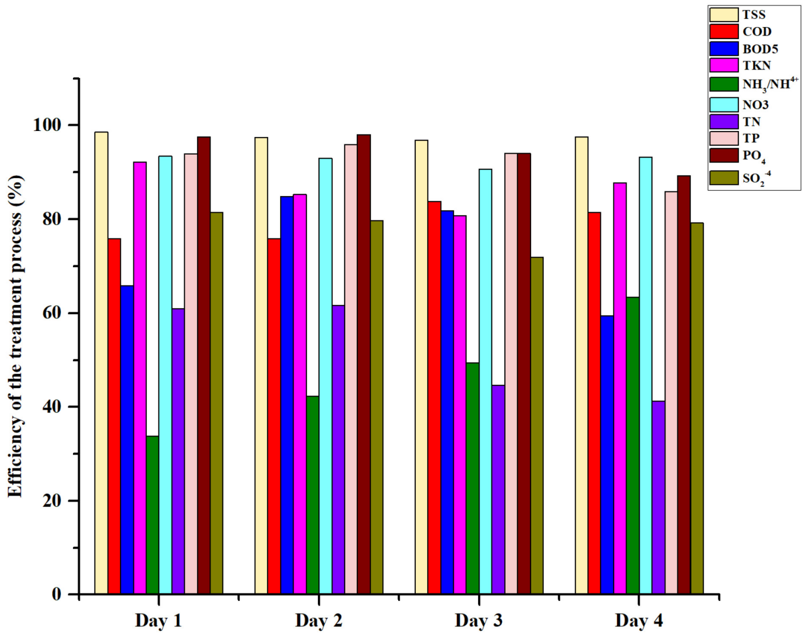

Fig. 5. The retention rate of the indicators determined before and after the DAF process.

3.4 The possibility of extending the treatment process in order to meet the requirements of the reuse of effluents

The current treatment, consisting of a coarse filter stage, equalization basin, flocculator system and DAF, has been shown to be effective to the extent that the treated effluents are discharged into the municipal sewage system. In other words, the effluents from the poultry slaughterhouse, subject to the current treatment process, comply with the technical standard NTPA 002. However, if it is desired to reuse the effluents for different purposes, either technical, irrigation or even for drinking purposes, the quality requirements increase according to existing EU and international quality standards. Table 4, shows the quality limit values that the effluent must meet after the industrial treatment process [19, 31, 32].

By integrating an advanced treatment step into the existing treatment process line, the maximum permitted quality limits can be met so that the resulting effluent can be reused for various purposes.

In the tertiary stage of industrial wastewater treatment, a wide range of modern and efficient technologies are included and used, among which we can mention: Membrane technology, electrodialysis, dialysis, pervaporation, electroosmosis, membrane reactors, etc, [33-35]. One of the most effective and current methods of retaining polluting compounds from industrial effluents is membrane technology applied individually after classical processes or accompanied by a disinfection step [35-37].

Table 4. Comparison of quality limits of effluents from a poultry slaughterhouse for their reuse [19, 31, 32].

Quality indicator	U.M.	Evacuation limit EU	Evacuation limit USA	Evacuation limit Australia	Evacuation limit World Bank
pH	-	6-9	6-9	6-9	6-9
TSS	mg/L	35	30	20	50
COD	mg/L	125	-	40	125
BOD5	mg/L	25	26	20	30
TN	mg/l	15	8	20	15
TP	mg/l	2	-	2	2
TOC	mg/l	-	-	10	-

Membrane technologies used in advanced treatment processes can be Microfiltration, Ultrafiltration, Nanofiltration and Reverse Osmosis. The particularity of these processes is given by the pore diameter of the membranes used, the molecular weight, the nature and composition of the membrane material and the pressure gradient used [38-40]. According to the studies carried out, the membrane technology used individually or accompanied by a disinfection step as an advanced treatment for the reuse of effluents from poultry slaughterhouses has proven to be very effective in retaining total suspended solids, organic and inorganic matter, pathogens, synthetic detergents, artificial colors etc. [41, 42].

4 Conclusions

As a result of slaughtering processes, large amounts of effluents with a high concentration of toxic pollutants are generated. Evisceration and washing of chicken carcasses are the most water-consuming and at the same time the most pollutants result from these stages. The treatment process applied in the poultry slaughterhouse consisted of a rotary filter, equalization basin and DAF accompanied by the flocculation system. The DAF process was set to an optimum operating regime with chemical additions that were adjusted according to the effluent load and flow rate. Following the analyzes performed and data interpretation, it appears that the DAF process was effective in reducing quality indicators, reaching a maximum of 99%, 98%, 93%, 93%, 92%, 85%, 84%, for TSS, PO4, NO3, TKN, BOD5 and COD. More than this, the vast majority of quality indicators comply with NTPA 002. Having said that, water consumption is significant, therefore it is necessary to reuse the effluents for various technological purposes or even to make them potable. Successive treatment steps including advanced purification processes could meet the quality requirements for an effluent to be reused. The application of membrane technologies accompanied by a disinfection step in the final treatment of effluent from poultry slaughterhouses could be a future research direction, aiming at the valorisation of effluent through reuse in slaughterhouse processes.

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