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AMENABILITY OF POULTRY ABATTOIR WASTEWATER FOR SEQUENTIAL ANAEROBIC-AEROBIC BIOLOGICAL TREATMENT PROCESSES

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Abstract

The scarcity of potable water availability worldwide is enhancing the search for innovative water resources to mitigate the effects of this problem. Reuse of wastewater is one of the resolutions that has a promising alternative to reduce the impact of water shortening. The wastewater from poultry slaughterhouses in western Malaysia was characterized in this study in order to check its suitability for sequential anaerobic-aerobic biological treatment and to produce secure water for environmental disposal. Three poultry slaughterhouses were selected according to their maximum capacity of 30000, 45000, and 12500 birds per day for Ayam Kempas, Ayamas, and PPNJ plants, respectively. To reduce contamination in the wastewater generated, these plants separate blood from wastewater. The parameters BOD_5 (range 271-1033 mg/L), TDS (range 275-1458 mg/L), TSS (range 237-1017 mg/L), TVSS (range 234-1006 mg/L), alkalinity (range 47-318 mg/L as $CaCO_3$), FOG (range 159-550 mg/L), TCOD (range 940-3402 mg/L), TN-N (range 42-205 mg/L), and PO_4^{-3}-P (range 17-64 mg/L) were measured in the laboratory. The characteristics of wastewater in these plants were fluctuating. However, the organic matter concentrations among these three selected plants were adopted to order them. Ayamas's wastewater occupies the first rank in the contamination level, followed by Ayam Kempas's and PPNJ's wastewater, respectively. The low strength of PPNJ wastewater is due to the lower production capacity of the slaughterhouse and the high usage of freshwater per bird slaughtered (24 L/bird) compared to the other two slaughterhouse plants.

Key words: organic pollutants, poultry abattoir characterization, poultry slaughterhouse wastewater, sequential anaerobic-aerobic biological treatment

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1. Introduction

Discharge of slaughterhouses wastewater to surface waters harm the water quality and environment, due to their high concentrations of organic matters measured as biological oxygen demand (BOD) and/or chemical oxygen demand (COD), and macro-nutrients measured as Nitrogen and Phosphorous (Alvarez and Liden, 2008; Danalewich et al., 1998). These industries are widely spreading, high in water consumption, and have a high environmental impact from the wastewater generated from these plants (Bustillo-Lecompte and Mehrvar, 2015). The activities of the poultry slaughterhouse plant could be summarized as follows: slaughtering process, scalding with hot water to facilitate feather

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removal, feather removal process, evisceration of internal organs (intestinal, livers and gizzards), cleaning carcass process with cold water (pre-chilled), chilling process with iced water, cutting process, and packaging process. The most processes that have high contribution fraction of wastewater formation are; scalding, pre-chilling, chilling, and plant's grounds and machinery's cleaning processes (Amorim et al., 2007; Bustillo-Lecompte and Mehrvar, 2015; Kist et al., 2009).

High quantities of water consumed in the poultry slaughterhouse plants (18-30 L/bird) generate a high amount of wastewater. This wastewater is characterized as high-strength wastewater that has a high negative impact on the environment without proper treatment. The common treatment plant for poultry slaughterhouse wastewater (PSW) consists of solids and feather strainer, dissolved air floatation (DAF), physicochemical treatment with sedimentation tank, aerobic biological treatment, filtration unit (optional), and disinfection unit. Other slaughterhouses use anaerobic biological processes for treating PSW using up-flow anaerobic sludge blanket (UASB) technology (Rajakumar et al., 2011). This technique has a low operation cost, and fat, oil, and grease (FOG) contaminant can be degraded without using the DAF system (costed-operation system) (Basitere et al., 2020). In addition, land application (discharge of slaughterhouse wastewater onto lands) is a highly recommended way to get rid of this type of wastewater because of its cost-effective technique and the benefits of the wastewater's elements to the land's fertilizing (Wu and Mittal, 2012).

The characterization study for the selected PSWs in Johor (southern state of Malaysia peninsular) contributed to reveal the contamination level of the selected parameters among the different poultry plants' effluents. This kind of wastewater characterized with high level of organic matter (biodegradable substances) resulting from blood content, fat presence, particles of organs, colloidal particles, and variation of suspended solids (Meiramkulova et al., 2020). The pollution levels of PSWs effluents highly fluctuate among them and even within the same plant depending on its production capacity, the blood capture strategy, and the water consumption policy that each factory adopts. The range of main contaminants concentrations for slaughterhouse wastewater measured as COD, BOD_5, pH, TSS, and FOG were 1100 - 15000 mg/L, 160 - 3900 mg/L, 5 - 7.8, 50 - 6400 mg/L, and 34 - 1385 mg/L, respectively (Aleksić et al., 2020). The determination of the pollution level for these industrial effluents provides a clear insight into choosing the suitable treatment technique (Meiramkulova et al., 2019; Njoya et al., 2019).

There are lack of data availability and fewer concerns regarding the characteristics of PSW which is produced in Malaysia. Most slaughterhouse wastewater quality data have been generated in Europe (Sayed et al., 1987; Tritt and Schuchardt, 1992), Australia (Johns, 1995), Canada (Masse and Masse, 2000), Serbia (Aleksić et al., 2020), and Indonesia (Budiyono et al., 2011). Furthermore, the characteristics of each selected PSW are deeply analysed for checking the suitability of these wastewaters to be treated biologically and comparing the quantities of organic matters and the organics to the nutrients ratios with the literature recommended values for good or poor biological contaminations removal (Njoya et al., 2019). The objective of this work is to identify the characteristics of the poultry slaughterhouse and processing plant's wastewater that is generated in Malaysia/Johor (southern state of Malaysia peninsular). Three poultry slaughterhouses, which are considered as the highest capacity plants in the Johor state, have been selected for this purpose.

2. Methodology

2.1. Selection of slaughterhouse

Characteristics determination of the PSW generated in Malaysia has been conducted through the selection of three poultry slaughterhouse plants, which are considered as the largest plants in Johor state, namely Ayam Kempas Sdn. Bhd., Ayamas Food Corporation Sdn. Bhd., and PPNJ Poultry and Meat Sdn. Bhd. Ayam Kempas is the first poultry slaughterhouse that had been visited for characterizing its wastewater using the procedure that had been described later. This factory is located in Persimpangan, Ulu Tebrau, in Senai City, Johor State, with a slaughtering capacity of 20.000-30.000 birds per day (Fig. 1). The collection of samples for this plant was lasting for 6 weeks, about each 5 days; one sample has been gathered from the sampling port (after feather removal strainer) and was conveyed to the laboratory for more analysing. Ayamas Food Corporation is the second poultry slaughterhouse that was visited in order to collect raw wastewater for conducting the physical and chemical properties. This factory is located in Bandar Tenggara city, Johor state (Fig. 1), and its slaughtering capacity was 30.000–45.000 birds per day. Thirty days was the total collection period of samples from this plant (six visits), similarly to the Ayam Kempas's raw wastewater gathering strategy had been followed for characterizing this plant's wastewater where about each 5 days one sample had been collected from the sampling port and was conveyed to the laboratory for more analysing.

Samples collection have been carried out depending on performing several visits for each slaughterhouse. Each collected sample has been conveyed to the laboratory in cooling box. All samples used in this characterization study were collected from the flow coming from the fixed strainer instrument which is located after feathers removal equipment.

PPNJ poultry and meat (The slaughtering capacity was 7.000-12.500 birds per bird/day) is the third poultry slaughterhouse that was visited in order to collect raw wastewater for determining its physical and chemical properties. This factory is located in

Ayer Hitam city in Johor state (Fig. 1). The total collection period of samples from this plant was 45 days, similarly to the previous two poultry industries' raw wastewater gathering strategy had been adopted for characterizing this plant's wastewater where approximately each 5 days, one sample had been collected from the sampling port then it was transferred to the laboratory for more analysing.

2.2. Analytical method

Some parameters were determined in the site by using portable instruments such as; pH meter (YSI QUATRO 15F100183), turbidity meter (HACH-2100Q) and temperature meter and electrical conductivity meter (EC) (Orion-model 122). Remaining parameters have been analysed on the second day after keeping the sample in the fridge which was setting on 4 ºC in order to reduce the microbial activity for the BOD_5 test, whereas 2 mL of the composite sample, after well shaking of the sample's container, was injected into each COD reagent vials (3 vials) and was stored in the fridge for the next day testing. The parameters those were tested in the laboratory are; BOD_5, Total dissolved solids (TDS), TSS, TVSS, alkalinity, FOG, TCOD, TN-N, and PO_4^{-3}-P. Where BOD_5, TDS, TSS, TVSS, alkalinity, and FOG were measured in accordance with the standard methods (Association A.P.H. and Association A.W.W., 1995) using 5210 B, 2540 C, 2540 D, 2540 E, 2320 B titration method, and 5520 B gravimetric method respectively, meanwhile, TCOD, TN-N, and PO_4^{-3}-P were determined using HACH system (DR6000) Spectrophotometer (Method 8000-reactor digestion method for COD, Method 10072 persulfate digestion method for TN-N, and Method 8114 Molybdovanadate method for PO_4^{-3}-P). All parameters are measured using triplicate manner in this study.

3. Results and discussion

Ayam Kempas is a poultry slaughterhouse plant only where the chickens have been slaughtered and prepared as a whole chicken or cut into several pieces with or without bones then it is delivered to the consumers as a cold or frozen product. The production capacity of this slaughterhouse is between 20.000 and 30.000 bird per day with average fresh water consumption of 200 m^3/d. This slaughterhouse has a system of harvesting rainfall in order to reduce the water consumption bill. Furthermore, in the slaughtering process, they have intensively separated the blood from flow in the wastewater's stream; this explains the contamination level of generated wastewater being relatively low. The wastewater treatment plant's technologies that are applied in this factory are. Feather removal drum, fixed strainer for removing large particles, dissolved air flotation (DAF) for removing FOG, physicochemical process, and biological treatment using SBR technique.

There are several issues, that have been reported by the interview with the factory's manager regarding the treatment of this wastewater, could be summarized by; high chemicals usage, high water consumption, and high ammoniacal nitrogen concentration in the treated effluent which is out of the desired limit. Table 1 illustrates the physical and chemical properties for the wastewater generated from this factory.

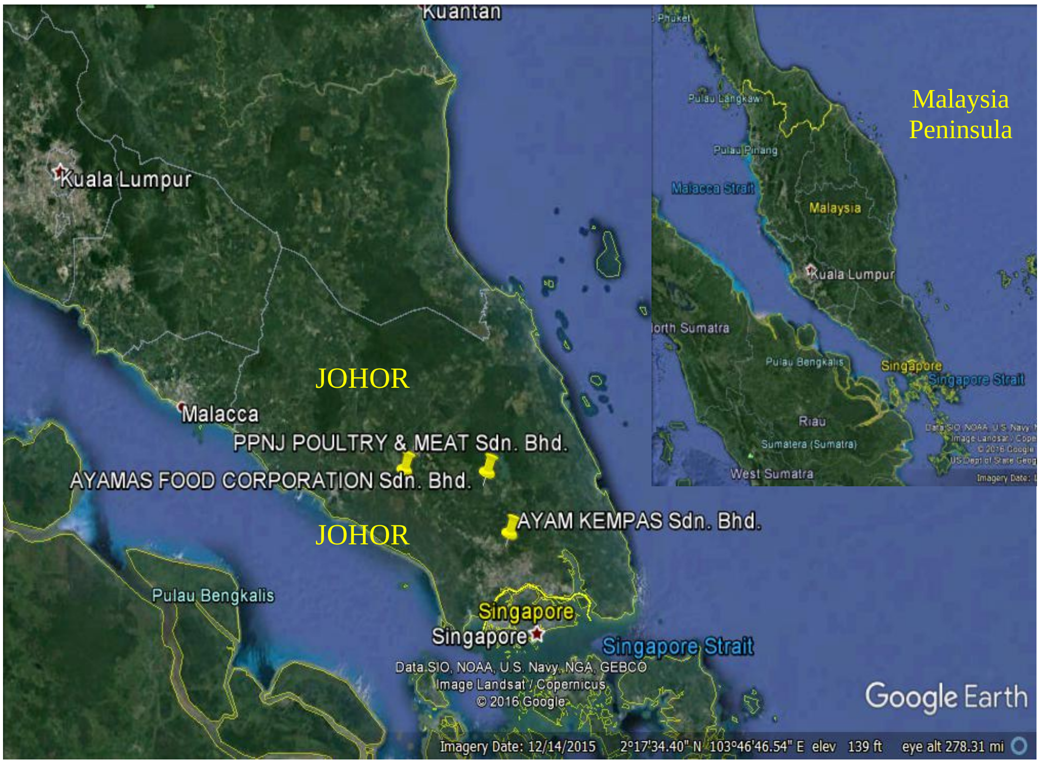

Fig. 1. Location of selected poultry slaughterhouses for wastewater characterization

Table 1. Physical and chemical properties for Ayam Kempas's wastewater

Parameter	*Unit*	*1st visit*	*2nd visit*	*3rd visit*	*4th visit*	*5th visit*	*6th visit*	*7th visit*
TCOD	mg/L	1320	1640	2165	1998	1645	2492	1590
BOD_5	mg/L	650	873	508	980	1033	770	893
TN-N	mg/L	160	202.5	205	188.3	164	156	157
PO_4^{-3}-P	mg/L	--	64.0	42.9	58.3	53.6	49.8	33.5
NH_3-N W. CH.*	mg/L	0.40	1.0	0.38	--	--	--	--
NH_4-N W. CH.*	mg/L	84.9	112.9	103.6	--	--	--	--
FOG	mg/L	--	--	287.2	550	184	545	282.5
Alkalinity	mg/L as $CaCO_3$	--	190	224	318	244	243	197
TSS	mg/L	480	675	956	565	542	607	751
TVSS	mg/L	416	670	941	548	542	606	700
TDS	mg/L	1339	1362	1458	1512	1141	1421	1294
pH		6.78	7.0	6.65	8.0	7.0	6.8	6.8
T	°C	28.9	29.0	30.2	30.0	27.0	28.8	28.2
Turbidity	NTU	730	733	> 1000	> 1000	690	969	750
EC	µs/cm	1673	1924	1840	2160	1837	1802	1475
DO	mg/L	1.39	0.9	0.97	--	--	--	--

* *Using water checker instrument (YSI Quartro 15F100183).*

It seems from Table 1 high fluctuation of constituents' concentrations that are measured each visit, this is pinpoint in this kind of wastewater and it is one of its characteristics. Where the average concentration and its standard deviation for TCOD, BOD_5, TSS, FOG, alkalinity, turbidity, NH_3-N, TN-N, and PO_4^{-3}-P parameters were 1836±401, 815±186, 654±160, 370±167, 236±46, 839±143 NTU, 101±14 176±22, and 50±11 mg/L respectively, additionally, other parameters exhibit less oscillation in its measurements such as pH, temperature (T), TDS, and EC where were 7.0±0.5, 28.9±1.1 ºC, 1361±122 mg/L, and 1816±211 µs/cm respectively.

Ayamas Food Corporation is a poultry slaughterhouse and processing plant where chickens are slaughtered and prepared either as whole chickens or cut into several pieces. The products are then served as chilled fresh chicken meat or frozen processed chicken meat. This plant supplies Halal chicken meat to KFC, Pizza Hut, and Rasamas restaurants across the southern states of Peninsular Malaysia.

The production capacity of this slaughterhouse ranges between 30,000 and 45,000 birds per day, with an average wastewater production of 800 m³/day. To reduce freshwater consumption, this slaughterhouse has dug a well to use groundwater for activities that consume a lot of water but do not require high-quality water, such as cleaning trucks, chicken cages, loading yards, humidifying chickens, and cleaning the WWTP area (Kist et al., 2009). Furthermore, in the slaughtering process, they have separated the blood from the wastewater stream to reduce the contamination level of the generated wastewater. Table 2 illustrates the physical and chemical properties of the wastewater generated from this factory.

The WWTP technologies used for treating PSW in this factory include: a feather removal drum, a fixed strainer for removing large particles, dissolved air flotation (DAF) for removing fats, oils, and grease (FOG), biological treatment using a continuous flow intermittent aeration reactor, a sedimentation tank, poly aluminium chloride as a coagulant for the sediment tank's effluent before it enters the multi-media filter, and a disinfection process before discharging into the water stream that ends in an artificial pond.

The existing treatment plant faces several critical issues, as revealed by its manager. These problems are similar to those previously noted in the Ayam Kempas section, including high chemical usage, high water consumption, and treated wastewater not always complying with Malaysian standards for industrial effluents, particularly regarding NH_3-N concentration. Additionally, this WWTP sometimes struggles to handle the influent organic loading rate (OLR) and cannot tolerate shock loading, especially when the production process is at its peak.

Table 2 shows similar fluctuations in constituent concentrations to those observed in the previously visited Ayam Kempas slaughterhouse plant. The average concentrations and standard deviations for parameters such as TCOD, BOD_5, TSS, FOG, alkalinity, turbidity, NH_3-N, TN-N, and PO_4^{-3}-P were 2711±534 mg/L, 931±105 mg/L, 835±177 mg/L, 281±69 mg/L, 160±23 mg/L, >1000 NTU, 85±23 mg/L, 153±35 mg/L, and 51±3 mg/L, respectively. Additionally, other measured parameters such as pH, temperature (T), total dissolved solids (TDS), and electrical conductivity (EC) were 6.8±0.3, 28.5±0.8ºC, 917±148 mg/L, and 795±120 µS/cm, respectively.

PPNJ poultry and meat is also a poultry slaughterhouse and processing plant where the chickens have been slaughtered and prepared as a whole chicken or cut into several pieces then it is shipped to customers as chilled fresh chicken meat as well as frozen processed chicken meat. The production capacity of this slaughterhouse is lower than previously stated of two slaughterhouses, where it is between 7.000 and 12.500 bird per day with average freshwater consumption of 24 L/bird. Furthermore, in the slaughtering process, they have also separated the blood from flow in the wastewater's stream for reducing the contamination level of the generated wastewater. Table 3 illustrates the physical and chemical properties for the wastewater generated from this factory.

The results also indicate similar fluctuations in the concentrations of constituents, though with a lesser magnitude, as observed in the previously visited slaughterhouse plants (Ayam Kempas and Ayamas). These fluctuations in wastewater characteristics may be attributed to the number of birds slaughtered per day, the amount of blood leaking into the wastewater stream, the quantity of water used per bird slaughtered, as well as the fats, scalding particles, and organ pieces flowing into the factory's sewer collection system. The average concentrations and their standard deviations for various parameters were as follows: TCOD, 1460±545 mg/L; BOD5, 466±176 mg/L; TSS, 510±202 mg/L; FOG, 233±59 mg/L; alkalinity, 87±33 mg/L; turbidity, 647±265 NTU; NH3-N, 38±16 mg/L; TN-N, 78±33 mg/L; and PO4-3-P, 33±13 mg/L. Additionally, other measured parameters included pH, 6.4±0.4; temperature, 26.4±2.7 ºC; TDS, 479±147 mg/L; and EC, 628±224 µs/cm.The technologies that have been used for treating the wastewater generated in this slaughterhouse plant are; feather removal drum, fixed strainer for removing large particles, physicochemical process, DAF for removing FOG, biological treatment using SBR, and thickener and conditioning sludge facilities.

The treated wastewater has been reused for outer cleaning purposes and the remaining quantity has been discharged into the water stream nearby. According to the WWTP manager’s statement, the existing treatment plant is suitable for treating the generated wastewater and producing effluents within the standards specifications (Malaysian standards B for industrial effluents such as COD < 200 mg/L, NH_3-N < 20 mg/L, FOG < 10 mg/L, and TSS < 100 mg/L). That means, the treatment technologies that are used in this slaughterhouse are sufficient for treating that lower-strength wastewater than other two poultry slaughterhouses (Ayam Kempas and Ayamas), the low-strength of this wastewater is due to the lower production capacity of PPNJ slaughterhouse and the high usage of freshwater per each bird slaughtered (24 L/bird) than other two slaughterhouses plants.

Table 2. Physical and chemical properties for Ayamas Food Corporation’s wastewater

Parameter	***Unit***	***1st visit***	***2nd visit***	***3rd visit***	***4th visit***	***5th visit***	***6th visit***
TCOD	mg/L	3402	2829.3	3030.7	1884.7	2334	2786.7
BOD_5	mg/L	1015	1032.5	1011.8	798.5	816.1	910
TN-N	mg/L	164	113.3	168	108	169.3	197.3
PO_4^{-3}-P	mg/L	52.4	49	54.8	48.3	48.9	51.3
NH_3-N	mg/L	125	85	90	59	69	79
FOG	mg/L	354.5	173.5	322.5	242.1	255.1	337.6
Alkalinity	mg/L as $CaCO_3$	158	156.5	176	194.5	134.5	138
TSS	mg/L	1017	982	979	610	706	718
TVSS	mg/L	1006	960	961	570	701	680.1
TDS	mg/L	1016	969	970	665	817	1062
pH		7.0	7.0	7.0	7.0	6.5	6.5
T	°C	29.1	28.7	27.1	28.6	28.0	29.3
Turbidity	NTU	> 1000	> 1000	> 1000	706	> 1000	> 1000
EC	µs/cm	740	756	869	692	707	1003

Table 3. Physical and chemical properties for PPNJ poultry and meat’s wastewater

Parameter	***Unit***	***1st visit***	***2nd visit***	***3rd visit***	***4th visit***	***5th visit***	***6th visit***	***7th visit***	***8th visit***
TCOD	mg/L	1572	940.5	1469	1085	950.5	2271.0	2254.0	1135.0
BOD_5	mg/L	773.3	332.5	446.3	271.3	428.8	630.0	380.6	-
TN-N	mg/L	122	44.5	113	42	55.5	113.0	74.0	61.0
PO_4^{-3}-P	mg/L	51.8	20.6	47.6	20.5	25.5	38.8	38.1	17.8
NH_3-N	mg/L	57	22	58	20	27	54	35	33
FOG	mg/L	221	246.5	360	228	251	190.4	208.4	159.0
Alkalinity	mg/L as $CaCO_3$	81	47.5	128	73	68	128.5	119.0	54.0
TSS	mg/L	699	237	452	555	286	821.0	621.0	405.0
TVSS	mg/L	604	234	415	450	266	753.0	589.0	391.0
TDS	mg/L	694	42	563	275	363	509.0	637.0	365.0
pH		7	6.5	6	6	6	6.0	6.5	7.0
T	°C	28.6	23.8	25.1	25.1	22.1	29.4	28.0	28.7
Turbidity	NTU	756	308	733	437	498	1000.0	1000.0	444.0
EC	µs/cm	764	476	1063	357	583	635.0	713.0	432.0

The characterization results for the three selected slaughterhouses have been combined and categorized into two groups. The first group includes the concentrations of organic matter and some physical and chemical parameters with high values (Fig. 2), while the second group includes the concentrations of nutrient constituents (NH_3-N, TN-N, and PO_4^{-3}-P) and some parameters with low values (Fig. 3).

The values in these Figures represent the average value of each parameter for each slaughterhouse, with the error bars indicating the standard deviation of each parameter. Figure 2 shows a significant differentiation in the concentrations of organic matter among the three selected plants.

Ayamas's wastewater has the highest contamination level of organics, followed by Ayam Kempas's wastewater in second place, and PPNJ's wastewater in third place.

The high pollution level of Ayamas's wastewater is attributed to its higher production capacity, the incomplete exsanguination process (resulting in a significant quantity of blood being discharged into the wastewater collection system), and additional contamination from the poultry meat processing sector. Conversely, for nutrient contamination levels, Ayamas falls to the second rank, Ayam Kempas rises to the first place, and PPNJ remains in third place.

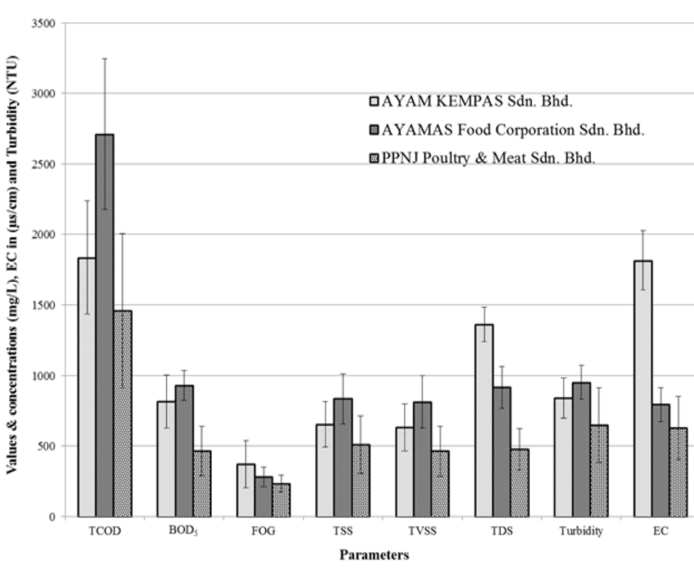

Fig. 2. Organic matters characterization and some parameters with high values for each slaughterhouse's wastewater measured as the average of the consecutive visits (Ayam Kempas n=7, Ayamas n=6, and PPNJ n=8), error bars represent the standard deviation of each parameter

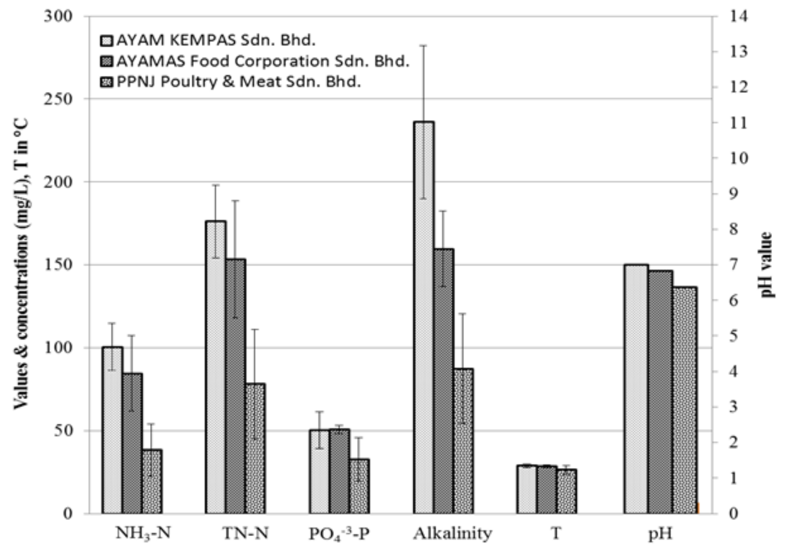

Fig. 3. Nutrients characterizations and other parameters for each slaughterhouse's wastewater are measured as the average of the consecutive visits (Ayam Kempas n = 7, Ayamas n = 6, and PPNJ n = 8), error bars represent the standard deviation of each parameter

The average concentrations of NH_3-N, TN-N, pH, and alkalinity in Ayamas's wastewater have decreased by 16%, 13%, 3%, and 32%, respectively, compared to Ayam Kempas's wastewater. However, the concentrations of PO_4^{-3}-P and the temperature are approximately equal between the two. The lower ranking of the Ayamas slaughterhouse is attributed to its higher usage of freshwater per bird slaughtered compared to Ayam Kempas. This increased water consumption in the Ayamas plant is primarily due to the chicken meat processing division.

The comparison between the selected PSW's (Ayamas) characteristics and the related characterization studies (Del Nery et al., 2016, Del Nery et al., 2013) had been conducted and listed in the Table 4. The high production capacity of Ayamas slaughterhouse and the high amount of polluted wastewater generated compared to the other two plants motivated the selection of this plant for the comparison with the literature. The data of Table 4 are recorded as the average values of each parameter with their standard deviation that companion with median values and their ranges for statistically checking of centralized distribution of the data around their average values. Even though the median values are near from their average values (i.e. data are centralized in their distribution around the average values), the standard deviation in most parameters is relatively high which is reflecting the big variation of this kind of wastewater's characteristics and even so, it is produced from the same plant.

The characterization of Ayamas's wastewater is close from the results of long-term performance study for PSW in the tropical area which was conducted by (Del Nery et al., 2013). Where the differentiation among the measured parameters is lesser than 14% for all parameters except for BOD_5 parameter where was 48% higher than Ayamas's BOD_5 parameter. This high differentiation value might be attributed to the extensive usage of sanitary substance for machinery hygiene such as sodium hypochlorite in accordance with the personnel evidence. More insight to the two publications in the Table 4. It could find the big difference between the industrial effluents' characterization of the same poultry slaughterhouse after elapsing three years, all measured constituents have increased except FOG constituent was decreasing, these increasing of pollution level may be due to the expansion of the poultry's production capacity after three years.

3.1. Adequacy of PSW characteristics to be treated biologically

Most literature was focusing on the amenability of industries' wastewaters to be treated biologically, where most of these characterization studies were dealt with some parameters and ratios that may be used for making a decision of using biological treatment or not. These parameters such as pH, alkalinity, organic strength (measured as COD, BOD, or TOC), inorganic elements (such as calcium, sodium, magnesium, sulfur, and iron), nitrogen (organic and inorganic), and phosphorus are commonly used as well as using some ratios between them for measuring the adequacy of their concentrations for confirming, to the decision makers for example, the suitability of this kind of wastewater to be treated using biological techniques (Ng et al., 2022).

For instance, the ratios of COD:TKN, BOD_5:TKN, and BOD_5:NH_3-N should be greater than 9, 5, and 8 for excellent nitrogen biologically removal and COD/TP ratio for moderate efficiency of anaerobic/aerobic (A/O) or anaerobic/anoxic/aerobic (A^2/O) processes with nitrification should be in range of (34-43) (Grady Jr et al., 2011). COD/BOD ratio is should be in typical values (2.0-2.5) for good indication of presence of biodegradable organic matters in the wastewater under investigation whereas higher values, more than 2.5, indicate organic matters difficult to be biodegraded, the high ratio of VSS/TSS (more than 0.8) means high fraction of organic matters in the suspended solids and so on (Henze et al., 2002). Slaughterhouse wastewater is suitable to be treated biologically (aerobically or anaerobically) after removing the FOG constituent as recommended by Masse and Masse (2000) because of the availability of most nutrients and micronutrients in this kind of wastewater. In accordance with parameters and ratios aforementioned, it could evaluate the sufficiency of the collected wastewater from the three slaughterhouses to be treated biologically using sequential anaerobic-aerobic processes under suspended growth system only and working as one unit for practical usage.

The results are tabulated in Table 5. From the Table 5, the two slaughterhouses' wastewaters (Ayam Kempas and PPNJ) have relatively low average TCOD concentration (1000 < TCOD < 2000 mg/L) than Ayamas slaughterhouse (> 2000 mg/L) where TCOD fractions could be percentiles as follow; about 66% of particulate COD, about 32% of soluble (easy biodegraded) COD, and about 2% of inert COD. High percentage of particulate COD may contribute to producing high ratios of TCOD/BOD_5, as shown in Table 5, which means these kinds of wastewaters contain hard biodegradable substances (Henze et al., 2002). Additionally, the extensive usage of sanitary substances for machinery hygiene (e.g. sodium hypochlorite) is another reason for raising the TCOD/BOD_5 ratios of these wastewaters because these materials are associated with reducing the aerobes microbes' developing which is consequently reducing the concentration of BOD_5. If considering the soluble COD fraction as an easy biodegradable COD and adopting the Fig. 4 for choosing the suitable biological processes for the three candidates slaughterhouses' wastewaters that could be assigned to be the influent for sequential anaerobic-aerobic processes. Figure 4 is a log-log plot, adapted from

Grady Jr et al. (2011), showing the relationship between biodegradable COD (bCOD) concentration and HRT for selected biological processes, including aerobic/anoxic treatment, high-rate anaerobic treatment, low-rate anaerobic treatment, and anaerobic digestion. According to Figure 4, the combination of aerobic and anaerobic processes becomes relevant starting from a bCOD concentration of 1000 mg/L, extending up to 4000 mg/L, at which point the anaerobic process becomes more cost-effective than aerobic processes (Grady Jr et al., 2011).

Consequently, since the bCOD concentrations for the wastewaters from the two slaughterhouses (Ayam Kempas and PPNJ) are much lower than 1000 mg/L, they were excluded from consideration. On the other hand, Ayamas's wastewater, with a bCOD concentration near or sometimes exceeding 1000 mg/L, was selected to be the influent for the proposed bioreactor configuration (Rajab et al., 2017). Furthermore, they have suitable pH, temperature, and alkalinity for aerobic/anoxic biological processes (Danalewich et al., 1998; Grady Jr et al., 2011; Mazlan et al., 2016) especially for Ayam Kempas and PPNJ because they have border limit for excellent biological nitrogen removal ratios of BOD_5/TN-N and BOD_5/NH_3-N as shown in Table 5. That means the easy biodegradable substances in these two slaughterhouses' wastewaters were limited and the aerobic biological treatment can be conducted with good (not excellent) nitrogen biological removal. Good biological nitrogen removal could be achieved after good managing and designing of treatment techniques and provides its substantial parameters such as suitable DO for nitrification, adequate equivalent electron donor (bCOD) for denitrification, and alkalinity for sustaining autotrophic NH_3-N conversion with producing neutral effluents. Vice versa with wastewater's characteristics of Ayamas slaughterhouse where all nutrients ratios are within and exceed the minimum limits, that means, according to the literature, this wastewater could achieve excellent nitrogen biological removal.

Table 4. Characterization comparison between the selected PSW (Ayamas) and related published data

Parameter		***Del Nery et al. (2013)***		***Del Nery et al. (2016) (N = 22)***	***This study (AYAMAS) (N = 6)***
		N	***Industrial effluent***	***Industrial effluent (±SD)***	***Industrial effluent (± SD)***
pH range		84	6.4 - 7.8	6.8 - 7.8	6.5 - 7.0
TCOD (mg/L)	Median	84	2990	4020	2808
	Mean		3160	4060 ± 687	2711 ± 534
	Range		1790 - 4760	2790 - 5520	1885 - 3402
BOD_5 (mg/L)	Median	84	1680	2127	961
	Mean		1780	2133 ± 373	931 ± 105
	Range		834 - 3186	1558 - 2988	799 - 1033
FOG (mg/L)	Median	84	246	115	289
	Mean		260	125 ± 44	281 ± 69
	Range		114 - 640	72 - 202	174 - 355
TKN (mgN/L)	Median	12		176	166
	Mean		142	169 ± 71	153 ± 35
	Range		90 - 196	62 - 313	108 -197
NH_3-N (mg/L)	Median		na	53	82
	Mean		na	57 ± 29	85 ± 23
	Range		na	16 - 95	59 - 125
TP-PO_4^{-3} (mg/L)	Median	12		na	50
	Mean		50	na	51 ± 3
	Range		22 - 84	na	48 - 55

N = number of samples tested; na = not available; eff. = effluent.

Table 5. Ranges, average, and ratios of selected parameters for investigating the amenability of selected slaughterhouses' wastewaters to be biologically treated

Slaughterhouse name	***Parameters for amenability of biological treatment***					***Organics to nutrients ratios***			
	pH	***T (ºC)***	***Alkalinity (mg as $CaCO_3$/L)***	***TCOD***	$\frac{TCOD}{BOD_5}$	$\frac{TCOD}{TN-N}$	$\frac{BOD_5}{TN-N}$	$\frac{BOD_5}{NH_3-N}$	$\frac{BOD_5}{TP-P}$
Ayam Kempas	6.6-8.0	27-30	236	1835	2.3	10.4	4.6	8.1	50.0
Ayamas	6.5-7.0	28-29	160	2711	2.9	17.7	6.1	10.9	56.0
PPNJ	6.5-7.0	22-29	87	1460	3.1	18.7	5.0	12.3	43.3
Requirements	6 – 8[c]	10– 50[c]	150 – 350[c]	> 200	2.5–3.5[c]	> 9[a]	> 5[a]	> 8[a]	20 - 25[b]

[a] Required for excellent biologically nitrogen removal (Grady Jr et al., 2011); [b] Required for moderate efficiency A/O or A^2/O processes with nitrification (Grady Jr et al., 2011);[c] For high domestic wastewater characteristics (Henze et al., 2002).

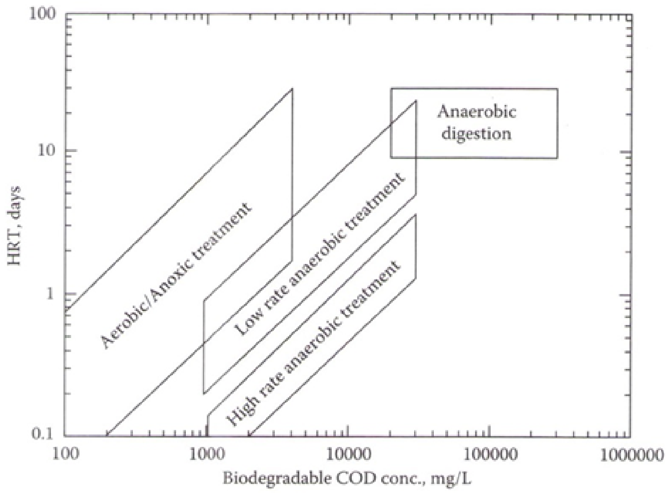

Fig. 4. Typical operating ranges for aerobic/anoxic and anaerobic suspended growth biochemical operations (Grady Jr et al., 2011)

In the meantime, to assess the potential for biological phosphorus removal (BPR) in the wastewaters from these three poultry slaughterhouses, it was found that the ratios of organic matter to phosphorus (P) in all PSWs exceed the required limits for removing 1 mg of phosphorus. This indicates a broad latitude for using various BPR processes, ranging from high-efficiency methods like the Virginia Initiative Plant (VIP) or University of Cape Town (UCT) processes to lower-efficiency techniques such as the 5-step Bardenpho process.

Among these, Ayamas's wastewater, selected for achieving the previous study's objectives (Rajab et al., 2017), maintains the highest BOD_5/TP-P ratio compared to the other slaughterhouses' wastewaters. It is important to note that these organics-to-nutrients ratios are valid for the influent to the specific biological treatment process designated for nutrient removal and are not suitable for the influent of the entire wastewater treatment plant. This is because the ratios will be significantly altered by the upstream biological treatment (anaerobic process) (Grady Jr et al., 2011).

4. Conclusions

The characterization of poultry slaughterhouse wastewater (PSW) generated in Johor State, Malaysia, was determined. The average concentrations of TCOD, BOD5, TN-N, TP-P, FOG, alkalinity, and TSS were 2171 mg/L, 652 mg/L, 124 mg/L, 40 mg/L, 355 mg/L, 182 mg/L, and 627 mg/L, respectively. A comparison between this study and the literature revealed slight differences in the characteristics of Ayamas's wastewater compared to other studies, with more significant differences noted in their 2016 study for the same poultry slaughterhouse.

Therefore, it is essential to characterize the wastewater of an individual industry before choosing the treatment technology.

Theoretically, the characterization study indicates the feasibility of achieving high organic and nitrogen removal biologically using anaerobic and anoxic processes for all PSWs investigated. The ratios ($COD/BOD_5 > 2.5$, BOD_5/TN-N > 5, BOD_5/NH_3-N > 8, and BOD_5/TP-P in the range of 20-25) suggest a positive potential for using biological treatment for this type of wastewater, although the removal of FOG constituents is essential.

For sequential anaerobic-aerobic biological treatment without removing FOG, further analyses are needed to assess the suitability of anaerobic effluents for subsequent aerobic treatment. Previous study results indicate a scarcity of organic matter compared to excess concentrations of nutrients after the anaerobic stage, reducing the chance of high nutrient removal in the subsequent aerobic process.

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