Chicken Slaughterhouse Wastewater Characteristics, Current Treatment and Future Challenges: A review

Siraprapa Chainetr[1 *], Rungnapha Khiewwijit[1], Nopadon Maneetien[2] and Suraphon Chaiwongsar[3]

[1] Department of Environmental Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna. 128 Huay Kaew Road, Muang, Chiang Mai, Thailand, 50300

[2] Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna. 128 Huay Kaew Road, Muang, Chiang Mai, Thailand, 50300

[3] Faculty of Science and Agricultural Technology, Rajamangala University of Technology Lanna. 128 Huay Kaew Road, Muang, Chiang Mai, Thailand, 50300

[*]Corresponding Author: Siraprapha42@yahoo.com. Phone Number 0-5392-1444

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Abstract

In this study, a thorough review of advancement in chicken slaughterhouse wastewater (CSWW) characteristics, current treatment and future challenges were presented. The data of CSWW characteristics and discharge limits were collected, in particular in Thailand, as well as in several other neighboring countries and the world's leading chicken meat producing countries. The data clearly showed that the CSWW typically contained high concentrations of organic matter in the forms of Biochemical Oxygen Demand and Chemical Oxygen Demand, suspended solids, oil and grease, and nitrogen in the form of Total Kjeldahl Nitrogen. For example, in Thailand the concentrations of mentioned parameters were ranged from 490-1200 mg/L, 890-1900 mg/L, 415-700 mg/L, 80-190 mg/L and 73-240 mg/L, respectively. In the treatment of CSWW, biological wastewater treatment was commonly applied for the removal of organic matter and nutrients. An overview of the typical CSWW treatment systems was also discussed. Moreover, this review also provided a better understanding of the future challenges of CSWW management that aimed at both high treatment efficiency and potential resource recovery.

Keywords: Chicken slaughterhouse wastewater, wastewater characteristics, wastewater treatment.

1. Introduction

Over the last centuries, the world population has increased many folds and will reach probably eight billion by 2030 and over nine billion by 2050 [1]. Such a high world population will be demanding for more water and food, including meat products. In 2016, poultry, including chicken, become the most popular processed meat products with a 38% share of the global market, while the red meat product of pork and beef accounts for about 33% [2]. Moreover, this global poultry market is expected to continue to grow as demand for both meat and egg products increase every year. In 2015-2019, the United States represent as the world's largest chicken meat producers, followed by Brazil and China, respectively. Thailand is also one of world's top ten largest chicken meat producers [3]. With a rich and wide variety of natural resources, low labor costs, and dedicated efforts of the government, the number of chicken production in Thailand has multiplied over the years, both for domestic consumption and for exports worldwide [4]. Consequently, the chicken production and processing industries, including slaughterhouses not only produce a large volume of chicken products daily but also produce a large volume of wastewater. The average wastewater generated by chicken slaughterhouse is 12 L per chicken slaughtered [5]. Using Thailand as an example, in 2017, there was in total 1,239 million chickens produced in Thailand and it is expected to rise to 1263 million chickens in 2022 [4]. This would translate to a wastewater production as high as 15 million m^3 from the chicken slaughterhouse in 2022. Therefore, with all the chicken slaughterhouses worldwide, an enormous volume of wastewater will be produced in the future.

The wastewater produced from chicken slaughterhouse comes from different activities, including stunning and slaughtering, de-feathering, evisceration, trimming and carcass washing, de-boning, chilling, rendering, waste disposal, and cleaning [3], [6]. The chicken slaughterhouse wastewater (CSWW) typically has high organic matter, which composes of complex mixtures such as blood, skin, feathers, and carcasses, as well as contained nutrients nitrogen (N) and phosphorus (P), suspended solids (SS), oil and grease (O&G), pathogenic microorganisms, and cleaning agents [6-8]. Therefore, the direct discharge of untreated CSWW into surface water streams leads to serious environmental and health concerns. For example, high organic matter in CSWW causes the problem of deoxygenation in the aquatic ecosystem, while the nutrients N and P may cause eutrophication. High SS and O&G in water streams can inhibit the penetration of light into the water and inhibit the biodegradation. Besides, the presence of pathogenic microorganisms and cleaning agents will cause the spreading of waterborne diseases and toxic compounds, which may lead to the death of aquatic life and the public health effects of human communities [9-12]. Therefore, the CSWW requires significant treatment for a sustainable and safe treated effluent before discharge to the environment.

However, limited information can be found in the literature on a local characterization of CSWW as well as on the integration of both treatment and resource recovery perspectives in the future of CSWW treatment plant. Chicken slaughterhouse or chicken processing industry commonly produce a large volume of wastewater, and this wastewater can be considered as a valuable resource, especially the potential energy benefit. Therefore, the objective of this study was to characterize the CSWW and review discharge limits for the discharge of chicken slaughterhouse effluent from different countries, in particular in Thailand, as well as in several other neighboring countries and the world's leading chicken meat producers. Moreover, this study also reviewed the current treatment of CSWW and its future challenges towards resource recovery.

2. Characteristics of chicken slaughter-house wastewater

As the characteristics of slaughterhouse wastewater may vary depending on the water usage and the type of animals slaughtered [13], therefore, the first step towards designing appropriate treatment processes for CSWW is to characterize its quality. Table 1 gives a summary of the essential characteristics of the CSWW and discharges limit in Thailand as well as in some other neighboring countries and the world's leading chicken meat producers [3], [14].

Moreover, in this study, an example of the CSWW was collected from a chicken slaughterhouse located in Chiang Mai Province, the Northern region of Thailand. This chicken slaughterhouse was one of the largest chicken slaughterhouses in Chiang Mai, which had an average slaughter capacity of 15,000 units per day. The physico-chemical parameters such as pH, SS, total dissolved solids (TDS), O&G, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), ammonia nitrogen (NH_3-N), and total phosphorus (TP) were analyzed, and the results are shown in Table 1. The pH was measured using pH electrode (OHAUS Starter ST5000-B Bench pH Meter, USA). The measurements of SS, TDS, O&G,

BOD, COD, TKN, NH_3-N, and TP were determined according to standard methods [15].From Table 1, it is noticeable that the parameters of CSWW characteristics investigated by the researchers were different, which commonly depending on the discharge limits and regulations applied to discharge effluent. As demonstrated by the data in Table 1, the average characteristics of CSWW were different concerning the location of chicken slaughterhouse. These differences in the CSWW characteristics could be driven by several factors, for example, the quantity of water used for slaughtering and other processing steps, scale in the production facilities, and the differences in the nutritional quality of the chicken slaughtered [7]. However, the data clearly showed that the wastewater discharged by the chicken slaughter house worldwide was characterized mainly by high organic matter in the forms of BOD and COD, and contained high concentrations of SS, O&G, and nutrients especially N as compared to the average characteristics of municipal wastewater [41]. For example, in Thailand, the concentrations of BOD and COD were ranged from 490-1200 mg/L and 890-1900 mg/L, respectively. Besides, the concentrations of SS, O&G and TKN were ranged from 415-700 mg/L, 80-190 mg/L and 73-240 mg/L, respectively. For the organic matter, high BOD and COD concentrations in CSWW came mainly from the discharge of blood and offal chicken by-products, such as feathers, heads, lungs, intestinal tracts, and carcasses [23], [42]. Also, it can be noticed that most of the organic matter in CSWW was presented in the form of biodegradable matter, as the BOD/COD ratio was more than 0.5 in most presented countries. This provides an initial selection for the appropriate treatment of CSWW that could be used both biological aerobic and anaerobic processes because of the good biodegradability potential of CSWW [43], [44]. Moreover, using the chicken slaughterhouse in Thailand as an example, it is important to note that the concentrations of BOD and COD in the small scale chicken slaughterhouse were lower than the medium and large scale chicken slaughterhouse. This could be explained by the meat processing steps applied in the chicken slaughterhouse, as the small scale chicken slaughterhouse is usually processed for slaughtering chickens only and not for other additional operations of such as whole carcass cutting-up, de-boning, and rendering. Therefore, less offal chicken by-products could be found in the wastewater generated from the small scale chicken slaughterhouse [18], [45]. The suspended solids content in CSWW was also high due to small organic and inorganic particles presented in CSWW and some of the offal chicken by-products. This high SS value indicates high levels of water pollution and can inhibit the penetration of light into the water, which causing photosynthesis to be disturbed. Besides, high SS can also lead to an increase in the water temperatures, as SS absorbs more heat from the solar radiation than the water molecules. This would result in ultimate reduction of dissolved oxygen [23], [44]. Besides, the oil and grease in CSWW came mainly from the fat content of chicken by-products and the rendering process. High O&G can cause pipelines clogging and lead to a lower treatment efficiency of wastewater treatment due to sludge deterioration and washout, the formation of scum layers at the surface of the reactors, and the inhibition of anaerobic biodegradability [11], [14]. For the nutrients, similar to other wastewater sources, the nutrients in CSWW refer to nitrogen and phosphorus. Nitrogen is available both for organic nitrogen and inorganic nitrogen, which presented in various forms such as ammonia nitrogen (NH_3-N), nitrite nitrogen (NO_2-N) and nitrate-nitrogen (NO_3-N). Because the major forms of nitrogen in wastewater and treated effluent are ammonia nitrogen, nitrite nitrogen, nitrate-nitrogen, and organic nitrogen, thus total nitrogen (TN) is more common to indicate the nitrogen in wastewater and discharge limits. TN is the sum of organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. However, as the nitrogen in raw polluted water is originally presented in the forms of organic nitrogen and ammonia nitrogen. Therefore, ammonia nitrogen

Table 1 Comparison of the crucial characteristics of chicken slaughterhouse wastewater and discharge limits in Thailand as well as in some other neighboring countries and the world's leading chicken meat producers.

Country	Chicken slaughterhouse wastewater characteristics (Except pH, all values are in mg/L)										Reference
	pH	SS	TDS	O&G	BOD	COD	TN	TKN	NH_3-N	TP	
Thailand											
1.[a]	6.6-7.2	593	NR	167	793	973	NR	124	NR	7.8	[16]
2.[b]	6.9-7.6	522	NR	177	913	1120	NR	82	NR	6.1	[16]
3.[c]	6.6-6.9	616	NR	96	602	896	NR	153	NR	21.6	[16]
4.[a]	7.31	543	890	110	1061	1342	NR	73	NR	7.5	[17]
5.[b]	NR	580	NR	133	910	1444	NR	186	NR	15.0	[18]
6.	NR	500	NR	218	490	890	NR	110	NR	8.0	[19]
7.[d]	NR	450-700	NR	80-190	700-1200	1300-1900	NR	150-240	NR	NR	[6]
8.	6.73	415	828	135	792	995	NR	118	72	14.3	This study
Discharge limits	5.5-9.0	50	3000[e]	5	60[f]	400[f]	NR	200[f]	NR	NR	[20]
Other countries[g]											
Malaysia											
1.	7.17	515	545	NR	1360	4979	NR	NR	110	NR	[10]
2.	8.02	3482	NR	NR	1602	5422	361	NR	NR	NR	[8]
3.	7.3	727	NR	NR	834	2069	NR	NR	NR	NR	[21]
4.	NR	297	NR	NR	2152	5381	NR	NR	NR	NR	[22]
Discharge limits	5.5-9.0	100	1000	NR	50	100	NR	NR	1.5	NR	[10]
Indonesia											
1.	7.19	126	NR	15	3215	6406	NR	NR	13.8	NR	[23]
Discharge limits	6.0-9.0	100	NR	15	100	200	NR	NR	25	NR	[23]
China											
1.	7.5	1158	NR	160	710	1450	NR	NR	120	NR	[24]
Discharge limits	6.0-9.0	60	NR	15	25	70	NR	NR	15	NR	[24]
USA											
1.	NR	1090	NR	NR	1645	3780	NR	133	11	26	[25]
2.	6.7	391	469	235	551	1085	NR	61	NR	NR	[26]
3.	NR	884-1255	NR	NR	NR	2499-3157	NR	125-236	NR	32-35	[27]
4.	NR	510-1526	NR	NR	1488-2166	NR	NR	65-112	NR	15-48	[12]
Discharge limits	6.0-9.0	20-30	NR	NR	16-26	NR	4-8	NR	NR	NR	[3]
Brazil											
1.	6.8-7.8	NR	NR	115	2127	4020	NR	176	53	NR	[28]
2.[h]	6.5-7.0	872	NR	375	1780	3102	NR	186	39	76	[29]
Discharge limits	5.0-9.0	NR	NR	50	NR	NR	NR	NR	20	NR	[28]

Table 1 Comparison of the essential characteristics of chicken slaughterhouse wastewater and discharge limits in Thailand as well as in some other neighboring countries and the world's leading chicken meat producers. (continued)

Country	chicken slaughterhouse wastewater characteristics (Except pH, all values are in mg/L)										Reference
	pH	SS	TDS	O&G	BOD	COD	TN	TKN	NH_3-N	TP	
Other countries[g] (continued)											
Canada											
1.	6.9	1164	NR	NR	1209	4221	427	NR	NR	50	[30]
2.	NR	760	NR	665	1662	NR	NR	54	NR	12	[31]
Discharge limits	6.0-9.0	5-30	NR	10	5-30	NR	1.25	NR	NR	1	[3], [31]
South Africa											
1.	6.9	794	NR	406	1667	2903	NR	211	40	17	[32]
2.	6.1-7.2	1654	1138	715	2477	5216	NR	NR	216	38[i]	[33]
Discharge limits	5.5-9.5	25	NR	2.5	NR	75	NR	15	6	10[i]	[34]
India											
1.	7.0-7.6	300-950	NR	800-1385	750-1890	3000-4800	NR	109-325	16-165	16-32[i]	[35]
Discharge limits	5.5-9.0	100	NR	NR	30-100	250	10-50	NR	NR	5	[3]
Mexico											
1.	6.6	938	1833	306	5500	7333	75	NR	62	9.5	[36]
Discharge limits	5.0-10.0	40-60	NR	15-25	30-60	NR	15-25	NR	NR	5-10	[37][j]
Turkey											
1.	6.7	NR	NR	143	1123	2171	NR	NR	NR	9.6[i]	[38]
Discharge limits	6.0-9.0	NR	NR	20	NR	160	NR	NR	NR	NR	[39]
EU											
1.	NR	2280-2446	NR	289-389	1900-2200	3610-4180	NR	NR	NR	NR	[40]
Discharge limits	NR	50	NR	5	50	250	NR	NR	NR	NR	[40]

NR: Data not reported.

[a] Data taken from the large scale chicken slaughterhouse with a slaughter capacity of higher than 80,000 units per day.

[b] Data taken from the medium scale chicken slaughterhouse with a slaughter capacity of 10,000 - 80,000 units per day.

[c] Data taken from the small scale chicken slaughterhouse with a slaughter capacity of lower than 10,000 units per day.

[d] Data taken from both the large and medium scale chicken slaughterhouse.

[e] When discharged effluent to the receiving water, TDS must not exceed 3000 mg/L.

[f] Data taken from the Notification of Pollution Control Department regarding determination of industrial types that allow for different industrial effluent standards in which notified by Ministry of Science, Technology and Environment in the Issue no. 3 (B.E. 2539) industrial effluent standards. Issued on 17th September B.E. 2539. Royal Thai Government Gazette; 1996.

[g] Data of scale production sizes and treatment processes are not reported.

[h] Considering the wastewater produced from only the slaughtering process, and not from the cleaning and sanitation processes.

[i] Considering the concentration of phosphate phosphorus (PO_4^{3-}-P).

[j] Considering the maximum permissible limits discharged into rivers for aquatic life protection.

and Total Kjeldahl Nitrogen (TKN) are also applied to qualify the characteristics of wastewater and treated effluent. TKN is defined as the sum of organic nitrogen and ammonia nitrogen [15], [41]. The high nitrogen content in CSWW was due to the mixture of blood and decomposition of organic matter microbiologically [13], [23]. In addition to the nutrients contained in CSWW, total phosphorus (TP) is defined as the sum of all organic and inorganic phosphorus compounds in wastewater, and treated effluent. However, TP in wastewater exists primarily as inorganic phosphorus compounds in the forms of orthophosphate (PO_4^{3-}) and polyphosphate. The phosphorus content in CSWW came mainly from detergent compounds and hygiene products used in the chicken slaughterhouse. High concentrations of nitrogen and phosphorus in water streams can accelerate eutrophication, which leads to an overgrowth of algae and plants in aquatic systems. Eutrophication has several adverse effects on water streams, for example, light inhibition into the water and oxygen depletion that dominated by the decay of algae and plant biomass; consequently, this is harmful to aquatic life [8], [12].

Additionally, discharge limits are necessary to mitigate the environmental impacts of slaughterhouse wastewater, including the chicken slaughterhouse. From Table 1, it is important to note that different countries have different discharge limits with different important parameters of effluent quality. However, the most common parameters of discharged wastewater quality were pH, SS, O&G, BOD, and COD, as these parameters provide an index to assess the effect of discharged wastewater that would have on the receiving environment [41]. Moreover, most countries do not have the specific discharge limits for the chicken slaughterhouse, but they generally apply the discharge limits for the discharge of industrial wastewater. According to Table 1, it is difficult to highlight the highest or lowest level of discharge limits among the presented countries. However, based on the data shown in Table 1, it clearly showed that most of the CSWW quality parameters were not suitable for direct discharge of CSWW into surface water streams without prior treatment. It is also recommended that the CSWW should not be discharged into the municipal sewage systems because of the differences in wastewater quality [10]. Moreover, due to the differences in discharge limits worldwide, the selection of appropriate treatment for CSWW should be considered both wastewater characteristics and the national discharge limits for discharging effluent.

3. Current treatment of chicken slaughterhouse wastewater

At present, the treatment of wastewater produced from the chicken slaughterhouse is not adequately managed, in particular in the small scale chicken slaughterhouse, which generally refers to the activities done in the wet market and chicken processing stall. Therefore, the wastewater can be exposed to some health hazards with regards directly to the workers and communities located nearby the slaughterhouse. Most of the small scale chicken slaughterhouse, which is commonly located near the residential and urban areas, applies only the preliminary treatment such as screening and grease and oil trap before discharging untreated wastewater directly into the municipal sewage systems [16], [18], [21], [22], [30]. While the medium and large scale chicken slaughterhouse have their wastewater treatment plant, which will be further discussed in more detail later on. However, currently, the small and medium scale chicken slaughterhouses are accounted for as the main producers of chicken processing products. Thus, the current treatment of CSWW will be focused on two different wastewater treatment systems, which are (1) for the small and medium scale chicken slaughterhouse and

(2) for the large scale chicken slaughterhouse [6], [16], [18], [22], [45], [46].

The typical treatment systems for CSWW are shown schematically in Figure 1. These CSWW treatment systems are currently applied in the chicken slaughterhouse that has its own wastewater treatment plant. The CSWW treatment systems consist of the preliminary treatment, primary treatment, and secondary treatment as well as the tertiary treatment can also be used if it is required by the discharge limits or safe reuse of treated effluent. However, in most cases, the quality of treated effluent produced from the secondary treatment indicates that the sequence of processes in CSWW treatment plant that including preliminary, primary and secondary treatment is adequate to meet the discharge limits for surface water streams [6], [16], [17], [28], [47-49].

As shown in Figure 1A and 1B, the preliminary treatment is used as the first step to removing solids and large particles from the liquid portion in CSWW. The most common unit operations for the preliminary treatment are screening, sieves, flotation, settlers, and equalization tank. The screening process is typically the simplest and most economical preliminary treatment unit applied in the chicken slaughterhouse. Most of the chicken slaughterhouse uses a two-stage series of the coarse and fine screens to remove the offal chicken by-products, such as feathers, heads, lungs, intestinal tracts, and carcasses. After that, grease and oil trap is used to remove O&G before the wastewater enters to further advanced treatment systems. In this grease and oil trap unit, the O&G that is less dense than water will be risen to the surface where these O&G are then trapped inside the grease and oil trap by using a system of baffles or plates. Besides, as the quality and quantities of the CSWW could be varied from day to day, and when there is an accident situation, thus the equalization tank becomes vital in the CSWW treatment systems. This equalization tank is used to minimize the fluctuations in the flow and quality of the wastewater, consequently providing optimum conditions for the subsequent treatment. Retention time in the equalization tank is usually designed for the 24-hour average flow [12], [36].

After that, the effluent processed from the preliminary treatment is passed on to a subsequent primary and secondary treatment. The primary treatment is applied to further remove SS and O&G from the CSWW as well as to reduce the organic content. Dissolved air flotation (DAF) system is commonly used as the primary treatment process for the poultry processing wastewater, including the CSWW. The main advantage of DAF system over a primary catch basin is that DAF system has a high ability to remove very tiny and light particles in a shorter time [12]. In this DAF unit, the liquid-solid separation is occurred by the use of a dissolved air in wastewater that produced in a pressure vessel for mixing and air saturation and then injected through the bottom of the DAF reactor. When the pressure decreases and the air comes out of the solution, resulting in the production of fine bubbles, which carry light solids and O&G to the surface of the reactor where these are skimmed off [47], [48]. In the study of Del Nery et al. (2007) showed that DAF unit could achieve the removal efficiencies of 37% for SS and 51% for O&G [29]. However, it is important to note that not all chicken slaughterhouses applied the primary treatment in their wastewater treatment plant. For example, most CSWW treatment systems in Thailand consist of coarse and fine screens, grease and oil trap, equalization tank, and biological treatment system prior to discharge the treated effluent into surface water streams [16], [17]. This could be explained by the lower concentrations of SS and O&G presented in the CSWW as compared to other countries, suchas in the USA, Canada, South Africa, and India (Table 1).

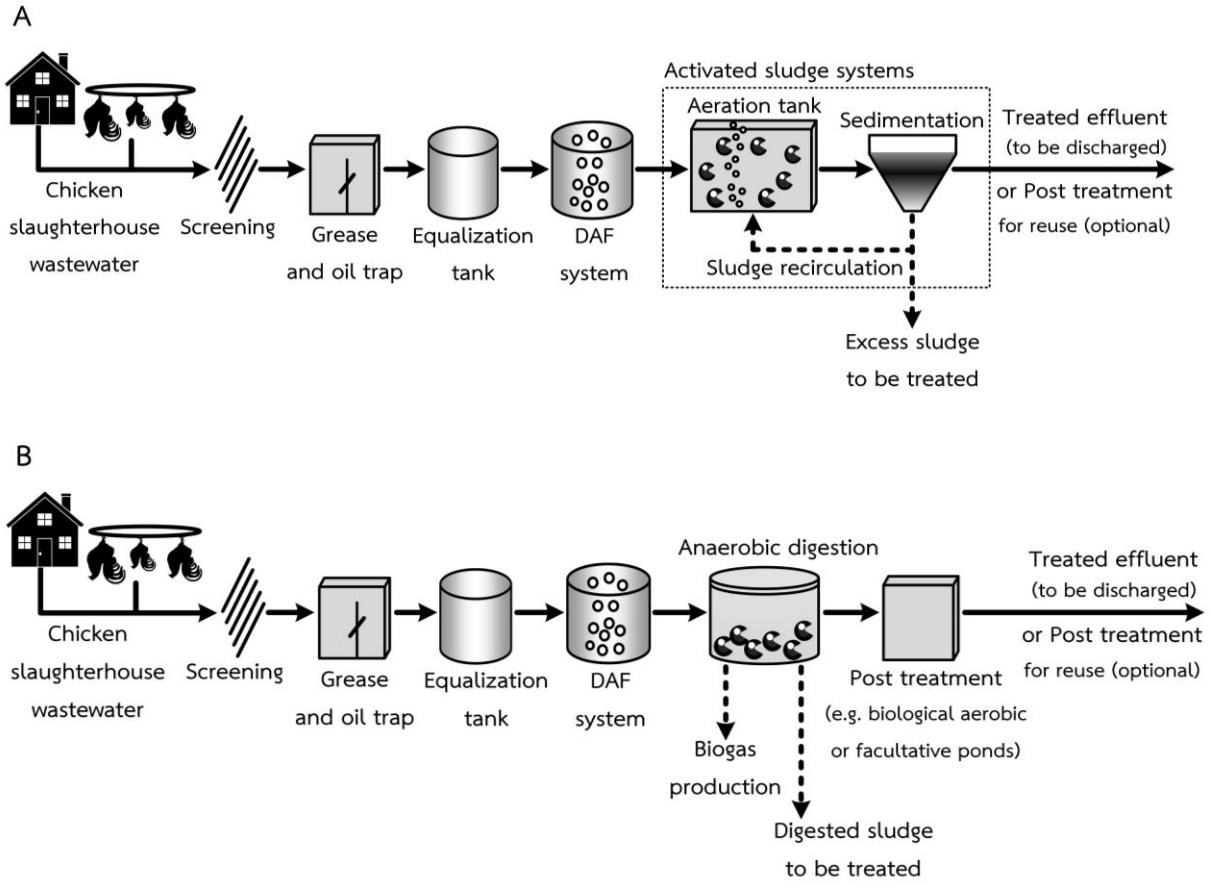

Figure 1 Schematic diagram of the typical chicken slaughterhouse wastewater treatment system; (A) Small and medium scale chicken slaughterhouse, and (B) Large scale chicken slaughterhouse.

For the secondary treatment, biological treatment processes are typically used to remove organic matter and nutrients and deactivated pathogens presented in the CSWW. There are different types of biological treatment processes, which include aerobic, anaerobic, and combined processes. Examples of microorganisms used in such a process would include bacteria, protozoa, fungi, and algae [41]. However, based on the literature data and recent research findings in the treatment systems of CSWW, the common biological treatment units for the secondary treatment are different depending on the production scale of the chicken slaughterhouse. In the small and medium scale chicken slaughterhouse, the biological aerobic processes are commonly applied for the secondary treatment (Figure 1A). There are several aerobic treatment processes available, such as activated sludge (AS) systems, aerated lagoons, aerobic sequencing batch reactor (SBR), and trickling filters. Among the alternatives in biological aerobic treatment processes, AS systems are the most frequently used in the current treatment systems of CSWW [18], [23], [45], [50], [51]. The main advantages of AS systems are that they are robust and generally produce an effluent quality that meets the discharge limits. The key processes in aeration tank are that the organic matter is aerobically mineralized to CO_2 and form new cells, whereas nutrients nitrogen is removed by the biological process, and phosphorus is removed by chemical or biological processes. The AS systems consist of two main units, which are an aeration tank and a sedimentation tank where the sludge is separated from the treated effluent. In the aeration tank, the aerators are used to provide aerobic microorganisms with the oxygen and induce sufficient mixing. Moreover, the sedimentation tank provides a quiescent environment to allow the activated sludge solids to separate by flocculation and gravity from the treated effluent. Some of the settled sludge is recycled to the aeration tank for the maintenance of microbial culture, whereas a large amount of excess sludge is discharged from the sedimentation tank. This excess sludge requires further sludge treatment and disposal processes [41]. In most cases, the AS systems generally produce an effluent of sufficient quality that meet the discharge limits for discharging effluent into surface water streams. However, the tertiary treatment is still required to permit safe reuse of treated effluent, such as for irrigation water or industrial process water. Tertiary treatment processes that would utilize for treating CSWW include chlorine disinfection, advanced oxidation processes (AOPs), and membrane filtration systems [12], [45], [47].

In the large scale chicken slaughterhouse, the most common biological treatment unit for the secondary treatment is the anaerobic biological processes (Figure 1B). As was discussed earlier, the aerobic AS systems are currently applied as the main biological treatment of CSWW for the small and medium scale production sizes. However, these systems cannot be considered sustainable because these require a large amount of energy for aeration, generate high CO_2 emissions and a large amount of sludge production, and do not recover valuable resources, especially organic matter [52]. In particular, a large volume of high strength wastewater that produces from the large scale chicken slaughterhouse would result in such a high aeration cost, which makes the AS systems not economically attractive. Thus, the anaerobic digestion processes become a promising alternative and effective system to use as a main biological treatment, especially for the large scale chicken slaughterhouse. In this anaerobic digestion unit, the organic matter is degraded by bacteria in the absence of oxygen. The major end product of anaerobic digestion is biogas, which is a mixture of main methane (CH_4) and CO_2 gases. The biogas production is considered as valuable renewable energy that can be converted into electricity and heat energy. The anaerobic digestion processes offer several advantages over the aerobic processes for treating high strength wastewater, such as low initial and operational costs, low sludge production, high biodegradation of organic matter, and potential energy benefit through the production of biogas, which make the systems technologically and economically attractive [35], [41]. However, a post-treatment for treating anaerobically treated effluent is usually needed to further remove the remaining of organic matter and nutrients down to reach the discharge limits. Because most organic matter and nutrients presented in anaerobically treated effluent are in the solubilized forms, thus the biological aerobic processes or simple, low-cost treatment technology, i.e., facultative ponds and constructed wetlands, are the most frequently applied as a post-treatment to remove organic matter and nutrients [9], [17], [28], [29], [53].

4. Challenges in the future treatment of chicken slaughterhouse wastewater

As mentioned earlier, the small and medium scale slaughterhouse are currently accounted for the main chicken processing producers. However, in the near future, the global business trends of chicken slaughterhouses have changed from the small and medium scale into large scale production [6], [35], [45], [49], [54]. Several factors are contributed to this change, for example (1) the replacement of local butchers by the high standard supermarkets, (2) the increase in numbers of restaurants and food businesses which required a large amount of standardized meat products, (3) new stricter regulations, such as on products quality, public safety, and wastes discharge that made it difficult for the small scale production, and (4) impacts of the virus pandemic that increased consumer awareness about food safety, in particular, the contamination caused by the workers, which made it difficult to control in the small scale production [54]. However, it is important to note that the differences in large, medium, and small scale production sizes may vary between countries, as the sizes can be described by various factors, such as production volume, the number of employees, the financial assets, and the annual profit. For example, over the last decades, the chicken slaughterhouse in Thailand was dominated by the small scale production size with a slaughter capacity of lower than 10,000 units per day, which accounted for 80% of the total chicken slaughterhouse. At present, the large scale chicken slaughterhouse with a slaughter capacity of higher than 80,000 units per day have continually increased, while the small scale chicken slaughterhouse is continually decreasing and tending towards zero in the future [16]. Changes in scale production size not only affect the demand for advanced equipment to handle a large amount of chicken at one time but also the appropriate treatment of a large volume of high strength wastewater should be developed.

Therefore, the challenges in the future treatment of CSWW have changed to the development of combined novel treatment systems that beneficial for cost-effective, high treatment efficiency and potential resource recovery, in particular for the large scale chicken slaughterhouse. Similar to Figure 1B, the preliminary and primary treatment steps of the novel CSWW treatment plant is still essential and suggested to apply the same treatment units. Besides, the performance of the DAF system can be further improved by chemical addition, such as aluminum sulfate, ferric chloride, and polymers, into the pre-treated wastewater before entering to the DAF system [28], [47], [55]. However, the main challenge of the novel CSWW treatment plant is to explore the appropriate secondary treatment processes for treating CSWW. Recently, several treatment technologies have been investigated, such as electrocoagulation process [38], [56], ultrafiltration [40], aerobic sequencing batch reactor (SBR) system with granular activated sludge [23], aerobic SBR system with granular activated carbon (GAC) [18], aerobic SBR with submerged fibers [50], and anaerobic digestion processes with different types of bioreactors, for example, anaerobic lagoons [57], static granular bed reactor (SGBR) [33], [58], SGBR coupled with ultrafiltration (UF) membrane [32], an expanded granular sludge bed (EGSB) [42], [59], an up-flow anaerobic sludge blanket (UASB) reactor [28], [29], [36], and an up-flow anaerobic filter reactor [35]. Among the different treatment systems suggested by the researchers, anaerobic digestion processes are still considered as a promising alternative and effective system to use as a main biological treatment. The anaerobic digestion processes have the advantage of providing potential benefits of organic waste utilization through the production of biogas [41]. The biogas produced can then be used to generate electricity and heat energy, which can be supplied within the CSWW treatment plant. This would help the CSWW treatment plant in a reduction of operational costs for treating CSWW, which will be finally resulted in a reduction of production costs for the chicken production and processing industries. Although the average concentration of organic matter presented in CSWW is typically lower than for beef and pork slaughterhouse wastewaters [13], the anaerobic digestion of CSWW is still potentially attractive substrate for renewable and sustainable energy because of its large production worldwide. However, limited information can be found in the literature on the performance, investment cost, and economic impact of an integration of both treatment and resource recovery perspectives on the future of CSWW treatment plant, and this should be further investigated.

Another challenge for the future of CSWW treatment plant would be focused on the opportunities for increasing the value of by-products from the CSWW treatment plant. For example, the anaerobic co-digestion of CSWW with other organic wastes should be further explored for enhancing biogas production. This anaerobic co-digestion of CSWW needs to be further investigated with respect to types of organic wastes used and mixing ratios. Examples of organic wastes used in the anaerobic co-digestion of poultry slaughterhouse wastewater and waste are trapped grease waste [60], dairy manure [61], crude glycerol [62], maize residues [63], and sewage sludge [64]. Additionally, other higher value by-products that can be produced from the CSWW need to be explored, such as volatile fatty acids (VFA) [65], [66]. Production of VFA is preferred over biogas because VFA can be used as the starting compounds for a wide range of higher value products, for example, medium-chain fatty acids, bioplastics, and lipids for biodiesel [67].

Finally, there are concerns about the pathogens and odor in the sludge production that generates from the CSWW treatment processes [51], [68]. Therefore, there is a need for more research on the appropriate treatment and utilization of sludge waste generation to reduce environmental impacts.

5. Conclusions

Recently, an interest in the advancement of CSWW treatment and its future challenges is significantly increasing among researchers throughout the world. Researchers have characterized CSWW quality as it is deemed necessary for the design of an efficient combined treatment and resource recovery processes. The CSWW is typically contained high organic matter, suspended solids, oil and grease, and nutrient nitrogen. The conventional biological aerobic treatment systems, which are applied to treat CSWW, cannot be considered sustainable. The major drawbacks are that these systems consume a amount of energy for aeration and do not recover valuable resources, in particular with the high organic matter as it is destroyed by aerobic mineralization to CO_2. Therefore, the development of sequential biological anaerobic-aerobic treatment processes presents as a promising option for the future treatment plant of CSWW for its potential resource recovery and high treatment efficiency. Moreover, the future of CSWW treatment plants could also be focused on the opportunities for increasing biogas production with the use of anaerobic co-digestion and for producing other higher value by-products. This provides more benefits and sustainable for the chicken production and processing industries in the future.

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