Advanced Treatment technologies for Poultry Slaughterhouse Wastewater

Phumeza. A. Dyosile, Moses Basitere, Seteno. K.O. Ntwampe

Abstract— Subsequent to the increasing poultry products' demand, the generated large volume of high strength poultry slaughterhouse wastewater, rich in organic compounds, nutrients and solids from the blood, urine, faecal matter and detergents has made treatment prevalent for environmental protection and water sustainability. This paper explores the conducted studies and since adopted technologies for successful treatment of poultry slaughterhouse wastewater: The benefits, deficiencies and remedial systems.

Keywords— Anaerobic Digestion (AD), High Rate Anaerobic Bioreactor (HRAB), Up-flow Anaerobic Sludge Blanket (UASB), Static Granular Bed Reactor (SGBR), Poultry Slaughterhouse Wastewater (PSW).

I. INTRODUCTION

At 13:58:00, August 26th, year 2019, the world population living in scarce water areas was recorded to be 2 326 604 575 and increasing by the second [1]. At this rate, Guppy and Anderson [2] believe that the global demand is expected to increase with a 50% margin by the year 2030. The growing scarcity of water around the globe is one of the most pressing worldly concerns that may lead to an international conflict among the nations with transboundary aquifers [2]. This certainty and the advancing industrialization and urbanization leaves the whole world in dire straits as of the 71% water covering the earth [3], 97% is saline and of the remaining 3%, 87% is in the form of ice [4], thus leaving only 0.3% potable water which is insufficient for the growing populations and made advancements. For this reason and the continued service to population growth and economic boosting industries such as poultry, that requires large volumes of potable water, continuous

improvisation for efficient and successful treatment is necessary to treat the intricate wastewater released.

The variation in the composition of poultry slaughterhouse wastewater lies in the various stages of slaughtering. Whether it is slaughtering, defeathering or cleaning of the facilities or the poultry itself, considerable amounts of high strength wastewater is generated from the set laws such as the South African Meat Safety Act no. 40 of 2000 and Abattoir Hygiene Act no. 121 of 1992, that seek to protect the consumer and hold the abattoirs accountable for quality products are put in place [5]. Due to this, a study performed by Avula *et al*. [6], showed the average water consumption per bird to be 26.5 L which means high rate abattoirs roughly produce over two hundred liters per day.

II. MATERIAL AND SYSTEM DESIGN

Figure 1 below shows the proposed design for treatment of Poultry slaughterhouse wastewater.
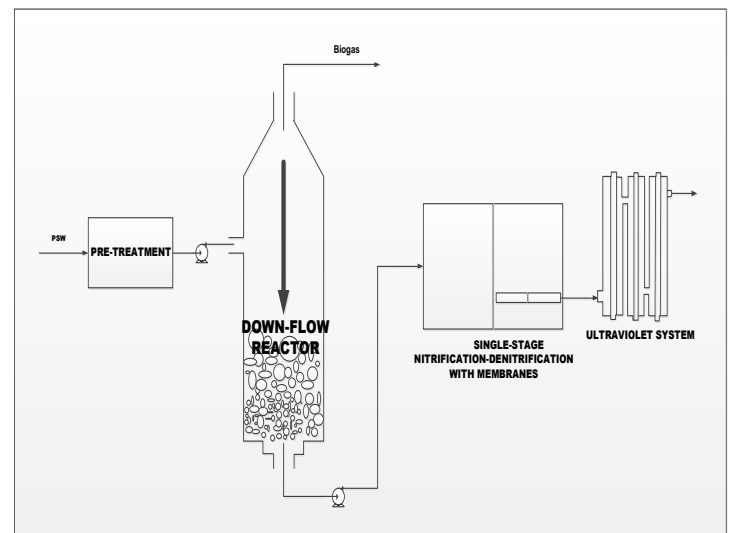

Fig. 1. Poultry slaughterhouse treatment system

The treatment system consists of biological treatment prior the anaerobic digestion process for the purposes of hydrolysis process. As the PSW contains high content of FOG, this stage plays an important role in lowering the organic load of the feed to the anaerobic digestion process, which will assist in

mitigating deficiencies such as sludge washout in up-flow anaerobic digestion and clogging of the underdrain for the downflow configuration.

The anaerobic digestion effluent is sent to the single stage nitrification and denitrification process for Nitrogen removal. The product of the SND is the further passed through membranes for solids removal and UV system for pathogen removal.

III. Poultry Slaughterhouse Characteristics

Though the poultry industry has become the confidant in the South African agricultural industry by contributing an approximate amount of 21% and providing over one hundred thousand jobs [7], through the increased demand, due to affordability and its wide range, the two-edged sector generates a high strength wastewater that contains 35% more protein and pathogenic microorganisms due to the presence of blood, fat, oil and grease (FOG) in it [8] and an excessive level of nutrients $(NH_4^+, NO^{2-}, PO_4^{3-})$, organics (COD, BOD, TOC), solids (TDS, TSS, VSS) and change in physical properties which is detrimental to the environment, municipal sewer systems and poses as a human health hazard [5].

Table 1 below, is a representation of typical poultry wastewater characteristics. Reported by Basitere [8].

TABLE I: TYPICAL POULTRY SLAUGHTERHOUSE WASTEWATER CHARACTERISTICS

Parameter	Unit	Range	Average
Ph	-	6.5-8	6.88
Alkalinity	mg/l	0-489	489
tCOD	mg/l	2133-10655	6394
sCOD	mg/l	595-1526	974
BOM	mg/l	1100-2750	1667
TKN	mg/l	77-352	211
TP	mg/l	8-27	17
FOG	mg/l	131-684	406
TDS	mg/l	372-936	654
TSS	mg/l	315-1273	794
VSS	mg/l	275-1200	738

A. General Limit for Effluent Discharge

Over the past decade, the growth of the poultry industry has made it the biggest segment on the AgriEconomy in South Africa [9]. The benefits of the industry include the wide range of products produced from a single bird that works to suit the individual budgets of all South Africans, such as the chicken feet, heads and offal (Liver, gizzard, heart). During the slaughtering and sorting process, the high rates create a large room for contamination of the meat and poses a risk in environmental hygiene and food safety [5], hence the use of

large volumes of high-pressured potable water, to ease the anxious consumers. However, as mentioned above, the generated wastewater contains unwanted constituents which may culminate into eutrophication and deoxygenating of freshwater bodies [8], [10].

Table 2 below shows standards for effluent discharge into sewage systems in South Africa. To bridge the gap and meet the general limit of effluent discharge, development projects have been done to successfully treat and potentially alleviate current water challenges.

TABLE II: GENERAL LIMIT FOR EFFLUENT DISCHARGE

Parameter	Unit	World Bank Standards	South African Standards
Faecal Coliforms	Per 100ml	-	1000
COD	mg/l	250	75
pH		6-9	5.5-9.5
Ammonia	mg/l	10	6
Nitrates	mg/l	10	15
Chlorine	mg/l	-	0.25
Suspended Solids	mg/l	50	25
Soap, Oil and Grease	mg/l	10	2.5

[11]

IV. Discussion

A. Poultry slaughterhouse wastewater treatment system trail

There have been numerous treatment technologies used for high strength PSW treatment, both aerobic and anaerobic. The use of aerobic treatment systems (ATD) require a large volume of oxygen to oxidize the biomass, thus making it an expensive treatment method. In comparison to anaerobic digestion, the operating costs are high and the generated sludge requires further dewatering [12].

B. Anaerobic Digestion

The anaerobic digestion (AD), which uses bacteria as a subjugator for the present organics and has been found as ideal treatment technology for FOGs and high concentration particulate removal [12]. In these types of biological reactors, in the absence of oxygen, at mesophilic temperature range (30-40 °C) and a pH range of 6.5-9 [12], microbial interaction takes place. It therefore results in a treated effluent with ± 90% treatment efficiency [10], [13] and by-products such as biogas,

bio-sludge, ammonium NH_4^+ and phosphate PO_4^{3-} compounds [12].

C. Microbial Interaction in Anaerobic Digestors

After reactor acclimation and microbial maturation, the PSW introduced into the reactor is broken down into soluble compounds in a process called Hydrolysis [8], [14]. Subsequently, these compounds are transformed by the fermentative bacteria resulting in alcohol, and unstable volatile acids in Acidogenesis [12], [15]. Following Acidogenesis, in Acetogenesis, the volatile acids break, due to instability, to form acetate, carbon dioxide and hydrogen [8], [14]. Lastly, in the presence of carbon dioxide, acetoclastic methanogens grow and result in the conversion of acetate to methane in a process called Methanogenesis [8], [14].

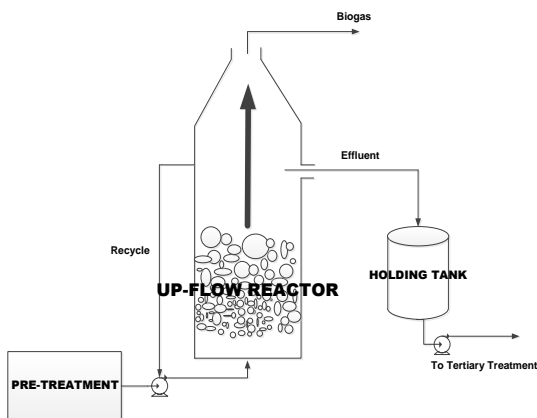### D. High Rate Anaerobic Bioreactor

Fig. 2. Up-flow configurated reactor

The Up-flow Anaerobic Sludge Blanket (UASB) is anaerobic digestion treatment technology, where wastewater enters at the bottom of the reactor and treated through the sludge blanket made of microbial granules [16] after which the Expanded Granular Bed Reactor (EGSB) was developed with the same working principle but an additional recycle stream. These reactors alone have a working efficiency of up to 90% of COD and have an ability to withstand high level of organics [16]. However, the success of these reactors relies on the gas-liquid-solid separation system [17], [18]. From studies conducted, Njoya et al. [19] noted that up-flow configurated reactors run the risk of sludge washout, resulting in the loss of the microorganisms which further results in increased solid concentration in the effluent and reduced quality of treatment [18].
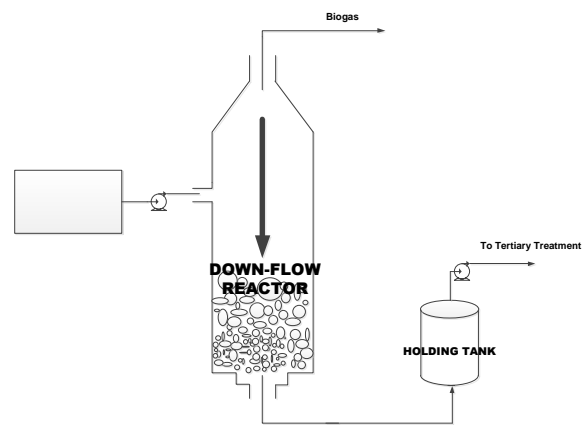

Fig. 3. Down flow configurated reactor

The static granular bed reactor (SGBR), an invention of Ellis from Iowa State University in the year 2000 [20] receives wastewater from the top and the effluent at the bottom of the reactor. From this configuration, the gas-liquid-solid separation stage is unnecessary [18], [19] as the produced biogas bubbles to the top while the gravity acts on the water [18] and present solids and particulates which, overtime, compact on the bed and may lead to reactor clogging [8]. The SGBR has been proven to produce a higher quality effluent than that of the up-flow reactor with COD removal greater than 90% [15].

E. Anaerobic Treatment technologies performances

Treatment technologies under the anaerobic digestion include reactors such as Up-flow Anaerobic Sludge Blanket (UASB), Expanded Granular Sludge Bed (EGSB) and Static Granular Bed Reactor (SGBR) each developed from performance evaluations on wastewater treatment.

The UASB, was created in the 1970's as a substitution to the septic tank [27]. As the name suggests, the reactor has an upward configuration that allows the created biogas to mix with the water and the FOG present in the PSW to attach to the granular sludge, thus resulting in the risk of sludge washout [12]. In study conducted by Saghir and Hajjar [28], for the treatment of poultry slaughterhouse wastewater, the reactor achieved its best COD removal of 83% at hydraulic retention time of 36 hours.

The EGSB is an up-flow velocity derivative of the UASB [27], created in Netherlands in the 1980s to remedy the short coming evident in the UASB [29]. However, along with the UASB, the EGSB's disadvantage includes the additional gas-liquid-solid separation stage, extra energy to overcome gravitational forces [30] and the increased risk of sludge washout, further leading to reduced efficiency [31].

The SGBR, an invention of Ellis [20] is a down flow configured reactor that is an advancement from the up-flow. The configuration requires less steps than the up-flow, less energy, and has a benefit of sludge retention ([18], [19]. However, when wastewater contains high total suspended solid and FOG

concentration, the reactor is prone to clogging of the underdrain due to the use of pea gravel at the bottom of the reactor.

TABLE III: COD AND TSS REMOVAL EFFICIENCIES

|	COD Removal (%)	TSS Removal (%)
UASB	>90	
EGSB	≈67%	≈83%
SGBR	<90	95%

In summary, with regards to the Table 3, drawn from studies by Rinquest [10], Basitere *et al.* [32] & Tilley *et al.* [16], the SGBR has shown a level of superiority over the other reactors. However, it runs a risk of clogging which can impede the entire system performance. In a study done by Basitere et al., [25] Exploring the Treatment of Poultry Slaughterhouse Wastewater Using Static Granular Reactor Coupled with UF membrane over a 9 week period, from the reactor performance of 93% and 95% COD and TSS removal, with the additional of the UF membranes, the system achieved 98% and 99.8% COD and TSS removal respectively. However, Basitere *et al.* [28] noted that compared to a SGBR study conducted in the year 2008 by Evans [18], the reactor performance reached 95.7% suggesting an error in the system which maybe a resulted of a solid build up in the granules or an influence of the organic loading rates. For remedial effect;

a. The addition of a pre-treatment may alleviate clogging and potentially reduce shock loading by reducing the FOG, suspended solids and surface tension in the PSW using the grown facultative microbes as a primary treatment prior to biological treatment. This is also improving the known clogging and fouling of membranes.

b. The addition of a recycle to periodically wake the sludge, thus resulting in a hybrid-SGBR may significantly reduce clogging, correct the little error possible in the reactor.

Though, overall, these high rate anaerobic reactors produce good quality effluents from the high strength poultry wastewater, the advancing requirements for effluent discharge care for produced by-products (NH^{4+}, PO_4^{3-}) as well, listed in the general limit for effluent discharge section, necessitating the need for tertiary treatments to improve the quality and remedy deficiencies not accomplished by the bioreactor. These include nutrient removal by single-stage nitrification-denitrification, particulates and pathogens by membranes.

Part of the disadvantages of anaerobic digestion, is its inability to remove maximal nitrogen. For curation, the single-stage nitrification-denitrification is used. However, prior nitrification and denitrification, ammonification takes place in the anaerobic reactor during hydrolysis where organic nitrogen is converted to ammonia [21]. The two equations below signify the nitrification process which begins in an aerated environment, where the Nitrosomonas bacteria converts ammonia and ammonium to nitrite at high retention times [10]. A study by Rinquest *et al.*

[22] showed that increased retention times resulted in an optimum TN removal that increased TN removal from 33% to 79%.

$$2NH_3 + 7/2O_2 \rightarrow 2NO_2 + 2H_2O + 2H^+ \text{ [14] (1)}$$
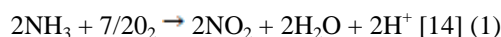
Followed by the conversion of nitrite to nitrate due to the nitrobacteria [10], [14].

$$NO_2 \xrightarrow{\text{Oxygen Environ.}} NO_3^- \text{ (2)}$$
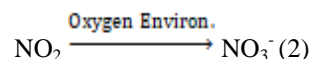
In denitrification, the nitrates are reduced to nitrogen gas [23]. Reaction requirements include; a sufficient carbon source, heterotrophic bacteria and an anoxic environment [10]; [23].

Combined SND reaction: $NH_4^+ \rightarrow NH_2OH \rightarrow N_2O \rightarrow N_2$ [14] (3)

Pochana and Keller [23] proved for a 95% total nitrogen removal, The ratio 5:20 TOD:TKN for denitrification, dissolved oxygen concentration lesser that 0.2mg/l for denitrification and higher than 0.5mg/l nitrification is necessary.

From the large range of membranes, classified by pore size, shape, material of construction or configuration, the selection is crucial depending on the wastewater to be treated. Similarly, for the treatment of high strength PSW multiple studies focus on the treatment using ultrafiltration with a pore size ranging from 0.002-0.1 microns which intern forms a barrier against pathogens and bacteria [24].

According to a study by Malmali *et al.* [24], can offer absolute barriers to pathogens and in terms of COD, TSS and FOG reduction, Basitere *et al.* [25] found average removal of 64%, 88% and 48% respectively which assisted in achieving a total of 98%, 99.8% and 92.4% . Its known advantages also include:
a) Simplicity
b) No chemicals required
c) Compactness
d) Cost Efficiency   [24]
To counter the permeation of pathogenic microorganisms due to unnoticed membrane fouling, the ultraviolet is an effective disinfecting method that exposes to the bacteria to a UV radiation via lamps [24].

The pathogenic microbes namely; coliforms and e-coli present as a result of blood and faecal matter traces present in the poultry slaughterhouse wastewater are reduced to ±6 CFU/100mg and 0 CFU/ 100mg which far exceeds the set South African general limit for effluent discharge [26].

However, to achieve success in the secondary and tertiary stages and reduce the strain on SGBR, SND and Membrane operation offered by the fatty and nutrient rich nature of PSW, biological pretreatment has been found as an effective method after screening. The combination of the pre-treatment that uses facultative microbes to reduce the hardwater and UV lamps on the hybrid-SGBR (with recycle), single-stage nitrification-denitrification and membranes will make of an efficiently running plant that produces an effluent reduced not only of organics, solids and nutrients but pathogens as well.

V. CONCLUSION AND RECOMMENDATIONS

The SGBR bioreactor, SND and UF membrane combination is a treatment combination which has been found effective. However, the poultry slaughterhouse wastewater highly contributes to bioreactor clogging and membrane fouling. The addition of the pre-treatment will release to the reactor an effluent that is healed of the heavy FOG, particulate and suspended solids that tend to clog the reactor and membranes. In the case of bed awakening, the additional recycle will periodically activate the bed, keeping the system and lessen the clogging tendency of the reactor.

As a last step, the UV lamps will safely rid the water of pathogenic microorganisms thus finally producing a quality effluent that far exceeds the set South African standards for general limit.

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