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Research article

CHARACTERIZATION OF WASTEWATER AND EVALUATION OF THE EFFECTIVENESS OF THE WASTEWATER TREATEMENT SYSTEMS

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Abstract

It was found to be not complying with the Ethiopian environmental protection authority discharge limit. Some study revealed that there was an adverse impact on the physiochemical and bacteriological characteristics of the receiving rivers as a result of the discharge of untreated and inadequately treated effluents from these slaughterhouse industries. There is a need of establishment and improvement of slaughterhouse wastewater treatment system, as well as an intervention of regulatory bodies to ensure production of high quality treated final effluents by the slaughterhouse industries.

Key words: Bacteriological loads, physicochemical characteristics, River Water quality, Slaughterhouse wastewater

Introduction

Ethiopia has the largest livestock population in Africa, with an estimated 47.57 million cattle, 26.12 million sheep, and 21.71 million goats (CSA, 2008). The increasing demands on meat in the country led to expansion of slaughterhouse industries in number and capacity. Despite the importance of those industries, they consume large amount of water resource for washing of carcasses after hide removal from cattle, goats and sheep; carcass washing after evisceration (remove the guts from); equipment and facilities washing; cooling of mechanical equipments. Untreated slaughterhouse wastewater comprises a mixture of fats, proteins and fibers, resulting in a high content of organic matter and causes a contaminating effect to the rivers and sewage systems (ECEMP, 2004).

Different countries practice different wastewater treatment systems and is reported that the most common wastewater treatment methods in developed countries are centralized aerobic wastewater treatment plants and lagoons for both domestic and industrial wastewater (Doorn et al., 2006). In similar way, in developing countries like Ethiopia, some slaughterhouse industries have started to use lagoons as wastewater treatment. However, due to limited holding capacity of the lagoons, during high production and wet season, wastewaters are over flown and discharged to nearby rivers and/or land. There are also slaughterhouses without any wastewater treatment facilities and their effluents are released directly into the rivers.

1.1. Sources of Wastewater in Slaughterhouses

The term wastewater is defined as the spent or used water of a community or industry which contains dissolved and suspended matter, and about 99% of which is liquid while the remaining 1% is solid waste (FAO, 1991). Industrial wastewater is generated from a wide variety of sources and has a broad diversity of chemical properties and constituents (Bielefeldt, 2009). The major sources of waste in the meat processing industry are from animal care, killing, hide or hair removal, eviscerating, carcass washing, trimming and clean up operations (USEPA, 2004). Slaughterhouses water consumption varies depending on the type of animal and the process used (Mittal, 2004). Most water consumed at slaughterhouses ultimately becomes effluent, and slaughtering operation is the largest single source of waste load in a meat packing plant (Carawan et al., 1979). Slaughterhouse effluent contains high levels of organic matter due to the presence of manure, blood and fat. It can also contain high levels of salt, phosphates and nitrates. The most significant contributor to the organic load is blood, followed by fat. Blood is also the major contributor to the nitrogen content of the effluent stream. Salt and phosphorus originate from the presence of manure and stomach contents in the effluent. At those plants where rendering occurs, the effluent from rendering typically represents the single most significant source of pollutant load in slaughterhouse effluent (Cowi, 2001). As explained in the above paragraph blood is a major contributor to organic load. It has an ultimate BOD of 405,000 mg/L (Carawan et al., 1979), and BOD5 between 150,000 and 200,000 mg/L and COD of 375 000 mg/L (Tritt and Schuchardt, 1992). Cattle contain up to 22.72 kg of blood per animal, and typically only 15.9 Kg of the blood is recovered in the sticking and bleeding area. The remaining 6.8 kg of blood is lost as wastewater which represents a waste load of 2.25 to 3.0 Kg BOD/1000 Kg LWK; LWK is the total weight of the total number of animals slaughtered during a specific period of time (USEPA, 2002). Total loss of the blood represents a potential BOD waste load of 7.4 to 15 Kg /1000 kg LWK.

Because very few meat plants practice blood control outside the bleeding area, the typical BOD load from blood losses in the slaughtering operation is estimated to be 3.0 Kg /1000 Kg
LWK. In beef plants, much of this loss occurs during hide removal (Carawan et al., 1979). Beef paunch or rumen contents are another major source of waste. Paunch manure, which contains partially digested feed material, has a BOD of 50,000 mg/L. At an average paunch weight of 22.72 Kg per head, dumping of the entire contents can contribute 2.5 Kg /1000 kg. LWK. However, the common practices are to either screen the paunch contents, washing the solids on the screen (wet dumping), or to dump on a screen to recover the solids, allowing only the "juice" to run to the sewer (dry dumping). Because 60 to 80 percent of the BOD5 in the paunch is water soluble, wet dumping of the paunch represents a BOD5 loss of about 1.5 kg /1000 kg LWK. If dry dumping is practiced, the waste load is much less than this. When none of the paunch is drained, but is processed or transported out of the plant for land disposal, paunch handling does not contribute to the waste load (Carawan et al., 1979).

1.2. Characteristics of Slaughterhouse Wastewater

Characterization of wastewater is done in terms of its physical, chemical, and biological composition. It is essential in the design, selection of appropriate treatment methods, deciding the extent of treatment, assessing the beneficial uses of wastes and utilizing the purification capacity of natural bodies of water in planned and controlled manner. It should be noted that many of the physicochemical and biological characteristics are interrelated. For example, temperature, a physical property, affects both the amounts of gases dissolved in the wastewater and the biological activity in the wastewater (Metcalf and Eddy, 2003). The slaughterhouse and meat processing wastewater comprise a mixture of fats /tallow, proteins, blood and mucosa resulting in having a high content of organic material and residues and consequently a high BOD and COD (Kobya et al., 2005), as well as high suspended solids (Bull et al., 1982). Such wastewater also has a high temperature (20 to 30 0C), high content of nitrogen (from blood) and phosphorus and with the absence of toxic compounds, pathogenic and non-pathogenic viruses and bacteria, and parasite eggs (AL-Mutairi, 2006; IFC, 2007).

The nature or quality of slaughterhouse wastewater depends on the following points: Firstly, the degree of separation of by-products such as blood, fat, manure, and undigested stomach contents from the effluent stream (Wilson, 1998; Mittal, 2004) and blood retaining during animal bleeding is considered to be the most important measure for reducing BOD (Tritt and Schuchardt, 1992). Secondly, water consumption i.e. water economy usually translates into increased pollutant concentration, although total BOD mass remains constant (Masse and Masse, 2000). Lastly, on type of animal slaughtered and type of plant or amount of rendering or meat processing activities which means plants that only slaughter animals produce a stronger wastewater than those also involved in rendering or meat processing activities (Johns, 1995).

1.3. Environmental Impacts of Slaughterhouse Wastewater

Slaughterhouse activities have direct and indirect impacts on the built-up environment and health of people especially residents in slaughterhouse vicinity. It has also a negative impact on air and water qualities of residents within slaughterhouse vicinity especially slaughterhouse where special or effective waste disposal system is not practiced (Bello and Oyedemi, 2009).The most significant environmental issues associated with slaughterhouse 8 operations are high consumption of water and energy, generation of high-strength effluent streams and byproducts, for some sites noise and odor may also be concerns (Cowi, 2001; ECDGJRC, 2003). Slaughtering and downstream processing sectors of meat processing are heavy users of water and energy especially during the slaughtering process and refrigeration as well as further processing, respectively (FAO, 2009). Discharge of wastewater to surface waters affects the water quality (FAO, 1996). One of the environmental effects of discharging slaughterhouse wastewater causes deoxygenation of rivers Quinn and Farlane (1989) and the contamination of groundwater (Sangodoyin and Agbawhe, 1992). Moreover, discharge of high levels of biodegradable organics into receiving streams results in increased microbial activity associated with excessive nutrient loadings which requires greater amounts of oxygen than natural aeration processes. This decreases the available dissolved oxygen which negatively affects aquatic organisms (USEPA, 2002).

Slaughterhouse wastewater also contains insoluble and slowly biodegradable suspended solids (Sayed et al., 1988). Increased suspended particulate matter can reduce light penetration into water body, and it may also alter benthic spawning grounds and feeding habitats (USEPA, 2002). Slaughterhouse wastewater contains phosphorus (P) and nitrogen (N) nutrients which primarily cause eutrophication of surface water that can reduce dissolved oxygen content of water bodies to levels insufficient to support fish and invertebrates. This may increase the incidence of harmful algal blooms that release toxins as they die and severely affect wildlife, as well as humans. Additionally, ammonia poses a direct toxicant to aquatic communities from the rapid breakdown of organic nitrogen in the wastewater (USEPA, 2002). Similarly, oil and grease are known to produce toxic effects on aquatic organisms such as fish, crustacea, larvae and eggs, gastropods, bivalves, invertebrates, and flora. Pathogens are also known to impact a variety of water uses including recreation, drinking water sources, and aquatic life and fisheries (USEPA, 2002).

1.4. Slaughterhouse Wastewater Treatment

Wastewater treatment plant (WWTP) of industrial, agricultural and domestic discharges plays an essential role in tackling the world wide problem of increasing water pollution. In WWTP, physical and biochemical procedures are applied in order to decrease or eliminate the organic matter levels, pathogenic organisms and improve water quality so that water can be reused or released into the environment with minimal consequences (Moura et al., 2009). Proper disposal of wastewater is necessary not only to protect the public's health and prevent contamination of groundwater and surface water resources, but also to preserve fish and wildlife populations and other beneficial uses (e.g., water-based recreation) (Nemerow et al. ,2009). Wastewater treatment practices vary from country to country across the world (Doorn et al., 2006). A wide variation in the type and extent of treatment are undertaken by the meat industries. This variation reflects local circumstances and requirements for discharge. All plants undertake some form of treatment by sedimentation, dissolved air flotation, screening, aerobic/anaerobic process (Sayed et al., 1993; Jian & Zhang, 1999). Some types of wastewater treatment commonly found in the meat processing and poultry industries are: (i) Primary treatments such as screening, oil and grease removal, dissolved air floatation (DAF), flow equalization; (ii) Secondary and tertiary treatment comprises biological treatment, filtration and disinfection (USEPA, 2008).

1.4.1. Basic Principles of Wastewater Treatment

Wastewater treatment systems are designed to remove the contaminants from wastewater for safe return of both the water and the contaminants to the environment (McKinney, 2004). Generally these are used to allow human and industrial effluents to be disposed without danger to human health or the natural environment (FAO, 1992). The fundamental principles of wastewater treatment includes: Preliminary treatment that removes large objects, rags, and grit. In primary treatment, floating particles are skimmed from the surface and heavy particles are removed by quiescent settling or sedimentation. In advanced primary treatment, chemicals may be added to enhance the sedimentation and removal of lighter suspended solids and, to a lesser extent, dissolved solids. Biological and chemical processes are used in secondary treatment to remove most of the organic matter and in certain instances, nitrogen and phosphorus. Additional combinations of physical, chemical, and biological processes are used in tertiary treatment to remove finer particles and other constituents that cannot be removed by conventional secondary treatment. Suspended solids may be removed to varying degrees by screening, sedimentation, and chemical precipitation. Biodegradable organics may also be reduced using aerobic and anaerobic bacteria in aerated tanks, lagoons, or membrane filters. Nutrients such as nitrogen and phosphorus may be reduced in concentration by chemical oxidation, biological treatment, air stripping, and carbon adsorption (Metcalf and Eddy, 2003).

1.5. Physicochemical Treatment Methods

Typical unit operations used for primary treatment of meat and poultry processing (MPP) wastewater are screening, catch basin, DAF, and flow equalization (USEPA, 2008). Similarly grit chambers, DAF, screens, and settling tanks are also widely used for the removal of suspended solids, colloidals, and fats from slaughterhouse wastewater. In DAF units, air bubbles injected at the bottom of the tank transport light solids and hydrophobic material, such as fat and grease, to the surface where scum is periodically skimmed off (Camin, 1970). In this treatment unit often chemicals such as flocculants or polymers are added to improve its performance (USEPA, 2008). In slaughterhouse and meat processing effluents, blood is considered the most problematic component, because of its capacity to inhibit floc formation (Bohdziewicz et al., 2002). Blood coagulants and flocculants such as aluminum sulfate and ferric chloride (coagulants) and polymers (flocculent) are sometimes added to the wastewater in the DAF units in order to increase protein flocculation and precipitation as well as fat flotation. These can also achieve COD reduction ranging from 32 to 90%, and are capable of removing large amounts of nutrients (Johns, 1995).

Physicochemical methods can also be used for nutrient removal from wastewater. Ammonia stripping and breakpoint chlorination are used for nitrogen removal, but in most cases biochemical removal is preferred (Kaszas et al., 1992). Again according to this author ammonia stripping has been adapted to remove ammonia from rendering plant wastewater using an aerated pond with lime addition. However, it is uneconomical given the large wastewater volumes of slaughterhouses, the high buffering capacity of the wastewater and the possibility of also stripping offensive odor (Anon, 1987). Breakpoint chlorination has been used as a standby system by slaughterhouses in the United State (US) to remove ammonia nitrogen, if biological nitrification failed to achieve discharge standards (Witmayer et al., 1985). However, regulatory agencies are growing increasingly concerned about the formation of trihalomethanes and other chlorinated organic during the process (Kaszas et al., 1992).

Studies also have been performed on the removal of nutrients from wastewater as insoluble crystalline materials, and Phosphorus has been successfully removed from slaughterhouse wastewater as calcium hydroxyapatite (Momberg and Oellermann, 1992). Simultaneously removal of nitrogen and phosphorus can also be obtained by precipitation as struvite (MgNH4PO4.6H2O), which has potential as a value fertilizer (Schultze Rettmer and yawari, 1988). Struvite formation was enhanced in piggery waste effluent from an anaerobic digester, by raising the pH to nine and adding magnesium sulfate (Wrigly et al., 1992). Even though chemical precipitation of phosphorous (P) permits very low levels to be achieved (about 0.3mg/L P), biological phosphorous removal is the most preferred process for new and /or large systems because chemical precipitation has some disadvantage (Farrimond and Upton, 1993; Van Starkenburg et al., 1993).

1.6. Biological Treatment Methods

The objective of biological treatment of industrial wastewater is to remove or reduce the concentration of organic and inorganic compounds as well as pathogens from the wastewater (Metcalf and Eddy, 2003). It can remove greater than 90% pollutants from the wastewater (USEPA, 2002). The reduction of BOD and total suspended solids can be accomplished by aerobic or anaerobic means, with suspended growth or attached growth treatment processes. Those processes require sufficient contact time between the wastewater and the microorganisms. Detergents and chemicals used in the slaughterhouse operations should be suitable for the biological treatment processes (USEPA, 2002). Biological wastewater treatment used in meat industries may include any combination of the following: aerobic lagoon, anaerobic lagoon, facultative lagoon, any activated sludge process, and/or other biological treatment processes (USEPA, 2008). Besides, aerobic processes such as extended aeration systems and trickling filters are also most popular for the treatment of meat packing and slaughterhouse wastewater (Bull et al., 1982).

Trickling Filter

A trickling filter (TF) is wastewater treatment system which consists of a basin or tower filled with support media such as stones, plastic shapes, or wooden slats along with a high surface area and permeability. The microorganisms in the wastewater become attached to the media and form a biological layer or fixed film. Organic matter in the wastewater diffuses into the film, where it is metabolized. Oxygen is normally supplied to the film by the natural flow of air/ forced air either up or down through the media, depending on the relative temperatures of the wastewater and ambient air. The thickness of the biofilm increases as new organisms grow. Periodically, portions of the film „slough off‟ the media. The sloughed material is separated from the liquid in a secondary clarifier and discharged to sludge processing. Clarified liquid from the secondary effluent and a portion is often recycled to the biofilter to improve hydraulic distribution of the wastewater over the filter (FAO, 1992, Al-Sayed, 2001). TF is used to reduce BOD, pathogens, and Nitrogen levels (Al-Sayed, 2001). High trickling filters have been used successfully as roughing filter to achieve preliminary removal of BOD from rendering plant (Frose and Kayser, 1985) and slaughterhouse wastewater subsequent to further treatment(Hopwood, 1977). Their advantage over other treatment systems is their low space and energy requirement (parker et al., 1990).

Activated Sludge

The activated sludge system is the most widely used biological treatment process for treating various types of wastewater in the world. The primary objective of the activated sludge system is the removal of soluble biodegradable compounds. It also removes pathogenic microorganisms from wastewater (Mara, 2004).The activated sludge process is an aerobic, continuous flow system containing a mass of activated microorganisms that are capable of stabilizing organic matter. The process consists of delivering clarified wastewater, after primary settling, into an aeration basin where it is mixed with an active mass of microorganisms, mainly bacteria and protozoa, which aerobically degrade organic matter into carbon dioxide, water, new cells, and other end products (UN, 2003). The advantages of the activated sludge process are the thorough mixing of substrates, flexibility in its operation, and low installation cost. However, it has drawbacks such as sludge bulking, excess sludge production, and demanding operation and maintenance (Chen and Lo, 2003).

Sequence Batch Reactor

The sequencing batch reactor (SBR) is a fill and draw reactor system that uses one or more complete mix tanks in which all steps of the activated sludge process occur. SBR systems have four basic periods: fill (the receiving of raw wastewater), react (the time to complete desired reaction), settle (the time to separate the microorganisms from treated effluent), and idle (the time after discharging the tank and before refilling). These periods may be modified or eliminated, however, depending on effluent requirements. The time for a complete cycle is the total time between the beginning of fill and the end of idle. SBR systems provide high removal of BOD and suspended solids. In addition, these systems can be designed for nitrification and removal of nitrogen and phosphorus (USEPA, 2008). These systems have been used to treat piggery and slaughterhouse wastewater, winery wastewater, and landfill leach ate (Bielefeldt, 2009). A modified SBR process was evaluated on full scale for the pretreatment of slaughterhouse effluent and for protein production that can be used as an animal feed supplement, and successful pretreatment was achieved with unfiltered COD removal in excess of 90 % and filtered COD less than 200 mg/L (De Villiers, 2000).

Wastewater Lagoon

Wastewater treatment lagoons are earthen impoundments that are engineered and constructed to treat and temporarily store human, industrial, animal wastewater (Zhang, 2001) as well as MPP wastewater (USEPA, 2008). They have also been widely used for the treatment of wastewater due to their low capital costs when sufficient land is available and simple operational and maintenance requirements are compared with other biological treatment systems (Surampall, 2004). However, their treatment capacity is often limited and unsuitable for direct discharge into surface waters due to the high contents of nutrients and organics in the animal wastewater (Zhang, 2001). But it is possible to use a variety of nutrient removal mechanisms that can operate in facultative and aerated /facultative lagoon systems, resulting in excellent nutrient removal, which include nitrification /denitrification and ammonia stripping for nitrogen removal and Phosphorous precipitation as a result of the elevated pH caused by algal photosynthesis (Surampall, 2004).

Biochemistry of Wastewater Lagoons

The treatment of wastewater in lagoons exploits the physical and biochemical interactions that occur naturally in aquatic systems to remove bacteria, BOD, suspended solids and nutrients (Maynard et al., 1998; Ghoualem, 2008). Lagoons depth is ranging from shallow to deep and often are categorized by their mode of biodegradation, as determined by the presence or absence of dissolved oxygen (aerobic or anaerobic), source of oxygen, and other design features. Biological degradation and sedimentation are the primary means for removal of organic and inorganic compounds from the wastewater in the lagoons (USEPA, 2008). Bacteria are the primary microorganisms responsible for waste degradation in all types of lagoons, and algae living symbiotically with bacteria in aerobic and facultative lagoons play an important role in removing nutrients from the wastewater (Zhang, 2001).

Aerobic Lagoons

Aerobic lagoons normally contain dissolved oxygen throughout the water depth. Aerobic heterotrophic bacteria degrade organic matter in the wastewater and resulting carbon dioxide (or bicarbonate) and algal cells use nutrients for photosynthesis. Oxygen released by algae in this process is the major source of oxygen required to satisfy the demand in the aerobic bacterial biodegradation process. The combined and mutually beneficial action of algae and bacteria in this process is termed algal-bacterial symbiosis. There is no net loss of influent carbon in the system, just the transformation of waste organic matter into living cells, mainly algae and bacteria. About 80 to 95% of the soluble BOD could be removed in this system (USEPA, 1992; Mara, 2001). In aerobic lagoons the dissolved oxygen can be supplied naturally or artificially (by mechanical aeration). Natural aeration is achieved by air diffusion at the water surface, by wind or thermal gradient induced mixing, and by photosynthesis (algae and cyanobacteria or blue-green algae). They are quite shallower (0.3-0.6 meters) than other types of lagoon as well as the artificial aerated lagoons (between 1 and 4 meters), to allow sunlight and penetrate throughout their depth to maintain active algal photosynthetic activity during daylight hours but algal photosynthesis plays an insignificant role in the mechanically aerated lagoons. The oxygen produced from the photosynthesis process in the naturally aerated lagoon is used by aerobic bacteria to degrade the organic waste. The dissolved oxygen level in the lagoon fluctuates (increases or decreases) throughout the day, depending on the solar irradiation available. The general chemical reaction for aerobic degradation of organic compounds is as follows (Zhang, 2001). Depending on the retention time, aerated lagoon effluent contains approximately one third to one half the incoming BOD value in the form of cellular mass. Most of these solids must be removed in a settling basin before final effluent discharge (UN, 2003).

Facultative Lagoons

Facultative lagoons operate in a similar manner as aerated lagoons and have many of the same benefits. But the facultative lagoons are relatively deeper, about 1.2 to 2.4 meters and do not require aeration system (USEPA, 2002). Waste is treated by facultative bacterial action occurring at the top layer exposed to wind agitation, sun, and contains enough oxygen is aerobic zone. The middle layer is called the facultative zone where, depending on the climate, both conditions are present to some degree. The bottom of the lagoon includes the layer of sludge that accumulates there, called anaerobic zone (Pfost and Fulhage, 2007). Facultative lagoons have good odor controlling system. Because the odorous compounds like hydrogen sulfide, generated in the anaerobic zone, rises to the surface and the dissolved oxygen present oxidizes it into sulfates that do not cause odors. The algae that grow in the lagoon are important to the successful stabilization of the organic load through photosynthesis

Anaerobic Lagoons

Anaerobic lagoons are used for treatment of industrial wastewater, mixtures of industrial /domestic wastewater with high organic loading. Typical industries include slaughterhouses, dairies, meat and poultry processing plants, rendering plants, and vegetable processing facilities (USEPA, 2002). Anaerobic lagoons vary in depth from 2.5 to 10 meters and built as deep as the local geography allows minimizing the surface area and reducing odor emissions and its top layer (less than half meter) may contain dissolved oxygen depending on wind, temperature, and organic loading rate (Zhang, 2001). However, this layer is very thin and the contribution of aerobic bacteria to the overall waste degradation is insignificant. Anaerobic bacteria can decompose more organic matter per unit lagoon volume than aerobic bacteria and are predominantly used for treatment of concentrated organic wastes (Barker, 1996).

Anaerobic decomposition of livestock waste can result in the production and emission of odorous gases, primarily hydrogen sulfide, ammonia, and intermediate organic acids (Barker, 1996). However, due to their low capital, operational, and maintenance costs combined with a high efficiency in reducing polluting charges have all contributed to the popularity of lagoons (Masse and Masse, 2000).

Conclusions

Raw wastewater of both slaughterhouses were characterized by high concentration of organic matter (COD and BOD), Nitrogen and phosphorus nutrients, sulfates, solids (TS and TSS) and fats, oil and grease (FOG) as well as high bacteriological load (FC and TC). The concentration of both slaughterhouses wastewater was significantly differing due to the difference in the type of animals slaughtered, rumen content separation, and live weight killed as well as water consumption in both slaughterhouses. The levels of most parameters monitored were generally higher in the discharge point of both rivers and further downstream than the levels obtained in the upstream of these rivers. However, it failed in managing and evaluating the existing status of its wastewater treatment system in reducing the pollution load. The overall performance of its wastewater treatment system was did not comply with EEPA and UNIDO effluent discharge limit with the exception of the pH and temperature.

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