Chapter 2
Slaughter Wastes-A Curse or Blessing: An Appraisal

Kashif Nauman, Atif Nauman, and Muhammad Arshad

Abstract Slaughterhouses are designated premises for slaughtering and processing of animals for meat. During processing, many edible and inedible by-products are produced. On further processing, these by-products could produce extra revenue for the facility vice versa and have a harmful effect on the environment. In developing countries, some edible by-products are utilised differently, while inedible by-products go wasted without technological interventions. Under these processing conditions, these wastes can cause adverse effects on the environment in the short and long term. During meat processing, ruminal contents in red meat, while feathers in poultry processing, are produced in high percentages. Different procedures like biogas production, rendering, composting, and biodiesel production could help deal with these wastes, while wastewater could be processed through physicochemical, biological, and advanced oxidation processes. These processes play a critical role in the BOD, COD, and TSS value of the treated water and make it acceptable for the regulatory institutions. In this chapter, a detailed description of these techniques and technologies is discussed to understand the use of different components of slaughterhouse waste for society's benefit, including revenue generation and, subsequently, environmental protection.

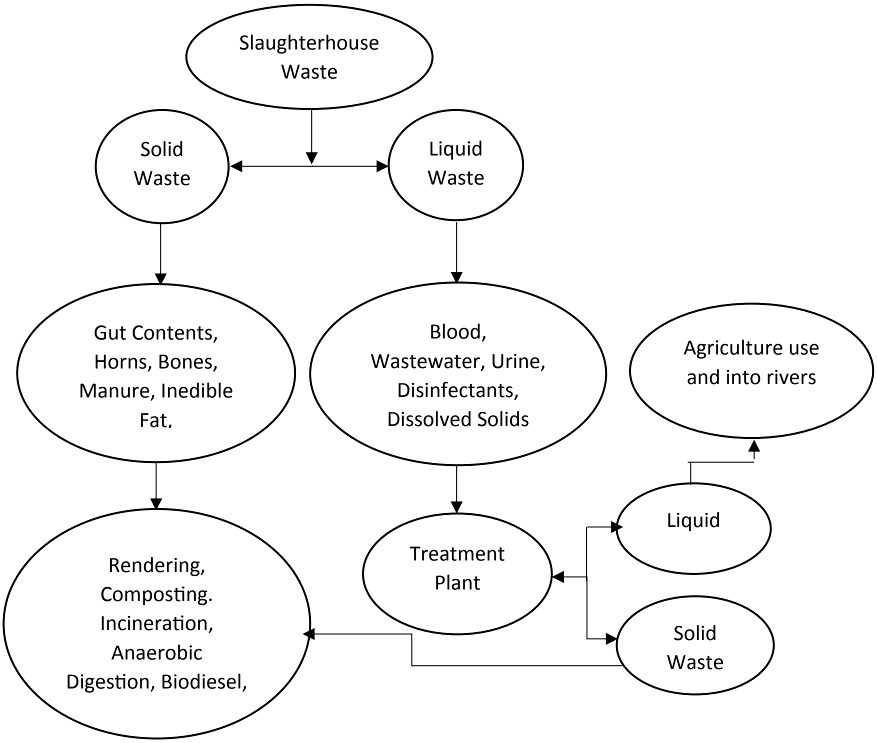
K. Nauman (✉)
Department of Meat Science and Technology, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan
e-mail: drkashif@uvas.edu.pk

A. Nauman
Department of Environmental Sciences, Quaid-I-Azam University, Islamabad, Pakistan

M. Arshad
Jhang-Campus, University of Veterinary and Animal Sciences Lahore, Lahore, Pakistan

M. Arshad (ed.), *Climate Changes Mitigation and Sustainable Bioenergy Harvest Through Animal Waste*, https://doi.org/10.1007/978-3-031-26224-1_2

Graphical Abstract



Keywords Slaughterhouse · By products · Economics · Value addition · Waste management · Processing

2.1 Introduction

The waste from the slaughterhouse consists of different parts of the animals generated during meat processing and production; blood and other by-products of animals are among this waste. This inedible waste includes animal tissues like ligaments, blood vessels, organs, integuments, bones, tendons, and feathers, contributing up to 45% to the waste of animals. Pet food manufacturing companies purchase these wastes from slaughterhouses in large amounts, which can be used as a supplement to animal and pet food (Salminen and Rintala 2002). A large amount of organic waste is also generated from the slaughterhouse, including fat, highly suspended solids, and liquids (Adeyemi and Adeyemo 2007). It is assessed that 52% of meat from goats or sheep, 50–54% from cows, 78% from each turkey, and 68–72% of every chicken is consumed, and the remaining animal waste is dumped (Tolera and Alemu 2020).

The solid waste generated from the bovine slaughterhouse is 27.5% of the animal's total live weight (275 kg/ton). During the sheep and goats slaughtering process, 17% of the animal weight and waste is produced, which is about 2.5 kg/head. The poultry shops and slaughtering plants generate about 32.5 to 37% of waste. Moreover, half of the animal by-products are unsuitable for further reuse (Mozhiarasi and Natarajan 2022) (Table 2.1).

A large volume of waste is generated from slaughterhouses globally. Primarily, slaughterhouse waste includes solids like rumen contents, bones, contents of the intestine, dung, feather, ligaments, hooves, and skin. Liquid waste includes urine, blood, internal fluids of the body, and water generated during the washing and cleaning of the animal. If the slaughterhouse waste is not managed correctly, it can contaminate the whole local environment by polluting soil, surface, and under-soil water resources. Poor waste management at landfill sites can raise health issues. Less awareness about slaughterhouse waste management resulted in poor and illegal waste management activities, which can further increase airborne waste, air pollution, highly contaminated wastewater, and infectious stormwater runoff and waste.

Animal by-products are a valuable source of protein at the industrial stage, which can be used in different processed products and applications. Nowadays, such resources are not fully utilised in producing high-value applications, resulting in low-value products. Slaughterhouse waste is highly proteinaceous, a significant source of protein, but currently, there are some hurdles in using feedstock from the valuable protein resource as bio-based product production. The reason is the often mixing of non-homogeneous material with non-proteinaceous material, which results in poor solubility and limited processibility. During the advanced utilisation of the proteinaceous slaughterhouse waste, protein is extracted and combined in the bio-based industrial production of valuable goods.

The waste with its by-products generated from the slaughterhouse can be sold out to increase the revenue of the slaughtering facility and lower operation costs. The practical use of waste trend is expected to increase in coming years because everyday industry searches to find new ways to utilise organic waste like biogas and compost.

Table 2.1 Waste generation (per cent) from animal slaughtering processes (Adhikari et al. 2018a; Mozhiarasi et al. 2020; Jayathilakan et al. 2012; Meeker and Hamilton 2006)

Type of waste	Waste generation (%)
Chicken slaughtering process	
Skin and feathers	57.37
Legs	14.8
Intestines	20.35
Other waste	<1
Lambs/cattle slaughtering process	
Manure	12
Ruminal contents	80
Blood	5
Other waste	3

The waste used for the industrial production of food for pets, animal food, and bone meal by the rendering industry is gaining attractiveness every day. From the rendering processes, poultry meal, meat, blood meal, a hydrolysed meal of feathers, animal fat, and fish meal are among the primary products generated during these processes. This waste can be further used for medical purposes. From the slaughtering facility, the generation of animal by-products and their processing in animal and pet foods production is an effective strategy for adopting the reuse concept. So, in the coming sections, various wastes, their processing, and utilisation are discussed.

2.2 Operations During Slaughterhouse and Waste Production on Each Step

Slaughterhouse operation consists of many steps, from the lairage to initial examination, slaughtering, de-hiding/deskinning, evisceration, post-mortem, deboning, and secondary and tertiary processing steps. In these processing steps, different wastes are produced, which could be divided into two categories as (Table 2.2).

During animal receiving, washing, and staying in lairage, manure, urine, odour, and wastewater are produced. Generally, these wastes are mixed with washing water and go into the sewage system. During slaughtering, animals are usually slaughtered in a killing box, hind limbs used for hanging, and then moved down through the overhead railing for slaughter procedures. During this operational step, a large volume of wastewater containing blood is produced as waste material.

Before starting the de-hiding, the head, hooves, and horns are removed as waste material. After this process, the skin/hide of the animal is removed, which is one of the most valuable wastes produced in a slaughterhouse. In another crucial processing step, evisceration, blood, the visceral organs, liver, intestines, pancreas, heart, lung,

Table 2.2 Edible and inedible parts of animals generated during the slaughtering process (Awan et al. 2015)

Edible parts	Inedible parts
Liver, heart, kidneys, and tails	Horns, hides and hair
Lungs, tongue, and tripe (stomach)	Blood vessels, fats, and bones
Chitterlings, fries (testicles), melt (spleen), natural casing (intestine), sweetbreads, and thymus or pancreatic gland, which depends on animal age	Teeth, blood integuments, and tendons
Lips, rinds, and fats	Feet, trimmings, ligaments, manure, and rumen contents
Trimmings and certain bones	Cartilage, feathers of glands, and glands
Edible by-product yield is around 12% of the live weight	Inedible parts can cover up to 45% or more of the slaughtered animal

stomach contents, paunch manure, digestive system, excretory systems, and wastewater are produced. This process removes white, green, and red offal for further processing or waste.

Deboning and cutting operations are performed in the secondary processing section. In this operation, bones are removed from the carcass and meat is cut into different cuts. During the deboning process, bones, tendons, ligaments, and fat are removed as waste material. Post-mortem inspection examines dressed carcasses and their organs, including head, pluck, and intestines, immediately after slaughter to produce hygienically wholesome meat under adequate light by a qualified meat inspector. During post-mortem, abnormalities and disease conditions noted during the ante-mortem are correlated in deciding to accept and reject the carcass. Only safe and wholesome meat will be provided to the market. In this operation, trimmed carcasses, rejected organs, carcass parts, or carcasses could be presented as waste (Mozhiarasi and Natarajan 2022).

2.3 Types of Waste and Their Handling

2.3.1 Solid Waste Process

In the meat industry, by-products that are in solid form and not further processed can happen are considered solid waste. It includes the remaining material that is in non-edible form and can be sold out, including bones, hoofs, horns, integuments, skin, ligaments, and cartilage tendons, the contents of the gastrointestinal tract and internal body organs. The most significant by-products obtained from the animals are intestinal products used as sausage casing, sports gut, musical string, and surgical sutures. Bone products are used in the gelatine formation, row bone, crushed bone, bone meal, bone ash, handicrafts, livestock feed fertiliser, and biodiesel.

2.3.1.1 Solid Waste Management

Solid waste management consists of several processes such as at the point of waste generation, handling of on-site waste, collection, processing and storage of waste, their transformation, transport to other locations, resource recovery, recycling, reuse, and final disposal (Mozhiarasi and Natarajan 2022). Different processes can manage solids produced in the slaughterhouse, including rendering, composting, incineration, anaerobic digestion, pyrolysis, landfilling, and biodiesel production. Among these processing processes, rendering, composting, and anaerobic digestion are well studied and recommended for application in the field as it destroys many pathogenic and public health significance bacteria, viruses, and parasites.

2.3.1.2 Liquid Process Waste

Liquid waste includes urine, oils, wastewater, fats, sludge, used oil, grease, unsafe household liquids, and gases. Unsafe disposal of this liquid waste is dangerous to human health and the environment. The water requirement on average to produce one-ton cattle meat is 15,500 m^3, for sheep 4000 m^3, for pigs 4800 m^3, and poultry meat production 4000 m^3 (Hoekstra and Chapagain 2006).

2.3.1.3 Liquid Waste Management

A large volume of wastewater is generated while processing meat in the slaughtering facility. Slaughterhouse wastewaters have high organic matter content like fat, protein, and several microorganisms. Mostly, the wastewater from the slaughtering facility is directly discharged to the municipal sewage system without any treatment.

Different processes and technologies are used during the treatment of slaughterhouse wastewater. The first process in the handling of wastewater is preliminary treatment. This step is inexpensive and effectively removes the large particles using specific size screens. These screens stop the large fat particles, feathers, and meat pieces. This step protects the downfall treatment machinery. These steps also help reduce the wastewater biological oxygen demand (BOD), which removes large particles of organic content during this treatment step. The primary treatment method removes the small particles of organic content. During this step, heavy particles are sedimented, and light particles are floated using inexpensive equipment.

In the next step, different techniques like dissolved air flotation, coagulation-flocculation and sedimentation, advanced oxidation process, etc.

2.4 Usage of Slaughterhouse Waste

2.4.1 Blood as a Resource of Bioactive Compounds

In the meat industry, during the slaughtering of animals, the generation of blood is an inevitable by-product and primary waste (effluent). The percentage of blood in the wastewater is 4.5% of live weight, which equals the 10% of the protein available in a slaughtering animal. It is estimated that 75% of blood is allowed to drain during the slaughtering of an animal from the body, which is 4% of the animal's live weight and 6–7% of the carcass meat content. Dried blood contents are rich in lysine, high in protein (80–90%) and have a reasonable reuse price (Wismer-Pedersen 1988). So, it appears as a significant waste that can cause contamination if not removed properly. As per the description of the resultant product, collection methods are adopted. Blood is collected directly from the animal's slaughtering site for medicinal products so contaminants can be minimised.

In contrast, for a blood meal and relevant products, blood is collected through underground pipelines from where blood moves out of the slaughterhouse/industry to blood collection tanks for rendering plants situated nearby or transported to the blood processing units present in other areas through trucks. Blood is a readily available source of protein from the slaughtering animal. From the slaughterhouses, blood supply offers economic, nutritional, and environmental benefits.

There are some religious restrictions on the use of blood; for example, in Jewish shechita and Islamic sharia, there is a prohibition on the use of blood. In some cultures, there are hurdles in using whole blood in food. The hydrolysis process for transforming blood into useable products may present a way for the blood products' acceptability in these cultures. The opinion about using blood products from religious scholars is yet to be presented.

Bioactive food molecules are naturally occurring non-essential elements from plants, animals, and marine that influence biochemical, physiological, and metabolic processes and other valuable effects beyond fundamental nutritious activities (Kris-Etherton et al. 2004). Bioactive compounds include oligosaccharides, peptides, enzymes, biopolymers, fatty acids, and water-soluble minerals. These substances can be naturally present in food sources (gastrointestinal digestion) by microbial fermentation or industrial enzymatic digestion (Hernández-Ledesma et al. 2011). These substances are absorbed primarily through the small intestine or into circulation. These chemicals may function as antioxidants or antimicrobials, cholesterol and blood pressure reducers, and antithrombotic agents. Some bioactive may have many functions (Korhonen and Pihlanto 2003).

The bioactive chemical compounds have the therapeutic and preventative capability for diseases of humans, work as modulation of bio-system function, play the role as substrates for biomolecule and bio-structure creation, antimicrobial properties, the capacity to transport medications, enzymes, and nutrients (Bah et al. 2013).

Due to their various biological effects, such as lowering cardiovascular disease risk factors and antioxidant, antimutagenic, antithrombotic, anticarcinogenic, antiallergenic, anti-inflammatory, antibacterial activity, blood pressure and cholesterol-lowering, and immunoregulatory effect, thus bioactive substances are crucial for the health of humans (Parvathy et al. 2009). In preventing chronic diseases, their role as bioactive substances is significant, including carotenoids, organic acids, vitamins, polyphenols, phytosterols, omega-3 fatty acids, nucleotides, and nucleosides have gained considerable attention.

2.4.1.1 Application of Animal Blood in Food

Animal blood and its components are used as a food or additive in different parts of the world. Some examples of the use of blood as a whole are as the source of protein in blood sausage (Spanish) (Santos et al. 2003), fortification of iron by using bovine haemoglobin in cookies (Walter et al. 1993), use of fat replacer in ham pate by bovine plasma and globin (Viana et al. 2005), fat replacer in Bologna sausage by using animal plasma (Cofrades et al. 2000), production of binder in restructured meat products from thrombin, fibrinogen and porcine transglutaminase (Tseng et al. 2006), protease inhibitor from plasma porcine (Visessanguan et al. 2000), generation of protease inhibitor from porcine plasma and its use in the Surimi (Rawdkuen et al. 2004), plasma of bovine as a white replacer of eggs in cakes (Myhara and Kruger 1998), and plasma of bovine in the cakes as egg white replacer and the use of a stabiliser in the minced meats produced from processed bovine plasma (Furlán et al. 2010).

2.4.1.2 Medicinal Applications of Blood

Several medically significant proteins, such as albumin, plasmin, thrombin, prothrombin, fibrinogen, immunoglobin M, immunoglobin G, haemoglobin, prothrombin, and transferrin, are present in blood as components (Bah et al. 2013). Animals who lose blood or fluids might be given purified bovine albumin to compensate for it. It is a vaccine stabiliser used to screen for the Rh factor in human subjects. Additionally, testing for antibiotic sensitivity employs it (Tanaka et al. 2001). The porcine plasmin enzyme dissolves blood clots in heart attack victims. Bovine thrombin aids in blood coagulation, the healing of wounds, and the retention of skin grafts (Jayathilakan et al. 2012). In serology laboratories, bovine fibrinogen is used as a standard reagent for blood coagulation. Bovine prothrombin is active in topical surgical haemostatic treatments and is a precursor to thrombin generation and purification.

Bovine plasma is utilised as a growing medium in laboratories for porphyrin and probiotic lactobacilli, which are employed in human medicine. Blood products nourish the tissue culture medium (Hyun and Shin 1998). Heme iron polypeptide tonics derived from animal haemoglobin are widely offered by businesses to cure an iron shortage. Bio-peptide tonics assert to lower blood pressure, cholesterol, and blood sugar, improve mineral absorption, boost immunity, and act as opioids (Opioid peptides that bind to opioid receptors as short sequences of amino acids in the brain). The best antigenotoxic impact was shown by bovine blood albumin peptic hydrolysate. Commercial food and nutraceuticals contain peptides from animal blood (non-medicinal nutrients used as supplements). Some businesses openly state that their dietary supplement contains bovine serum, yet many conceal it.

2.4.1.3 Animal Blood in Other Applications

The use of animal blood other than in food can be used in industrial applications. Examples of blood used as a protein source are generated from the slaughtering of sheep, cows, and chickens, which use in the production of pet and animal food. Animal blood has medical field-related applications like plasmin and thrombin, which are recovered from the blood of a slaughtered animal (Tanaka et al. 2001; Pierce et al. 2005; Jayathilakan et al. 2012).

2.4.2 Composting

Organic materials (such as waste from slaughterhouses) are destroyed through the actions of a subsequent set of bacteria during the controlled biological process known as composting (Dees and Ghiorse 2001). The composting slaughterhouse waste may consist of inorganic and organic wastes, paunch, municipal solid waste, pig or poultry manure, sewage sludge, and garden waste (Asses et al. 2019). Sanabria-León et al. (2007) describes that compost made from slaughterhouse waste is often a stable product that may improve soil quality and provide plants with nutrients. Understanding compost's chemical and microbiological characteristics can help to comprehend the composting process that organic leftovers undergo. This method has several advantages, including decreasing environmental pollution, valuable by-products, and eradicating most infections (NABC 2004). The survival and spread of pathogens in animals, people, and plants during the composting process is a common worry.

Composting should not harm people's and animals' health when done under strict care (Franke-Whittle and Insam 2013). Prions and bacteria that generate spores are pathogens that cannot be eliminated. Composting is used to serve as an acceptable, inexpensive, potentially eco-friendly approach to the disposal of was generated from the slaughterhouse. This process significantly lowers the number of pathogens during decomposition due to the temperature rise. The microbial community which takes part in the organic content breakdown is usually fungi and actinomycetes. During breakdown, the microorganisms convert the organic matter into water, carbon dioxide, humus, and heat (Epstein 1997). In this process, anaerobic digestion of waste material takes place, reducing the chance of disease separation by microbes and parasites. Composting technique has certain disadvantages, including space requirements for the remote site, which increases transportation costs. This is challenging to maintain the high-rate conditions of the compost turning ratio; when the required conditions are not met, the compost will be coarser and have a significant oversized fraction of compost. Mainly composting produces leachate, dust water, odour, litter, contamination, vectors, pests, fire, and noise under less control. It is more difficult to achieve consistent results.

There are two types of composting exits; one is windrow composting, while the other is in-vessel composting. Windrow composting is also called aerated (turned) composting (Cekmecelioglu et al. 2005). This composting involves converting organic content into long piles called windrows. Windrows are aerated occasionally by mechanical or manual turning. Windrow composting facility requires equipment, large tracts of land, and labour. In warm, arid climates, windrows are covered to prevent water evaporation. Leachate is a liquid produced during composting that can contaminate groundwater, while odours must also be controlled. There is a modified type of windrow composting called aerated static windrow composting. In this composting type, layers of organic matter are loosely piled so air can pass from top to bottom. Air blowers might be activated. Compost is relatively quickly produced in 3–6 months during the static pile process (da Silva Vilela et al. 2022).

While in other composting types, in-vessel composting involves adding organic content into a silo, drum, or concrete line reactor. It processes a large amount of waste without taking up much space and offers better control and efficiency than windrow composting. This method produces compost within a few weeks. While on the other side, this method is expensive, requires technical expertise to operate correctly, and requires insulation in extremely cold weather (Hoitink and Boehm 1999).

2.4.3 Anaerobic Digestion

Anaerobic digestion is the process in which controlled biological degradation occurs in the absence of oxygen but in the presence of different types of microorganisms inoculated for their specific functions and degradation of organic waste. The products of the procedure are a generation of added value products such as volatile fatty acids, bio manure, biohydrogen, biogas, and alcohols (Moukazis et al. 2018), used as an energy source and fertiliser, respectively. Activities from slaughterhouses generate a large volume of organic wastes in a biodegradable form, such as blood, animal faeces, fat, urine, paunch contents, and animal trimmings. In developing countries, non-availability of technologies and infrastructure, these wastes become part of landfills responsible for water, soil, and air pollution through heavy loads of microorganisms, if untreated or poorly managed. The quantity of these wastes is produced according to the slaughterhouse size and species of the animals slaughtered (Urlings et al. 1992).

Mainly slaughterhouse waste consists of the rumen, stomach, intestine contents, lipids, protein, and blood contents which are ideal for anaerobic digestion, thus elevating the quantity of biogas that could be produced (Chen et al. 2008). Feedstock should be used from different sources to avoid fat flotation, ammonia production, and biomass washout. Certain waste components consist of long-chain fatty acids, primarily responsible for upsetting the digestor working and resulting in desired products.

The technology of anaerobic digestion has been for many years. Renewable energy production and material recovery are aided by anaerobic digestion. Anaerobic digestion occurs throughout four sequential stages: methanogenesis, acidogenesis, hydrolysis, and acetogenesis. Different types of microorganisms' interactions drive and complete these four steps. All collected waste is added at once in the single-stage batch reactors, and these processes are sequentially permitted to take place in the reactor. The final produced compost is then evacuated after a predetermined retention period and when biogas production stops.

Different components of the slaughterhouse waste have different carbon-to-nitrogen ratios (*C*/*N* ratio), which show distinct characteristics like blood has and low carbon-to-nitrogen ratio and high protein contents; due to this, it needs to be processed with high *C*/*N* ratio contents. In contrast, ruminal contents have high *C*/*N* rations along these factors, temperature, pH, volatile fatty acids, alkalinity, carbon-to-nitrogen ratios, solid and volatile solids, solid retention time, and hydraulic retention time that are essential to be considered (Selormey et al. 2021).

Organic material found in anaerobic digesters generally contains polymers in a complex form that are difficult for microbes to degrade without further pre-treatments and hydrolysis. Therefore, hydrolysis breaks down organic macromolecules into smaller parts (Castellucci et al. 2013). Much focus has been placed on ways to speed up hydrolysis in anaerobic digesters because of how crucial it is to the kinetics of anaerobic digestion.

By absorbing hydrolysis by the cell membranes during acidogenic and acidogenesis, bacteria can create fatty acids in volatile form (VFAs) and other compounds. Organic acids like acetates and more powerful organic acids like propionate and butyrate belong to the class of VFAs. Even then, trace levels of lactate and ethanol may exist. Methane is produced during the digestive process of methanogenesis by methanogenic microbes by consuming available intermediates. It was discovered that 99% of Methanococcus vannelli and Methanococcus voltae cells had been killed within ten hours when exposed to oxygen takes place while showing methanogenic microorganisms' rapid sensitivity to oxygen.

Methanosarcina spp. are thought to withstand pH shocks and are relatively resilient and withstand higher levels of sodium, acetate, and ammonia concentrations that can harm methanogenic microorganisms, although methanogenic species in the anaerobic digestion are among the sensitive microbial groups. When in the reactor, biogas production stops, and methanogenesis ends; this process takes up to 40 days. The volatile solids content in the sludge and dewatering capacity can be used to assess how much digestion has taken place.

2.4.4 Rendering

Animal waste that is inappropriate for human consumption is transformed into stable, value-added materials like bone meal and refined fats like lard and tallow through the rendering process. Several drying and separation procedures are primarily used for this. Additionally, the procedure produces bone and poultry meals used to make pet food. The significant steps in the rendering process include removing water from the waste, isolating fats, and applying heat. In the first step, the waste is reduced, put into a cooking vessel, and cooked. The melted fats are subsequently separated from the protein by pressing this waste. Bone fragments and moisture are also taken out. After then, fat can be kept for later use. While the raw material is dried in dry processing, the addition of boiling water or steam causes the fat to surface in wet processing. It is significant to note that the length of the heating process and temperature is essential to the outcome. The rendering benefits include lowering the amount of generated waste dumped directly in landfills, killing protozoa, bacteria, parasites, and viruses, and producing a high-quality product that may be sold to create more cash. Disadvantages of rendering include high energy costs, the need to treat effluent water, and odour annoyance. Removing water from condemned trash also results in high energy expenditures.

Integrated rendering plants work alongside slaughterhouses or poultry processing facilities, whereas independent rendering plants are off-site facilities that gather raw materials from multiple sources. Independent plants can get animal by-product materials from the following places: slaughterhouses, supermarkets, butcher shops, animal shelter restaurants, poultry processors, farms, ranches, fast-food chains, and feedlots. These sources supply complete animal blood, carcasses, offal, grease, feathers, and other by-products.

Food-grade and non-food-grade animal rendering are the two categories of procedures as these facilities are typically run in combination with meat processing facilities, fatty animal tissue converted by edible rendering plants into palatable proteins and fats. Independent renderers or integrated processes that include rendering run inedible rendering plants. Typically, these facilities gather trash from slaughterhouses from facilities nearby. These factories create non-edible grease and tallow that is further used in poultry and animal feed, bone and meat meal, fatty acid production, chicken meat, fish meal, blood meal, hydrolysed feather meal, soap, and biodiesel manufacturing (Meeker and Hamilton 2006). In the nineteenth century, when animal by-products were predominantly used in the large-scale manufacturing of fertiliser, the rendering business underwent tremendous development. They were not necessary economically before it. Nowadays, the rendering sector creates hundreds of valued goods (MLA 2009).

Most solid slaughterhouse wastes were once rendered, giving the facilities an additional source of revenue. However, the commercial worth of such goods has drastically decreased due to the possibility of TSEs and treated as garbage in many situations (Palatsi et al. 2011). As a result, properly disposing of slaughterhouse waste prices has significantly increased lately. This is partly because the bacteria in such wastes pose a health danger.

It is possible to render by using a dry batch system and other technologies, in which the system has a cooker with steam-jacketed walls that keep the steam from coming into direct contact with the material inside. Water and fat are expelled as a result of the procedure. Due to no direct live steam contact, the fat is not substantially damaged. The cooling substance is eliminated, and the freely flowing fat is removed. The humid form material is subsequently squeezed using a continuous screw press, hydraulic press, and decanter centrifuge.

The autoclave system contains a cooker loaded with already-ground raw materials that are sealed prior to a steam injection (about 140 °C). Typically, this procedure lasts three to four hours and begins with high pressures (such as 360 kPa) that eventually drop to roughly 100 kPa of ambient pressure. A continuous dry system operates continuously, much like a dry batch system. Under specific atmospheric pressures, it operates. Heat is generated inside the cooker using steam jackets. To drain the water and fat, the automated process used by a continuous low-temperature system is frequently referred to as a dewatering system (mechanical). In general, the by-products in the uncooked form are squeezed and then placed in a wet or dry cooker at low temperature, where they are held at 60–90 °C for 10–30 min.

2.4.5 Incineration

It is a waste treatment process by destroying something like waste and useless things, burning to convert waste into ash, flue gas, and heat. In this process, waste volume is reduced to less than 5%, which is easy to maintain and reduces the need for landfill space. Heat can be covered during this process; it is the only solution for specific waste types. Most gases are burnt-well-designed systems produced. In the incineration process, relatively simple devices can achieve high removal efficiency. At sufficiently high temperatures and residence time, any hydrocarbon vapour can be oxidised to carbon dioxide and water.

After animal slaughtering to lower the danger of disease, animal by-product incineration is a quick, affordable, and secure disposal option. Abattoir and slaughterhouse waste is a possible breeding ground for pathogens that can infect humans and animals, including bacteria, viruses, prion diseases, and parasites. Heavy metals, dioxins and furans, particulate matter, and acid gases are the pollutants produced by this process. The waste is first received, sorted using an overhead crane, and placed into the incinerator's combustion chamber to begin the burning process. During the burning fuel and waste materials, the heat from the waste produced is collected and can be used to turn water into steam to produce electricity. A high-efficiency filtering system captures emissions 34 from the combustion process, and leftover ash from the system is collected and processed before transportation to a landfill using covered and waste leak-proof vehicles.

Typical waste produced by slaughterhouses and abattoirs is a biosecurity risk and must be disposed of immediately and thoroughly. By-products, including offal, hair, bone, fat, blood, and corpses, can all be efficiently burned in incinerators. It is okay to incinerate any of these waste types. Pollution from this procedure is lower than that from burning. Although it is believed that all viruses and bacteria will be destroyed during incineration, bovine spongiform encephalopathy (BSE) can withstand a high temperature in this incineration procedure not achieved (Franke-Whittle and Insam, 2013).

The incineration process has various advantages, including generating heat to create steam, which generates power and lowers the demand for fossil fuels. Pathogens and waste are destroyed during high-temperature treatment, which results in rising prices for collecting animal by-products but annual cost savings because there are no longer rendering or fallen stock expenses. There is no chance of contamination because trucks carrying potentially hazardous materials are not allowed to enter the site, boosting overall biosecurity. Storage is unnecessary because garbage is burned every day. There are certain obvious advantages that an incinerator provides, such as biosecurity, a decrease in garbage volume, lower expenses, and in some circumstances, a way to produce electricity. Due to the massive amounts of air pollution produced by the smoke released, other drawbacks include the need for high start-up costs, regular maintenance, and proper operation.

2.4.6 Biodiesel Production

The production of biodiesel from vegetable oils, cooking oils, yellow grease, or animal fats is sustainable, biodegradable fuel. Biodiesel is described by the American Society for Testing and Materials (ASTM) as a blend of long-chain monoalkylic esters from fatty acids from renewable resources used in diesel engines. Due to their high lipid content and availability, vegetable fat, animal, or slaughterhouse waste are a possible substitute source for biodiesel generation. One of the most acceptable biofuel options is biodiesel, which is produced using biological materials rather than fossil fuels. Using biodiesel could lessen emissions of hydrocarbons, suspended particulate matter, oxides of sulphur, and carbon monoxide, in addition to potentially extracting valuable products (lipids) from the wastes during this process (Mahyari et al. 2021).

Animal fats used to produce biodiesel include lamb/goat tallow, fish, and chicken fat, lard. Animal fat is the by-product of the rendering process of animal slaughter waste for meal production. Its drawbacks in biodiesel production could be removed, and the transesterification process could be used for production. Animal fat consists of saturated and unsaturated fatty acids, whereas saturated and monosaturated fatty acids are ideal for biodiesel production and polyunsaturated fatty acids make diesel heavy.

Animal waste is heated at 60 °C, and it breaks down the fat elements. Then, the extracted fat will be washed with water. The resultant oil will be filtered/centrifuged and decanted to remove the suspended particles and contamination. The processed fat is separated and stored. The content of free fatty acids, water, iodine number, peroxide value, saponification value, and acid number is vital to achieve high conversion efficiency. The efficiency of the reaction diminishes with the increase of the oil's acidity.

The composition knowledge of the chemical mixture is helpful while performing a reaction. Chemical process reactions take place in the first few minutes. The three stages required for forming esters from triglycerides are supported by the lack of mono- and diglycerides at the start of the chemical reaction and the rise and fall in their concentrations throughout the reaction. Fatty acid methyl esters (FAME) and glycerine are separated by decantation in two phases due to their different densities. In the separator chamber, this occurs in contrast to the majority of fatty acid methyl esters, glycerine, and excess alcohol concentrate in the upper phase.

There are two distinct phases. Decantation is the only method of separation, and because it relies on gravity, it could take several hours to complete. A quicker but more costly alternative is centrifugation. Fatty acid methyl esters have contaminants, including catalyst and methanol residue left over after the separation of glycerine. These raise cloud points; hence, a purification procedure is required. The combination of fatty acids and methyl esters must be purified to meet the appropriate quality standards for biodiesel. Because of this, it is cleaned, neutralised, and dried. The catalyst, methanol, and glycerine remnants are eliminated through repeated washings with water. The production of emulsions during the washing steps must be avoided because these contaminants are water-soluble, decreasing effectiveness. A series of washing procedures are used, with the first washing step using acidic water to neutralise the esters combination. After that, just water is used for two more washing steps. Finally, a drying procedure is required to remove any remaining water residues. The refined product is ready to be used as biodiesel once it has dried.

Glycerine (By-product): Glycerine is also known as glycerol, glycerine, or glycol alcohol. Chemically, it is alcohol with high viscosity at room temperature, odourless, transparent, colourless, low toxicity, and sweet taste. The boiling point of glycerine is high, 290 °C, and its viscosity increases noticeably at low temperatures. Glycerine is hygroscopic and has humectant properties. Glycerine is obtained as a sub-product of soap and biodiesel production. It is purified further to eliminate contaminants.

One of the primary benefits of using biodiesel is energy efficiency. Biodiesel is environment friendly as it emits a low number of sulphur oxide (So_x) and other harmful gases. Biodiesel is highly renewable. Biodiesel is sourced from natural organic matter like plants and animal oils.

Biodiesel is a non-toxic fuel producing lower emissions than fossil fuels when burnt. This lessens the risk of respiratory illnesses due to reduced air pollution. It helps ease the movement of engines as it has a more significant lubricating effect, extending engine lifespan.

On the contrary side, slightly higher fuel consumption than diesel fuel while emitting slightly higher nitrous oxide. Higher freezing point than diesel, while biodiesel is less stable than diesel fuel and therefore cannot be stored for the long term. These disadvantages are significantly reduced when biodiesel is used in blends with diesel fuel. The use of biodiesel as an alternative to diesel fuel has many benefits. After the raw ingredients have been processed, a reaction known as transesterification creates a mixture of fatty acids methyl esters (FAME) and glycerine as a by-product. The glycerine must be removed, and the mixture must be purified for the mixture of methyl esters to meet the specifications defined by global biodiesel standards. Since glycerine is a valuable material with numerous uses in the chemical, cosmetics, and pharmaceutical sectors, it is typically recovered and refined in large-scale production facilities.

2.4.7 Wood Adhesives

Slaughterhouse produces a large quantity of water containing a wide variety of components. Generally, these wastes are utilised for manufacturing meals, pet food other products. However, according to different legislative requirements in developed countries, these materials cannot go into animals' feed as a disease hazard caused by prion protein named bovine spongiform encephalopathy (BSE) is humungous. So, a significant amount of proteinaceous material goes into landfills or is incinerated, causing a financial burden and wastage of limited resources in this circular economy. Different methods are implemented to recover usable and value-added protein-based waste; one is thermal or alkaline-based hydrolysis. This method helps recover hydrolysed-based protein fragments from hydrolysate, which could further be utilised for value-added products, including biocomposites and bioplastics, which could replace formaldehyde-based resins identified as carcinogens (Adhikari et al. 2018a, b).

According to some research publications, the covalent bonds that develop due to the functional group's interaction in the adhesive formulation with those in the wood provide protein-based adhesive systems with their high sticky strength. These adhesives are thought to operate better under low moisture conditions. Peptides combined with synthetic resins or denatured/hydrolysed protein cross-linking are two potential solutions to this problem.

A large portion of the phenol is replaced by the protein component from traditional phenol–formaldehyde resins in the adhesive systems of protein-phenol–formaldehyde. One such formulation, which was created using hydrolysed protein recovered from poultry industry waste, was performed as well as wood glue based on phenol–formaldehyde resin. These applications show a considerable possibility for wood adhesives using a hydrolysed protein recovered from waste streams.

2.4.7.1 Major Types of Adhesive Systems

Adhesive system based on protein-phenol–formaldehyde

In the adhesive systems of protein-phenol–formaldehyde, the components of formaldehyde-based resins are co-reacted with protein through co-polymerisation with the pre-polymers of phenol and formaldehyde or by irreversible incorporation into the phenol–formaldehyde network. This method substitutes phenol from phenol–formaldehyde resins with protein, a sustainable feedstock.

Development of formaldehyde-free adhesive systems by hydrolysed/denatured protein cross-linking chemical modification

The denatured protein is chemically altered or crosslinked in the formaldehyde-free proteinaceous adhesive systems by utilising peptide/protein cross-linking reagents. For these applications, the cross-linking reagents are multifunctional compounds with highly reactive functional groups with peptides and proteins.

In a recent US patent (Patent No. US9522515 B2), Wu and Wang (2016) went into more detail on the embodiments of wood adhesive preparation from spent hen protein and its use for the manufacture of wood specimens from birch veneer. The patent further states that wood glue made from denatured chicken protein had water resistance and greater strength when compared to denatured canola and soy proteins. Under dry conditions, the hydrolysed protein recovered from poultry industry waste used to make wood adhesives was shown to have excellent adhesive strength. However, the formulations created from hydrolysed protein did not achieve water resistance.

By tertiary protein structures partially destroyed with denaturing agents like sodium dodecyl sulphate and urea, water resistance and adhesive strength of protein-based adhesives derived from chicken by-products can be improved. A significant drawback is the water resistance ability of adhesive compositions created only from denatured protein as competitive with commercial wood adhesive resins. In order to identify commercial uses, enhancing the water resistance of such formulations is essential for peptides recovered from the poultry industry in wood adhesives.

2.4.7.2 Bone and Meat Meal

From the meat and bone meal, the disease spread potential is extensive, and relevant institutions strictly monitor this slaughterhouse waste segment and its processing. Although, until now, no such case has been reported concerning paratuberculosis, BSE, and salmonella from slaughterhouse waste, zero tolerance of these disease-causative agents are forcing to explore new value-adding ways (Park et al. 2000). The bone and meat meal consists of 56% crude protein generally. As a constituent of this crud protein, 0.32% tryptophan, 2.87% lysine, and 0.58% cysteine are among the polar amino acids which can further interact with wood (Goedeken et al. 1990).

A patent is the only scientific document developing adhesive formulations for wood bonding from bone and meat meal protein applications (Yang and yang 2010). This patent also describes the potential use of bone and meat meal protein in preparing flocculating agents and bioplastics.

While (Adhikari et al. 2018a, b) worked on the development of plywood adhesives which are hydrolysed protein-based derived from slaughterhouse waste, and their effect on moisture resistance of formulated adhesives by chemical modification of hydrolysed protein (Park et al. 2000) heating suspensions of bone and meat meal protein developed the adhesive formulations at pH values from 5.0 to 9.0, in water for 30 min and at temperature setting ranging from 60 to 90 °C.

Different testing criteria were used using pH values between 6.0 and 7.0 and formulations, in which adhesive performed better than those with lower or higher pH. The best adhesive efficacy was found at pH 6.0 and 7.0, probably due to increased secondary contact between the wood surface and protein in bone and meat meal. Additionally, the effects of partially hydrolysed bone and meat meal protein being chemically crosslinked with glutaraldehyde and glyoxal were investigated. Compared to the control adhesive made from protein concentrate but without cross-linking, the adhesive strength by about 8% is boosted by glutaraldehyde-crosslinked bone and meat meal protein concentrate. This process helps to increase water resistance by up to three times the formulated adhesive. Protein molecules form stiff three-dimensional structures with better water resistance and binding strength due to the addition of cross-linking agents to the formulation.

2.4.7.3 Blood and Blood Meal

Blood-based adhesives are historically highly significant for the adhesive industry since blood and soluble blood meal have been used for ages to manufacture adhesives. Blood albumin glues were the most significant water-resistant glues for the plywood industry until the development of synthetic resins. In the past, blood-based glues were offered as dry powders that could be dissolved in water and other chemicals to create an alkaline, homogenous substance that could be easily dispersed. Sodium hydroxide, lime, sodium silicate, or a mixture of these substances were the chemicals utilised for this.

Typically used as dry extenders, sawdust, wood flour, or other lignocellulosic ingredients were included in conventional blood-based adhesives preparations. Extenders were used to minimise the adhesive price by reducing the quantity of primary binder required per unit area and enhancing the adhesive system's void-filling capabilities. In order to assure uniform loading of the adhesive on the adherend, defoaming agents like terpineol were typically used in wood adhesives. This is because protein solutions generate stable foams that might affect volumetric measurements.

The bond strength and water resistance of the final adhesive system were studied by Yan et al. (2016) after combining acrylic latex- and cow blood-based adhesives. Although they lost market dominance after introducing synthetic adhesives, blood protein-based adhesives from water-soluble blood meal have long been recognised for manufacturing waterproof composite wood panels. However, the emergence of various studies and patents in the recent years suggests increased interest in using blood and blood meal to create proteinaceous adhesives. Some adhesive formulas made from scratch have demonstrated adhesive strength and water resistance on par with industrial resins used to make composite wood goods. Blood protein-based formulations containing up to 70% (w/w) blood protein have been produced by blending and co-reacting the protein with acrylic latex-based glues and partially condensed phenol–formaldehyde resin. These formulations have shown adhesive performance comparable to phenol–formaldehyde resin-based wood adhesives (Adhikari et al. 2018a).

2.4.8 Agriculture Water

After treatment, wastewater from the slaughterhouse could irrigate cultivated land. In many developed and developing countries, effluent water from the slaughterhouse is regulated through different standards to protect the environment, land, and sewerage systems. Slaughterhouse wastewater is heavily loaded with fat, ruminal contents, meat trimmings, disinfectants, cleaners, blood, and disposal from washrooms. For the utilisation of slaughterhouse wastewater as agricultural water, separation of these contaminants through physical and chemical separations needs to be adopted, otherwise irrigated land upper layer respiration will be blocked, and chances are there that it gets barren along with this spoilage of organic matter will cause a nuisance smell for the nearby population. Generally, agriculture after treatment could be a good source of extra income as sweat water availability is getting scared due to a drop in underground water and increasing cost of fetching it, so the mutual benefit for slaughterhouse, environment, and irrigation for cropped land.

2.5 Environmental Challenges Related to Slaughterhouse Waste

The location of the slaughtering facility and its planning is critical issues in an urban setting. The leftovers from animal slaughter end up in our lakes and canals, contaminating the water and becoming a part of our bodies. Untreated slaughterhouse wastewater contains paunch, faeces, urine, blood, lint, fat, carcasses, undigested food, pharmaceuticals, oil and grease, suspended particles, loose meat, disinfectants, and facility cleaners. This results in a high organic matter content and contaminates rivers and drainage systems. Municipal wastewater is not as strong as effluent from slaughterhouses. Such waste products raise phosphorus, nitrogen, sediments, and BOD levels in the receiving water body when dumped directly into it, which may cause eutrophication. All slaughterhouses regularly release enormous amounts of wastewater, an environmental problem.

Land contamination, which occurs due to slaughterhouse waste, is an aesthetic issue rather than one relating to pollution. The slaughterhouse wastewater mainly contains ruminal contents that are a rich source of fibre and could have an effect as a fertiliser and aeration of the internal layers of the land for better root growth and having a positive impact on the nodules of the nitrogenous crops. However, generally, on the negative side, rotten contents could irritate nearby passers. Other contents of the wastewater consist of blood, which will also harm the environment, but the richness of its nutrients may positively impact the irrigated land.

A minute quantity of wasted fat and protein-based trimmings could attract pests and birds in the facility, which could spread disease in the outskirts of the facility. Usually, it is observed that by-products are processed inside the vicinity of the slaughterhouse, in a separate location; this facility is managed with fewer safety measures than the meat processing facility, so resultantly, hazards, particularly biological ones, could slip into the meat processing facility. Slaughterhouses not following local and internationally implemented good hygiene practices because severe environmental and health damage due to discrete waste disposal, highly polluted effluent discharge, burning of bones and hooves, etc. Illegal slaughtering and practices pose a significant environmental risk in developing countries, where the implementation of laws and standards is weak compared to developed countries.

2.5.1 Slaughterhouse Wastewater

Slaughterhouse wastewater contains blood, animal body parts, fat, and animal dug. In a slaughterhouse, no toxic chemicals are used during the operations, but natural material can cause bacterial contamination. Slaughterhouse wastewater contains different compounds such as sulphates, nitrates, and phosphates. These compounds are in high concentrations of wastewater, contaminating the receiving water bodies and leading to environmental contamination (Mees et al. 2009). In developed countries, where water in and out quality is strictly monitored, water treatment plants are installed to minimise the BOD and COD of the disposed water. This water then becomes part of the nearby running canal or rivers, while generally, it is observed in developing countries that slaughterhouses are established near the municipal sewerage system to get rid of environmental obligations.

Such materials are present in slaughterhouse wastewater, which have oxygen demand, i.e. BOD and COD. When discharged to the receiving water bodies, such materials cause severe water quality damage. When discharged, these materials consume dissolved oxygen and cause oxygen deficiency in the streams, killing living organisms (Kundu et al. 2013). Nitrogen and phosphorus also go to the receiving bodies as nutrients and cause eutrophication, resulting in vegetation growth in excessive amounts. In 2019, slaughterhouses in the USA released 28 million pounds of nitrogen and phosphorus into nearby rivers and streams. Excessive vegetation blocks the path of slaughterhouse wastewater and causes overflooding in the path. If from the slaughterhouse, several pathogens are released into the streams, which can be transmitted to humans via water-ground leaching.

Pollutants present in the slaughterhouse can be leached into the underground water resources and cause alteration to the water quality. Humans consume this groundwater, causing several types of diseases like viral diseases in the community. Raw slaughterhouse wastewater is irrigated with polluted groundwater, causing soil pollution again. The presence of pollutants in organic nature can be known by several indications like odour, taste, and foaming. In a study, a soil profile of 4 m was analysed for nitrate concentration irrigated by the slaughterhouse wastewater, and the concentration was 3783 kg in high amounts (López and Borzacconi 2010).

Another vital aspect of slaughterhouses themselves is that they rely heavily on underground water for in-facility utilisation. It is observed that slaughterhouse waste also contaminates the underground water, and resultantly, obtained water is heavily contaminated with pathogenic microorganisms like E-coli. When this water is used for cleaning the facility, equipment, utensils and particularly meat, it will cause contamination and control measures like reverse osmosis plants to be installed. In meat processing facilities, where meat is mainly exported, this condition causes significant losses and sometimes bans the facility from exports.

2.5.1.1 Biodegradable Organic Compound

Activities at the slaughterhouse generate biodegradable material in large volumes, including blood, paunch contents, animal faeces, blood, and urine. Suppose the biodegradable material is not managed correctly and treated and becomes the primary source of water, soil, and air pollution. This organic material is characterised by high concentrations of carbohydrates, mainly in the form of lipids, lactose, and protein. Biodegradable organic material is considered energy rich. Slaughterhouse organic waste comprises long fatty acid chains, ammonia, and hydrogen sulphide (Limeneh et al. 2022).

2.5.1.2 Eutrophication

When released, the direct and indirect discharge of partially and untreated effluent causes eutrophication, a global problem. When the nutrients like phosphorus and nitrogen are in high concentrations and released into the waste bodies, plants and algae growth block the path of sunlight to the water body (Yaakob et al. 2018). The amount of dissolved oxygen in the water bodies consumed by the plants for their excessive growth and, finally, water bodies become water deficient. This process decreases the water quality, and living organisms die, like fishes. Eutrophication causes severe damage to environmental health because water uses become limited and causes outbreaks of diseases when used by living organisms (Sieng 2019).

2.5.1.3 Toxic Compounds

Slaughterhouse wastewater may contain toxic compounds like unionised ammonia, decontaminants, cleaners, disinfectants, surfactants, and steriliser agents, which are highly toxic to aquatic life. Due to improper slaughterhouse wastewater treatment, these surfactants, a component of detergents, can cause short- and long-term effects on the environment, resulting in increased environmental challenges (Yarandi et al. 2021).

2.5.2 Solid Waste

Annually, slaughterhouses produce thousands of tons of solid waste. Slaughterhouse waste generally contains unutilised animal by-products, which need to be accounted. With the growing population in urban areas, the demand for meat is also increasing and putting pressure on slaughterhouses. More solid waste will be generated when more animals are slaughtered, which will be one of the significant problems of handling and dumping. It is estimated that one-third or one-half of the total weight of the slaughtered animal is considered unusable and dumped as solid waste. When the solid waste does not dump with management, this will cause challenges to environmental components, such as degrade the soil, air, and water (Loganath and Senophiyah-Mary 2020).

2.5.2.1 Waste Open Disposal and Landfilling

Solid waste disposal in the open environment is defined as open dumping. When the waste is dumped openly on the empty without following proper waste disposal guidelines, it causes harmful effects on the environment and its components. On the other side, landfilling is the disposal of waste by following the disposal rules, but if proper landfill design is not followed may have a profound effect on the environment

(Omole and Ogbiye 2013). In developing countries, slaughterhouse solid waste is dumped openly in empty spaces. On such dumping sites, organic material degradation contaminates the space, further leaching down and affecting the environment. In the landfills, slaughterhouse waste is dumped properly to generate energy from the organic waste. If dumping guidelines are not followed, flies and insects become a pathway of disease transmission to nearby areas, and viral diseases become common. From the open dumping, nutrients and contaminants with rainfall runoff to the nearby water bodies cause severe environmental conditions such as eutrophication, killing fish, and degrading water quality. Improper slaughterhouse waste disposal when takes place causes the release of greenhouse gases which are responsible for global warming (Selormey et al. 2021).

2.5.3 Air Pollution

Besides, the soil and water pollutions from slaughterhouses also cause air pollution. Greenhouse gases like carbon dioxide and methane are released in high concentrations. These gases are a contributor to climate change. These gases are produced during the degradation of slaughterhouse wastewater and in the slaughtering process. Improper disposal and burning of slaughterhouse waste generate contaminants, affecting the ambient air quality (Mozhiarasi and Natarajan 2022). Slaughterhouse waste contains high concentrations of nitrate, phosphorus, and sulphides, which are released into the air when the waste is burnt out, causing air pollution. When the slaughterhouse works in residential areas, these greenhouse gas emissions create health issues for nearby residents and damage the local air quality. From the disposal of slaughterhouse waste, foul odour is also released, affecting the air quality.

2.5.3.1 Pollution of the Slaughterhouse Environment

The slaughterhouse generates such waste, which generates such odour, which can be a source of local air pollution and disturb the daily tasks in life. Several odorous compounds are stubborn, like mercaptans, organic acids, sulphates, amines, etc. These compounds can attach to clothes, persist for longer, and cause issues (Sweeten 1980).

2.5.3.2 Impact of Solid Slaughterhouse Waste Exposure on the Air Quality

When the slaughterhouse wastewater is disposed of improperly and burnt at the disposed site causes severe damage to the local air quality. Waste burning releases several noxious air pollutants such as carbon dioxide, sulphur dioxide, particulate matter, and nitrogen oxides. When released into the atmosphere, these pollutants affect human health and cause several diseases like cardiovascular diseases, colds, cancer, respiratory diseases, and allergies (Kundu et al. 2013). From the dumpsite, pollutants and pathogens can leach and contaminate the nearby surface and groundwater resources from which water is supplied, which further results in the risk to living beings. When the nutrients-enriched animal faeces and blood is released illegally into the environment cause accumulation of toxic compounds in the environmental components and becomes part of the life cycle of living beings.

2.6 Measures Proposed to Improve the Slaughterhouse Wastewater Management

Proper management of slaughterhouse solid waste and wastewater is vital because it contains a high amount of organic waste that needs to be managed as produced. Wastewater from the slaughterhouse is highly loaded with degradable materials that must be treated before being released to the receiving water bodies. Different wastewater treatment techniques must be applied to meet the National wastewater discharge limits and make wastewater reusable (Bustillo-Lecompte et al. 2016). Different treatment technologies like the coagulation/flocculation process are highly used for the abattoir's wastewater treatment. Abattoir wastewater mainly contains a substantial quantity of solids that can settle down. Settling wastewater has an extended effect on COD and suspended solids reduction, which is helpful for the coagulation and flocculation process. When the wastewater is settled down for 30 min, the 75–79% suspended solids are reduced. The suspended solids settling is further reduced when the settling time exceeds 30 min. On the other side, COD removal in the first 30 min was thirty-two per cent, and when the settling time increased to one hour, COD removal per cent further increased to thirty-eight per cent. In the following treatment stage, biological settling is essential. Chemical treatment of abattoir wastewater is also reported in the literature. Aluminium and ferric salts are also used in the abattoir's wastewater chemical treatment. Different coagulants are used in the treatment (Baker et al. 2021).

The use of common coagulants does not completely flocculate the abattoirs wastewater. The development of alternative treatment methods like anaerobic digestion, media filtration, aerobic and anaerobic sequencing batch reactors, enhanced media, and biofilter systems could be beneficial. On the other side, the coagulation and flocculation methods are energy-saving, easy to operate, and cost-effective compared to other methods for abattoir wastewater. Due to the insufficient treatment facilities, wastewater from the abattoir is deposited on land and finally goes into the water channels, which further causes pollution. In many countries, pollution caused by meat production activities results from the failure of good hygiene practices and good manufacturing practices (Hilares et al. 2021).

To prevent this pollution, it is suggested to seal the gut of slaughtering an animal to avoid the leakage of organic contents. Abattoir wastewater effluent has complex nature, due to which this type of wastewater is harmful to the environment. For example, when the wastewater contains slaughtered animals, blood released into the water channel causes dissolved oxygen (DO) depletion. Due to the paunch manure's improper disposal in the receiving environment, this can exert oxygen, and due to this, large population of decomposers can breed, which can cause a pathogenic effect. Animal waste improper disposal can depletion of oxygen in receiving environment. This situation further causes the enrichment of nutrients in the receiving environment, and toxins in the biological system can accumulate (Musa and Idrus 2021).

The concentration of organic matter in the meat processing plant's effluent is high, and the remaining residues are solubilised, leading to pollution due to the pathogens and organic content in the abattoir's wastewater. Abattoir wastewater is also considered a bulk parameter because various pollutants are derived from the facility and the slaughtering of animals, which fluctuate in the meat industry. In treating the abattoir's wastewater, anaerobic treatment is the preferred biological treatment. On the other side, in the anaerobic treatment, post-treatment requires the discharge to comply with the discharge limits because organic matter stabilisation alone is not possible with the anaerobic treatment. The effluent of anaerobic treatment contains organic matter in solubilised form, which can be done using aerobic processes. So, in contrast with anaerobic processes, aerobic treatment is frequently used because aerobic processes operate at higher rates than conventional processes (Meiramkulova et al. 2020). In the aerobic treatment processes, the treatment time and oxygen demand are directly proportional to the wastewater quantity and pollutant load. Aerobic treatment is used for post-treatment of the effluent of anaerobic treatment but also the removal of nutrients.

The biological processes not only help to produce effluents from the highly organic contain wastewater that complies with local discharge limits, but on the other side, the biological processes like aerobic and anaerobic treatment processes have the potential for resource recovery from the abattoir wastewater with high-level treatment (Filali-Meknassi et al. 2004). Abattoir wastewater also contains bio-resistant, non-biodegradable, recalcitrant, etc. These substances in the abattoir can be removed or transformed using advanced oxidation processes (AOPs) and improve the biodegradability of wastewater. AOPs could be an alternative treatment for the abattoir's effluent and can be attached to biological processes to improve treatment. By combining the AOPs and biological processes, we can achieve an economical and easy operation method with several advantages. For resource recovery, we can use these processes in the abattoir's wastewater (Ng et al. 2022).

2.6.1 Preliminary Treatment

Preliminary treatment is the primary and first step in every wastewater treatment process. This treatment's main objective is to remove large particles and solids from the slaughterhouse wastewater. Effluent quality is improved by primary treatments, including traditional screens, sieves, fat separators, and settlers. In the slaughterhouse wastewater, solids of 10–30 mm diameter are retained on the mesh or sieve screen. In order to avoid clogging and fouling in the other treatment processes, rotary screeners are used to separate solids of a diameter of more than 0.5 mm. To compact and transport the separated solids from the screens, screw screen compactors are used, which further minimise the moisture content and volume of solids treated as solid waste. This process removes about a BOD of 30%. In preliminary treatment, several operations are included, like screening and sieves. Large solids of diameters 10–30 mm are separated while wastewater passes (Bustillo-Lecompte and Mehrvar 2015).

2.6.2 Physicochemical Treatment

After the preliminary treatment, it is recommended that the wastewater should be treated with primary and secondary treatment depending on the characteristics of the raw wastewater. To reduce the BOD, fat and total suspended solids in slaughterhouse wastewater (SWW) dissolved air flotation (DAF) are considered a typical method for primary treatment. The solids are separated from the liquid in the physiochemical treatment methods. Physicochemical methods which are mainly used are given below.

Membrane processes: For treating the abattoir industry wastewater, using membranes are an alternative method. To remove the organic matter, pathogens and macromolecules, several membranes can be used, which include reverse osmosis (RO), ultrafiltration (UF), nanofiltration (MF), and microfiltration (MF) (Almandoz et al. 2015). The removal efficiency of membrane processes is up to 90%. To achieve nutrient removal from wastewater, membrane technology must operate or combine with conventional processes. There are several disadvantages of using membranes in abattoir wastewater treatment: the blockage of membranes and the fouling of membranes. These disadvantages restrict the treatment efficiency (Fatima et al. 2021). Yordanov (2010) used ultrafiltration technology for the treatment of slaughterhouse wastewater. Results showed that ultrafiltration is an effective tool to remove fats and total suspended solids with higher removal efficiencies of 99 and 98%. COD and BOD removal efficiency by UF was 94 and 97%. Bohdziewicz and Sroka (2005) evaluated the performance of RO technology in the treatment of slaughterhouse wastewater. Before using RO, raw wastewater was pre-treated by using activated sludge. TN, TP, BOD, and COD removal efficiency was 90, 97.5, 50, and 85.8% using RO treatment.

2.6.2.1 Dissolved Air Flotation (DAF)

Dissolved air flotation (DAF) is considered a primary treatment in wastewater treatment processes. This DAF process includes introducing air at the pressure of 4–6 bar, which aids the liquid and solid separation. The supplied dissolved air escapes from the liquid in the form of bubbles. Bubbles attach to the targeted solids and make a sludge blanket on the surface containing grease and fat with some light solids. This surface blanket can be removed by scraping. Flocculants can be added to the DAF treatment method to denature the protein present in the slaughterhouse wastewater. Before using biological treatment processes, the DAF system was ideal for removing fatty objects and suspended solids. This process addition increases the BOD and COD removal efficiency to 75%. DAF system at a large scale can remove total phosphorus (TP), total nitrogen (TN), grease, and oil by 70%, 55%, 85%, and 70% (Dlangamandla et al. 2018). Combining dissolved air flotation with a membrane reactor (MBR) in slaughterhouse wastewater treatment seems promising to meet discharge limits. If reverse osmosis technology is used as a final step after the previous process, wastewater can be reused in the facility.

2.6.2.2 Coagulation-Flocculation and Sedimentation

In the coagulation process, particles in the form of the colloidal present in slaughterhouse wastewater are grouped to form large particles called flocs. Negatively charged particles that are resistant and stable are present in the abattoir wastewater. For this reason, coagulants are added, and positively charged ions destabilise these colloidal particles and flocs. Aluminium potassium sulphate is mainly used as a coagulant. The flocculation process makes the suspended colloidal particles into flocs after settling down. To increase the efficiency of treatment, coagulation and flocculation are both processes used (Mahtab et al. 2009). Ferric chloride, aluminium chlorohydrate, aluminium sulphate, and ferric sulphate are the coagulants used to treat wastewater. Using poly aluminium chloride as a coagulant, the removal efficiency of COD, TN, and TP was 75, 88.8, and 99%. When the inorganic coagulant is used, the volume of the sludge produced can be reduced by 41.6%. Amuda and Alade (2006) used the coagulation-flocculation technology to treat the slaughterhouse wastewater at the lab scale to remove COD, TSS, and TP. Different coagulants, like alum, ferric chloride, and ferric sulphate, were used. Results showed that the alum coagulant effectively removed the TSS and TP by 34 and 98%. Tariq et al. (2012) used coagulants to treat the slaughterhouse wastewater, i.e. lime and alum. When each coagulant was used in combination, the removal efficiency of COD was 85%, but sludge generation was low in these conditions.

2.6.2.3 Electrocoagulation

In the slaughterhouse wastewater treatment processes, electrocoagulation (EC) is considered cost-effective and advanced treatment. Electrocoagulation is considered effective technology for removing nutrients, organics, heavy metals, and even the removal of pathogens. An electric current is induced without adding any chemicals in the electrocoagulation process. Using different materials electrodes, the EC process generates M^{3+} ions, mainly Al^{3+} and Fe^{3+}. Different types of electrodes are used, like TiO_2, SnO_2, and Pt, which can be used in alkaline and acidic conditions with a high removal efficiency of TSS, BOD, COD, TN, and colour (Emerick et al. 2020). For removing COD from wastewater using electrocoagulation, Bayramoglu et al. (2006) used sacrificial electrodes of Fe and Al with a focus on the operating cost. Results showed that Fe sacrificial electrodes perform better and cost-effectively than the Al electrode. The operating cost of using the Fe electrode is also 50% less than the Al electrodes. Operating costs include sludge handling, electricity, maintenance, etc. Asselin et al. (2008) used the EC process to evaluate its economic cost for removing organic compounds from the slaughterhouse wastewater. In the EC process, Al sacrificial and mild steel electrodes were used for lab scale study. The study result showed that by using steel electrodes, the removal efficiency of BOD, COD, turbidity, TSS, and oil grease was 87, 84, 94, 93, and 99%.

2.6.3 Biological Treatment

To meet the local discharge limits, abattoir wastewater cannot be treated entirely with the primary and physicochemical processes. Biological/secondary treatment methods remove soluble organic compounds to eliminate this limitation. In the biological treatment methods, aerobic, and anaerobic methods include anaerobic digestors, anaerobic lagoons, anaerobic filters, baffled reactors, biological contactors, and sequencing batch reactors. The secondary treatment's primary focus is reducing BOD concentration in slaughterhouse wastewater by removing the remaining organic compounds that are not removed by primary treatment. Biological treatment is considered a secondary treatment, whereas aerobic and anaerobic digestion in combination or individually depends on the characteristics of slaughterhouse wastewater (Mittal 2006a, b). In biological treatment, using microorganisms, organics are removed with pathogens. By using the anaerobic and aerobic processes in the biological treatment, BOD removal efficiency is up to 90%. Biological treatment may include other processes in the combination, like trickling filters and aerobic, anaerobic, and facultative lagoons. Anaerobic treatment is considered ideal in all biological processes when the target is to treat highly contaminated wastewater. In the anaerobic treatment, organic compounds are degraded without oxygen with the help of different bacteria into CH_4 and CO_2. In the aerobic treatment, the organic material is degraded in the presence of oxygen. Aerobic treatment is mainly used after physiochemical treatment to decompose and remove nutrients (Musa and Idrus 2021).

2.6.4 Advanced Oxidation Processes

Advance oxidation processes are becoming alternatives to the complimentary and conventional treatment processes, either pre-treatment or post-treatment to the current biological processes. Compared to using chlorine as a disinfection chemical which can cause the formation of other by-products, AOPs are a cleaner option to inactivate microorganisms. Due to these benefits, AOPs are considered handy for pollution control, water reuse, and advanced degradation processes with better results than complementary processes. Ozonation, gamma radiation, and UV/H_2O_2 are among the AOPs widely used in slaughterhouse wastewater treatment. Wu and Doan (2005) used ozonation in the treatment of slaughterhouse wastewater, and the results showed that the disinfection of wastewater was achieved to 99% by using the ozonation process for 8 min, and the ozone dosage was 23 mg/min per litre. The removal of BOD and COD was low, with the removal efficiency of only 23.06 and 10.7%. The use of UV/H_2O_2 in slaughterhouse wastewater is considered effective in this process; the degradation and oxidation of the pollutants mainly depend on the hydroxyl radicals (*OH), which is a highly reactive species that are produced from the reaction between H_2O_2 and UV (Hamad et al. 2014). Compared with other treatment methods, UV/H_2O_2 is considered effective, with an optimal removal efficiency of up to 50%, but the operating cost is high. To lower the operating cost, it is recommended to use this method with biological processes (Besharati et al. 2020).

2.6.5 Treatment System Maximum Removal Efficiency

Every slaughterhouse wastewater treatment system has separate removal efficiency. The removal efficiency depends on decreased biological content, BOD, COD, and nutrients on the input and output concentration difference. Each treatment system has a minimum and maximum removal efficiency for every pollutant. Figure 2.1 shows the maximum removal efficiency of every treatment system.

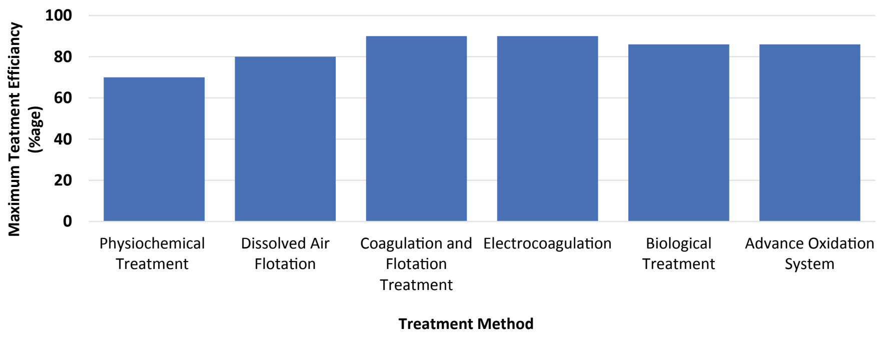


Fig. 2.1 Maximum treatment system efficiency (Mittal 2006a, b; Yordanov 2010)

2.7 Conclusion

Different types of waste are generated in solid and liquid form during the slaughtering process, which needs to be handled timely because the organic material starts degrading quickly and cause environmental pollution, such as the processing of fat which constitutes most of the slaughtering waste. Slaughtering facilities release a high volume of wastewater containing blood and organic content that also needs to be treated; otherwise causes severe environmental challenges. Different products can be produced by processing organic material, blood, and wastewater to increase revenue and solve environmental concerns. In the treatment of slaughterhouse wastewater, different techniques are used with a separate removal efficiency of pollutants like primary and secondary treatment methods, DAF, coagulation/flocculation, advanced oxidation processes, and electrocoagulation. These methods can effectively treat the slaughterhouse wastewater and release the treated water, which can be used as agricultural water or goes into canals/rivers. Solid waste from slaughtering facilities is processed by incineration, composting, rendering, and anaerobic digestion steps and valuable products like wood adhesive and biodiesel are produced, which also increase the return revenue. If we process the slaughtering waste in time, this can be a blessing for us as the source of revenue, but on the other side, if not processed and dumped openly without any treatment can be a curse to the environment and cause serious environmental and health issues and challenges. In developing countries, mostly slaughtering solid and liquid waste is dumped/released without any treatment and causes environmental degradation and health issues in the nearby community.

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