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Review

Handling and Treatment of Poultry Hatchery Waste: A Review

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Abstract: A literature review was undertaken to identify methods being used to handle and treat hatchery waste. Hatchery waste can be separated into solid waste and liquid waste by centrifuging or by using screens. Potential methods for treating hatchery waste on site include use of a furnace to heat the waste to produce steam to run a turbine generator or to use an in line composter to stabilise the waste. There is also potential to use anaerobic digestion at hatcheries to produce methane and fertilisers. Hatcheries disposing wastewater into lagoons could establish a series of ponds where algae, zooplankton and fish utilise the nutrients using integrated aquaculture which cleans the water making it more suitable for irrigation. The ideal system to establish in a hatchery would be to incorporate separation and handling equipment to separate waste into its various components for further treatment. This would save disposal costs, produce biogas to reduce power costs at plants and produce a range of value added products. However the scale of operations at many hatcheries is too small and development of treatment systems may not be viable.

Keywords: hatchery waste; poultry; infertile eggs; shell; dead embryos; wastewater; anaerobic digestion; integrated aquaculture

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1. Introduction

The poultry industry produces large amounts of hatchery waste which includes solid waste and wastewater. The solid hatchery waste comprises empty shells, infertile eggs, dead embryos, late hatchings and dead chickens and a viscous liquid from eggs and decaying tissue. The wastewater comes from water used to wash down incubators, hatchers and chick handling areas. The sustainability of the poultry industry including hatcheries is at risk. Seepage of effluent from livestock industries into the ground water or run off into streams and rivers is one of the causes of increasing concentration of nitrates and phosphates in drinking water. Agro-Industrial growth, a vital factor for economic improvement including employment generation depends on the sustained growth of the primary industries. Achieving the primary industry’s growth targets is likely to have significant impact on the landscape and regional communities and is heavily dependent on continued access to reasonable priced and high quality land and water.

Traditional disposal methods for solid hatchery waste include land fill, composting, rendering, and incineration [1]. Most of the hatchery waste is sent to land fill or composting, which costs the chicken meat industry millions of dollars each year in disposal costs [1]. Some of the hatchery waste is rendered. The methods for wastewater disposal include sending it to land fill, using it for irrigation, disposing it directly into the sewer or into a wastewater lagoon. Some hatcheries use a wastewater treatment system. Land fill hatchery waste will break down naturally and produce methane which escapes to the atmosphere. Capturing and using the methane to prevent its release to air is beneficial to environment since methane has 21 times more global warming capacity than CO_2 [2].

Hatchery waste is a high protein waste with 43–71% moisture [3,4]. Dried hatchery waste contains 33.1% crude protein (CP), 29.0% ether extract, 12.1% crude fibre, 21.5% ash and 28.8 MJ/kg of gross energy [5]. Apparent metabolisable energy (AME) of the hatchery waste by-product meal is 23.9 MJ/kg [6] and the apparent amino acid availability of the hatchery waste by-product meal is 73.5% [7]. Hatchery waste could be developed into high protein feedstuffs, other value added products or utilised as an organic fertiliser after appropriate treatment.

If large amounts of wastes from animal production are directly applied into the soil, it pollutes the environment, including the ground water [8,9]. In particular high protein waste leads to high nitrogen losses with 50% of total nitrogen lost in a few months [10]; resulting in enrichment of ground water, lakes or streams, pathogen distribution, production of phytotoxic substances, air pollution and greenhouse gas emissions. Bitzer and Sims [11] reported that over application of organic waste as fertiliser for cropping can result in nitrate (NO_3) contamination of groundwater. High levels of NO_3 in drinking water can result in the blue baby syndrome, cancer and respiratory illness in humans and foetal abortions in livestock [12,13].

Given the large volumes of hatchery waste that needs disposal a review was conducted to identify potential methods of handling and processing the hatchery waste.

2. Handling of Hatchery Waste

The majority of hatcheries use a vacuum extraction system to transfer the waste into bins. Some hatcheries store the waste in a cool room and then place the waste into a Bio-Bin. Other hatcheries will crush the waste first, then use a vacuum or auger system to transfer waste into the bin. In the USA, one disposal option is to transport the hatchery waste to a facility that separates the liquids from the solids by using a centrifuge [14]. The liquid is refrigerated and transported to a pet food manufacturing plant. The solids are sent to land fill.

2.1. Separation of Waste at the Hatchery

Hatchery waste can be separated into solid and liquid components and then treated separately. For example the liquid in hatchery waste can be separated from the solid hatchery waste by spinning [15]. In addition inclined screens, followed by the use of belt or filter presses can be used for separation of solid and liquid portions of the waste. These methods produce about 45% of solid materials [16]. In other industries a flexible multi-layer filter can be used to separate liquid wastes from sludge wastes. The principle of this process relies on liquid waste passing through the liner into the container by gravity [17].

Another system for separating liquid and solid waste is to use a conveyor with an upper and lower conveyor roller and an endless conveyor belt extending around the conveyor rollers. A waste deflector extends above and along the lowest portion of the upper run. Liquid and solid wastes are separated and placed in collectors which are located near the upper and lower rollers [18]. The separator can be set up for different solid separating rates (Table 1).

Table 1. Total solids capture efficiency for the different solid/liquid separators [19].

Solid/Liquid Separators	**Total solids capture efficiency**
Static Inclined Screen	10–20%
Inclined Screen with Drag Chain	10–30%
Vibratory Screen	15–30%
Rotating Screen	20–40%
Centrifuge	20–45%
Screw or Roller Press	30–50%
Settling Basin	40–65%
Weeping Wall	50–85%
Dry Scrape	50–90%
Geotextile Container	50–98%

2.1.1. Separating egg shells from hatchery waste

A powerful suction vacuum is used to only remove the dry, very light shells from the hatchery waste, leaving the heavier infertile eggs (World Intellectual Property Organization-WO/2001/074491, Eggshell waste processing method and device). The shell and non-shell materials can also be separated by using a vibrating or shaking device (e.g., a shaker-sieve belt), which can separate lighter parts from heavier parts in the hatchery waste. A stream of gas (such as a cyclone forced-air separator) also can be used to separate lighter materials from heavier materials in hatchery waste. After hatching, live chicks and unhatched chicks or clear eggs from the hatching tray are placed on a moving belt with fixed gaps that only allow chicks to slide through, while shells and unhatched eggs are retained on the belt. Then the shell is vacuumed up for further separation, with the dead embryos being disposed into a separate container (World Intellectual Property Organization-WO/2001/074491, Eggshell waste processing method and device).

2.1.2. Methods to recycle egg shells

Eggs shells can be composted with other organic materials to increase the mineral content of the compost. Other minor uses for crushed egg shells include; 1) spread around plants to deter slugs and snails, 2) mixed with garden soil for use as a fertiliser; 3) fine pieces of crushed egg shell mixed with seeds for use as a feed for aviary birds; 4) added to cement to increase its strength; 5) used by artists to make mosaics and; 6) to make textured paint for 3D effects in artwork. These are small niche uses and not suited to industrial volumes of egg shells [20,21].

Complete separation of the membrane and the shell increases the value of the resulting products. One method is to use a meat processing machine to grind egg shells into a powder, and then mix the powder with water to separate the membrane. The shell sinks and the membrane stays suspended in the water. Another method is to place the egg shells into a tank containing a fluid mixture and use cavitation (vapour bubbles in a flowing liquid) in the fluid mixture to separate the shell membrane. The fluid mixture is ideally recirculated to continue the separation process [22]. Egg shell membrane contains about 10% collagen, which can be used in medicine. The market price for purified collagen is US$1000 per gram. Collagen glue is used as a filling in corneal wounds. It can be also used for skin grafts, dental implants, angioplasty sleeves, plastic surgery and treatment of osteoporosis and in pharmaceuticals as well as food casings and film emulsions. The pure shell powder can be used in the paper industry, or as a lime substitute [23] or calcium supplement in agriculture [24].

Other uses of egg shell membrane include:

- Use as a component of biodegradable plastic.
- Alter food-borne bacterial pathogen heat resistance with an egg shell membrane bacteriolytic enzyme.
- Adsorbent for the removal of reactive dyes from coloured waste effluents.
- Eliminate heavy metal ions from a dilute waste solution [24].

2.2. Storage of Waste on Site; Bio-Bins and Skip Bins

Most of the hatchery waste is stored in dump bins before disposal to land fill or to composting sites. Some hatcheries use Bio-bins for waste storage. This is a container which enables initial composting of the hatchery waste (Biobin Technologies Pty Ltd.). Hatchery waste is placed into the Bio-biN, it is closed and made air tight and air is pumped through the bin to start the composting whilst removing odours and bacteria. The bins are also used in the chicken meat industry to compost dead birds. The composted material is used as a soil conditioner. The contents of Bio-bin are then taken to the waste sites for completion of the composting cycle. It can also be used temporarily for hygienic storage of hatchery waste. Bio-bins have the following advantages:

- The collection system satisfies biosecurity requirements.
- Odours are removed or significantly reduced.
- No fly and rodent contamination.

2.3. Solid Waste Treatments Systems

2.3.1. Power generation

The hatchery waste can be automatically fed by conveyor belts into a furnace which is equipped with a rotating shredder unit for chopping and grinding solid waste. An incinerator system can be used as a furnace to heat the solid and liquid waste to produce steam. The steam can power a turbine generator to produce electricity [25]. The use of a steam turbine at a hatchery may only be economic if the hatchery is producing a large volume of waste.

2.3.2. Rendering

The rendering process simultaneously dries the material and separates the fat from the protein [26] and yields fat and a protein meal (e.g., hatchery waste by-product meal) similar to meat and bone meal or fertiliser [27]. There is shortage of protein meals world wide for use in diets particularly in the pig and poultry industries. The decision to render hatchery waste depends on whether it is cheaper to transport the waste to a rendering facility or to send to landfill. A major issue when using by-products such as hatchery waste meal in diets is whether they are pathogen free.

2.3.3. Outoclaved and extruded

Extruded or autoclaved hatchery waste could be used as livestock feed. Said [28] reported that dry extrusion was an effective method to treat hatchery waste. For example Miller [29] extruded a mixture of ground hatchery waste and yellow maize meal (25:75) at 140 °C for 10 s, while Lilburn *et al*. [30] autoclaved turkey hatchery waste for 15 min at 125 °C and 1.76 kg/cm^2 and then dried it at 50 °C for 1 hour. Similarly Verma and Rao [31] autoclaved hatchery waste (infertile eggs or eggs with dead embryos) and dried it at 100 °C for 10 h. Ravindra-Reddy and Rajasekhar-Reddy [32] autoclaved day old cull male chicks for 30 min. The product was dried and powdered and used as poultry feed.

2.3.4. Boiling

Hatchery waste could be treated in the same way as poultry waste (feathers, heads, feet and inedible entrails (intestine, lung, spleen) by boiling at 100 °C with a pressure of 2.2 kg/cm^2 for 15 min; then boiled again at 100 °C for 5 hours, followed by boiling at 130 °C for 1 h then cooled to ambient temperature [33]. Likewise dead embryos could be boiled for 100 °C for 30 min, soaked in cold water for 20 min to remove shells, sun dried for 4d and used in poultry feed [34]. Cooking hatchery waste with water (2:1) then dehydrating to a dried product has been used as livestock feed [35-37]. Nutritive value of the dried dead embryos is 36% CP, 27% ether extract, 17% ash, 10% calcium and 0.6% phosphorus [38].

2.3.5. Ensiling

Kompiang [39] reported a method of ensiling rejected hatchery eggs. The eggs were mixed in a 1:1 ratio with formic and propionic acids for 8 weeks at room temperature. Formic acid is suitable for the ensiling of materials such as wet and protein-rich resources. Propionic acid and formic acid have been used to preserve and ensile non fertile eggs and dead embryos. The acids act by intervening specifically in the metabolism of the microorganisms involved in spoilage. In addition, the reduction in the pH creates an environment which is unfavourable for microorganisms. The rapid reduction in the pH diminishes the growth of bacteria which produce butyric acid and ammonia and promotes the growth of lactic acid-producing bacteria. The lactic acid is responsible for the low pH necessary for storage of the by-product before being used in animal feed.

2.3.6. Enzyme or sodium hydroxide treatments

Kim and Patterson [40] treated culled birds for 12 h at 21 °C with 25.6 mg of INSTAPRO enzyme or 2 h at 21 °C in 0.4 N NaOH. The resulting product was fermented (with added sugar) for 21 days. After fermentation the products were autoclaved at 124 kPa and 127 °C for 90 min, then dried in a forced-air oven at 60 °C and the final product was used as poultry feed [40]. The advantage of the enzyme or NaOH treatment is that nutrients in poultry meal are more readily digestible by birds and improve the availability of essential amino acids in the treated meal.

2.3.7. Composting

Composting is a common method for solid organic waste disposal [41,42]. In this process, mesophilic and thermophilic micro-organisms convert biodegradable organic waste into a value added product [41,43,44]. The decomposition of organic waste is performed by aerobic bacteria, yeasts and fungi. The composting process kills pathogens, converts ammonia nitrogen to organic nitrogen and reduces the waste volume [41]. The product can be used as a fertiliser. Disadvantages of composting are loss of some nutrients including nitrogen, the land area required for the composting and odour problems. Das *et al*. [1] reported that composting hatchery waste with sawdust and yard trimming in a ratio of 3:2:1 or composting it with sawdust, yard trimmings and poultry litter in a ratio of 2:1:1:2 eliminated 99.99% of *E. coli*. Composting with litter also eliminated *Salmonella*, but *Salmonella* was present if temperature was too low.

When hatchery waste is composted with poultry litter it will produce a safe and rich organic product which is a good organic fertiliser. It is important to control the moisture content and keep raising the temperature of the compost to eliminate the pathogens. Composting hatchery waste with poultry litter produces a product that contains 1% nitrogen, 2.5% phosphorus and 0.25% potassium on a dry weight basis. The product also contains high calcium and other micro-nutrients [45].

A potential method for treating hatchery waste on a hatchery site is to use an ‘in-vessel’ composting technique to decompose and stabilize the un-separated hatchery waste obtained directly from the hatchery. The hatchery waste can be mixed with wood shavings to reduce the moisture then composted [14]. There are a number of ‘in vessel’ composters on the market that could be used for stabilising hatchery waste. The composter turns manure, litter, sour feed stuffs and carcasses into compost in 4 days with minimal labour and mechanical devices [46].

DiCOM®

AnaeCo Ltd. has invented a composting process called DiCOM® which is a novel method for treating the organic part of municipal solid waste. It combines aerobic composting and anaerobic digestion of solid wastes in a single closed vessel. The end products are biogas and a stabilised compost material that can be used in agricultural applications. A commercial-scale demonstration plant was established in early 2007 to treat 20,000 tonnes of municipal solid waste per year. This will lead to the development of a fully commercial plant with an annual processing capacity up to 60,000 tonnes of waste [47].

2.3.8. Anaerobic digestion systems

While anaerobic digestion has not been used to treat hatchery waste it is the most popular process used to treat human effluent and other livestock waste. It has the advantage of being a high efficiency process and produces biogas [48] for power generation or heating. The Poultry Industry has overlooked using anaerobic digestion as a means of treating hatchery waste. It is by far the most popular process used to treat organic wastes in a number of other organic waste industries. The biosolids remaining after the digester process can be sold as a high quality fertiliser. Kumar [49] demonstrated the use of a two stage anaerobic process for effluent from piggeries and abattoirs will produce methane and the nutrients can be also recovered from the waste to grow algae, zooplankton and fish. The treatment system has clear advantages in cost and environmental benefit due to recycling of waste. The benefits also include income from the sale of electricity generated through biogas and fertiliser to produce bioproducts such as algae, zooplankton and fish as livestock feed. Anaerobic digestion involves the degradation and stabilisation of an organic waste under anaerobic conditions by microbial organisms to produce methane and inorganic products [13] as described in the equation below.

$$\text{Organic matter} + \text{water (anaerobes)} \rightarrow CH_4 + CO_2 + \text{new biomass} + NH_3 + H_2S + \text{heat}$$

This process is commonly used to treat wastewater sludge and organic wastes as it reduces the waste volume, produces valuable products and reduces the emission of methane and CO_2 from land fill sites. The end product of digestion is the nutrient-rich solid which can be used as a fertilizer [50].

There are two basic types of anaerobic digesters;

(1) *Batch*: Batch digesters are the simplest. The process involves loading the waste into the digester and starting the digestion process. The retention time depends on temperature, pH and other factors. Once the digestion is complete, the residue is removed and another batch started.

(2) *Continuous*: Continuous digesters involve regular feeding of waste into the digester to continuously produce biogas. This type of the digester is suitable for large-scale operations.

The following examples involve treatment of organic waste which may be adaptable to hatchery wastewater with various levels of solids;

(1) *Covered lagoons*: The organic waste is covered by a pontoon or other floating cover. This digester is suited for manure waste with 2% or less solid content and requires high throughput to

provide enough solids for the bacteria to produce gas. It is better for warmer regions, where digester temperatures can be easily maintained.

(2) *Complete mix*: The organic waste is added into a silo shaped tank, then heated and mixed for anaerobic digestion. It is suited for organic waste with 2–10% of solids.

(3) *Plug flow*: This method comprises a cylindrical tank in which the end products are released from one end while fresh organic waste is fed in from the other end. Hot-water is piped through the tank to maintain the digester temperature. It is suited for organic wastes with 11–13% solids.

(4) *Fixed film*: A tank is filled with a plastic medium that supports a biofilm. It is suited for 1–2% solids in an organic waste and a short retention time (2–6 days) [51].

(5) *Plug-flow type polybag digesters (polydigesters)*: These are prototype digesters developed for organic waste treatment systems [49] and operate on the same principle as a continuous flow digester.

Since the 1970s, underground anaerobic digesters at various scales of operation to process rural organic wastes have been used in China. In these systems, a cylinder shaped reactor made from concrete and brick with a cement lid are used. Waste is manually fed into the reactor through a port connected to the base of the reactor The heavy lid prevents gas leaks [52] and pressurises the methane produced enabling it be piped to various areas for domestic or commercial use.

2.3.9. Anaerobic co-digestion

This is a process where various organic wastes are mixed for co-digestion. The advantage of co-composting and co-digestion is it achieves a better balance of nutrients and can improve the treatment efficiency [53], particularly for pig and poultry waste at land fill sites. The effect of using various ratios of pig and poultry waste on gas production was studied by Magbanua *et al*. [54]. The waste was incubated at 35 ± 2 °C for up to 113 d. This process produced high levels of biogas [54]. In another trial best results for methane production were achieved when 3 wastes were used; cattle and poultry waste and cheese whey (w/w on dry weight basis). The digesters initially operated at 40 °C with a 10 day retention time [55]. Clearly hatchery waste has the potential to be included as a material for co-digestion.

2.3.10. Two stage anaerobic digestion

Song *et al.* [56] used two stage anaerobic digestion of sewage sludge. While there is an additional energy requirement required to operate a two stage digester, the advantages of the system is the higher reduction of volatile solids, and increased methane production compared to single stage mesophilic or thermophilic digesters. Likewise the pathogen reduction was similar in the two stage system. More recently Dareioti [57], Sakar *et al.* [58]; Kara *et al.* [59]; Parawira *et al.* [60]; Nishio and Nakashimada [61]; Perez-Elvira *et al.* [62]; Alatriste-Mondragon *et al.* [63] and Ke ShuiZhou *et al.* [64] have reported on the role of and variations to approaches in two stage anaerobic digestion in treating a range of organic wastes. Kumar [49] used two stage anaerobic digestion on piggery effluent. The first stage involved the hydrolytic and acidogenic process and the second stage involved the methanogenic process. The two-stage anaerobic digestion system was configured such that the thermophilic acidification reactors operated with 7 days of hydraulic retention time at 55–70 °C while the mesophilic digesters operated with 22 days of hydraulic retention at ambient temperature. There was a low degree of acidification in the first stage due to the low organic content of the raw piggery effluent which allowed the methanogens to establish and generate methane (>40% methane composition). This was not the desired function of the first-stage reactors, as the majority of methane needs to be generated in the second-stage (methanogenic). Increasing the organic load of the raw piggery effluent was found to be necessary to produce a higher level of volatile fatty acids in the first stage or by adjusting the pH of the effluent by addition of acids.

Kumar [49] reported that increasing digestion temperature from 55–70 °C reduced pathogen survival in an exponential pattern with concomitant die-off at longer hydraulic retention time. The pathogens, *Clostridium perfringens* and *Campylobacter jejuni*, survived thermophilic digestion at 50 °C. At the lower thermophilic temperatures, larger numbers of *Clostridium perfringens* were found in the mesophilic stage. Other strategies to reduce pathogen survival include aeration, free ammonia, biological control (*Tetrahymena spp.*) and peractic acid. Free ammonia levels reduced the survival of these pathogens, but it is not clear if the solubilisation would also be reduced if free ammonia levels were manipulated artificially. Peracetic acid, as a strong oxidising agent, effectively reduced the number of these pathogens at very low concentrations.

2.4. Wastewater Treatment Systems

2.4.1. Anaerobic digestion

Digesters can be used for any biodegradable waste. However, for biogas production high organic levels in the sludge are required to produce high gas yields from the system. The composition of the waste is a major factor influencing methane production. More gas is produced if the material has high moisture content, a large volume and surface area. The optimal C:N ratio for a microbe is 20–30:1 [65]. The waste contamination level is a key factor affecting anaerobic digestion. If waste has significant levels of physical contaminants such as plastic, glass or metals then pre-treatment will be required. The digesters will not function efficiently if these contaminants are not removed. Often the waste is shredded, minced and mechanically or hydraulically pulped to increase the surface area that is available to microbes in the digesters and increase the speed of digestion. Reactors/digesters should be designed according to the waste characteristics to achieve effective digestion results. Some of the reactors include;

(1) *Reactor with membrane filtration*: Membrane filtration improves the stability of the digestion process and reduces hydraulic retention time for wastewater treatment. It also retains all micro-organisms to improve the efficiency of the process [66,67].

(2) *The membrane bioreactor*: This reactor is suited for the treatment of wastewater which contains slowly degradable solids. The bioreactor uses a ceramic cross-flow membrane [68].

(3) *The upflow anaerobic sludge blanket* (*UASB*) *reactor*: UASB is an effective method to treat wastewater from different industries [69-72]. This method is used for treating wastewater in whisky distilleries, coffee processing wastewater, slaughterhouse wastewater and dairy wastewater. The UASB reactor is a compact system for removing and digesting sewage organic waste. Full scale UASB reactors are operated in India, Colombia and Brazil [73-75]. These UASB reactors are operated at hydraulic retention times of 5–19 h. The efficiencies of removal of total chemical oxygen demand

(CODtot), biochemical oxygen demand (BOD) and total suspended solids (TSS) are 51–74%, 53–80%, and 46–80% respectively [73,76,77]. The reactors could be operated at temperatures from 18–32 °C and organic loading rates (OLR) (0.9–3.55 kg COD/m^3/d) [78]. Gao *et al*. [79] reported that OLR could be 10–25 kg COD/m^3/d. In the UASB reactor system, the up-flow mode of operation removes suspended solids effectively by gravity settling and by entrapment mechanism. During the process, the anaerobic micro-organisms agglomerate to form biogranules. As the liquid passes through this system, the soluble solids will be biologically oxidated and produce biogas. The biological conversion of the organic matter in the UASB reactor is processed through three steps (hydrolysis, acidogenesis and methanogenesis). The function of the UASB reactor depends on the physical characteristics and biological processes in the sludge [80].

Sabry [81] concluded that UASB reactor could treat any type of liquid organic waste sludge. It is envisaged that the liquid portion of the hatchery waste could be used as a waste stream in these reactors. The suitability of the UASB process for the pre-treatment of a liquid part of hen manure has been reported. The OLR is 11–12 g COD/L/day and HRT is 1–2 days with an efficiency of 70–75% on the basis of total COD reduction [82].

Anaerobic sequencing batch reactor (*ASBR*): ASBR is used for wastewater treatment and has high efficiency for both COD removal and gas production and has flexible control. This new technology is used to treat slaughterhouse wastewater, municipal sludge [83], dairy wastewater [84] and brewery industry wastewater [85].

A sequencing batch reactor enables the same reactor to treat solids with a longer retention time while the liquid portion has a shorter retention time [86,87]. The advantage of ASBR is that it treats more substrate per unit time compared to conventional reactors. The high nutrient/microorganism ratio initially allows high substrate degradation rates and more biogas production [86-88]. These characteristics make the ASBR technology particularly suited for the treatment and recovery of biogas from high water content animal waste that would require extremely large volume digesters [87-90].

Buoyant Filter Bioreactor (BFBR): The BFBR reactor has been developed for treating wastewater with high lipid content. The reactor utilises a granular filter bed made of buoyant polystyrene beads. There is no filter clogging in this system due to an automatic backwash driven by biogas release, which fluidizes the granular filter bed in a downward direction. During filter backwash, the solids caught in the filter are reintroduced into the reaction zone and mixed again with the components. This process has no influence on the hydraulic retention time in the reactor.

The anaerobic film expanded bed (AFEB) process: The AFEB process includes inert, sand-sized particles which expand as a result of the upward direction of recycle flow. The inert particles provide a large surface (as the particles are small) for the growth of micro-organisms. The AFEB process is a completely-mixed system and provides excellent contact between micro-organisms and substrate. The micro-organism can be kept for a long period in this system [91].

Electro coagulation (EC): Treatment of poultry slaughterhouse wastewater by EC was studied by Kobya *et al.* [92]. Aluminium electrodes could remove 93% of the COD and iron electrodes could remove 98% of oil-grease materials. Combination of both electrode materials in the EC unit may achieve high process performances in terms of COD and oil-grease removal [92].

Biofilters: Biofilters can be used to convert ammonia nitrogen into nitrate nitrogen, which is a nutrient for algae [93]. Drum, disk, bead and sand filters are commonly used to capture and remove particles as small as 60 microns from the water [93].

Leachbed (LB)-up-flow anaerobic sludge blanket (UASB) to treat dead chickens: In this system, one UASB (35 or 55 °C) plus 3 LB reactors were used. A closed-loop pair consisting of a LB and an UASB reactor treated dead chickens in 118 days. This system had better efficiency at 35 °C than 55 °C [94].

2.4.2. Integrated aquaculture method

If the wastewater contains high organic materials with high nutrients such as abattoir or hatchery wastewater, pre-treatment is required before discharge to the ponds. Cavitated Air Flotation system can reduce content of fat, oil and grease and suspended solids through polymeric chemical coagulation and flocculation.

Growing algae in wastewater ponds such as abattoir or hatchery wastewater could be an option if lagoons are used at hatcheries to dispose wastewater. The wastewater is managed through a series of ponds to produce algae, zooplankton, ornamental fish and cleaner water that is suitable for irrigation. (*Note that the ornamental fish industry is a mutli-billion dollar industry worldwide with high demand for various fish species*). However, good management and design of ponds are required to optimise ornamental fish production. Fresh water molluscs are potential species to introduce into the ponds to filter the waste water and improve algal and zooplankton growth. The zooplankton and micro-algae are grazed by the fish. Management of nutrients in ponds (particularly P levels) is critical if pond production is to be optimised [49].

2.5. Design of an Anaerobic Digestion System

In many countries there has been a strong interest in the development of anaerobic digestion systems technologies to utilise renewable sources of energy. In particular biogas has been considered a very useful source of energy that could be produced from hatchery waste. Anaerobic digestion of waste by bacterial populations can be used to produce methane. Methane generating systems can provide a range of benefits which include production of energy, high quality fertilizer as wells as reducing pathogen loads.

Cost, size, local climate and type of organic waste material should be considered when designing an anaerobic digestion system. The digesters can be made from concrete, steel, brick, or plastic. They can be shaped like silos, troughs, basins or ponds, and may be placed underground or on the surface. The anaerobic digestion system includes a pre-mixing area or tank, a digester vessel, a system for storing the biogas and a system for distributing the solid residue.

2.6. Micro-Organisms Used in Digestion

Bacteria involved in an anaerobic digestion include acetic acid-forming bacteria (acetogens) and methane-forming bacteria (methanogens). Different species of bacteria survive at different temperatures. Optimal temperatures for mesophilic bacteria are 35–40 ℃, while thermophilic bacteria can survive at temperatures between 55–60 °C. There are more species of mesophiles than thermophiles. These bacteria are more tolerant to environmental changes than thermophiles. Mesophilic systems are more stable than thermophilic digestion systems (http://en.wikipedia.org/wiki/Anaerobic_digestion).

Anaerobic digestion kills pathogens such as *E. coli* and *S. Aureus.* Likewise *P. multocida* and *S. enteritidis* serovars *typhimurium* and *anatum are killed* within 48 h at 20–30 °C, while *Salmonella choleraesuis is* eliminated after 72 h of digestion [95]. Russell *et al*. [96] fermented ground broiler offal with 6% sucrose, commercial silage culture and lactic acid bacteria (106 cfu/g offal) for 120 h at 37 °C and found that *Salmonella* levels decreased from 3.7 to <1.5 log cfu/g. Deshmukh and Patterson [97] reported that the product resulting from the digestion of culled day-old chicks and shells did not contain any *E. coli* or *Salmonella* after 21 d.

High concentrations of active micro-organisms can be used to treat industry waste. There are two ways to achieve high concentrations of micro-organisms in the process. Using a stirred reactor assists micro-organisms to maintain close contact with the waste to improve efficiency of hydrolytic activity. A settler is used in the reactor to recycle the micro-organisms into the reactor. At the methanogenic reactor phase, immobilization is used to achieve a high density of organisms [98]. During this process, temperature plays an important role [99]. Bacteria (*Bacillus subtilis*) can effectively remove soluble organic matter and total ammonia nitrogen from wastewater [100]. *Methanosarcina* spp. is the main aceticlastic methanogen in unstable co-digesters with high levels of acetate, while *Methanosaeta concilii* is the main organism in stable digestion systems. *Syntrophobacter wolinii* growth can be improved during stabilization of a co-digester with a well-developed population of *Methanobacteriaceae*, as sufficient levels of these methanogens increases the syntrophic oxidation of propionate [101].

2.7. Factors Affecting Anaerobic Digestion

Temperature, pH and loading rates play important roles on efficient breakdown of the waste materials. Disturbing a digester can lead to failure. Maintaining the quality of waste to the digesters and monitoring the process effectively are very important to ensure good performance of the digester.

2.7.1. Temperature

Temperature plays an important role in bacterial digestion. The optimal function temperature for mesophilic bacteria are 32.2–43.3 °C and 48.9–60 °C for thermophilic bacteria. Thermophilic digestion eliminates more pathogenic bacteria but requires higher energy costs to achieve the higher temperatures required and may be less stable. Digestion slows down or stops completely when the temperature is below 15.6 °C. Maximum conversion occurs at about 35 °C in conventional mesophilic digesters. The amount of methane produced decreases with decreasing temperature [52,102]. Maintaining stable temperatures in the reactor is very important. Fluctuation of temperature inside the digester can cause system failure [52].

2.7.2. Nutrients

Digestion will proceed well with a C:N ratio between 15:1 and 30:1 (optimum is 20:1). If the system is over loaded with organic waste, adding low nitrogen content and high carbon materials such as crop residues or leaves can improve digestion performance [52]. High protein waste will produce high levels of ammonia nitrogen during anaerobic digestion and result in an unstable digestion process, reduce biogas production and produce ammonium toxicity [103-106]. Lipids in the waste could form floating materials and accumulate long-chain fatty acids in anaerobic digestion [27,107,108].

Trace nutrients are known to influence reactor performance. Whey powder supplemented with nitrogen and phosphorus was found to be limited by either Ni, Fe or Co, or a combination of those elements. After the addition of these elements to a reactor, COD removal efficiencies increased and the level of volatile organic acids decreased [91]. The effects of ionic chromium, cadmium, lead, copper, zinc, and nickel on the methanogenic UASB have been examined [109]. The effects noted for metals depend on types of metal, zones of sludge, types of VFA and HRT. The relative toxicity of the metals to total VFA degradation was Cu>Cr>Cd=Zn>Ni>Pb for both bed and blanket sludges. However, different levels of toxicity were found for individual VFAs and sludges. For the degradation of total VFA, the copper toxicity resistance of blanket sludge was lower than that of the bed sludge [109].

2.7.3. Loading rate

A uniform loading of manure with 6–10% solids on a daily basis generally works well with the load’s retention time in the digester ranging from 15–30 days [52]. An issue with digesters is that blockages can be caused by using waste resources that have a variable solid content. In the case of hatchery waste the content of solids can be variable depending on whether most of the waste comprises mainly non fertile eggs that are removed from the incubators during incubation or if the waste is made up mainly of dead embryos after hatch.

2.7.4. Mixing

The effluent in the digester needs to be mixed regularly to prevent settling and to maintain contact between the bacteria and the manure. The mixing action also prevents the formation of scum and facilitates release of the biogas [52]. In the case of livestock effluent it sometimes contains fibrous materials which can cause blockage in digesters.

2.7.5. Management

Regular monitoring, maintain a constant required temperature of the digester is important if the system is to run smoothly. Failure to properly manage the digester can result in poor gas production and some systems take months to get back into operation if there is a breakdown [52]. Quality control needs to be implanted to manage the waste resources being utlised in the digester as well the biogas and other products being produced. Records need to be maintained on biogas and other products produced and the effluent that has been fed into the system [52].

2.7.6. Safety

Biogas is primarily composed of methane and carbon dioxide, with traces of ammonia and hydrogen sulphide. Caution should be taken as methane is highly explosive when mixed with air. In addition, because digester gas is heavier than air, it displaces oxygen near the ground, and if hydrogen sulfide is still present, the gas can act as a deadly poison. It is critical that digester systems be designed with adequate venting to avoid these dangerous situations. Exposure to any of these gases may result in ill-health or death, and levels in the biogas may vary widely and cyclically. Carbon dioxide, ammonia and hydrogen sulphide are all toxic gases, and are subject to the regulations as substances hazardous to health [52].

2.7.7. Gas storage

Because biogas is not used at exactly the same rate at which it is produced, it must be stored somewhere. The gas must be efficiently transported from digester to storage tank. Because of the high pressure and low temperature required, it is impractical to liquefy methane for use as a liquid fuel. Instead, the gas can be collected and stored for a period of time until it can be used. The most common means of collecting and storing the gas produced by a digester is with a floating cover-a weighted pontoon that floats on the liquid surface of a collection/storage basin. Skirt plates on the sides of the pontoon extend down into the liquid, thereby creating a seal and preventing the gas from coming into contact with the open atmosphere. High-pressure storage is also possible, but is both more expensive and more dangerous and should be pursued only with the help of a qualified engineer [52].

3. Challenges Associated with Disposal of Hatchery Waste

The cost for an average hatchery to dispose their hatchery waste in Australia is high (Aud$127/tonne and 10.4 tonnes per week). In other countries the cost is greater due to reduced areas available for landfill. The current world population of chickens is approximately 8 billion birds; 90% of these chickens are hatched in commercial hatcheries. The volume of hatchery waste that needs to be disposed of yearly is millions of tonnes. Disposing hatchery waste to land fill causes environmental problems such as releasing methane in the air and possible spread microbial contamination. It is likely that hatcheries in the future will not be permitted to dispose hatchery waste to landfill. Sustainability of these hatcheries is threatened and the challenge is to design a system that converts waste on site to valuable products which can be used on site or sold.

The real challenges for the poultry industry in general is to turn all the waste into economically-valuable outputs using low-cost treatment systems. The huge volume of waste generated by the industry needs to be treated using bioprocesses to produce feed, fertiliser and fuels. These processes need to be applied to the organic waste streams (e.g., poultry manure, hatchery waste) and turn the cost of waste disposal into a source of income, recycle nutrients and reduce pollution This can be achieved by characterising and separating waste, develop products, design systems, and provide risk assessment and quality control. These approaches enable maximum conversion of carbon, nitrogen, phosphorus, and water in waste streams into biofuels and agri-products while at the same time achieving pathogen and odour control.

4. Conclusions

This review has identified alternate methods of handling and processing hatchery waste that could be utilised.

- Hatchery waste can be separated into solid waste and liquid waste by centrifuging
- Alternatively inclined screens and the use of a belt or filter press can separate the components of the waste
- Flexible multi-layer filters can be used to separate liquid wastes from solid wastes
- Another system for separating liquid and solid waste is to use a conveyor with an upper and lower conveyor roller. Liquid and solid wastes are separated and placed in collectors which are located near the upper and lower rollers

Shells can be separated from the hatchery waste as follows;

- A powerful suction vacuum is used to only remove the dry, very light shells from the hatchery waste leaving the heavier infertile eggs
- Eggshell waste can be separated by using a vibrating or shaking device and a cyclone forced-air separator to further separate lighter materials from heavier materials in hatchery waste
- Alternatively live chicks and unhatched chicks or clear eggs from the hatching tray are placed on a moving belt with fixed gaps that only allow chicks to slide through, while shells and unhatched eggs are retained on the belt while dead embryos are disposed into a separate container

Products that can be developed from shell include;

- increase the mineral content of compost
- spread around plants to deter slugs and snails
- mixed with garden soil for use as a fertiliser
- mixed with seeds for use as a feed for aviary birds
- added to cement to increase its strength
- used by artists to make mosaics
- to make textured paint for 3D effects in artwork
- produce collagen from the egg shell membrane.

Methods which can be used for treating the solid waste include the following;

- Use of a furnace to heat the waste to produce steam to run a turbine generator and produce electricity
- Rendered, autoclaved, extruded, boiled, ensiled, enzyme treated to produce pet or livestock feed or composted to produce fertiliser
- On site stabilisation of product by using an in-line composter.

The most effective method for treating hatchery waste on site is to establish an anaerobic digester system. It is by far the most popular process used to treat organic wastes in all other organic waste industries. It has the advantage of being a high efficiency process and produces biogas which can be used for heating or generating power. The biosolids remaining after the digester process can be used as a high quality fertiliser.

Off the shelf digester systems for purchase by hatcheries are not available and need to be designed by engineers and built specifically to the requirements of each hatchery. Hatcheries disposing wastewater into lagoons could adopt the integrated aquaculture approach to produce water suitable for irrigation and other potential products such as ornamental fish; a multi-billion industry worldwide. The ideal system in a hatchery would incorporate separation and handling equipment to separate waste into its various components for further treatment. This would save disposal costs, produce biogas to reduce power costs at plants and produce a range of value added products.

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