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Review article

Application of solar thermal technologies on poultry waste management: A review

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ABSTRACT

The poultry market in India attained a market size of USD 30.46 billion in year 2023. The market is projected to see a compound annual growth rate (CAGR) of 8.1% over the projection period spanning from 2024 to 2032, ultimately reaching an estimated value of around USD 61.41 billion by the year 2032. With the rate at which this industry is expected to grow, the waste from the industry is also expected to grow at the same pace. The disposal of this waste and the various environmental implications has led to finding new ways of disposing the waste in a cleaner way. The review given here provides the details of the various disposal routes (composting, anaerobic digestion and direct combustion) of the poultry waste. To deal with these implications related with disposal of poultry waste is one of the most promising applications of solar energy, as it is abundantly available clean and less polluting. Solar energy or the heat produced using solar technologies such as photovoltaics or by using concentrating thermal systems (CST) can be used for drying, pyrolysis, gasification, hydrolysis, combustion and incineration of poultry waste. The application of solar energy in the thermochemical conversion of biomass has the potential to contribute to sustainable development by mitigating greenhouse gas (GHG) emissions resulting from the overreliance on traditional energy sources.

1. Introduction

The energy consumption is an important and much needed infrastructure for the economic well-being and development of a country. The energy consumption of any countries peoples and industries is an indicator of the prosperity of that country. Currently India's contribution in the world population is around 17.76% and it consumes around 6.1% of the world's energy consumption. Waste coming out from the poultry industry is a mix contains broken eggs, litter, dead birds, waste feed, feathers, bedding material, also the waste from cage and conveyor belt etc. coming out of poultry houses. This waste contains a significant amount of manure, which is having an enormous amount of nutritional value, which makes it a good material to be put to use as an organic fertilizer, so facilitating the recovery of essential nutrients in the soil like nitrogen, phosphorous and potassium. The process of utilising this poultry litter as a type of soil amendment has historically involved the distribution of its constituent components onto land surfaces. Nevertheless, over utilization of the material might result in the augmentation of water nutrients, leading to eutrophication in aquatic ecosystems. Additionally, it can contribute to the proliferation of infections, the generation of phytotoxic compounds, air pollution, and the release of greenhouse gases. Eutrophication has been proposed as the primary factor contributing to the degradation of surface water supplies (**USEPA, 1996**). It has also been found that over utilization of the poultry waste litter in the fields can cause serious implications like contamination of groundwater by nitrate and also if nitrate consumed in drinking water can lead to various health problems like blue baby syndrome, respiratory illness and carcinogenic diseases in the humans and livestock**. Stevenson et al. (1986)** has given in his article that alternate disposal routes that are environment friendly and economic may be those which uses large scale biomass to energy scheme that could make way to handle the by-product fertiliser easily.

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1.1 Solar thermal technologies overview

Solar thermal technologies convert sunlight into thermal energy, which can be used for heating, drying, and various thermochemical processes. Key components include solar collectors, storage systems and heat exchangers. Table 1 shows the efficiency of different solar thermal collectors.

Table 1 Various types of solar thermal collectors and their efficiencies

Type	Description	Efficiency (%)
Flat-plate	Simple design, suitable for low to medium temperature applications	30-60
Evacuated tube	High efficiency, suitable for high temperature applications	50-80
Parabolic trough	Concentrates sunlight, suitable for industrial processes	60-75
Solar tower	Uses a field of mirrors to concentrate sunlight onto a central receiver	50-70

2. Waste generation from poultry industry

The poultry industry, regarded as a highly efficient livestock sector in terms of feed-to-food conversion (**Mata-Alvarez et al., 2014)** and involves the generation of a substantial quantity of waste throughout the entire process, that goes from bird hatching to slaughtering. This waste not only presents significant challenges in terms of disposal and management but also presents additional environmental issues and health hazards **(Brandelli et al., 2015**).

2.1. Poultry litter and manure waste

Poultry litter and manure waste refers to a composite substance comprising poultry manure, feed remnants and bedding materials utilized in poultry farming, constituting the primary waste by-product of poultry production. According to estimates, a single chicken bird is projected to produce roughly 1 kilogram of poultry litter and manure waste over the 47-day growing-out phase **(Ma et al., 2019)**. Figure 1 represents the litter produced in the poultry farms. Additionally, several studies have reported higher values ranging from 1.5 to 5.7 kilograms within a 42-day production cycle for each poultry bird **(Bolan et al., 2010; Edwards and Daniel, 1992)**.

Fig. 1 Poultry litter and manure waste

Poultry litter and manure waste possess a considerable concentration of essential elements, including nitrogen, phosphorous, potassium, as well as various macro- and micronutrients, which can effectively enhance the availability of nutrients in agricultural soil.

2.2. Feather waste

The chicken business worldwide generates a significant amount of feather waste **(Sinkiewicz et al., 2017)**. According to estimates from previous studies, birds have the capacity to carry something equivalent to about 5% to 10% of their overall body weight in feathers **(Karuppannan et al., 2021; Gurav et al., 2016**). This has resulted in the generation of millions of tons of the feather waste globally, primarily originating from the poultry sector **(Bhari et al., 2018; Zhao et al., 2012)**. Bird feathers mostly consist of keratin, a fibrous, and resistant protein (**Bhari et al., 2018**), constituting around 85% to 99% of the overall weight of dry feathers. Figure 2 shows the feather waste in the poultry farms. The keratin protein exhibits an extensive range of uses in the various industries such as textiles, leather production and agricultural activities. Nevertheless, the issue of feather waste is a significant worry in terms of potential environmental impacts (**Mazotto et al., 2011)**. This is mostly due to the presence of several viruses and bacteria, including Salmonella and Vibrio, which are commonly found in feathers.

Fig. 2 Pictorial view of feather waste

2.3 Abattoir waste

Abattoir waste refers to the residual trash produced during the process of the slaughtering process, including offal, organs, tissues, blood, and bones. These components are typically classified as inedible in various countries (**Ferreira et al., 2018)**. This waste has been found to include viruses, bacteria, and residues. It has been observed that chicken wastes, including feathers, feet, and intestinal contents, harbour several hundred kinds of microorganisms **(Muduliet al., 2019).** In the past, abattoir waste has commonly been managed like common waste, with its disposal taking place in local dumpsites **(Alam et al., 20**19). However, this practice significantly intensifies the potential for disease and bacterial transmission. Figure 3 is the representation of abattoir waste in the slaughter houses. The disposal of this abattoir waste can be effectively managed through the utilization of burning and various other burial methods (**Nicholson et al., 2005**).

Fig. 3 Pictorial view of Abattoir Waste

2.4 Poultry hatchery waste

Furthermore, poultry yields an enormous quantity of additional waste materials. In addition to them, a significant quantity of waste is also produced by chicken hatcheries. The poultry hatchery generates a significant amount of both solid and liquid waste throughout the process of bird hatching. Figure 4 is the example of hatchery waste in poultry industries. This waste includes various materials such as egg shells, infertile eggs, dead-in-shell embryos, and decaying tissue. It is essential to handle and manage these waste products with caution, ensuring proper treatment and exploring potential opportunities for their beneficial utilization.

Fig. 4 Pictorial view of poultry hatchery waste

3. Methods of poultry waste management using solar thermal technologies

3.1 Solar drying

Solar drying reduces the moisture content of poultry waste, minimizing odor and volume, and making it easier to handle and store. This process involves spreading the waste in thin layers and using solar collectors to heat the air circulated over the waste. Table 2 shows the efficacy of solar drying system.

Table 2 Parameters of solar drying systems

Parameter	Value
Initial moisture content	70-80%
Final moisture content	10-20%
Drying time	3-7 days
Average temperature	40-60°C

3.2 Solar-assisted composting

Solar-assisted composting accelerates the decomposition of poultry waste by maintaining optimal temperatures for microbial activity. Table 3 provides the information of solar assisted composting method. Solar collectors provide the necessary heat to maintain composting temperatures, enhancing the efficiency and speed of the process.

Table 3 Comparison of composting methods

Method	Composting Time	Temperature Range	Final Product Quality
Traditional composting	2-3 months	20-40°C	Moderate
Solar-assisted composting	1-2 months	40-60°C	High

3.3 Pyrolysis

Pyrolysis refers to the thermal process of breaking up of biomass in the absence of oxygen, resulting in the conversion of biomass into various forms of matter, such as solid bio-charcoal, liquid bio crude oil, and gaseous products like syngas, predominantly composed of biogas **(Demirbas and Arin, 2002).** The thermal energy required during the pyrolysis process may be obtained by utilising solar photovoltaics or solar concentrators for the generation of heat. The various technologies are parabolic trough system, solar power tower systems, solar dish and linear Fresnel reflector. Solar dish has been used for the pyrolysis of chicken litter waste as an alternate source of energy in the study which in turn reduced GHG emissions **(Weldekidan et al., 2019).**
Solar pyrolysis is considered a promising option for mitigating environmental impact and reducing heating expenses, as well as for its ease of construction. The integration of a solar heating system primarily focuses on the essential aspect of reactor heating which is very important in pyrolysis.

3.4 Gasification

Gasification refers to the transformation of organic matter found in waste from poultry into secondary products. This conversion occurs under specific conditions involving moisture, temperature and oxygen. The resulting secondary products primarily consist of syngas, liquid fuels, and solid residues. These products have the potential to contribute to energy production and environmental remediation efforts **(Rasheed et al., 2021)**. Due to growing apprehensions over environmental sustainability and the security of energy supply, gasification has emerged as a widely used approach for the disposal of biomass waste and the generation of energy.
Solar energy, which is a kind of green and environmentally friendly energy, can be efficiently harnessed to supply the necessary thermal energy required in the process of gasification. Additionally, concentrated solar power (CSP) systems like solar dishes or concentrators can be utilised to provide the necessary heat, which might end in an enhanced gasification yield.

3.5 Hydrolysis

Hydrolysis refers to the enzymatic breakdown of peptide bonds present in animal waste materials. This process involves subjecting these substances to a specialized solution, which is characterized by the increasing temperature and pressure. The application of these conditions leads to the denaturation of proteins, resulting in the conversion of proteins into amino acids. Additionally, hydrolysis facilitates the breakdown of lipids and the dissolution of carbohydrates **(Arias et al., 2018)**. Through the process of hydrolysis, it is possible to utilize poultry waste as a means of generating a secondary product that possesses added value. This secondary product consists of high-quality protein and bioactive components, thereby offering a viable resource for the food and feed industry. Moreover, this utilization of poultry waste brings about supplementary economic advantages and aids in the mitigation of the adverse environmental consequences associated with its disposal.

Solar energy can be utilized in hydrolysis process to achieve higher temperature, which would in turn be beneficial due to its low cost, and it is a clean and environmental friendly source of energy. Application of solar photovoltaics system or solar thermal system can be used here.

3.6 Direct combustion of poultry litter

The other disposal methods of the poultry waste is the combustion of the poultry waste (litter) which also helps in heating the space of the poultry houses also it could help in generating heat and power. The systems for the combustion of the waste includes combustion inside a closed chamber, which has systems to trap the gases generating by the combustion of waste. The calorific value of this poultry waste decrease with an increase in the moisture content of waste. Solar energy systems can be utilised here to dry out the poultry litter so as the waste has minimum moisture content and maximum calorific value. In addition, the solar thermal chimneys can be used here or the solar power tower systems which would generate energy which would use for the purpose of incineration.

4. Economic benefits

Solar energy consumption is considered the most appealing option due to multiple benefits in comparison to alternative sources of energy. The utilization of this technology in the poultry brooding industry is expected to enhance and optimize the quality of the environmental air, leading to improved production of healthy chicks and increased profitability. Also it would help to reduce the spread of diseases in the farms due to which large number of chickens die and loss is occurred to the owners.

5. Environmental benefits

The utilization of conventional methods for poultry waste disposal, including direct dumping, landfilling and burning are common in less developed and developing nations, posing significant threats to the environment. The proper disposal of waste with the help of solar technologies that is cheap and abundantly available will help to resolve the threats that arises due to improper disposal of waste. Table 4 provides the benefits of solar thermal technology to the environment. In addition, it would help to reduce the emission of GHGs which are a part of the efforts against global warming. The reduced dependency on fossil fuels and the promotion of waste-to-energy concepts contribute to sustainable waste management.

Table 4 Environmental benefits of solar thermal technologies

Benefit	Conventional methods	Solar thermal technologies
CO_2 emissions (kg/year)	High	Low
Energy consumption (kWh/year)	High	Low
Water usage (liters/year)	Moderate	Low

6. Social benefits

The proper disposal of poultry waste covers various social benefits, including the mitigation of various diseases spread by infections, restoration of air quality, and generation of additional employment prospects. Poultry species are considered a suitable medium for the growth of various harmful bacteria's. Additionally, poultry waste has a wide range of viruses capable of infecting both humans and animals, including zoonotic avian influenza. In addition, it is important to note that food or water polluted by poultry waste has the potential to host a range of pathogens and water pollutants. These contaminants have been associated with the development of gastrointestinal illnesses, such as typhoid fever, cholera, and hepatitis E infections. All of these issues could be easily handled and resolved with the proper and environment friendly disposal of the poultry waste.

Furthermore, the implementation of poultry waste disposal would generate a substantial number of employment prospects, thus strengthening the economic well-being of several households.

7. Conclusion

Solar heating system can help to reduce the energy consumption in the poultry farms. A large amount of energy is consumed by the poultry houses for space heating. Solar energy photovoltaics and solar thermal systems can play a very important role in disposing of the poultry waste in an environmental friendly way. This could help to reduce the diseases spread due to improper disposing of the poultry waste. Solar thermal systems, which include concentrators, collectors, solar dishes, and solar chimneys, have shown very good results when used for disposal of poultry waste. Solar panels can be installed in the roofs of the poultry farms itself so that their will not be any requirement of new land. The other advantage of this system includes that these solar technologies can be used in the remote areas where there is no power or energy source available.

Solar energy is an exciting technological advancement that holds the potential to enhance sustainability and mitigate manufacturing and disposal expenses. Furthermore, it is possible to mitigate the risk of increasing input costs by having prior knowledge of the expenses, which are associated with escalating energy prices. At last, solar energy does not deplete finite fossil fuel stocks and is a green and environment-friendly source. It is logical to allocate a substantial portion of poultry operations' budget towards solar energy, as it would reduce the budget of energy consumption for various purposes such as ventilation, heating, cooling, and water pressure.

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Author contributions
Anil Singh (Research scholar) has conceptualize, prepared a draft of the article and formal analysis. Dr. Dhamodharan Kondusamy (Supervisor) has reviewed edited and validated manuscript.

Conflicts of Interest
There are no conflicts of interest declared by the authors.

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