Food Processing Industry Waste and Circular Economy

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Food Processing Industry Waste and Circular Economy

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Abstract: The continuous rise in world human population increases the demand for food supply thereby increasing food wastage throughout the supply chain which results in environmental pollution and scarcity of natural resources. In addition, food processing industries produce huge quantity of inedible food waste. Land filling and incineration are not the promising approaches of food waste management system for environmental sustainability and economic viability. Recycle and reuse are the major principles of circular economy which focus on the energy and resource recovery from food waste for sustainable environment. Food wastes are mostly rich in organic matters such as carbohydrates, proteins and lipids which can be used as a feed stock for production and/ or recovery of bio fertilizers, biofuels, bio gas, valuable bioactive compounds, natural nutrients and industrial enzymes by adapting suitable technologies including composting, anaerobic digestion, and fermentation. In addition, an integrated biological approach for recovery of energy and resources from food waste with the concept of zero solid discharge is found to be economically viable. This review highlights the technological advances in management of food waste including processing methods and product recovery.

1. Introduction

Food waste is a universal concern which is noteworthy in the developed and developing nations which, connects food health, food security and other primary sustainability aspects [1]. Sustainable consumption and production are a new concept for achieving the productive growth that draws more focus for effective and sustainable use of resources, energy, and infrastructure to ensure good quality of human life. This seeks to formulate overall development strategies with reduced economic, environmental and social costs, improve global productivity, and reduce poverty. The use of global natural resources has increased, reaching 92.1 billion tons in 2017 and 254% from 27 billion in 1970, with the annual production rate mounting since 2000 [2]. The bioeconomy is characterized as the development of biological renewable resources and the transformation of these resources into value-added products which includes food, feed, biofuels and bioenergy. As a result of the emerging bioeconomy, the land demand is rising, where some of the land has to be maintained to meet particular needs such as sequester carbon afforestation. In this way, the efficient and synergistic use of resources should be promoted with the growth of bioeconomy rather than adding to the pressures on resources. This study intends to elucidate how circular economy can be achieved through sustainable food waste management.

In this review the section 1 states about the waste produced from different food industries that includes fruit and vegetable industries in which the peel, seeds are considered to be waste, meat industries in which the skin, feathers are treated as wastes, oil industries in which the chuck remaining is said to be waste, and dairy industries in which the whey concentrates, oil are considered as waste. The section 2 provides a description about the conventional approaches on waste management which states about land filling which is the deposition of food wastes in to specially constructed land surface, incineration which is the combustion of food waste in a controlled atmosphere and pyrolysis which is a thermochemical process of treating the waste. Then the section 3 states about circular economy, resource recovery i.e. about REDUCE, REUSE, RECYCLE and RECOVER through which the

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resources can be recovered and used again, and includes some method followed for waste utilization like composting which is a biological and microbial digestion of organic waste and anaerobic digestion which deals with the breakdown of biological matter in the absence of oxygen. This section also includes about value addition to the waste through which the value of the treated waste can be increased. Then comes to the section 4 which describes about zero solid discharge in which all the waste is been recovered by applying some techniques.

1.1 Wastes produced by various food industries

In food industries the large volume of wastes is produced in both the solid and liquid form during the receiving stage, processing and packing. Basically, the food wastes are highly rich in nutrient and energy sources which can be utilized as food, feed and fodder. Food processing industries produce different kinds of wastes that are detailed below:

1.1.1. Fruit and vegetable industry. In fruit and vegetable industries except the edible part, remaining fragments like leaves, peel, pomace, rind, stem, seeds, spoiled fruits and vegetables are considered as waste. These items are collected during the time of washing, cleaning and processing. For example, pectin will be extracted from apple, pineapple, guava and also oil from the seeds of tomato and other vegetables too. Even the grape pomace is a rich source of ethanol, tartrates and malates [3]. In these industries the materials are considered to be waste when the consumer rejects the product due to unacceptance quality like off color, off flavor or also some of the damages caused during transportation [4].

1.1.2. Meat industry. Since ancient period we the humans consume meat and the meat products; this meat processing industry produces billion and billion tons of waste. Nowadays people prefer mostly to the deboned meat, this also gives more wastage during the time of processing and it gives liquid waste (water- contains body hairs, blood, fat, feathers at the slaughterhouse). A study says that, in the meat and livestock wastes the average overall solid content of the waste was 28.7% reached with the screw press. Additional chemical or thermal technologies were suggested to further dewater the paunch to increase its energy performance [5]. None of the dewatering instruments tested were able to remove the maximum sludge particle size spectrum of 1–2000 μm [6].

1.1.3. Oil industry. One of the essential ingredients of human diet is oils and fats which forms a vital component of many cell constituents. Oil is extracted from seeds which is of two types, the edible (cotton seed, soy, sesame, groundnut) and non-edible (castor beans) among these seeds the groundnut has high amount of oil. Oilseeds are processed and refined during the extraction of edible oil, producing large amounts of different waste including wastewater, organic solid waste (i.e. seeds and husks) and inorganic residues [7]. Those wastes are processed and also utilized.

1.1.4. Dairy industry. Dairy industries produce milk, milk powder, cheese, curd, butter, ghee and other dairy based products which produce large volume of liquid wastes. The parameters mostly present in the effluents from dairy industry are the suspended solids and organic matter, some whey concentrates oils, grease, residues of cleaning products, nitrogen, phosphorus, sodium chloride residue etc. When this waste water left in any of the water resources without treating, the presence of these fat molecules will affect the living organisms in the water resource [8]. The composition of raw milk wastewater varies mainly depending on the type of product and service [9].

2. Typical approaches on waste management

2.1. Land filling

Land filling is the deposition of waste into a specially developed or constructed area in the land surface. Generally, when the wastes are dumped into the land, there exist biological, chemical and physical process which degrades the waste matter and produce leaches and gases [10]. It has been estimated that approximately 125 m^3 of landfill gas is generated by land filling a ton of food waste [11]. Globally 11 – 13% of total methane emission is done by the landfills [12]. In the year of 2015, China alone accounted for 13% of global methane emissions (making it the world's largest methane emitter) of which 5% of its total emissions came from landfill sites [13]. The substances that present in the landfill gas are also considered to be the reason for the environmental impact like global warming [14]. Some of the unescapable drawbacks in land filling are (1) generation of huge quantities of leachate with heavy metals and pathogenic bacteria; (2) the complexity of mechanical compression; (3) poor sanitary conditions; (4) massive footprint; (5) production of methane, generating field safety concerns. In addition, landfilling also reduced due to land restrictions and also creates a threat to the health and sanitation of peripheral areas as it spreads pests and rodents and emits foul odors in the periphery. Landfill gas is also considered to be a threat to social security, because of these challenges associated in land filling, this practice has been banned in European Union, United States and Japan [15].

2.2. Incineration
Incineration is one of the most generally utilized advances in food waste management worldwide and it is the societal use of ignition at 800^o C. Incineration and gasification have received an expanding consideration because of their high potential for energy and resource collection. Incineration could be compelling and reduces the measure of solid waste by 90–95 % leaving an inert residue of debris, glass, metal and other solid materials called bottom ash, anyway the subsequent waste in the incineration cycle makes a blend of unsafe byproducts that are dangerous to the climate and to overall population [16]. The heat created during this process of incineration can likewise be utilized in thermal power plants for power generation. The slag is the primary source of incineration. The sum delivered relies upon the quality of waste ash remains. In addition to the slag, the plant contains residues from more or less advanced dry, semi-dry or wet flue gas. The quantity of residues and its ecological qualities rely on the technology utilized. Appropriate cleaning treatment of fly debris and different traces of flue gas must be considered as well. In general, however it ought to be treated as unsafe waste and discarded by the leachate properties. The little molecule size of the deposits requires special precautionary measures during treatment at the plant and in the landfill [17]. New leachate from metropolitan solid waste incineration plants is another significant natural waste source. As of late, municipal solid waste incineration in China has been growing quickly because of the amazing efficiency of waste reduction. However, due to high moisture content and low calorific estimation of municipal solid waste, it produces high proportion of food waste (50–60% by mass) it is been demonstrated that it couldn't be viably ignited without fuel expansion or exact and accurate separation [18]. Presently, the municipal solid waste was put away shelters for 3–7 days before incineration. The moisture content was in this way diminished and the calorific value expanded [19]. A lot of new leachate (10–20% of municipal solid waste (by weight)) was created during the storage period. Consequently, new leachate from storage tanks of municipal solid waste incineration plants might be a specific waste stream for developing countries. The new leachate is wealthy in organic matter, ammonia-N and metal elements [20].

2.3. Pyrolysis
Pyrolysis is a thermochemical process of heating materials at high temperatures in the absence of oxygen which gives pyrolytic gasses at the end. Char and liquid oil are the other pyrolysis materials [21]. It is also a promising pre-treatment technique that is better to take low quality food waste into a more functional product. Usually, the feedstock is heated to temperatures above 400 °C [22]. The pyrolyzed waste cereals and waste peanut chips at 800 °C in a retort are placed in a tube furnace during processing of gaseous materials. Large concentration of H_2 in pyrolysis gas was about to be

66% and 61% during the pyrolysis process by applying peanut chips and cereals respectively [23]. This is of 3 types: (1) Slow pyrolysis – takes more time to complete the process and results in biochar as main product. (2) Flash pyrolysis- results up 75% of bio oil and in an inert atmosphere it rapidly de-volatilize. (3) Fast pyrolysis- completes within few seconds and gives up 60% of bio-oil yield, 20% of biochar and 20% of syngas.

The suitable decision of input materials and optimal process conditions are the requirements for their effective application. Of these reasons, the adequacy or inappropriateness of the chosen types of waste for the pyrolysis procedure has been checked by research facility experiments with a corresponding evaluation of the quantity and consistency of the individual things [24]. As of late pyrolysis condensate attracted enormous consideration because of its various applications in different areas. Despite the fact that it has been demonstrated to be a feasible option in contrast to petroleum derivatives, it additionally has a potential for use in the manufacturing of value-added chemicals. Bio-oil creation by flash pyrolysis is right now being researched on an industrial scale. Restrictions of bio-oil, for example, low thermal stability, low fuel properties and destructive nature are known. There are only a couple of introductory discoveries on the creation of bio-oils from food waste by pyrolysis. [25]. Thus, studies using economic methods have shown that biofuels can be reduced emissions of greenhouse gasses relative to conventional fuels [26].

3. Circular economy

We produce a huge amount of food waste. Each year the food industry wastes about two-billion-dollar worth of food, but why to waste it, when we can use it, food and bio- based research believes in an economy in which all agri-food residues are used to create value added products. Actually, food waste isn't truly waste; it's a valuable nutrient and energy- rich resource. If all this waste was recycled and the energy is extracted, we could power one million households with renewable electricity. These food wastes are been collected and sorted accordingly and turned into useful products such as nutrient-rich bio fertilizer and renewable energy in the form of biomethane and electricity. Raw materials including fossil fuel, minerals, metals, biomass, would be generated, exchanged, used, and then entered the waste hierarchy by exchanging, reusing, redistributing and recycling [27]. In this circular economy, the bio wastes from the waste processing plants are used in small scale and medium scale chemical plants. The carbon dioxide emitted from the treating plants are used by the plant species for photosynthesis and the hub and fine chemicals from the chemical plants are used by the end users and then again, the wastes from the users will move to the waste treating plants [28]. Circular economy provides a broad opportunity to circulate resources and waste in a closed loop network [29]. Two sectoral goals were explicitly related to bioeconomy, namely food waste and productive biomass conversion. Food items that are excreted and digested end up in the collection of food waste, energy recovery or disposal in landfills. Biodegradable products can undergo the recycling of organic waste as an end-of - life alternative to carbon capture for CO_2 sequestration [27]. To further explore the possibilities for circular bioeconomy in sustainable food waste management, understanding existing food waste situations around the world is a crucial cornerstone.

3.1. Resource recovery

The resource recovery says about the 4R concept - REDUCE, REUSE, RECYCLE and RECOVER. Due to the constraints in the processing strategies, storage and cooling amenity, packaging, infrastructure and marketing frameworks, around 20 – 30% of food wastes happen in the developing nations during the preharvest phase of the food supply chain, which brings about ecological effects. A survey says that in India because of lacking in facilities and insufficient framework for capacity and cooling, around 72% of fruits reaped were wasted along the food supply chain. Rentizelas et al., **[30]** structured the end to end supply chain of agricultural plastic waste reusing. Zhang and Jiang [31] built up a model to locate the ideal structure of the supply chain which is concentrating on extraction of biodiesel from waste cooking oil. Abnisa et al., [32] configured a high-grade pyrolytic fluid which can

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be utilized as a fuel from the blend of palm shell and polystyrene waste. Papapostolou et al., [33] smoothed out a streamlining model for the ideal structure of the biofuel supply chain considering both specialized and economic boundaries that influence the performance. At one-point corncob was explored as an optional feed stock for the creation of fuels and synthetic chemicals through pyrolysis in a fixed-bed reactor. The pyrolysis temperatures will be in the range from 300 to 800 °C as well as the catalytic effects on the products have been considered. Therefore, corncob bio-oils can be utilized as a fuel and are a significant source of synthetic raw materials [34]. This resource recuperation is likewise affected by the circular economy; this is supported by three rules that address the difficulties experienced by linear economies. The first principle spotlights on safeguarding and improving regular capital, for example, soil nutrients and water resources, by controlling and adjusting scarce resources. The subsequent rule concerns the streamlining of resources through remanufacturing, repairing and reusing of items inside their technical and biological cycles. On account of the Food Supply Chain, the subsequent rule is satisfied by the utilization of food manufacturing by- products and the recuperation of nutrients from waste in imaginative manners that create an incentive in the equivalent or new supply chain [35]. The third guideline intends to make steady an incentive through the productivity of biological systems by controlling externalities, for example, water, environmental change and the arrival of unsafe contaminants into the earth.

3.1.1. Compost. Composting is a regulated biological and microbiological degradation of organic matter. This is a biochemical cycle in which aerobic and anaerobic microorganisms used to break down organic waste into manure under some physical, chemical and microbiological conditions that may vary from one food waste to another. The cost of collecting and transporting the food wastes are high. Guo et al., [36] had analyzed the viability and reliability of a pilot scale composting plant on food waste sorting and in-situ composting in a populated residential area, with full equipment. Researchers found that labor, waste storage, and processing costs amounted to $23.02 per ton of food waste, accounting for 83.95% of overall spending. To decrease the cost of transportation, the volume of the waste can be reduced at the home by the user itself. The normal kitchen waste can be separated and can be composted in house scale itself [37]. But when the wastes are been treated in small scale level (at home) there exists some problems like blockage of wastes, disgusting smell of wastes at degradation. To overcome these problems many advanced equipment's are in existence with crusher, plug flow composting bin, heating system, spiral stirrer, odour neutralizer and control panel. The composting plug-flow bin will work at different temperatures, and the volume of the reaction is minimal. In the plug flow composting container, the waste is agitated, aerated, mixed and decomposed, and uniform compost can be generated in a short time [38].

3.1.2. Anaerobic digestion. Anaerobic digestion is used for handling food waste treatment with the arrangement of energy recuperation and volume decrease [39]. Changing to this anaerobic digestion method to process the food waste, faces few difficulties like volatile fatty acid accumulation, low buffer limit, more expense for handling and transportation and so on. It has been set up that anaerobic digestion is restricted by the low hydrolysis limit of food waste, which implies that just around 40–60 percent of volatile solids in food waste can be degraded and at last changed over to biogas, while simultaneously delivering a lot of residual solids that definitely require further removal [40]. To improve the effectiveness of anaerobic digestion, co-digestion of food waste with certain natural feedstocks (for example animal dung, straw crop and activated sludge) were researched [41]. Roughly 30–40 percent of the firm debris is delivered for additional removal. Proof shows that the processed firm debris is unacceptable for horticultural use. The digestate delivered from anaerobic assimilation is as of now precluded for rural use in the increasing number of nations. Solid deposits from anaerobic processing ought to be additionally taken care-off in an appropriate way, for example burning or landfill. Meanwhile, it should also be remembered that essential resources for food waste (e.g. nitrogen & phosphorus) cannot be easily recovered by anaerobic digestion.

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3.2. Value addition to the waste

Over the last few decades, a large amount of food waste has been disposed continuously by the food processing industries. Reports indicated that the food processing industries generate 14 million metric tons of waste [42]. According to a report from FAO (Food and Agriculture Organization) on 2019 Philippines, USA, India and china are the leading food waste producers in the world. [43] These food wastes also cause many health problems. So, this food waste must be processed into value-added goods or used as a source of diverse bioactive extractions [44]. Bioactive extraction from food waste creates the main income for the food, cosmetics and pharmaceutical companies due to the low source cost and adequate presence of these molecules in the discarded waste. Value addition is producing valuable products from the wastes. One of the value-added products is single cell protein which is processed with some microbes and been used for protein deficiencies. Next is the extraction of enzymes. Enzymes are of great importance in the food industry due to their substrate and product specificity. Enzymes like pectin, amylases, and cellulases can be extracted from food wastes [45]. Physical, chemical and biochemical methods must be used to remove these active compounds found in food waste from the central matrix. Different techniques have been used to extract bio actives, and for better production these processes are repeatedly modified. Cellulose, hemicellulose, and lignin are rich in agro-industrial residues. These polymers interfere with the extraction procedures, and therefore certain pre-treatment procedures must be carried out to properly extract bio actives from the food waste. Before extraction is performed, physical, chemical, and biological methods are used. Physical pretreatment includes reduction in size through milling, steam treatment, hydro thermolysis, ultrasonic treatment with microwave [46]. Chemical pre-treatments typically undergo treatment with alkali, acid, calcium hydroxide, ammonia, organic solvents, and hydrogen peroxide [47].

4. Zero solid discharge

Zero solid discharge is an engineering approach which is used to treat the wastes at the place where all the wastes are recovered by applying some techniques. Food waste which contains ample organic matter and nutrients can extremely be used as good raw material to produce biofuels and biofertilizers. However, because of the presence of complex structure and refractory organic elements, aerobic or anaerobic digestion of food waste seems difficult [48]. For example, due to low hydrolysis only 40 - 60% of volatile solids of food wastes can be converted aerobically to biomethane [41]. In order to optimize food waste hydrolysis before aerobic or anaerobic fermentation, multiple chemicals, biological, ultrasonic, thermal and expelling pretreatment methods have been investigated [49]. Enzymatic pretreatment method of approach is considered as a green solution with no secondary emissions and requirement of any special equipment than the other pretreatment approaches of food wastes [50]. Commercial enzymes, however, were extremely costly, rendering them inapplicable for food waste hydrolysis due to the high cost of activity. Likewise, commercial enzymes are normally accessible in a solitary structure, which is unacceptable to hydrolyze complex food waste containing starch, cellulose, protein, and so forth. To resolve this challenge, compound hydrolytic catalysts known as fungal mash delivered from food waste were utilized to upgrade the solubilization of food waste and ensuing anaerobic processing, with the production of biomethane expanding by 240% [51]. Much after such high-effectiveness hydrolysis of food waste by fungal mash, around 20–30 % of firm debris was still delivered and must be additionally dealt with by burning or landfill. While simultaneous energy and resource recuperation with zero solid discharge is obviously difficult to achieve with current food waste management methods. Recently, a resource recovery approach powered by zero solid discharge had been suggested and explored towards zero-solid charge with parallel energy and resource recuperation for food waste management.

5. Conclusion

This review highlights the (1) resource recovery by adopting REDUCE, REUSE, RECYCLE, and RECOVER concept and (2) developments need to be done to recover the wastes through the technologies like composting, biological and microbiological degradation and anaerobic digestion.

Value addition plays a vital role in the food waste management and circular economy. Advancements in integrated biological procedures for concurrent generation of energy and recuperation of resources with zero solid disposal ought to give a promising path for management of food processing industry waste in future.

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