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FOOD WASTE AS A RENEWABLE ENERGY SOURCE

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Abstract

Food wastes arise during food processing. Most of them are the leftovers from extraction processes or separated uneatable parts. Typically for food wastes are their constant and high quality and a rapidly perishableness. For the energetic use the contents of cellulose, hemicellulose, fat and carbohydrates are signified. The use of food wastes as cosubstrates in anaerobic digestion plant leads to a high biogas yield. For a direct incineration most of the food wastes have to be dewatered or dried. Dry stabilisation is derived from the composting process. The heat of the first degradation processes in a compost pile is used to evaporate water. Afterwards the material is for the microbiological point of view stabilized and due to the lower water content well suited for the incineration. Some food wastes can also be dewatered mechanically for the incineration. This process is shown for spent grains from the brewery.

Keywords

Food waste, renewable energy source, anaerobic digestion, dry stabilisation, incineration

Definition and problems of food waste

There are several ways of defining waste. The EU Commission, the Secretariat of the Basel Convention and OECD each has formally its own definitions. The EU Commission in the Waste Framework Directive 75/442/EEC provides the legal definition of waste: "'Waste' shall mean any substance or object […] which the holder discards or intends or is required to discard." (EC, 1975).

This definition is not sufficient enough to characterize the waste from the food industry. Food wastes are organic residues from the processing of agricultural raw materials to food, which arise as liquid (wastewater) and solid wastes. That means there are two categories of waste: non product specific waste and product specific waste. Non product specific waste is in its composition totally independent from the kind and quality of the produced food e.g. containers, cardboard boxes or waste paper. On the other hand the product specific wastes are strongly related to the product. Product-specific waste is characterized by the fact that the generated mass of waste relates to production levels in a certain ratio. It can only be altered through technological changes, which often unavoidably leads to a change in product quality. Typical examples of product-specific waste are spent grains from beer production, slaughterhouse waste from meat production, tea leaves, orange and potato peels or old bread.

During the food processing in various steps the desired components are typically affected by the extraction or separation of the nutritionally valuable portion of the raw materials. After extraction there are still often other potentially useful components present in the remaining materials. A typical example is pomance from winery: The sugar and aromatic components containing juice is squeezed of the grapes. The residue is rich in fibre materials (cellulose, hemi-cellulose), polyphenolics and oil. As a second characteristic its quality is constant.

The food and beverage industry is the largest manufacturing sector in the EU. With 13.6 % of total turnover in the EU-15 manufacturing sector in 2002, it is larger than the automobile, chemical, machinery and equipment sectors (CIAA, 2004).

The traditional lines of utilization of product-specific food waste are closely bound to the agricultural origins of raw materials themselves. The two general methods of traditional waste utilization are the use as either animal feed (e.g. spent grains, distiller's wash) or fertilizer (filtration sludge, carbonation sludge).

The subsequent use of food waste is limited by some restrictions caused by the biological origin:

- Many types of waste material either already contain large numbers of microbes and/or will be altered quickly through microbial activity. Hygienically unacceptable conditions can arise, e.g. through maggots or moulds. The breakdown of protein by microorganismens is always characterized by the generation of strong odours.
- The water content of meat and vegetable waste lies between 70 and 95 % by mass. High water content increases transport costs of the waste. Mechanically removing the water through use of a press can lead to further problems with waste water disposal, due to the high level of organic material in the water.
- Waste with a high fat content is susceptible to oxidation, which leads to the release of foul-smelling fatty acids.
- In many types of waste arising from vegetables and fruits, enzymes are still active, which accelerate or intensify the reactions involved in spoilage.

Typical examples of food wastes suitable as energetic resources and their contents

Beer brewing, sugar production and olive oil extraction are typical examples for the extraction of the desired products.

During the beer production water is used to extract desired substances from coarsely grinded malt. The wort, the liquid extract, is separated from the spent grains which stay behind as waste. Spent grains are rich in cellulose and hemicellulose (53 – 80 % by mass DM). They contain also protein (19 – 23 % by mass DM) and fat (9 – 12 % by mass DM).

Sugar beets consist round about 9 to 20 % of sugars. After the sugar extraction the dominant fraction is the N-free extract, almost carbohydrates, aside fat (8 – 9 % by mass DM) and 14 – 24 % by mass DM fibres.

For the olive oil extraction the olives are milled and the oil is removed with a pressing and a washing process. About 80 % of the used olives arise as waste with dry matter content between 8 and 10 % by mass.

Slaughterhouse wastes can be differentiated in by products (inwards, blood and rind), which possibly can be used and wastes, which have to be disposed according hygienic laws.

For the energetic use of food waste the contents of fat, fibrous material and carbohydrates are determining. Table 1 gives an overview about potential food wastes and their substances of content.

Calorific value and water content of food wastes

The average elemental composition of vegetable dry matter is shown in table 2.

With the knowledge of the elementary composition the calorific value of the dry matter can be calculated as a first approximation according the formula of Dulong:

$$H_u = 33.9\,C + 121.4\,(H - O/8) + 10.47\,S$$

H_u: calorific value of the dry matter in [MJ/kg]

C: mass.-% carbon

H: mass.-% hydrogen

O: mass.-% oxygen

S: mass.-% sulphur.

The real calorific value of the dry matter can only be determined by an experiment, because it depends from the molecular structure. Typically the calorific value of the dry matter is between 13 000 and 19 000 kJ/kg DM. The calorific value is determined by the water content. Food wastes are very often wet. Due to their organic origin, often combined with an extraction process with water as solvent, the water content can rise up to 95 % by mass water.

The calorific value is directly connected to the water content. This relationship is summarized in a linear function that is idealised.

$$H = (1 - w) * H_u - w * 2250 \text{ kJ/kg}$$

H_u: calorific value of the dry matter in [kJ/kg]

H = calorific value in [kJ/kg]

W = water content

According to the German "Kreislaufwirtschafts- und Abfallgesetz (KrW-/AbfG)" a law which governs also recycling and waste management (Bilitewski et al., 2000) the calorific value of a waste for incineration must be higher than 11 000 kJ/kg. Assuming that the calorific value is given with 16 000 kJ/kg DM in the average of the food wastes the water content must not exceed 39 % by mass. The consequence is that for direct incineration the water content of food wastes must be reduced by mechanical dewatering, thermal drying or a combination of either. Mechanically removing the water by means of a press can lead to further problems with waste water disposal, due to the high level of organic material in the water. Thermal drying requires energy which leads to inefficient costs. A promising alternative is the anaerobic digestion with the production of methane. This process is always bond to a high amount of process water. So the water content of the food wastes plays any role.

Anaerobic digestion of food waste for the conversion to methane as energy source

"Anaerobic microbial conversion of organic matter into a renewable energy source, so called biogas, is a well established process and state of the art. New techniques and technologies offer possibilities to treat pasty and solid organic wastes by means of anaerobic digestion (AD) as well as liquids." (Pesta, 2006)

The degradation of substrate by anaerobic bacteria takes place within two main phases: hydrolysis (decomposing of organic material) and methanogenesis (production of biogas). The degree of degradation as well as biogas quality can be affected in various ways by technological and procedural measures. Figure 1 shows the single steps of anaerobic digestion processes within the two main phases.

Step 1: Hydrolysis: Complex structured substrates e.g. carbohydrates, proteins or lipids, are hydrolysed into simple water soluble compounds, such as monosugars, aminoacids or fatty acids by the excellular enzymes of bacterias.

Step 2: Acidification: The same fermentative bacterias further brake down the intermediates into water soluble organic substances (e.g. short chained fatty acids, alcohols and carbon dioxide).

Step 3: Acetogenesis: The end products of the foregoing step are converted by acetogenic bacterias into short chained volatile fatty acids (VFA's), mainly into acetate, CO_2 and hydrogen. This conversion can only take place at a low concentration of H_2, which is produced while the acetogenesis as a by-product.

Step 4: Methanogenesis: Methanogenic bacterias living in symbiosis with acetogenic bacterias are using H_2 and CO_2 for the formation of methane. Methanogenics are strictly anaerobic. Oxygen inhibits their metabolism or mortifies the microorganisms. (Pesta 2006)

Although most of substrates listed in table 3 are suitable for mono-digestion normally biogas plants are operated with a mixture of various substrates. By using a homogenous mixture of two or more substrates the digestion process is termed "co-digestion", as well as "co-fermentation". The applied substrates are so called "co-substrates".

The basic material is almost manure. It is often

Table 1. Food waste's contents (abbreviated according to Russ and Meyer-Pittroff, 2002 and 2004). All values are given as % by mass; the contents of the waste are given as % DM

Waste	Water-content	Protein	Fat	Fibrous material[a]	Minerals	Other[b]
Waste with a high cellulose/hemicellulose content						
oat husks	7.1	3.4	1.4	33.5		61.7
pulp from sugar beets	9.4	10.0	0.9	20.6		68.5
broken grains, seeds, peels, husks	10 – 15	15	4 – 5	20 – 30	1 – 3	53 – 60
Waste with a high carbohydrate content						
dough waste, noodles	10.7	12.3	2.8	3.4	0.9	69.9
bran	10.9 – 12.2	14.7 – 18.0	3.5 – 5.2	5.8 – 15.8		51.2 – 76
middlings	10 – 15	13 – 15	3 – 4		1	80 – 83
waste from oats (flour, flakes)	8.4 – 9.1	14.3 – 14.9	7.4	2.2 – 5.3		72.4 – 76.1
oat bran	9.2	8.9	3.5	2.8		84.8
brown rice waste	13.1	8.3	2.5		1.4	87.8
rice bran	9.0	13.0	14.0	15.2		57.8
rice flour	9.7 – 10.8	14.1 – 14.5	14.0 – 16.7	8.8		50.8 – 53.4
silverskins	75.0	17.5	1.0	9.4	1.2	70.9
molasses	33.0	12.9	0.2	0.5		86.4
small beets, roots and other parts	83.0	11.0	2.0	14.0		73
whey	93.4 – 94.4	12.1 – 17.9			7.6 – 14.3	76.8 – 80.3
potato peels	77.8	2.0	0.1	2.5	1.0	
Waste with a high fat content						
slaughterhouse waste	74	34.6	53.8		7.7	3.9

[a] Cellulose and hemi-cellulose

[b] This column represents the remainder of the contents not included in one of the categories in each row, and brings the total percentage of the mass up to 100 %. This consists primarily of carbohydrate substances.

Table 2. Average elemental composition of vegetable dry matter of food waste

element	% by mass
carbon	45
oxigen	42
hydrogen	6
others	7
approximated empirical formula	$C_{38}H_{60}O_{26}$

Table 3: Gas yields of selected co-substrates

	DM %	ODM % DM	gas yield m³ CH_4/ kg oDM
liquid manure-chickens		15	0.2 – 0.4
liquid manure-pigs	5 – 7	77 – 85	0,2 – 0,3
vegetable matters	10 – 20	76	0,4
old bread	90	96 – 98	0,7 – 0,75
distiller's wash-potatoes	12 – 15	90	0,55
distiller's wash- crop	6 – 8	87 – 90	0,6
whey	95		0,5 – 0,6
oilseed residues	92	97	0,58 – 0,62
food oddments	9 – 18	90 – 95	0,5 – 0,6
flotate slurry		5 – 24	83 – 98

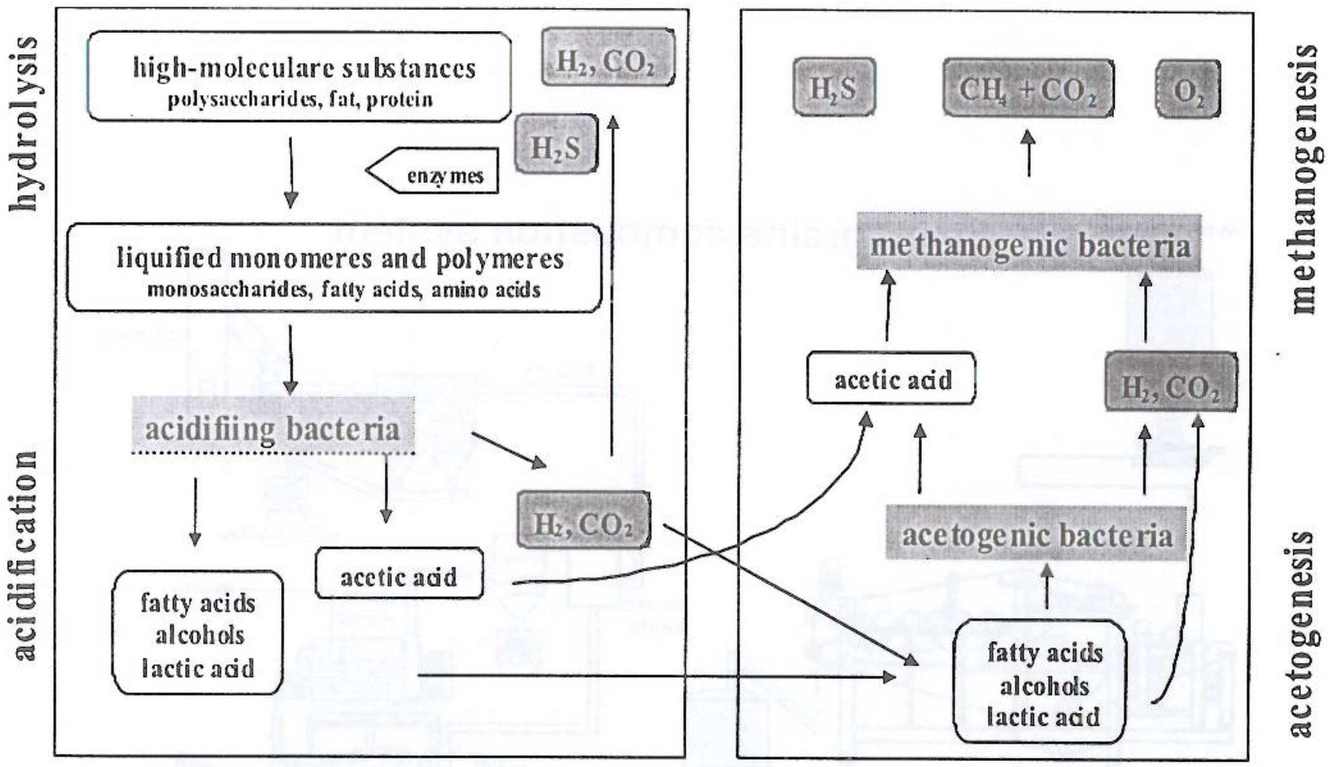

Figure 1: Degradation steps of anaerobic digestion (according to Grepmeier, in Pesta 2006).

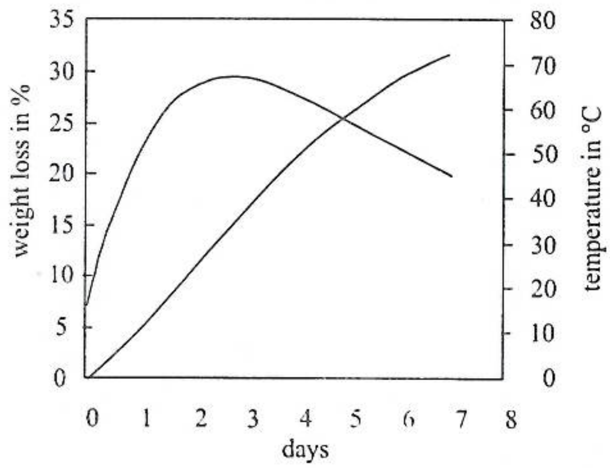

Figure 2: Weight loss and temperature of waste in a dry stabilisation system

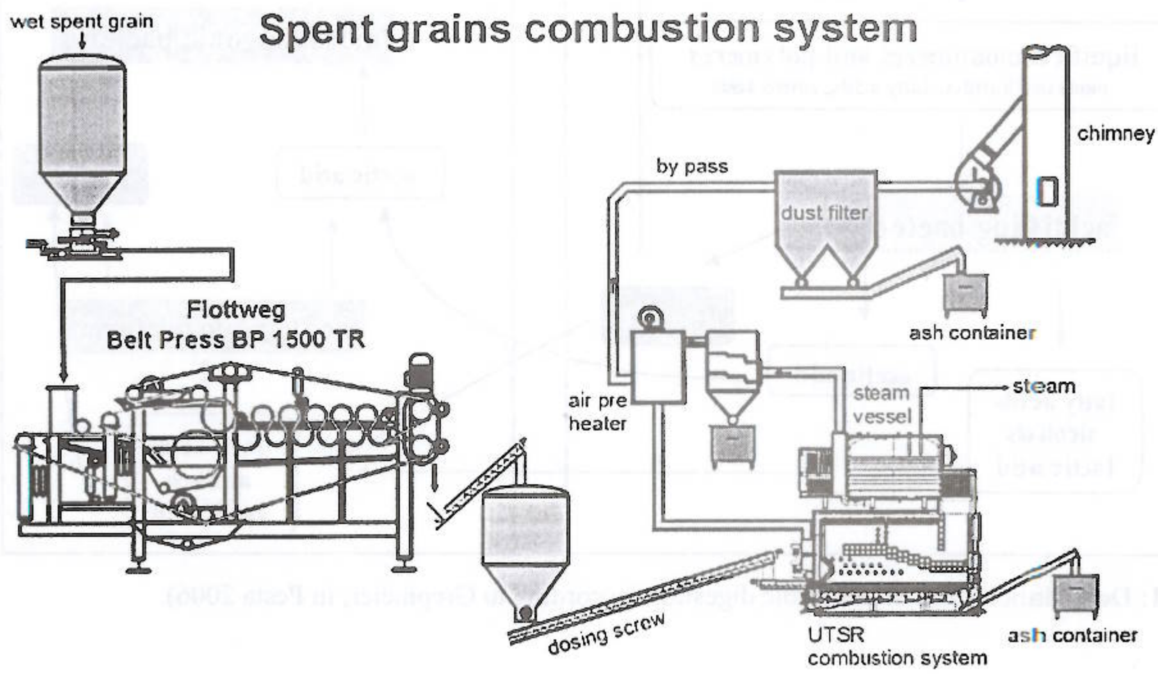

Figure 3: Spent grain combustion system (Kepplinger, 2006).

combined with several co-substrates like different food wastes.

The combination of several substrates allows changing the ratio of carbon to nitrogen in certain manner. The ratio of carbon to nitrogen influences the total gas yield and the performance of the biogas plant.

The content of methane in the produced biogas ranges between 50 and 85 % by volume. Usually the biogas is used in cogeneration plants with engines adapted to biogas.

Dry stabilisation of food wastes as energy saving technology

Dry stabilisation is a new promising alternative to the conventional thermal drying process. The waste is processed similar to the rotting process during composting. The process is a defined process under aerobic conditions, where easy degradable organic matter of wastes is decomposed under the release of heat. The process is mediated of different microorganisms actuating in aerobic environment like bacteria, fungi, actinomycetes, algae, protozoa. Under optimal conditions the degradation of biological material leads to an increase of the temperature in the rotting pile up to 70 °C. This heat can be used for the drying process by blowing air in the pile (Fig. 2).

After 6 – 10 days the easy degradable material is metabolized. The resulting material is drier and relatively stabile in its hygienic status due to the reduced water content and lack of directly convertible nutrients for microorganisms. The stabilized waste can be used in conventional incineration systems.

Incineration of food waste (e.g. spent grain)

Spent grains arise as a waste during the brewing process. They are residues from the extraction of sugars out of malt (germinated and kilned barley) in the brew house. Their water content is approximately 75 - 80 % by mass.

Using the spent grain as energy source is an interesting alternative. But without dewatering the calorific value is very low.

The core components are a dewatering system and the combustion. A suitable technology for the dewatering is a belt press. It generates the highest possible dry matter content by low costs of machinery. The water content is reduced from 80 % by mass below 58 % by mass. For the combustion a special vessel, adopted to the special burning characteristics of the spent grain, is necessary. The thermal rating of these boiler types is between 2 000 and more than 10 000 kW/h. It is possible to run the boilers at ± 25 % of nominal rating. The plant design, as it works in an Austrian brewery, is shown in figure 3. Burning out 1 t of wet spent grain approximately 1 000 kWh of thermal energy can be. The furnace is designed to the characteristics of burning wet biomass. e.g. a boiler with a nominal rating of 4 000 kW/h can be run at between minimum 3 000 and maximum 5 000 kW/h. (Kepplinger, 2001, 2003).

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