

04-04: Odd biomass fractions – Properties and processes

Introduction

There are mainly five different processes to choose from to produce useful energy from any type of biomass.

Three different thermal process routes

- Combustion for direct generation of heat and electricity in CHP-plants or co-firing in industrial processes,
- Thermal gasification for subsequent combustion of the gas (“product gas”) in CHP-plants, in industrial processes, or for further chemical processing of the product gas
- Pyrolysis for subsequent combustion of the solid, liquid and/or gaseous product fuel in CHP-plants, in industrial processes or further chemical processing of the pyrolysis product. The pyrolysis can be high-temperature (about 700 °C) or low-temperature (about 300 °C, “torrefaction”), yielding different ratios of solid residue (“char”), liquid residue (“pyrolysis oil”) and gaseous residue (“pyrolysis gas”)

Two different biochemical process routes

- Fermentation for subsequent combustion of the liquid fuel (alcohol, mainly ethanol) in IC-engines or as an additional fuel in CHP-plants, in industrial processes or as raw material for subsequent synthesis to a new product
- Anaerobic digestion for subsequent combustion of the gas (“biogas”) in IC-engines or as an additional fuel in CHP-plants, in industrial processes or as raw material for subsequent synthesis to a new product

The processes each have their own characteristic as outlined in chapter 04-00 and they all put different demands of the raw material entering the process.

For all the three thermal processes, a major aspect is the ash amount, composition and melting behaviour. Large amounts of molten ash may – in some types of equipment – cause severe operational problems and should be avoided. Volatile ash components such as some of the heavy metals will also escape in gas phase from high-temperature processes and may be a constraint to the choice of process. Inorganic materials will distribute between bottom ash and fly ash and the usefulness of this by-product will be affected of the process temperature and the process conditions. The water content of the fuel, i.e. the lower heating value, see section 04-00-01a, will also be an important factor.

For the two thermal conversion processes – gasification or pyrolysis – the total efficiency obtained in the more complex process in combination with the cost for the conversion as well as the market for the products are often the limiting factors.

For the two biochemical routes, the composition of the organic material (see 03-03-03) is one of the determining factors while the usefulness and the potential market for the residue as a fertilizer or a soil improvement agent is to a great extent influenced by the composition of the inorganic fraction.

Concentrating on combustibles from solid household waste (MSW) the most significant property is that it is variable between countries, regions and cities. The composition of the household waste is also population dependant in the respect that the refuse “produced” by different age and income groups in society tends to differ because of different consumption patterns and different standards of living.

However, some things may be stated.

Typically, the combustible fraction is composed by nine major components, here characterized by their ultimate analysis with respect to carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S), together with ash.

The analysis is given in % by weight on a dry basis and the (very approximate) reference heating value in MJ/kg:

	C	H	O	N	S	Ash	$q_{NET,DAF}$
1: Plastics	60	7.2	22.8			10	25.9
2: Rubber	78	10		2		10	37.2
3: Leather	60	8	11.6	10	0.4	10	27.9
4: Textiles	55	6.6	31.2	4.6	0.15	2.5	21.1
5: Wood waste	49.5	6	42.7	0.2	0.1	1.5	17.4
6: Paper	43.5	6	44	0.3	0.2	6	16
7: Cardboard	44	5.9	44.6	0.3	0.2	5	15.9
8: Food waste	48	6.4	37.6	2.6	0.4	5	18.4
9: Garden waste	47.8	6	38	3.4	0.3	4.5	17.9

Table 04-04 1: Typical ultimate analysis for combustible fractions in MSW

The plastic fraction is certainly combustible but is not biomass. Typically, the plastic fraction present in household waste is some 5-15 % and mainly consists of food packaging and plastic bags.

The two below the dotted line – food waste and garden waste – should both, preferably, be separated into the general waste fraction treated by anaerobic digestion rather than being present in the combustible fraction.

Federal European statistics on waste are not yet fully co-ordinated but compiling data from a number of different investigations one can see that the over-all composition between states tend to vary significantly with paper and cardboard about 20 ± 10 % and plastics 10 ± 5 % making up about one third of the total. Glass, ceramics and metal, together with other inert fractions like renovation waste and alike is typically about the same amount, one third, with biodegradables making up for the rest. However, as pointed out, the composition is highly variable and depending on local/regional conditions.

Using 16 MJ/kg for the paper fraction (20 % by weight), 26 MJ/kg for plastics (10 %) and 18 MJ/kg for biodegradables (33 %), the remaining 37 % non-combustible this yields 11-12 MJ/kg dry material.

The moisture content in the fuel fraction depends strongly on the fractions present but is also affected by the way the collection is organized but may generally be assumed at about 20 %, finally yielding a typical heating value for the wet waste about 8-10 MJ/kg. This is a typical value and may well be used for dimensioning purposes though it must be remembered that the collection logistics (see chapter 03-04) will have a strong influence and may contribute to a higher value.

As mentioned previously (chapter 01-04), the content of chlorine in MSW may sometimes be high, almost up to 1 % by weight (dry basis). The chlorine sources are mainly two, namely plastics (i.e. PVC) and common salt as remains in food residues. In combustion, chlorine may contribute to the formation of chlorinated hydrocarbons, such as dioxin. Since any detailed description of the combustion chemistry would go far beyond the scope of this handbook, this has not been mentioned explicitly but the role of chlorine has been mentioned several times in chapter 04-00 and one major role of the “waste incineration directive”, 2000/76/EC, is to suppress the formation of such compounds. Hence, any waste combustion equipment aimed for waste fuels must be thoroughly dimensioned to fulfil the demands set in this directive.

04-04-01: Direct combustion

Whichever are the previous processes, the final extraction of the energy contained in a fuel is always through a complete oxidation. In case this oxidation occurs in a fuel cell, as may be the case with pure fuels such as purified alcohol, hydrogen or purified hydrocarbons, it is usually not called “combustion” – but in all other cases it is. You find fuel cells mentioned in text section 04-00-09, but since the fuel cells require a very clean fuel they would not be a realistic alternative for fuels produced from waste fractions.

In the present context, we shall use the term direct combustion for the combustion of the solid, combustible fraction resulting from a proper fractioning of solid, municipal waste and for sorted and clean combustible fractions of solid industrial and societal waste.

A general introduction to direct combustion is found in 04-00-02 and some more details will be found in 04-00-08, especially in 04-00-08e about district heating, 04-00-08f and -g outlining system aspects about CHP and electricity production and 04-00-08h where solid-fuel boilers are introduced.

With waste, the ash content is usually high, only scarcely below 15 % by weight, and the ash starts melting already at low temperatures, sometimes as low as 700 °C. Typically, the waste will be shredded prior to feeding into the boiler and magnetic materials will be separated, but there will still be significant amounts of ashes and the melting temperature will not be affected by the separation of magnetic materials.

Hence, boilers for direct combustion will have to be designed to cope with large amounts of molten ash in the fireplace. Such dedicated boiler designs are available on the market since long and show a very high availability and reliability.

The gases from waste combustion will contain several corrosive components in relatively (as compared to clean biofuels) high concentrations. In CHP-applications, this will limit the steam superheating temperature, usually to about 350-420 °C, and hence the total electricity efficiency that can be obtained from waste combustion.

Direct combustion for heat production or, if the low electricity efficiency can be accepted, CHP is one major alternative for the combustible waste fraction.

04-04-02: Thermal gasification

The product gas flow after a gasifier is smaller than the gas flow after combustion and hence it may be cheaper to clean the gas from corrosive and other harmful components after a gasification process. However, the gas cleaning requires that the gas is cooled, and this will then involve a process where heat is lost and the total efficiency be lowered. In some cases – provided the gas can be sold or used in a process where the added value is high enough – this may sometimes prove a more feasible way than direct combustion.

The product gas, depending of the gasification process (see text section 04-00-01), may have a high heating value and may even be used in gas turbine cycles (text section 04-00-08f). The gas can also be used in industrial processes.

In spite of the cost increase and the efficiency decrease through gasification, this is sometime a feasible alternative for thermal treatment of the combustible waste fraction.

04-04-03: Pyrolysis, including torrefaction

Basically pyrolysis – be it a high or low temperatures – aims at producing combustible gas, a combustible liquid and a combustible solid. In a low-temperature process like torrefaction, typically about 300–400 °C the main part of the inorganic fraction will be retained in the solid fuel, the char. Hence, the solid fuel produced may exhibit a higher heating value but it will usually not be environmentally superior to the original fuel.

At higher pyrolysis temperatures, a larger fraction of the energy-containing compounds will be distilled off from the char and will instead be found in the gas or in the liquid. At the same time, a larger fraction of the impurities will also be distilled off from the char. So the higher the pyrolysis temperature, the cleaner the char but at the same time the total energy retained in the solid fuel is reduced. Impurities from the fuel will distribute between the gaseous fuel (pyrolysis gas), the liquid fuel (pyrolysis oil) and the solid fuel (char) and the distribution will be temperature- and process dependant.

Pyrolysis of an extremely complex mixture of materials – such as a waste fraction – will be a highly unpredictable process because of varying feed composition and varying heating value. Hence, the products will also become unpredictable and it will be virtually impossible to claim that the process adds value to the products to such an extent as to defend the cost increase inherent in an additional process step.

However if a specific fraction, such as car tyres or similar, can be separated, the situation changes completely and pyrolysis may become a viable process adding significant value to the feedstock – from an energy perspective.

04-04-04: Biochemical fermentation

Obviously, biochemical treatment of waste should be exclusively restricted only to the wet organic fraction and not to the combustible fractions.

Alcohol fermentation, which is what we typically mean by the word fermentation in this context, requires that the feed contains sufficient amounts of readily available fermentable sugars (refer back to 04-00-01). Such sugars are known as hexoses, i.e. they contain six carbon atoms in the molecule, while many of the sugars present in biomass as a whole only contain five carbon atoms.

In case an organic fraction with high sugar content is easily available in sufficient amounts, such as waste from a sugar factory, it may be feasible to erect a separate fermentation plant. If this is not the case it is most probably wiser to mix the sugar-rich waste with a substrate containing more nitrogen and feed the mixture to an anaerobic digester.

04-04-05: Biochemical (anaerobic) digestion

Basically, any organic material can be biochemically decomposed and anaerobic digestion is one main mechanism. However, different materials will decompose at different rates and the gas produced (“biogas”) will also differ in composition.

As shown in text section 03-03-05a, the biogas from digestion of organic waste will typically exhibit significantly lower methane contents as compared to the gas produced from manure or from wastewater treatment plants. You will also notice, see table 03-03 2, that the gas from household waste will contain more of chlorinated compounds and more of aromatic hydrocarbons.

The amount of chlorinated compounds is partly due to the presence of salt in the organic (food-) waste from households and may give rise to corrosion problems in case the un-cleaned biogas is used in an IC-engine for CHP.

Also the digestate from waste digestion will be contaminated and cannot be used as a soil improvement agent or as a fertilizer on agricultural land.

Both properties – the lowering of the gas quality and the lowering of the digestate quality – tend to point towards one and the same conclusion: Anaerobic digestion of waste streams should be kept separate, to disturb neither the quality nor the process stability in digestion processes fed with cleaner substrates.

04-04-06: Planning aspects

Direct combustion for heat production or, if the low electricity efficiency can be accepted, CHP is one major alternative for the combustible waste fraction.

In spite of the cost increase and the efficiency loss through gasification, this may sometime be a feasible alternative for thermal treatment of a combustible waste fraction.

Pyrolysis of an extremely complex mixture of materials – such as a waste fraction – will be a highly unpredictable process because of varying feed composition and varying heating value. Hence, the products will also become unpredictable and it will be virtually impossible to claim that the process adds value to the products to such an extent as to defend the cost increase inherent in an additional process step.

To make the pyrolysis process economically viable, the product fuel must be predictable and to achieve that, the feedstock must consist of a well-defined fraction sorted out from the waste stream. If this can be achieved, then pyrolysis may be a very good way to produce a useful secondary fuel out of a waste fraction

In case an organic fraction with high sugar content is easily available in sufficient amounts, such as waste from a sugar factory, it may be feasible to erect a separate fermentation plant. If this is not the case it is most probably wiser to mix the sugar-rich waste with a substrate containing more nitrogen and feed the mixture to an anaerobic digester.

Since the presence of household waste tends to lower not only the gas quality but also the digestate quality, anaerobic digestion of waste streams should be kept separate, to disturb neither the quality nor the process stability in digestion processes fed with cleaner substrates.