Raw material requirements of biorefinery processes: Introduction and summary

The raw material quality requirements of important biorefinery processes have been surveyed. It is concluded that homogeneity and correct characterization of the feedstock may be as important as its particular properties. The cost per unit energy content is a likely key parameter for many biorefinery processes. The cost per mass unit of sugars and the composition of the sugars is important for biochemical processes. There is a trade-off between the cost to tailor a feedstock for a given process and the costs and additional complexity involved in adapting a process for a range of feedstock properties.

Background

The raw material quality requirements of future biorefineries may differ from those of the current industries. Different raw material characteristics may be desirable for different types of biorefineries, and the industry can be expected to strive to acquire raw material with high value for their process at the lowest possible cost. An important task of the forest refine project is to find relevant parameters to characterize the raw material by, and to describe the key characteristics that are relevant for different biorefinery processes. This info-sheet covers several key biorefinery processes, but excludes pulping processes, which will be included in future publications. Transportation, storing and feeding properties of the feedstock may be very important for all types of biorefineries, but are not discussed in this info-sheet.

Stakeholder Survey

Existing knowledge about raw material quality requirements for biorefineries have been surveyed through a review of technical and scientific publications, and through contacts with stakeholders. A questionnaire has been produced and used as the basis for acquisition of information from stakeholders. A number of stakeholders have been contacted and interviewed – in a physical meetings or over telephone - and the questionnaire has further been emailed to a number of stakeholders. However, none of the stakeholders who only received the questionnaire by email responded. It can be concluded that it is necessary to make direct contact with the stakeholders in order to acquire this kind of information.

Results

Some general observations can be made. Firstly, since many of the biorefinery technologies are still in a development stage, there is no complete picture of their respective raw material requirements in industrial-scale applications. Some of the ongoing development work specifically aims at adapting the processes so that they can accept a wider range of feedstock qualities. Thus, there are no definite, fixed, raw material quality criteria that have to be met. Rather, it is a question about the trade off between a stricter feedstock specification and a more complex process. It is also a question of where it is most efficient to perform feedstock preparation to adapt it to a specific process – at the industry or along the supply chain. A general observation is that a given process often can be adapted to handle specific feedstock-related problems, but that variations in the feedstock properties may be more difficult to handle. Hence, cost-efficient supply of a homogenous, well-characterized feedstock would be highly prioritized from the industry's point of view. Cost per unit energy content would be a key parameter for biorefineries which produce energy products (such as solid and liquid fuels, heat and electricity). The cost per unit mass of sugar molecules, and the composition of the sugars, would be important to biorefineries based on sugar chemistry (for example cellulosic ethanol production via the biochemical route).

Forest feedstock contains a huge variation of small-volume substances which could, potentially, be utilized for high-value chemical products. Certain parts of the tree (such as the knots) are richer in these substances. However, commercial developments within this area are scarce, and the present study has, so far, not been able to draw any general conclusions regarding feedstock requirements for these high-value chemical applications. The requirements will probably be highly specific to the individual application.

The influence of key raw material properties on important biorefinery processes have been summarized in Table 1. The information in Table 1 draws on a report by Väisänen (2010), in addition to the stakeholder interviews. The main biorefinery processes are briefly described in the following.

Pelletizing
Small particles are pressed through a die with holes to form pellets of a desired dimension. The process requires a relatively dry feedstock with adapted particle size. The energy requirements of the pelletizing process and the physical durability of the pellets are affected by the raw material properties. The intended end-use of the pellets determines the quality requirements.

Thermochemical processes
In thermochemical processes, the feedstock is chemically converted through the application of heat and, potentially, an oxidizing medium such as air, oxygen or steam. Thermochemical processes can be characterized by the reaction temperature, time and availability of oxidizing medium.

Torrefaction is a pre-treatment process performed at relatively low temperature and long time, in the absence of an oxidizing medium, to obtain a compact and brittle solid material.

Pyrolysis is performed at higher temperature in the absence of an oxidizing medium, often with a liquid as the main product, which can replace fuel oil or be upgraded to other fuels or chemicals

Gasification is typically performed at even higher temperature, with a limited supply of oxidizing medium to produce a gas consisting of, mainly carbon monoxide, carbon dioxide, hydrogen, methane and nitrogen, the exact composition depending on the process conditions. The gas can be used for conversion into fuels and chemicals or combusted for heat and power production.

Combustion generates heat by the full conversion of the feedstock into, mainly, carbon dioxide and water, through complete oxidation. The heating value, moisture content, the ash content and the ash properties are, in general, relevant for thermochemical processes. The particle size governs the reaction rate, which is a key parameter.

Biochemical processes
Biochemical processes apply enzymatic processes to chemically convert the feedstock. An example is the hydrolysis of polymeric sugars (cellulose and hemicelluloses) into monomeric sugars through enzymatic treatment and subsequent fermentation of the sugars into ethanol by microorganisms. Important raw

material properties include the molecular composition (especially concerning the sugars content and type of sugars), properties affecting the accessibility of the enzymes or microorganisms to the substrate and the tendency of the feedstock to produce unwanted substances in the process, which inhibit the biochemical reactions.

Table 1. Summary of key raw material properties' influence on important biorefinery processes.

	Feedstock composition	Physical properties	Other
Pelletizing	Lignin is beneficial for pellet production while high concentrations of extractives may be unfavorable. The acceptable ash content varies with the end use. Household pellet boilers and stoves generally require low ash content, and thus low bark content in the feedstock. Impurities such as sand and rocks can be very detrimental to the pelletizing equipment.	Ideal moisture content to the pelletizer is around 10%. The material may have to be dried or wetted. Particle sizes to should not exceed 60% of the pellet diameter (typically 6-10 mm). For the drying process, a small particle size is beneficial. The desired particle sizes may also vary with the end use. Smaller particle sizes are preferred when the pellets are crushed into dust before end use.	Variations in particle size and moisture content cause severe problems in drying and pelletizing. Uneven moisture content of the dried material and plugged die holes in the pelletizer may be the result. The desired properties are to a large extent governed by the intended end-use of the pellets.
Combustion	A high heating value is desired, but also the ash content and ash characteristics are of interest. Relatively insensitive to impurities, although both ash and non-wood components are undesirable. Metals, salts and large rocks may cause big problems. The sensitivity to impurities and ash properties vary with the combustion technology. Grate boilers tolerate impurities well in comparison to other combustion methods.	Higher moisture content gives lower heating value of the raw material, which is generally unfavorable, but large-scale combustion technologies are relatively insensitive to moisture content. Particle size is not crucial for large-scale combustion technologies, but should preferably be known, so the process can be adapted. Very small particles – fines – may cause problems.	Fluctuations in the raw material feed may lead to high levels of unwanted emissions from the combustion. Some raw material variability can be accepted but abrupt changes are difficult to handle. Variations may also cause feeding problems. In general, grate boilers are more sensitive to particle size variations than BFB boilers.
Gasification	The ratio between oxygen, hydrogen and carbon in the feedstock affects the gasification process and should preferably be known. Catalytic conversion of the gas into fuels or chemicals is negatively affected by sulphur, phosphor and alkali metals. Gas turbines less sensitive but corrosion and erosion may be problems. For indirect gasification, more volatile substances and less coke is desirable. Ash content and properties are important. Low ash melting point is a problem in FB gasification. Impurities may cause jams in feeding equipment. Metals are detrimental as they cause corrosion and sintering of bed material in FB gasifiers. The content of, for example, active silicon, phosphor and calcium affects the ash melting behaviour. Clay minerals may reduce potassium-related problems.	Moisture levels should be below 10-20% for syngas production (depending on gasification technology). EF gasifiers require lower moisture content than does FB gasifiers. Drying is often needed and could preferably be integrated with the gasification process. Desired particle size depends on gasification process, but, in general, the size must not vary much. EF gasifiers require a powder-like feed (particle size typically lower than 0.5 mm) but large fractions of too fine material may also cause problems. FB gasifiers are more tolerant to feed quality changes and larger particle sizes (up to 50 mm for BFB gasifiers). Too fine materials may cause problems, especially in BFB gasifiers, while circulating FB gasifiers are less sensitive.	Raw material homogeneity is very important to gasification processes. The moisture level affects the consumption of gasification agent which must be carefully controlled. EF gasification is particularly sensitive to particle size variations. Feeding, especially to pressurized reactors may be problematic. Bulk density is one important parameter. For the EF process, grinding of the feed into a suitable powder is crucial. Factors that affect the grindability, such as moisture content, are important. Also, less fibrous material, such as bark and torrefied materials may be easier to use.
Pyrolysis	Impurities are detrimental to the pyrolysis process. Rocks and metal parts must be removed. High levels of extractive substances in the raw material reduce the yield. The effect of impurities in large-scale applications is not yet totally clarified.	Pyrolysis processes require moisture content to be below 10%. Variations in moisture are generally also a problem. In fast pyrolysis, particle sizes should be small (<3mm).	A homogenous feed is desired. Variations in the feed properties cause undesired variations in the end products' properties.
Torrefaction	All organic matter is of interest. High share of easily volatilized substances lowers the yield. Relatively insensitive to impurities. However, the amount of impurities and ash etc affects the end product quality. The quality requirements depend on the intended end use.	The material needs to be pre-dried before entering the torrefaction process (to ~10%). The particle size is not so critical. Chips (10x20x40 mm) is good. High share of fines may give dusting problems. Oversized material may give feeding problems.	Homogeneity in particle size and other properties is beneficial for process optimization – easier to get homogeneous degree of torrefaction.
Hydrolysis	The content and composition of sugars is important. For fermentation to ethanol, glucose is preferred, followed by other hexoses. Pentoses are more difficult to ferment. There are three main groups of fermentation inhibitors: Furans (sugar degradation product), acids, especially acetic acid (mainly from hemicelluloses) and phenols (probably from lignin). Lignin is in general undesirable as it lowers sugar yields and has a negative affect on enzymatic hydrolysis. Also extractives may cause some problems in the process. Hydrolysis is relatively insensitive to impurities. Sand and rocks cause wear on equipment.	Moisture is not a big problem in ethanol production, however, the feedstock should not be too dry. Small particle size is in general desirable, but various sizes, such as chips and sawdust can be used. Fine materials may cause problems in filtering operations.	The particle size should be homogenous to control process conditions. Moisture variations are tolerable, but process optimization is easier with stable moisture content. Bark may cause problems according to some sources. Some sources say that bark and logging residues can be handled.

Nomenclature: EF: entrained flow, FB: Fluidized bed, BFB: Bubbling fluidized bed

KEYWORDS

Biorefinery processes, forest biomass, biomass properties, feedstock quality requirements, feedstock characterization

LITERATURE

Väisänen, J. (2010). The requirements for wood based biomass in different bio energy processes and biomass properties and logistics. TAMK University of Applied Sciences.

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