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Biomass Conversion to Intermediate Bioenergy Carriers, Sustainable Biofuels and Bio-Based Products

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PRODUCTION OF CLEAN AGRO-PELLET COMMODITIES (CAPCOM) FROM AGRO-RESIDUES

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ABSTRACT: Large quantities of biomass will be needed to feed the biobased economy. Use of crops and wood may cause (indirect) land use change related greenhouse gas emissions. Agro-residues could be an interesting alternative. However, several issues are hindering efficient application: high potassium and chlorine content and low bulk density are the most important issues. In this research, a series of processes is proposed to overcome these issues. Through a combination of extraction (to remove potassium and chlorine), steam treatment and pelleting, Clean Agro-Pellet Commodities(CAPCOMs) were produced. The pellets showed improved handling properties. Combustion tests showed improved ash melting behavior, reduced fouling of heat exchangers and low emissions of NO_x and fines. Fermentation tests showed that pellets produced at low severity factors were easily hydrolized and fermented to produce ethanol at normal yields. Some inhibition was seen with undiluted hydrolysates. Based on the results a techno-economical evaluation showed that pellets from agro-residues could be produced and transported at a cost of around 6 EURO/GJ_{HHV}. Sustainability analysis revealed that pellets could be produced with GHG emissions of 3 to 6.4 $kgCO_{2eq}/GJ_{LHV}$. Via the combination of processes described in this paper, a huge potential of nowadays unused biomass can be made applicable for the bioeconomy.
Keywords: agro-industrial residues, agro-pellet, alkali, fermentation, pretreatment, CO_2 reduction

1 INTRODUCTION

Large quantities of biomass will be needed to feed the biobased economy. Use of crops and wood may cause land use change related greenhouse gas emissions. Agro-residues could be an interesting alternative, but several issues are hindering efficient application: high potassium and chlorine content and low bulk density are the most important issues.

In this paper the outcomes of a recent project named CAPCOM-NL are presented. The CAPCOM-NL project aims at the development of a series of processes to produce an intermediate commodity from agro-residues. This commodity should be stable, dense, nutrient depleted and applicable in both thermochemical and other biobased applications. Bagasse, Sugar Cane Trash (SCT) and Empty Fruit Bunch (EFB) were taken as starting materials.

First, extraction with a counter current simulated moving bed was applied to remove potassium and chlorine (Chapter 2). Thereafter, steam pretreatment and pelleting were applied to achieve higher density, better stability, improved grindability and to make the biomass available for enzymatic hydrolysis (Chapter 3).The produced commodities were tested for logistic properties, combustion applications as well as fermentation applications (Chapter 4) [1].

Furthermore, based on the experimental data, a process design was made (Chapter 5) [2]. This process design was used in performing preliminary techno-economic and sustainability analysis in order to assess feasibility and environmental performance of the agro-pellets (Chapter 6 and 7) [3].

2 REMOVAL OF POTASSIUM AND CHLORINE

2.1 Principle

Potassium, chlorine and other water soluble components are removed from the biomass via extraction with water. Water is sprayed over the biomass and will leach out the water soluble components. In order to reach sufficient removal with a minimum amount of water, a counter current simulated moving bed (CC SMB) setup was used [1].

In CC SMB Extraction, a series of columns is applied to efficiently extract the target components from the biomass. The extraction liquid runs from top to bottom through each column. After a certain period (the switch time), valves are actuated to shift the liquid flow to the next column. This way, it seems as if the solids are moving from right to left (Figure 1).

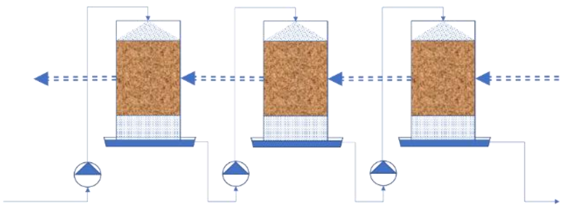

Figure 1: CC SMB Extraction Setup

2.2 Experiments

Single column extraction trials were performed. The conductivity of the effluent was measured as a proxy for the concentration of monovalent ions (

Figure *2*). The expected behaviour for a continuous stirred tank reactor (CSTR) without mass transfer limitation is given by line D. A logarithmic fit of the last 7 data points (where mass transfer limitation is dominant) is given by FIT. It was shown that the characteristic time for mass transfer was around 1-2 hours.

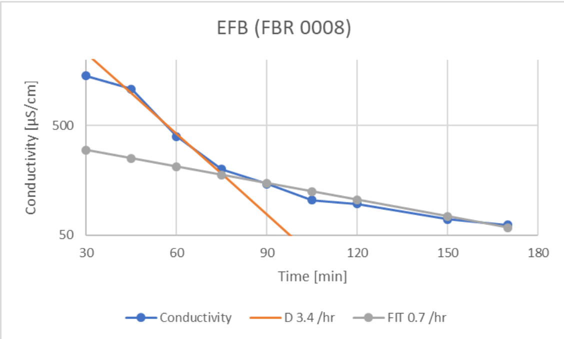

Figure 2: Conductivity profile for single column EFB extraction

A pilot scale CC SMB extraction with three columns in series was performed. Based on the single column experiments, a switch time of 2 hours was applied. The ash and potassium content were reduced and the ash melting behaviour was improved (Table I).

Table I: Properties of raw vs. extracted EFB

		EFB	Extracted EFB
Ash content	w/w%	5.15	2.06
Potassium	g/kg	20.7	1.3
SST	°C	910	740
DT	°C	1040	1150
HT	°C	1150	1360
FT	°C	1180	1410

SST Shrinking Starting Temperature
DT Deformation Temperature
HT Hemisphere Temperature
FT Flow Temperature

3 PRETREATMENT AND PELLETING

The biomass was pretreated with steam at different severity factors (Table II) [1]. The severity factor is a function of time and temperature that indicates the severity of the treatment. Pelleting of pretreated samples was much easier than pelleting of raw materials. Steam treated biomass flowed through the pelletizer more smoothly. A reduction of up to 30% energy consumption could be expected at industrial scale by using steam treated biomass compared to raw biomass.

Table II: Applied severity factors

Bagasse	SCT	EFB
		3.6
3.9		3.9
4.2	4.2	
4.6	4.6	

4 PELLET TESTING

The pellets were tested for their logistical properties, for application in combustion processes and for application in fermentation processes [1].

4.1 Testing for logistics

The pellets were tested for their logistical properties (density, durability and biological stability). The density of all pellets was around 600 kg/m^3. The durability was tested acc. toEN15210-1, 2009: pellets are tumbled in a cage and the loss of mass through fines was measured: the remaining mass (>3.15 mm) is a measure of durability. All pellets showed reasonable to good durability. Good durability was seen for bagasse and EFB treated at a severity factor of 3.9.

The biological stability is usually a function of water uptake from the environment. Therefore the pellets were incubated in humid air and the moisture uptake was monitored in a climate chamber (28 °C and RH 90%). Clearly the pretreated pellets showed less moisture uptake. At the same time, the loss of dry matter was monitored as an indicator for biological degradation (Fig.3). Here it was observed that biological degradation was reduced for pretreated pellets in the beginning of the experiment, but increased in later stages, when moisture uptake becomes significant (10-15%). This was also obvious from visual inspection, where molds were observed to grow faster in the steam exploded pellet materials after c.a. 1 month.

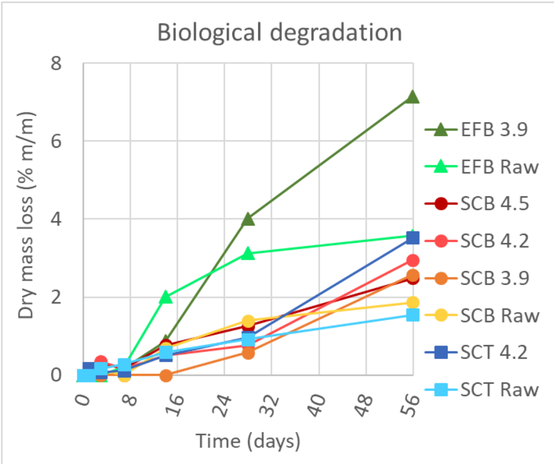

Figure 3: Biological stability tests

4.2 Testing for combustion

Combustion tests were performed in a Combustion and Gasification Simulator (LCS). Washed materials clearly showed less fouling potential, given by the slope of the lines depicted in Fig. 4. Fine particle formation was significantly reduced after washing of the biomasses and the NO_x formation was lower compared to coal combustion. This clearly shows that agro-wastes can be successfully upgraded to replace the fossil fuel in coal power stations.

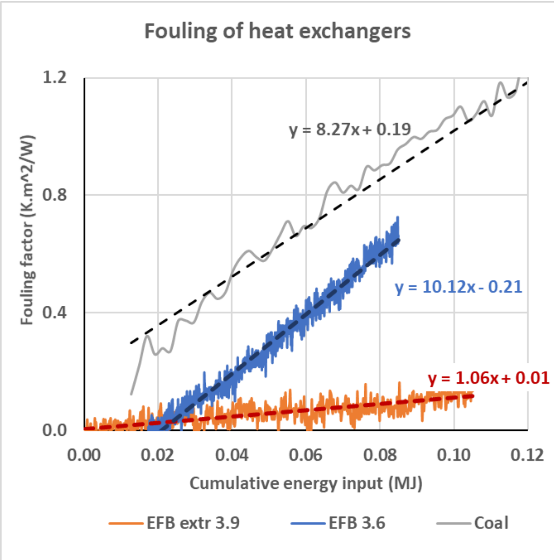

Figure 4: Combustion tests (heat exchanger fouling)

4.3 Testing for hydrolysis and fermentation

Selected samples were hydrolysed. Good sugar yields were reached with EFB pretreated at a severity factor of 3.6.

Fermentation was performed in diluted and concentrated hydrolysates. The fermentation on diluted hydrolysate should indicate the maximum yield of ethanol on fermentable sugars, the fermentation on concentrated hydrolysate should indicate any toxicity issues. From the experiments (Fig.5) it is clear that sugar is readily converted into ethanol. The concentrated hydrolysates show a longer lag phase, indicating some toxicity. In the end however, this toxicity was overcome and nearly all glucose was converted to ethanol.

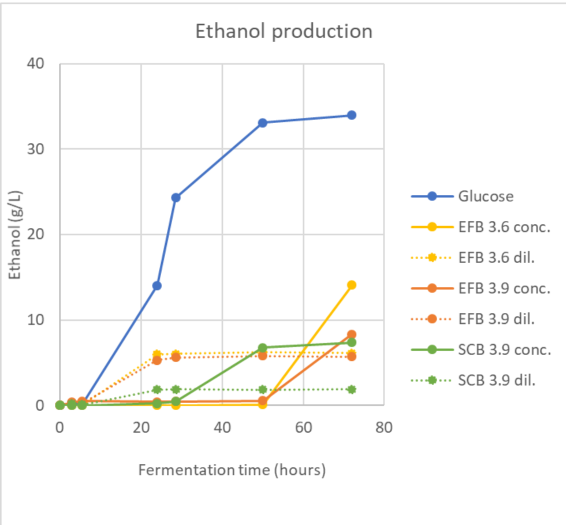

Figure 5: Concentration of ethanol as a function of time

5 PROCESS DESIGN

Based on the experimental data, mass and energy balances as well as a process design were made [2].The washing, pretreatment and pelleting were assumed to take place at or adjacent to the sugar cane mill or palm oil mill. Therefore, heat and electricity can be retrieved from the boilers of the main process and no transport will be needed for process residues. Transport of sugar cane trash from the field to the sugar mill was taken into account in the economic evaluation and sustainability analysis.

The sugar cane bagasse (SCB) is already processed in the sugar mill with an extraction process and therefore the washing step was skipped. On the contrary, the trash (SCT) and the EFB needed to be pre-washed to remove the K and Cl, prior to steam explosion. The mass balance calculations, based on the experimental results, gave a mass yield of 0.76, 0.78 and 0.90 for the SCT, EFB and SCB CAPCOMs respectively. The energy yields were 0.78, 0.85 and 0.96 for the SCT, EFB and SCB CAPCOMs respectively. The estimated total net-energy required (electricity plus heat) per input biomass energy (based on the HHV of the biomass on dry basis) was about 20% for the SCT and EFB and about 14% for the SCB (no washing required).

6 ECONOMIC EVALUATION

Based on the process design, an economic evaluation was made. It was shown that the pellets could be produced at 6 Euro/GJ$_{HHV}$ (Fig. 6) [3]. In all cases the transport costs are considerable. The costs are lowest for the pellets produced from EFB. This is caused by the low feedstock costs as well as the value of fertilizer that is assumed to be returned to the field (which was taken as negative costs).

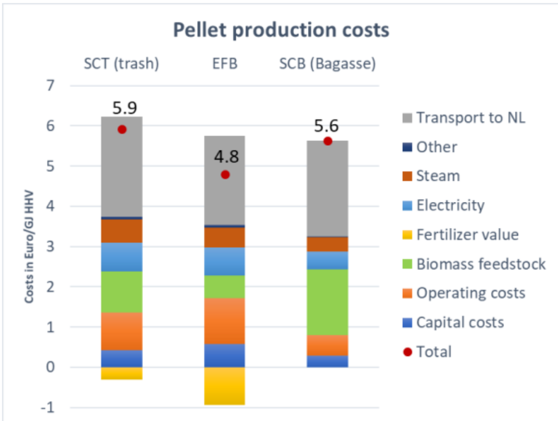

Figure 6: Pellet production costs

7 SUSTAINABILITY ANALYSIS

Based on the process design, a sustainability analysis was performed. It was shown that the GHG emissions vary from 3 to 6.4 kgCO_{2eq}/MJ$_{LHV}$ (Fig. 7) [3].Transport emissions show the highest contribution to the overall impacts. The emissions are lowest for EFB derived pellets. This is due to the low transport emissions (for EFB transport by rail over a shorter distance than for the sugar cane residue derived pellets was assumed) and due to credits for the returned nutrients (which were taken as a negative emission).

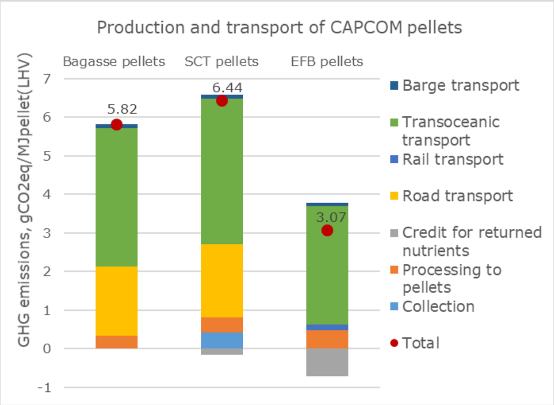

Figure 7: GHG emissions for agro-residue based pellets

8 CONCLUSIONS

The extraction experiments have shown that potassium and chlorine can be removed by extraction with water. The typical characteristic time for mass transfer is around 1-2 hour.

After pretreatment the biomass flows through the pelletizer more smoothly. This is expected to reduce the energy demand of the pelleting process.

Steam treatment reduced the initial water uptake rate of the pellets, but increased mould growth was seen after one month. Pellets treated at a severity factor of 3.9 showed durability values of 99%. All pellets showed low emissions of fines and NO_x. The extracted materials showed less fouling of heat exchangers than raw materials. The lowest severity factor resulted in the best hydrolysis results. The hydrolysate could be fermented to produce ethanol. The concentrated hydrolysates showed a longer lag time, indicating some toxicity that can be overcome by standard yeasts.

Pellets produced from residues could be produced and shipped to Europe at a cost of around 6 Euro/GJ_{HHV}. GHG emissions vary from 3 to 6.4$kgCO_{2eq}/GJ_{LHV}$.

A procedure for production of agro-residue derived commodities was developed. So far, it was not possible to produce a commodity that has ideal properties for both combustion and fermentation applications. Pellets optimized for fermentation applications would still be applicable in combustion processes. An alternative solution would be the production of two types of pellets: one for combustion applications and another for fermentation applications. Both types could be produced with the same equipment and could share the same distribution lines.

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