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INFLUENCE OF INCREASING SHARES OF MISCANTHUS ON PHYSICAL AND MECHANICAL PROPERTIES OF PELLETS PRODUCED IN AN INDUSTRIAL SOFTWOOD PELLETS PLANT

Part 2: Results & Conclusions

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Abstract

It has been possible to pelletize Wood-Miscanthus mixtures (12.5 – 25 & 50%) without modifying production process settings of a softwood pellets plant. Pure Miscanthus material tested in the same conditions has led to unstable production, mainly explained by hammer-mill overfeeding. The unstable production has been identified as the main responsible factor of the low quality of pellets produced with pure Miscanthus for these trials. The produced pellets were tested in a 25 kW boiler and compared with agro-pellets of various origins: winter barley straw, rapeseed straw, reed, old hay, Miscanthus, &wood pellets. During the trials, O_2, CO, CO_2, CH_4, SO_2 and NO_x emissions were measured. The flue gas chlorine (content was also determined and the data were linked to the specifications of the fuels used. Trials showed that pure agro-pellets do not reach the combustion quality of wood or wood-Miscanthus mixes.

Keywords: pellets, miscanthus, solid biofuels, wood, mixture, physical properties, combustion, emissions, straw, agro-pellets

3. Results

3.1. Pelletizing trials on wood Miscanthus mixes

a. Raw material and pellets moisture content.

The raw material moisture content stays stable for the different mixture and is about 10%, which is appropriate moisture content for pelletizing process. The standard deviation indicates variations of this parameter within mixtures are low.

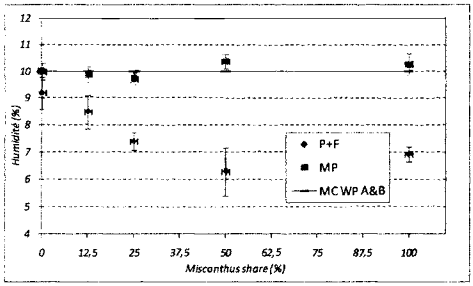

Figure 5. Mixture moisture content prior and after pelletizing (standard deviation as error bar). *– P+F : Pellets and Fines – MP : raw material – MC WP A&B : class A and B moisture content limit*

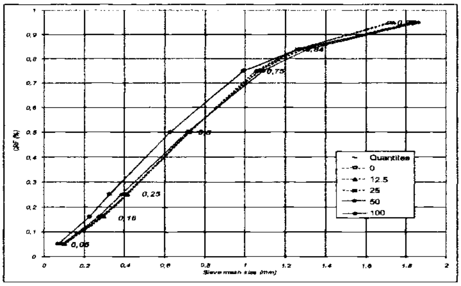

Figure 6. Cumulated relative distribution and quantile for particle size of the tested mixtures, prior to pellets press feeding – 100 - 50 – 25 - 12,5 – 0 are the Miscanthus proportion for the different mixtures.

Pelletizing process induces moisture content losses, which is not surprising as the material is heated during the process. The variability of moisture content is higher compared to the raw material variability for this property.

If pure Miscanthus is not considered, the moisture content difference between raw material and pellets seems to become higher for higher Miscanthus shares in the mixture. But the moisture content of the produced pellets remains lower than 10%, which is the limit stated in EN 14961.

b. Raw material Particle size distribution

After milling, particle size distributions are similar for all mixtures, except for pure Miscanthus. If pure Miscanthus is not considered, 95% (quantile 95) of the particles have a size less than 1.8 mm. The median size of the distribution is about 0.7 mm. The particle size distribution of pure Miscanthus is smaller, 95% of the particles have a size less than 1.7 mm and the median size is about 0.6 mm. The thinner particle size distribution of pure Miscanthus may be explained by the overfeeding of the hammermill that occurred for that material. As particles remain longer in the milling chamber particlesthey become thinner. This could indicate the use of Miscanthus to produce pellets should be subordinate to pre-milling of the material or to process settings modification.

c. Mixture content influence on pellets Durability

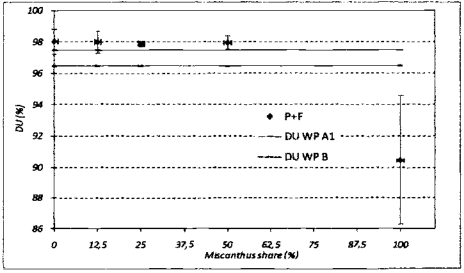

Figure 7 . Pellets mean durability for different wood-Miscanthus mixtures. (Standard deviation as error bar) – *P+F : Pellets & Fines – MP : Raw material – DU WPA1 : class A1 durability limit – DU WP : class B durability limit*

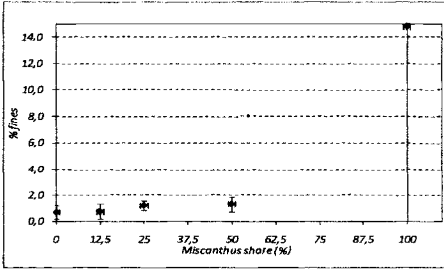

Figure 8. Fines proportion after cooling (but before screening) for different wood-Miscanthus mixtures. (Standard deviation as error bars)

The pure Miscanthus mixture has led to highly unstable production, if DU is considered. Moreover, in this case, the pellets mechanical durability is low. This low quality results have to be linked with problems that occurred during production for that mixture. In consequence, it may not be concluded the raw material as a direct influence on the durability of the production. Indeed other hypothesis may be proposed: the thinner particle size distribution compared to other mixtures, the unstable press feeding and the not adapted process settings regarding Miscanthus.

The other mixtures lead to more stable production and higher product durability. This allows the classification of the produced pellets in class A1, if only Durability is regarded.

d. Fines proportions

Except for pure Miscanthus (which produce up to 15% fines) the fines proportion after cooling is under 2% for all tested mixture. No comparison with EN14961 quality classes has been done for this property, as pellets will be further screened in a next step of the production.

e. Particle density

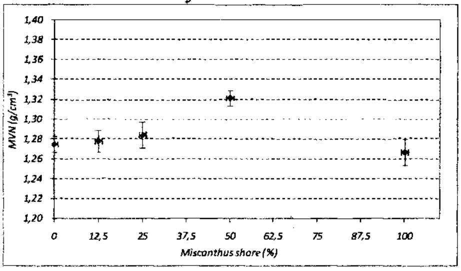

Figure 9 . Pellets particle density for different wood Miscanthus mixtures (Standard deviation as error bar).

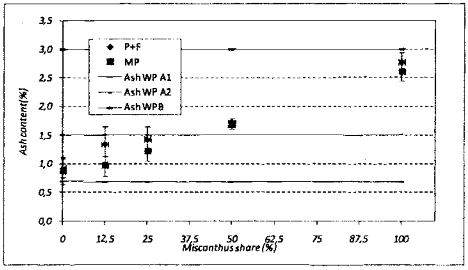

Figure 10 . Ash content for increasing shares of Miscanthus in the raw material and in the pellets produced. (Standard deviation as error bar – n=10) – *P+F : Pellets & Fines – MP : Raw material – Ash WP A1, Ash WP A2, Ash WP B: Ash content limits for classes A1, A2 & B, respectively*

Up to a share of 50% Miscanthus in the mixture, the particle density of the produced pellets seems to increase as a function of the Miscanthus proportion. Pellets made of 100% Miscanthus seem of lower particle density, which is most probably a consequence of the unstable production of this mixture. Further trials should include a 75% Miscanthus mixture, which would confirm the influence of the Miscanthus proportion on the particle density.

f. Ash content

Not surprisingly, the ash content increases as the Miscanthus share. No significant difference between ash content of raw material and the produced pellets has been observed, for any of the tested mixtures. This indicates there were no segregations between Miscanthus and wood

g. Gross calorific value

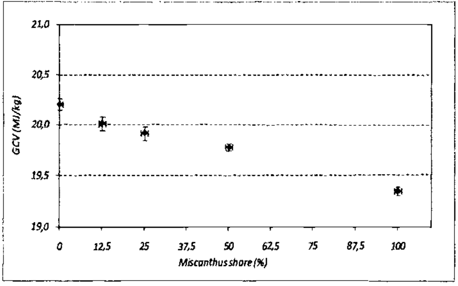

Figure 11 . Gross calorific value depending on the Miscanthus share in the mixture.

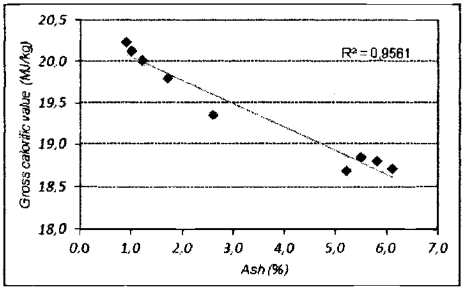

Figure 12. Gross Calorific Value (MJ/kg) plotted against Ash Content (%).

The higher the Miscanthus proportion is, the lower the gross calorific value is. This is explained by the higher ash content of the mixtures containing higher share of Miscanthus.

3.2. Combustion trials

a. Interaction between Properties of Test Fuels

The tests clearly illustrated the interaction (R^2=95%) between the gross calorific value and the ash content (Figure 7).

These interactions have already been shown many times in the literature (for instance: [1]).

b. Combustion related Parameters

CH_4 and CO Emissions

Both, CH_4 and CO are combustion quality indicators, the higher is the concentration, the combustion is the poorest. The CH_4 concentration scale (Figure 13) is much lower than for CO (Figure 14). This is because methane forms upstream of carbon monoxide. The observation in Figure 8 thus shows the CH_4 concentration rising exponentially in the flue gas as the quantity of wood in the mix increases. This is confirmed by Figure 14, but the observation has not been explained. On the other hand, the high CO and CH_4 concentration from the winter barley pellets is probably attributable to incomplete combustion because of the short length of the pellets

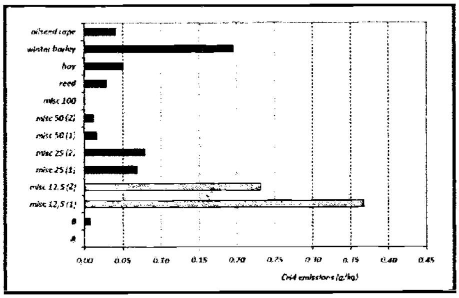

Figure 13. CH4 emissions in combustion flue gas per kg of pellets burned (g/kg) for the different substrates.

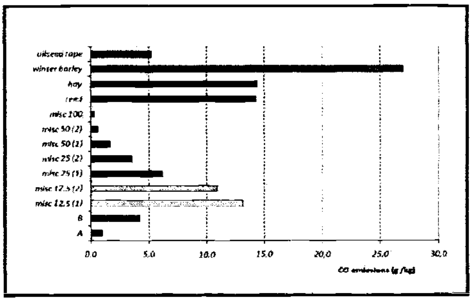

Figure 14. CO emissions in combustion flue gasper kg of pellets burned (g/kg) for the different substrates.

c. Fuel related Parameters

NO Emissions

Figure 14 shows the NO emissions for each fuel. The substrate composition, and especially the nitrogen (N) content, affects significantly NO emissions (R^2: 79% – Figure 15). This has already been shown, notably in [2].

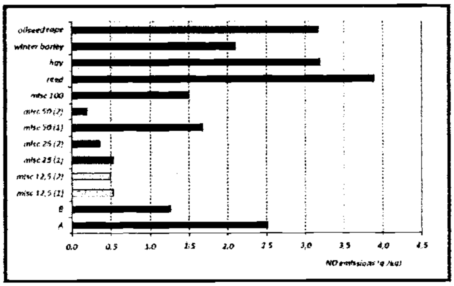

Figure 15. NO emissions in combustion flue gas per kg of pellets burned (g/kg) for the different substrates.

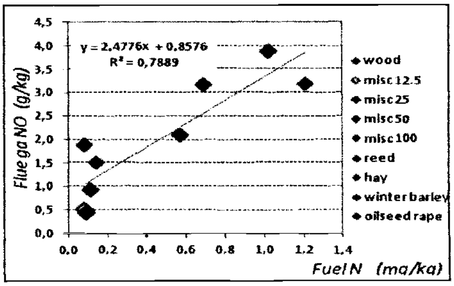

Figure 16. Average NO Concentration in flue gas (g/kg of pellets burned) according to substrate N content.

Reed was the only substrate to deviate from standard EN 14961-1 (Table 2). This is confirmed by the observation in Figure 15.

SO_2 Emissions

The SO_2 emissions are shown in Figure 17. The observations reported in [3] concerning the strong effect of the fuel S content on SO_2 emissions were not confirmed by the here described tests (Figure 18). The moisture content appears to affect the flue gas SO_2 values more significantly than the S concentration (Figure 19).

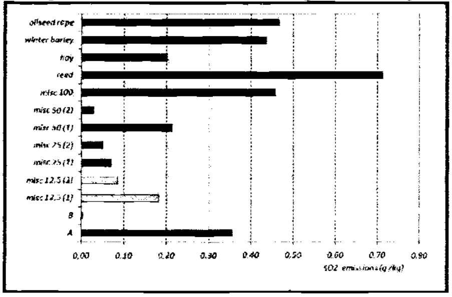

Figure 17. Flue gas SO_2 emissions per kg of pellets burned (g/kg) for the different substrates.

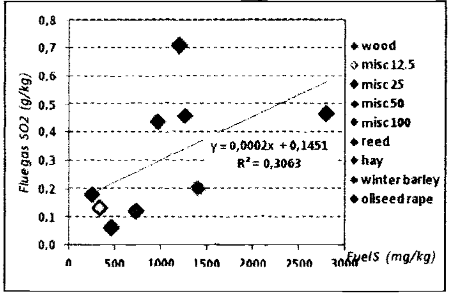

Figure 18. Average flue gas SO_2 concentration (g/kg of pellets burned) according to substrate S content.

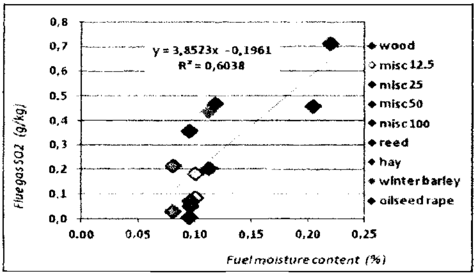

Figure 19. Flue gas SO_2 concentration (g per kg of pellets bBurned) trend according to fuel moisture content.

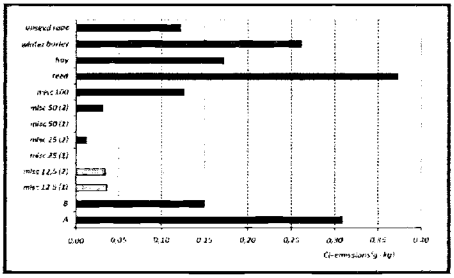

Figure 20. Flue gGas Cl^- discharge per kg of pellets burned (g/kg) for the different substrates.

Cl^- Emissions

Chloride concentrations (Figure 20) were of the same order of magnitude as the SO_2 concentrations.

Surprisingly, wood emitted more than the Miscanthus mixes, although the pellets complied with EN 14961-1. The four agro-pellets did not conform to pre-standard prEN 14961-6 in terms of fuel chloric concentration (Table 2).

Slag production

Miscanthus was the only fuel to induce slagging (Type 2) (Table 2). Wood produced none (Type 1), and all the other fuels produced a friable clinker (Type 3).

Pellet behavior with regard to slag formation clearly depends on the mix, as shown by [3,4]. Slag formation is thus linked to varying concentrations of silicon, calcium, potassium and magnesium.

5 Conclusions

It has been possible to pelletize wood-Miscanthus mixtures without modifying production process settings of a softwood pellets plant. Pure Miscanthus material tested in the same conditions has led to unstable production, mainly explained by hammermill overfeeding. The unstable production is identified as main responsible factor of the low quality of pellets produced with pure Miscanthus for these trials. These results suggest that pelletizing wood – Miscanthus mixtures may be done on softwood pellets production plants, without modifying process settings.

The unstable production observed with pure Miscanthus material prevents to drawn any conclusion regarding the possibility to pelletize that material. Especially it has been shown possible by previous studies. However, it indicates the process settings (e.g. hammermill design) have to be adapted to that material. Or the Miscanthus has to be prepared prior to delivery. The better option should be indentified after assessment of the overall efficiency of the process.

Concerning Miscanthus shares up to 50% in softwood, following observations have been noticed. The Miscanthus share seems not to influence the durability of the produced pellets, lead to higher particle density, higher ash content, lower gross calorific value, and seems not to influence the pellets length distribution.

The measurement performed during these trials have highlighted the sulfur content of the produced pellets is high, without being problematic. This was surprisingly not the case for chlorine, which was measured at low levels in the product. Trials should be repeated and further setup to determine to which extend agricultural practice (harvesting or conditioning) could enhance lixiviation of these elements.

The combustion trials allow confirming the relationship between NO emissions and the fuel N concentration. However, the tests did not clearly show a similar interaction with S. The tests could indicate that SO_2 emissions may be affected by the fuel moisture content. This remains to be confirmed. The complexity of combustion and the many interactions between the parameters involved is thus confirmed.

The agro-pellet material that performed best in emission terms was old hay. Reed, on the other hand, is less recommendable being systematically the worst polluter. Moreover, the reed pellets did not conform to four values according to the prEN 14961-6 standard.

Results for the wood-miscanthus mixes were good overall. Taking into account the pellet composition and compliance with the EN 149641-2 standard, the 12.5% miscanthus - 78.5% wood sawdust appears to be the best compromise, except that the combustion parameters were less good (CO concentration very much higher than with the other mixes). The combustion parameters therefore need to be adapted to the fuel. The 25%-75% or 50%-50% mixes can be recommended. The 100%Miscanthus pellets are not recommended because of the amount of slagging.

However, on completion of these two series of trials, the results are fairly encouraging for the future, regarding both agro-pellets and wood-Miscanthus mixes.

6. References

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