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DEMONSTRATION OF COMBUSTION OF GRAIN DRYING BY-PRODUCTS AND WOOD CHIPS FUEL MIX IN A HEATING BOILER

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ABSTRACT: Promoting renewable energy projects are strongly linked to national goals to curb the use of fossil fuels and to help move towards a carbon-neutral society in Finland. One objective in the national development project "Changing rural energy production" is to increase the utilization rate of agricultural by-products in energy production in the province of Southern Ostrobothnia. In the project, by-product of grain drying was briquetted and was tested as fuel in conventional heating boiler for solid bio fuels with chips. The aim of the combustion tests was to find out the effect of the spent fuel mixture on the efficiency and emissions of a conventional bio heating boiler. Five different combustion tests were performed on the grain fraction, the variables being the share of the grain fraction in the incineration of the chips and the use of the grain fraction unprocessed and briquetted. The tests were performed at the boiler testing laboratory of the Bioeconomy Institute of Jamk University of Applied Sciences (Jamk) in Saarijärvi, Central Finland. The experiments showed that the increase in grain by-product fraction in the fuel mix in combustion did not clearly affect the efficiency of the boiler. However, the increased share of grain fraction did result higher NO_x emission and dust levels.
Keywords: Biomass, boiler, combustion, efficiency, waste.

1 BACKGROUND AND OBJECTIVES

Combating climate change and replacing fossil fuels with renewable energy sources require urgent action globally and nationally. The goal of the Finnish government is carbon-neutral Finland in 2035 [1]. According to national emission forecasts, the need to reduce greenhouse gas emissions in Finland will average 7.6% per year in order to achieve the government's goal [2], which also requires promotion measures in energy production and use. In Finnish rural areas, the use of local biomass as an energy source develops the region's self-sufficiency, supports industry and employment, and helps combat the growth of greenhouse gas emissions [3]. Energy-related businesses are a natural part of agricultural activity and are to be promoted in order to ensure the vitality of rural areas.

National "Maaseudun muuttuva energiantuotanto" (in English "Changing rural energy production", 01.10.2020-31.12.2022) project aims promoting the use of renewable energy and entrepreneurship in the Finnish project area (the province of Southern Ostrobothnia). The main goal in the project is to increase the sustainable use of forest-based energy in the province, but the second goal is to increase the utilization rate of agricultural by-products in energy production. The project's measures are intended to support curb climate change in the region, reduce the use of fossil fuels and help move towards a carbon-neutral society. The project also promotes the regional economy and networking between entrepreneurs, and there is a direct dialogue with companies and other actors during the project. [4]

According to both statistics and empirical data, there are still untapped by-products in agriculture that could be used as fuel locally for energy production in Finland [5, 6]. For example, in the drying of grain, there are fractions (bark, straw fragments and weed seeds) that are currently of little use. Their suitability for energy production in practise is worth exploring further. Information on total potential and suitability for combustion as such or processed is required. [4]

Jamk's part in the project includes two research and test parts, one of which focuses on exploring the potential for combustion of grain drying by-products in heating applications. This is also linked to increasing farm self-sufficiency. The research is done in the boiler-testing laboratory and environment in Saarijärvi, Central Finland, in the premises of Jamk's Institute of Bioeconomy. The laboratories in Jamk have offered a place for the testing for solid biofuels in Finland already for more than ten years, and has also been a known and active player on development projects, testing activity and other cooperation with companies. [7]

The starting point for the work was the assumption that the by-product of grain drying could be utilized in both on-farm and by heat entrepreneurs. The by-product resulting from the drying process has low mosture content, which affects positively its calorific value. Substantial amounts of by-product are generated in the area, especially in co-dryers, and this material has not been systematically utilized as an energy source. The project has already investigated the potential of by-products in the province and the briquetting of the biomass. This paper focuses on the use of both processed and non-processed by-product as a blend fuel with conventional chips in a 500 kW test boiler with analyzing the fuel quality.

2 EXPERIMENTAL SETUP AND METHODS

2.1 Previous project results from briquetting of by-product

The aim of the briquetting experiment was to find out the effect on the processability and handling of the fuel and the effect on the fuel supply and combustion in the boiler. The briquetting was performed with Jamk's own briquetting equipment in September 2021. No separate additives were used for briquetting. A local by-product mixture from the drying of barley and oats (around 65 % in volume and around 35 % in volume, respectively) was used as raw material. The device used for drying is an old type of overpressure dryer yearly in use. The raw material contained all the by-products from the dryer (waste from pre-cleaning, bottom vacuum, air cleaning; see Figure 1).

Figure 1. By-product from grain drying in Jamk storage.

In briquetting machine (see Figure 2), the settings were retrieved to result in a permanent briquette. The lengths chosen were 40 mm and a pressure of 120 bar. The oat-barley by-product fraction was compressed to a third of its volume, and the processing capacity at those settings was about 0.16 cubic meters of finished briquettes per hour.

Figure 2. Briquetting machine and setup in Jamk.

The briquetting resulted in a neat briquette with relatively good shape and durability without additives (see Figure 3). The briquettes were stored for 3 weeks before the combustion tests.

Figure 3. Briquetted by-product.

2.2 Fuel characteristics

Table 1 shows the results of fuel analyses of the test fuels. The analysis were done in the fuel analysing laboratory in Jamk just before the combustion tests. Grain by-product has slightly higher calorific value as received (14,16 MJ/kg) resulting from lower moisture content. However, grain by-product contains more in-organic material when compared to wood resulting 5,3 m-% d in ash content. Both gross calorific values and ash content of the grain were in line with the literature. [8]

Table 1. Fuel analysis for the test fuels.

Analysis, raw materials	**Chips (wood)**	**Grain by-product, loose**	**Grain by-product, briquette**
Moisture as received (m-%)	32,1	17,1	17,5
Gross calorific value (MJ/kg d)	20,26	18,95	18,98
Net calorific value, $q_{p,net,d}$ (MJ/kg d)	18,93	17,57	17,61
Net calorific value, $q_{p,net,d}$ (MWh/t d)	5,26	4,88	4,89
Net calorific value as received, $q_{p,net,ar}$ (MJ/kg)	12,07	14,16	14,10
Net calorific value as received, $q_{p,net,ar}$ (MWh/t)	3,35	3,93	3,92
Bulk density, as received (kg/m³)	228,1	187,3	424,3
Bulk density, dry (kg/m³ d)	155,0	155,3	350,0
Ash content (m-% d)	0,6	5,3	5,3

2.3 Combustion tests

The purpose of the combustion tests was to find out the effect of the spent fuel mixture on the efficiency and emissions of a conventional boiler. At the same time, observations were also made in terms of usability from the point of view of actual farming or heating plant activity. It should be noted that there are no emission limits for use in this size range heating boilers in Finland. However, the results can be compared for guidance with the emission limits of the standard for testing bioheating boilers (EN 303-5, updated 2021).

Five combustion tests were planned and performed: [1] chip-only test (nominal power), [2] 10% by-product share as such (nominal power), [3] 10% by-product share as briquette (nominal power), [4] 10% by-product share as briquette (partial power, 30 %) and [5] 30% by-product share as briquette (nominal power). The percentages and details were designed based on experience of the laboratory staff within the allocated project budget. Testing was performed under laboratory conditions in JAMK's own 500 kW test boiler. The chips used in the burning experiments were standard local mixed wood chips (moisture level 30-35 %).

The test runs were performed in the boiler test hall of the Institute of Bioeconomy in October 2021 with the organisation's own heating boiler (Ariterm Bio Twin 500) for research use (see Figure 4). The length of the test runs for each fuel mixture was at least two hours. In practice, a uniform period of power level and O_2 and CO concentrations was sought, in which particles were measured on the filter three times.

Figure 4. Test boiler in Jamk.

Fuel was fed from a common screw feeder system from silo, adding grain fraction to the chips. That is, no separate feed line was added for grain fraction. The test boiler is equipped with some additional masonry in the furnace. In addition to the combustion air (3 stages control option), it was possible to adjust the fuel supply and the movements of the grate during combustion. Fuel consumption was measured on a scale. The following measurements were used for testing: CO, OGC, O_2, NO, NO_X, NO_2, SO_2, CO_2, particulate matter/ dust (PMCE Stack 990) and particulate matter/ dust (Paul Gothe, see Figure 5).

Figure 5. Dust particle measurement set up in Jamk laboratory.

3 RESULTS OF THE COMBUSTION TESTS

3.1 Fuel behaviour

As mentioned above, the calorific value at the point of arrival of the grain fraction is higher than that of the chips, but it has a relatively higher ash content. The particle size of the loose grain fraction is small, so its uniform miscibility in the silo with the chips is uncertain. Uneven fuel mixing also causes variability in combustion.

The particle size of the briquetted grain by-product fraction is initially larger than that of the chips, but the briquette decomposes into a smaller piece size in the silo and conveyor. In the experimental setup of Jamk, the feeding of the briquetted side fraction into the furnace is found to be more even among the chips than the loose fraction.

However, the combustion results also show some unevenness in the supply of briquettes to the boiler, i.e. the amount seems to vary in the fuel mixture during the test. If it is desired to standardize the share, of briquettes or loose fraction among the chips, there should be a separate feed and, in the case of briquettes, possibly a manual feed arrangement.

3.2 Boiler test efficiencies

Based on the combustion tests, it appears that 10% of the by-product of grain drying (here mix of oats and barley) can be used in the heating use, either in bulk or briquetted among the chips, without significantly affecting boiler operation or emissions. However, this is exactly true only for that measurement set-up, although the tests sought uniformity for practical boiler operation without fine-tuning the combustion conditions. In the tests, basic type adjustments were made to the starting points for burning the chips. In addition, adjustments may well be boiler specific.

The efficiencies in the tests were between 76-84% (see Figure 6), the lowest efficiency was achieved with basic adjustments in the mixture combustion of loose by-product fraction (10%) (nominal power, test [2]). It should be noted that the grain briquette burns hotter on the grate than wood chips, which is affected by, among other things, the density and calorific value of the fuel.

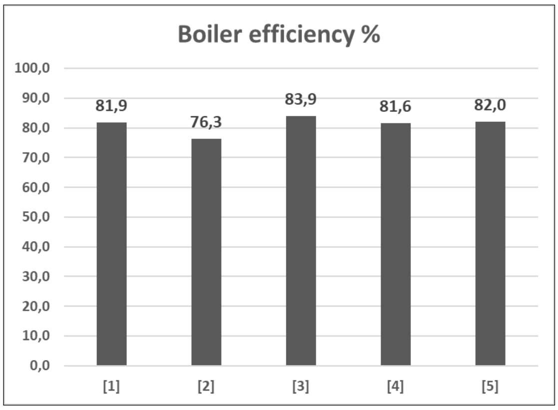

Figure 6. Efficiency comparison between five tests.

The amount of unburned fuel in the ash after the combustion tests was also examined. As a result, in test 2 (loose fraction, nominal power) 18.8% remained unburned in ash, in test 3 (10% briquettes, nominal power) the proportion of unburned was 29.6%, in test 4 (10% briquettes, partial power) 2.0% and in test 5 (30% briquettes, full power) 12.8%.

3.3 Emissions

The briquetted 10% by-product fraction test (test [3]) resulted in significantly lower CO emissions than the loose fraction (10%) test (test [2]) (both nominal power). However, the CO concentrations in the flue gases remained at good levels in all test runs resulting averages 30-120 ppm in 10% oxygen (see Figure 7).

When the proportion of briquettes was increased (30%) (test [5]), particulate emissions and NO_x emissions were found to be higher than in 10% share tests. The NO_x emission level varied between tests 81-245 ppm (see Figure 8).

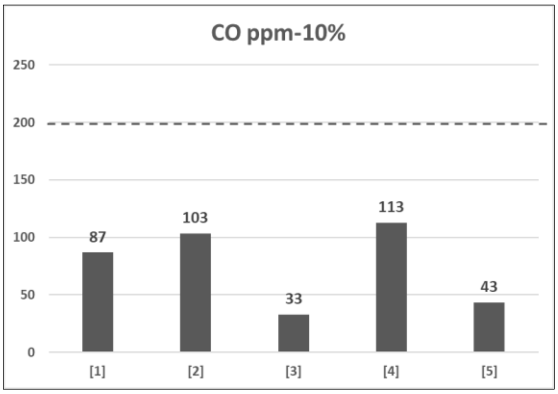

Figure 7. CO measurement comparison between tests.

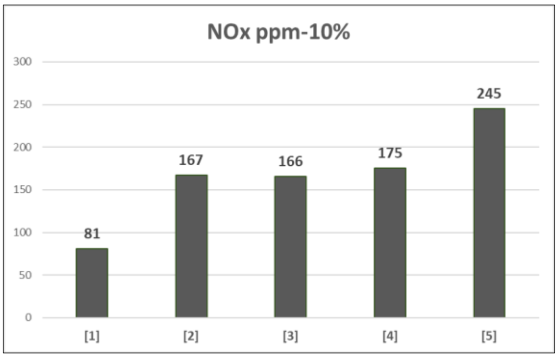

Figure 8. NO_x measurement comparison between tests.

In the partial power run of 10% briquette (test [4]), the smallest particulate emissions of the test series were measured (filter measurement) as 35 mg/Nm^3 in 10 % oxygen (see Figure 9). The known emission limit value for a such bioheating boiler for particulate emissions is 40 mg/Nm^3. The explaining factor for lower dust emissions in test [4] can be lower boiler airflows and draft, leaving more particles in the ash. It should be noted that the test results may have been affected by the following: a few manual agitations of the fuel silo (to allow the test situation to continue smoothly), automatic grate cleaning, condensation of moisture (low flue gas temperature).

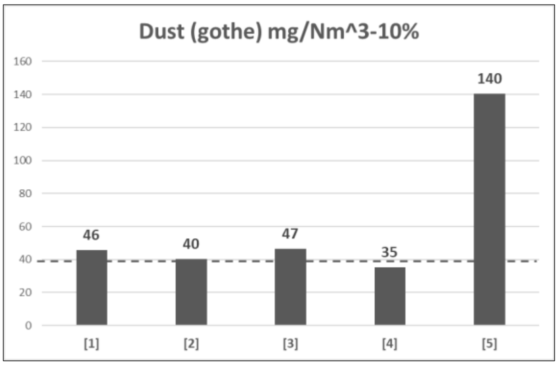

Figure 9. Dust measurement comparison between tests.

Sulfur dioxide is produced more when the amount of by-product is increased, because the raw material contains more sulfur. Reliable measurement of sulfur dioxide was not completely successful during the experimental setup, so the results and comparison between tests will not be published.

Figures 10 and 11 show visually examples of flue gas measurement results in the same presentation (CO, CO_2, O_2, NO_x, SO_2, dust) and differences between two tests for 10 % share of the grain by-product. In the Figure 10 are the results of combustion test (test [3]) with 10% of briquette combusted with chips and on the right about the combustion test (test [2]) with 10% non-briquetted by-fraction with chips - both with nominal power. Immediately, it can be seen that the combustion and emissions of briquetted raw material in combustion are more even than in the combustion of loose fraction.

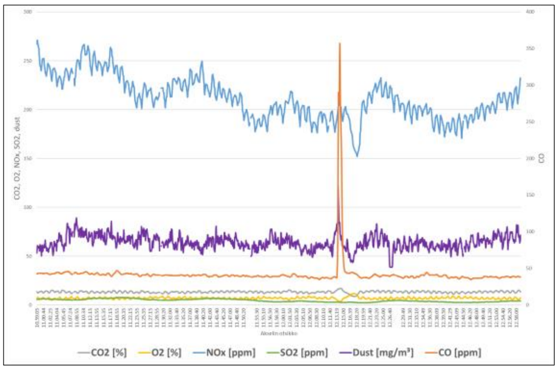

Figure 10. Compilation of the emission measurements of the test 3 (10 % of briquette combusted with chips, nominal power).

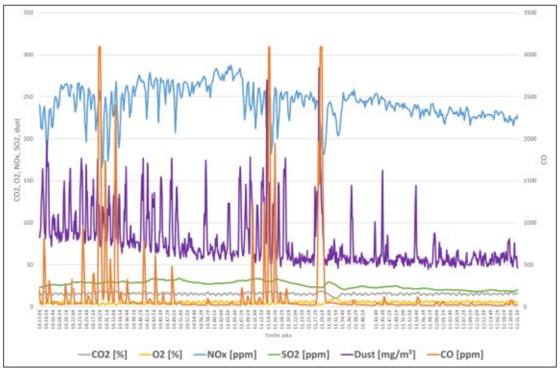

Figure 11. Compilation of the emission measurements of the test 2 (10 % of non-briquetted by-fraction combusted with chips, nominal power).

4 CONCLUSIONS

The briquetting of the by-product of the drying of barley and oats was successful with the used briquetting equipment without separate added additives. Fuel analyzes were performed and their bulk densities, moisture, calorific values and ash contents were examined. In addition, the proportion of unburned organic fuel in the ash was also investigated in the combustion tests.

The experiments show that the increase in by-product fraction in combustion did not clearly affect the efficiency of the boiler. The CO concentrations in the flue gases remained at good levels in all test runs. However, The NO_x

emission level and dust levels increased when the share of grain fraction was increased from 10 % to 30 % share in the fuel mix. If the share of grain drying by-product among chips is increased above 10 %, it seems that flue gas cleaning equipment for dust would be required for a such heating system in the future.

It would appear that the test boiler was able to utilize 10% of the grain drying by-product both in non-processed and briquetted forms among the chips without greatly affecting the boiler's operation and emissions. Briquetting of the grain fraction appeared to promote smoother combustion conditions at nominal power in the tests in 10 % share in the fuel mix.

The next step of the project is to make profitability calculations from a practical point of view for the collection and utilization of grain drying by-products in local energy production.

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