XyloChips – Continuous measurement of woodchips energy content

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Abstract

Today, the energy content of wood chips is determined based on metering of heat delivered by the boiler. Consequently, the wood chip supplier can only bill for the useful heat that the consumer is able to produce with his boiler. The goal of this project was to develop a system able to determine the energy content of wood chips at the time of delivery, as it is the case for any other type of fuel.

In order to achieve this goal, a dedicated device, which incorporates a continuous measurement of moisture and of mass flow, was designed and built. These two parameters, in addition to the constant values of the dry higher heating value and the average hydrogen content, allow to quickly determine the energy content of wood chips. The first measurements under real conditions in the field showed that the energy contained in a load of 40 m³ could be determined in less than 10 minutes with an error smaller than 3%. If these results are confirmed during the next phase of the project, much more precise and objective measurement, independent from this customer's boiler efficiency will significantly simplify woodchips billing practices.

Zusammenfassung

Die Bestimmung des Energieinhalts von Waldhackschnitzeln basiert derzeit hauptsächlich auf der Wärme, die von dem mit einem Wärmezähler ausgerüsteten Kessel geliefert wird. Der Hackschnitzellieferant berechnet daher nur die Nutzenergie, die der Verbraucher mit seinem Kessel produzieren kann. Das Ziel dieses Projekts war, den Energieinhalt von Hackschnitzeln bei der Lieferung, wie bei jedem anderen Brennstoff, zu bestimmen.

Zu diesem Zweck wurde eine Sondereinrichtung entwickelt und gebaut. Es beinhaltet eine kontinuierliche Feuchtigkeit- sowie eine Massedurchfluss-Messung. Die Verwendung dieser zwei Größen, zusätzlich zu einem konservativen Wert des oberen Heizwerts des trockenen Holzes und des durchschnittlichen Wasserstoffgehalts ermöglicht, den Energiegehalt der Holzschnitzel zu bestimmen. Die ersten Feldmessungen unter realen Bedingungen ermöglichten in 10 Minuten, die in einer Last von 40 m³ enthaltene Energie mit einer Fehler von weniger als 3% zu bestimmen. Würden diese Ergebnisse im Rahmen der nächsten Phase des Projekts bestätigt, wäre diese Messmethode viel präziser und objektiver als die derzeitige Praxis, die auf der Kombination eines Wärmezählers und einer Schätzung der durchschnittlichen Kesseleffizienz basiert.

1 Introduction

Nowadays, the woodchips energy content is most of the time determined based on the heat supplied by the boiler, measured by a dedicated device. As a consequence, the woodchips supplier cannot charge for the raw energy that is available, but for the useful energy fraction that the consumer can produce with his boiler. For comparison, in the case of a motorist, this would be equivalent to paying the fuel based on the mileage traveled and not based on the amount consumed. In some other cases, billing is based on the mass (price per ton) or volume (price per m³) of the woodchips supplied.

Although attractive by their apparent simplicity, the current economic systems are inappropriate from the point of view of the supplier as well as that of the consumer. Indeed, if the current billing method seems at first glance to be in favor of the consumer, it also has a number of major disadvantages. The billing via a heat meter forces the consumer to work with a single and unique supplier. On the other hand, for a given fuel quality, it cannot directly recover the benefits of an optimal management of heat production facilities and related investments. This is already currently the case for billing modes to mass or volume. However, with this type of contract, the supplier is not encouraged to supply woodchips with low humidity especially when the bill is based on ton. Indeed, the wet woodchips has in this case more commercial value than the dry one.

1.1 General description

1.1.1 Overall purpose

The aim of this project was to implement a system that allows the continuous determination of the energy content and moisture content of woodchips during their delivery, and thus control their homogeneity.

The energy content can be determined by measuring the wood mass and its moister.

A significant contribution of such a system is that it allows to partially control the quality of the woodchips provided and to give in any case their humidity class according to the standard EN ISO 17225-4 [1].

Indeed, when passing under a humidity sensor, not only the average moisture of the batch is determined, but also its dispersion. Large variations can then alert the user to either:

- The presence of several different batches of woodchips;
- A high degree of wood heterogeneity that could degrade the energy performance of the boiler and increase pollutant emissions [2].

1.1.2 Study conducted

Initially, after conception and realization, the device was characterized in laboratory by comparing the measurements carried out on samples series with those obtained by conventional measurement according to the standard procedure. In a second step, the results having been conclusive, measurements of several real loadings (40 m³) were carried out under real conditions.

In summary, the work carried out was:

- The design and the production of a flexible measuring device capable of reproducing the operating conditions expected under real conditions (in particular the speed of measurement);
- The characterization of the measurement accuracy according to the conditions of use by comparing the results with those established on the basis of standardized sample measurements, considering various species (beech, poplar, spruce / spruce, hardwood / softwood mixtures, etc.) and grain sizes (P45S, P31S and P16S according to EN ISO 17225-1 [3]);
- The development of an interface capable of calculating the energy content, based on the total mass, on the average humidity and its range of variation, and on other parameters (i.e. the average heating value and the average hydrogen content) needed for the characterization of the delivery;
- The issue of any useful recommendation for the next phase of testing in real conditions of use.

1.2 Technical description

Based on a set of specifications established by the HEIG-VD, the measuring device was designed and manufactured by the Aficor SA company in Chanéaz (VD),

In the laboratory, the system works in batch mode, processing volumes of material ranging from 2 to 3 m³, depending on the following process (Figure 1 & Figure 2):

- Loading of the raw material in a hopper (1) equipped with a weighing system, a conveyor belt with a width of one meter and an opening with a fixed width (70 cm) but with a variable height. It is possible to load the hopper from the top via a bucket or laterally from a trailer with a height of 1.10 m;

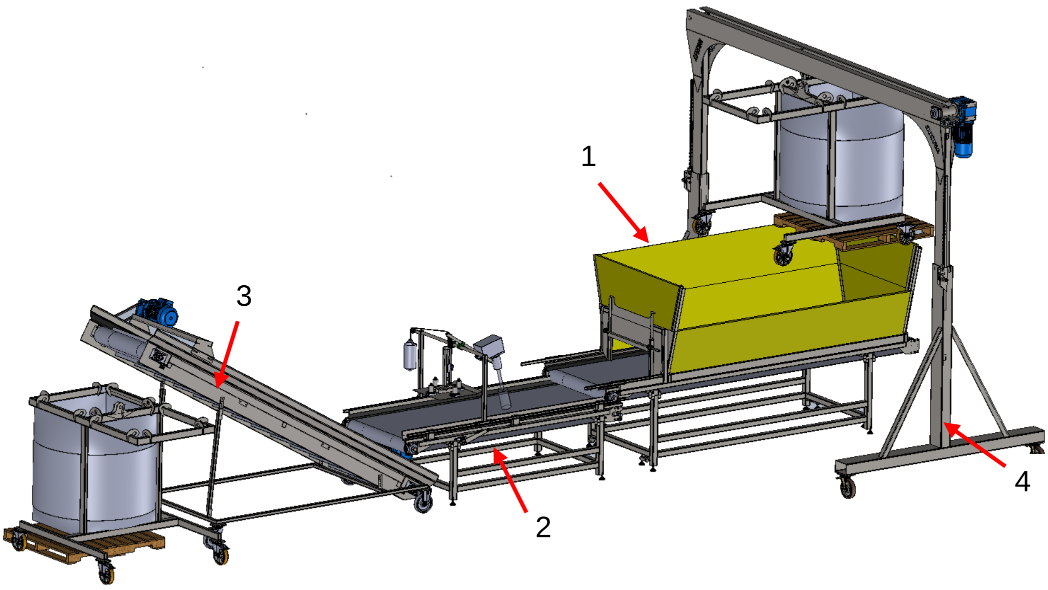

Figure 1 laboratory measuring configuration

- The hopper band conveyor (1) discharges onto the measuring conveyor belt (2), which is equipped with a continuous weighing system (5) and with supports for the EDIT Laser (6) infrared moisture analyzer (IR), as well as the SWR M-Sens 2 microwave sensors (µW) (7). The configuration of this system can be freely set up longitudinally or laterally (see Figure 2);

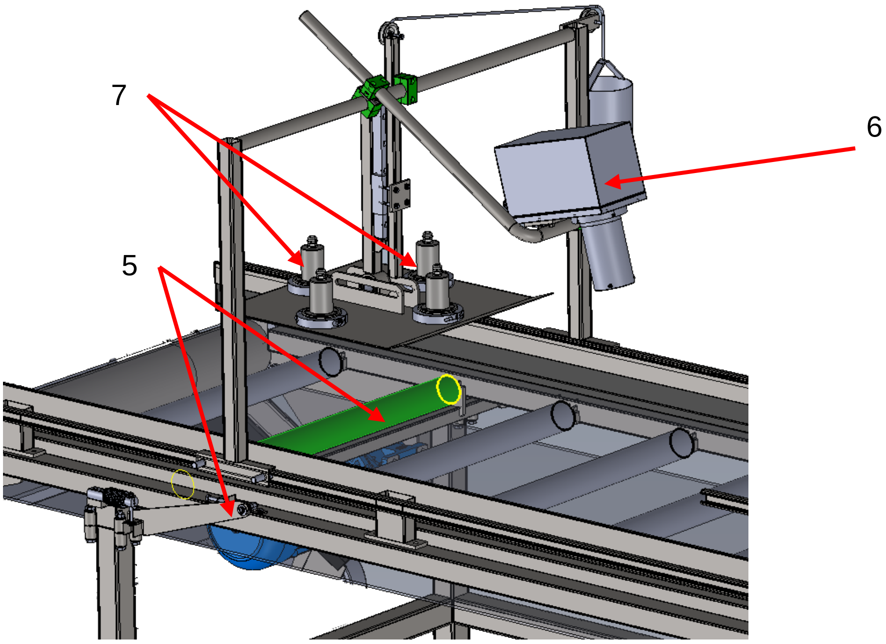

Figure 2 positions of mass and moisture sensors on the measuring conveyor

The evacuation of the woodchips is done by a lifting conveyor belt (3) which drops the material into big bags.

The return of the woodchips occurs via a carriage carrying two big bags which are emptied into the hopper using a loading gantry (4).

The measuring device is operated centrally by a programmable controller.

All conveyors are mobile and can be easily set up during the field tests.

The continuous weighing system (5, TeleMetrix TMX 1010) consists of a roller fixed on two load cells and of a speed sensor placed on a fixed roller. The assembly is connected to a computer that transmits a mass flow signal to the controller.

By its operating principle, the infrared humidity sensor (6) does not require contact with the measured material. It is fixed on a gantry at a height ranging from 250 to 450 mm with the conveyor belt and is coupled to a material detector.

Unlike the infrared sensor, the microwave moisture sensor (7) must be in direct contact with the material. It is fixed on a skid mounted on a rail and supported by a counterweight allowing the assembly to follow the height variations of the moving woodchips. The device consists of two sensors that can be positioned longitudinally or laterally on the pad. If two sensors are used, the humidity value is transmitted from the SWR computer to the PLC as a weighted average.

The gantry supporting the humidity sensors can be freely positioned on the measuring module (2) or at the outlet of the hopper (1).

1.3 Work conducted

The initial tests consisted of making the line fully operational, of making the programming of the PLC reliable, and of calibrating the different sensors with different wood types and levels of humidity. The steps were carried out in this particular order:

- Reliability of the PLC program;
- Calibration of the mass sensor and partial calibration of humidity sensors;
- Final calibration of humidity sensors;
- Continuous measurement of the energy contained in wood pellets under laboratory conditions and analysis of the accuracy and reproducibility;
- Test of the line under real conditions.

The set of tests for the first three bullet points above represents 200 runs.

2 Results

2.1 In laboratory

2.1.1 Weight determination

Each test campaign mentioned in the X-axis of Figure 3 includes between 5 and 18 runs. The relative differences between the load weight measurement when starting (via the hopper, equipped with load cells) and the continuous measurement (via the weighing roller of the measuring conveyor belt) are small.

In Figure 3, the weighing roller device is slightly over-calibrated since the overall average of the differences is + 0.3%. But the gain and compensation conditions of the five last tests were correct to validate the calibration of the mass sensor. They have relative differences smaller than 0.5% with confidence interval smaller than 1% of the overall average.[1]

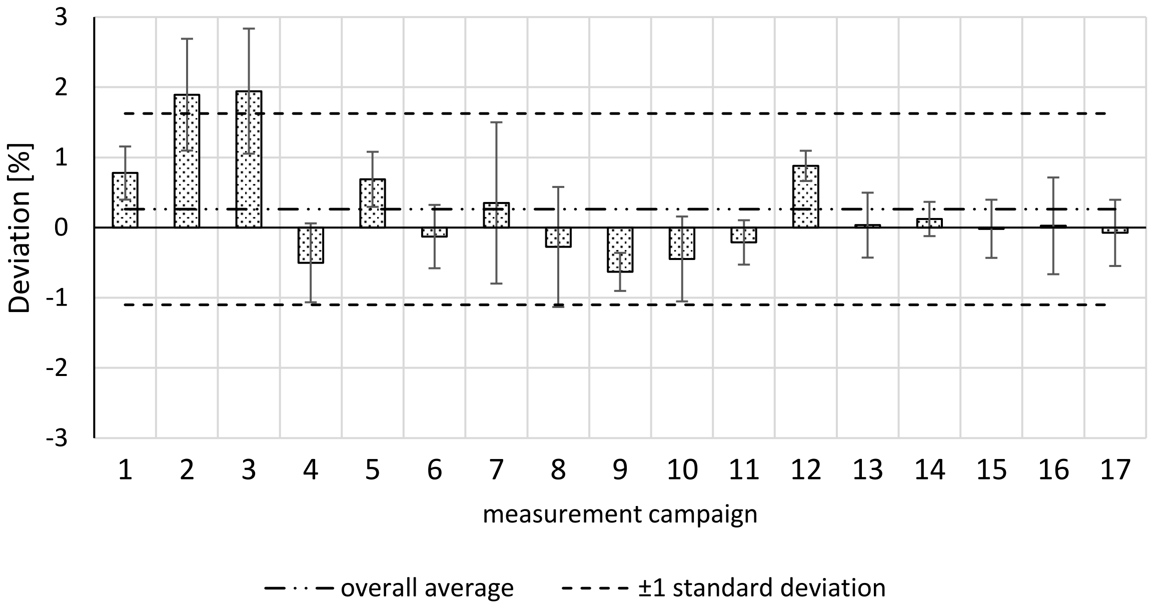

Figure 3 relative difference between the effective mass and continuous measurement

2.1.2 Moisture determination

Once the humidity sensors were calibrated, five test campaigns (# 13 to # 17 in Figure 3) were performed, each comprising seven runs. Five configurations representative of the market in terms of wood species (ash, spruce, beech and poplar), moister content (from 19% to 40%) and particle size class (P16, P31 and P45S) were selected.

[1] Reminder concerning the error bars: a standard deviation contains approx. 68% of the values on both sides of the overall average (assuming a normal distribution). The error bars in Figure 3 represent the confidence interval, determined for an α risk of 5%. This means that a test under the same conditions will give a value contained within this range in 95% of the cases. Example: the mass measured in campaign 15 has an average of -0.02% and 95% of its variability is contained in a range of 0.4% around this value

The difference between the measured humidity and the reference humidity, as shown in Figure 4, is expressed as the relative humidity point. The reference humidity was determined by laboratory analysis of samples collected during the woodchips passage.

During these tests, a single measuring cell was used for the microwave sensor. The average relative humidity point of each sensor is close to zero. However, the standard deviation is greater for the microwave sensor (3.0% on average) than for the infrared sensor (1.7% on average). These differences are notable in configurations 3 and 5 (Figure 4).

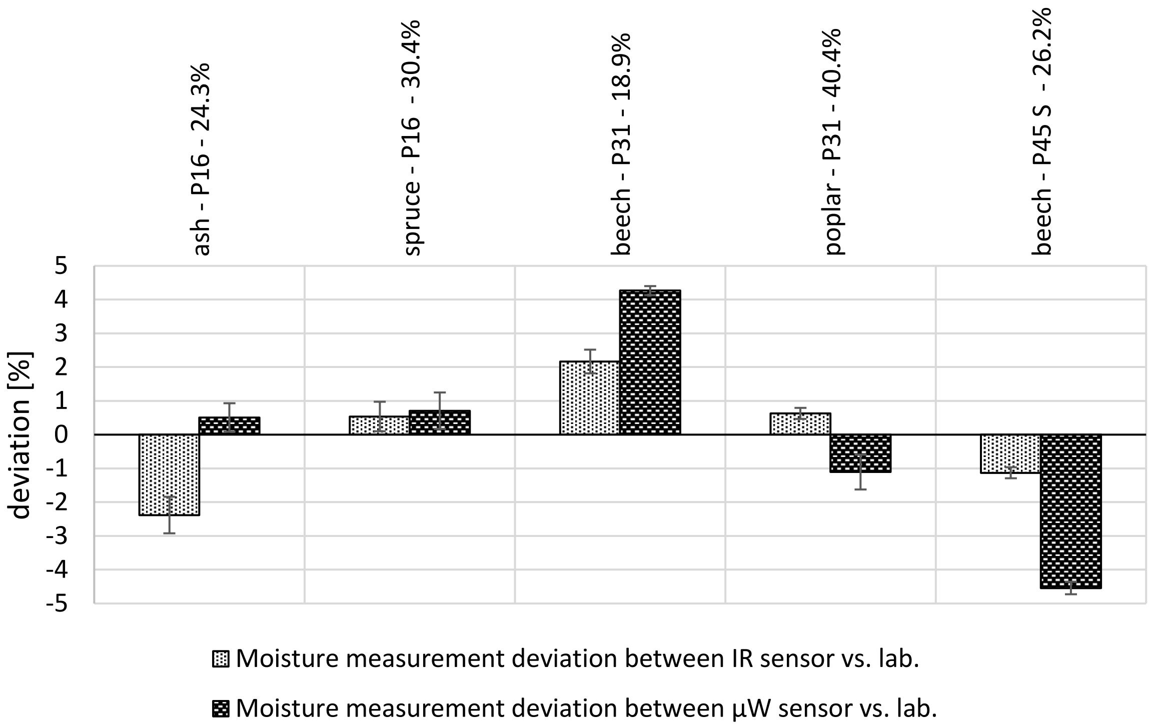

Figure 4 difference between the effective humidity and that measured via the IR and µW sensors

The bigger variations observed with the microwave sensor are due to the different woodchips rates expansions (the particle size class of batch 3 is P31 against P45 S for batch 5). The signal of this sensor is influenced by the effective sensor surface in contact with the material.

Surface moisture is also an important element, which can significantly influence the final result. Specific tests allowed to evaluate the sensitivity of sensors to this phenomenon. After having measured the moisture of a batch during a first passage under normal conditions, a second run was carried out after having watered the surface of the same woodchips, upstream of the sensors. Only small quantities of water (i.e. less than 0.5 l) were used in order to not significantly influence the average moisture of the batch.

The results in Table 1 show that both sensors recorded significantly higher humidity levels during the second run and are therefore strongly influenced by the surface moisture. For the IR sensor, this can be explained by the fact that spectrometer measurement only looks at the surface of woodchips. For the µW sensor, a stronger bias was observed despite the fact that it can measures humidity deeper inside woodchips. This is likely due to the fact that the measuring cell of the µW sensor is in direct contact with the surface and so with the water.

One of the expected qualities of this measurement principle is that it should not be sensitive to surface variation, which is unfortunately not the case here.

Table 1 influence of a water film on the measured moisture content

Sensor	Standard run	+ watering	Deviation	Laboratory value
IR	20,8%	33.6%	+62%	21,3%
µW	25,7%	61.1%	+138%	

However, these results may be put into perspective because such a situation should not occur under real conditions of use. Indeed, even if woodchips are subjected to heavy rain during transport, the batch can be homogenized during its unloading in the hopper.

In addition, protections can be installed on the measuring conveyor belt to avoid any bias when passing the woodchips under the moisture sensors, in case the complete installation could not be fully protected against the rain.

2.1.3 Energy determination

The determination of the energy contained in woodchips is assessed based on the determination of their mass, their humidity, and their net calorific value.

The gross calorific value at constant volume of the fuel with moisture content was determined according to EN ISO 18125 [4]. Equation 1 expresses the net calorific value as received, according to ISO 1928 [5] (January 2011), as a function of the dry gross calorific, the biofuel moisture content as well as its hydrogen content (on a dry basis):

$$q_{V,net,m} = \left[q_{V,gr.d} - 206 \cdot \omega_{H,d}\right] \times (1 - 0{,}01 \cdot M_T) - 23{,}05 \cdot M_T \qquad (1)$$

- $q_{V,gr,d}$ = gross calorific value at constant volume of the dry (moisture-free) fuel [kJ·kg⁻¹];
- $q_{V,net,m}$ = net calorific value at constant volume of the fuel with moisture content M_T [kJ·kg⁻¹];
- $w_{H,d}$ = hydrogen, percent mass fraction of the moisture-free fuel (includes the hydrogen from the water of hydration of the mineral matter as well as hydrogen in the coal substance);
- M_T = total moisture content of the fuel for which the calculation is required.

Energy is the product of calorific value and mass (equation 2)

$$E_m = q_{V,net,m} \times m_m \qquad (2)$$

- E_m = energy delivered from wet fuel [kJ];
- m_m = wet fuel mass [kg].

These formulas have been used for the determination of continuous and static energy content (laboratory control).

The actual average values, obtained from 42 samples, including several species, were: $q_{V,gr,d}$ = 19.670 kJ·kg⁻¹ and $w_{H,d}$ = 6.1%. Note that the confidence interval for $q_{V,gr,d}$ was 90 kJ·kg⁻¹ and for $w_{H,d}$ = 0.03%, which confirmed their small derivation.

The energy collected is the result of the combination of mass and moisture measurements from test campaigns 13 to 17 (shown in Figure 3), each consisting of seven runs.

The reference energy was calculated from the humidity, PCS and hydrogen values determined in the laboratory. The reference mass was measured by the hopper weighing device.

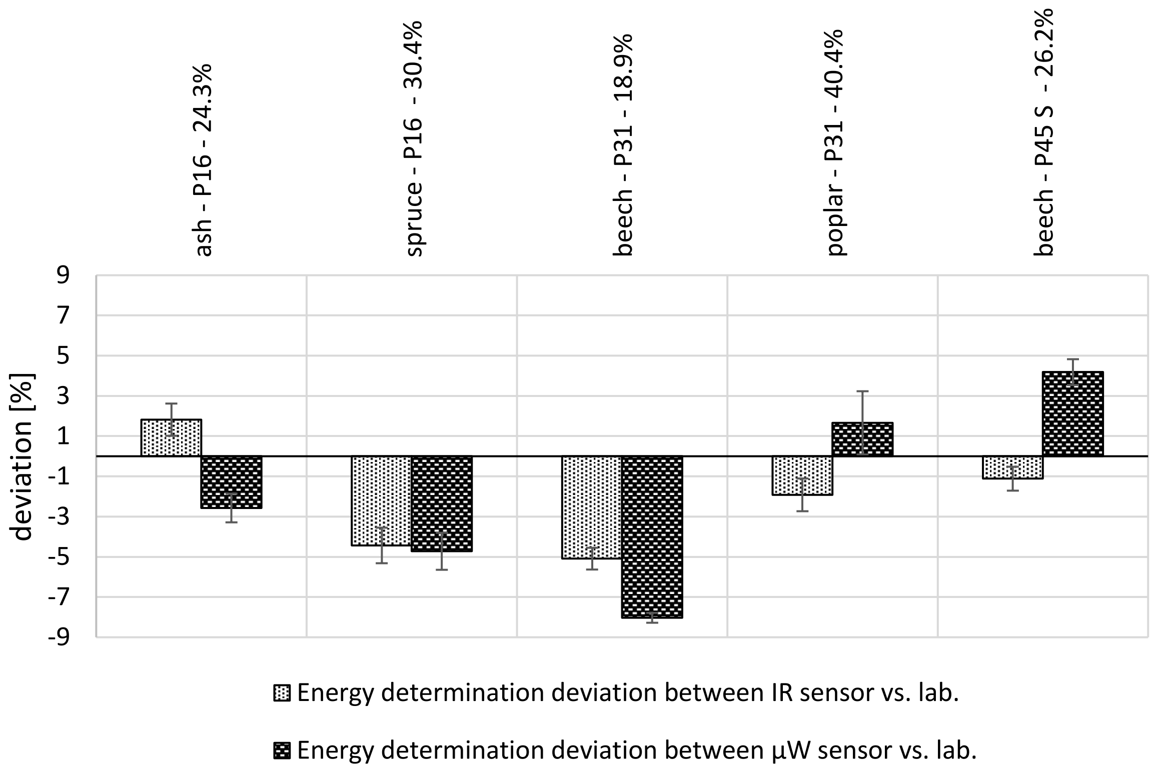

Figure 5 Comparison between the effective energy and that measured via the IR and µW sensors

The total energy contained in a batch of woodchips can be determined by integrating the instantaneous energy, calculated on the basis of instantaneous mass and humidity or by using the total mass and the average moisture. Both methods were evaluated experimentally and the results showed greater precision and better repeatability for the second one. These are the results that are presented in this report in Figure 5.

On average, the energy measured on the basis of the microwave sensor is 1.9 ± 4.8% point lower than the reference value determined in the laboratory against 2.1 ± 2.9% point for the IR sensor. These differences are at least partially due to the error of the mass sensor.

2.2 Field campaign

2.2.1 Presentation

The validation tests under real conditions took place over two days, on the site of the company Germaplaket in Yverdon-les-Bains (Figure 6). Three batches of different woodchips (moisture, size or specie, approximately 40 m³ / batch) were used for this purpose. Each batch was measured twice.

Due to the continuous unloading of the material, the hopper weighing device could not be used to determine the reference masses. To overcome this, each batch was weighed using an official truck scale before the first pass.

In order to account for the woodchips that were not measured (woodchips left in the skip or in the hopper, woodchips that fell beside the hopper during unloading, samples collected, etc.), the reference mass of the batches were estimated by subtracting 50 kg for the first run and 60 kg for the second run, to the mass measured by the truck scale.

Wood samples were taken at regular intervals during each run and analyzed in the laboratory to determine the calorific value and the reference moisture. The measurements of 40 m³ of woodchips took ten minutes.

Figure 6 field test under real conditions, with a 40 m³ load

Since the number of tests was minimal (three test configurations, repeated twice), the error bars on the following graphs no longer represent a 95% confidence interval (which would be calculated from two samples only) but directly the standard deviation.

The woodchips tested are representative of the products delivered by Germaplaket.

2.3 Results

The average mass error is -0.9% with a reproducibility of ± 0.5% (Figure 7).

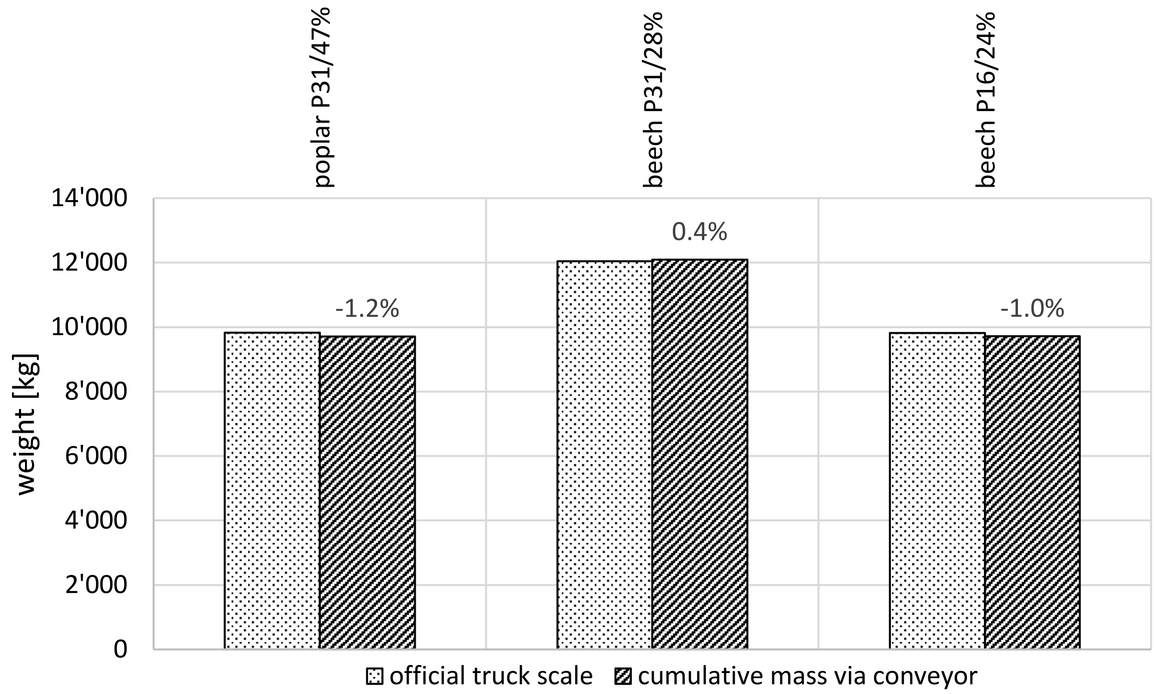

Figure 7 Comparison between the official weight and the cumulative mass

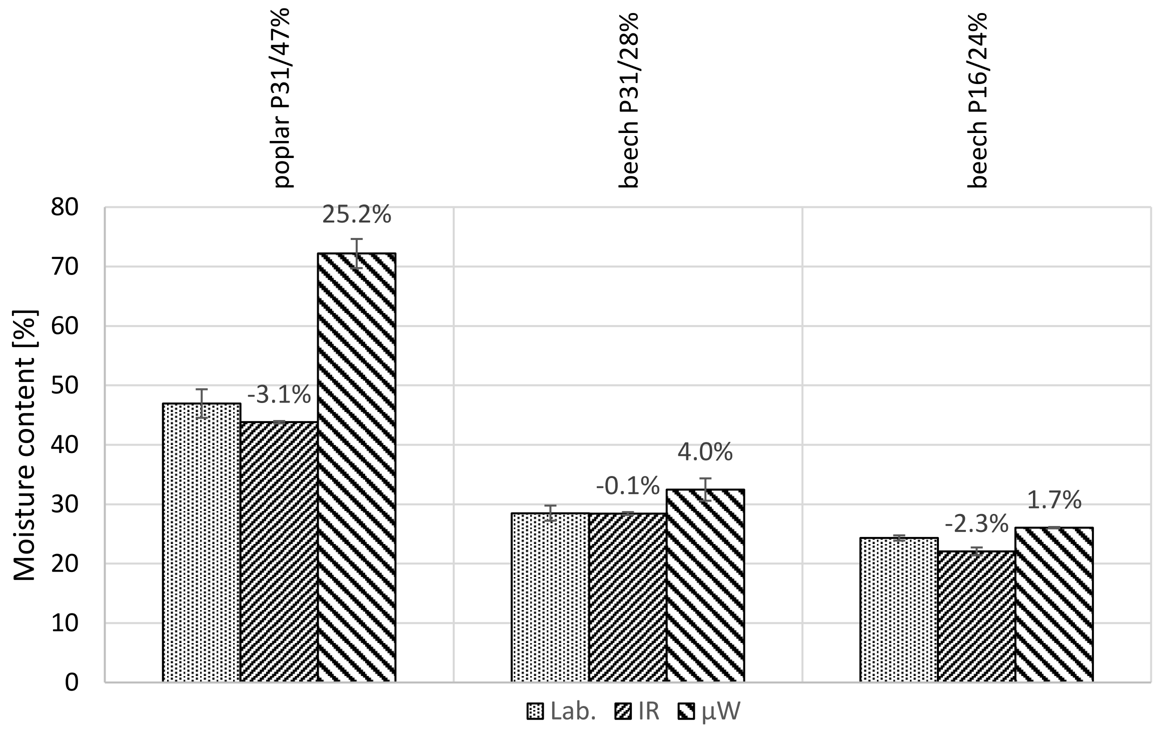

Figure 8 Comparison between the effective humidity and that measured by the IR and µW sensors

The humidity sensors have been calibrated to operate in a range of 20 to 40%. The poplar tested had a moisture content of 47%. If the IR sensor slightly differs from what was determined in the laboratory, the µW sensor far exceeded the target value (Figure 8). Therefore, it seems that the latter:

- does not tolerate extrapolation to the calibration range as well than IR;
- and/or that the surface humidity was too high in this case, which could humidify the measuring cell of the sensor and produce the same effect noticed during laboratory watering tests (Table 1).

Figure 9 shows directly the consequence of an error in the moisture measurement on the energy content. The variations between the laboratory and the field can reach 61% in the case of the energy determined from the µW sensor.

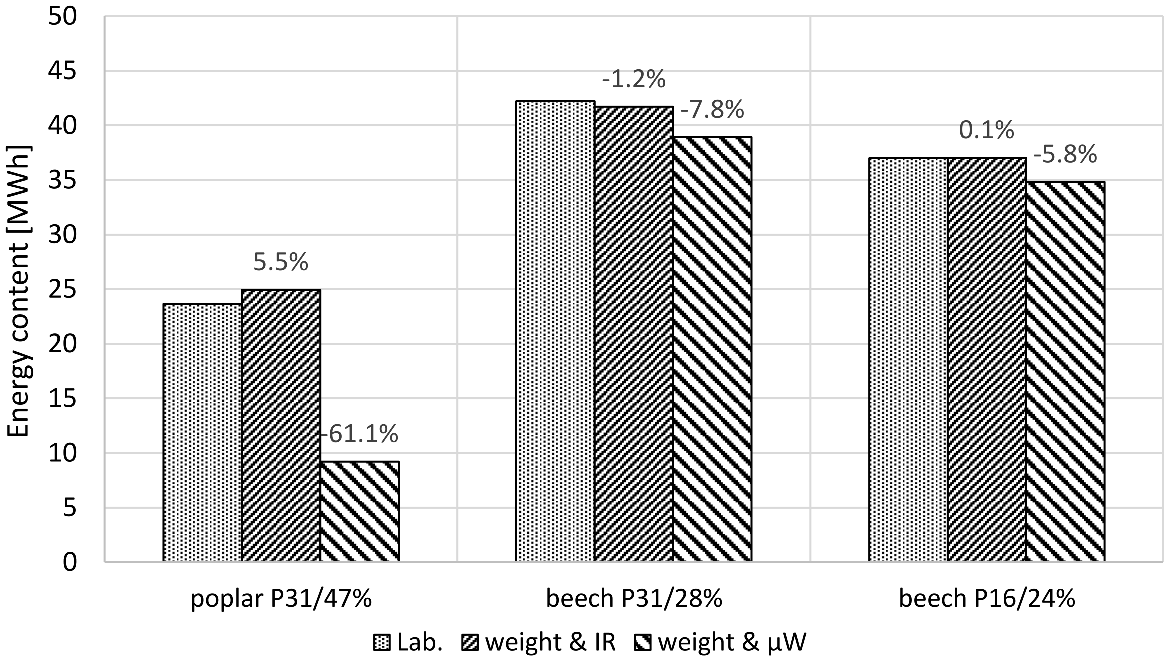

Figure 9 comparison between the effective energy and that determined via the IR and µW sensors

When considering only batches with humidity falling within the calibration range (20% to 40% of moisture), the maximum error on the total energy is 1.4% for the IR and 9.5% for the µW. These values are comparable to the tolerated errors on a thermal energy meter (between 2 and 7% depending on the class and the conditions of use according to EN 1434-1 [6]). However, in the case of customer billing based on a heat meter, it is very difficult to estimate the seasonal efficiency of the heat generator, which can be as low as 50% to 60% and it strongly depends on the design of the installation, its maintenance, and the operating conditions.

3 Conclusions

The current difficulties in determining the woodchips energy content at delivery by the supplier and the customer led to the development in a complete system that can measure energy contained in wood pellets continuously and repeatable manner during delivery.

The first tests carried out in laboratory conditions allowed to validate a concept comprising an unloading hopper conforming the material to a measuring conveyor equipped with humidity sensors of different technologies (infrared and microwave) and a weighing roller. A validation phase under real conditions confirmed the performance of the system.

On the one hand, the mass is measured with an accuracy of less than 1% and a repeatability of the order of 0.5%. On the other hand, the infrared moisture sensor has been shown to be more accurate and reliable than the microwave one because it is less biased by the surface humidity of woodchips, and because it does not depend on woodchips sizes.

The first tests under real conditions have shown that the measuring device is able to determine in 10 minutes the energy contained in a load of 40 m^3 of woodchips, with a humidity of 20 to 40% and with an error less than 3%. These promising results, however, still need to be confirmed by further tests encompassing a wider type of woodchips, comprising different species, size and moisture levels.

4 References

[1] EN ISO 17225-4, June 2017, Solid biofuels — Fuel specifications and classes — Part 4: Graded wood chips.

[2] Ropp 2017, Émissions de particules fines lors de la combustion de plaquettes forestières - Étude de l'influence des taux d'humidité et de fines - pour Énergie Bois Suisse.

[3] EN ISO 17225, June 2014, Solid biofuels — Fuel specifications and classes — Part 1: General requirements.

[4] EN ISO 18125, July 2017, Solid biofuels — Determination of calorific value.

[5] ISO 1928, January 2011, Determination of gross calorific value by the bomb calorimetric method and calculation of net calorific value.

[6] EN 1434-1, November 2016, Heat meters — Part 1: General requirements.