Final report

1.1 Project details

Project title	Sporbar online fugtmåling i træflis – SOFT (Traceable online measurement of moisture in wood chips)
Project identification (program abbrev. and file)	EUDP 64017-05150
Name of the programme which has funded the project	Energiteknologisk Udviklings- og Demonstrationsprogram (EUDP)
Project managing company/institution (name and address)	Teknologisk Institut, Gregersensvej, Postboks 141, 2630 Taastrup
Project partners	Teknologisk Institut, Insatech, Verdo Produktion, Aabybro Fjernvarmeværk, HedeDanmark, Ørsted, Tarm Fjernvarme (left consortium Oct. 2018), Mark & Wedell (joined consortium Nov./Dec. 2018)
CVR (central business register)	DK 5697 6116
Date for submission	

1.2 Short description of project objective and results

1.2.1 Short description of project objective and results (English)

The aim of the project is to develop a method for improvement of the quality of measurement of water content in wood chips used for biomass boilers for district heating or combined heat and power.

The project addresses the following main activities:

- Identification of a reference analysis method
- Investigation of the importance of the composition of the fuel (wood, bark, branches, needles, impurities)
- Optimization of the sampling procedure
- Development of a representative calibration procedure
- Establishment of a measurement system
- Onsite evaluation efficiency and accuracy of the measurement systems.

The goal is a to achieve a significant reduction of the uncertainty determination of the water content in wood chips with online measurement equipment and to validate the basis of the reference method.

1.2.2 Short description of project objective and results (Danish)

Formålet med projektet er at udvikle en metode til kvalificering af målinger af vandindhold i flis til biomassefyrede anlæg.

Projektet imødekommer ovenstående ved at gennemføre følgende hovedaktiviteter:

- Identificering af en referenceanalysemetode
- Undersøgelse af betydningen af brændslets sammensætning (ved, bark, grene, nåle, urenheder).
- Optimering af proces til prøveudtagning
- Udvikling af en repræsentativ kalibreringsmetode
- Etablering af målesystem
- On-site evaluering af målesystemets effektivitet og nøjagtighed

Målet er en signifikant reduktion af usikkerheden på bestemmelsen af vandindholdet i flis med on-line måleudstyr samt at få valideret referencegrundlaget.

1.3 Executive summary

The aim of the project was to improve water content measurement of wood chips used in district heating- and combined heat and power plants. Water content is an important parameter to assess the heating value of a fuel and is used e.g. in billing of wood chip deliveries. The accepted method to determine water content is to take a random sample and measure the amount of water by loss-on-drying. This technique, however, has several disadvantages. Results are available only with delay due to a 24h drying period. Additionally, manual sample extraction can be a source of sampling bias as well as limiting the number of samples that can be processed (due to the cost of labour involved). A low number of samples is problematic since water content within a single load of wood chips may vary considerably.

This project sought to address several of the above issues. NIR- and microwave instruments, as well as impedance moisture transducers were investigated. Instruments were installed on (microwave, NIR) or at (transducer) a conveyor belt at a combined heat and power plant. Samples for calibrating the instruments (via loss-on-drying) were taken directly from the belt. Results showed that these devices could give acceptably accurate online measurements of water content, e.g. when mounted above a conveyor belt. It was found that the accuracy of the measurement was to a large degree based on the quality of the data used for calibrating the instruments. NIR and microwave methods yielded similar results.

The second part of the project dealt with the quality of calibration data, and whether an error is introduced by using loss-on-drying measurements as a basis for the calibration of the measurement equipment. By loss-on-drying, other volatiles besides water may evaporate during drying and/or drying may leave residual water. In a new method developed by Danish Technological Institute, the sample is heated and purged with a dry gas stream (air or nitrogen). As the water evaporates and the vapour mixes with the dry gas, the water content of the sample can be derived from the measured humidity and flow of the purging gas. This method is a traceable primary reference method detecting only water and all the water from the sample and has been validated in an international intercomparison. Comparison of the new traceable method with loss-on-drying experiments on wood chips showed that differences between the results of the two methods was consistently less than the uncertainty of the traceable reference method. This suggests that the traditional loss-on-drying method is sufficiently accurate for calibrating the online instruments used in the project to determine water content in wood chips. The minimum obtainable expanded uncertainty of the loss-on-drying measurements can be deducted from the comparison with the new reference method to amount 2 % of the measured water content.

To improve sampling, an automated auger-sampler and divider was designed and manufactured. The auger/divider allows samples to be taken in a shorter time and in a more representative way than by manual sampling. It was successfully tested at a district heating plant. Water content was determined on-site with a NIR-instrument as well as by loss-on-drying, and the results showed good agreement. The sampler was designed for smaller particle sizes than the lot sampled. Particle size distributions of the automatically sampled wood chips were therefore slightly skewed towards smaller particles (compared to samples extracted manually). Further investigations showed that the water content however did not vary significantly among wood chips of different size regarding the samples tested.

Overall, the study revealed calibration to be one of the major challenges for online water content measurement. Calibration data should span the entire range of expected water contents (typically 20–60 % for wood chips). Wood chips used for much of this project had an unusually homogeneous moisture content (35–45 %) due to a dry summer in 2018, making it difficult to test the systems at the extremes of the measurement ranges.

During the project, two commercial products were developed. The first is a NIR-device for determining water content of wood chip samples at-line (i.e., samples are extracted from the process, but measurement results are available immediately). The device will be marketed by the project partner Insatech. The second product, pending few final adaptions, is the auger-sampler/divider, which will be commercialized by project partner Mark & Wedell. In addition to marketable products, consultant services and a training course on techniques for sampling and water content measurement aimed at plant operators have been established. The course will be held for the first time in November 2020.

The project has furthermore resulted in a series of publications, largely targeted at audiences in the relevant industries. It has also been presented to the international scientific community. Based on results from this work, Danish Technological Institute and Verdo have gathered a consortium of leading metrology institutes in the EMPIR-project BIOFMET (starting July 2020). Goals of BIOFMET are, among others, the development of reference materials and transfer standards for calibration of in-line water content measurement equipment used

for solid and liquid biofuels. These developments are foreseen to reduce the uncertainty of calibration of the in-line equipment and thereby the overall uncertainty of measurements.

1.4 Project objectives

1.4.1 Objectives

The main objective of this project was to develop and demonstrate improved on-line methods to measure water content in wood chips. Wood chips are widely used as a fuel in biomass-fired boilers for district heating and in combined heat and power plants. Billing of wood chip deliveries is based on the heating value, which is assessed by the (dry) weight of each delivery. As wood chips will readily take up or lose free water, the measurable gross (wet) weight of a delivery will be strongly influenced by the wood's moisture at the time of weighing. As a standard method for measuring the water content of the wood chips sampling combined with the loss-on-drying technique is used. This method is however time-consuming, inherently inaccurate, and prone to sampling errors. Specific objectives in this project were therefore:

1. To develop automated, online measurement techniques for water content to replace the standard loss-on-drying technique
2. To develop this measurement technique to allow for calibrations traceable to basic SI-units
3. To develop procedures and automated devices for representative sampling of large piles of wood chips.

1.4.2 Background

Moisture in solid fuels can be determined by the loss-on-drying method (LoD), where a small sample (less than 1 kg) is heated to typically 105 °C in a defined time period (typically 24 hours) allowing the water to evaporate. The water content is then determined by the difference in mass before and after drying. The underlying assumptions are that (1) all water evaporates under these conditions, (2) no other volatile materials are released, and (3) that the sample is representative of the bulk material it is taken from.

Representative manual sampling requires a larger number of samples to be taken to even out stochastic variations between the samples. Especially smaller district heating plants do not have the capacity to perform this time-consuming work. Moreover, the moisture content of the sample may change during or before weighing, if it is not handled and stored properly. The present methods utilised for moisture measurement in solid biofuels were transferred from documentary standards developed for coal. However, these standards are not traceable in a metrological sense. The implication of this is that these methods cannot be used to properly calibrate online measurement equipment, as the true water content of a sample in principle is unknown. Measuring water content in wood chips is also complicated due to the inhomogeneous nature of the material. Wood chips can include stem wood, bark, branches, needles, or leaves, as well as tramp objects and other impurities.

1.4.3 Project activities and organization

The main activities in this project were:

- Identification of a suitable reference analysis method
- Investigation of the importance of the composition of the fuel
- Optimisation of the sampling procedure
- Development of a representative calibration procedure
- Establishment of a measurement system
- Onsite evaluation of the efficiency and accuracy of the measurement systems.

Progress in the project was evaluated based on 8 milestones and 5 commercial milestones. Milestones 1 and 2 concern the establishment of the project working group (consortium agreement and kick-off meeting, respectively).

The other milestones were:

M3: Technical note on optimized methods and economic consequences of incorrect sampling
M4: Technical note on reference methods

M5: Guideline for moisture measurement at district heating plants firing wood chips developed and published
M6: Technical note on results from an on-site proof-of-concept measurement campaign
M7: Article(s) published in relevant media
M8: National or international presentation of the project's results.

The commercial milestones KM1–KM5 were:
KM1: Measurement system market-ready in Denmark (01/2020)
KM2: Completed development of sampling system for small district heating plants (12/2020)
KM3: First complete measurement system sold (03/2021)
KM4: Training/course established, including educational material (06/2020)
KM5: Consultant service for moisture measurement in biomass (08/2020)

The project's technical milestones were all reached. Commercial milestones KM1, KM4 and KM5 were reached within the project, while KM2 and KM3 are planned to be completed within the first half year after completion of the project. Unforeseen events such as: the Covid-19 pandemic interrupting normal work procedures and the inclusion of the winter 2019/20 heating period to gain additional field experience resulted in minor delays and the project was completed after a total of 48 months (vs 39 originally planned).

The following risks for completing the project were initially identified:

1. The uncertainty of online measurement cannot be improved. Consequence: unacceptably high uncertainty. Mitigation: include other, less well-established measurement principles
2. The equipment is not assembled on time. Consequence: Measurements at district heating plants cannot be carried out. Mitigation: Activity is given high priority and progress is monitored closely.
3. The sampling procedure is not economically feasible or too time-consuming. Consequence: sampling uncertainty remains high. Mitigation: none, high uncertainty is accepted in procedure.

The above risks could be averted in the project.

The following risks for marketing products and services developed in the project were identified:

1. Data management and measurement procedure cannot be implemented in heating plants' daily operation. Consequence: system/method is not commercially viable. Mitigation: Project is extended to two heating seasons, allowing more development time.
2. The new online method does not meet speed and/or accuracy requirements. Consequence: the target industry will hold on to the loss-on-drying method. Mitigation: Activity is given high priority and progress is monitored closely.
3. CO_2-quotas for biomass combustion are introduced. Consequence: fewer new plants and existing plants are less profitable. Mitigation: communication activities in the project (e.g., publications, seminars) can support public opinion in favor of biomass.
4. Establishment of new biomass facilities is banned in Denmark. Consequence: market potential in Denmark decreases. Mitigation: project results are presented in an international setting to better spread products on the European market.

Initial results from the project were promising with respect to near-term market introduction. While the sustainability of biomass combustion for heat and power remains debated, the overall political and legal framework has not changed in a way that would affect the products' market success.

1.5 Project results and dissemination of results

Following the objectives of the project, activities took place in three parallel, largely independent tasks: development of improved online measurement, development of a traceable reference method and development of improved sampling methods.

This section contains a short summary of the main findings. Additional results and details on procedures can be found in the technical notes for milestones M3, M4, M5 and M6 (see appendix).

1.5.1 Definition of terms used in this report

The term "online" applies to all methods presenting results in real time, thus permitting usage as a control input for downstream processes. The corresponding measurements can be "inline", i.e. without removing samples from a process (e.g. measuring directly on the moving conveyor belt); "at line", i.e. a device set up immediately next to the process, so that samples can be extracted, analysed and potentially returned without further delay; or "off-line", i.e. where removal of the sample, transport to another site and potentially pretreatment are required before the analysis.

Traceability in a metrological sense means that a measurement can be traced to basic SI units via an unbroken chain of calibrations.

A calibration is an operation that, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties

Calibration should not be confused with adjustment of a measuring system: Adjustment is a set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured. This means that in principle a calibration is a prerequisite for adjustment.

Accuracy means the closeness of agreement between a measured quantity value and a true quantity value of a measurement.

Precision is defined as the closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.

Water content in the following is given as "wet-based" ("as received") fraction.

1.5.2 Online measurement equipment

At the start of the project, general requirements for online measurement equipment were defined as follows:

1. The measured sample is representative of the whole batch
2. Extraction of samples for offline analysis and calibration is possible at the measurement site.
3. Accessibility for inspection, calibration, and maintenance
4. A calibration routine is defined.

Online measurement in a location where the material is well mixed and moving is preferable. Early in the project, it was considered whether the devices could be installed to measure falling wood chips (e.g. when passing from one conveyor to the next). This was however judged to be unfeasible, and inline equipment was installed above a conveyor belt instead (with the risk of stratification of the material on the belt).

As calibration method, loss-on-drying was adopted in lack of other practicable alternatives. Calibration is then performed by comparing the indication of the instrument to be calibrated with the water content of a material sample determined by loss-on-drying. Ideally, calibration can take place "on the spot" by using the exact same material that has been analyzed online for calibration. In practice, it is difficult to identify and extract wood chips from the conveyor with the required accuracy. As an alternative procedure, several samples can be taken at defined time intervals. These samples are then thoroughly mixed, and three subsamples extracted for loss-on-drying measurement. Calibration samples should have different water content levels to ensure proper calibration of the entire measurement range of the measuring instrument.

For a case study at Verdo's combined heat and power plant in Randers, several measurement principles were applied simultaneously. The objective was to compare measurements based on these different principles as well as to establish whether a combination of instruments would yield more accurate results. The measurement principles used in these experiments were:

- Microwave transmission (inline)
- Infrared-reflection/NIR (inline)
- Impedance-based moisture-transducer (at line)

Inline instruments were installed above a conveyor belt connecting silo and burners. The microwave instrument had already been installed and in use prior to the project. A series of auxiliary measurement principles were applied to interpret and correct the primary measurement signals:

- Radioactive measurement of area density [kg/m²] (inline)
- Photography/color analysis (tested offline)
- Ambient and surface temperatures
- Ambient relative humidity

The installed inline measurement equipment can be seen in **Fejl! Henvisningskilde ikke fundet.**. Signals from the different systems were synchronized by a common timestamp. The sampling rate was 1 Hz.
Calibration was carried out by loss-on-drying with representative samples as outlined above.

Figure 1: Microwave (1) and NIR (3) installed on the conveyor belt. The microwave instrument consists of a transmitter and a receiver, which are placed below (not visible in the image) and above the conveyor, respectively. The device for measuring area density to complement microwave measurements is the small black box to the right of the warning sign (2).

Microwaves penetrate the material and therefore give an indication of the water throughout the volume sampled. Phase shift and attenuation depend on water content, corrected for the sample's area density. They can be related by the following formula:

$$\textit{water content} = \mathrm{A} \cdot \frac{\textit{phase shift}}{\textit{area density}} + \mathrm{B} \cdot \frac{\textit{attenuation}}{\textit{area density}} + \mathrm{C}$$

A, B and C are constants to be fitted by regression analysis from calibration data. Results are shown in Figure 2. The precision of the model was ±2.8 percentage points.

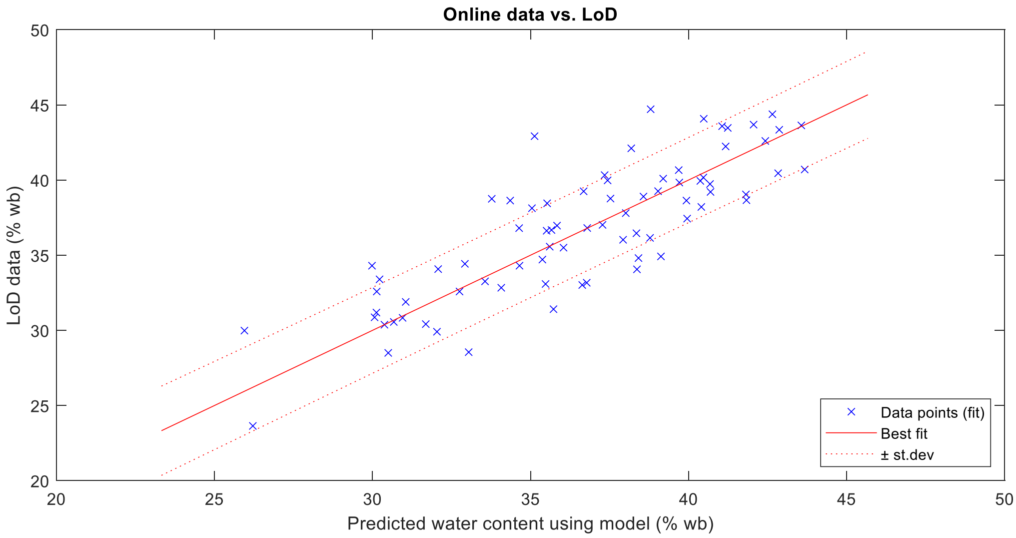


Figure 2: Water content modeled from online microwave data vs. loss on drying

Near-infrared (NIR) reflectance in several specific wavelengths can be related to water content. The measurement mainly covers the surface area (up to approximately 1–3 mm depth). The device used internally relates reflectance to water content using a proprietary algorithm. Unfortunately, neither algorithm nor raw data are accessible. In this project, output from the instrument was corrected by a linear expression:

$$water\ content = A \cdot water\ content\,(\mathrm{NIR}) + B$$

where A and B are constants fitted by calibration data. Results can be found in Figure 3. The model precision was ±1.8 percentage points.

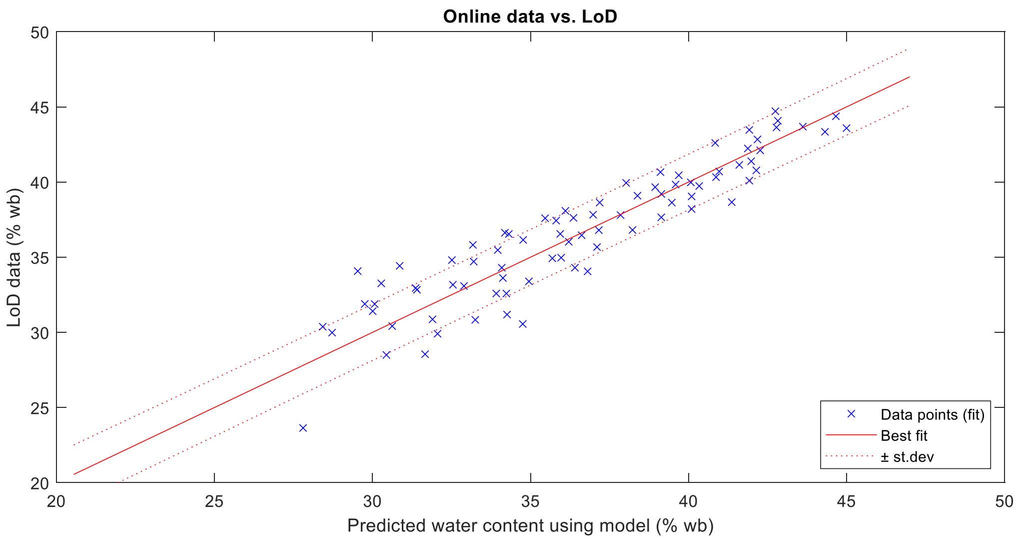


Figure 3: Water content modeled from online NIR-data vs. loss-on-drying

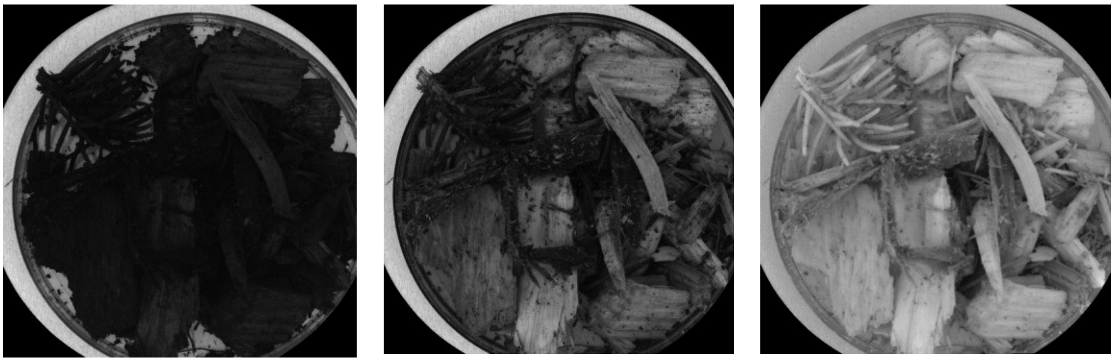
Combining NIR and microwave data via linear superposition gave no further advantage over NIR alone. A model of the following type can be fitted to the data:

$$water\ content = A_2 \cdot \frac{phase\ shift}{area\ density} + B_2 \cdot \frac{attenuation}{area\ density} + C_2 \cdot water\ content\,(\mathrm{NIR}) + D_2$$

Using data shown in Figure 2 and Figure 3 gave a precision of ±1.7 percentage points. The main advantage of the combined measurement would be in the redundancy, i.e. failure or unavailability (e.g., due to maintenance) would still allow a continuous online measurement. It was further investigated whether machine learning techniques could be used to reduce measurement uncertainty. In practice, this can be done by incorporating mixed- and higher order terms in the above equation, resulting in a significantly higher number of fitted model parameters. Based on the data available, this machine learning approach gave no clear advantage. Likewise, correction of measured data with surface and/or ambient temperature did not appear to improve model-based predictions of water content.

Impedance-based moisture measurement (moisture transducer) could not be implemented as an inline method. Instead, samples had to be transferred from the conveyor belt to a sampling container (i.e., at line). The actual measurement device was installed below the sampling chamber. The measurement principle is like microwave measurements, i.e. analysis of phase shift and attenuation, but Impedance-based measurement uses radio-waves instead of microwaves. A linear model had a precision of ±2.5 percentage points.

Image analysis was investigated as a tool to distinguish wood, bark, as well as leaves and needles (**Fejl! Henvisningskilde ikke fundet.**). These components may have slightly different absorption and reflectance



(a) 410 nm (b) 653 nm (c) 913 nm

Figure 4: Optical analysis shows that different components (wood, bark, needles) reflect light at different wavelengths.

characteristics, which may in the future enable correction of NIR/microwave signals. It was found that the wood, bark, and other components can be identified by their different absorption behavior in the UV to near-IR spectrum. For the present state-of-the-art moisture analyzers, the complexity of integrating this imaging technique into the measurement setup did not appear to have a reasonable relation to the possible increase in precision and accuracy.

Calibration samples for loss-on-drying were extracted from the conveyor belt four times per week, i.e. Mondays through Thursdays. Samples were then weighed, dried for 24 hours, and weighed again. Wood chips used in this campaign had an unusually homogeneous water content (35–45 % vs. typical range 20–60 %) due to a dry summer in 2018, making it difficult to test the system at the extremes of the measurement range. It was also noted during the process that irregularities in sampling may significantly influence the results obtained by loss-on-drying. It is therefore essential to establish and follow a standard procedure in sampling to assure representative and repeatable results that can be used for calibration.

In conclusion, both NIR and microwave instruments gave a satisfactory online estimation of water content when compared to loss-on-drying. NIR can operate as a standalone device, while microwave water content measurement requires an extra area density measurement. Accuracy of the measurements was found to depend mainly on the quality of the (loss-on-drying) data used for calibration of the instruments. Digital tools such as image recognition and calibration by machine learning did not significantly improve measurements but may be of interest for future moisture analyzers.

1.5.3 Traceable reference method for calibration of online measurement

The basic assumption underlying the loss-on-drying method is that all water and only water is removed during the drying process. For biomass, this is not necessarily the case, as low temperature oxidation and pyrolysis processes may remove some of the light volatile organics during the 24 h drying at 105 °C. Specifications in the applicable standard (minimum sample mass of 300 g and a scale with minimum 0.1 g resolution) suggest a relatively low uncertainty (0.03 %) of the method. However, the accuracy of the instrument is likely not as limiting as the conceptual uncertainty.

A new method has been developed, using instruments with an unbroken calibration chain to SI units.[1] The method is therefore 'traceable' in a metrological sense. Similar to the loss-on-drying method, all water and potentially other volatile substances are evaporated from the sample. Instead of measuring the mass loss of the sample, the amount of water (humidity) added to the surrounding atmosphere is measured. The basic layout of the system can be seen in Figure 5: The sample is placed in a closed sample chamber, which is constantly

[1] More details can be found in: P. Østergaard & J. Nielsen, SI-Traceable Water Content Measurements in Solids, Bulks, and Powders, Int. J. Thermophys. 39 (1), 2018. DOI: 10.1007/s10765-017-2325-4

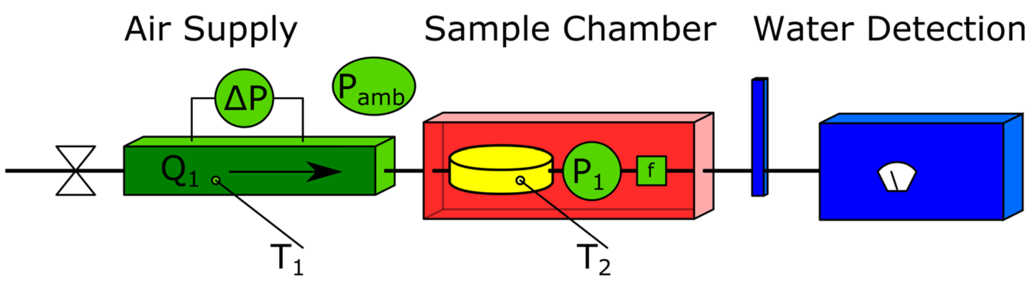


Figure 5: Setup for water content measurement. Original: Østergaard & Nielsen, Int. J. Thermophys., 39 (1), 2018.

purged with dry air (or air with a known, low humidity). The outlet of the sample chamber is connected to a water detection unit, where humidity in the air stream is determined independently by a capacitive sensor and a chilled mirror hygrometer. Integration of the product of humidity and gas flow rate over time yields the total water content of the sample.

The following individual parameters are measured to determine sample water content:

- Dew point/water vapour pressure
- Gas flow
- Atmospheric pressure
- Pressure in the sample chamber
- Ambient temperature
- Temperature in the sample chamber

Uncertainty of the method is determined from the combined uncertainty levels of the individual measurements. As interactions are non-linear, the overall uncertainty is found via Monte-Carlo-simulation. The minimum obtainable expanded uncertainty was found to be 2 % of the measured water content. The new method performed well in an international round-robin-test of twelve laboratories (**Fejl! Henvisningskilde ikke fundet.**). Methods applied in the other laboratories included coulometric Karl Fischer, electrolytic cells, water vapor analyzer, and dew point detection[2]. The sample used for the round-robin test was wood pellets with a water content just below 8 % (wet basis).

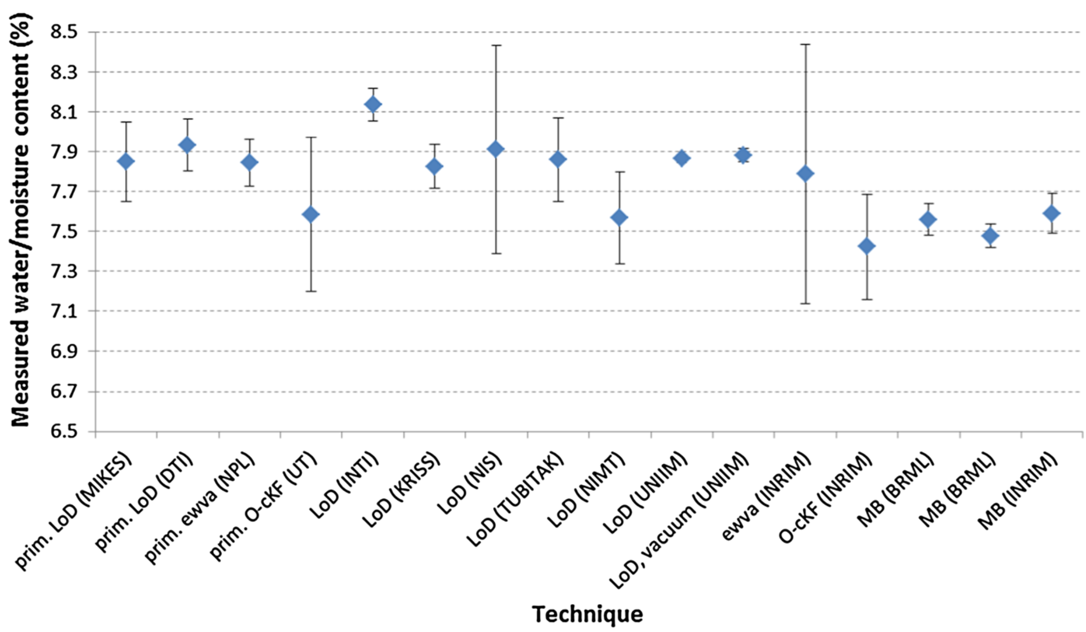


Figure 6: Round-robin test. The new method is marked "prim. LoD (DTI)" (second from left). Original: Heinonen et al., Int. J. Thermophys., 39 (1), 2018

[2] M. Heinonen et al., New Primary Standards for Establishing SI Traceability for Moisture Measurements in Solid Materials, Int. J. Thermophys., 39 (1), 2018. DOI: 10.1007/s10765-017-2340-5

The new reference method was furthermore compared to the standard loss-on-drying method (**Fejl! Henvisningskilde ikke fundet.**) using wood chips. Differences in water content between the two methods were less than the minimum obtainable uncertainty of the new reference method for the examples shown. Actual uncertainties of the new method were moreover always slightly higher than the minimum obtainable uncertainty. Comparison of the new traceable reference method with the standard loss-on-drying method suggests that the latter is sufficient for practical use with wood chips. This means that the non-water content of the evaporated material is less than the uncertainty of the reference method. Loss-on-drying cannot be 'better' than the new method, since this method is not metrological traceable (the new method can be used to validate loss-on-drying, but not vice versa). Therefore, the minimum obtainable uncertainty of loss-on-drying is the same as the minimum obtainable uncertainty of the new reference method, i.e. 2 % of the measured water content.

Table 1: Comparison of the new reference method with the standard loss-on-drying method.

Sample	Reference method: Water content	Uncertainty (k=2)	Lowest possible uncertainty (k=2)	Moisture content, LoD	Difference reference–LoD
1	22.29 %	0.58 %	0.45 %	22.44 %	-0.15 %
2	31.73 %	0.85 %	0.64 %	31.49 %	0.24 %
3	30.87 %	0.79 %	0.62 %	31.18 %	-0.31 %

1.5.4 Representative sampling procedures and automatic sampling devices

The project has included other researchers' work, in which errors from non-representative sampling of wood chips had been investigated. Sampling at different positions from the same truckload showed measured water contents between 34–66 % for 29 samples (mean: 51 %). Current practices for sampling were reviewed. In larger facilities, delivery trucks are often assigned a randomized parking position, from where an automatic sampler takes up material at a randomized depth. While not necessarily representative, this sampling method avoids human bias. In smaller facilities, it is typically up to the truck driver to take a sample with a bucket from a (freely chosen) location.

Data collected in this project furthermore showed variations in average water content between hardwood and softwood, as well as seasonal variations among deliveries.

The financial impact of incorrectly determining the moisture content was estimated using a model calculation. The main results are shown in **Fejl! Henvisningskilde ikke fundet.**. The data illustrate the changes in heating value and cost resulting if the moisture content is assumed to be 40 %, while the true value varies between 30–50 %. Underestimating the moisture content by 10 percentage points led to a "loss" of 21 % in heating value. If scaled up to

Table 2: Model calculation of the effect of erroneous fuel water content measurement on annual cost (based on 40 % moisture, 4 mio. GJ/year and 45 kr/GJ)

Moisture [%]	Heating value (wet) [GJ/t]	Change in heating value (relative to 40 % moisture content) [%]	Value difference (relative to 40 % moisture content) [Mio. DKK]
30	12.57	21	370
35	11.50	10	185
40	**10.42**	**0**	**0**
45	9.35	-10	-185
50	8.28	-21	-370

the annual use of wood chips in Denmark (40 mio. GJ/year in 2020) and using an approximate price of 45 kr/GJ, this corresponds to a financial loss of DKK 370 million for district heating plants.

Different approaches have been suggested to increase sampling accuracy. Dansk Fjernvarme suggests taking at least 5 samples of 5 L each from different locations of the same patch. Samples are to be stored in diffusion-tight containers for transportation and storage. Water content is to be determined by loss-on-drying. In this project, the consortium developed a procedure of taking 3 samples of 10 L, which are then placed in round, transparent containers and analysed by NIR. Rotating the containers allows testing of different fractions of the sample. Water content can be determined from NIR-data with the aid of calibration curves, and each sample can then be further investigated with the standard loss-on-drying method.

An automated auger-sampler including a sample divider was developed by Mark & Wedell to extract randomized, representative samples from wood chip piles. The sampler was designed to take a cross sectional cut of wood chips from a lot, based on ISO 18135:2017 (Solid Biofuels – Sampling), and dimensioned for particles up to 71 mm in size (D_{95} = 30 mm). The main part is a vertical screw conveyor (auger), which can be lowered into a wood chip pile. The intake is designed to avoid sampling errors (e.g., by extracting only chips within a certain size range). The sample to be measured can then be extracted from a divider placed on top of the conveyor. Suspended from a crane or attached to a rigid frame, the device can also be used to sample wood chip loads directly on the truck. The sampler/divider was tested successfully at a measurement campaign at Aabybro Fjernvarmeværk (Figure 7).

Figure 7: Test of the sampler/divider at Aabybro. Top left: sampler suspended above wood chip pile, top right: sampler lowered towards pile, bottom left: sample intake (detail), bottom right: samples are extracted at the top of the screw conveyor.

In order to assess systematic errors from the sampling device, it was further investigated (1) whether the sampling device led to any kind of size fractionation in the samples, and (2) whether water content varied between wood chips of different size from the same location in a pile.

Minor differences between manual and automatic sampling were seen (Figure 8), with the automatic sampler distribution slightly skewed towards small- and medium sized chips. This could be expected, as the auger was designed with an inlet diameter of 213 mm, appropriate for wood chips with a characteristic length of 71 mm. A considerable fraction of larger wood chips (>63 mm) are possibly either rejected or crushed, leading to a higher mass fraction with sizes 16–45 mm.

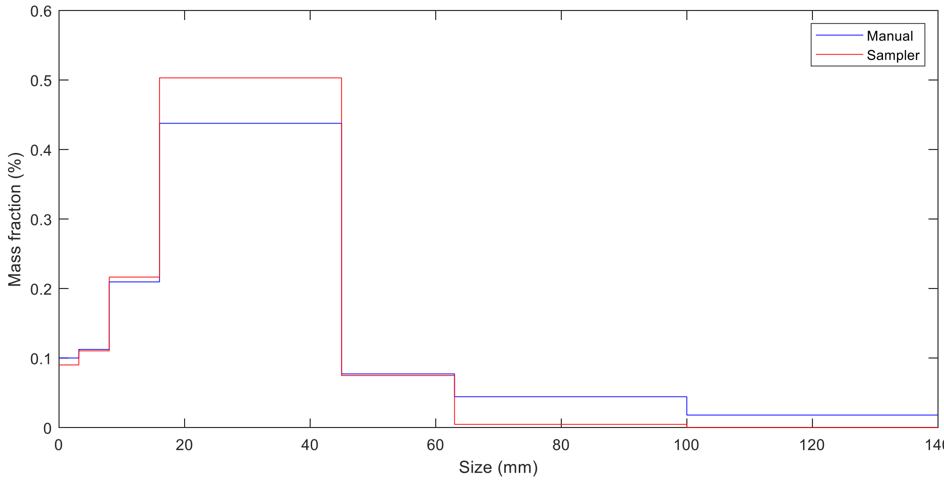


Figure 8: Particle size distribution for automatic sampler and manual sample extraction

For the second part, two buckets of wood chips were sampled from a larger pile. Samples were divided following DS/EN ISO 14780:2017. For the first sample, the particle size distribution was determined according to DS/EN ISO 17827-1:2016, which includes pre-drying as the water content exceeds 20 %. The second sample was sieved before drying, after which water content in each fraction was measured according to DS/EN ISO 18134-2:2017. Results are summarized in Table 3. The pile was somewhat unusual, as all sampled chips could pass through the 63 mm-sieve. Typical stacks contain wood chips up to 125 mm in size. When comparing the two samples, relatively large differences in water content could be seen (51 % vs. 25 %), depending on the location from which the sample was taken. This confirms earlier findings and underlines the necessity of representative sampling. Size distribution differed slightly between the two samples, with most chips in the 16–45 mm size fraction (note that this is also the broadest sieving interval). Water content did not differ much among wood chips of different size from the same location (sample 2), and varied by less than 1.5 percentage points around the mass-weighted average for particles >3.15 mm. Particles smaller than that had a lower water content, but these make up only a small part of the total mass. Sample 1 could not be sieved into fractions due to its high (average) water content (>50 %) without prior drying.

Table 3: Water content in different size fractions.

Size fraction	Mass fraction [%]		Water content [%]	
	sample 1	sample 2	sample 1	sample 2
< 3.15 mm	7	3.3	—	15.2
3.15 – 8 mm	14.4	6.6	—	23.9
8 – 16 mm	29.2	23.4	—	25.9
16 – 45 mm	47.4	62.8	—	25.7
45 – 63 mm	1.9	3.9	—	24.7
> 63 mm	0	0	—	—
total	99.9	100	51.3	25.2

Although by no means exhaustive, the results from this experiment suggest that water content varies more between chips in different locations of a pile than it does between chips of different size at the same location. The relatively homogeneous distribution of water among chips of different size in sample 2 suggests that water is absorbed throughout the volume of the chips, and not only on the surface. As a tentative conclusion, a possible fractionation of the sample by the sampling device should therefore not lead to relevant measurement errors. Further systematic investigations may be necessary to clarify this point.

Samples extracted manually and automatically were analyzed by NIR and loss-on-drying (Figure 9). Agreement between NIR- and loss-on-drying was generally good. There appeared to be a systematic difference between samples extracted manually (32–35 % water) and those taken by the sampler (35–37 % water) in NIR data. Loss-on-drying data showed more overlap of the two groups of samples. Owing to the overall small number of samples, it is however difficult to judge whether the difference between sampling methods is significant.

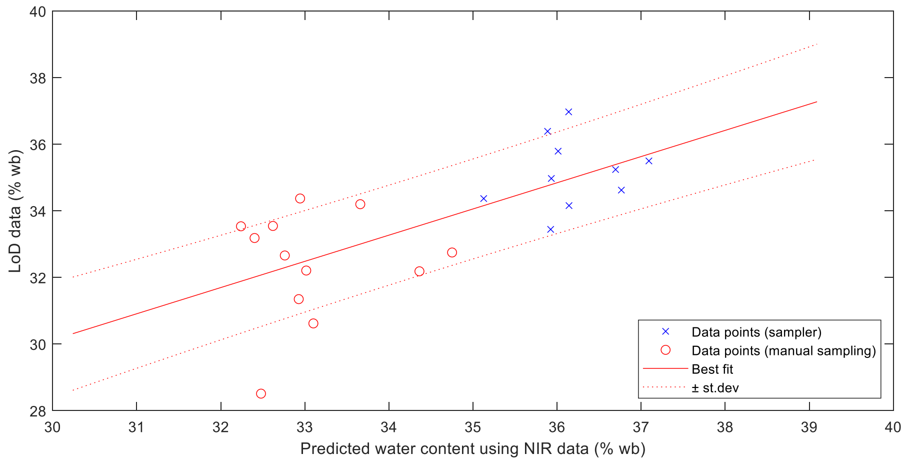


Figure 9: Water content sampled automatically and manually at Aabybro Fjernvarmeværk

A second measurement campaign was carried out, during which wood chip deliveries were (manually) sampled and analyzed over the course of ca. one month (113 samples). Comparison of at-line NIR and loss-on-drying are seen in Figure 1Figure 10. The overall precision in this campaign was ±4 percentage points (compared to ±1.8 percentage points for the earlier on-line campaign). Measurements up to ca. 40 % water content showed a better agreement between NIR and LoD-data. The NIR-instrument used was different from the one used in the rest of the project, which may explain some of the discrepancy. Other possible explanations are incorrect handling of the NIR instrument or errors from dividing the loss-on-drying samples (typically only one fifth of the extracted sample is analyzed).

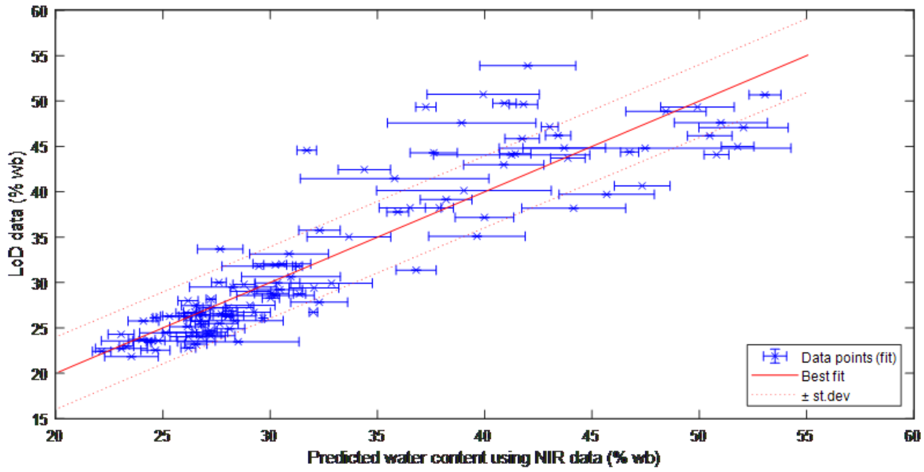


Figure 10: Results of at-line NIR-measurements at Aabybro Fjernvarmeværk. Error bars show the spread of three NIR-measurements per data point.

1.5.5 Commercial results

The project had 5 commercial Milestones (KM1-5), the results of which are described below.

KM1: Fully developed measurement system market-ready in Denmark (M28):
This milestone is connected to the product developed by Insatech, the NIR water content measurement system. The device was tested at Aabybro district heating pant in this project. The system is ready for introduction on the market and will be presented to customers in late 2020 by Insatech. The system is shown in Figure 11**Fejl! Henvisningskilde ikke fundet.**.

KM2: Completing development of sampling system for small district heating plants (M39 after project is finished):
This milestone is connected to the development work performed by Mark & Wedell. The prototype sampler is shown in Figure 12**Fejl! Henvisningskilde ikke fundet.** at the final measurements at Aabybro district heating plant. At the end of the project, the sampler still needs further development (especially the ability to sample larger wood chips) to ensure market readiness. The project however has shown that this is a viable approach to automate the sampling process at smaller district heating plants.

KM3: First complete measurement system sold (M42, after project start):
With the completion of the automated sampler system (expected around M39 after project start), the combination of the complete system can be assembled by Insatech and Mark & Wedell.

Figure 11: Insatech NIR-system

Figure 12: Mark & Wedell sampler/divider

KM4: Training/course established, including educational material (M33):
In collaboration between the partners of the project, and Danish District Heating Association (Dansk Fjernvarme) a training course[3] on sampling and measurement of water content was established. The first training will be held on the 25th of November 2020.

KM5: Consultancy service for moisture measurement in biomass (M23):
Based on the research in the project, Danish Technological Institute has developed a consultancy service with regards to moisture measurement. The service[4] is among others presented by DTI outside of the project.

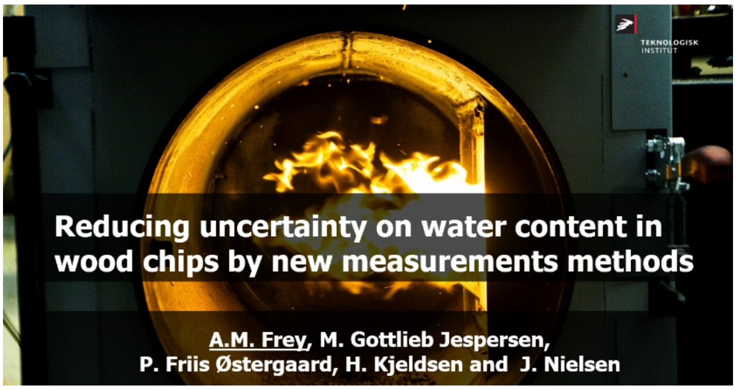
1.5.6 Dissemination

Throughout the project focus has been on disseminating the results both nationally and internationally – both to raise awareness of the issue but also to show possible solutions on how to reduce the uncertainty of the measurement of water content in wood chips. The dissemination is part of WP 4, completing milestones M7 "*Article(s) published in relevant media"* and M8: "*National or international presentation of the project's results"* as well as KM4 "*Training/course established"*. A summary of the project is available online at https://teknologisk.dk/39064, where links to the final results of the project will be updated and available (in Danish).

Publications and other activities:
26th European Biomass Conference and Exhibition 2018, Copenhagen, Denmark oral presentation by Anne Mette Frey. https://www.eubce.com/wp-content/uploads/2018/04/Conference-Programme_27042018.pdf (p. 41)

[3] https://www.danskfjernvarme.dk/nyheder/nyt-fra-dansk-fjernvarme/arkiv/2020/200826---m%c3%a5ling-af-fugt-i-br%c3%a6ndsler

[4] www.teknologisk.dk/ydelser/retvisende-fugtmaaling-af-trae/retvisende-fugtmaaling-af-trae/42254?cms.query=fugtm%E5ling



Article in FiB 63 (2018) – page 18-19 - https://www.biopress.dk/PDF/fib-nr.-63-marts-2018 in Danish

Måling af vandindholdet i flis – en udfordring

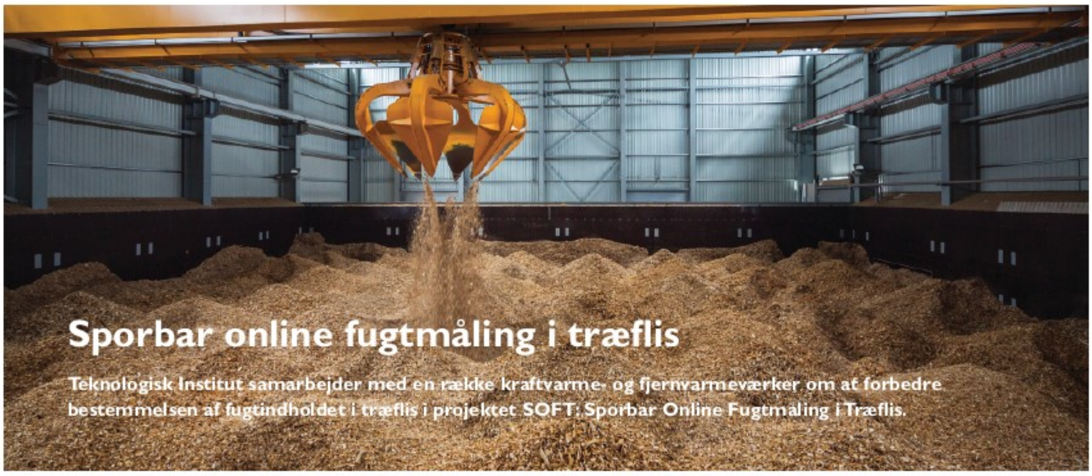
I dag er det muligt at foretage online målinger af vandindholdet i flis, men erfaringerne viser, at målingerne ofte er upålidelige og problematiske at anvende i praksis. Et nyt EUDP-projekt skal være med til at sikre en mere korrekt bestemmelse af vandindholdet i flis.

Af Jan Nielsen, Peter Friis Østergaard og Anne Mette Frey

"loss-on- drying" eller blot LoD-teknikken.

analyser for at kunne få et retvisende billede af vandindholdet.

Article in "Metrologi Nyt" August 2018 – prepared by Jan Nielsen, Anne Mette Frey and Lene Skov Halgaard.



Biomasse er blevet den helt store vedvarende energikilde i det danske energisystem. Mange værker er skiftet fra at benytte fos-

Desværre er metoden ikke sporbar: Der er ikke sikkert, at alt vandet fordamper, men derimod kan yderligere massetab forekomme ved

Training course developed and planned for the 25th of November 2020 in cooperation with Danish District Heating Association – Focus groups is employees of Danish district heating plants. https://www.danskfjernvarme.dk/kurser/produktion/optimal-pr%C3%B8veudtag-ning-og-fugtm%C3%A5ling-af-br%C3%A6ndsel

26. AUG 2020 KURSER & ARRANGEMENTER

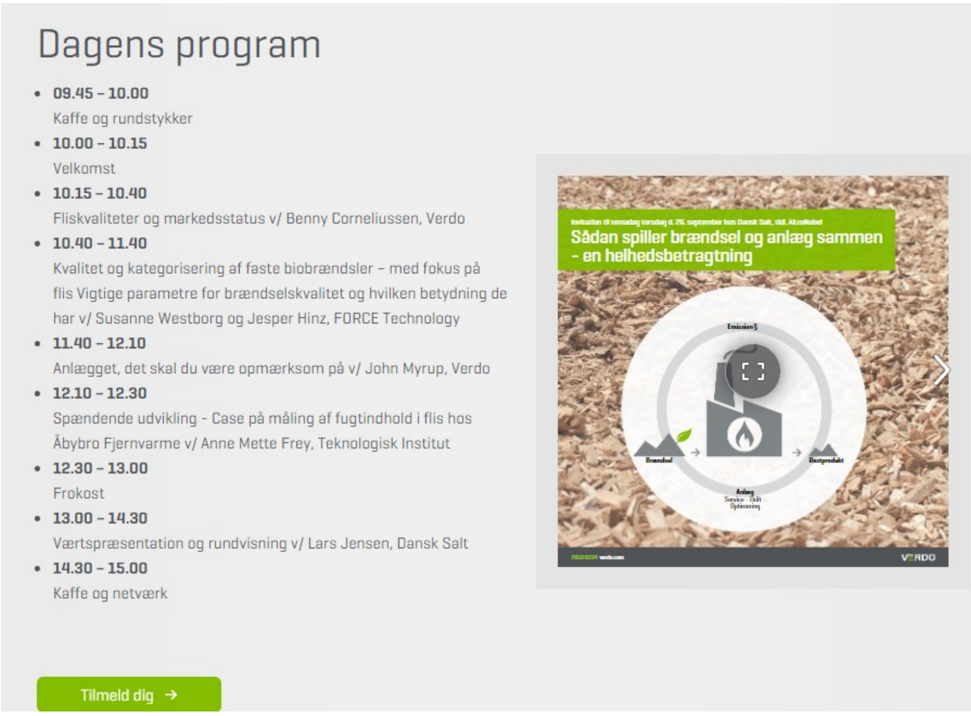
Nyt kursus: Prøveudtagning og måling af fugt i brændsler

Måling af fugt i brændsler og at udtage en retvisende prøve kan være udfordrende. Deltag på kursus og få indsigt i den helt rigtige målemetode.

Facebook LinkedIn Twitter Print

De forskellige typer af brændsler har hver sine udfordringer, ligesom valg af rette målemetode kan være uoverskueligt. Derfor har vi udviklet dette helt nye kursus i samarbejde med Teknologisk institut, hvor vi går i dybden med hele processen for en fugtmåling, og vi undersøger både på træpiller, halm og flis.

Presentation on conference held by Verdo - oral presentation by Anne Mette Frey.



Dagens program

- 09.45 – 10.00
  Kaffe og rundstykker
- 10.00 – 10.15
  Velkomst
- 10.15 – 10.40
  Fliskvaliteter og markedsstatus v/ Benny Corneliussen, Verdo
- 10.40 – 11.40
  Kvalitet og kategorisering af faste biobrændsler – med fokus på flis Vigtige parametre for brændselskvalitet og hvilken betydning de har v/ Susanne Westborg og Jesper Hinz, FORCE Technology
- 11.40 – 12.10
  Anlægget, det skal du være opmærksom på v/ John Myrup, Verdo
- 12.10 – 12.30
  Spændende udvikling - Case på måling af fugtindhold i flis hos Åbybro Fjernvarme v/ Anne Mette Frey, Teknologisk Institut
- 12.30 – 13.00
  Frokost
- 13.00 – 14.30
  Værtspræsentation og rundvisning v/ Lars Jensen, Dansk Salt
- 14.30 – 15.00
  Kaffe og netværk

Tilmeld dig →

1.6 Utilization of project results

The project has 7 partners, three of which have direct commercial interests in the products developed (Insatech, Mark & Wedel and HedeDanmark). Three other partners are utility or district heating plant owners (Verdo, Aabybro and Ørsted) and the seventh partner is a research and technology organisation (Danish Technological Institute). Even though the project has led to direct products/or close to market products, no patents are expected to be taken out.

1.6.1 Utilisation of project results in a commercial framework

Insatech will use the project results including the unit developed during the project to promote the product. The marketing of the product as a stand-alone unit has started in October 2020, where the product has been presented for the existing client list. Insatech will continue to work further on developing online measurements systems.

Mark & Wedell have through the project developed an automated auger-sampler including a build-in divider to extract randomized (representative) samples from wood chip piles. The final development of the auger solution is planned to be completed after the project period. Mark & Wedell will use the final experiments at Aabybro to optimize the design. The auger solution can be attached to a rigid frame, crane or be used to sample in a truck or a pit.

HedeDanmark will not directly use the results in a commercial scale but will use the knowledge gained in the project as a part of the contractual work with partners within district heating. HedeDanmark already provides solutions for fast settlements of accounts, where digital tools are used. If water content values could be measured online and fed to an electronic database, e.g. using systems like those of Mark & Wedell and Insatech, this process could be fully automated to increase the speed of settlement of accounts.

1.6.2 Utilisation of project results in District heating framework

Verdo has through the project enhanced the knowledge with regards to the measurement of water content in wood chips. This knowledge will be used in the long term to optimize the measurements. Optimization includes equipment but also how and in which environment the system should be installed to ensure optimal conditions. Verdo will focus on both the measurement itself but also how optimal calibration/adjustment can be performed. As there are still issues to handle with measurements of the quality of the fuel, Verdo has entered the European project BIOFMET[5] which will address this further.

Aabybro has also enhanced their knowledge with regards to the measurement of water content in wood chips. Aabybro is aiming at further automizing and digitalising of sampling than is the case today. There is still not a complete solution for this, but the value of having a system is clear. When Mark and Wedell have completed the development of the automated auger-sampler this will be of high interest at Aabybro. The interest is not only about saving man hours but also about the speed of the measurement and an improved and more accurate method than the one used today.

Ørsted will use the knowledge gained in the project to optimise the procedures used on the conveyer belts to calibrate the measurement systems, and thereby have a more accurate system with a known uncertainty.

1.6.3 Utilisation of knowledge gained in the project:

Danish Technological Institute has used the results in the creation of a training course and a consultancy service for users of biomass. In addition, the project results have been used to gather an international consortium for further development of the metrology framework of measurements of biomass. The new project, BIOFMET, is funded under the Euramet program *European Metrology Programme for Innovation and Research (EMPIR)*[6]. The project will support the introduction of faster, more accurate calculations of calorific value for solid and liquid biofuels.

Even though talks on the political scene are addressing issues with biomass and the sustainability of the sources, biomass plays an important role in the conversion from a fossil-based energy system to a renewable energy system. The results from the SOFT project will increase the efficiency in using biomass, thus aiding the trade and utilisation of the biomass for energy purposes.

1.7 Project conclusion and perspective

In this project, different online measurement techniques to determine water content in wood chips were investigated. The project specifically addressed the question of calibrating these instruments in a metrologically traceable way. Furthermore, it was investigated, how extractive sampling can be made representative in an industrial/production setting.

[5] http://www.biofmet.eu/partners/

[6] https://www.euramet.org/research-innovation/search-research-projects/details/project/new-metrological-methods-for-biofuel-materials-analysis/

Results from an on-site test showed that NIR- and microwave instruments as well as impedance-based moisture transducers can be used for online water content measurement in wood chips. While NIR performed slightly better (±1.8 percentage points precision in modelling loss-on-drying data) than the other methods (microwave: ±2.8 percentage points, transducer ±2.5 percentage points model precision), the tests showed no clear advantage of one method over the other. In terms of practical handling, both NIR- and microwave instruments can be used for inline, contact-less measurements, while the moisture transducer required extraction of samples.

The overall accuracy of the online measurements was found to depend mainly on the quality of the calibration data. Procedures should therefore be implemented to ensure that these data are as accurate as possible. Calibrations should furthermore be carried out over the whole measurement range of interest. The minimum obtainable uncertainty with the current loss-on-drying method was found to be 2 % of the measured water content. Digital tools such as image recognition (to identify different fractions in wood chips) and calibration by machine learning did not significantly improve measurements. These methods may nevertheless be of interest for a new generation of more precise analyzers. The focus of work in the immediate future should be on improving calibration methods.

A device for water content measurement based on a NIR-instrument as well as an automated auger-sampler were developed in the project. A first version of the NIR-instrument has been presented to potential customers. The automatic sampler is approaching market-readiness. Further work on the prototype is however needed, e.g. to sample wood chips with larger particle sizes. Prospectively, sampler and NIR could be combined into a single, integrated device.

Scientifically, work will continue in the framework of the EMPIR-project BIOFMET. In this new project, further properties of biofuels are considered (ash content, heating value) and the scope is extended to different solid and liquid biofuels. As a direct continuation of the present project, reference materials for online moisture measurement calibration will be developed within the BIOFMET-framework.

Annex
Annex 1 - M3 (Danish)
Annex 2 - M4 (English)
Annex 3 - M5 2nd Version (Danish)
Annex 4 - M6 2nd Version (Danish)

Relevant links

- https://www.teknologisk.dk/projekter/projekt-soft-sporbar-online-fugtmaaling-i-traeflis/39064

- http://biofmet.eu/
- https://www.danskfjernvarme.dk/kurser/produktion/optimal-pr%C3%B8veudtagning-og-fugtm%C3%A5ling-af-br%C3%A6ndsel