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Raw material measurement methods evaluation and ranking for pellet production

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Abstract
Pellets production and consumption are steadily increasing as a kind of energy source. The production and combustion properties of pellets are defined by molecular structure and elemental composition of raw materials. Quality control tools are different in terms of areas they cover the pellet-production cycle, but it is somewhat typical that they regulate only the origin of raw materials. In the light of these deficiencies, the evaluation of the quality properties in finished product had been overviewed. There are standardized analytical methods to the biomass product qualification, and these methods are capable to the raw material qualification too. Using these methods together with the control and diagnostics of production parameter, the finished product quality can be forecasted with high accuracy. An evaluation process is proposed in the paper for the measurement methods assessment. The introduced evaluation solution is ranking these methods, based on measuring device-needed, time-requirement and measurement complexity.

I. INTRODUCTION

Pellets are special kind of biomass-based biofuel. The speciality of this product is, that they have high energy density, low moisture constant, and uniform shape at the same time [1][2]. These features can provide nearly the same comfort level of application, like as natural gas-based heating system provides [3].

Favourable characteristics of pellets are contributing to the continuously spreading of consumption. This is evidenced by the fact, too, that over the past 15 years, nearly thirty-fold increase in the amount of consumed pellets in Europe [4][5].

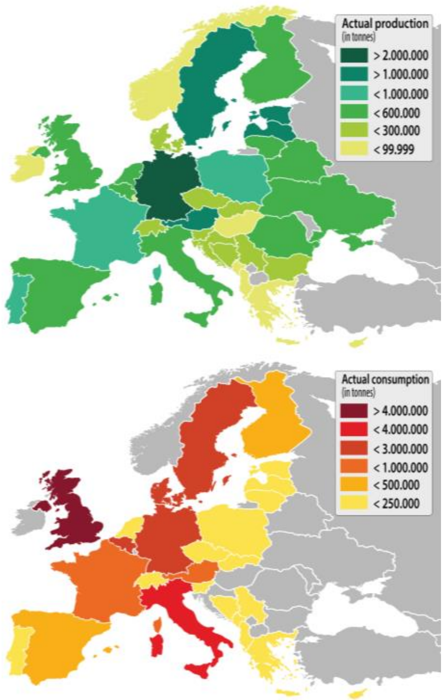

Fig. 1. European wood pellet production (above) and consumption (below) in 2015.[5]

In 2015, 50% of world production of wood pellets (14.1 million tons) was in the EU, and in the same time 70% (20.3 million tons) was consumed here [6]. Both production and consumption of pellet shows a continuously growing trend. The amount of produced pellet in the EU has increased by 4.7% and the amount of consumed pellets by 7.8% from 2014 to 2015. [6] [7]. The amount of consumed pellet is small percentage (0.6%) of the EU's primary energy consumption [8], but the pellets are valuable and evolving energy sources, which fits in the energy policy of the European Union according to security of supply, competitiveness, and sustainability aspects, too [9]. Since pellets are relative young energy sources lots of questions arise about pellet production and consumption today and answering them requires further intensive research activities.

II. PELLET PRODUCTION

During the pellet production, with use many types of biomass raw materials, a compact, cylindrical shape, low moisture constant and high calorific value biofuel is produced [10].

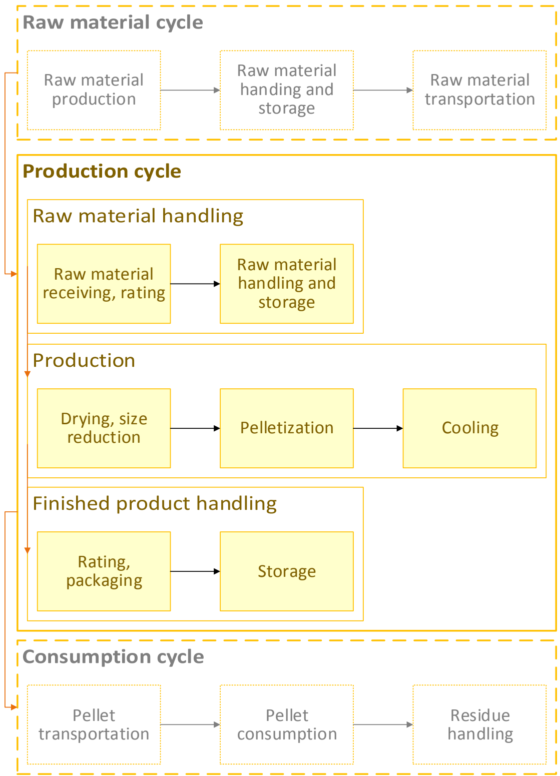

Fig. 2. Pellet production cycle.

The whole pellet production cycle is more. It contains the various origin raw material production, handling and transportation; the pre-produced raw material handling and the finished product manufacturing and packaging that has predefined quality classes and storage; the finished product transferring to the end-user, and finally, the residues handling, too [10].

A. Production cycle

After the arrival of the raw materials they have to be stored and handled. Studies confirm, that the storage time of raw materials has affects to the finished product quality parameters [12]. Microbiological and chemical processes are the root causes of this effect - which are dependent of the raw material molecular structure, elemental composition and moisture content, as well as of the storage mode and conditions, too [13] [14]. These processes result in negative effect to the raw material quality, so, to the finished product, too. In the production phase happens the raw material drying and grinding, its moisture content is adjusted with drying, for the optimum value to the pelletization. The optimum moisture value is defined by parameters of the raw material mixture, and it is 10-14% usually [3][15]. The pellet production require 2-4 mm sized, fine materials, and optimum pressure has to be applied in order to reach appropriate compressibility and evolving natural lignin-based bondings. During pressing the material and the die temperature is increasing due to the friction, and without using auxiliary materials natural material bonding can be realized. The moisture content has an effect on coefficient of friction, like a main factor. Also on the generated heat and the finished material bonds quality, too. The temperature of the finished pellets is high, and pellets are in a fragile state in this condition. Pelletability and combustion properties are decisively influenced by the raw material parameters and the production processes [3][18][19][20].

These quality factors are critical parameters and certified biofuels satisfying the current standards can be manufactured only with optimization of the raw material and the production processes, too.

III. PELLETS' QUALITY AND OTHER PARAMETERS

Pellets are compressed organic fuels, which typically made of wood raw material. New raw materials had been involved in production, in the interest of the greatly growing consumer demand [21][22]. These new, non-woody raw materials can be the following: herbaceous biomass, fruit biomass and aquatic biomass (e.g. algae). The quality of the raw materials is a crucial factor concerning for the quality of the finished product, and in the production processes, too [23]. In spite of the the wood raw materials mixture, the non-woody materials compound have higher variation, which results great challenge to the production [24][3].

The International Organisation for Standardisation (ISO) have published the ISO 17225 (Solid biofuels - Fuel specifications and classes) standard series in May 2014. This series has replaced EN 14961 in November 2014. The EN ISO 17225 has bigger scope than the previous standards, and has better accordance the new non-woody raw material, which has greatly growing spread. The first part of the standard (EN ISO 17225 -

Part 1) contains the general requirements related to biofuels. The second part of the standard (EN ISO 17225 - Part 2) includes property classes for wood pellets, and the sixth part for non-woody pellets. The ISO standard regulates the origin and source of raw materials, furthermore, categorizes based on possible application (industry or non-industrial application), too. Based on measurement results of quality parameters, the finished product is classified to additional property classes. These quality parameters are the following:

- diameter and length,
- moisture content,
- ash content,
- mechanical durability,
- amount of fines,
- bulk density,
- net calorific value,
- amount of specified elements (Cl, N, S, As, Cd, Cr, Cu, Pb, Hg, Ni, Zn).

Table 1. Scope of the quality control tools

Standard / Scope	Raw material		Product		Purchase		**Consumption**
	Quality	Origin	Production	Quality	Transportation	Storage	
ENplus 3.0:2015*		✓	✓	✓	✓	✓	
ISO 17225:2014		✓	✓	✓			
EN 14961:2010		✓	✓	✓			
National standards*				✓			

** only for wood pellet*

Quality control tools are different in terms of which pellet production cycle areas are covered [25][26]. The regulator and classifier tools do not cover to the raw material quality and classes, neither the activities between production and transfer to the end-user, nor the consumption.

The different areas of the whole cycle are covered by the ENplus standards in the most comprehensive way. This standard was published by the European Biomass Association (AEBIOMA), but it doesn't contain regulation in relation to the raw material, and it's scope is just for wood pellets.

The different areas of the whole cycle are covered by the ENplus standards in the most comprehensive way. This standard was published by the European Biomass Association (AEBIOMA), but it doesn't contain regulation in relation to the raw material, and it's scope is just for wood pellets. However the used raw materials quality is also determined by their molecular structure and chemical compound. So, the pelletability and combustion properties will be influenced by the raw material quality, too. Knowledge on these parameters are required for the regulation of the entire production process, too. Furthermore, it may define the quality of consumption [27][28].

IV. MEASUREMENT OF QUALITY PARAMETERS

There are various, standardized analytical methods for the biomass qualification, which are suitable for the raw material qualification, too [29][30]. Using these methods, in addition to controlled production parameters, the finished product quality can be forecasted with high accuracy [31]. These methods are featured usually by high device- and time requirement, as well as a high degree of complexity. The measurement samples preparation times are high usually, and there are only few methods, which can be fully automated.

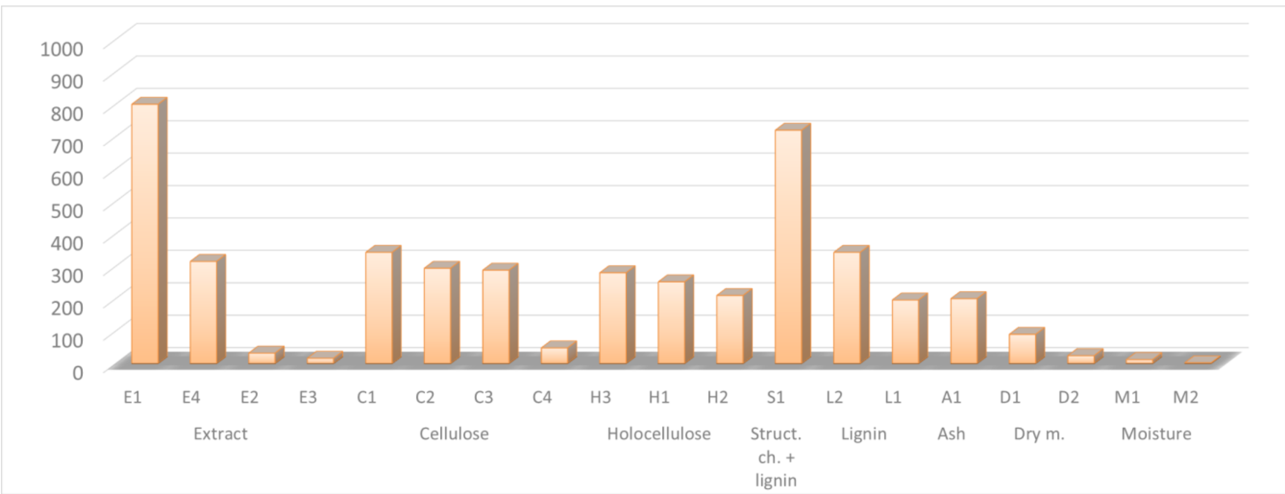

Fig. 3. Raw material measurement methods ranking for pellet production

Table 2. Analytical methods evaluation based on complexity, time- and device demand

Analytical methods	Symbol	Degree of complexity [1-10]	Time requirement [1-10]	Device requirement [1-10]	Applicability index
Determination of cellulose					
Gross-Berau method	*C3*	6	8	6	288
Kürschner-Hoffer method	*C4*	3	4	4	48
Normann-Jenkins method	*C2*	7	7	6	294
Wise method I.	*C1*	7	7	7	343
Determination of extract					
Hot water solubility	*E3*	1	4	4	16
Cold water solubility	*E2*	1	8	4	32
NREL/TP-510-42619	*E1*	10	10	8	800
Organic solvents solubility	*E4*	5	9	7	315
Determination of ash content					
NREL/TP-510-42622	*A1*	5	5	8	200
Determination of holocellulose					
Jayme method	*H3*	7	8	5	280
Chlorination módszer	*H1*	7	6	6	252
Wise method II.	*H2*	7	6	5	210
Determination of lignin					
Halse method	*L2*	7	7	7	343
König-Komarov method	*L1*	7	4	7	196
Determination of moisture content					
Distillation method	*M1*	2	2	3	12
Based on conductivity	*M2*	1	1	2	2
Determination structural carbohydrates and lignin					
NREL/TP-510-42618	*S1*	9	8	10	720
Determination of dry matter content					
NREL/TP-510-42621	*D1*	3	5	6	90
Drying method	*D2*	2	3	4	24

A. Evaluation of the measurement methods

The paper is proposing a classification, for the measurement methods by introduction of three test coefficients (device-, time requirement, and degree of complexity):

- The *degree of complexity* was determined by difficulty, multiplicity and circumstantiality of the method.
- The *time requirement* was estimated by conduction time of the method, with the sample preparation time, and waiting time if it is necessary.
- The *device requirement* was measured by the number and features of using equipments, materials, devices, and estimated value of those.

All three test coefficients were ranking from 1 to 10, for the qualification of the various measuring methods.

The examined methods are able to determine the structural component of the biomass, the lignin and the extracts, as well as the moisture, dry matter and ash content. All three test coefficients were determined by the authors for all examined methods, than the multiplication of these three values result the final score of the individual solutions. This is an usability index, which can be between 1 and 1000. The best method applicability index is 1, and the least favourable is 1000, so, the small values represent efficient measuring methods. Several methods were examined within the same method-group, and the applicability of the methods showed high variance in most of the cases. So, based on applicability index, there are favourable and less favourable methods for same parameter determination, in same method-group.

Within overviewed measurement methods, the Kürschner-Hoffer method is the most optimal to determination the cellulose content. There are two outstanding methods (hot water solubility, cold water solubility) to the extract content determination, but the hot water solubility is somewhat better, than the other. The NREL/TP-510-42622 is capable to the ash content determination, and the NREL/TP-510-42618 to the structural carbohydrates and lignin. Based on less favourable applicability index of structural carbohydrates and lignin determination, it is worth to consider to determine those with other methods, separately. There are not significant variances between holocellulose determination methods, but based-on applicability index, the most favourable method is the Wise-method. The König-Komarov method is the most optimal to determination of lignin content. The leading method to determination the moisture content is conductivity approach. Determination of the dry matter content, the drying method offers the best alternative.

There are promising methods to the moisture, to the dry matter and to the extract content determination, within overviewed measurement methods, however, the solutions for measuring of holocellulose, cellulose, structural carbohydrates, lignin and ash content are more difficult (since, their applicability index is relative poor/high), may be their integration into pellet production cycle is more complicated.

V. CONCLUSIONS

Their growing market make necessary to apply new biomass raw materials for energy production beyond wood. In the case of pellets, the quality of the raw materials is a crucial point. Pelletability and combustion properties of solid biogenic raw materials are determined by

- their molecular structure
- and their elemental composition.

The mixes of wood raw materials have low variability, but in case of non-woody raw materials the variability is high. Especially important is to define critical factors for these materials, because high-quality biofuels, that can satisfy the requirements can be produced with optimized raw material parameters and production processes. Regardless of this, the quality standards do not include the raw material qualification. The origin of the raw material is the only controlled raw material parameter for the finished pellets classification. Consequently, the quality tools have to be supplemented with rules about material quality and qualification, too. Broad range of the related and available methods was examined. These methods are suitable to determine the structural component of the biomass, the lignin and the extracts, as well as the moisture, dry matter and ash content. During the examination, applicability index was proposed and estimated for all analysed methods using three test coefficients, which were:

- complexity of the method.
- device requirement of the method,
- and time requirement of the method.

The obtained applicability index is able to rank the individual measuring solutions within the method-group too. The analysed methods showed high variance according to applicability within method-group, and based-on applicability index, there are favourable and unfavourable methods, too. There are promising methods to the moisture, to the dry matter and to the extract content determination, within overviewed measurement methods, however, the solutions for measuring of holocellulose, cellulose, structural carbohydrates, lignin and ash content are more difficult (since, their applicability index is relative poor/high), may be their integration into pellet production cycle is more complicated. Considering the further research, the analytical methods for the biomass raw materials and the finished products classification can be integrated in principle to the pellet production cycle, but put it into practise raise lots of questions. Furthermore, the improvement is planned concerning the number of the examined methods, modelling the whole pellet production process, investigating the opportunity of the methods to the production process, finally preparing a proposal to execution.

ACKNOWLEDGEMENT

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