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THESIS OF PhD DISSERTATION

EXTENDING THE PELLET PRODUCT CYCLE CONTROLLING AND MEASURING SYSTEM

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1. EXPLANATORY MEMORANDUM

Utilizing energy sources has been a part of human life since discovering the fire [1]. Continuous change in usage patterns and the development of industrial and household energy needs results in a **steady increase in the world's primary energy consumption**. The rate of this growth is getting more and more drastic, a 60% increase in demand has been generated in the last quarter of this century [2]. Energy consumption is influenced by a number of factors. Besides the population density of the given region, important indicators include weather conditions of the region, the quantity and price of available energy sources, the culture of energy consumption, the relevant energy efficiency indicators, as well as industrial development and production features.

Meeting the growing demand for energy poses continual challenges to mankind. Regarding the diminishing energy resources of the Earth, a steady decline in stocks raise a supply-security issue, just as the availability of local sources for several states [3]. The stocks of renewable energy sources, on the other hand, do not diminish in absolute terms, or their supply is constant, fast and continuous. For these, the challenges are location space, time-varying availability and storing, although this difficulty can be easily managed by an optimally diversified energy mix.

The renewable energy sector is constantly expanding globally, partly because of the things mentioned above, and **almost one fifth of the world's final energy consumption is already covered by renewable sources** [4]. Biomass materials play a leading role in the utilization of renewable energy sources: **more than 75% of the renewable sources used are of a biomass origin**. One of the reasons is that heat, electricity, liquid and gaseous fuels can also be produced using these materials in different ways. **Pellet fuels stand out from these materials.** During the production of pellets the various biomass feedstocks are formed into small, cylindrical, low-moisture and high calorific biofuels through a compression process [5]. Due to the positive properties of the pellets, their market is constantly expanding, the volume of produced and marketed fuel is increasing intensively. Regarding the categories of use, pellets produced using pure **dendromass material are referred to as wood pellets, and**

non-dendromass based pellets are commonly known as agripellets or non-wood pellets [6] [7]. There is a significant difference between these two categories concerning the consistency of the chemical composition of their raw material. **The composition of the raw material of wood pellets made from woody materials**, more precisely from the barked part of wood, **is well predictable on the basis of tree species** and has low fluctuations [8]. In contrast, **in the case of agripellets, the composition is not a constant feature of the raw materials, therefore the investigation and development of pellets concerning their raw materials is a current issue today, which also raises several research questions** [8] [9].

2. OBJECTIVES, RESEARCH STRATEGY

Continuous market expansion and the increasing number of market participants require uniform products which meet high quality requirements on the market. To provide an adequate foundation for this requirement for any product, including fire pellets, there is a need for a well-designed, uniform measuring and control system that runs over the entire product cycle.

The limited availability of bark-, leaf- and branch-free woodworking and grinding raw materials that are considered ideal for pellet-production, makes it necessary to include new softwood and woody materials.

The inclusion of new raw materials may pose new challenges to the pellet sector, as **the basis of steady, high quality production is the existence of standardized, controlled production processes and raw materials** [11] [12].

In order to examine the fulfilment of these conditions, to eliminate any shortcomings and to extend the pellet product cycle control and measuring system, the areas to be regulated should be defined as the first step; after that, it is appropriate to develop and extend the regulatory instruments further, considering their adequacy and efficiency.

3. SUMMARY OF THE WORK, MAJOR RESEARCH RESULTS

Evaluation of pellet cycle control devices

The gradual increase in the production and use of pellets has made it particularly important to lay down quality standards and to develop certification systems.

National, European and international quality control devices differ in the areas they cover from the pellet product cycle. Quality control of pellets may include:

- the classification of the raw materials on the basis of quality and origin,
- production and certification
- activities after production and before reaching the consumer.

Standard	Raw material		Product		Purchase	
	Quality	Origin	Production	Quality	Transportation	Storage
ENplus:2015[1]		✓	✓	✓	✓	✓
ISO 17225:2014		✓		✓		
EN 15234:2012[2]		✓	✓	✓	✓	✓
EN 14961:2010[2]		✓		✓		
National standards				✓		

[1] *Only pellets which made of woody material are covered.*
[2] *Only non-industrial pellets are covered*

Table 1: Scope of Quality Control Devices

Quality control devices cover most of the standardization of pellet manufacturing and final product qualification methods, the definition of relevant concepts, and the standardization of procedures and measurements, but they do not cover the entire process of the pellet product cycle, only partial areas are regulated.

Previously, when the market for agripellets made from herbaceous materials was not spread, this kind of regulation was satisfactory. The composition of woody materials can be well predicted based on tree species using literature data, so the quality of the finished product can be predicted with great precision. **However, after the regulation of quality categories permitting the use of soft stem raw materials, regulation by origin is no longer valid because the chemical composition of soft stems is changeable and the quality of the finished product cannot be determined on the basis of origin.** Currently the pellet product cycle is covered by EN 15234: 2012 and ENplus: 2015 regulatory devices in the most comprehensive way. **At the same time, the coverage of these tools are not complete either, as they share the main defect that they cover the origin of the raw materials, but they do not classify the raw materials by their quality (similarly to other quality control devices). (Table 1).**

Development and application of a system for evaluating pellet feedstock measurement methods

There are standardized and other methods available for controlling the quality of feedstocks, which are suitable for determining raw material parameters. In the paper, **eight critical pellet feedstock parameter types** (moisture content, dry matter content, carbohydrate content, ash content, cellulose content, holocellulose content, lignite content, extraction content) **have been selected, controlling of which can result in high quality finished products even when using soft stem raw materials.**

Although there are different measurement methods available for the evaluation of biomass materials, these are mostly highly complex methods, therefore the selection of optimum procedures for pellet life cycle **requires support, and for this, no devices have been available before**.

The newly developed system for regulating pellet production feedstocks and evaluating measuring methods aims to classify the measurement methods that are suitable for testing the raw material, and to rank them in a comparable way, thus helping the manufacturers to select and integrate the optimal test methods in their processes. The newly developed system for evaluating the measurement methods gives a new, scientific aspect to the field of raw material qualification.

The basis for developing the evaluation system was the determination of the test factors that could place measuring procedures from different test groups on a common platform. To this end, I defined three evaluation factors during the development of the evaluation system: device requirement, time requirement and complexity. The understanding and evaluation of these factors ensure that the requirements of the measurement evaluation system can be fully met. The contents of the three test factors are as follows:

- *device requirement* - the number and value of all devices specified in the standardized procedure, together with the devices of the sample preparation;
- *time requirement* - the average time required for conducting the procedures, together with any expected waiting time, plus the time of the sample preparation, as defined in the standardized procedure;
- *complexity* - the complexity of the procedure specified in the standardized procedure (number of steps) and human resource requirements.

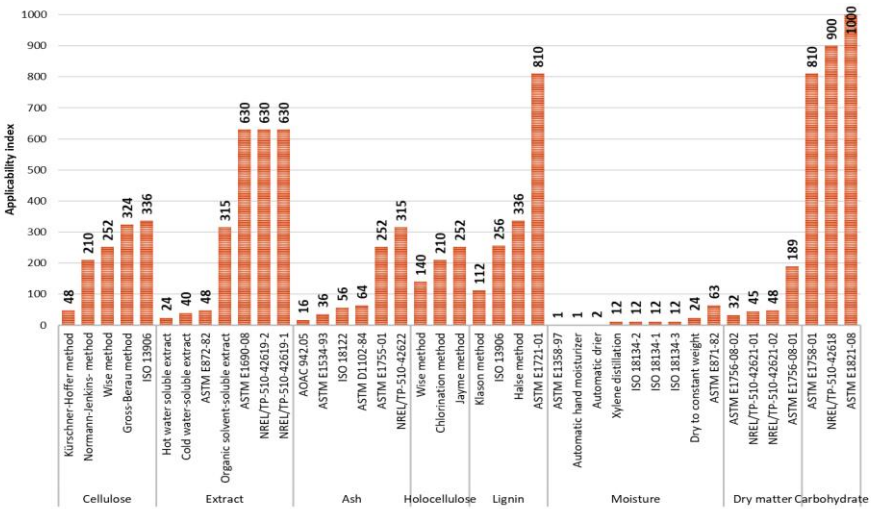

Figure 1: Ranking of raw material qualification procedures

When evaluating the various tests, all three factors can score between 1 and 10 *(the best: 1, the worst: 10),* **and their product shows**

the applicability index of the given process. On the basis of the evaluation system, the applicability index of the most favourable procedure is 1, and that of the worst one is 1000. The measurement procedures have become evaluable and comparable with this new method (Figure 1).

The dissertation includes the evaluation of 41 different measuring methods used for testing the eight critical raw material parameters. Overall, it can be concluded that there are several processes with low application index (i.e. efficient) available for the determination of moisture, dry matter, ash and extract content. In contrast, tests for the determination of cellulose, holocellulose, lignin and carbohydrate content have a higher (i.e. worse) index of applicability. I suggest the use of the following methods in the pellet life cycle by parameter group, based on the application of the evaluating system for measurement methods:

- Moisture content: ***Automatic manual humidity meter*** *(Ai = 1)*
- Ash content: ***AOAC 942.05*** *(AI = 16)*
- Extract content: ***Dissolving extracts with hot water*** *(Ai = 24)*
  (for determination of water soluble part)
  Organic solvent-soluble extract *(Ai = 315)*
  (for determination of organic solvent-soluble part)
- Solid content: ***NREL / TP-510-42621-02*** *(Ai = 32)*
- Cellulose content: ***Kürschner-Hoffer procedure*** *(Ai = 48)*
- Holocellulose content: ***Wise method*** *(Ai = 140)*
- Lignite Content: ***Klason procedure*** *(Ai = 112)*
- Carbohydrate content: ***ASTM E1758-01*** *(Ai = 810)*

Adjusting pellet feedstock measuring processes into the manufacturing process

Deciding if a measuring procedure is adjustable to the process is very important because the position of measurement methods in the production process determines the strength of the regulation, thus also the feasible level of control on the manufacturing process. As a result, it is fundamental to determine the optimal adjustment points for procedures of the different test groups.

The different feedstock measurement methods can theoretically be added to any part of the pellet production process (or before), but practical implementation raises a number of questions, as the goal is to provide an efficient solution and to produce high quality products. If a test parameter is controlled early in the manufacturing process, it is possible to detect deviations / errors at the beginning of the process, which means in strong control, and results in efficient and cheaper production.

Using the newly developed evaluation system, it has become apparent that the methods available for the qualification of biomass substances are mostly highly complex procedures. These methods typically cannot or can only be partially automated, and their pursuit is human resource-intensive. These properties of the procedures are clearly inhibiting factors when it comes to adjusting them to various process-elements of the manufacturing cycle, so the various measurements can mostly be interpreted between two process stages. With few exceptions, the processes are also time consuming, which makes it difficult to align them with the normal flow of the production cycle, which also makes it critical to integrate them into the process.

Methods for measuring cellulosic content are typically time-consuming, and therefore they are difficult to fit between two process steps. They can be efficiently performed before the manufacturing process starts, at the time when the raw material is qualified. The same is true for holocellulose content, lignin content, and dry matter content.

There are fully automated, fast measurement methods available for measuring moisture content. This method can be considered the most advantageous in terms of process-adjustability as it can be effectively integrated between practically any operations.

Adjustment is difficult also in the cases of measuring ash content, extract content, and carbohydrate content, since all these processes have high time requirement and their complexity is an inhibiting factor, too. **Due to the above described limiting factors (high device-requirement, high time-requirement and complexity), most of the procedures can only be effectively integrated into the process at the very beginning of the product cycle, during the raw material cycle. The measurement procedures available for moisture content are the only exceptions, as**

they have low applicability indexes, and can be adjusted successfully to the product cycle at several points in the manufacturing process, not only at the initial stage.

Of course, the finished product may also be qualified afterwards, at the end of the process, after the pelletization phase, using the measurement procedures. In this case, however, these parameters cannot be controlled, the quality of the finished product cannot be predicted based on the origin of the raw material (typical with soft stem feedstocks) so it cannot be influenced by a possible recipe change or other means. This solution is ineffective.

<u>**Suggestions for extending pellet control devices**</u>

In the process that describes the typical development of standards, new, higher level international standards replace European and national measures. At the same time, the principles of higher level regulation are homogenized, and with the harmonization of previous standards, international standards come into force. The development of pellet standards is following the typical method, i.e. national standards were replaced by European norms and later by the guiding standards of the International Standardization Organization. When assessing the alternatives of the extension, the ENplus standard system developed by the European Biomass Federation, the umbrella organization of the European biomass community, was also screened. Due to the synthesizing nature of ENplus, it incorporates the elements of international regulation, following them in structure and content.

The existing regulatory instruments classify finished products according to their parameters and to the origin of the feedstocks used to produce them. The pellet sector is a young industry that has changed a lot recently. The inclusion of new, typically soft stem materials has brought about changes. **Thus, current regulations can no longer be considered sufficient** since in the case of soft stem materials and materials with high proportion of crusty, leafy, branchy parts, as well as the mixtures of these, the composition of the material cannot be predicted based on the origin of the feedstocks, unlike in the case of high-quality woody shavings.

The current regulation has a further limitation: finished products, even those that meet the requirements for the highest finished product category but have soft stem feedstocks, may not be included in the given quality category (since based on their origin they cannot be feedstocks of the highest quality pellets). In order to resolve this, I propose to extend the regulation of pellets by introducing the modifications described as follows, introducing a composition-based regulatory system independent of the origin of feedstocks.

I have found that the standard amendment is to be recommended for the highest standards series, the international standard series relevant to the qualification of feedstocks, called ISO 17225: 2014 "Solid biofuels. Fuel Standards and Classes", as such modifications cover the lower level regulatory devices as well as those with synthesizing nature. In addition to marking the place of the standard amendment, I have also developed the content of the proposed standard amendment:

Amendment proposal (1): *I propose abolishing the grouping by origin, and defining new quality classification based on the composition of feedstocks, which will provide guidance for the categorization of new, typically soft-stemmed feedstocks / feedstock mixtures based on their inner value.*
When defining the quality categories, I propose to keep the categories issued in Volume 2 and 6 of the ISO 17225: 2014 series of standards for the finished product qualification with the same parameter limits.
Based on them, the feedstocks and feedstock mixtures can be categorized as A1, A2, B, I1, I2, I3, C, D.

Amendment proposal (2): *I propose to apply the list of qualified procedures presented in the thesis (to be displayed under the heading "Recommended Measurement Procedures" in the standard), always indicating the applicability index of the methods.*
In addition, I propose the implementation of the developed measurement evaluation system, thus supporting the certified party to select the optimal feedstocks qualification procedures, also in cases of other, previously not evaluated procedures.

Amendment proposal (3): *I propose to create categories based on a purely qualitative classification, independent of the origin of the feedstocks, by combining Volume 2 and Volume 6 of ISO 17225. The finished product quality categories should be the same as the feedstocks categories - in accordance with the modified ISO 17225-1 standard.*
Thus, the finished product quality categories are A1, A2, B, I1, I2, I3, C, D

4. THESES

(T1) The soft stem materials used as feedstocks for agripellets show high variability based on their chemical composition, their composition cannot be considered constant based on their origin (species). Therefore, a much higher level of regulation and control than the present one has to be introduced for these feedstocks. The quality control devices differ in the areas they cover from the pellet product cycle, but all these devices share the determinative defect that they do not cover the quality control of the feedstocks, so it is necessary to complete the standards.
(3.3.1 Feedstocks cycle, 5. Determination of pellet product cycle characteristics)

Published in:

- **Konrád K., Németh G.: The basics of research into the combustion properties of wood and agripellets.** Sopron, ERFARET Non-profit Ltd., 2013, Wood Industry, Volume 61, pp. 28-34.
- **Konrád K., Viharos Zs. J., Németh G.: Extension of quality control systems on pellet feedstocks.** Cluj-Napoca, *XVII. International Energy Technology Conference (ENELKO),* p. 2016: 72-77.
- **Konrád K., Viharos Zs. J.,: Pellet product cycle control, measurement system and challenges.** Keszthely, XXII. Youth Science Forum, 2016 pp. 1-6. ISBN: 978-963-9639-83-6.
- **Konrád K., Viharos Zs. J.: Hungary: raw material quality as a crucial factor**. Wels, *European Pellet Conference*, 2March 1, 2018

The quality of the feedstocks is determinative for the production of pellets with appropriate quality, and the regulation of the pellet manufacturing process has limited influence on the quality of the finished product. Knowing the molecular structure and elemental composition, i.e. the feedstocks parameters of the solid biogenic materials used in the production of the pellets, can not only infer the combustion technical parameters of the final product, but also makes it possible to control the entire production process. With the knowledge of the parameters of feedstocks, manufacturing formulas become easier and more economical to create, and it is possible to keep the quality fluctuations of the finished product low, even with the use of feedstocks with varying parameters.

(5. Determination of pellet product cycle characteristics)

Published in:

- **Konrád K., Viharos Zs. J., Németh G.: Extension of quality control systems on pellet feedstocks.** Cluj-Napoca, *XVII. International Energy Technology Conference (ENELKO),* p. 2016: 72-77.
- **Konrád K., Viharos Zs. J.,: Pellet product cycle control, measurement system and challenges.** Keszthely, XXII. Youth Science Forum, 2016 pp. 1-6. ISBN: 978-963-9639-83-6.
- **Konrád K., Viharos Zs. J., Németh G.: Evaluation, ranking and positioning of measurement methods for pellet production.** *Measurement*, 2018, vol. 124, pp. 568-574.

(T2) There is a significant difference between the analytical procedures for the qualification of biomass feedstocks in terms of their adjustability into process. I have elaborated a new complex measurement evaluation system which can individually analyse the methods for measuring biomass materials based on their device requirements, time requirements and complexity. Using the developed applicability index, the various measurement methods can be evaluated, ranked and compared.

(7.2. Developing a system for evaluating measurement procedures)

Published in:

- **Konrád K., Viharos Zs. J., Németh G.: Evaluation, ranking and positioning of measurement methods for pellet production.** *Measurement*, 2018, vol. 124, pp. 568-574.
- **Konrád K., Viharos Zs. J., Németh G.: Raw material measurement methods evaluation and ranking for pellet production.** Budapest, *International Measurement Confederation* (IMEKO), 2017. pp. 164-169. ISBN:978-92-990075-5-6

(T3) Using the measurement method evaluation system developed, I have determined the most favourable procedures in terms of their adjustability into process. I have found that except for the moisture measurement, which is a fully automated method with one operational element, measurement procedures can only be effectively integrated into the production cycle at the beginning of the process, during the feedstocks cycle.

(7.3. Using the evaluation system 7.4. Adjusting feedstocks measurement procedures into production process)

Published in:

- **Konrád K., Viharos Zs. J., Németh G.: Evaluation, ranking and positioning of measurement methods for pellet production.** *Measurement*, 2018, vol. 124, pp. 568-574.

- **Konrád K., Viharos Zs. J., Németh G.: Raw material measurement methods evaluation and ranking for pellet production.** Budapest, *International Measurement Confederation* (IMEKO), 2017. pp. 164-169. ISBN:978-92-990075-5-6

(T4)

I have indicated that the extension should be made for the ISO 17225: 2014 standard series. I have developed the content and indicated how to supplement the existing regulatory instruments. The intended modifications in the standard structure and content will resolve the defect that is rooted in the lack of feedstocks qualification, and make a recommendation for the International Organization for Standardization.

(7.5. Suggestions for extending regulatory instruments)

Published in:

- **Konrád K., Viharos Zs. J.: Hungary: raw material quality as a crucial factor**. Wels, *European Pellet Conference*, 2March 1, 2018

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[1] **Konrád K., Viharos Zs. J.:** *Hungary: raw material quality as a crucial factor.* Wels, European Pellet Conference (2018)

[2] **Konrád K.; Viharos Zs. J. ; Németh G.:** *Evaluation, ranking and positioning of measurement methods for pellet production,* MEASUREMENT 124 pp. 568-574. , 10 p. (2018)

[3] **Konrád K.**: *Evaluation of measurement procedures for supporting the energy use of biomass materials*, Keszthely, XXII. Youth Science Forum (2018) pp. 1-6. ISBN: 978969639-90-4

[4] **Konrád K.; Viharos Zs. J. ; Németh G.:** *Raw material measurement methods evaluation and ranking for pellet production pp. 164-169.,* 15th IMEKO TC10 International Measurement Confederation, Budapest, (2017) p. 206, ISBN:978-92-990075-5-6

[5] **Konrád K.; Németh G. ; Viharos Zs. J:** *Extension of the quality control systems to the raw materials of pellets pp. 72-77.,* Cluj-Napoca, XVII. International Energy Technology Conference (ENELKO) (2016)

[6] **Konrád K.; Viharos Zs. J.:** *Pellet product cycle control, measurement system and challenges.* Keszthely, XXII. Youth Science Forum (2016) ISBN: 978-963-9639-83-6.

[7] **Konrád K.; Németh G.:** *The basics of research into the combustion properties of wood and agripellets.* Sopron, ERFARET Non-profit Ltd., 2013, Wood Industry, Volume 61, pp. 28-34.

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