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The regression model for the evaluation of the quality parameters for pellets

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Abstract. In Latvia no European legislation concerning the quality of the production of pellets is adopted. Since the market is not regulated by any governmental regulations, biofuel testing is not compulsory. This aspect leads to a situation where pellets of various qualities are available on the market.

The main objective of this paper is to compare the characteristics of the pellets which are produced in various regions of Latvia. The second goal is to develop a regression model which describes the influence of the independent aspects (physical parameters, price, trading form, transportation distance etc.) on the pellet quality.

The quality parameters for the solid biofuels were determined according to the methods described in the Technical Specifications of the European Commission for Standardization. The regression model for the pellet quality has been implemented using the software STATGRAPHICS Centurion 16.1.15.

The results of the research emphasize that the physical parameters of the pellets vary widely. Three regression models were built in order to describe the influence of the various parameters on the indicator (price per net calorific value) and on the mechanical quality of the pellets. The fitted Models were described by the regression equation given in the paper.

Keywords: biomass pellets, pellet quality, calorific value.

Introduction

Based on the Renewable Energy Directive 2009/28/EC adopted in the European Union (EU) –the final share of 20% of renewable energy sources (RES) by the year 2020 is a mandatory target for the overall EU energy consumption (EU, 2009). Latvia's individual target is to increase the use of RE Sup to 40% by the year 2020 (Ministry of Economics of Republic of Latvia, 2010).

Of all energy source import in Latvia, 32.4% or 42,014 TJ accounted for the natural gas import in the year 2010; at the same time the equivalent quantity of 46,192 TJ of the RES sources(biomass, wood, wood waste and renewable waste) was exported (EUROSTAT, 2012). The statistical data shows huge potential for the natural gas substitution with local RES.

If the RES for the heat production are compared, wood log and wood chip stoves and boilers have the highest market distribution in Latvia (Central Statistical Bureau of Latvia, 2011). Due to the higher possibility of automatization and better quality of the biomass fuel, nowadays the end-user becomes more attracted to the technologies of wood pellet boilers. Based on the statistical data Latvia was one of the five leading wood pellet producers in the EU in the year 2008, therefore they are all required preconditions for the development of pellet-based technologies in the country (Pellet market data 2008).

The possibilities of the pellet stoves and solar heating systems integration in the single family house has been investigated (Persson et al., 2005) and three main parameters, which affect the efficiency of the pellet technologies, were identified: the construction phase, the control system and the fuel parameters. The investigation regarding the importance of the fuel parameters on the performance of the boiler was carried out (Gonzalez et al., 2004) in order to test the influence of the different types of the pellets on the boiler efficiency.

Since the maximal emission rate from the pellet boilers in different European countries is regulated (e.g. Sweden and Germany (BAFA 2007; SIS 1999; Boverket 2006.; RAL 2003a; RAL 2003a), the fuel parameters are vital for the emission calculations. In Latvia no European legislation concerning the quality of the production of pellets is adopted. Since the market is not regulated by any governmental regulations, the biofuel testing is not compulsory. This aspect leads to a situation where pellets of various qualities are available on the market.

The main objective of this paper is to compare the characteristics of different pellets which are produced in various regions of Latvia. The second goal is to develop a regression model based on the influence of several independent aspects (physical parameters, price, trading form, transportation distance etc.) related to the pellets quality. The regression analysis aims to identify the independent variable parameters which cause the highest influence on the pellet quality.

Materials and methods

The pellet samples were gathered from different regions of Latvia, covering the whole country. Different samples of various biomass types (wood, straw and peat) were collected. A total amount of twelve pellet samples was analysed, seven from producers and five from resellers. The location of producer, reseller and the transportation distance of the pellet sample were recorded. The price for the tested pellets was obtained for further comparison.

The physical parameters for the pellets were determined according to the methods described in the Technical Specifications of the European Commission for Standardization (CEN/TS). The enumeration of the tested parameters and the precision for each method is summarized in Table 1.

The interactive statistical data analysis tool STATGRAPHICS Centurion 16.1.15 was used to construct a statistical model demonstrating the impact of quantitative factors on a dependent variable. The aim of the regression analysis was to find the independent variables which have the greatest influence on the dependent variable. By using the linear regression tool, three regression models were elaborated. The indicator (*I)* – price per net calorific value (Euro MJ^{-1}) was introduced as a dependent variable in the regression model.

Table 1. CEN/TS methods for determination of the physical parameters for solid biofuels

Parameter	Method	Repeatability limit
Ash content, w-%,d	(LVS EN 14775:2010)	<2% of the mean result (*A*≥10%) <0.2% absolute (*A*<10%)
Moisture content, w-%	(LVS EN 14774-3:2010)	<0.2% absolute
Net calorific value, MJ kg^{-1}	(LVS EN 14918:2010)	<120 J g^{-1}
Gross calorific value, MJ kg^{-1}	(LVS EN 14918:2010)	< 120J g^{-1}
Durability, w-%	(LVS EN 15210-1:2010)	<0.4% absolute (*DU*≥97.5%) <2% absolute (*DU*<97.5%)
Bulk density, kg m^{-3}	(LVS EN 15103:2010)	<4% (*BD*≥300 kg m^{-3}) <6% (*BD*< 300 kg m^{-3})
Energy density, MWhm^{-3}	(LVS EN 14961-1:2010)	---
Fines, w-%	(LVS EN 15149-1:2011)	<2 w-%

Results and discussion

Data input for the regression models

Based on the CEN/TS methodology, physical parameters of the pellets were obtained and results are presented in Table 2.

Table 2. The physical parameters of the tested pellets

Sample	Biomass type	Parameter									
		Ash content, w-%, d	Moisture content, w-%	Net calorific value, MJ kg^{-1}	Gross calorific value, MJ kg^{-1}	Durability, w-%	Mean diameter, mm	Mean length, mm	Bulk density, kg m^{-3}	Energy density MWh m^{-3}	Fines, w-%
1	wood	1.2	6.1	17.87	20.49	97.7	8.20	13.37	660	3.3	0.49
2		0.8	7.1	17.70	20.53	97.5	8.28	19.96	670	3.3	0.44
3		0.7	4.4	18.33	20.58	96.0	8.21	18.20	720	3.7	1.06
4		0.7	6.7	17.61	20.34	98.7	6.17	21.15	700	3.4	0.14
5		0.4	4.0	18.38	20.52	97.5	6.19	14.64	720	3.7	0.28
6		0.4	8.1	17.58	20.64	92.6	6.60	12.86	590	2.9	1.02
7		0.5	6.9	17.44	20.20	97.7	8.42	14.47	680	3.3	0.74
8		2.4	8.2	16.61	19.60	94.4	6.27	8.71	660	3.0	1.10
9		0.6	7.5	18.00	20.95	97.8	8.08	11.20	700	3.5	0.40
10	straw	4.3	8.8	16.02	19.10	96.9	8.11	13.81	620	2.7	1.11
11		5.4	8.5	15.90	18.89	98.7	8.04	11.06	760	3.3	0.28
12	peat	5.6	12.2	17.70	21.78	93.8	7.81	13.22	780	3.8	1.61

The results show that the physical parameters for the tested pellets vary widely. This behaviour could be associated with different manufacturing technologies, various origins of the used biomass, storage time and conditions and transportation distance.

The net calorific value of pellets changes in the range between 16.0 and 18.4 MJ kg^{-1} as shown in Table 2. Lower moisture content was observed for pellets bought from resellers in comparison to ones bought form producers. This could be due to the storage conditions in both cases. Most producers store their pellets in warehouses near the production site, while the resellers store the pellets at their facilities, where the indoor climate is usually adjusted for the thermal comfort of customers. A major factor concerning the long-term storage of pellets is the tendency to reach equilibrium with the ambient air moisture content (Lehtikangas, 2000). In regard to this, the storage conditions would mainly explain the differences for samples obtained in two trade forms, assuming that in reseller facilities the relative air moisture is lower than in producer warehouses. The price for pellets is higher at resellers due to transportation costs from the producer to the shop, reseller expenses, profit, etc. The data about the price and transportation distance of pellets are given in Table 3.

Table 3. The price and transportation distance of the tested pellets

Sample	Biomass type	Trade form	Price, Euro per 1000 kg without VAT	Distance from the producer to laboratory (DPL), km	Distance from the producer to closest port (DPP), km
1	Wood	resellers	138.73	159.2	-
2			193.87	69.6	-
3			181.86	190.6	-
4			166.95	228.0	-
5			159.36	349.0	-
6		producers	142.29	109.0	108.0
7			156.52	42.1	42.2
8			149.40	275.0	275.0
9			142.29	155.0	69.0
10	Straw		99.60	151.0	151.0
11			99.60	151.0	151.0
12	Peat		99.60	12.2	12.3

The regression models

Three regression models were elaborated: the independent and dependent variables selected for all models are given in Table 4.

Regression Model I was used to state the influence of moisture and ash content on the price per net calorific value of the pellets. The biomass type and quality of the pellets manufacturing process should have an influence on the price of the final product (see Table 4). Model II deals with the influence of the physical parameters on the mechanical quality of the pellets. The transportation distance is added to the model in order to see if there is any correlation between the transportation distances from the producer to the final user (DPU) on the mechanical quality of pellets. Model III gives an answer to the question – does the DPP has an influence on the price of wood pellets in Latvia?

Table 4. The dependent and independent variables for the regression model

Regression model	Variables	
	Dependent variable	Independent variable
I	The indicator: Price per net calorific value (Euro MJ^{-1})	Moisture content Ash content
II	Fines	Durability Mean diameter Mean length DPL
III	The indicator: Price per net calorific value (Euro MJ^{-1})	DPP

The data analysis done in STATGRAPHICS Centurion 16.1.15 environment shows that the fitted Model I is described by Eq.1.

$$I = 10.11 - 0.54AC - 0.11MC \quad (1)$$

Data analysis shows that in Model I the most influential parameter on the indicator is ash content, see Eq. 1. This is mostly due to the higher ash content of non-woody biomass and the lower price for non-woody pellets. According to Model I, pellets with the highest ash content have the lowest calorific value, and only peat pellets are an exception to this statement. This can be explained by higher content of carbon in peat in comparison to woody biomass. As net calorific value is also dependent on the moisture of the pellets, pellets with lower moisture content have higher calorific value.

Since *P*–value in the analysis of the variance (ANOVA) table is less than 0.05, there is a statistically significant relationship between the variables, see Table 5. Durbin-Watson statistics is close to 2 the reforest here is no autocorrelation observed between the independent variables. The moisture content shows *P* – value greater than 0.05, which means that moisture content is not statistically significant at the 95.0% confidence level. Linear regression analysis shows that by decreasing ash content and moisture content the value of the indicator will rise.

Fitted Model II is described by Eq.2.

$$F = 20.1218 + 0.00232ML + 0.00049DPL - 0.21969DU + 0.22617MD \quad (2)$$

The proportion of the fines is a function of the mean diameter and durability, see Eq. 2. The mean length and the transportation distance have a minor influence on the mechanical quality at 95% confidence level. Coefficient of determination $R^2$and adjusted R^2 explains 79.37% and 67.58% of data input for the regression model, see Table 5.

The regression analysis for the Model III showed that there is no sufficient correlation between the price for the pellets and the distance to the closest port at 95% confidence level, since R^2 is 8.31%, see Table 5.

Table 5. Data analysis of the regression model

Reg. model	Variables	Standard Error	*P*-value	*P*-value for the ANOVA	R^2& adj. R^2 %[b]	Durbin-Watson statistic
I	The indicator (Euro/MJ)	1.39	0.0000	0.0097	64.27 56.33	2.02341 *P*=0.4317
	Moisture content	0.23	0.6293			
	Ash content	0.23	0.0504			
II	Fines	4.38	0.0025	0.0151	79.37 67.58	2.3011 *P*=0.7256
	Durability	-0.22	0.0046			
	Mean diameter	0.14	0.1564			
	Mean length	0.023	0.9241			
	DPL	0.00049	0.7275			
III	The indicator (Euro/MJ)	0.96	0.0008	0.5306	8.31 0.00	0.636632 *P*=0.0158
	DPP	0.0068	0.5306			

The linear regression model shows a sufficient correlation between the indicator and moisture content in the pellets (see Eq.1 and Fig. 1). In this case the pellets with lower moisture content and therefore higher available energy content are more expensive and vice versa. As assumed previously, the reasons for this correlation might not be truly dependent on the pellet production process, but also on the storage conditions and storage duration.

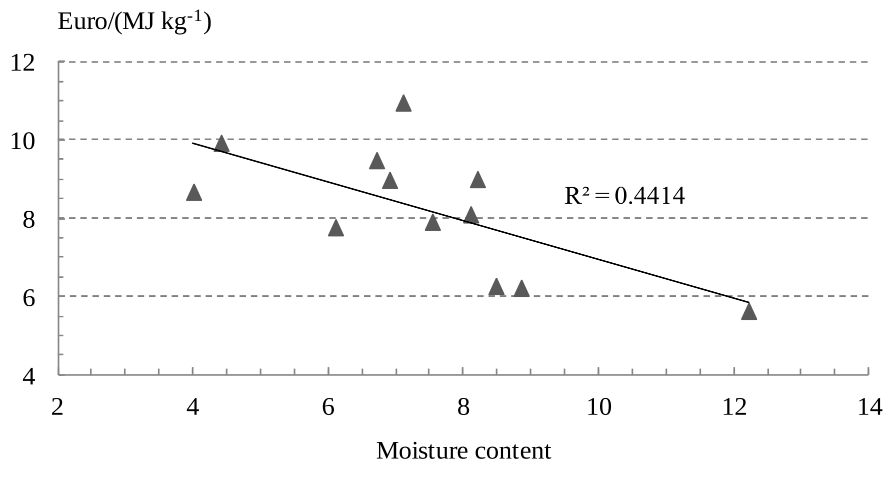

Fig. 1. The relationship between indicator value and moisture content in the pellets.

Conclusions

In total twelve pellet samples were gathered and analysed. The results for the physical parameters for tested pellets vary widely, which can be explained by the different manufacturing technologies of pellets, various origins of the used biomass, storage time and condition and the transportation distance of the samples.

Tree regression models were proposed to describe relations between quality parameters and market behaviour for the biomass pellets. Two of the models have a sufficient correlation between the variables to be used for describing the actual situation.

Data analysis shows that in Model I the most influential parameter on the indicator is ash content. The moisture content is not statistically significant at the 95.0% confidence level. Linear regression equation shows that by decreasing ash content and moisture content the value of the indicator will rise.

For the Model II the mechanical quality (expressed as a proportion of fines) is a function of the mean diameter and durability. The mean length and the transportation distance have a minor influence on the mechanical quality at 95% confidence level. Coefficient of determination $R^2$and adjusted R^2 explains 79.37% and 67.58% of data input for the regression model at 95% confidence level.

The regression analysis for the Model III shows that there is no sufficient correlation between the price for the pellets and the distance to the closest port at 95% confidence level, since R^2 is 8.31%.

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