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INDIRECT METHOD FOR EVALUATING LIGNITE MOISTURE

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(6 figures, 2 tables)

ABSTRACT. The inherent moisture of lignites is an important property in combustion of coal. The literature abounds in numerous models for assessing this property based on the known values of other properties, which are determined using standard methods. As a rule, these correlations are only valid for coals from the same deposits.

Based on sixteen Polish and one Australian lignite samples, an attempt was made to create a universal regression model for predicting the inherent moisture of lignites based on ash content and depth of deposition. A non-linear asymptotic model is elaborated. Its verification shows a high geological effectiveness.

KEYWORDS: coal properties, linear regression, prediction model.

1. Introduction

Total moisture of lignites (W_t^r) belongs to the most important technological parameters characteristic of coal, mainly when power applications are concerned. However, laboratory determinations of this property are made rarely. In such a case direct evaluation methods have to be employed. Functions of W_t^r and other parameters known from standard laboratory analyses are of great use. Such dependences usually have the form of regression equations of high correlation coefficients. Nonetheless, they are closely connected with a definite place of lignites occurrence. For this reason, they are often used for solving local problems. Attempts were made to fit the general equation (independent of local conditions within a given formation or region of lignite occurrence) [Fąfara, 1996, 1998, 1999a, 1999b, Fąfara & Twardowski, 1999, Twardowski & Fąfara, 1995]. Regression models for natural humidity prediction were analysed in various forms (linear and non-linear: polynomial, logarithmic, exponential, and mixed). Generalisations are made in this paper.

2. Results of laboratory determinations

A set of data encompassing 1149 laboratory results of total moisture and ash content on an analysis basis in lignite samples taken from a definite depth, were prepared. The collected results come from 17 regions of lignites occurrence (sixteen in Poland and one in Australia [Fąfara, 1996, 1999b, Fąfara & Twardowski, 1999, Twardowski & Fąfara, 1995]. The obtained package consists of verified coal samples (from a few to almost 200 m of depth) having different quality (Table 1). There are samples of high quality lignites (ash content below 5%) and coalified ones (ash content over 50%). Total moisture varies from ca. 15% to 80%. Age of deposition of the lignite is Lower Miocene. All of the lignite samples were collected in borehole. Before the measurements, samples were stored in air-tight containers.

Parameter	Unit	Number of samples	Minimum value	Maximum value	Average value	Standard deviaton
H	m	1149	7,5	199,5	74,80	46,41
W_t^r	%	1149	14,4	80,0	50,36	7,16
A^r	%	1149	1,75	79,32	13,44	11,13
S_t^d	%	613	0,12	6,73	1,63	0,76
V^{daf}	%	544	48,11	73,42	56,09	3,17

Table 1. Differences between the properties of the lignite samples in input file.
where: H – means depth of deposition of analysed lignite sample, W_t^r – total moisture of lignites, A^r – ash content in lignites, S_t^d – total sulfur in dry mass of lignites, V^{daf} – volatile fraction content in dry mass ash free.

3. Discussion

3.1. Linear model considerations

A fit of regression equation to the linear model was made:

$$W_t^r = a + b \cdot A^r \qquad (1)$$

where: a, b – coefficient of linear regression.

They show a function of total lignites moisture and ash content. In this way, 17 regional equations were obtained for individual areas of lignites occurrence and a dependence of all data (basically of high correlation coefficients). Then the results underwent statistical analysis of significance of differences of regression coefficients (a, b) for all possible pairs of analysed equations. The equations did not show significant differences in over 17% of all cases, at significance level $\alpha = 0{,}05$. The obtained results exhibit that in the case of such a complex form, the prediction model cannot be unified.

The model was modified by adding an element related with the depth of lignite deposition:

$$W_t^r = a + b \cdot A^r + c \cdot H \qquad (2)$$

where: a, b, c – coefficients of linear regression.

The depth influence on inherent moisture of lignites has been known for years. Schurmann's rule defines it best. The obtained regression relations have even higher correlation coefficients. Similar to the previous case, the results were analysed for significant differences of regression coefficients (a, b, c) for all possible pairs of equations. The equations did not exhibit significant differences in ca. 50% of analysed cases, at significance level $\alpha = 0{,}05$. This congruity was insufficient to work out a universal prediction model.

3.2. Non-linear model considerations

Another step was to enrich the linear regression model (2) with nonlinear polynomial elements of the order of −2 to +2. Fittings of more complex equation are more accurate (higher correlation coefficients) and higher similarity of regression coefficients (congruence in ca. 60% of cases.) is obtained. Nonetheless, no universal model was obtained, regardless of the place of lignite deposition.

Analysing statistical distributions of individual parameters in the collected set of data, the linear model was modified in a different way:

$$\ln(W_t^r) = a + b \cdot A^r + c \cdot \ln(H) \qquad (3)$$

A certain improvement of correlation coefficients of fit equations was observed. The regression coefficients were congruent in ca. 80% of cases, at significance level $\alpha = 0{,}05$. With this result a universal formula could be searched for. With this formula inherent moisture of lignites could be predicted, regardless their place of deposition.

After making a statistical analysis of parameters distribution, a non-linear model (similar to equation (3)), can be made:

$$\ln(W_t^r) = a + b \cdot A^r + c \cdot H \qquad (4)$$

This model is treated as exponential. Basically, it has the same properties as its counterpart in eq. (3).

3.3. Regression analysis of prediction models

Using a multiple regression method, the relation between total moisture of lignites and ash content on a analysis basis and depth of deposition was fitted to a linear model (2), non-linear mixed model (3) and exponential model (4). The results of regression analysis are listed in Table 2. Each fitting has a high correlation coefficient, R, ranging from ca. 0,88 to 0,89 (almost 80% variability described) at a relatively low standard deviation $S_{y/x}$. The correlation coefficient of a linear equation is much lower (by ca. 0,1) compared to the non-linear models.

It follows from the considerations that the non-linear mixed equation fitted to the model 3:

$$\log(W_t^r) = 1{,}89 - 0{,}0055 \cdot A^r - 0{,}066 \cdot \ln(H) \quad (5)$$

assuming after transformation the form:

$$W_t^r = \frac{78{,}43}{1{,}013^{A^r} \cdot H^{0{,}066}} \qquad (6)$$

can be treated as a universal model for predicting inherent moisture of lignites. In Fig. 1 there is a correlation of prognosed values W_t^r according to the non-linear mixed regression equation as well as laboratory determination.

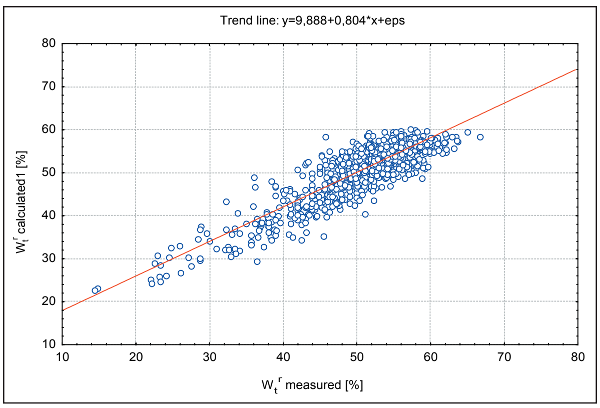

Figure 1. Correlation of prognosed value of W_t^r based on a mixed regression equation and laboratory determinations.

Model	Linear	Non-linear mixed	Exponential
Regression equation	$W_t^r = a + b \cdot A^r + c \cdot H$	$\log(W_t^r) = a + b \cdot A^r + c \cdot \log(H)$	$\log(W_t^r) = a + b \cdot A^r + c \cdot H$
Characteristic parameters:			
N	1149	1149	1149
R	0,877	0,890	0,889
F	1905,7	2192,9	2153,9
$S_{y/x}$	3,229	0,031	0,031
Coefficients:			
a	60,72	1,894	1,800
b	-0,5308	-0,00552	-0,00553
t_b	-60,99	-65,68	-65,21
c	-0,0371	-0,0662	0,00033
t_c	-18,06	-17,09	-16,49

Table 2. Results of regression analysis used for determining a prognostic model for assessing natural humidity in lignites. where: N – number of samples, F – Fischer-Snedecor's variable, $S_{y/x}$ – standard deviation of equation, t_x – t-Student's test value for *x* component of regression equation.

It follows from the figure that measuring points were sufficiently densely distributed, especially in the area typical of Polish lignites occurrence, for moisture ranging between 40% and 55%. A histogram in Fig. 2 presents differences between the result of laboratory experiments and predicted humidity. The histogram is symmetrical and in over 95% of cases the absolute difference does not exceed 4%, giving a relative error of the prognosis for typical lignites (W_t^r equals to ca. 50%) of ca. 8%.

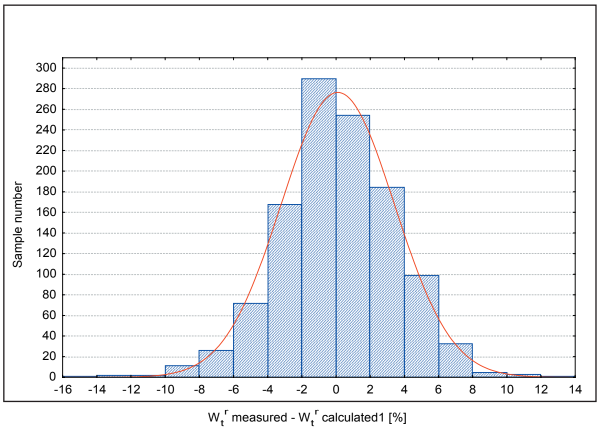

Figure 2. Histogram of differences between laboratory and prognosed values of W_t^r, based on a mixed regression equation.

After transformation, the fitted exponential model (4)

$$\log(W_t^r) = 1{,}80 - 0{,}0055 \cdot A^r - 0{,}00033 \cdot H \qquad (7)$$

assumes the form:

$$W_t^r = \frac{63{,}04}{1{,}013^{A^r} \cdot 1{,}00076^{H}} \qquad (8)$$

giving similar accuracy of description as in the mixed model; statistically, these models do not significantly differ. The correlation shown in Fig. 3 and histogram of differences in Fig. 4 are similar to plots for the non-linear mixed model. The exponential model is more advantageous mathematically (concise in form) and physically-geologically (physically justified form of relations between parameters). In Fig. 5, a relation of inherent moisture and ash content at different depths of lignites deposition was shown for an exponential regression model, and in Fig. 6 a relation of inherent moisture on depth of deposition of lignites for different ash contents.

When ash content and depth of deposition are zero in regression equations (6) and (8), the obtained moisture parameter corresponds to natural and ash-free coal (W_t^{raf}):

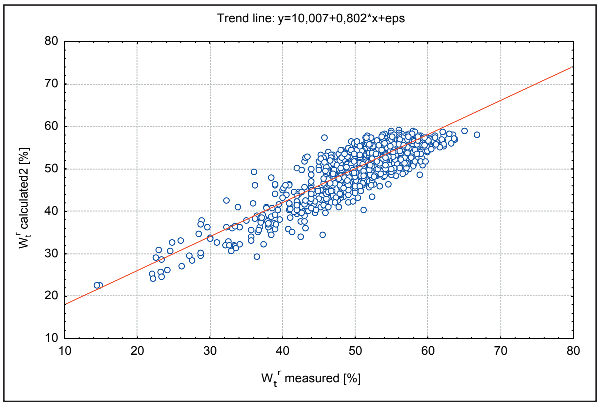

Figure 3. Correlation of prognosed values of W_t^r, based on an exponential regression equation and laboratory data.

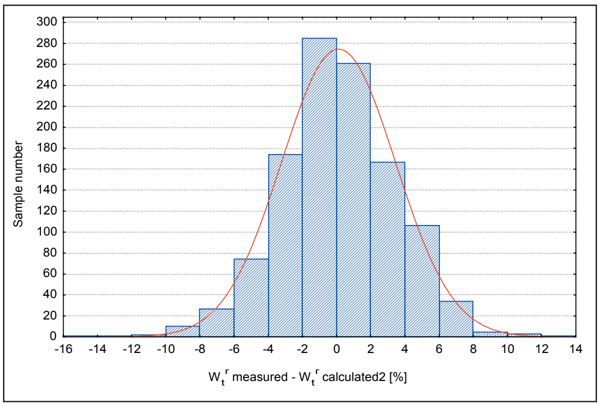

Figure 4. Histogram of differences between laboratory and prognosed W_t^r values, based on an exponential regression equation.

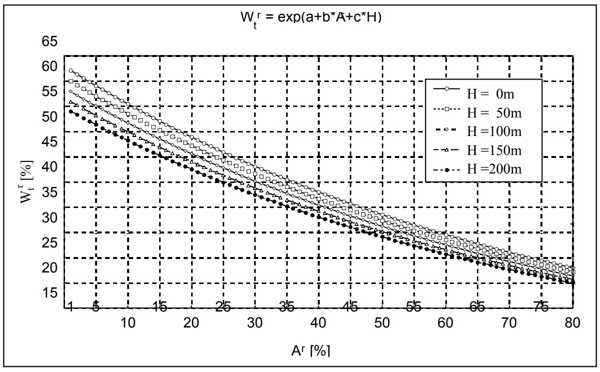

Figure 5. Exponential regression model of dependence of inherent moisure W_t^r on ash content A^r and depth of deposition H in lignites.

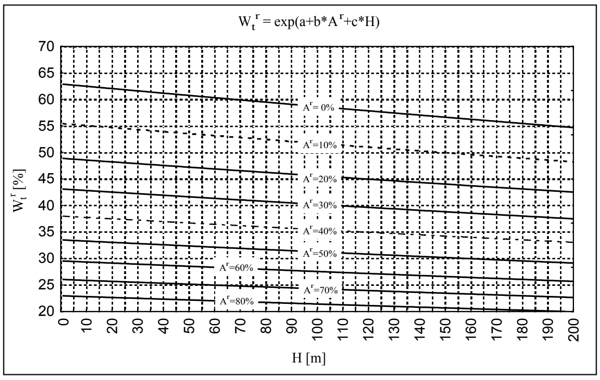

Figure 6. Exponential regression model showing dependence of inherent moisure W_t^r on depth of deposition H and ash content A^r in lignites.

- For mixed model $W_t^{raf} = 78,43\%$
- For exponential model $W_t^{raf} = 63,04\%$

Moisture in the natural and ash-free states should range between 60 and 70% [Gabzdyl, 1987]. The mixed model causes that moisture to be too high at low ash content, whereas W_t^{raf} obtained for the exponential model stays within the observed limits. For this reason, the exponential model seems to be more adequate.

4. Conclusions

By analyzing variability of inherent moisture of lignites, it was possible to statistically fit the exponential moisture-prediction model based on other standard parameters. The obtained equation has a relatively high correlation coefficient R = 0,89 (determination coefficient $R^2 = 0,79$). Its form and generated boundary values seem to be justified physically and geologically. In 80% of cases, fitted coefficients of the regression equation insignificantly differ from their local counterparts, fitted within individual deposits and regions of lignites occurrence. The obtained regression model meets the generality condition, thanks to which inherent moisture of lignites can be evaluated, regardless the region of lignites occurrence. The results of analyses can be successfully used in practice.

5. References

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