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Coal preparation versus losses of chemical energy in combustion processes

Key words

Hard coal, preparation coal, lasses of chemical energy, combustion coal

Abstract

Polish energy sector comprises nearly exclusively the conventional power plants, based on the domestic raw material, i.e. hard coal and brown coal. Coal is the basic source of energy, as well as the main factor providing the positive balance in the country's energy balance. The assumptions of Poland's Energy Policy for years to come anticipate a gradual reduction of the coal share in the electricity production. However, coal will continue to play the leading role in the sector of electricity production due to lower costs comparing to other energy carriers and due to the energy safety of the country.

Run of mine coal is characterised by various qualitative parameters. The quality of the coal is not always in conformity with the standard conditions designed for the boiler. The combustion of the coal of parameters considerably different than those designed causes the deterioration of the boiler operation quality, thereby, lowering the efficiency. In extreme cases, the boiler may even become damaged. In order for the recipient of the coal to receive the product with parameters exactly reflecting those ordered the coal must be subject to preparation processes. The process that is most often used is coal preparation in dense media, in jigs, or in centrifugal separators. The deeper the preparation is, the purer coal is obtained, of the better quality parameters. However, too deep preparation causes large amount of grains (organic substance) to transfer into the waste, thereby increasing the losses of chemical energy. Also the quality of processing machines contributes to the amount of losses. The quality of preparation can be described by

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performance curves. These curves are prepared on the basis of densimetric analysis of tested coal. The boiler is another place where the losses of chemical energy occur. The losses in the boiler are indicated through the boiler instrumentation systems, which allows drawing up the corresponding diagrams. The relation between yield of coal in the preparation process and the losses in the boiler can be determined by a two step analysis. In the first step the relation between the densimetric fractions yield and the calorific value of prepared coal is found. In the second step the relation between the losses in the boiler and the calorific value of burnt coal is determined. The superposition of the two functions gives the relation between yield of coal and losses in boiler. The relation in question allows setting such preparation conditions at the preparation plant that the losses in the boiler during combustion are minimised.

Introduction

Coal washing, as each technological process, causes some losses. This arises out from the fact that not all grains of the coal come to the concentrate and grains of waste rock come to the waste. Each preparation process can be characterized by a specific accuracy. This is related to the natural easiness or difficulty of beneficiation, accuracy of the preparation machines, applied technology of preparation and the extent to which the processes are automated. Easily washable coal is such one from which the concentrate may be easily achieved. The more often coal substance is connected with mineral substances the more difficult is the process of washing. The factors having the enormous impact on the washing accuracy is the automation and computerization of the beneficiation processes. Continuous adjustments and on-line control of coal quality parameters reduces the losses of coal in the waste and improves the efficiency of washing (Inoue, Cierpisz S. 1994).

The paper describes the analyses done using steam coal (Polish type 34.1). The coal was subject to beneficiation in dense media separator into 11 densimetric fractions. The analysis of calorific value was performed for each fraction. The washing was done in two variants, notably at the separation density of 1.80 g/cm^3, i.e. the density similar to the one used in the industrial conditions, and at the separation density equal to 1.35 g/cm^3, i.e. theoretical density. At such low density, half of the raw coal would come to the waste. However, the density was set at that low level due to the willingness of examining the differences in the losses of chemical energy of coal with relation to the separation density. The results of the densimetric analysis for the tested coal are given in Table 1.

When the first variant of washing was applied, the significant amount of concentrate (above 80%) was obtained. The calorific value of the concentrate was 26.959 MJ/kg. The remaining part, i.e. waste, was of the calorific value 4.709 MJ/kg. For comparison — the calorific value of the feed was 23.288 MJ/kg. In the second variant of washing, the calorific value of the concentrate was 27.874 MJ/kg, while the calorific value of the waste was 13.631 MJ/kg. Obviously, the calorific value of the feed was the same. In order to achieve the relation of the yield [γ] and the calorific value [Q], the empirical data obtained from the densimetric analysis were approximated with the polynomials of the first and second degree.

A number of methods exist for approximation of the washibility curves of coal. In the second half of the last century, the graphic method of determination the washibility

TABLE 1

Results of densimetric analysis of tested coal

TABELA 1

Wyniki analizy densymetrycznej badanego węgla

No.	Separation density [g/cm^3]	Yield [%]	Cumulative yield [%]	Calorific value [MJ/kg]
1	<1.30	50.6	50.6	28.062
2	1.30—1.35	17.2	67.8	27.322
3	1.35—1.40	5.9	73.7	26.187
4	1.40—1.45	2.9	76.6	24.956
5	1.45—1.50	2.2	78.8	22.843
6	1.50—1.55	1.0	79.8	21.202
7	1.55—1.60	0.7	80.5	19.343
8	1.60—1.70	1.8	82.3	18.137
9	1.70—1.80	1.2	83.5	13.914
10	1.80—1.90	0.8	84.3	12.432
11	>1.90	15.7	100	4.315

Source: Own testing results

parameters of coal concentrate was developed (Blaschke, Tumidajski 1972; Tumidajski 1993, 1994). The works of the above-mentioned authors show that the washibility curves of steam coal concentrate may be approximated by means of the complement of cumulative distribution function of Weibull, according to Jampolski and Chesin. This method involves the graphical determination the coefficients of the equation on the special logarithmic grid in the (lnx, ln lny) system. Due to the graphical character of the method, it is not widely used now. The attempts were also made to approximate the washibility curves by means of cumulative distribution functions of selected random variables, e.g. Pareto distribution, logarithmic and normal distribution, Johanson distribution, three-dimensional gamma distribution or four-parameter beta distribution (Tumidajski 1987). In this paper, the approximation of empirical data has been done using polynomials of the first and second degree. In the first case, this was the equation:

$$\gamma = a_1 \cdot Q + b_1$$

While in the second case:

$$\gamma = a_1 \cdot Q^2 + b_1 \cdot Q + c_1$$

As shown by the square correlation coefficients analysis, the coefficients were considerably higher for the approximation by the polynomials of the second degree. Therefore, this method was adopted for further calculations. For the tested coal, the following relation was achieved:

$$\gamma = -0.0513Q^2 + 1.3168Q + 75.004$$

This relation is presented in the figure 1.

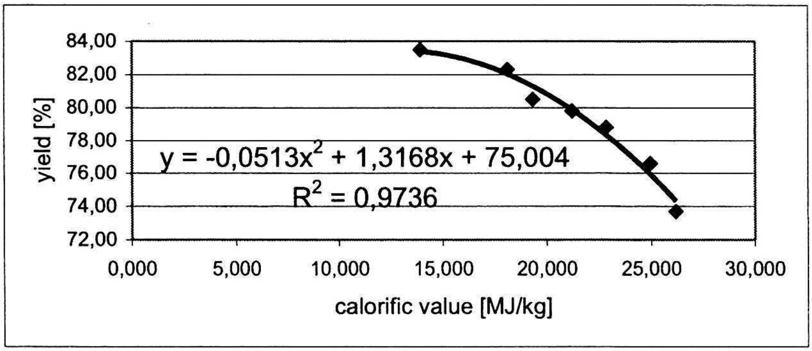

Fig. 1. Relation between yield and calorific value of the tested coal
Source: Own calculation

Rys. 1. Zależność pomiędzy wychodem a wartością opałową badanego węgla

Then the losses [S] in the boiler were evaluated as a function of the calorific value [Q] of burnt coal. The losses in the boiler depend on many phenomena occurring in during coal combustion. They also depend on the method of the boiler slag removal. For liquid method of the boiler slag removal the following losses can be recognized: the losses in the furnace due to incomplete combustion, conductance and radiation losses, losses of heat in the slag and outlet losses. Where the dry method of boilers slag removal is used, the incomplete combustion losses, losses for conductance and radiation and outlet losses occur (Mikucki 1954; Ostrowski 1969; Ziółkowski 1974; Orłowski at al. 1979; Laudyn at al. 1997; Pronobis 2002; Mokrzycki, Olkuski 2003; Olkuski 2004).

The approximation was done using two methods: application of the first and second degree polynomials. Both methods turned out to be very good in this case. The squares of correlation coefficients R^2 and r^2 were equal to 0.9998 for the approximation by the second degree polynomial, and to 0.9972 for the approximation by the first degree polynomial.

The example of the relation between the outlet loss and the calorific value of the tested coal burnt in the boiler, is given in the figure 2.

The relation between the losses in the boiler and the calorific value of the burnt coal presented in the figure 2, can be described by the following formula:

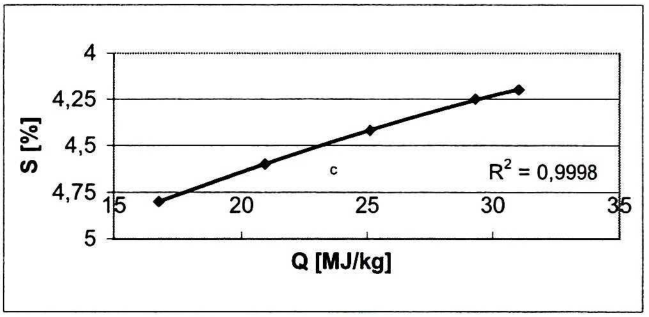

Fig. 2. Relation between the outlet loss S and the calorific value Q of the tested coal burnt in the boiler
Source: Own calculation

Rys. 2. Zależność pomiędzy stratami S i wartością opałową Q badanego węgla spalanego w kotłach

$$S = a_2 \cdot Q^2 + b_2 \cdot Q + c_2$$

For the tested coal the formula gets the form:

$$S = 0.0006Q^2 - 0.0688Q + 5.7983$$

The residual errors were also calculated, but these turned out minimal. They change from the value 0.0073 MJ/kg for the outlet loss at the dry method of slag removal to 0.0942 MJ/kg for the outlet loss at the liquid method of slag removal. This confirms that the matching is almost ideal. For further calculations, the approximation by the second degree polynomial was adopted due to slightly higher values of R^2. For the level of significance $\alpha = 0.05$, the critical value of the correlation coefficient R_{kr} is equal to 0.6710 for $n = 10$ degrees of freedom, while the coefficient R_{kr} is equal to 0.8360 for $n = 5$ degrees of freedom. For the approximation by means of the first degree polynomial, the r_{kr} is equal to 0.4973 for $n = 10$ degrees of freedom, and to 0.6694 for $n = 5$ degrees of freedom. In order to get the relation between the losses in the boiler S and the coal yield γ, two functions were combined: the relation between the coal yield γ and the calorific value Q with the relation between the losses in the boiler S and the calorific value Q.

The equation:

$$\gamma = a_1 \cdot Q^2 + b_1 \cdot Q + c_1$$

was transformed into the following form:

$$\gamma = a_1 \cdot \left[Q + \frac{b_1}{2a_1} \right] - \frac{b_1^2}{4a_1} + c_1$$

If r means the value beyond the brackets, i.e.

$$r = c_1 - \frac{b_1^2}{4a_1}$$

After performing simple transformations, the calorific value Q can be calculated. It is given by the formula:

$$Q = \sqrt{\frac{\gamma - r}{a_1}} - \frac{b_1}{2a_1}$$

Inserting this formula to the equation that presents the relation between the losses in the boiler S and the calorific value Q of burnt coal, we get the formula showing the relation between the losses in the boiler S and the coal yield γ, as follows:

$$S = a_2\left(\frac{\gamma - r}{a_1} - 2\sqrt{\frac{\gamma - r}{a_1}} \cdot \left(\frac{b_1}{2a_1}\right) + \frac{b_1^2}{4a_1}\right) + b_2\left(\sqrt{\frac{\gamma - r}{a_1}} - \frac{b_1}{2a_1}\right) + c_2$$

This formula allows calculating the losses of chemical energy of coal burnt in the boiler with relation to the yield of concentrate obtained in preparation plant. As the yield of concentrate depends on the separation density, the density may be controlled so that the value of losses is at the adequate level, acceptable by the power plant. The adjustment of the separation density is a well-known process and is relatively simple. It does not require significant financial outlays and complex and complicated equipment.

Conclusions

1. Losses of chemical energy in the boiler depend on a number of factors and change within very wide ranges, from a few to a few dozen percent.
2. Through adjusting the yield of concentrate in the preparation plant, which is technically relatively easy, we may influence the level of the losses of chemical energy of coal burnt in the boiler, as the rate of concentrate depends on the separation density that can be controlled.
3. Applying deeper beneficiation of coal in coal preparation plant, the concentrate of better quality is obtained. However, the amount of concentrate achieved is significantly lower in such case. Also the amount of chemical energy in the obtained concentrate is less, as the mass of the coal is smaller. The increase of the calorific value does not make up for the loss of mass.

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LIDIA GAWLIK, TOMASZ MIROWSKI, EUGENIUSZ MOKRZYCKI, TADEUSZ OLKUSKI, ADAM SZURLEJ

WZBOGACANIE WĘGLA A STRATY ENERGII CHEMICZNEJ W PROCESACH SPALANIA

Słowa kluczowe

Węgiel kamienny, wzbogacanie węgla, straty energii chemicznej, spalanie węgla

Streszczenie

Polski sektor energetyczny składa się prawie wyłącznie z konwencjonalnych elektrowni pracujących w oparciu o krajowe surowce, tj. węgiel kamienny i brunatny. Węgiel jest zatem podstawowym źródłem energii, jak również głównym czynnikiem równoważącym krajowy bilans energii. Założenia polityki energetycznej Polski na najbliższe lata przewidują stopniowe obniżenie udziału węgla w produkcji energii elektrycznej. Jednak

w dalszym ciągu węgiel będzie pełnił wiodącą rolę w produkcji energii elektrycznej z powodu niższych kosztów w porównaniu z innymi nośnikami energii i dla zapewnienia bezpieczeństwa energetycznego kraju.

Węgiel surowy ma różne parametry jakościowe. Jakość węgla nie zawsze jest zgodna z tą, na jaką zaprojektowano kocioł. Spalanie węgla o parametrach znacząco odbiegających od parametrów na jakie zaprojektowano kocioł powoduje obniżenie jakości działania tego kotła, a co za tym idzie — obniżenie efektywności. W skrajnych przypadkach może dojść do zniszczenia kotła. Aby odbiorca węgla mógł uzyskać produkt o parametrach zamówionych, węgiel musi być poddany procesowi wzbogacania. Procesem najczęściej stosowanym jest wzbogacanie w cieczach ciężkich, osadzarkach lub w hydrocyklonach. Im głębsze wzbogacanie, tym czystszy węgiel, to znaczy węgiel o lepszych parametrach jakościowych. Jednak zbyt głębokie wzbogacanie powoduje przedostawanie się do odpadów większej ilości ziaren substancji organicznej, co powoduje straty energii chemicznej. Na ilość strat wpływa również jakość maszyn przeróbczych. Krzywe wzbogacalności są tworzone na podstawie analizy densymetrycznej testowanego węgla. Kocioł jest następnym miejscem, w którym pojawiają się straty. Straty w kotle są wykazywane w instrumentach pomiarowych stanowiących oprzyrządowanie tego kotła. Pozwala to na wykreślenie odpowiednich diagramów. Zależność pomiędzy wychodem węgla w procesie wzbogacania a stratami energii w kotle może być określona w dwustopniowej analizie. W pierwszym kroku znajduje się zależność pomiędzy wychodem poszczególnych frakcji a wartością opałową badanego węgla. W drugim kroku określa się zależność pomiędzy stratami w kotle a wartością kaloryczną spalanego węgla. Złożenie tych dwóch funkcji daje zależność pomiędzy wychodem a stratami w kotle. Relacja ta pozwala na określenie takich warunków wzbogacania węgla w zakładzie przeróbczym, by zminimalizować straty podczas spalania w kotle.