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Susceptibility of coal to spontaneous combustion verified by modified adiabatic method under conditions of Ostrava-Karvina Coalfield, Czech Republic

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Abstract

The susceptibility of coal to spontaneous combustion is a physical-chemical property of coal that can be determined by a laboratory test. A number of laboratory methods verifying the coal susceptibility to spontaneous combustion exists, e.g. the oxidation method under adiabatic conditions, method according to the author Olpinski, method of pulse calorimetry, CPT (Crossing Point Temperature) method etc. Any versatile method has not been so far developed, which would become a generally respected and utilized laboratory procedure of objective assessment. The paper deals with verification of this method resulting from the widely used method of adiabatic oxidation. The modification of the method in question consists in the adjustment of the test process by increasing the initial temperature. This procedure enables shortening the test process. Shortening the laboratory test duration creates conditions for wider utilization of the method in practice.

1. Introduction

Issues of endogenous fires in the Ostrava-Karvina Coalfield (OKC) were solved especially in the seventies and eighties of the last century. It concerned particularly the workplace of the Scientific Research Coal Institute in Ostrava-Radvanice, at present VVUÚ, a. s. Three laboratories work today in OKC dealing with the assessment of coal susceptibility to spontaneous combustion. It is the above mentioned site of VVUÚ, a. s. (Olpinski method [1], adiabatic oxidation method), next the workplaces of the Department of Chemistry of the Technical University in Ostrava (pulse calorimetry) and the Institute of Mining Engineering and Safety of Faculty of Mining and Geology of VSB-Technical University Ostrava (CPT method, method of isothermal oxygen absorption) [2]. The method of coal oxidation under adiabatic conditions generally named Adiabatic Calorimetry is considered as the one of the most credible laboratory imitation of a real process of spontaneous combustion under operating conditions. The adiabatic method has indisputably become the one of the most often used methods of the assessment of coal susceptibility to spontaneous combustion in general [3]. The adiabatic method is respected worldwide, lit. [4 - 21]. The laboratory devices used for the adiabatic method vary in different laboratories by their workmanship, adjustment of the initial test temperature, utilization of oxidizing mixture, volume flow rate etc. One of the adiabatic method modifications was the version being used in the INSEMEX Research Institute in Petrosani, Romania, consisting in increasing the initial test temperature to 120°C [22]. The classical adiabatic test takes usually long time, many hours or days. The tested modified adiabatic method needs only 3,5 hours to get a relevant result. The modified adiabatic method have not been used in the Czech Republic before. The novel aspects of the research described in this paper are in the first tests of this method for coal of Ostrava-Karvina Coalfield.

2. Background of oxidation under adiabatic conditions

The adiabatic oxidation method is based on the assessment of verified samples during a contact with an oxidation medium (pure oxygen, air etc.) on conditions approaching the conditions adiabatic, i.e. without any energy exchange with the environment under a sufficient oxygen supply and minimum heat removal . One of the first information about research of coal oxidation comes from Great Britain [4]. The information about adiabatic method was particularly published by Davis and Byrne in the year 1924 in USA [5]. Resulting from the previous experience at the University of Nottingham, the Department of Deposit Engineering, the adiabatic method has been chosen in the Great Britain as a major method for verifying the coal susceptibility to spontaneous combustion [6]. The principle of this method have been used in many countries, e.g. in Australia [7], [8], [9]. Australian authors from Queensland tested coal by adiabatic methods in two versions, using a 2-metre adiabatic column and in a 16m^3 reactor. The New Zealand coal have been testes by adiabatic test from an initial temperature of 40°C. The index R-70 was used for determination of spontaneous combustion propensity [10]. The South Africa research have been designed to be run in a rising temperature mode and in an adiabatic incubation mode. Total temperature rise, initial rate of heating, minimum self-heating temperature and kinetic constants were investigated [11]. USA research used electrical stove [12].

At present this method is the one of the methods credible for verifying the susceptibility to spontaneous combustion. The outputs are, except for the coal categorization into the susceptibility classes, also kinetic parameters of oxidation, i.e. the assessment of spontaneous combustion process related to the conditions in mining operations, determination of oxidation rate, definition of the critical temperature of spontaneous combustion and forecast of incubation period.

3. Apparatus of modified adiabatic method

The existing equipment of the Laboratory of Spontaneous Combustion of Substances of the Institute of Mining Engineering and Safety, VSB-TU Ostrava has been used, Fig. 1. The main part of apparatus is created by the 16 l oil bath filled with silicone oil and a heating coil 1,72 kW. The reactor placed in the oil bath was in the form of a glass washing vessel of the capacity of 0.5 l with a filter glass at the bottom, was also fitted with a preheating glass coil used for the temperature compensation of the incoming oxidizing medium, i.e. pure O_2. To sense the temperature of the coal sample verified and the oil bath temperature two thermoelectric couples were used of the K type. Integral parts of the apparatus were also of two integrated AD595AQ amplifiers produced by Analog Devices, Inc., which served for increasing the output voltage of the thermoelectric couples. This apparatus included Cole Parmer's flow meters (rotameters) and pressure bottles with technical gases and pressure control valves. The oxidizing medium flow rate was set to 40 $ml.min^{-1}$ of pure oxygen. The thermostat PC control ensured the A/D card, AX 5210 type, AXIOM producer, and KUAN power triac inverter of KSD225ACB type. The controlling application was realized by the Czech software of the Control Panel 2.2 produced by Alcor – Moravské přístroje, a. s. The wiring diagram of the apparatus of the modified adiabatic method is illustrated in Fig. 2.

Fig. 1. Research workplace of Faculty of Mining and Geology of VSB-Technical University of Ostrava

Fig. 2. Scheme of the apparatus of modified adiabatic method

A coal sample, having grain size of 0.1-0.3 mm, was placed into a reaction vessel, into which a thermoelectric couple was inserted serving for tracking the temperature behaviour. The measured temperature values were saved in the file "*.DBF". Archiving takes place every minute into a selected file. Both the measured temperatures of the reactor's coal sample and the oil bath temperature were archived. A coal sample was preheated to 120 ^{o}C as an initial test temperature, later temperature rose due to the oxidation initiated equilibrating the oil bath temperature by the heating coil.

3.1 Verification of repeatability and operations of the modified adiabatic method apparatus

To verify the repeatability a quintuple test was performed of the same homogenized coal sample. The diversity in measurements was caused only by the difference in temperature in the laboratory. During the first two measurement processes there was a lower temperature in the laboratory. During the next three measurements the laboratory temperature was maintained at a constant value of 24 °C. The dynamic of rising of temperature was identical in the second case.

For this reason we proceeded for the next measurement to tempering the laboratory using air conditioning to 24 °C. The apparatus was verified as well by means of an inert “blank” sample. As a suitable inert material limestone was chosen. The goal of the verification was to prove that after the tempering the sample placed into the thermostat and starting the adiabatic mode of the apparatus as well as the substitution of sucked nitrogen during the tempering for pure oxygen no spontaneous sample temperature growth occurs. The test process is shown in Fig. 3.

Fig. 3. Test of inert "blank" sample (limestone) by the modified adiabatic method

4. Coal samples

The coal sample grain size was chosen for the given method with a view to the oxidation dynamics. The lower grain size value was limited by the filter glass of the reactor - 0.1 mm. The influence of grain size was verified for the coal samples no. 4, no. 17 and no. 26 of Table 2. We verified the grain size of 0.1-0.3/0.3-1.0/1.0-2.5mm. The temperature rise of all three verified samples was for the grain size of 0.1-0.3 mm higher than for the grain size of 0.3-1.0 mm. While using the grain size of 1.0-2.5 mm, no oxireactivity was proved for the samples no. 17 and no. 26 and the oxireactivity of the grain size of 1.0-2.5 mm for the sample no. 4 was very low. So commonly known fact was confirmed that lump coal tends to oxidation more difficult than coal comminuted.

The samples taken from coal seams of OKC deep mines were shortly after sampling de-aerated using food vacuum storage system by Zepter. The samples of 287 g were prepared 1 hour before measuring. The list of coal samples is given in Table 2.

5. Assessment parameters

Based on the accomplished measurements of 36 coal samples from active workplaces of OKR Table 1 it was proposed to evaluate first 60 minutes of the test. This time interval proved to be quite satisfactory, since after 60 minutes the temperature equilibrated in many samples due to exhaustion of the oxidizing medium. Fig. 4 illustrates the temperature rise of the coal sample with the oxygen concentration (output of reactor) during a measurement.

Based on the time reduction of the sample test using the modified adiabatic method as the assessment parameter the temperature gradient Δt_{60} was chosen. The parameter Δt_{60} is determined using the formula (1):

$$\Delta t_{60} = t_k - t_p \tag{1}$$

where: Δt_{60} – temperature difference during 60 minutes, (°C),
t_k – finale temperature, (°C),
t_p – initial temperature, (°C).

Fig. 4. O_2 consumption during measurements by the modified adiabatic method

6. Classification scale of modified adiabatic method

From the performed measurements of coal samples the sample was taken into account with a maximum temperature gradient, i.e. the sample no. 7, Δt_{60} = 34,5 °C, and the sample with the lowest temperature gradient, i.e. the sample no. 25, Δt_{60} = 4.7 °C, Table 2. Based on the variation range of the parameter Δt_{60} an assessment scale was proposed and classification categories of the susceptibility of coal to spontaneous combustion listed in Table 1.

Table 1
Assessment scale of the susceptibility to spontaneous combustion of the modified adiabatic method

Category	Average temperature rise Δt_{60} [°C/hour]	Susceptibility to spontaneous combustion
1	0 to 19	Low
2	19 to 30	Medium
3	Over 30	High

The temperature behaviours of the verified coal samples according to Table 2 are illustrated in Fig. 5. The graph reflects also the diversity of oxireactivity of the samples originating from coal seams of the Ostrava Formation and samples from the Karvina Formation. Here it is seen that oxireactivity of the coal samples of Ostrava seams is within the lower values of Δt_{60}. It is generally known that the risk of spontaneous combustion of coal seams of the Ostrava carboniferous layers is low.

Fig. 5. Temperature rise behaviours of verified coal samples - differentiation of susceptibility to spontaneous combustion of Ostrava and Karvina coals

Resulting from the above mentioned assessment scale of the modified adiabatic method the individual samples were included into the proposed categories of the susceptibility to spontaneous combustion, Table 2. The table shows that the majority of samples (6 samples) originating from Ostrava layers (total number of samples 10) were assessed as low prone to spontaneous combustion.

Table 2
Identification and results of verified coal samples

Coal sample				Susceptibility to spontaneous combustion	
Sample no.	Colliery	Seam ID	Formation	Δt_{60} /°C/	Susceptibility
1	Darkov3	40	Karviná	20,2	Medium
2	Darkov3	40	Karviná	20,9	Medium
3	Darkov3	40	Karviná	18,1	Medium
4	Darkov2	34	Karviná	19,2	Medium
5	Darkov2	37	Karviná	16,4	Low
6	Darkov2	22	Karviná	24,6	Medium
7	Darkov2	34	Karviná	34,5	High
8	ČSA	24	Karviná	27,7	Medium
9	ČSA	23	Karviná	33,4	High
10	ČSA	40	Karviná	23,1	Medium
11	ČSA	40	Karviná	22,1	Medium
12	ČSA	40	Karviná	19,4	Medium
13	ČSA	34	Karviná	30,2	High
14	ČSA	40	Karviná	15,9	Medium
15	LAZY	NATAN	Ostrava	16,4	Low
16	LAZY	NATAN	Ostrava	18,0	Low
17	LAZY	40	Karviná	31,5	High
18	LAZY	NATAN	Ostrava	22,7	Medium
19	LAZY	39	Karviná	31,4	High
20	LAZY	39	Karviná	33,4	High
21	PASKOV	21A	Ostrava	10,1	Low
22	PASKOV	22B	Ostrava	20,8	Medium
23	PASKOV	22F	Ostrava	13,5	Low
24	PASKOV	059 10	Ostrava	18,8	Low
25	PASKOV	17B	Ostrava	4,7	Low
26	PASKOV	17B	Ostrava	19,4	Medium
27	PASKOV	17B	Ostrava	19,5	Medium
28	ČSM-SEVER	32	Karviná	24,0	Medium
29	ČSM-SEVER	37a	Karviná	15,8	Low
30	ČSM-SEVER	33a	Karviná	-	-
31	ČSM-SEVER	30	Karviná	25,7	Medium
32	ČSM-SEVER	36b	Karviná	17,6	Low
33	ČSM-JIH	29b	Karviná	21,7	Medium
34	ČSM-JIH	40	Karviná	29,2	Medium
35	ČSM-JIH	40	Karviná	21,6	Medium
36	ČSM-JIH	40	Karviná	17,2	Low

7. Summary, discussion and conclusion

The assessment of the coal susceptibility to spontaneous combustion is performed for the purpose of the evaluation of spontaneous combustion risk with the subsequent selection of preventive measures. There is currently no universal method for determining the susceptibility of coal to spontaneous combustion.

The modified adiabatic method have been used in Czech Republic first time. It was confirmed that oxireactivity of the coal samples of Ostrava seams were lower then oxireactivity of coal samples of Karvina seams, which is generally known. It confirmed an applicability of this method for using in Ostrava-Karvina Coalfield.

The validate modified adiabatic method has no ambition to become a universal method, however it can contribute to improving the state of research on the susceptibility of coal to spontaneous combustion. By reason of an acceptable time-consuming (about 3.5 hours) the method in question has prerequisites for further use in comparison with the "classical" adiabatic method, whose tests in many cases take up to several days.

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Figures

Tables

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Fig.1.

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Fig.2.

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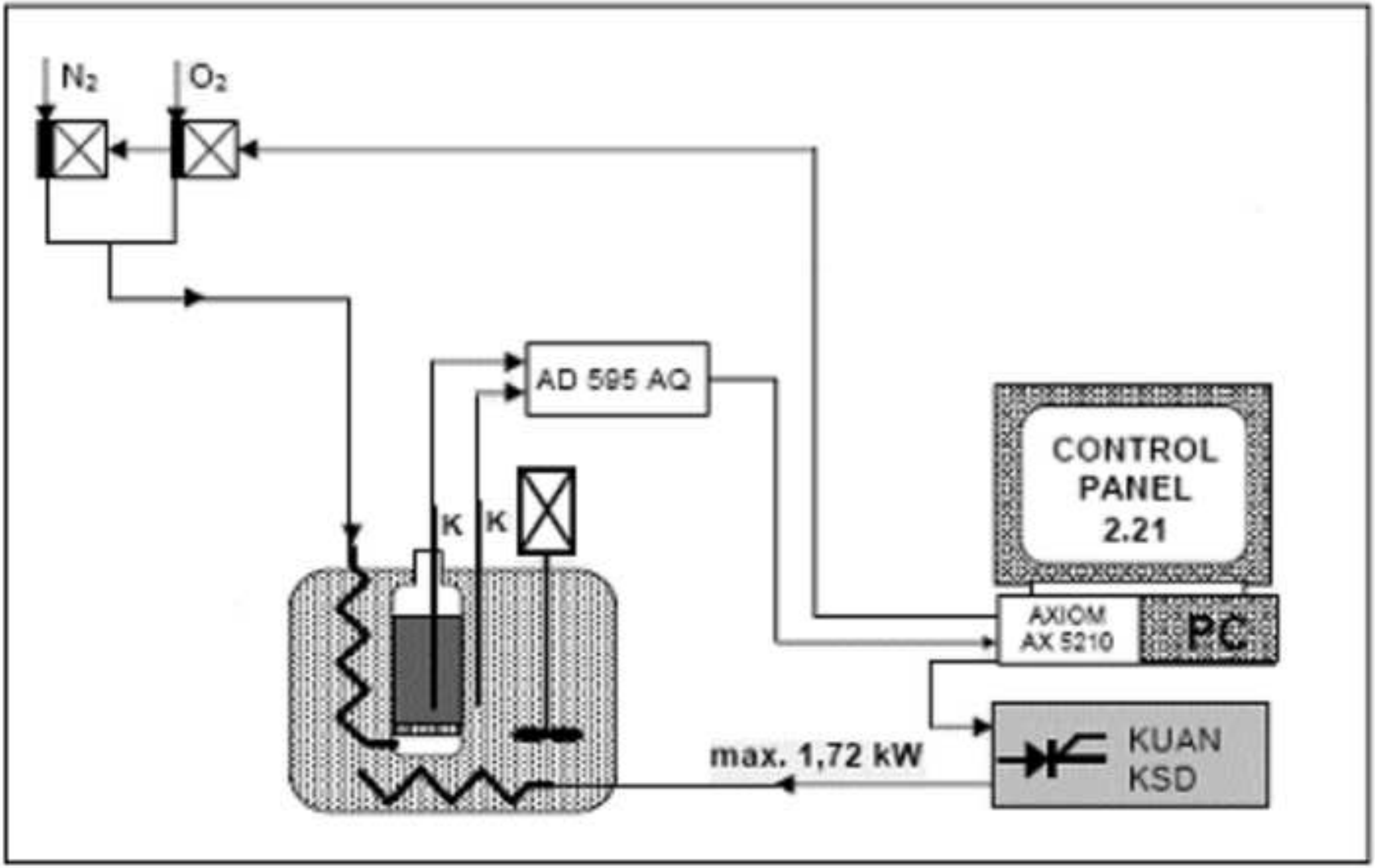

Fig.3.

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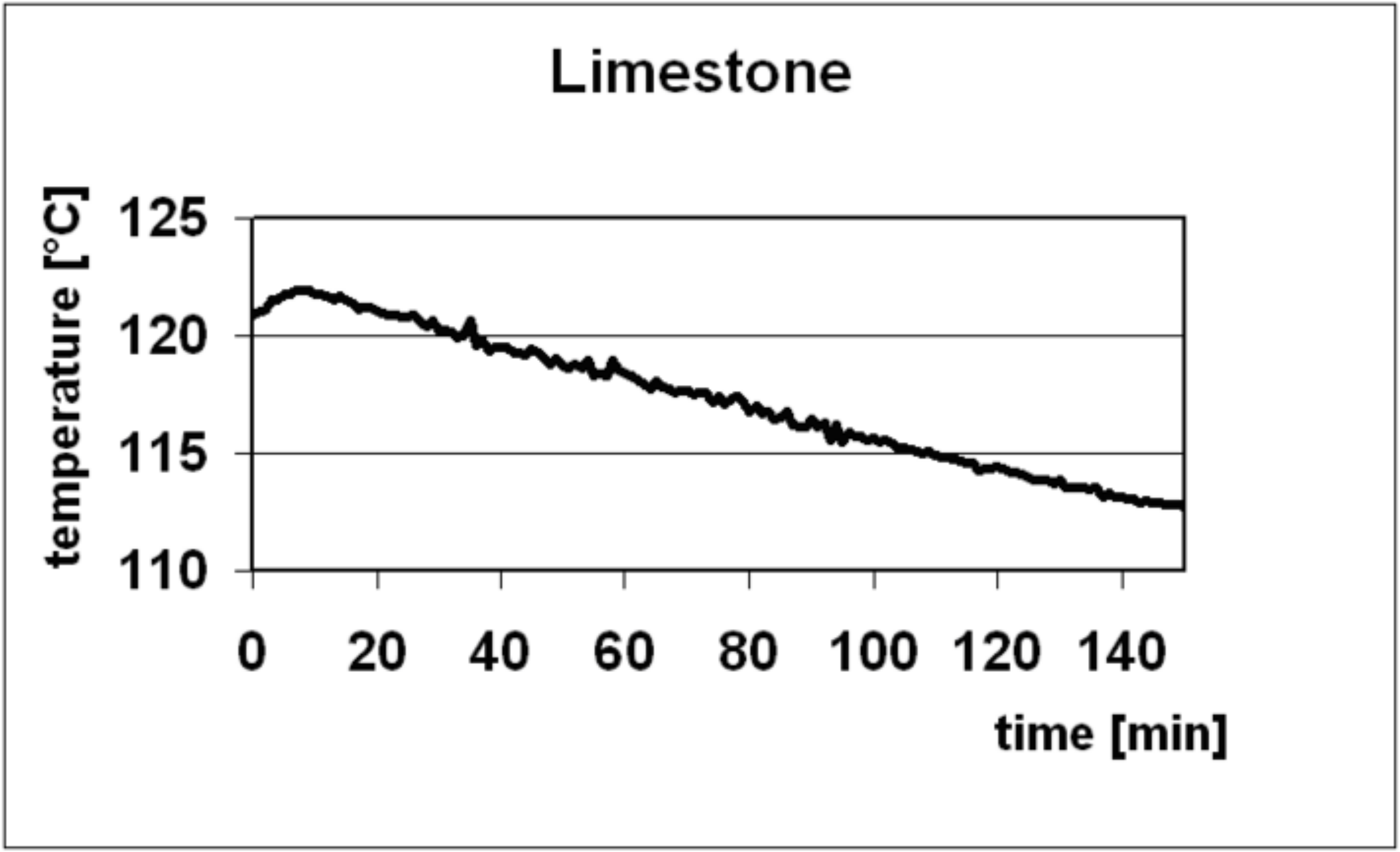

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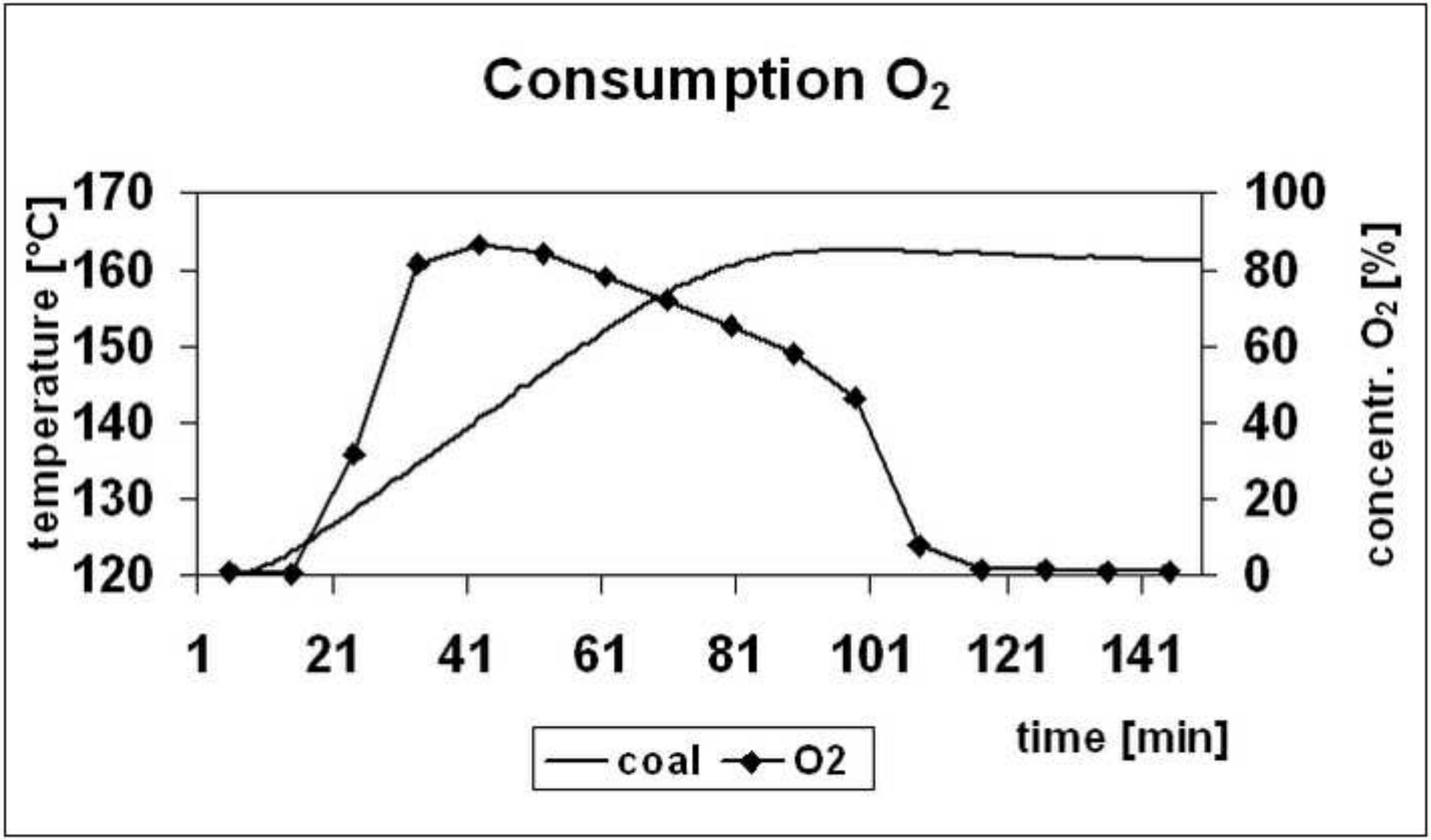

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