



Central Mines Rescue Station

POLAND, 41-902 Bytom, 25 Chorzowska Str, tel.: +4832 2822525

www.csrg.bytom.pl e-mail: info@csrg.bytom.pl

METHOD FOR DETERMINATION OF FIRE HAZARD ON THE BASED ON GASEOUS PRODUCTS OF COAL OXIDATION AND THERMAL DECOMPOSITION

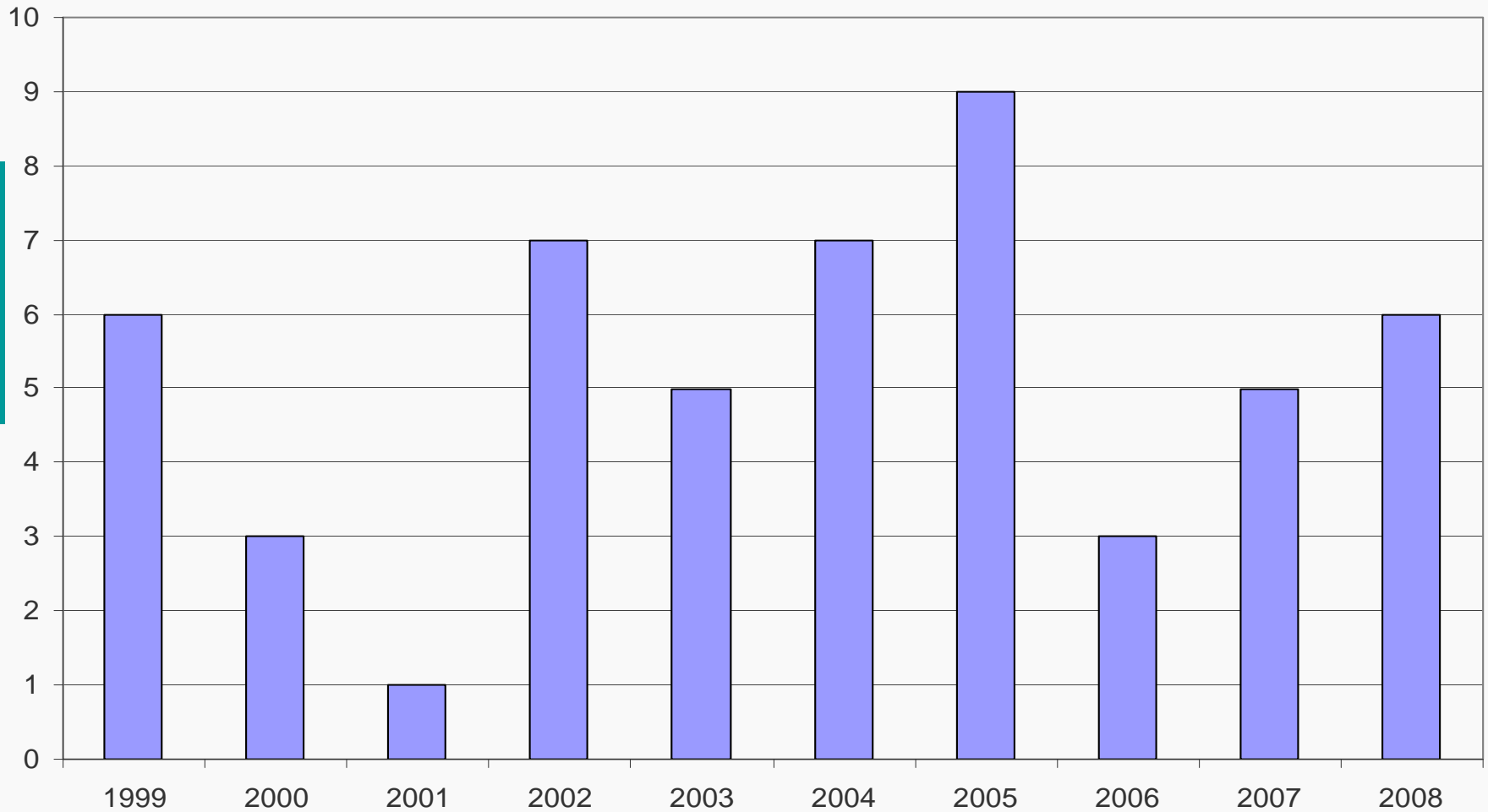


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Number of fires in Polish mines 1999 - 2008

Quantity



Years

Analysis of endogenous fires makes it possible to state that about 90% of all the fires occurred in the regions of coal extraction.

Close look to all these fires brings about to the finding that the most important reasons for breakouts and development of fires in Polish coal mines are the following:

- *variable thickness of extracted beds with numerous geological faults and poor cohesion of roof rocks,*
- *high ventilation intensity of workings that is generally applied for fighting methane and climatic hazard. It brings about to more intense penetration of air via goafs and cracked pillars.*
- *effect of hazard from rock bumps, which, in combination with prophylactic measures leads to disturbances and destruction of coal structure and consequently results in formation of cracks that enable penetration of air.*

Evolution of fire hazard in coal extraction areas

During each endogenous fire the following phases can be distinguished:

- **incubation** – decrease of air content in the colliery air;
- **self-heating** – further drop of oxygen content, increase of humidity and growth of the CO_2 concentration, appearance of CO by the end of this phase;
- **ignition** – coal carbonization (pyrolysis) associated with emission of hydrogen, methane and other hydrocarbons, mainly ethane and propane, substantial growth of coal temperature,
- **coal burning (the fire itself)** – further increase of CO_2 and CO concentration in fire gas while fumes and flames;

When the basic parameters of the air are known, such as stream V of the air volume that flows throughout the extraction area, concentration values of oxygen and carbon oxide in % by volume at the area inlet and outlet as well as mass densities thereof, it is possible to use very simple formulas to calculate weight of the oxygen stream that enters into reaction with coal to produce CO as well as stream of oxygen decrease due to formation of CO₂. After calculation of the foregoing values for the weight of the oxygen stream one can find out, how much of coal is burnt to produce CO and CO₂.

Analysis of timings for weight of coal that is subject to oxidation within the extraction area it is possible to predict trends in variations of hazards from underground fires, Moreover, information on the amount of combusted hard coal along with its calorific value makes it possible to roughly evaluate the approximate stream of heat that is released during the coal oxidation process.

The staff of Chemical Laboratory in the Central Mining Rescue Station plc. has developed a test bench for thermal oxidation of coal in the atmospheric air and under coating layer of other gases, e.g. inert gases and their mixtures with various percentage configuration. Such examinations as well as calculated coefficients make it possible, with pretty high degree of accuracy, to find out what kinds of exothermal oxidation processes actually take place over a specific period of time in mining excavations and eventually determine temperature of heated coal.

When scope of the analysis is extended to determination of trace amounts (at the magnitude of ppm or even parts of ppm) of saturated or non-saturated hydrocarbons, much additional information can be obtained about temperature and status of a hidden fire centre, which consequently increases efficiency of early detection of endogenous fires.

Diagram of the chamber for thermal oxidation of coal

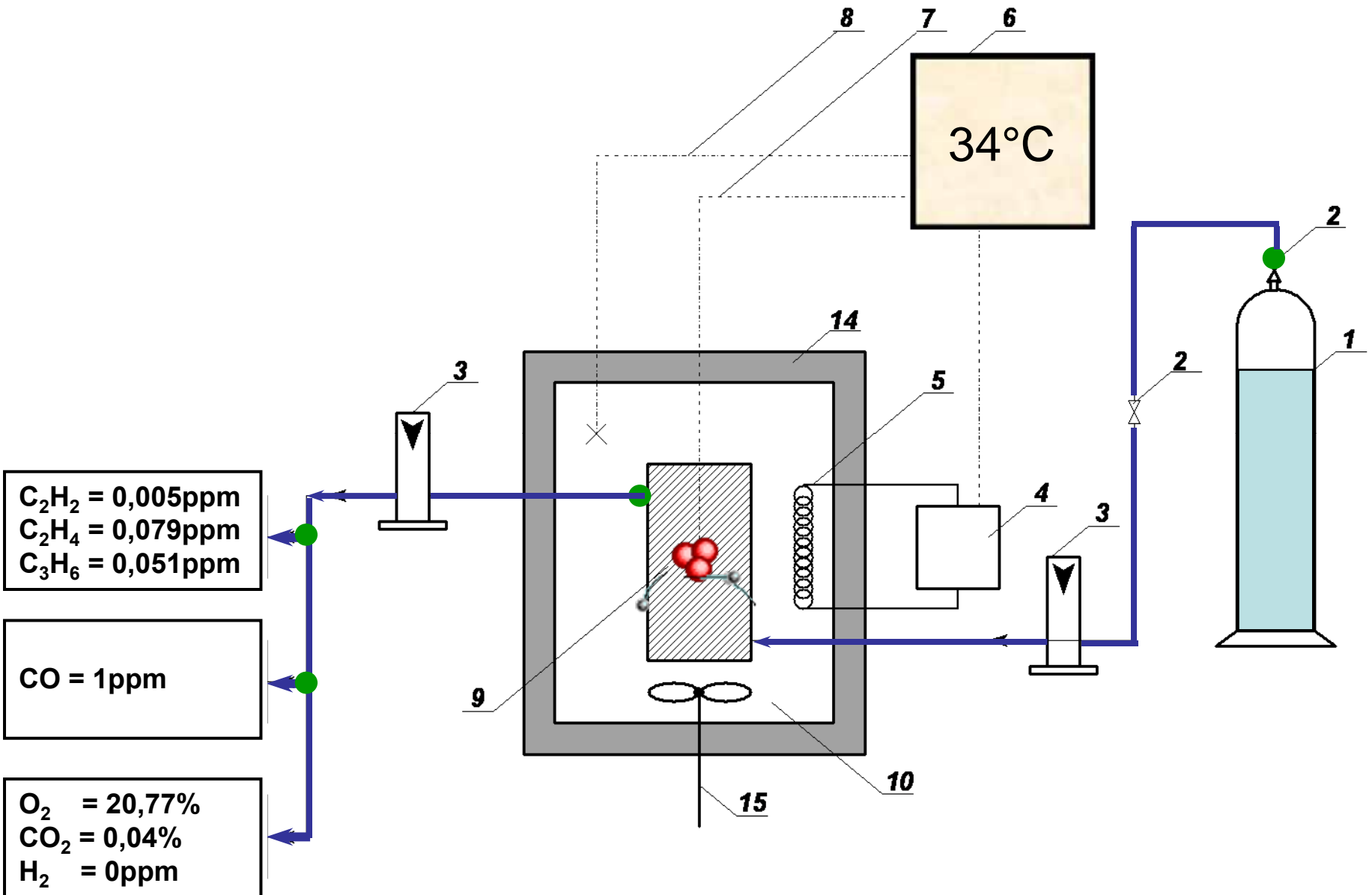


Diagram of the chamber for thermal oxidation of coal

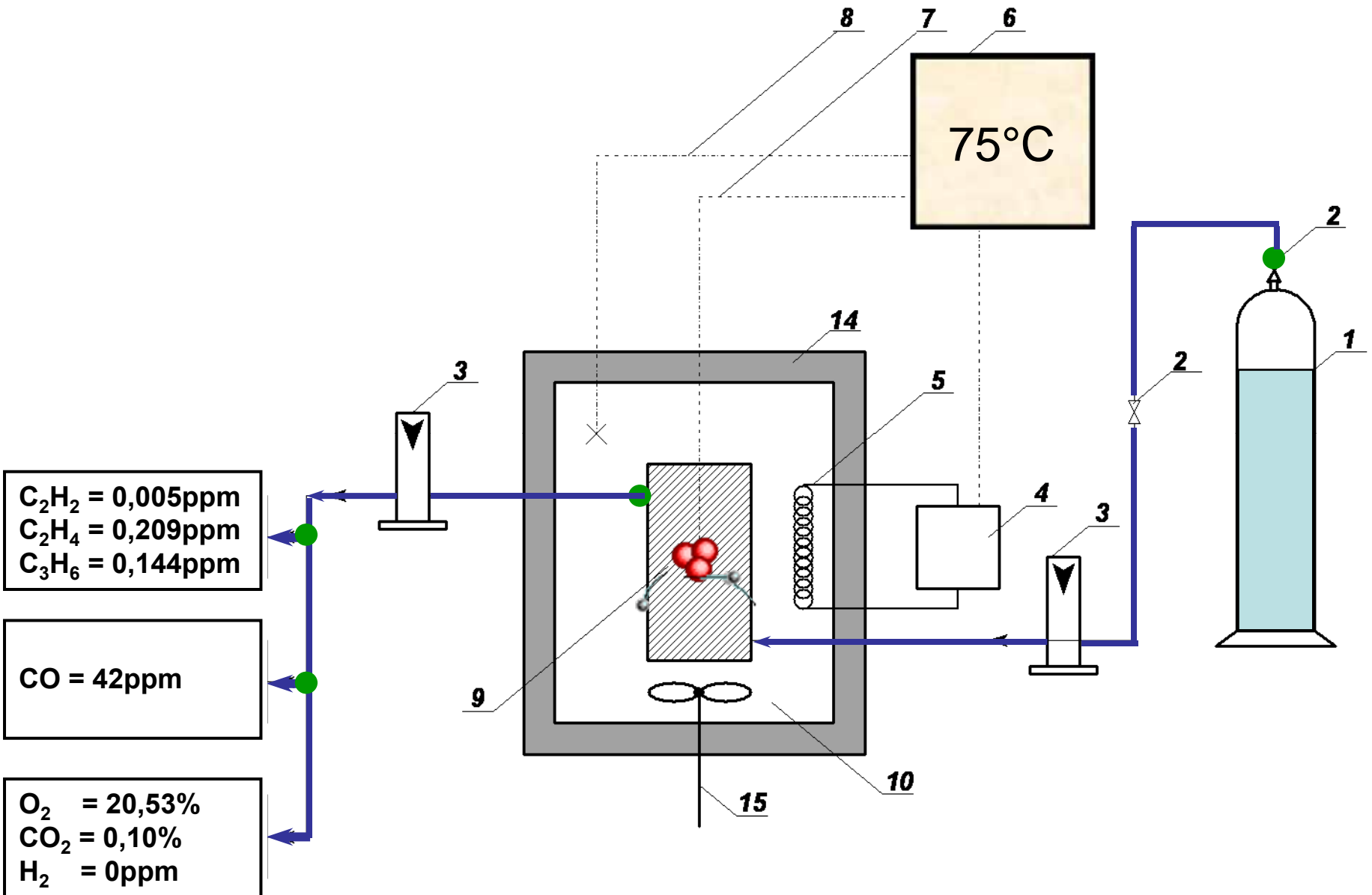


Diagram of the chamber for thermal oxidation of coal

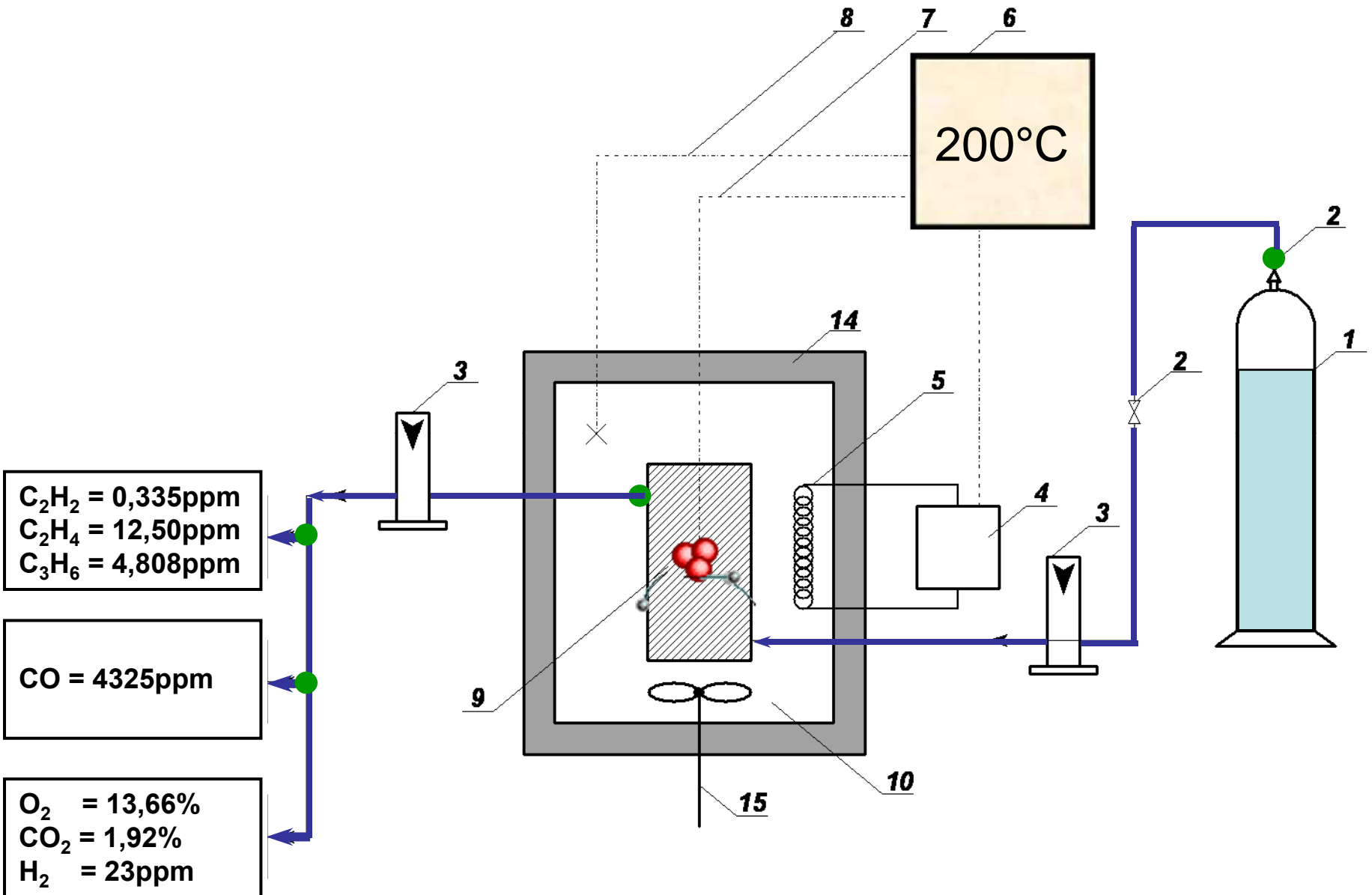
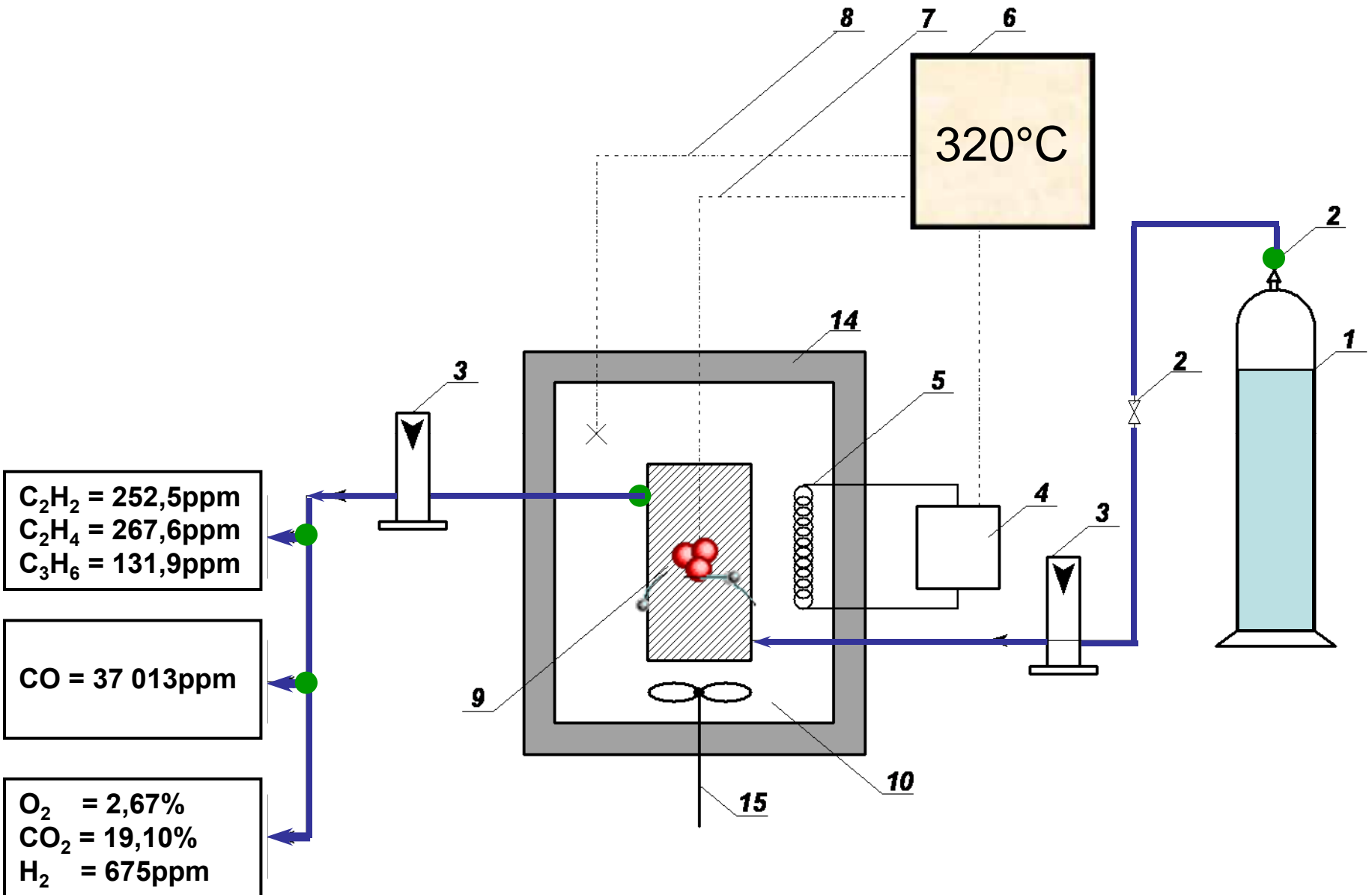
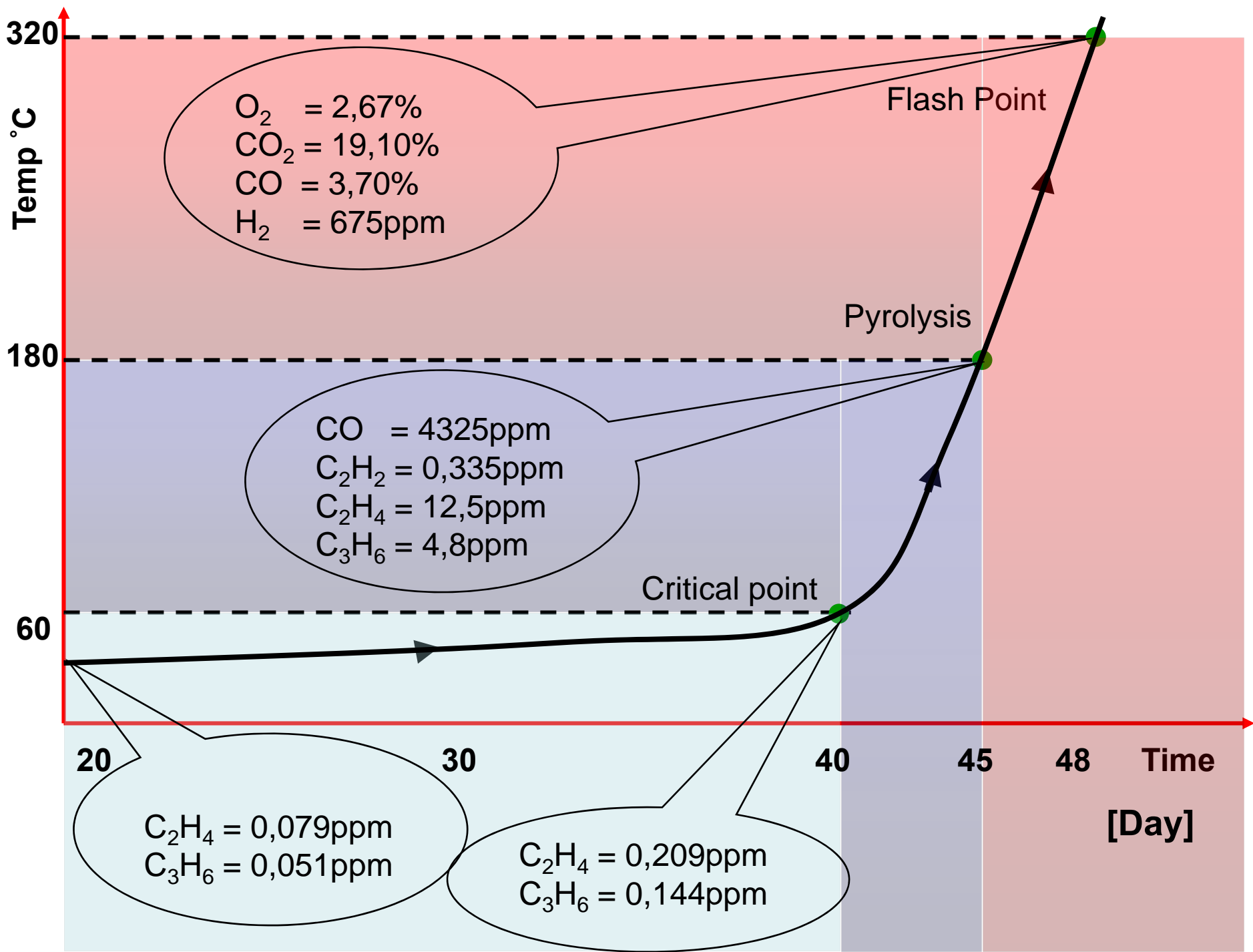


Diagram of the chamber for thermal oxidation of coal



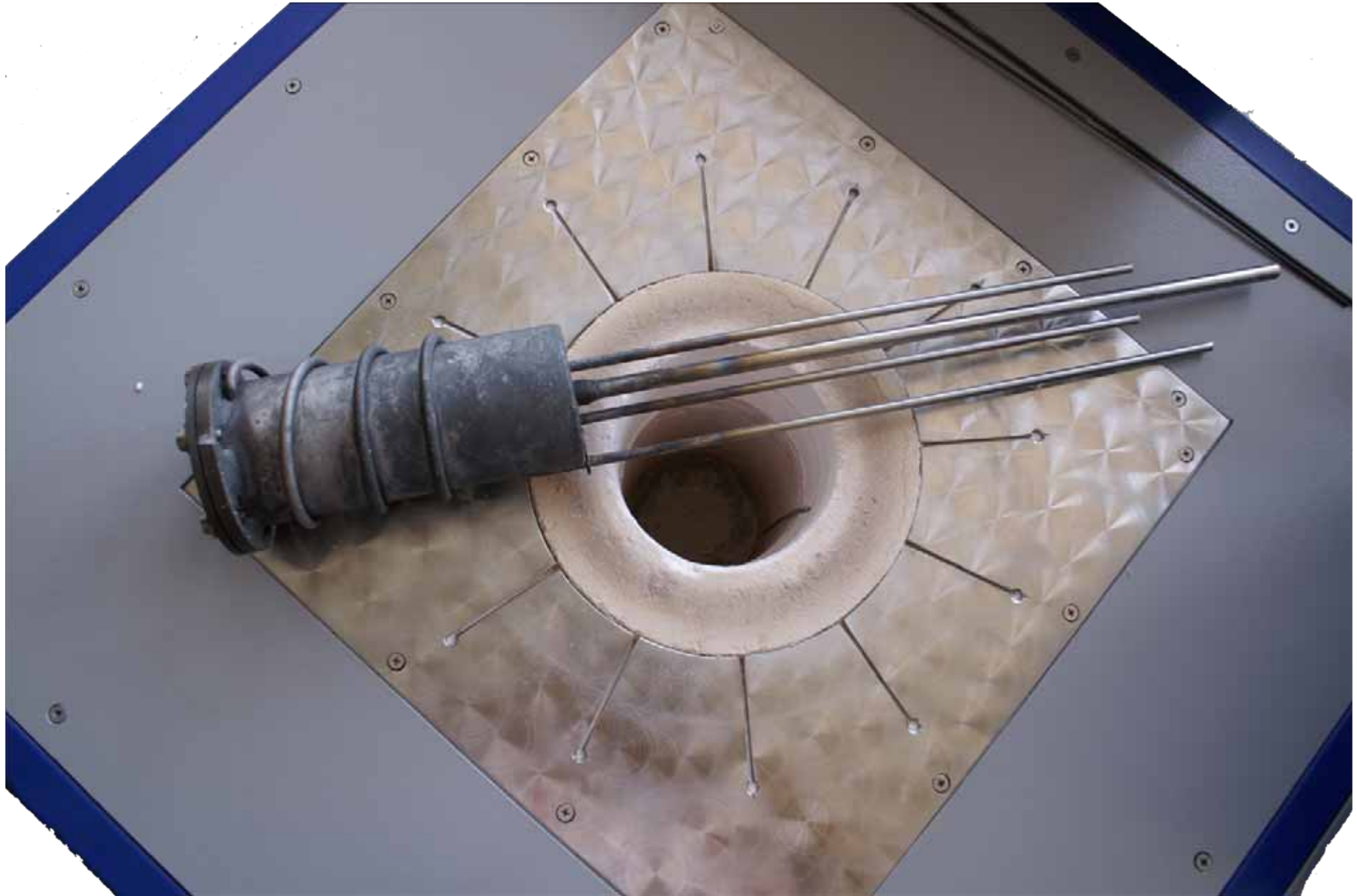


Coal temperature inside the retort [°C]	Gas concentrations					Non-saturated hydrocarbons (C_xH_y)		
	O_2	CO_2	CO	CH_4	H_2	C_2H_2	C_2H_4	C_3H_6
	[%]	[%]	[ppm]	[%]	[ppm]	[ppm]	[ppm]	[ppm]
34	20,77	0,04	1	0,0003	0	0,005	0,129	0,051
75	20,53	0,10	42	0,0003	0	0,005	0,209	0,144
100	19,04	0,38	150	0,0005	0	0,01	0,646	0,543
150	14,00	1,64	958	0,0026	17	0,06	10,512	4,274
200	13,66	1,92	4325	0,0025	23	0,335	12,505	4,808
250	3,97	13,51	35062	0,17	143	106,385	105,077	51,478
320	2,67	19,10	37013	0,19	675	252,527	267,691	131,901
350	2,72	19,65	40531	0,37	1505	409,838	430,453	264,679
400	1,70	19,16	43776	0,88	2694	1066,59	722,336	648,091
450	0,98	18,68	42798	1,53	7718	739,773	656,598	519,578
500	0,38	18,75	37649	1,47	12885	245,584	248,787	65,206
550	0,38	18,33	34871	1,55	28303	46,107	41,142	9,031
600	0,37	17,41	36441	0,65	30698	12,441	11,237	1,564
650	0,26	16,00	45638	0,56	40388	15,225	7,501	1,779

Test bench for examination of coal at variable temperature



Chamber for thermal oxidation of coal

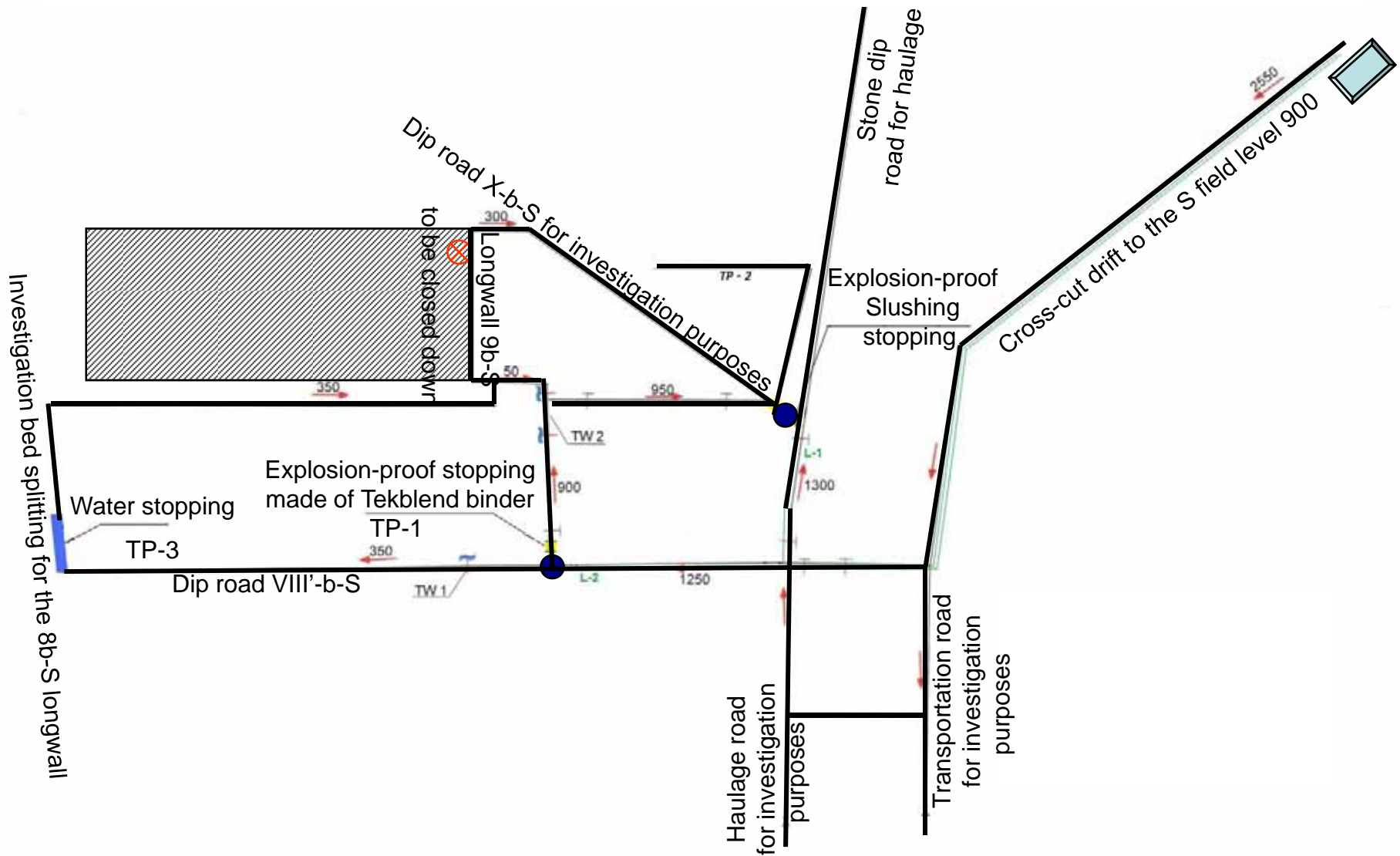


Chromatograph Agilent 7890 with a thermal desorber



Analysis and assessment of the fire hazard degree carried out on the basis of calculations for the total stream of combusted coal and fire power

Spatial diagram of the endangered region of coal extraction



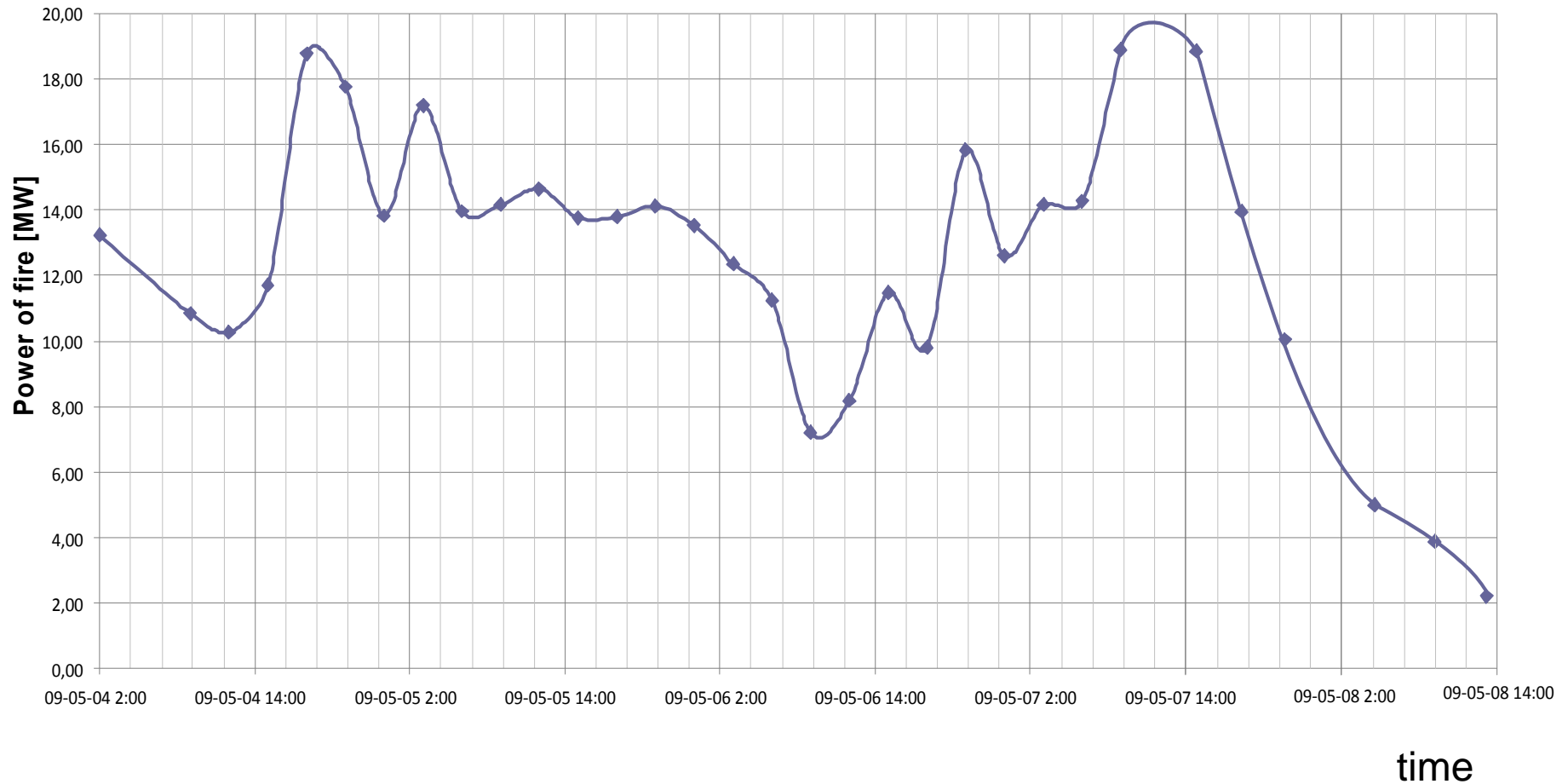
When the rescue action was in progress, samples of air from the inflow and outflow airstreams (supplied to and evacuated from the endangered region) were taken for detailed analysis.

When the volumetric flow V of air that passes throughout the endangered longwall region is known, it was possible to calculate amounts of coal that are combusted with generation of CO and CO₂.

Moreover, assuming the calorific value of coal in the bed 510 for granted, the approximated stream of heat generated during the process of coal oxidation

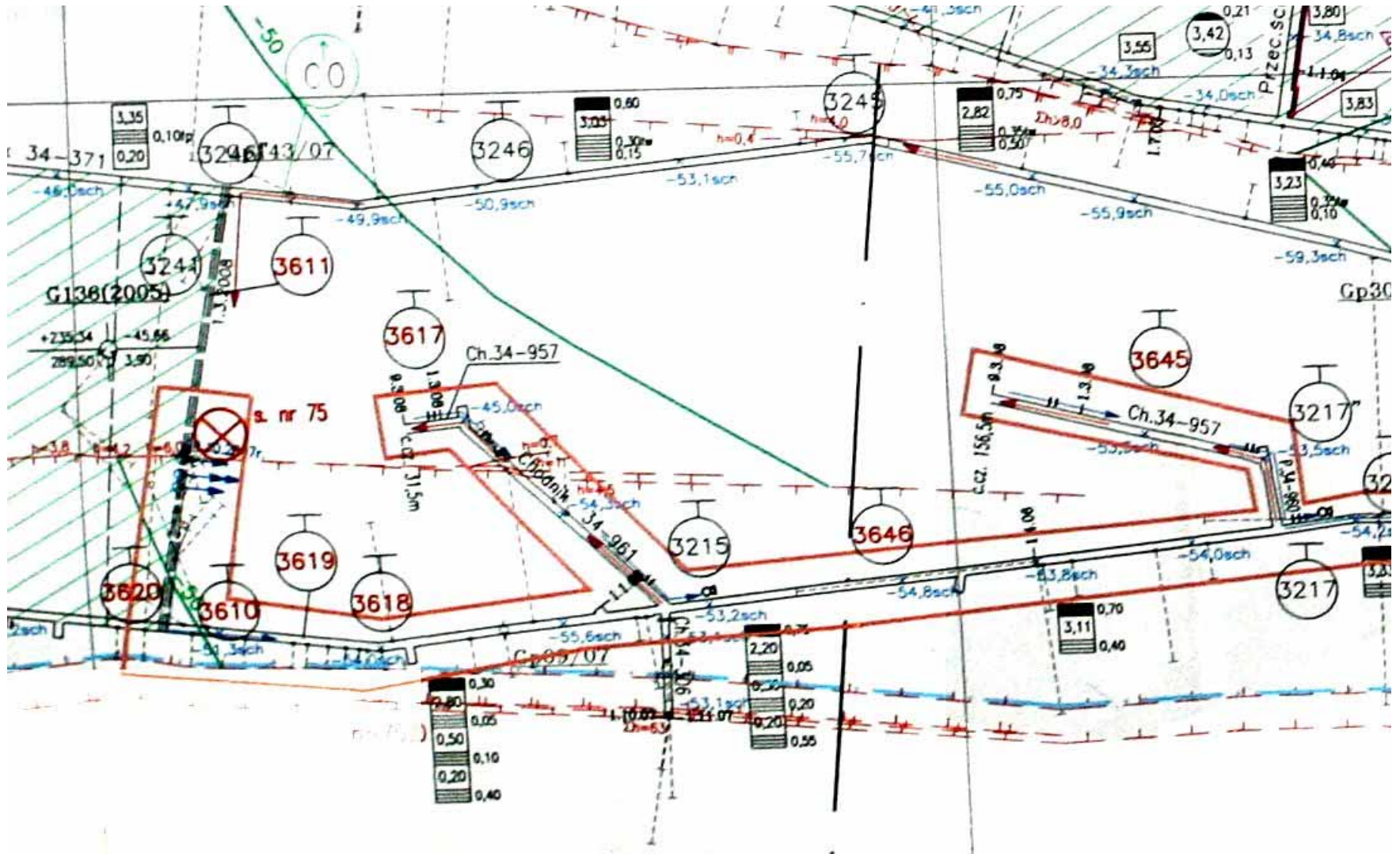
Moments of time	Assumed heat of reaction [kJ/kg of coal]	Content of CO ₂ in the inflow stream supplied to area in fire[%]	Content of CO in the inflow stream supplied to area in fire [%]	Content of CO ₂ in the outflow stream [%]	Content of CO in the outflow stream [%]	Delivery [m ³ /min]	Stream of coal combusted to CO ₂ [kg/s]	Stream of coal combusted to CO [kg/s]	Overall stream of combusted coal [kg/s]	Power of fire [MW]
09-05-04 2:00	33000	0,2	0	2,54	0,69	1500	0,316	0,085	0,401	13,23
09-05-04 12:00	33000	0,2	0	2,15	0,39	1500	0,263	0,048	0,311	10,27
09-05-05 0:00	33000	0,2	0	2,82	0,53	1500	0,354	0,065	0,419	13,83
09-05-05 12:00	33000	0,2	0	3,25	0,98	1250	0,343	0,100	0,444	14,64
09-05-06 0:00	33000	0,2	0	2,98	0,95	1250	0,313	0,097	0,410	13,53
09-05-06 12:00	33000	0,2	0	2,01	0,43	1250	0,204	0,044	0,248	8,18
09-05-07 0:00	33000	0,2	0	3,22	0,41	1250	0,340	0,042	0,382	12,60
09-05-07 9:00	33000	0,2	0	5,13	0,4	1200	0,533	0,039	0,572	18,88

Power of fire as a function of time



During a fire burning in every minute underwent approximately 24 kg of carbon.

Section of the seam map for the endangered region of coal extraction



Samples of air were taken from both the inflow and outflow airstreams, supplied to and drained from the endangered area, both during the rescue action and after its completion. At the same time, coal samples from the 118 bed were taken after completion of the rescue action in order to analyze them during roasting (pyrolysis) as described in Section 3.

After collection of information from laboratory examinations and from on-site measurements in the colliery it was possible to calculate variation of the self-heated coal weight as a function of its temperature.

Distribution of weight and temperature values for the self-heated coal was roughly determined in the following way:

- 100** kg of coal at temperature ca. 710°C,
- 22 000** kg of coal at temperature of 110°C,
in accordance to the accurate analysis of samples that were taken on 10th March 2008, as well as
- 22 000** kg of coal at temperature of 110°C,
in accordance to the accurate analysis of samples that were taken on 12th March 2008.

Example results from the mine Janina

Date and time of sampling	Air delivery at the measuring station [m ³ /min]	Content of gases – concentration values											
		O ₂ oxygen	CO ₂ carbon dioxide	CO carbon oxide	CH ₄ methane	H ₂ hydrogen	C _x H _y non-saturated in total	C _n H _{2n+2} saturated in total	N ₂ nitrogen	C ₂ H ₂ acetylene	C ₂ H ₄ ethylene	C ₃ H ₆ propylene	C ₄ H ₈ butene
		[%]	[%]	[ppm]	[%]	[ppm]	[ppm]	[ppm]	[%]	[ppm]	[ppm]	[ppm]	[ppm]
08-03-10 17:00	550	20.10	0.26	260	0.0059	373.0	7.923	1.2	78.64	0.146	5.059	2.118	0.6
08-03-12 17:00	150	20.18	0.24	13	0.0005	0.0	0.623	0.2	78.65	0.016	0.253	0.154	0.2

Underground measurement station - chromatographic analyzers



Example results from the mine Staszic

	O ₂ [%]	CO ₂ [%]	CO [%]	CH ₄ [%]	H ₂ [%]	C ₂ H ₄ [%]	C ₂ H ₆ [%]
2009-05-04 02:00	16,55	2,54	0,69	1,80	0,63	0,04	0,03
2009-05-04 12:00	17,33	2,15	0,39	1,66	0,57	0,04	0,02
2009-05-05 00:00	16,25	2,82	0,53	2,00	0,54	0,05	0,03
2009-05-05 12:00	15,50	3,25	0,98	1,81	0,89	0,02	0,03
2009-05-06 00:00	16,00	2,98	0,95	1,52	0,67	0,01	0,02
2009-05-06 12:00	17,50	2,01	0,4300	0,89	0,35	0,01	0,01
2009-05-07 00:00	16,21	3,22	0,4100	1,50	0,41	0,02	0,02
2009-05-07 09:00	14,20	5,09	0,4000	1,60	0,36	0,01	0,02

The process associated with analysis and assessment of the fire hazard degree on the basis of accurate analyzes must take account for effect of gaseous compounds that are generated by technological processes normally involved in coal extraction of underground collieries.

These processes include blasting operations and use of machinery with Diesel engines.

Content of gases that are essential for all the performed analyzes affects the dynamic image of gases within the monitored colliery region, endangered by the hazard of endogenous fires. These interferences must be considered during analyzes and assessments .

Influence of technological operations onto composition of coal-mine air

Sampling location	Content of gases – concentration values							Graham coefficient	C _x H _y non- saturated in total	C _n H _{2n+2} saturated in total
	H ₂ hydrogen	C ₂ H ₂ acetylene	C ₂ H ₄ ethylene	C ₃ H ₆ propylene	C ₂ H ₆ ethane	C ₃ H ₈ propane	N ₂ nitrogen			
	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[%]			
Bering the exhaust system of the Diesel machine No 1	21	0.724	10.2	2.3	1.5	0.2	79.79	127	15.22	3.0
Bering the exhaust system of the Diesel machine No 2	50	0,671	9,9	2,4	0,3	0,1	79,82	156	15,37	1,8
Explosive (Barbaryt), at a coal and stone face	0	0.150	0.681	0.480	0.6	0.1	79.65	13	1.31	0.7
Explosive (Barbaryt), at a coal and stone face	0	0.504	3.927	0.831	1.4	0.3	79.96	40	5.26	1.7
Explosive (Dynamite), at a stone face	0	0.050	0.008	0.006	0.0	0.0	79.45	5	0.06	0.0
Explosive (Dynamite), at a stone face	0	0.053	0.262	0.059	0.0	0.0	79.52	9	0.37	0.0

Conclusions

1. Examination of coal under laboratory conditions with preprogrammed temperature variations makes it possible to record images of gaseous atmosphere around heated /roasted coal.
2. The mixture of gases that flows around the examined coal samples must be modified in the appropriate manner to make its composition really similar to actual on-site conditions.
3. Similarities of thermodynamic properties and chemical composition as well as mathematical analysis of the volumetric stream of gases that are essential for both the reference (laboratory) roasting and actual on-site self-heating of coal make it possible to determine degree of possible fire hazards, i.e. approximated weight and maximum temperature of the self-heated coal.
4. Current practice of regular and accurate chromatographic analyzes of air within the endangered region of collieries enables determination of directions for potential fire hazards, which is the crucial factor for both prophylactic measures and for rescue operations.
5. Sampling of gases for accurate analyzes must be carried out with consideration of other technological processes that are in place in underground excavations as these processes substantially affect results of the analyzes.

THANK YOU FOR ATTENTION



Centralna Stacja Ratownictwa Górniczego S.A.

41-902 Bytom, ul. Chorzowska 25

POLAND

Tel.: +4832 282-25-25

Fax: +4832 282-26-81

e-mail: info@csrg.bytom.pl

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