Substantiation into Mass and Heat Balance for Underground Coal Gasification in Faulting Zones

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Abstract

In this article, the mass and heat balance calculations of underground coal gasification process for thin coal seams in faulting zones of Lvivskyi coal basin are defined. The purpose of the research is to establish regularities of heat and mass balance changes in faulting zones influence due to usage air and oxygen-enriched blast. A comprehensive methodology that included analytical calculations is implemented in the work. The output parameters of coal gasification products for the Lvivvyhillia coal mines are detailed. The heat balance is performed on the basis of the mass balance of underground coal gasification analytical results and is described in detail. Interpretations based on the conducted research and investigation are also presented. Conclusions regarding the implementation of the offered method are made on the basis of undertaken investigations. According to conducted research the technology of underground coal gasification can be carry out in the faulting zone of stable geodynamic and tectonic activity. The obtained results with sufficient accuracy in practical application will allow consume coal reserves in the faulting zones using environmentally friendly conversion technology to obtain power and chemical generator gas, chemicals and heat.

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Introduction

The analysis of coal deposits development under modern conditions shows the necessity of new solutions for a line of problems to provide safety of mines exploitation, complex development of mineral resources and protection of the environment [1]. There are two types of underground coal mining: conventional and alternative. Underground coal gasification is one of the modern methods by which coal is converted in-situ to a valuable syngas, which can be used for the production of energy or chemicals [2, 3]. The first research and practical work on underground coal gasification began in 1933. There have been a number of experimental, laboratory and industrial studies in the field of the underground gasification process during the 80-year period [4]. The main tasks of these researches were determination of the capacity, cost-effectiveness and study the chemistry of the gasification process. The best qualitative and quantitative indicators of the coal seams were selected for research. So, only coal seams ranging from 2.5 to 8 m were studied by the governmental, industrial and private programs UCG in the United States from 1971 to 1988. Much later in Australia from 1997 to 2003 a commercial project Chinchilla was implemented, where the lignite seams with a thickness of 10 m were exposed in gasification [5, 6].

Despite the sufficient thickness of coal seams, great attention was paid to consistency of geological criteria, especially to the tectonic structure of the seams. Because, as we know from the experimental stations experience, the geological factor mainly affected the efficiency of the thermochemical reactions, flowing in the process of gasification. The coal seams were developed in different ways. So at the beginning of the technology development, the vertical grid was used, the so-called wells of gasification. Due to the great number of faulting at the Lysychansk station "Pidzemgas", coal seams were gasified with these wells.

In 1998, the European Union continued their investigations of the UCG technology. For the construction of underground coal gasification was selected the area near Teruel in Spain. During the experiment, a method of CRIP (Controlled Retraction Injection Point) was used, the so-called method of controlled feed point of the injected blast. Since 1984, great attention to the UCG development was paid in the China Republic. The center of the UCG investigation in Chinese University of mining and technology (Beijing) conducts research on underground and surface gasification. It has developed a theoretical basis for research and conducted a number of industrial experiments and developed the technological scheme of the two-stage gasification [7, 8].

Tab. 1. Classification of geological faults in the SC "Lvivvuhillia" mines
Tab. 1. Klasyfikacja uskoków geologicznych w kopalni SC "Lvivvuhillia"

Type	Stratigraphic throw, m	Amount	The average length of stretch, m
5	< 1	~ 2100	~ 90
4 – 5	< 1 – 5	~ 450	~ 260
4	< 5 – 10	~ 200	~ 750
3	> 10	~ 30	~ 1000

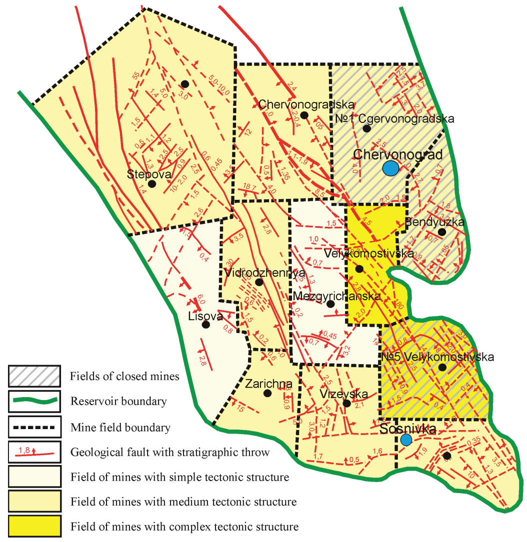


Fig. 1. The tectonic map of SC "Lvivvuhillia" mines
Rys. 1. Mapa tektoniki kopalni SC "Lvivvuhillia" mines

The Carbon Energy Company is the owner of the coal basin in Queensland. This company participated in the first test of the UCG in Rocky Hill (USA). Carbon energy, like most of the modern companies, has used the technology of directional drilling in which two wells were connected near the ignition wells [9].

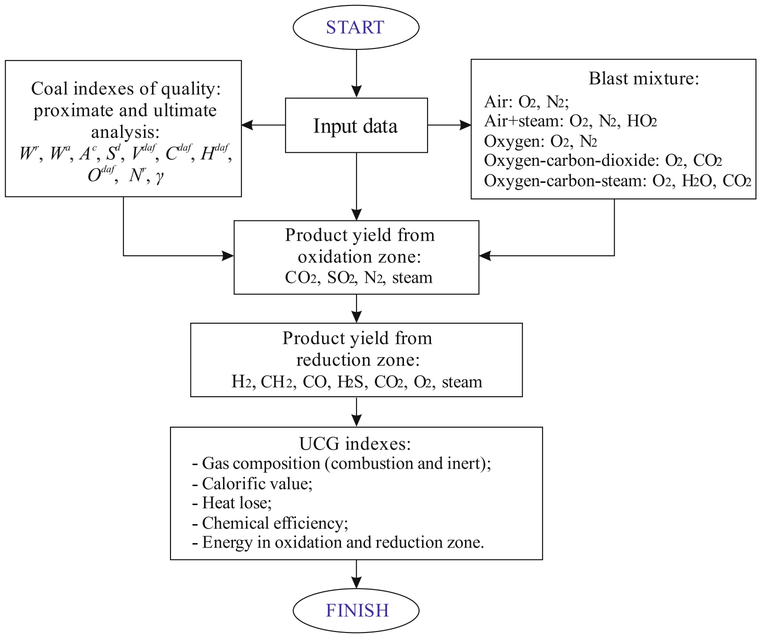
The above progressive schemes and methods that were successfully tested in underground coal mines, had a successful conclusion. The problem is that the development of these technological schemes were completely focused on the sustained occurrence of the coal seams, without faulting, in other words almost perfect conditions of occurrence, because as faulting coal seams were not taken into account. Nowadays there is a need in reviewing the possibility of developing seams using the well method of underground coal gasification, because of complex geological conditions and because of other ways of developing are economically feasible, and require major capital expenses and the use of miners' hard work.

In the case of disjunctive fault in the plane that is backlined with drilling wells of the coal seam, it is possible to use only the first technological scheme, where dense grid of wells is drilled. At the same time, the costs on drilling wells may not recoup the cost of the produced raw gas, if the coal seam lies at a considerable depth. The second and the third methods may be used only with adjustments in technological schemes and substantiation of gasifier rational parameters with the development of new technological solutions and approaches.

An important aspect of ensuring technological process of gasification is its adaptation to the specific geological conditions of the coal seam occurrence [10]. Therefore, the investigation of the potential areas for the UCG is essential in order to establish the parameters of the mass and heat balance and environmental application of this technology.

The problem of gasification process conducting under increased rocks fracturing conditions is practically problem, due to the significant influence of fracturing on the heat and mass balance in the underground gasification. Conductive as well as convection heat transferring processes occurred in terms of major fracturing. This leads to the loss of blasting interfusion and exhaust gas. Shorting of the air flow is also possible in the gasification channel bypass, where the coal gasification process occurred.

Except rock pressure, georeactor system thermal treating in underground gasification affect fracturing formation in the footwall and seam roof. Rocks of roof are under the influence of heat-treat taking, as a result



Tab. 2. Ultimate and proximate analysis of coal
Tab. 2. Analiza elementarna i techniczna węgla

W^r, %	W^a, %	A^c, %	S^d, %	V^{daf}, %	C^{daf}, %	H^{daf}, %	O^{daf}, %	N^r, %	Q^r, MJ/kg	γ, g/cm^3
1.8	2.1	37.2	1.3	39.0	80.8	6.2	6.9	4.8	24.7	1.45

changes in their structure and elemental composition occurred [11, 12, 13]. One of the main tasks of underground gasification is to ensure well integrity, combustion face from the roof collapse and create the best possible conditions for all physical-chemical reactions occurrence.

Tectonics of the Lvivskyi coal basin

The Lvivskyi coal basin occupies an important place in providing energy to Western regions of Ukraine. It has considerable stocks of bituminous coal with total amount of balance reserves – 196 million tonnes [14].

The geology of Lvivskyi coal basin, which is located in the South-Western part of the Volynsko-Podolska plate, in the zone of the East European platform part immersion near the Poland border, is characterized with shallow asymmetrical sags [15] The coal basin is bordered with main yielding of the Carpathian geosyncline in the South-West and is characterized by specific features of the geological structure, associated with its formation during the geological development, namely the minor faults expansion with the weak zones in countries [16].

The results of geophysical works indicate on a complex structure of the basin, which includes a widely developed disjunctive tectonics and fracturing. Most of the faultings belong to the 4th and 5th grades, but nevertheless there are often ones with the dip slip amplitude from 100 to 1000 m, which belong to the 3rd and 4th grades [17].

According to the structural features in the basin there are units with coal-bearing deposits: Volynska monocline with step fold, Zabuzka monocline, Sokalska poor brachysyncline, Mizhrychanska, Tyahlivska and Karivska synclinal folds [18].

Tectonics of the Lvivskyi basin is affected by the higher grades faultings. The main of which are Volodymyr-Volynskyi fault, Zabuzkyi, Volynskyi and Chervonoselsyi normal faults, Sashkivska, Belz-Mitiatinska, Butyn-Hlivchanska and Nesterovska thrust fault areas.

According to the structure plan, Chervonohrad geological and industrial area contains Zabuzka monocline, Mizhrychanska and Sokalska synclinal folds. This area is separated from Novovolynskyi area with relatively deep Jurassic rock strata erosion. Zabuzka monocline is located in the entral part of Lvivskyi basin. Besides plicative tectonics within this basin, disjunctive faults are also widely developed. The largest of them are Zabuzkyi, Krasnoselskyi and Cebrivskyi normal faults and Dibrovskyi and Zhuzhelianskyi thrust faults [15, 16].

Due to the geological exploration, analysis of geological materials and opening of mine fields using main and auxiliary workings, the tectonics of the Lvivskyi coal basin is associated with disjunctive locations of the deep horizons. It is obvious that these deep locations represent parallel-step systems which were formed as a result of large gaps division, which thickness is reduced in the upper horizons. The individual structural elements are constantly formed at different

Tab. 3. Air injected blast composition
Tab. 3. Kompozycja podawanego powietrza

Mixture composition	Flowing condition				
	Mass content %	Density, kg/m^3	Rate of blowing, kg/kg of coal	Rate of blowing, nm^3/kg of coal	Volume ration. %
O_2	21	1.42904	1.57	1.1	18.9
N_2	79	1.2505	5.91	4.73	81.1
CO_2	0	1.9768	0	0	0
H_2O	0	0.8041	0	0	0
Total amount	100	1.2879	7.48	5.83	100

Tab. 4. Mass balance of oxidation zone (air blast)
Tab. 4. Bilans masy w strefie utleniania (podmuch powietrza)

Materials for oxidation zone	Combustion gas yield from oxidation zone						
Coal: 100 kg; Air: 748 kg; Total amount: 848 kg	Blast composition	Molecular mass	Kilomole	kg	m^3	%	Reaction energy
	CO_2	44	4.0958	180.22	91.17	14.87	1617.80
	H_2O	18	1.9850	35.73	44.43	7.25	456.20
	SO_2	64	0.0247	1.58	0.54	0.09	7.30
	N_2	28	21.2959	596.29	476.84	77.79	-
Blast amount	-	-	27.4014	813.82	612.98	100.00	2081.30
Ash	-	-	-	37.37	-	-	-
Total amount	-	-	27.4014	851.19	612.98	100.00	2081.30

Tab. 5. Mass balance of reduction zone (air blast)
Tab. 5. Bilans masy w strefie redukcji (podmuch powietrza)

Materials for reduction zone	Combustion gas yield from reduction zone						
Combustion products of oxidation zone: 813.82 kg; Coal: 148.46 kg; Total amount: 962.28 kg	Blast composition	Molecular mass	Kilomole	kg	m^3	%	Reaction energy
	H_2	2	1.6803	3.36	37.39	4.99	70.20
	CH_4	16	1.595	25.52	35.60	4.75	327.00
	CO	28	6.9013	193.24	154.59	20.65	-897.20
	N_2	28	21.2959	596.29	476.84	63.68	-
	H_2S	34	0.0647	2.20	1.43	0.19	-1.40
	CO_2	44	1.6803	73.93	37.40	4.99	-430.00
	O_2	32	0.2470	7.90	5.53	0.74	-
Blast amount	-	-	33.4600	902.44	748.78	100	-
Ash	-	-	-	55.48	-	-	-
Total amount	-	-	-	957.92	748.78	100	-931.4

time and in different areas with a varying direction and pressure intensity.

The forces that accompanied the change in the structure of the rock massif can be judged by the type of faulting [19, 20]. Therefore, in gaps fault extensible effort is dominated, while incondensable seam is often found on crack displacement [21]. In addition, there are areas with open cavities, which could be channels for migration of water and gas in normal fault displacement. Normal faults unlike strike slip faults, which are usually developed in the form of a crack, often form a number of geological faults system [22, 23].

Nearly 3.000 of geological faults were found during mining works in SC "Lvivvuhilla" and SC "Volynvuhillya". Their classification is given in Tab. 1. 85% of minor faults have plane shifts 20 to 60º in the Lvivskyi coal basin geostructure [24]. In addition, the minor fault with displacement amplitude up to 3 m and with average length 260 m makes up 75% of all geological anomalies [16].

The intensity of the geological faults differs substantially on the separate areas. So, within the SC "Lvivvuhillia" mines the tectonic faults are found more frequently than in SC "Volynvuhillia" primarily due to the geographical location, because the South-Western part of the basin is located closer to the Carpathians. The Northern part of the basin area is structurally more sustainable [25].

Most SC "Lvivvuhillia" mines have a simple or complex tectonic structure. Mines No. 5 "Velykomostivska" and No. 1 "Velykomostivska" have complex tectonic structure. The most simple forms of coal seams occurrence are in areas No. 3 "Mezhyrichanska" and No. 6 "Lisova" mines. The tectonic map of the main Chervonograd mining area geological faults is based on the exploration and development work on SC "Lvivvuhillia" mines. The tectonic map of the main Chervonograd mining area is shown in Figure 1.

Tectonic faults of normal and thrust nature, including faults without a rupture of seam entirety are identified on separate seams in the fields of active and closed mines from 90 ("Mezhyrichanska" mine) to 440 ("Velykomostivska" mine). Each 100 – 200 m geological faults are met during mining operations at "Velykomostivska" mine. They differ in amplitude, direction and extension length. From the analysis, it is established that amount of balance reserves in SC "Lvivvuhillia" makes up 65 million tons, including 35 million tonnes that are in faulting zones [26]. This makes up about 21% of balance reserves in SC "Lvivvuhillia", processing which would give the opportunity to provide the region with a combustible energy source for more than one decade.

The methods, technological implementations and the construction of gasifiers designed in the National Mining University [27, 28] allow us to manage the process of underground coal gasification by keeping the thermo-chemical balance of conversions and the physical processes of coal seam gasification after detail heat and mass balance consideration.

The modelling of the heat and mass balance process of underground gasification

The heat and mass balance (HMB) is calculated in order to determine the parameters of the underground coal gasification process. The basis for the heat and mass balance calculation is the laws of mass and energy.

The heat and mass balances are used to analyze the effectiveness of the underground gasification process. It is clear that actual production, the efficiency of energy, substances, fuel and other materials consumption are determined using calculations. Balances calculation is divided in two stages. Firstly, mass balance is calculated, and then based on this calculation, heat balance is calculated. The amount of the substances inflow into the gasification zone in the mass balance should be equal to the number of received major and minor substances.

Mass balance of underground coal gasification calculations are based on a mathematical model of the physical and chemical processes occurring at coal seam gasification, simulating two stages of thermo-chemical processes: oxidation and reduction. The gasification channel at length can be divided into two main areas, depending on the type of chemical reactions. In the first zone, where remained oxygen is contained in the gas stream, oxidation reactions are dominated. Accordingly, this area is called oxidation. Heterogeneous and homogeneous reactions in the oxidation zone due to the heat generating reactions, cause high temperature of gas when exit from it. In the second part of the combustion face, reduction reactions are occurred (endothermic reaction), is called reduction zone.

The mass balance consists of the combined chemical reactions' equations taking into account the parallel and side reactions. Determination of mass substances, is often done separately for solid, liquid and gaseous phases according to the equation:

$$M_s + M_l + M_g = M'_s + M'_l + M'_g \tag{1}$$

where:

M_s, M_l, Mg – masses of solid, liquid and gaseous substances that have to be reconverted (receipts);

M'_s, M'_l, M'_g – products masses obtained through chemical transformations, that is matter discharge.

The mass balance equations are consisted of reassessment per unit of end product mass, unit of raw material or unit of time. To compose mass balance it is

Tab. 6. Oxygen injected blast composition
Tab. 6. Skład strumienia dodawanego tlenu

Mixture composition	Flowing condition				
	Mass content %	Density, kg/m^3	Rate of blowing, kg/kg of coal	Rate of blowing, nm^3/kg of coal	Volume ration. %
O_2	42	1.42904	1.57	1.10	18.90
N_2	58	1.2505	2.17	4.73	81.10
CO_2	-	1.9768	-	-	-
H_2O	-	0.8041	-	-	-
Total amount	100	1.3254	3.74	5.83	100

Tab. 7. Mass balance of oxidation zone (oxygen blast)
Tab.7. Bilans masy w strefie utleniania (podmuch tlenu)

Materials for oxidation zone	Combustion gas yield from oxidation zone						
Coal: 100 kg; Air: 748 kg; Total amount: 848 kg	Blast composition	Molecular mass	Kilomole	kg	m^3	%	Reaction energy
	CO_2	44	4.0958	180.22	91.17	29.04	1617.80
	H_2O	18	1.9850	35.73	44.43	14.15	456.20
	SO_2	64	0.0247	1.58	0.54	0.17	7.30
	N_2	28	7.9424	222.39	177.84	56.64	-
Blast amount	-	-	14.0479	439.92	313.98	-	-
Ash	-	-	-	37.37	-	-	-
Total amount	-	-	-	477.29	-	-	2081.30

necessary to know the proximate and ultimate analysis of coal, some physical and physico-chemical properties of raw materials, wastes, main and by-product [29].

Proximate analysis is a broad analysis which determines the amount of moisture, volatile matter, fixed carbon and ash. This is the most fundamental of all coal analyses and is of great importance in the practical use of coal. Ultimate analysis of coal consists of the determination of carbon and hydrogen as gaseous products of its complete combustion, the determination of sulphur, oxygen, nitrogen and trace elements.

The heat and mass balance calculations of underground gasification is a quite challenging task, primarily due to the large number of variables. It could be concluded that it is necessary to adjust the HMB calculations when geological conditions are changing to ensure reliable results.

Special software that can quickly convert parameters for a given coal proximate and ultimate analysis indicators changing was used to model the mass balance calculation. Software "MTBalanse SPGU" is developed by the employees of Underground Mining Department at the National Mining University conservation [30]. It provides an algorithm for calculating the parameters of underground coal gasification process, related with thermochemical solid fuel conversion into a gaseous state with the introduction of proximate and ultimate analysis of coal (Table 2) and the percentage of blasting interfusions that will be inflow into the gasifier in the determined correspondence. A program algorithm is presented in figure 1.

The program for calculating mass and heat balance parameters of underground coal gasification processes also takes into consideration the following conditions:

- changes of anthropogenic situations in rock layers that contain in situ gasifier qualities taking into account mining and geological conditions including the rate of faulting and technological parameters of the gasification process;
- the peculiarity of the composition of air blast mixtures and their influence on coal seam gasification processes;
- the change of qualitative and quantitative indices of output gas with grades of coal seams and air blast mixture;
- the influence of gasification process ballast gases on the qualitative indices of an in-situ gasifier, etc.;

- the influence of geometrical parameters of oxidation and the reduction zone of gasifier reactions channeled on the balance of kinetic indices of chemical reactions and physical rates;
- the influence of coal seam gasification efficiency on heat balance;

Analysis, based on the obtained heat and mass balance calculations data, is carried out as to application of certain blasting interfusion types for effective underground gasification process management. The summarized calculation mass balance results in the form of tables, using the software "MTBalanse SPGU", are given in Tables 3–8.

In tab. 2. under coal seam gasification speed is understood the nonlinear datum line smoke jet advancing ahead of oxidation zone in relation to reduction one. As gasification process is unbalanced, it is necessary to conduct revers injected blast mode with the same time intervals to prevent the curvature of gasification channel. To make this, firstly, it is necessary to take the reading of the speed independently for air and oxygen injected blasts. Injected blast composition, supplied to the gasifier, has a direct impact on exhaust gas, discharged from the experimental gasifier. So, gas discharge from 1 kg of coal due to the oxygen injected blast amounts to 1.81 m3, and in case of an air injected blast is 3.01 m3. However, under oxygen injected blast within an hour of experiment the gas discharge is much higher. This is due to the more intensive thermochemical reactions progress in the gasification channel, under the increasing of oxygen percentage in air mixture.

Having made the calculations of the gasification linear speed for each type of injected blast, it can be concluded that the application of uniformly-integrated blast injection system has provided gasification speed – 0.09 m/hour.

Thus, complete gasification would be approximately 20 hours when the length of the coal seam is 1.8 m per hour and will depend on the degree of gasification process controllability. Compliance with these time frames will indicate the balance of the chemical reactions and physical speeds under the coal seam gasification.

The heat balance is performed on the basis of the mass balance of underground coal gasification analytical results. The main purpose of the heat balance calculation is determining obtained gas of underground gasification final temperatures, taking into account their volume composition, ultimate and proximate analysis of coal, blasting interfusion temperature and heat loss [31, 32]. It is offered to elaborate on the main components of the heat balance calculation for air and oxygen injected blasts, as far as it is not calculated with the help of the software product.

Underground gasification heat balance components are calculated from original and approve authors equations, based on conservation of energy theorem, at 1 kg of coal gasification:

$$Q_c^c + Q_p^c + Q_p^a = Q_p^g + Q_c^g + Q^1 + Q^2 + Q^3 + Q^4 + Q^5 \quad (2)$$

where:
Q_c^c – the chemical heat of 1 kg coal, MJ/kg.

$$Q_c^c = 339 \cdot C^r + 1030 \cdot H^r - 109\left(O^r - S^r\right) - 25 \cdot W^r \quad (3)$$

where:
C^Y, H^Y, O^Y, and W^Y are carbon, hydrogen, oxygen, sulfur contents and total moisture (as received, includes total moisture),
Q_P^c – the sensible heat of 1 kg coal, MJ/kg.

$$Q_p^c = 10^{-6}\left(T_c - 273\right)\overline{C_c} \quad (4)$$

where:
T_C – the initial temperature of coal that participates in the gasification process,
C_C – the average in the range of 273… the specific coal heat capacity, J/kg·K,
Q_P^a – the sensible heat of air for 1 kg coal gasification, MJ/kg.

$$Q_p^a = 10^{-6}\left(T_a - 273\right)V_a \cdot \overline{C_a} \quad (5)$$

where:
T_A – the initial air temperature involved in gasification, °K,
V_A – питомий specific injected blast volume supplied for 1 kg coal gasification, nm³/kg,
C_A – average volumetric air heat capacity in the temperature range of 273… , J/nm³ °K,
Q_P^g – the sensible gas heat generated by the 1 kg coal gasification, MJ/kg.

$$Q_p^g = \frac{285640 \cdot CO + 241800 \cdot H_2 + 805564 \cdot CH_4}{22.4} \quad (6)$$

where:
CO, H_2, CH_4, – volumetric percentage of combustible gas, %,
Q_c^g – the chemical gas heat generated by 1 kg coal gasification, MJ/kg.

$$Q_c^g = Q_p^g \cdot V_g \quad (7)$$

where:
V_g – exhaust gas volume obtained from 1 kg of coal,
Q^1 – ash and slag heating losses, formed during 1 kg coal gasification, MJ/kg.

$$Q^1 = 10^{-8} \cdot A^r \cdot \left(T_{ash} - 273\right) \cdot \overline{C_{ash}} \quad (8)$$

Tab. 8. Mass balance of reduction zone (oxygen blast)
Tab. 8. Bilans masy w strefie redukcji (podmuch tlenu)

Materials for reduction zone	Combustion gas yield from reduction zone						
	Blast composition	Molecular mass	Kilomole	kg	m^3	%	Reaction energy
Combustion products of oxidation zone: 813.82 kg; Coal: 148.46 kg; Total amount: 962.28 kg	H_2	2	1.6803	3.36	37.39	8.31	70.2
	CH_4	16	1.595	25.52	35.6	7.91	327
	CO	28	6.9013	193.24	154.59	34.37	-897.2
	N_2	28	7.9424	222.39	177.84	39.54	-
	H_2S	34	0.0647	2.2	1.43	0.32	-1.4
	CO_2	44	1.6803	73.93	37.4	8.32	-430
	O_2	32	0.247	7.9	5.53	1.23	-
Blast amount	-	-	20.11	528.54	449.78	-	-
Ash	-	-	-	55.48	-	-	-
Total amount	-	-	-	584.02	-	-	-931.4

Tab. 9. The output parameters of coal gasification products
Tab. 9. Parametry produktów końcowych procesu gazyfikacji

Type of injected blast	Output UCG gas, %							Chemical materials yield, kg/t of coal			
	H_2	CH_4	CO	N_2	H_2S	CO_2	O_2	Coal-tar	Benzol	Ammonia	Sulphur
Air O_2 – 21 % N_2 – 79 %	4.99	4.75	20.65	63.68	0.19	4.99	0.74	44.0	3.7	9.1	0.1
Oxygen O_2 – 42 % N_2 – 58 %	8.31	7.91	34.37	39.54	0.32	8.32	1.23	43.9	3.7	5.8	0.1

where:
A^r – the mass ash content percentage in 1 kg of coal (as received, as received),
T_{ash} – ash and slag temperature in the gasifier, °K,
$\overline{C_{ash}}$ – specific ash and slag heat, averaged in the temperature range of 273... , °K.
Q^2 – heat loss for water heating and evaporation, MJ/kg.

$$Q^2 = 2.5 \cdot 10^6 \cdot q_{H_2O} \quad (9)$$

where:
$2.5 \cdot 10^6$ – the amount of heat, necessary to 1 kg of water transformation, MJ/kg,
q_{H2O} – specific water inflow, kg of water/kg of coal.
Q^3 ,Q^4 – the heat loss for adjacent rocks heating due to the convectional and conductive heat exchange, MJ/kg.

$$Q^3 + Q^4 = \frac{\overline{q \cdot S_s}}{Q_i \cdot \tau} \quad (10)$$

where:
$\overline{q}$ – the average heat flow in 1 m2 of the surface rock walls channel by radiation and convection, J/m2,
S_n – the surface of the coal channel, m2,
τ – time for coal seam gasification to the coal channel width, s,
Q_i – the intensity of gasification, kg/s.
Q^5 – additional heat losses into the environment (unaccounted losses), made on the basis of practical data. If it is impossible to determine these losses, their value is determined by the difference between the amount of receipts and matter discharge.

The heat balance calculation was carried out for air and oxygen injected blast according to the above formula. The results of the coal gasification heat balance calculations are shown in the summarized Tab. 8.

Rational parameters and UCG process modes choice ensure the balance of physical and chemical reactions

Tab. 10. Physical characteristics of coal gasification
Tab. 10. Parametry fizyczne procesu gazyfikacji węgla

Type of injected blast	Injected blast discharge, m^3/hr	Gas discharge, m^3/kg of coal	UCG gas discharge, m^3/hr	Coal seam gasification speed, m/day	Chemical efficiency, %	Lower gas calorific value, MJ/m^3	Gas humidity, g/m^3	Coal gasification intensity, t/hr
Air O_2 – 21 % N_2 – 79 %	97.61	3.01	161.72	1.44	72.72	4.88	60	0.0361
Oxygen O_2 – 42 % N_2 – 58 %	58.57	1.81	191.92	2.88	93.88	8.12	120	0.0522

Tab. 11. The parameters of heat balance of coal gasification process
Tab.11. Parametry bilansu masy w procesie gazyfikacji

Index	Injected composition			
	air blast		oxygen blast	
	MJ/kg	%	MJ/kg	%
Chemical coal heat, Q_c^c	33.12	98.01	33.12	98.50
Sensible coal heat, Q_p^c	0.34	1.02	0.34	1.02
Sensible air heat, Q_p^a	0.33	0.98	0.16	0.48
Total:	33.80	100.00	33.63	100.00
Sensible gas heat, Q_p^g	4.88	14.44	8.12	24.16
Chemical gas heat, Q_c^g	14.69	43.46	14.71	43.73
Ash and slag heating losses, Q^1	0.30	0.89	0.30	0.90
Heat loss for water heating and evaporation, Q^2	3.99	11.81	2.00	5.93
Heat loss for adjacent rocks heating, Q^3, Q^4	3.60	10.65	1.46	4.34
Total amount of accounted losses:	27.46	81.26	26.59	79.06
Unaccounted losses, Q^5	6.33	18.74	7.04	20.94
Initial air temperature in gasifier, ºC	709.84	-	779.84	-
Temperature of gas discharge out of the gasifier, ºC	114.68	-	172.42	-

flowing, and, as a result, the efficiency of underground gasifier depends on the ways of the mass and heat balance change in specific geological conditions.

Conclusion

In consequence of conducted research was established that coal seam in faulting zones of Lvivskyi coal basin can be extracted using the environmentally friendly technology of underground coal gasification. Lower gas calorific value depends on the type of injected blast and makes 4.88 MJ/m^3, when injecting air and 8.12 MJ/m^3 using oxygen blast. The heat balance also indicates to gasification process stability in faulting zones.

The software for determining the mass balance of underground coal gasification process is an efficient and convenient mechanism for obtaining quantitative and qualitative indicators of the output parameters of coal gasification products prediction. This greatly simplifies the data processing and allows to quickly obtain end-results with a high degree of compliance.

Enterprises using UCG technology enjoy the automation of production processes. The final product of such processes does not become coal, rather it is an element for further conversion, such as, kilowatts of thermal, electric energy and chemical row materials. As compared to traditional mining, during UCG it is possible to reduce the miners' labour, and to use uneconomical and unconditional coal reserves.

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Bilans masy i ciepła w podziemnym zgazowaniu węgla w strefach uskoku

W artykule przedstawiono obliczenia bilansu masy i ciepła dla procesu podziemnego zgazowania węgla dla cienkich pokładów węgla w strefach uskokowych lwowskiego basenu węglowego. Celem badań jest określenie zmian w bilansie ciepła i masy w strefach uskoków. W pracy zastosowano kompleksową metodologię obejmującą obliczenia analityczne. Wyszczególniono parametry wyjściowe produktów zgazowania węgla w kopalni Lvivvyhillia. Bilans cieplny jest oparty na bilansie masy dla wyników analitycznych z podziemnego zgazowania węgla. Przedstawiono interpretacje oparte na prowadzonych badaniach i analizach. Wnioski dotyczące wdrożenia proponowanej metody wynikają z przeprowadzonych badań. Zgodnie z przeprowadzonymi badaniami technologię podziemnego zgazowania węgla można przeprowadzić w strefie uskoków o stabilnej aktywności geodynamicznej i tektonicznej. Uzyskane wyniki pozwalają na prognozowanie z dostateczną dokładnością wyników zastosowania zgazowania węgla w strefach uskoków dla pozyskania energii elektrycznej i gazu, chemikaliów i ciepła.

Słowa kluczowe: podziemne zgazowanie węgla, błędy, bilans ciepła i masy, gaz, reakcje chemiczne