Advanced Engineering Forum
ISSN: 2234-991X, Vol. 25, pp 118-127
doi:10.4028/www.scientific.net/AEF.25.118

Submitted: 2017-10-26
Accepted: 2017-11-03
Online: 2017-11-27

Underground Coal Gasification Efficiency in Areas of High Faulting Frequency

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Keywords: underground coal gasification, faulting, efficiency, coal seam, mine

Abstract. The purpose of this paper is substantiating of efficiency during application of borehole underground coal gasification technology based on target coal seam geology. Comprehensive methodology that included analytical calculation is implemented in the work. To determine the efficiency of coal seam gasification in faulting areas, an economic calculation method was developed. The obtained conditions of coal seam allow to provide rational order of mine workings. Conclusions regarding the implementation of the offered method are made on the basis of undertaken investigations. 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.

Introduction

Coal is the main fossil fuel used in power generation. Coal makes about 70 % of world reserves of energy resources [1]. The concentration of coal seams in difficult mining and geological conditions at a considerable depth requires a comprehensive review of development opportunities [2]. There is a need to develop an alternative technology of extraction based on scientific investigation, consistent with the modern development of science and technology, which is cost-effective and environmentally safe and, most importantly, belongs to Clean Coal Technology [3, 4]. Underground coal gasification (UCG) is such kind of technology.

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 [5]. An important aspect of ensuring technological process of gasification is its adaptation to the specific geological conditions of the coal seam occurrence [6-8].

The efficiency of the gasification in the faulting zone influence will depend on the of gasifier water-proofing degree in a considerable extent. The underground gasifier water-proofing may be provided by the developments of scientists of the National Mining University (9, 10), the essence of which is to use injection stowing and fractured roof rocks (11, 12).

Geology

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 [13]. 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 [14] 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 [15].

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.

Sedimentary deposits of Carboniferous, Jurassic, Cretaceous and Quaternary periods were found in boreholes on mine field “Velykomostivska”. Carboniferous deposits are represented by Namurian stage, the maximum revealed capacity of which reaches 134.5 m. Namurian deposits are represented with sandstone, claystone, siltstone, coal seams and sheds, and carbonaceous-argillaceous shale layers in lithology. The total number of coal seams and sheds on the mine field area in Namurian stage sediments is 11, but the only 4 layers reache working power – n_7^{Low} (Sokalskyi), n_7^{Top} (Zahidnobuhskyi), n_8 (Mezhyrichanskyi), and n_8^{Top} (Tonkyi).

Claystone is occurred in the coal seams roof which gradually goes into siltstone. Sandstone or siltstone of underclay type is occurred in the bottom of layer. In some areas of the mine field there is a lack of coal seams as a result of substitution of coal carbon-bearing or carbonaceous-argillaceous shales, inner fault wash or tectonic fault.

Mezhyrichanske mineral deposits and Velykomostivska mine, placed on it, are adapted to the south-east side of overall synclinal structure of the so-called Lviv basin in geologic and tectonic relationship. Zabuzkyi normal fault with amplitude of about 80 m is put down to the east from the deposit, approximately 2.5 km from the eastern border of the mine field. To the south-west of the deposit there is Kamiano-Buzkyi normal fault. Apophyses of these two normal faults as well as tectonic faults that are located on Zabuzke occurrence with amplitudes of displacement 20 – 80 m, are crossing through the mine field “Velykomostivska” and have a north-western stretch.

All the explosive tectonic faultings, which are located on the mine field, refer to small-amplitude (from 0.10 to 3 m) and usually are accompanied with zones of intense fracturing as coal seam and adjacent strata.

The faulting zones dimensions depend on the amplitude of the coal seam displacement, the angle of fault plane and range from 5 to 30 m. The fracturing on the north side as well as on the field of the entire mine is developed in the two systems, mutually perpendicular to each other. The main system parameters are: dip azimuth105 – 125°, with the angle < 80 – 85°.

At crossing small-amplitude faultings with excavations in the North side with the displacement amplitudes from a few centimeters up to 1.5 – 3 m, weak roof is observed, increased fracturing and roof fall sometimes up to 2 – 2.5 m in some places. Thus, the above description indicates that in tectonic relationship the mine field “Velykomostivska” has a complex structure.

Site Selection

To conduct the study the Northern part of the mine “Velykomostivska” SC “Lvivvyhillia” was selected on the seam n_7^{low} (Sokalskyi). Coal seam n_7^{low} is the lower working layer. The total reserves of n_7^{low} seam are mainly extracted. There was an insignificant amount of reserves on certain site of the Southern and Northern sides, and near the roadways of principal direction. A seam with simple structure is 1.00 – 1.45 m thickness. Lithologically the seam is represented with humus band in the upper side and sapropelic in the bottom one. Roof is claystone, bottom is siltstone. The seam occurrence depth ranges from 423 m in the Eastern part of the mine field to 482 m in the Western part.

According to the results of previous studies two abandoned coal seams sites with disjunctive geological fault without abandonment of the coal seam were selected for BUCG. Method of gasifier preparation is taken for shaftless technology, by drilling from the earth’s surface vertically inclined and horizontal wells. The horizontal part is held along the coal seam. Coal gasification is envisaged under the scheme with a direct coal heat-treated and periodic opposite change of injected gas flow. Coal seam ignition is charged binary through the injected gas well.

The north-western part of the abandoned mine field, due to complex geological conditions, was selected as the first mine section for in-seam working using the BUCG technology. Within it there is an explosive geological fault with coal seam abandonment (Fig. 1).

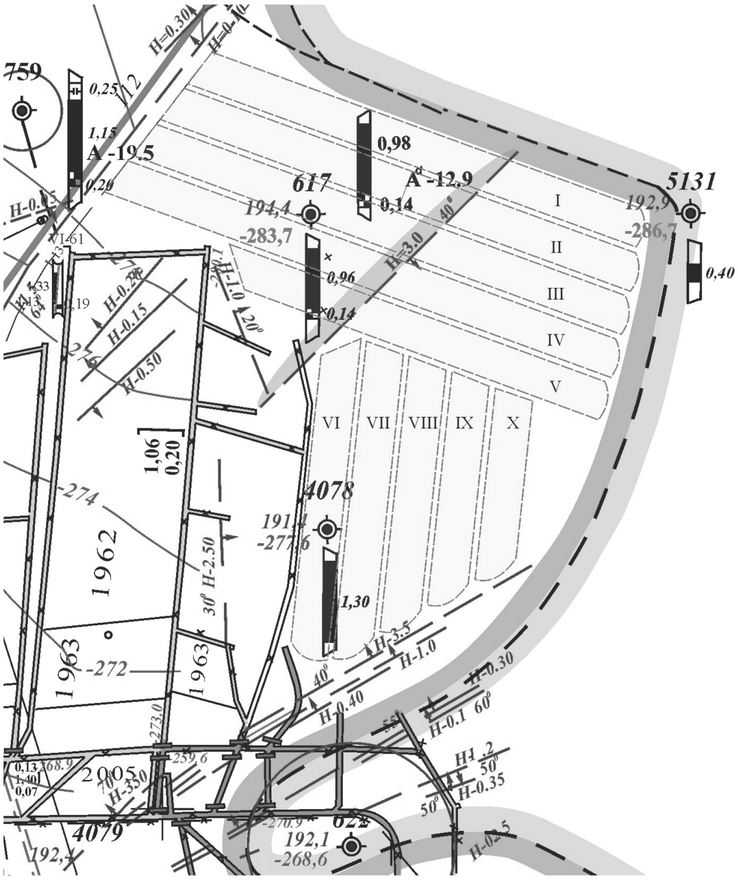

Fig. 1. The site No. 1 plan for the BUCG technology implementation

The average thickness of the seam in this area is 1.0 m. First well gasifiers drilling is driven from the terrene, where the coal seam completion is at 5 m distance from an existing geological fault amplitude 0 – 10 m, and from 112 exploration roadway located at a distance of 10 m. In view of faulting occurrence it was not possible to work out the north 20 longwall in mining operations, that is why the longwall has been abandoned. Gasifiers laying within longwall are impossible because of carrying out a large number of exploratory workings.

Wells drilling on the coal seam is firstly performed in the handing wall to the stress increased zone, and then there is deviation of the hole to the seam in foot wall, bypassing the appropriate stresses. The gasifier length in these conditions is determined with coal seam boarders and can be increased in case of confirmation of its thickness to the specification limit of high and aerodynamic capacity.

The gasification process takes place up the dip of a coal seam. The alternative of the shortest generators gasification is determined from an economic justification of their development advantages and described in the following section. After coal gasification in the foot wall of the gasifier it is essential to reignite the coal. To implement the combustion face formation it is proposed to use the ignition with binary charges method, developed by the Department of Underground Mining and the Department of Chemistry of the National Mining University [9]. This method allows to carry out the ignition though the injected blast well without much expenses.

As for the site No. 2 which is in the northern part of the mine field, mine-take working of which does not require complex surface cleaning and processing reequiping, as it is located near site No. 1. Schematic drawing of gasifiers planning for site No. 2 is shown in Figure 2. Within this area, on the mine field edge, the explosive faulting without formation integrity was revealed. Though, it is possible to accommodate four gasifiers on this site. The coal loss compared with site No. 1 is minor, however, at a certain stage of gasification, in connection with the geological fault crossing, the efficiency of gasification will decrease, as will be seen in the poor quality of gas output.

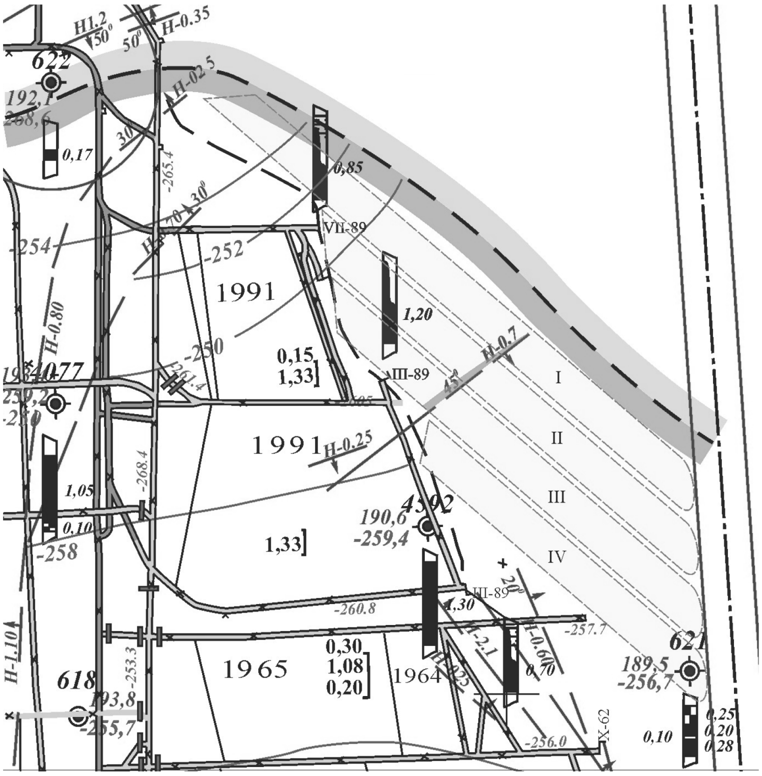

Fig. 2. The site No. 2 plan for the BUCG technology implementation

Unlike the site No. 1, gasifiers length at site No. 2 is determined with the mine field border. Between the gasifiers, wells and roadways coal pillars are left to prevent losses of blast and gas. A detailed geological and mining conditions study of coal seam occurrence, that is undertaken during mining, is essential for choosing an appropriate places for gasifiers laying.

Based on the analysis of the existing coal gasification experience at pilot and experimental plants, and also own experimental investigations, the above-described coal seam sites can be developed, implementing the proposed technology. In the future it is necessary to explore other coal seam sites very thoroughly, left after mining. Due to the ineffective and unnecessary traditional ways of underground mining at these sites, their extended criteria can be used to BUCG.

An Economic Assessment

One of the main reasons of raising interest in the underground gasification is an economics. The experience of the near past [16-18] shows that the problem-solving, related to the insufficient estimation of geological faults influence on the underground coal gasification process, can be rather expensive. Expenses include not only charges due to the wells configuration changes but also large financial losses as a result of the left coal reserves loss [19]. Accordingly, in this work an author tries to reduce losses, investigating the faultings influence on the underground coal gasification process taking into account exploitation wells stability in the stress increased zone.

As mentioned before, geological faults occurrence in coal seams is one of constraints at the underground gasification [1, 4, 19]. Moreover, any faulting crossing is connected with considerable additional processing complexity and economic expenditures. Before drilling, it is necessary to carry out the predictive assessment of underground coal gasification process economical efficiency for prioritizing all required ways in order to provide the gasifiers reliability with minimum capital and operating expenses [20, 21]. Except this, process engineering solution on geological faults crossing depends on certain terms and must be assessed individually, due to the difficulty of technological mining operations in faulting zones influence and complexity of coal seam sites crossing with physical and mechanical faulting properties.

The detailed analysis of commercial breakdown is very important for making effective and reasonable decisions according to planning, building, exploitation and monitoring of the BUCG plant [22-24]. For today, there is no cross functional methodology of gasification process economical efficiency calculation yet, and the existent plants of underground gasification work according to their own economic estimations, comparing individual expenses and profits that are got from products marketing.

The economic assessment of required ways is given at the cost-efficiency factor calculation, as ratio of the got results toward losses, that cause them [25, 26]. Such coefficient can be got from the following formula:

$$E = \frac{P}{C}, \quad (1)$$

where P – is a total cost of products marketing, thsd. UAH.;
C – are total expenses on gasifier preparation and its gasification, thsd. UAH.

$$C = \frac{100}{K} \cdot C_1, \quad (2)$$

where K – is a percentage component of drilling cost to the expenses on handling operations and providing gas output (according to the data of underground gasification stations work K = 30%);
C – are expenses on gasifier preparation, thsd. UAH.

$$C_1 = \left(\left(h_{c.d} + l_g\right) \cdot N_c + l_{g.c}\right) \cdot C_c, \quad (3)$$

where $h_{c.d}$ – is a coal depth, m;
l_g – is gasifier length, m;
N_c – is an amount of mining wells for gasifier release, pc.;
$l_{g.c}$ – is length of gasification channel of underground gasification, m;
C_c – are expenses on 1 m well drilling, thsd. UAH.

From Eq. (1) the total price of products marketing P can be found from the following formulas:

$$P = P_1 + P_2, \quad (4)$$

where P_1 – is a cost of got energy realization, thsd. UAH;
P_2 – is a cost of got chemical products realization, thsd. UAH.

$$P_1 = \Sigma V_{g.o} \cdot Q_{c.v} \cdot P_Q, \quad (5)$$

where $\Sigma V_{g.o}$ – is a total gas output from a gasifier, thsd. m^3;
$Q_{c.v}$ – is an average calorific value of gas, MJ/m^3;
P_Q – is a cost of 1 MJ energy, UAH.

$$P_Q = \frac{P_{n.g}}{Q_{c.v.n.g}}, \quad (6)$$

where $P_{n.g}$ – is a cost of natural gas, UAH/thsd. m^3;
$Q_{c.v.n.g}$ – is calorific value of natural gas, MJ/thsd. m^3.

$$P_2 = M_c \cdot \left(M_{c.p} \cdot P_{c.v} + \left(M_{c.p} \cdot P_{c.v}\right)_n\right), \quad (7)$$

where M_c – is mass of gasified coal, ton;
$M_{c.p}$ – is mass of chemical product release, ton;
$P_{c.v}$ – is a commercial value of 1 chemical product tonne realization, thsd. UAH.

$$M_c = M_{c.g} - M_{c.l}, \quad (8)$$

where $M_{c.g}$ – is a mass of coal in a gasifier, ton;
$M_{c.l}$ – is a mass of coal loss, ton.

$$M_{c.g} = S_{g.a} \cdot \gamma \cdot m\,, \qquad (9)$$

where $S_{g.a}$ – is gasifier area, m^2;
γ – s coal density, ton/m^2;
m – is coal seam thickness, m.

$$M_{c.l} = M_{l.g.c} + M_{l.r} + M_{f.c}\,, \qquad (10)$$

where $M_{l.g.c}$ – are coal losses on gasification channel_formation, ton;
$M_{l.r}$ – are coal losses on reignition of the gasification channel, ton (at faulting crossing with coal seam abandonment),
$M_{f.c}$ – are coal losses on faulting crossing without coal abandonment, ton.

Performed accounting results, that are done on the basis of gasifier geometrical parameters, and undertaken studies (Table. 1) for each of the gasifiers of two sites, are given in Tables 2-4.

Table 1. Geometrical parameters of gasifiers

No of gasifier	Length of gasifier, m	Area of gasifier, m^2	Mass of coal in gasifier, ton	Area of coal seam abandonment, m	Coal losses		
					in the zone of coal seam abandonment, ton	On gasification channel(-s) formation, ton	From gasifier, %
Area No. 1							
I	370	11 100	16 095	330	479	174	4.05
II	390	11 700	16 965	450	653	174	4.87
III	410	12 300	17 835	480	696	174	4.88
IV	425	12 750	18 488	530	769	174	5.10
V	310	9 300	13 485	480	696	174	6.45
VI	250	7 500	10 875	-	-	87	0.80
VII	245	7 350	10 658	-	-	87	0.82
VIII	210	6 300	9 135	-	-	87	0.95
IX	180	5 400	7 830	-	-	87	1.11
X	150	4 500	6 525	-	-	87	1.33
Area No. 2							
I	475	14 250	20 663	-	-	196	0.95
II	375	11 250	16 313	-	-	218	1.33
III	370	11 100	16 095	-	-	261	1.62
IV	285	8 550	12 398	-	-	87	0.70
Total	4 445	133 350	193 358	2 270	3 292	2 066	2.77

Table 2. Accounting results of got energy realization

Area		1	2	Total
Gasified coal, ton		123 294	64 706	188 000
Total gas output from a gasifier, thsd. m^3		271 246	142 354	413 599
Gas output, thsd.m^3	CH_4	29 837	15 659	45 496
	CO	66 455	34 877	101 332
	H_2	17 631	9 253	26 884
	Inert gas	157 323	82 565	239 888
An average calorific value, MJ/m^3			7.75	
Cost of 1 MJ energy, UAH			0,16	
Cost of got energy realization, thsd. UAH		326 420	171 310	497 730

Table 3. Accounting results of got chemical products realization cost

Area			1	2	Total
Chemical products output, ton per 1 ton of coal	Resin	0.044	5 425	2 847	8 272
	Benzol	0.037	4 562	2 394	6 956
	Ammonia	0.099	12 206	6 406	18 612
	Sulfur	0.074	9 124	4 788	13 912
	Phenols	0.008	925	485	1 410
	Ammonium	0.014	1 726	906	2 632
Cost of chemical products thsd. UAH	1 ton of chemical product				
	Resin	2.7	14 647	7 687	22 334
	Benzol	7.9	36 039	18 914	54 952
	Ammonia	5.5	67 133	35 233	102 366
	Sulfur	3.4	31 021	16 280	47 301
	Phenols	50.0	46 235	24 265	70 500
	Ammonium	2.6	4 488	2 355	6 843
Cost of got chemical products realization, thsd. UAH			199 563	104 734	304 296
Total, thsd. UAH			525 983	276 044	802 026

Table 4. General efficiency

No of gasifier	Length of gasifier, m	Gasified coal, ton	Expenses for gasifier prepa-ration, thsd. UAH	Sales costs, thsd. UAH	General costs, thsd. UAH	Commercial efficiency
Area No. 1						
I	370	15 443	15 652	65 879	44 720	1.47
II	390	16 139	16 016	68 849	45 760	1.50
III	410	16 965	16 380	72 374	46 800	1.55
IV	425	17 545	16 653	74 849	47 580	1.57
V	310	12 615	14 560	53 817	41 600	1.29
VI	250	10 788	13 468	46 023	38 480	1.20
VII	245	10 571	13 377	45 095	38 220	1.18
VIII	210	9 048	12 740	38 600	36 400	1.06
IX	180	7 743	12 194	33 032	34 840	0.95
X	150	6 438	11 648	27 465	33 280	0.83
Total	2940	123 294	142 688	525 983	407 680	1.29
Area No. 2						
I	475	20 467	17 563	87 313	50 180	1.74
II	375	16 095	15 743	68 663	44 980	1.53
III	370	15 834	15 652	67 549	44 720	1.51
IV	285	12 311	14 105	52 518	40 300	1.30
Total	1 505	64 706	63 063	276 044	180 180	1.53
Summary	4 445	188 000	205 751	802 026	587 860	1.36

From the economic point of view, in-seam working within the site No. 2 is more effective, as deviation of the hole_occurred within the coal seam and there is no need in its reignition. At faulting crossing with coal seam abandonment, coal loss makes up 6%, and at faulting crossing without coal seam abandonment a maximal value makes up 1.6%.

For the analysis of economic assessment, the cost-efficiency factor change diagram was built on horizontal part of underground gisifier length (Fig. 3).

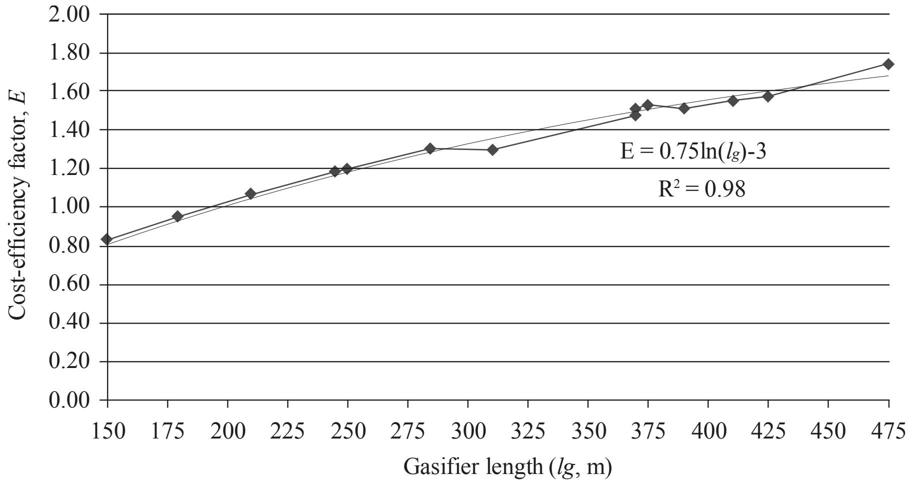

Fig. 3. The cost-efficiency factor changes diagram of underground gasifier length

According to the analysis of the obtained cost-efficiency factor, its value confirms the expediency of a suggested projects and process engineering solutions at massif faulting zones crossing in the Lvivskyi coal basin only for gasifiers with length that exceeds 200 m. In other case the expenses on gasifiers lead through and coal seam degassing will not cover the purchased commodity products expenses.

Conclusions

Applying innovative engineering developments has significant economic effect as well as ecological advantages of clean coal technologies application. Advanced technological decisions are worked out on the up-to-date science level, minimize negative influence on an environment. and promote the effectiveness of technological process, which allows to implement all borehole underground coal gasification benefits.

Underground coal gasification closed cycle gives an opportunity to solve the ecological problem of cuttings handling, fuel gas refinery and wastes recycling of utility companies. BUCG gas does not require additional preparation and is used as energy source to obtain thermal and electric energy at the underground gasification plant by means of reciprocating aggregates, steam-turbine or gas-turbine installations.

Economic assessment that is conducted on the basis of cost-efficiency factor calculation confirms application expediency of borehole underground coal gasification in faulting zones of massif with gasifiers length that exceeds 200 m on covering the purchased commodity products expenses.

Acknowledgements

This work was supported by the Ministry of Education and Science of Ukraine, grants No. 0116U008041 and No.0115U002293.

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