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ON THE MECHANISM OF FORMATION OF VOLUMETRIC EXPLOSIONS AND DETONATION OF HYDROCARBON GASES IN COAL MINES

The issues of self-ignition, volumetric explosion and detonation of hydrocarbon gas mixtures in coal mines. Sets forth method for detecting areas of hydrocarbon gas accumulations with high pressure (>100 kg/ cm^2), underlying coal seams. Made you- water about the causes of volumetric explosions. Preventive measures are proposed for preventing volumetric explosions in coal mines.

Key words: coal seams, processes of self-ignition of hydrocarbon-hydrogen gas mixtures, volumetric explosions, detonation

Introduction. The safety problem in methane-hazardous mines is very relevant. Every year at coal enterprises from gas explosions miners die, coal mining operations are stopped for a long time, and significant material damage is caused.

In connection with the mining of thermal coals at great depths, cases of volumetric gas explosions have become more frequent, resulting in the death of a large number of miners and destruction of mining equipment (Ukraine, Russia). Despite the fact that enterprises are taking serious measures for comprehensive degassing of mines, more advanced systems for preventing
explosions, volumetric explosions do not stop. Analysis of accidents at coal mines mines of Ukraine, carried out under the guidance of a corresponding member of the AGN Ukraine, Doctor of Geological Sciences E. Rudneva [1] shows that the main reasons are (from an analysis of 46 accidents):

1. Explosions with loss of life due to sudden entry into the workings large volumes of methane and heavy hydrocarbons (40 accidents), or death people from injuries and gas suffocation (6

accidents). This can only happen due to the instantaneous opening of areas with high gas pressure under coal seams during the development of seams (coal seams are drilled before development, there are volumes of gas in them with cannot be under high pressure). Moreover, these explosions were not initiated by a spark, and the gas mixture spontaneously ignited, and then volumetric explosions and detonation.

2. The presence of very complex and diverse tectonics - primary (classical) and secondary (gravity) over the entire area of the mine

a line through which gas with high pressures and temperatures can flow from great depths (>1.5÷3.0 km). 3. When hydrocarbon gases enter the mixture from great depths which contains methane and heavier hydrocarbons, which can lead to spontaneous ignition and explosion of the mixture if it instantly enters air production zone (at methane concentrations much lower than 5%). **Goals and objectives of scientific research.** The main objectives of the study are:

ÿ Checking the effectiveness of remote geophysical equipment complex for detecting gas accumulations located under coal seams and in geological faults, characterized by high pressure values (> 10 KGs/cm2) and located at depths of up to 3000 m.

ÿ Determination of gas migration paths from great depths or from sources located outside the boundaries of mine fields (mine named after A.F. Zasyadko - Ukraine, 2008; Erunakovskaya mine – VIII, – JSC OUK "Yuzhkuzbasugol", (2009); mines – Zarechnaya, Oktyabrskaya, Sibirskaya, Polysaevskaya (2011, Russia).

ÿ Search and delineation of gas sources with high pressure and temperature values located under coal seams and beyond border of mine fields; ÿ

Measurement of gas pressure and temperature values in geological faults and in areas of hydrocarbon gas accumulations, as well as the thickness of gas horizons located under coal seams, using remote field equipment “Search”.

ÿ Determination of the causes of volumetric gas explosions and proposals for preventing these explosions in mines producing energy valuable coals at great depths.

Research methods. The following research methods were used in the work. 1. To quickly accomplish the assigned tasks, remote cosmogeological exploration methods and field resonance test equipment of the remote geophysical subsoil sensing complex “Poisk” (developed by SNUYAEiP) were used. The equipment allows you to remotely detect sources of gas accumulations at depths of up to 5 kilometers, delineate them and determine the direction of gas migration, the number of gas horizons, gas pressure in each horizon, and also identify the types of rocks of gas-permeable reservoirs.

The basis for the use of the Poisk equipment for these purposes was the successful work on detecting gas anomalies with high gas pressure in them, located under the ore bodies of a uranium mine (Novokonstantinovskaya mine, Ukraine), study of occurrence features gas anomalies in shale rocks (Texas, USA) and remote discovery of industrial oil and gas fields (Australia, Indonesia, USA, Russia, Ukraine, Mongolia). The work was carried out by specialists

from SNUYAEiP together with commercial structures that were involved in providing the work, as well as the head institute of the Ministry of Fuel and Energy of Ukraine (UkrNIPIpromtekhnologii and Research Center IGN of the National Academy of Sciences of Ukraine (NASU). The success of these

works is evidenced by the conclusion of the Institute of Civil Engineering of the National Academy of Sciences of Ukraine on feasibility of using remote complex equipment "Search" for performing prospecting and geological work[9]. 2. The

use of exploratory drilling of wells to identify gas accumulations, accurately determine the depths of gas horizons, pressures and gas temperatures in them. These works were carried out specialists of mining and geological structures of mines or specialized companies involved by Customers in conducting prospecting drilling 3.

Electrical prospecting and other traditional geophysical methods for searching for gas anomalies or analysis of available geological materials on mines (carried out by SRC IGN NASU, Kiev) for confirmation (or comparison) of the results of remote detection of gas anomalies to start of exploratory drilling. 4.

Mathematical modeling of the processes of self-ignition, volumetric explosions and detonation of gas mixtures and calculations to establish boundary conditions for the self-ignition of these mixtures with various hydrocarbon gases under conditions close to real gas conditions conditions in coal mines. Carried out under the guidance of Doctor of Technical Sciences, Professor of SNUYAEiP V.A. Pukhliy [2-7].

During the period of this work, the mine field of a coal mine was examined named after Zasyadko (Ukraine) with field resonant test equipment of the complex "Search" by specialists from SNUYAEiP (Sevastopol) together with the commercial enterprise MGSP (Donetsk) and the Scientific Research Center IGN NASU, and also carried out research work at 5 coal mines of OJSC OCC "Yuzhkuz-bassugol" (Kemerovo region, Russia) – only by SNUYAEiP specialists [10].

Remote identification (recognition) of gas anomalies in in the bowels of the earth (up to depths of 5 km) using the equipment of the "Poisk" complex was carried out using the resonance phenomena of substances under the influence of radio frequency radiation on atoms of elements (NMR spectroscopy) included in a specific type of hydrocarbons (oil, gas) and oil and gas rocks. nasal collectors [8]. To send radio frequency

resonant radiation to great depths, microwave radiation generators with a rotating electromagnetic field were used. The frequency resonance spectra of atoms of reference chemical elements of reservoir rocks (Ni, V, C, P, Si, S, etc.) and information-energy spectra were modulated to the operating frequency of the microwave generator.

three samples of oil, methane and higher hydrocarbon gases (ethane, propane, butane).

Resonance spectra (NMR spectra) of metal atoms included in the composition of the identified substances and selected as reference elements were recorded on NMR installations with a frequency of 60 MHz and 250 MHz [11, 13], and their information energy spectra of substances were recorded on atomic absorption spectrophotometer (atomization of substances in a gas burner) with a sensitive wide-frequency attachment. Information

and energy spectra of identifying gases and rocks [14] were transferred to "working" magnetic carriers ("working matrices"), and the atomic spectra of metals to "test matrices" and were used for resonant excitation of these substances in the bowels of the earth (to depths 3 km). Resonant excitation of substances was carried out by exposure on them the signals of microwave generators modulated by the frequency of the resonant (atomic) NMR spectra or by frequency of information-energy spectra of the desired substance.

To study the elemental composition of reservoir rocks, we used neutron activation method for determining the concentration of metals and non-metals in them. Elementary composition of sample samples and amplitudes of their integral spectral characteristics (information-measuring spectra) were entered into the data bank of the Poisk stationary complex and were used as recognition signs of hydrocarbons and reservoir rocks (located at depths of up to 5000 m) when processing the results of field work [15]. To set up the equipment and confirm

the remote detection (identification) of types of hydrocarbons, before the start of field work, tests were carried out in laboratory conditions of stationary and portable equipment of the Poisk complex for selective registration of samples (samples) of gas and samples of types reservoir rocks from different distances (25 m and 50 m).

In field conditions, a modulated signal is sent from the high-frequency unit of the microwave generator using a narrowly directional antenna at a certain angle deep into the Earth for remote resonant perturbations of atoms of a reference element or the entire identifiable substance. In this case, over the area of the hydrocarbon field, a high-frequency electromagnetic field characteristic of a particular type hydrocarbons and rocks. This electromagnetic field is recorded by a sensitive receiver device tuned to the resonant frequency a specific atom of a reference element or the integral spectrum of a substance (type of rocks, hydrocarbon gas). This provided remote selective identification of a specific substance located at various depths. Based on the results of decoding satellite

photographs using radiation-chemical technologies [16], the boundaries of the contours of areas with hydrocarbon anomalies are determined in this photograph. Data

boundaries are clarified in the field using mobile equipment and GPS receivers, then plotted on a map of the search area. The
the delineation method is practically similar to existing aerospace remote sensing methods, however, the probability of practical identification of the type of hydrocarbons (hydrocarbon gases) using the equipment of the Poisk complex increases sharply (more reliable
95%).

Resonance test field equipment allows you to calculate the depth occurrence of gas horizons, their thickness and gas pressure in them.

Results of the work. When inspecting the mine field of a coal mine named after Zasyadko (Fig. 1) it was found that it is crossed from west to east 3 geological “channel” faults with increased gas pressure in them and one from north to south [17].

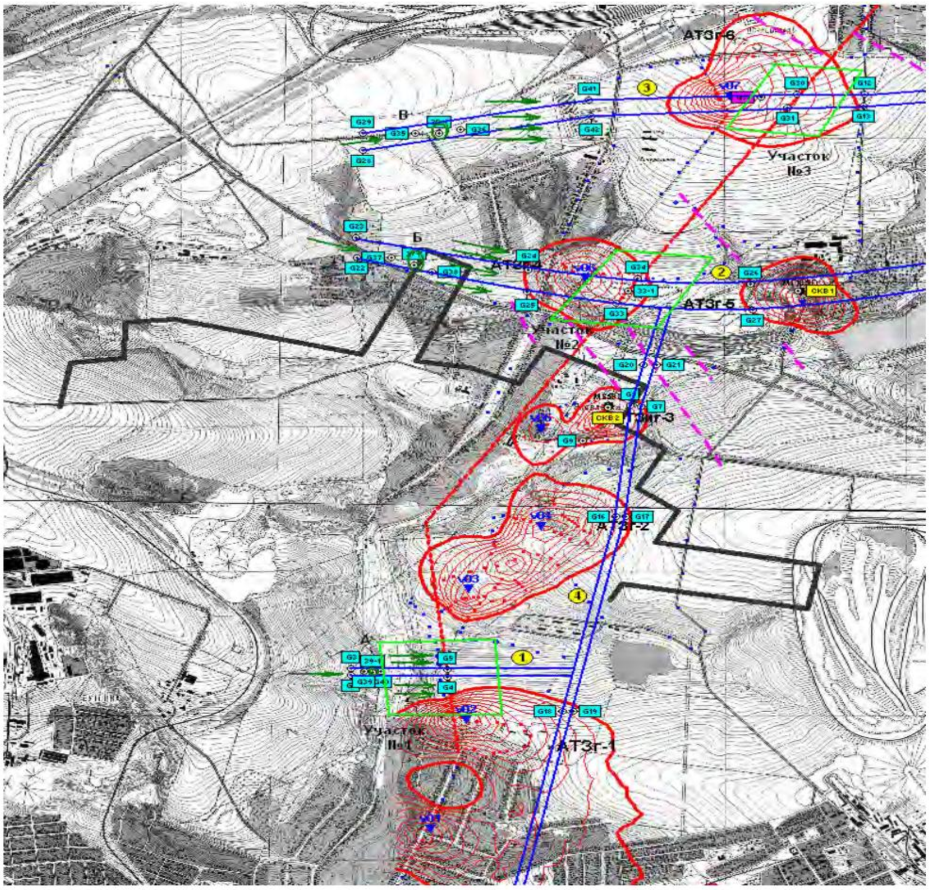

Fig.1. Contours of geoelectric anomalies of the ATZ and boundaries of gas-permeable "channels" on the topographic map of the mining allotment area of the coal mine named after A.F. Zasyadko [17].

Vertical gas-permeable sections (pillars) were located outside the mine field (1÷1.5 km before its border) and were located on each of 3 faults (“channels”). Migration took place through all “channels”
gas from west to east, which ensured a certain gas pressure in each house channel.

The width of the “channels” ranged from 40 to 80 m. Each “channel” had 4 gas-permeable horizons, representing fractured medium-grained sandstone occurring in each channel at depths from 410 m to 1690 m. The thickness of gas-bearing horizons ranged from 20 to 80 m, the excess gas pressure in the horizons (depending on the depths) was from 16 kgf/cm2 (upper horizon from 160 kgf/cm2 (lower horizon). Gas horizons were located under coal seams. Main source of gas with high pressure was located outside the mine field (5 km from him). Gas from it entered the mine field through 3 faults crossing the mine field. Moreover, the distribution of gas in the “channel” under the coal seams occurred from the lower horizon (1690 m) with high gas pressure (230 kgf/cm2) to the upper horizon (16 kgf/cm2) along the general gas permeable vertical section “pillar” from a depth of 1690 m to a depth of 410 m (Fig. 2).

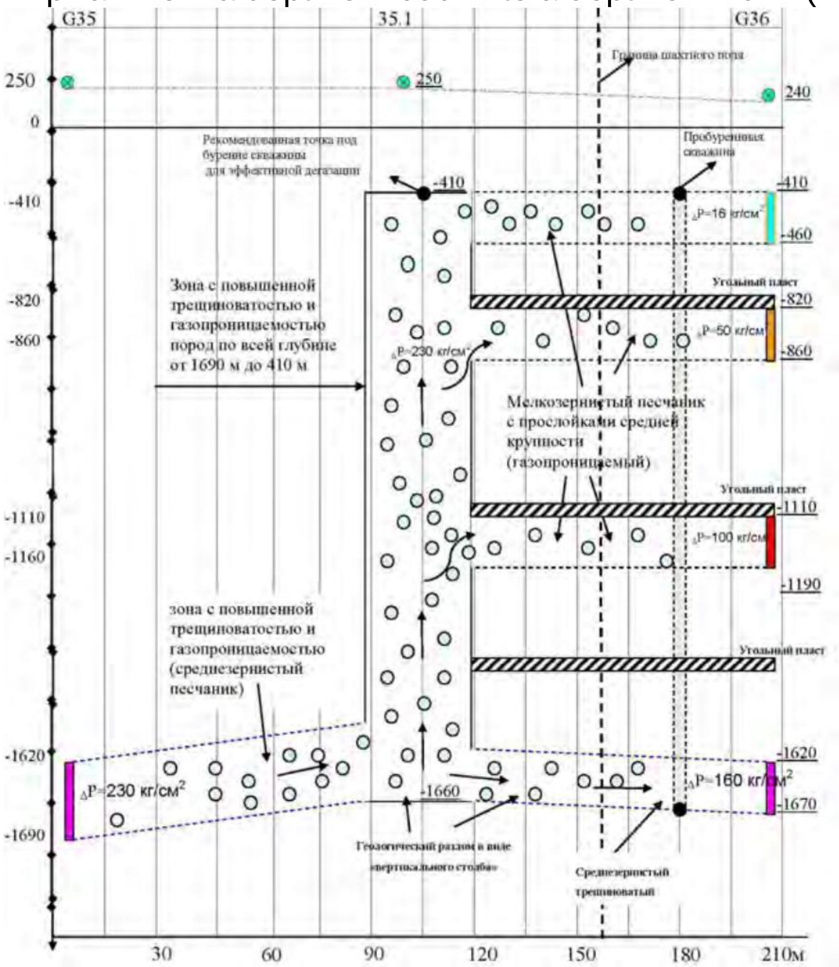

Fig.2. Depth section 035-036 of the gas-bearing channel in the mine field of a coal mine. At a

distance of ÿ5 km to the west of the mine field, a large gas-bearing deposit (diameter ÿ4 km) with a gas pressure in it of 350 kgf/cm2 , from from which the “channels” of gas flow under the coal seams originated. As we approached the mine field, the gas pressure in the gas-bearing reservoirs decreased (throttled to 230 kg/cm2). An analysis of the sites of mine accidents with methane explosions (and deaths) showed that explosions occurred when developing coal seams above gas-bearing “channels” (faults) with high gas pressure in them (>50 kgf/cm2). A well drilled in

the northern gas “channel-1” in all 4 horizons confirmed the presence of natural hydrocarbon inflows (and not
“coal”) gas with corresponding gas pressures significantly higher (P4ÿ160 kgf/cm2) gas pressure in coal seams (usually 5-10 kgf/cm2). That. data from remote determination of the parameters of gas “channels” (collectors), their depths and gas pressure in them were confirmed. Consequently, if you drill degassing wells directly in vertical

gas-permeable “pillars” or “channels”, then this

will sharply reduce the total pressure of gas approaching the mine field, which means the situation under the coal seams throughout the mine field will improve.

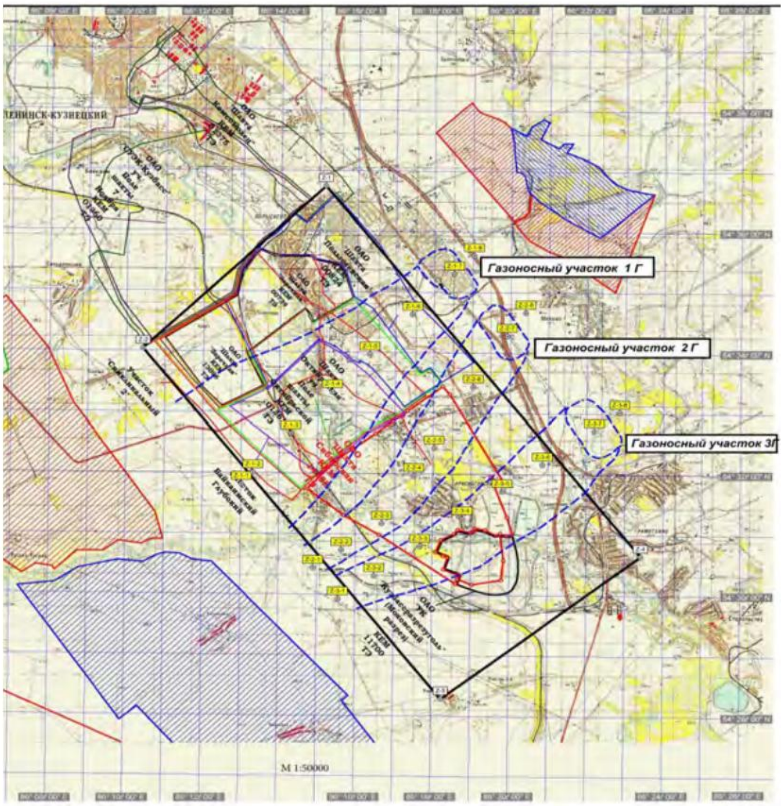

Fig.3. Boundaries of identified gas anomalies on the territory of mining allotments coal mines Polysaevskaya, Zarechnaya, Oktyabrskaya and Sibirskaya (S=99 km^2).

It is advantageous to use gas from such a well with an industrial inflow and a pressure of 160 kg/cm2 for the technical needs of the city, rather than degass it it in the OS. A similar picture was revealed at several Russian mines (Fig. 3, Fig. 4). Recommendations were given for drilling degassing wells in gas-bearing “collectors” with high gas pressure, which can significantly reduce the gas danger throughout the entire mine field.

Similar work performed at 5 coal mines in Russia confirmed a similar situation by the presence of several “channels” of incoming injection of gas with high gas pressure > 350 kg/cm2 under coal seams from sources located at great depths and located beyond mine fields.

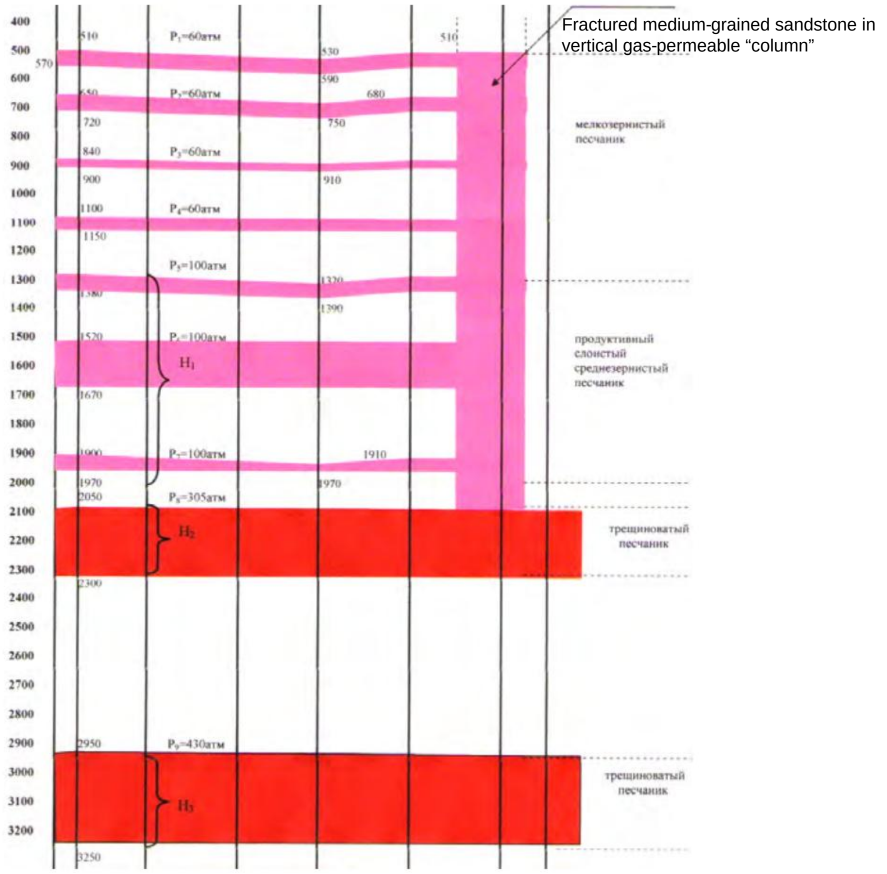

Fig.4. Depth profile of gas section No. 1G in the mine field (mine "Zarechnaya", Russia).

High gas pressures under coal seams were recorded at depths ÿ500 m. Accumulations of gas with high pressure (>50 kg/cm2) pose a great danger during mining operations, because When coal seams are opened near such accumulations, there is an instantaneous release of large volumes of a gas mixture into the air-oxygen environment of the roadway, where a methane-gas mixture with a methane concentration is constantly located below the permissible norm (ÿ3÷4%). Due to the constant oxidation of gas mixtures with such a concentration of methane in the drift air, this mixture has a certain degree of readiness of “excitation” to ignite. IN the moment large volumes of a gas mixture with a high methane content are injected, instantaneous self-ignition of hydrocarbon gases occurs and their volumetric explosion even at CH4 concentrations in the working drift is less than 5%. The automated warning system does not even have time to respond to an increase in the concentration of methane in the

mixture. The results of mathematical modeling of the processes of self-ignition and explosions also confirm the possibility of volumetric explosions with sudden influx of gas in large volumes into the working drift. In this case, a shock wave front can additionally form at a speed

>1000 m/sec, which is an additional initiating factor for a volumetric explosion.

Detonation. It should be noted that flame propagation and rapid combustion of hydrocarbon mixtures are determined by chemical reactions that maintain concentration gradients, as well as molecular transport processes that cause these gradients to move into

space. In contrast

to these processes, the propagation of detonation is caused by a pressure wave, which is fueled by chemical reactions and the accompanying release of heat. A characteristic property of detonation is ÿ 1000v m/s, the speed of propagation of the detonation wave is of the order of than the speed of propagation of the combustion flame of the hydrocarbon magnitude greater mixture (usually 0.5 m/s). Velocity of detonation wave propagation v

children , density ÿÿ and

pressure p_v of burnt gases is calculated according to the Chapman-Jouguet theory [4]. They depend on the pressure pu and the density of unburned gases, on the specific heat

reaction q and on the value of ÿ, determined by the ratio of heat capacities at constant volume and pressure (ÿ CC ÿ vp/).

Basic Chapman-Jouguet detonation equations: ÿ

q)1(2v ÿÿÿ ; ^{2} $\frac{v}{ÿ_u}$ ÿ $\frac{ÿÿ ; 1}{ÿ}$ $\frac{ÿ_v}{ÿ_u}$ ÿÿÿ)1(2 $\frac{q_u}{p_u}$.

It should be emphasized that the issue of the transition from rapid combustion (de-flagration) to detonation is very important for many practical applications, in particular it is very important for coal mines. Mathematical modeling makes it possible to analyze such processes. Figure 5 shows the transition

to detonation in a hydrogen-oxygen environment. Deflagration accelerates and turns into detonation. It should be noted that, as a

rule, detonation waves are not plane; the formation of a cellular structure of the detonation front is experimentally observed.

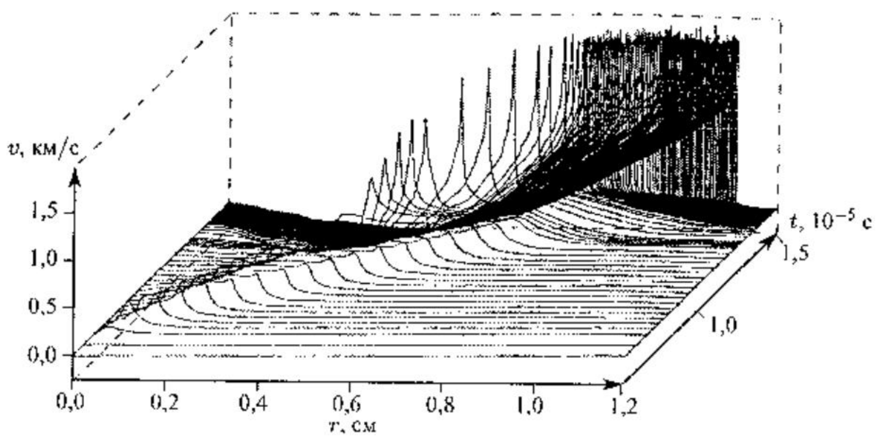

Fig.5. Velocity profiles during the formation of a detonation wave in hydrogen-oxygen mixture H_2-O_2 at an initial pressure p = 2 kgf/cm2 [17].

In conclusion, we note that for the kinetic description of the combustion processes of even such a simple fuel as hydrogen (the total reaction $2H_2 + O_2$ ÿ $2H_2O$) a mechanism is required that includes about 40 elementary reactions. For a kinetic description of combustion processes, especially processes self-ignition of the simplest hydrocarbon fuel - methane (CH_4), the total number of reactions taking into account surface reactions in chemical The mechanism includes several thousand elementary reactions. All these issues, namely chemical kinetics, reaction mechanisms, simplification of reaction mechanisms, etc., were previously considered in the works of the authors [2-7].

Conclusions 1. Under coal seams in zones of increased fracturing there are areas of accumulation of hydrocarbon gases, which “instantly are opened" at the moment of removal of coal seams, and there is an instant release of gas with high pressures and temperatures in production with the content of oxygen and constant products in the air oxidation of methane, although its content is below the permissible norm (2÷3%), where a volumetric explosion occurs. 2. Due to the influx of hydrocarbon gases with heavy fractions at high pressure and temperature, an instantaneous ejection of rock occurs and the mixture spontaneously ignites at a gas concentration much lower 5% followed by volumetric explosion and detonation. If it happens supply of gas in small volumes (due to lower gas pressure in horizon), then a volumetric explosion does not occur, but poisoning of miners with gas is possible. 3. The presence of areas of accumulation of hydrocarbon gases with high pressure and temperature under coal seams creates conditions for the instantaneous entry of gas into the workings with subsequent volumetric explosions gas and detonation.

4. The most dangerous (instantaneous) gas emissions, volumetric explosions and detonation can occur during the development of coal seams at thermal coal depths of 500 m or more.

Offers

1. Additional measures should be taken to ensure safety of work in thermal coal mines, especially when developing them at great depths (>500 m).
2. The equipment of the Poisk complex can be successfully used for detection of areas of gas accumulation with high pressure and temperature under coal seams and in geological faults, ensuring

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to select points for drilling wells for effective gas degassing behind.

3. The most effective measures to prevent the instantaneous entry of gas under high pressure can be the timely detection of gas in the faults of mine fields and their degassing through drilled wells, as well as the detection of gas near mine fields

deposits. Near mine fields with thermal coals, there are always gas deposits located on large depths connected by faults with coal deposits. Before developing coal seams at depths close to 500 m, it is necessary open gas deposits near coal mines to reduce pressure in them and thereby improving the gas danger in mines.

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