Thermal technologies of producing nonconventional gases

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Introduction

Recently world energy system had to address the development of nonconventional gases (coal-bed methane, shale gas, natural gas hydrates, underground coal gasification gas and etc.). Security of energy supply and sustainability of future community require integration of these nonconventional sources of hydrocarbon material into industrial consumption.

That is why world engineers and scientists launched industrial exploration projects. There is an acute need in new breakthrough technologies.

Here we proposed new technical solutions for underground coal gasification (UCG), coal-bed adsorbed methane extraction and natural gas hydrates exploration. Other sources of nonconventional gases, such as shale gas, need separate research.

Underground coal gasification (UCG)

The idea of UCG was proposed as early as 1888 by our famous compatriot D.I. Mendeleev. The USSR started active elaboration of this problem in 1933-1935. During the period of 1946-1996 5 experimental-industrial enterprises were operated (bituminous and lignite coals), totally 15 mln. tons of coal were gasified and about 50 bln. m^3 of gas with combustion value of 3.5-4.2 MJ/m^3 were produced, .

Despite a half-century experience, the underground gasification process remained insufficiently stable and heat efficient.

UCG control in traditional schemes was ensured by operating numerous wells that were integrated into the system when the produced gas combustion heat decreased. At the same time this process created disordered flow dynamics in the underground gas generator, wandering flows of oxidants and fuel components and led to partial postcombustion of the received UCG gas.

Useful power rate of the coal in traditional UCG process is less than 35-45%.

Large-scale industrial introduction of UCG is possible only after improvement of process control, simultaneous reduction of cost per unit and increase of coal-bed gas output.

Fig.1 shows principal scheme of underground gas generator module with stationary reaction channel along which injection flows are moving.

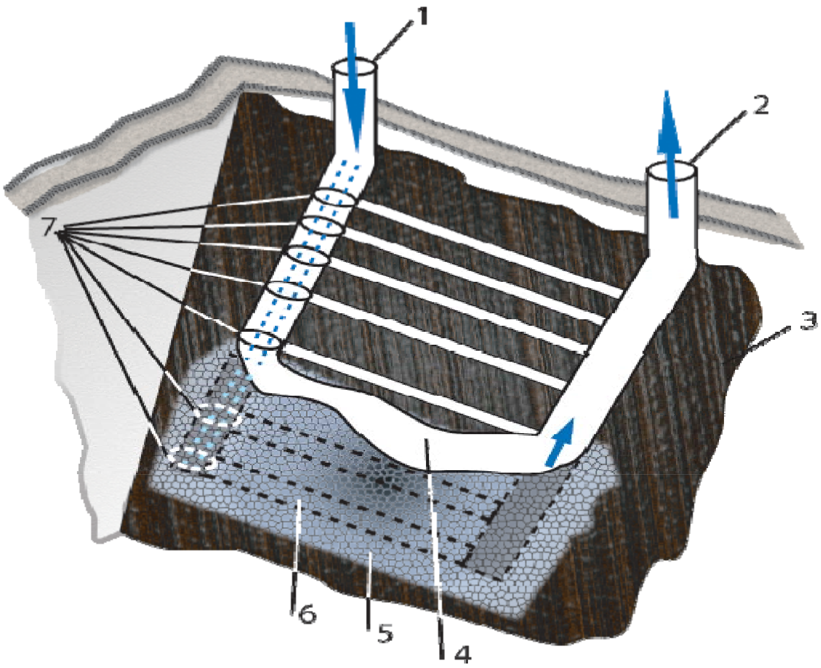

Figure 1 – Principal scheme of the underground gas generator module new technology:

1-injection, cased in coal-bed; 2 – gas production well not cased in coal-bed; 3 – coal-bed; 4 – reaction channel; 5 - cavings of the roof and slag; 6 – initial gasification channel; 7 – injection supply movement.

Gas generator is represented in the section of coal-bed (incline or horizontal). Injection well is fully cased length-wise and gas production well – only up to the entrance into the coal-bed. Both wells are connected in the lower part into the unified hydraulic system. Combustion face is formed in the drilling channel of the injection well and with gasification of the coal-bed between the wells the injection supply point moves upwards along the well. Thus, the process ensures direct supply of the oxidant to reaction coal surface. Active heterogeneous reaction in the channel, the walls of which are, primarily, coal, determines both high surface temperature and minimum fractional loss of heat into the surrounding formations.

The UCG enterprises shall be regarded as complex chemical production plants. At this the equipment configuration of the surface complex depends on the use of UCG gas.

Almost regardless of the UCG gas use, compulsory (first) stage of work is its purification of liquid tar substances the output of which exists in all thermal coal processing works. At this, the produced gas condensate contains ammonia, pyridine bases, and tar. After hydrocracking the tar can be used in organics, production including benzol homologies.

UCG gas transport is rational only after collection of all accompanying tar substances in surface complex. So the gas can be supplied to the consumer only after the primary UCG gas purification of liquid and hard substances.

There are three most probable consumption spheres: local fuel – as a rule, boiler one; electricity generation at the thermal power plants and synthetic natural gas ($CO + H_2$) used for production of synthetic hydrocarbons. At this, if for the first two uses the UCG gas can be received with air injection (~ 4 MJ/m^3), the production of synthetic natural gas requires vapour-oxygen injection.

The Figure 2 shows variants of complex energy and chemical enterprise using UCG after vapour-oxygen injection. After the purification (stripping) of H_2S and CO_2, synthetic natural ($CO + H_2$) gas remains. This valuable product can be used as a raw material for ammonia, methane (natural gas substitute), methanol, light petrol, diesel fuel synthesis and as a fuel for different industrial and domestic energy units.

The Figure 3 represents the example of complex mining and energy enterprise including three facilities: underground gas generator, gas treatment unit and combined cycle power plant.

Complex character of UCG enterprise is predetermined both by the fact it extracts and refines tar and gas condensate and by the availability of multiple options to use the produced gas (from synthetic natural gas to pure hydrogen).

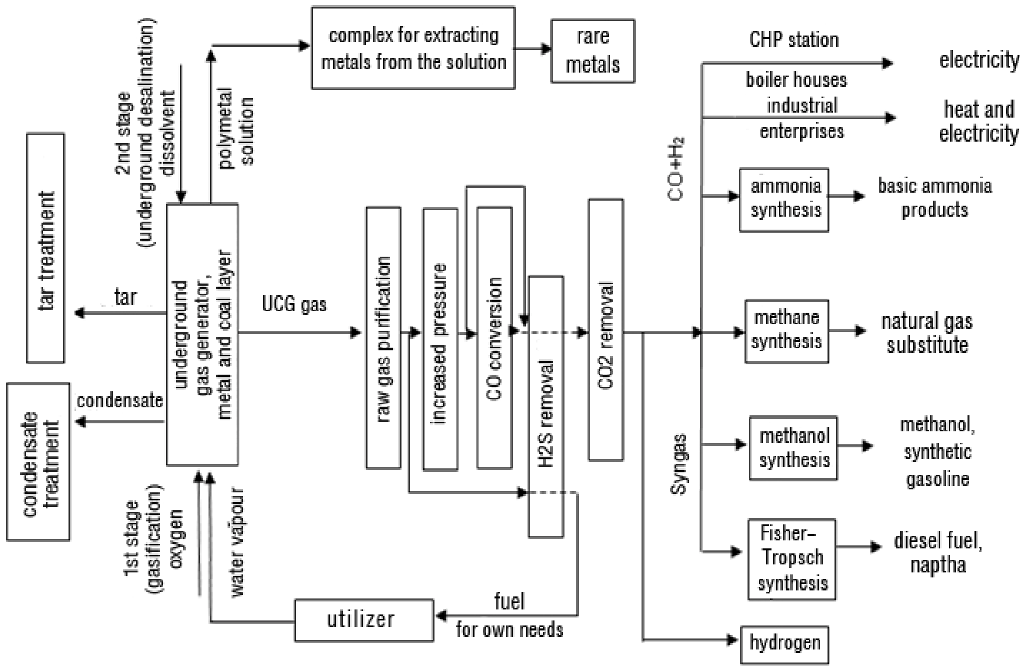

Figure 2 – Variants of treatment and use of UCG gas

The possibility to produce synthetic hydrocarbons on the basis of UCG gas using Fusher-Tropsch synthesis (FTS) is of special interest.

FTS was implemented in the frameworks of a bench test. Two gas mixtures produced by USG with injecting air and air enriched with oxygen up to 65% of O_2 were used as raw material.

After technical and economical assessment of the FTS capacity the unified heat capacity of the UCG-FTS industrial enterprise working with air and enriched injection was approved – 800 MW. In the first case the annual gas production output is 6 bln. m^3, in the second case – 3.3 bln. m^3.

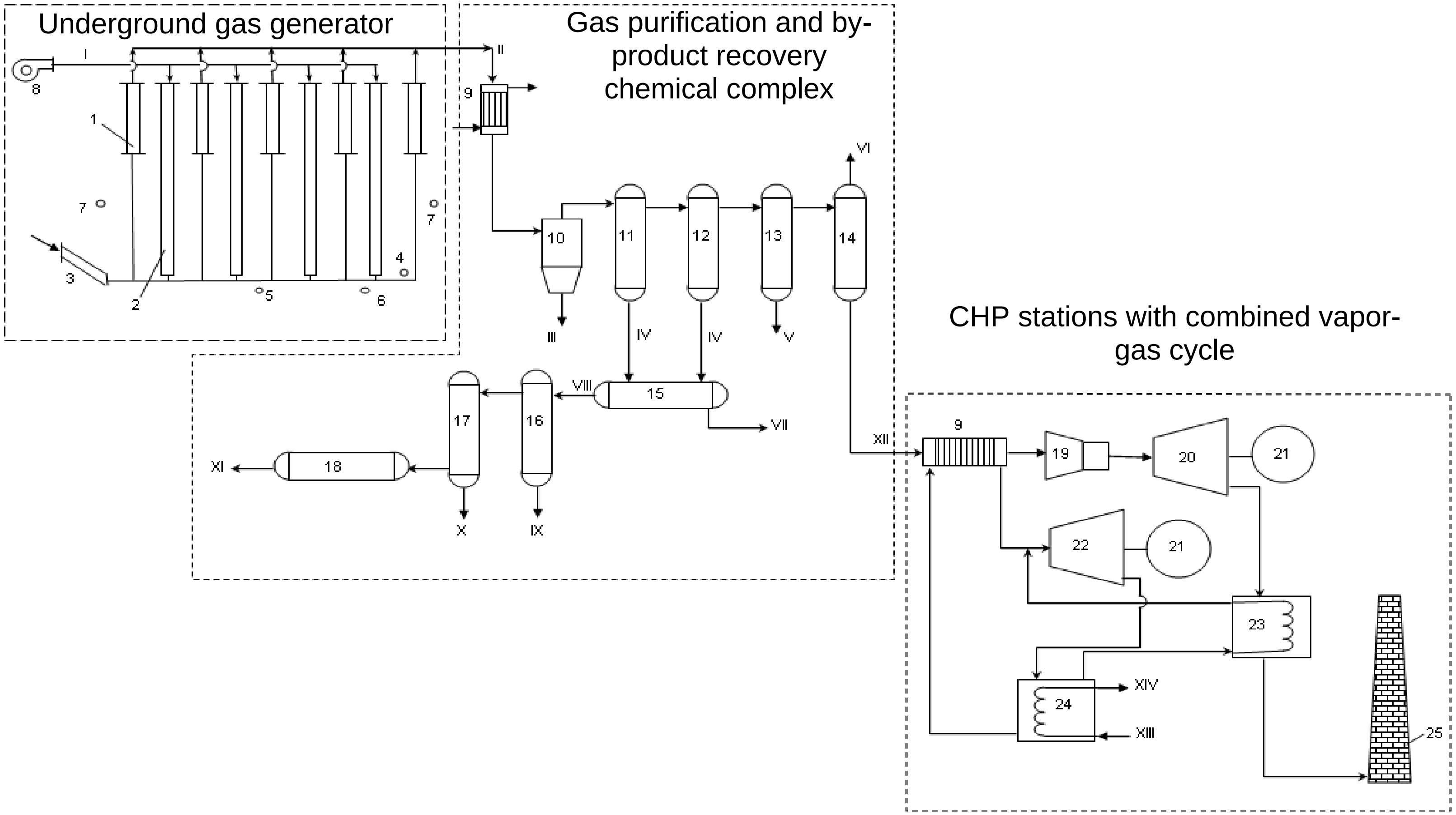

Figure 3 – UCG-CHP complex scheme

- injection well, 2 - gas production well, 3 - directional crosscut hole, 4 – ignition hole, 5 - drain hole, 6 – dewatering hole, 7 - water monitoring hole, 8 – fan blower, 9 – heat exchanger, 10 - centrifugal apparatus, 11 – separator, 12 – Venturi scrubber, 13 – hydrogen sulfide recovery block, 14 – CO2 recovery block, 15 – clarifying basin, 16 – ammonia water recovery block, 17 – phenol recovery block, 18 – drain water recovery block, 19 – compressor, 20 – gas turbine, 21 – electricity generator, 22 – steam turbine, 23 – steam boiler, 24 – condenser, 25 – smoke pipe. I – air, II – UCG gas, III – mechanical impurities, IV – tar and condensate, V – hydrogen sulfide to recovery, VI - carbon dioxide to recovery, VII – tar to the store, VIII – condensate to recovery, IX – ammonia to the store, X – phenolic water, XI - water to the cycle, XII – purified gas, XIII – water from the treatment station, XIV – heat energy (hot water)

The typical gas generator at the lignite field at the depth of 150 m is represented by a construction consisting of 15 injection and gas production vertical-horizontal holes laid in the coal-bed with thickness of 8 m and 6-7 vertical holes for hydro-geologic purposes. The coal resources at this generator amount to 1.7 mln. tons (500 m × 350 m × 8 m = 1.4 mln. m^3 ≅ 1.7 mln. tons).

The content of produced gas and consumption rates of injection, gas and coal are adopted upon the actual data.

The primary data for economic assessment are represented in Table 2. The economic analysis was made using Excel computer program.

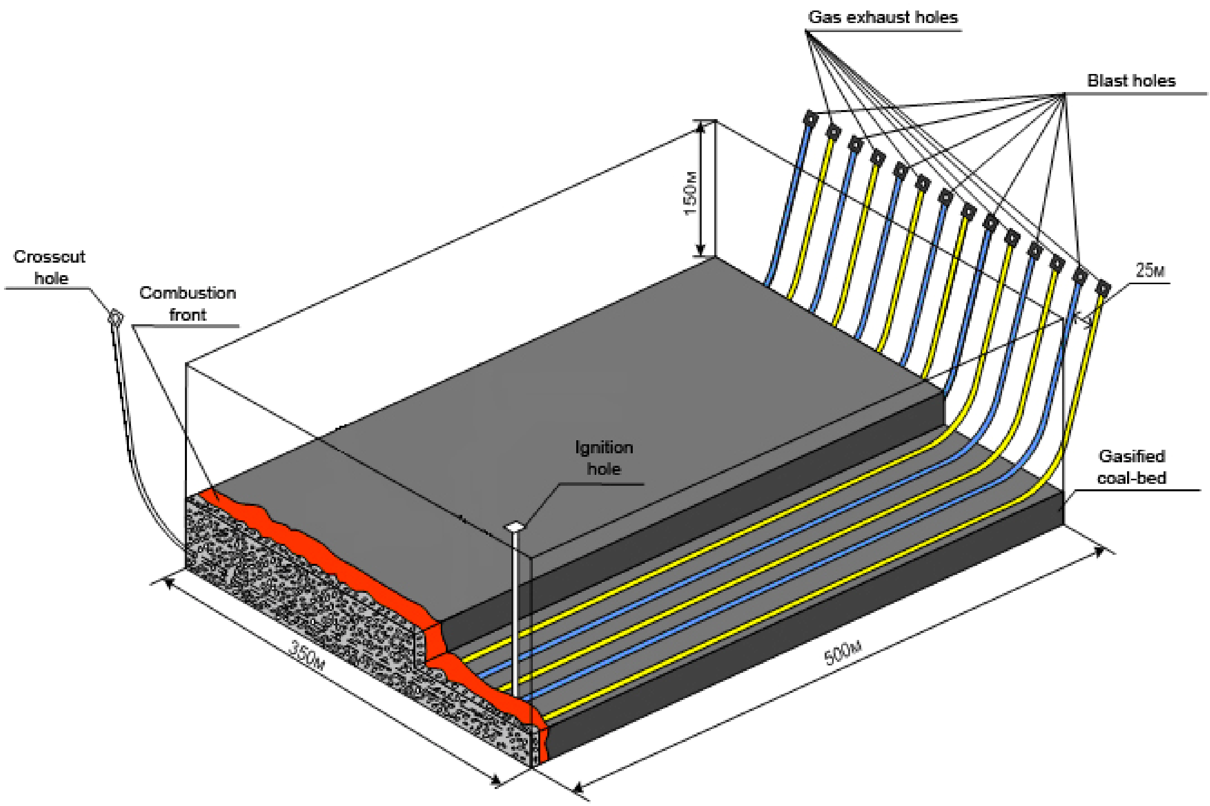

Figure 4 – Underground gas generator scheme

According to table 1 high cost of gas distribution unit (GDU) and operation costs (UCG enterprise injecting air enriched with oxygen) capital expenses of such enterprises are 1.5-2.0 times more than of enterprises using pure air.

Economic assessment of two types of UCG-synthetic hydrocarbons industrial enterprise will be limited to comparison of the total expenses and corresponding output of synthetic gas and liquid hydrocarbons represented in the Table 1.

Table 1 – Economic assessment results

No	Parameter	Injection	
		air	enriched air (O_2 = 65%)
1	Capital expenditure, mln. US dollars	392	572
2	Operational expenses, mln. US dollars	13	26
3	Gaseous hydrocarbon specific output, (C_1-C_4), g/m^3	12	28
4	Synthetic methane output, Tons/year m^3/year	$72 \cdot 10^3$ $100 \cdot 10^6$	$92.4 \cdot 10^3$ $130 \cdot 10^6$
5	Gaseous hydrocarbons price, US dollars/100 m^3	100	100
6	Annual revenue from gas hydrocarbons, US doll./year	$10.0 \cdot 10^6$	$13.0 \cdot 10^6$
7	Liquid hydrocarbons specific output (C_{5+}), g/m^3	37	65
8	Liquid hydrocarbons output, tons/year	$222 \cdot 10^3$	$214.5 \cdot 10^3$
9	Liquid hydrocarbons price, US doll/l	0.3	0.3
10	Annual revenue from liquid hydrocarbons, US doll./year	$66.6 \cdot 10^6$	$64.3 \cdot 10^6$
11	Payback time, years	6	15
12	NPV, mln. US doll./year	294	22
13	IRR, %	22	5

The gaseous fraction (C_1-C_4) includes methane, ethane, propane, butane, and the liquid one (C_{5+}) – diesel, naphtha and heavy hydrocarbons. Annual production volumes (table 1, it.4 and 8) are determined with respect to annual gas output.

Let us try to give expert technical and economic assessment of both variants of UCG-FTS enterprises.

Taking into account the fact that the heat rate of both enterprises is adopted as equal to 800 MW, the production with air injection will give 2 times more gas than production with enriched injection (6.0 and 3.3 m^3/year respectively). At this, relative output of synthetic hydrocarbons with enriched injection is 2 times more (table 1, it. 3 and 7) and annual production volumes (table 1, it. 4 and 8) differ insignificantly.

And we have the next conclusion. If the heat rate of UCG-FTS enterprise is equal, capital and operation expenses of UCG with air injection are 1.5 less than UCG with enriched injection. Generation of synthetic hydrocarbons in both variants differ insignificantly.

So, production of synthetic hydrocarbons using FTS at the UCG enterprise with air injection is economically feasible, because required investments of this variant are 1.5 times less than at the UCG enterprise with enriched injection. Investment return time is 5-6 years.

So, UCG-FTS enterprises shall be considered not only innovative and prospect but also economically attractive ones.

Coal-bed methane

Occluded methane (methane-bearing of the coal-beds reaches 45-50 m^3/ton) is, on the one hand, a cause of explosions in coal mines and, on the other hand, a valuable hydrocarbon material. The task is to find efficient technologies of coal-bed weakening and destruction of hard physic-chemical occlusion connection between coal and methane.

Existing technologies of methane coal extraction are based on the use of hydro-fracture process via vertical wells or on drilling lengthy horizontal wells in the coal seam.

These technologies were widely used first in the USA and later on in China, India, Australia and other countries. In 2005-2006 the USA annually produced 45-50 billion m^3 of coal-bed methane.

In Russia (in the Kuzbass, Vorkuta, East Donbass fields) utilization of methane is scarce, though its proved reserves reach some 13 trillion m^3. At this, about 2 billion m^3 of coal-bed methane is emitted into the atmosphere essentially (mostly via mine ventilation shafts) and damage the environment with greenhouse pollutants.

In Russia new technologies of intensified coal-bed methane production were developed and patented. One of the methods is essentially based on pneumatic hydro-fracturing of coal seams (water-air treatment). Percussion (alternating) treatment of hydro-fracturing slit provides for inter-well cavitation and allows propane-free fixture of the slit.

Second approach includes combusting of the coal seam in the hydro-fracturing slit or in the horizontal drilling channel and blasting of hot combustion products (CO_2, N_2 and H_2O) through the coal formation. This method is associated, on the one hand, with surging (by several degrees) of the formation gas permeability factor, and, on the other hand, with coalmine methane desorbtion by (substitution with) carbon dioxide and nitrogen.

The task is the focused implementation of intensive coal-bed methane production methods supported by application of effective technical solutions not by drilling numerous production wells but ensuring coal formation softening via limited number of operation wells.

Table 2 represents the results of assessment of methane output for 4 different technologies. First and third variants reflect traditional technologies, daily methane outputs are close to actual outputs. Second and fourth variants reflect new (developed by us) technical solutions mentioned above. Comparison of these 4 variants confirms that predicted outputs of new technologies are 4-5 times higher than of traditional ones (at this, the outputs are conventionally proportional to lateral surface of the created artificial collector).

Table 2 – Efficiency of new technologies

It. No.	Degasation channel	Channel parameters		Methane inflow	
		Surface, m2/linear m	Section m2	m^3/hour	m^3/day
1	Hydro-fracturing slit of traditional technology (section 20 x 5 cm, L = 400 m)	0.41	0.01	302	7250
2	Hydro-fracturing slit of new technology after pneumohydraulic washing (section 40 x 40 cm, L = 400 m)	1.6	0.16	1180	28300
3	Lengthy drilling channel of the coal seam (Ø 15 cm, L = 400 m)	0.47	0.0044	345	8300
4	Lengthy drilling channel after fire treatment (Ø 75 cm, L = 400 m)	2.35	0.11	1730	41500

Natural gas hydrates

Crystal compounds of water and hydrocarbons (natural gas hydrates) are widely spread in the world. Global reserves of gas hydrates are estimated to reach $2 \cdot 10^{14}$ - $2 \cdot 10^{16} m^3$. Of these reserves 98 % are located in ocean areas, and only 2 % (300 – 400 trillion m^3) – in the continent coastline area.

The development of gas hydrates production industrial technology will ensure extension of "gas break" for several centuries.

Balance conditions for existence of natural gas hydrates: pressure – 8-10 MPa, temperature - (-8)-(-12) ^{0}C. Change of this thermal and pressure conditions (pressure decrease or increase of in the deposit) causes changes in crystal structure of hydrates and transfer of hydrocarbon into unbalanced gas condition.

Today several countries (Japan, Canada, the USA, India) has created international consortium and execute experimental researches in natural settings. The main aim of the experiments is increase of the temperature in the gas hydrate deposit by feeding external heat-bearer (hot water, water vapour) through the wells.

Our domestic technical proposals are also based on heating of the hydrate deposit using external heat-bearer.

We think that the use of the external heat-bearer to heat the deposit is energy-inefficient due to huge heat losses during its transport along the whole length of the vertical well hole. The experiments held in Japan and Canada confirmed inefficiency of this technology.

JSC "Gazprom promgaz" has developed a new thermal technology of gas hydrates extraction (the RF patent No. 2271442, 2006, the RF patent No. 2412345, 2011) consisting in combustion of part of hydrocarbon material at the deposit and use of the hot products for heating the productive formation. Energy efficiency of this method as compared to other technologies is obvious.

The developed thermal technology of gas hydrates production is based on several methods of underground coal gasification and consists of drilling the inclined vertical wells with fan termination within the formation depth through the gas hydrate formation. Fan horizontal terminations are inter-crossed with vertical well and connected into the hydraulic unified module.

Air

Products

Products

Air

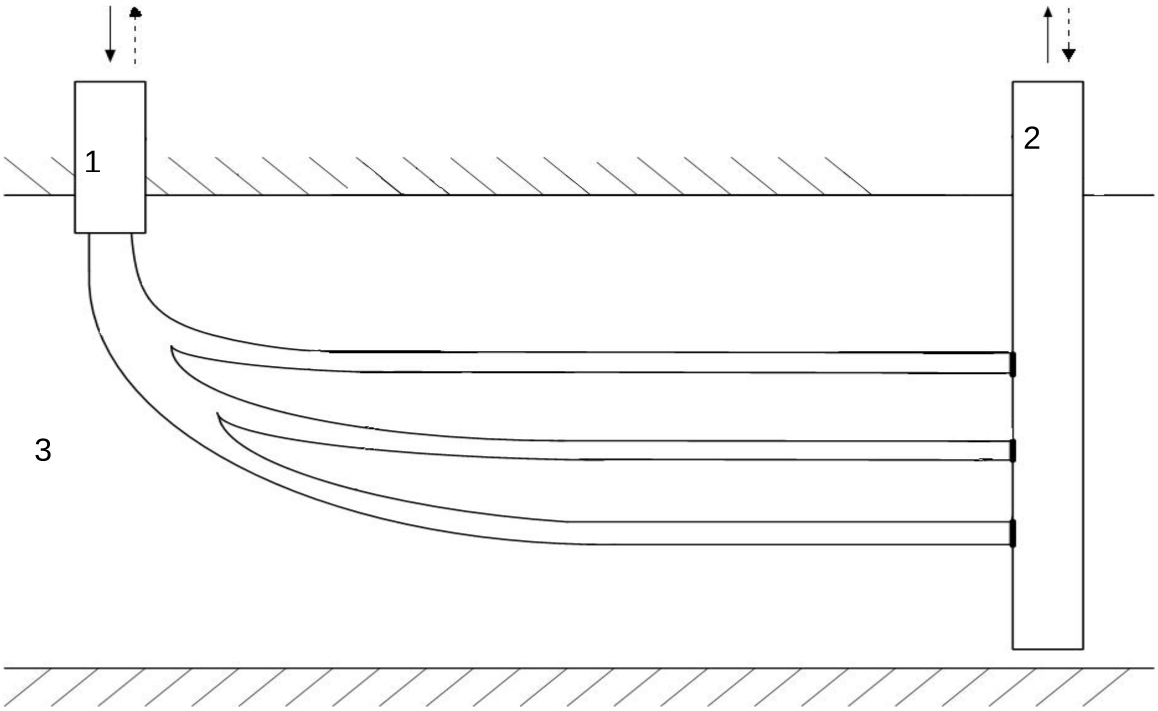

Figure 5 – Principal scheme of the drilling module used in gas hydrates thermal production: 1 – vertical-horizontal wells with fan termination; 2 – vertical well; 3 – gas hydrate deposit.

The ignite gas hydrate in the deposit and commence injecting air into the module. Produced hot products heat the deposit, and it becomes unbalanced and starts to actively yield gaseous products. It is possible to construct different combinations of blast and gas flows in the module of vertical-horizontal and vertical wells aimed at increase of efficiency of gas hydrate deposit heating.

The elaborated mathematic model allows predicting deposit heating modes and optimizing their settings.

So, difficult to access natural gas hydrates deposits can significantly increase gas resources and positively change gas strategy for the period up to 2030. It is necessary to ensure pilot industrial testing of the proposed thermal technology in the nearest years.

Conclusion

The mentioned nonconventional sources of gaseous energy are the important reserve of hydrocarbon material. And though their role in Russia is insignificant (traditional natural gas and oil resources are rather large), in future nonconventional gases can and shall replenish heat and energy balance.

It is necessary to start development of nonconventional sources so that in 10-15 years we could use them. There should be constructed demonstration (pilot) modules for each type of the mentioned source to fine-tune and master corresponding technical solutions and technological operating rules. The investments spent today will ensure energetic balance of the country tomorrow.