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The potential of water-soluble gases in Ukraine

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SUMMARY

The prospects of the development of hydrocarbon water-soluble gases are explained. The main sources of water soluble gases have been identified. Gas saturation-to-depth relation is determined. The variation of gas saturation with distance from reservoir limit are thoroughly analyzed. The qualitative composition of water-soluble gases as well as its variation in depth are explained. The challenges that arise while developing water-soluble gases are provided.

Introduction

The percent of traditional hydrocarbon sources in the world's fuel and energy balance is gradually declining due to the depletion of reserves of traditional hydrocarbon deposits and sharp increase of the use of them in the industry. Therefore, it is necessary to develop unconventional hydrocarbon sources, notably water-soluble gases. The ones are marked by significant resource potential. Commercial production of water-soluble gasses is successfully performed in Japan and Italy. Moreover, the production of water-soluble gases from subsurface water constitutes 300 million cu. m per year in Japan. Water formations with commercial content of water-soluble hydrocarbon gasses are identified within the territory of Ukraine. The development of very complexes may contribute to the energy independence of Ukraine.

Method and Theory

Water-soluble gases represent the part of unconventional resources of natural gases dissolved in water. Within the CIS, they total reserves are estimated at (1-4) x 10^{15} cu. m while the world's total resources of water-soluble gasses in subsurface water of the sedimentary basins exceed one hundred and fifteen times the resource of traditional nature gas. (Liu, 1991).

Dissolved gas includes mainly methane and its homologs and is contained in reservoir water of oil-and-gas-bearing complex, thus forming huge areals in the central part of oil-and-gas province. The concentration of hydrocarbon gases in reservoir water of oil-and-gas-bearing complexes varies from hundredths to 10 m^3/m^3 and in some cases may increase from 20 to 40 m^3/m^3. Natural gases are soluble in water and oil. The solubility of hydrocarbon gases in oil amounts to tens and hundreds of m^3/m^3, while the gases, enriched in heavy methane homologs, dissolve better. The amount of water-soluble gases depends directly upon the abundance of natural gas resources and sufficient pore water volume. The pore water volume of permeable beds in sedimentary basins mainly depends on the size of the basin, the distribution area, thickness, porosity and water saturation of the main permeable beds. (Xu et al., 2012).

Pressure along with temperature, salinity, the chemical composition of water, and gas composition affect gas solubility in water. As the reservoir pressure increases, the gas solubility in water rises proportionally to the increase in pressure up to 5 MPa, with further increase in pressure it rises but slowly. There is an inverse relation between gas solubility and water salinity: the higher salinity is, the less of gas can dissolve in water (salting-out effect). The dependence of gas solubility in water on temperature is complex. As the temperature rises up to 100 °C, it decreases, and with further increase in temperature, it rises sharply. In addition, the solubility of gases reaches the minimum at 80 °C (Yang et al., 1993). The solubility of non-hydrocarbon gas is greater than the same of hydrocarbon one; the solubility of hydrocarbon gas rises with the increase of carbon number value.

The content of heavy hydrocarbons and nitrogen in water-soluble gas increases as the depth. Nitrogen often predominates in the water-soluble gas of Paleozoic sediments of ancient platforms. The content of water-soluble gas grows as the depth, from flank towards the center, within the individual oil-and-gas-bearing basins; the composition of very gas varies from nitrogen to methane.

To display gas solubility in water the Figure 1 may be used. It shows the solubility of methane in pure water within the temperature range from 21 to 360 °C and pressure varies from 4,137 to 110 kPa. Figure 1 shows that the critical point of water occurs at the temperature of 374,15 °C and a pressure of 22,114 kPa. A discontinuity in properties of water-methane mixtures would occur at the critical temperature. The distinction between fluid and vapor would disappear, so that water and methane should be completely miscible in all proportions above this point (Bonham, 1978).

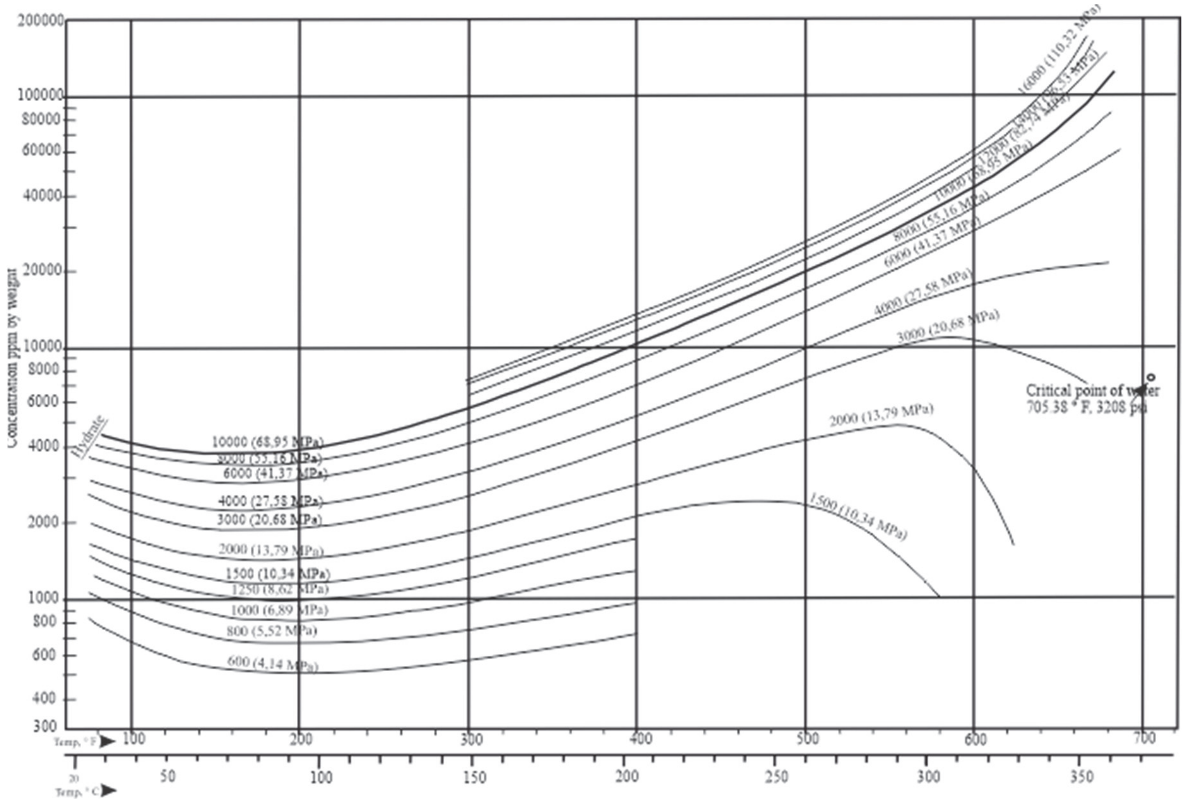

Figure 1 *Methan solubility in water by Bonham L.C. Methane solubility data: 77 to 340 °F, Culberson and McKetta; 340 to 680 °F, Sultanov et al (1972) by Bonham L.C.*

To sum up, the following sources of water-soluble gasses are identified:
1. subsurface gas-saturated water of shallow depth (up to 1 km); the gas-oil ratio within these zones are small (from 1,5 to 2,5 m^3/m^3) and they don't have widespread occurence;
2. gas-saturated water that contact with conventional gas deposits and are widespread; the gas-oil ratio within these zones varies significantly (usually from 5 to 10 m^3/m^3), and they decline with distance from the deposit;
3. highly gas-saturated water of deep depth – the main source of water-soluble gases; these zones feature high content of gas, particularly when abnormally high formation pressure.

The following parameters define economic value of gas-saturated water: a) gas-bearing capacity and gas composition; b) capacity-filtration properties, lithologic and facies, and structural properties; c) formation depth; d) hydrodynamic characteristics and formation pressure; e) salinity and temperature of subsurface waters. Moreover, it is necessary to consider economic assessment to determine the feasibility and cost-effectiveness of hydrocarbon exploration. (Karpenko et al., 2020). Considerable increasing of efficiency of oil and gas prospecting is possible upon condition of novel high technology facilities of gas-geochemical predicting oil and gas nature by means of system innovation of methodological and procedural framework (Yarema et al., 2020).

Zones and complexes with commercial content of water-soluble gases have been identified on the territory of Ukraine. Nitrogen-methane and methane gases are prevailing among water-soluble gases within the exterior of the Precarpathian Depression. The first ones belong to the Mesozoic deposits. The Neogene deposits contains mainly methane. The gas-saturation of water doesn't exceed 600 cm^3/l, while for Sarmatian deposits it constituted from 1200 to 1300 cm^3/l.

Gas saturation of subsurface water reaches maximum value (it exceeds 2000 g/cm^3) within the border zone of the deposit. Gas saturation of water also increases with the increasing of depth. In this direction, nitrogen-methane gases are replaced by methane and hydrocarbon-methane (Kolodii et al., 2004).

Within the exterior of Boryslav-Pokutsk elevation, water-soluble gases of the Jurassic horizon are nitrogen-methane and heavy hydrocarbon-methane. The methane content ranges from 52 to 84 % vol (Herasymchuk, 2003). The amount of nitrogen in the Jurassic sediments of the Lopushnya deposit increases from 0.5 to 30% vol as its distance from the reservoir. Gas saturation of water changes slightly as the depth and varies from 290 to 310 cm^3/l. Water-soluble gases of the Cretaceous water-bearing horizon are characterized by nitrogen-methane and heavy hydrocarbon-methane composition. The content of heavy hydrocarbons rises from 16 to 18% vol. in the edge and bottom water of oil deposits. The proportion of methane homologs in water-soluble gas is less than 3,8 % vol within the water that do not contact the hydrocarbon deposits. Water-soluble gases of the Upper Badenian deposits to a depth of 500 m have nitrogen-methane and methane-nitrogen composition. The gas saturation of the water of the Upper Badenian horizon varies from 210 to 6000 cm^3/l and depends mainly on the distance to the gas deposit. One may note the following change pattern of gas component of water-soluble gases. When approaching oil or gas deposits, the quantitative content of CH_4 and HC increases (Yaremak et al., 2020*)*. Moreover, the amount of water-soluble gases increases when approaching the tectonic fault.

The resources of water-soluble gases amount approximately to 49 billion cu. m by the C3 + D1 categories in Sarmatian and Jurassic deposits within Bilche-Volytsia zone of the Precarpathian Depression; where the gas saturation of reservoir water reaches up to 2 m^3/m^3. Jurassic deposits may be of interest within Rudkivske field, where massive gas reservoir belongs to the Jurassic erosion scarp of dolomitic limestone (Khovanets et al., 2019). Gases of flysch deposits of the interior of the Precarpathian Depression are marked by significant methane content. Gas saturation of water varies widely from 800 to 2000 cm^3/l and more. The water-soluble gases of deep layers of the Skyba zone of plicated Carpathians are similar to gases of the interior of the Precarpathian depression. Hydrocarbon water-soluble gases are widespread in the Cretaceous, Paleocene and Neogene deposits within the Trans-Carpathian depression. It is notable that at a depth of 50 m, the content of water-soluble gases is less than 70 cm^3/l, while the methane content is close to zero. Methane is the major component of gases within the horizons of the Sarmatian stage. Gas saturation of water reaches 600 cm^3/l, and at a depth of 3000 to 3500 m the gas content reaches 5000 cm^3/l. The composition of gas is presented by methane. The presence of the second regional catagenetic caprock, which is formed by quartz rocks, is assumed within the Dnipro-Donetsk Depression in the geothermal zone of about 180 °C; according to the drilling data, the heavy gas-water inflows from geopressured zone are obtained. The results of the final phase of gas generation and degassing of Earth’s mantle assumed to be the main source of gas (Zelenko and Karpenko, 2015).

Water drive system of North Black Sea aquifer basin turns to be undersaturated by water-soluble gases. Nitrogen-hydrocarbon and carbon-nitrogen compositions of water-soluble gases are typical for the pre-Cretaceous deposits of the Plain Crimea according to O.D. Shtohryn, A.S. Tervydov and S.V. Niechyna; gas saturation of water does not exceed 380 cm^3/l. Gas saturation of subsurface water of the Neogene complex at depths of 380 to765 m ranges from 200 to 784 cm^3/l. Water-soluble gases of the Upper Cretaceous complex at the Golitsyn deposit features methane composition and total gas saturation that is up to 1674 cm^3/l. Gas saturation of water ranges from 2051 to 3148 cm^3/l within Karkinit area. The Eocene depoits, tested at the Selska and Karkinit areas, are characterized by gas saturation, which ranges from 1178 to 1378 cm^3/l, respectively. The gas saturation of the water of the water-bearing horizons of the Maikop series exceeds 1000 cm^3/l at depths ranges from 570 to 960 m within Holitsyn deposit, Flanhove and Prydniprovsk elevations. Gas saturation of subsurface water of the Neogene complex at depths of 380 to 765 m ranges from 200-784 cm^3/l. Water-soluble gases of the offshore area belong to methane, seldom nitrogen-methane with various contents of homologs (from 0.005 to 19.4% vol.) and non-hydrocarbon components (0.3-36.5% vol.) Gas saturation of water samples increases with depth and turns to be the largest in the Maikop and Paleogene aquifer system, where it reaches values of 4480 to 4760 cm^3/l.

Despite significant prospects, the development of water-soluble hydrocarbon gases is a challenge. Since the amount of water-soluble gas may differ from what is expected, it is necessary to drill wells to release wastewater, which is associated with material expenses. Another problem is the significant subsidence of the earth's surface. At the Nishikambara gas field in Niigata, Japan, the earth's surface collapsed by

200 mm per year in the early stages of development in the 1950s. As a countermeasure, all extracted water has been reintroduced into each reservoir since the early 1970s, making it possible to extract gas without settling the earth's surface for many decades. The environmental issues caused by the development of geopressured zone and large volumes of fluids withdrawal from the depths (opened flowing, subsidence of the earth's surface, artificial earthquakes, etc) should be considered.

Conclusions

Ukraine is marked by the significant potential of water-soluble hydrocarbon gases, which one day may substitute for conventional gas resources and contribute to the development of the fuel and energy industry.

References

Bonham, L.C. [1978] Solubility of methane in water at elevated temperatures and Pressures. *The American Association of Petroleum Geologists Bulletin*, **62**(12), 2477-2488.

Herasymchuk, V.Yu. [2003] Water-soluble and free gases of South-East part of exterior of the Precarpathian Depression. *Geology and geochemistry of combustible minerals*, **1**, 50-61. (in Ukrainian).

Karpenko, M.O., Mykhailiv, I.R., Boiko A.P. and Dubei N.V. [2020] Factors affecting the value of oil and gas reserves in the bowels. *Proceedings of the 19th International Conference on Geoinformatics - Theoretical and Applied Aspects (*Ukraine, Kyiv, May 2020*).* Volume 2020, p.1–5.

Khovanets, N.P., Kurovets, S.S., Anikeev, S.H., Zderka, T.V. and Yarema A.V. [2019] The Oil and Gas Potential Objects of Krukenychi Depression (according to the data of geological and gravity modeling) *Proceedings of the 18th International Conference on Geoinformatics - Theoretical and Applied Aspects (*Ukraine, Kyiv, May 2020). Volume 2019, p.1 - 5.

Kolodii, V.V., Boiko, H.Yu., Boichevska, L.E., and other [2004] Carpathian oil-and-gas province. Kyiv, Ukrainskii vydavnychyi tsentr Publ., 390. (in Ukrainian).

Liu, J. [1991] Natural gas resources dissolved in underground water circle and its development feasibility evaluation principles**.** Trans. *Geological Science and Technology News*, **10**, 9-11.

Xu, S., Li, S. and Yuan C. [2012] Resource potential of water-soluble gas in the Palaeogene Huizhou Sag, Pearl River Mouth Basin. *Petroleum Exploration and Development*, **39**(2), 194-201.

Yang, Y., Li, S. and Zhu J. [1993] Water-soluble gas: a new resource of natural gas in Sichuan Basin. *Journal of Southwestern Petroleum Institute*, **15**(1), 16-22.

Yarema, A.V., Zderka, T.V., Kurovets, S.S. and Khovanets, N.P. [2020] Gas-geochemical predicting and system assessment of oil and gas prospects for the purpose of increasing exploration efficiency. *Proceedings of the 19th International Conference on Geoinformatics - Theoretical and Applied Aspects (*Ukraine, Kyiv, May 2020*).* Volume 2020, p. 1–5.

Yaremak, R., Zhuchenko, G., Khomyn, V., Gorvanko, G. and Goptarova N. [2020] Information criteria for oil and gas content Boryslav-Pokutska area of the Precarpathian deflection. *Proceedings of the 19th International Conference on Geoinformatics - Theoretical and Applied Aspects*. May 2020, Volume 2020, p. 1 – 5.

Zelenko, Y. and Karpenko, O. [2015] Spatial prediction of gas-generating sequences based on evaluation of vitrinite reflectivity in Dnieper-Donets Depression. *Proceedings of the 14th EAGE International Conference on Geoinformatics - Theoretical and Applied Aspects*. Kyiv. May, 2015, Volume 2015, p. 1–5.