Asian Journal of Water, Environment and Pollution, Vol. 18, No. 1 (2021), pp. 59-65.
DOI 10.3233/AJW210008

Abiogenic and Biogenic Petroleum Origin: A Common Theory for Geological Surveys

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Received November 30, 2020; revised and accepted December 10, 2020

Abstract: Biogenic and abiogenic origins of petroleum are a pertinent problem today, which have been examined in this article including the current state of theories and experimental facts. The paper provides an overview of works on this subject over the past decade. As analysis of scientific research efforts, majority of scientists suggest that petroleum is organic in origin. The second theory also includes reliable facts and hypotheses about the existence of abiogenic hydrocarbons. This origin is associated with tectonic geological processes, in particular, orogenesis, rifting, excessive releases, erosion, sediment deposition, deep gas releases, etc. The results of experimental studies, the existing concepts presented in this review, show that despite disagreements between the proponents of both theories, common beliefs remain prevalent, namely, about the process of hydrocarbons formation both on Earth and other objects of the solar system. The analysis concludes that the consolidation of these theories is of high scientific interest and has great potential for confirmation of numerous hypotheses, facts from the scientific point of view and the search for alternative energy sources due to environmental and economic issues associated with the impoverishment of natural resources. This review study is valuable for generalising various scientific theories, which can be used for future research efforts and modelling new ideas about the origin of hydrocarbons.

Key words: Chemolithoautotrophs, hydrocarbons, petroleum, sedimentary rocks, theory of petroleum origin.

Introduction

In geology, a debatable theory of the abiogenic and biogenic origin of gas and petroleum has prevailed since decades (Behrouzifar et al., 2019; Ostovar et al., 2020). Recently, improvising the theory of petroleum formation has often raised in petroleum and gas geology as these resources are strategic in different branches of the economy (Karanfil and Omgba, 2017). Modern classification of natural resources puts petroleum as an irreplaceable substance. This classification is based on the theory of the biogenic origin of petroleum (Genovez et al., 2017; Walters, 2017). Methodological errors in the geophysical modelling of oil reserves and difficulties in creating a valid microeconomic forecasting model of oil production have destabilised markets and led to global economic crisis (Efimov et al., 2020). According to geological exploration, only 30% of sedimentary basins are commercial oil fields (Kolesnikov et al., 2017; Liu et al., 2018). At the same time, the density of oil and gas reserves in some large oil-and-gas bearing basins of the world significantly exceeds the forecasted figures.

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It is also inexplicable that many oil fields are still producing petroleum, although the balance oil reserves present are believed to be exhausted long ago (Lei et al., 2018; Muslimov and Plotnikova, 2019; Yuan and Wang, 2018). Thus, a relevant problem of oil field resiliency has arisen (Blankart, 2017; Kwok, 2017). First of all, oil or gas production should be preceded by a study of geological and field conditions, as well as spatial and temporal regularities of gas oil properties, change, field and formation fluid parameters, reservoir mode, the deep structure of sedimentary basin, geodynamic activity, pressure, flow rates, etc. (Gashimov et al., 2017; Ma, 2020; Shelepov and Tyukavkina, 2020). At the stage of regional works of oil and gas fields prospecting and discovery, the geological exploration complex should include a set of heat and mass transfer processes, representing a multiphase pulse and controlled geodynamic mode (Hutter and Beranek, 2020; Scisciani et al., 2019). Abiogenic hydrocarbons were found in hydrothermal systems of the seabed (Ma, 2020), crystalline rocks of both continental and oceanic origin (Kolesnikov et al., 2017), in meteorites (Zolotov and Shock, 2000) and other planets of solar systems (Lorenz et al., 2008). The atmosphere of any celestial body has suitable conditions for the formation of organic compounds from low molecular weight gases such as H_2, CO_2, CH_4. These compounds are considered as precursors of crude oil by some authors. The hypothesis of the abiogenic petroleum origin is subject to criticism because numerous facts confirm the connection of petroleum formation with biomass. Moreover, space chemistry confirms the presence of organic compounds on celestial bodies that do not have life.

The purpose of this study was to review scientific publications on the theories of petroleum origin and petroleum engineering to establish common patterns of oil and gas formation. The objective is to determine the probability of replenishment of world hydrocarbon reserves and search for alternative sources of hydrocarbons outside of the globe.

Justification of the Theory of Biogenic Petroleum Origin

The biogenic theory of oil and gas formation implies the fossilisation of biological material of sapropel type into the sedimentary rock mass. At a temperature of about 50°C, kerogen, a precursor of oil, starts forming. Further processes of thermocatalytic destruction, polymerisation, and polycondensation promote the production of hydrocarbons with carbon atoms ranging from 1 (methane) to 22. The mechanism of petroleum synthesis following the scheme "biomass-organic compound of geological rocks-petroleum" correlates with the findings of numerous researchers (Ma, 2020), who adhere to the biogenic theory of petroleum origin. At present, the biogenic theory is considered to dominate in biology and oil and gas geology.

The biogenic theory of petroleum and gas origin is based on the genetic connection between chlorophyll and oil porphyrins (Liu et al., 2018). The adherents of the biogenic theory believe that the source material for oil generation is biomass formed in the hydrosphere. These assertions are confirmed by the presence of particular biomarkers indicating the biogenic origin of petroleum. Studies on oil biomarkers and different types of natural hydrocarbons of aliphatic and aromatic series have special focus (Genovez et al., 2017). Markers for determination of genesis of petroleum hydrocarbons are, for example, isoprenoid hydrocarbons, porphyrins, and hydrocarbons containing an uneven number of carbon atoms (e.g., 13, 15, 17, and 19). The majority of biogenic fatty acids, which are precursors of oil, have an even number of 14, 16, 18, and 20 carbon atoms.

Justification of the Theory of Abiogenic Petroleum Origin

The abiogenic theory of petroleum and gas origin implies a short geological and geochemical cycle of hydrocarbons synthesis from chemical elements located in the Earth's interior and their subsequent conservation. In the nineteenth century, volcanic and carbide hypotheses were formulated. The first hypothesis assumed that crude oil appears from hydrocarbons released during the magma eruption, and the second hypothesis suggested that crude oil was formed in the subsoil as a result of water vapour exposure to heavy metal carbides. Scientists around the world are working to reproduce the transformation process of hydrocarbon derivatives into petroleum. Research work show that water plays an important role in the synthesising processes of hydrocarbons, resins, asphaltenes, and other substances, caused by the action of γ-rays and neutron flux on hydrocarbons and crude oil.

The oxidised medium does not affect the stability of the hydrocarbon mixture. Consequently, oil accumulations may exist throughout the depth mass of the Earth's crust, also, the oil balance of the Earth's crust may be much greater than currently expected. According to this concept, hydrocarbons are considered a product of the chemical reaction of inorganic compounds (carbon donors such as carbonates, CO_2, iron carbides, and pure carbon and hydrogen donors such as water, hydroxyl groups of minerals, and iron hydride) in the upper mantle. These compounds are found to be in a solid or molten (liquid) state in the mantle. In thermodynamically suitable thermobaric conditions and oxidation-reduction medium, hydrocarbon liquid is formed from carbon and hydrogen donors (Kutcherov et al., 2020; Serovaiskii, 2018):

$$nCaCO_3 + (9n + 3)FeO + (2n + 1)H_2O \rightarrow nCa(OH)_2 + (3n + 1)Fe_3O_4 + C_nH_{2n+2} \quad (1)$$

According to Barenbaum (2019) and Sorokhtin et al. (2020), hydrocarbons can be synthesised in the Earth's crust following the abiogenic scheme of reaction:

$$7Fe_2SiO_4 + 28H_2S + 4CO_2 = 14FeS_2 + 7SiO_2 + 22H_2O + 2C_2H_6 \quad (2)$$

Table 1 shows the calculation for the thermodynamic probability of the ethane formation reaction under normal conditions.

The data presented in the table demonstrate that this reaction is possible when the temperature rises to 1509.1°K and, due to the negative value of isobar-isothermal potential, is spontaneous even at normal pressure and temperature. Thus, during the subduction, the hydrocarbons of oil react with an iron-containing plate and mantle environment, which form iron hydrides in a depth of 100-120 km (2.6 GPa) (Barnes et al., 2018). At depths of 210 km (7.4 GPa), a mixture of iron carbide and iron hydride is formed. These substances can be stable in the upper mantle and participate in abyssal processes such as element cycles and the formation of abiogenic hydrocarbons. In addition to iron carbide, the carbons in hydrocarbons are converted into graphite and methane. A part of the hydrocarbons remains in the mixture whereas paraffin hydrocarbons are converted into aromatic substances and methane. CO_2 is not formed from petroleum hydrocarbons under oxidation-reduction and thermobaric conditions of the sinking plate and upper mantle. Methane is converted into heavier hydrocarbons in a simulated C-O-H fluid under thermobaric conditions corresponding to the upper mantle. A complex hydrocarbon mixture (up to C7) is formed from methane in colder zones of the upper mantle. The hydrocarbon mixture consists of waxes with linear and branched chains, naphthene, and aromatic hydrocarbons.

Unsaturated hydrocarbons seem to be intermediate products of methane transformation. CO_2 is not formed in a C-O-H fluid under pressure and temperature corresponding to the thermobaric conditions of the upper mantle. In warmer zones of the upper mantle layers, the hydrocarbon mixture formed from methane consists only of light hydrocarbons (up to C5). The hydrocarbons of oil are assumed to be actively involved in subduction. During this process, carbon from oil hydrocarbons turns into iron carbide, which can be transported to the mantle zones under appropriate thermobaric conditions becomes a donor for the abiogenic synthesis of hydrocarbons. Due to its very high density, iron carbide can form a single phase that can sink to greater depths, transporting hydrogen and reduced iron.

Thus, the current study suggests that oil hydrocarbons accumulated in the Earth's crust are actively involved in deep carbon processes. The possible existence of oil deposits in the entire range of depths of the Earth's crust, and therefore more oil subducted into the mantle, suggests a significant influence of hydrocarbons on the deep carbon cycle, which must be taken into account. However, this fundamental process does not result in the formation of CO_2. Instead, oil hydrocarbons are decomposed to simpler compounds, which can become intermediate links in the process of abyssal abiogenic formation of hydrocarbons, contributing to the accumulation of oil in the crust (Hovland et al., 2018). Thus, hydrocarbons may also occur on other planets (Schuster et al., 2020). The disadvantage of this theory is that characteristic markers for biological processes of petroleum formation are found in oil fields (Chen et al., 2017; Sun et al., 2020).

General Theory of Petroleum Origin: Role of Chemolithic Autotrophy in the Process of Oil Field Formation

As presented above, the general theory of oil and gas formation is based on the presence of biomarkers in oil. It determines the similarity between the chemical and morphological compositions of oil and biomass. Considering the biogenic and abiogenic theories, the general concept of hydrocarbons formation assumes the process of chemolithoautotrophy with the participation of active living matter at the intermediate stage of oil and gas formation. This process is not considered in oil and gas geology, however, it is widely studied by world scientists (Priyadarsini et al., 2020). The combined theory considers the following stages of hydrocarbon formation:

Table 1: The calculation for the thermodynamic probability of the ethane formation reaction under normal conditions

Type of substance	*Chemical compound*	*$\Delta G°f_{298.15}$, kJ/mole*	*Stoichiometric factor*	*ΔG, kJ/mole*	*ΔH, kJ/mole*	*ΔS, kJ/mole K*	*ΔG, kJ/mole t=298 K*	*Equilibrium temperature, K t_{eq}=dH/dS*
Reaction product	FeS_2	-151.82	14.00	-2125.54	-163.17	0.05	-	-
Reaction product	SiO_2	-856.67	7.00	-5996.68	-910.94	0.04	-	-
Reaction product	C_2H_6	-32.98	2.00	-65.96	-69.23	0.23	-	-
Reaction product	H_2O	-237.25	22.00	-5219.39	-285.80	69.96	-	-
Reacting agent	Fe_2SiO_4	-1377.00	7.00	-9639.03	-1477.79	0.15	-	-
Reacting agent	H_2S	-33.81	28.00	-946.68	-20.92	0.20	-	-
Reacting agent	CO_2	-394.38	4.00	-1577.52	-393.51	0.21	-	-
Thermodynamic parameters of the reaction	-	-	-	-7114.832	-8184.716	-5.423712	-6568.449	1509.1

1. Degasification: The chemical reactions occurring in the entrails of the earth are accompanied by the formation of carbon and other inorganic gas compounds and diffusing through the foundation into sandstone (59%), limestone, and dolomite (40%) horizons of sedimentary rocks. This stage includes the main provisions of the abiogenic theory of petroleum formation.
2. Metagenesis takes place after the stage of catagenesis in deep layers of sedimentary rocks occurring at elevated temperatures and pressures. Endogenous methane flows can be localised even at the bottom of water areas (Chen et al., 2017).
3. The chemolithic autotrophic cycle follows the stage of metagenesis in sedimentary rocks. The chemolitho-autotrophic process occurs in the lower horizons of sedimentary rocks and supply channels of the crystalline foundation of the oil field through the life activity of thermophilic strains of anaerobic organisms with the chemolithoautotrophic type of metabolism. Depending on the geological and geomorphological conditions of the field, the synthesis of hydrocarbons in the chemolithoautotrophic cycle is possible on a local or global scale. Chemicals similar to the composition of natural oil are obtained through the process of chemolithoautotrophy. Thus, the process of chemolithoautotrophy may be involved in the evolution of organic substances and the formation of oil deposits (Stetter and Huber, 2000; Youssef et al., 2009). The metabolism products of these microorganisms are methane hydrocarbons and water (Sun et al., 2020). The presented scheme is a link between biogenic and abiogenic theories of petroleum origin.
4. Oil and gas formation: As mentioned above, the biomass is considered a precursor of biomarkers of oil, porphyrins, and paraffin and unsaturated hydrocarbons with an uneven number of carbon atoms. Numerous scientists believe the sapropel to be the precursor of oil. At this stage, the processes of oil and gas formation occur that describe the biogenic theory of petroleum origin, including processes of fluidisation, the formation of micro-oil and water, and the subsequent process of oil migration.

Several groups of bacteria such as Proteobacteria (29.2%), Firmicutes (8.3%), Bacteroidetes (8.3%), and Actinobacteria (4.2%) were identified in the oil fields. Some authors suggest the dominant role of these bacteria in the elimination of oil contamination in the ground.

Thus, the main thesis of the unified concept of oil and natural gas formation in the interior's of the Earth explains the discrepancies in the biogenic and abiogenic theories and related inconsistencies and contradictions. However, an ecosystem approach is required for detailed studies in this area. The theses and calculations presented above suggest that the process of oil and gas formation includes some essential elements of bio- and chemosynthesis of hydrocarbons. The formation of methane from anaerobic microorganisms following the principle of chemolithic autotrophy is widely studied to produce methane in biogas from organic waste (Butar-Butar et al., 2020). The possible occurrence of anaerobic biosynthesis of hydrocarbons has been proven in the sedimentary rock mass (Stetter and Huber, 2000).

Hydrocarbons formed through hydrogen and oxide carbon are present in hydrothermal and fumarole natural gas mixtures and endogenous gases. These reactions are exothermic and emerge in active geodynamic zones like ketogenesis and unloading centres.

Synthesis of methane from CO or CO_2occurs through an exothermic reaction as follows (3):

$$CO + 3H_2 \rightarrow H_2O + Q \quad (3)$$

Biogenic methane is generated by anaerobic microorganisms in sedimentary rocks from biomass obtained at the stage of the chemolitho-autotrophic process. The methane then reacts with endogenous carbon oxides:

$$CH_4 + CO_2 \rightarrow 2C + 2H_2O + Q \quad (4)$$

$$CH_4 + 2CO \rightarrow 3C + 2H_2O + Q \quad (5)$$

Besides the methanogenesis process, chemolitho-autotrophic microorganisms enrich sedimentary rocks with organic compounds. Chemolithic autotrophs use inorganic compounds for their life activities synthesising organic compounds in the cell. These processes lead to the formation of hydrocarbon deposits in the depths in the form of layers and lenses. These types of deposits are not subject to the processes of primary migration. In further geological cycles, these organic layerings may become deposits of oil and gas.

Petroleum synthesis under anaerobic conditions is proved to be possible from endogenous methane, hydrogen, and carbon, which are deposited in sedimentary rocks (Liu et al., 2018; Roedder and Wolf, 1976). The geological approach is the most acceptable for the development of the general theory of oil and gas use. The combined theory provides the possibility of refining the existing classification of oil and energy resources. To predict the situation in the oil and gas market, it is important to clarify the possibilities of oil and gas reserves regeneration in the fields. According to the abiogenic and combined theory of petroleum and gas synthesis, fossil hydrocarbons are renewable natural resources. According to the new concept, one should expect stabilisation of the oil market and the emergence of alternative technologies for petroleum product synthesis, which revolve around the use of anaerobic microorganisms.

Conclusions

The analysis of literature sources stating the origin of hydrocarbons established that the chemolithoautotrophic cycle of oil and gas synthesis can elaborate a general theory of hydrocarbon origin. It combines both sources of organic substances synthesized following the mechanism of photosynthesis and chemosynthesis into a general scheme of oil hydrocarbons formation. A detailed elaboration is required for the general concept of oil and gas synthesis. According to the abiogenic theory for petroleum origin, hydrocarbons may contain fragments of other planets and probably a source of energy resources in the future. The thermodynamic calculation of hydrocarbon synthesis reactions performed in this research revealed the possibility of its occurrence even under normal conditions.

Acknowledgements

The work of Irina Volkova was within the framework of the state-ordered research theme of the Institute of Geography RAS, no. 0148-2019-0008 (AAAA-A19-119022190170-1) "Problems and prospects of Russia's territorial development in terms of its unevenness and global instability".

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