

The Origin of Petroleum: The Mystery Remains

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Summary

World's demand for oil is projected to grow 60% over the next two decades. In this respect, one may need to take a new look at the origin of petroleum to explore new horizons and better manage and predict hydrocarbon production in the existing oil and gas fields.

Despite overwhelming volume of data and visibly strong “pros” and “cons” of both theories of the origin of petroleum, the mystery remains. Research is being conducted to have a better understanding of the formation of hydrocarbon deposits and processes taking place in the rock/oil/brine system during the life of oil and gas fields. Petroleum is a system of hydrocarbons, metals and other components kept together by a variety of chemical and physical forces. Generation of hydrocarbons and formation of oil and gas deposits are not the same processes though they are close in nature. The paper provides a brief overview of the major biogenic and abiogenic theories of the origin of petroleum and results of the recent laboratory studies and field observations.

Theory

Two schools of thoughts exist in regards to the origin of petroleum: a Western school suggests that its origin is biogenic resulting from biological matter and stored in sedimentary basins while a Russian-Ukrainian school proposes that it is abiogenic with the deep origin in the Earth's crust. The first theory implies a finite source of petroleum whereas the second theory suggests an almost unlimited one.

Evidence for the organic origin of petroleum seem to be overwhelming: (1) petroleum oil is mostly found in sedimentary rocks rather than igneous rocks, such as granite and basalt; (2) petroleum has ability to rotate the polarization of light, which is typical for organic matter and is attributed to the presence of cholesterol; (3) many crude oils contain porphyrins, which may come either from chlorophyll in plants or from red cells in blood; (4) most crude oils contain nitrogen, which is an essential element in amino acids; (5) the chemical composition of the petroleum is similar to the composition of the organic material, although there is more carbon and hydrogen and less oxygen and nitrogen in the oil compared to the organic material, etc. [1-4].

However, as early as in 1877, D.I. Mendeleev, the Russian chemist who proposed the modern version of the periodic table, wrote that the petroleum deposits of the World are likely to be controlled more by tectonics than by the age of sedimentary rock [5]. Mendeleev proposed the metal carbide theory. In this model metal carbides deep within the Earth react with water at high temperatures to form acetylene which subsequently condenses to form heavier hydrocarbons. The Fischer–Tropsch process [6] is probably the second well known example of the possibility of formation of synthetic lubrication oil and synthetic fuel, typically from coal, natural gas, or biomass. The Fischer–Tropsch process involves a series of chemical reactions that produce a variety of hydrocarbons, in particular alkanes.

The carbon cycle, i.e. carbon exchange among the biosphere, atmosphere and other spheres of the Earth, also need to be considered. Volume and rate of carbon exchange is not well defined and is a matter of continuous debate. However, no one debates that the total share of carbon exchange is only 0.1 % of total carbon of the planet and majority of the carbon is stored in the Earth's depth.

While discussing the organic of petroleum, one need to understand what is "petroleum". Petroleum is a system of hydrocarbons, metals and other components kept together by a variety of chemical and physical forces. Generation of hydrocarbons and formation of oil and gas deposits are not the same processes though they are close in nature. Generation of hydrocarbons may take place in the Earth's depth while formation of oil and gas deposits is more complicated and involves microbiological activity [7], physical and chemical reactions associated with components of reservoir rock [8], plate tectonics [9] and other factors. Crude oils associated with different formations, age and locations have similarities in the composition but differences as well. An assumption can be made that more than one mechanism is responsible for formation of a particular petroleum deposit. One also need to take into account that petroleum deposits are not static and both reservoir fluids and reservoir rock change characteristics due to both natural factors and technology.

Results and Discussion

Results of several recent laboratory studies and some field observations an interesting development of the theory of petroleum genesis. If the observations are correct, then hydrocarbon reserves can be considered renewable and the peak oil predictions are to be left to the past.

A series of autoclave experiments with water, FeO and CaCO₃ was conducted by V.G. Kucherov and team to simulate conditions in the Earth's mantle at temperature as high as 1250°C and pressure as high as 50 MPa. Test results show formation of hydrocarbons such as methane, ethane, propane, etc. [10]. The authors show certain similarity of the hydrocarbon mix with light oil produced in the Bach Ho field, offshore Vietnam, where hydrocarbons are being produced from the highly fractured granite basement rock [11].

Petroleum genesis is typically studied in organic geochemistry based on biomarkers (pristane, phytane, sterane, etc.). Petroleum is known to also contain adamantane, diamantane and analogues. The spatial arrangement of carbon atoms in adamantane molecule is the same as in the diamond crystal. Reserach is currently underway to use adamantane and diamantane as geochemical parameters in particular for condensate and light oil which often contain no typical hydrocarbon biomarkers or such parameters provide little information. A recent study shows two different mechanisms of the formation of adamantanes. Adamantanes can form when paraffins (high-molecular n-alkanes) are exposed to high temperature (above 350°C) and can be also formed by bacteria [12].

In addition to the laboratory studies, some interesting field observations related to possible re-charge and/or infill of oil and gas fields have been recently published. The first example is Azerbaijan, one of the birthplaces of oil industry. Azerbaijan produces about almost 9 mln barrels oil per day and 29 bln cubic meters of gas per year [13]. Some wells drilled to the Pliocene deposits continue production after 100 years. Production data, 4 D seismic and detailed analysis of reservoir fluids give an evidence of the vertical fluid migration from the deep to more shallow horizons due the hydrodynamic effects [14].

The second example is Tatarstan. Tatarstan has been a major oil production region in the former USSR and still produces over 20% of all Russia's oil. Romashkino, a supergiant oil field discovered in 1948. The field has over a dozen of so-called "millionaire wells" which have produced over 1 mln bbl of oil and still keep on production. Despite different methods of reserves evaluation and some discrepancies in the old and new formation evaluation systems, the total volume of produced hydrocarbons is 4 times larger than expected [15]. Geological and production data collected for producing wells over a long period of time allowed researchers to come up with a hypothesis about of the re-charge or refill of oil wells which

takes place in the present time [16]. Crude oil properties in some wells change with time and it is expected (biodegradation, sulphate reducing bacteria, etc.). However, other wells keep producing the same crude oil as that in the moment of discovery. Does it mean that those wells are being supplied by “new oil”, i.e. one observes the oil field re-charge?

A study has been conducted for heavy oil in carbonates in the Akanakskoe field, Tatarstan. The study shows a re-charge of the Bashkirian deposits of the Middle Carboniferous carbonates containing heavy oil with oil [17]. Is it the oil inflow from closely located deposits or the oil is formed in situ, i.e. it is “new oil”? This is the question.

Changes in the crude oil composition after the discovery of the oil deposit and the beginning of production is known. Alekseevskoye oil field located in the Volgograd area in Russia is an example. The oil becomes lighter and the in situ pressure increases due to an inflow of light hydrocarbons [18].

Distribution of chemical elements in rock and fluids from oil and gas fields can provide valuable information about migration paths of hydrocarbons and processes associated with formation and a life cycle of hydrocarbon deposits. The emission spectral analysis is used in the study of the distribution of metals in petroleum asphaltenes and bitumoids extracted from the reservoir and basement rock of the Romashkino field [19]. Distribution of a number of trace elements supports the hypothesis about fluid migration between basement rock and sedimentary deposits of the oil field. A study of the distribution of iron-bearing minerals and Fe(II)/Fe(III) ratio by the Mossbauer spectrometry has been conducted for the basement rock samples taken from the well drilled in the basement of the Romashkino oil field [20]. The study shows reduction conditions in the rock which is a requirement for hydrocarbon migration paths.

Among different methods, isotope analysis is used to establish the source of hydrocarbons in the Volga-Ural basin. An overview of the studies in the regional geological context and data indicating the presence of several source rocks and independent petroleum systems in the Volga-Ural basin is provided [21].

The mystery of the origin of petroleum remains unsolved. More experimental and theoretical studies are needed. Results of the studies and hypotheses also need to be confirmed by the field observations.

Conclusions

Organic geochemistry, elemental analysis of reservoir rock and hydrocarbons, microbiological studies, isotope analysis are useful tools in understanding the origin of hydrocarbons in a particular reservoir and provide useful information about processes taking place in the formation while the oil and gas field is being developed. Both biogenic and abiogenic theories of the origin of petroleum have their “pros” and “cons” and need to be taken into account. This includes an integrated approach to get a better understanding of the life cycle of existing oil fields and exploration for oil and gas.

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