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The Role of Microorganisms in the Oil and Gas Industry

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1. Introduction

Microbial processes play an important role in industry, the protection of the natural environment and also in many parts of the economy. In recent years, interest in these processes and their practical application to prospecting for and exploring hydrocarbon deposits have increased rapidly. Microbiology Department of the Oil and Gas Institute has conducted research using various microbiological techniques and technologies. The results of this work, which has practical applications in the oil and gas industry, have been implemented in the Polish industry.

Microbiological methods are still attractive to the oil and gas industry, thus the methodology is being improved and modified to answer current needs and problems.

Microorganisms and biogenic processes can be used for a rational approach to prospecting for hydrocarbon deposits and in their exploration. On the other hand, uncontrolled and excessive microbe growth can lead to bacterial contamination e.g. the biodegradation of drilling fluids, microbiologically influenced corrosion and microbial contamination of oil and stored gas.

Several practical applications of microbial processes are listed below.

2. Microorganisms as indicators in prospecting for hydrocarbon deposits

In view of the connection between bitumen deposits and microorganisms, microbiological research has been a part of complex geochemical and geological prospecting methods in oil exploration for many years. The Oil and Gas Institute has conducted research using the microbial well survey technique and a surface method based on the isolation of bacteria which use hydrocarbons as their sole carbon source.

The first technique – the microbial well survey technique is based on the isolation of indicator microbes from oil and gas-bearing zones of cores representing different geological deposits using specialized microbiological media.

Mogilevsky's methodology has been modified, so that its scope has been enlarged and new methods of sample collection and analysis have been developed. The modified method allows us to determine the distribution of particular microbial groups and their level of activity in a geological profile by observing their hydrocarbon-oxidizing activity. Moreover, it allows an assessment of the potential areas of interest, and the geo-microbial data confirm the geochemical data on the distribution of an organic substance in materials. The advantage of this method is its high sensitivity, which allows us what allows to detect trace amounts of hydrocarbons. Examples of profiling diagrams were presented at the 11th International Scientific and Technical Conference "New Methods and Technologies in Petroleum Geology, Drilling and Reservoir Engineering" [9].

The second method, the surface-prospecting method [11] is based on the detection of anomalies in microbial distribution in soil samples. It is a method based on the premise that hydrocarbons are generated and/or trapped in subsurface oil reservoirs (at depth) and migrate upward in varying but detectable quantities. The seepage of hydrocarbons is a long-lasting process, but it is recognisable by the presence of analytically detectable (anomalous) concentrations of light hydrocarbons (C1-C5) in soils and waters. A higher concentration of these hydrocarbons is often correlated with an increased concentration of hydrocarbon-oxidizing microbes, such as methane-oxidizing bacteria and propane- and butane-oxidizing microbes, in the area above hydrocarbon reservoirs. Hence, the discovery of a surface geochemical anomaly can establish hydrocarbon accumulation in the area. Traps and structures along such pathways should be considered as significantly more promising than those not associated with such anomalies. The results of microbiological analysis of soil samples have been applied in geological studies [6] which concern concentrations of methane and the bacteria that oxidize gaseous hydrocarbons.

The advantages of the surface-prospecting method are many and include:

- evidence of the presence of hydrocarbon generation and migration,
- the low cost, ease and rapidity of sample collection and analysis,
- high sensitivity, which allows us to detect even “discrete” anomaly state on the assumption that the threshold value is estimated properly,
- the detection of hydrocarbons in both soils and on the sea-floor,
- the possibility of prospecting before conducting detailed seismic surveys,
- having little or no negative environmental impact and having the ability to evaluate areas where seismic surveys are impractical or ineffective due to geological factors,
- providing methods applicable to both stratigraphic traps and structural traps, with the ability to locate traps invisible or poorly imaged with seismic data or due to environmental factors,
- reproducibility of results,
- providing methods applicable in many different climate conditions,
- establishing a clear distinction between gas reservoirs and oil-bearing structures with gas caps.

The success of this method depends on defining background values adequately. This can fluctuate widely depending on the geological area. The level of background should define individually. Microbial examinations are a valuable supplement to complex geochemical and geological surveys conducted for the exploration of hydrocarbon deposits.

3. Biodegradation of drilling muds

The biodegradation of materials used in process of drilling, especially organic chemicals in drilling fluids, cement grouts and packer fluids, seems to be a problematic process. The presence of water and the availability of trophic substances are necessary for microbial growth in the drilling fluids. Organic polymers of high-molecular weight are the main source of carbon and energy for microorganisms, while mineral nutrients are taken up from emulgators, corrosion inhibitors, the water base or inorganic agents in drilling muds.

Complex microbiological studies of the water base used to prepare drilling fluids [1], polymer flushes at various stages of use and the biodegradation processes of polymer agents were conducted to obtain high quality and high stability materials for application in the drilling industry [15, 20]. The drilling companies are interested in an evaluation of the microbiological contamination of flushes as in the selection of effective antibacterial substances to meet technological demands and depositional conditions. This kind of research is common in the oil industry and gives a lot of useful information concerning the efficiency of applying antibacterial substances in deposits. Laboratory studies relating to the selection of suitable substances and their application in polymer flushes have been done in The Microbiology Department of The Oil and Gas Institute. The results of microbiological analyses of basic waters and drilling fluids were presented in an article in Nafta-Gaz, 1999 [15], tab. 1÷2 and in a publication (monograph) of The Oil and Gas Institute, 2007 [20], Fig. 1÷10.

The biological decomposition of many natural, semisynthetic and synthetic polymers in spite of their high microbial resistance are well described in the literature [22, 23]. Specific bacterial enzymes act on the bonds in polymer molecules and reveal the monomeric units which are used as sources of carbon, nitrogen and phosphorus by micro-organisms. For many years polymeric agents have been used in the technology of drilling fluids. Compared to conventional fluids, organic polymer-based drilling fluids are more efficient, less toxic and more environmentally friendly. However, they are characterized by high sensitivity to biodegradation, thus protection against degradation, especially polymeric agents, involves using suitable biocidal agents. On the other hand, the biodegradation process is beneficial for the remediation of waste drilling fluids [12, 13].

Microorganisms are the key players in many environmental processes as in technological processes thanks to their metabolic activities. Their fast metabolism, the variety of their catalyzed chemical reactions, their physiological adaptations and the variety of products synthesized by using them affect microbial applications and allow us to control the course of microbiological processes. As mentioned, the biodegradation of polymer-based drilling fluids has an important impact on drilling technology. The root of this is the metabolic utilization of organic compounds contained in drilling fluids by many groups of bacteria, yeasts and fungi. Aerobic microorganisms are heavily responsible for the fast, biological decomposition of flushes. Anaerobic biodegradation is also important and results in changes in the parameters of flushes, although these processes are much more slower than aerobic ones. The presence of microorganisms in drilling fluids results from contamination during the preparation and storage of flushes and also from contact with bacteria in deposits.

This processes can be troublesome during well drilling. In spite of preventative action, the uncontrolled development of microflore, resulting as it does a deterioration (decrease) in the technological and rheological parameters, is a problematic phenomenon. Appropriate parameters of flushes are specially important during the process of drilling. The microbiological state of the water base used to prepare drilling fluids in industrial conditions influences the quality and stability of flushes. The microorganisms in the water participate actively in biodegradation processes and are a cause of the contamination of flushes. The numbers and activity of these microorganisms depend on the chemical composition of the drilling fluid and on other parameters such as temperature, pH and the conditions of water storage.

In the high alkaline conditions of drilling fluids, some enzymes are inactivated and cell structures are damaged. However, some microorganisms adapt to these severe environmental conditions and can tolerate or even prefer an extremely high pH for their optimal growth and activity.

Studies in this field include:

- an evaluation of the microbial contamination of the drilling fluids used in the national oil,
- industry,
- the isolation of microorganisms which cause the polymer biodegradation,
- the influence of microorganisms on the rheological parameters of drilling fluids,
- the elaboration of preventative strategies against polymer biodegradation.

The drilling fluids used in the national drilling industry have been examined in recent years. We have controlled the degradation of the polymers, i.e. carboxymethylcelullose, starch derivatives and polyacrylamide, found in drilling fluids. Many fluides contain organic compounds to block leakage of fluid during drilling, but this sharply accelerates the biodegradation. Laboratory studies have been carried out to address this problem. Moreover, the biological sulphate reduction processes by anaerobic sulphate-reducing bacteria were examined.

With this in mind, changes in the rheological properties of the drilling fluids caused by microorganisms were measured. The aim of these studies was to establish how microorganisms influence certain properties of fluids and also to assess their quality and stability. Isolated microorganisms were used to assess the permeability of reservoir rocks [4, 5, 17]. This data was necessary to estimate the utility of these microorganisms in the elimination of damage to a wellbore zone as a result of clogging. The results of bacterial clogging and damage to rock permeability are shown in Fig 1÷2 [17]. The examined microorganisms decrease damage to the wellbore zone and remove filter cake in model cores. It is important that bacteria degrading the polymers should not block the pore zone of the rock. Currently we are focusing on searching for microorganisms which are capable of decomposing more resistant polymers like xanthan and guar gum. One result of microbiological analysis which concern on the isolation of bacteria that degrade xanthan polymers was the publication of three new DNA sequences in The International Center of Biotechnology Information. These sequences of *Pseudomonas sp.* and *Mycobacterium sp.* (presented by P. Kapusta. J.

Brzescz, A. Turkiewicz) were submitted to the GenBank database in December 2010.

3. Microbial Enhanced Oil Recovery (MEOR)

One of the major concerns facing the oil industry today is the recovery of the large percentage of oil remaining unrecovered in mature and in nearly depleted oil fields. Loss of production caused by paraffin and asphaltene depositions is also problematic.

Thus, enhanced oil techniques such as gas injection, water flooding, chemical and surfactant flooding have all been investigated. However, these methods, which are called tertiary oil recovery technologies, have limitations that restrict their effectiveness. In particular, the total cost of oil exploration using EOR techniques is higher, so that in many cases these processes are not found to be economically viable. Therefore, alternative cost-effective methods which are also environmentally friendly are in demand. On these grounds, microbiological methods based on the metabolic activities of bacteria seem to be attractive [2, 7]. Several specialized companies which apply microbial enhanced oil recovery methods have been set up.

MEOR is already used in Argentina, China, Canada, Venezuela and the U.S. Outcomes obtained from hydrocarbon deposits localized in the North Sea, Mexico, Trinidad and Australia have shown great potential for the application of this technique. Among the useful microorganisms in MEOR are *Pseudomonas sp., Bacillus sp., Brevibacillus sp., Agrobacterium sp., Sphingomonas sp., Rhizobioum sp., Coprothermobacter sp., Thermolithobacter sp.* [25], tab. 1, Fig. 2.

The selection of appropriate microorganisms, with a demonstrated potential to be used in oil recovery is crucial.

Microbes can influence and improve the oil recovery process by:

- generating gases that increase reservoir pressure and decrease oil viscosity
- generating acids that dissolve rock, thus improving absolute permeability
- reducing permeability in channels
- producing bio-surfactants that decrease interfacial tension

- reducing oil viscosity by degrading long-chain saturated hydrocarbons

Microbial enhanced oil recovery (MEOR) involves stimulating indigenous reservoir microbes or injecting specially selected consortia of natural bacteria into the reservoir to produce specific metabolic products that help to improve the recovery of crude oil from the reservoir rocks. The microbes in MEOR are typically hydrocarbon-utilizing microorganisms, so the ability to degrade hydrocarbon is the main criteria for the selection of microorganisms. The MEOR processes that facilitate the oil production are complex and involve multiple biochemical processes in crude oil. The proportion of short-chain hydrocarbons (<C15), as the transport fluid portion of the oil, is increased, whereas suspended debris and paraffins are degraded and removed from the region near the wellbore.

There are several environmental factors which affect MEOR operations which should be considered for successful microbial treatment and the resulting enhanced oil recovery. Those are salinity, wide range of pH, tolerance of bacteria to growth in anaerobic and aerobic conditions, and tolerance to higher temperatures. These factors should be taken into account before MEOR operations. The motility of microorganisms used to be considered a crucial factor although now it is believed that microbes are transported with reservoir fluids, colonize in the pore space of the reservoir rock and interact only at the water-oil phase boundary.

Fundamentally, MEOR technology is based on the injection of microbes into the reservoir, and frequently nutrients must be injected to stimulate their growth and enhance their performance. However, the preparation of microbial suspensions is a time-consuming process. The stimulation of the metabolic activity of indigenous bacteria in the oil reservoir can effectively reduce the cost. As well as the stimulation of oil extraction, control of corrosion and elimination of H_2S are also possible.

4. Prevention of the biogenic formation of H_2S

The underground storage of natural gas in depleted reservoirs [14] needs an evaluation of methods for preventing the harmful actions of microorganisms. The main reason for the decreased quality of natural gas is the bioreduction of sulphates leading to the sulphating of gas.

The metabolic processes of sulphate-reducing bacteria (SRB) result in the formation of H_2S which hampers exploitation. These groups of microorganisms exhibit a significant tolerance to extreme environmental conditions and are also resistant to many antibacterial substances.

Contamination of the water in hydrocarbon deposits is causes suphating in the storage of gas. These conditions create a convenient environment for the bacteria. The hydrocarbons stimulate bacteria growth and cause the formation of biofilm (a membrane consisting of bacterial cells and their metabolic products) on the inner surface of reservoirs and pipes. Among the sulfate-reducing bacteria under reservoir conditions are *Desulfovibrio gabonensis, Desulfovibrio longus, Desulfobacter vibrioformis, Desulfotomaculum nigrificans, Thermodesulfobacterium mobile* [24].

In order to efficiently prevent the processes which lead to the formation of H_2S in deposits and microbiologically influenced corrosion, it is necessary to control the bacterial and chemical state of the water in a hydrocarbon deposit, and the composition of natural gas in storage. Underground stores regulate the daily, monthly and seasonal demands of gas and guarantee the energy security of Poland, so microbiologically induced corrosion in the underground storage of gas is a particularly dangerous phenomenon.

The tasks of isolating sulphate-reducing bacteria and sulphate-oxidizing bacteria from the deposits, and selecting efficient antibacterial substances were carried out, performed at several storage locations and resulted in many practical applications. The stages of applying biocides into reservoirs (underground gas storage) have been described in a patent submission and publication [18, 21]. These results met with special interest from specialists (Society of Petroleum Engineers), and were presented at an ATCE Conference in Houston [6]. The results are shown in tables 1÷3 in the SPE Paper nr 89906 and in an article presented at The

Scientific Conference, Łódź 2003 [16], tab. 1÷2. Most efficient H_2S Scavengers and biocidal agents tested in laboratory were products based on triazine derivatives – SULFAKS BS 11 and BIOSTAT (products of PSPW Company). Patent submission P. 383874 which concerns methodology for the elimination of bacterial pollution in salt cavern – underground gas store won a distinction at “The Belgian and international trade fair for technological innovation – EUREKA”, which took place in November 2009 in Brussels.

Fig. 1, 2. The Polish underground store of natural gas, where technology evaluated by the Oil and Gas Institute was applied. The synergistic use of biocidal agents and H_2S Scavengers
Rys. 1, 2. Polskie podziemne magazy gazu ziemnego, w których zastosowano technologię opracowaną przez Instytut Nafty i Gazu. Jednoczesne zastosowanie bakteriobójczych reagentów i usuwania H_2S

5. Microbiological degradation of liquid fuels

Liquid fuel storage, apart from gas storage, is also an important problem, since fuels can constitute a substrate in metabolic pathways for many groups of microorganisms. Microbial activity, harmful to many types of fuels causing degradation, causes the economical losses. Biogenic processes on the bottom of ground storages of fuels, in the water phase and at the boundary between the water and oil phases are the reasons for this phenomenon. The biodegradation of liquid fuels is a result of the metabolic activity of bacteria (mainly *Actinobacteria*) and also fungi. Based on microbiological studies of polluted diesel oil and heating oil, we have established the presence of aerobic and anaerobic microorganisms.

The microorganisms were isolated from 3 media:

- oil phase,
- water-oil phase,
- water phase.

Thus, tests were conducted to select optimal antibacterial substances, i.e. those which most effectively eliminate the microorganisms which cause biodegradation. Biocidal agents based on amines applied to liquid hydrocarbon storage, were used in these studies. The results of the microbiological tests were put into practice applied by the national oil refinery industry [3] and published at The International Conference "Geopetrol 2000" [8].

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Zastosowanie metod mikrobiologicznych w przemyśle naftowym i gazowniczym

Streszczenie

Artykuł omawia zastosowanie metod mikrobiologii złożowej w przemyśle nafty i gazu. Przedstawiono badania procesów związanych z poszukiwaniem oraz eksploatacją złóż węglowodorów, w których istotną rolę pełnią mikroorganizmy i procesy biogenne. Szczególną uwagę zwrócono na występowanie i aktywność bakterii wskaźnikowych oraz na procesy zachodzące w płynach wiertniczych, a także omówiono mikrobiologiczną metodę intensyfikacji wydobycia ropy naftowej. Ponadto zaprezentowano badania procesów mikrobiologicznych w problematyce magazynowania gazu ziemnego w warunkach złożowych.