ISSN 0965-5441, Petroleum Chemistry, 2012, Vol. 52, No. 2, pp. 133–137. © Pleiades Publishing, Ltd., 2012.
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Environmental Problems of Sustainable Management of Oil and Gas Resources and Production of High-Quality Petroleum Products

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Received January 22, 2011

Abstract—Sustainable management of oil and gas resources implies solving environmental problems pertinent to all sectors of the oil and gas complex. Progress in this area associated with advanced technologies for reducing crude oil production and transportation losses, improving the environmental safety of petroleum products and their production processes, and recycling waste petrochemicals has been discussed.

DOI: 10.1134/S0965544112020065

The global depletion of resources of raw materials for the oil and gas complex and in other industries has become the matter of serious concern [1]. In view of the current and projected demands for the quantity and quality of petroleum products to be supplied to the consumer, it is necessary to develop prospective mineral deposits in order to ensure the required production gain from inactive fields, to significantly intensify works on reactivation of suspended wells, and to unconditionally start implementation of up-to-date enhanced oil recovery techniques.

Physicochemical methods are basically used for increasing the oil recovery factor in order to improve the production potential and current production of developed fields [2–4]. There is information about the use of techniques that involve hydraulic fracturing of formation [5–9] or acid treatment of bottom-hole zones [10–19]. We do not deny the efficiency of these methods; however, some factors, such as noncompliance with technical specifications, can lead to failure of reservoir integrity (hydraulic fracturing) and, hence, a decrease in the oil recovery factor and soil and sewage water pollution with aggressive fluids.

An environmentally friendly method is the use of microbial technologies in the petrochemical industry, which has found wide application, in particular, with the use of compositions that do not contain corrosive components for enhancing oil recovery. These compositions stimulate the vital activity of oil formation microflora, thereby leading to an increase in concentration of biosurfactants and, as a consequence, in the oil recovery factor [20–23]. These effects are enhanced if there is evolution of an additional amount of CO_2, which is formed during the biohydrolysis of the components of oil-displacing compositions. In addition, oil viscosity decreases.

Recent years have seen a rise in the number of studies concerning enhanced oil recovery techniques that involve thermal stimulation, such as steam injection [24–26], and wave treatment of formations [27–29]. Methods for improving the oil recovery factor using nanotechnology [30–33] and polymer materials [34] have been also developed. Aiming at sustainable management of mineral resources, a long-term state program of oil production is being implemented now. It is supposed to limit through licensing agreements the minimum and maximum levels of oil production at each site and to toughen the safety regulations for pipeline transportation systems.

However, it should be noted that even the strictest requirements for reliability and trouble-free operation of the entire process flow of production and transportation of oil cannot ensure the absolutely safe operation of pipeline systems. Therefore, oil companies foresightedly invest in measures on corrosion protection, timely pipeline cleaning, and the use of viscosity-reducing petroleum additives that will ensure the maximum possible readiness to prevent accidents. Unfortunately, domestic corrosion protection materials for pipeline coating are quite rarely used. However, new materials, including those based on polymers, are being tested at present; a development that can be regarded as very promising [35–38].

There are a fair number of proposals on the use of polymer compositions not only for improving oil rheology, but also for oil production and transportation technologies [39, 40]. Polymer compositions have been tested in practice for cleaning pipelines and oilfield equipment to remove the products of crystallization of normal paraffins [37].

The environmental management undoubtedly covers the cleanup of oil spills. As before, the bulk of spilled oil is currently removed by mechanical means

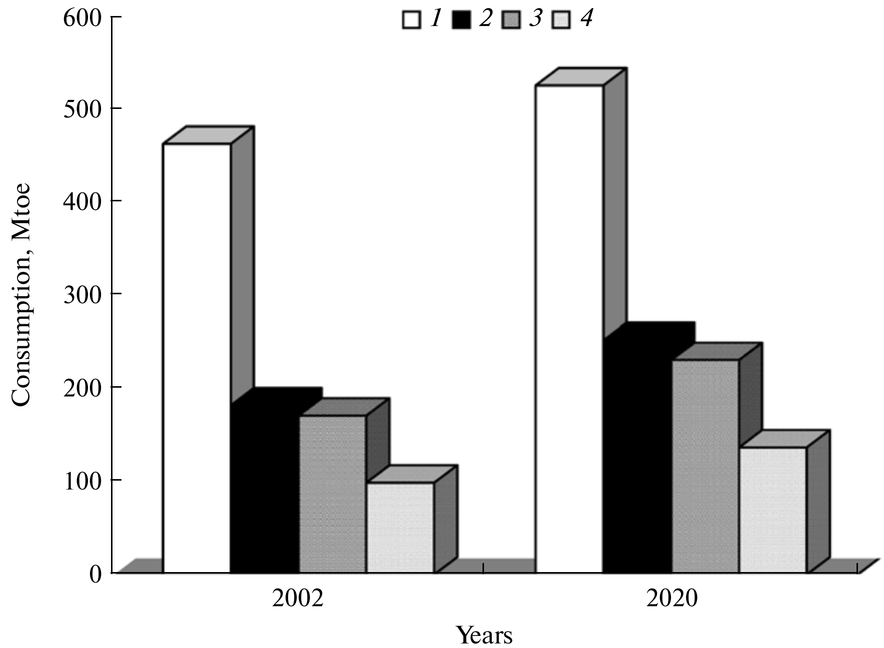

Fig. 1. Structure of the domestic consumption of fuel and power resources: (*1*) gas, (*2*) crude oil and refined products, (*3*) coal, etc., and (*4*) nonfuel resources [59].

[41, 42]. Of course, the design of oil skimmers is being perfected, of which drum skimmers are most widely used [43]. The use of various sorbents for remediation of soil and water contamination makes it possible to significantly improve the situation [44–48].

At present, in addition to the above methods, in situ burning of oil spills on water surface is used; it provides a possibility to almost completely remove spilled oil from the water surface; however, this partially disrupts the functioning of aquatic ecosystems.

For oil-polluted soils, mechanical treatment is followed by their fine purification on off-site bioremediation pads. At present, there are promising research works that expand the possibilities for the cleanup of soils using surfactants, bioremediation, and other methods [49–57].

The so-called method of fine soil remediation, including the use of mixed cultures that are well digested by microorganisms, also holds much promise. The most impressive results are obtained with the use of soil-ameliorating minerals and peat–mineral compositions, which contain a significant amount of hydrocarbon-oxidizing microflora [58].

The oil refining industry is a key element of the oil complex; it determines the efficiency of use of hydrocarbon feedstock, which meets the country's demand for motor fuels, lubricating oils, and other petroleum products. According to the development strategy of the oil and gas complex, the structure (Fig. 1) and dynamics (Fig. 2) of the domestic consumption of fuel and power resources are expected to change [59]. By 2020, the increase in oil refining throughput can reach 210–215 million tons per year with a simultaneous increase in oil refining efficiency to 80–85%. The overall production of motor fuels (gasoline, diesel fuel, aviation kerosene) can increase to 130 million tons in 2020. However, the current status of oil refining in Russia leaves much to be desired. According to the quantitative characterization of this branch, Russia ranks second in the world, but as regards the quality, it is one of the last among 75 countries that cover 98% of global refining.

By the intensity of negative impact on the environment, oil refining keeps up with oil production. The hazardous emissions into the atmosphere are composed of the following compounds (in percent of total emission): hydrocarbons, 23.0%; sulfur oxides, 16.6%; nitrogen oxides, 2.0%; and carbon oxides, 7.3%. The concentration of harmful substances in water and air near oil refineries exceeds the maximum allowable concentration by tens or hundreds of times [60].

It is obvious that one of the most urgent problems is the treatment of oil sludge, which is large-scale waste from the petrochemical and petroleum refining industries, and other waste solids. This problem is discussed in detail in review [61]. Unfortunately, since then, the situation has not changed significantly, and the developments are still far from practical implementation. The number of publications on this problem has not significantly increased in recent years [62, 63].

In addition, solid wastes at oil refining facilities include various chemicals, unrecyclable adsorbents,

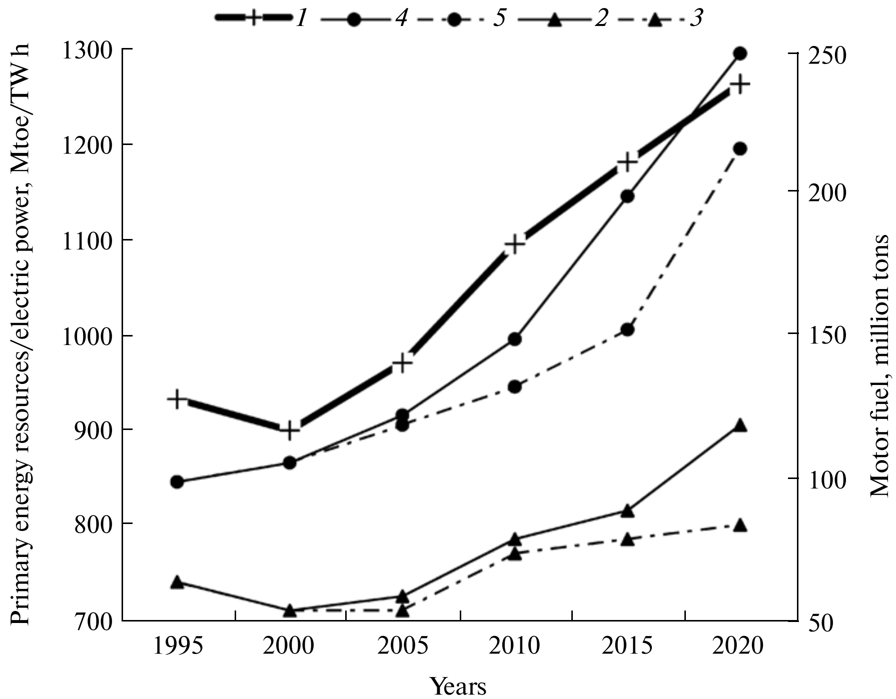

Fig. 2. Dynamics of the domestic consumption of fuel and power resources: (*1*) primary energy resources; (*2, 3*) motor fuel: optimistic and moderate case, respectively; and (*4, 5*) electric power: optimistic and moderate case, respectively [59].

ashes and solid products that result from thermal sewadge treatment, various deposits, tars, trapped particulate emissions, spent catalysts, etc.

The simplest scheme for their disposal, if appropriate in principle, is destruction via burning in furnaces of various types. The resulting ashes and slag in some cases can be used as a filler in the production of construction materials; less frequently, they are used as a fertilizer and even more rarely as a source for recovery of individual components.

Waste water contains various compounds, such as sulfates, chlorides, nitrogen compounds, phenols, and heavy metal salts. To date, wastewater treatment processes including the use of ash and slag waste, plant raw materials, individual organic compounds, and surfactants [64–67].

Other proposed methods involve the use of modified sorbents [68–80], including the ones based on various polymers and polymer materials [77], ultrafine oxide adsorbents [78], and natural zeolites [79, 80]. The diagram shows some quantitative data that characterize the ecological situation in the oil refining industry of Russia [81].

The principal line in the development of oil refining is retrofitting and fundamental reconstruction of operating refineries with the advanced building of facilities with enhanced oil refining efficiency, improvement in quality of petroleum products, and manufacture of catalysts. In this context, the problem of implementation of environmental catalysis is of particular importance. Here, new approaches to the design of environmentally clean processes have been clearly identified. The advances in this area were discussed in [82].

The new environmental catalysis processes proposed are far from being fully implemented, and the reconstruction of refineries must involve vacuum gas oil catalytic cracking units, in which the losses during coke firing make 5.0–6.5% of the feedstock and the gas emissions of carbon, sulfur, and nitrogen oxides from tube furnaces are large. Even the most popular hydroforming and dewaxing processes are a source of air pollution with benzene, other aromatic hydrocarbons, etc., despite the fact that practical recommendations on the improvement of the environmental situation at refineries, including off-gas cleanup and recovery of precious metals from spent catalysts and other solid waste from oil refining facilities, were advanced long ago [60]. The processes for multipurpose utilization of zeolites have been recently proposed [83]. If at least part of the waste were recycled to derive hydrocarbon products, this would be an excellent supplement to the production of hydrocarbon feedstock.

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