Technogenic hydrocarbon reservoirs and geoenvironmental issues in the city of Grozny

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Abstract. This paper is devoted to the history and current state of the issue of pollution of the geological environment and formation of technogenic petroleum reservoirs in the territory of the city of Grozny as a consequence of petroleum-related industrial activities. The area of Grozny was analyzed for subsurface contamination with petroleum products. Recommended actions for the remediation of the geological environment from petroleum contaminants are provided.

1. Introduction

Hydrocarbon contamination of the natural environment has become one of the most acute environmental problems, especially in the areas where oil is extracted, processed, and transported. The main pockets of pollution (technogenic hydrocarbon fields) are connected with oil extraction sites, oil processing facilities, and other sources. In the areas of such sources, technogenic flows form around production wells of well pads, sludge pits, and sites of accidents at wells and pipelines; technogenic pollution also occurs at the sites where oil and its products are processed and consumed [2].

The Chechen Republic is one of the oldest oil-producing and processing regions both in the country and in the world, and the long history of petroleum-related industrial activities here caused the technogenic transformation of the natural environment. Numerous oil spills at extraction sites, from transportation pipelines, and storage terminals of petrochemical enterprises have led to the formation of technogenic petroleum reservoirs that cause contamination of groundwater and water intakes with petroleum products and phenols. For these reasons, the issues connected with the further understanding of the geological environment are particularly acute for the territory of the city of Grozny [3-7].

2. Materials and methods

This research is based on the results of the studies carried out by the Grozgiproneftekhim institute, the Chechen-Ingush geological expedition, the Soviet-German joint venture "EPEK", and OAO Geosintez from 1966 to 2008, on the data from the available literature, as well as on the results of research by particular authors [1-8].
3. Research results and discussion.

The issues of the history of petroleum industry development in the Chechen Republic have been considered in a number of studies [1, 7 et al.]. The extraction and use of oil at the sites of its natural seep to the surface began in the territory of the Chechen Republic in the distant past. From 1819 to 1892 oil was extracted using improvised methods. At that period, the technique of oil extraction was limited to scooping it out of a well with buckets or ladles. The purpose of makeshift oil processing in Grozny was to obtain lighting kerosene. At that time, the leftovers of oil processing (gasoline, naphtha, heavy oil, etc.) were dumped into drain wells and pits.

As the volume of oil processing and transportation increased, the scale of the environmental pollution increased along with it. The processing facilities polluted the river water and the air with their waste. The increase in oil extraction rate facilitated the need to build oil refineries, whose output in 1900 amounted to 303 thousand tons of oil per year. Due to the primitiveness of the technologies, the output of refined oil products comprised: 5-10% gasoline, 3-4% naphtha and 7—11% kerosene. The total output of light fractions was 18—20%. The rest went to waste.

The mainstream petroleum product in the early 20th century was fuel oil, whose average output was 75% from oil. Kerosene was the second in importance, gasoline was the third. The total output of kerosenes, depending on the demand, was 12—20% of all refined oil. Naphtha was used for heating steam boilers and distillation stills. The naphtha that was left undemanded was dumped into absorption wells. This is why the territory of Grozny is still marked with groups of wells that emit gases generated by the oxidation of oil products (CO, CO₂, aldehydes, etc.). Until 1902, the output of gasoline did not exceed 2%. In 1906—1907, its average output was 6.5%. 1516 thousand tons of crude oil and natural gasoline were processed in 1917.

In 1926—1928, four-fifths of all gasoline and kerosene produced in the country was yielded by the plants of Grozny and 38% of the entire country's petroleum export was made out of Grozny [1]. In 1931, the share of Grozny petroleum facilities in the total oil production in the USSR reached 36.1% while in terms of gasoline, now the leading product, it was 73%. In 1980, the volume of oil processing reached 18 million tons per year, meeting the demand of the southern regions of the USSR for the basic types of petroleum products. In 1970—80, the volume of oil processing was at a stable level of 20 million tons per year. It was in the Grozneft enterprise where the maximum oil extraction volume of 21.6 million tons was achieved in 1971 and the maximum oil processing volume of 20.3 million tons was reached in 1982.

Technogenic reservoirs of oil products form in the areas of intense petroleum extraction and processing as a result of hydrocarbon spillage and their oozing below the surface. One of such areas is Groznensky District. Oil processing started in Grozny in 1864 when oil distillation stills were built in its vicinity to produce lighting kerosene. During the distillation, 40% of the oil was refined into lighting kerosene while the leftovers of the process (heavy oil, gasoline, etc.) was dumped into drain pits. This was what started the petroleum contamination of soils and groundwater in the city of Grozny. Industrial extraction and processing of oil started in the late 19th century. Spilling of oil and its penetration into the topsoil has started here back in 1895 when a strong gush of oil was produced from Well 7. In the first days, the well would spew up to 16 thousand tons of oil, which flooded a significant territory around it.

In 1917—1918, 11 wells at Grozny oilfield were blowout wells. In the early 30s of the 20th century, the annual output of oil was increased to 8 million tons. Oil was stored in pits and more than 10% was wasted (it seeped into the ground). Some products of oil processing (kerosene, heavy oil, etc.) were burnt due to lack of storage facilities. Several reservoirs of hydrocarbons formed in the course of the long period of operation of an oil processing facility in Zavodskoy district of Grozny.

Water bodies of the Chechen Republic were characterized with a high degree of contamination. The maximum content of harmful contaminants was identified in the Sunzha River. The highest contamination of both the surface water and groundwater occurred due to petroleum products (concentrations between 2 and 24 TLV) and copper compounds (2–8 TLV).
Armed conflicts in the Chechen Republic resulted in the destruction of oil terminals, oil refineries, a chemical plant, as well as of pipelines for oil and oil products. The political instability allowed for the widespread occurrence of theft of oil products from storage facilities and pipelines accompanied by large-scale spills of oil and its products. This caused the contamination of soils, surface water, and groundwater.

The armed conflict caused a virtually complete halt of all activity of the Republic's oil-extracting and processing industry that used to be the main source of the contamination of water bodies, but their quality continued to deteriorate. Theft and makeshift extraction of oil were rampant. The number of makeshift oil distillation stills in the territory of the Republic amounted to approximately 1.5 thousand. The stills themselves were frequently erected on river banks, which aggravated the negative impact to water bodies. As the result, large river such as Terek, Sunzha, and Argun were polluted. Oil spills in water are considered more dangerous than land spills where oil and its products are contained by soil particles for a certain time. The oil settling at the bottom and the bituminous substances absorbed by the bottom sediments often become buried, which increases the duration of the natural self-purification. Such bottom sediments become the source of secondary contamination of water bodies.

As a result of the operation of the oil industry, significant amounts of oil products accumulated in the vadose zone and formed floating lens at the surface of groundwater that partially dissolved in the underground waters. The mobility of groundwater lead to its becoming a powerful agent of transporting contaminants to large distances from their focus point with partial wedging out of the oil products that accumulated underground to surface water streams and bodies.

As indicated by the industry practice, spills are estimated to comprise 1-3% of the annual production volume. The cumulative production of oil from the oil fields of the Chechen Republic throughout the period of more than 100 years amounts to around 350 million tons. Consequently, the total volume of spills at the facilities can be estimated at approximately 3-6 million tons. Besides, the total losses of oil caused by the armed conflicts on the territory of the Chechen Republic in the period from 1994 to 2004 are estimated to be around 14 million tons.

Three oil processing plants, a petrochemical facility, and other industrial enterprises the existed previously on the territory of Zavodskoy District of Grozny have been destroyed, but the largest industrial dump for oil processing waste located to the northwest of the District in the Andreevskaya valley remains a source of groundwater contamination.

Another source of petroleum products in the groundwater are the contaminated soils in the territory under research. Large fields with increased concentration of petroleum-derived organic carbon have formed in them due to leaks, spills, etc.

Regardless of the intense extraction and production of oil, environmental problems did not receive appropriate attention, which can be seen in the fact that the first works to delineate the technogenic lens of petroleum products began only in 1966. In 1991—1993, these studies were continued. However, the work was interrupted due to the breakout of hostilities in 1994. In that period, technogenic reservoirs were developed indiscriminately, chaotically, and using barbaric techniques: digging deep trenches, opening the formation in long intervals with deep moats, all in the complete absence of any systems to monitor the "behavior" of the petroleum lenses. The second military campaign (1999—2000) was marked with high-intensity warfare in Zavodskoy District accompanied with aerial bombardment of the oil industry infrastructure objects. This lead to the formation of hydraulic windows and boudinage of the united technogenic reservoir. In was only in 2007—2008 that the studies could be continued.

The effect of the petroleum industry on the geoenvironmental environment is clearly visible in the example of the city of Grozny where the largest oil-processing and petrochemical enterprises in the country were concentrated and connected by a dense network of pipeline communications. In 1960—1970s, three large fields of petroleum product accumulation were identified in Zavodskoy District of Grozny: Eastern, Central, and Southwestern (Fig. 1). The Eastern reservoir is the largest. The first works to delineate the lens began in 1967 and continued in 1978. The Eastern reservoir occupies the entire territory of the Lenin plant and spreads far outside its limits into the urban development [5].
In 1991, NPPF GIDEK carried out specialized geophysical studies in the area of the Eastern reservoir using high-frequency geolocation. This allowed to identify the limits of the reservoir and the thickness of the layer of oil products floating on the surface of groundwater. More than 10 observation core-drill wells were drilled that confirmed that the geophysical materials were interpreted correctly. Furthermore, around 30 previously drilled wells were restored. Test pumping was performed for all wells. All of this allowed to obtain the necessary materials to estimate the volume of the accumulated petroleum products. Contour lines of the thickness of the floating petroleum products were drawn according to the data from the geophysical and drilling works. The area of the Eastern lens within the limits of its delineated part comprises about 2.5 km$^2$. The thickness of the oil products, according to the radar data, varies from 0.5 to 3.5—4 m, reaching 4—6 m for specific wells. The volume of the accumulated petroleum products is estimated to be 800—900 thousand m$^3$.

The Central petroleum lens is territorially coincident with the southern edge of the Sheripov oil refinery. The lens is U-shaped and stretches for 700 m from the southwest to the northeast. The petroleum lens overlies groundwater. Formation depth: from 4.3 to 7.8 m. Petroleum thickness: 3.5 m. The Southwestern petroleum lens is dispersed along the southwestern part of Zavodskoy District. The maximum thickness of the petroleum layer was 1.85 m. Formation depth: from 2.4 to 7.4 m. The total area of the lens is estimated to be 0.56 m$^2$.

In 1991, The Soviet-German joint venture EPEK started borehole extraction of petroleum products using inefficient technology that exacerbated the situation. In the current situation, without localizing and remediating the pockets of groundwater pollution by oil products, the main reserves of fresh groundwater in artesian aquifer basins of the Republic can be irretrievably lost in a matter of several decades. It should be noted here that the petroleum products that have already penetrated into the underground hydrosphere of the region are enough to contaminate all geological reserves of fresh groundwater up to the level of 50—150 TLV [4].

Further studies were started in 2002. The scope of the research carried out by OAO Geosintez was very large and reflected the environmental and geological components of the natural environment that was negatively affected. The performed set of ground-penetrating radar studies, geochemical sampling of waters, gas survey, and studies of thermal fields allowed to identify and delimit the anomalous areas interpreted as zones of maximum pollution of groundwater by petroleum products. The obtained data was used to carry out drilling works [6].

The results of the work conducted to assess the state of soils in the area of Grozny showed their significant contamination. The analysis of soil samples allow to make a conclusion that all the anomalies are technogenic. The main contaminant metals are Pd, Zn, and to a smaller extent Sd, Cu, and Hg. The organic compounds detected in many locations included the increased content of benzo[a]pyrene and petroleum products.

The vertical movement of oil along the cross-section of soil creates a chromatographic effect that allows to differentiate its composition. The upper humus horizon accumulates all high-molecular-weight components of oil that contain resins and asphaltenes and cyclic compounds. The lower horizons are penetrated by low-molecular-weight compounds that have higher solubility in water and higher diffusion capacity than the high-molecular-weight components. As a rule, light hydrocarbons are highly toxic and are difficult to digest by microorganisms, so they remain in the lower parts of the soil cross-section in the anaerobic environment for a long time.

Sandy soils allow for a continuous frontal zone of oil movement. In clay loams, oil penetrates through the cracks along the root systems of plants and accumulates in particular horizons, determining the mosaic-like, spotted image of the soil cross-section pollution. The more the soil is moist, the lesser the possibility of oil settling in the soil and thus the higher the activity of its lateral movement. In any case, exceeding the level of moisture in the oil capacity of soil substrates leads to the excessive pollutants draining down to the lower horizons of the soil cross-section and the groundwater.

In case of the loamy composition of substrates, the main mechanism of oil transportation to the lower soil horizons and groundwater is the free gravitational passage along the weakened zones.
(migration channels) accompanied by the saturation of smaller and larger cracks with oil and the further relatively weak absorption into small capillaries and diffusion in the inter-fracture mass.

The contamination of the natural environment on the territory of Zavodskoy District goes back decades. Various researchers estimate the total volume of the hydrocarbons accumulated on the groundwater surface to be from several hundred thousand to 1.5—2 million m$^3$. A substantial share of the work was undertaken by the Grozgiproneftekhim institute and the Chechen-Ingush geological expedition. Their teams drilled 400 wells 30 to 52 m deep but the results of these studies do not allow to draft a scientifically sound project of measures to localize and remediate the pockets of contamination due to the lack of a wide range of the necessary initial data.

**Figure 1.** Layout of the technogenic reservoirs within the city of Grozny

The works to identify and delimit the areas of the underground technogenic lens of petroleum within the territory of Grozny and estimate their volume were resumed by OAO Geosintez in 2007. They included: the ground-penetrating radar, gas, and geochemical surveys of test wells using the materials of high-definition space imagery. The geochemical studies carried out in 2007—2008 in Zavodskoy District of Grozny were used to assemble a photomosaic of the anomalous content of radioactive gases, CH$_4$ and its homologues, and vapors of Hg, H$_2$S, and CO. A projected photomosaic of the areas subjected to the accumulation of technogenic petroleum reservoirs associated with the production spaces of petrochemical plants was created.

In the course of the previous research activities, the territory of the Staro-Sunzhenskiy water intake was left out of the field studies. Regardless of the fact that petroleum spills have stopped, the technogenic reservoirs continue to pose a real hazard, which demonstrates the need to proceed with the studies on the territory of the Staro-Sunzhenskiy water intake.

On the other hand, the hydraulic mechanism that is concerned with the rise and decline of the water table not only seasonally but also in the several years' perspective facilitates the gradual extrusion of the technogenic reservoirs through hydraulic windows into the Sunzha River. For this reason, the coverage area of the research using a combination of geophysical methods needs to be expanded. At the same time, it is necessary to carry out geological and geophysical studies in combination with drilling engineering wells to identify the way the technogenic reservoirs of petroleum products change in time and space and specify their parameters and boundaries.

**4. Conclusion**

Analyzing the results of the drilling works performed on the left bank of the Sunzha River indicated that the surveyed territory does not contain the technogenic lens on the groundwater that existed before but contains residual contamination (petroleum influx from the drilled wells was not obtained). The existing contamination is the result of the extraction of the available oil products during the previous 20 years (using illegal and uncontrolled makeshift designs) and the possible migratory exodus of the residual "lens" in the direction of the Staro-Sunzhenskiy water intake. The samples indicate the continuous increase of petroleum products in the waters of the Staro-Sunzhenskiy water intake.
To solve the geoenvironmental problems conditioned by the development of the technogenic oil reservoirs within the territory of the city of Grozny, the following activities are proposed:

- Carrying out comprehensive geophysical, geochemical, and ground-penetrating radar surveys to study the current spatial layout, migration, and dynamics of the oil reservoirs.
- Designing an optimal network of well locations to study the time and space status of the technogenic reservoirs in Grozny and its outskirts.
- Perform additional studies in the area of the Staro-Sunzhenskiy water intake, which is the source of drinking water for a significant part of the population of Grozny.
- Carry out regular monitoring of the migration of the technogenic reservoirs within the territory of Grozny and its outskirts.
- Develop a database of geoenvironmental data about the condition of the technogenic reservoirs using geographic information systems.

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