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# OIL AND GAS WELL DRILLING WASTE DISPOSAL IN THE RUSSIAN ARCTIC ZONE: REVIEW

*The oil and gas industry is a key economic sector in Russia. Considerable oil reserves of the country occur in its Arctic Zone. Within the internationally defined borders of the Russian Arctic Zone and Arctic Shelf, 282 oil fields are discovered, including 26 oil fields on the shelf and in the coastal transition zone. Major proven reserves occur in the Yamalo-Nenets and Nenets Autonomous Areas within the Arctic Zone of Russia. Well drilling produces much drilling mud, drill fluID and drilling wastewater. Drilling mud represents the bulk of the industry waste which pollutes the environment. The ecological safety of the Russian Arctic is a top-priority problem. As a result of drilling mud impact, the natural environment and underground water alter greatly. This article analyzes methods and means of drilling waste treatment and conversion to different materials. The scope of the analysis encompasses thermal treatment, bioconversion, the use of drilling mud as a natural fine aggregate to replace limestone and clay in the cement industry, as well as manufacturing of constructional materials and propping agents. It seems to be a promising trend to create mobile facilities in the Russian Arctic for the in-situ production of constructional materials from drilling waste.*

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## Introduction

The Arctic Zone of the Russian Federation contributes greatly to the national energy economy. In recent decade, the Arctic gains much attention of the government, business and public [1]. The Arctic Zone of Russia is the northern end of the European and Asian parts of the country coastwise the Barentsev, Kara, Laptev, East Siberian and Chukchi Seas. The Arctic Zone covers one-fifth of the area of the country and embraces the country's nine regions. Four regions belong in the Arctic totally (Murmansk, Nenets, Chukotka and Yamalo-Nenets), and five regions–partly (Arkhangelsk, Krasnoyarsk, Karelia, Komi and Sakha (Yakutia)). The Arctic area is 4.8 Mkm² [2].

The oil and gas industry is a leading sector of the economy of Russia and an essential source of the country's federal budget. The oil and gas discovery burst in the late 1960s–early 1980s. Major deposits were discovered in the Polar region, Northwestern Siberia and in the Far East of Russia at that time. Currently, Russia holds around 2400 oil reservoirs, including 45% of reservoirs being suspended or explored [3].

Oil reservoirs nonuniformly occur across Russia. Proven reserves occur mostly in Western Siberia, in the Russian Arctic, in the Ural and in the Volga Region. Within the internationally defined borders of the Russian Arctic Zone and Arctic Shelf, 282 oil fields are discovered, including 26 oil fields on the shelf and in the coastal transition zone. According to the Russian State Commission on Mineral Reserves, the Russian Arctic Zone has 7.3 Bt of proven and estimated oil reserves, including 0.58 Bt (7.9%) of oil reserves in the fields on the Russian Arctic Shelf. The cumulative oil production totals 1.4 Bt and the annular oil production is 554.3 Mt [4].

Ecological condition of the Arctic Zone of Russia is a topical issue [5, 6]. The Arctic area features unique ecosystems, climate and bio-diversity. Oil and gas industry waste exert harmful effects on the environment. As a consequence, subsoil integrity is violated, air and water bodies are polluted, and vegetation cover and wildlife are endamaged [7, 8]. In the Arctic Zone of Russia, special terms are set for the ecosystem exploitation and nature protection, including pollution monitoring. Extraction and use of natural resources should have a minimized environmental impact. In this context, the oil and gas industry waste management is a grand challenge in the Russian Arctic.

## Oil and gas fields in Russia's Arctic

The largest proven reserves occur in the Yamalo-Nenets and Nenets Autonomous Areas in the Arctic Zone of Russia. Yamalia holds 133 oil and gas fields and Nenetsia holds 93 oil and gas fields. Much less reserves occur in the Komi Republic and in the Krasnoyarsk Krai. The rest Arctic Zone has no proven oil and gas fields. The largest oil and gas fields (OGF) are Urengoy, Yamburg, Bovanenkovo, Kharampur, Komsomolskoye and others, and the largest oil fields (OF) are North Samburg, Paiyakh and West Irkino. **Table** gives information on the most promising oil and gas fields [9].

It is clear from Table 1 that the total accumulation of drilling waste in the main oil and gas fields in the Russian Arctic Zone reaches 1 Mt. The forecast says drilling waste will grow additionally by 4.5 Mt. Urengoy OGF has the largest waste accumulation of 243 Kt. West Irkino OF is the youngest field. It holds huge oil reserves and the predicted drilling waste is 600 Kt. It can be expected that new fields will be discovered in the Arctic Zone in the future, and, consequently, the oil and gas industry waste will build up.

## Drilling waste

Drilling process produces waste. The most hazardous components of drilling waste are drilling mud, drill fluID and drilling wastewater [10–13].

Drilling mud is a water suspension of solID rock cuttings, chips of friction between drill string and casing, and clayey material (in case of mud flushing) [14, 15]. Drilling mud is composed of 60–80% rock, 8–10% organic matter and 6% water-base salt. Contaminating influence of drilling mud on the environment is mostly due to toxic properties of the components which, subject to the origin, can have environmental hazard class 3 to 5. Storing of drilling mud leads to environmental pollution [16–18]. Drilling mud can also contain oil and chemical agents as additives. The content of chemical agents can reach 15% [19].

Drill fluID is a multicomponent disperse system of fluids. It takes an important part in stability of wellbore wall, removal of cuttings, reduction of friction and in pressure control [20, 21]. Depending on liquID medium, there are four types of drill fluids: water-base, oil-base, gas-base and synthetic-base [22, 23].

Drilling wastewater is water from washing of drilling floor, drilling equipment and tools, and it can contain remainders of drill fluid, oil and chemical agents. Drilling wastewater can contaminate immense zones in hydro- and lithosphere. Contaminating influence of drilling wastewater is

**The most promising oil and gas fields in the Arctic Zone of Russia**

| Name of field | Location | Oil reserves, t | Gas reserves, $m^3$ | Gas condensate reserves t | Year of production commencement | Waste currently accumulated, t | Additional waste forecast, Kt |
|---|---|---|---|---|---|---|---|
| Urengoy OGF | Purovsky District, Yamalo-Nenets Autonomous Area | 400 M | 10.9 B | 1.2 B | 1978 | 243.0 | 237.0 |
| Komsomolskoye OGF | Purovsky District, Yamalo-Nenets Autonomous Area | 700 M | 831.7 B | 4 M | 1993 | 136.4 | 703.6 |
| Kharampur OGF | Southeast Yamalo-Nenets Autonomous Area, area of the Polar Circle | 125.2 M | 903 B | 88 M | 1990 | 105.6 | 44.6 |
| Yamburg OGF | Tazovsky Peninsula, north of West Siberian petroleum basin | 1.3 B | 8.2 T | 18 M | 1980 | 187.2 | 1372.8 |
| Bovanenkovo OGF | Center of the Yamal Peninsula | 204.1 M | 4.9 T | 1.6 M | 2012 | 6.8 | 238.1 |
| Vyngapur OGF | Purovsky District, Yamalo-Nenets Autonomous Area | 416 M | 20.3 B | 48 M | 1982 | 48.0 | 451.2 |
| Sutorminskoye OGF | Purovsky District, Yamalo-Nenets Autonomous Area | 250 M | 18 B | 42 M | 1982 | 115.7 | 184.3 |
| North Samburg OF | Purovsky District, Yamalo-Nenets Autonomous Area | 426 M | – | – | 2017 | 32.0 | 479.2 |
| Paiyakh OF | Krasnoyarsk Krai, within Taimyr–Dolgan–Nenets area | 163.1 M | – | – | 2009 | 69.6 | 126.1 |
| West Irkino OF | North Polar Circle a | 500 M | – | – | 2024 | 0.04 | 600.0 |

**Drilling mud storage**

governed by chemical agents used to prepare drill fluids and by composition of rock being drilled [24–26].

Drilling mud makes the main portion of drilling waste. Drilling mud is put into storage on disposal sites and in slurry ponds, which leads to heavy pollution of air, surface and underground water, and soil owing to leakage of hydrocarbons and other pollutants. Researches show that 1 m-long drilling produces averagely 0.4 $m^3$ of drilling mud. All in all, in Russia, drilling waste accumulation reaches 10 Mt, and not more than 10% of such waste undergo recycling. Thus, drilling waste recycling is a grand ecological challenge [27–29].

At the current stage of oil recovery, the common method of drilling mud accumulation and storage is arrangement of different-design slurry ponds [30]. A slurry pond is an environmental facility meant for gathering, detoxification and disposal of toxic waste of oil well drilling (**Figure**). The depth of such slurry ponds may reach 100 m. For eliminating adverse impact on surface and underground water, impervious seal is used—geotextile underlayment. It is advisable to cover such ponds with sand. The covering cost may go up to million rubles. However, irrespective of covering, chemical compounds continue with harmful impact on the environment.

It is very difficult to store drilling mud in slurry ponds in the Arctic. Slurry ponds freeze, while the Arctic ecosystem is incapable of handling and neutralizing industrial waste [31]. SolID stockpiling in the permafrost ground is very specific. SolID waste under low temperatures can turn into manmade stony gletchers. Collapse of such huge ice-and-stone masses can do great damage to people and nature. Aside from that, permafrost ground is endangered by thermal influence of production waste delivered to places of storage under high temperature. As a consequence, frozen ground thaws, which degrades permafrost.

Thus, it is necessary to find ways of reducing the impact of drilling mud on the environment in the Arctic Zone of Russia.

### Drilling mud reclamation

The latest technologies of drilling mud reclamation include a few basic approaches [32–34]. One of the approaches is thermal treatment such as pyrolysis and arc gasification. Pyrolysis allows decomposing organic components of drilling mud under high temperature in an oxygen-free medium. The resultant gaseous and liquID product can be used in power generation. Arc gasification ensures deeper decomposition of waste, with generation of synthesis gas also usable as a fuel or a feedstock in the chemical industry. These approaches boast high efficiency and essential reduction in volume of waste but need much energy and investment [35, 36].

Another attractive way is bioconversion of drilling mud. The use of microorganisms to decompose organic components of drilling mud contributes to waste reduction and to production of valuable bioproducts such as biogas or organic fertilizers [37]. Bioremediation succeeded to reduce the content of hydrocarbons in drilling mud [38], and to reduce the content of heavy metals by 46% for As, by 70% for Pu and by 100% for Hg. The researchers [38] suggested to use the produced mixture as a material for construction of roads and buildings. The major advantages of biological methods are their ecological safety and relatively low cost; however, their application needs much time and close control.

The oil and gas industry extensively uses mechanical and physicochemical reclamation such as dewatering, centrifugal separation, filtration etc. The disadvantages of these methods are high cost and special conditions of operation flows [39].

Drilling mud contains reactive calcium lime, silica, alumina and ferric oxide, and the promising way of drilling mud reclamation can be its recycling in production of constructional materials, for example, ceramic, bricks, paving slabs, expanded clay, curbstone, surfacing materials for roads and drilling sites [40]. For instance, well drilling waste and slug was used as a partial replacement of limestone and clay in production of Portland cement [41]. It was found to be possible to replace up to 38% limestone and to 72% clay. The study [42] demonstrated usability of 20% drilling waste as an aggregate material in production of concrete and bricks. Drilling mud was stabilized by mixing with pozzolanic fly ash, limestone and cement [43], and was used as a road base in road construction. Drilling mud was employed as an additive to road concrete mix [44]. It was found that it was possible to add up to 20% drilling mud without worsening of the mixture properties.

The most available and cheapest method of oil and gas recovery enhancement today is hydraulic fracturing with synthetic propping agents (proppants), which allows a few times higher productivity in wells when conventional oil recovery is impossible or marginal [45, 46]. Drilling mud was used to produce ceramic proppants for fracking [47]. The proppants possessed: the disturbance ratio of 5.5% at a pressure of 52 MPa, the bulk density of 1.71 g/cm$^3$ and the apparent density of 2.98 g/cm$^3$. In another case of making ceramic proppants using drilling mud [48], the product possessed the disturbance ratio of 5.25% at a pressure of 52 MPa, the bulk density of 1.48 g/cm$^3$, the apparent density of 2.94 g/cm$^3$ and the acID solubility of 4.80%.

Disposal of drilling mud in the Arctic Zone of Russia involves some difficulties such as harsh climate, low temperature and permafrost. Rehandling of drilling mud in the Russian Arctic, in the oil-producing regions or in the near neighborhood is the most promising trend of the material recycling as shipment of drilling waste from the Arctic Zone is ecologically and economically inexpedient because of remoteness of this area. To that end, it is necessary to create mobile waste processing stations to reclaim drilling mud before it becomes permafrost. The relevance of production of constructional materials in the immediate vicinity of oil producing wells is governed by an acute shortage of high-quality conventional feedstock (aluminosilicate clay minerals such as kaolinite). At the same time, housing development and road construction in the severe climatic conditions of the Arctic needs materials with special and non-conventional operational properties [49, 50]. For instance, materials for the housing construction must possess reduced thermal conductivity, and increased cold endurance and strength.

Thus, production of constructional materials for housing development and propping agents for oil recovery is of current interest in the Arctic Zone of Russia. A steadfast increase in consumption of propping agents is primarily connected with the expansion of horizontal drilling and multiple hydraulic fracturing, governed by geological conditions of hydrocarbon occurrence. At the same time, all Russian manufacturers of proppants concentrate in the northwest of the European part of the country and in the Ural, and are absent in the Arctic Zone. For this reason, development of manufacturing technology and compositions of propping agents using drilling mud of oil production is of high priority. The other promising line of development is creation of mobile facilities to manufacture such materials from drilling waste in situ across the area of the Russian Arctic.

**Summary**

The Arctic Zone of the Russian Federation contributes greatly to the national energy economy. Drilling practices produce drilling mud which is aggressive to the environment. Contaminating influence of drilling mud is governed by the presence of oil and chemical reagents in this material. At the same time, the chemical composition of drilling mud makes it a secondary resource usable instead of a fresh raw material. The best way is to use drilling mud to manufacture constructional materials for housing development and road construction, and propping agents for oil recovery. It is possible to manufacture constructional materials nearby oil-producing well. This is particularly topical in the Arctic Zone of Russia because of the heavy deficit of high-quality conventional raw materials (such as alumosilicate clay minerals, e.g. kaolinite), and also since this area is remote and hard-to-reach.

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