ISSN 1995-4255, Contemporary Problems of Ecology, 2011, Vol. 4, No. 6, pp. 601–608. © Pleiades Publishing, Ltd., 2011.
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Ecological Consequences of Different Stages of the Development of Oil and Gas Deposits in the Taiga Zone of the Tyumen' Region

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Abstract—Major kinds of the technogenic impact of oil and gas production on the ecosystems of taiga forests in the Tyumen oblast at all stages of deposit development—exploration, construction, extraction, abandonment—are considered on the basis of the statistical data and the results of own long-term field investigations. The most severe negative consequences at each stage are determined.

DOI: 10.1134/S1995425511060063

Keywords: oil production, technogenic impact, stages of deposit development, Tyumen' oblast

The oil and gas producing industry forming the basis of Russia's economy is one of the most dangerous branches of the economy as a factor affecting the natural environment (NE). The world largest West Siberian oil-and-gas bearing basin occupies the entire territory of the Tyumen region. Besides, the majority of explored and operating deposits especially of oil are located in the taiga zone.

The peculiarity of oil and gas production consists in the fact that all the components of natural ecosystems are affected by negative influence—the atmospheric air, soil mantle, surface and ground waters, vegetable and animal worlds. A component-specific investigation of transformations does not lead to a comprehensive understanding of loss of resource, environment forming, and nature conservation functions of ecosystems. In this connection complex ecological investigations of the functioning of ecosystems under intensive oil and gas production conditions and developing a theoretical basis for the preservation of their stability, improving the system of monitoring and recultivation gain especial currency.

The methodology of assessment of anthropogenic impact on NE in using natural resources is based on a number of integral approaches. When investigating the impact of the Tyumen' oblast's oil and gas producing complex on the ecosystems of the taiga zone we combined the ecosystemic and ecologic-geoinformation approaches, which allowed carrying out a comprehensive assessment of ecological factors that are transformed under the influence of production activity and considering oil and gas production objects and NE components as a spatio-temporal system, the stable state of which is the main goal of harmonious exploitation.

In order to understand the most complex processes of development of deposits of hydrocarbons in both historical aspect and at the present time it is necessary to solve the methodological question of division of the whole period of deposit development into a number of stages. At present several classifications of staging for hydrocarbon raw stock deposit development depending on ecological consequences are worked out. E.V. Serbina distinguishes five stages of development of the Caspian oil deposits: geological prospecting (pre-investment, regional, preparation for preliminary drilling, deposit reconnaissance), development (construction of surface facilities, production activity), primary processing and treatment of hydrocarbons (primary processing, transport, construction and operation of oil refineries), liquidation (liquidation of production facilities), postproject [1].

A. P. Khausov and M. M. Redina taking into account the new economic policy of the state in the sphere of cession of rights to the development of deposits also single out five stages of overland oil deposit development: (1) acquisition of rights to exploring, arrangement, and development; (2) prospecting; (3) deposit producing test; (4) field exploitation (commercial production); (5) completion of field exploitation [2].

In our opinion the separation of a producing test as a special stage is not justified for two reasons: first, for a producing test advance production wells with an oil recovery pipeline system, installations for oil treatment and associated gas utilization are built. This means the beginning of a full-scale arrangement and exploitation of a field with all associated ecological consequences. Second, if a producing test is carried out at existing expendable wells then the ecological consequences of this process are minimal (additional facilities are not built, well production sampling is performed as a rule, into tank trucks). That is, according to the Rules of development of oil and gas-and-oil deposits one should distinguish a producing test of prospecting wells and a producing test of pools or their separate parts [3]. A. V. Solodovnikov divides the period of anthropogenic impact in oil and gas production on the environment into four major stages: exploration work, drilling, arrangement and exploitation of fields. In geological prospecting the main types of impact add up to laying profiles and drilling and blasting. At this stage the environment is subjected to weak disturbances which are not always observable during on-site investigations. The following stages—drilling of wells and arrangement of deposits—include building of drilling sites, arrangement of facilities for preparation and processing of oil, gas, condensed fluid, construction of motor roads, pipelines, power lines. During these works waste products appear and their disposal is connected with improvement of operations, with construction of appropriate refuse dumps and mobile units. The ecological consequences are manifested in geomechanical, hydro-, hydrogeological, and biomorphic disturbances. The field exploitation stage is carrying out repair and overhaul of equipment, observation of its functioning. The types of impact are—water consumption and water disposal, emission of pollutants, noise, formation of waste products; the degree of impact is local [4].

In our opinion this approach is not quite correct: first, it is absolutely wrong to reduce all exploration work to only prospecting seismology. Second, it is unjustifiable to unite exploration drilling in search for deposits and commercial drilling in arranging well clusters into one category 'well drilling' because of considerable differences in the work techniques, scales and types of impacts on the adjacent territories. It is hard to agree to the 'local' level of impact at the stage of field operation of deposits.

Consequently, analysis of the time sequence of production steps, problems to be solved and their ecological consequences allowed us to divide the entire process of oil and gas production impact on the natural complexes of the Tyumen region into four stages: exploration, construction, production, and liquidation. The separation of these stages is based on the designated interdependence of technological processes as well as on the peculiarities and scale of ecological impact on the environment at each of them.

A characteristic feature of the region under consideration at present is temporary coexistence of all stages. This situation is caused by the ongoing geological investigation of the region's territory and by discovery of new deposits as well as by development of previously known deposits and hydrocarbon-bearing formations. In case of exhaustion of their resources oil and gas production fields may be abandoned at any of the stages. In the oil and gas production areas NE is constantly subjected to a specific complex of technogenic influences, a phasic supersession of which is illustrated by the reference fragments of satellite photographs (Fig. 1).

<u>The exploration stage.</u> Of the whole set of various technological processes carried out at the exploration stage the most ecological dangers for taiga ecosystems are: (1) seismological prospecting and (2) construction (drilling) of earth bores. Analysis of satellite photos and archival materials performed by us has shown that 2/3 of the taiga zone territory of the Tyumen' region passed through the stage of regional exploration work (Fig. 2).

At this stage the most significant negative factor for NE is the occurrence of accidents as a result of breaching the techniques of drilling-in or testing of oil pools during the construction of deep exploration wells. An examination of 52 explorations in the Nefteyugansk district has shown that 21 exploration areas are polluted with oil-containing products of wells directly in the wellhead area and the slurry pits contain oil, besides the negative impact of exploration stage sites continues after completion of prospecting work. In consequence of lengthy down time and the absence of maintenance service the wells erode, which leads to seal failure and to shows of oil-gas and water at the wellhead (17 wells).

To prevent the negative impact on NE at the exploration stage it is necessary to take an inventory of the total stock of expendable wells in order to reveal the facts of wellhead unsealing and to carry out repair and elimination work as well as rehabilitating drill pits containing oil and drill slurry.

<u>The construction stage.</u> Analysis of ecological consequences of construction of oil and gas production facilities has shown that the most influence on NE is connected, first, with transfer of considerable areas of land resources and, second, with the formation and storing of drill process waste in the territory of drill sites.

According to official data in the territory of Khanty-Mansi AD–Yugra around 0.1% of the land of forest resources is annually withdrawn (for example, in 2005, 37 549.8 ha or 0.08%).

The peculiarities of impact on the environment in many respects are determined by the spatial configuration of oil and gas production facilities. According to this feature it is accepted to divide all objects into linear and areal. Those the length of which is hundreds and thousands times their width are referred to as linear: motor roads, and railways, power lines and communication lines, different purpose pipelines (oil, water, gas and products pipelines, etc.). A characteristic feature of arranging oil and gas deposits in the Tyumen' oblast is joint construction of communication passages—motor roads, power lines, and pipe lines, which entails a considerable concentration of impacting objects and allows a more economical use of land resources. Objects of deposit development having commensurate values of length and width are referred to as areal: production facilities for oil gathering and treatment (DNS, KNS, TsPPN, UPSV, UKPG, GPP, flares, etc.), residential settlements, drydug and wetdug pits, oil and gas producing well clusters and single wells, field drilling drill

Fig. 1. A picture of oil and gas production facilities from a QuickBird photograph (spatial resolution 2.5 m, GoogleEarth).

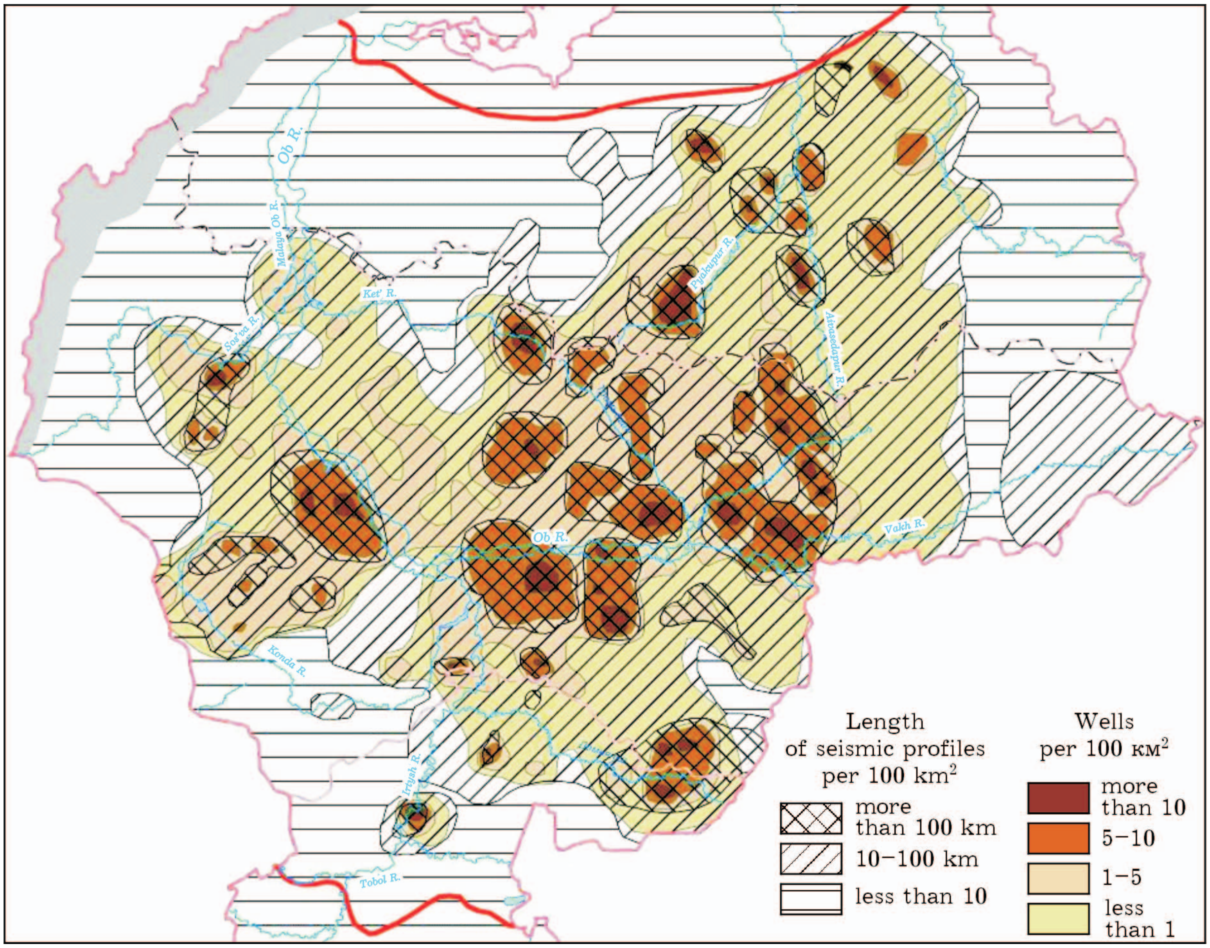

Fig. 2. Involvement of the Tyumen' oblast taiga zone territory in exploration work.

sites, dumps for industrial and domestic waste (landfills).

The most part of areas allotted for oil production needs is occupied by linear structures. Analysis of 17 oil and gas deposits of KMAD–Yugra performed by us has shown that that land allotment for linear structures considerably exceed the allotments for areal ones. On average, for 1 ha allotted for areal facilities (21% of allotments) there are 3.8 ha of land allotted for linear communications (79% of allotments) (Table 1).

Slurry pits containing toxic drill waste are the most ecological danger at the stage of construction of oil and gas production fields. Many of them are located in water protection zones and pose a serious hazard to river, lake, and bog ecosystems. The results of measurements of several slurry pits at the Novo-Pokurskoe deposit have shown that the size of pits with drill waste amounts to, in thousand m^3 : cluster #17, 10; cluster #25, 12; #27, 12; #33, 11; #40, 12. The dimensions of the pit at a cluster with 10 wells were 24×148 m; with 11, 24×156, and with 12, 24×172 m with depth 3 m. By the beginning of 2008 in the KMAD—Yugra territory 1740 slurry pits in area around 766 ha remained unrehabilitated. Our investigations into the condition of 50 slurry pits at a number of deposits of PLC "Yugansk-neftegaz" performed in 2004 showed that on average each pit contained up to 5000 m^3 of drill slurry and around 3000 m^3 of water polluted with soluble chemicals and oil. Besides, 80% of the pits contained oil in the form of a film, every fifth pit had a broken border and only 7 were rehabilitated. According to the data of PLC "Yuganskneftegaz" reports on the formation of toxic waste by form #2-TP (toxic waste), drill waste includes on average around 80% of slurry, 19.1% of liquid waste, and 0.9% of chemicals [5]. The main pollutants in the drill slurry are petroleum hydrocarbons (Table 2).

The main area of nature conservation work at the construction stage is timely recycling of drill waste, especially in water protection zones. At present several technologies have been developed and are used for slurry pit recultivation and utilization of drill slurry and drill wastewater to manufacture building materials (for example, the burolit mixture used in building motor roads).

Table 1. Ratio of the areas of land allotment for areal and linear oil and gas production objects

License area, deposit (arrangement of 2003–2006)	Oil and gas production objects				Total, ha
	areal		linear		
	ha	%	ha	%	
Vodorazdelnyi	49.10	18.5	216.40	81.5	265.50
Varyngskii	16.60	35.6	29.98	64.4	46.58
Galyanovskii	41.34	20.8	157.50	79.2	198.84
Em-Egovskoe	25.85	23.6	83.930	76.4	109.78
Kamennyi	44.60	17.1	215.74	82.9	260.34
Nizhne-Shapshinskoe	49.08	35.0	91.02	65.0	140.28
Novo-Pokurskoe	19.40	15.5	105.80	84.5	125.2
Ombinskoe	15.81	32.6	32.65	67.4	48.46
Paitykhskii	60.30	13.0	404.21	87.0	464.51
Peschanoe	25.33	27.1	68.31	72.9	93.64
Potanai-Kartop'inskii	16.63	15.0	94.25	85.0	110.88
Priobskii	378.83	26.2	1067.66	73.8	1446.49
Serginskii	7.12	12.6	49.30	87.4	56.42
Srednemulym'inskoe	6.45	8.0	74.15	92.0	80.60
Symor'yakhskoe	6.32	14.5	37.12	85.5	43.44
Tal'nikovoe	86.02	25.4	252.74	74.6	338.76
Khanty-Mansiisko-Frolovskii	45.08	18.6	197.71	81.4	242.79

Table 2. The content of gross forms of heavy metals, chlorides, and hydrocarbons (C_{10}–C_{40}) in the bottom sediments of PLC "Yuganskneftegaz" slurry pits, ppm

Substance	*n*	Average	Min	Max	Std.Dev.	MPC (APC)*
Chlorides	32	1340.15	692.30	2840.00	982.04	Not control.
Pb	16	23.62	8.93	45.06	12.16	32.0
Cu	16	0.89	0.68	1.09	0.16	55.0
Ni	16	0.94	0.50	2.09	0.60	85.0
Σ TPH C_{10}–C_{40}	52	34 070.58	590.00	152 600.00	39 730.98	20.0**

Note.*, for soils according to HS 2.1.7.020-94. **, a KMAD–Yugra regional standard in accordance with KMAD–Yugra Government Regulation # 441-p of 10.11.2004.

Ecological consequences of the stage of oil and gas production. The strength of oil and gas production impact on the environment depends on several factors: the anthropogenic load on a field territory, the duration of a production period, areas of transformed landscapes, degree of chemical pollution of natural media, successfulness of recultivation measures. Absolute areas of deposit ecosystem disturbance are in direct dependence on the duration of development and general well fund [6]. Our investigations at the Fedorovskoe and Mamontovskoe deposits showed that for every hectare allotted for placing of wells and cluster equipment there were from 0.3 to 3.0 ha of disturbed land. Besides, the construction of one well is accompanied by degradation

Table 3. The ratio of multiple well platform size to disturbed land at oil and gas deposits, ha

Deposit	Platform size	Area of disturbance	Correlation ratio
Fedorovskoe	1.22 ± 0.41	1.72 ± 0.92	0.73*
Mamontovskoe	0.72 ± 0.32	1.63 ± 0.61	0.67*

* $P < 0.05$.

Table 4. The technogenic impact on NE within some deposits, percentage of the allotment area, %

Deposit	Oil and salt pollution	Mechanical transformation
Samotlorskoe*	9.5	12.2
Pokachevskoe	4.0	6.3
Yuzhno-Balykskoe	4.0	7.5
Fedorovskoe	3.0	5.2
Mamontovskoe	2.3	6.0

* A reference area in the OGPA "Belozerneft" territory.

and pollution of soil on average 2000 m^2 beyond the multiple well platform. Correlation analysis showed that the scale of disturbances was in many respects determined by the dimensions of the platforms (Table 3).

Oil and salt pollution, the main reason of which is the corrosive wear of intrafield collectors and leaks from areal objects, becomes the main type of negative impact at the production stage. As the examination results of some KMAD–Yugra oil and gas deposits showed the oil and salt pollution of field territories in its scale was comparable with mechanical transformation of land (Table 4), which is in agreement with the data from work [7] for the Vatinskoe and Aganskoe deposits: the share of all pollution forms accounts for 41.5% of areas, and mechanically impacted areas (including impounding and fuel sprays)—for 58.5%. Moreover, if to the areas of polluted land the areas of polluted riverbeds and lake bottoms are added then the total size of polluted aqua- and territories will exceed the maximal size of the mechanically disturbed landscape. By way of example a calculation of areas for the Samotlorskoe deposit is given: the total area of oil pollution of the deposit was as large as 263 ha (water bodies, 175 ha; land, 88 ha), the area of disturbed land, 183 ha.

According to official data in the KMAD–Yugra territory there occur on average more than 2.5 thousand accidents per year in the oil gathering system. We have analyzed the dynamics of accident rate of the oil gathering collectors in the KMAD fields from 1991 to 2007 and have drawn trend lines (Fig. 3). The maximal numbers of accidents were observed in the middle of the 90s of the XXth century and in 2007. The growth of accident rate in the 1990s is confirmed by the information from work [8] evidencing that the total length of faulted pipelines in 1991–1995 in the district grew by 7.5 times considering an only 1.4 times increase in the general network length, the application of corrosion inhibitor during the same period became 2.6 times less. At present a growth in the number of accidents is observed reaching in 2007 the most value of the entire observation period, 5480. Our opinion is that this is related to the fact that in 2001–2003 after the 'decline' period in the 90s a period of recovery ensued when intensive use of the idle capacities (including also collectors) and construction of new ones started. Owing to considerable watering of the product of many operating deposits an increase in the number of accidents (gaps) was to be expected in the systems of oil gathering and PPD in 2–3 years, which was the case.

In official reports practically all spills of oil containing fluids take place in accidents (failures) on pipelines

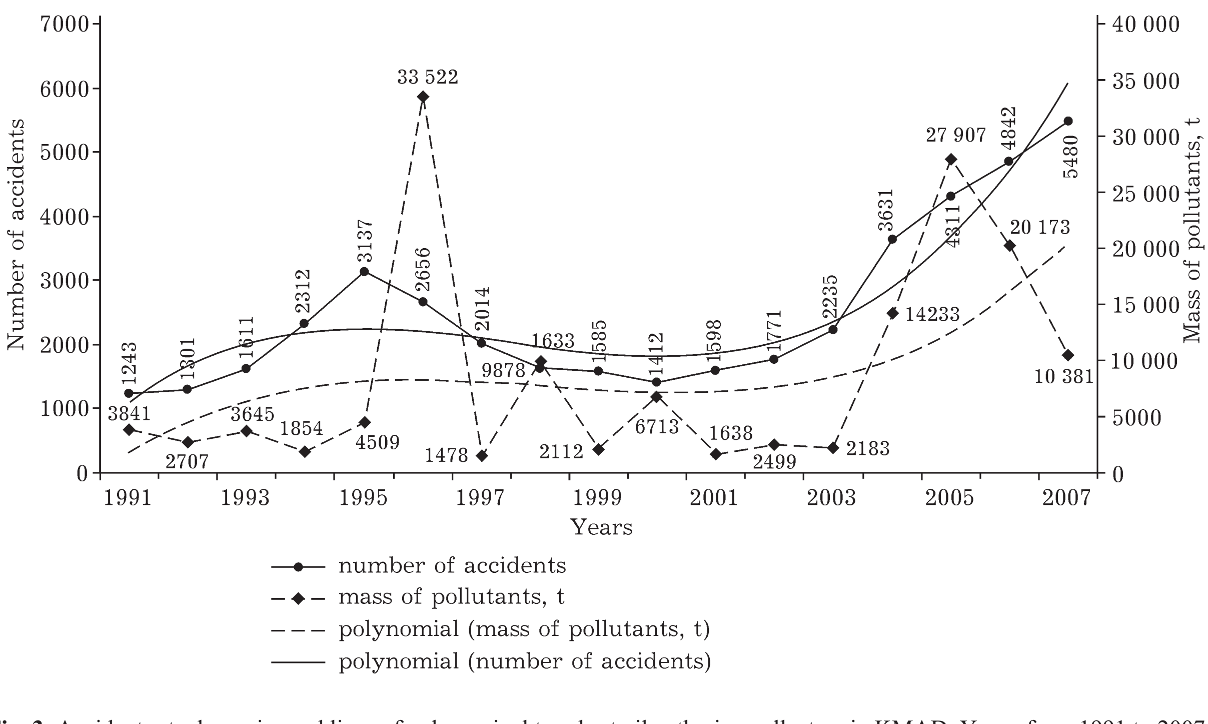

Fig. 3. Accident rate dynamics and lines of polynominal trends at oil gathering collectors in KMAD–Yugra from 1991 to 2007.

Table 5. Oil-spill distribution by object types

Deposit	Multiple well platforms				Oil-pipelines			
	pcs.	%	*S*, ha	%	pcs.	%	*S*, ha	%
Aganskoe	113	57	36.48	65	87	43	19.83	35
Mykhpaiskoe	47	50	50.13	59	47	50	34.80	41
Samotlorskoe*	209	54	157.44	41	181	46	227.01	59

* OGPA "Belozerneft" territory.

Table 6. The concentration of oil products (OP) at pollution sites

Facility	OP, ppm
Leaky exploratory well, soil near the well head	$0.5\times10^5 - 1.5\times10^5$
Exploratory well, FL storage place, soil	$0.1\times10^5 - 0.3\times10^5$
Tank batteries of tank farms, soil	$0.2\times10^5 - 0.9\times10^5$

Note: The results of pot experiments performed by us to assess oil impact on seed sprouting and the development of plant germs showed that the 'safe' level of oil pollution of soils for the young growth of coniferous species was 0.1×10^5 ppm, and for grassy plants, 0.5×10^5 ppm. The most toxic are oil fractions entering the composition of diesel fuel.

and leaks from multiple well platforms are not taken into account. The results of ground mapping performed by us indicate that in deposits with a long term of operation the share of leaks from areal objects is 50–60 % in the number and 40–65 % in the area in total pollution (Table 5). Such one-sidedness in statistical reporting is one of the reasons for evident discrepancy of official information and factual pollution of land by oil. It should also be taken into account that the users of mineral resources trying to avoid both personal and corporate responsibility conceal the real rate of accidence.

Taking into consideration the fact that it is exactly cluster bases that account for the most part of areal objects constructed on deposits one should agree with B. E. Chizhov's opinion [9] that well clusters are environmentally the most dangerous oil production objects requiring constant control. This is also confirmed by the results of checking the condition of 2436 multiple well platforms carried out by the committees for protection of the environment and natural resources of KMAD–Yugra in 1996. it was revealed that oil pollution was present in 39.9 % of platforms, besides, every seventh spreads pollution beyond the border.

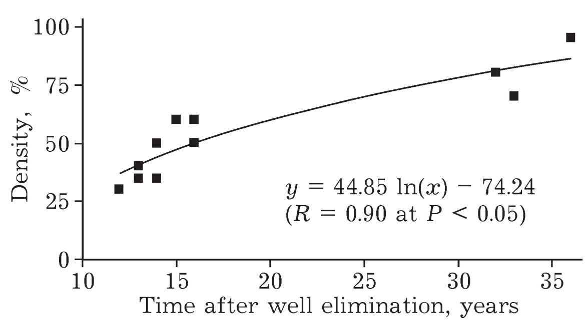

Fig. 4. Crown density of woody plants at exploratory drilling platforms.

Thus at the production stage oil and salt pollution assumes a general character and becomes a leading ecological factor impacting taiga ecosystems. In this connection nature conservative measures should be directed at developing anticorrosive technologies to provide accident-free transport of oil containing well products, recultivation of the existing slurry pits of oil-polluted and salted land and water bodies.

<u>Ecological consequences at the elimination stage</u>. At the elimination stage a deposit is withdrawn from the balance sheet, the wells are removed from service, shut down or abandoned. In the nearest future the volume of elimination work will be building up, which will require a justified forecast of ecological consequences. As a basis for such a forecast may serve analysis of the condition of expendable wells removed from service, of oil gathering goods depots, and other facilities. The examination results of the territories of old exploratory wells and dismantled tank farms showed that vegetation self-repair processes in the middle- and south-taiga forests go on well. The amount of coniferous undergrowth (Siberian spruce *Picea obovata* Ledeb. and Archangel fir *Pinus sylvestris* L.) reached in some areas of drill sites 100 000 pcs. In Fig. 4 the dynamics of crown density of woody plants at abandoned exploratory facilities is shown. In 30–35 years a stand of trees is formed throughout the entire platform. Tank farm territories are completely overgrown by grassy and shrubby vegetation immediately after completion of operation. At the same time the main hazard for vegetable restoration is presented by persistent sites of oil pollution of soil that are formed as a result of abandoned well head leakage, leaks of oil and fuel from left tanks and unrehabilitated slurry pits (Table 6).

The complex of technological measures in eliminating oil production facilities should prevent shows of oil-gas and water at well heads as well as recultivation of oil-polluted land and oil-containing pits.

With existing working methods and oil extraction standards minimizing the level of negative consequences of development and maintenance of deposits in the Tyumen' oblast territory, as well as in all West Siberia will be dragging out for decades. One can speak of the full restoration of the natural environment only discussing the natural course of biogeocenotic and geological processes on Earth and man's role in them.

The work was carried out under the state contracts of FTP "Scientific and Scientific-Pedagogical Personnel of Innovative Russia" (no. 16.740.11.0049) and the grant of RF Government Regulation no. 220 of 09.04.2010 (no. 11.634.31.0036).

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