Decisions to prevent pollution and restore the environment within the impact of abandoned oil and gas wells

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Abstract. Decommissioned oil and gas wells that pose a danger to the environment due to emissions of methane, which is a powerful greenhouse gas and one of the man-made factors that weaken the stability of the planet in the context of global climate change. The prospects of using resistant plants common in natural phytocenoses to the influence of oil contaminants in phytoremediation practice are analyzed. The bioindication suitability of oil-sensitive plant species, which are recommended for use in monitoring studies of the quality of technogenic-transformed environment, is revealed. The choice of equipment for the restoration of abandoned wells has been made.

1. Introduction
Currently, the planet is exacerbating the negative effects of global climate change: a significant number of extreme weather conditions, floods, increased geodynamics and more. The danger is growing due to the fact that the ecological balance is disturbed as a result of the existing consumer format of human life: growing needs, depletion of resources, waste accumulation, etc. The transition to alternative energy sources does not allow to obtain the expected effect during extreme weather conditions. For example, wind power generators are not able to operate at wind speeds greater than 25...28 m/s due to the fact that the automation of the wind turbine specifically “takes it out of the wind” for safety reasons. With even more intense hurricanes there is a possibility of destruction of the wind turbine structure [1]. Therefore, increasing the volume of hydrocarbon production and geological exploration of new deposits remains an important area of socio-economic development to ensure reliable energy sources. At the same time, the development of innovative alternative energy sources continues [2].

Oil and gas facilities pose a potential environmental hazard, both due to the presence of aggressive chemicals in technological processes and due to the large number of these facilities in all regions of the planet. The consequences of oil and gas production, which occur during the life cycle of wells, cause significant environmental damage and in many cases form irreversible
changes in the natural environment. Thus, in the process of oil and gas extraction, the air, water bodies and soil are polluted. This causes discharges, emissions and vapors of harmful gaseous substances, the inflow of a significant amount of associated reservoirs of high mineralization and spills of hydrocarbons destroy the biota of water bodies, disrupt the soil cover [3, 4]; tens and hundreds of barns with drilling mud remain unliquidated; torches burn about 35 billion a year of associated gas [5]; gas and oil manifestations and open fountains, which can occur at all stages of construction and operation of wells.

Decommissioned wells need special attention. Decommissioned oil and gas wells pose a danger to the environment, as most of them produce methane, which is a powerful greenhouse gas and one of the man-made factors that weaken the stability of the planet in the context of global climate change. The number of abandoned oil and gas wells is not fully established. Determining their number is complicated by the fact that many of the abandoned wells are "lost" without any evidence of their existence on the surface.

2. Literature analysis and problem statement
The problem of abandoned oil and gas wells is common on all continents. A recent investigation by Reuters estimates that the United States could have more than 3.2 million orphaned and abandoned wells. Some states have a few hundred; others have a few thousand. And some have a staggering number of them: Pennsylvania reportedly has more than 330,000 of these wells within its borders [6]. The website of the Department of Environmental Protection Commonwealth of Pennsylvania contains information on abandoned wells, orphaned wells and plugged wells (figure 1) [7].

![Figure 1. Accounting for decommissioned wells abandoned and plugged in Pennsylvania [7].](image)

“Orphaned” wells are those for which no former owner or operator can be located, while the term “abandoned well” typically refers to an unproductive well with a known owner/operator. They are essentially open holes in the ground that need to be cleaned and plugged with cement to stop their pollutants from escaping into the environment [6].

The authors of the article [8] note that millions of abandoned oil and gas wells are scattered across the United States, causing methane emissions and other environmental hazards. Governments are increasingly interested in decommissioning these wells but want to do so efficiently. And to provide cost estimates for decommissioning oil and gas wells and key cost drivers. It is also noted that older wells are more costly than newer ones. The closure of orphan...
sites is a multi-year process. Therefore, it is important to determine the correct list of equipment for restoration work in such wells and the choice of environmental restoration technologies within their influence.

Phytocenotic diversity is one of the key indicators of stability of functioning and development of any ecosystem, and the nature of location and projective coverage of the species in the phytocenosis are the most important parameters for assessing the impact of environmental factors on the ecosystem [9, 10]. Plants play the role of primary absorbers of man-made pollutants and phytomeliorants of the environment, and at the same time can reflect at different levels of biological organization the degree of anthropogenic transformation of the environment.

The toxic effects of petroleum components on living organisms are known, in particular the ability of heavy metals and hydrocarbons to block vital biochemical processes in cells and migrate through trophic chains [11, 12]. Oil has an inhibitory effect on plant growth and development, especially at the stage of seed germination, so most seeds of plant organisms can not germinate in conditions of high oil concentrations [13, 14].

3. Purpose and objectives of the study
The global negative impact of the oil and gas industry consists of the local impacts of individual facilities. Therefore, addressing the environmental issues of individual facilities, including decommissioned wells, is one of the main tasks to improve the environmental safety of the industry. The main tasks of this article are:

- to analyze of the probable environmental impact of the old stock of decommissioned wells;
- to investigate the species composition of phytocenoses and the taxonomic characteristics of the oil-contaminated ecosystem plant groups phyto objects to offer a range of equipment methods for decommissioned wells restoration;
- to offer a range of equipment for abandoned wells restoration;
- to determine the principles of environmental safety management of the old fund abandoned wells.

4. Research methods
The choice of separate types of equipment for restoration works is conducted, in particular: the device for unscrewing of pipes, the device for cleaning of the tool which rises from a well, metal catcher and foam generating device. Identifying the stages in the life cycle of a well with the highest risk to the environment involved the use of a life cycle assessment method. The methods of biological monitoring of the environmental state are used in the work: observation, surveys and field researches, which provide the description, study of plant groups as components of ecosystem, in natural conditions, research of their functioning, structure and development. Field research includes preliminary preparatory, field and in-house methods.

5. Research results
5.1. Analysis of the potential environmental impact of decommissioned wells old fund
The global negative impact of the oil and gas industry consists of the local impacts of individual facilities. Therefore, solving environmental issues of individual facilities, including decommissioned wells, is one of the main tasks to improve the environmental safety of the industry [15, 16].

On the location of the man-made object, in our case oil and gas wells, the degree of environmental risk from the conducted activity depends. It is important to consider the length of the life cycle of the object.

In the western part of Ukraine, oil and gas facilities are located near natural recreational areas of national importance (Truskavets, Skhidnytsia, Morshyn, Bukovel resorts), which creates
a high risk of man-made disturbance of valuable areas. Since the main negative impacts are on
the surface layer of the atmosphere and surface and groundwater, the areas of distribution of
pollutants may become transboundary. Factors of natural origin can also increase the degree of
risk, in particular for mountainous areas where there is a high risk of mudslides.

Seismic movements can activate these wells and provoke accidental oil and gas emissions. The
result is the transformation of large areas into areas of ecological disaster. Tightness of
wells during their conservation is designed for 20-30 years. Over time, the cement bridges in
the well may collapse, the mouth equipment and the column itself may corrode, causing the
well to depressurize. There are research data and there are real facts of hydrocarbons from the
deep layers, which causes uncontrolled leakage of fluid or gas into the environment during the
depressurization of the well structure. Sources of information systematically publish information
about oil leaks and the destruction of conservation structures in abandoned wells around the
world. Therefore, the problem of handling wells in the post-operational period is currently
extremely acute.

The Association Agreement between Ukraine and the EU, the Paris Agreement on Climate
Change, the provisions of Directive 2003/87/EU and the Concept for the implementation of state
policy in the field of climate change until 2030, approved by the Cabinet of Ministers of Ukraine
from 07.12.16 № 932-r, Ukraine provides for the introduction of a system of monitoring, reporting
and verification of greenhouse gas emissions [17]. Emissions must be controlled at all stages of
the life cycle, so one element of eco-efficiency is the choice of technologies based on the use
of equipment that minimizes environmental impacts both during the technological process and
in the process of manufacture, delivery and disposal. European Union Directives 2008/50/EU
on ambient air quality and cleaner air for Europe and 2010/75/EU on industrial emissions
essentially set out prevention principles, complemented by restrictions, quality monitoring and
control of air emissions. The Directives also state that preference should be given not to
traditional measures (treatment facilities, etc.), but to measures that prevent pollution at
technological facilities and do not increase the burden on other natural environments [18,19].

Pollution prevention is currently a top priority in most countries around the world. Thus, in
section 6602(b) of the Act, the US Congress establishes a priority national policy:

- contamination should be prevented or reduced at source, if possible;
- uncontrollable pollution should be involved in the recycling cycle (recycling) in an
  environmentally sound way, if possible;
- contamination that cannot be prevented or cannot be involved in the re-use cycle should
  be treated in an environmentally sound manner, if possible;
- location, storage or other release into the environment should be used as a last resort and
  carried out in an environmentally sound manner.

5.2. The analysis results of the phytocenoses species composition and taxonomic characteristics
of plants groups of the oil-contaminated ecosystem

The urgent task of environmental science is to find effective remediate plants that are resistant to
oil pollution. However, the isolation of plants with valuable bioindicative properties is necessary
for timely monitoring of changes in the ecosystem in oil-contaminated areas. The study of plants
at the population-species level, which is one of the key structural components of the biosystem
organization of living organisms, allows to assess the bioproductive potential of the autotrophic
block of the ecosystem, and hence its ability to self-sustain and self-restore.

The analysis of phytocenotic diversity was performed on three sites with an area of 25 m²,
located around the source of oil pollution according to the tested method (figure 2). The nature of
the location and projective cover of the species in the phytocenosis was determined by the Brown-
Blanke method, and the identification of species was conducted using the electronic determinant
Plant Snap and reference books. Taxonomic characterization of species was performed in the laboratory.

Figure 2. Experimental area of phytocenotic diversity analysis of oil-contaminated area.

The phytocenotic diversity of the study area is represented by 13 species of herbaceous plants, 12 genera, 7 families, 7 orders, 2 classes and 1 division of Angiosperms. The class of Monocotyledons includes two families found in the territory of oil pollution Poaceae and Cyperáceae, represented by two species *Poa pratensis L.* and *Carex hirta L.*, respectively. The class Dicotyledons includes five families Asteraceae (6 species *Helianthus annuus L.*, *Taraxacum officinale Wigg.*, *Erigeron canadensis L.*, *Atremisia vulgaris L.*, *Artemisia absinthium L.*, *Achillea millefolium L.*), Fabaceae (2 species *Medicago sativa L.*, *Trifolium pratense L.*), Apiaceae (1 species *Daucus carota L.*), Linaceae (1 species *Linum usitatissimum L.*), Polygonaceae (1 species *Fagopyrum esculentum L.*).

The highest projective coverage is characterized by *Poa pratensis L.*, *Carex hirta L.*, *Daucus carota L.*, *Achillea millefolium L.*, which are resistant to oil pollution and can be used as promising objects in phytorecultivation practice table 1.

*Linum usitatissimum L.*, *Helianthus annuus L.*, *Fagopyrum esculentum L.*, which are very scattered in the phytocenosis with a projective cover of up to 25%, were the most vulnerable to stressful growth conditions. These species can be used in bioindication studies of oil-contaminated environments. Intermediate place is occupied by the following species that have adapted to living in an oil-contaminated environment *Taraxacum officinale Wigg.*, *Erigeron canadensis L.*, *Atremisia vulgaris L.*, *Artemisia absinthium L.*, *Medicago sativa L.*, *Trifolium pratense L.*

Thus, in the conditions of oil pollution, a stable phytocenosis was formed, represented by a small number of species of herbaceous plants, most of which have adapted to adverse living conditions. Further studies of morphological, physiological, biochemical and accumulative
Table 1. The nature of the location and projective coverage of herbaceous plant species in the phytoecenosis of the oil-contaminated area.

| Score | Nature of the species placement in the phytoecenosis | Projective cover | Plant species                                                                 |
|-------|------------------------------------------------------|------------------|-------------------------------------------------------------------------------|
| 1     | very scattered                                       | up to 25%        | Linum usitatissimum L., Heliánthus annuus L., Fagopyrum esculentum L.        |
| 2     | scattered                                            | 26-50%           | Taraxacum officinale Wigg., Erigeron canadensis L., Artemisia vulgaris L., Artemisia absinthium L., Medicago sativa L., Trifolium pretense L. |
| 3     | grouped                                              | 51-75%           | Poa pratensis L., Carex hirta L., Daucus carota L., Achillea millefolium L.   |
| 4     | thicketed                                            | 76-100%          | -                                                                              |

parameters of these plants will reveal the range of response rates of phytoobjects as bioindicators and bioremediates of man-made environment.

5.3. The choice of equipment for restoration of abandoned wells
Abandoned wells, the number of which is not clearly recorded on the planet and in Ukraine, pose an increasing threat to the environment every year. The danger is the breach of the casing due to corrosion and, as already mentioned, due to the increasing frequency of seismic oscillations. Conditions are being created for the inflow of oil and gas product in abandoned wells, which enters the upper aquifers and pollutes large areas. Such wells are a source of methane in the environment.

To be able to develop technical and technological solutions to reduce risks to the environment from abandoned oil and gas wells it is necessary:

- to collect data on the location of wells;
- to form a database of passport data or other information sources about the well;
- to conduct a study of the location of the well;
- to establish the condition of the well and the possibility of further work.

All wells that are abandoned or decommissioned must be under constant supervision. This leads to the creation of a structure that can give a “second life” to such wells and should be responsible for the environmental safety of such facilities. Due to the need to establish relations with the owners of areas where abandoned wells are located, it is necessary to develop a plan and strategy for the use of abandoned wells. The work should be aimed at obtaining a positive effect, both environmental and economic. At this stage, there are cases of restoration of wells and oil or gas receiving. In addition, it is possible to obtain thermal energy from these wells.

Most of the abandoned wells are low flow due to complications and accidents, which led to their abandonment or conservation. Therefore, one of the first stages of technical and economic decisions should be research and repair work of these wells. It is necessary to select modern, reliable, highly efficient devices, equipment and special tools for cleaning wells from destroyed
equipment and other unnecessary items and dirt. Indicative options for selecting individual items of equipment and devices will be discussed below.

In the process of descent into the well of long-term equipment (e.g., pipes, rods) it is necessary to monitor the condition of this equipment. To do this, it is advisable to use a rod magnetic flaw detector. The essence of the device is explained by the drawing (figure 3), which shows a general view of the rod magnetic flaw detector in working condition when passing through the protrusion and coupling of the rod or pipe when descending into the well. Figure 3 shows the moment of passage of the flaw detector through the landed end of the rod with the coupling.

![Figure 3. General view of the rod magnetic flaw detector in working condition.](image)

The rod magnetic flaw detector consists of a frame 1 and a magnetizing system mounted on it. This system is made in the form of a U-shaped magnetic circuit 2 with permanent magnets 3 and a magnetic field sensor 4, located between the permanent magnets 3. The sensor is also connected to electronic recording equipment (shown in figure 3). The protective element 5 of non-magnetic material (e.g., polyurethane) is present to protect the permanent magnets 3 and the magnetic field sensor 4. In the holes in the frame 1 and the protective element 5 mounted upper spring rods 6 with roller 7 and lower spring guide rods 8 with roller 9. Protective element
5 with landed ends 11 at an angle in contact with the controlled surface of the rod 10. Between the landed ends of the rod 11 is a coupling 12, and on the frame 1 is a lever balancing mechanism 13 in contact with one end with the upper spring rods 6 and the other end with the lower guide spring rod 14 of U-shaped magnetic conductor 2.

This control will prevent damaged elements from flowing into the well, which could cause additional complications.

To accelerate the unscrewing of pipes or rods left in the well, it is advisable to use a device for unscrewing the pipes in the well [19]. Figure 4 shows a laboratory experimental sample of the device.

This device for unscrewing pipes in the well contains a hollow cylindrical body with a left adapter located in the lower part, and a right adapter located in the upper part of the device. Anchor assembly with locking elements, reversible mechanism in the form of a planetary gearbox, consisting of a hollow gear shaft, a carrier with satellites, which are installed to interact with a hollow gear shaft and a toothed surface made on the inner cylindrical surface of the hollow cylindrical body of the device. The hollow gear shaft itself is mounted on rotatable bearings with respect to rotation relative to the device body, and the means for actuating the anchor assembly comprises a housing which is fixedly connected to the carrier and mounted on the middle part of the gear shaft. Fixing elements that are rotatable about axes parallel to the axis of the device. And the outer working cylindrical surface of the fixing elements is made by moving the generating along the part of the Archimedes spiral. The means for triggering the anchor assembly includes a spacer sleeve, which is installed with the possibility of limited axial movement on the splined surface made on the upper part of the gear shaft. The anchor assembly also contains thrust carriers, which are fixed on the upper end surface of the fixing elements and made in the form of cylindrical rods with spherical ends. Adjusting nut screwed on the threaded surface made on the gear shaft below the splined surface. The anchor assembly also includes a spring mounted between the upper end surface of the adjusting nut and the spacer sleeve, the lower end surface of which is made in the form of a cone arranged to interact with the spherical ends of the thrust bearings.

Execution of the outer working cylindrical surface of the fixing elements by moving the generating along the part of the Archimedes spiral and enabling the rotation of the fixing elements around axes parallel to the axis of the device to change the outer diameter of the device, provides more interaction with the inner surface of the casing. This prevents it from being damaged by contact, which could be a source of future damage. In addition, the proposed design of the locking elements allows the device to be used in casings of different diameters without replacing the locking elements themselves.

To capture ferromagnetic parts that have accumulated in the well, it is necessary to use the end and peripheral magnetic metal traps.

In a peripheral magnetic trap, placing the paws on top of each other with belts allows you to cover the entire gap between the drill string and the well walls, providing simultaneous centering of the trap and protection of magnetic systems from destruction. The placement of the lower belt paws between the upper belt paws provides full coverage of the flushing fluid flow by the action of the magnetic field. The flux that is not exposed to the magnetic field in the lower belt falls within the range of the magnetic field in the upper belt. The formation of magnets and magnetic conductor systems allows to create different combinations and ensure their performance removable and autonomous. Making magnetic systems removable allows you to quickly replace them on the surface when replacing the bit or layout of the drill string, which significantly reduces the time to clean the metal trap from ferromagnetic particles and reduces time spent during lowering and lifting operations. Execution of autonomous systems ensures their independence from external energy sources, as well as the independence of their performance from the conditions of formation of the magnetic circuit with the body of the metal
catcher.

To prevent the absorption of liquid in the process of washing the well, it is advisable to carry out foam washing. And to obtain a fine stable foam, it is necessary to use a foam-generating device (figure 5).

![Figure 4. Laboratory experimental sample of a device for unscrewing pipes.](image1)

![Figure 5. Foaming device.](image2)

This foam generating device has a positive effect due to the introduction of a multi-nozzle insert, instead of one nozzle, allows to increase the productivity of the device and its efficiency due to increased contact surface area of liquid jets in pre-mixing chambers with air or gas, from many nozzles in the cavitation chamber of intermediate mixing, where the dispersion takes place, which contributes to the effective mixing of air or gas with liquid and the formation of a foamy solution. In the chamber of turbulent motion of the flow of the mixture placed in the diffuser is the process of consolidation of the obtained effect a stable controlled foamed mixture is obtained.

5.4. Definition of environmental safety management principles of the old fund abandoned wells

Decommissioning and abandoned oil and gas wells are currently being accumulated, some of which are not accounted for anywhere, posing a potential risk to the environment. At the same time, there is an increase in inflows and outflows in the later stages of field operation. Therefore,
there is a need to develop strategic solutions based on the principles of eco-efficiency to prevent environmental pollution during the life cycle of oil and gas wells [20].

The main positions of the Strategy are:

• to analyze each stage of the life cycle for the possibility of reducing not only output flows (emissions, discharges, waste etc.), but also reduce input flows, which involves resource conservation and efficient use of energy. Achieving such effects is possible with the modernization of existing technologies and equipment;

• constant control of wells decommissioned by developing innovative tactics for their involvement in the life cycle of energy flows;

• reduction of the risk of emergencies by monitoring the condition of equipment: timely diagnosis and selection of criteria for equipment perfection;

• development of forecast estimates in emergency situations, in particular in gas and oil pipelines and open fountains, which will allow to make effective management decisions for rapid localization of the accident and reduction of negative environmental effects on the environment;

• formation of an environmental safety management system at all stages of the life cycle of oil and gas wells, based on the principles of sustainable development, eco-efficiency and continuous improvement by adapting best practices of developed countries and developing their own management approaches.

6. Discussion of the results

The process of well restoration is complex and requires a significant number of specialists and resources to achieve the expected effect. The work should be carried out systematically with the planning of successive stages. Equipment and methods of restoration of abandoned wells should be determined individually according to the characteristics of each well and the specifics of the landscape. Selection of plant bioindicators and bioremediators of technogenic-changed territories should take into account climatic zonation and their phytodiversity.

7. Conclusions

The problem of abandoned wells significant number presence, where there is insufficient or no control over their condition and processes occurring in the wellbore space, which can pose a threat to the environment. The prospects of using resistant plants common in natural phytocenoses to the influence of oil contaminants in phytoremediation practice are analyzed. The bioindication suitability of oil-sensitive plant species, which are recommended for use in monitoring studies of the quality of technogenic-transformed environment, is revealed. The selection of equipment that allows for the effective restoration of abandoned wells is done.

The solutions proposed in the work will allow to monitor these wells condition, to reduce the uncontrolled flow of fluids into the environment and to restore areas affected by long-term exposure to hydrocarbon pollution.

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