Development of an operational environmental monitoring system for hazardous industrial facilities of Gazprom Dobycha Urengoy

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Abstract. The article presents an assessment of the technogenic impact on the atmospheric air inflicted by oil and gas extracting and processing facilities in Western Siberia. It is revealed that heterogeneity and areal dispersion of emission sources are the key features of the considered industry. Mathematical statistics techniques allowed grouping sources of air pollution and determining the major air pollutants at the considered production facilities. It is proposed to design an automated operational environmental monitoring system with a hierarchical two-level structure for operational and reliable control of the natural environment in the impact area of the studied facilities.

1. Introduction
Over the past 20 years, global energy consumption has tended to increase continuously [1]. Thus, in 2017 alone, global energy consumption increased by 2.9 %, with the share of hydrocarbons in the global energy balance of 80-85% [2]. Due to this, extraction, processing and transportation of hydrocarbons is one of the main factors of global environmental pollution [3, 4, 5, 6].

Oil and gas companies inflict complex and intense environmental impact primarily through the atmosphere, lithosphere and hydrosphere. The effects of such exposure are found often at a considerable distance from the sources [7, 8, 9]. The negative impact of oil and gas facilities is due to the toxicity of natural hydrocarbons and related resources, and a variety of chemicals used in technological processes.

The main feature of oil and gas production and processing enterprises is the presence of flows of fire- and explosion-hazardous products and raw materials, leading to major accidents, environmental and economic damage from which amounts to hundreds of millions of dollars [10, 11, 12, 13].

The production oil and gas facilities of increased environmental and technogenic danger were studied at one of the fields of Western Siberia; the enterprise produces natural gas, gas condensate, oil, prepares hydrocarbon raw materials for transportation, builds the raw material base. The resource base of the enterprise is provided with reserves of hydrocarbons of Urengoyskoe, Yen-Yakhinskoe, Severo-Urengoyskoe and Pestsovoe fields located in the Yamalo-Nenets Autonomous Okrug of the Russian Federation.

Air protection is the top significant and multifaceted environmental aspect of the production activities of oil and gas companies [14, 15, 16]. The priority in this direction is the work aimed at
reducing the emissions of major greenhouse gases (carbon dioxide and methane).

In this regard, the main objectives of the research were to study the landscape-geochemical situation [17, 18, 19] under the influence of intensive anthropogenic load on the territories of the production facilities; to identify the main causes and consequences of pollution, taking into account the specifics of the production process; and to improve the organisational structure of industrial environmental control based on the creation of GIS-technology for the safe functioning of the studied objects.

2. Materials and methods

The sources of influence on the atmospheric air during the development of the field and primary processing are numerous areal and linear objects of the main and auxiliary technological process, as well as the accompanying infrastructure [20, 21]: complex gas treatment plants (CGTP), condensate stabilisation units (CSU) central production facilities (CPF), booster pipeline pumping station (BPPS), well clusters, pipelines, etc.

During the five-year period, studies were carried out at the production facilities to monitor the main emission sources by using a mobile environmental laboratory.

The mobile laboratory is designed for sampling, measurements and data processing by the crew both in stand-alone mode and for delivery of samples and data to the place of further stationary processing. The car-based mobile environmental laboratory is equipped with:

- gas analysis stand;
- modern gas analysers;
- meteorological complex;
- set of air intake devices;
- and data collection and processing unit.

As a result of the conducted research, the data on emission sources, their intensity, location, and range of emitted harmful substances were collected, taking into account climatic conditions, which allows assessment of the environmental load on the study area.

Currently, the total number of pollutant sources at the enterprise is 6213, 6022 of which are organised. All the organised emission sources are low-height (up to 50 m high).

We propose to group the losses (costs) of gas directly or indirectly resulting in emissions into the atmosphere as follows:

1) direct gas losses caused by the production activities of all facilities. These include the consumption of fuel gas in the operation of fuel-using equipment (diesel plants, boilers, gas pumping units, etc.);
2) irretrievable losses of gas with emissions into the atmosphere, which are divided into two subgroups:
   2.1. technological losses of gas with emissions into the atmosphere, taking place in the performance of various technological operations at the facilities (for example, as a result of technological losses of extracted, processed and transported hydrocarbon raw materials);
   2.2. technical losses, the presence and volume of which depends on the level of construction, operation, reliability of equipment and other factors. This subgroup includes gas losses due to gas leaks from process equipment and leakages of shut-off valves, as well as losses in case of accidents, breaks and equipment damage.

The interpretation of the received field materials showed that the main pollutants of atmospheric air from the considered enterprises are [23]:

- components of oil and natural gas, i.e. hydrocarbons and carbon dioxide released into the air pool through leaks during extraction, processing and transportation of oil and gas condensate;
- carbon oxides, nitrogen oxides, sulphur oxides, resulting from the operation of heat consuming equipment;
- soot coming into the atmosphere from plants for the production of carbon black;
- toxic chemicals used in the extraction and transportation and at different stages of preparation and
3. Results
We propose to create an automated operational environmental monitoring system (OEM) for continuous reliable control of the state of the natural environment in the impact area of the studied oil and gas field.

The OEM system, formed using GIS software, is an information and measuring system designed to control the natural environment in the zone of interaction of production facilities with the components of the natural environment. The system carries out operational collection of measurement data on the state of the observed natural objects, their processing and analysis, as well as the dissemination of monitoring results between different production units of an enterprise [24].

The operational environmental monitoring system is based on technical, software, information and organizational means, based on the following principles:

- the system provides comprehensive control over the entire set of observed components of the natural environment that are exposed to negative effects from either hazardous production facilities or those that can adversely affect these facilities;
- the control of the natural environment in the system is based on a combination of point and line ground observations and remote information, which enables the area coverage and extrapolation of observations;
- the monitoring data processing at all the stages from primary measurements, data collection and accumulation to decision support on environmental safety and security management of facilities is based on single information technology;
- the system monitors the current state of the components of the natural environment, evaluates the dynamics of its development and allows making environmentally sound and economically sound management decisions.

To design the optimal OEM structure, the issue of choosing the number and location of control points becomes relevant, for which it is proposed to divide the emission sources into homogeneous groups so that within the groups the quantitative characteristics of emissions should be subject to the normal distribution law [25].

The division of emission sources by independent groups is proposed to be carried out not by separate features, but by their cumulative effect, for which there is a need for multiple correlations. For performing such classifications, cluster analysis is the optimal solution.

If there are \( p \) objects and \( m \) characteristics are measured, then the data set forms a matrix of \( p \times m \) order. After that, a similarity level or match criterion is calculated between each pair of objects. A standardised \( m \)-dimensional Euclidean distance \( d_{ij} \) is used as the similarity quotient, which is calculated as (1):

\[
d_{ij} = \sqrt{\frac{\sum_{k=1}^{m} (X_{ik} - X_{jk})^2}{m}}
\]

(1)

Where: \( X_{ik} \) is the value of the \( k \)-th variable at the \( i \)-th object, \( X_{jk} \) is the value of the \( k \)-th variable at the \( j \)-th object.

A small value for this distance indicates that the objects are similar or "close" to each other, while a large value indicates no similarity.

The next task is to obtain a hierarchical grouping of objects in which the objects with the highest similarity quotient are placed together. The selected groups of objects are then joined to the new ones with which they are most closely related, and this continues until a complete classification of objects is obtained.

After being divided into clusters, the average values of harmful substances in emissions are calculated for each cluster and graphs of the dependence of these averaged contents on the type of
harmful substances are built for each cluster. The comparison of the graphs allows understanding the parameters by which the clusters are radically different from each other, as well as determining the contribution of each cluster to environmental pollution [26].

Taking a set of objects belonging to one cluster as an area pollution source, it is possible to compute the location of observation posts (the point with the maximum surface concentration) according to the *Ecologist* software (Version 3.0).

To monitor industrial objects of oil and gas field we propose installing an observation station at each site, equipped with gas analysers for determining a full range of polluting components and operating in automatic mode. Stationary posts are proposed to be located at the point of the total maximum surface concentration of a certain substance generated by emission sources, taking into account the statistical grouping of sources. The choice of substances is determined by the priority list of pollutants [27].

The data obtained by an automatic gas analyser will be received every second and processed at the automatic control point, which will allow, in case of destabilisation of the environmental situation at the facility, conducting a survey from the route posts located in the areas allocated by means of correlation grouping.

Location of a sensor is selected based on the need to determine the surface concentration of harmful substances in the atmosphere at an altitude of 1.5–3.5 m. The following meteorological parameters are determined simultaneously with air sampling: wind direction and speed, air temperature, weather conditions.

The automated environmental monitoring system provides a complete observation programme and has a hierarchical two-level structure. The lower level consists of devices and sensors, as well as software and hardware transmitting equipment. A central computer of the system and receiving equipment (a central point of data collection and processing) form the upper level. Switched telephone wires carry out the communication between the system levels. Information transfer from stationary posts is carried out by a complex of software and hardware for collecting and issuing output information in a convenient form for the operator of the central point.

The creation of the GIS-based software system for a comprehensive evaluation of environmental conditions in areas of influence of the considered enterprises suggests the following algorithm (Fig. 1). processing of gas (methanol, diethylene glycol, etc.).

![Figure 1. Functioning algorithm of the GIS technology](image-url)
The analytical unit is a part of the structure of the information management system of the OEM that implements the ability to manage environmental safety [28] on the basis of GIS and includes the following operation sequence:
– data import (in particular, the results of monitoring studies) via GIS allows creating and modifying databases, as well as importing standard Excel and Access files and processing various graphic files;
– data verification, checking the test point coordinates for the data integrity [29-32];
– initial statistical analysis is carried out to identify representative samples, remove the so-called top-cut grade values from the calculations, establish patterns of distribution of concentrations of a pollutant, the effect of proportionality, the general trend, variability and other statistical parameters;
– data interpolation [33-37].

The analysis and processing of spatially distributed data should be done by geostatistics techniques, which will give an answer to a number of specific issues:
– to evaluate the value at the point where no measurements were taken [38-40];
– to draw a map, draw contours (define values on a dense grid);
– to estimate the interpolation error;
– to take into account measurement errors;
– to determine the probability of exceeding the specified level;
– to perform a joint spatial analysis of correlated variables;
– to describe spatial variability and uncertainty;
– to visualise results: score and error maps, contour and mosaic maps, and probability and risk maps.

4. Conclusion
The conducted research allowed the solution of a relevant R&D issue of improving the organisational structure of industrial ecological control and safe functioning of an oil and gas field:
1. the regularities of the formation of halos and pollution flows are revealed with the use of standard and original methods of numerical simulation;
2. an original method of optimising the location of environmental observation posts is developed based on pollution source categorisation by cluster analysis;
3. an optimal hierarchically organised structure of OEM based on GIS technology for the safe operation of oil and gas field facilities is proposed.

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