Assessment of carbon dioxide propagation in a pipeline emergency

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Abstract. One of the most important problems of our time is the annual growth of greenhouse gas emissions into the atmosphere. To combat this phenomenon, emission reductions or the development and application of technologies for capturing, storing, using and utilizing carbon dioxide are possible. The need to implement projects for the decarbonization of technological processes is also relevant in connection with the international climate agenda. To reduce emissions, one cannot do without measures aimed at carbon sequestration. Of great interest is the creation and implementation of industrial carbon sequestration technologies that use the existing oil and gas infrastructure and allow obtaining additional benefits by increasing oil and gas recovery. The implementation of this technology largely depends on the environmental and economic feasibility of the project, which is influenced by the selected technologies for capturing and cleaning gas from impurities, the length of the pipeline to the field, a reasonable injection technology, and many other factors. For this reason, scientific and practical research in this direction are of practical importance and are quite relevant. The article presents the results of an analysis of the consequences of a violation of the tightness of a pipeline for pumping carbon dioxide. The calculation of the distribution zone of the release, as well as changes in the concentration in the flow, was carried out. The conclusion is made about the possibility of estimating the time required for the distribution of the carbon dioxide flow in the air volume to reduce its concentration to acceptable values. The work performed is important in terms of profile planning, location and safety measures in the construction and operation of pipelines for carbon dioxide transfer.

1 Introduction

An important problem that has received considerable publicity in the last decade is the increase in the average temperature on the planet due to the emission of greenhouse gases into the atmosphere [1-2]. At the same time, the main greenhouse gas, which accounts for more than 70% of global emissions, is carbon dioxide (CO₂) [3]. However, there are currently no signs of reducing greenhouse gas emissions [4-5]. At the same time, the potential growth of industrial production in developing countries, the slow transition to

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renewable sources and energy crises suggest a potential increase in these emissions in the coming years [6].

Activities aimed at the decarbonization of technological processes are quite diverse, some of them, for example, improving energy efficiency through equipment modernization, digitalization of technological and management processes, can be implemented by all companies, while most activities, such as the transition to low-carbon energy sources, capturing, storing and using carbon is more difficult to implement, which is primarily due to technological difficulties, high economic costs and the lack of state support for the implementation of projects. To reduce Scope 3 emissions, carbon sequestration activities are indispensable.

Carbon sequestration is carried out by physicochemical, biological and geological methods. The physicochemical method is based on carbon capture by physicochemical methods, if necessary, its compression and transportation, as well as further processing to obtain products with high added value [7].

The biological method of sequestration involves the use of the potential of natural living systems (plants, algae), which are natural absorbers of carbon dioxide [7–9].

Geological methods are based on the injection of greenhouse gases into underground storage facilities, which in principle is quite safe, because most of the repositories should not be disturbed by tectonic processes over the next million years, but from an economic point of view, they are quite expensive, requiring the development and implementation of monitoring systems for the object even after its conservation [7].

Of great interest is the creation and implementation of industrial technologies for carbon sequestration, using the existing oil and gas infrastructure, and in addition, allowing to obtain additional benefits by increasing oil and gas recovery [10], according to some data, it can be increased up to 28% [11].

Transportation is an integral part of the technological process of capturing, storing and pumping carbon dioxide. Gas transportation can be carried out in various ways: by water transport - ships, by land transport - trucks, trains, as well as through pipelines.

Transportation of carbon dioxide by rail is possible only with an existing railway line, in addition, a loading and unloading and storage infrastructure is required. When transported using tank trucks, it is possible to transport 2–30 tons per trip. Not economical for large-scale carbon capture, storage and use projects. Maritime transport is characterized by high operating costs, low capital costs. Currently used in the food and brewing industry for small volumes and various conditions. Transportation through the pipeline has high capital costs, but low operating costs, it is used to transport carbon dioxide in order to increase oil and gas recovery [12].

A comparative analysis of carbon dioxide transportation methods is presented in Table 1.

<table>
<thead>
<tr>
<th>Transport method</th>
<th>Conditions</th>
<th>Phase state</th>
<th>Capacity, million tons of CO₂/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline</td>
<td>4.8–20 MPa, 283–307 K</td>
<td>Gaseous and solid state</td>
<td>~100</td>
</tr>
<tr>
<td>Ships</td>
<td>0.65–4.5 MPa, 221–283 K</td>
<td>Liquid</td>
<td>&gt;70</td>
</tr>
<tr>
<td>Tank trucks</td>
<td>1.7–2.0 MPa, 243–253 K</td>
<td>Liquid</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Railway transport</td>
<td>0.65–2.6 MPa, 223–253 K</td>
<td>Liquid</td>
<td>&gt;3</td>
</tr>
</tbody>
</table>

Analyzing the data obtained, it can be noted that for industrial technologies for the use of CO₂ in the oil industry, pipeline transport is of the greatest interest. The purpose of our study is aimed at reducing the risks of oil and gas companies in the transportation of carbon dioxide from the place of formation to the place of use when injected into the reservoir to enhance oil or gas recovery.
2 Materials and methods

When designing a pipeline, in order to avoid emergency situations and normal operation, it is necessary to take into account the operating conditions - temperature, pressure, environmental conditions, for the materials from which the pipes are made and for auxiliary equipment (overpressure protection systems), the location of the pipeline - the topography of the route, remoteness from settlements, access roads.

To assess the potential risks arising from emergency situations as a result of transportation, a carbon dioxide generation facility was selected, the location of the pipeline providing transportation of gas from the place of generation to the destination was theoretically determined, as well as a gas injection well corresponding to the possible beneficial use, namely increase in oil recovery. The object of carbon dioxide formation is one of the technological processes for refining oil with a carbon dioxide content of 79%.

The carbon dioxide injection site is one of the fields in the Perm Territory. Transportation of gas will be carried out by the main pipeline for carbon dioxide. The pipeline is planned from a settlement with a source of carbon dioxide, along roads and settlements. The minimum distance from the proposed pipeline route to the nearest settlement boundary is less than 0.1 km, the maximum distance is 2 km, and the average distance is 0.37 km.

One of the most complex but important problem of modern science is the assessment of the dispersion of various impurities in the atmosphere. The spreading area during releases of a toxic substance depends on the release rate, the characteristics of atmospheric transport, primarily on wind speed, and also on the topography of the site.

To assess the possible spread of gas during a leak, information was used on the wind rose for the planned location of the pipeline, which characterizes the wind regime in the area based on long-term meteorological observations.

To calculate the volumetric concentration, it is necessary to calculate the volume of space in which the gas spreads, in our case carbon dioxide. The volume of space in which propagation occurs can be determined as follows (formula 1):

\[ V = \frac{2}{3} \pi abc, \]  

(1)

Which corresponds to half the volume of the ellipsoid. Here a and b are parameters determined from the coordinates of the front, the parameter c is assumed to be 1 m, since CO₂ is a heavier gas than air and its propagation occurs near the earth's surface.

The leakage volume is calculated using formula 2:

\[ V_{ym} = Q_{ym} \cdot t, \]  

(2)

Where \( Q_{yr} \) is the volume flow for leakage, \( t \) is the time elapsed since the start of the leak.

When transporting carbon dioxide, it is necessary to take into account the conditions of transportation (temperature, pressure), the presence of impurities in the gas mixture, and exclude the possibility of corrosion of the pipe material. All these measures allow to exclude emergency situations that may arise during project implementation.

According to [13], it was determined that at a carbon dioxide concentration above 0.1% (1000 ppm), there is a feeling of weakness, headache, general discomfort, and concentration of attention decreases. The concentration of 0.5% corresponds to the limit of 8 hours. A concentration of 1.5% is deadly.
3 Results

To assess the possible spread of CO$_2$ in the event of a leak, we used information on the wind rose (Figure 1) for the city of Perm, which characterizes the wind regime in a given area based on long-term meteorological observations.

Fig. 1. Wind rose for Perm.

The considered pipeline is designed for transportation of CO$_2$, transports 1084 tons of gas per day, which corresponds to a volume flow $Q = 361333$ m$^3$/day, at an inlet pressure of 1.6 MPa and an outlet pressure of 0.5 MPa.

Based on the wind rose (Figure 1), it is assumed that wind propagation is possible in all directions of the world, however, it is necessary to recalculate the speed depending on the probability of wind propagation in each direction. The calculation of the potential CO$_2$ propagation front, taking into account the wind rose for a leak time of 1 minute, is shown in Figure 2. To simplify further calculations, this front is approximated by an ellipse.

Fig. 2. Calculation of the potential front of CO$_2$ spread, taking into account the wind rose. Wind rose for the city of Perm.

To estimate the concentration of carbon dioxide in the course of time, we perform the calculation according to formula 2. To do this, assume that the pressure drop in the pipeline was 30%, which means a leakage of 4516.6 m$^3$/h. To calculate the volumetric
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**Fig. 3.** The dependence of the average volume concentration on time.

**4 Discussion**

A decarbonization policy aimed at reducing greenhouse gas emissions and reducing the carbon footprint of enterprises' technological processes encourages enterprises to implement various methods of carbon sequestration. The development of environmental protection measures and recommendations to prevent damage to the environment by the planned activities for the transportation and utilization of carbon dioxide at the field is relevant and important for justifying the implementation of these projects.

The paper describes a method for determining the distribution profile of carbon dioxide in the event of an emergency, an example of a technological calculation of the distribution of carbon dioxide concentration over time is given. The performance of these calculations will make it possible to assess the optimal time for stopping the compressor, the time for the possible elimination of an accident, the required distance from settlements and other issues important in the design of pipelines.

**5 Conclusions**

- It was determined that for a correct assessment of risks, it is necessary to determine the operating conditions of the main pipeline. To minimize the risks, it is necessary to equip the pipeline with wireless pressure sensors to minimize the response time of maintenance personnel to pressure reduction.
- Based on the calculation of the change in the volume concentration of CO$_2$ in the leakage zone, it was found that in the conditions of Perm, after the start of carbon dioxide emissions, employees should be allowed into the accident zone no earlier than 15 minutes later to avoid harmful effects.

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