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Reduction of Risks when Transporting Carbon Dioxide to the Injection Site

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Abstract

The need to implement projects for the decarbonization of technological processes is relevant in connection with the international climate agenda. To reduce greenhouse gas emissions, especially in Scope 3, carbon sequestration activities are indispensable, which can be implemented in various ways. Of great interest is the creation and implementation of industrial carbon sequestration technologies that use the existing oil and gas infrastructure, and in addition, 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, an emergency monitoring system, and many other factors. For this reason, scientific and practical research in this direction are of practical importance and are quite relevant. 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. The article presents the results of the analysis of possible emergency situations during the transportation of carbon dioxide to the place of injection. Recommendations are given to prevent them, namely, equipping the route of the pipelines being designed with pressure sensors, justifying the reaction time to stop the compressor equipment, which is no more than 6 minutes and the departure of technical specialists to the emergency facility no earlier than 15 minutes after the incident. It is noted that in order to reduce pipeline corrosion and prevent carbon dioxide leaks, it is recommended to comply with the conditions under which the gas is in a supercritical state, in addition, to purify the gas from impurities in the transported carbon dioxide stream and use a corrosion-resistant material for the manufacture of the pipeline.

Keywords: *Sequestration; Gas methods of enhanced oil recovery; Gas transportation; Emergency situations.*

1. Introduction

Recently, the global climate agenda has been focused on reducing the rate of global warming; accordingly, the activities of many companies are aimed at accounting for and reducing greenhouse gas emissions, as well as the transition to low-carbon development.

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 government support for the implementation of projects.

To reduce greenhouse gas emissions, especially in Scope 3, carbon sequestration activities are indispensable. Carbon sequestration is carried out by physico-chemical, biological and geological methods. Of great interest is the creation and implementation of industrial carbon sequestration technologies that use the existing oil and gas infrastructure, and in addition, allow obtaining additional benefits by increasing oil and gas recovery.

According to [1] currently existing and planned carbon utilization and storage facilities: North America - 36, Europe - 30, Asia - 27, Middle East - 5, Africa - 2, Central/South America – 1. Most of the ongoing projects are related to enhanced oil recovery. The largest ongoing projects for the injection of carbon dioxide to enhance oil recovery are the projects [Global CCUS projects, 2021]:
- ACTL (Canada), with a capacity of 1.7-14.6 million tons/year;
- Abu Dhabi Cluster (United Arab Emirates), with a capacity of 2.7-5.0 million tons/year;
- Xinjiang Junggar (China), with a capacity of 0.2-3.0 million tons/year.

Oil production facilities are classified as hazardous production facilities and can pose a serious threat to humans and the environment. The analysis of the probability of occurrence of emergencies must be assessed on the basis of an analysis of the accident rate at specific facilities similar to the one being designed.

Transportation is an integral part of the technological process of carbon dioxide capture, storage and injection. Gas transportation can be carried out in various ways: by water transport – ships, by land transport – trucks, trains, as well as by pipelines. The level of technical readiness of the projects corresponds to TRL 9.

The use of pipelines is the most common method, for example, 85% of all pipelines used for the transportation of carbon dioxide operate in the USA [2]. The length of the pipeline is of great importance, which affects, first of all, the cost of the project, and of course, the likelihood of emergencies.

2. Materials and methods

The purpose of our study is aimed at reducing the risks of oil and gas companies when transporting carbon dioxide from the place of formation to the place of use when injected into the reservoir to increase oil or gas recovery. To achieve this goal, it is necessary to solve a number of theoretical and practical problems:
– analysis of existing pipeline systems intended for the transportation of carbon dioxide, as well as emergency situations on them;
– on the basis of theoretical data to determine the conditions of gas transportation;
– analysis of possible emergency situations and their prevention during the implementation of carbon dioxide transportation with its subsequent injection in a certain area of the projected facility.

When designing the pipeline, in order to avoid accidents 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 place of passage of the pipeline – the topography of the route, distance from settlements, access roads [3-4].

To assess the potential risks arising from emergencies as a result of transportation, a carbon dioxide formation facility was selected, the location of the pipeline providing gas transportation from the place of formation to the destination was theoretically determined, as well as a gas injection well corresponding to the most beneficial use, namely, an increase in oil recovery.

One of the most difficult but important problems of modern science is the assessment of the dispersion of various impurities in the atmosphere. The area of distribution during emissions of a toxic substance depends on the power of the release, the characteristics of atmospheric transport, primarily on wind speed, as well as on the topography of the site.

To assess the possible spread of gas in the event of a leak, information about the wind rose for the planned location of the pipeline was used, characterizing the wind regime in this area according to long-term meteorological observations.

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

$$V = \frac{2}{3}\pi abc, \quad (1)$$

where a and b – parameters determined from the coordinates of the front, parameter c is assumed to be equal to 1 m, since CO_2 is a heavier gas compared to air and its propagation occurs near the earth's surface.

The leakage volume is calculated by the formula 2:

$$V_{leak} = Q_{leak} \cdot t \quad (2)$$

where Q_{leak} – volumetric flow rate for leakage; t – time elapsed since the beginning 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, to exclude the possibility of corrosion of the pipe material. All these measures will make it possible to eliminate emergency situations that may arise during the implementation of the project.

3. Results

The place of injection of carbon dioxide is one of the deposits of the Perm Region. Gas transportation will be carried out in the most common way using a pipeline. The minimum distance from the route of the projected pipeline to the nearest border of the settlement is less than 0.1 km, the maximum is 2 km, and the average distance is 0.37 km.

Gas pipelines are subject to various external influences. To reduce the negative consequences, pipelines are located underground, however, in this case, their integrity or deformation may occur, leading to leaks of the transported gas. When a pipeline breaks, the high-pressure gas escapes. There is a decrease in gas pressure in the pipeline and the transition to emergency operation. At the same time, the ingress of gas into the atmosphere can adversely affect the environmental situation.

As part of the development of recommendations, an assessment of the possible impact of leakage on the environment for the pipeline under consideration was carried out. This pipeline is designed for the transportation of CO_2, transports 1084 tons of gas per day, which corresponds to a volume flow rate of Q = 361333 m^3/day, at inlet pressures equal to 1.6 MPa, at outlet – 0.5 MPa.

To assess the possible spread of CO_2 during leakage, information about the wind rose for the territory was used – the location of the planned pipeline, characterizing the wind regime in this area according to long-term meteorological observations. The average annual wind speed is 2.4 m/s. Thus, it is assumed that wind propagation is possible in all directions of the world, but 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, is shown in Fig. 1.

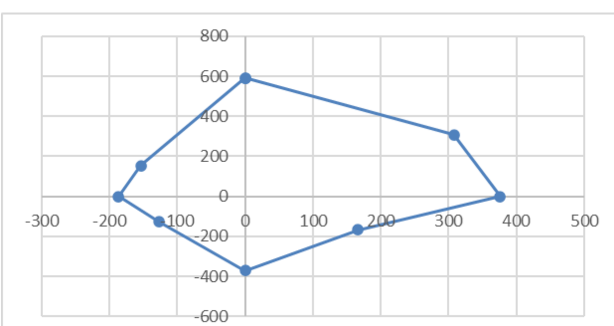

Figure 1. Calculation of the potential CO_2 propagation front taking into account the wind rose. *Source:* compiled by the authors.

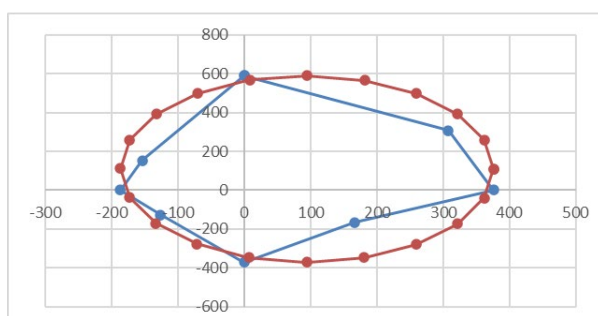

Figure 2. Approximation of the curve shape characterizing the propagation of gas by an ellipse. *Source:* compiled by the authors.

Let us calculate the variant of a possible leak in one of the most dangerous places - not far from the place, the distance to which from the pipeline is less than 500 meters. To calculate the volumetric concentration, we calculate the volume of space in which CO_2 spreads. Approximation of the shape of the curve, which characterizes the propagation of gas by an ellipse, is shown in Fig. 2.

Let us carry out the calculation for different values of the volume flow rate of the leak. We will assume that the change in pressure is proportional to the change in the volumetric flow rate of the gas in the event of a leak.

Let's simulate three options: the pressure drop is 10%, 20% and 30%. Thus, we obtain the following values of volume flow rates for leakage, based on their gas volume flow in the pipeline: Q1 = 1505.5 m^3/h, Q2 = 3011.108333 m^3/h, Q3 = 4516.6625 m^3/h. Let us calculate how the average volumetric concentration changes at different points in time. For the moment of time t = 0.1 h, we have the following values for the average concentration of CO_2 in the volume: 0.478450083, 0.956900166 and, respectively, 1.435350249.

At the maximum volume flow rate for carbon dioxide leakage, concentrations are close to deadly. However, it is worth noting that the concentration decreases linearly as it moves away from the source, due to constant wind transport. The concentration of carbon dioxide depending on the distance from the center of the leak at time t = 0.1 h for the maximum volume flow rate of the leak is shown in Fig. 3.

Based on the data in Fig. 3 (for the largest leak), at the initial moment of time, the maximum concentration of CO_2 is observed at the center of the leak, however, as it moves away, the concentration drops rather quickly and tends to 0 at the edges of the front.

At the time t = 0.3 h, the average concentration values are: 0.159483361, 0.318966722, 0.478450083. The decrease in the average concentration occurs due to the spread of CO_2 into a larger volume of the environment. These values are no longer deadly and there is enough time to eliminate the leak and its consequences.

In many respects, the actions of technical personnel are decisive in an emergency. Depending on the speed of reaction to the pressure drop in the measuring units and the stop of the compressor, the damage radius can be reduced. The calculated dependence of the damage radius on the reaction rate is shown in Fig. 4.

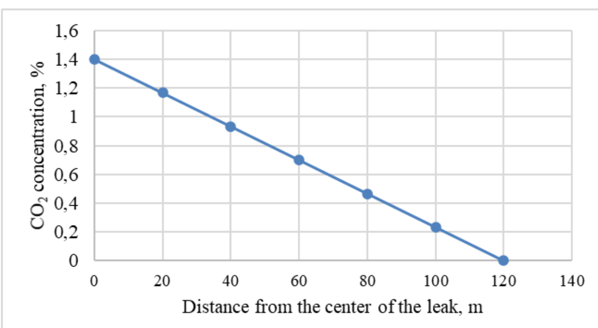

Figure 3. CO_2 concentration depending on the distance from the center of the leak at time t = 0.1 h for the maximum leak volume flow. *Source:* compiled by the authors.

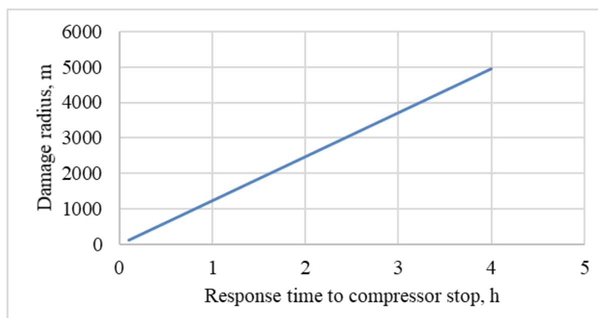

Figure 4. Estimated dependence of the damage radius on the reaction rate. *Source:* compiled by the authors.

Despite the increase in the lesion radius with time, the average value of the volume concentration decreases with time (Fig. 5). This is due to the constant distribution of CO2, which leads to an increase in the volume of space in which it is distributed.

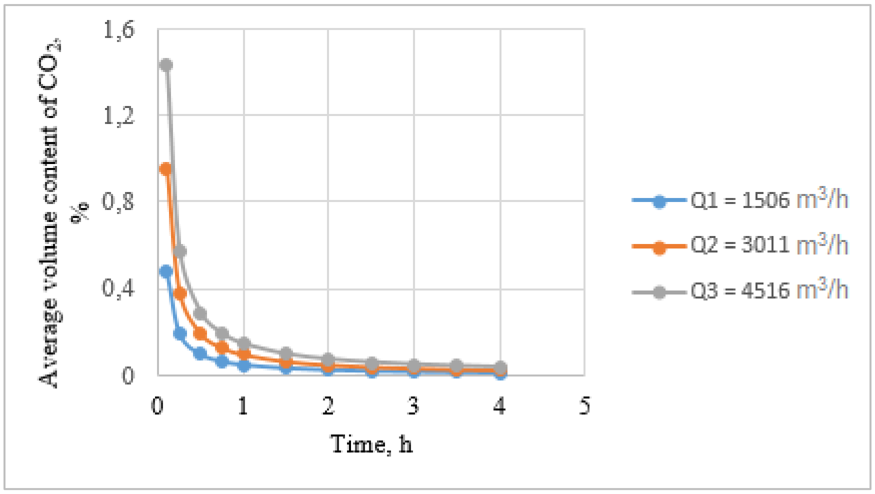

Figure 5. The dependence of the average volume concentration on time. *Source:* compiled by the authors.

As a result of the study, the following recommendations for the operation of the designed pipeline system were formed:

1) Equip the route of the projected pipelines with pressure sensors, measurements from which will be transmitted to the operator's automated control system in real time.
2) When fixing a decrease in the actual pressure below the calculated 30%, the reaction time to stop the compressor equipment should be no more than 6 minutes.
3) After stopping the compressor equipment, the departure of technical specialists to the emergency facility is allowed only no earlier than 15 minutes.

To reduce corrosion of the pipeline and prevent carbon dioxide leaks, it is recommended to observe the conditions under which the gas is in a supercritical state (temperature – 31°C, pressure 7.2 MPa), to avoid the presence of impurities in the transported carbon dioxide stream, to use a corrosion-resistant material for the manufacture of the pipeline.

4. Discussion

Based on the literature studied, it has been established that existing pipeline systems for transporting carbon dioxide operate in the USA, Canada, Norway, the Netherlands, the United Arab Emirates, as well as in Saudi Arabia, their length varies and can be more than 50 km, and in some cases more than 1000 km. The number of incidents and deaths associated with the transportation of carbon dioxide through the pipeline system is significantly less than when transporting oil or natural gas. This can be explained by the fact that, on the one hand, CO_2 is less dangerous than oil and gas, and on the other hand, the number of pipelines for transporting carbon dioxide is not large [5].

Carbon dioxide is recommended to be transported in its supercritical form. This state is achieved at a temperature of -31°C and a pressure of 7.2 MPa [6]. Thus, the pressure and temperature in the pipeline must be controlled to ensure that the gas stream remains in a supercritical state and to avoid the formation of two-phase flow, which can cause serious disturbances. For this reason, it is necessary to install centrifugal pumps at regular intervals along the entire length of the pipeline to recompress CO_2 in the event of pressure loss [7].

The purity of the transported gas must be greater than 90% [5]. Impurities (water, hydrogen sulfide, mercury, etc.) that may be present in the gas stream may adversely affect the transportation technology.

The presence of water can provoke the formation of hydrates, which can block the pipeline. In addition, water can react with CO_2 to form carbonic acid, which is a very corrosive substance. The content of hydrogen sulfide in the CO_2 stream must be significantly reduced, as it is a toxic gas that can pose a significant health risk in the event of a leak. In addition, adding it to CO_2 in the presence of moisture leads to a synergistic effect in the development of a corrosion process that can lead to leakage [5].

Mercury is another impurity that is typically present in the trapped CO_2 stream. At high concentrations, mercury can cause some problems in pipelines and therefore must be removed. For the operation of the process it is necessary to exclude corrosion of the pipeline, which can lead to CO_2 leakage, for this reason the choice of material from which the pipeline will be made is important. Preference is best given to corrosion resistant materials [3].

5. Conclusion

Decarbonization policies aimed at reducing greenhouse gas emissions and reducing the carbon footprint of technological processes orientate enterprises to implement various methods of carbon sequestration. Of great interest is the introduction of carbon dioxide injection into the reservoir to increase oil or gas recovery.

To implement such projects, an assessment was made of existing transportation facilities, many of which are located in North America and have a length of more than 50 km. Based on theoretical data, the conditions for gas transportation (temperature, pressure, presence of impurities, etc.) are determined, which will reduce the load on process equipment and prevent accidents.

The analysis of possible emergency situations and their prevention during the implementation of the transportation of carbon dioxide with its subsequent injection in a certain area of the projected facility, on the basis of which recommendations for the operation of the projected pipeline system were formed, namely, the presence of pressure sensors, measurements from which will be transmitted to the operator's automated control system in real time, allowing to record the decrease in actual pressure. In addition, after stopping the compressor equipment, the departure of technical specialists to the emergency facility is allowed only no earlier than 15 minutes.

Further research is aimed at evaluating the effectiveness of the project in terms of minimizing greenhouse gas emissions, taking into account the carbon footprint during the implementation of the project for the capture, transportation and placement of carbon dioxide.

Acknowledgments

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