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Modeling of CO_2 Injection in North Stavropol Underground Gas Storage Reservoir (Russia)

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ABSTRACT

North Stavropol Underground Gas Storage (UGS) has been established on the basis of sufficiently large depleted gas field (33 x 18 km), intra-structural Pelagiada rise (16 x 11 km) is considered as a reservoir of CO_2 injection. The production horizon is represented by Paleogene sediments of the lower Oligocene with total thickness of 80-95 m. After the establishment of the UGS, the pressure in the horizon stands at 3 MPa. TOUGH2-TMVOC modeling of CO_2 injection in 16 wells was assigned with rates from 16 to 160 kg/s. The modeling results show that no more than 8% - 10% of the injected CO_2 is dissolved in the liquid phase, of which not more than 1.4% is dissolved in the marginal waters. With a maximum rate of injection, the pressure in Pelagiada reservoir remains below the critical value. Modeling proved potential of CO_2 sequestration during 30 years was estimated 0.005 gigaton.

1. INTRODUCTION

The studies, which examine carbon dioxide CO_2 behavior in geological environment, aim at the compensation of the negative effect of anthropogenic CO_2 emissions into the atmosphere, and at the same time check CO_2 characteristics as a working fluid in the geothermal cycle operated at the EGS and the role of CO_2 in the volcanic activity.

CO_2 concentration in the pre-industrial era (before 1800) was about 0.29%. However, the intensive development of industry has been accompanied by increase in CO_2 concentration in the atmosphere. Currently the level of carbon dioxide CO_2 in the atmosphere is approaching 0.37% (http://geothermal.marin.org). The increase of CO_2 in the atmosphere is accompanied by increase in average surface temperature of the Earth (about 1^oC over the time period since 1800, Chapman, 2010). It is assumed that the change in CO_2 concentration is the driving force of climate change (Condi, 2005). According to forecasts, CO_2 concentrations in the middle of the 21st century could increase by 0.08 %, which can cause global warming and environmental catastrophe (Feely et al, 2004). The highest CO_2 emissions occur at electric power plants (running on coal, gas and fuel oil), cement plants, refineries, steel and chemical plants . The total of anthropogenic CO_2 release is estimated as 35 gigaton per year 2010 (T. Gerlach, 2011) and includes land use changes (3.4 gigaton per year), light duty vehicles (3.0 gigaton per year), cement production (1.4 gigaton per year), etc. A 300 MW coal-fired power plant generates approximately equivalent to 90 kg/s of CO_2 rate.

Anthropogenic CO_2 emissions exceed to a great extent natural CO_2 emissions from volcanic activity. According to (T. Gerlach, 2011), volcanic emissions inclusive of CO_2 from erupting magma and degassing magma beneath volcanoes are estimated 0.18-0.44 gigaton per year. For example, volatile flux emissions from Gorely volcano (Gorely volcano is one of 31 active volcanoes of Kamchatka) in September 2010 were estimated as ~130 kg/s ((H_2O ~93.5%, NCG~7.5%, including CO_2~2.6% (Aiuppa et al, 2012)). This is just 3.4 kg/s or 0.0001 gigaton per year.

One of the technologies allowing maintain the CO_2 balance in the atmosphere is the utilization of the industrial CO_2 emissions in geological structures. North Stavropol UGS (underground gas storage) is considered to assess possible options for such utilization in Russia. CO_2 transition from supercritical to subcritical state at the pressure of about 74 bar is accompanied by a significant decrease in density, which creates a potential risk of instability for the CO_2 disposal in shallow horizons. Therefore in validating CO_2 injection under subsurface conditions it is necessary to ensure subcritical conditions, and this problem is solved using TOUGH2-TMVOC-modeling.

2. GEOLOGICAL SETTING

North Stavropol Underground Gas Storage (UGS) has been established on the basis of a sufficiently large depleted gas field (33 x 18 km). Producing Khadumsky horizon depth ranges from 650 to 750 m. Intra-structural Pelagiada rise (16 x 11 km) is considered as a reservoir of CO_2 injection. The total area of gas bearing capacity is 590 km^2, whereof 460 km^2 falls on the North Stavropol structure, and 130 km^2 cover Pelagiada rise (Ruban et al, 2000) (Fig. 1).

The Khadumsky production layer is represented by Paleogene sediments of the lower Oligocene, with two main productive layers: the upper one comprises aleurites, clayey aleurites and clayey aleurolites, of the most permeable (300-1700 mD), porous (0.25-0.3), and gas-saturated kind with a thickness of 25 - 30 m (Fig. 2), while the lower unit comprises very clayey aleurolites with 10-300 mD permeability, porosity 0.13-0.25 and thickness 55 - 65 m. The initial reservoir pressure was 6.6 MPa, the reservoir temperature 66°C. Gas composition is methane, with methane content up to 98 %. The rocks include clastic 75 - 100% and clay 0 - 25% fractions. The clastic part is represented by: quartz 80 - 95%, feldspars 5 - 12%, glauconite 7%, mica 3 - 12%. The clay part includes hydromica, montmorillonite with small amounts of kaolinite and chlorite. For 27 years the field has been developed for gas production with insignificant intrusion of marginal waters, pressure dropped to 0.8 MPa during the development of the reservoir. After the establishment of the UGS, the pressure in the horizon began to grow and now stands at 3 MPa. Groundwater is characterized by a sodium bicarbonate composition with the salinity of 11.5 g/L, pH=7.3.

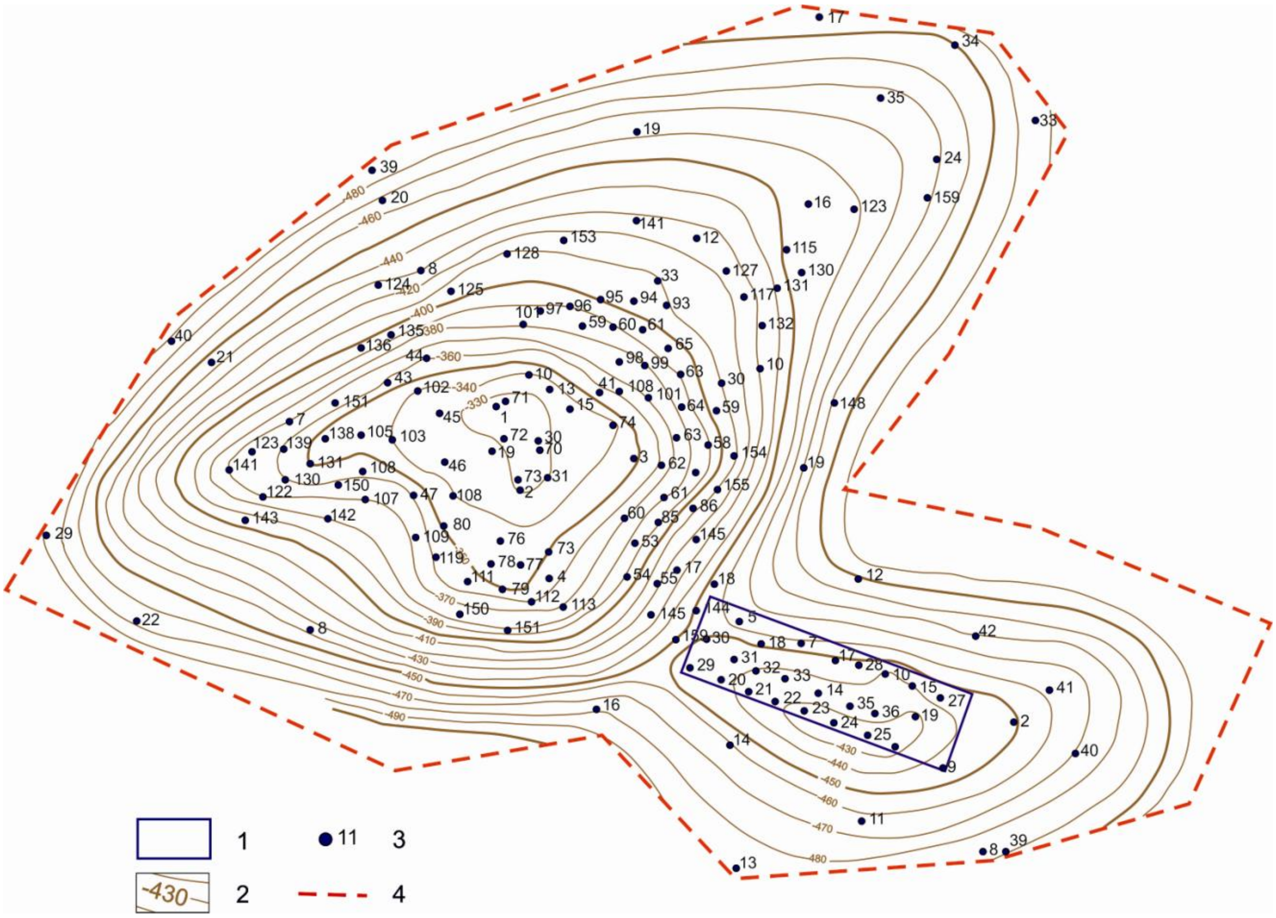


Figure 1: The top surface of the North Stavropol UGS. 1 – CO_2 injection polygon designated on the model, 2 – the reservoir top surface, 3 – wells, 4 – UGS boundaries in plan.

2. MODEL SETUP

The model area was divided into 14 000 elements (140 x 100) using regular grid with the size of each element 290 m x 290 m. The outer boundary of the model area coincides with the contour of gas bearing capacity area and is impermeable (Fig. 3). The model defines a system made up of two layers. The upper layer is represented by laterally alternating aleurites, clayey aleurites and clayey aleurolites (Fig. 2 and 3). The lower layer includes highly clayey aleurolites (Table 1).

The top and bottom of the relevant layers were set with the structure map of the top of the Khadumsky horizon (Fig. 1). The thickness of the first layer, which is set on the model, equals 33 m, and that of the second – 67 m. The hydrogeological and petrophysical properties were set according to the data in Table 1.

In determining initial conditions, was chosen a system of variables describing a two-phase (gas+water) state, whereby the pressure in the reservoir was set at P = 3 MPa, temperature t=60 ^{0}C, the initial saturation of the gas phase was set at 0.8-0.95 (Fig. 4), the initial composition of the gas phase – methane 100%, carbon dioxide 0%. To analyze the effect of contour waters one of the options sets water saturation along the deposit contour as equal to 0.95 (correspondingly, gas saturation as 0.05).

Corey relative permeability functions were used with residual water saturation set at 0.3, residual gas saturation - 0.05, while capillary effects were not taken into account. The diffusion coefficients of methane and CO_2 were taken as follows: 10^{-5} m^2/s in the gas phase, $1.5\text{-}2.1{\cdot}10^{-9}$ m^2/s in the aqueous phase, correspondingly.

The injection on the model is defined in sixteen wells, and Figs. 1 and 2 designate their location. CO_2 injection in 16 wells was assigned with rates from 16 to 160 kg/s. The injection of carbon dioxide is set with constant discharge and enthalpy of the injected carbon dioxide at 80 kJ/kg. The duration of the injection which is set on the model is 30 years.

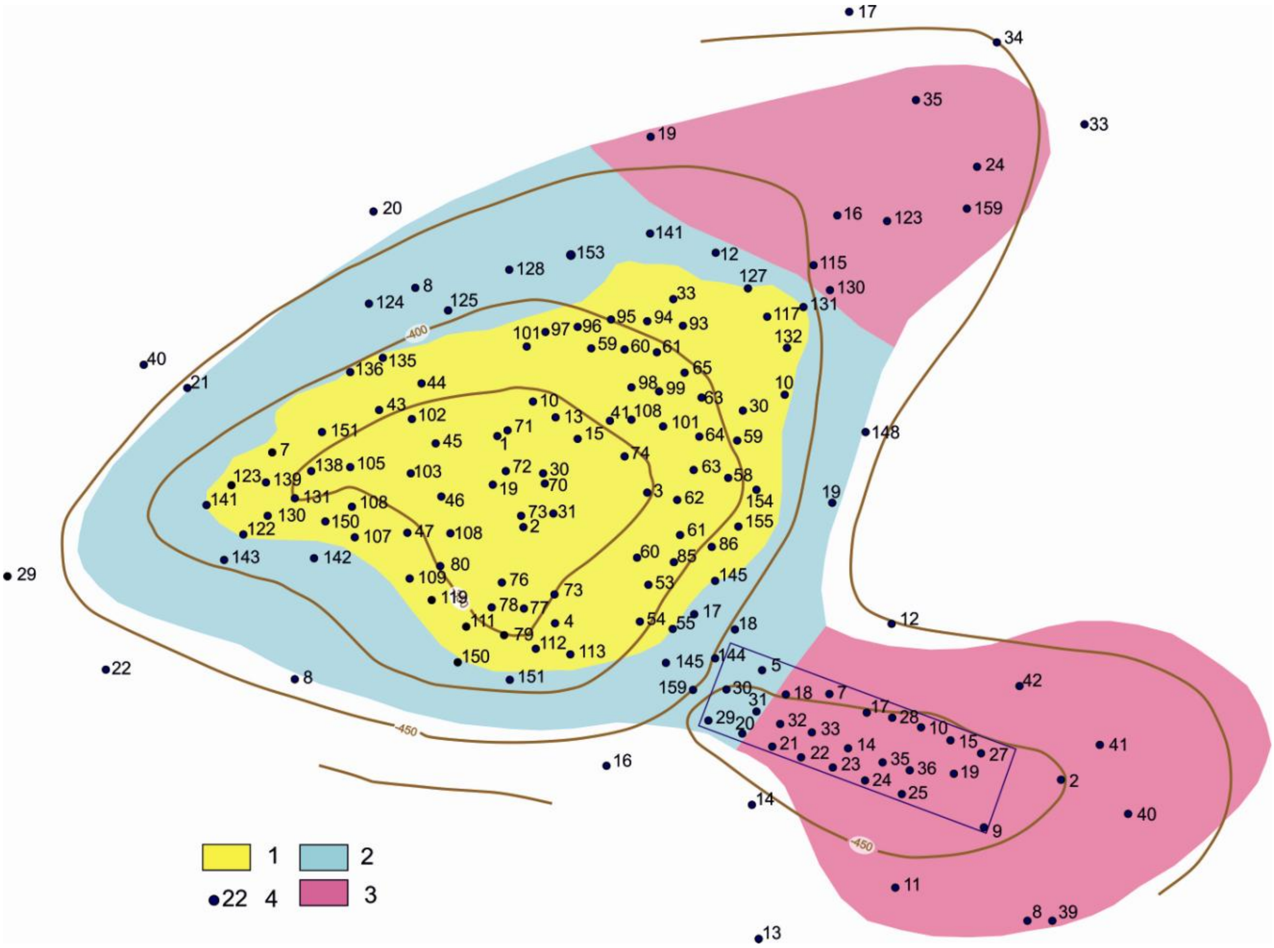


Figure 2: Reservoir's zonation in the North Stavropol area. 1- aleurites, 2- clayey aleurites, 3 - clayey aleurolites, 4 – wells.

Table 1 – Hydrogeological and petrophysical properties of the Khadumsky horizon rocks.

Parameters	Aleurites ALEVR	Clayey aleurites ALGLI	Clayey aleurolites ASGLI	Very clayey aleurolites GLINA
Thickness, м	up to 33	up to 33	up to 33	67
Effective porosity, %	31	27	21	15
Permeability, 10^{-15} m^2	1250	550	200	55
Density of the mineral phase, kg/m^3	2660	2680	2690	2690
Thermal conductivity, W/(m K)	2	2	2	2
Specific heat	864	864	864	864

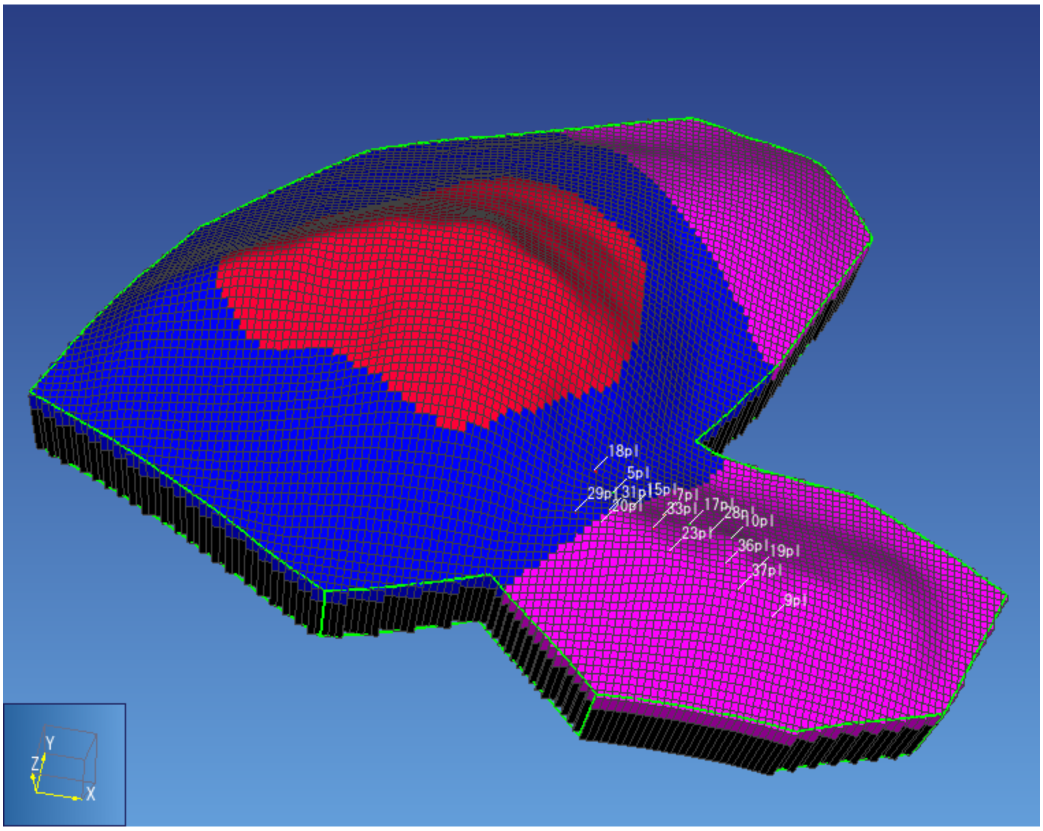


Figure 3: Zonation of the Khadumsky horizon (upper layer) according to hydrogeological properties.

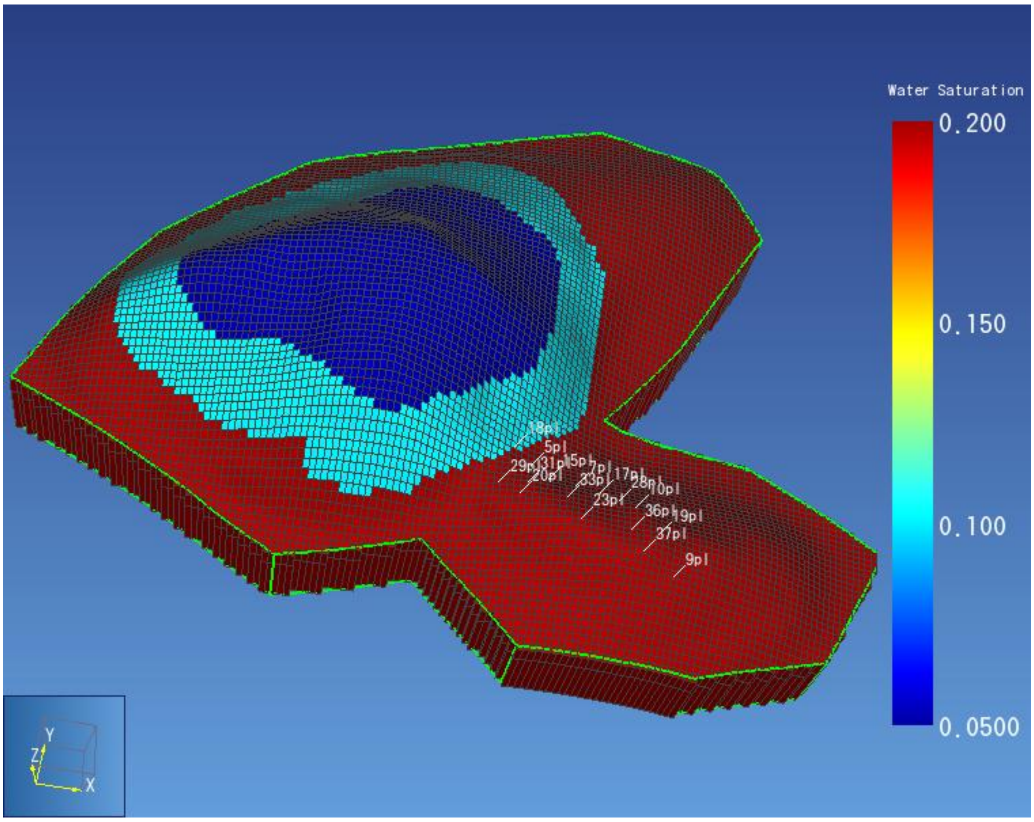
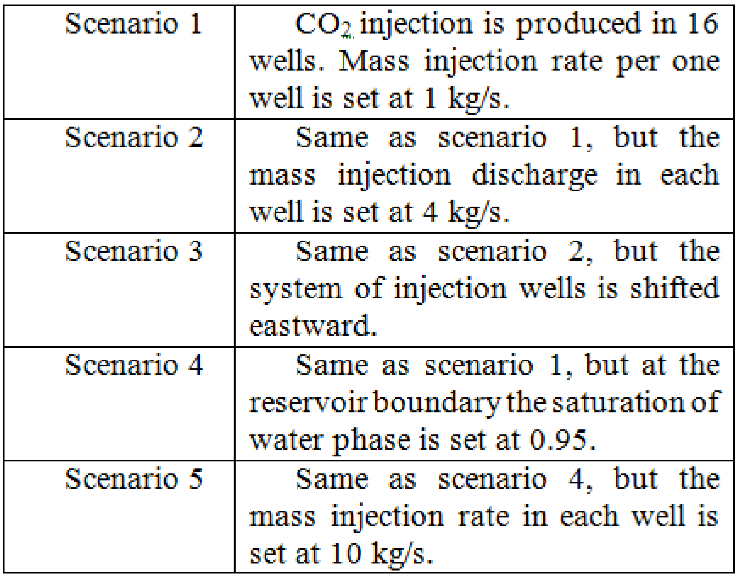


Figure 4: Zonation of the Khadumsky horizon (upper layer) according to initial water saturation.

2. MODELING RESULTS

At modeling were considered 5 options of boundary conditions, location of wells and CO_2 injection rates (Table 2).

Table 2. Modeling scenarios of CO_2 injection.



Scenario 1	CO_2 injection is produced in 16 wells. Mass injection rate per one well is set at 1 kg/s.
Scenario 2	Same as scenario 1, but the mass injection discharge in each well is set at 4 kg/s.
Scenario 3	Same as scenario 2, but the system of injection wells is shifted eastward.
Scenario 4	Same as scenario 1, but at the reservoir boundary the saturation of water phase is set at 0.95.
Scenario 5	Same as scenario 4, but the mass injection rate in each well is set at 10 kg/s.

Scenario 1. The modeling results with CO_2 injection at a total discharge of 16 kg/s have shown that the reservoir pressure at the given conditions in the zone of North Stavropol rise is virtually unchanged. Maximum pressure is observed in CO_2 injection zone and reach 3.17 MPa in the centre of Pelagiada rise. The control of pressure change and CO_2 distribution was carried out in the elements of the model in the transitory area between North Stavropol rise and Pelagiada. Fig. 5 shows spatial distribution of reservoir pressure at the final modeling time period (30 years). The greatest CO_2 flow is observed in the most permeable part of the Khadumsky horizon.

Scenario 2. In scenario 2 the total CO_2 injection discharge amounts to 64 kg/s. Modeling results show that CO_2 distribution occurs in the direction of North Stavropol rise. The reservoir pressure rises up to 3.5 MPa, and intermixture of CO_2 with the natural gas CH_4 due to diffusion and convection observed, also partial CO_2 dissolution in the liquid aqueous phase is observed.

Scenario 3. The conditions of scenario 2 are preserved in scenario 3 except the location of the system of injection wells, shifting to the eastern part of Pelagiada. The considered location of the injection wells is optimal from the viewpoint of its minimal influence on North Stavropol UGS. The reservoir pressure in the injection zone increases to 3.7 MPa. CO_2 expansion towards North Stavropol rise is observed. Within 30 years, the reservoir in Pelagiada area is saturated with CO_2 by 80%. More than 9% CO_2 is dissolved in the liquid phase.

Scenario 4. Of special interest for the study of the reservoir formation are the data on the solubility of gas in the liquid aqueous phase of the underground storage contour water. For the examination of this process along the formation contour, the initial saturation of the liquid phase is set at 95%. All other model parameters are set as in Scenario 1. Modeling results show that 8% - 10% of CO_2 are dissolved in the liquid phase of the main reservoir, about 1.4 % is dissolved in the Pelagiada contour waters.

Scenario 5. It considers CO_2 injection in the reservoir with an increased rates (10 kg/s in each of 16 wells), i.e. total discharge of CO_2 injection is set at 160 kg/s. Such consideration is needed for the check of the possibility of CO_2 transition to supercritical state (pressure above 7.3 MPa) with injection discharge increase. Fig. 6 shows special distribution of reservoir pressure at the final modeling time period (30 years). Modeling results have showed that maximum pressure in the reservoir at specified conditions will rise to 4.79 MPa, i.e. CO_2 will be in a subcritical state.

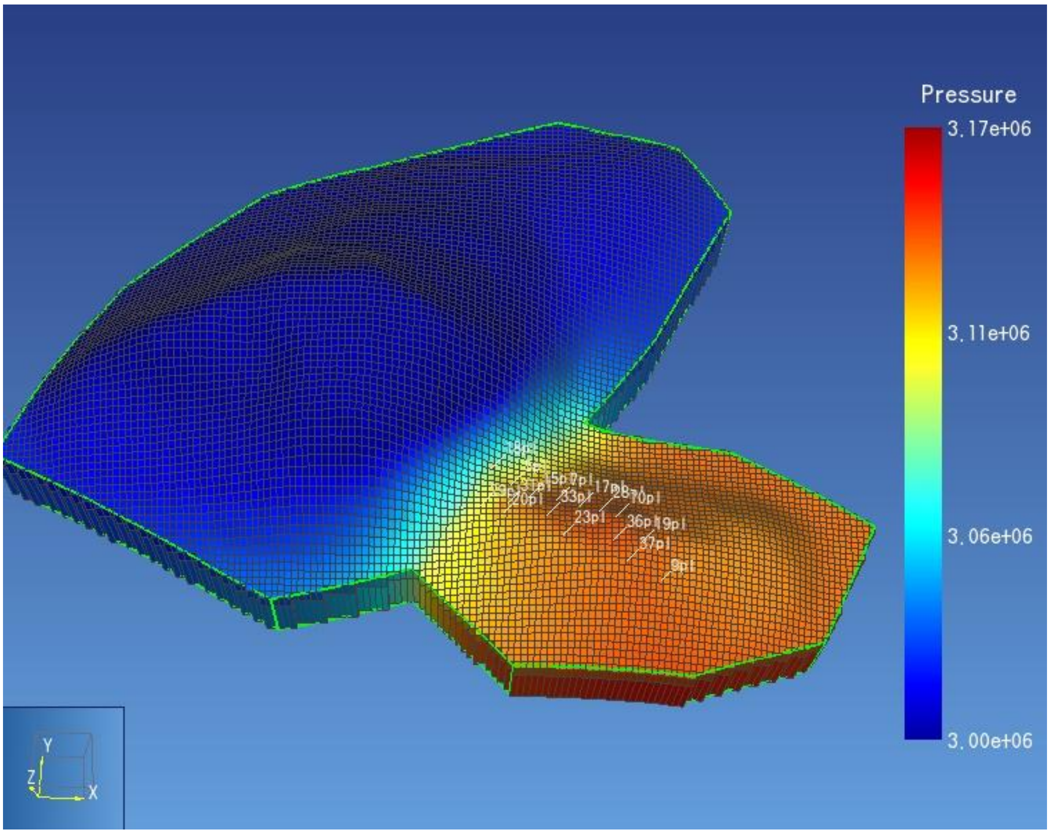


Fig. 5. Spatial distribution of reservoir pressure in the Khadumsky horizon 30 years after the start of CO_2 injection with a total discharge of 16 kg/s (Scenario 1). Pressure in Pa.

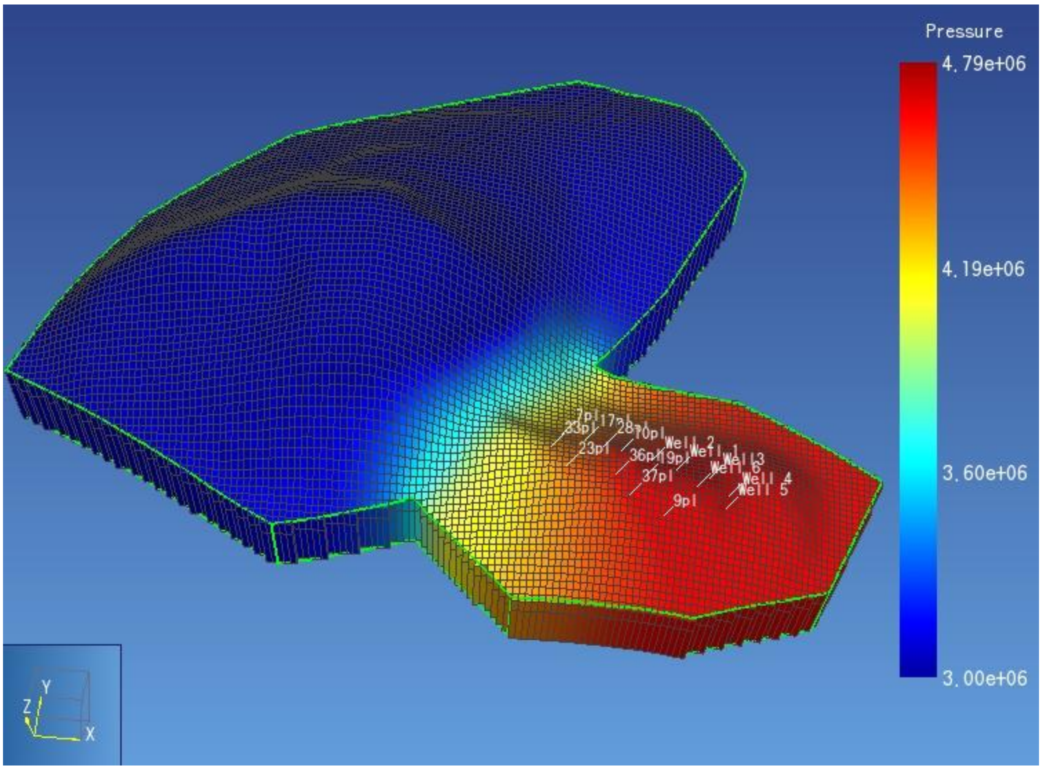


Fig. 6. Spatial distribution of reservoir pressure in the Khadumsky horizon 30 years after the start of CO_2 injection with a total discharge of 160 kg/s (Scenario 5). Pressure in Pa.

CONCLUSIONS

CO_2 injection modeling was performed with the use of TOUGH2-TMVOC. The modeling results show that no more than 8% - 10% of the injected CO_2 is dissolved in the liquid phase, of which not more than 1.4% is dissolved in the marginal waters. With a maximum modeling rate of injection 160 kg/s the pressure in Pelagiada reservoir remains below the critical value (7.38 MPa). Modeling proved potential of CO_2 sequestration during 30 years is estimated 0.005 gigaton.

Further study testing capabilities of the TOUGH2 with EOS7C module, and of the extent of CO_2 absorption by means of a secondary mineral formation supposes the use of the program TOUGHREACT, is on going on.

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