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UNDERGROUND STORAGE OF ACID GAS IN POLAND – EXPERIENCES AND FORECASTS

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ABSTRACT

This paper presents the experience and achievements on underground disposal of acid gas in Poland. According to actual ecological tendency, in order to reduce environmental impact, the acid gas from sour gas sweetening facilities is injected into oil or gas reservoirs.

The present paper is based on the above mentioned project resulting in an original disposal technology. In 1993 and 1996 two industrial plants for acid gas injection were activated. Acid gas reinjection eliminates sulfur compounds and carbon dioxide emission into atmosphere. The main task is to reduce the environmental impact of the gas sweetening process, however injected sour acid increase also efficiency of oil reservoir production and displacing light hydrocarbons from underlying reservoir waters.

The authors have been involved in computer simulation, designing and monitoring of the injection systems for more than 10 years. This experience allows us to evaluate the process with respect to technology and ecology and to perform the analysis of injection impact on the reservoir performance. This paper discusses some technological considerations for acid gas injection and some physical phenomena influencing process efficiency. Also computer simulation results in comparison with current field observations are reported.

The first sour gas injection facility reported here, injects gas containing about 15% H_2S and 4 % CO_2 into oil reservoir, at an average rate of 250 000 scum/month. Laboratory tests performed on slim tube models have showed that at the actual reservoir pressure, the oil displacement process will be immiscible, achieving theoretically final recovery of 60%. Presently recovery factor is above 40%.

The second plant reinjects acid waste gases from the process of amine sweetening of natural gas into the reservoir zone. Similar technologies, where acid gases from sweetening process are injected into gas/oil reservoirs are known in the literature; however, the acid gas is usually disposed in water saturated layers that have no contact with the gas reservoir. The project implemented in Poland has shown that it is possible to inject acid gas directly into a water layer having a hydrodynamic contact with gas reservoir, without any negative impact on the composition of the produced natural gas. Previous computer simulations and PVT tests showed that there would be no H_2S inflow into the gas cap for more than 12 years. It was found, that CO_2 concentration in the produced gas should be first increased and this was confirmed by the current reservoir performance.

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1. INTRODUCTION

The hydrocarbons produced from the reservoirs of the Polish Lowland geological province may contain large amounts of sour gases, i.e. H_2S and CO_2. Their concentrations in natural gases may be as high as 20% and some percent, respectively. The Claus type installations with sulphur production rate over 5 ton of sulfur per day are used for conversion of H_2S to the elementary sulfur. Recently the oversupply of sulfur on the world market and problems with sulfur disposal caused that the sulfur recovery methods became less attractive. Moreover, the discharge of H_2S combustion products like SO_2 and CO_2 to atmosphere, which was used up to the 1980s, is nowadays unacceptable because of environmental regulations. Actually, the reinjection of acid gases produced during gas sweetening process, seems to be a promising and economically attractive alternative [1-4]. Up to now, the reinjection of acid gases into oil reservoirs was used to increase the recovery or maintain the reservoir pressure. The other option, which is worth considering, is disposal of acid gases into the water bearing zones. In previous projects reported in the literature the acid gases were injected into oil reservoirs, depleted gas reservoirs or water zones which had no direct hydrodynamic contact with gas horizon being produced [2]. In the present paper the authors indicated that reinjection of acid gases into an aquifer underlying actually produced gas reservoir, seems to be a possible and good solution to the sour gas disposal problem. Of course the reservoir flow rate must be controlled to avoid excessive contamination of produced gas with H_2S and CO_2. The present paper shows results of computer simulation which demonstrate how the acid gas injection affects the composition of produced gas.
In the middle 1980s the two acid gas -injection facilities started to operate in Poland. The authors of the present paper were involved in this project [5,6]; they developed all necessary concepts and simulation models for predicting the performance and designing process of these facilities.

2. INJECTION OF ACID GASES INTO THE KAMIEŃ POMORSKI OIL RESERVOIR

The first acid gas injection facility reported here has been used for injecting gas containing H_2S and CO_2, the concentrations of which are about 15% and 4%, respectively. The gas released in the oil separation process is injected into oil zone of Kamień Pomorski reservoir with average rate of 250000 scum/month (fig. 1). The previous feasibility studies indicated that sweetening of gas from oil separation process was unprofitable because of small gas production rate, very high concentration of H_2S and CO_2 and large distance to the potential users. Before starting the injection, the routine procedure over the past 20 years was to burn the gas; 0.3 bln of scum of gas were flared and 80 000 tons of sulfur were burned and released to atmosphere.
Analyses of reservoir parameters and results of laboratory experiments carried out using the slim tube model indicated that the oil displacement by gas was an immiscible process characterized by interactions between flowing phases. The laboratory experiments indicated that the gas pressure equal to reservoir pressure (i.e. 44.9 MPa in analyzed case) results in a higher recovery factor and initiates the miscible displacement process. For the actual reservoir pressure (equal to 19 Mpa), the oil

displacement process is immiscible and the theoretical recovery factor is 60%. Presently, the total oil recovery factor is above 40% of the geological reserves

3. INJECTION OF ACID GASES INTO THE BORZĘCIN GAS RESERVOIR

The second facility reported here is used for reinjecting acid gases containing 60% of CO_2 and 15% of H_2S into an aquifer directly underlying the Borzęcin gasreservoir, see fig. 2. The reinjected gases are by-products of amine gas sweetening process. Such a method of acid gas disposal where the injection zone is in hydrodynamical contact with a gas-bearing reservoir has not been referenced to in the literature. In this method the injected gas dissolves in the underlying water which has a hydrodynamic contact with the gas horizon and thus may influence the composition of the produced gas. The acid gas reinjection into the Borzęcin gas horizon has been in operation since 1995, i.e. from the moment when 67% of gas (3.5 bln scum) was produced. The original gas reserves of the Borzęcin gas field were 5.2 bln of scum of gas.

Before designing the for injection facility, the PVT experiments were carried out. They indicated that the upward movement of H_2S and CO_2 to the gas cap would be very slow owing to the high solubility of these gases in the reservoir waters, which was much higher than that of the native gas.

The laboratory experiments indicated that:

- Solubility of native gas which contained 65% of hydrocarbons, 35% of nitrogen and small volumes of H_2S and CO_2 was 1.55 scum of gas per one cum of reservoir water at 58^oC and 97 bars.
- Solubility of acid gas which contained 60% of CO_2, 15% of H_2S, 20% of hydrocarbons and 5% of nitrogen was 13 scum of gas per one cum of reservoir water at the same temperature and pressure as specified above; this means that it was 8.4 times grater than solubility of native gas
- Phase diagram, presented in fig. 3 (constructed using the computer simulation of PVT experiments) indicated that the gas remained in a gaseous phase at the reservoir conditions.
- Acid gas dissolvers in reservoir water preferentially displacing the originally dissolved natural gas.

Displacement of the native gas which originally saturated the underlying water with acid gases injected into reservoir may increase the recoverable gas reserves. Such a displacement process enables replenishing the gas cap by volume equivalent to the methane gas dissolved in the underlying waters. The PVT test results indicated [7] that volume of methane gas displaced from reservoir water is an increasing function of volume of CO_2 injected into reservoir (see fig. 4).

A considerable drop of injection pressure from 10.4 MPa to 6.6 MPa was recorded after 18 000 of scum of acid gas was injected into reservoir. This drop of injection pressure was probably caused by an increased permeability due to a chemical interaction between carbonate reservoir rocks and injected acid gas with high CO_2 concentration (60%). The decrease of injection pressure and related decrease of power consumption improved the economical effectiveness of the whole project.

Computer simulation

The computer models simulating the acid gas injection into reservoir were developed in 1995. They were used for predicting the acid gas distribution pattern and for evaluation of possible changes in the chemical composition of the produced gas. The simulation was carried out using the Eclipse 300 compositional simulator which was commercially available on the market. Eclipse 300 is based on compositional mathematical model which assumes that the phase equilibrium constants may be computed using the Peng-Robinson equation of state. The Soreide and Whitson modification was included to account for water solubility of N_2, CO_2 and H_2S, respecting actual salinity and temperature of reservoir water.

The results of computer simulation are shown in figures 5 and 6. The predicted CO_2 and H_2S concentrations in produced gas are shown in fig. 5 which indicates that an increase of CO_2 content appears much earlier than an increase of H_2S concentration. This is caused by a high CO_2 content in the injected gases which is four times as large as H_2S concentration. The predicted concentration of CO_2 in production wells is shown in fig. 6. The CO_2 content was expected to increase in two wells already in 2004, i.e. after 8 years of continued injection. The CO_2 concentration (and so H_2S content) in the remaining wells will be on a constant level by 2010. The reduced concentration of CO_2 in some wells is caused by an invasion of reservoir waters.

As shown in table 1, a good agreement between predicted and measured data is observed, i.e. increase of CO_2 concentration was initially observed in B4 well, followed by an increase of H_2S content in the same well in 2005.

Wells	CO_2 (H_2S) content in the produced gas in the years 2001 to 2005					
	05. 2001	06. 2002	06. 2003	03. 2004	12. 2004	12.2005
Ż-1	0.263 (<0.05)	0.328(<0.05)	0.277(<0.05)	0.302(<0.05)		
B-4	0.445 (<0.05)	0.428(<0.05)	0.752(<0.05)	0.883(<0.05)	1.415(<0.05)	1.446 **(0.152)**
B-6	0.292 (<0.05)	0.328(<0.05)	0.354(<0.05)	0.337(<0.05)	0.348(<0.05)	0.31(<0.05)
B-21	0.223(<0.05)	0.273(<0.05)	0.296(<0.05)	0.275(<0.05)	0.278(<0.05)	0.291(<0.05)
B-22	0.272(<0.05)	0.322(<0.05)	0.342(<0.05)	0.296(<0.05)	0.331(<0.05)	0.314(<0.05)
B-24	0.264(<0.05)	0.340(<0.05)	0.308(<0.05)	0.313(<0.05)	0.353(<0.05)	0.335(<0.05)
B-27	0.254(<0.05)	0.374(<0.05)	0.361(<0.05)	0.343(<0.05)	0.363(<0.05)	0.308(<0.05)
B-29	0.235(<0.05)	0.200(<0.05)	0.125(<0.05)			
B-30	0.126(<0.05)		0.148(<0.05)			

Table 1. Observed CO_2 and H_2S concentration in gases produced from various wells of the Borzęcin reservoir

4. PROBLEM OF CORROSION

High partial pressure of H_2S and CO_2 components and elevated temperature are the factors which promote the corrosion process [8]. API 6A and NACE MR 0175 standards indicate that partial pressure of CO_2 and H_2S above 0.21 MPa and 0.34 kPa, respectively are considered as a highly corrosive environment. The CO_2 partial pressure in the Borzęcin injection facility exceeds 3.6 MPa if

CO_2 is injected into the water zone. The H_2S partial pressure is 1.8 MPa if the gas is injected into the reservoir. However, the measurements indicated that the actual corrosion is much lower than expected in these conditions.

The wall thicknesses of steel pipes of the acid gas injection facility were checked in the years 1998 to 2002. The surface pipes of the injection facility were made of an ordinary carbon steel. The condition of downhole pipes was evaluated using a Sondex Multi Finger Memory equipment. In spite that the corrosion inhibitors used, it indicated a negligible corrosion of the whole injection installation only in the first period of injection. The results suggest that monoethanolamine vapors, which are present in the injected gas, inhibit corrosion process in installation which injects the acid gas into the water zone. In the case of acid gas injection into an oil reservoir, the hydrocarbons which condense on the inner pipe walls eliminate corrosion effects in installation used for acid gas. This was observed in the Kamień Pomorski injection project.

5. CONCLUSIONS

The applied technological solution and good control enable a trouble-free exploitation of injection facilities in spite of unfavorable chemical composition of gases involved. The economical effectiveness and correct technology of acid gas injection facility were confirmed during the ten years of its exploitation. The presently available data speak in a favor of the presented method when compared with the results of the existing methods used for developing H_2S containing reservoirs. Actually, the application of the acid gas reinjection technology is being considered for two other gas reservoirs and one oil reservoir in Poland.

Our experiences indicate that the acid-gas reinjection may be a safe and cheap alternative for traditional acid-gas neutralization technology. The computer aided simulation of gas injection process allowed us to predict and optimize the process parameters including chemical composition of produced gases.

Nowadays, similar technologies are used in other countries but usually the gas is injected into isolated water zones which do not have hydrodynamic contact with reservoir being produced. The technology tested in Poland consists in injection of acid gases directly to water zone underlying the gas reservoir without inflicting the detrimental impact on quality of produced gas. Up to now 2 bln of cum of acid gases were injected into water bearing Rotliegendes formations and only a small change in the produced gas composition was observed. In one well a negliglible increase of CO_2 concentration observed in 2004 (see table 1) was followed by an increase of H_2S concentration in the same well in 2005. The PVT experiments indicated that methane dissolved in reservoir water may be displaced by acid gases due to a considerable difference in solubility of these gases. The displacement process enhances the gas recovery and may cause some increase of recoverable gas.

A similar downhole injection technology may be also used for sequestration of CO_2 or some combustion products generated by the power industry. This may open new prospects for oil companies in Poland and Europe.

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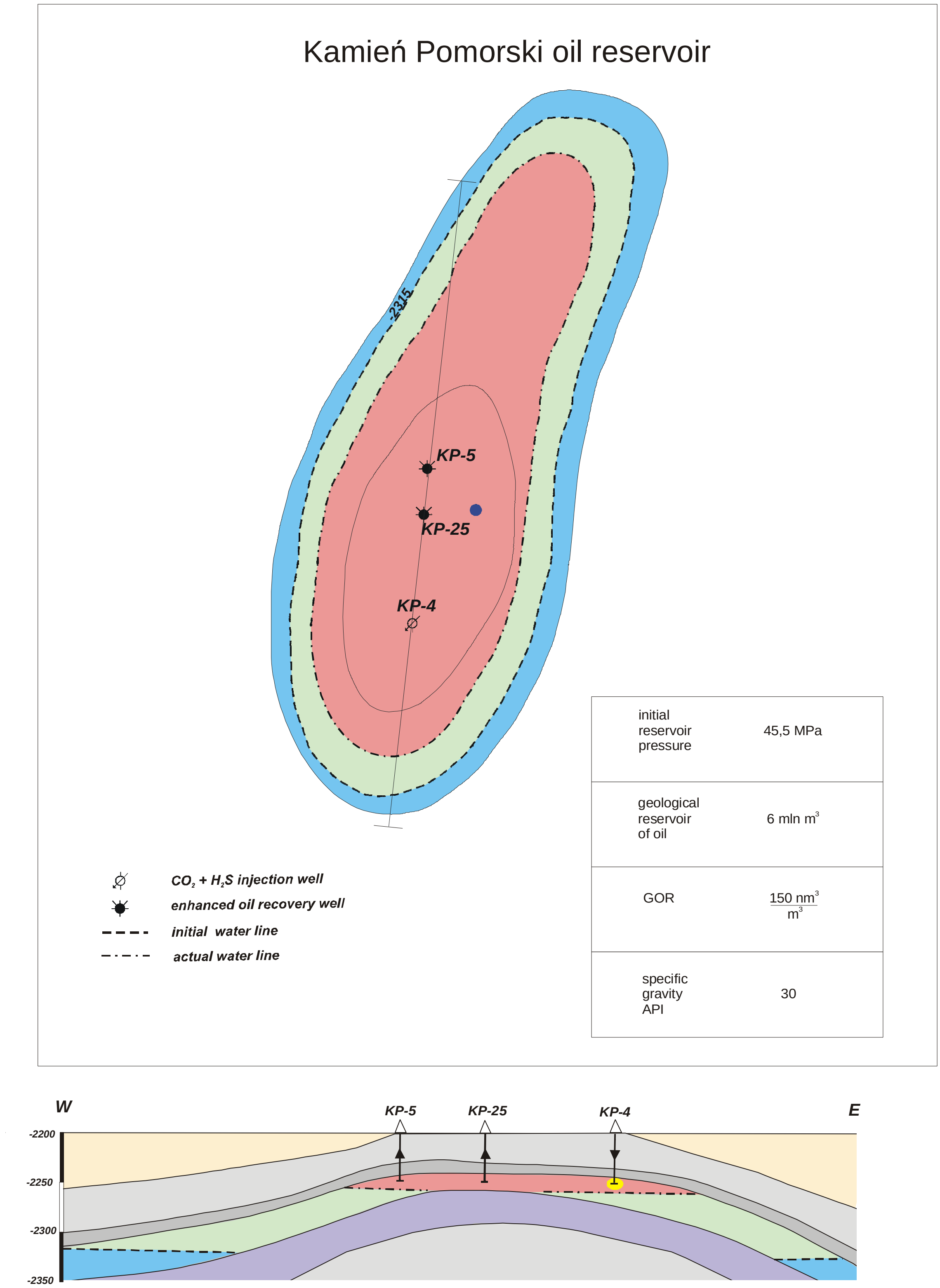
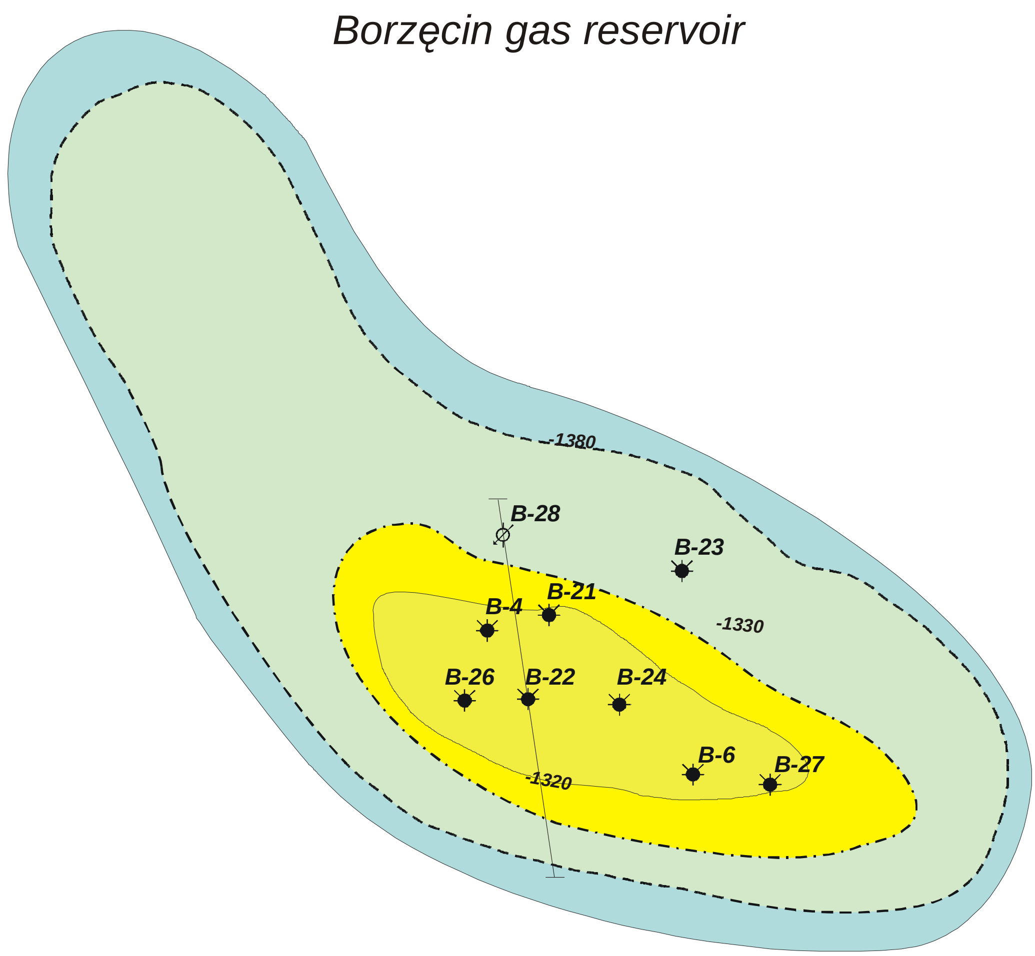
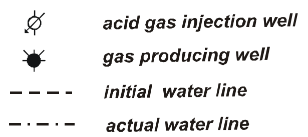


Fig.1. Kamień Pomorski oil reservoir





acid gas composition		natural gas composition	
CO_2	60%	C_1	63%
H_2S	15%	C_2	2%
C_1	19%	C_{3+}	0,4%
N_2	6%	N_2	34%
		H_2S	0,05%

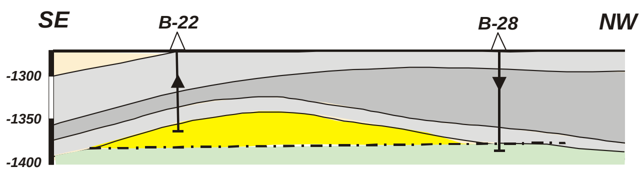


Fig.2. Borzęcin gas reservoir

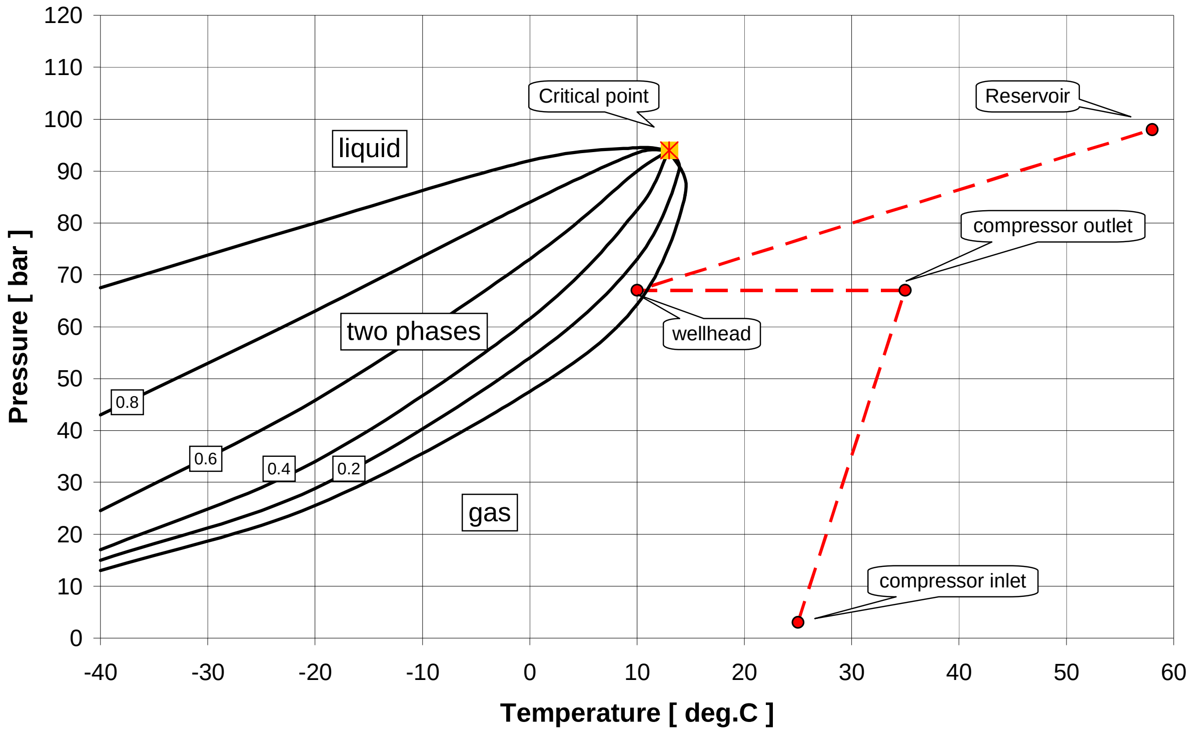


Fig.3. P-T diagram of acid gas injected into Borzęcin reservoir

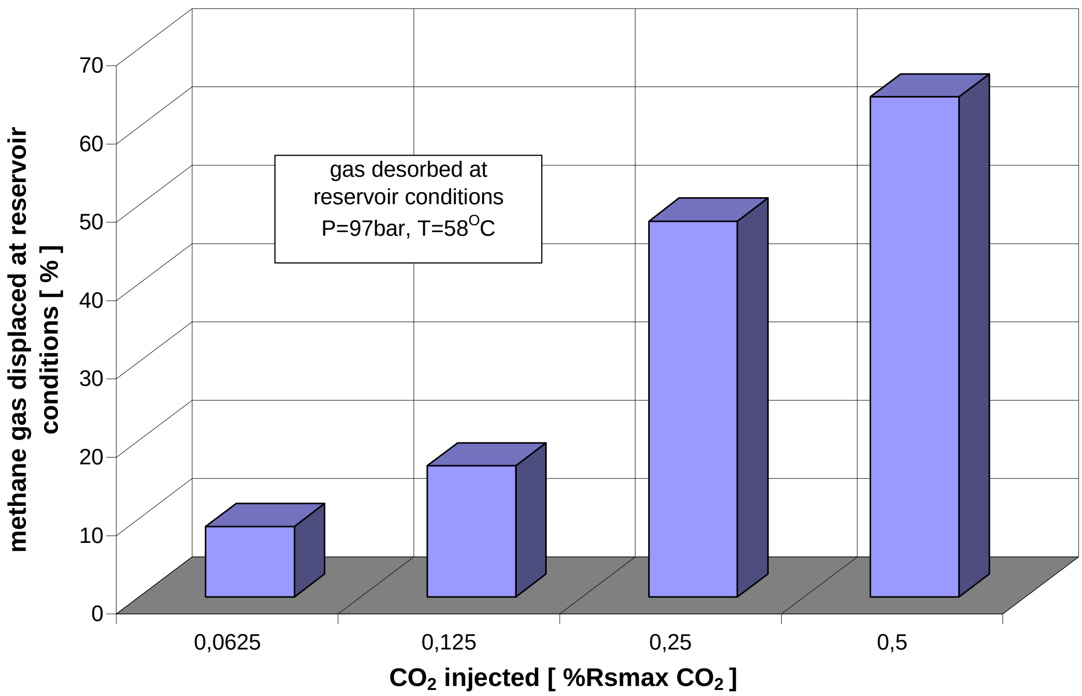


Fig. 4. Methane displacement from reservoir water by acid gas injection

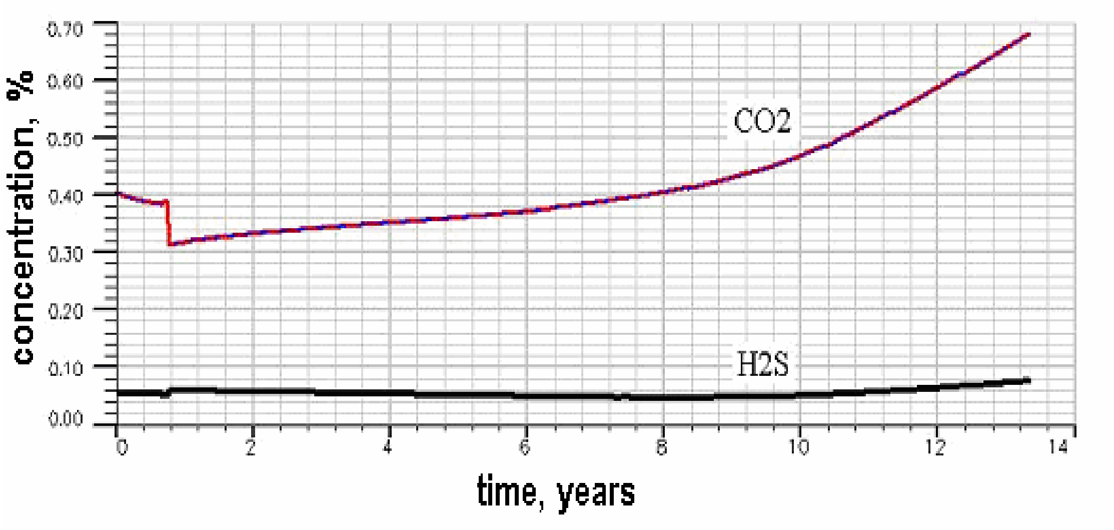


Fig. 5. Simulated concentration of CO_2 and H_2S in produced gas

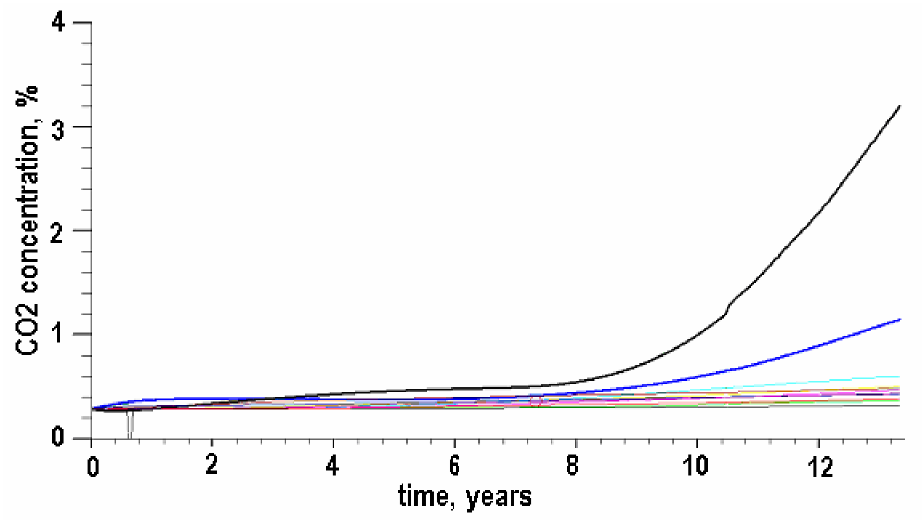


Fig. 6. Simulated CO_2 concentration in gas produced from various wells