



## CARBON DIOXIDE INJECTION INTO USELESS AQUIFERS AND RECOVERY OF NATURAL GAS DISSOLVED IN FOSSIL WATER

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### ABSTRACT

Huge reserves of natural gas in saline aquifers remain still unused in many sedimentary basins in the world. The authors propose an underground injection system of gaseous carbon dioxide into useless saline aquifers in sedimentary basins. The gaseous carbon dioxide is recovered from flue gas of fossil fuel fired power stations possibly by amines.

Recovery of natural gas dissolved in the pumped-up saline groundwater can compensate the loss of electric power for the carbon dioxide injection. Our tentative survey suggests that small fractions of useless saline aquifers in sedimentary basins in the world are enough to host about 320 gigaton of carbon dioxide.

A preliminary technical and economical survey was conducted on this carbon dioxide injection system for fossil fuel fired power plant. The CO<sub>2</sub> emission-free electric power generation is possible by this underground carbon dioxide injection system with the probable 35% cost increase for LNG fired power plant or 60% increase for coal fired power plant.

### KEYWORDS

Carbon dioxide injection; saline aquifers; aquifer-type natural gas; sedimentary basin; CO<sub>2</sub>-emission-free generation of electric power.

### INTRODUCTION

The free discharge of carbon dioxide into the air by burning of fossil fuels is accused as the main cause for global warming. However, fossil fuels should remain as the most important energy sources still in the near future in spite of the world-wide intensive efforts for development of alternative energy sources. The enormous volume of carbon dioxide emission resulting from the combustion of fossil fuels makes the development of effective mitigation technology extremely difficult.

A simple but serious question is "where should we accommodate huge volumes of CO<sub>2</sub> which are emitted enough to cover the whole earth's surface with the thickness of 2 cm, every year." We cannot let the carbon dioxide occupy much of precious spaces near the earth's surface. Huge volumes of carbon dioxide require a lot of energy even for minimum treatment and transportation. If we use a lot of energy for the treatment and transportation of carbon dioxide, we would not only waste precious

energy resources but also emit excess carbon dioxide.

### UNDERGROUND INJECTION OF CARBON DIOXIDE

The authors propose the underground injection of carbon dioxide into saline aquifers with recovery of hydrocarbons (mostly methane) in the aquifer or heat energy of deep groundwater(Fig.1). Saline aquifers, which are suitable for injection of carbon dioxide, can be found under many large carbon dioxide emission sources: power plants and large factories which locate on sedimentary basins. Saline water cannot be used as drinking water nor for agricultural use.

The carbon dioxide is to be recovered from flue gases of large plants by amine absorption or other separation methods. The distance of transportation of carbon dioxide is very important. Where adequate injection sites are found within the distances of some tens of kilometers from a carbon dioxide source, we can send the carbon dioxide in the gaseous state and directly inject it into aquifers.

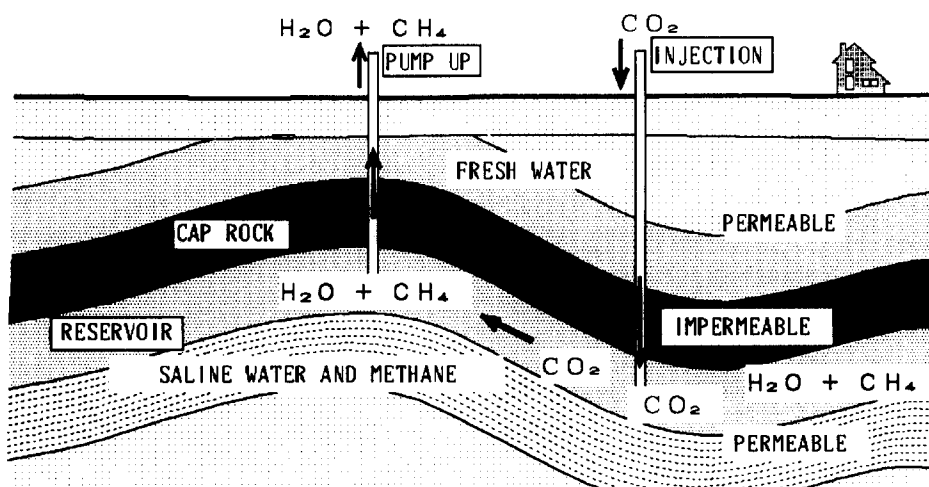


Fig.1 Underground injection of carbon dioxide and recovery of methane in aquifer.

Inland saline aquifers are more or less isolated from circulating fresh groundwater. Salinity of groundwater approximately indicate the completeness of isolation. Old fossil water is usually of high salinity, such as brine in some oil fields.

As the circulating fresh groundwater is difficult to penetrate into deep aquifers trapped under impermeable layers, deep aquifers tend to contain old fossil water which is not suitable for ordinary use due to the high salinity. There distribute widely useless saline aquifers in deep sedimentary basins in the world. Exploration drilling rarely hits economically valuable petroleum or natural gas deposits but often encounter useless aquifers which contain saline groundwater with dissolved hydrocarbons.

Connate groundwater in sedimentary basins often contains methane which is derived from decomposition of organic materials. In some regions(Chiba, Niigata and Miyazaki Prefectures) of Japan, they pump up fossil groundwater which is saturated with methane, and recover the dissolved methane to use as fuels or as industrial raw materials. Although such aquifer-type natural gas deposits distribute in many sedimentary basins in Japan, most of them are not enough rich to be recovered economically. Huge volumes of unused natural gas (mostly methane) are dissolved in saline aquifers in the many sedimentary basins in the world, such as the Gulf of Mexico, Hungarian basin, etc. Carbon dioxide is much more soluble in water than methane under same temperature and pressure(Fig.2). We can extract methane and dissolve carbon dioxide more than 10 times of methane into groundwater. The estimated total reserve of aquifer-type natural gas (mostly methane) reaches about 837 billion cubic meters in the standard state(0.1MPa,15.6°C). If we can replace the whole

volume of natural gas by carbon dioxide, the saline aquifers in Japan could contain well more than 26 billion tons (about 13 trillion cubic meters in the standard state) of carbon dioxide which is equivalent to about 30 years of carbon dioxide emission by burning of fossil fuels in Japan.

Carbon dioxide in groundwater may become carbonic acid but be readily neutralized by the reaction with carbonates and silicates in rocks to form the hydrogencarbonate ion. In alkaline groundwater, carbon dioxides may precipitate as carbonates, although more study is

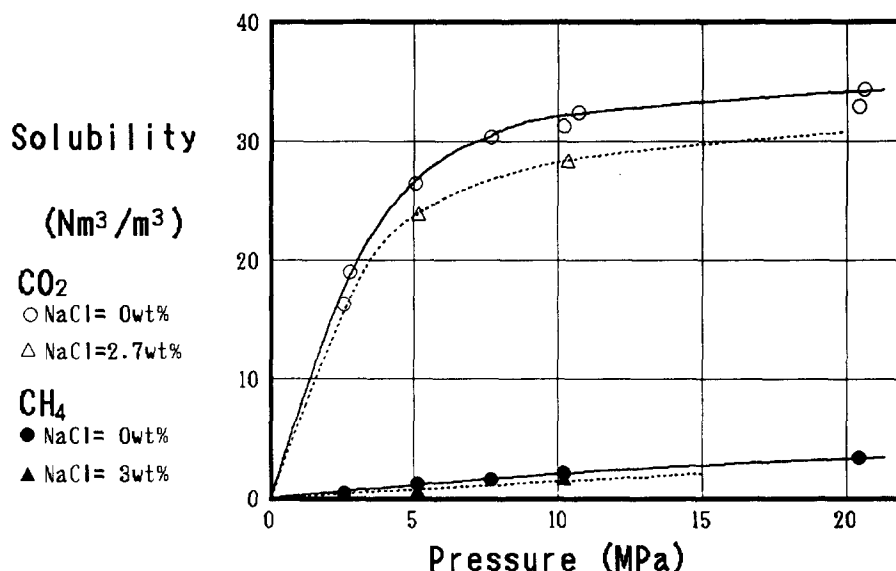


Fig.2. Solubility of carbon dioxide and methane in water at 30°C (Experimental data by H. Horioze: personal communication)

necessary about the behavior of carbon dioxide in various properties of groundwater and in various kinds of rocks.

As useless aquifers are expected commonly in the depth of sedimentary basins, a brief estimation suggest that the CO<sub>2</sub> storage capacity in sedimentary basins could reach well over 320 billion tons in the world (Koide *et al.*, 1992).

#### CARBON DIOXIDE INJECTION SYSTEM

The authors designed a prototype of CO<sub>2</sub> injection system into useless aquifers and estimated the storage cost (Koide *et al.*, 1992). This system was assumed to inject 5,000 tons of carbon dioxide daily which was recovered from a fossil-fuel power plant. Natural gas and carbon dioxide are separated from the pumped-up fossil groundwater. The recovered natural gas from the groundwater is burned in the power plant to compensate the loss of electric power for the CO<sub>2</sub> injection. The separated carbon dioxide from the groundwater is reinjected into the aquifer with the other carbon dioxide. The rest of groundwater would be discharged into sea through a water treatment unit.

The initial cost for this 5,000 tons/day CO<sub>2</sub> injection system was estimated at ¥46 billion yen. The total underground storing cost of CO<sub>2</sub> in aquifer is ¥3,000 yen/ton-CO<sub>2</sub>, excluding the separation cost of CO<sub>2</sub> from flue gas. This does not include electricity charge, because recovered natural gas can compensate loss of electric power although injection systems spend 82 kWh of electric energy per ton-CO<sub>2</sub>. The

recovery of carbon dioxide from flue gas of power plants is estimated to cost ¥4,600 yen/ton-CO<sub>2</sub>. Then, the total cost of recovery and injection of carbon dioxide would reach ¥7,600 yen /ton-CO<sub>2</sub>.

Our preliminary cost estimation in Japan suggests that the CO<sub>2</sub>-emission-free generation of electric power may become possible with the cost increase of 35% for natural gas-fired power station, of 45% for petroleum-fired power station and of 60% for coal-fired power station where carbon dioxide is separated from the flue gas by amines and injected into deep aquifers.

## CONCLUSION

Deep aquifers, which contain fossil water and are not used due to high salinity, can host larger amount of carbon dioxide under their high formation pressure. Useless aquifers of fossil water are found around oil and gas reservoirs and commonly in deep sedimentary basins. Small fractions of aquifers in terrestrial sedimentary basins in the world are enough to host about 320 gigatons of carbon dioxide.

A preliminary technical and economical survey on the carbon dioxide injection system suggests that the CO<sub>2</sub>-emission-free generation of electric power by fossil fuels may become possible with the cost increase of 35% for natural gas-fired power station and of 60% for coal-fired power station.

This underground injection technology is applicable to the separation and reinjection of CO<sub>2</sub> from the natural gas, too. In the world, there exist the huge reserves of natural gas that contain high ratio of CO<sub>2</sub>.

Chemical reaction of carbon dioxide with groundwater and rocks may contribute to fixation of carbon dioxide into deep geologic formations. More investigations are necessary for assessment of effect of carbon dioxide injection on groundwater environments.

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