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Influence on the global warming of the exhaust heat the consumption of mining energy resources accompanies

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According to a published scientific book[1)], we should apprehend that increases in the consumption of mining energy resources which accompanies the emission of exhaust heat may bring about climate change. Nevertheless, it seems that the influence on the global warming of the emission of exhaust heat have not been well discussed in IPCC Fourth Assessment Report. The reason for this is probably due to the estimation that urban heat islands which are partly attributed to exhaust heat would not almost influence on the global warming if judged from observation of semisphere or sphere scale. However, the mankind's activities such as industrial production, transportation, communication and house living which are performed in the modern world consume vast amounts of thermal energy produced by combustion of the fossil fuel in the driving of various heat engines. Exhaust heat generated in the processes in which those engines of the whole world consume vast amounts of thermal energy is thought to be emitted not only into the atmosphere near urban areas, but also into the atmosphere, river and sea of larger areas of global environment.

In this study, the total amounts of exhaust heat generated through the consumption of energy of the whole world are estimated from the world energy statistic, and compared to the radiative forcing induced by an increase in CO_2 concentration of the atmosphere. In conclusion, it is surmised that the influence on the global warming of exhaust heat is not disregarded, though may be small compared to that of CO_2 radiative forcing. Also, it is shown that the combustion heat accompanied by generation of CO_2 gas of unit mass is different depending on kinds of the compound contained in fossil fuel. These things suggest that not only the amounts of CO_2 but also the amounts of exhaust heat should be examined as a criterion for restraint of global warming.

According to a world statistic[2)], the world energy consumption Q_{WF} increases monotonously year after year, in which the amounts in 2000 are Q_{WF}(2000) = 8075 [Mtoe yr^{-1}] = 1.072/10^{-13} [W]. We assume that exhaust heat Q_{WE} emitted into environment is approximately expressed by Q_{WE} = Q_{WF}(1 - h), where h(0 ˜ 0.4) is an average thermal efficiency. Also we assume that the amount of exhaust heat that contributes to global warming is expressed by F_{EH} = Q_{WE}/A_{glob}, where A_{glob} is surface area of earth. Then, the F_{EH} in 2000 is estimated to be F_{EH}(2000) = 0.0126˜0.0210 [W m^{-2}]. On the other hand, CO_2 concentration in the atmosphere increases from 370ppm to 372ppm in 2000, and radiative forcing F_{CDO} by CO_2 is estimated to be F_{CDO}(2000) = 0.0288 [W m^{-2}]. Thus, it is inferred that F_{EH}(2000) is not disregarded though it may be smaller than F_{CDO}(2000).

From the above thinking, it is surmised in spite of a rough estimation that not only CO_2 gas but also exhaust heat which are generated in combustion of fossil fuel may contribute to increasing in temperature of the atmosphere. By the way, it is thought that the combustion energy accompanied by generation of CO_2 gas of unit mass are different depending on kinds of fossil fuel and that the exhaust heat released via combustion of hydrocarbon accompanied by the generation of H_2O is larger than that by combustion of carbon without generation of H_2O. Therefore, it is inferred that not only the amount of CO_2 but also the amount of exhaust heat should be examined as a criterion for suppression of global warming. This suggests that there is a necessity to take account of also the exhaust heat that is emitted from nuclear power stations.

1) SMIC, Inadvertent Climate Modification, MIT Press (1971) pp.51-74.
2) BP Statistical Review of World Energy 2009.

Keywords: energy consumption, mining energy resources, fossil fuel, heat engine, exhaust heat, global warming

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Assessing the geomechanical responses of storage system in geological CO2 storage: An introduction of research program i

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The geomechanical responses of CO2 reservoir and the rocks around the storage region are crucial for Japanese geological CO2 storage (GCS). The CCS Investigation Commission, METI, recommended screening out the areas having large-scale faults from candidates of a storage site for large-scale demonstration (2009). At present, however, we do not exclude fully the possibility of unintended rock-mechanical motions and leakage due to the storage of pressurized CO2. The examples of such phenomena are the activation of pre-existing faults, induced seismicity, reservoir failure and unintended uplift and so on. These unintended phenomena are essentially connected with the increase in underground fluid pressure, or pore pressure, around the area of GCS, which is inevitable as GCS injects pressurized CO2 into an underground reservoir. We are conducting research to develop a scheme how to assess a possible increase in underground fluid pressure and possible geomechanical responses around a storage region of CO2, under the geological conditions postulated in GCS sites in Japan. We consider that the coupled simulation of fluid flow and geomechanics is the most important tool in developing the scheme of assessment. Our final goal is to make such a tool to be applicable to Japanese young sedimentary areas in which we cannot exclude the possible presence of small-scale fractures even after the intensive seismic survey. We will present the detail on the objectives, the whole structure, and the present status of the research program in poster presentation. This research is funded and supported by METI.

Keywords: geological CO2 storage, pore pressure, geomechanical response, coupled simulation, soft rock, natural analogue

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Time-lapse field experiment using seismic ACROSS at the air injection into the shallow ground in Awaji Island-II

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1. Introduction

Seismic ACROSS has been developed in Japan as one the time-lapse (4D) methodology to monitor a change of transfer function along the propagating ray paths by transmitting accurately-controlled signals and repeatedly receiving the steady continuous signals (Kumazawa et al., 2000; Kasahara et al., 2010).

Time-lapse observation is very useful for monitoring some changes in the seismic characteristics of the particular phases propagating through the time-variant target regions such as oil-gas/CO2 and magma reservoirs. We expect to detect the small changes by using both accurate-and-steady repeated seismic signals and high-quality multi-receiver's data.

In this paper, we show the preliminary but impressive results of the time-lapse experiment with an air injection into the shallow ground in Awaji Island, Japan, by using ACROSS system.

2. Outline of the Air-injection and Seismic ACROSS Observation

We conducted thefield experiment near the active Nojima fault in Awaji Island from Feb. 11 to Mar. 10, 2011, using two seismic ACROSS sources and temporal 32 three-component geophone sets installed at the sedimentary-rock surface and a stationary 800-m borehole site (operated by Kyoto Univ.) located at the hard-rock site.

During five days (Feb.26-Mar.3), 81 tons air in total amount were injected with 21 atoms in pressure into the 100-m depth point of the Osaka formation (Kasahara et al., 2012).

We used two different mass-rotation-type ACROSS sources, Source-A and Source-B. The Source-A (operated by Nagoya Univ.) locates in a southern east area has a vertical rotational axis (Yamaoka et al., 2001). Source-A and B transmitted the seismic signals in a frequency range of 10-30 Hz in a horizontal plane and 10-35 Hz in a vertical plane, respectively.

3. Data and Results

The combination of clockwise and anti-clockwise rotation signals provide us the linear vibration (Kunitomo and Kumazawa, 2004). We obtained the transfer function, H, as a second order tensor with 9 elements from U = H F, where U and F represent the observed displacement and the transmitted single force. Subscripts, r, t and z, denote the radial, transverse and vertical directional components, respectively.

We here show the transfer functions related to the Source-A. We found that a small P-wave arrival appeared with a relatively larger S-wave in the Hzr component while a large S-wave arrival revealed with an unclear P-wave in the Htt components. The apparent velocity of P and S waves (Vp and Vs) were evaluated to be about 2.3 and 0.7 km/s, respectively. In the northern area, the apparent Vp were about 1.6, 2.5 or 4.5 km/s, and Vs was less than 0.5 km/s (Kasahara et al., 2011).

The transfer function obtained at the receiver-#7 showed the small first P-wave arrival appeared around 0.2-sec in travel time and S-wave and its later phases appeared after 0.4-sec. The waveform differences between the reference trace recorded at Feb. 24, 00:00 before the air injection and each trace at every hour. We found that the remarkable changes of the waveforms, particularly of the S-wave and its later phases, appeared about one day after the start time of air injection. The travel time of the later phase mostly delayed during the air injection. However such changes disappeared after the stop time of the injection.

4. Conclusions

We conducted the time-lapse experiments in the Awaji island, Japan, by using an ACROSS methodology. As preliminary results, we found that the waveforms, particularly of the S-wave and its later phases, remarkably changed in time and space after the air injection into the shallow ground. We conclude that ACROSS methodology is useful enough to detect and monitor the changes of the seismic properties relating with geophysical changes around the reservoir accompanying with the air/gas injection into the subsurface.

Acknowledgements: We appreciate the support and cooperation by JCCP.

Keywords: CCS, time lapse, ACROSS

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Development of risk assessment tool, GERAS CO2-GS

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We introduce our risk assessment tool named 'GERAS-CO2GS' (Geo-environmental Risk Assessment System, CO2 Geological Storage Risk Assessment System) for 'Carbon Dioxide Geological Storage (Geological CCS)'. GERAS-CO2GS aims to assist understanding of size of impact of risks related with upper migration of injected CO2, and assist safety and risk management around Geological CCS. For gaining public recognition about feasibility of Geological CCS in adjacent area of injection planned site, it is important to quantitatively estimate risks and know the level of the risk to be negligible. Generally, as a matter of course of risk assessment procedure, potential hazards could be identified within Geological CCS's various facilities such as: reservoir, cap, rock upper layers, CO2 injection well, CO2 injection plant and CO2 transport facilities. Among them, hazard of leakage of injected C02 is crucial, because the rate of CO2 retention presents the effect of geological CCS against reduction of CO2 emission, and it is clue to understand risks around a specific injection plan. Our risk assessment tool named GERAS-CO2GS evaluates volume and rate of retention and leakage of injected CO2 in relation with fractures and/or faults, then it estimates impact of seepages on the surface of the earth. At this moment, GERAS-CO2GS is consisted from four major processing segments: (a) calculation of CO2 retention and leakage volume and rate, (b) data processing of CO2 dispersion on the surface and ambient air, (c) risk data definition and (d) evaluation of risk. As regard with injection site, we defined a model, which is consisted from an injection well, and a geological strata model with a reservoir, a cap rock, an upper layer, faults, seabed, sea, the surface of the earth and the surface of the sea. As regard with retention rate of each element of CO2 injection site model, we use results of our experimental and numerical studies on CO2 migration within reservoirs and faults. Being given CO2 injection rate, lithologic conditions and atmospheric conditions, GERAS-CO2GS evaluates volumes and rate of CO2 retention and leakage of each segment of strata model including injection well, reservoir, fault, upper layer, seabed, and atmosphere. It also evaluates dispersion of CO2 on the surface of the earth and ambient air, and displays evaluated risk level on Goole earth contour of risk levels with color classification. At this moment, the development of GERAS-CO2GS is in prototype stage. We are going to extend GERAS-CO2GS functions and evaluate risks of further risk scenarios. Concerning to the route of seabed to sea and the surface of the sea, we are going to implement outer research findings into our logics. In the course of further research, we are going to develop GERAS-CO2GS will be able to estimate broader risks, and expecting to support the efforts for legislations and standards of CO2 Geological storage.

Keywords: CO2 geological storage, risk assessment, CO2 migration, the surface of the earth, impact analysis

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A numerical simulation Study for the Distributed CCS

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Hydrogen energy is expected as energy source of the low carbon society and is utilised in fuel cell co-power generation system as a distributed generation system. Hydrogen has to be manufactured cheaply without destroying environment in order to become widespread. Producing hydrogen on a large scale is conducted in petroleum refining industry from the refinery off-gas and so on, where hydrogen is used in refinery processes. The potential of hydrogen supply from the refining industry are so large and CO_2 in high purity is constructed as by-products. The method of combining the CO_2 geological Storage of the CCS technology with hydrogen manufacture in the refining industry is proposed and examined for the low carbon society.

The purity of CO_2 produced through the hydrogen manufacturing process in the refinery has not less than 98% by the absorbing method. In order to utilise such high CO_2 purity a research work with a tentative model and the simulation of the CO_2 geological storage is conducted. The amount of CO_2 generated in an oil refinery, which is typically 100, 000 tonnes per year, is suitable for planning a small-medium size CO_2 geological storage in the distributed CCS plant.

In this research work, several subjects have been examined about the geological structure as well as the surface equipments Those subjects are bundled to aim to create a promotion model for the geological storage of a small-medium CO_2 storage. The research subjects are as follows; survey for the hydrogen generation methods, examination for the operation to inject a small amount of CO_2 (method and facility); estimation of the geological storage potential near the refinery sites; conceptual geological model for the CO_2 geological storage in or near hydrogen manufacturing unit, and simulation for the CO_2 movement in the geological storage aquifer in the model field.

Simulation was carried out in a model field for the injection of CO_2 in an amount of 100,000 tonnes per year. The simulation was conducted by TOUGH2 and the CO_2 was injected in a shallow aquifer. CO_2 is injected into a storage reservoir deeper than 800m to satisfy the super-critical CO_2 condition. However, the deep injection needs a deep injection well and the deeper the well is drilled the higher the cost becomes. Since in a small-middle scale storage the scale merit cannot be expected, the purpose of a simulation is to confirm the safety storage of a small amount of CO_2 in a shallow (200-600m) layer.

CO_2 micro-bubble seems to be the most suitable method to inject CO_2 into a shallow reservoir but there is no simulation code including the CO_2 micro-bubble characteristics. We tentatively use TOUGH2 code with the parameters as suitable to the micro-bubble as possible but the upward movement of CO_2 is expected by the buoyancy. However, if the storage is stable on this condition, it can come to a conclusion that the CO_2 in micro-bubble will be stored much safely because of the smaller buoyancy of the CO_2 micro-bubble. The simulation results inferred that gaseous CO_2 is stored in the shallow reservoir in the model field and no leakage is detected during the 20 years injection period.

The large-scale storage is expected and examined to inject an amount of 1Mt CO_2 annually for several 10 years. The large-scale CO_2 storage, however, needs not only much cost but also the large and wide CO_2 storage reservoir. The suitable storage site becomes very limited. Moreover, the local resident's agreement will become difficult to be obtained. In Asian countries, the reservoir suitable for the large-scale storage is very hard to find out. The idea to store in a small amount of CO_2 in a shallow geological layer should be adopted in the country where no storage space is expected.

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Keywords: Distributed CCS, Geological Storage, Simulation, Petroleum refining industry, Hydrogen energy

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Analysis and Application of Water-Rock-CO2 Reaction Using Basalt

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Carbon dioxide underground sequestration is able to reduce enormous quantities of CO_2 emission. It has been attracted and researched.

But, there are several unclear mechanism of CO_2 behavior in underground. Therefore, it is difficult to estimate exact time for CO_2 storage.

For estimating time of CO_2 sequestration, we consider water-rock-CO_2 reaction.

Water-rock-CO_2 reaction attract attention in many parts of science. It consists of three following reactions:

$CO_2 + H_2O = H_2CO_3 = H^+ + HCO_3^-$ (1)

$MSiO_3 + 2CO_2 + H_2O = M^{2+} + H_4SiO_4 + 2HCO_3^-$ (2)

$M^{2+} + 2HCO_3^- = MCO_3 + CO_2 + H_2O$ (3)

where M is bivalent metal ion.

There are two steps. First, CO_2 dissolves in the water by (1) or mineral and water react CO_2 by (2). Next, bivalent metal ion and hydrogen carbonate ion generate and carbonate minerals (MCO_3) precipitate by (3).

If CO_2 is fixed as MCO_3 by (3), it is very safety. But, this reaction mechanism is very complex. And calculation method of dissolution rate constant is not clear. Furthermore, water-rock-CO_2 reaction is useful for estimating ancient CO_2 concentration and considering carbon flux in the global circulation, too.

In this study, the purposes are

1)To consider dissolution mechanism in water-rock-CO_2 reaction.

2)To compare many calculation method of dissolution rate constant.

3)To estimate time of CO_2 storage by precipitation of carbonate minerals.

We used basalt samples for the dissolution experiment. Because,

1) It contains metals which can become divalent cation.

2) It is widely distributed in the world.

3) Oceanic ridge is almost composed of basalt.

The basalt samples ware obtained nearby Mt. Fuji.

Keywords: Basalt, Water-Rock Reaction, CO2 Sequestration

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Continuous gravity measurements at Crystal (CO2) Geyser, Utah

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We made continuous gravity measurements using a CG5 gravimeter at Crystal Geyser, Utah in December 2011. Crystal Geyser is a gassy cold geyser which is activated primarily by the evolution of carbon dioxide. We have two purposes regarding the measurements. (1) Natural analogs for gravity measurement provide a potential way to obtain information for one important potential mode of CO2 leakage from wells. (2) Trial of a similar continuous gravity measurement which is being planned for gravity monitoring for geo-sequestration at a field, where formation is similar but deeper than at Crystal Geyser.

Observed geyser activity was different from the activity based on the 76 days observation (Gouveia and Friedmann, 2005). The previous observation revealed a striking bimodal distribution in eruption duration. About two thirds of the eruptions were short (7-32 min), and about one third were long (98-113 min). However, our observation revealed that eruption duration were 60-90 seconds, much shorter than the shorter eruptions in 2005.

A microprocessor-based automated gravimeter, Scintrex CG5 can be operated in cycling mode, when data acquisition is triggered at a pre-defined sampling rate. It has a capability of raw data acquisition, which enables us to store the unprocessed 6 Hz data (gravity, tilt-x, tilt-y, and internal temperature) in memory. We detected a particular signal not in gravity but in tilt at Crystal Geyser. We have ever made similar measurements at Hirogawara CO2 geyser, Japan and geothermal geysers in New Zealand. Continuous gravity record at each site constrains the volume and/or the depth of the reservoir which is supposed to supply fluid for each geyser activity. This result is of particular interest in field surveys of temporal gravity changes related to some environmental or geodynamical processes, where gravity variations are expected to occur in hours or shorter period.

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Keywords: Crystal Geyser, CO2, gravity