Dating groundwater with sulfur hexafluoride (SF_6) using labor-saving sampling method

NARO
National Agriculture and Food Research Organization
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This report documents dating of groundwater with sulfur hexafluoride using labor-saving sampling method. The use of a well bailer bucket in this method rather than a pump simplifies and reduces the weight of the survey equipment, which is effective in reducing the burden on users and improving research efficiency in addition to shortening the water sampling time.

Introduction

Hydrological investigations to assess groundwater resources and develop sustainable management strategies require not only information on "location", such as recharged area or flow layer, but also information on "age", such as time since last recharge or residence time of groundwater.

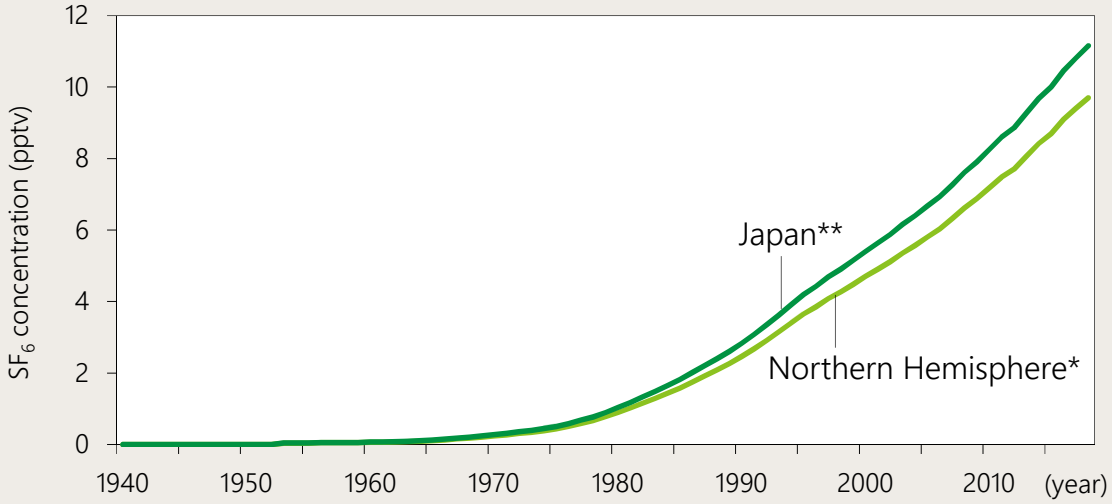
In hilly and mountainous areas with relatively fast groundwater flows and areas where shallow groundwater is frequently used (e.g., rural and agricultural areas), groundwater is relatively young. For the dating of such young groundwater, dissolved sulfur hexafluoride (SF_6) gas has been effectively used at several sites.

The average concentration of SF_6 in the atmosphere of the Northern Hemisphere has been rising since the 1970s owing to significant production from the beginning of industrial use in the 1960s. The SF_6 concentration of groundwater that was recharged in past decades is lower than that of the current atmosphere. By comparing the SF_6 concentration of groundwater and the historical record of atmospheric concentration, groundwater can be dated from about the 1970s to the present.

We therefore need to collect samples using an SF_6-free pump or similar device, which prevents contact of the sample with the atmosphere, thus ensuring that atmospheric SF_6 does not mix with the sample. Reduction of both the time and effort for water sampling caused by this constraint will result in more efficient investigation.

We have established a simple manually operated water sampling method using a well water sampler (well bailer bucket) for SF_6-based dating of groundwater. This method can shorten the water sampling time and reduce the weight of survey equipment without using pumps. The use of this method enables efficient collection of water samples as well as reduced survey burden.

Historical atmospheric SF_6 concentration in the Northern Hemisphere and Japan



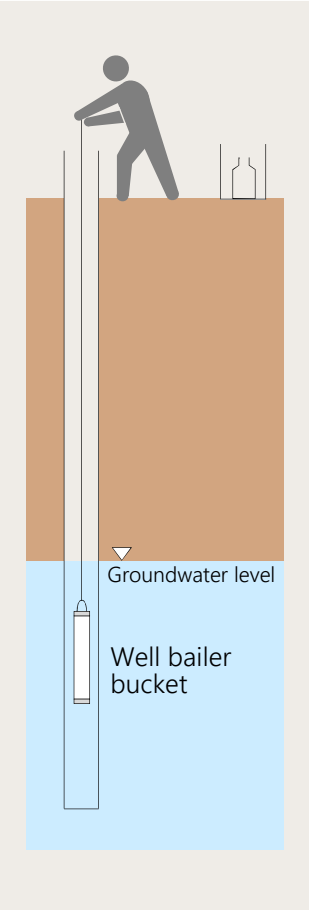
* Northern Hemisphere: average concentration of atmospheric SF_6 in Northern Hemisphere provided by NOAA (National Oceanic and Atmospheric Administration)

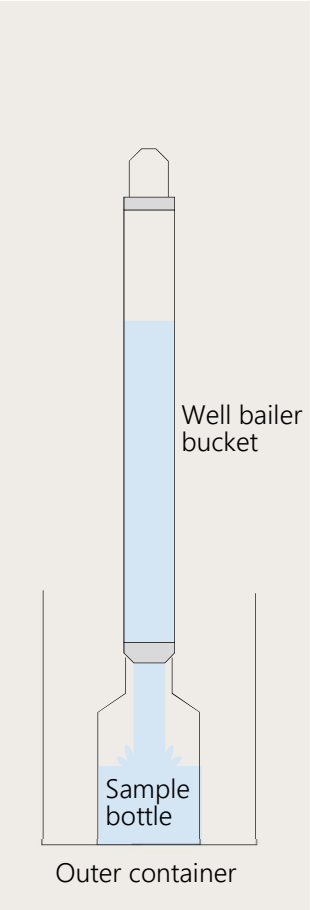
** Japan: atmospheric concentration in a central mountain region located far from urban areas in Japan (115% of Northern Hemisphere value) (Asai et al., 2017)

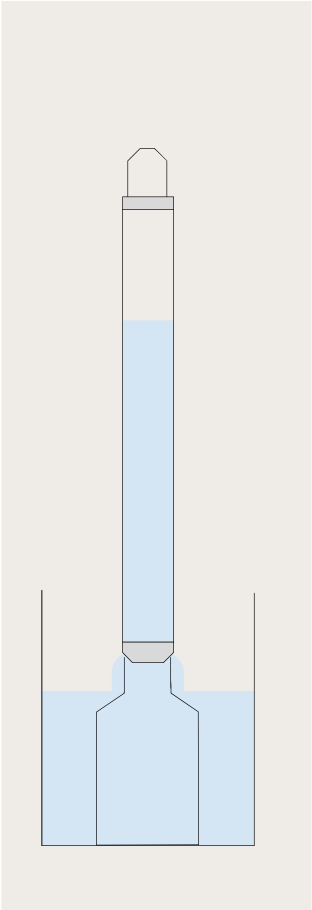
When using the SF_6-based dating method, pre-measurement of atmospheric SF_6 concentration at a survey site and the calculation of the excess ratio over the Northern Hemisphere concentration are necessary for the adjustment of the input atmospheric curve.

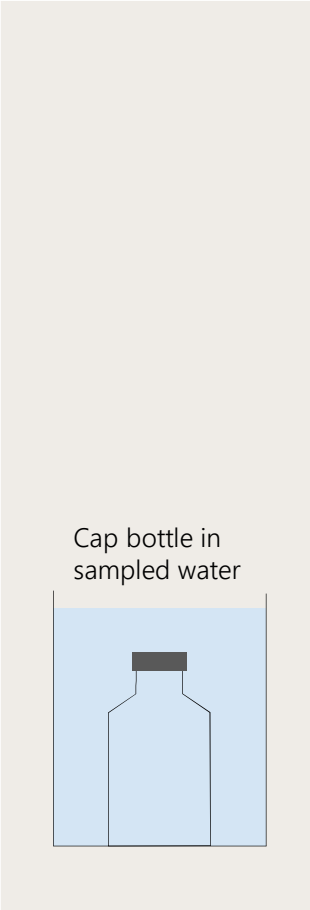
Water sampling method using well bailer bucket

This water sampling method for the analysis of SF_6 concentration in groundwater involves collection of groundwater using a general well bailer bucket. Select the well bailer bucket that matches the diameter of the well/borehole and sample the groundwater according to the following procedure.









1 Sampling

The well bailer bucket is lowered into groundwater at a predetermined depth using a rope with scales and pulled up.

2 Injection

Sampled water is injected from the well bailer bucket into a glass bottle inside the outer container.

3 Repeat

Repeated sampling and injection fill the bottle with groundwater and allow it to overflow to the outer container.

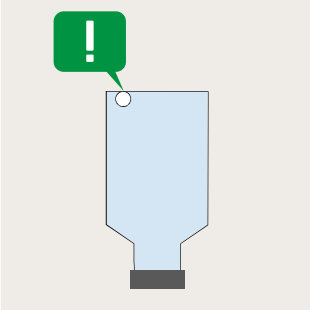
4 Cap

Cap the bottle in the sample water to avoid air bubbles from remaining inside the bottle and the lid.

5 Check for the presence of air bubbles

Close the cap tightly and check that there are no bubbles in the sample bottle. If air bubbles remain, collect the sample again.

If air bubbles remain in the sample bottle, SF_6 gas in the air bubbles will dissolve and lead to an increased concentration in the sampled water during storage before analysis.

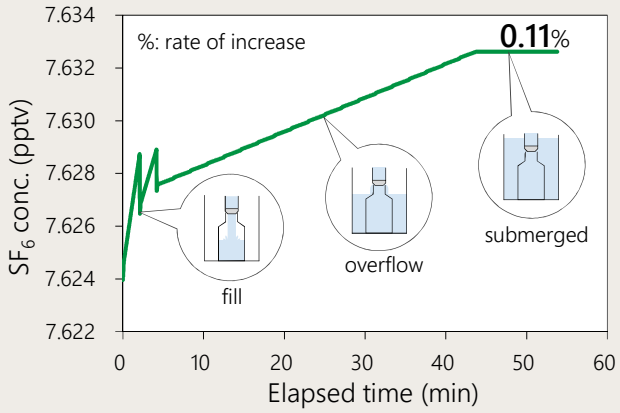


Influence of contact with atmosphere

During the process of groundwater sampling using a well bailer bucket, the sample comes into contact with the atmosphere. The calculation of SF_6 transfer from gas to liquid phase indicates that during this process, the theoretical increase in the SF_6 concentration of groundwater is less than 1%, which corresponds to a residence time of 0.2 years and is within the range of analysis accuracy of 3%. (In this document, SF_6 concentration in groundwater is converted to air concentration.)

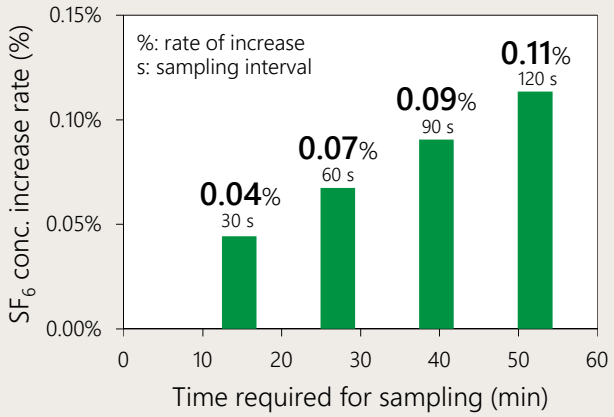
Increase of SF_6 concentration in sampled groundwater due to contact with the atmosphere during well-bailer sampling

Temporal variation of SF_6 conc. during sampling



Well bailer bucket: 200 mL
Sampling bottle: 500 mL; outer container: 5 L
Sampling interval: 120 s
Sampling time: 52 min

Increase rate by sampling time



Well bailer bucket: 200 mL
Sampling bottle: 500 mL; outer container: 5 L
Sampling interval: 30 to 120 s
Initial SF_6 conc.: 7.624 pptv

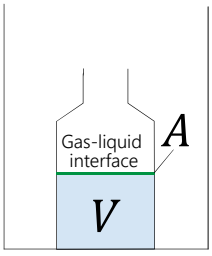
More information: gas transfer into open water body

$$\frac{dc}{dt} = \frac{A}{V} k_L (c^{eq} - c) = k_L a (c^{eq} - c)$$

V: volume of water body; A: surface area of gas–liquid interface; c: bulk water concentration of dissolved gas; c^{eq}: dissolved gas concentration in equilibrium with air; k_L: liquid-phase gas transfer coefficient; a: ratio of surface area of the gas–liquid interface to volume of water body (=A/V). When the gas–liquid interface is disturbed and it is difficult to estimate a, kLa is treated as one variable and represented as the overall capacity coefficient of gas transfer, which corresponds to a reaeration coefficient. For detail, refer to Tsuchihara et al. (2018).

Sampling

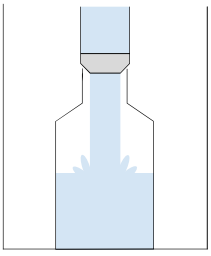
No water-surface turbulence



using $\frac{A}{V} k_L$ for calculation

Injecting

Water-surface turbulence

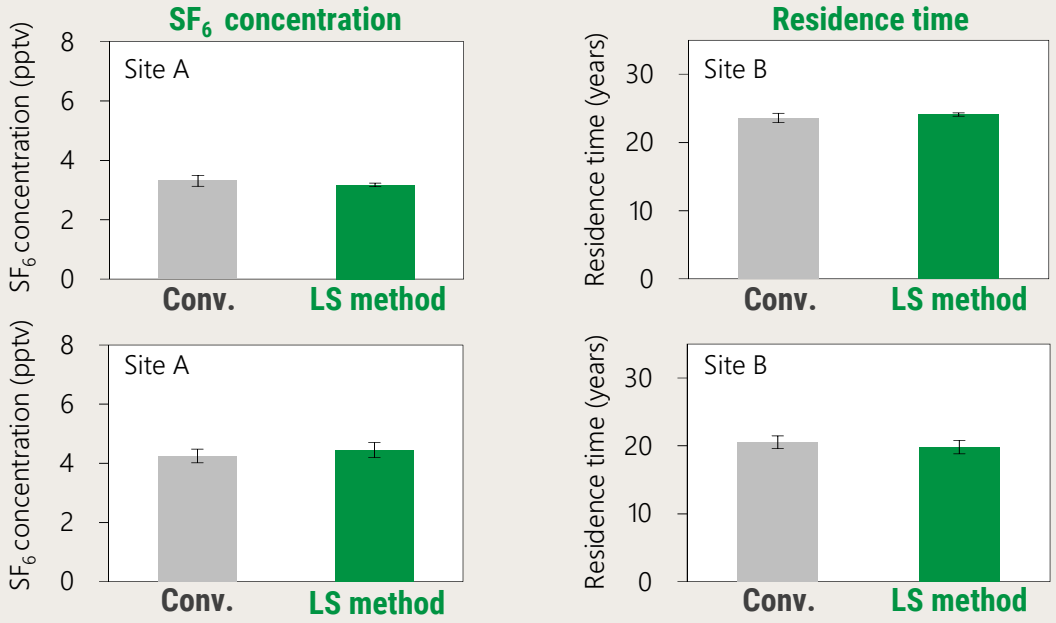


using $k_L a$ for calculation

Comparison with conventional method

This simplified labor-saving method using a well bailer bucket (below, the **LS method**) can obtain the same results as the ordinarily used sampling method (below, the conventional method) in which water samples are collected without contact with the atmosphere.

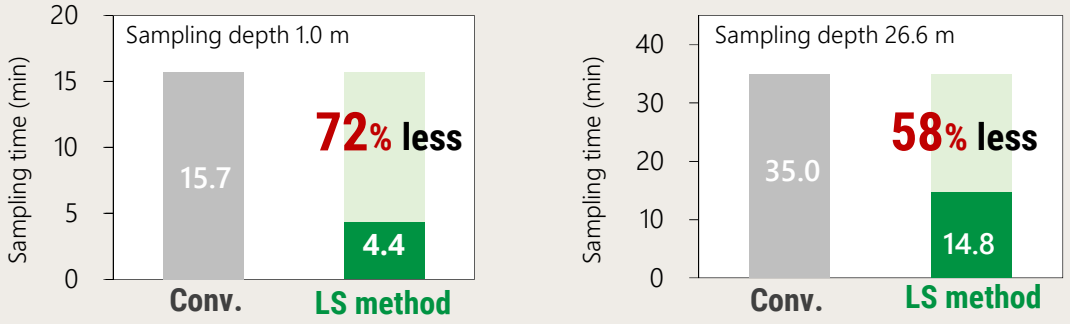
Comparison of SF_6 concentration and residence time in groundwater collected by conventional and labor-saving methods



(Error bars indicate variations in the concentration and residence time of two samples)

The difference between the SF_6 concentration of the conventional method and that of the LS method is about 2% of the average value of both, which corresponds to about 0.5 years of apparent residence time. Even if sampled water comes into contact with the atmosphere during the sampling process by using the LS method, **the dissolution of atmospheric SF_6 into the sampled water is extremely small.**

Reduction of sampling time by using LS method



Collect two bottles: 500 mL×2
Outer container: 5 L
Conventional method: tube pump

Collect two bottles: 500 mL×2
Outer container: 5 L
Conventional method: piston pump

(Sampling time includes time for preparation)

Depending on the sampling depth and survey equipment, the LS method can reduce the sampling time (including preparation for sampling). The LS method, which does not use a pump, has no sampling depth restriction due to the pump head. Furthermore, the LS method can lessen the weight of equipment, reducing the burden on survey participants.

Tools

A well bailer bucket, rope with scale, two pairs of 500-mL glass bottles, synthetic rubber-lined caps, and a 5-L stainless pail are used.

Well bailer bucket

Rope

Sample bottle & cap

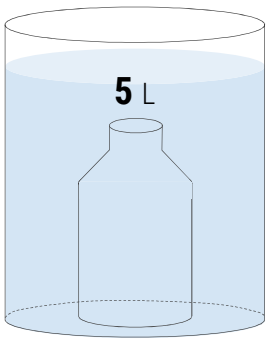
Outer container

Equipment used in this report

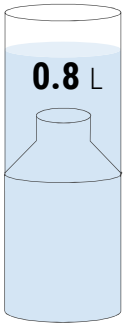
Well bailer bucket	IS-200, 400 (TGK) (200, 400 mL)
Sample bottle	Glass bottle (DURAN GL-45) (500 mL)
Bottle cap	Synthetic rubber-lined cap for GL-45
Outer container	Stainless pail (5 L)

For more efficient investigation

Using an smaller-capacity outer container enables a reduction of the sampling volume of groundwater, further shortening the sampling time.



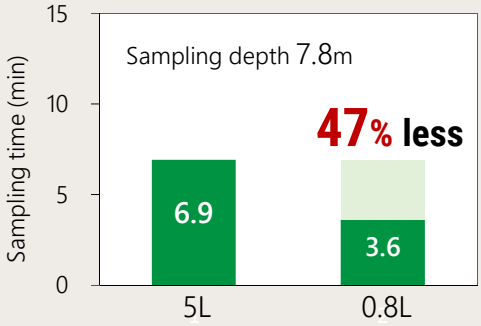
Outer container (5 L)



By Yamagata University

Smaller outer container (0.8 L)

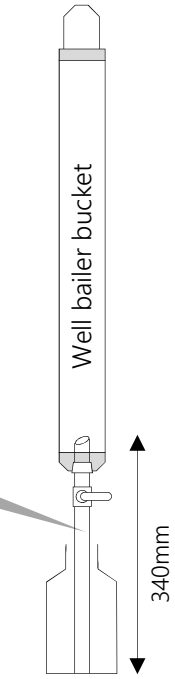
Reduction of sampling time by using small outer container

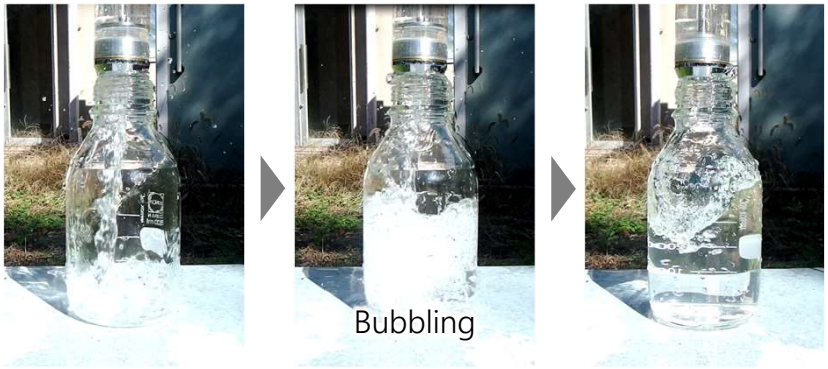


For reduction of residual air bubbles

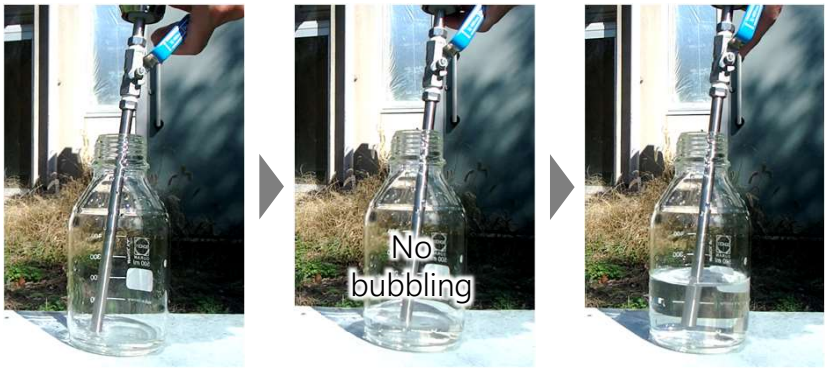
When using the well bailer bucket, air bubbles generated during the injection of water may adhere to the inner wall of the sample bottle and remain. By connecting a stainless-steel pipe "**bailer attachment**" (see figure below) to the water inlet of the well bailer bucket, bubbling during the injection of the water sample into the bottle can be avoided, resulting in a **reduction of residual air bubbles** in the bottle.

Bailer attachment (BA)





Without BA

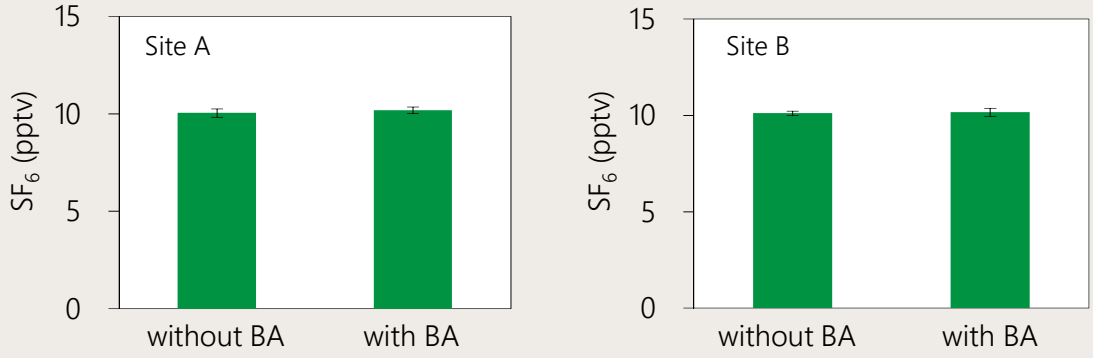


With BA

(*Outer container omitted for clarity.)

When using the bailer attachment, the water is slowly injected into the sample bottle and the sampling time slightly increases. Even when the attachment is not used, the same result as when using the attachment can be obtained by paying attention to residual air bubbles in the sample bottle.

Difference in SF_6 concentration in groundwater with and without bailer attachment (BA)



(Error bars indicate variations in the concentration of two samples)

References Cited

Tsuchihara, T., Okuyama, T., Ishida, S., Shirahata, K. (2018): Effect of different sampling methods on concentrations of sulphur hexafluoride (SF_6) in groundwater and age dating, Journal of Groundwater Hydrology, 60(1), pp.41-52. (in Japanese with English abstract)

Asai, K., Tsujimura, M., Mogi, K. (2017): Distribution of atmospheric SF_6 around urban area in Japan – Impact for groundwater dating using SF_6 –, Journal of Groundwater Hydrology, 59(4), pp.345-354. (in Japanese with English abstract)

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