Improvement of pumping system for continuous monitoring of dissolved gas in groundwater

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Our destinations

- Explore effective seismo-chemical signal in groundwater
  - How to sample, extract and measure
  - How to postprocess data
  - Reveal correlation with seismicity
- Aspire to realize the short term prediction of earthquakes
  - Statistical verification of correlation between seismicity and signal
  - Improvement of reliability

Rn is a good predictor, but…

- Rn is continuously generated from U contained in the crust.
- Because half-life of Rn is 3.8 days, the concentration provides us fresh information about the crust.
- Rn concentration sometimes responds to the mechanical stress of the crust.

- Rn is an indirect notifier from an epicenter.
- The depth of a Rn source cannot be understand by the concentration only.

Combinatorial seismo-chemistry

- In order to make Rn to be a effective predictor, it is essential that the variation of the Rn concentration should be checked by another information.

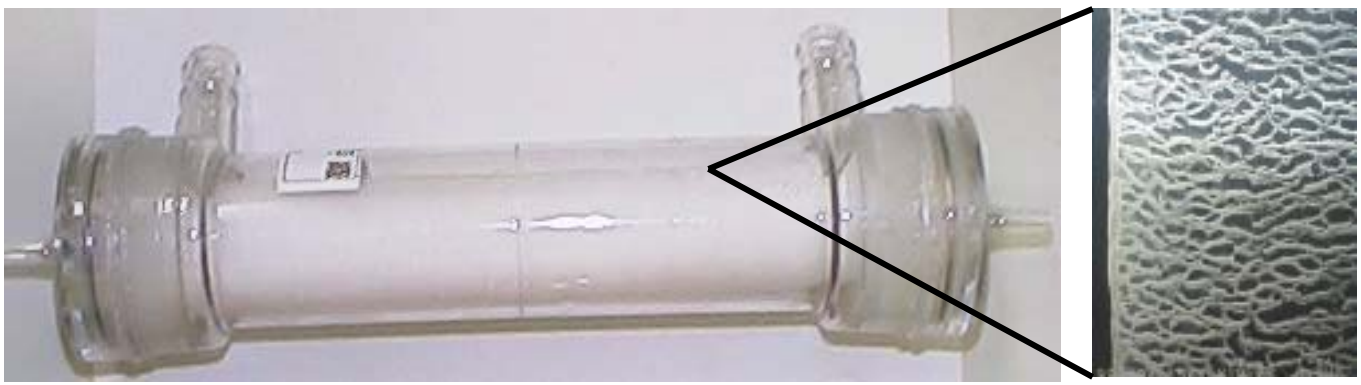
- Noble gases like He, Ar and Kr carries knowledge of origin of measured gas.
- Gas composition in groundwater may provide us important keys to understand seismo-chemical signals.

How to get dissolved gas?

- Evaporate sampled groundwater
  - Absolute composition can be measured.
  - Because water vapor, that will be the main component, deflects a mass spectrum, data processing will be more difficult.
- Extract by a membrane filter
  - Extraction is easy by the use of a gas extraction module.
  - Measured composition is affected by permeation characteristic.

What is a gas extraction module?

- It is a commercial product.



  - 3000 silicone hollow fibers are contained in a polycarbonate housing.
  - Inner diameter of a hollow fiber is 60μm.
  - Surface area is 0.74m^2.
    - M60-3000, Nagayanagi Co., Ltd(http://www.nagayanagi.co.jp)

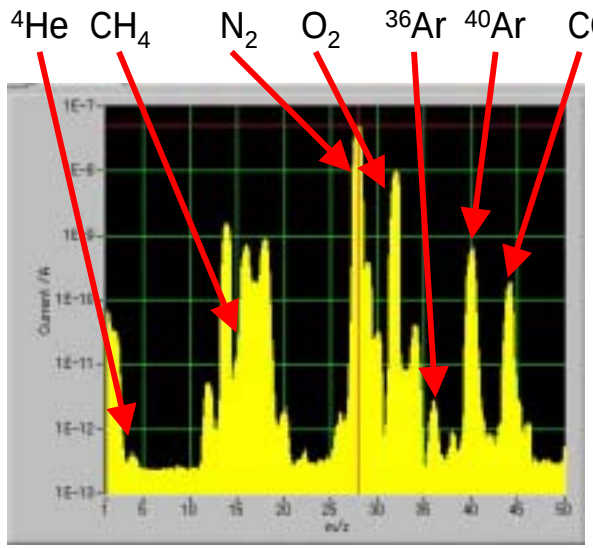
How to sample groundwater?

- No sampling
  - Putting a module in a bottom of well is the best way.
  - Generally a well is not straight, and there is a lot of projections on a wall of a well.
  - It is not easy to install.
- Sampling from aquifer
  - A module can be set on the ground.
  - Pumped groundwater must be returned to the aquifer.
  - Nonetheless it will affect the water level.

How to measure concentration?

- Gas chromatography
  - Apparatus is compact if a micro-GC is available. H_2 can be detectable.
  - Because it needs carrier gas, it requires scheduled maintenance. Measurement interval is relatively long(about 15min).
- Mass spectroscopy
  - Isotope measurement can be carried out. Measurement interval is short(about 1sec). Maintenance free.
  - Size of an apparatus is not compact. H_2 is not valid because of cracking of H_2O.

Prototype system



Quadrupole Mass Spectrometer

Extraction Module

Capillary (30μm)

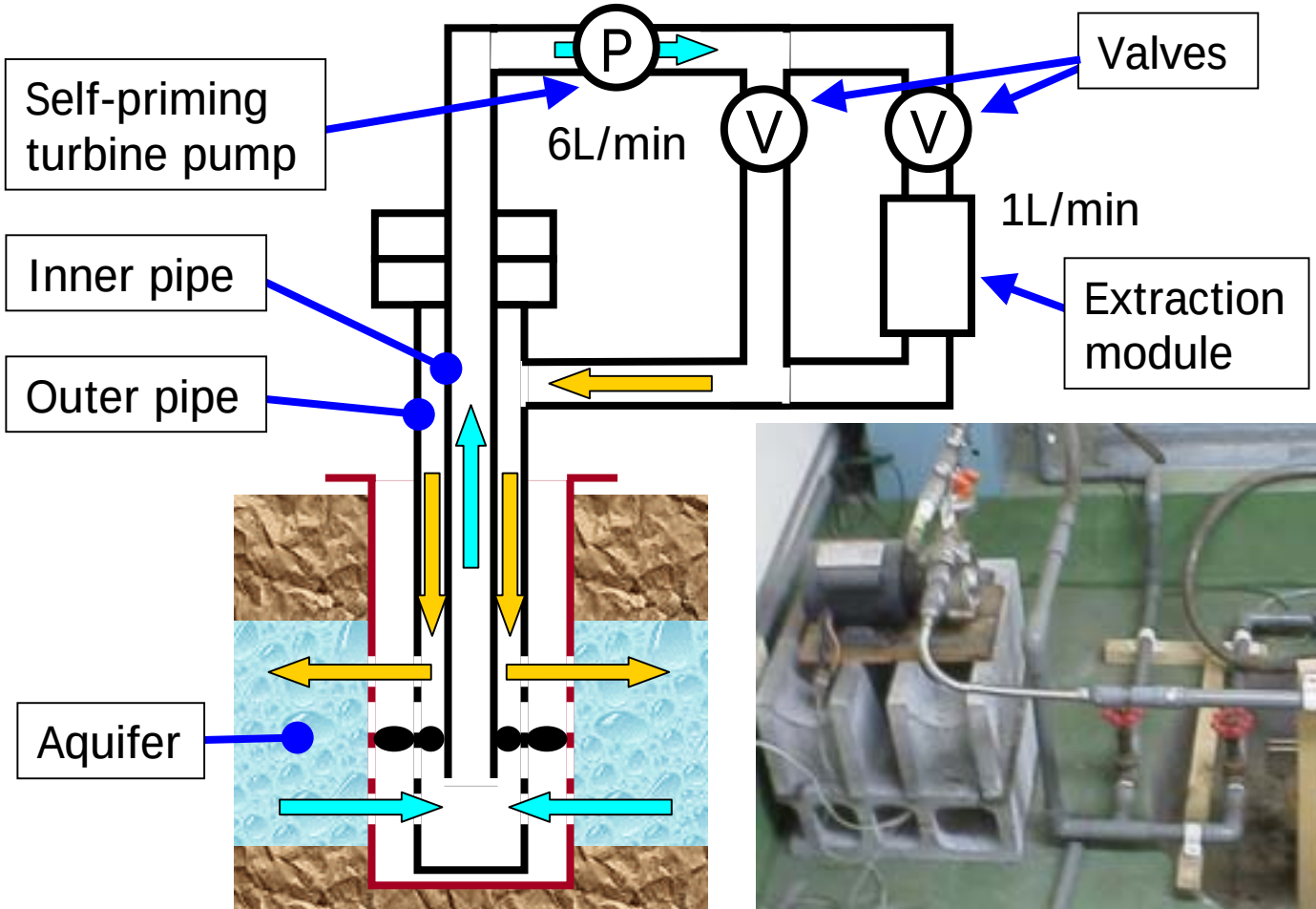
Diaphragm pump

air

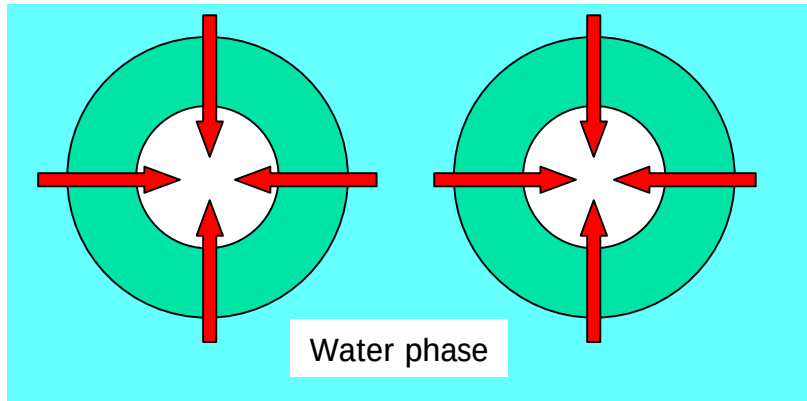
groundwater

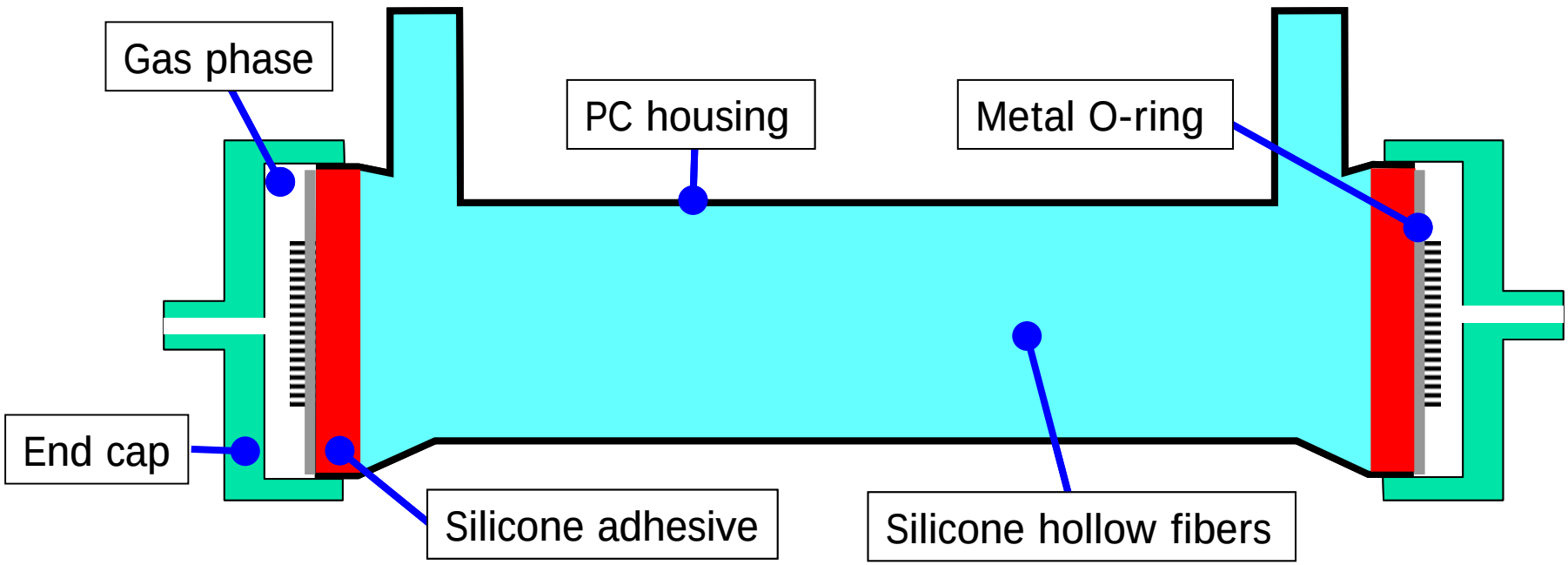
Structure of pumping system

- Coaxial pipe arrangement



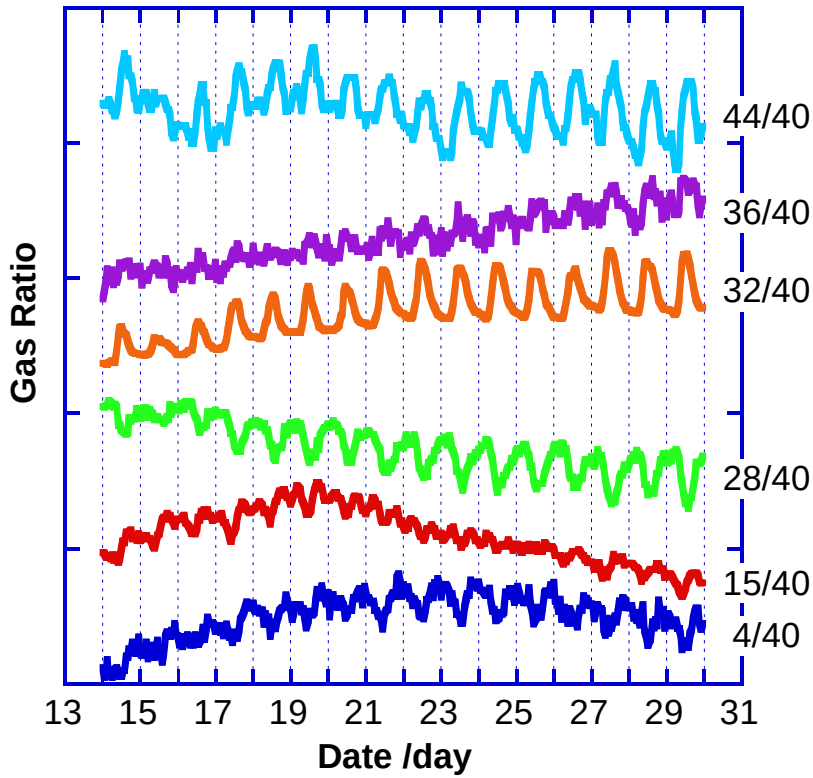
Structure of gas extraction module





Preliminary result at Omaezaki 500m

- Tidal responses of $^{4}He/^{40}Ar$ and $CH_4/^{40}Ar$ were detected.



- These signals gradually disappeared in 1 month.

Problems in prototype system

- Water leakage from a gas extraction module happened sometimes.
  - Leaked water was drawn into an analyzer tube of QMS.
  - Therefore we could not introduce a radon counter which uses a semiconductor sensor.
- Effect of pumping on water level and aquifer temperature are not verified.

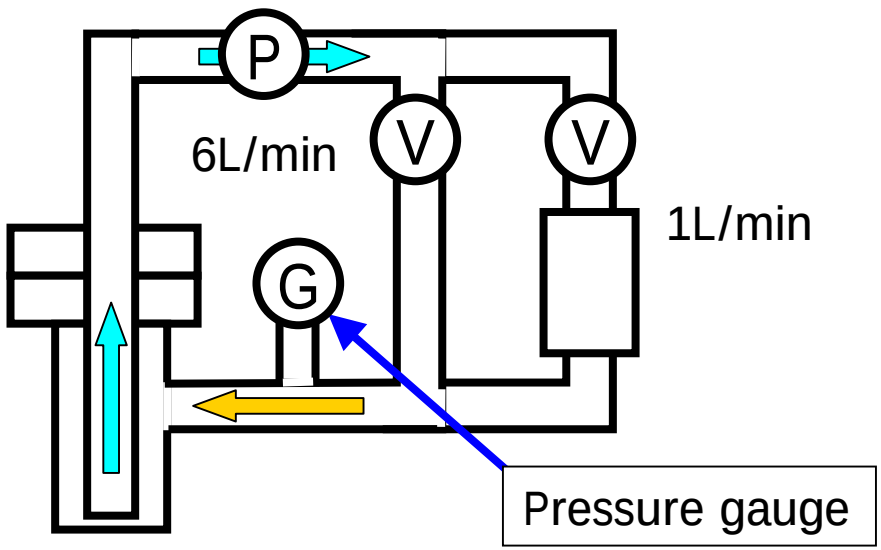
What is the cause of leakage?

- Petroleum liquid contained in groundwater affects both hollow fibers and silicone adhesive.
- Flow rate of groundwater in a module is too high.
- Pressure difference between inner and outer phases of hollow fibers is too high.

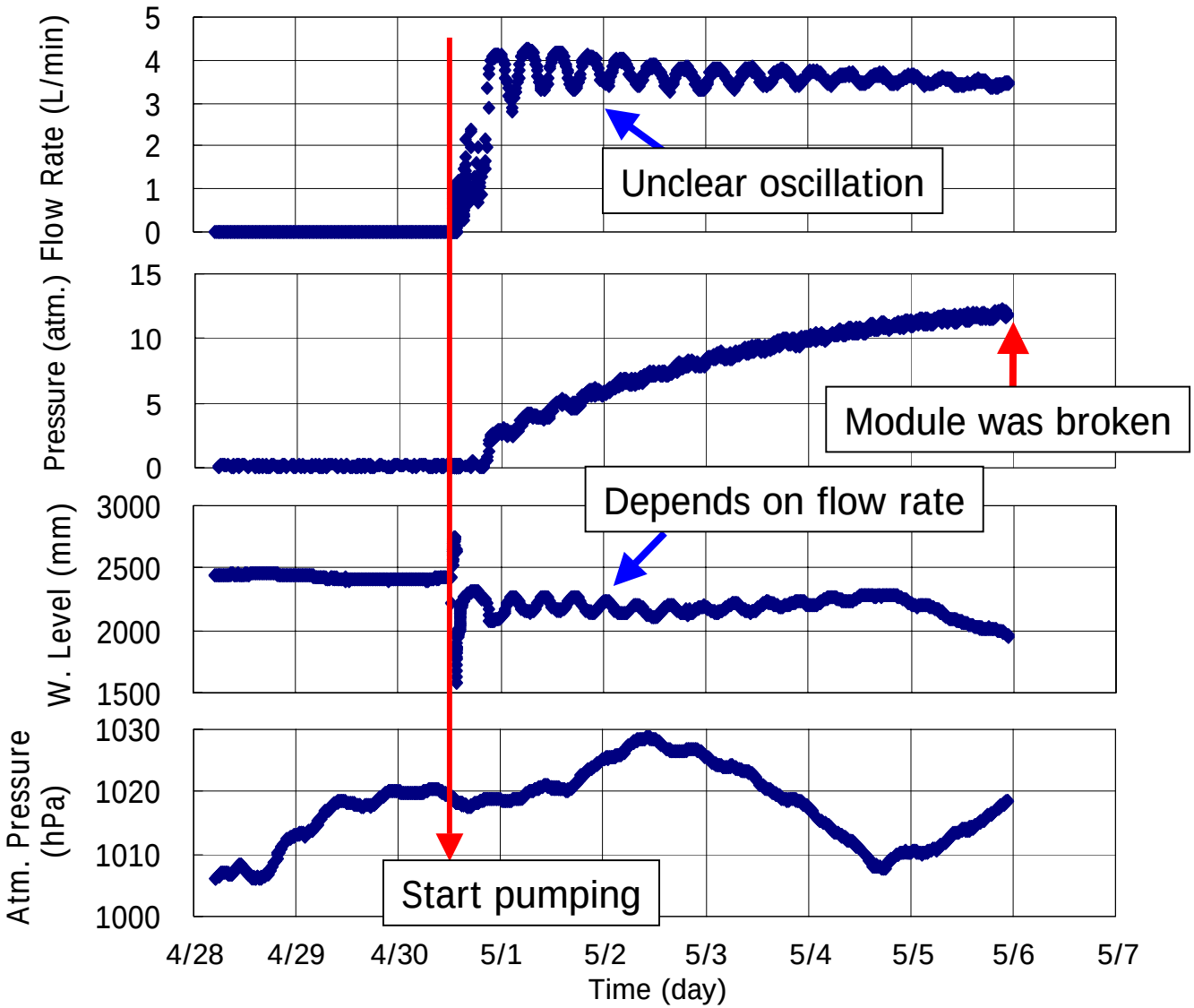
- However these were not a cause of the water leakage.

Pressure in return ductwork

- When we remove a broken module just after water leakage, we found that the pressure in the return ductwork is too high.
- We decided to check the pressure of a gas phase in the return ductwork.



Breakage test at Omaezaki 500m

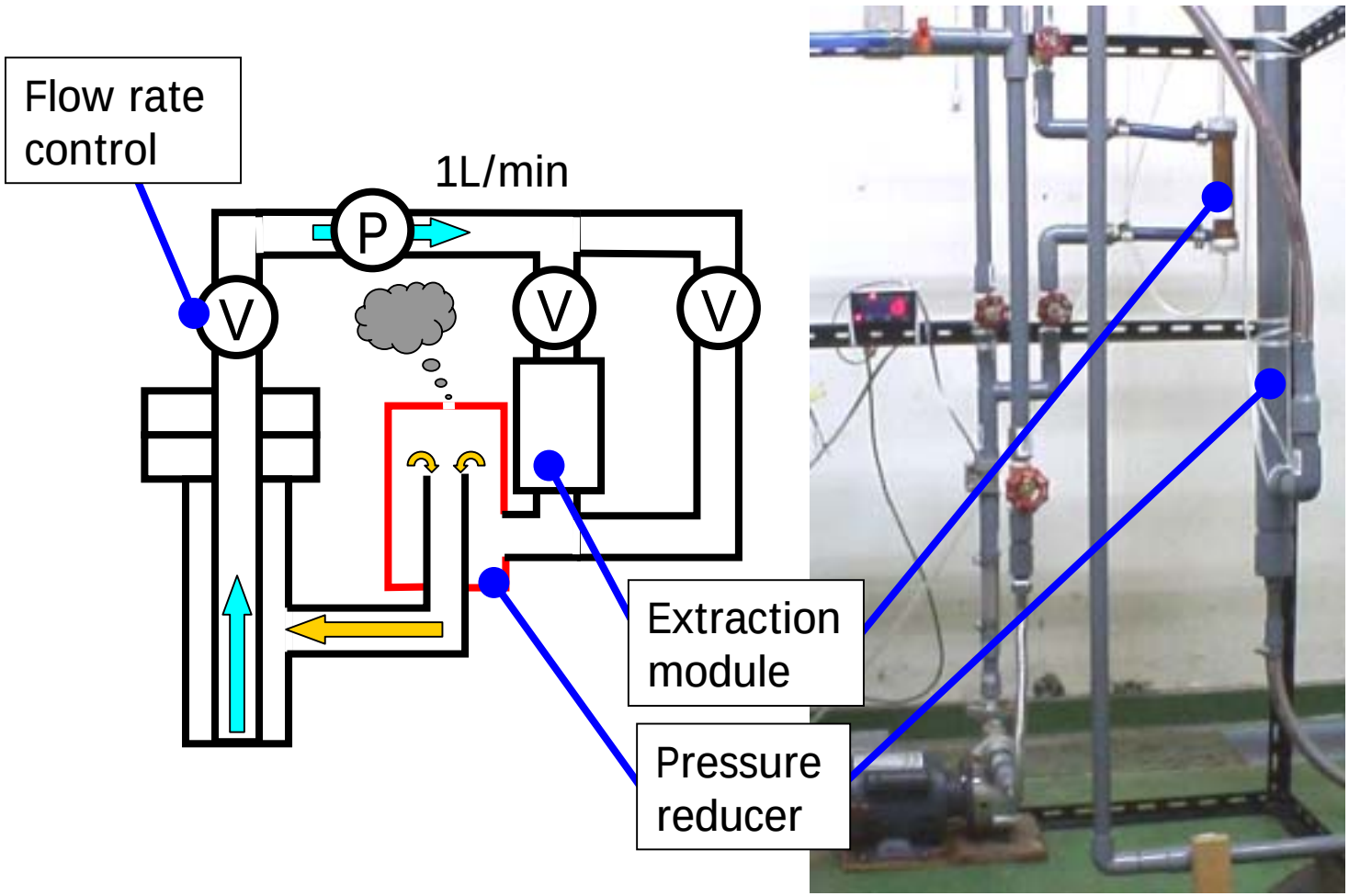


Bubbles leaved from groundwater

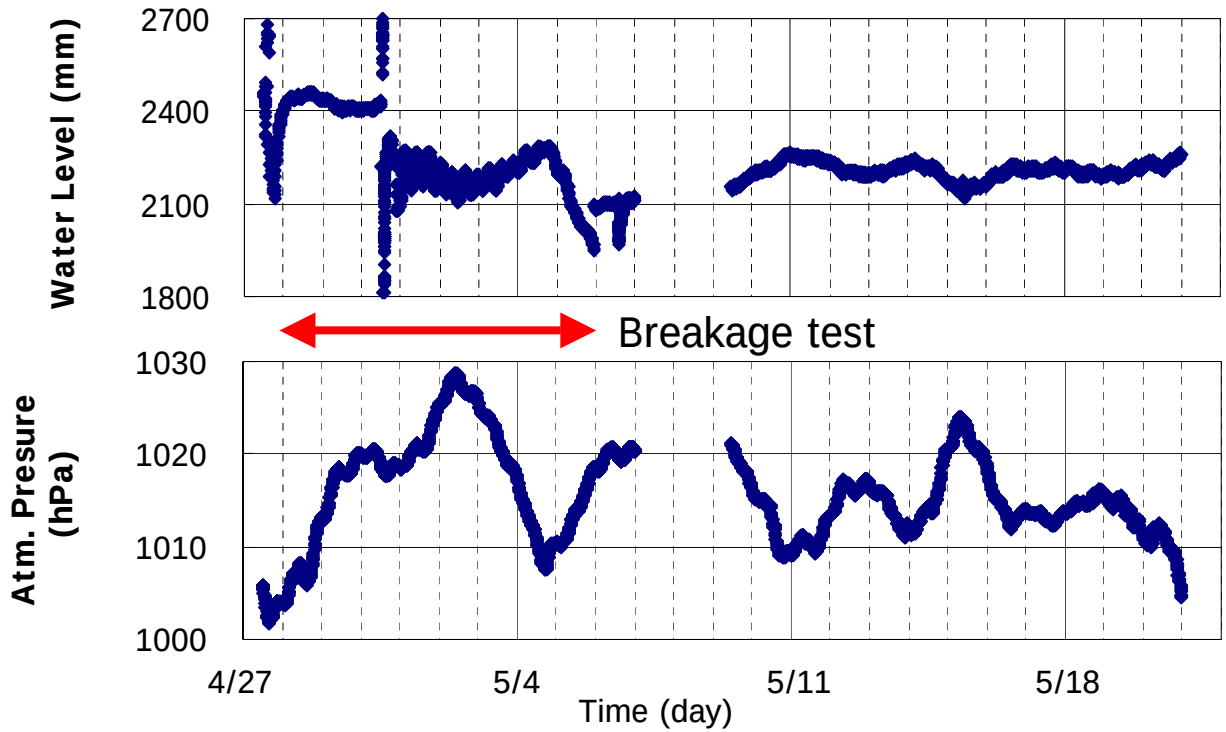
- In the case of a 500m depth well, the pressure of dissolved gas is 50 atm at maximum.
- Pumping triggers an eruption of bubbles from groundwater.
- Bubbles are accumulated in the return path of the ductwork.
- Pressure of the gas phase, generated in the return path of the ductwork, progressively increases.
- Silicone adhesive falled off at last.

Improvement of pipe arrangement

- Introduction of a pressure reducer



Effect of pumping on data



- Water level decreased about 30cm after pumping. The value coincides with the volume of the ductwork over groundwater head.

Results

- Sealing in a gas extraction module is broken by pressure increase due to gas emission from pumped groundwater.
- A pressure reducer, which is put in a return ductwork, is useful for continuous gas monitoring in groundwater by a extraction module.
- Water level is affected by pumping. The variation consists with the volume of a ductwork over the groundwater head.
- The tidal response of the water level is not disturbed by pumping.

Remaining tasks

- To scale up the volume of extracted gases. That depends on the extraction efficiency of a module.
- To consider the use of bubbles gases for composition analysis.
- To contrive a method to plot the gas composition.
- To examine the effect of pumping on the gas composition, and on the water temperature at the aquifer depth.
- To install a Rn counter.