Mechanism and frequency change of pressure oscillation in the laboratory geyser system

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Geysers are hydrothermal activities seen in volcanic areas, which have the similarities with volcanos in seismicity. It is known that the pressure pulses occurring inside geyser's conduit excite tremors, but the source and mechanism of the pressure pulses are still unclear. Because phenomena of natural geysers are complex due to additional factors such as the influence of atmospheric conditions, and because their interiors are hardly observed directly, simplified laboratory experiments which allow us to directly observe what are happening in the interior may be useful. In this study, we tried to reveal the mechanism of the pressure oscillation and factors controlling its dominant frequency using our fluid oscillation model and pressure and temperature data measured in our laboratory experiments.

We designed an experimental setup which reproduces cyclic eruptions of natural geysers. The setup mainly consisted of a flask and a glass tube, which correspond to natural hot water chamber and conduit, respectively. Heating the flask by the hotplate, we measured pressure and temperature in the flask, and erupted mass of each eruption. We also took video images of flask interior and water surface in the conduit with normal-speed and high-speed video cameras. From the movies of the water surface, we digitalized the vertical water column movement in the conduit using a video analysis software. We examined the effects of experimental conditions on characteristics of pressure oscillation by varying three geometric parameters of the experimental system: (i) inner flask volume, (ii) initial water level in the conduit, and (iii) cross-sectional area of the conduit.

In interpreting experimental results, we used the model proposed by Toramaru et al. (Volcanological Society of Japan 2010 Fall Meeting), in which the frequency of pressure oscillation is represented in terms of geometric parameters of the experimental system and the effective bulk modulus K* of fluid in the flask. In our experiments, it was difficult to determine correctly the effective bulk modulus K* from the movie analysis or another measurement, so we calculated the values of K* using a model to relate the pressure variation in the flask ΔP and water level in the conduit ΔL, by $AK^*/Vo=\Delta P/\Delta L$, where, A is cross-sectional area of glass tube, Vo is inner flask volume, respectively. The values other than K* were obtained from our experimental measurements. From these expressions, we calculated theoretical values of the resonance frequency and compared it with the measured values of dominant frequency of pressure oscillation.

The results showed that the measured pressure oscillation in the flask consisted of high-frequency pulses and subsequent low-frequency damped oscillation. The damped pressure oscillation had a strong inverse correlation with vertical water column movement in the conduit. From the observation of video images synchronized with pressure record, we found that the bubble formations in the flask bottom caused the pressure pulses. From an eruption to the next eruption, the dominant frequency of pressure oscillation decreased systematically. This monotonic decrease in the dominant frequency was explained by the reduction of K*, as a result of increase in the gas volume in the flask by heating. We found that the dominant frequency of pressure oscillation varied depending on experimental conditions. The variations in temporal behavior of dominant frequency could be interpreted by differences in the setting of geometric parameters and in the initial values of K* just after eruptions due to various erupted masses of the preceding eruptions.

In conclusion, the pressure oscillation in the experimental geyser system is caused by bubble formations in the flask and vertical water column movement in the conduit. The dominant frequency of pressure oscillation is controlled by the geometric parameters of the experimental system and the erupted mass of the preceding eruption.

Keywords: Laboratory experiment, Geyser, Pressure oscillation, Fluid oscillation, Frequency change