

## Study of potential gas eruption by seismic survey in Lake Kivu

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### Summary

We have investigated potential risk of gas eruption by air gun operation in a seismic survey on the Lake Kivu, East Africa, which contains a huge amount of gas dissolved in the water zone below a depth of 260 m. Measured data suggest that gas nucleation and bubble growth in a large body of water require super-saturated condition (pressure significantly lower than the bubble pressure (B. P.) and significant long relaxation time ( $> 1$  second). Initial homogeneous gas nucleation in water enhances viscous behavior of gas exhaustion from a large body of water. Therefore, a seismic survey on the lake surface will not likely trigger gas outburst from the Lake Kivu.

### Introduction

The Lake Kivu as shown in Figure 1 located at the East Africa rift in the board between Rwanda and Democrat Republic Congo (DRC) is one of the great lake with  $\sim 2700$  km<sup>2</sup> in area, 1500 meter in elevation and 500 meter in depth. The Lake Kivu has been investigated as a dangerous killer because tremendous gas storage in the lake (Tietze et al., 1978, 1980). Total CO<sub>2</sub> storage was estimated as  $\sim 500$  million tons. In addition, the Lake Kivu is also highly saturated with producible methane gas of  $\sim 35$  million tons (Isager, COWI, 2010). A schematic of the lake is shown in Figure 2. Aside of volcano Mt. Nyiragongo tremendous gases in the lake are generated by bacterial fermentation or reduction of both organic and magmatic CO<sub>2</sub> in the bottom of the lake with a support of magmatic activities from deep. Water zones in the Lake Kivu consist in the top seasonal mixed layer (to 50 m depth) above the permanent density stratification (to  $\sim 260$  m depth) and deep zoon (to  $\sim 500$  m) with high gas saturation. Density stratification is the main factor to stabilize gaseous water in the deep zone. Figure 3 is the model result of depth profiles with cumulated effects of temperature, salinity, CO<sub>2</sub> and CH<sub>4</sub> saturation on density at atmosphere pressure (Schmid et al., 2004), which is consistent with our prediction (FLAG, 2010) and measured density data from water samples. Recently, the basin below the Lake Kivu becomes a target for oil exploration. A seismic survey with an air gun as a source on the surface of the Lake Kivu has been proposed. However, the survey is impossible to carry out without carefully evaluation of the risk of a seismic survey on the Lake Kivu to trigger dangerous gas outburst, which is the purpose for this study.

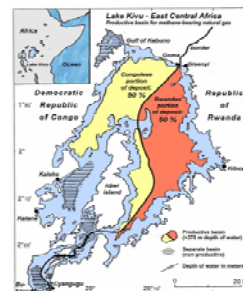


Figure 1: Geography around Lake Kivu.

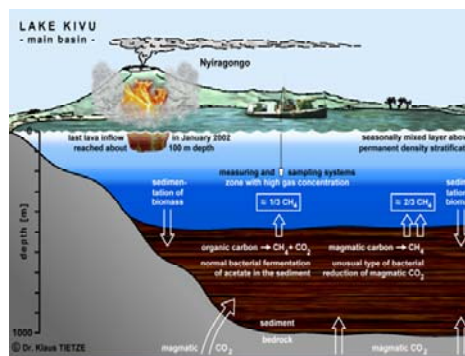


Figure 2: Schematic profile of the Lake Kivu with relevant processing.

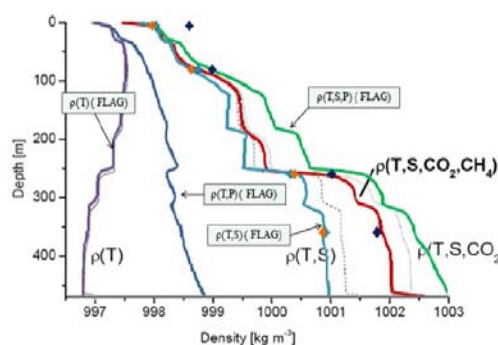


Figure 3: Density data in comparison with the model by Schmid et al. (2004), and the FLAG model (2010) of temperature, salinity and pressure versus depth in the Lake Kivu.

## Risk of Gas Eruption

Air gun has been suggested to be used in seismic survey on the Lake Kivu. First question obviously: can such operation trigger gas eruption from the lake? Fortunately, surface water in the top of 50 meters of the Lake Kivu contains no harmful gas. Pressure wave generated by an air gun attenuates quickly as wave propagates in a spherical pattern,

$$e = e_0 * \frac{1}{r^2}.$$

At the gas zone below 260 m, pressure disturb from seismic survey is estimated less than 0.0001 MPa.

### Measurement conditions

Make a live water sample: use the dead water sample from depth of 360 m with dissolved CH<sub>4</sub> (GWR: 0.372 L/L, Sa: 35.4%) and CO<sub>2</sub> (GWR: 1.953 L/L, Sa: 8.9%) to simulate live water at in situ. The bubble pressure is estimated as 167 psi for CH<sub>4</sub> and 40 psi for CO<sub>2</sub> with the FLAG program. Total bubble pressure is assumed as 207 psi (linear superposition of the CH<sub>4</sub> and CO<sub>2</sub> bubble pressure).

We use ISCO digital syringe pump to make measurement. We use distill water with known compressibility to calibrate the pump effect, which has been used for correction in measured data. In our measurement designed pressure drop is ~ 2 orders bigger with relaxation time equivalent to 3 Hz or less, which are much favor condition than that of the air gun surface seismic survey for gas eruption.

### Experiment 1

We measure both distill (dead) and live water samples with volume of ~10 cc and start pressure at 1000 psi. Given pressure drop of 100 psi and running time of 0.15 s per step down to 300 psi first, and then given pressure drop increment of 20 psi and running time of 0.15 s per step with start pressure of 300 psi, we measure pressure and volume. At pressure higher than the bubble pressure, there are no significant differences between dead and live water as shown in Figure 4. With given 20 psi increment of pressure drop from 300 psi down to 10 psi, there is no more volume increase for the live water sample than the dead water sample. Figure 5 shows measured volume versus pressure for both dead and live water samples. As pressure below 210 psi, both pressure drop and volume increase of the live water is systematically slow than those of dead water. There is no indication of gas exhaustion with the given condition.

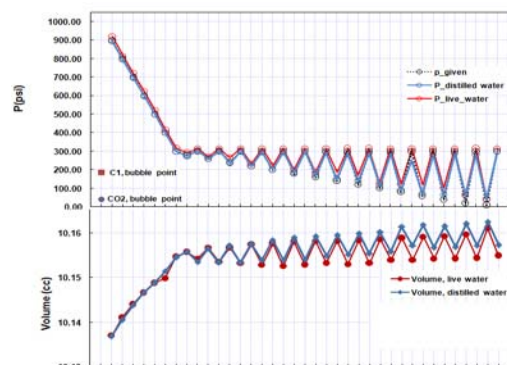


Figure 4: Measured pressure and volume on both dead and live water for each step with running time of 0.15 s.

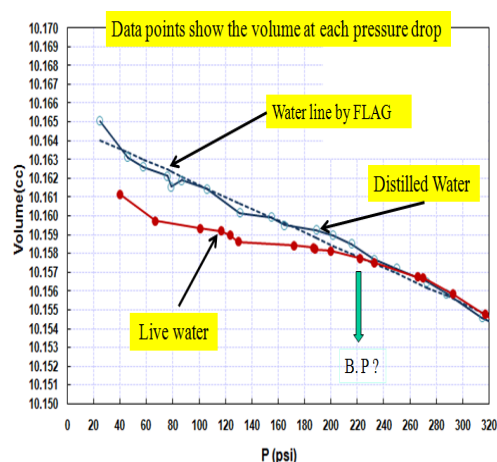


Figure 5: Measured volume vs. pressure for each pressure step to show low expansibility of water with running time of 0.15 s.

### Experiment 2

We measure both distill (dead) and live water samples with volume of ~10 cc and input pressure drop 20 psi, measuring pressure and volume at 0.15 s starting from ~300 psi. Figure 6 shows models for volume expansion as function of pressure for equilibrium state of CH<sub>4</sub>-CO<sub>2</sub>-water system of the water sample. Data clearly show that almost no gas phase has been detected in volume expansion with pressure drop from 300 to ~50 psi. Figure 7 shows volume-pressure data from two tests with pump running time of 0.15 and 1.0 s separately. In comparison with the dead water data we observed a clear turn to lower volume

### Risk of Gas Eruption

expansibility of the live water than that of dead water starting at the bubble pressure of ~210 psi to the low pressure of ~ 55 psi. Then, volume of the live water shows a rapid volume increase with a slow drop of pressure, which may suggest that there start gas nucleation and gas bubble expansion.

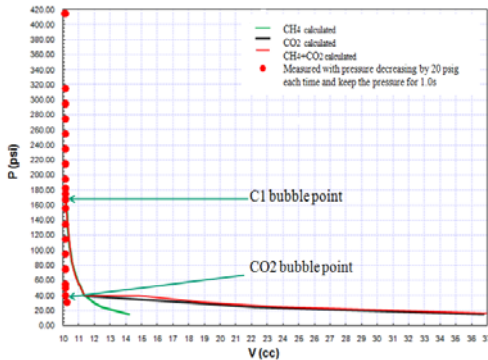


Figure 6: Measured pressure volume for each pressure drop within 1s in comparison with model.

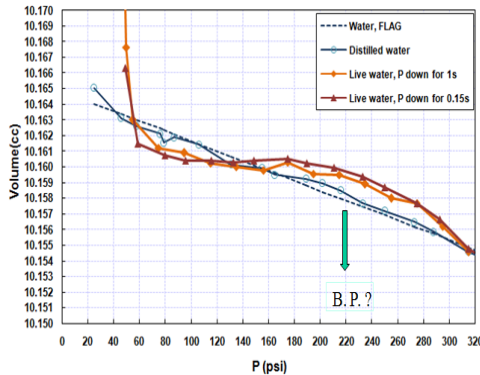


Figure 7: Volume vs. pressure data for live water with 0.15 and 1s relaxation time separately in comparison with data and model of distilled water.

### Experiment 3

Our data in the experiments 1 and 2 show clearly that there are no effect of pressure drop with short time on gas exhaustion. In the experiment 3, we take multiple steps to drop pressure and up to hours to observe the process of gas exhausting. Figure 8 shows that measured volume data recorded in a video on 9 steps of pressure drop from 400 to 55 psi within 60 s. The volume increases almost instantaneously with pressure drop, then maintain as a

constant, which is same as that of distill water at pressure higher than 115 psi. Then, we observed volume expansion continuously, but only 0.04% with the pressure drop from 115 psi to 55 psi. Figure 9 shows how fast gas can exhaust with continue pressure drops from 55 to 25 psi in 60 s relaxation. Measured data suggest that Pressure for initial gas nucleation could be much less than the bubble pressure. In addition, gas nucleation is a slow processing. Oscillated seismic wave has less effect to trigger gas eruption.

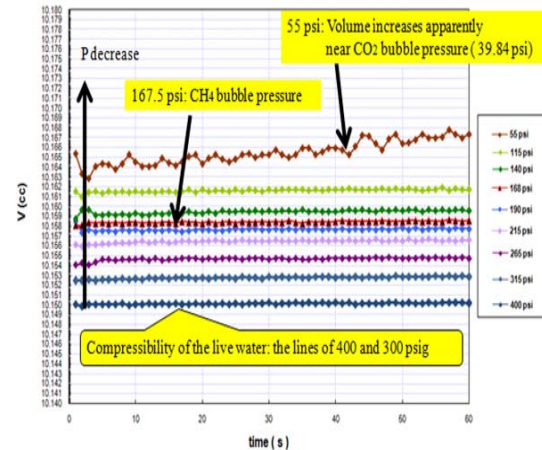


Figure 8: Measured volumes in 9 steps of pressure drop with 60 s relaxation.

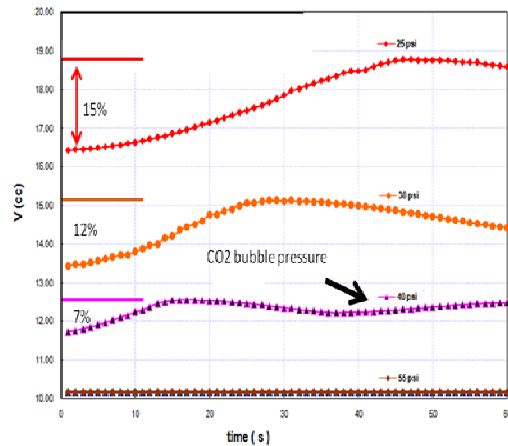


Figure 9: Measured volumes in 4 steps of pressure drop with 60 s relaxation.

## Risk of Gas Eruption

### Conclusion

From measured data on the gas charged water sample with the bubble pressure of ~210 psi from the Lake Kivu, we can summarize:

1. For the water sample with the bubble pressure of 210 psi from 360 m depth in the Lake Kivu, we cannot identify the gas even with a pressure drop to as low as 10 psi with a time period less than 1.0 second.
2. Homogeneous gas nucleation requires super-saturated water and long period time. We observed that for a water sample with ~210 psi bubble pressure, gas can be nucleated at pressure lower than 115 psi, but higher than 55 psi. And reaching to gas-water equilibrium requires many hours.
3. Data show that Initial homogeneous gas nucleation in water enhances viscous behavior and cause a long time processing for gas exhaust from water.

Therefore, cycling pressure wave generated by a surface seismic survey with frequency higher than 1 Hz is not likely to trigger a gas eruption for the under-saturated water zone below 260 meter depth in the Lake Kivu.

### Discussion

Zhang et al. (2006) reviewed in the measurement to simulate gas eruption and observed a constant acceleration of bubbles grow in the order of 10 milliseconds. The result seems in controversy with our data. This is due to different measurement conditions. In order to demonstrate gas eruption, favored conditions has been introduced into the gas-water system such as turbulence movement of water, half opened space to dilute exhausted gas, add catalyst, continue support chaos energy (impurity particles, gas intrusion, heat flow and so on). But all of these conditions are kind of heterogeneous gas nucleation with artificial creation, and not proper to simulate the homogeneous gas nucleation occurred in large body of confined water. Homogenous nucleation is a difficult and slow processing even for a super-saturated gas-water system as shown in this study. The Lake Kivu has shown a tremendous stability to against all the chaos generated by the natural disasters. However, many observations show that many other factors may favor to gas nucleation and trigger gas eruption, which can cause humongous disaster for humanity and environment. Therefore, carefully monitoring change of lake condition is also recommended.

### Acknowledgement

We appreciate our colleague Professor Stewart of AGL geophysical lab of University of Houston for his initiation of the project. He has collected samples from the Lake Kivu and carried them to our lab.

**EDITED REFERENCES**

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2011 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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