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Development of Mist-Cyclone System for Hydrogen Sulfide Sampling in Sewer Line

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Abstract. There is a strong need to develop pipe inspection robots that can measure hydrogen sulfide (H_2S) at low concentrations in sewer lines. The Mist-Cyclone system would be the system for detecting odor-causing substances in applications involving the inspection robot. This system has been developed to obtain highly concentrated solutions of odor-causing substances by blowing gas mixtures through aqueous NaOH mists generated by an ultrasonic transducer and then separating the liquid portion from the two-phase fluid using a cyclone unit. In our tests with H_2S, the S^{2-} component was detected in the sample phase at a sufficient level that would be measurable by conventional sensor systems.

Keywords: Sulfide, sampling, mist, solutions, sewer pipe

1. Introduction

Odor-detecting technology—the purported "electric nose"—has recently attracted significant attention. This technology, mainly utilized for gas sensors, has been widely used in environmental, medical, and other industrial applications.

The development of this technology requires not only sensor research but also the improvement of sampling techniques—the quality of detection largely depends on the acquisition of a high-density sample in a short period of time. The authors have proposed a unique system, i.e., the Mist-Cyclone system, in which a gas mixture is entrained through a mist generated by an ultrasonic transducer, and this is followed by separation of the two-phase fluid by a cyclone unit. High concentration solution samples can be obtained in a short time. Our previous studies[1], [2] using eugenol and DNT as model odor substances have confirmed this as an effective sampling trace method.

One practical use of odor-detecting technology is to explore the sources of hydrogen sulfide (H_2S) within city sewer systems. This gas has been identified as the cause of several recent system problems, such as corrosion of concrete pipes, manhole-related sewer-gas poisoning, or foul odors at sewer line outlets. A pipe inspection robot, consisting of a pan-tilt camera and a crawler (Figure 1), is generally necessary for investigating and preventing these problems. To detect the exact location of a H_2S source in a sewer line,

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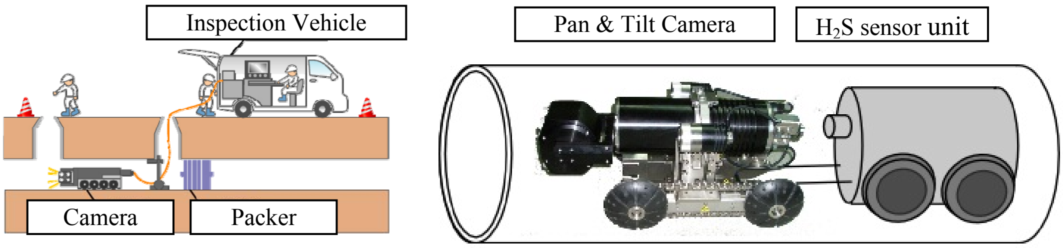

Fig. 1: Pipe inspection robot.

a highly sensitive measurement method would be required. At present, however, no sensing devices or technologies are available to accurately measure low concentrations in real time, within a limited space. The Mist-Cyclone system would be the best system for this application.

In this study, an experimental model that can be inserted into a main line pipe (250 mm) was built and tested with a standard H_2S-air gas mixture. The solution samples obtained by this unit were analyzed by the methylene blue absorption spectroscopy method to confirm that H_2S gas was captured effectively via this system.

1.1. Outline of the Mist-Cyclone system

The Mist-Cyclone system is depicted in Figure 2(a). It is minimally constructed with simple component parts; this is a large advantage for installation in mobile robot systems. The inlet port [IN] is connected to a sampling bag that is filled with a standard H_2S-air gas mixture. The outlet port [OUT], a flow meter (20 L/m), a vacuum chamber, and a vacuum pump are connected in series. The sampling process is as follows:

1) The inner pressure of the system becomes negative when the vacuum pump is on, and the gas in the sampling bag is drawn into the sprayer unit.
2) In the sprayer unit, a stored solution (such as water) is atomized by the ultrasonic generator mounted on the bottom of the case.
3) H_2S standard gas enters through the inlet, makes contact with the mist, and saturates the solution in the sprayer unit.
4) The two-phase, gas-liquid fluid flows to the end cap and rushes into the cyclone unit through the tube.
5) The two-phase fluid is separated into gas and liquid by a centrifugal force in the cyclone unit. The gas is discharged from the outlet [OUT], and the liquid is collected in the sampling cell. Future development will include the mounting of a sensor in the sampling cell to evaluate the liquid component.

1.2. Ultrasonic mist generator

Figure 2(b) shows the ultrasonic mist generator and the circuit board installed in the system. The ultrasonic mist generator makes a water column over the solution and generates a substantial amount of mist from its apical part, as shown in Figure 2(c).

1.3. Sampling methods for capturing H_2S

For the detection of H_2S-air gas in sewer lines, the capability to measure a target concentration of 0.1 ppm or less is desirable. Generally, the available semiconductor gas sensors are easy to handle and inexpensive, but their sensitivity (approx. 5–6 ppm) or accuracy (approx. 2 ppm) is too low to adequately measure the target gas. In contrast, gas-chromatographic methods have the requisite sensitivity but are not suitable for in situ monitoring.

The Mist-Cyclone method ensures the acquisition of a high concentration solution by spraying misted NaOH solution, which has a very large surface area, to make contact with and dissolve the H_2S-air gas easily. Once dissolution is achieved, sensing devices analyze the solution.

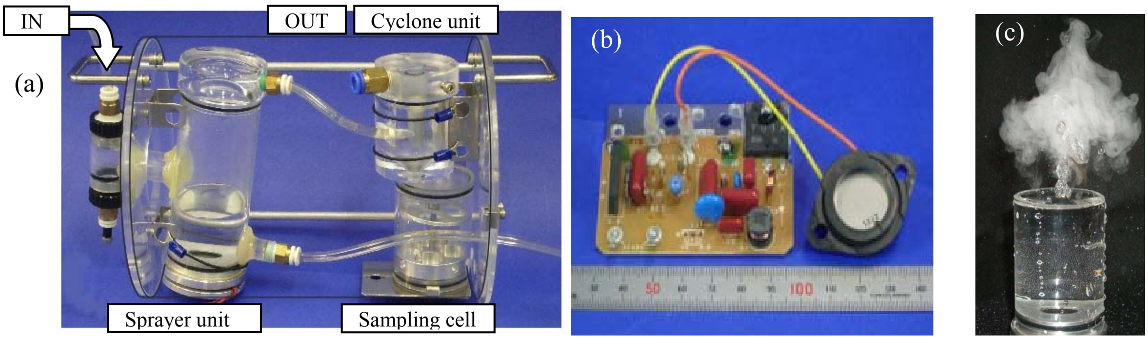

Fig. 2: Image of mist-Cyclone System

The bubbling method provides another route for gas capture and involves the discharge of H_2S gas in the form of bubbles from nozzles into a solution with circulation flow. To obtain highly concentrated solutions, it is necessary to increase the number of cycles. However, it is difficult to reduce the sampling time or the total volume of solution obtained because of the limited contact surface between the bubbles and the solution.

The solution samples obtained by the Mist-Cyclone system were analyzed by the absorption photometry method, which is widely used to measure trace amounts of H_2S in liquids. This method is also known as the methylene blue method, as the dye methylene blue is formed when H_2S solution reacts with ferric chloride ($FeCl_3$) and N,N-dimethyl-1,4-phenylenediamine. The absorbance of the dye is measured by the spectrophotometer. The experiment involves the following steps:

1) Separately prepare H_2S-air standard gas at three different concentrations (10 ppm, 1 ppm, and 0.1 ppm) in a 50-L sample bag.
2) Prepare three misting solutions—plain water and NaOH at two different concentrations (0.005 mol/L and 0.01 mol/L).
3) Introduce water or one of the NaOH solutions into the sprayer unit, as high as 40 mm from the bottom.
4) Connect the sample bag to the inlet of the Mist-Cyclone unit, and turn on the vacuum pump. Approximately 6 min are required to draw the gas from the bag through the unit at a flow rate of 8 L/min.
5) Measure the weights of the solutions in the sampling cell and in the sprayer unit.
6) Add 1 ml of N,N-dimethyl-1,4-phenylenediamine solution and 0.5 ml of ferric chloride solution to 10 ml of each sample.
7) Measure the absorption value of each solution spectrophotometrically (UVmini-1240, Shimazu) at a wavelength of 668 nm.

Repeat this test using the three different misting solutions with H_2S-air standard gas at three different concentrations. Because NaOH reacts with H_2S to generate Na_2S, it promotes the process of gas absorption and efficiency of capture, leading to predictably higher concentrations of sampled solutions. NaOH solutions at different concentrations were used in the experiment.

2. Experimental Results and Discussion

Table 1 and Figure 3 show the test results for H_2S-air gas sampled by the Mist-Cyclone system. S^{2-} was detected in each sample obtained, indicating that H_2S was efficiently captured by this unit.

Liquid samples obtained through the absorption of H_2S-air gas into NaOH solutions at various concentrations were analyzed by the methylene blue absorption spectroscopy method. According to the experimental results, the concentration of H_2S could be determined by examining the solution because the concentration of S^{2-} in solution is proportional to the density of H_2S, as shown in Figure 3.

If an aqueous sample can be rapidly and effectively obtained, as in this study, it would be possible to measure H_2S continuously on a real-time basis by attaching an amperometric electrode [3] at the outlet of the cyclone unit. This would enable a pipe inspection robot to pinpoint the source position against the concentration gradient.

As expected, the concentration of S^{2-} in the liquid samples varied with H_2S density in the gas as well as the concentration of NaOH in solutions. Very small increases in NaOH concentration resulted in dramatic increases in the S^{2-} concentration of the sampled solutions.

TABLE I. Experimental result of H_2S Gas sampling by Mist-Cyclone unit

NaOH Solution		0.0 mol/L		0.005 mol/L			0.01 mol/L		
Concentration of H_2S-Air gas (ppm)		1	10	0.1	1	10	0.1	1	10
Concentration of S^{2-} in obtained solution (mg/L)	In Sampling cell	0.23	0.84	0.29	5.15	35.67	0.67	17.25	201.55
	Within Sprayer unit	0.02	0.03	0.04	0.22	1.90	0.03	0.36	4.19

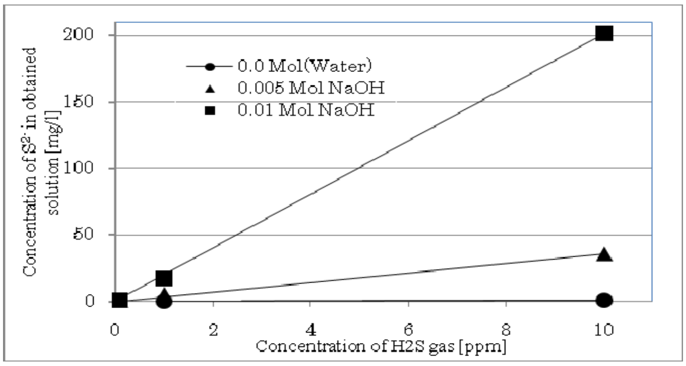

Fig. 3: Concentration of H_2S-Air gas vs. Concentration of S^{2-} in obtained solution.

As shown in Table 1, the concentration of S^{2-} in the sampling cell was much higher than that in the sprayer unit. This indicates that most of the gas-liquid was transferred to the cyclone unit, with the remainder returned to the solution in the sprayer unit. Circulation of flow would cause this undesirable effect on the measurement results. This problem will be solved with further research.

3. Conclusions

In this study, a Mist-Cyclone system was tested using 0.1 ppm H_2S-air standard gas. Solution samples containing S^{2-} were obtained in a short time and analyzed by the methylene blue absorption spectroscopy method. As a result, a 0.67 mg/L concentration of S^{2-} was obtained when using 0.01 mol/L NaOH solution.

1) Using the Mist-Cyclone system, a huge contact surface between H_2S-air gas and NaOH solution was realized, affording a very effective mass transfer process for obtaining S^{2-} solutions.
2) A sufficient level of H_2S (or S^{2-}) could be obtained in solution samples in a short time (approx. 6 min.) to allow measurement by a conventional sensing device.
3) A pipe inspection robot that can measure H_2S and detect the exact location of a H_2S source at low concentrations in sewers can be implemented using the Mist-Cyclone system in combination with an electrode sensor.

The next step of this study is to install a highly sensitive H_2S sensor at the outlet of the Mist-Cyclone system for field tests in an actual sewer line.

4. References

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