Research on Next-Generation Technologies for Improving the Safety of Gas Pipelines

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1. Background

City gas is supplied through a vast pipeline network. The effective maintenance management of the pipeline network, while ensuring adequate safety, is an important issue to meet societal needs for a safe and stable supply of city gas.

The city gas industry has continued to take measures to develop various technologies to improve the current level of safety. However, in order to cope with the extremely strict societal recognition that has been seen in recent years for gas safety, such as dealing with accidents due to unavoidable, external causes which accompany with other construction works, it has become necessary to achieve a breakthrough by the introduction of new technologies based on an approach that differs from a mere extension of traditional methods when investigating the future direction of technological development.

2. Abstract

In this project, we carried out an extensive investigation into technology seeds that have the potential to contribute to the improvement of the safety and effective management of city gas pipelines toward 2030, which marks the next generation. This investigation focused on other industries that until now have been unrelated to the gas industry. Technologies that appear promising were selected. Among these, technologies that were particularly promising from the viewpoint of city gas suppliers were tested on sites where it was assumed that they would be introduced into the gas industry and sample assessments of these technologies were carried out. Figure1 shows the technologies tested for the sample assessments.

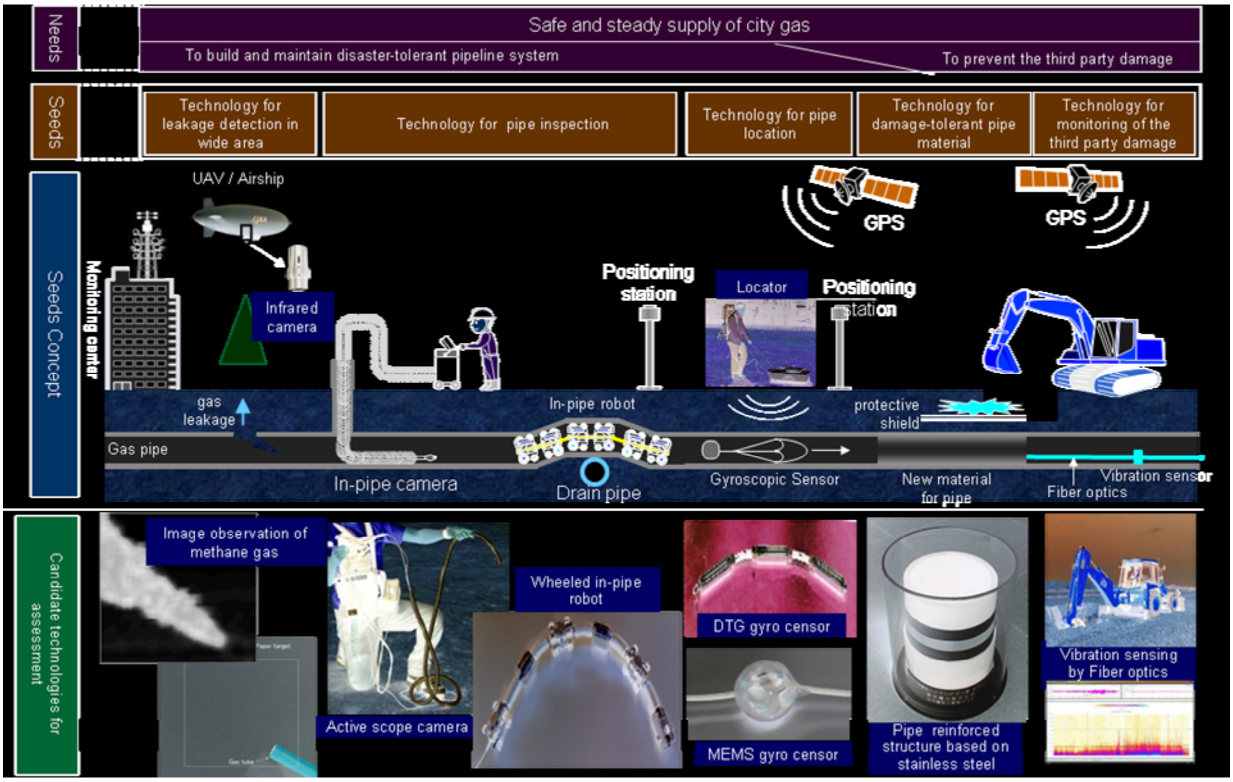

Fig.1 Technologies conducted the sample assessments

These results were evaluated from the technical and applicational aspects from the viewpoint of city gas suppliers. These results were then used to perform a selection and organization of element technologies that can be utilized for technical approaches for safety improvement. An elemental technology matrix table was then created. Figure 2 shows the frame of the elemental technology matrix table.

Evaluation items	Requirement specifications	Promising technologies			Current level	Comprehensive evaluation	Challenges
		1	2	3			
Objectives							
Principles							
Summary							
…							
…							
…							
Comprehensive evaluation							

Fig.2 Frame of elemental technology matrix table

In the near future, this table will be put to practical use with increasing demand in the gas industry, and it is expected to be fully adopted by the gas industry with the technological progress in the market. In this paper, we will introduce this project as a whole.

3. Research

Element technologies in the following five categories have been selected based on actual needs.

1. Robots that operate in pipes
2. Probes to detect gas leakages by aerial observation
3. Probes to detect accurately the locations, shapes, and dimensions of buried pipes
4. Pipe materials resistant to damage by third-party works
5. Monitoring systems to protect pipelines from third-party works

3-1. Robots that operate in pipes

It is expected that robots operating in pipes will be equipped with diagnostic functions in the future. Existing in-pipe robots were investigated. As to the propulsion mechanism, there are advantages and disadvantages depending on the pipe diameter and so the applicable diameters were divided into large and small diameters. With large diameters, attention was focused on the mechanism of in-pipe wheeled propelling device[1)] that presses the inside surface of the pipe through air pressure to avoid slipping. With small diameters, attention was focused on the mechanism of the active scope camera[2)] that obtains propulsive power via the supply of oscillations to cilia that cover the surface of the device.

Robots were run through pipes which simulated large-diameter and small-diameter buried gas pipelines, and the running performance was assessed. A horizontal elbow pass experiment was conducted to find the limit of the number of elbow passes in horizontal direction. Likewise, a vertical elbow pass experiment was performed to find the limit of the number of elbow passes in vertical direction.

With the in-pipe wheeled propelling robot, it is generally expected that around 20 bends can be passed in the horizontal elbow pass experiment. However, it was found that there was a large impediment depending on the condition inside the pipe, such as dirt, dust, and differences in the welding line. Moreover, as a result of the vertical elbow pass experiment, it is expected that about 15 bends can be passed fewer than in the case of the horizontal elbows because the robot must have the additional capacity to climb vertical pipes. Since there is sufficient attractive force in the robot by pulling a high-capacity battery and mounting a device which records the inspection results instead of having to pull a cable, it enables real-time monitoring. It is also possible to reduce the restrictions on the distance travelled due to the traction load. This is a promising technology with the potential to expand the range of use by customizing the robot to suit the purpose and operating procedure. However, in case the robot does not pull a cable, it is important to establish an extraction method if the robot should break down inside the pipe.

On the other hand, with the active scope camera, it was confirmed that with the exception of the vertical elbow pass experiment, an even greater number of bends could be passed than with the in-pipe cameras currently used by gas suppliers. Moreover, it was learned that in climbing vertical pipes, because no propulsive power is obtained from the active unit, passing bends after that becomes difficult. Although an optimization study on the passage through a pipe was not conducted, it confirmed the robot's capacity to pass through a number of elbows. Even the current in-pipe robot technology has many elements, by which it is possible to make further improvements in pipeline inspections and maintenance. However, even more compact and higher-output motors will have to be developed in response to the need of streamlining the external form of the robot.

3-2. Probes to detect gas leakages by aerial observation

Probes to detect gas leakages by aerial observation were investigated for promptly detecting gas leakages over a wide area after a disaster. Attention was focused on the technology to detect methane gas by using laser light[3)] and also on the technology to detect methane gas from remote distances with infra-red cameras[4)].

An intense examination to evaluate the minimum concentration of city gas and an examination at a distance to evaluate the range of the minimum detection of city gas during a disaster were conducted.

In principle, the technology to detect methane gas using laser light has been well established, but reproducibility has not yet. In this experiment, although it was not possible to reproduce the oscillation and detection of the laser light, optical parametric oscillators and differential wave technology are developing the applicability of the wavelength used in this experiment every year. A sound basis is being formed toward commercialization with higher outputs as well as more stable and more compact technology. Theoretically, the gas detection performance can become extremely high by combining sum frequency conversion technology, which transforms detected signals into simple and short wavelengths, with cutting-edge infra-red light source technology. In the future, instead of the performance varying with ambient temperature and background conditions as with passive systems, gas imaging systems which are less affected by the measurement environment will be realized.

The infra-red camera detects the infra-red rays emitted from a material, the wavelength differing with the temperature of the material, so that in the case of a background with low temperature, such as bad weather, soil, vegetation, water, moisture and cold regions, the camera's performance lowers. This means that the range of use is limited. A study of the identification of city gas leakages becomes important because of the effect of infra-red rays that emit gas (e.g. heat source ventilation) where there are differences in temperature. In particular, in the event that a great number of fires occur in a large-scale disaster, whether or not it is possible to distinguish between the heat and smoke of the fires and city gas leakages becomes a vital problem. In principle, in passive infra-red gas detection systems, dealing with the above problem is difficult. However, if it is possible to perform imaging not only with just the wavelength absorption band but also in the sensitivity mode, the effects of the heat source can be reduced.

3-3. Probes to detect accurately the locations, shapes, and dimensions of buried pipes

Specifying the exact locations, shapes, and dimensions of buried pipes not only increases the efficiency of excavating work but also prevents damage during excavation. Here, the technology to locate buried pipes from above the ground and inside the pipe was investigated.

3-3-1. Probes to detect buried pipes from above the ground

Probes to detect buried pipes from above the ground were investigated, focusing on the latest radar locators. The locators currently used by gas suppliers transmit electromagnetic wave impulses and visualize the signals reflected by buried pipes. However, attention was focused on (1) devices that use the GPS and link absolute coordinates, putting them into 3D form and also on (2) those that use continuous waves, not impulses in waveform. The former is the 3D Ground Penetrating Imaging Radar (3DGPR)[5)]. The latter is the Optimized Radar for Finding Every Utility in the Street (ORFEUS)[6)].

An assessment of these two types took place in the form of a comparison with locators owned by gas suppliers in simulated fields with multiple buried pipes with different applications.

The ORFEUS demonstrated a locating performance comparable with that of the locators now used by gas suppliers. Compared with images displayed by regular locators, because the 3DGPR changed images into 3D, it was easier to visualize the convergence, or congestion, of buried pipes.

The locating technology currently used by gas suppliers is at a high level called the pulse wave transmission system, so that the machines sampled for assessment were equally good in exploration performance. However, there are new technologies in the Stepped Frequency Continuous Wave (SFCW) transmission system of the ORFEUS and the 3D display of the 3DGPR. It is possible to expect further developments in these systems. The ORFEUS was at a stage where the technological development project had finished in the previous year. Further improvements are continuing toward commercialization and it is believed that its locating accuracy and operability will be improved due to advanced signal processing. There is a good prospect for 3D imaging technology creating and utilizing absolute coordinates, which is a feature of the 3DGPR. There is a possibility to construct a more advanced locator that has both improved performance and accuracy, by combining the 3D imaging technology with a high-performance locator. In particular, it is believed that this combined function will become very important when it has become necessary to compile a database on objects that have been laid underground.

3-3-2. Probes to detect buried pipeline shapes from inside the pipe

Probes to detect buried pipeline shapes from inside the pipe were investigated with emphasis on position sensing technology using a gyroscope. A large mechanical gyroscope (DTG)[7)] was used in large-diameter pipes and a compact MEMS gyroscope[7)] was used in small-diameter pipes.

Gyroscopes were run through pipes which simulated the shapes of large-diameter and small-diameter buried gas pipelines, and route measurements were taken.

It was found that if gyroscopes can be run through pipes, it is possible to detect the shape of the pipeline and if they can be run through pipes smoothly, high measurement accuracy can be obtained. Further, cases were found where the gyroscope recognized wrong angles and directions when it received a large impact from differences in levels in the pipes while being run through them and also due to becoming unsteady from sudden changes in approach and back tension.

If higher capacity of batteries is achieved, there is a high possibility of further miniaturization of the gyroscope. Then, the ability of gyroscopes will be improved, followed by an increase in measurement accuracy. Moreover, error correction will be possible with map information from the GPS network adjusted for high precision and through the use of the absolute coordinates of the current location. In addition, the planned launch of the Quasi-Zenith Satellite System is expected to enhance the accuracy of the GPS. This system, combined with the above technologies and the development of software specialized in the applications by gas suppliers, is expected to see a further increase in measurement accuracy. This is a promising technology with the potential to expand the range of intended use for the improvement of pipeline safety in the next generation by combination with in-pipe running robots mentioned in 3-1.

3-4. Pipe materials resistant to damage by third-party works

Pipeline damage by third-party works is increasing with the wider use of polyethylene (PE) gas pipes. In this category, pipe materials that are resistant to damage by thirty-party works were investigated as a method to prevent third-party damage with attention to materials already used for other purposes.

Pipes for underwater cables, water service and agricultural use, both multiple-layer and single-layer types, were selected for the test. A protective material was also selected. Heavy machinery used on construction sites was employed and push, shock, and scratch mode tests were carried out by simulating the working mode of heavy machinery.

The PE100, which is widely used in waterworks systems, ha d some advantage over the PE80 against scratches. Nylon pipes, which have proven results as gas pipes overseas, demonstrated a high resistance to pressing and scratches by heavy machinery. Pipes made of composite materials and reinforced with fiber and steel bands withstood pushes, shocks, and scratches. The wrapping protective material around the PE80 pipe prevented damage by heavy machinery just as composite pipes did.

The PE80 is currently used for gas pipes in Japan and it combines superior performances in earthquake proofing, corrosion resistance, chemical resistance, flexibility, workability, reliability, and economic efficiency. Therefore, when investigating the introduction of new materials, it is important to look at the scope and method of introducing a combination of existing and new materials from a long-term perspective, comprehensively taking into account the other assessment items in addition to these sample assessment results.

In addition, there are plans to utilize these sample assessment results as expertise in future investigations of supply infrastructure where safety and reliability have been further enhanced toward the hydrogen society that is expected to arrive in the near future.

3-5. Monitoring systems to protect pipelines from third-party works

Systems that monitor the pipes damaged by third-party works were investigated, focusing on security technology using optical fibers for intrusion detection. Attention was paid to optical fibers to detect the transmission of vibrations and sounds to pipes in order to detect other construction works going on without prior notice[8)].

In fields where optical fibers have been laid underground, civil engineering work accompanying with other construction works was also simulated. The detection performance against occurrences with a risk of damage to pipelines was thus confirmed.

There is a great deal of vibration in the initial stage of road construction work, such as removing asphalt by cutters and heavy machinery, and it is highly likely that such vibrations will be reliably dealt with even in areas with a heavy traffic of vehicles, because the engine noise of heavy machinery is greater than the vibrations due to the passage of vehicles. This will make it possible to judge if the excavation work by heavy machinery will have any unfavourable effect on gas pipelines.

As a method to detect vibrations, this technology has already been basically completed, and what remains to be done is how promptly and accurately to analyze the detected signals for reliable diagnosis of pipeline conditions. Accumulation of data by technological breakthroughs and their application to the gas industry and possibly to other industries will improve this soft technology. The fibers installed for detection are still few, and if fibers owned by the communication industry can be used also for gas pipelines, it will help to construct a comprehensive infrastructure monitoring system.

4. Conclusions

As explained above, promising elemental technologies in five categories that had been selected from other industry were selected. Sample assessments were carried out in the field where gas suppliers would introduce these technologies and their capabilities were confirmed. The results are as follows.

In general, the elemental technologies which have already been introduced in other industries have reached a high level of maturity and it was found that there were several technologies which seemed to have a potential to be deployed in the gas industry through further refinement. Furthermore, because of the nature of these improved technologies, it was not necessary to specify only particular uses for their introduction into the gas industry and it was confirmed that when adopting these technologies for multiple purposes, it would be possible to expect the same degree of sophistication and innovation within the gas industry as elsewhere.

On the other hand, several elemental technologies were evaluated that had not yet to be introduced into any industry. They were still at various stages of development, and it was hard to imagine their introduction into the gas industry without further breakthroughs and refinement. The first step would be the introduction of these technologies into the industries that are already planning to adopt them, followed by gas suppliers.

Among the elemental technologies that were assessed, although there were not yet sufficient specifications ready for use in 2030, when the introduction of innovative city gas distribution technologies is anticipated, several technologies excelling those already in use by gas suppliers were confirmed. These seed technologies need further progress to comply with the 2030 specifications but are attractive technologies that are worth investigating for adoption by the gas industry.

The elemental technology matrix table that has been created in this project records the investigative challenges to arrive at the new specifications for realization in 2030. Along with this, we anticipated as much as possible the year of development completion of each elemental technology that was extrapolated from technological strategy maps and similar surveys published every year by the Ministry of Economy, Trade and Industry in Japan as an outlook for future technologies. By utilizing this matrix table and observing the technological trend in the market, it is now possible to predict the time when the renewed age of gas distribution technology will begin.

Through the implementation of this project, it will be possible to look ahead at the buds of technology that will contribute to improved safety of gas pipelines in 2030. This project addressing an extensive overview of technologies with possible application to gas pipelines is a major achievement for the gas industry.

In addition, this project was ended in 2010. From 2011, it is cooperation of several companies among the gas utilities who were taking part in this project, and goes into examination towards developing two kinds of technology estimated that the completeness of seeds and needs are great.

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6. Remarks

This is a national project, which has been commissioned by the Ministry of Economy, Trade and Industry to the Japan Gas Association from 2008 to 2010.