Pipeline Diagnosis through Examination of Water Quality Degradation

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ABSTRACT

Pipelines are a major constituent of overall water facilities assets, and proper renovation and replacement of aged pipelines is an essential requirement for maintaining a sustainable and stable water supply. The current study aims at developing a method for evaluating the deterioration of the inner surfaces of pipes as one of the technologies for function diagnosis of pipelines, using index factors of water quality changes such as reduction of residual chlorine concentration.

The reduction of residual chlorine in drinking water is influenced by factors such as water quality and purification methods. Within the pipe, variables such as the condition of the internal surfaces and detention time come into play (Japan Water Research Center 1999). The current research uses a number of field tests on actual pipes to test these factors. In particular, it was established that hydraulic conditions such as the flow velocity (detention time) as well as the presence or absence of lining inside the pipe have a major impact on residual chlorine concentration.

The current paper is an interim report for a study that is one of the major projects implemented by the Japan Water Research Center, started in 2005 and scheduled to run for a period of three years.

KEYWORDS

Pipeline; pipeline diagnosis; residual chlorine; water quality degradation

INTRODUCTION

An important aspect of water pipelines is their water quality maintaining function. Aging of pipes and other factors will cause a pipeline to gradually lose this function, leading to water quality degradation, which eventually requires pipeline replacement or improvement. For hygienic reasons and to reduce effects on the environment, it is important that these activities are planned properly and optimized for maximum efficiency. However, because most pipelines are buried underground, grasping the degree of deterioration is not an easy task. Consequently, the development of methods to diagnose the degree of aging of pipelines, involving an overall diagnosis and assessment of the loss of pipeline functionality and the state of deterioration of internal and external pipeline surfaces, and elemental technologies in this regard is highly desirable. The diagnosis and assessment would be based on decreases in R-Cl (residual chlorine) in the pipelines and the degree of deterioration in water quality including the presence of suspended solids.

The current study will examine methods for diagnosing and assessing the state of deterioration of internal pipe surfaces with changes in water quality such as decreases or disappearances of residual chlorine as a major indicator. It aims at development research on technologies for the overall functional diagnosis of pipelines, combining this with existing physical assessment methods. This will allow water utilities to efficiently plan their renewal strategies by establishing priorities keyed to the degree of deterioration in the pipes.

In 2005, JWRC started the current study which is part of so-called New Epoch Project. The project is a joint research venture with participants from three sectors; namely, industries, water public utilities, and academies. This is scheduled to run for three years, aiming at developing diagnostic and evaluative methods for pipeline facilities. There are two main topics. The first is, “Research on water-quality deterioration in decrepit pipelines and preventive measures”.
Using the reduction of R-Cl in pipes as an index, a measurement method for determining the degree of deterioration is being developed (Fujiwara et al. 2007b).

The second topic is, “Research on diagnosis technology for decrepit pipelines”. This is aimed at developing new methods for evaluating the aging condition of buried pipes with minimum excavation using impact elastic waves, sound waves, and electromagnetic waves (Fujiwara et al. 2007a).

METHODS
In order to evaluate the current situation with regard to the influence of aged pipelines on water quality, a preliminary study which takes the form of a questionnaire survey as well as a document survey was carried out.

Preliminary study

Questionnaire survey. To collect information on decrepit pipeline and water quality degradation, JWRC sent out a questionnaire to 332 water utilities. Out of this target group 195 utilities, or 58.7 percent, provided a response. Some of the main points that emerged from the survey are listed below.

• Almost 30 percent of respondents listed turbid water (red water) caused by rust, and 10 percent listed sand and other impurities as the major source of complaints. Regarding the countermeasures taken in response to complaints, draining and flushing were at the top of the list with about 80 percent.
• About 40 percent of the respondents answered that reduction of R-Cl was noticed.
• More than 60 percent of the respondents gave detention of water in the pipes as a cause for the reduction of R-Cl. Only about 30 percent listed deterioration of pipes as a cause.

Document survey. In order to explore the mechanism of R-Cl reduction in pipes, the document database JSTPlus was used, searching for the keywords "residual chlorine" and "pipeline". Out of 335 retrieved records, 46 were selected as relevant to the topic of this study. Some of the main points that emerged are listed below.

• Materials that are preferable with regard to low R-Cl consumption are, in descending order of desirability: (1) epoxy-resin lining pipes, polyethylene pipes, stainless steel pipes; (2) mortar lining pipes, polyvinyl chloride pipes; and (3) no-lining iron pipes (Matsumura et al. 2002). With aged pipes, chlorine consumption is higher than with new pipes, and small-diameter pipes (in particular below 300 mm) have notably higher chlorine consumption.
• Laboratory experiments with no-lining iron pipes showed that chlorine consumption is higher when mixing is performed, as compared to the stationary condition. At higher temperatures, in particular above 20 degrees centigrade, chlorine consumption increases notably. (Fuchigami et al. 2005).
• Compared to the conventional treatment process involving intermediate chlorination, treated water using ozone and granular activated carbon has lower chlorine consumption (Fuchigami et al. 2003). This is due to the lower level of organic matter in such water. A favorable correlation exists between the concentration of dissolved organic carbon and potassium permanganate consumption which are indexes of organic matter, and R-Cl reduction coefficient.
• Adjusting the Langelier's index is effective in controlling water quality degradation, which points to the possibility that it could be beneficial also for controlling chlorine consumption (Funahashi 1999).

Procedure of research

From the results of the preliminary study, the following points emerged.

• Factors that affect the consumption of R-Cl are type of pipe (material, diameter, etc.), flow condition (flow velocity, water temperature, etc.), and water quality resulting from purification methods.
• By adjusting the Langelier's index, a film of calcium carbonate can be created in the pipe interior that helps to prevent water quality degradation.

Based on the above considerations, the current study has adopted the steps listed in Figure 1 below. The
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The aim is to develop a method for diagnosis and evaluation of pipe function focused on water quality in aged pipes, hydraulic conditions, pipe material, burying period, and pipe interior degradation status.

**Step 1**
With regard to aged pipe facilities owned by water utilities, investigate the relationship between defined factors (water quality, hydraulic conditions, pipe material, burying period, pipe interior degradation status) and residual chlorine reduction as well as the incidence of problems due to turbid water (such as iron rust quantity).

**Step 2**
Based on the investigation results of step 1, explore methods that utilize the reduction in residual chlorine to assess the degree of influence that pipe aging has on water quality and that allow diagnosis and evaluation of the internal pipe condition.

**Step 3**
Develop overall method to diagnose and evaluate of pipe function using the existing evaluation methods for pipe aging and earthquake resistance in addition to the above water quality based evaluation method.

**Fig. 1 Research Procedure**

**RESULTS AND DISCUSSION**
According to the procedure step 1 in Fig.1, an investigation was carried out. The results were reported below.

**Relationship between water quality and R-Cl reduction**
To examine how differences in water quality affect R-Cl reduction, test samples from seven water utilities with different water sources and purification methods were used, and the changes over time of R-Cl concentration and other water quality factors were measured. The water-source categories were river water, ground water, and dam water. The purification methods were water treatment using ozone and granular activated carbon, rapid sand filtration, slow sand filtration, and chlorination alone. Besides R-Cl concentration, the examined water quality items were turbidity, pH, TOC, conductivity, iron, and manganese.

**Fig. 2 k Value (Residual Chlorine Concentration Reduction)**
Figure 2 plots the change in R-Cl concentration over time. The trend can be expressed by the reaction equation of the first order given in the figure (Hashimoto et al. 1996). When R-Cl concentration drops significantly, the value of k becomes large. Conversely, when the reduction in R-Cl concentration is slight, the value of k is small.

Looking at the variation in k value depending on water quality (water source, purification method), the highest value of 0.0115 was measured for city M with ground water/chlorination, and the lowest value of 0.0043 for city N with river water/rapid sand filtration.

**Relationship between pipe material and R-Cl reduction**

To investigate this aspect, an experiment using samples of no-lining grey cast-iron pipes* and mortar-lining steel pipes taken from buried pipelines as well as five different new-material pipes was carried out. The sample pipes were filled with solvent water with adjusted pH, R-Cl and alkalinity, and the changes over time of R-Cl concentration and other water-quality factors were measured.

* Inner surface of the pipe was coated with liquid tar-epoxy resin when manufactured.

When looking at the change in R-Cl concentration over a period of 24 hours, the results for different internal surface materials showed that with the no-lining gray cast-iron pipe, the R-Cl was completely used up, while the mortar-lining steel pipe had an R-Cl concentration of 0.3 mg/L at the end of the period.
The new-material pipes showed almost no drop in R-Cl concentration.

A calculation of the k value for pipes taken from actual installations yielded 2.0717 for the no-lining gray cast-iron pipe, which means that the rate of chlorine reduction is extremely high. The k value of 0.0144 for the mortar lining steel pipe on the other hand is very close to the maximum value of the Water-Quality-Dependent k value. When a pipe is provided with a lining, the rate of reduction in R-Cl concentration remains comparatively low, even if the pipe is a number of years old.

**Relationship between hydraulic conditions in pipes and R-Cl reduction**

For this topic, actual pipeline in city Y was examined before and after renewal. The pipes before renewal were no-lining gray cast-iron pipes with diameter of 200 mm and a length of 277 meters. The year of construction was unknown. The pipes after renewal were ductile cast-iron pipes with mortar lining, having diameter of 100 mm and laid in the year 2006. In this particular pipeline installation, low water demand during normal operation hours meant that the flow velocity dropped, immediately creating a detention condition. This was the reason why the diameter was downsized to 100 mm.

For the experiment, fire hydrants upstream and downstream of the examined pipeline were used to install hydraulic and water-quality monitors. Items including flow velocity, water pressure, R-Cl concentration, and suspended solids were measured continuously for about one week. Besides the "normal flow" condition, a "controlled flow" condition was established, with valves in the vicinity operated to create a one-way flow. Additionally, drainage was used at the pipeline end to allow the flow velocity to be set to 5 and 10 centimeters per second.

The experimental results of pipeline in city Y before renewal showed a maximum reduction of 0.27 mg/L between the upstream and downstream point in the normal condition, with a flow velocity of 1 to 2 centimeters per second. In the controlled flow condition, chlorine concentration, which was 0.57 mg/L at the downstream point, dropped to zero in 27 hours. When the flow velocity was set to 5 cm/sec using drainage, the maximum reduction between the upstream and downstream point was 0.08 mg/L. At a flow velocity of 10 cm/sec, there was almost no reduction.

With no-lining gray cast-iron pipes, when detention occurs, the rate of R-Cl reduction is high. When the flow velocity is around 10 cm/sec, the rate of R-Cl reduction is comparatively low. This allows the conclusion that the R-Cl concentration within a pipeline is affected not only by the internal pipe condition but also by hydraulic factors such as flow velocity.
The measurements undertaken after the renewal show that in the normal condition, the R-Cl reduction, which had been as much as 0.27 mg/L between the upstream and downstream point before the renewal, now was almost non-existent. In the detention condition, chlorine concentration dropped from 0.68 mg/L at the downstream point to 0.57 mg/L even after four days, whereas before it had dropped to zero in 27 hours. In the controlled flow condition, the k value was 0.0056, which is close to the Water-Quality-Dependent k value of 0.0045. When the flow velocity was set to 5 and 10 cm/sec using drainage, the R-Cl concentration showed almost no drop between the upstream and downstream point.

Replacing no-lining gray cast-iron pipes with mortar lining ductile cast-iron pipes resulted in a significant improvement of pipe-material-dependent R-Cl reduction values.

The relationship between flow velocity in the pipe and k value is shown in Figure 7. With no-lining gray cast-iron pipes, the k value becomes large when detention occurs, but the higher the flow velocity, the smaller the k value.

The k value for pipes with internal lining did not vary much with flow velocity, and was at about the same level as the Water-Quality-Dependent k value.

**CONCLUSIONS**

The following results were obtained from the field tests with existing buried pipes.
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- Reduction of R-Cl concentration due to water quality has been confirmed as being connected with both the quality of source water (i.e. kind of water source) and the method of purification.
- Reduction of R-Cl concentration in pipelines is affected by the presence or absence of lining on inner surface, and also changes significantly depending on hydraulic conditions such as flow velocity.

A topic for future research is the establishing of methods for evaluation and diagnosis of deterioration in pipes based on water quality degradation such as R-Cl reduction. Besides the measurement of R-Cl concentration, the field tests using actual pipes also included a capturing survey of suspended solids. Using the results of this survey, diagnosis/evaluation methods of the internal condition of pipes from the amount of captured substances is being investigated.

REFERENCES