The 15th International Symposium on District Heating and Cooling
September 4-7, 2016, Seoul, Republic of Korea (South Korea).

ADVANCED MONITORING TECHNOLOGY FOR DISTRICT HEATING PIPELINES USING FIBER OPTIC CABLE

Sukyong Song[1], Jooyong Kim[2]

[1] AP Technologies Inc, 1213, 21, Yangpyeong-ro 22-gil, Yeoungdeungpo-gu, 150-105, Seoul, Korea

[2] KDHC, 781, Yangjae-daero, Gamgnam-gu, Seoul 135-220, Korea

Keywords: Monitoring system, District heating, Fiber optic cable, Leakage Detection, Code correlation technology

ABSTRACT

District heating is an efficient system that transports hot water produced from heat sources such as heat plants, waste incinerators, etc. The heated water can then be used for heating and hot water needs in apartments or large buildings. A district heating pipe is a sandwich construction consisting of a steel carrier pipe, a polyurethane insulation, and a high-density polyethylene casing to protect from the condition of installation and operation also to prevent heat loss.

Heat pipes should be monitored for leakages; in case they are damaged or become old. District heating pipes are designed to use a leakage detection system inside the insulation. However, most detection systems cannot adequately identify the exact location or the extent of damage of a leak, which can lead to expensive repairs.

In this study, a fiber-optic based monitoring system is used to monitor the status of the buried district heating pipelines, with the results verified by evaluation tests and field applications.

An optical fiber acts as a temperature sensor. A low-powered semiconductor laser sends pulses along the fiber. By using code correlation technology, the back-scattered light is measured, If a leakage occurs the change in temperature can be located to within 1 meter in real time.

This study confirms that the fiber optic sensing performance in a variety of locations and conditions can quickly and accurately identify leakages. As a result, the fiber optic monitoring system was confirmed to accurately detect the temperature near the ground in accordance with the pipe above.

By locating leakages quickly and accurately, the correct safety and repair measures can be taken quickly, keeping damages and repair costs low.

INTRODUCTION

Heat transfer pipe buried underground can have degradation due to its heat shock and pressure occurred over long period of time. Degradation also can come from external geological changes and vibrational stress. It is visually challenged to examine the level of degradation underground. Thus, importance of separate sensor installation is increasingly recognized to prevent the incidents. In general, degradation becomes an issue at connection areas. When the HDPE connection is damaged, exposed internal insulation (Polyurethane foam) begins to be melted with penetration of external fluid. If it were exposed to degradation for long, it would accelerate the aging speed, ultimately causing damage to steel pipe. If steel pipe (primary pipe) were deteriorated, high heat and pressure from it would be exposed to over ground, leading to significance consequences. In deed, there actual cases have been reported. To prevent such cases, it intends to make the database to expect the possible damage area for repair.

BACKGROUND

The monitoring technology for this research is based on DTS (Distributed Temperature Sensing) instrument which is optimized and certified for measuring temperature over distance. This system utilizes Raman-effect which was discovered 90 years ago by C.V. Raman, Indian physicist. [1] This phenomenon is that the light is reflected changes in wavelength. [2]

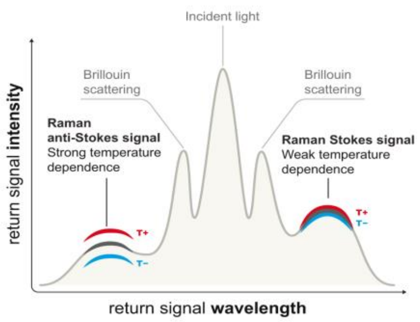

Figure 1. Distribution of laser reflection scattered light

$$\frac{Ias}{Ia} \propto \exp\left(-\frac{hcv}{kT}\right) \quad (1)$$

Ias: intensity of Anti – Stokes light
Ia: intensity of stokes light

The backscattered light is spread across a range of wavelengths. Some of these wavelengths (Stokes and anti-Stokes scattering) [2] are affected by temperature changes while others are immune. Their ratio depends on the temperature (which can practically be exploited for the measurement of temperature).

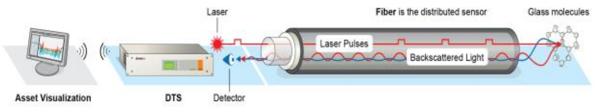

Figure 2. Conceptual diagram of DTS temperature and distance measurement

By very accurately measuring the difference in the signal intensity of the backscattered light an accurate temperature measurement can be made. [3]

$$x = c \times \frac{t}{2} \qquad (2)$$

c: Speed of light in an optical fiber$(2 \times 10^8 m/sec)$ [5]

SYSTEM DESIGN AND STRUCTURE

Feature of heat transfer is to find thermal equilibrium. And the process of heat transfer involves conduction and convection. For heat transfer occurred underground, it largely depends on conduction, which take long time to transfer heat, as there is almost no convection. Heat generated from damaged heat transfer pipe is conducted via soil media as described in the following equation.

$$q = kA\frac{T_1 - T_2}{L} \qquad (3)$$

It is possible to install the optical sensor cable for heat transfer line underground directly for two to fifty kilometers. It is possible to measure the thermal change and indicate the temperature by length. Thus, it is ideal to use a DTS system to monitor distinct pipes. In particular, DTS systems and the passive optical fiber have very long lifespans and are basically maintenance-free.

OUTLINE OF TEST

We bury two heat transfer pipes 1.5 m under the ground while diameter of one pipe is of 300A[3] and the other 150A[4] just same as the typical structure. To measure the heat source release by damage type, we did similar damage to the connection areas of pipes. Optical sensor cables which were coiled over perforated drainpipe with helical shape of 0.1m installed over the top of the heat transfer pipes vertically to measure and analyze the vertical heat transfer. In order to test detection performance during heat sources release of heat transfer pipe, sensor cable was also installed in depth with 0.5m, 1m, and 1.5m from the surface along the burial route.

The test described above is performed to verify the efficiency of new heat transfer pipe installation and validity of optical sensor cable installed over the existing heat transfer pipe.

[3] 300A: HDPE O/D-450, Insulation-434.4, Steel-318.5/ (mm)

[4] 150A: HDPE O/D-250, Insulation-242, Steel-165.2 / (mm)

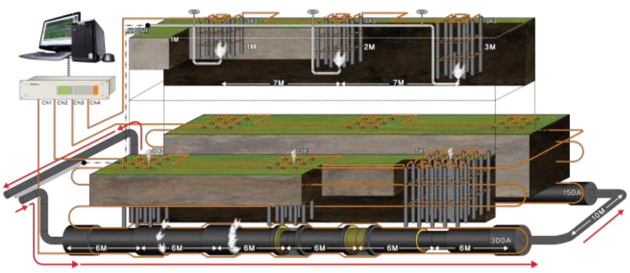

Figure 3. Test setup diagram

TEST EQUIPMENT

1. DTS (Distributed Temperature Sensing)

   Manufacture: AP Sensing

   Model: Linear Power Series N4385B 4Km 4Ch

   Spatial Resolution: 0.5m

   Sampling Interval: 0.25m

   Measurement time: 60sec per channel

2. Fiber Optic Cable Sensor

   50/125 ㎛ /Multi-mode Fiber and special designed cable (Single-end configuration)

TEST CONDITION

✦ Heat source supply condition

1. Heat source temp: water at 95 ℃
2. Supply pressure: 5.81gf/cm2
3. Return pressure: 5.18kgf/cm2

✦ Damage conditions of heat transfer pipe

To differentiate the heat quantity of source, it sets 3 different sizes for damages and two for insulation damages.

Table 1. Failure scenarios of heat transfer pipe

Part / Damage	①	②	③	④	⑤
Insulation material	100%	50%	100%	100%	50%
Connection damage	PE 100%	PE upper	PE upper	Sleeve gap	Sleeve gap

*Damage on upper area: 280(W) x 110mm(L) cutting

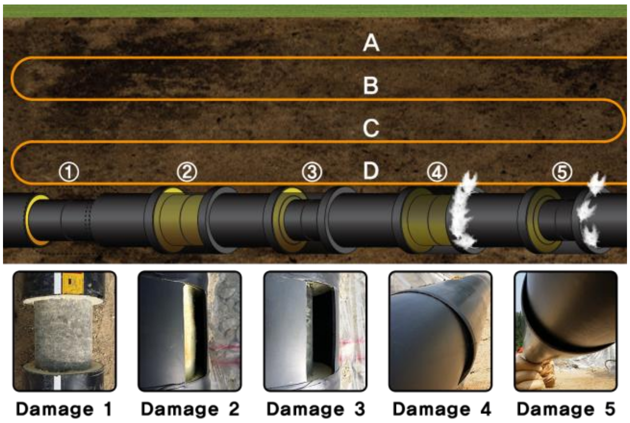

Figure 4. Image and picture of regular damage of heat transfer pipe

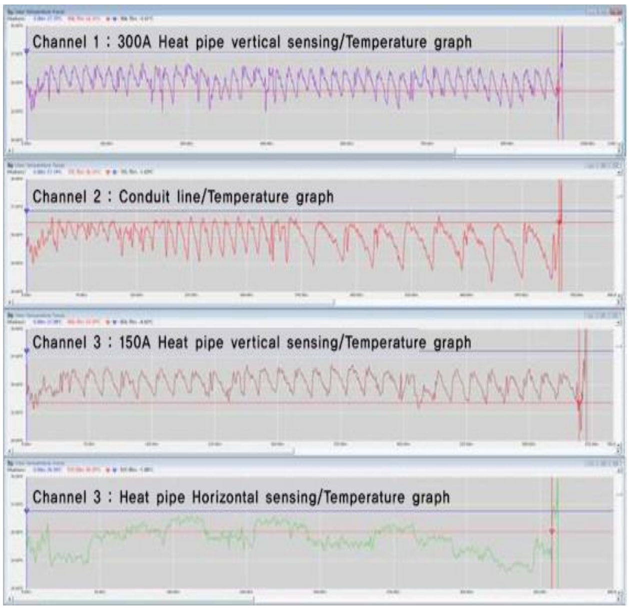

Figure 5. Raw data screen of whole area after installation

As indicated in the feature above, the test result shows that the performance of optical cable sensor is good regardless of horizontal or vertical, and size of heat transfer pipe. The reason why upper 3 graph patterns are different from lower 1 pattern is from installation method. (Upper 3 are installed at 0.1m in perforated pipes in helical shape to do monitoring in triangular wave while lower 1 is installed on tope of heat transfer pipe in a lineal way to do monitoring in horizontal wave.)

Table 2. Test result of temperature

	PIPE SIZE	Jan/ 27th	Feb/3rd					
			*[4]	①	②	③	④	⑤
A[5]	150A		2.3	4.9	3.1	3.5	3.4	3.3
	300A		2.3	5.4	3.6	5.7	3.7	4.5
B[6]	150A	6.1	4.8	8.4	6.9	7.9	6.8	6.3
	300A	6.1	4.8	9.8	7.3	11	9	7.4
C[7]	150A	7.8	7.6	15	10	15	11.4	9.6
	300A	7.8	7.6	19.3	11	21.1	13.8	11.2
D[8]	150A	9.3	9.4	42	18.5	42.7	36.1	19.5
	300A	9.3	9.4	53.3	18.4	56.5	36.7	20

[4] Normal underground temp. (outer temperature measures by Meteorological administration: 0.6℃)

[5] A: underground 0.1m (above heating pipe 1.4m)

[6] B: underground 0.5m (above heating pipe 1m)

[7] C: underground 1m (above heating pipe 0.5m)

[8] D: underground 1.5m (above heating pipe 0m)

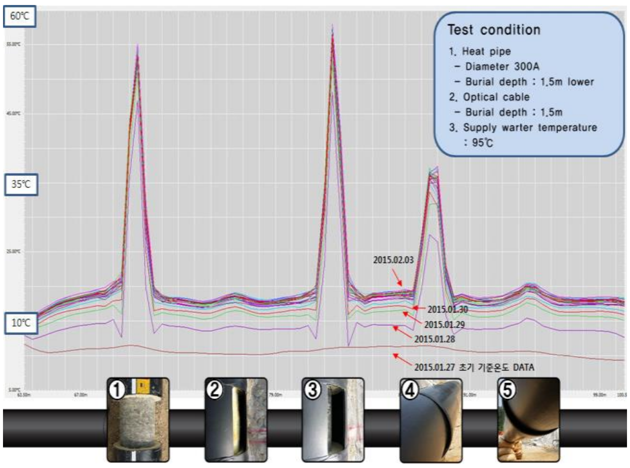

Figure 6. Setting of pipe damage_ temperature trend in time (1 week)

Table 3. Temperature trend over time (1.5m depth)

Date / Temp	①	②	③	④	⑤
1/27	9.3℃	9.3℃	9.3℃	9.3℃	9.3℃
1/28	50.1℃	15.5℃	51℃	30.1℃	16.7℃
1/29	51.4℃	16.3℃	52.9℃	31.9℃	17.5℃
1/30	51.6℃	17.1℃	54℃	33℃	18.3℃
1/31	52.1℃	17.4℃	54.3℃	33.8	18.7℃
2/1	52.2℃	17.9℃	55.9℃	35.5	19.4℃
2/2	53.2℃	18.4℃	56.7℃	36.2℃	19.9℃
2/3	53.3℃	18.4℃	57℃	37℃	20℃

Time consumed to transfer heat depends on the quantity of heat source and distance. It is expected the heat would disperse further as time goes by. However, within less than one day, the significant temperature changes are recorded for each failure mode during the test.

In other words, heat is estimated transferred by conduction not by convection.

For the purpose of this test, we created the condition of heat source as doing vertical and horizontal installation at the interval of 0.5m, 1.0m, and 1.5m on the top of heat transfer pipes (150A, 300A). And the test result is summarized in the table above.

As optical cable is wired close to heat transfer pipe, it is possible to get a relatively accurate temperature values. The bigger the outer diameter of pipe is, the higher the temperature goes. (In other words, compared to 150A, pipe of 300A is having proportionally larger insulation damage of pipe, so heat source turns out to be bigger.)

It means that the degree of insulation damage is more detrimental than the degree of external PE damage to heat source release.

It is expected that insulation damage without PE damage would release huge heat source. When both insulation and PE are damaged at the same time, it would pose a rick to not only heat source release but to safety related accidents.

CONCLUSION

To tell and identify the degree of degradation of heat transfer pipe, we regular damage heat transfer under 5 different conditions and analyse the temperature measured by optical sensor cable, which is installed on top of transfer pipe. By doing so, it is possible to determine correctly the degree of damage and its location of heat transfer pipe without visual check of heat transfer pipe.

Throughout the whole life span of heat transfer pipe from the initial burial, it is possible to monitor the heat transfer condition effectively through DTS using optical sensor cable. And it also allows us to have optimal maintenance. In addition, DTS helps us to secure and collect enough data for analysis. If collected and analyzed data through DTS develops into life span expectation program, it would dedicate to enhance the overall safety management system and the efficiency of heat transfer, and prevention of huge safety accidents.

ACKNOWLEDGEMENT

It develops a program to control risky areas through seasonal DB and alarm setting since installation. It also studies screen composition to control temperature boundaries and effective installation method.

In addition, it verifies heat source leakage test via measuring tube and on-site verification test (Bundang, Seoul) to proof the efficiency of supervising function of heat transfer pipe via optical sensor cable.

Medium of soil consist of aggregate, sand, fine sand, and clay. We couldn't test them under diverse conditions. It was impossible to analyze the degradation development with long term (longer than 1 year) environmental experimental data.

REFERENCES

[1] C.V Raman, Wikipedia, www.wikipedia.org, accessed October, 2015

[2] Raman Scattering, Wikipedia, www.wikipedia.org, accessed October, 2015

[3] AP Sensing GmbH, N4385B Linear Power Series User Guide, Edition 10, March 2015

[4] S.O.Kim, "The Status of Soil Temperature Observations and Their Climatology in Korea", Unpublished master's dissertation, Kongju National University, Korea(2004),pp.28-32.

[5] C.K.Lee, Y.S.Kim, M.M.Gu,B.G.Kim," Real Time Temperature Monitoring System Using Optic Fiber Sensor", published dissertation, Korea Society of Computer & Information, Korea(2010),pp.209-212.