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Enhanced Anti-Freezing Heating Cable Standard for Fire Prevention

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Abstract: Among the fire reports caused by seasonal devices registered with the Korea Fire Information Center in 2021, fires caused by heating cables accounted for the largest portion with 350 cases. As a result of analyzing the heating cable fires from 2015 to 2021, we have classified the heating cable fires into four types according to the method of winding the heating wire. First, we hypothesized that the temperature is high when the density is high due to the overlap of the hot wires or when there is a thermal insulating material. We predicted that the temperature would rise through a random game and established a reproducibility test plan. In order to check how heat generation changes depending on the winding method of antifreeze heating cables, we selected 10 manufacturers and checked the temperature characteristics according to the test conditions (Paragraph 11, Paragraph 19.101) of the Technical Regulations for Electrical and Telecommunication Products and Components of Korea (K 10013), tested the four methods mentioned in this thesis and compared and analyzed the results. The experiment results indicate that the temperature of the heater part in antifreeze heating cables was mostly higher than the conditions required by the existing standards in cases 1 to 4. In particular, in the case of No. 5 manufacturer's sample, the temperature of the heating cable of Case 1 was measured to be the highest at 119.0 °C. In addition, as a result of applying the data engineering reproducibility test results in the framework of the random game λ proposed in this thesis, we have derived the same results as the predicted hypothesis. Case 1 refers to the case where a fire occurs due to the heating cable being wrapped around the water pipe and insulation or taped outside; It is one of the methods that users actually use a lot in the field. Based on experiment, we have concluded that the fire risk is high under the Case 1 condition. Thus, the test conditions in the existing K 10013 Standard need to be strengthened according to the Case 1 condition.

Keywords: safety; fire; electric fire; fire prevention; deterioration of heater unit; data collection; anti-freezing heating cable; self regulating heating cable

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1. Introduction

Republic of Korea has four distinct seasonal climatic features, which result in a large annual range. The highest temperature in summer was 41.0 °C, and the lowest temperature in winter was −27.7 °C according to records by the Korea Meteorological Administration over the last 10 years (2011–2021). This climate characteristic has many advantages, but there are also many disadvantages [1,2]. In particular, the disadvantage can be fatal in the water and water grid, which is indispensable in human life. The volume increases when water freezes, and the increase in volume tends to destroy the water transport path, leading to a limited supply of water, which is essential to human life [2]. It can even affect individual happiness and cause great social and economic losses. Therefore, preventive measures are necessary. Prevention requires maintaining the temperature of the water transport path above a certain value. There are various approaches to it, but using anti-freezing heating cables can be considered a method that is easy to implement and cost-effective. However, the anti-freezing heating cables that convert electric energy into thermal energy can increase the risk of fire due to aging and faulty installation by the users. As shown in Figure 1, fires caused by heating cables were the most frequent among the fires caused by seasonal devices reported to the National Fire Information Center last year, followed by fires due to wood-fired boilers.

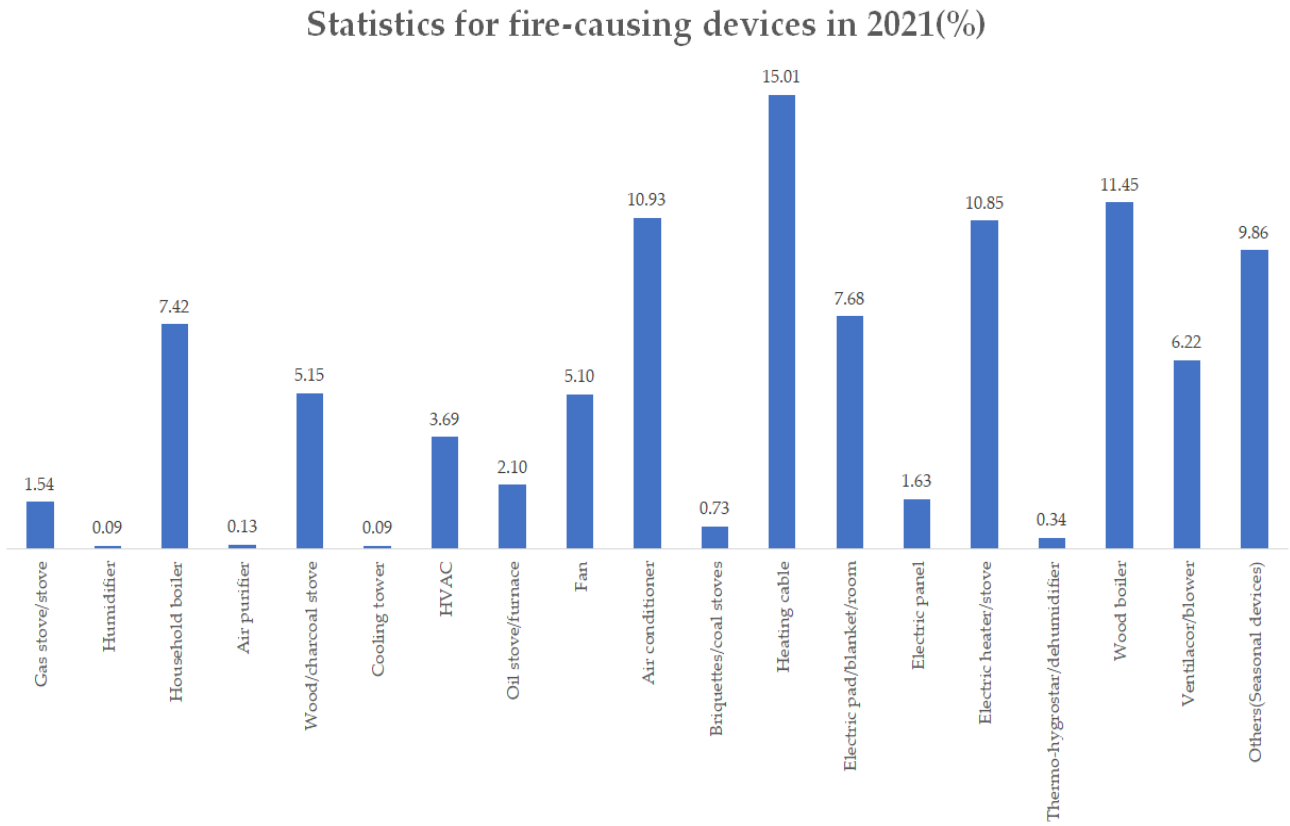


Figure 1. Statistics of fire-causing devices reported to National Fire Information Center.

These cables are easily installed, and the installation cost is low, hence their increasing use. However, the number of fires occurring in general households or farms is proportionally higher compared to other appliances according to the device classification of fires by electrical factors.

As such, although heating cables are seasonal devices that can be efficiently suitable for the geographical characteristics of the Republic of Korea with its large annual range, it is necessary to prepare measures to prevent fires caused by electrical factors as they account for the highest percentage.

In the paper, we analyze the cause of fire due to heating cables and conduct a reproducibility test to determine the data engineering approach to prevent fires. In other words, fires caused by anti-freezing heating cables are increasing every year, and they can lead to large fires. As a result, there is an urgent need to analyze the cause of fires in anti-freezing heating cables and provide a fire prevention measure. Thus, this study sought to classify fire cases through the fire survey reports and analyze comparatively the test conditions in the safety evaluation standards of anti-freezing heating cables and conditions by fire cases, thereby deriving a basis for strengthening reasonable test standards (drafts) when operating a system of electrical appliance safety standards.

2. Related Research

The study on the fire hazards of short-circuiting of the anti-freezing heating cable by Lim Jung-Ho, Bang Seon-Bae, and Park Kwang-Mook [3] studied the risk of short-circuit fire by comparing the serial heating cables and self-regulating cables. According to the paper, in the case of serial heating cables, the current was three times higher during a short circuit, but the measured temperature of the sheath was lower than the rated temperature.

However, the risk of fire due to heat storage increased over time. In the case of self-regulating cables, the risk of fire due to the arc was high due to the current flow of 30 amps or more during a short circuit [3,4]. The study on natural convection thermal flow characteristics in closed circular piping with anti-freezing heating cables by Seo Gyu-Weon, Park Hyeong-Seon, and Yun Joon-Kyu [4] analyzed the thermal flow characteristics in closed circular piping according to the location of the heating cable. It showed that the heat transfer was best when $\theta = 135^{\circ}$ with one heat source, and that the heat transfer efficiency can be increased when $\theta = 135^{\circ}$ and $\theta = 180^{\circ}$ with two heat sources. The study on the potential fire due to anti-freezing heating cables by Lee Jeong-Hoon and Park Jeong-Yeol [5] identified four sources of fire by anti-freezing heating cables (fire due to short circuit, heat storage, defective contact, and electric leak) and analyzed the fire potential from them.

The headline analysis on natural convection for nanofluids [6–9] confined within square cavities with various thermal boundary conditions by Basak, T., and Chamkha, A.J. reported [7] that the average Nusselt number showed greater enhancement of heat transfer rates for all nanofluids for Ra = 105, and that alumina-water and copper-water exhibited greater enhancement of heat transfer rates. The paper "A Comparative Study on Arrhenius Equations and BP Neural Network Models to Predict the Hot Deformity Behaviors of Hypereutectoid Steel" developed [10] a BP neural network model using the data obtained from heat-to-heat compression tests at a specific temperature range to predict the high-temperature deformation state of hyper eutectoid steel. The paper "Fatigue life prediction of tire sidewall using modified Arrhenius Equation" proposed [11] a method of assessing tire fatigue life using the Arrhenius Equation.

2.1. Anti-Freezing Heating Cable (Self-Regulating Heating Cable)

Anti-freezing Heating Cables (Self Regulating Heating Cables) are mainly used as freeze protection for various types of pipes or tanks such as water pipes, water meters, and tanks during the winter season [12]. Although the use of these cables is increasing due to their simple installation method and low cost, the number of fire incidents caused by them in general homes or farms is continuously rising proportionally. The heating cables that are being used for the anti-freezing purpose include self-regulating cables, belt heaters, and constant wattage heating cables [13].

Among these three cables, self-regulating heating cables are being used widely to protect water pipes and tanks from freezing and bursting as they are easy to install with a low cost and maintenance. The user can cut the cable to any required length.

C Erickson [14] published Reliable and Cost-Effective Electrical Heating of Pipelines with Self-Regulating Heating Cable, proposing a method that utilizes the cable resistance when controlling the pipeline temperatures feedback.

Additionally, L Lardear [15] published Control of Self-Regulating Heating Cable for Use in Pipeline Heating Applications, focusing on the method of controlling temperatures without using existing sensors.

In the study Extreme Overheating in Self-Regulating Heating Cables by Hansen, Walter [16], it was found that the saltwater intrusion caused by the mechanical damage of cable or its leaking end resulted in cable damage.

The study Structure and Applications of CB/Crystal Fluoride Resin Alloy in Self-Regulated Heating Cables was published by J Wang et al. [17].

Meanwhile, a research work Application Self-Regulating Heating Cable Curing of Concrete in Winter was presented by Jin Bao Guo et al. [18], where he proposed a specific method that uses self-regulating heating cable for curing concrete in the winter season.

Additionally, N Khrenkov [19] published The Influence of Environmental Conditions on the Characteristics of Self-Regulating Cables. Meanwhile, Li-Chun Wang et al. [20] studied the charring effect and flame retardant properties of thermoplastic elastomer composites applied for cable. Yanyan Zou et al. [21] researched the determination of the solid-phase reaction mechanism and chlorine migration behavior of co-pyrolyzing PVC-$CaCO_3$-based polymer using temperature-dependent FTIR and XRD analysis. Zhi Wang [22] conducted a comprehensive study on the flame propagation of horizontal laboratory wires and flame-retardant cables under different thermal circumstances.

2.2. Related Domestic and International Regulations

Electrical appliances that require safety management by the product certification system as prescribed by the Electrical Appliances and Consumer Products Safety Control Act should meet the minimum safety requirements before they are released to the market. Even for certified products and products that are not subject to prior certification, those that pose or are likely to pose a threat to consumers' safety are recalled from the market or consumers through safety investigations based on the Framework Act on the Safety of Products as shown in Figure 2.

Figure 2. Product Safety Management System.

The anti-freezing heating cable is controlled by the product safety management system and is classified as a "product subject to safety confirmation" based on the safety standards of electrical appliances subject to the safety certification in attached 25 of Article 63 of the Operation Guidelines for Electrical Appliances and Consumer Products Safety Control, Public Notice No. 2021-0177 by the Korean Agency for Technology and Standards [2].

Based on the regulation, any party that manufactures or imports anti-freezing heating cables are allowed to sell only those products that have been reported to the Minister of Trade, Industry, and Energy (delegated to the certifying body) after undergoing product test from the safety certifying body and receiving confirmation that they meet the safety standard, as shown in Figure 3 (no factory examination and regular inspection).

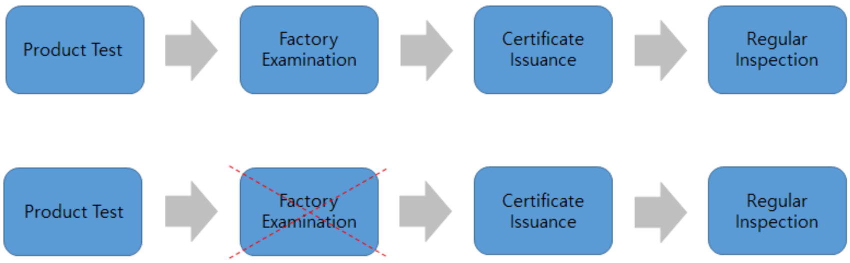
Figure 3. Safety Verification and Certification Procedure.

2.3. Anti-Freezing Heating Cables According to the Electrical Appliances and Consumer Products Safety Control Republic of Korea Act

Since 1974, the Republic of Korea has designated relatively high-risk items among the electrical appliances using AC power of no more than 1000 volts or DC power as electrical appliances subject to safety certification as prescribed by the Electrical Appliances and Consumer Products Safety Control Act to protect the people from the risk of electric shock/fire and other hazards caused by electrical appliances [1]. The electrical appliance safety certification scheme allows sales of only electrical appliances certified for safety by the safety certification bodies (Korea Testing Certification, Korea Testing Laboratory, and Korea Testing and Research Institute).

Since 2009 [2], only 66 low-risk products have been classified as products subject to safety verification to be sold after being tested by a government-designated safety verification testing body and reported to the safety verifying agency. However, the existing Safety Certification Scheme is still in place for parts like wires and products with relatively high risk due to the built-in heater and others.

Figure 4 shows comparison of procedures for electrical appliances subject to safety certification and those subject to safety verification.



Type		Safety Certification	Safety Verification
Product test		○	○
Factory confirmation	Manufacturing and inspection equipment	○	X
	Raw material and process equipment	○	X
	Product inspection	○	X
Certification and report issuance		Certificate	Report
Regular inspection (Product test + factory confirmation)		○	X
No. of items		37 types	66 types

Figure 4. Comparison of procedures for electrical appliances subject to safety certification and those subject to safety verification.

Figure 5 shows fire statistics related to heating per year. The anti-freezing heating cables (classified as Water service anti-freezing device under the electrical appliance safety standard) are currently classified as subject to safety verification. The reports on fire accidents in the past 7 years show that heating cables have caused an average of 315 fire accidents in the past 7 years.

Although their use is increasing due to their advantages such as simple installation and low cost, self-regulating heating cables account for a large proportion of seasonal appliance fire accidents that occur in homes and farms.

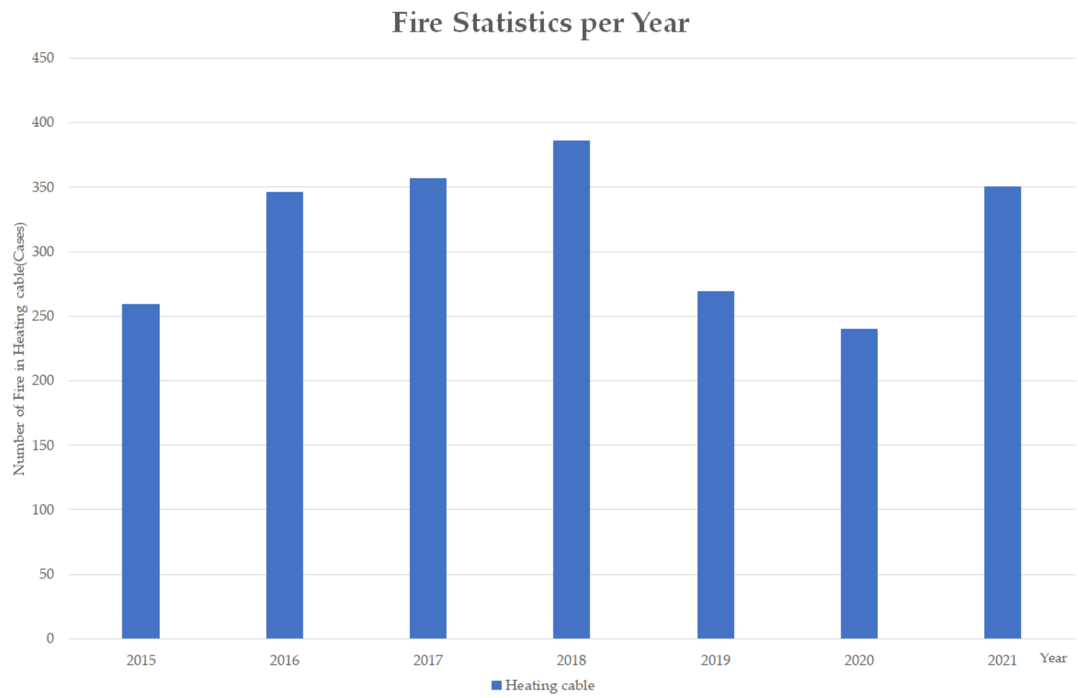


Figure 5. Fire statistics related to heating per year.

3. Anti-Freezing Heating Cables

Anti-freezing heating cables refer to equipment that prevents the water inside the water service pipe from freezing as the temperature sensor in the anti-freezing machine is run automatically when the water temperature inside the exposed pipe drops due to the cold wave in winter and reaches the freezing point.

They are defined in the K 10013 Standards by the Korea Agency for Technology and Standards, which are applied to the safety of anti-freezing appliances or flexible heating appliances that deliver heat to things for household and similar purposes under rated voltage of 250 V.

3.1. Work with Anti-Freezing Heating Cables

The survey on the ways users work with anti-freezing heating cables shows four main types. They can be classified into ① heating cables wrapped around water service pipes and thermal insulation or taping on the outside, ② insulations around water service pipes and heating cables wrapped around them, ③ heating cables irregularly wrapped in multiple layers around a water service pipe, and ④ heat cables wrapped around water pipes at regular intervals. Among them, case ① accounted for the highest proportion, followed by ④, ②, and ③.

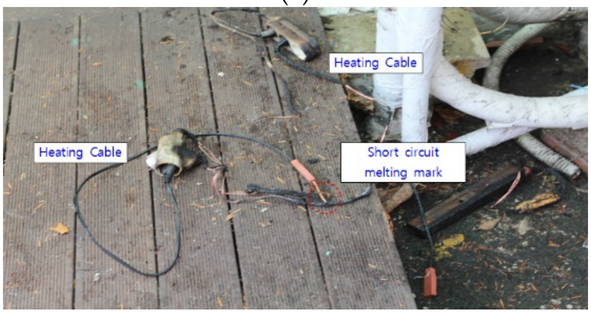
3.2. Four Cases of Sites of Fire Caused by Anti-Freezing Heating Cables during the Period

3.2.1. Case 1: Fire Caused by Heating Cables Wrapped around Water Service Pipes and Thermal Insulation or Taping on the Outside

The case is a fire from anti-freezing heating cables wrapped around water service piping installed outside a house, resulting in the loss of some pipes and wires before the fire was self-extinguished (October 2019).

The investigation indicated that the anti-freezing heating cables themselves caused the fire as there was a statement from an official that there were sparks and flame from the water service pipes, and an electrical arc (short circuit) trace was found in the heater part of the heated wire as shown in Figure 6.

(**a**)



(**b**)

Figure 6. Case of fire caused by heating cables wrapped around water service pipes and thermal insulation or taping on the outside. (**a**) Case 1—Fire site ①. (**b**) Case 1—Fire site ②.

Figure 6 shows the fire that occurred in the heating cables wrapped around the water service pipes and thermal insulation or taping on the outside. As a brief summary, a fire occurred in the anti-freezing heating cables in the water service pipes installed outside the house in an anonymous area in South Korea in October 2019, burning the water service pipes and some wires before it was extinguished.

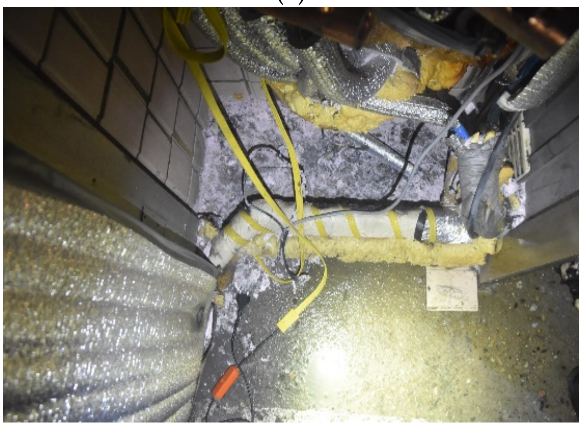
The fire investigation results revealed that sparks and flames were seen in the water service pipes as stated by the person concerned, and there were no negligent factors such as cigarette butts around or fire source neglect. In addition, electrical arc (short circuit) traces were found in the heating cables. Based on this evidence, the fire seemed to have been caused by the anti-freezing heating cables themselves. Figure 6a shows the photo of the actual fire site, and Figure 6b is the photo of the collected and spread heating cables as the cause of the fire in Figure 6a for fire investigation.

3.2.2. Case 2: Fire Caused by Insulations around Water Service Pipes and Heating Cables Wrapped around Them

The case is a fire that started from heating cables installed on the water pipes connected to an outside boiler room on the first floor but was extinguished with a fire extinguisher after some loss of insulation and others (July 2020).

The investigation indicated that the anti-freezing heating cables themselves caused the fire as there was a statement from a witness that the fire started on the floor of the boiler room. No parts other than the heating cables were lost as shown in Figure 7, and the heating cables have been there for a long time.

(**a**)



(**b**)

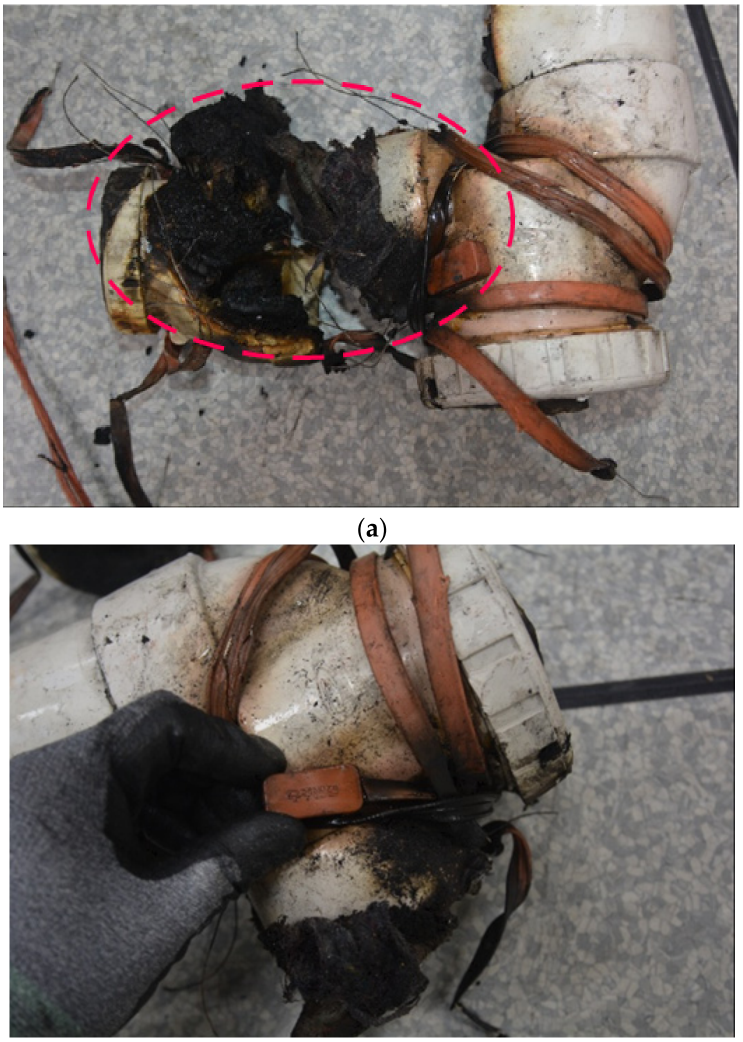
Figure 7. Fire caused by insulations around water service pipes and heating cables wrapped around them. (**a**) Case 2—Fire site ①. (**b**) Case 2—Fire site ②.

Figure 7 shows a case of fire caused by insulations around the water service pipes and the heating cables wrapped around them. As a brief summary, a fire was ignited from the heating cables installed in the water service pipes, which were connected to the external boiler room on the first floor in an anonymous region in Korea in July 2020, and the insulations, etc. were partially burned before the fire was extinguished by an extinguisher.

The fire investigation results revealed that the person concerned witnessed the fire from the floor in the boiler room and that parts other than the surrounding areas of the heating cables were not burned and were attached for a long time. Based on these circumstances, the anti-freezing heating cables themselves seemed to have been the cause of the fire. Figure 7a shows the photo of the actual fire site, and Figure 7b is the photo of the spread heating cables as the cause of the fire in Figure 7a.

3.2.3. Case 3: Fire Caused by Heating Cables Irregularly Wrapped in Multiple Layers around a Water Service Pipe

The case is a fire caused by heat accumulated by anti-freezing heating cables installed in the drainpipe in the ceiling of the entrance to the parking lot (ground level 1) of a five-story building (March 2015). The investigation revealed that the anti-freezing heating cables themselves caused the fire as there was a statement from a witness who saw the first smoke inside the parking lot, and there were no flammable materials other than the anti-freezing heating cables around the drainpipe in the ceiling of the parking lot as shown in Figure 8.



(**a**)

(**b**)

Figure 8. Fire caused by heating cables irregularly wrapped in multiple layers around a water service pipe. (**a**) Case 3—Fire site ①. (**b**) Case 3—Fire site ②.

Figure 8 shows the heating cables irregularly wrapped in multiple layers around a water service pipe.

As a brief summary, the fire was due to heat accumulation in the anti-freezing electrical heating cables installed on the ceiling drain pipes at the entry of the parking place (ground floor) in a five-story building in an anonymous area in Korea in March 2015.

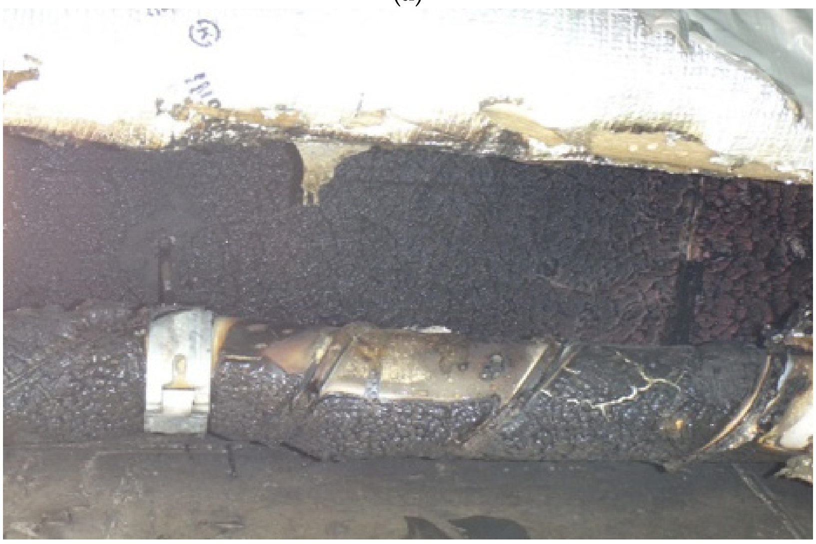
The fire inspection results revealed that the first smoke occurred inside the parking place as witnessed and stated by the person concerned and that there were no materials that could be ignited other than the anti-freezing heating cables around the ceiling drain pipe at the upper part of the parking place. Based on this evidence, the fire seemed to have been caused by the accumulated heat in the anti-freezing heating cables.

Figure 8a shows the photo of the actual fire site, and Figure 8b is the photo enlarging the heating cable product to confirm the cause of the fire shown in Figure 8a.

3.2.4. Case 4: Fire Caused by Heat Cables Wrapped around Water Pipes at Regular Intervals

The case is a fire caused by heating cables installed to prevent the freezing of boiler pipes of the sewage drain pipes on top of the terrace in a row house (March 2015). The investigation found no fire factors such as arson, gas leak, or flammable material. Considering the fact that the anti-freezing heating cables have always been powered on for three years since installation, and the combustion was centered on the sewage pipe as shown in Figure 9, it is estimated to be a fire caused by the anti-freezing heating wire itself.

(**a**)



(**b**)

Figure 9. Fire caused by heat cables wrapped around water pipes at regular intervals. (**a**) Case 4—Fire site ①. (**b**) Case 4—Fire site ②.

Figure 9 shows the heating cables wrapped around water pipes at regular intervals. As a brief summary, it was a fire caused by the heating cables installed to prevent freezing at the boiler drain pipes in the wastewater drain pipe at the upper part of the veranda in an anonymous area in Korea in March 2015.

The fire investigation results revealed that the ignition was not caused by arson or gas leaks and ignitable substances. Power was supplied constantly for about 3 years after the installation of the anti-freeze heating cables, and burning occurred around the waste drain pipe. Comprehensively considering these circumstances, the fire seemed to have been caused by the anti-freezing heating cables.

Figure 9a shows the photo of the actual fire site. Figure 9b shows the photo that enlarges the heating cables to confirm the cause of the fire shown in Figure 9a.

4. Design and Experiment with Reproducibility Tests from a Data Engineering Perspective

A correlation is a relationship between cause and effect. It is possible to express a cause-and-effect relationship between an act and a subsequent occurrence of facts.

Demand decreases as the price rises. The price rise is the cause, and the decrease in demand is the effect. Price increases as market demand increases. The increase in market demand is the cause, and the price rise is the effect. As the price increases, the supply increases. (The Law of Supply) When the supply in the market increases, the price goes down.

So, what are the causes of the fire? The answers vary depending on the situation. In the case of autumn forest fires, dry environments or hikers' cigarette butts can cause fires. In the case of electric vehicles, a defective battery can cause a fire. However, as opposed to its results, it is not easy to clearly prove fire causes. Because a fire alters potential evidence of fire causes, it is hard to infer the causes from damaged evidence (burned ash, generated thermal energy, etc.). As such, we have designed a random game λ as a data engineering reproducibility test design and applied it to identify the factors that cause a high-temperature situation through the information given in the fire situation.

The following is a setup to check the cause and effect of the fire case due to the heating cable: Consider the situation in three dimensions according to the density of heating cables, presence of insulation material, and sequence of insulation material and heating cables. Assume the presence and absence of insulation material in each case of the high- and low-density heating cables as shown in Table 1. The situation of the insulation material being present can be divided into the situation of the insulation material or heating cables being wound first. Suppose a program returns either 1 or 0 depending on whether the increase or decrease in asset A matches the results of asset B's rise or fall.

Table 1. A program that returns a value according to the density of heating cables.

-	High-Density of Heating Cables	The Low Density of Heating Cables
Presence of insulation material	1	0
Absence of insulation material	0	−1

On the other hand, assume program R that adds the points shown in the table if there is a fire in the presence or absence of insulation material while the heating cable density is high or low, as shown in Table 2. The program returns 1 in the event of fire when the insulation material is present, and the heating cables are densely wound first. It returns 0 in the case of a fire with the insulation material having low heating cable density or if the density of the heating cables is high but there is no insulation material. It returns -1 when there is no insulation material and the density of the heating cables is low and returns Σ return value/n when the test count is n. The average program result value varies according to the correlation between the density of the heating cables, the presence/absence of the insulation material, and fire. Let us assume that many fires occur if the insulation material is present and the density of heating cables is high. Assuming each case occurs with the same probability, the program's return value for the situation converges at 0.25.

Table 2. Program 2 returns a value according to the density of the heating cables.

Assuming That Insulation Material Is Present	High-Density of Heating Cables	The Low Density of Heating Cables
Insulation material later	1	0
Insulation material first	0	−1

However, it would not be accurate to assume that the fire occurs more often as the return value deviates more from 0.25, the insulation material is present, and the density of heating cables is high.

In Tables 1 and 2, three state values are classified according to the presence or absence of each insulation and the density of the cable. In Table 1, the density of heating cables is high. It can be defined as returning a value of 1 in case of fire when insulation is present. Similarly, it can be defined as returning a value of -1 when a fire occurs in a hot wire with no insulation and low density.

In addition, this program can be defined to return 0 when the density is low when there is insulation or when the density is high when there is no insulation. Let's consider a situation in which insulation is present and a high density of heat rays is repeatedly provided. At this time, as the average value returned by the corresponding program is closer to 1, it can be seen that the frequency of occurrence of fire will be high when the insulation material is present and the density of the heating cable is high. It can be assumed that as the average of the returned values is farther from 1, the fire, the presence of insulation, and the denseness of the heating wire will be less related to the fire.

In Table 2, three state values were assigned according to whether or not the insulation was first installed and the three state values were according to the density of the cable. If a hot wire is first constructed and a fire occurs when the density of the installed hot wire is high, a program that returns a value of 1 can be defined. This program constructs the insulation material first and returns a value of 01 if a fire occurs when the heating wire is low. In the case of the heat wire not being dense, the heat wire constructed first, and if the heat wire is dense, a value of 0 is returned.

If the heating cable is first constructed, let's assume that the average of the returned values of 1 is repeatedly given a situation in which the density of the installed hot wire is high. The closer the value is to 1, the greater the correlation between the variable and fire, while the farther the value is from 1, the lower the correlation between the variable and fire.

Assume program R to examine the relationship between the density of heating cables and the sequence in which the insulation material and heating cables are installed. The program returns 1 in the event of fire when the insulation material is installed later and the heating cables are densely wound first. It returns 0 in the case of fire when the insulation material is installed later with low heating cable density, or the density of the heating cables is high but the insulation material is installed first. It returns -1 when the insulation material is installed first and the density of heating cables is low and returns Σ return value/n when the test count is n. The program's output differs depending on the correlation between the installation sequence of the insulation material and heating cables and the density of the heating cables. Assume that the heating cables are wound first followed by the insulation material while the density of heating cables is high. Moreover, if each case occurs with the same probability, the output value is likely to converge at 0.25 when the correlation with the fire is high.

4.1. Design of Reproducibility Test

We purchased anti-freezing heating cables (10 units) from an online market and compared and analyzed the test results according to the Electrical Appliance Safety Standard (K 10013) and the results of the reproducibility test applied to fire accident cases. The analysis is then tested with the random game λ mentioned above.

The test conditions are as follows. Anti-freezing heating cables are subject to conformity assessment according to safety standards KC 60335-1 (Household and similar electrical appliances—Safety Part 1: General requirements) and K 10013 (Individual requirements of heating devices having the safety of household and similar electrical devices and the flexibility of water service anti-freezing devices and similar) for conformity assessment. The product test items related to fire are "11. Additionally, temperature rise and "19. Abnormal operation." Therefore, the conditions for comparing the results of the conformity assessment test and the reproducibility test for the anti-freezing electric heating cables should be the same as the "General conditions for the test" stated in K 60335-1 and K 10013. Meanwhile, Table 3. below shows the abovementioned Bell test modified for the reproducibility test.

Table 3. Modification of the bell test for the reproducibility test.

Modified Random Game λ	The Low Density of Heating Cables	High-Density of Heating Cables
Insulation material later	1	-
Insulation material first	0	-
No insulation material	-	2

Rule 1: +1 point in the case of heating cables wrapped around water service pipes and thermal insulation or taping on the outside.

Rule 2: 0 points in the case of the insulation around water service pipes and heating cables wrapped around them.

Rule 3: +2 points in the case of heating cables irregularly wrapped in multiple layers around a water service pipe.

Since program R in this random game λ is a reproducibility test, assume that it returns the average by adding the points presented in cases of the highest temperature. Use the anti-freezing heating cables (10 types) purchased online. Program R's output values are between 0 and 2. A value closer to 1 means that case 1 is more likely to record a higher temperature. A value closer to 0 means that case 2 is more likely to record a higher temperature. A value closer to 2 means that case 3 is more likely to record a higher temperature.

Each value in the table is the score obtained in the corresponding state. Lambda Game is a program that proves a causal relationship exists when the average of random values approaches a specific value as the number of trials increases. The unit for the game is not separately marked because the purpose of the game is to show cause and effect more objectively, and the value output as a result of the game is a kind of score that shows how likely it is to be the cause of a fire according to the closeness of the value.

The case temperatures in Table 4. are the averages of the three measures for the product. The result of assigning the score of the case of the highest average value is the output value of 1.3. Therefore, the temperature value of the anti-freezing heating cables is highest in case 1, meaning the risk of fire increases when heating cables are wrapped around water service pipes and thermal insulation or taping on the outside. Table 5 shows the results of the reproducibility test and the score for the random game λ.

We have chosen six samples from 10 local manufacturers, respectively. The materials of the selected products were Polyethylene, Poly Vinyl Chloride, Polyolefin, and Silicone. Table 4 shows the temperature rise (11.) and abnormal operation (19.101) tests along with the test results of cases 1 to 4 according to the conditions of the K 10013 standard.

The tests of clauses 11 and 19.101 and cases 1 to 3 of Table 4 were carried out in a test environment condition of −10 °C to 5.0 °C while the test of case 4 was conducted in a test environment condition of 20 °C. As for the test methods, 1.15 times the rated input (W) is applied in the case of clause 11, and 1.24 times the rated input (W) is applied in the case of clause 19.101 and cases 1–4 [23–25] (1.15 times was referenced from the condition in Paragraph 11 in the IEC 60335-1 Standard.)

The abnormal operation test method involved applying 1.24 times the rated power input (W) for each product [23–25].

(1.24 times was referenced from the condition in Paragraph 19.3 in the IEC 60335-1 Standard.)

Table 4. Comparison of the results of the K 10013 test and reproducibility test.

No.	Photo	Sheath Material	Paragraph 11	Paragraph 19.101	Reproducibility Test (Case 1)	Reproducibility Test (Case 2)	Reproducibility Test (Case 3)	Reproducibility Test (Case 4)
			Temperature (°C)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Temperature (°C)
1		Polyethylene	49.1 68.4 59.8	53.8 54.8 55.3	60.4 62.7 65.2	51.2 53.6 56.5	62.0 64.3 62.9	60.5 61.8 62.0
2		Poly Vinyl Chloride	30.4 23.2 18.1	44.6 45.9 47.5	46.5 49.5 52.2	27.1 25.8 23.2	37.4 33.8 36.7	42.1 43.6 44.0
3		Polyolefin	28.7 35.9 27.4	39.5 37.5 38.2	40.2 38.4 39.2	25.5 25.6 28.9	33.0 31.9 32.1	34.9 34.3 34.4
4		Poly Vinyl	57.2 51.8 21.8	53.6 50.9 21.8	68.7 71.5 78.3	34.4 34.5 33.2	41.8 15.1 45.4	47.0 47.5 45.7
5		Chloride	41.5 79.0 63.4	42.9 78.8 66.1	95.8 110.9 119.0	46.0 45.7 52.3	58.1 54.9 55.5	30.7 30.4 29.7
6		Poly Vinyl	19.2 20.1 26.2	19.6 19.9 28.0	53.2 58.0 60.8	22.8 23.2 21.1	26.4 30.1 27.5	26.0 36.5 27.0
7		Silicone	24.7 26.2 25.4	24.6 24.4 25.2	57.6 57.6 57.9	27.9 27.2 27.6	42.4 47.6 44.9	46.9 48.0 47.5
8		Poly Vinyl	7.9 29.6 29.8	24.0 27.2 27.0	27.8 27.5 28.4	27.8 29.9 33.0	25.8 26.8 25.5	55.9 56.7 55.8
9		Chloride	17.8 18.6 21.5	18.5 19.3 20.5	25.7 38.0 32.6	16.0 16.4 15.6	25.0 37.2 32.2	39.2 38.3 39.2
10		Silicone	44.1 15.6 42.1	45.5 46.4 41.8	63.9 69.4 77.3	36.1 36.9 40.9	45.1 45.6 46.5	43.5 47.0 43.6

Table 5. Results of the reproducibility test and score value of random game λ.

No.	Case 1 (°C)	Case 2 (°C)	Case 3 (°C)	Max. Value (°C)	A Score of Random Game λ
1	62.7	53.7	63.0	63.0	2
2	49.4	25.3	35.9	49.4	1
3	39.2	26.6	32.3	39.2	1
4	72.8	34.0	46.7	72.8	1
5	108.5	48.0	30.2	108.5	1
6	57.3	22.3	29.8	57.3	1
7	57.6	27.5	47.4	57.6	1
8	27.9	30.2	56.1	56.1	2
9	32.1	16.0	38.9	38.9	2
10	70.2	37.9	44.7	70.2	1

Case 1: 4.2.1. Case 1: Fire caused by heating cables wrapped around water service pipes and thermal insulation or taping on the outside.

Case 2: 4.2.2. Case 2: Fire caused by insulations around water service pipes and heating cables wrapped around them.

Case 3: 4.2.3. Case 3: Fire caused by heating cables irregularly wrapped in multiple layers around a water service pipe.

Case 4: 4.2.4. Case 4: Fire caused by heat cables wrapped around water pipes at regular intervals (20.0 °C).

Cases 1 to 4 show the results of the test conducted equally after dividing the test in 19.101 into four detailed methods.

The theory was designed to show a correlation between the fire and heating cables/thermal insulation. For Cases 1, 2, and 3, a score was given. When a certain score was close to that score, it was considered to be related to fire. Each case was a circumstance that was likely to induce fire. We will see the correlation with fire for cases wherein an average of the sum of all scores converged when the number of trials was large. This was designed to explain the data engineering of the fire scenarios.

Based on these results, if we conduct an experiment under the same temperature condition, we can conclude that the Case 1 condition has a relatively high temperature (with thermal insulation) and a high risk of fire due to the electrical factor.

Most of the fires on the anti-freeze heating wire lead to fires due to the factors of the heating wire itself, as mentioned above and as shown in this fire case analysis. The fundamental cause is the rupture of the coating of the heating wire (deterioration phenomenon and overcurrent due to moisture infiltration, etc.). As indicated in the experimental results, the temperature difference by manufacturer and installation condition was about 91 °C (28.4–119.0 °C).

Thermal deterioration varies depending on the composition of covering materials, which are made of cross-linked polyethylene (XLPE), polyethylene (PE), vinyl chloride (PVC), ethylene propylene rubber (EPR), etc. The continuous rated temperature is 90 °C for XLPE, 75 °C for PE, 60 °C for PVS, and 80 °C for EPR. When the rated temperature is continuously exceeded, the covering material hardens and weakens (embrittlement) due to thermal deterioration, and cracks occur when bending or impact is applied.

The score of the random game λ in Table 5 is a simple score, so it is not indicated in a separate unit. The cable was investigated for the fire correlation of the following three variables such as “the density of heating cables,” “the presence or absence of insulating materials,” and “the presence or absence of the priority of heating cables and insulating materials.” We have ignored other variables. That is to reproduce the danger of fire to which civilians are exposed. To this end, we purchased heating cables and insulation materials that could be easily purchased on the market and conducted tests without any adjustments made to the products.

4.2. Data Engineering Perspective of Reproducibility Test

As Investigated earlier, there were four types of fire incidents involving anti-freezing electric heating wires (Four types fire incidents involving anti-freezing electric wires during the period from 2015 to 2021). Although these wires are being tested with a conformity assessment system (KC Certification) according to Electrical Appliances Safety Standards (K 10013), they are not clear enough.

Section 11.7 of K 10013 states that the submersibles should be submerged and those to be used by attaching themselves with the testing sample should be attached to their normal state of use. For the others, the testing samples having an automatic temperature regulator should be placed on a surface-flat wooden platform (10 mm), setting the temperature at maximum. For those without any temperature regulators, operate the sample as it is.

However, it was possible to find four different cases of use and in order to investigate which of them had the worst conditions, the conformity test was performed for each case with the same assessment standards (K 10013), among which Section 11 (heating) and 19 (abnormal operation) directly associated with the possibility of fire were applied. A comparative test was conducted for Section 19 to check the maximum temperature for each type.

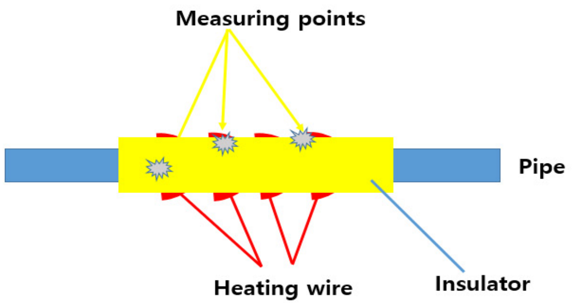
Meanwhile, the three measuring points include internal and external temperatures of each heating wire coiling around the sample (i.e., between the pipe and heating wire and the wire itself: two points) and one point for the insulator.

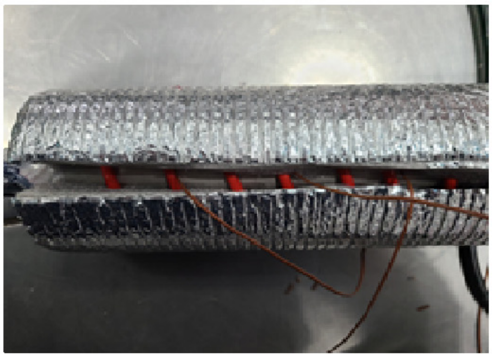
The temperature measurement method was measured using a calibrated digital thermometer (FW1012, YOKOGAWA). In addition, the accuracy of this equipment is verified by calibration once a year at the domestic KOLAS calibration institute. The calibration date is 10 February 2022.

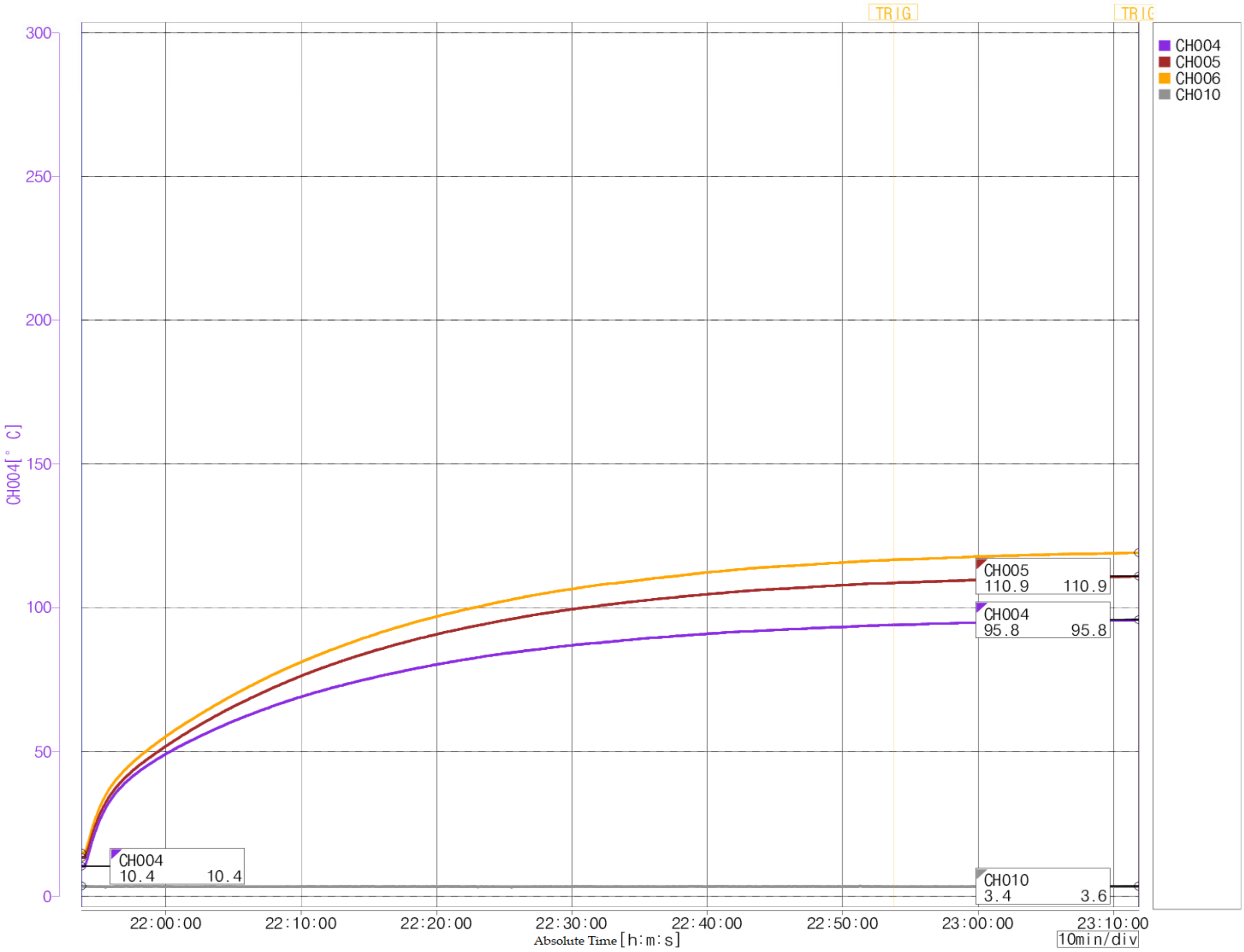
- Setup conditions: Four types.
- Test environment: −10 °C~5 °C, 20 °C (only case4).
- Testing voltage: 1.24 X Rated Input of each appliance (Section 19 Abnormal Operation).
- Temperature channel information:

CH004: Measured between the thermal insulation and heating cable (if there is no thermal insulation, measure between the heating cables).
CH005: Measurement of the heating cable.
CH006: Measured between the water service pipe and heating cable.

The results of the temperature rise (Paragraph) and abnormal operation (Paragraph) tests according to the K 10013 test specification showed a temperature deviation of 58.0 °C in the heater parts (Paragraph 11: 21.5–79.0 °C and Paragraph 19: 20.5–78.8 °C) as shown in Figure 10 Moreover, the reproducibility test showed that case 1 (heating cables wrapped around water service pipes and thermal insulation or taping on the outside) was the highest temperature condition and that the difference in temperature at heater parts by-product was about 91.0 °C (28.4 °C to 119.0 °C).

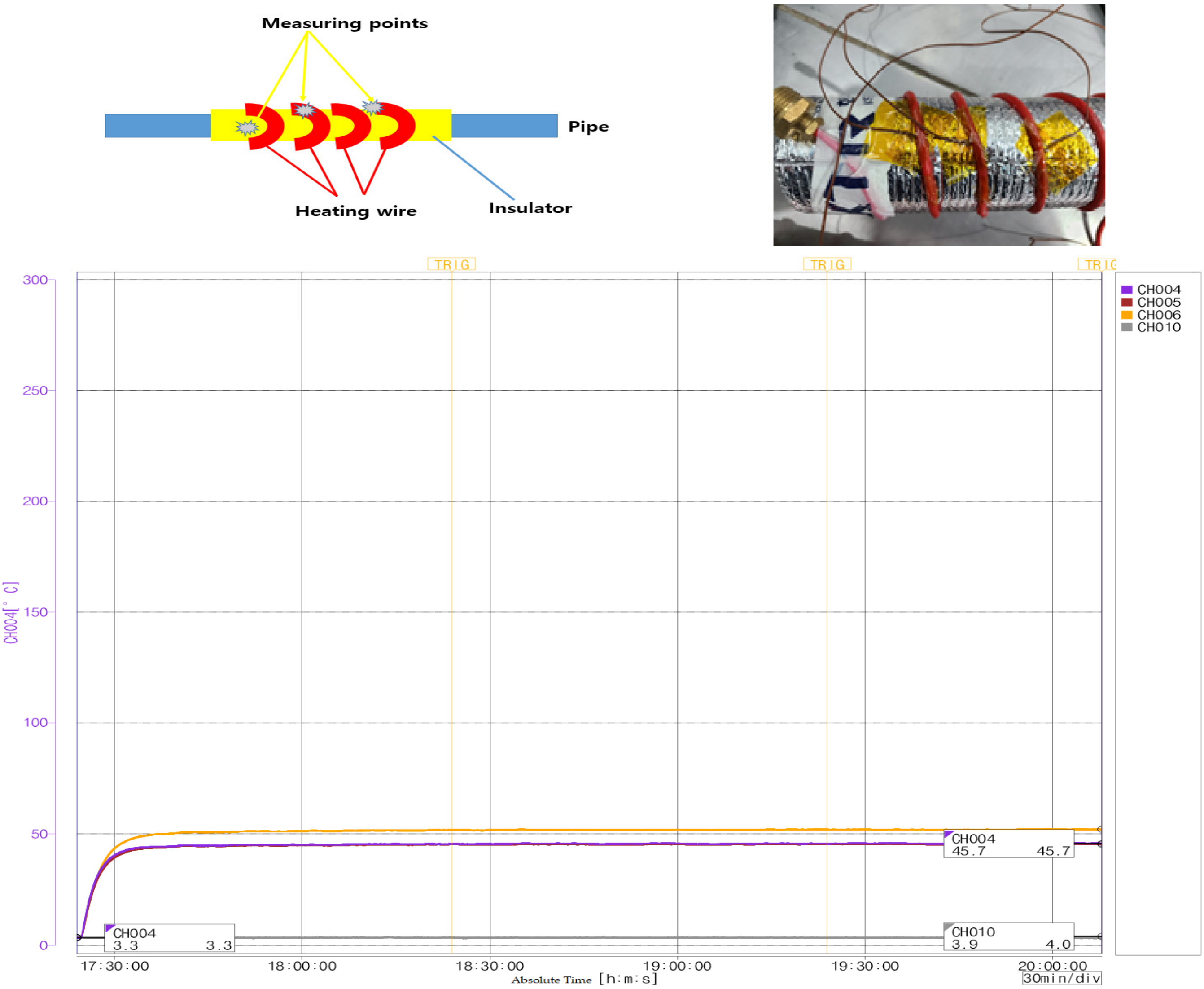






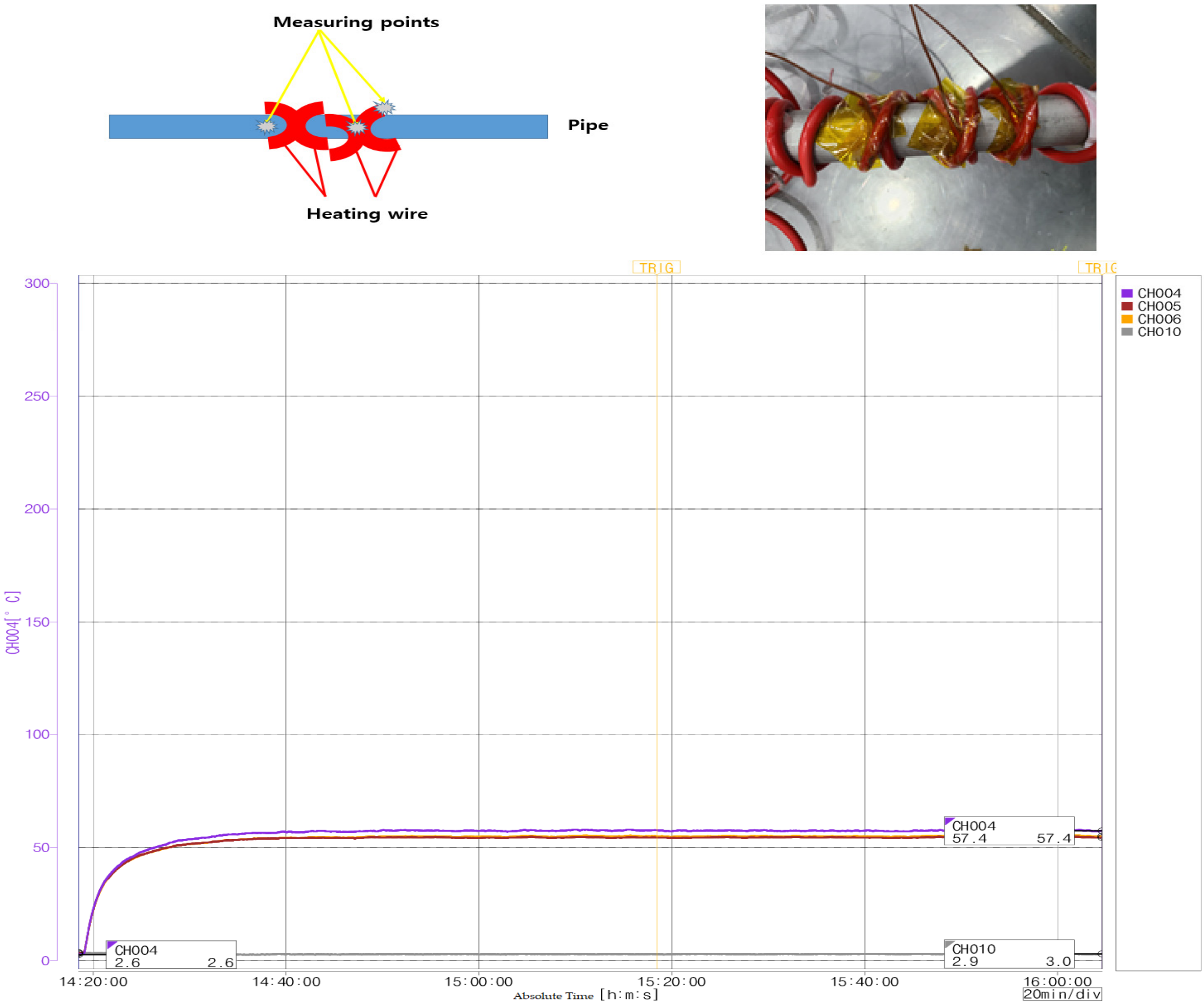
(a)

Figure 10. *Cont.*



(**b**)

Figure 10. *Cont.*



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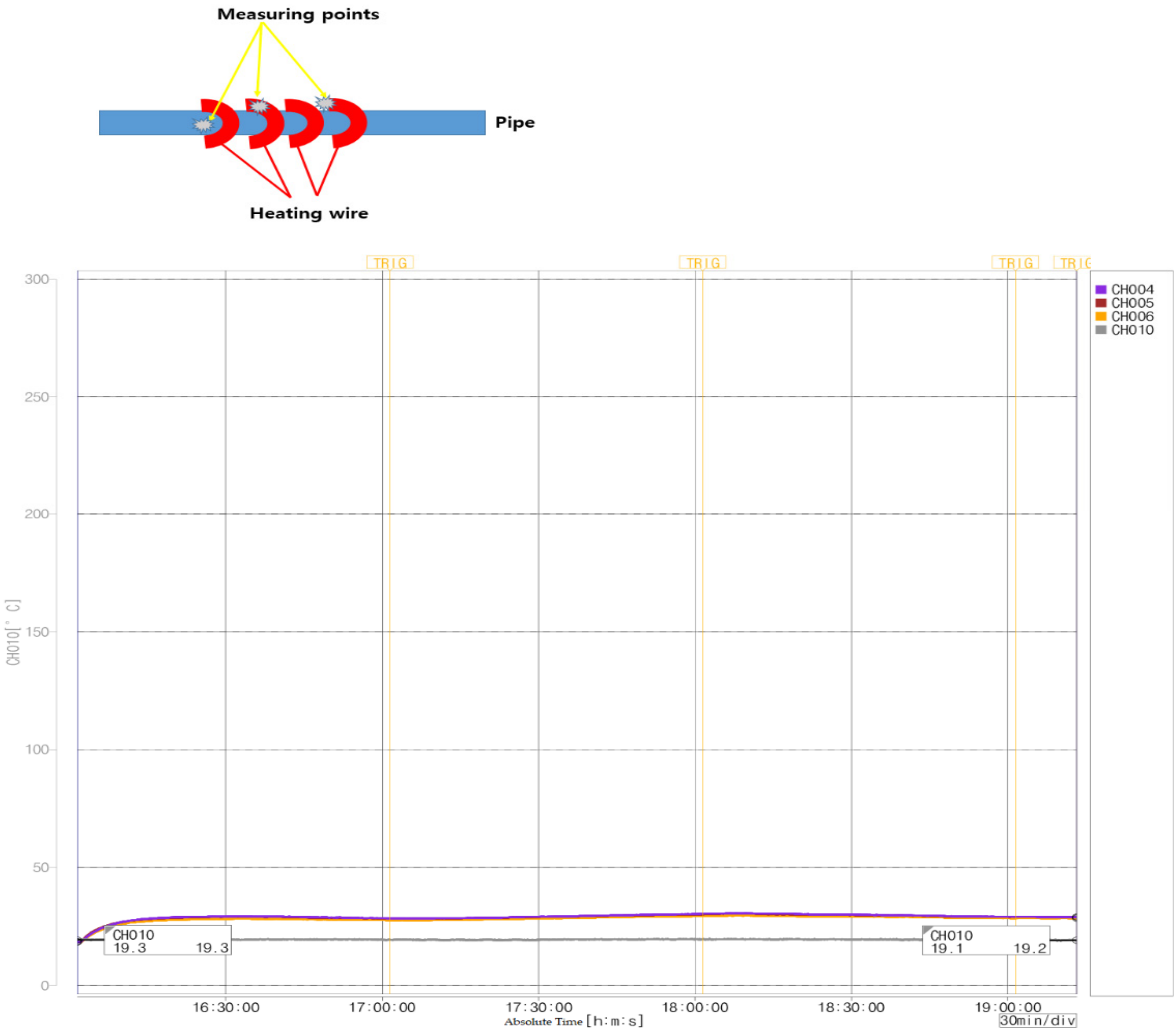


(**d**)

Figure 10. (**a**) Sample reproducibility test Case 1: Heating cables wrapped around water service pipes and thermal insulation or taping on the outside. (**b**) Sample reproduction test Case 2: Insulation around water service pipes and heating cables wrapped around them. (**c**) Sample reproduction test Case 3: Heating cables irregularly wrapped in multiple layers around a water service pipe. (**d**) Sample reproduction test Case 4: Sample reproducibility test: Undetectable temperature (20.0 °C).

Figure 10a shows the test results of Case 1 for the No. 5 product in Table 4. The experiment in Figure 10a showed the No. 5 sample data wherein the anti-freezing heating cables were wrapped around the water service pipe, and then thermal insulation was taped on the outside. Here, three different temperature points were designated to observe the highest temperature rise (Case 1). The result verified that the temperature at CH006 (measurement point between the water service pipe and heating cable) was the highest at 119.0 °C.

Figure 10b shows the test results of Case 2 for No. 5 product in Table 4. In the experiment in Figure 10b, thermal insulation was wrapped around the water service pipe, and anti-freezing heating cable was taped on the outside. Afterward, three different temperature points were designated to observe the highest temperature rise. The results verified that the temperature of CH006 (measurement point between the water service pipe and heating cable) was the highest at 52.3 °C.

Figure 10c shows the test results of Case 3 for No. 5 product in Table 4. In the experiment in Figure 10c, the anti-freezing heating cable was wrapped around the water service pipe without thermal insulation. However, the heating cable's interval was irregular, and the cables were overlapped. Afterward, three different temperature points were designated to observe the highest temperature rise. The results verified that the temperature of CH004 (measurement point between the water service pipe and heating cable) was the highest at 58.1 °C.

Figure 10d shows the test results of Case 4 for No. 5 product in Table 4. In the experiment in Figure 10d, the anti-freezing heating cable was wrapped around the water service pipe without thermal insulation. However, the heating cable's interval was irregular, and cables were overlapped. Afterward, three different temperature points were designated to observe the highest temperature rise. The results verified that the temperature of CH004 (between the heating cables) was the highest at 30.7 °C.

Figure 11a shows the test results of Case 1 for No. 8 product in Table 4. The experiment in Figure 11a exhibited the No. 8 sample data, wherein anti-freezing heating cables were wrapped around the water service pipe and then thermal insulation was taped on the outside. Here, three different temperature points were designated to observe the highest temperature rise (Case 1). The result verified that the temperature at CH006 (measurement point between the water service pipe and heating cable) was the highest at 28.4 °C.

Figure 11b shows the test results of Case 2 for No. 8 product in Table 4. In the experiment in Figure 11b, thermal insulation was wrapped around the water service pipe, and then an anti-freezing heating cable was taped on the outside. Afterward, three different temperature points were designated to observe the highest temperature rise. The results verified that the temperature of CH006 (measurement point between the water service pipe and heating cable) was the highest at 33.0 °C.

Figure 11c shows the test results of Case 3 for No. 8 product in Table 4. In the experiment in Figure 11c, the anti-freezing heating cable was wrapped around the water service pipe without thermal insulation. In the experiment in Figure 11c, thermal insulation was wrapped around the water service pipe, and anti-freezing heating cable was taped on the outside. However, the heating cable's interval was irregular, and the cables were overlapped. Then, three different temperature points were designated to observe the highest temperature rise. The results verified that the temperature of CH005 (measurement point at the heating cable) was the highest at 26.8 °C.

Figure 11d shows the test results of Case 4 for No. 8 product in Table 4. In the experiment in Figure 11d, the anti-freezing heating cable was wrapped around the water service pipe without thermal insulation. However, the heating cable's interval was irregular, and the cables were overlapped. Afterward, three different temperature points were designated to observe the highest temperature rise. The results verified that the temperature of CH005 (at the heating cable) was the highest at 56.7 °C.

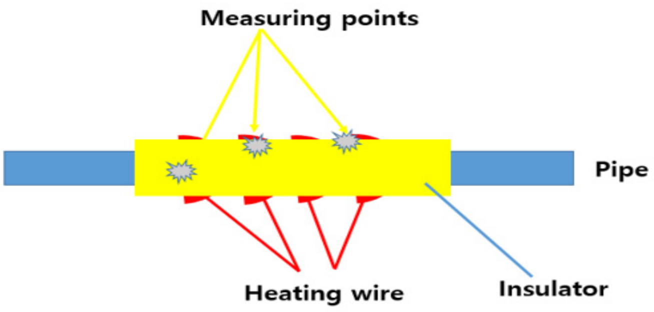
Figures 10 and 11 Results of the reproducibility test. As shown in Figure 10a,d with No. 5 products and Figure 11a,d with No. 8 products, tests were conducted under the conditions of Cases 1, 2, 3, and 4, which are summarized as follows:

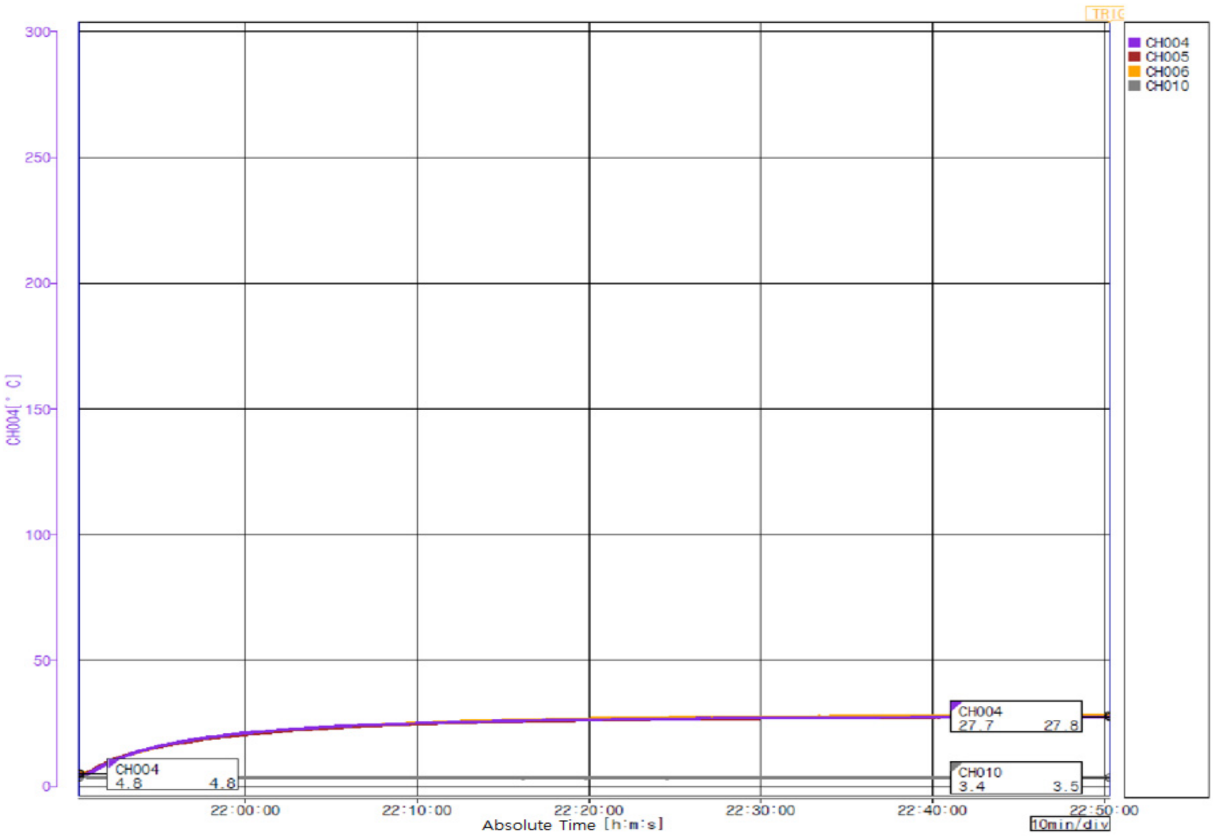
Overall, for Product Nos. 1 to 7 and 10, the temperature of most products was the highest under the Case 1 condition; for Product Nos. 8 and 9, the temperature was the highest under the Case 4 condition.

These results were attributed to the effect of internal heat storage as the test progressed under the condition of the thermal insulation installed. As shown in Case 1, the temperature was high. Note that, for Product Nos. 8 and 9, the temperature was assumed to be high under the Case 4 condition because of the structural characteristics according to the product operation mechanism.

(For Cases 1 and 2, experiments were conducted with thermal insulation; for Cases 3 and 4, however, experiments were conducted without thermal insulation.)

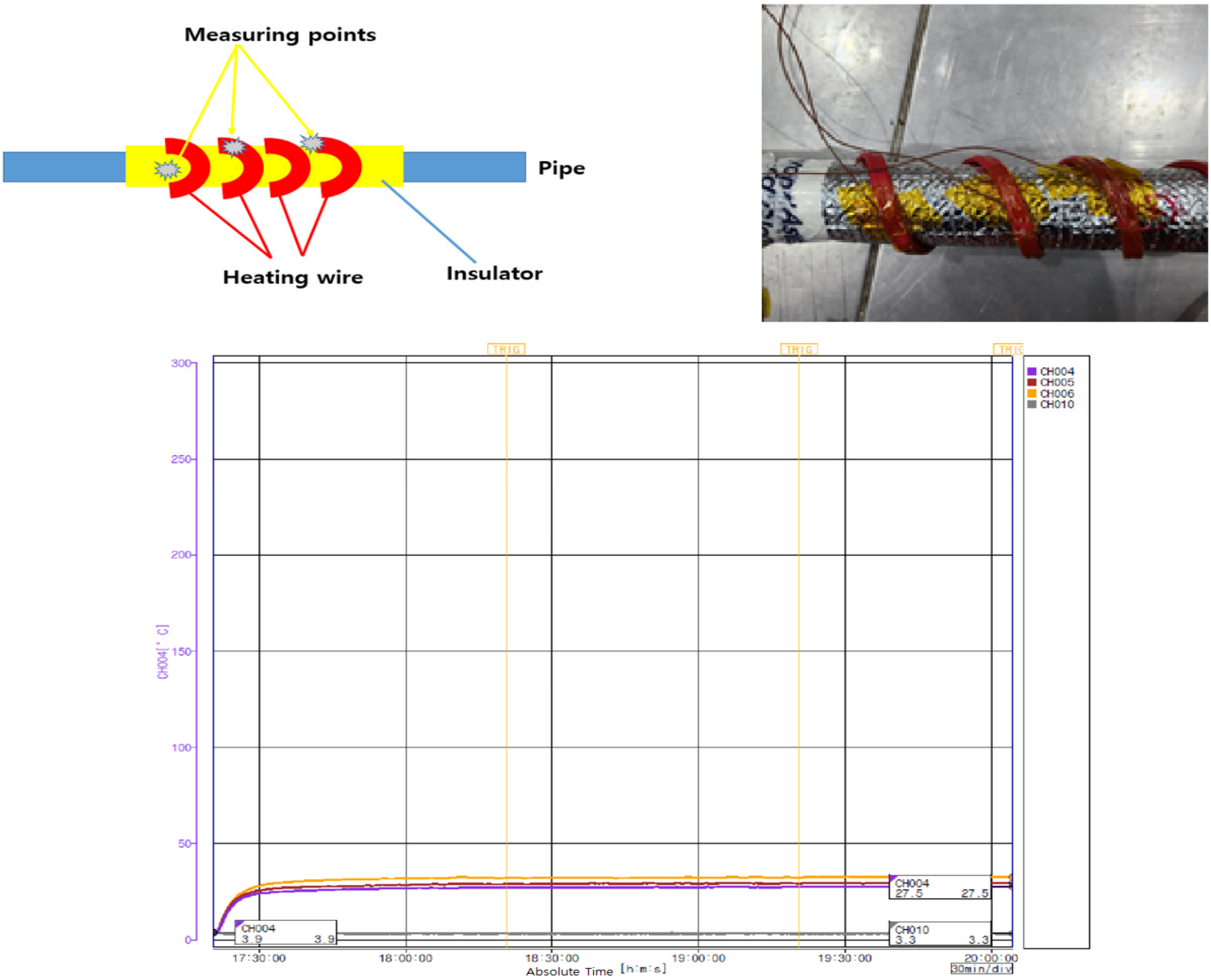
In addition, for Case 4, tests were conducted at 20.0 °C unlike Cases 1 to 3. For Cases 1 to 3, experiments were conducted at a range of -10 °C to 0 °C according to the K 10013 standard.





(**a**)

Figure 11. *Cont.*



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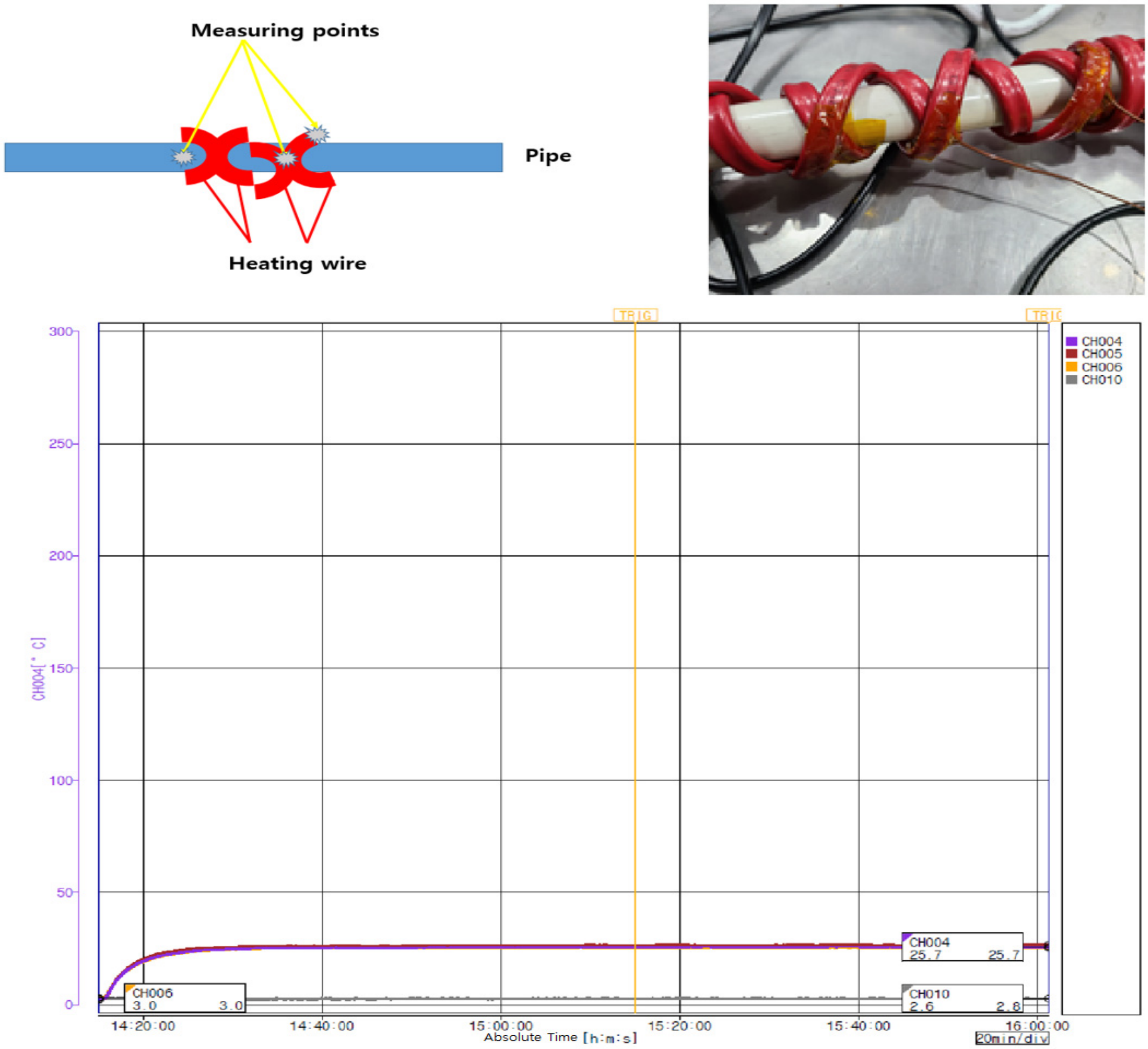
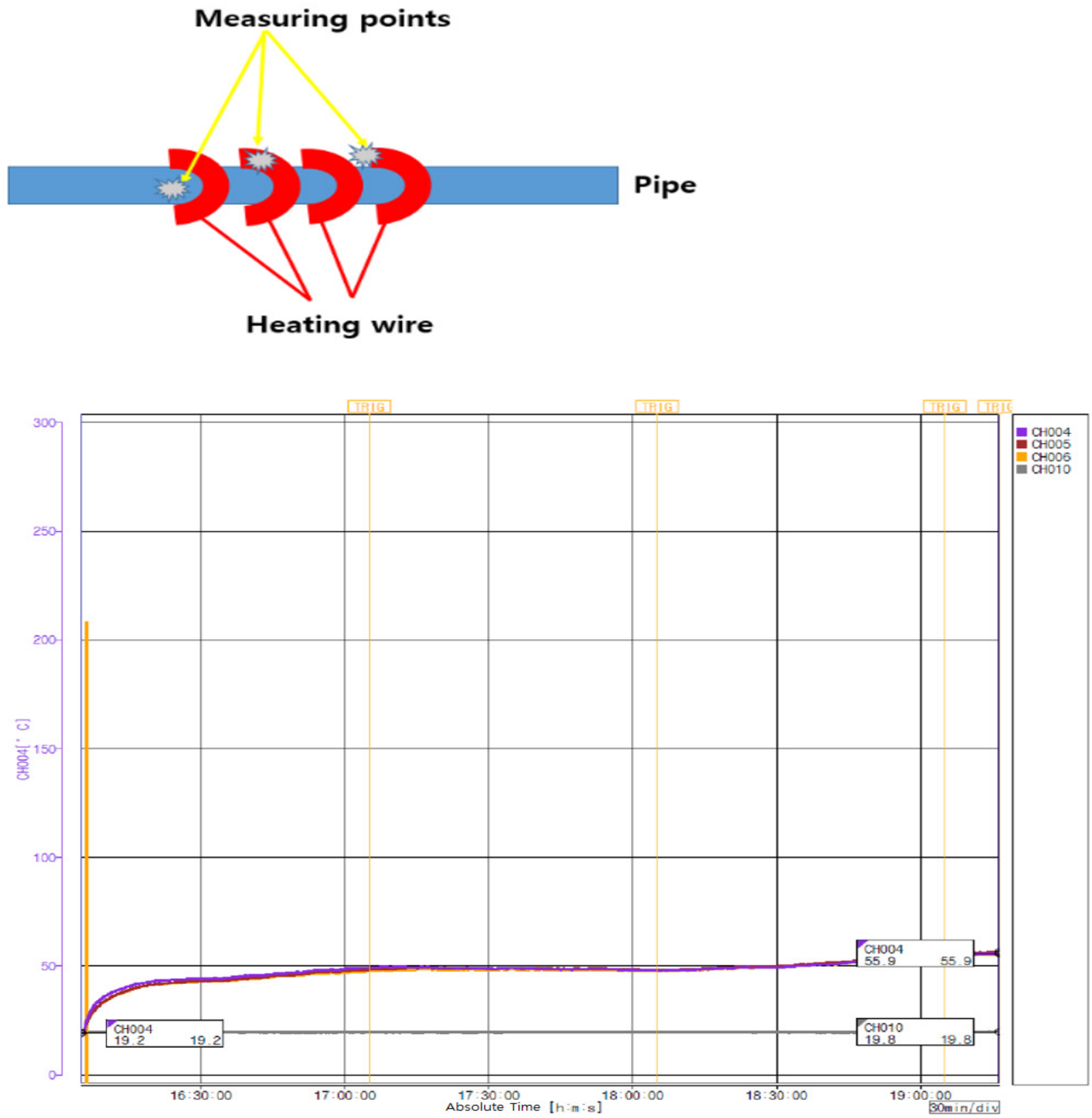


(c)

Figure 11. *Cont.*



(**d**)

Figure 11. (**a**) Sample reproducibility test: Case 1: Heating cables wrapped around water service pipes and thermal insulation or taping on the outside. (**b**) Sample reproducibility test Case 2: Insulation around water service pipes and heating cables wrapped around them. (**c**) Sample reproduction test: Case 3: Heating cables irregularly wrapped in multiple layers around a water service pipe. (**d**) Sample reproduction test: Undetectable temperature (20 °C).

5. Conclusions

The occurrence of a fire can be inferred from the winding method of the antifreeze heating cables. In order to figure out how the heat differs depending on the winding method of heating cables, we have selected 10 manufacturers, checked the temperature characteristics under the test conditions (Paragraph 11, Paragraph 19.101) of the Technical Regulations for Electrical and Telecommunication Products and Components of Korea

(K 10013), tested the four methods mentioned in this thesis and compared and analyzed the results.

This paper aims to clearly present the cause of fire on heating cables exposed to the general public by using the experimental design framework of Lambda Game while creating a policy and utilization environment that can reduce the risk for users.

To this end, this paper uses products that can be easily purchased on the market and examines the variables such as "the density of heating cables," "the presence or absence of insulating materials," and "the presence or absence of the priority of heating cables and insulating materials" from the perspective of actual users, in order to suggest in which cases the risk of fire is high.

To meet the goal, it would be better to use and test a large number of products, but we thought that doing so would rather hinder the purpose of this paper, as there were limits to the types of products that users actually purchased frequently among the products available in Korea at that time. Therefore, we purchased heating cables that could be easily purchased on the market and conducted experiments."

The experiment results indicate that the temperature of the heater part in antifreeze heating cables was mostly higher than the conditions required by the existing standards in cases 1 to 4. In particular, in the case of the No. 5 manufacturer's sample, the temperature of the heating cable of Case 1 was measured to be the highest at 119.0 °C. In the process of comparative analysis of the results, we have applied the data engineering reproducibility test results in the frame of the random game λ and derived the same results as the predicted hypothesis.

In future work, we will analyze the thermosetting life expectancy prediction experiment and durability according to the chemical material (component ratio) of the water freeze prevention device (hereinafter "heating wire") heating wire coating, and come up with the most reasonable method for fire prevention.

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Abbreviations

Anti-freezing Heating Cable	Self Regulating Heating Cable
Electrical arc	Short Circuit
KC 60335-1	Household and similar electrical appliances—Safety Part 1: General requirements
K 10013	Individual requirements of heating devices having the safety of household and similar electrical devices and the flexibility of water service anti-freezing devices and similar.
CH004	Measured between the thermal insulation and heating cable (if there is no thermal insulation, measure between the heating cables).
CH005	Measurement of the heating cable.
CH006	Measured between the water service pipe and heating cable.

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