

Table 4.5 Flow rates set in various elements in ICAN-4

	Recirculation	Spray	Pressure loss measuring element 1	Pressure loss measuring element 2
Flow rate (L/min)	28.3	28.3	21.76	1.46
Flow velocity (cm/s)			2	0.3

## 4.2.2 ICAN-5

In some PWR plants, hydrazine ( $N_2H_4$ ) is employed as a pH regulating agent. Table 4.6 shows chemicals that were dissolved in the test tank in ICAN-5. Tables 4.7 and 4.8 show the insulating materials and structural materials that were placed in the liquid phase portions and gas phase portions, respectively. Table 4.9 shows the simulated debris that was placed in pressure loss measuring elements 1 and 2. Table 4.10 shows the recirculation flow rate, spray flow rate, and flow rates of pressure loss measuring elements 1 and 2. Boric acid ( $H_3BO_3$ ) was dissolved in 944 L of test water prior to placement of the insulating materials and simulated structural materials, and hydrochloric acid (HCl) was added just before the start of spraying. A 993.5 g quantity of hydrazine monohydrate ( $N_2H_4 \cdot H_2O$ ) was dissolved in 40 L of water and introduced simultaneously with the start of spraying. The introduction period was 30 minutes. One hour after the start of spraying, 182 g of sodium hydroxide (NaOH) [sic] was dissolved in 16 L of water and introduced over 10 minutes. Spraying was conducted for 4 hours.

Table 4.6 Chemicals dissolved in the test tank in ICAN-5 The hydrochloric acid concentration was 35 percent.

$H_3BO_3$	NaOH	$LiOH \cdot H_2O$	HCl
16010 g	0 g	2.4 g	286 g

Table 4.7 Insulating materials and structural materials placed in the liquid phase portion in ICAN-5

Insulating materials			Metals			Concrete	Paint
Calcium silicate	Rock wool	Glass wool	Aluminum	Copper	Carbon steel		Carbozinc 11
0	9680 g (0.121 m <sup>3</sup> )	0	13 x 13 mm	17 sheets	7 sheets	0 sheet	1 sheet

Table 4.8 Insulating materials and structural materials placed in the gas phase portion in ICAN-5

Insulating materials			Metals			Concrete	Paint
Calcium silicate	Rock wool	Glass wool	Aluminum	Copper	Carbon steel		Carbozinc 11
0	1280 g (0.016 m <sup>3</sup> )	0	56 x 56 mm	51 sheets	126 sheets	0 sheet	0 sheet

Table 4.9 Quantities of simulated debris of insulating materials in pressure loss measuring elements 1 and 2 in ICAN-5

Pressure loss measuring element 1

Calcium	Rock wool	Glass wool

silicate		
0 g	30 g	0

Pressure loss measuring element 2

Calcium silicate	Rock wool	Glass wool
0 g	13.4 g	0

Table 4.10 Flow rate settings in various elements in ICAN-5

	Recirculation	Spray	Pressure loss measuring element 1	Pressure loss measuring element 2
Flow rate (L/min)	28.3	28.3	21.76	1.46
Flow velocity (cm/s)			2	0.3

### 4.2.3 ICAN-6

In BWRs, pure water is the basic coolant. When control rods are properly inserted, there is no need to employ a boric acid in water injection system. Nor are pH-regulating agents employed. Accordingly, in the test, just 80.9 g of hydrochloric acid (concentration 35 percent) produced by deterioration of cables and the like was added to 1,000 L of test water just prior to the start of spraying. It was assumed that at this level, chlorine would be released from all of the cable coverings in the PCV. In reality, only some of the cables are exposed to temperatures high enough to cause the release of chlorine, and time is required for such a release to take place. Thus, this level is considered quite conservative. Tables 4.11 and 4.12 show the insulating materials and structural materials that were placed in the liquid phase portions and gas phase portions, respectively. Table 4.13 shows the simulated debris that was placed in pressure loss measuring elements 1 and 2. Table 4.14 shows the recirculation flow rate, spray flow rate, and flow rates of pressure loss measuring element 1 and 2. Strainer replacement has already advanced in BWRs, so no high flow velocity test was conducted. A flow rate in the vicinity of the 0.56 cm/s of pressure loss measuring elements 1 and 2 was set and the uniformity of pressure differential measurement in the various measuring elements was observed. Following the addition of hydrochloric acid, spraying was conducted for 4 hours.

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Table 4.11 Insulating materials and structural materials placed in the liquid phase portion in ICAN-6

Insulating materials			Metals				Concrete	Paint
Calcium silicate	Rock wool	Glass wool	Aluminum	Copper	Carbon steel	Zinc steel		Carbozinc 11

0	94.4 g (0.00118 m <sup>3</sup> )	0		0 sheet	1 sheet	1 sheet	0 sheet	1 sheet
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Table 4.12 Insulating materials and structural materials placed in the gas phase portion in ICAN-6

Insulating materials			Metals				Concrete	Paint
Calcium silicate	Rock wool	Glass wool	Aluminum	Copper	Carbon steel	Zinc steel		Carbozinc 11
0	39.4 g (0.000492 m <sup>3</sup> )	0	56 x 56 mm	32 sheets	1 sheet	64 sheets	0 sheet	0 sheet

Table 4.13 Quantities of simulated debris of insulating materials in pressure loss measuring elements 1 and 2 in ICAN-6

Pressure loss measuring element 1

Calcium silicate	Rock wool	Glass wool
0 g	30 g	0

Pressure loss measuring element 2

Calcium silicate	Rock wool	Glass wool
0 g	13.4 g	0

Table 4.14 Flow rate settings in various elements in ICAN-6

	Recirculation	Spray	Pressure loss measuring element 1	Pressure loss measuring element 2
Flow rate (L/min)	12.3	4.4	6.09	2.73
Flow velocity (cm/s)			0.56	0.56

#### 4.2.4 ICAN 7

Although there was not a greater difference in the chemicals that were added to test water in ICAN-1 and ICAN-3, which were tests simulating dry condenser-type plants, a difference was observed in trends in change in pressure loss. In pressure change measuring element 1 in ICAN-1, the pressure loss increased as the pH rose due to spraying, and for 100 hours thereafter, the pressure differential decreased. From 200 hours to 350 hours, the pressure loss increased again, assuming a nearly constant value after 350 hours. Additionally, in pressure loss measuring element 2 of ICAN-3, the pressure loss increased after placing insulating material in the liquid phase portion of the test tank. When hydrochloric acid was added, causing the pH to drop, the pressure loss was nearly identical to what it had been prior to placement of the insulating material. Although spraying caused the pressure loss to increase slightly, it was not as much as in ICAN-1. The pressure loss was nearly constant even after spraying. The main difference in the test conditions of ICAN-1 and ICAN-3 was that in ICAN-3, a recirculation system cooling device was employed, temporarily reducing the temperature of the test water to about 55°C. Accordingly, the tests were conducted again under conditions in which a

cooling device was not employed to confirm that the differences in change in pressure loss behavior in ICAN-1 and ICAN-3 were due to the effects of cooling and heating. The test procedure was identical to that in ICAN-1 and ICAN-3. Table 4.15 shows the chemicals that were dissolved in the test tank in ICAN-7. Tables 4.16 and 4.17 show the insulating materials and structural materials that were placed in the liquid phase portion and gas phase portion, respectively. Table 4.18 shows the simulated debris that was placed in pressure loss measuring elements 1 and 2. Table 4.19 shows the recirculation flow rate, spray flow rate, and flow rates of pressure loss measuring elements 1 and 2. The chemicals, simulated structural materials, insulating materials, and simulated debris employed were identical to those in ICAN-3. Boric acid ( $H_3BO_3$ ) was dissolved in 960 L of test water prior to placement of the insulating material and simulated structural materials. Hydrochloric acid (HCl) was added just prior to the start of spraying. Simultaneously with the start of spraying, 8,347.8 g of sodium hydroxide dissolved in 40 L of pure water was introduced through the spray line. Sodium hydroxide was introduced over 94 minutes from the start of spraying. Spraying was conducted for 4 hours.

Table 4.15 Chemicals dissolved in the test tank in ICAN-7 The hydrochloric acid concentration was 35 percent.

$H_3BO_3$	NaOH	$LiOH \cdot H_2O$	HCl
16010 g	0 g	2.4 g	286 g

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Table 4.16 Insulating materials and structural materials placed in the liquid phase portion in ICAN-7

Insulating materials			Metals			Concrete	Paint
Calcium silicate	Rock wool	Glass wool	Aluminum	Copper	Carbon steel		Carbozinc 11
0	9680 g (0.121 m <sup>3</sup> )	0	13 x 13 mm	17 sheets	7 sheets	0 sheet	1 sheet

Table 4.17 Insulating materials and structural materials placed in the gas phase portion in ICAN-7

Insulating materials			Metals			Concrete	Paint
Calcium silicate	Rock wool	Glass wool	Aluminum	Copper	Carbon steel		Carbozinc 11
0	1280 g (0.016 m <sup>3</sup> )	0	56 x 56 mm	51 sheets	126 sheets	0 sheet	0 sheet

Table 4.18 Quantities of simulated debris of insulating materials in pressure loss measuring elements 1 and 2 in ICAN-7. Dry adjusted insulating materials were placed in pressure loss measuring element 1 and wet adjusted insulating materials were placed in pressure loss measuring element 2.

Pressure loss measuring element 1

Calcium silicate	Rock wool	Glass wool
0 g	30 g	0

Pressure loss measuring element 2

Calcium silicate	Rock wool	Glass wool
0 g	13.4 g	0

Table 4.19 Flow rate settings in various elements in ICAN-7

	Recirculation	Spray	Pressure loss measuring element 1	Pressure loss measuring element 2
Flow rate (L/min)	28.3	28.3	21.76	1.46
Flow velocity (cm/s)			2	0.3

4.2.5 ICAN-8

The test water in ICAN-5 assumed a tea-brown color during the test. This was attributed to the fact that hydrazine had been employed as a pH-regulating agent, causing carbon steel to corrode without the pH increasing any higher than when sodium hydroxide was employed. In an actual plant, not carbon steel, but zinc steel is employed in gratings and the like. Accordingly, the change in pressure loss when zinc steel was employed instead of carbon steel was measured. The test procedure was identical to that of ICAN-5. Table 4.20 shows the chemicals that were dissolved in the test tank in ICAN-8. Tables 4.21 and 4.22 show the insulating materials and structural materials that were placed in the liquid phase portion and gas phase portion, respectively. Table 4.23 shows the simulated debris that was placed in pressure loss measuring elements 1 and 2. Table 4.24 shows the recirculation flow rate, spray flow rate, and flow rates of pressure loss measuring elements 1 and 2. Boric acid ( $H_3BO_3$ ) was dissolved in 944 L of test water prior to placement of the insulating material and simulated structural materials. Hydrochloric acid (HCl) was added just prior to the start of spraying. A 993.5 g quantity of hydrazine monohydrate ( $N_2H_2 \cdot H_2O$ ) was dissolved in 40 L of water and introduced simultaneously with the start of spraying. The introduction period was 30 minutes. One hour after the start of spraying, 182 g of sodium hydroxide (NaCl) dissolved in 16 L of water was introduced. Spraying was conducted for 4 hours.

Table 4.20 Chemicals dissolved in the test tank in ICAN-8 The hydrochloric acid concentration was 35 percent.

$H_3BO_3$	NaOH	$LiOH \cdot H_2O$	HCl
16010 g	0 g	2.4 g	286 g

Table 4.21 Insulating materials and structural materials placed in the liquid phase portion in ICAN-8

Insulating materials			Metals				Concrete	Paint
Calcium silicate	Rock wool	Glass wool	Aluminum	Copper	Carbon steel	Zinc steel		Carbozinc 11

0	319 g (0.0049 m <sup>3</sup> )	0	13 x 13 mm	17 sheets	1 sheet	7 sheets	0 sheet	1 sheet
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Table 4.22 Insulating materials and structural materials placed in the gas phase portion in ICAN-8

Insulating materials			Metals				Concrete	Paint
Calcium silicate	Rock wool	Glass wool	Aluminum	Copper	Carbon steel	Zinc steel		Carbozinc 11
0	262 g (0.0033 m <sup>3</sup> )	0	56 x 56 mm	51 sheets	2 sheets	126 sheets	0 sheet	0 sheet

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Table 4.23 Quantities of simulated debris of insulating materials in pressure loss measuring elements 1 and 2 in ICAN-8. Insulating materials were adjusted to render them wet.

Pressure loss measuring element 1

Calcium silicate	Rock wool	Glass wool
0 g	30 g	0

Pressure loss measuring element 2

Calcium silicate	Rock wool	Glass wool
0 g	13.4 g	0

Table 4.24 Flow rate settings in various elements in ICAN-8

	Recirculation	Spray	Pressure loss measuring element 1	Pressure loss measuring element 2
Flow rate (L/min)	28.3	28.3	21.76	1.46
Flow velocity (cm/s)			2	0.3

## 4.3 Results and Discussion

### 4.3.1. Analysis of change in pressure loss and test water

#### 4.3.1.1. ICAN-4

Fig. 4.1 shows relations between the flow rate of pressure loss measuring element 1, the flow rate of pressure loss measuring element 2, the spray flow rate, the recirculation flow rate, the test tank temperature, the temperature of pressure loss measuring element 1, the temperature of pressure loss measuring element 2, and the test duration. The flow rate after 780 hours was intentionally changed to examine the relation between flow speed and pressure loss using a chemical effect assessment loop.

Fig. 4.2 shows the change in pressure loss and pH over 10 hours before and after spraying in pressure loss measuring element 1 (approach flow velocity 2 cm/s). In the figure, the pH was picked up on line, and differs from the analytic value obtained by sampling. The pH of the test water to which lithium hydroxide and boric acid had been added was 5.9 (analytic value) prior to spraying. After placement of the simulated

structural material (coupon) and insulating material in the liquid phase portion, the pressure loss began to increase at about two hours after the start of spraying, rising from 1.5 kPa prior to placement to 2.4 kPa during the introduction of hydrochloric acid. At the point of the introduction of hydrochloric acid just prior to the start of spraying, the pH dropped to 2.5 (analytic value). Accompanying this, the pressure loss dropped to 1.4 kPa, which was about the same as before placement of the insulating material. The increase in pressure loss due to placement of the simulated structural material and insulating material was attributed to precipitation of corrosion products of the simulated structural material and insulating material in the pressure loss measuring element. The drop in pressure loss due to the addition of hydrochloric acid was thought to have occurred as a result of the dissolution of precipitates on the debris. With the introduction of sodium tetraborate from the start of spraying, both the pH and pressure differential increased. At the point where the introduction of sodium tetraborate ended, the pH was 8.3 (analytic value) and the pressure loss was 2.3 kPa. The pressure loss temporarily became 0 around the end of spraying (4 hours), but this was due to a problem with the data acquisition system. Fig. 4.3 shows changes in pressure loss and pH over the entire course of the test. Once spraying had ended, the pressure loss gradually decreased. The pressure differential at 400 hours was 1.7 kPa. Beyond 600 hours, the pressure differential increased. The pressure loss at 720 hours (30 days) was 1.8 kPa. After continuing testing at a flow rate yielding an approach flow velocity of 2 cm/s through 788 hours, the flow rate was changed to an approach flow velocity of 0.3 cm/s. The pressure loss at an approach flow velocity of 0.3 cm/s was 0.27 kPa, which was smaller than the pressure loss of 1.5 kPa (Fig. 4.4, described further below) at the same approach flow velocity in pressure loss measuring element 2. A return was made to a flow rate of an approach flow velocity of 2 cm/s at 860 hours, but the pressure loss at 900 hours was 1.6 kPa, which was lower than the original value of 1.8 kPa prior to changing the flow rate and did not constitute a return to the original value.

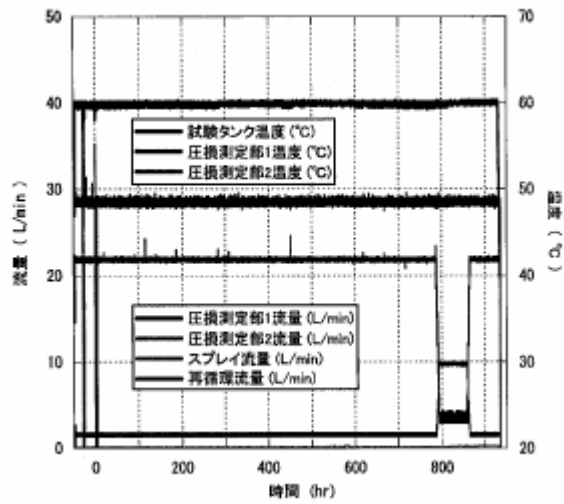
Fig. 4.4 shows changes in pH and the pressure loss over the 10 hours before and after spraying in pressure loss measuring element 2 (approach flow velocity of 0.3 cm/s). In contrast to pressure loss measuring element 1, neither an increase in pressure loss following placement of the insulating material nor a reduction in pressure loss due to the

addition of hydrochloric acid was observed. With the rise in pH with the addition of sodium tetraborate, the pressure loss increased from the 0.2 kPa prior to the addition to 1.9 kPa, and just before the end of spraying, increased to 2.1 kPa. Fig. 4.5 shows the change in pH and the pressure loss over the entire test period. The temporary drop in pressure loss at 20 hours was due to valve operation accompanying a problem with the differential pressure gauge. The fluctuation in pressure loss was greater than that in pressure loss measuring element 1. After spraying, the pressure loss tended to decrease somewhat, but fluctuated between 1 kPa and 1.5 kPa through 600 hours. After 600 hours, a certain increasing trend was observed. At 788 hours, the approach flow velocity increased from 0.3 cm/s to 2 cm/s. The pressure loss at an approach flow velocity of 2 cm/s was 4.3 kPa, which was higher than the pressure loss of 1.7 kPa at the same approach flow velocity in pressure loss measuring element 1. There was a return to a flow rate with an approach flow velocity of 0.3 cm/s at 860 hours, but the pressure loss at that time was 0.7 kPa, which was lower than the value prior to changing the flow rate.

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Figs. 4.6 and 4.7 show the results of analysis of test water sampled from the piping and tanks. There was no marked difference in the analytic values of test water from the piping and tanks. The pH, at about 8.3 following the end of spraying, changed little. The Al concentration and Si concentration increased through about 300 hours, but then remained nearly constant. At the end of testing, they were 4.4 ppm and 14.9 ppm, respectively. The Ca concentration continued to increase during the test, reaching 19.5 ppm at the end of the test. This value was lower than the 30 ppm Ca concentration at the end of the test in ICAN-3. Further, in ICAN-3, the K concentration and the Mg concentration were 5 ppm and 0.3 ppm, respectively. However, in ICAN-4, they were 1 ppm and 3.5 ppm, respectively, reversing the trend.





[(left) Flow rate (L/min) (bottom) Time (h) (right) Temperature (°C)

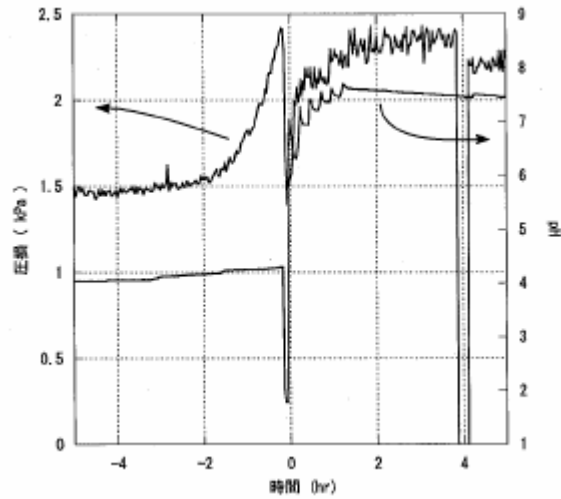
(top 3 lines)

- Test tank temperature (°C)
- Pressure loss measuring element 1 temperature (°C)
- Pressure loss measuring element 2 temperature (°C)

(bottom 4 lines)

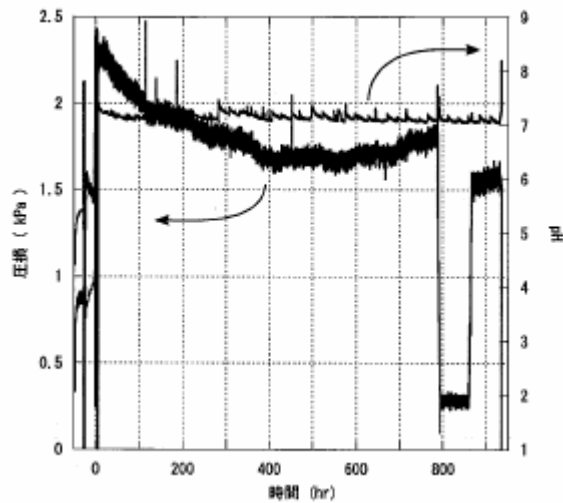
- Pressure loss measuring element 1 flow rate (L/min)
- Pressure loss measuring element 2 flow rate (L/min)
- Spray flow rate (L/min)
- Recirculation flow rate (L/min)]

Fig. 4.1 Flow rates and temperatures in ICAN-4. The flow rates and temperatures were stable during the test.



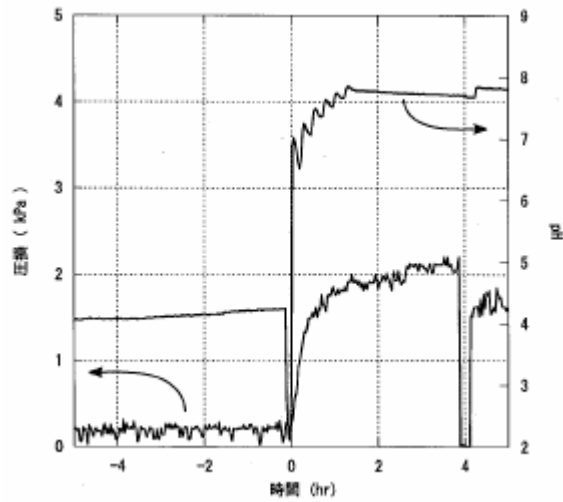
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.2 The relation between time, pressure loss, and pH in pressure loss measuring element 1 in ICAN-4.



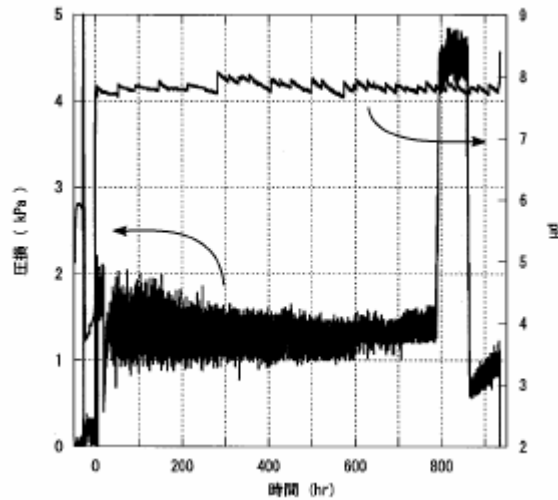
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.3 The relation between time, pressure loss, and pH in pressure loss measuring element 1 in ICAN-4.]



[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.4 The relation between time, pressure loss, and pH in pressure loss measuring element 2 in ICAN-4.



[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.5 The relation between time, pressure loss, and pH in pressure loss measuring element 2 in ICAN-4.

[(top1) --- pH in pressure loss measuring element 1 (top2) --- pH in pressure loss measuring element 2 (left) Concentration (ppm) (bottom) Time (h)

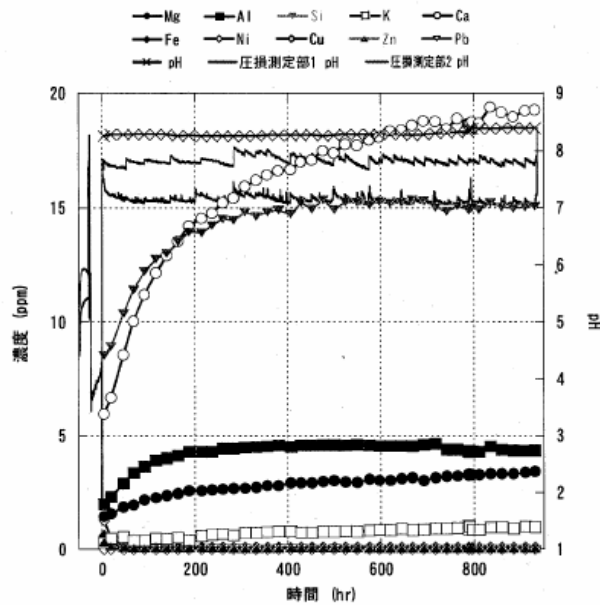
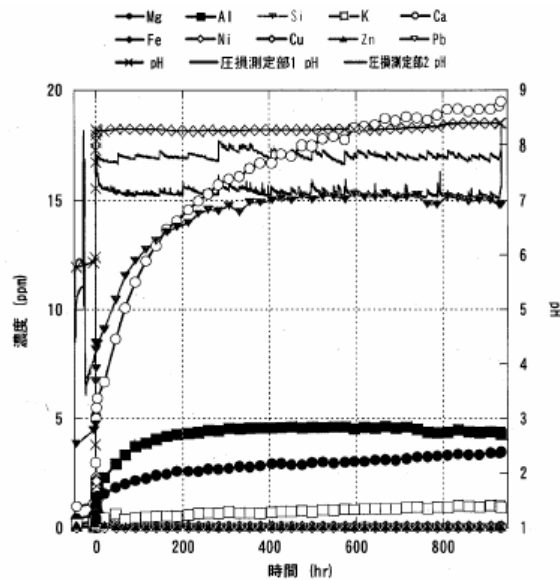


Fig. 4.6 The relation between the pH of test water samples from the piping and eluting elements in ICAN-4.



[(top1) --- pH in pressure loss measuring element 1 (top2) --- pH in pressure loss measuring element 2 (left) Concentration (ppm) (bottom) Time (h)]

Fig. 4.7 The relation between the pH of test water sampled from the tanks and eluting elements in ICAN-4.

#### 4.3.1.2 ICAN-5

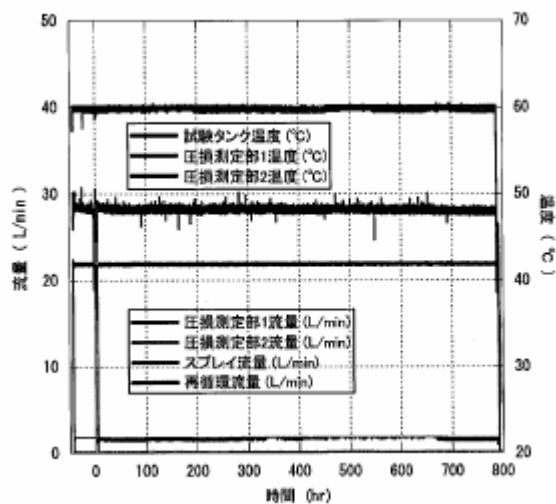
Fig. 4.8 shows the relation between the flow rate of pressure loss measuring element 1, the flow rate of pressure loss measuring element 2, the spray flow rate, the recirculation flow rate, the test tank temperature, the temperature of pressure loss measuring element 1, the temperature of pressure loss element 2, and the test duration. During the test period, values nearly identical to the settings were exhibited. Although there is no clear distinction with Fig. 4.8, with the start of spraying, the flow rate of pressure loss measuring element 1 dropped from 21.8 L/min to about 16 L/s [sic]. This was because a pressure regulating valve was provided at the recirculating pump outlet for the first time in ICAN-5 to protect the transparent vinyl chloride pipes of the pressure loss measuring elements, reducing the pressure applied to the pressure loss measuring elements. The recirculation flow rate was also maintained during spraying.

Fig. 4.9 shows changes in the pH and the pressure loss during 10 hours before and after spraying in pressure loss measuring element 1 (approach flow velocity of 2 cm/2). In the figure, the pH was obtained on line, and differs from the analytic value based on sampling. The pH of the test water to which boric acid and lithium hydroxide were added prior to spraying was 4.4 (analytic value). The pressure loss began to increase 3 hours after the start of spraying following placement of the simulated structural materials (coupons) and insulating material in the liquid phase portion, rising from the 0.67 kPa prior to placement to 1.6 kPa when the hydrochloric acid was introduced. At the point when hydrochloric acid was introduced just prior to spraying, the pH dropped to 2.4 (analytic value). This was accompanied by a decrease in the pressure loss to about the same level of 0.7 kPa prior to placement of the insulating material. This was accompanied by a decrease in the pressure loss to about the same level of 1.4 kPa prior to placement of the insulating material. The increase in pressure loss due to the placement of the simulated structural material and insulating material can be attributed to precipitation of corrosion products of the simulated structural materials and insulating material in the pressure loss measuring elements. Further, a decrease in pressure loss due to the addition of hydrochloric acid can be attributed to the dissolution of precipitates on the debris. Accompanying the decrease in the flow rate in pressure loss measuring

element 1 due to spraying, the pressure loss during spraying decreased to 0.6 kPa. The introduction of hydrazine during spraying caused the pH to rise to 7.5 (analytic value) at the end of spraying. No rise in pressure differential accompanied the rise in pH. Fig. 4.10 shows the change in pH and pressure loss over the entire test period. After the end of spraying, the pressure loss remained fairly constant at 0.9 kPa through 150 hours. Subsequently, there was sharp fluctuation in pressure loss. Through 550 hours, there was no marked increase in pressure loss. Subsequently, there was a slight increase in pressure loss; the pressure loss at 720 hours was 0.94 to 1.2 kPa.

Fig. 4.11 shows the change in pH and pressure loss during 10 hours before and after spraying in pressure loss measuring element 2 (approach flow velocity of 0.3 cm/2). The increase in pressure loss following placement of the insulating material and the decrease in pressure loss due to the addition of hydrochloric acid were smaller than those in pressure loss measuring element 1. In contrast to pressure loss measuring element 1, the pressure loss accompanying the rise in pH due to the addition of hydrazine during spraying increased from 0.15 kPa at 0 hours to 0.42 kPa at 4 hours. Fig. 4.12 shows the change in pH and the pressure loss during the entire test period. Following the end of spraying, the pressure loss through 150 hours was nearly constant, at 0.43 kPa. Subsequently, as the pressure loss climbed slightly to 0.45, sharp fluctuation occurred. Through 550 hours, there was no marked increase in pressure loss. Subsequently, there was a slight increase in pressure loss; the pressure loss through 720 hours was 0.49 to 0.67 kPa.

Figs. 4.13 and 4.14 show the results of analysis of test water sampled from the piping and tanks. There was no marked difference in the analysis levels of the test water from the piping and tanks. The pH following the end of spraying, at about 7.5, changed little. The concentration of Al remained nearly constant throughout the period of the test, at about 0.5 to 1 ppm, which was lower than the test in which boric acid and sodium hydroxide were employed (pH of about 10) and the test in which sodium tetraborate was employed (pH of about 8.3). The results reflect the fact that Al solubility is low in the neutral range. The Ca concentration continuously increased during the period of the test, reaching 30 ppm at the end of the test. The concentrations of Fe, Cu, and Zn were lower than 0.2 ppm.



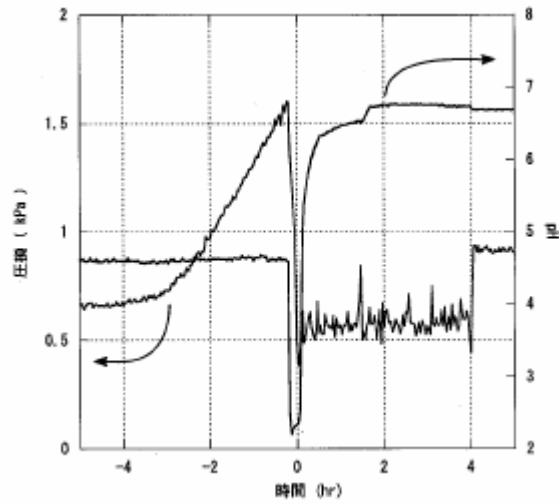
[(left) Flow rate (L/min) (bottom) Time (h) (right) Temperature (°C)  
(top 3 lines)

- Test tank temperature (°C)
- Pressure loss measuring element 1 temperature (°C)
- Pressure loss measuring element 2 temperature (°C)

(bottom 4 lines)

- Pressure loss measuring element 1 flow rate (L/min)
- Pressure loss measuring element 2 flow rate (L/min)
- Spray flow rate (L/min)
- Recirculation flow rate (L/min)]

Fig. 4.8 Flow rates and temperatures in ICAN-5. The flow rates and temperatures were stable during the test.



[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.9 The relation between time, pressure loss, and pH in pressure loss measuring element 1 in ICAN-5

[(left) Pressure loss (kPa) (bottom) Time (h)]

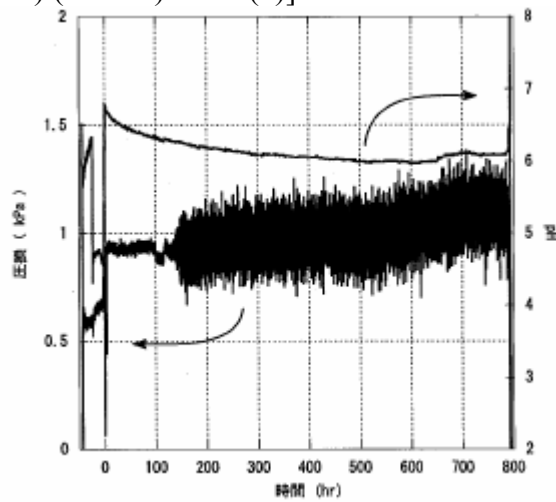
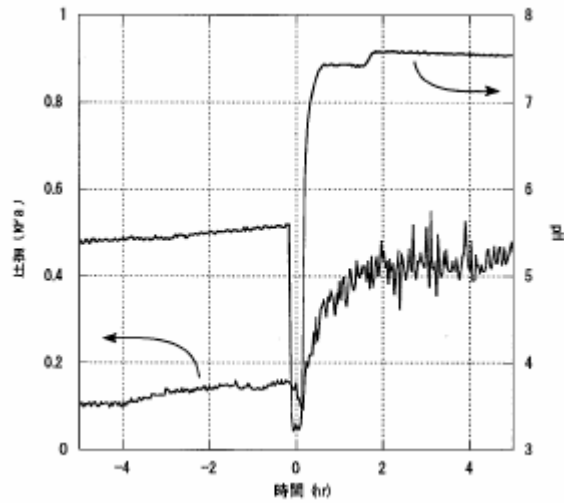


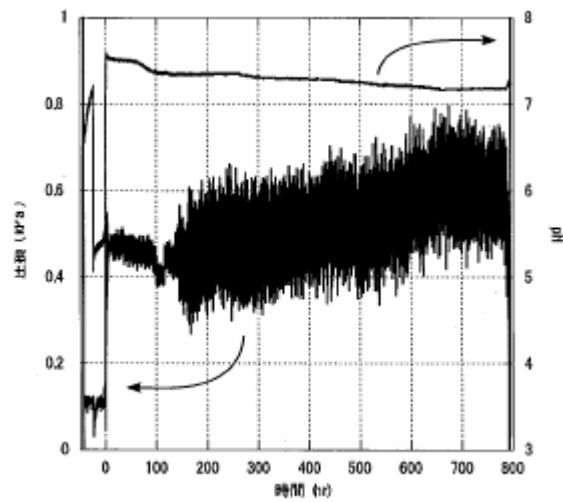
Fig. 4.10 The relation between time, pressure loss, and pH in pressure loss measuring element 1 in ICAN-5





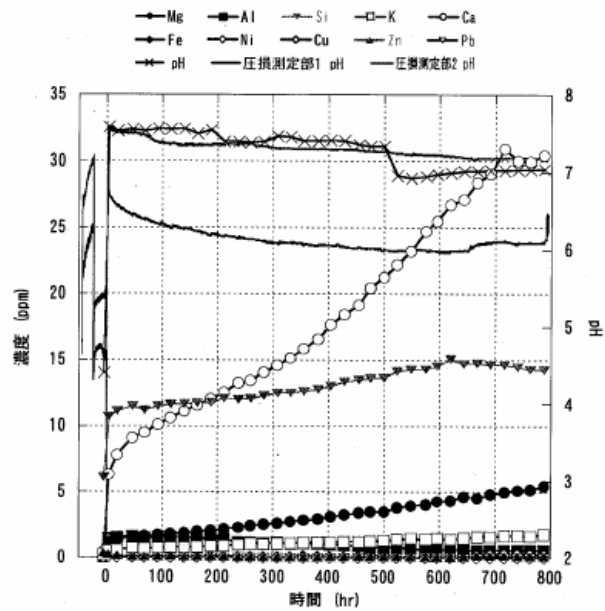
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.11 The relation between time, pressure loss, and pH in pressure loss measuring element 2 in ICAN-5

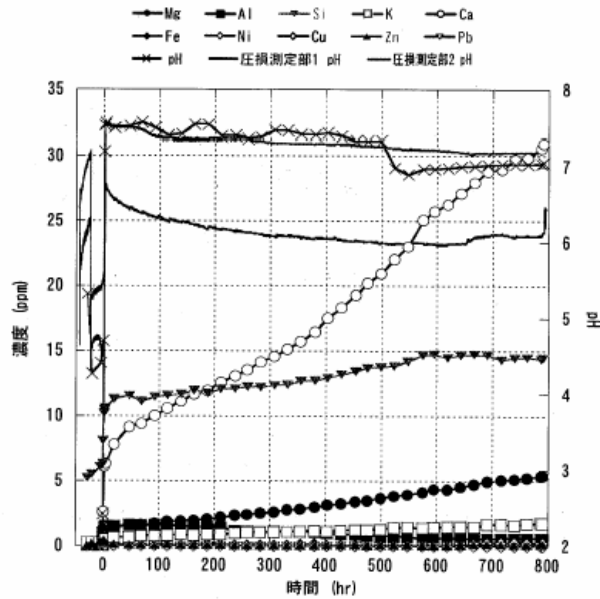


[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.12 The relation between time, pressure loss, and pH in pressure loss measuring element 2 in ICAN-5



[(top1) --- pH in pressure loss measuring element 1 (top2) --- pH in pressure loss measuring element 2 (left) Concentration (ppm) (bottom) Time (h)]  
 Fig. 4.13 The relation between the pH of test water samples from the piping and eluting elements in ICAN-5.



[(top1) --- pH in pressure loss measuring element 1 (top2) --- pH in pressure loss measuring element 2 (left) Concentration (ppm) (bottom) Time (h)]  
 Fig. 4.14 The relation between the pH of test water sampled from the tanks and eluting elements in ICAN-5.

#### 4.3.1.3 ICAN-6

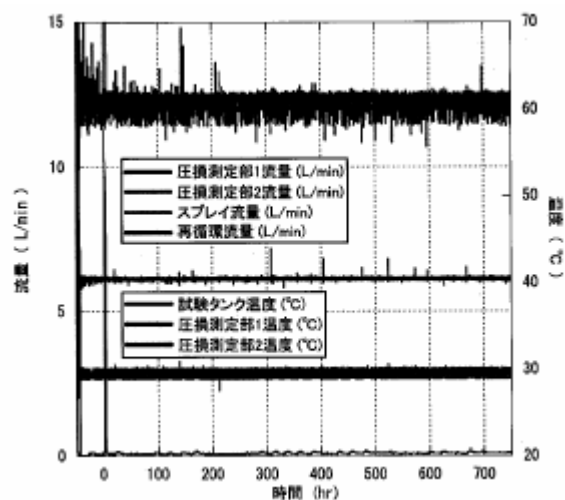
Fig. 4.15 shows the relation between the flow rate of pressure loss measuring element 1, the flow rate of pressure loss measuring element 2, the spray flow rate, the recirculation flow rate, the test tank temperature, the temperature of pressure loss measuring element 1, the temperature of pressure loss element 2, and the test duration. During the test period, values nearly identical to the settings were exhibited. Because the setting flow rates were low (Table 4.14), great fluctuation in the flow rate was exhibited relative to the other tests.

Fig. 4.16 shows the change in pressure loss and pH during 10 hours before and after spraying in pressure loss measuring element 1 (approach flow velocity of 0.56 cm/s). In the figure, the pH was picked up on line, and so varies from the analytic value obtained by sampling. The pH of the test water with the insulating material and structural material in place was 6.5 (analytic value), and the pH of the test water when hydrochloric acid was added just before spraying was 3.2 (analytic value). The pressure loss prior to addition of hydrochloric acid was 0.31 kPa. From the start of spraying to one hour, the pressure loss decreased slightly, but subsequently remained constant at about 0.26 kPa during spraying. Fig. 4.17 shows the change in pH and pressure loss over the entire test period. From the end of spraying to 100 hours, the pressure loss gradually decreased, reaching 0.23 kPa at 100 hours. Subsequently, there was sharp fluctuation in the pressure loss through 300 hours, but through the end of the test, there was little change in the pressure loss. The pressure loss at 720 hours was 0.21 to 0.26 kPa.

Fig. 4.18 shows change in the pH and pressure loss during 10 hours before and after spraying in pressure loss measuring element 2 (approach flow velocity of 0.56 cm/s). The pressure loss prior to the addition of hydrochloric acid was 0.34 kPa. At the same approach flow velocity, the pressure loss was greater than that of pressure loss measuring element 1. From the start of spraying to one hour, the pressure loss decreased slightly, and then remained nearly constant at 0.28 kPa during spraying. Fig. 4.19 shows the change in pH and pressure loss during the entire test period. From the end of spraying to 100 hours, the pressure loss gradually decreased, reaching 0.23 kPa at 100 hours. Subsequently, the pressure loss gradually dropped through 300 hours, and fluctuation in

the pressure loss became sharp at 350 hours. From 300 hours through the end of the test, the pressure loss varied little, reaching 0.17 to 0.25 kPa at 720 hours.

Figs. 4.20 and 4.21 show analysis results of test water sampled from the piping and tanks. There was no marked difference in the analytic values of test water from the piping and tanks. At 20 hours, the pH increased to 4.5, after which it gradually increased. At about 400 hours, it increased from 5.5 to 6.3. At about 630 hours, it dropped from 6.3 to 5.9. The increase in the pH was attributed to dissolution of insulating materials. The fluctuation in pH was attributed to the fact that since only hydrochloric acid was employed as a chemical, there was little buffering effect on the pH and the environment tended to have an effect. In this test, the Fe and Zn concentrations were high and the Si concentration was characteristically low. The Fe concentration continued to increase over the entire period of the test, reaching 38 ppm at the end of the test. The results correspond to the great solubility of Fe on the acid side. The Zn concentration increased to 15 ppm at one point, and then dropped, reaching 6.6 ppm at the end of the test. This was attributed to the decreased solubility of Zn as the pH increased. Accordingly, throughout the test, at least 8.4 g of zinc precipitated. The Si concentration was nearly constant following spraying, at 2 to 2.5 ppm. This was thought to be the result of the low solubility of Si on the acid side. Al was placed only in the gas phase portion, and not in the liquid phase portion. Thus, at the end of spraying, the Al concentration was 0.4 ppm, reaching 1.4 ppm at the end of the test. This was low compared to the other tests.



[(left) Flow rate (L/min) (bottom) Time (h) (right) Temperature (°C)  
(top 4 lines)

--- Pressure loss measuring element 1 temperature (L/min)

--- Pressure loss measuring element 2 temperature (L/min)

--- Spray flow rate (L/min)

--- Recirculation flow rate (L/min)

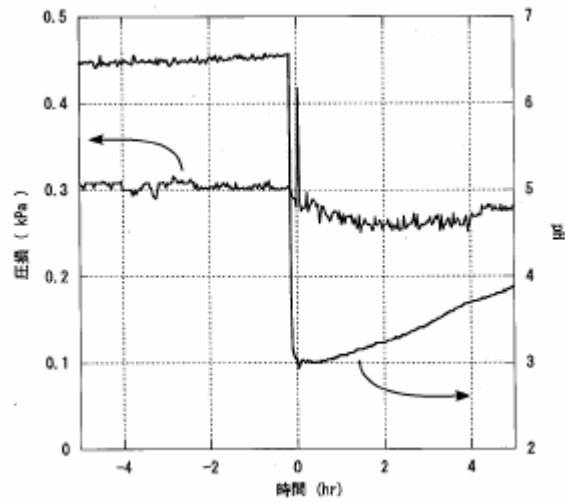
(bottom 3 lines)

--- Test tank temperature (°C)

--- Pressure loss measuring element 1 flow rate (°C)

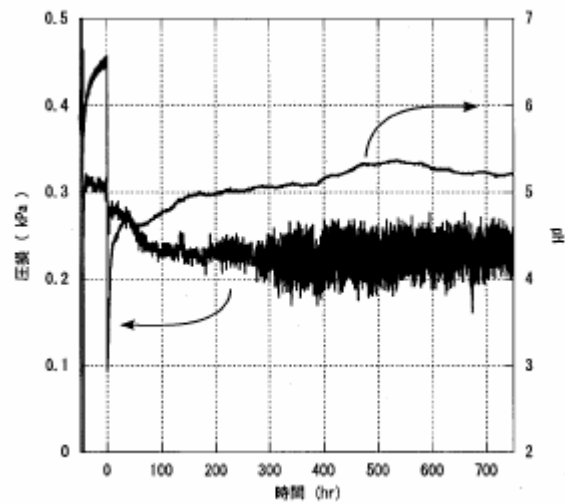
--- Pressure loss measuring element 2 flow rate (°C)

Fig. 4.15 Flow rates and temperatures in various elements in ICAN-6. The flow rates and temperatures were stable during the test.



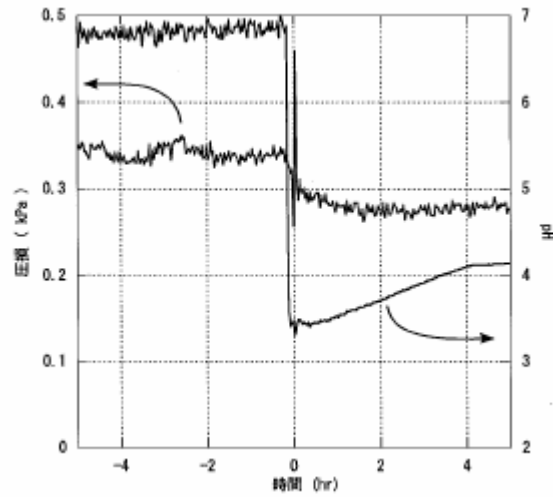
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.16 The relation between time, pressure loss, and pH in pressure loss measuring element 1 in ICAN-6.



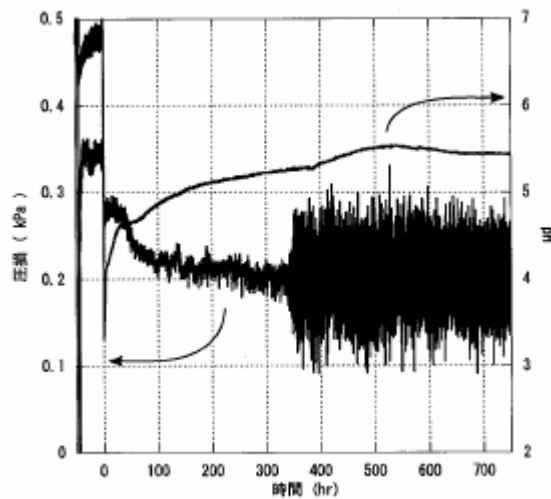
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.17 The relation between time, pressure loss, and pH in pressure loss measuring element 1 in ICAN-6.



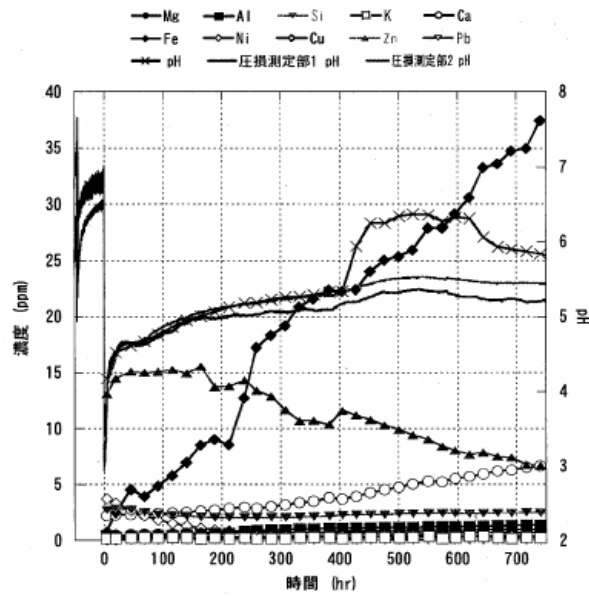
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.18 The relation between time, pressure loss, and pH in pressure loss measuring element 2 in ICAN-6.



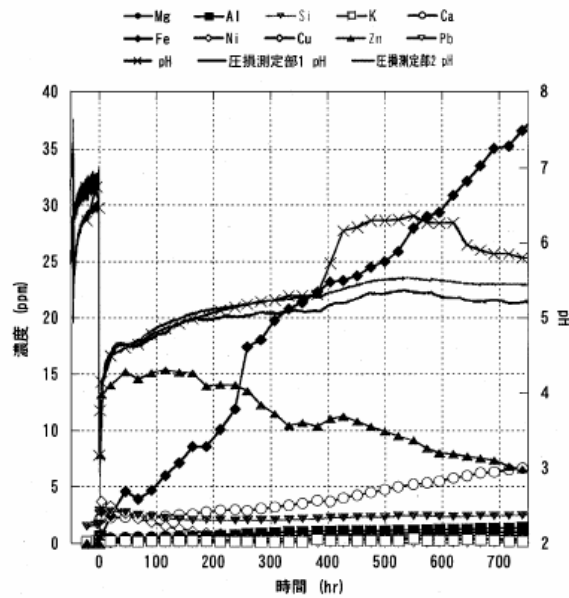
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.19 The relation between time, pressure loss, and pH in pressure loss measuring element 2 in ICAN-6.



[(top1) --- pH in pressure loss measuring element 1 (top2) --- pH in pressure loss measuring element 2 (left) Concentration (ppm) (bottom) Time (h)]

Fig. 4.20 The relation between the pH of test water samples from the piping and eluting elements in ICAN-6.



[(top1) --- pH in pressure loss measuring element 1 (top2) --- pH in pressure loss measuring element 2 (left) Concentration (ppm) (bottom) Time (h)]

Fig. 4.21 The relation between the pH of test water sampled from the tanks and eluting elements in ICAN-6.



#### 4.3.1.4. ICAN-7

Fig. 4.22 shows the relation between the flow rate of pressure loss measuring element 1, the flow rate of pressure loss measuring element 2, the spray flow rate, the recirculation flow rate, the test tank temperature, the temperature of pressure loss measuring element 1, the temperature of pressure loss element 2, and the test duration. Since the bypass valve was open only slightly prior to the start of spraying, the recirculation flow rate prior to hour 0 was about 23 L/min. Following spraying, the recirculation flow rate was maintained at a set level. With the start of spraying, the flow rate in pressure loss measuring element 1 decreased from the prescribed 21.8 L/min to about 18.5 L/s, as in ICAN-5. After completion of spraying, it was maintained at roughly the set level.

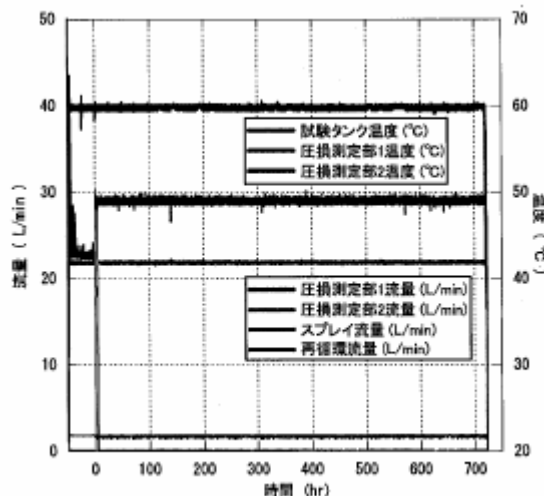
Fig. 4.23 shows the change in pressure loss and pH over 10 hours before and after spraying in pressure loss measuring element 1 (approach flow velocity 2 cm/s). The pH in the figure was picked up on line, and differs from the analytic value obtained by sampling. The pH of the test water to which lithium hydroxide and boric acid had been added was 5.9 (analytic value) prior to spraying. After placement of the simulated structural material (coupon) and insulating material in the liquid phase portion, the pressure loss began to increase at about four hours after the start of spraying, rising from 0.86 kPa prior to placement to 3.3 kPa up to the introduction of hydrochloric acid. At the point of the introduction of hydrochloric acid just prior to the start of spraying, the pH dropped to 2.7 (analytic value). Along with this, the pressure loss dropped to 1.3 kPa. The increase in pressure loss due to placement of the simulated structural material and insulating material was attributed to precipitation of corrosion products of the simulated structural material and insulating material in the pressure loss measuring element. The drop in pressure loss due to the addition of hydrochloric acid was thought to have occurred due to the dissolution of precipitates on the debris. The pH increased with the introduction of sodium hydroxide at the start of spraying. No increase in pressure loss accompanied the rise in pH; the behavior was identical to that in ICAN-3. At the end of spraying, the pH was 9.9 (analytic value) and the pressure loss was 1.6 kPa. Fig. 4.2.4 shows changes in pH and pressure loss during the entire test period. The behavior tended

to be close to that in ICAN-3. Once spraying had ended, the pressure loss decreased somewhat through 70 hours; the pressure differential at 70 hours was 1.4 kPa. After 70 hours, the pressure differential increased. The pressure loss at 720 hours (30 days) was 1.6 kPa.

Fig. 4.25 shows changes in pH and the pressure loss over 10 hours before and after spraying in pressure loss measuring element 2 (approach flow velocity of 0.3 cm/s). An increase in pressure loss was observed following placement of the insulating material, although it was not as great as in pressure loss measuring element 1. Due to placement of the insulating material, the pressure differential increased to 0.43 kPa from 0.26 kPa prior to placement. In contrast to pressure loss measuring element 1, the addition of hydrochloric acid caused the pressure loss to increase to 0.51 kPa. This difference was attributed to dry debris being produced in pressure loss measuring element 1 and wet debris being produced in pressure loss measuring element 2. As the pH climbed due to the addition of sodium hydroxide, the pressure loss increased to 0.72 kPa over the first hour, and then gradually dropped, and reaching 0.64 kPa at four hours. Fig. 4.26 shows the changes in pH and pressure loss over the entire test period. The fluctuation in pressure loss was greater than in pressure loss measuring element 1. The pressure loss decreased slightly through 100 hours, at which time it reached 0.55 kPa. Subsequently, the pressure loss increased through 300 hours and then tended to decrease, but there was no marked change. The pressure differential at 720 hours was 0.38 - 0.58 kPa.

Figs. 4.27 and 4.28 show the results of analysis of test water sampled from the piping and tanks. There was no marked difference in the analytic values of test water from the piping and tanks. The analytic results were identical to those in ICAN-3. The pH, at 9.8 to 9.9 following the end of spraying, changed little. The Al concentration and the Si concentration increased through about 250 hours, and then roughly leveled off. They were 5.3 ppm and 12.5 ppm, respectively, at the end of the test. The Ca concentration continuously increased through the test period, reaching 30 ppm at the end of the test. At the end of the test, the Cu, K, and Mg concentrations were 0.9 ppm, 3.2 ppm, and 0.9 ppm, respectively. Almost no Fe was detected, and Zn was 0.1 ppm or lower.

In ICAN-7, the behavior of the pressure loss in pressure measuring element 1 was identical to that in ICAN-3, but the behavior of the pressure loss in measuring element 2 differed from that in both ICAN-1 and ICAN-3. The debris in ICAN-1 was ripped to fine shreds by hand, and the debris in ICAN-3 was pulverized in a food processor. In ICAN-7, the debris in pressure loss measuring element 1 was pulverized in a food processor, and the debris in pressure loss measuring element 2 was finely shredded in a shredder, mixed with water, and still more finely shredded in a food processor. Although quantitative evaluation was not conducted, the debris employed in ICAN-1 was the coarsest, the debris employed in ICAN-3 and in pressure loss measuring element 1 in ICAN-7 was the next coarsest, and the debris employed in pressure loss measuring element 2 in ICAN-7 was the finest. Accordingly, the differences and similarities in pressure loss behavior in ICAN-1, 3, and 7 were thought to be the result of the fineness of the debris.



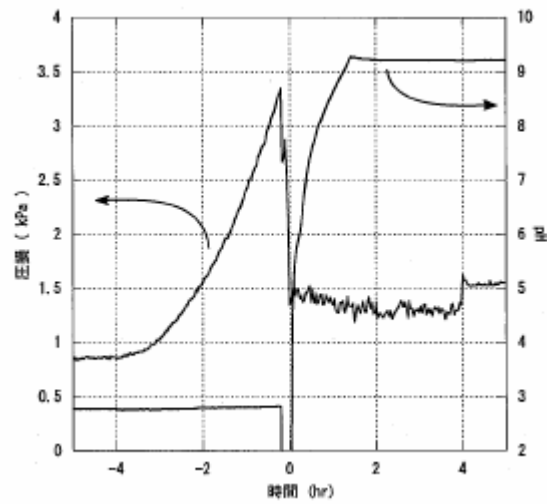
[(left) Flow rate (L/min) (bottom) Time (h) (right) Temperature (°C)  
(top 3 lines)

- Test tank temperature (°C)
- Pressure loss measuring element 1 temperature (°C)
- Pressure loss measuring element 2 temperature (°C)

(bottom 4 lines)

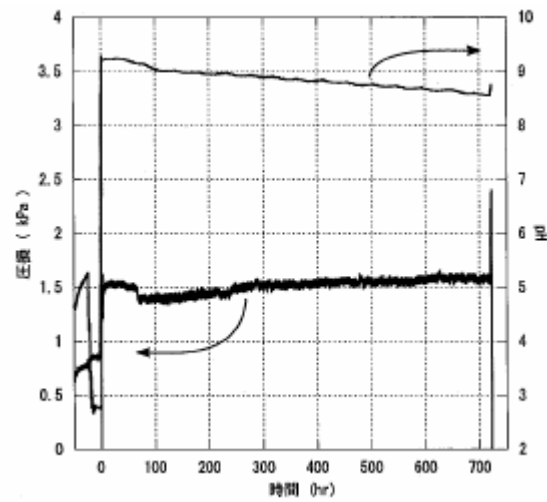
- Pressure loss measuring element 1 flow rate (L/min)
- Pressure loss measuring element 2 flow rate (L/min)
- Spray flow rate (L/min)
- Re-circulation flow rate (L/min)]

Fig. 4.22 Flow rates and temperatures in the various elements in ICAN-7.



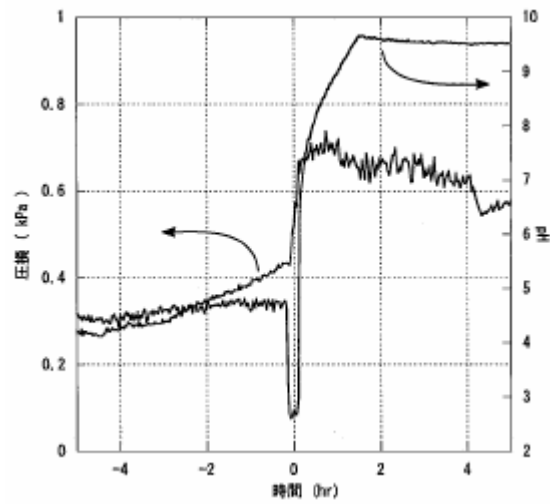
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.23 The relation between time, pressure loss, and pH in pressure loss measuring element 1 in ICAN-7.



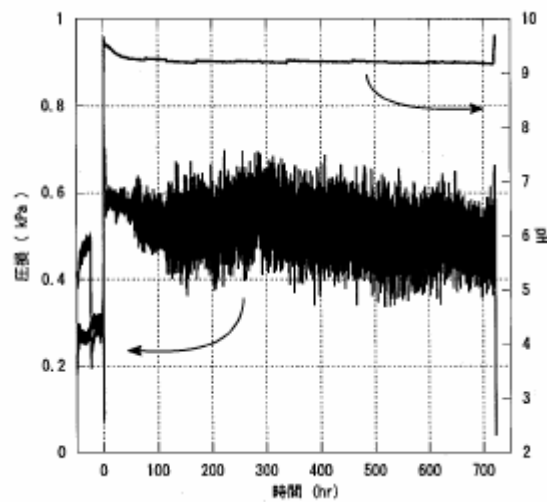
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.24 The relation between time, pressure loss, and pH in pressure loss measuring element 1 in ICAN-7.



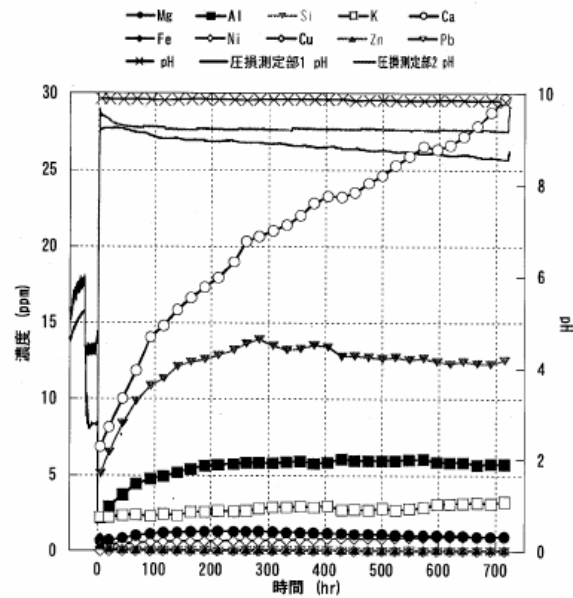
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.25 The relation between time, pressure loss, and pH in pressure loss measuring element 2 in ICAN-7.



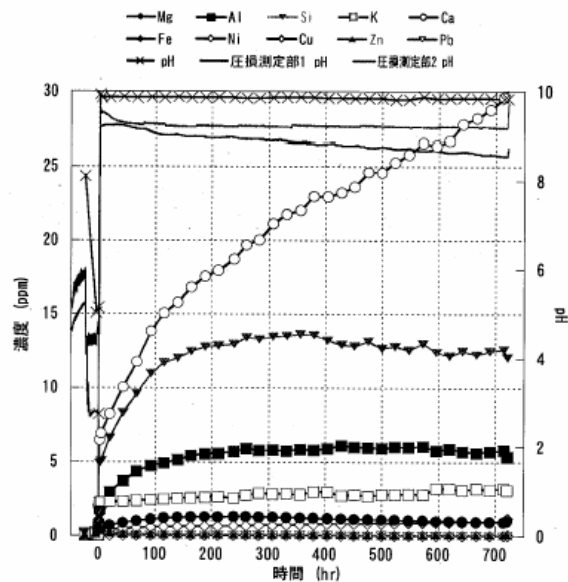
[(left) Pressure loss (kPa) (bottom) Time (h)]

Fig. 4.26 The relation between time, pressure loss, and pH in pressure loss measuring element 2 in ICAN-7.



[(top1) --- pH in pressure loss measuring element 1 (top2) --- pH in pressure loss measuring element 2 (left) Concentration (ppm) (bottom) Time (h)]

Fig. 4.27 The relation between the pH of test water samples from the piping and eluting elements in ICAN-7.



[(top1) --- pH in pressure loss measuring element 1 (top2) --- pH in pressure loss measuring element 2 (left) Concentration (ppm) (bottom) Time (h)]

Fig. 4.28 The relation between the pH of test water sampled from the tanks and eluting elements in ICAN-7.

#### 4.3.1.5 ICAN-8

Fig. 4.29 shows the relation between the flow rate of pressure loss measuring element 1, the flow rate of pressure loss measuring element 2, the spray flow rate, the re-circulation flow rate, the test tank temperature, the temperature of pressure loss measuring element 1, the temperature of pressure loss element 2, and the test duration. During the test period, values nearly identical to the settings were exhibited. Since it was conceivable that water flowing out of a broken pipe during LOCA would spray onto structural parts, corroding them, spraying was recommenced after 720 hours in a simulation of this to see what the effect would be. In this process, the flow rate in pressure loss measuring element 1 decreased from a prescribed 21.8 L/min to about 16 L/s. The re-circulation flow rate was maintained during spraying.

Fig. 4.30 shows the change in pressure loss and pH over 10 hours before and after spraying in pressure loss measuring element 1 (approach flow velocity 2 cm/s). Due to a problem with the pH meter in pressure loss measuring element 1, the pH in the figure was obtained by the pH meter in pressure loss measuring element 2. Further, the pH in the figure was picked up on line, and differs from the analytic value obtained by sampling. The pH of the test water to which boric acid and lithium hydroxide were added prior to spraying was 4.4 (analytic value). After placement of simulated structural materials (coupons) and insulating material in the liquid phase portion, the pressure loss began to rise three hours after the start of spraying, rising from 1.9 kPa prior to placement of the insulating material to 3.2 kPa at the introduction of hydrochloric acid. When hydrochloric acid was introduced just before spraying, the pH dropped to 2.4 (analytic value). At that point, the pressure loss temporarily rose to 4.5 kPa, but then dropped to 1.5 kPa at the start of spraying. The increase in pressure loss due to placement of the simulated structural materials and insulating materials was attributed to precipitation of corrosion products of the simulated construction materials and insulating materials in the pressure loss measuring element. The temporary rise in pressure loss due to the addition of hydrochloric acid was attributed to a temporary advance in corrosion due to the drop in pH, and the precipitation of corrosion products on the debris. The subsequent drop in pressure loss can be attributed to dissolution of the precipitates on the debris. With the

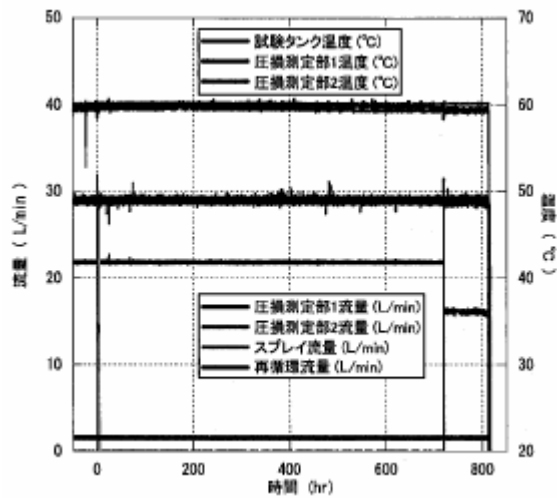
decrease in the flow rate of pressure loss measuring element 1 due to spraying, the pressure loss during spraying dropped to 0.7 kPa. The introduction of hydrazine during spraying caused the pH to rise to 7.5 (analytic value) at the end of spraying. There was no increase in pressure differential accompanying the rise in pH. At the end of spraying, with the return of the flow rate in the pressure loss measuring element, the pressure differential became 1.5 kPa. Fig. 4.31 shows changes in pH and pressure loss during the entire test period. At the end of spraying, the pressure loss continued to increase to 30 hours, reaching 2.0 kPa at 30 hours. Subsequently, the pressure loss remained roughly constant through 500 hours. Subsequently, the pressure loss began to rise, reaching 2.7 kPa at 720 hours. After 720 hours, spraying began. Since the flow rate of pressure loss measuring element 1 decreased, the value of the pressure loss decreased. However, there was no marked difference in the tendency of the pressure loss to increase.

Fig. 4.32 shows changes in the pH and pressure loss during 10 hours before and after spraying in pressure loss measuring element 2 (approach flow velocity 0.3 cm/s). There was almost no rise in pressure loss after placement of the insulating material nor change in the pressure loss due to the addition of hydrochloric acid. The pressure loss prior to the placement of the simulated structural materials and insulating materials was 0.21 kPa. The pressure loss at 0 hours was 0.22 kPa. Fig. 4.33 shows changes in pH and pressure loss during the entire test period. After the end of spraying, the pressure loss increased to 30 hours. The pressure loss at 30 hours was 0.62 kPa. Subsequently, the pressure loss remained nearly constant through 370 hours. Thereafter the pressure loss rose, reaching 2.3 kPa at 720 hours. Spraying was begun at 720 hours, but there was no marked difference in the tendency of the pressure loss to increase.

Figs. 4.34 and 4.35 show the results of analysis of test water sampled from the pipes and tanks. There was no marked difference between the analytic values of test water from the pipes and the tanks. The pH after spraying had ended, at about 7.3, changed little. The Al concentration was roughly 0.1 ppm or less during the test period after spraying; this was lower than in the test in which boric acid and sodium hydroxide were employed (pH of about 10) and in the test in which sodium tetraborate was employed (pH of about 8.3). The results reflect the fact that Al has low solubility in the neutral range. In ICAN-5, in which the same chemicals were added to the test water, no



zinc steel was placed. However, in ICAN-8, zinc steel was provided. Reflecting this difference, the level of Zn dissolution in ICAN-8 was high, reaching about 13 ppm at the end of the test. Additionally, the Ca concentration was not higher than in ICAN-5, and the Si concentration decreased as the Zn concentration rose. Zn was thought to affect the solubility of Ca and Si. The Cu concentration was 0.1 ppm or lower, and the Fe concentration was nearly 0.



[(left) Flow rate (L/min) (bottom) Time (h) (right) Temperature (°C)  
(top 3 lines)

- Test tank temperature (°C)
- Pressure loss measuring element 1 temperature (°C)
- Pressure loss measuring element 2 temperature (°C)

(bottom 4 lines)

- Pressure loss measuring element 1 flow rate (L/min)
- Pressure loss measuring element 2 flow rate (L/min)
- Spray flow rate (L/min)
- Re-circulation flow rate (L/min)]

Fig. 4.29 Flow rates and temperatures in the various elements in ICAN-8.