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PWR Sump Screen
Chemical Effect Test

JNES-SS Report

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Preface

The present report is a test report prepared by the Central Research Institute of Electric Power Industry as part of the Fiscal 2007 PWR Chemical Effect Assessment Test which the Japan Nuclear Energy Safety Organization commissioned from the Central Research Institute of Electric Power Industry in fiscal 2007.

Currently, modifications such as enlarging the screen are being made in various countries, including Japan, as a countermeasure to clogging of the sump screen,. The Chemical Effect Test implemented in fiscal 2007 included tests under various aqueous solution conditions, and is thought to have served as a reference, both by plants within Japan and in other countries. The aim of the present report is to permit the effective use of test data and render countermeasures to sump screen clogging more effective by publishing the test report of the Central Research Institute of Electric Power Industry early on as a JNES-SS report.

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1. Foreword

In 1992, a safety valve in the No. 2 reactor (a boiling light-water reactor (BWR)) at the Barseback Atomic Energy Electric Power Plant in Sweden opened, releasing pressurized steam into the dry well of the containment vessel. This resulted in a scram of the atomic reactor, and the emergency reactor core cooling system (ECCS) operated automatically. In this process, about 200 kg of rock wool insulation material that was covered with a metal jacket was stripped away by steam released by the safety valve. About 100 kg of this material flowed into the suppression pool, and a portion of this clogged the strainer of the suppression pool. This clogging caused a great loss of pressure ("pressure loss" below) in the strainer. Cavitation occurred in one of the ECCS pumps, compromising the ECCS function. This incident shows the possibility of loss of the ECCS function in all light-water reactors under similar circumstances. Accordingly, in the U.S., the NRC has imposed on BWR operators the obligation of enlarging the strainer to maintain the integrity of the ECCS, and has released General Safety Issue (GSI) 191 for pressurized light-water reactors (PWRs) in an effort to solve the problem.

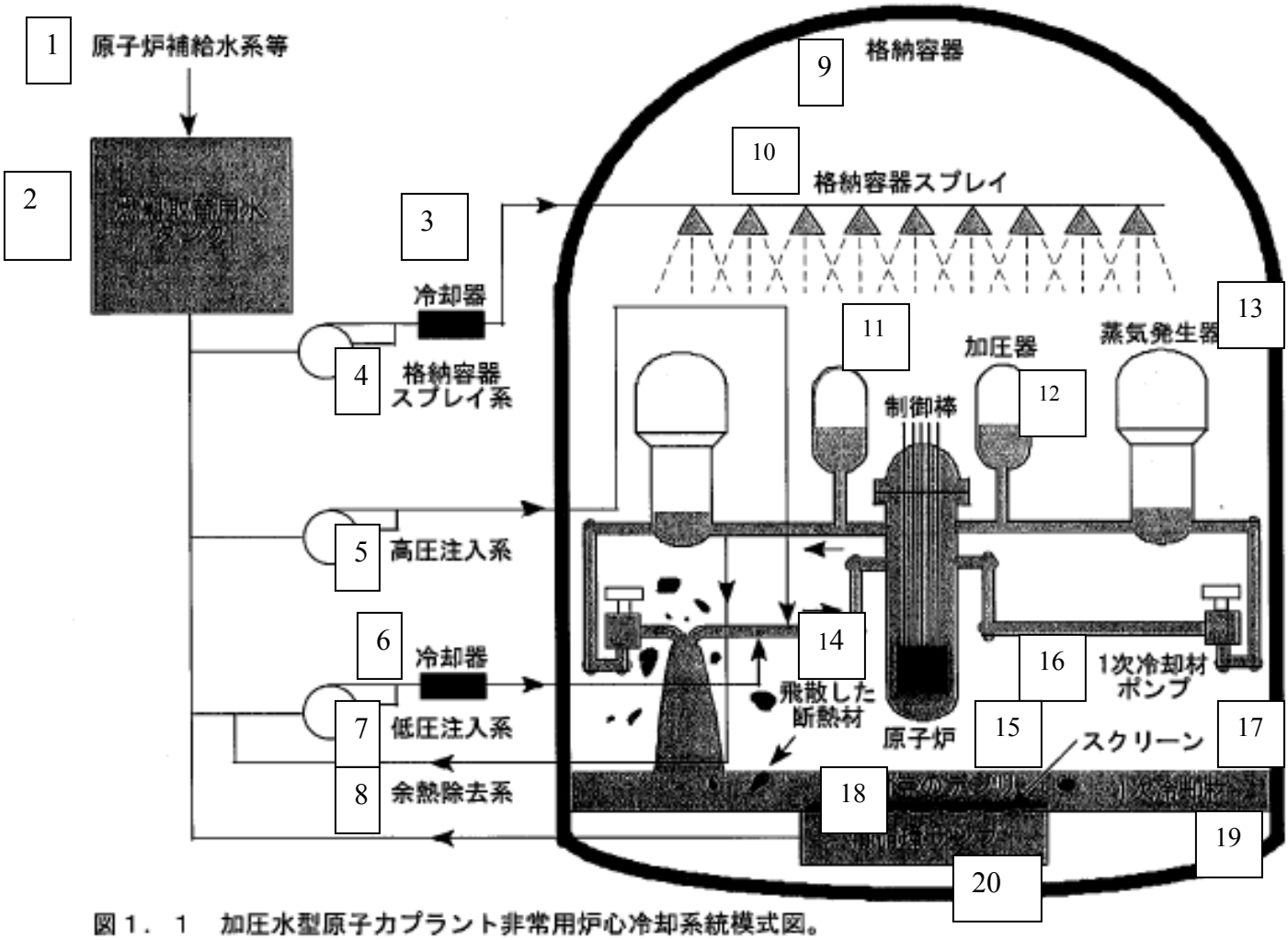

図１．１　加圧水型原子力プラント非常用炉心冷却系統模式図。

[Fig. 1.1]

[(1) Atomic reactor water supply system, etc. (2) Fuel replacement water tank (3) Cooling device (4) Containment vessel spray system (5) High-pressure injection system (6) Cooling device (7) Low-pressure injection system (8) Excess heat removal system (9) Containment vessel (10) Containment vessel spray (11) Control rods (12) Pressurizing device (13) Steam generating device (14) Scattered insulating material (15) Atomic reactor (16) Primary coolant pump (17) Screen (18) Debris such as insulating material (19) Primary coolant (20) Re-circulating sump (21)]

Fig. 1.1 Figure showing a model of an emergency reactor core cooling system at a pressurized water atomic power plant.

Fig. 1.1 shows a model of a loss of coolant accident (LOCA) caused by a pipe breaking in a PWR. Either a high-pressure injection system or low-pressure injection system is employed depending on the situation within the containment vessel. As shown in Fig. 1.1, the broken pipe causes insulation material and other substances (such as paint chips and concrete dust) to be damaged and separate. A portion of this then accumulates on the sump screen. The debris on the sump screen causes the pressure loss to increase to a degree that cannot be handled by the net positive suction head (NPSH), presenting the possibility of cavitation of the ECCS pump. With regard to such clogging of the pump

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screen, GSI-191 considers the chemical interaction between the coolant (water), structural items within the containment vessel, and insulating materials. In the accident at Three Mile Island in which the ECCS in Reactor No. 2 engaged, gelatinous substances thought to have been produced by chemical reactions on the floor and walls of the containment vessel were observed 153 days after the accident. It was pointed out that such chemical reaction products might have greatly increased the pressure loss. Accordingly, in the U.S., a number of projects have been undertaken by the NRC to evaluate chemical effects on the sump screen. As a study of the interaction between structural materials within the containment vessel and insulation materials with spray water and re-circulating water , the Los Alamos National Laboratory (LANL) conducts an integrated chemical effect test (ICET)[(1)]. A pressure loss test based on the results of the ICET is conducted at the Argonne National Laboratory[(2)]. Similar chemical effect assessment tests are also being conducted in France[(3)].

In Japan, a project for effectively evaluating PWR sump screens is being conducted by the Japan Nuclear Energy Safety Organization. The current study is being implemented as part of this project. This report discusses the typical insulation material corrosion tests, pressure loss tests, and integrated chemical effect tests that are being used in Japanese plants.

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2. Corrosion testing of insulation materials

2.1 Objectives

When considering the results of integrated chemical effect tests and pressure loss tests, it is necessary to have an adequate understanding of the leaching behavior of elements from insulating materials. Accordingly, the corrosion behavior of the rock wool insulating materials and calcium silicate insulating materials employed in Japan were investigated.

2.2 Methods

The insulating materials employed in the test were the rock wool insulating material Thermboard 1080 (Nippon Rockwool Corporation) and the calcium silicate insulating material Keical-Ace/Super-Silica (Nippon Keical Limited).

Sodium tetraborate solution, hydrazine solution, and a solution of hydrochloric acid in pure water, which is a BWR condition, were employed as corrosion test solutions. As in pressure loss tests and integrated chemical effect assessment tests, a food processor was used to cut and pulverize the insulating materials; heat treatment was not conducted.

Table 2.1 gives the test conditions. A prescribed quantity of insulating material was weighed out and placed in a 500 mL test tube. To this was added 500 mL of test solution, and the mixture was maintained at 60ºC for 3, 6, 24, 120, or 480 hours. Subsequently, the test solution was passed through a filter with a pore size of 0.45 μm. The pH was measured at room temperature and ICP emission analysis was conducted to determine the elemental concentration of Si, Al, Ca, Na, and Mg in the solution. After 24, 120, and 480 hours, the insulating material was filtered out with a 0.45 μm filter, and the filtrate was dried, and weighed. After weighing, the insulating material was washed with water, dried, and weighed again.

Table 2.1 Corrosion test conditions

Test No.	Insulating material	Weight (g)	N2H4 H2O	NaB4O7 10H2O	H3BO3	B	NaOH	HCI	Temp.	Sampling
		(g)	(g)	(g)	(g)	(ppm)	(g)	(g)	(ºC)	(h)
1	Rock wool	0.5		3.892	4.088	2312			60	3,6,24,120,480
2	Keical	0.5		3.892	4.088	2312			60	3,6,24,120,480
3	Rock wool	0.5	0.497		8.005	2800	0.091		60	3,6,24,120,480
4	Keical	0.5	0.497		8.005	2800	0.091		60	3,6,24,120,480
5	Rock wool	0.5						0.040	60	3,6,24,120,480
6	Keical	0.5						0.040	60	3,6,24,120,480

2.3 Results and Discussion

Table 2.2 and Figs. 2.1 and 2.2 give the corrosion test solution analysis results for rock wool and calcium silicate.

In the rock wool corrosion test, there was no major change in pH during the test period (Fig. 2.1). As the pH increased from hydrochloric acid solution (pH = 4.1) to hydrazine solution (pH = 7.5) to sodium tetraborate (pH = 8.3), the concentration of elements dissolving out increased (Fig. 2.1). The solubility of Gibbsite ($Al(OH)_3$) at pH 4.1, 7.5, and 8.3 was 3.7, 0.005, and 0.0034 ppm, respectively (Attached Fig. A.1). The Al concentration measured for these pH levels at 480 hours was 1.8, 4.2, and 5.6 ppm, respectively. Neither the solubility nor the pH dependency were constant. This showed that when seeking to determine the solubility of Al, the effects of ions and the like that are present must be taken into account. The solubility of quartz (SiO_2) at pH = 4.1, 7.5, and 8.5 was 2.8, 2.8, and 2.9 ppm, respectively (Attached Fig. A.3). This did not match the Si concentrations of 5.6, 9.4, and 12.4 that were measured at these pH levels, but the dependency of solubility on pH matched. For the sodium tetraborate solution and hydrazine solution, the element concentrations tended to increase even after 480 hours, indicating that dissolution progressed (Fig. 2.1).

In the calcium silicate corrosion test, with the exception of the test in HCl solution, the pH did not change substantially during the test period (Fig. 2.2). For the HCl solution, since the solution afforded little buffering effect, the pH increased to 9.2 over the first three hours after the start of the test (Fig. 2.2). The concentration of the dissolved elements was nearly constant when 120 hours had elapsed; as the pH of the test solution was increased, there was a reduction tendency (Fig. 2.2).

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Table 2.3 and Figs. 2.3 and 2.4 show the change in weight in rock wool and calcium silicate due to the corrosion test. For the sodium tetraborate solution and the hydrazine solution, washing with water produced a large reduction in weight that was attributed to the elimination of adhering salts (Figs. 2.3, 2.4). For the hydrochloric acid solution not containing salt, there was almost no difference in the reduction in weight due to washing with water (Figs. 2.3, 2.4).

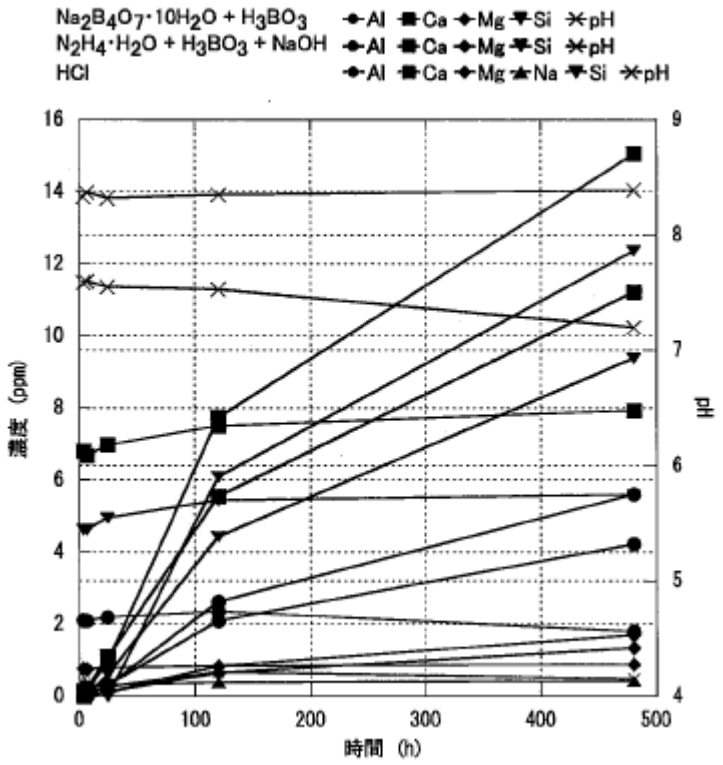
For rock wool, there was a smaller reduction in weight at 120 hours than at 24 hours (Fig. 2.3). This was attributed to chemical species that had dissolved in the

solution precipitating back out onto the insulating material. Since the trend of the measurement results for solubility (Fig. 2.1) differed from the trend for the time dependency of the change in weight, different compounds were thought to be involved in the dissolving substances and the precipitating substances.

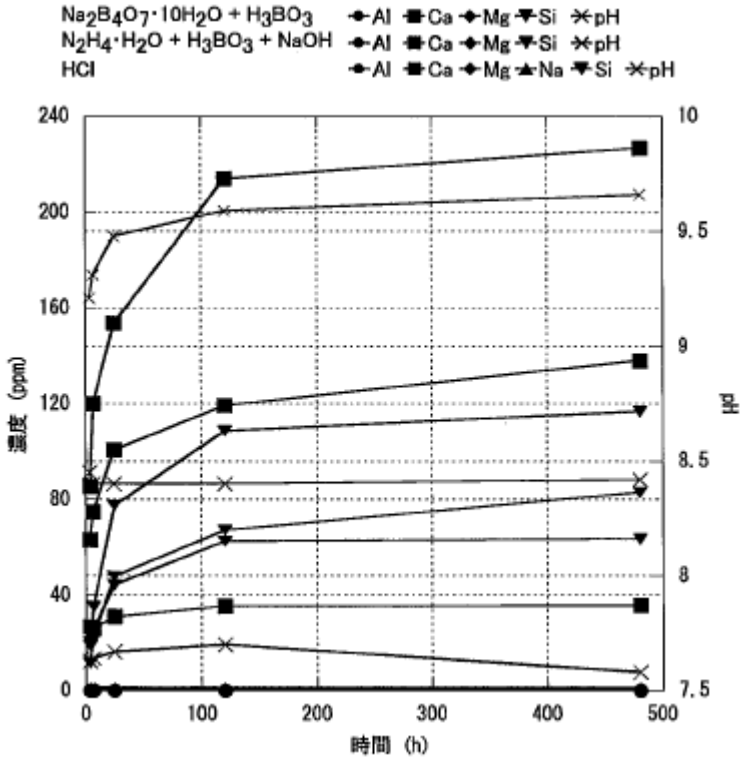
Calcium silicate underwent a much greater reduction in weight than rock wool (Fig. 2.4). The reduction in weight and the solution dependence of solubility were identical; a large reduction in weight was accompanied by high solubility (Figs. 2.2, 2.4). Additionally, since the trend of the measurement results for solubility (Fig. 2.2) differed from the trend for the time dependency of the change in weight, it is possible that for rock wool, as well, the substances that dissolved out may have precipitated as different compounds.

Table 2.2 Corrosion Test Analysis Results

Test No.	Solution	Sample	Time (h)	Al	Ca	Mg	Na	Si	pH
1	Na2Bo7	Rock	3	<0.05	<0.1	<0.05		<0.05	8.33
	10H2O+H3BO3	wool	6	<0.05	0.15	<0.05		<0.05	8.37
			24	0.30	0.97	0.11		0.56	8.32
			120	2.63	7.74	0.84		6.10	8.35
			480	5.60	15.05	1.70		12.37	8.39
2		Keical	3	<0.05	63.06	0.10		11.74	8.45
			6	<0.05	74.89	0.13		21.83	8.40
			24	<0.05	100.81	0.19		47.94	8.40
			120	<0.05	119.28	0.24		67.03	8.40
			480	<0.05	137.94	0.35		82.99	8.42
3	N2H4	Rock	3	<0.05	0.14	<0.05		<0.05	7.59
	H20+BO3+NaOH	wool	6	<0.05	0.23	<0.05		<0.05	7.60
			24	0.32	1.10	0.13		0.61	7.55
			120	2.10	5.55	0.65		4.44	7.53
			480	4.23	11.23	1.34		9.39	7.20
4		Keical	3	<0.05	85.64	0.15		20.45	7.63
			6	<0.05	120.19	0.21		35.36	7.64
			24	<0.05	153.76	0.31		77.48	7.67
			120	<0.05	214.10	0.44		108.70	7.70
			480	<0.05	226.7	0.49		116.92	7.58
5	HCI	Rock	3	2.11	6.80	0.77	0.25	4.62	4.21
		wool	6	2.10	6.67	0.76	0.25	4.62	4.04
			24	2.19	6.98	0.79	0.32	4.95	4.08
			120	2.35	7.51	0.84	0.38	5.44	4.21
			480	1.80	7.93	0.88	0.42	5.59	4.15
6		Keikal	3	<0.05	26.62	0.08	1.05	18.75	9.21
			6	<0.05	26.01	0.08	1.10	25.84	9.31
			24	<0.05	30.85	0.08	1.11	44.27	9.48
			120	<0.05	35.30	<0.05	1.23	62.42	9.59
			480	<0.05	35.64	<0.05	1.07	63.59	9.66



[Fig. 2.1]
[(left) Concentration (ppm) (bottom) Time (h)]
Fig. 2.1 Results of analysis of corrosion test solutions on rock wool



[Fig. 2.2]
[(left) Concentration (ppm) (bottom) Time (h)]
Fig. 2.2 Results of analysis of corrosion test solutions on calcium silicate

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[Table 2.3]
Table 2.3 Corrosion test weight changes

Test No.			Hours (h)	Weight reduction (g) After test	After water washing
1	Na2B4O7 10H2O+H3BO3	Rock wool	24	0.0728	0.0895
			120	0.0400	0.0506
			480	0.0601	0.0619
2		Keical	24	0.2823	0.3036
			120	0.2738	0.2894
			480	0.2338	0.2591
3	N2H4-H2O+H3BO3+NaOH	Rock wool	24	0.0286	0.0525
			120	0.0156	0.0325
			480	0.0425	0.0589
4		Keical	24	0.3172	0.3326
			120	0.2956	0.3327
			480	0.3442	0.3621
5	HCI	Rock wool	24	0.1116	0.1116
			120	0.0339	0.0305
			480	0.0382	0.0399
6		Keical	24	0.0989	0.1034
			120	0.1162	0.1144
			480	0.2022	0.2018

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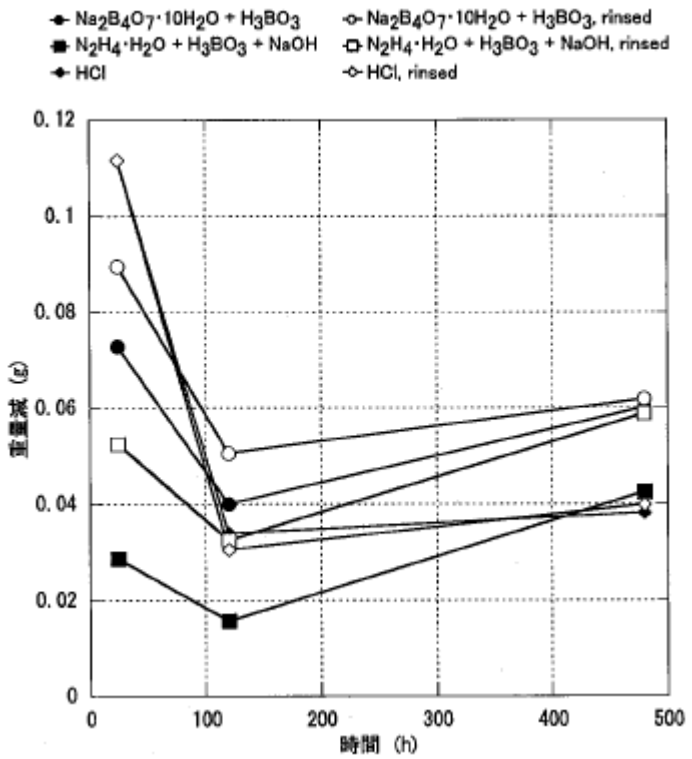
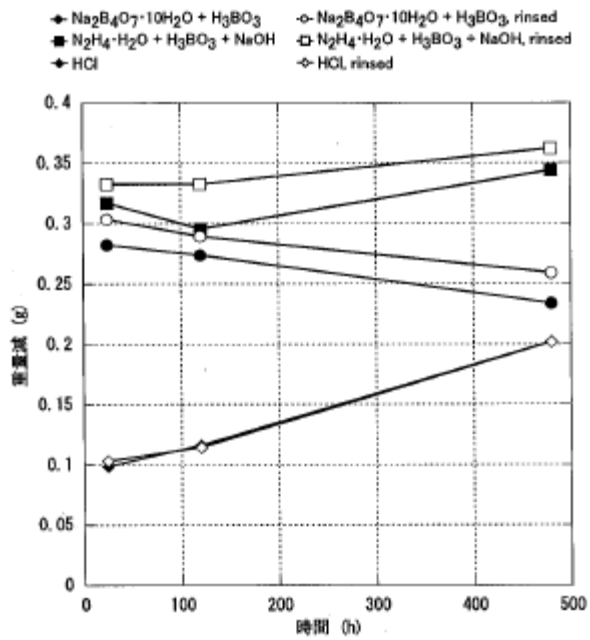


[Fig. 2.3]
[(left) Weight reduction (g) (bottom) Time (h)]

Fig. 2.3 Weight change in rock wool in corrosion test



[Fig. 2.4]
[(left) Weight reduction (g) (bottom) Time (h)]
Fig. 2.3 Weight change in calcium silicate in corrosion test`

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3. Pressure Loss Test

3.1 Objectives

An integrated chemical test (ICAN) is a long-term test in which the period of the test under actual reactor specification conditions can reach up to 30 days. Accordingly, element tests are required to examine ICAN test conditions and test methods in advance.

Thus, we conducted tests for determining ICAN subjects, preparatory tests prior to starting an ICAN, pressure loss tests employing various colloids, and water quality effect tests in pressure loss (PL) tests.

3.2 Test Conditions and Test Devices

3.2.1 Test conditions

Table 3.2.1 shows the test conditions. The test numbers were continued from the test numbers of 2006 (fiscal 2006 ended with PL#3.12).

Since wet rock wool was shown to exhibit a greater tendency to cause increased pressure loss than dry rock wool based on the test results of fiscal 2006[(4)], and since there

is actually a certain degree of variation in the approach flow rate of the sump screen, approach flow rate conditions were adopted in the form of 2 cm/s for dry rock wool and 0.37 cm/s for wet rock wool. See the report of fiscal 2006 for the calcium silicate particles and the methods used to produce the various rock wools.

(1) Repeated reproduction tests using calcium silicate (PL#3.13 to 3.15)

Repeated reproduction tests were implemented using calcium silicate. The test water was pure water. Rock wool that had been produced by a wet pulverization method was employed. In PL#3.15, calcium silicate was introduced after mixing up the wet rock wool provided in the area of pressure loss measurement to roughen the surface.

(2) Test of rock wool compression based on flow rate (PL#3.16)

In an actual reactor, there is a possibility that the flow rate may increase based on the operating mode of the pump and the spot on the screen, compressing the rock wool. To determine the effects of such compression based on flow rate, the flow rate was increased to compress the rock wool prior to introducing calcium silicate, after which the flow velocity was lowered to 0.37 cm/s in the same manner as in PL#3.13 to 3.15, and the amount of calcium silicate that caused a sudden increase in pressure loss was determined. The test water was pure water. Rock wool that had been produced by a wet pulverization method was employed.

(3) Pressure loss test employing pulverized rock wool (PL#3.17)

In an actual reactor, there is a possibility that rock wool that has passed through the screen will be finely pulverized by the impellor of the pump and be redeposited on the screen. To determine this effect, rock wool was stirred with a stirrer to obtain a finely pulverized product, this was caused to accumulate on the rock wool that had been wet pulverized, and a pressure loss test was conducted. A test was also conducted in which calcium silicate was introduced after causing the pulverized powder to deposit. The test water was pure water. Rock wool that had been produced by a wet pulverization method was employed.

(4) Pressure loss test employing various colloidal particles (PL#3.18)

From the results of the ICAN test of fiscal 2006, it was determined that the substance that gets trapped by the rock wool on the screen consists of colloidal microparticles comprised of Si, Al, Fe, Cu, and the like.

Thus, in the current fiscal year, independent hydroxides such as Fe, Cu, and Al that can be simply produced in a beaker test were produced, and a comparison was made with calcium silicate in terms of the amount introduced that caused a sudden increase in pressure loss. The test water was pure water. Rock wool that had been produced by a wet pulverization method was employed.

(5) Pressure lost test employing ICAN test solution (PL#3.19)

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One reason the pressure loss did not increase in the ICAN was thought to be that dry rock wool was employed. Thus, the test solution was sent to the PL device following the end of the ICAN test, wet pulverized rock wool was placed in the pressure loss measuring element of the PL device, and a pressure loss test was conducted.

(6) Pressure loss test II employing various colloidal particles (PL#3.20)

A pressure loss test was conducted using iron hydroxide, copper oxide, copper hydroxide, aluminum hydroxide, and calcium silicate prepared in the beaker test in continuation of PL#3.18. Rock wool quantities of 30 g and 59 g were employed and the effect of the quantity of rock wool on pressure loss was determined. Further, a pressure loss test was conducted in which iron nitrate and copper nitrate were introduced into the PL device, after which sodium hydroxide was introduced, and colloidal particles similar to those in the beaker test were produced within the PL device (produced *in situ*). The water employed was pure water.

(7) Tests of the effect of water quality (PL#3.21 to PL#3.23)

Pressure loss tests were conducted employing various colloidal particles in which the pure water employed as test water was replaced with (1) boric acid/sodium hydroxide, (2) sodium tetraborate/boric acid, and (3) hydrazine/boric acid/sodium hydroxide systems.

(8) ICAN#1 and #3 reproduction tests (PL#4.1 to PL#4.2)

Differences in pressure loss occurred in fiscal 2006 ICAN#1 (dry condenser type, with cooling and reheating) and ICAN#3 (dry condenser type, without cooling and reheating). It was thought that the reason might have been the effects of cooling and reheating. Thus, in this fiscal year PL, a reproduction test was implemented. The test method was as follows. A cooling device was employed downstream from the

circulating pump of the PL device, in the same manner as in the ICAN, and once the temperature of the test water had been lowered by about 6ºC, a heater located downstream from the cooling device was used for reheating. Since the test was conducted with a PL device, no carbon steel, copper, rock wool, or the like was employed.

(9) ICAN preliminary tests (PL#5.1 to PL#5.3)

A preliminary test was conducted in advance using PL device before ICAN tests #4 to #6. In the same manner as in PL#4.1 and PL#4.2, no carbon steel, copper, rock wool, or the like was employed in the tank.

3.2.2 Test devices

Figs. 3.2.2 and 3.2.3 show a system diagram and the external appearance of the pressure loss loop (PL device).

The temperature of test water of adjusted quality that had been stored in a water storage tank was raised with a heater by the circulating pump. The water passed through a water color pressure loss detection element, returning to the storage tank. A flowmeter downstream from the cooling device, a thermometer in the pressure loss measuring element, a differential pressure gauge, and a pH meter downstream from the pressure loss measuring element permitted continuous monitoring of the flow rate, temperature, pressure loss, and pH.

Currently, a debris inlet (a flan [ge] opening and closing type) has been provided for introducing debris such as calcium silicate and colloids between the heater and the pressure gauge. Under the basic test conditions, the quantity of test water is 300 L and the water temperature is 60ºC.

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3.3 Test Results

3.3.1 Repeated reproduction tests using calcium silicate (PL#3.13 to 3.15)

The test results are given in Figs. 3.3.1.1 to 3.3.1.2. When wet rock wool was employed in PL#3.14 and 3.15, the pressure loss increased sharply at a calcium silicate introduction quantity of 9.3 to 12.4 g; rough reproducibility was thought to exist.

In the case where the debris surface was roughened in PL#3.15, the introduction of 12.4 g of calcium silicate produced a sharp rise in pressure loss. This showed that, due

to the roughened up surface, 3.1 g more became necessary to cause the pressure loss to increase sharply.

By contrast, a sharp rise was achieved with 6.2 g of calcium silicate in PL#3.13. This was attributed to an increased flow rate and compression of debris when debris was utilized. Thus, a rock wool compression test based on the flow rate was conducted in section 3.3.2. Incidentally, the possibility of changes in flow rate occurring exists in actual reactors.

3.3.2 Test of rock wool compression based on flow rate (PL#3.16)

Figs. 3.3.2.1 to 3.3.2.3 show the test results. PL#3.16-1 is shown in Fig. 3.2.2.2 as a representative photograph of the test. When the flow velocity was increased to 3.7 cm/s, the rock wool did not return to its original state after being compressed, not even after the flow velocity was returned to 0.37 cm/s. Further, the pressure loss increased sharply when 3.1 g of calcium silicate was introduced. Fig. 3.3.2.3 collectively shows these results. Even when the flow velocity was set to 1.85 cm/s, the pressure loss rose sharply at 6.2 g of calcium silicate. At a flow velocity of 0.93 cm/s, the quantity of calcium silicate that had to be introduced to produce a sharp rise in pressure loss was 9.3 g. Thus, it was thought that at a flow velocity of 0.93 cm/s and lower, there was no rapid pressure loss increase effect due to compression of the rock wool.

3.3.3 Pressure loss test employing pulverized rock wool (PL#3.17)

Figs. 3.3.3.1 and 3.3.3.2 show the test results. As shown in PL#3.17-2 of Fig. 3.3.3.1, just pulverized rock wool did not produce a sharp rise in pressure loss, even when 30 g was introduced. This showed that rock wool alone did not cause an increase in pressure loss simply by being finely pulverized.

As shown in Fig. PL#3.17-1, the introduction of 3.1 g of calcium silicate after finely pulverizing 10 g of rock wool resulted in a sudden increase in pressure loss. This showed that pulverized rock wool powder caused a reduction in the surface voids of the rock wool, resulting in a tendency to be clogged by calcium silicate.

3.3.4 Pressure loss test employing various colloidal particles (PL#3.18)

Figs. 3.3.4.1 and 3.3.4.2 show how iron hydroxide and copper oxide were prepared in a beaker. Here, preparation was conducted by adding sodium hydroxide to

iron nitrate or an aqueous solution of copper nitrate that had been heated to 60ºC. The reaction equations are given below:

$Fe(NO_3)_3 + 3NaOH \rightarrow FeOOH + 3NaNO_3 + H_2O$

$Cu(NO_3)_2 + 2NaOH \rightarrow CuO + 2NaNO_3 + H_2O$

Fig. 3.3.4.3 shows an enlarged photograph of the iron hydroxide and copper oxide colloids thus prepared taken by scanning electron microscopy (SEM). The particle size of the iron hydroxide colloid was 0.1 to 0.2 μm, that of the copper oxide colloid was 0.2 to 0.4 μm, and for reference, that of the pulverized calcium silicate particles employed in the pressure loss test was several μm to several tens of μm. Following preparation, some of the colloids settled to the bottom of the beaker, so in some of the tests, 5 minutes of ultrasonic dispersion was conducted before testing.

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The results of the pressure loss tests conducted with these colloids are shown in Figs. 3.3.4.4 to 3.3.4.6. The quantities introduced that produced sharp increases in pressure loss were 0.6 to 1.0 g as Fe (1.0 to 1.6 g as FeOOH) for iron hydroxide and 3.3 to 4.2 g as Cu (4.1 to 5.3 g as CuO) for copper oxide. In both cases, an increase in pressure loss was produced by smaller quantities than for calcium silicate.

3.3.5 Pressure lost test employing ICAN test solution (PL#3.19)

Figs. 3.3.5.1 and 3.3.5.2 show the results of tests using the test waters of ICAN#5 to #7. In all cases, when wet rock wool was employed, the loss of pressure increased by 1 to 30 kPa in about 1 to 2 hours. In particular, the increase in the loss of pressure with ICAN#6 (BWR conditions) was quite large. There was the most suspended matter in the test water of ICAN#5. The reason the pressure differential was not raised by ICAN#6 might have been that the quantity of test water employed was 300 L.

3.3.6 Pressure loss test II employing various colloidal particles (PL#3.20)

(1) Figs. 3.3.6.1 to 3.3.6.8 show test results for the use of iron hydroxide, copper oxide, copper hydroxide, and aluminum hydroxide under pure water conditions. The reason copper hydroxide was added this time was that in the pressure loss test by the in situ method, described further below, the substance obtained when sodium hydroxide was introduced into an aqueous solution of copper nitrate was copper hydroxide. In preparation on a beaker scale, the temperature at the bottom of the beaker exceeded 60ºC,

so the copper hydroxide that was produced was thought to undergo a dehydration reaction, changing to copper oxide.

$Cu(OH)_2 \rightarrow CuO + H_2O$

Based on these pressure loss test results, the collective results for the relation between quantity introduced and pressure loss are given in Figs. 3.3.6.7 to 3.3.6.8. Thus, the results obtained were as follows:

① Even at a low flow velocity of 0.37 cm/s, wet rock wool produced an increase in pressure loss even when introduced in small quantities.

② Wet rock wool tended to produce a sudden increase in pressure loss relative to the quantity introduced.

③ The tendency for the pressure loss to increase was as follows: iron hydroxide > aluminum hydroxide > copper oxide, and copper hydroxide > calcium silicate.

④ A comparison of 59 g and 30 g of rock wool revealed no major difference with respect to the quantity introduced and the increase in pressure loss.

(2) Tests were then conducted for the additive property of the quantities introduced when various colloids were simultaneously introduced with calcium silicate. The quantity of various colloids and calcium silicate added at once were respectively halved, the components were mixed, and the mixture was introduced through the debris inlet. As a result, a sharp increase in pressure loss occurred when 1/2 the quantities of each that normally produced a sharp pressure loss were introduced. Thus, additive properties were found to exist for the quantities introduced.

(3) Even when colloids prepared in situ using metal salts of nitric acid were introduced, increases in pressure loss similar to those generated when colloids were prepared in beakers resulted.

For example, a comparison of copper hydroxide prepared by the in situ method and copper hydroxide prepared in advance in a beaker revealed that although the introduction of 7 g as Cu for dry rock wool and 3 g for wet rock wool produced a sharp increase in the pressure differential in the in situ method, the introduction of 6 g as Cu for dry rock wool and 2 g for wet rock wool produced the same when prepared in advance. This result showed that colloid prepared in advance in a beaker had roughly the same effect in increasing the pressure differential as colloid prepared by the in situ method.

3.3.7 Tests of the effect of water quality (PL#3.21 to PL#3.23)

The water quality of pure water was changed to (1) a boric acid/sodium hydroxide, (2) hydrazine/boric acid/sodium hydroxide, and (3) sodium tetraborate/boric acid systems and pressure loss tests were conducted with each of the various colloids. The test results are given in Figs. 3.3.7.1 to 3.3.7.7. Fig. 3.3.7.8 collectively shows the relation between the quantity introduced and the increase in pressure loss for four sets of water quality conditions, including pure water.

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① Wet rock wool produced an increase in pressure loss with the introduction of smaller quantities.

② Wet rock wool tended to produce a more sudden increase in pressure loss.

③ The tendency to increase the pressure loss was: iron hydroxide > aluminum hydroxide > calcium silicate.

There were cases in which copper hydroxide had a greater tendency to increase the pressure loss than iron hydroxide based on water quality for dry rock wool, so it was difficult to assign a position to this substance in the above sequence.

Further, when comparing water quality, the sodium tetraborate/boric acid system was thought to have a greater tendency to increase pressure loss, while the hydrazine/boric acid/sodium hydroxide system tended not to increase pressure loss.

3.3.8 ICAN#1 and #3 reproduction tests (PL#4.1 to PL#4.2)

The results of ICAN#1and #3 reproduction tests employing a PL device are given in Figs. 3.3.8.1 to 3.3.8.9. In PL#4.1.1, as shown in Fig. 3.3.8.2, a jelly-like substance appeared in marked fashion on the rock wool. This was thought to be the result of matter that had adhered to the heater separating when the hydrochloric acid was introduced and depositing on the rock wool. Thus, under [otherwise] indentical conditions, washing with hydrochloric acid was subsequently conducted during the device flushing implemented at the end of each test in PL#4.1.2. In PL#4.1.2, such jelly-like substances were not produced.

In PL#4.1.3, in testing duplicating PL#4.1.2, a large quantity of test water leaked from the pump, and the test was halted after the introduction of sodium hydroxide. However, the results up to that point were identical to those in PL#4.1.2.

In PL#4.2.1, the quantity of sodium hydroxide was large, causing a rise to pH 12, so PL#4.2.2 became a duplicate test of ICAN#3.

Thus, the collective results for change in pressure loss with the introduction of pure water, boric acid in water, and hydrochloric acid immediately after the introduction of sodium hydroxide, and for the introduction of sodium hydroxide, in the various tests with the exception of PL#4.1.1 are given in Table 3.3.8.1. When trends in these values for just pressure loss were examined, no major difference in change over time in pressure loss due to the presence or absence of cooling and reheating of the test water was observed. There were no major differences between the analysis results for the test water of the tests; all revealed a sharp increase in elements detected due to the introduction of hydrochloric acid. The approximate concentration following the introduction of hydrochloric acid was, in [descending] order, Ca, Si, Al, Mg, Fe. (In some cases, the Si concentration exceeded the Ca concentration.)

Further, following tests PL#4.1.2, #4.1.3, and #4.2.2, there was no major difference in the external appearance of the rock wool. On this basis, no [significant] difference was found in either the ICAN#1 and #3 reproduction tests employing a PL device.

3.3.9 ICAN preliminary tests (PL#5.1 to PL#5.3)

To determine whether there was a sharp increase in pressure loss in ICANs #4 to #6, preliminary tests were conducted. The test results are given in Figs. 3.3.9.1 to 3.3.9.6.

(1) In preliminary test PL#5.1 of ICAN#4, a gradual increase in pressure loss was observed in pure water and boric acid in water and a sudden drop in pressure loss was observed with the introduction of hydrochloric acid. When sodium tetraborate was introduced, the pressure loss gradually increased about 0.7 kPa over 20 hours.

Subsequently, the pressure loss gradually decreased.

Although the increase in pressure loss after the introduction of sodium tetraborate was relatively gradual, the analysis results of the test water and the external appearance of the rock wool following the test exhibited the same behavior as in reproduction tests PL#4.1.2 and 4.1.3 of ICAN#1.

(2) In preliminary test PL#5.2 of ICAN#5, the pressure loss gradually increased about 0.4 kPa over about 30 hours after the introduction of hydrazine and sodium hydroxide; this increase was more gradual and the amount of the increase was smaller than in the ICAN#4 preliminary test. The test water analysis results and the external appearance of the rock wool after the test were similar to the results in PL#5.1.

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(3) In the ICAN#6 preliminary test, although the pressure loss decreased somewhat following the introduction of hydrochloric acid, the change was not major and no jelly-like slime was observed on the rock wool following the test.

3.4 Discussion

3.4.1 Causes of increase in pressure loss

The following results were obtained from the fiscal 2006 tests:

(1) When the rock wool packing density increases, the quantity of calcium silicate producing a sharp increase in pressure loss decreases.

(2) The deposition of calcium silicate on rock wool has a greater tendency to produce an increase in pressure loss than when rock wool and calcium silicate are mixed.

(3) For rock wool alone, both boric acid and sodium hydroxide cause in increase in pressure loss. Components leaching out of the rock wool may be caused to precipitate back out by these chemicals.

(4) Since sodium hydroxide works to dissolve calcium silicate, the pressure loss tends not to increase when sodium hydroxide is added to the test water.

(5) The larger the quantity of rock wool and the more rapid the flow rate, the smaller the quantity of calcium silicate that causes a sharp increase in pressure loss becomes.

(6) Components leaching out of the rock wool and the calcium silicate react with each other to produce precipitates that cause an increase in pressure loss. However, at the current stage, it is several kPa or less, and no sudden increase in pressure loss occurs.

(7) Rock wool compresses when the pressure loss increases, trapping small diameter particles and further increasing the pressure loss. Thus, there is thought to be a tendency for a sharp increase in pressure loss to occur. Due to plastic deformation,

when a large pressure loss occurs, there is a tendency not to return to the original state even when the pressure loss is reduced.

Additional results and discussion for the current fiscal year tests are given below.

(8) Wet rock wool at a flow velocity of 0.37 cm/s has a greater tendency to increase the pressure loss than dry rock wool at a flow velocity of 2 cm/s; the method of manufacturing rock wool is a major factor in increased pressure loss.

(9) Similar increases in pressure loss are exhibited for quantities of rock wool ranging from 30 to 59 g. As is also clear from the results of rock wool pulverized powder introduction tests and tests in which wet rock wool was introduced onto dry rock wool, an increase in pressure loss tends to occur when the surface of the rock wool on the screen becomes dense.

(10) When rock wool is compressed by the water flow, the introduction of a small quantity tends to produce a sharp pressure loss. This effect does not occur at a flow velocity of about 1 cm/s, but begins to occur at about 2 cm/s. That is, at a flow velocity of 2 cm/s, the rock wool is thought to be compressed by the water flow and undergo plastic deformation.

(11) Colloidal particles have a greater tendency to cause an increase in pressure loss than calcium silicate. This varies by substance; iron hydroxide and aluminum hydroxide have a greater tendency to cause an increase in pressure loss than calcium silicate. Generally, microparticles with great compressibility (for example, viscous microparticles) have a greater tendency to cause an increase in pressure loss than particles with little compressibility (for example, sand). This is because great compressibility results in small voids between particles, preventing liquid flow. The iron hydroxide, aluminum hydroxide, and the like prepared this time were not floc-like, but they had a low precipitation property. As a result, since the stationary bulk density was low, the compressibility was thought to be greater than calcium silicate, copper oxide, and the like.

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(12) Although the pressure loss increased more rapidly in ICAN tests in which dry rock wool was employed than in ICAN tests in which test water was employed, regardless of the test fluid employed in PL, there was an increase of about 1 kPa

over about 2 hours for wet rock wool. When colloids were employed in PL device tests, there were cases in which the pressure loss stopped climbing with dry rock wool. Even when comparing wet and dry types at an identical flow velocity (2 cm/s) in ICAN#8.5, the wet rock wool clearly had a greater tendency to clog.

Further, in PL employing calcium silicate particles, the drop in pressure did not stop climbing for dry rock wool.

This was attributed to the following causes:

(a) Dry rock wool

Colloidal particles produced in ICAN tests and their aggregate particles tended not to be trapped by dry rock wool. The reason for this was that large voids are produced in dry rock wool, and a portion of the test water passes through these voids. The colloidal particles initially enter and pass through the interior of rock wool that is in the form of fiber clumps, but are trapped by the rock wool, clogging the passages, and then begin passing through the voids.

Since colloidal particles are free particles, they ride the current and pass through the voids, and thus do not bury the voids.

However, calcium silicate consists of large particles that have settling properties. They thus tend not to enter into the interior, but settle out and deposit in the voids of rock wool, burying the voids. They tend not to pass through the rock wool, and are thus trapped by the rock wool, increasing the pressure loss.

(b) Wet rock wool

In wet rock wool, there are few of the voids found in dry rock wool. Accordingly, colloidal particles enter the interior of the rock wool and begin to deposit in the vicinity of the surface, producing a great loss in pressure in only small quantities. In particular, iron hydroxide, with its great compressibility, tends to bury the microvoids during compression, exhibiting a high pressure loss in only small quantities.

Further, since calcium silicate consists of large particles, it tends not to enter into the interior. However, due to its high compressibility, it tends not to enter microvoids, requiring the introduction of a larger quantity than colloidal particles to produce a high pressure loss.

(13) As regards water quality, based on the current test results, sodium tetraborate had an overall tendency to increase pressure loss, while hydrazine tended not to produce an increase. As set forth further below, this was attributed to the solubility of Cu and Al being lowest in the vicinity of the pH of sodium tetraborate, pH 9, and being highest in the vicinity of the pH of hydrazine, pH 7. That is, for hydrazine, a portion of the hydroxide that is introduced dissolves, so that a large quantity must be introduced to cause a sharp increase in pressure loss.

For pure water, the pH rises above 7 when the hydroxide that is introduced dissolves, effectively increasing the pH to greater than 7.

There is not necessarily a match with ICAN results. However, a pressure loss of at most several kPa is produced by any water quality in an ICAN, there being little difference between water qualities. However, the generation of colloidal particles by coupons and rock wool, in terms of the appearance of the test water, was hydrazine > sodium tetraborate > pure water + HCl > boric acid. When these are trapped by the screen, the pressure differential should rise in an order such as that given for the PL test results.

That is, hydrazine, which tends to corrode metals such as iron, tends to form

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colloidal particles in water qualities such as pure water + HCl, and is not thought to be suitable as a water quality.

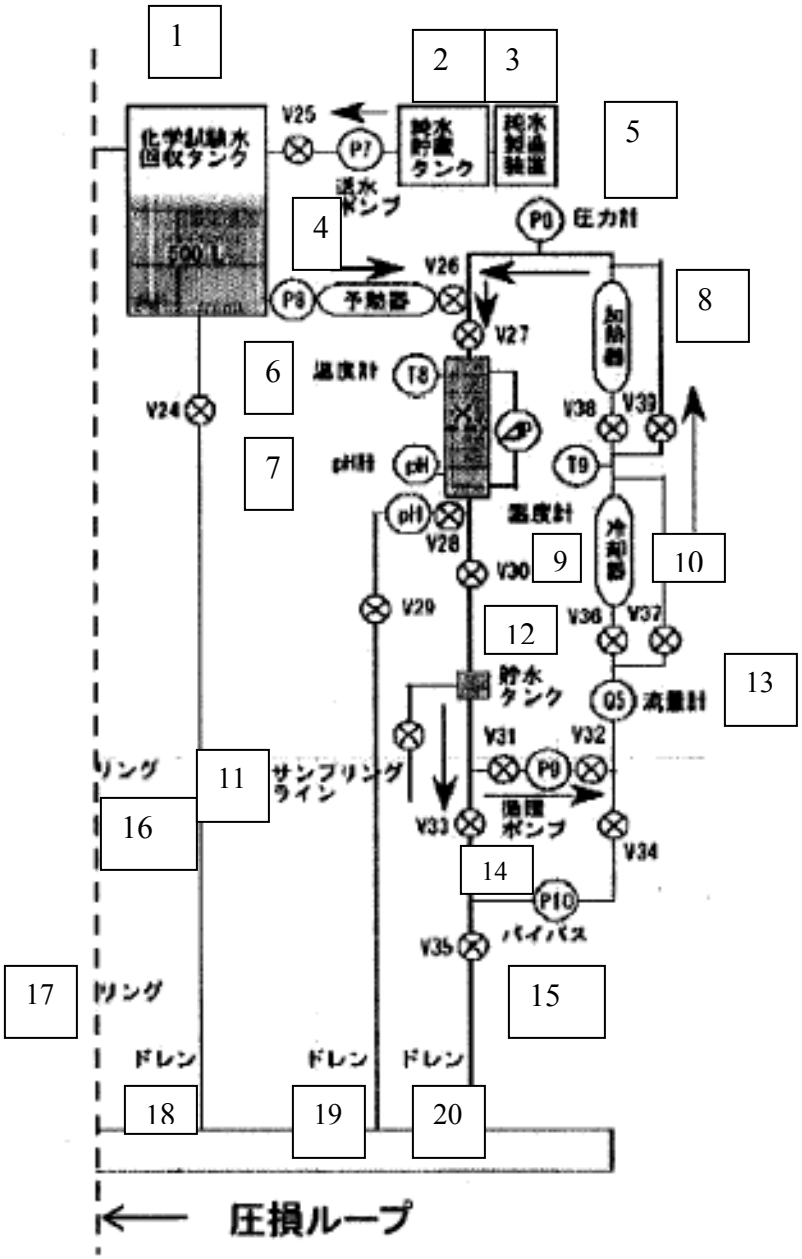
Table 3.2 PL test conditions

No.	Test. No.	Debris Rock wool		Calcium silicate	Colloid			Test solution		Flow rate (flow velocity)	Objective
		Production method	Qty. employed (g)	Qty. employed (g)	Substance	Production method	Qty. employed (g)		Chemical	L/min (cm/s)	
1	3-13-1	Wet		3.1 each				pure water	none	4(0. 37)	Reproducibility test of increase in pressure loss by introduction of calcium silicate
2	3-13-2		59	1.55 to 3.1 each							
3	3-14		59	3.1 each							
4	3-15-1		59	3.1 each							
5	3-15-2		59	3.1 each							
6	3-16-1	Wet	59	3.1 each	compressed flow velocity 3.7 cm/s x compression time 1 hour			pure water	none	4(0. 37)	Effect of flow rate on rock wool compression
7	3-16-2		59		compressed flow velocity 1.85 cm/s x compression time 1 hour						
8	3-16-3		59		compressed flow velocity 0.93 cm/s x compression time 1 hour						
9	3-16-4		59		compressed flow velocity 3.7 cm/s x compression time 5 minutes						
10	3-16-5		59		compressed flow velocity 3.7 cm/s x compression time 0.5 minute						
11	3-16-6		59		compressed flow velocity 1.85 cm/s x compression time 5 minutes						
12	3-17-1	Wet	59	3.1 each after introducing pulverized rock wool powder		pure water		pure water	none	4(0. 37)	Effect of micro rock wool
13	3-17-2		59	Only rock wool pulverized powder							
14	3-18-1	Wet	59	0	iron hydroxide	prepared in advance	0.2 to 0.4 each	pure water	none	4(0. 37)	Effect of colloidal particles
15	3-18-2		59	0			0.2 to 0.4 each			4(0. 37)	
16	3-18-3		59	0			0.2 to 0.4 each			4(0. 37)	
17	3-18-4		59	0			0.2 to 0.4 0each			4(0. 37)	

18	3.18-5		59	0	copper oxide		0.3 to 0.6 each			4(0. 37)	
19	3.18-6		59	0			0.6 to 1.2 each			4(0. 37)	
20	3.19-1	Wet	59	0				ICAN#5 test water	none	4(0.37) 21.76(2)	Comparison of wet and dry methods
21	3-19-2-1		30	0				ICAN#6 test water	none	6.09(0.51)	Comparison of wet and dry methods
22	3-19-2-2		30	0							
23	3-19-3		59	0				ICAN#7 test water	none	21.76(2)	Comparison of wet and dry methods in compression measuring element 1
24	3-20-1	Dry	59	0	iron hydroxide	prepared in advance	0.2 to 0.4 each	pure water	none	21.76(2)	Comparison of various colloidal particles in a pure water system; comparison of wet and dry rock wools; the effect of the quantity of rock wool
25	3-20-2		59	0	iron hydroxide		0.4 to 0.8 each			21.76(2)	
26	3-20-3		59	0	copper oxide		1.0 each			21.76(2)	
27	3-20-4		30	0	copper oxide		1.0 to 2.0 each			21.76(2)	
28	3-20-5		59	0	copper hydroxide		1.0 to 2.0 each			21.76(2)	
29	3-20-6		59	0	aluminum hydroxide		0.5 to 1.0 each			21.76(2)	
30	3-20-7		30	0	aluminum hydroxide		0.5 each			21.76(2)	
31	3-20-8	Wet	30	0	iron hydroxide	prepared in advance	0.2 to 0.4 each	pure water	none	4(0. 37)	
32	3-20-9		30	0	copper oxide		1.0 each			4(0. 37)	
33	3-20-10		59	0	copper hydroxide		0.5 to 1.0- each			4(0. 37)	
34	3-20-11		59	0	aluminum hydroxide		0.4 each			4(0. 37)	
35	3-20-12		30	0	aluminum hydroxide		0.4 each			4(0. 37)	
36	3-20-13-1	Wet	59	3.1 each mixed with iron hydroxide	iron hydroxide	prepared in advance	0.2 each	pure water	none	4(0. 37)	Determination of whether an additive property exists for calcium silicate and colloids.
37	3-20-13-2		59	1.55 each mixed with iron hydroxide	iron hydroxide		0.1 each				
38	3-20-14		59	1.55 each mixed with	copper oxide		0.7 each				

				copper oxide							
39	3-20-15		59	1.55 each mixed with aluminum hydroxide	aluminum hydroxide		0.2 each				
40	3-20-16	Dry Wet	30 10	3.1 each				pure water	none	4(0. 37)	Comparison of increase in pressure differential when wet rock wool was deposited on dry rock wool.
41	3-20-17	Dry Wet	30 5	6.2 each							
42	3-20-18	Dry	59	0	iron hydroxide	in situ	5 as Fe	pure water	none	21.76(2)	Comparison of colloidal particles prepared in advance in a beaker with colloidal particles prepared in situ.
43	3-20-19		59	0	copper hydroxide		7 g as Cu			21.76(2)	
44	3-20-20		59	0	aluminum hydroxide		5 g as Al			21.76(2)	
45	3-20-21	Wet	59	0	iron hydroxide	in situ	1 g as Fe	pure water	none	4(0. 37)	
46	3-20-23		59	0	copper hydroxide		3 g as Cu			4(0. 37)	
47	3-20-23		59	0	aluminum hydroxide		1.5 g as Al			4(0. 37)	
48	3-21-1	Dry	59	0	iron hydroxide	prepared in advance	1.0 each	boric acid/NaOH	none	21.76(2)	Comparison of pure water system and boric acid/NaOH system
49	3-21-2		59	0	copper hydroxide		0.5 to 1.0 each			21.76(2)	
50	3-21-3		59	3.1 each						21.76(2)	
51	3-21-4	Wet	59	0	iron hydroxide	prepared in advance	0.2 to 0.4 each	boric acid/NaOH	none	4(0. 37)	
52	3-21-5		59	0	copper oxide		0.5 to 1.0 each			4(0. 37)	
53	3-21-6		59	0	copper hydroxide		0.5 to 1.0 each			4(0. 37)	
54	3-21-7		59	0	aluminum hydroxide		0.4			4(0. 37)	
55	3-21-8		59	3.1 to 6.2 g each						4(0. 37)	
56	3-22-1	Dry	59	0	iron hydroxide	prepared in advance	1.0 each	hydrazine	none	21.76(2)	Comparison of pure water system and hydrazine system.
57	3-22-2		59	0	copper hydroxide		0.5 to 1.0 each			21.76(2)	
58	3-22-3		59	0	aluminum hydroxide		0.5 to 1.0 each			21.76(2)	
59	3-22-4		59	3.1 each						21.76(2)	

60	3-22-5	Wet	59	0	iron hydroxide	prepared in advance	0.2 to 0.4 each	hydrazine	none	4(0. 37)	
61	3-22-6		59	0	copper hydroxide		0.5 to 1.0 each			4(0. 37)	
62	3-22-7		59	0	aluminum hydroxide		0.4 each			4(0. 37)	
63	3-22-8		59	3.1 to 6.2 g each						4(0. 37)	
64	3-23-1	Dry	59	0	iron hydroxide	prepared in advance	0.5 to 1.0 each	tetraboric acid/boric acid	none	21.76(2)	Comparison of pure water system and tetraboric acid system.
65	3-23-2		59	0	copper hydroxide		0.5 each			21.76(2)	
66	3-23-3		59	0	aluminum hydroxide		0.5 each			21.76(2)	
67	3-23-4		59	3.1 each						21.76(2)	
68	3-23-5	Wet	59	0	iron hydroxide	prepared in advance	0.4	tetraboric acid/boric acid	none	4(0. 37)	
69	3-23-6		59	0	copper hydroxide		0.5 each			4(0. 37)	
70	3-23-7		59	0	aluminum hydroxide		0.2 each			4(0. 37)	
71	3-23-8		59	3.1 each						4(0. 37)	
72	4.1	Dry	30	0				boric acid/NaOH	none	21.76(2)	ICAN#1 reproduction test without water cooling and reheating
73	4.2	Dry	30	0						21.76(2)	ICAN#3 reproduction test without water cooling and reheating
74	5.1	Dry	30	0				tetraboric acid/boric acid	none	21.76(2)	ICAN#4 preliminary test, boric acid/sodium tetraborate
75	5.2	Dry	30	0				hydrazine	none	21.76(2)	ICAN#5 preliminary test, boric acid/hydrazine/sodium hydroxide conditions
76	5.3	Dry	30	0				pure water	none	21.76(2)	ICAN#6 preliminary test, BWR (pure water) conditions



[(1) Chemical test water recovery tank (2) Pure water storage tank (3) Pure water producing device (4) Preheater (5) Pressure gauge (6) Thermometer (7) pH meter (8) Heater (9) Thermometer (10) Cooling device (11) Sampling line (12) Water storage tank (13) Flowmeter (14) Circulating pump (15) Bypass (16) Ring (17) Ring (18) Drain (19) Drain (20) Drain (21) Pressure loss loop]

3.2 System diagram of pressure loss loop (PL device)

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Debris inlet

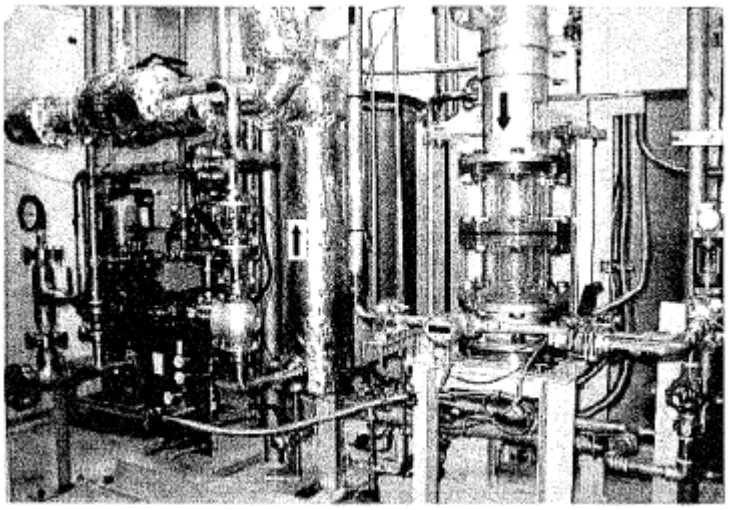


Fig. 3.2.2 External view of pressure loss loop (PL device)

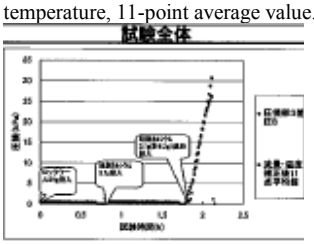
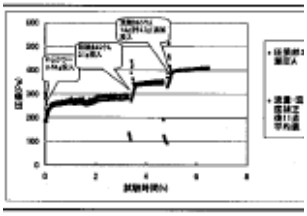
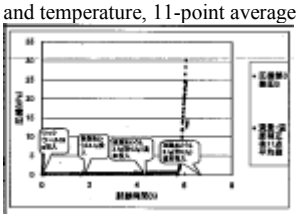
PL#	Test conditions			Complete test
3.13-1	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (left capsule from left) 59 g of rock wool introduced (middle capsule) 3.1 g of calcium silicate introduced (right capsule) Additional 3.1 g of calcium silicate introduced (total 6.2 g) (right top bullet) Pressure differential B in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value.
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Total	6.2	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. Calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system			
3.13-2	Rock wool (g)		59	[(left) Pressure loss (Pa) (bottom) Test period (h) (left capsule) 59 g of rock wool introduced (middle capsule) 3.1 g of calcium silicate introduced (right capsule) Additional 1.6 g of calcium silicate introduced (total 4.7 g) (right top bullet) Pressure differential A in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value.
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	1.6	
		Total	4.7	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. Calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following PL#3.13 test was employed.			
3.14	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (left capsule) 59 g of rock wool introduced (second capsule) 3.1 g of calcium silicate introduced (third capsule) Additional 3.1 g of calcium silicate introduced (total 6.2 g) (right capsule) Additional 3.1 g of calcium silicate introduced (total 9.3 g) (right top bullet) Pressure differential B in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value.
	Preparation method	Dry pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Third	3.1	
		Total	9.3	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. Calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following PL#3.13 test was employed.			

Fig. 3.3.1.1 Results of reproducibility test of increase in pressure loss by introduction of calcium silicate

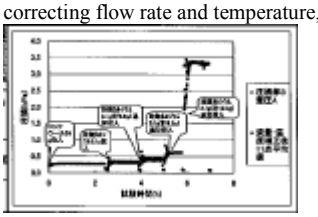
3.15-1	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (top box) Done over (left capsule) 59 g of rock wool introduced (second capsule) 3.1 g of calcium silicate introduced (third capsule) Additional 3.1 g of calcium silicate introduced (total 6.2 g) (right capsule) Additional 3.1 g of calcium silicate introduced (total 9.3 g) (right top bullet) Pressure differential B in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value. Being done over due to failure in generating unevenness with debris.
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Third	3.1	
		Total	9.3	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. Calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following PL#3.14 test was employed.			
3.15-2	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (left capsule) 59 g of rock wool introduced (second capsule) 3.1 g of calcium silicate introduced (third capsule) Additional 3.1 g of calcium silicate introduced (total 6.2 g) (fourth capsule) Additional 3.1 g of calcium silicate introduced (total 9.3 g) (fifth capsule) Additional 3.1 g of calcium silicate introduced (total 12.4 g) (right top bullet) Pressure differential A in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value. 
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Third	3.1	
		Fourth	3.1	
		Total	12.4	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. Calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following test PL#3.15-1 was employed.			

Fig. 3.3.1.1 Results of reproducibility test of increase in pressure loss by introduction of calcium silicate (cont'd)

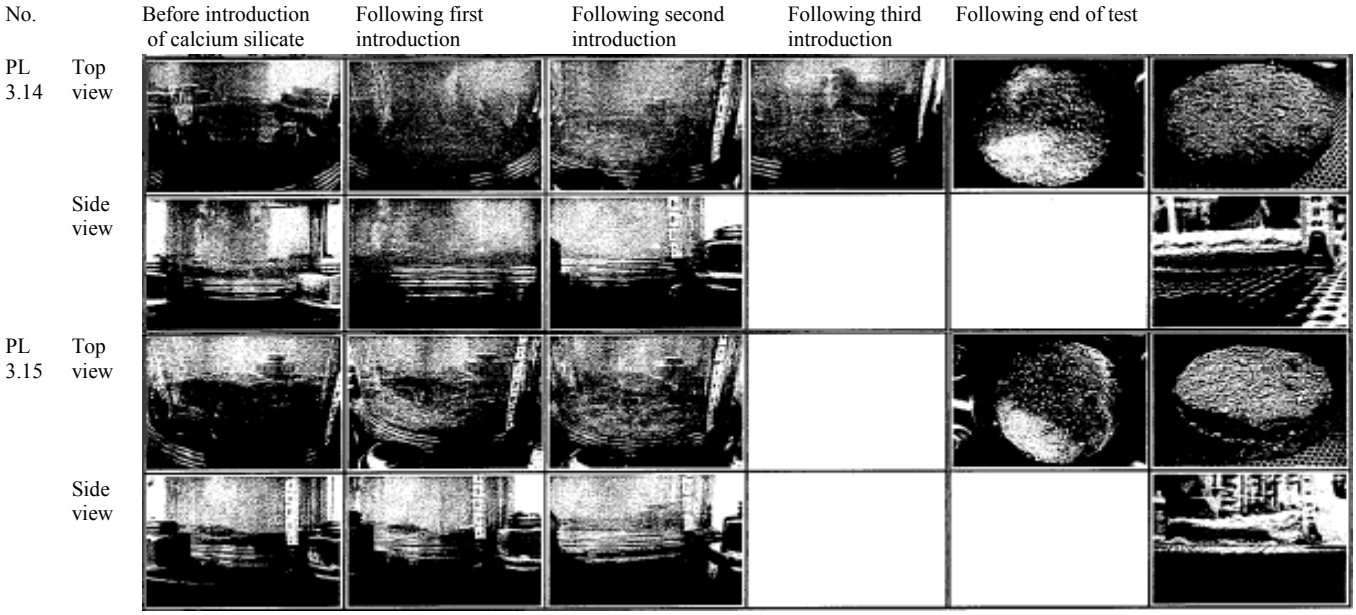


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Fig. 3.3.1.2 Overview of reproducibility test of increase in pressure loss by introduction of calcium silicate

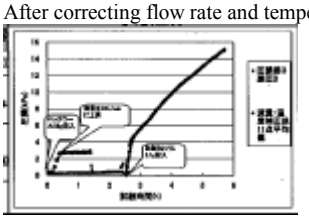
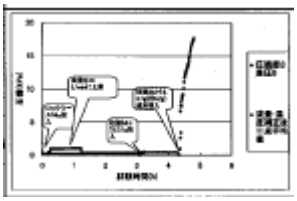
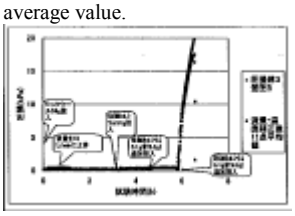
PL#	Test conditions			Complete test
3.16-1	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (left capsule) 59 g of rock wool introduced (middle capsule) Flow rate raised to 40 L/min. (right capsule) 3.1 g of calcium silicate introduced. (right top bullet) Pressure differential B in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value. 
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Total	3.1	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. The flow rate was increased to 40 L/min, operated for 1 h, and then returned to 4 L/min, after which calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system			
3.16-2	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (left capsule) 59 g of rock wool introduced (second capsule) Flow rate raised to 20 L/min. (third capsule) 3.1 g of calcium silicate introduced. (right capsule) Additional 3.1 g of calcium silicate introduced (total 6.2) (right top bullet) Pressure differential B in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value. 
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Total	6.2	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. The flow rate was increased to 20 L/min, operated for 1 h, and then returned to 4 L/min, after which calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following PL#3.16-1 was employed.			
3.16-3	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (left capsule) 59 g of rock wool introduced (second capsule) Flow rate raised to 10 L/min. (third capsule) 3.1 g of calcium silicate introduced. (fourth capsule) Additional 3.1 g of calcium silicate introduced (total 6.2) (right capsule) Additional 3.1 g of calcium silicate introduced (total 9.3) (right top bullet) Pressure differential B in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value. 
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Third	3.1	
		Total	9.3	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. The flow rate was increased to 10 L/min, operated for 1 h, and then returned to 4 L/min, after which calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following PL#3.17 was employed.			

Fig. 3.3.2.1 Results of test of effect of rock wool compression due to flow velocity

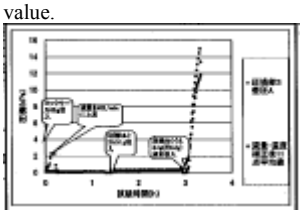
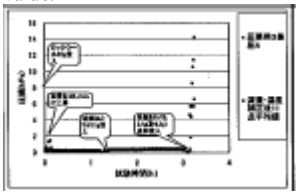
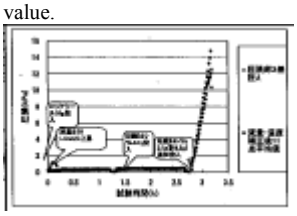
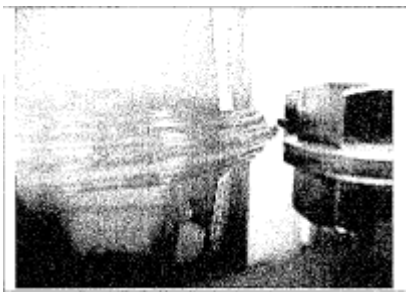
PL#	Test conditions			Complete test
3.16-4	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (left capsule) 59 g of rock wool introduced (second capsule) Flow rate raised to 40 L/min. (third capsule) 3.1 g of calcium silicate introduced. (right capsule) Additional 3.1 g of calcium silicate introduced (total 6.2) (right top bullet) Pressure differential A in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value. 
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Total	6.2	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. The flow rate was increased to 40 L/min, operated for 5 min, and then returned to 4 L/min, after which calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following PL#3.17-2 was employed.			
3.16-5	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (Top capsule) 59 g of rock wool introduced (second capsule) Flow rate raised to 40 L/min. (third capsule) 3.1 g of calcium silicate introduced. (right capsule) Additional 3.1 g of calcium silicate introduced (total 6.2) (right top bullet) Pressure differential A in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value. 
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Total	6.2	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. The flow rate was increased to 40 L/min, operated for 0.5 min, and then returned to 4 L/min, after which calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following PL#3.16-4 was employed.			
3.16-6	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (Top capsule) 59 g of rock wool introduced (second capsule) Flow rate raised to 20 L/min. (third capsule) 3.1 g of calcium silicate introduced. (right capsule) Additional 3.1 g of calcium silicate introduced (total 6.2) (right top bullet) Pressure differential A in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value. 
	Preparation method	Wet pulverization		
	Calcium silicate (g)	First	3.1	
		Second	3.1	
		Total	6.2	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. The flow rate was increased to 20 L/min, operated for 5 min, and then returned to 4 L/min, after which calcium silicate was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system Test solution following test PL#3.16-5 was employed.			

Fig. 3.3.2.1 Results of test of effect of rock wool compression due to flow velocity (cont'd)

Introduction of rock wool



Flow rate 4 L/min (flow velocity 0.37 cm/s)

Flow rate 20 L/min (flow velocity 1.85 cm/s)

Flow rate 40 L/min (flow velocity 3.7 cm/s)

One hour after returning flow rate to 4 L/min.

Three hours after introducing 3.1 g of calcium silicate

Fig. 3.3.2.2 Test of effect of rock wool compression due to flow velocity (PL#3.16-1)

[(left) Quantity (g) of calcium silicate causing rapid increase in pressure loss (bottom) Compression time (min)]

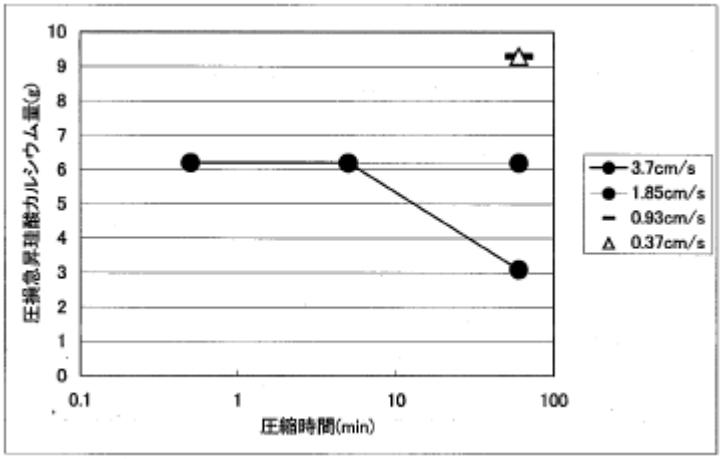


Fig. 3.3.2.3 Results of test on effect of rock wool compression based on flow velocity

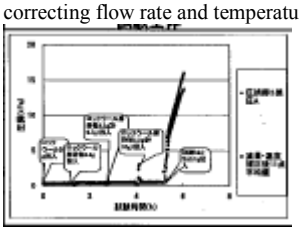
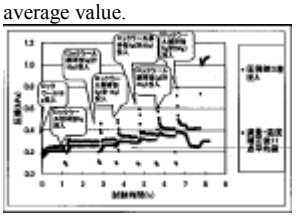
PL#	Test conditions			Complete test
3.17-1	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (left capsule) 59 g of rock wool introduced (middle capsule) (second capsule) 3.3 g of pulverized rock wool powder introduced (third capsule) 3.3 g of pulverized rock wool powder introduced (total 6.7 g) (fourth capsule) 3.3 g of pulverized rock wool powder introduced (total 10 g) (right capsule) 3.1 g of calcium silicate introduced (right top bullet) Pressure differential A in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value.
	Preparation method	Wet pulverization		
	Rock wool pulverized powder (g)	First	3.3	
		Second	3.3	
		Third	3.3	
		Total	10	
	Calcium silicate (g)	First	3.1	
		Total	10	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. The pulverized rock wool powder was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system The test solution following test PL#3.16(2) was employed.			
3.17-2	Rock wool (g)		59	[(left) Pressure loss (kPa) (bottom) Test period (h) (capsules from left, first capsule) 59 g of rock wool introduced (second capsule) 5 g of pulverized rock wool power introduced (third capsule) 5 g of pulverized rock wool power introduced (total 10 g) (fourth capsule) 5 g of pulverized rock wool power introduced (total 15 g) (fifth capsule) 5 g of pulverized rock wool power introduced (total 20 g) (sixth capsule) 5 g of pulverized rock wool power introduced (total 25 g) (seventh capsule) 5 g of pulverized rock wool power introduced (total 30 g) (right top bullet) Pressure differential A in pressure loss element 3 (right bot bullet) After correcting flow rate and temperature, 11-point average value.
	Preparation method	Wet pulverization		
	Rock wool pulverized powder (g)	First	5	
		Second	5	
		Third	5	
		Fourth	5	
		Fifth	5	
		Sixth	5	
		Total	30	
	Test method Pressure loss measuring element was built into the device. Rock wool was introduced through debris inlet. The pulverized rock wool powder was introduced through the debris inlet. Flow velocity cm/s (flow rate L/min) 0.37(4) Pure water system			

Fig. 3.3.3.1 Results of test of effect of minute rock wool