National Energy Authority
Reykjavík, Iceland

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RAPID SCALING OF SILICA IN TWO DISTRICT HEATING SYSTEMS

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ABSTRACT

Two district heating systems in Iceland exploit wells fed with water at 200°C and 212°C. The hot water is flashed at atmospheric pressure, and the steam is discharged but the water fraction is utilized. One system, at Námafjall (2 MW, thermal), began operation in 1971, and the other, in Hveragerdi (8 MW, thermal), was connected to an already-existing distribution system in 1973. The flashed water that is used contains 330-420 ppm SiO_2. This silica is considerably diss-ciated because of the high pH (9.6-9.8). Therefore, saturation with opaline silica was predicted at about 60°C and no precipitation was expected above this temperature. However, rapid scaling of silica takes place in the distribution pipes and in heat-exchangers, which are located in each house, at temperatures as high as 95°C. x) Preliminary investigations indicate the presence of chalcedony in a few samples of the silica precipitate. Most of the samples display, however, amorphous X-ray pattern only. The deposits in the pipes are loose, leaflike flakes, pointing against the flow. In 1974, the deposits had grown to 15-30 mm inside an 8 inch pipe at Námafjall, and were removed by pulling two wire-wheel bruches, spaced 40 cm apart, through the pipes. The heat-exchangers have to be

x) Preliminary analyses show 11% Al_2O_3 in the scale suggesting that it may be an amorphous aluminium silicate.

cleaned at 3-6 months' intervals by wire brushing. To solve the scaling problem in Hveragerdi, 35% dilution of the drillhole fluid with cold water, mixed before flashing at atmospheric pressure, was started in December 1974. So far silica scaling appears to be reduced.

INTRODUCTION

Although there are numerous district heating systems in Iceland, the two described here are unique, in that they exploit geothermal wells with much higher temperatures, and higher dissolved mineral content as well. These are located at Námafjall in the North, where the wells produce steam for a diatomacious earth plant, and for a small electric generating station (Ragnars et al 70), and in Hveragerdi in the South, where 8 wells were drilled for a proposed electric generating station (Einarsson 61). These wells were, however, not put to use, as the project was cancelled. The district heating systems were designed to make use of the water fraction coming from these wells. The wells and collection system are operated by the National Energy Authority. This report is concerned with the scaling occurring at both these locations.

DESCRIPTION OF COLLECTION AND DISTRIBUTION SYSTEM

In Hveragerdi, two wet steam boreholes are used, both located on the outskirts of the town. These were connected to an existing distribution system in 1973. Previously, boreholes and hot springs within the town had been used to heat 350 homes and 35000 m^2 of greenhouse space, with no scaling problems occurring. The temperature of the water entering the wells is 200°C, and the wells are 400 and 695 meters deep, respectively. The steam/water mixture is transferred as two-phase flow from the wellhead in steel pipes, to a separator located on a hill above the wells. The separator is an open tank, the mixture entering tangentially, the steam being discharged to the atmosphere, and the 100°C water collected in a surge tank. From the surge tank, the hot water flows by gravity through a 450 m long asbestos cement pipeline (dia 250 mm) to the town limits. The pipeline is covered by a 75 cm high mound of earth for insulation. Within the town, polyurethane-insulated steel pipes, with a polyethylene outer cover, are used in the distribution system. It was originally assumed that the distribution system would be free of silica scaling, as silica precipitation was not expected to take place above 60°C. Nevertheless, as a special precaution, heat-exchangers that could be cleaned were specified for each house, (fig. 1) since passage of water through the central heating system will result in a temperature drop to 40°C. Furthermore, the water is too high in H_2S for tap water usage. This feature contrasts with other geothermal district heating systems in Iceland, where the water is used directly.

At Námafjall, the distribution and collection system is similar to the one previously described for Hveragerdi, except that the well discharge is first separated at 10 atg, to supply the steam mains, as was mentioned in the introduction. The water from the well-separator is subsequently piped to the separator of the district heating system. The pipeline to the community is 3 km long; the first part is a 200 mm aspestos cement pipe, the remainder having a diameter of 150 mm.

SCALING PROBLEMS

Shortly after the new wells were taken into use in Hveragerdi, scaling was noted in the flow control equipment and heat-exchangers located in each house. The scaling was fairly rapid, requiring cleaning at 3-6 months' intervals. The plate heat-exchangers were cleaned by wire brushing. Other methods, such as high pressure water cleaning, freezing coupled with brushing, and chemical cleaning with ammonium bifluoride have also been tried with fair success, but these require special equipment. Increased resistance to flow has also been measured in the distribution pipes.

At Námafjall, the entire district heating system was installed in 1971. By 1974, scale deposits had accumulated to 15-30 mm inside the 200 mm pipe (fig. 3). As a result, the flow had decreased to 13 l/sec from the design value of 25 l/sec. This scaling was removed in 1974 by pulling two wire-wheel brushes, spaced 40 cm apart, through the pipeline, to remove the scales, which were leaf-like in appearance, pointing against the flow. The cleaning operation succeeded, and the flow increased to 20 l/sec. The scaling problem in the heat exchangers is similar to that described for Hveragerdi above, except that at Námafjall the sewer pipes, into which the water was discharged, soon became clogged through scaling. As a result, the water from the heat-exchangers is now discharged into the ground, which is porous lava.

WATER COMPOSITION AND THEORY OF SILICA SCALING

The composition of the water entering the wells that are exploited for the district heating at Námafjall and Hveragerdi is presented in table 1. The analysed composition of the flashed water fraction at 100°C is also included.

The silica content of the water entering the wells (the "deep well water") is determined by the solubility of quartz. The solubility of this mineral increases with temperature (fig. 2). When steam separation occurs in the well, the silica concentration in the residual water increases, and the temperature of the water drops. Both of these effects lead to silica supersaturation, with respect to quartz. It is, however, expected, because of the slow crystal formation of quartz, that silica will be precipitated from solution only as opal. But as can be seen from fig. 2 opal is much more soluble than quartz.

Much of the carbon dioxide and hydrogen sulphide which is in the "deep well water" is transferred to the steam upon flashing. This transfer raises the pH of the residual water to about 9,5-10 pH units, sufficiently to cause substantial ionization of the dissolved silica, but the ionized silica does not participate in equilibrium with opal. The increase in pH of the water fraction which occurs therefore lowers the opal saturation temperature. For the wells at Námafjall and Hveragerdi, opal saturation was estimated to be at about 30°C and 60°C, respectively, and above this temperature precipitation of silica in the form of opal was not expected. However, as it turned out, precipitation occurs in the distribution pipes where the temperature is 95°C.

X-ray analysis of the scaling shows that the material is mostly amorphous, although some samples also yield quartz reflection peaks, suggesting the presence of some chalcedony. Calcite in small quantities was present in some samples. This calcite may originate in wells, as calcite is deposited in the wells at Hveragerdi at depths of 40-150 m, and has to be drilled out twice a year. Chemical analyses indicate a high content of Al_2O_3 in the scaling (table 2), suggesting together with X-ray analyses that this scaling may be an amorphous aluminium silicate. Preliminary infrared analyses indicate that aluminium is bound to the silica in the amorphous precipitate. No data on the aluminium content of the hot water are available.

Water separated from steam at 4 atg pressure from well 4 in Hveragerdi (the compositions of wells 2 and 4 in Hveragerdi are identical, see table 1) has been used to heat greenhouses on a nearby farm Fridastadir for a period of 15 years, and practically no scaling has occurred in the pipelines during that time. The water has cooled to about 50°C when it is discharged. Apart from pH, which tends to be lower at Fridastadir, no compositional differences are observed between this water and the water used in the district heating system in Hveragerdi. The discrepancy in scaling behaviour for water coming out of the same well is not understood.

An experimental station is currently in operation in Hveragerdi, where scaling tests are being conducted under controlled conditions. One of the objects of the experiments is to simulate the operation of the two separate systems just described, to isolate the cause of scaling in the Hveragerdi district heating system. Further work on this problem is of vital importance for the future exploitation of the water fraction from the many wet-steam fields in Iceland.

DILUTION WITH FRESH WATER

To reduce the scaling tendency, dilution of the drillhole fluid, prior to flashing in the separator, was started in Hveragerdi in December 1974. The silica content of the water was thus reduced from 347 ppm to 188 ppm (table 1).

Corrosion coupons were installed at two locations in the pipeline - the weight increase being a measure of the scaling tendency in the distribution pipes. It is interesting to note that the precipitation on galvanized steel is 10 times greater than on other materials tested. A photograph of the coupons after one month's exposure in the diluted hot water shows this clearly (fig. 4). So far, the dilution has reduced the scaling tendency, as can be seen from a photograph of 3 months old heat-exchanger plates, with and without dilution water (fig. 5). Inspection of heat-exchangers after the dilution was started reveals that the scaling has not stopped altogether, and this problem is therefore still under study.

To solve the problem at Námafjall, it is proposed to install a tubular heat-exchanger that will heat fresh water with steam to above boiling, and the water will then be deaerated before entering the district heating system.

REFERENCES

1. Ragnars, K. et al. 1970 - Development of the Námafjall Area - Northern Iceland. U.N. Symp. on the Dev. and Utiliz. of Geothermal Resources, Pisa 1970. Vol. 2, part 1.

2. Einarsson, S.S. 1961 - Proposed 15 Megawatt geothermal power station at Hveragerdi, Iceland. U.N. Conf. New Sources - Energy, Rome, G/9.

CAPTIONS TO FIGURES:

1. Typical domestic heating system in Hveragerdi and at Námafjall.

2. The solubility of quartz and opal along the three-phase curve solid + water + steam. Silica concentrations are shown for residual water attained by adiabatically cooling solutions at 200° and 280°C.

3. Scale deposits in the 200 mm asbestos cement pipe at Námafjall in 1974.

4. Corrosion soupons from the pipeline to Hveragerdi, showing scale deposits on copper, galvanized steel, stainless steel and mild steel.

5. Heat-exchanger plates, removed after 3 months of use while exposed to the undiluted and diluted water in Hveragerdi.

TABLE 1. The composition of water from wet-steam wells used for district heating at Námafjall and Hveragerdi. Concentrations in ppm.

	Well 5 Námafjall		Well 2 Hveragerdi		Hveragerdi	Hveragerdi	Hveragerdi
	"Deep well water"	Flashed water fraction at 100°C	"Deep well water"	Flashed water fraction at 100°C	Fridarstadir	Dilution water	Mixture
Temp. °C	212	100	200	100		10	100
pH/°C	7,48/212	10,21/20	7,76/200	9,58/20	9,41/20	7,21/18	8,95/20
SiO_2	318	418	270	347	296	27	188
Na^+	102,7	150,0	155,5	191,5	160,9	12,9	
K^+	16,9	23,0	12,6	15,0	12,6	1,2	
Ca^{++}	1,3	2,1	1,9	2,4	2,1	9,8	
Mg^{++}	0,02	0,04	0,06	0,10	0,02	0,33	
CO_2(total)^x	62,2	17,9	176,0	48,0	46,8	36,1	47,8
SO_4^{--}	37,7	56,3	65.0	75,8	55,4	5,7	
H_2S(total)^{xx}	106,8	40,0	30,2	7,8	15,4	0,1	7,2
Cl^-	17,7	17,2	125,0	152,3	124,0	13,4	
F^-	0,9	1,2	1,9	2,1	1,9	0,30	
Diss-solids.	597	879	740	879	747	100	

x $H_2CO_3 + HCO_3^- + CO_3^{--}$

xx $H_2S + HS + S^{--}$

TABLE 2. Preliminary analyses of scaling from Hveragerdi and Námafjall.

%	Hveragerdi	Námafjall
SiO_2	61,52	73,27
TiO_2	0,42	0,05
Al_2O_3	11,70	11,05
Fe_2O_3 (total)	4,02	0,26
MgO	0,81	0,38
CaO	4,11	3,26
Na_2O	0,92	1,44
K_2O	1,34	2,02
Ignition loss	16,53	11,80

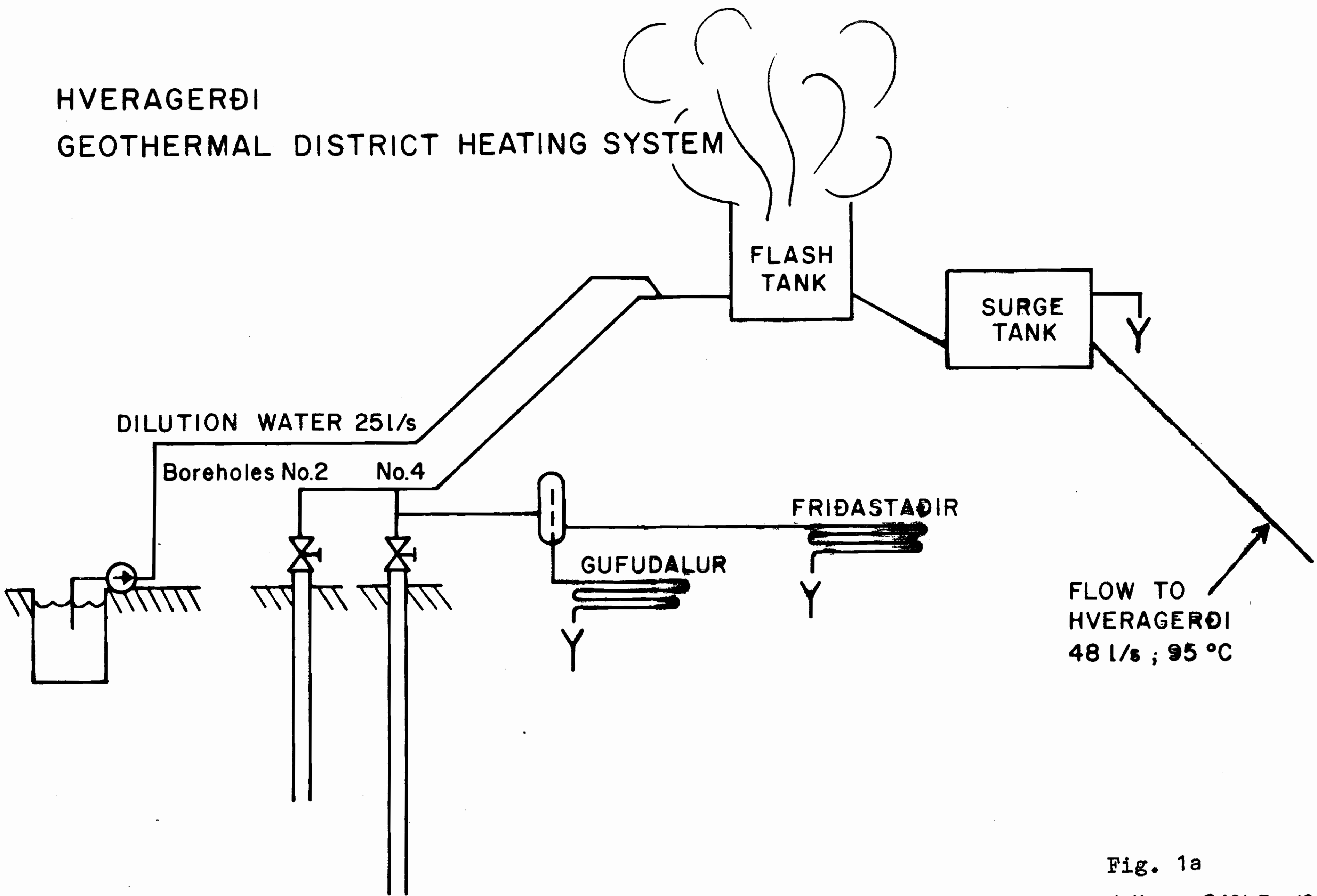


Fig. 1a

J-Hverag. T.191 Fnr. 12825

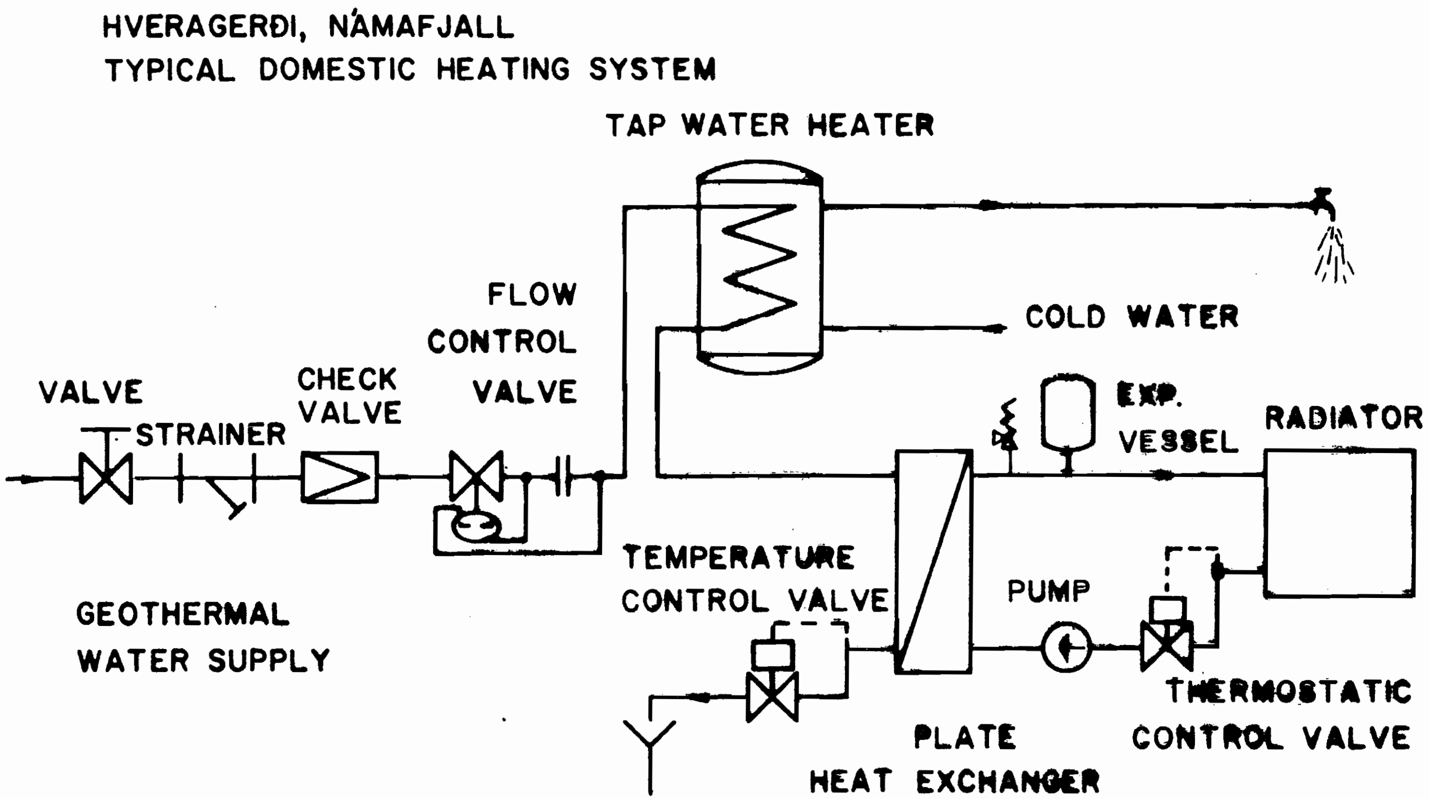

HVERAGERÐI, NÁMAFJALL
TYPICAL DOMESTIC HEATING SYSTEM
TAP WATER HEATER
FLOW CONTROL VALVE
COLD WATER
VALVE
STRAINER
CHECK VALVE
EXP. VESSEL
RADIATOR
TEMPERATURE CONTROL VALVE
PUMP
GEOTHERMAL WATER SUPPLY
THERMOSTATIC CONTROL VALVE
PLATE HEAT EXCHANGER

Fig.1b

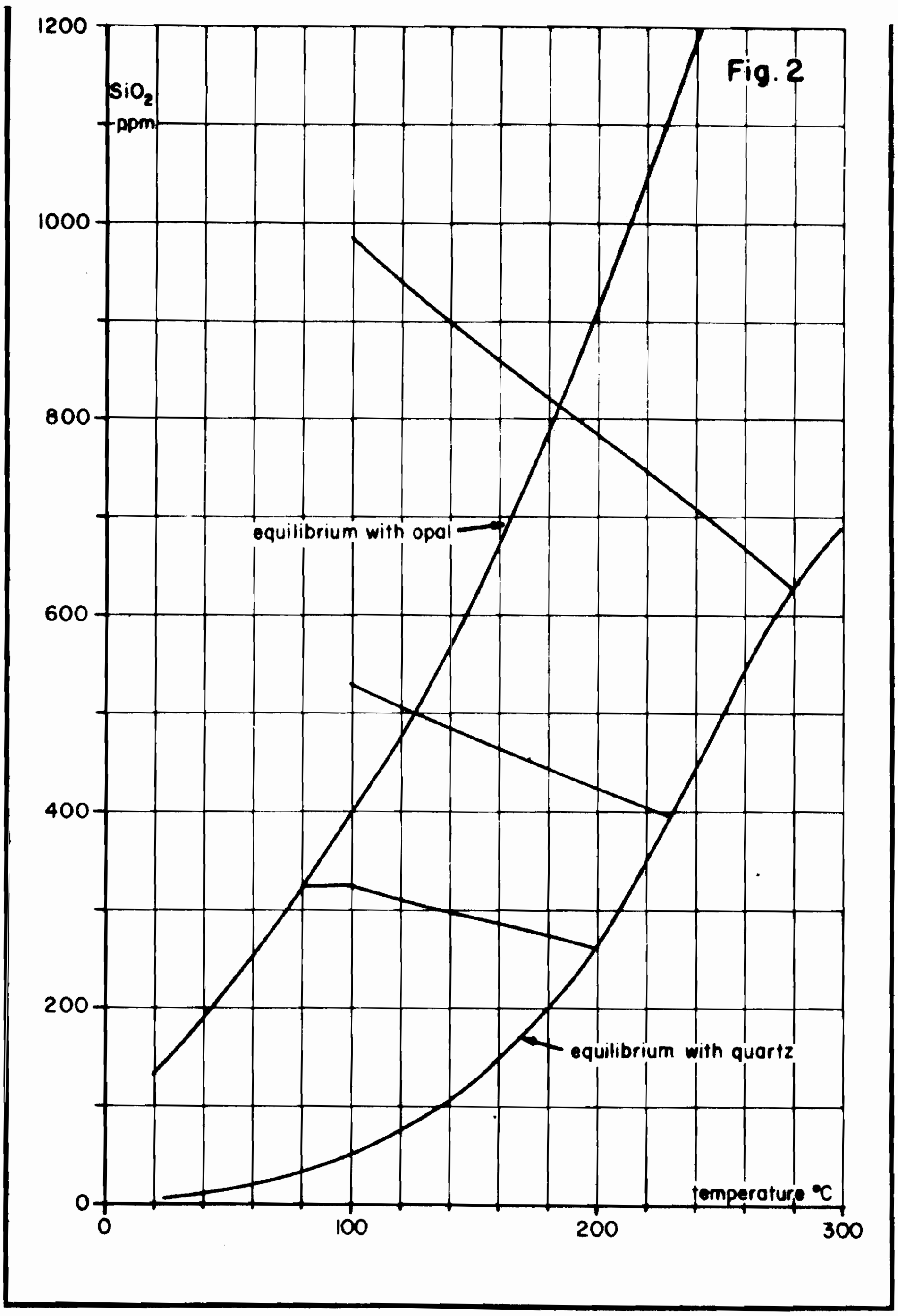


Fig. 2
SiO2 ppm
1200
1000
800
600
400
200
0
0
100
200
300
temperature °C
equilibrium with opal
equilibrium with quartz

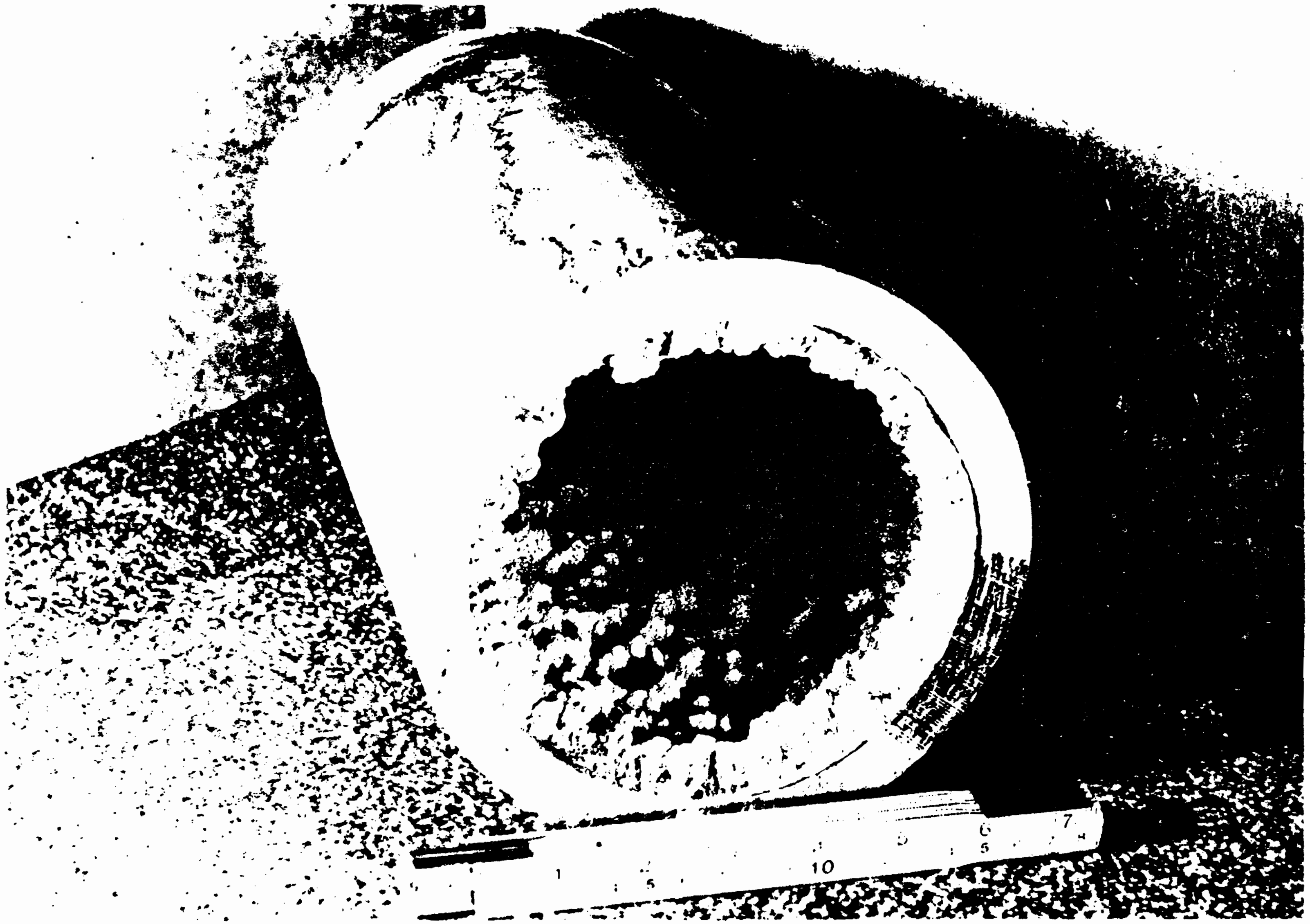
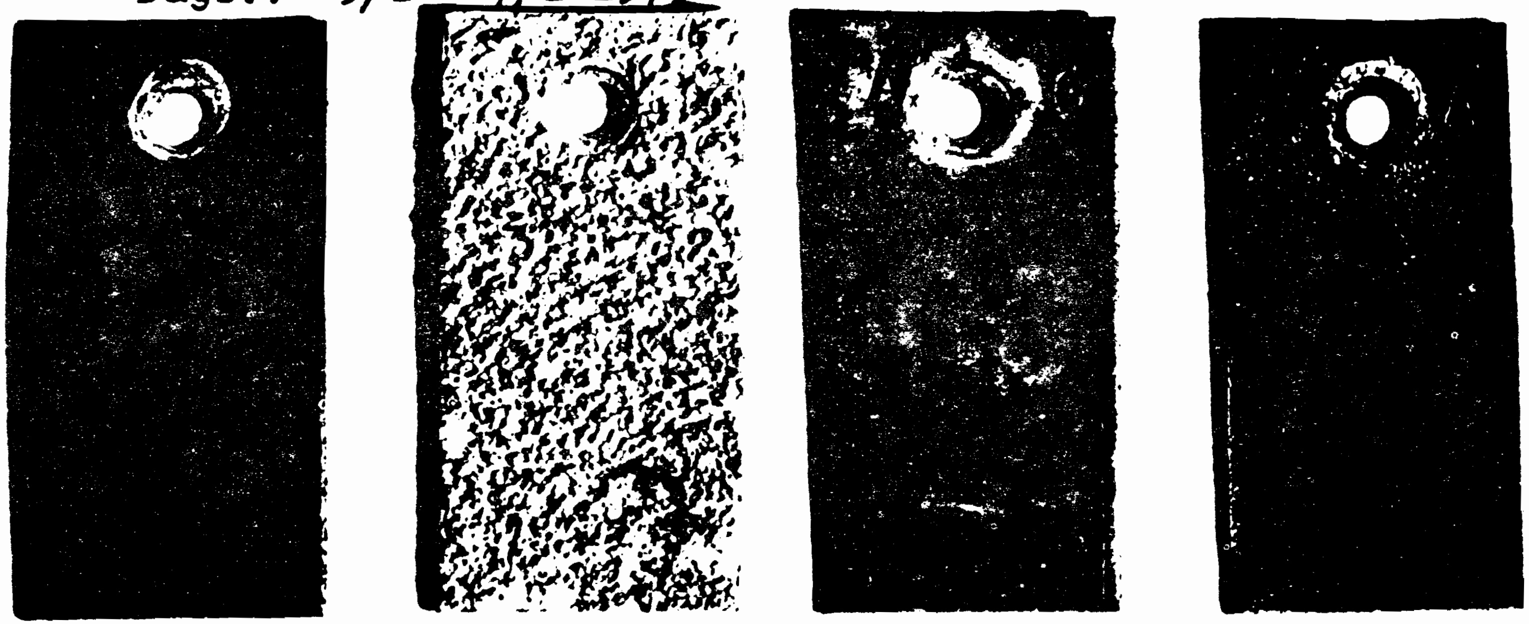


Fig. 3

ORKUSTOFNUN
LAUGAVEGI 116, REYKJAVÍK

HITAVEITA HVERAGERÐIS
TÆRINGATENINGAR

Staður: Úttak í toppbrunni hitaveitunnar
Dags.: 9/1 - 7/2 1975



Kopar Galvaniserað Ryðfrítt Stál

Fig. 4

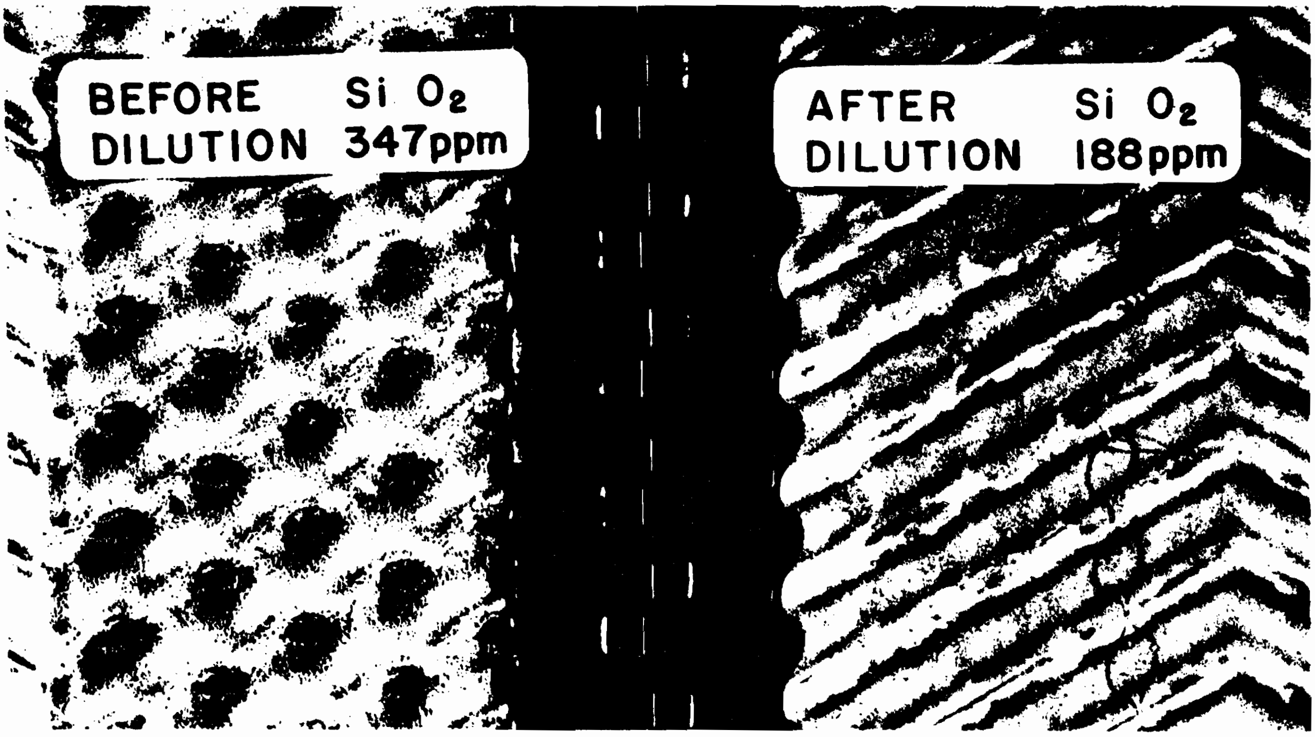


Fig. 5