CORROSION OF STEAM WELL CASINGS AND STEAM LINES IN ICELAND

R. #10,367
PC #3202

August 26,1953

SAM TOUR & CO., Inc.
44 TRINITY PLACE
NEW YORK 6, N. Y.

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Introduction:

In accordance with a contract negotiated through the Mutual Security Administration and between Sam Tour & Co., Inc. and the Icelandic Government, the writer went to Iceland to make certain studies in connection with corrosion of hot water systems in various cities. Having completed the necessary local work in connection with the study of the hot water system in the City of Reykjavik and in the City of Selfoss, the matter of studying the hot water systems in two villages in the northern part of Iceland was discussed with Mr. Gunnar Bodvarsson of the State Electricity Authority. Mr. Bodvarsson was of the opinion that the information gleaned from the study of the hot water systems in the City of Reykjavik and in the City of Selfoss would be adequate for the two villages in Northern Iceland and that an on-the-spot study of the hot water systems at Souderkrokur and at Olafsfjordur could be omitted. Mr. Bodvarsson with the approval of the Icelandic representative of the Mutual Security Administration asked that the time saved in not making such on-the-spot studies of additional hot water systems be devoted to a study of the corrosion problems in and around steam wells in Iceland. Mr. Gunnar Bodvarsson took the matter up with the various agencies of the Icelandic Government that would be involved and having obtained their approval made arrangements for this change in plans. A full week was spent in connection with the study of corrosion problems in and around steam wells at several locations in Iceland.

Mr. Baldur Lindal of the State Electricity Authority accompanied the writer on the trip to Northern Iceland and the study of the steam wells in the Namasjall region. Mr. Gunnar Bodvarsson accompanied the writer in trips to study the steam wells in the Krisuvik area and in the Hveragerdi area.

This report covers the observations made during this study, the information obtained with regard to steam, water and gas carried with the steam, the samples selected for laboratory study in the laboratories of Sam Tour & Co., Inc., the results of the studies made in the laboratories and the conclusions and recommendations derived therefrom.

Namasjall-Northern Iceland:

Accompanied by Mr. Baldur Lindal, on May 25, 1953, the writer flew from Reykjavik to Akureyri. From Akureyri, we traveled by car about 60 kilometers to the east to Lake Myvatn and around the lake to Reykjahlith and Namaskard to the steam wells in the Namasjall area. In the valley, just before reaching the steam wells, is a small plant being erected to produce sulphur by a straight liquation of the high sulphur-bearing soil in the neighborhood of many old steam wells or steam escape craters. Throughout this area are many outcroppings on the hills and in the valleys that appear quite yellow in color. Mr. Lindal reported that some of the ore taken from this area runs as high as 45 to 50% of free sulphur. The plant is set up to melt this down with fuel oil as a source of heat. The liquation is to be carried out in a steel drum made of about 1/2 inch thick steel plate. The drum is 5 feet in diameter by 8 ft. long, is mounted on trunions, has a manhole and a drain valve. The drum takes about a two-ton charge and rotates at 15 R.P.M. A batch is heated in about three hours until an internal pressure is built up representing a temperature of 130° Centigrade. The water solution inside of the drum develops an acidity of pH 3 to pH 4. One corrosion problem is in connection with the attack of this acid solution on this steel drum. A straight high chromium ferritic stainless steel would be much more suitable than the plain steel being used but would be very expensive.

There is a possibility that metallizing applied to the inside of the drum would prove satisfactory. It is not certain just what metallized surfaces might be most satisfactory. It was suggested that some panels be made up metallized in various ways and inserted inside the drum to see which might give the best life. Accordingly, on return to the United States, the writer made arrangements with the Metallizing Engineering Co., Inc. of Long Island City, New York, to prepare six panels and send to Mr. Baldur Lindal in Iceland. The six panels were prepared and shipped on July 31, 1953 and are described as follows:

Base Material: 1/8" hot rolled 1020 steel.
Size: 4" x 6", with rounded edges and two holes in each for fastening.
Coatings: (panels notched 1 to 6 for identification)

1. Sprayed molybdenum .010" thick,
2. " " .002" plus .012" aluminum,
3. " 1010 steel .002" " .012" "
4. " molybdenum .002" plus .012" aluminum bronze,
5. " 1010 steel .002" plus .012" aluminum bronze,
6. " Monel .012".

Going on a short distance from this plant, we arrived at the active steam valley where steam was issuing from dozens of places in the earth and on the side of a hill. Some five or six wells have been drilled in this location. Only one is giving a good delivery of steam. This one is shown in Figure 1. The steam is issuing into the air at considerable velocity and carries some water with it, although not very much. Some steam issues from a side valve as shown in the illustration. To the rear of the picture showing this steam well is a drill jig where another steam well is being drilled.

Around this area, the smell of hydrogen sulphide is quite intense. In the side outlet of this well was some yellow sulphur and some white salt incrustation. Surrounding the valve on the top of the well casing was a white crust of residue. Samples of the white scale around the 6-inch valve on this steam well and of the white and yellow deposits in the side blow-off of this well were taken for analysis.

The analysis of the steam, the gas issuing with the steam, and the water issuing with the steam was supplied by Mr. Lindal and is shown in Table I attached to this report. It will be noted that this steam carries a very considerable amount of gas which is quite rich in hydrogen sulphide. When this moist hydrogen sulphide reaches the air, some of it is oxidized to sulphur dioxide. Sulphur dioxide and hydrogen sulphide react in the presence of moisture to deposit free sulphur. The free sulphur in finely divided form as deposited on the ground may slowly oxidize to sulphur dioxide and produce sulphurous acid in the soil. In view of the high quantity of sulphur available from the steam issuing from these wells, there is a proposal to obtain the sulphur from the steam by condensing the steam and converting the hydrogen sulphide to sulphur by the reaction referred to above. A concrete pilot plant type of installation is being built in the valley for this purpose. The plant will consist of a steam condensing chamber and a circulating basin made of concrete for circulating the cooling water.

One question raised was how to protect the concrete in this circulating water system from attack by the acid nature of the water. The writer suggested that a water-glass type of paint might be the solution to this problem. Another question raised was what to use for pipes to carry the steam. Some consideration is being given to the use of asbestos pipe. The writer pointed out that the acid nature of the water might destroy the cement bond of the asbestos pipe unless it is also given a water-glass treatment such as recommended for the concrete tank. Other types of pipe which might be used would be plastic lined pipe. Unfortunately there are no all-plastic pipes on the market which have sufficient strength at steam temperatures to be suitable. A plastic lined steel pipe should serve quite well.

There is a possibility, although faint, that aluminum might be satisfactory. In order to determine whether or not aluminum would be satisfactory, a short piece of about a 2-inch diameter aluminum pipe was found by the local man who tends these steam wells. This short piece of pipe, approximately 15 inches long, had a small aluminum casting on one end of it. The writer hung this piece of aluminum pipe and casting in the horizontal blow-off trench in the casing of the steam well #3 shown in Fig. 1. It is hoped that this piece of aluminum pipe and this aluminum casting will stay in place long enough to be able to give some indication as to whether or not aluminum pipe would be suitable for handling the steam and the water from this steam well. If aluminum will stand up, there is a possibility that steel casings could be metallized with aluminum and sealed with water-glass for this service. Mr. Lindal pointed out that he had tried metallizing with aluminum and sealing with water-glass in a 10% sulphuric acid solution, but that this did not stand up in such a high concentration. It is quite evident that no such high concentrations are reached in actual practice. It is doubted that in actual practice, the concentration would ever reach the equivalent of 1/10th of 1% of sulphuric acid and probably largely sulphurous rather than sulphuric acid.

Throughout this area some five or six wells have been drilled but only one is giving steam at the moment. One well drilled a few years ago was lost. The cement top was about 3 or 4 ft. square and the casing some 20 meters deep. It gave steam for a year or so and then caved in and the concrete top, casing and all disappeared into a boiling mud bath about 40 ft. in diameter. It is quite evident that the steel casing of this well perforated and the steam issued from the perforations to wash out all of the soil around the casing and cause the complete collapse and loss of this steam well. This indicates how necessary it is to have a material for steam well casings that will stand the combination of carbon dioxide, hydrogen sulphide and steam on the inside and the acid soil on the outside. Cathodic protection by the use of magnesium anodes buried in the soil around such steam well casings might offer some assistance but would be expensive in maintenance and it would be necessary to by-pass sufficient water to maintain fully wet soil at all times around the casing. This procedure does not seem practical.

From the boiling mud pond where the steam well had disappeared, a sample of the solution was taken for analysis. Another sample was taken in the form of soil near the surface and adjacent to #3 well. No. 4 well was not giving much steam but showed some corrosion on the inside of the casing. A sample of scale from the inside of the top of this casing of well #4 was taken. It was reported that this well erupts every day or so but does not give steam continuously.

The entire area between the steam well shown in Fig. 1 and the small pilot plant being built, as referred to above, is quite active from the standpoint of steam issuing from many places in the ground.

Figure #2 is a general view of this ground showing steam issuing in hundreds of places. The large mud pool where steam well #1 disappeared is just left of center of this picture. In addition to this steam rising in the valley area, steam is also rising from many fissures in the side of the hill to the left of the steam well #3 shown in Fig. 1.

Samples #1, #2, #3 and #4, taken from various places as indicated previously, were analyzed in the laboratories of Sam Tour & Co., Inc. with results as shown in Table II. It is quite evident that the principal ingredient in the water carried with the steam is sodium silicate and sodium sulphate. The pH of the water in the soil around #3 well was not as low as expected. However, it is sufficiently low to cause fairly rapid attack upon the steel casing especially in the presence of chlorides. It is evident that steam well casings must be made of a material which is resistant to this acid condition or must be coated with a protective coating which will stand this service. If some form of metallizing on the outside of steel cases plus a high temperature asphalt paint could be used, the exterior of the casing might be given adequate protection. For the inside of the casing, the problem is complicated by the erosive action of the water carried with the steam and by the amount of hydrogen sulphide and carbon dioxide in the water. It is doubted whether Silicone paints would have sufficient adherence. If aluminum stands up, an aluminum liner or a hot dip aluminized coating might be tried for the inside surface of the pipe. A pipe lined with a thermosetting type of bakelite phenol formaldehyde lacquer might be given consideration, although there is little similar service data to prove whether or not such a coating would have reasonable life.

Krisuvik Area - Southern Iceland:

In company with Mr. Gunnar Bodvarsson, a visit was made to the steam wells in the Krisuvik area on May 28, 1953. This trip was made by car from Reykjavik through Hafnarfjordur, over the lava beds alongside Lake Kleifarvatn to the steam wells at Krisuvik.

A number of wells have been drilled at Krisuvik. The principal producing well is #14 as shown in Fig. 3. This #14 well has been emitting steam for approximately five years at a reported rate of about 20 tons per hour. The analysis of the steam, the gas carried with it and the water carried with it as reported by Mr. Baldur Lindal is shown in Table I. It will be noted that the volume of gas coming with the steam from these wells in Krisuvik is less than half the volume of gas coming with the steam in the wells in Northern Iceland. Also it will be noted that the percentage of hydrogen sulphide in the gas is less in these southern wells than in the northern wells. Nevertheless, there is sufficient hydrogen sulphide present to oxidize and react with oxidized sulphur to deposit free sulphur. The yellow markings of free sulphur are evident around these wells which have been drilled and around the various spots where steam is issuing from crevices in the ground where wells have not been drilled. Such steam can be seen coming from the ground in the center of Fig. 3. Fig. 4 is a general view showing a number of the steam wells in action. Well #14 is in the center of the picture. Fig. 5 is a closeup picture of the steam coming from a natural opening in the earth where the water and mud is boiling continuously. Fig. 6 is a view from a distance of the various steam wells in this area. Well #14 is in the center of the picture; #19 is to the far right.

The large valve on the top of the concrete head for steam well #14 shows severe corrosion of the body. The valve seems to be one with a cast steel body. The inside trim is not known. Some of the heavy scale on the surface of this valve body was taken as a sample for analysis and is shown as sample #5 in Table II. It will be noted that this scale consists of iron plus silica deposit from the water. Also this scale contains some sulphates and some chlorides. The analysis of the water entrained with the steam from #14 well in Krisuvik is shown in Table I. Attention is called to the very high chloride content of this water.

A short distance beyond Krisuvik are a number of greenhouses at a place known as Hveradalir. Here there are several steam wells supplying steam at much lower pressure than the wells pictured at Krisuvik. These sources of steam have been used for some time for heating the greenhouses in this area. Here it is reported that the water with the steam shows much lower chlorine content and a higher sulphate content and higher calcium than that reported for the water in Krisuvik wells #14 and #19. Also it is reported that the water in this case is of a lower alkalinity of the order of 7.4 instead of 9.0. The brass valves, brass valve stems, and all brass parts in these systems show deep blue to black colors showing the rapid attack of the hydrogen sulphide on the copper.

Steam well #14 at Krisuvik has been proven to be a steady producer. The amount of steam issuing and the pressure at which the steam is issuing is sufficient to warrant the installation of a steam turbine generator unit to produce electrical power. The water could be separated from the steam in a centrifugal or cyclone type of separator. The problem becomes one of obtaining a steam turbine built of suitable material to give an economical service life when operated with steam carrying a gas high in carbon dioxide and hydrogen sulphide. There is no way known to remove these gases from the steam. Steam turbine practice throughout the world has shown that carbon dioxide in steam is objectionable from the standpoint of life of turbine blades. When hydrogen sulphide is present in addition to carbon dioxide, the conditions are worse. In some parts of Italy, power is being produced from natural steam. It is understood that the steam in Italy also carries some carbon dioxide and hydrogen sulphide. It is believed that the experiences gained to date in these installations in Italy would be applicable to the problem of harnessing the steam in Krisuvik for the production of electrical power.

Hveragerdi - Southern Iceland:

On May 29, 1953, a visit was made to the Hveragerdi area in company with Mr. Gunnar Bodvarsson. In this area many steam wells are producing small quantities of steam at low pressure and quantities of boiling hot water. The steam and hot water is used for heating of the many greenhouses in the area. Fig. 7 is a view of a large number of greenhouses in this area.

The only analysis available of the steam and water from this area is shown in Table I. It will be seen that the hydrogen sulphide content is much lower than in the Krisuvik area. The total gas content is very much lower and the hydrogen sulphide content of this gas is lower. However, there is sufficient hydrogen sulphide being emitted in this area so that the smell is prevalent throughout. The water carried with the steam is much lower in chlorine content and higher in silica content and total solids than that in the Krisuvik area. In this area, many types of pipe are in use for carrying both the steam and the hot water. Steel pipes, asbestos pipes, concrete pipes, cast iron pipes, steel valves and brass valves and steel valves with brass trim were seen. Several pieces of asbestos pipe which had been in service for some time showed a build-up of a hard internal scale of silica that gradually reduced the inside diameter of the pipe by a major amount. Scale 3/8" thick on the inside of a 4-inch pipe was considered as not excessive. It was interesting to note that less scale seemed to build up on the inside of steel pipes that were not insulated than built up on the inside of the asbestos pipe. No logical explanation of this phenomena was arrived at. It was noted that the steel pipe seemed to corrode somewhat on the inside but corrode severely on the outside in contact with the moist soil which seems to be fairly acid in nature. All brass valves and brass trim on valves showed deep blue to purple-black colors. Packings around valve stems seemed to be discolored and have a tendency to leak. In spite of the reported analysis, all steam in this area had a decided odor of hydrogen sulphide.

Since the steam in these wells carries considerable water with it, the practice is to take the steam plus water into a tank called a "water separator". Several of these tanks are 2 to 3 ft. in diameter by 4 to 6 ft. long. The steam is allowed to enter these tanks and as the water separates, it is drawn off from a bottom valve and the steam off of a top valve.

In one case, it was noted that the steam was being allowed to enter vertically from the bottom of the tank and that the tank had corroded through and perforated on top directly above this steam inlet. It was reported that this perforation took place after about five years of service. It was noted that wherever there was a leak in the system, a white crust of deposited salts had formed. Around some of the leaky valve stems and around some of the leaks in the steam lines, some yellow sulphur was noted indicating that the amount of sulphur or hydrogen sulphide carried by the steam is sufficient to produce some free sulphur when mixed with the air.

In view of the presence of free sulphur, it is quite logical that the wet soil is acid in nature and when it is in contact with the exterior of iron or steel pipes the pipes will corrode rapidly. To avoid this type of corrosion, it would be necessary to apply adequate high temperature coatings to the outside of steel pipes and to keep them as dry as possible. In connection with the steam and hot water distribution systems in this area, it was noted that most of them were completely makeshift in nature. Each householder or greenhouse operator apparently has installed his own pipe system, some above ground, some below ground, some insulated, some not insulated, some of asbestos pipe, some of steel pipe, etc. It was quite evident that much of the steam and much of the hot water in this area goes to waste.

Many places in the ground are emitting steam and hot water even where no wells have been drilled. Actually, besides the driven wells, steam is issuing from hundreds of spots in the ground. These spots are both in the valley and up on the sides of the adjacent hills.

Steam Well Casings:

It is evident from the discussions in connection with the actual steam wells that one of the major problems is that of corrosion of steam well casings. The combination of erosion plus hydrogen sulphide corrosion on the inside and acid soil corrosion on the outside is a most difficult situation to meet. The nickel-containing stainless steels would not be suitable for this use from the standpoint of service life even if they were not too expensive. There is a possibility that some of the newly developed manganese-chromium stainless steels, containing no nickel or up to 1% of nickel only, might be suitable but large diameter steel pipe is not being made from these steels as yet. Mr. Bodvarsson suggests the possibility of steam well casings of three sizes beginning with a larger diameter casing at the top, an intermediate size casing at intermediate depths and a smaller size casing for greater depths. For example, he suggests the possibility of the first 25 meters of casing being of 13-3/8" outside diameter, from 25 to 250 meters of 10-3/4" diameter, from 250 to 500 meters of 8-1/8" outside diameter and beyond 500 meters deep of 6-1/2" outside diameter. Instead of attaching these sizes of pipe from large to next size and down to each other, the proposal is that the casings be of multiple wall near the surface. One question arises as to how to seal the area between the casings, although it might be possible to seal this area by pumping in the proper type of cement.

If this type of construction were adopted, the writer knows of no examples of this type of construction in use, the problems with respect to internal corrosion due to hydrogen sulphide would apply only to the smaller internal diameter or 6-1/2" O.D. pipe. The problems with respect to external corrosion would apply to the outside surfaces of each of the sizes of pipe casing.

Since the water carried by the steam is alkaline in the majority of cases, the use of unprotected aluminum would not seem advisable. There is a possibility that aluminum bronze would be satisfactory. Certain tests along this line will be made in connection with the aluminum bronze metallized samples being tried out in the sulphur plant in Northern Iceland. If an expensive casing material, such as some form of high alloy steel, is to be avoided it will be necessary to develop some type of surface coating on ordinary steel pipe to provide adequate protection. Of the many types of metallizing available and many types of seal coatings which can be applied on top of this metallizing, there may be a combination which will be adequate on the one hand for the inside of the pipe, and on the other hand for the conditions on the outside of the pipe. At the moment, the answers are not known.

The problem of metallizing developed in connection with the equipment at the small sulphur extraction plant in Northern Iceland and developed in connection with the possibility of using metallizing for steam well casings in all steam wells in Iceland. A visit was, therefore, made to a number of shops in Reykjavik doing metallizing to determine whether or not they were in a position to apply experimental metallized coatings for trial. This set of visits was made on Saturday, May 30, 1953, with Mr. Baldur Lindal. Several metallizing shops were visited in the City of Reykjavik. Only one modern shop was found. This was the general ship and machine repair shop known as the Hedinn Limited. While this shop is not equipped with all of the types of metallizing guns available, they do have both wire guns and powder guns. Arrangements have been made to send them more specific information in connection with the various types of spraying of metals represented by the samples made for test in Northern Iceland. If any of these samples prove satisfactory, it should be possible for this shop to apply them either in their own building or in the field.

Conclusion:

The corrosion problems in connection with the steam wells in Iceland are quite serious. A number of suggestions have been made throughout the body of this report and will not be repeated in concluding. It is hoped that some of the experimental work initiated will lead to some satisfactory solution to some of the problems.

Throughout the studies of the steam wells of Iceland, Mr. Gunnar Bodvarsson and Mr. Baldur Lindal were of great assistance, spent much time with the writer and made the work pleasant and, it is hoped, worth while.

Respectfully submitted,

SAM TOUR & CO., INC.

Sam Tour

Sam Tour,
General Manager

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TABLE I

Steam Wells in Iceland

	Namasjall No. 1	Namasjall No. 3	Krisuvik No. 14	Krisuvik No. 19	Hveragerdi No. 46
Gas Composition % Volume:					
Moisture %	39	40	90	85	
Gas 1/kg. steam	7	7	3	2	.62
CO_2	50	51	81	87	86.1
H_2S	19	19	12	7	5.4
H_2	29	28	4	4	2.3
CH_4	0	0	0	0	0.3
N_2	2	2	3	2	5.9
Water Accompanying the Steam:					
Conductivity 10^{-3}/Ohm.Cm.	2.0	0.8	2.7	1.8	---
SO_4 mg/l	1200	360	80	60	74 46
Cl	---	5	780	470	156 262
SiO_2	170	230	130	220	340 475
B_2O_3	---	2	8	---	
Hardness mg/l $CaCO_3$	1200	140	27	21	
pH	4.3	8.5	9.0	8.9	9.03 7.23
Total Solids					885 1130

TABLE II

Analysis of Steam Well Samples from Iceland

Sample #	1	2	3	4	5
pH	4.6	4.9			
Moisture	80%	37%	70.5%		
* Free S	1.	0.22	16.4	3.5	0.1
* SiO_2	41.6	43.	61.2	3.	21.3
* Fe	17.4	12.6	9.5	49.	45.
* Cl	0.2	0.2	---	0.14	0.23
* SO_4	0.2	0.1	0.5	1.6	3.8
* CaO	---	---	0.2	N.F.	N.F.

* - Analysis on Dry Basis.
NF - Not found.

#1. - Mud and water from site of old #1 well.

#2. - Sand and soil near #3 well.

#3. - Water deposit from blow-off of #3 well.

#4. - Scale from inside of casing of #4 well.

#5. - Scale from valve body Krisuvik #14.

Fig. 1

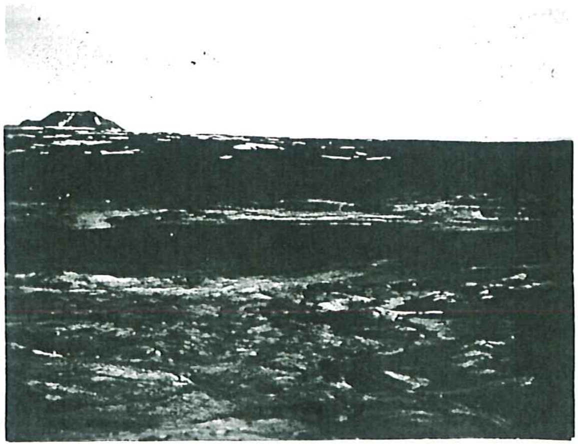

Fig. 2

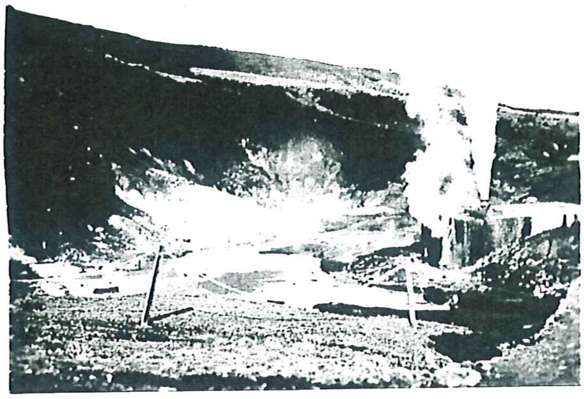

Fig. 3

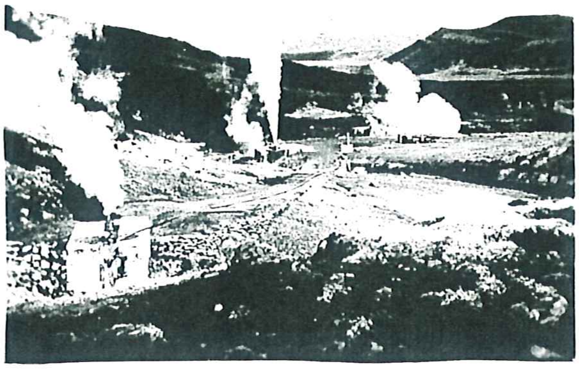

Fig. 4

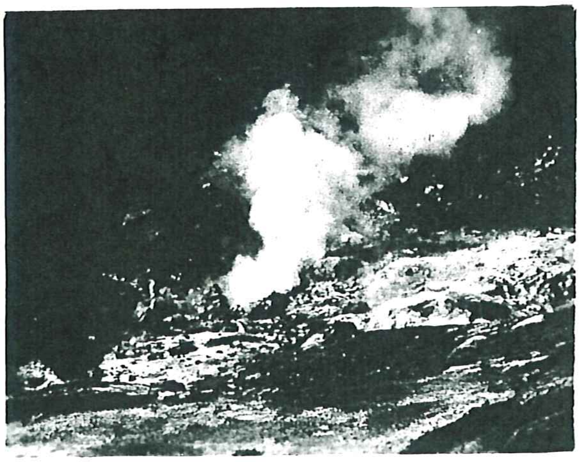

Fig. 5

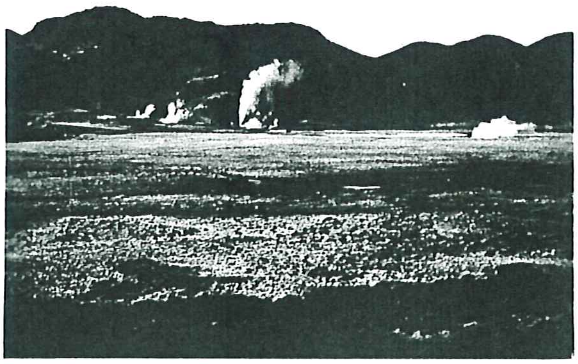

Fig. 6

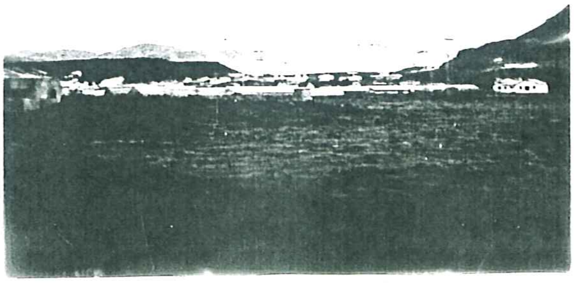

Fig. 7