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HEAT EXCHANGERS PILOT PLANT AT SVARTSENGI, ICELAND.

by

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Introduction.

On the Reykjanes peninsula on the south-west coast of Iceland, there are three geothermal areas, at Krýsuvík, Svartsengi and Reykjanes.

The area discussed here is the Svartsengi area, but in 1971 there were drilled two shallow wells, up to 400 m depth, and they indicated that this was a promising geothermal area. The bottom well temperature was measured 220 C^{o} and the total discharge is approximatly 100 kg/sec.

The wells produce a geothermal brine with a salinity of 2/3 of sea water and is rich in silica, carbondioxide and hydrogensulphide. Because of the proximity to fishing villages and the international airport in Keflavík, an interest in using the heat for domestic heating was developed. The heat market for this area is approximately 100 Mw power and 350 Gwh energy per year. Exploration of the area is continuing and drilling of two 1800 m wells is now under way. A source of fresh water is also beeing sought in the neighbourhood. As the brine is not useable for direct use, the heat has to be transfered to fresh water, that can be used for the district heating system.

A pilot plant for the investigation of heat transfer equipment was put in service jan. 1974.

The following is a progress report of findings to date, but the testing will be continued until next autumn.

The geothermal brine.

In a high temperature area as in Svartsengi, hot water is to be found at several hundred meters depth, with a temperature of over 200 C^{o}. In fissures and boreholes, the water begins to boil because of decreasing pressure. The water deep in the formation, which has not boiled is called deep water.

The deep water at Svartsengi, entering the boreholes at a depth of 300 - 400 m, has a salinity approximately 2/3 of that of sea water.

Composition of the deep water is:

K:	1040 ppm
Na:	6800 "
SiO_2:	410 "
HCO_3:	175 "
SO_4:	30 "
Cl :	13100 "
H_2S :	5 "

The origin of the salinity is believed to come from sea water, which permeates the formation and is mixed with fresh water by 1/3 parts.

It has not been determined whether the mixing of sea water and fresh water takes place in the upflow in the geothermal area or in the downflow of the convection cell. Such a down flow condition must take place outside of the area, although it is not clear how far away. Considering the high porosity of the bedrock, and decreasing denstity of the water with an increase in temperature, it is considered unlikly that the mixing takes place in the upflow. This will become clear after the two 1800 m. boreholes have been drilled. Should the above hypothesis be true, the salinity af the deeper holes will not be greater than for the present shallow holes. The reason for the different concentration ratio between sea water and the brine, is that reaction has taken place with minerals in the formation or new minerals have been formed. Ca and K have increased in cencentration but Mg and SO_4 have decreased. As in other thermal areas the concentration of the silicicacid in deep water is determined by the soulubility of quarts.

Usually the concentration of CO_2 and H_2S is high in high temperature areas. These gases are removed with the steam upon flashing. For this reason water heated with direct injection of steam can not be used directly. The CO_2 and H_2S lower the pH and results in high corrosion rates.

At Svartsengi the deep water contains little CO_2 and H_2S compared with other high temperature areas. The low concentration of H_2S is caused by the salinity of the deep water. The reason for the low CO_2 content is not known.

Description of the pilot plant.

Testing of heat exchange equipment was started at Svartsengi in January 1974. The purpose of the plant is to study how the geothermal brine can be used to heat fresh water

The plant has four types of heat exchangers. Two shell and tubes heat exchangers, steam injector and a barometric condenser. One of the tubular heat exchanger is for steam/ fresh water and the other for brine/fresh water.

The heating fluid is carried inside the tubes and the fresh water outside. This indirect heating of the fresh water has the advantages that undesireable gases and minerals do not mix with the fresh water. On the other hand, scaling is a problem requiering frequent cleaning of the equipment.

The steam injector heats the water by direct injection of steam into the fresh water where it condenses. Steam is supplied to the injector from a separator, where the steam is separated from the brine. In this arrangement the gases are carried with the steam to the fresh water.

The brine from the first separator is sent to a second separator where it is flashed under vacuum from a barometric condenser. The barometric condenser is used as the first stage in heating of the fresh water. The barometric condenser makes it possible to utilize the heat from the brine to a temperature of 50 C^{o} by operating the condenser at a pressure of 0,14 ata. The flash steam from the second stage is free of gases. The steam separators have proven to be very effectiv, having an efficiency of 99,9% for water droplets. Fig. 5, shows the different flow configurations that can be used in the pilot plant. The most promising arangement and the one that has been tested for the longest time, is the direct heating method.

Fresh water is preheated in the barometric condenser to 40 - 45 C^{o}, and then pumped to the steam injector where the temperature is brought up to 110 - 120 C^{o}. From the steam injector the water goes to a deairator, where the water flashes down to 100 C^{o}, the flash steam removing the dissolved gases from the water. Direct heating of this type is undoubtedly the least expensive heating method available.

Precipitation of silica.

Precipitation of silica does not occure until the brine becomes saturated with silica. If the temperature of the brine entering the borehole is below 148 C^o, the brine could be cooled in the barometric condenser down to 20 C^o without scaling.

If the temperature of the brine is 175 C^o scaling occurs at 50 C^o. As the existing bottom well temperature is measured 230 C^o, scale formation will start at 126 C^o and scaling can thus not be prevented when the heat of the brine is used down to 50 C^o.

Fig. 6, shows the temperature and pressure at which precipitation of silica starts, given the temperature of brine entering the borehole. With this in mind temperature of the brine has been maintained above saturation temperature in every equipment except for the second stage separator, where the brine is flashed from 137 C^o down to 50 C^o. Experience has shown that silica precipitation is limited to the barometric leg and sealtank on the brine side.

Dissolved gases and pH value of heated fresh water.

The concentration of dissolved gases in the fresh water is increased because of direct injection of steam.

Assuming a steam temperature of 135 C^o in the steam injector, the percentage of the steam in the fresh water is 14,7 - 19,5%, when the fresh water is heated from 5 C^o to 100 C^o to 130 C^o. Under this condition the CO_2 content is increased by 113 - 150 ppm and for H_2S by 4,5 - 6,0 ppm.

Corresponding values for heating from 40 C^o are for CO_2 75 - 114 ppm and for H_2S 3,0 - 4,6 ppm. This is in good agreement with the measured values. Because of increase of CO_2 and H_2S the pH value is lowered to 6,2 - 6,5. By flashing and deairating the pH value is increased to 8 to 9, which is suitable for district heating system. Fig. 7 and 8 show the measured pH and CO_2 concentration of the deairated water, as a function of the hot water temperature entering the deairator.

Preliminary flow diagram for heat exchange station.

Our experience to date of the pilot plant indicates that direct heating of the fresh water is practical and considerably less expensive than indirect heating. It should be pointed out, that the hot water produced by direct heating, has to be deairated because of the gases present in the steam. The steam produced when the hot water is deairated by heating it to 110 C° - 120 C° and flashing to 100 C° is too rich in gases to be used again for direct injection. The flash steam from the deairator which contains 10% - 20% of the total heat, could be used in an indirect heat exchanger. As this steam is very rich in gases (pH 3,0) it is very corrosive which limits its use. Fig. 10, shows a preliminary flow diagram for heat exchange station. The flows shown are those requiered to produce 6 kg/sec. of 100 C° fresh water.

This is chosen as the basis because 6 kg/sec. represents 1 Mw of the heating market for the temperature drop from 80 C° to 40 C° in the domestic heating system.

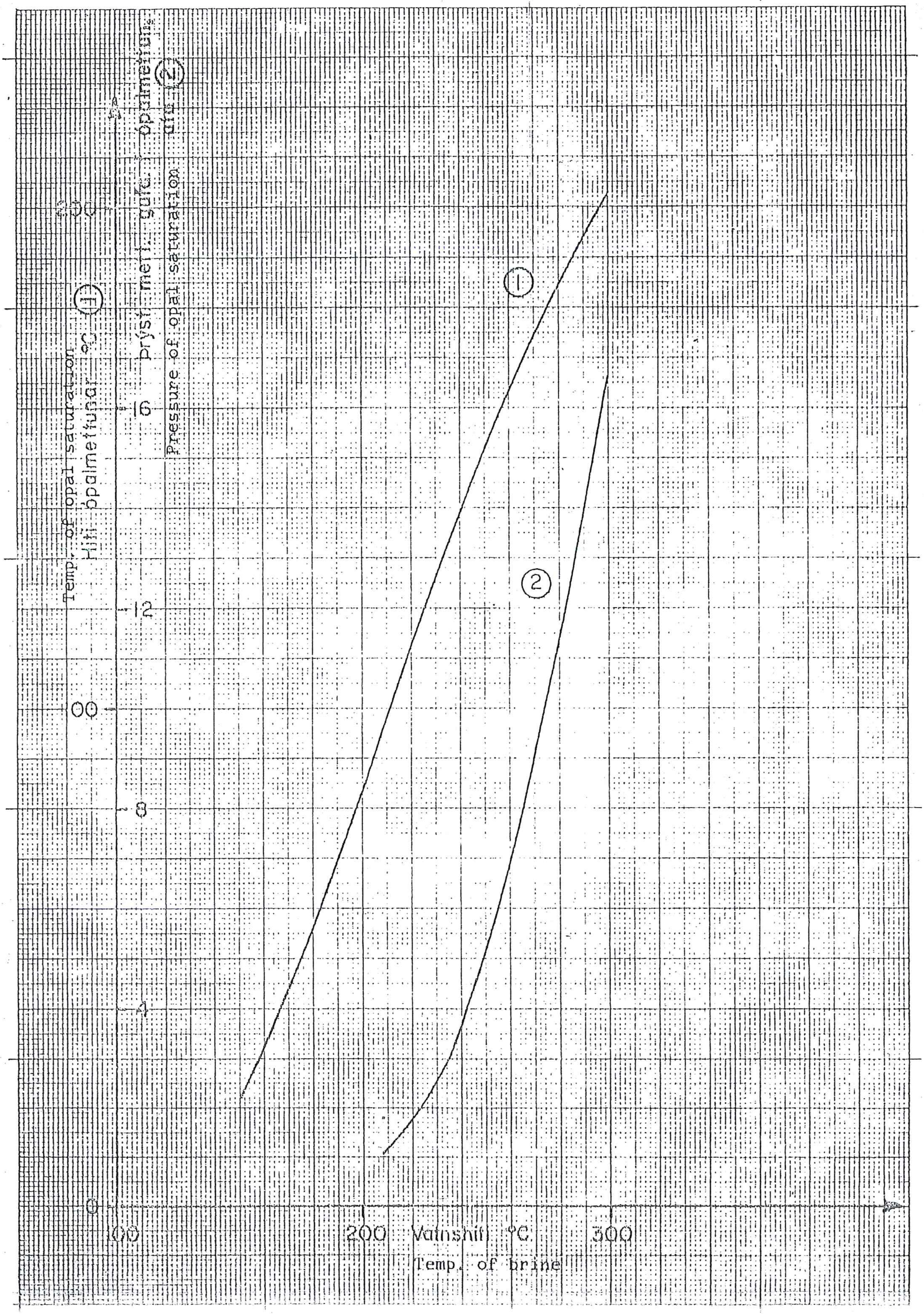
Calculations have been made to determine a practical pressure range for the first separator. The minimum pressure is limited because of silica precipitation, and the upper limit is because of heat balance, as too high a separator pressure will not produce enough steam.

Assuming a brine temperature entering the well at 200 C° the operating range is 0 - 1,5 atg. Corresponding values for 230 C° are 1,5 - 3,5 atg. and for 260 C° the pressure range is 5,8 - 6,0 atg.

If the temperature of brine entering the well is above 260 C°, silica precipitation can not be prevented in the seperator unless the recovery of heat from the brine will be less.

FIG. 6

Temperature and pressure at wich silica precipitation starts as a function of temperature of brine entering the borehole



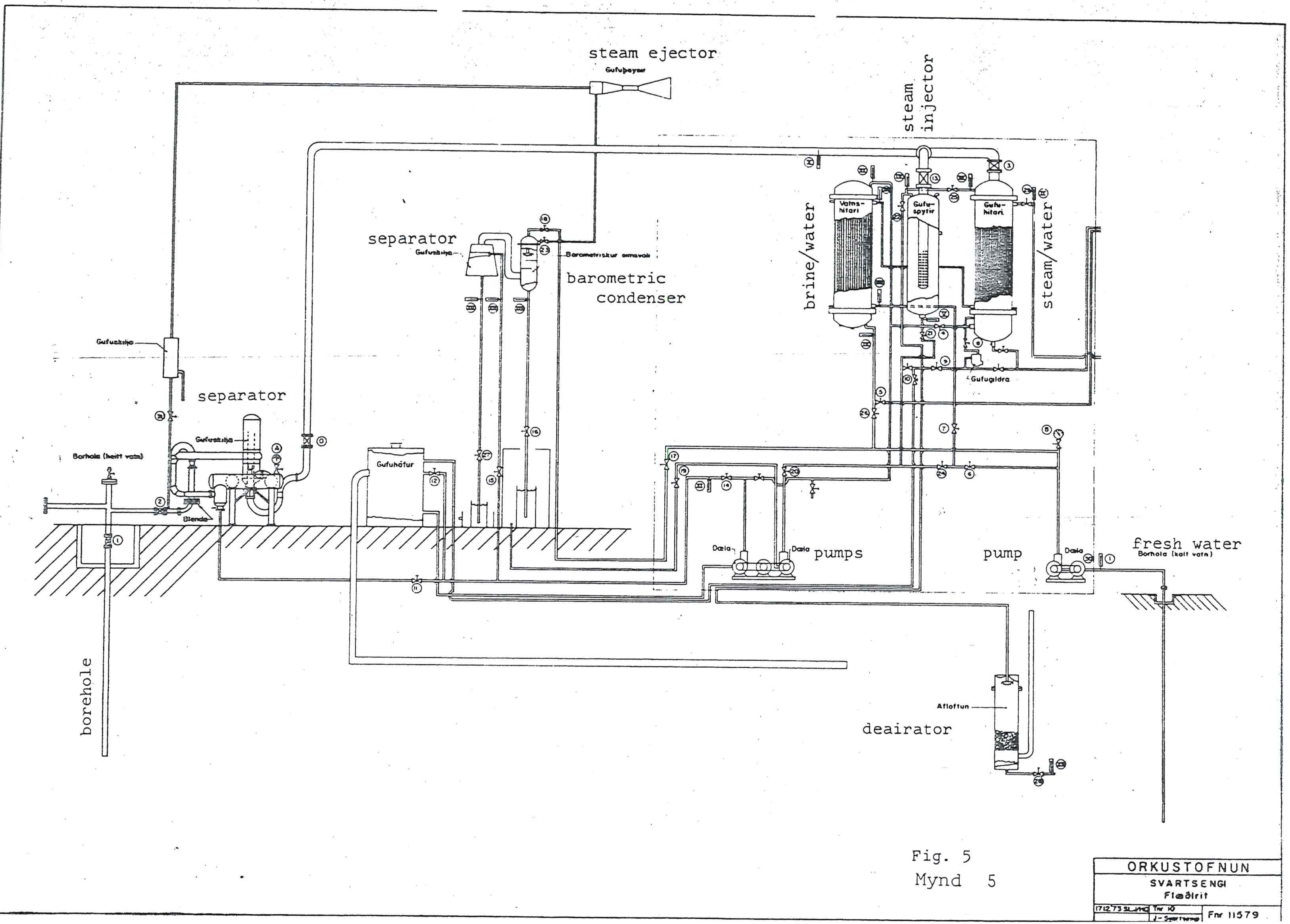

steam ejector
Gufuþeyar
steam injector
separator
barometric condenser
separator
brine/water
Vatns-hitari
Gufu-spytir
Gufu-hitari
steam/water
Gufugildra
Gufuháfur
Borhola (heitt vatn)
Blenda
pumps
Dæla
pump
fresh water
Borhola (kalt vatn)
borehole
Afloftun
deairator
ORKUSTOFNUN
SVARTSENGI
Flæðirit
Fnr 11579

Fig. 5
Mynd 5

ORKUSTOFNUN

SVARTSENGI

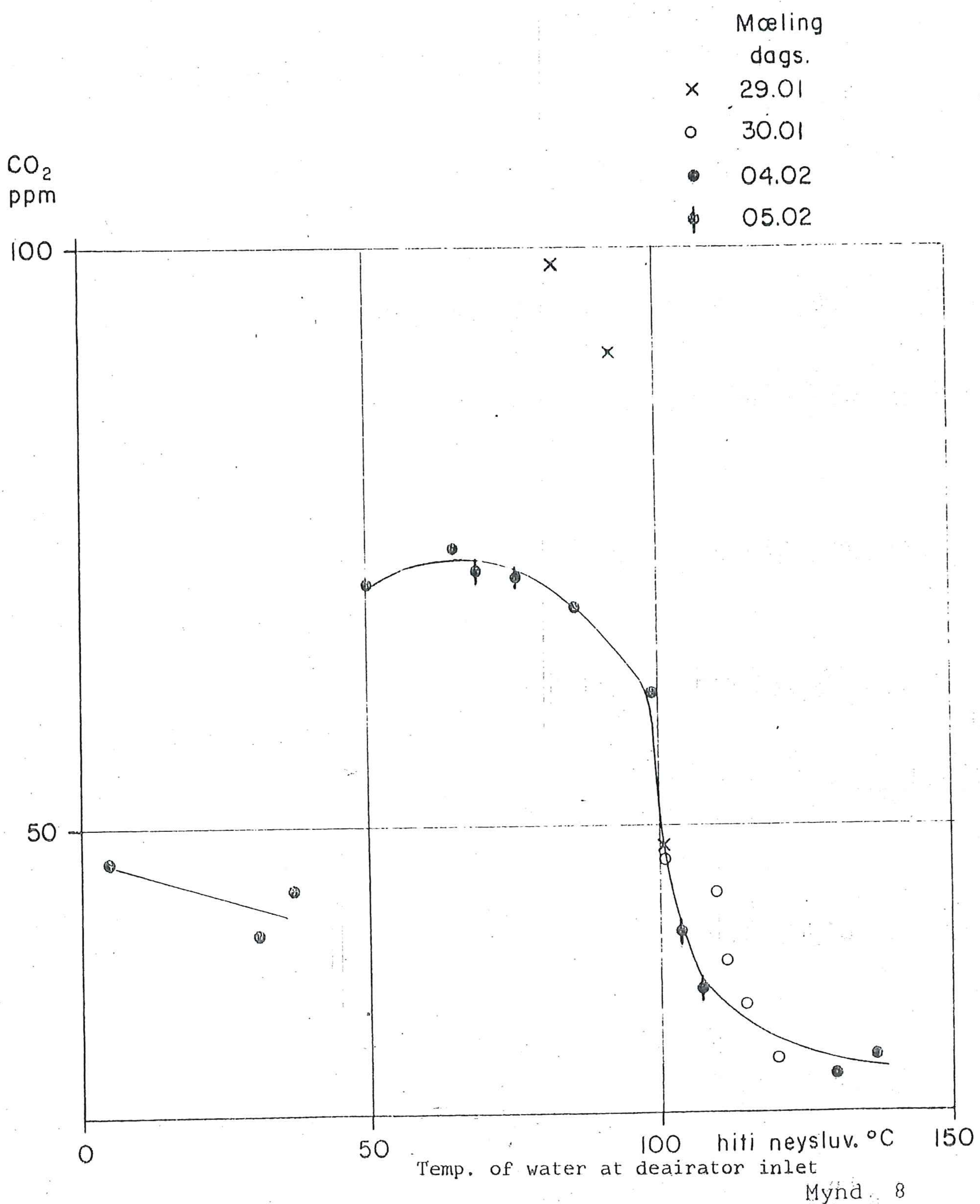
Varmaskiptatilraunir

29.2.'74 SA/EK
Tnr. 18 Tnr. 90
J-Svartse. J-Jarðe.
Fnr. 11677

CO_2 concentration as a function of temperature of water entering the deairator

Samband kolsýruinnihalds og hitastigs í upphituðu fersku vatni við beina innspýtingu gufu (4.2 ata) frá aðalskilju og forhitun í 31–37 °C með gufu (0.14 ata) á eimsvala.

Sveiflur á CO_2 frá degi til dags eru taldar stafa af breytingu á CO_2 innihaldi djúpvatnsins.



Mynd 8
Fig. 8

ORKUSTOFNUN

SVARTSENGI

Varmaskiptatilraunir

29.2.'74. SvP/SA/EK

Tnr. 19 Tnr. 91

J-Svarts.e. J-Jarðe.

Fnr. 11678

pH of deairated water as a function of temperature of water entering the deairator

Samband sýrustigs og hitastigs í upphituðu fersku vatni við beina innspýtingu gufu (4.2 ata) frá aðalskilju og forhitun í 37° með gufu (0.14 ata) í eimsvala

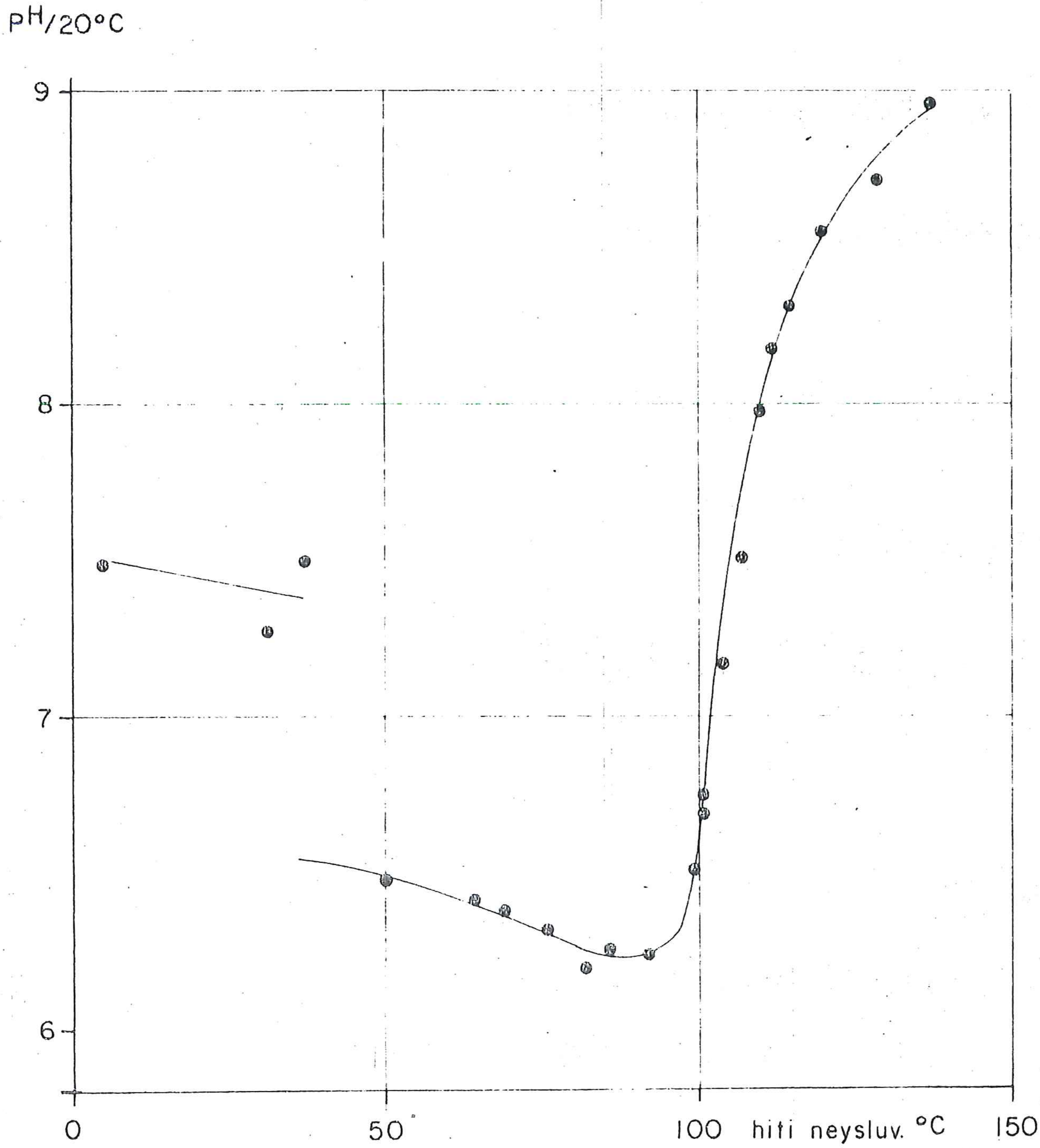


Fig. 7
Mynd 7

ORKUSTOFNUN	25.2.'74 KR/EK
SVARTSENGI	Tnr. 14
Fyrirkomulag varmaskiftistöðvar	J-Svartsengi
	Fnr. 11666

Tillaga I

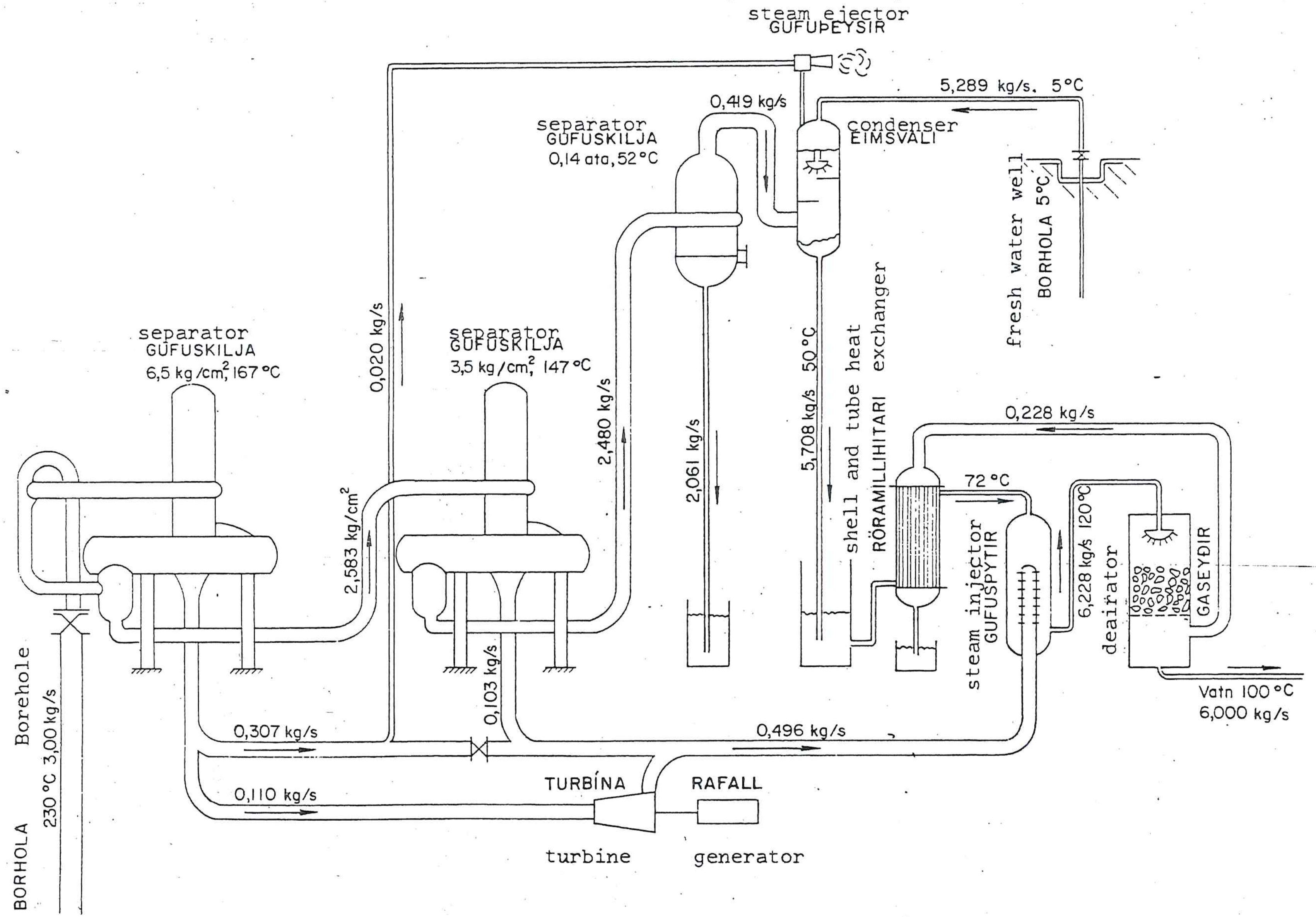


FIG. 10

Mynd 10