National Energy Authority
Geothermal Division

Methods of exploration and exploitation of low temperature geothermal fields in Iceland

by

Karl Ragnars

OS JHD 7833

May 1978

National Energy Authority
Geothermal Division

Methods of exploration and exploitation of low temperature geothermal fields in Iceland

by

Karl Ragnars

OS JHD 7833

May 1978

National Energy Authority
Geothermal Division

Methods of exploration and exploitation of low-temperature geothermal fields in Iceland

by

Karl Ragnars

May 1978

INTRODUCTION.

Geothermal heat has been utilized in Iceland for many years for swimming pools, institutions, heating of homes and industrial plants. The major part of this utilization is for house heating, and today there are about 20 district heating services operating and 61% of the population have geothermal space heating. Installed power of these district heating services is 450-500 Mw, while installed hydropower is 392 Mw. In addition to this, two district heating services are under construction, and when they are finished, 75% of the inhabitants are expected to enjoy the benefits of geothermal space heating.

Of the total energy consumption in Iceland - that is, oil, hydropower and geothermal heat - the geothermal energy accounts for about 20%. According to information from the Reykjavik district heating service, the cost of geothermal heating is 25-30% of what expenditure would be if fossil fuel were used.

This paper (report) deals mostly with exploration and exploitation of low-temperature fields. Certain chemical problems connected with this will also be discussed.

TYPES OF GEOTHERMAL AREAS.

There are two types of geothermal fields in Iceland, referred to as high and low temperature areas. The high-temperature areas are characterized by reservoir temperatures in excess of $200^{\circ}C$. In the low-temperature areas, reservoir temperatures are below $150^{\circ}C$.

The 17 known high-temperature fields in Iceland are all locat d within the rift zone that extends through the country. This zone - a land section of the Mid-Atlantic Ridge - is dotted with active volcanoes. Many of the high-temperature areas are near major volcanic centers. The heat sources are magma intrusions, which are abundant near such sites and relatively close to the surface.

The low temperature areas are found outside the active volcanic zones in the Tertiary and early Quaternary regions. The early Quaternary regions bordering the active volcanic zones are characterized by abundant productive horizontal aquifers in subglacially erupted formations. The Tertiary rocks farthest away from the active volcanic zones are less permeable and the flow of the thermal waters is controlled by vertical structures, dykes and faults. The heat source of the low temperature areas is related to the general heat flow, which becomes systematically lower with increasing age of the rocks, and with increasing distance from the active zones of rifting and volcanism.

GEOTHERMAL EXPLORATION TECHNIQUES.

In known geothermal areas the first step in exploration is geological mapping, and a study of the hot springs themselves, and, if possible, the structures that control them.

Geochemical investigations of the hot spring water are made in order to get information about the quality of the water and about reservoir temperatures by use of geochemical thermometers.

Magnetic ground surveys are used extensively in Iceland in the low-temperature geothermal areas for tracing hidden dykes or faults that may act as aquifers or upflow zones.

Electrical resistivity surveys have been used in geothermal exploration for over 25 years. With this technique, it is possible to outline the underground geothermal reservoirs. The temperature effect on resistivity is greatest at low-temperatures, less than 100°C, but becomes small above 200°C.

Information about reservoir temperatures can therefore only be estimated crudely from resistivity surveys.

The most extensively used method in resistivity surveys has been the so-called Schlumberger method, but in recent years the dipole method, which gives information on deeper strata, has also been used.

Thermal gradient measurements in boreholes, generally 100 m deep but occasionally over 1 km, give information about the heat flow pattern. Abnormally high gradients possibly indicate hot water reservoirs at depth. Recognition of such anomalies may thus help us to discover such reservoirs.

Gravity maps, studies of seismic layering and magnetic-telluric resistivity methods give information about conditions in the crust that may be useful for a better understanding of the thermal regime and movement of water through the crustal layers. Isotope studies give information about the recharge areas and about the rate of flow through the rock from the recharge area to the production area. Isotopes are used also in aquifer studies. Gravity measurements are, more over, important in geothermal work connected with exploitation. Withdrawal of fluid from a hydrothermal system may lead to net mass transfers that affect the gravity values measured in the area.

DRILLINGS.

Five drilling rigs are mainly used for geothermal drilling in Iceland.

They are the following:

	Name	Type	Depth Capacity
1.	Jötunn	(Gardner Denver 700 E)	3600 m
2.	Dofri	(Oilwell 52)	1800 m
3.	Narfi	(Failing 3000 CF)	1400 m
4.	Glaumur	(Wabco 2000 CF)	800 m
5.	Ýmir	(Mayhew 1000)	400 m

Drilling procedures vary extensively, depending on whether a high-temperature or a low-temperature field is being drilled.

The main difference lies in the well-casing program, and in the blow-out equipment used.during drilling..

Drilling of a typical well in a low-temperature area involves the following operations. Initial drilling is done with cable drill down to approximately 30 meters, and loose surface layers are cased off. Rotary drilling starts at this point. Drilling depth and hole diameter depends upon the area, the size of the drilling rig, amount of expected flow and the size of deep-well pump to be used.

The production casing normally extends down to 300 m, and the trend has been to make the casing longer because of draw-down during production. The production casing is cemented in the borehole to protect the steel from possible corrosion by thermal water, and to stop the flow of water outside the casing, as surface water could contaminate the thermal water with oxygen and lower the temperature. When the production casing has been cemented, the wells are normally completed without casing or liners. The final depth of the well is determined by results obtained during drilling, expected depth of aquifer and depth capacity of rig, but difficulties encountered during drilling may also affect the final depth. The most common problems during drilling is collapse of the borehole and insufficient removal of cuttings because of loss of circulation. Water is used as drilling fluid, but occasionally a slug of bentonite slurry is circulated to remove cuttings, though its use is restricted because of its tendency to permanently clog producing formations.

Upon completion of drilling, an open hole packer is used to stimulate the well. This method has been used in Iceland since 1968 to increase productivity of 30 hydrothermal drillholes. During stimulation, the inflatable packer is set between two or more producing horizons in the borehole, and water in turn injected beneath and above the packer. The rate of pumping is from 30 to 100 l/s and varies according to the resistance of the producing horizons to flow. Well head pressures range from a few kg/cm^2 to 60-70 kg/cm^2 at 30 l/s in highly resistive horizons. This increase in productivity is predominantly attributed to the reopening of producing horizons clogged by drill cuttings and lost circulation materials during drilling, but also to the removal of zeolite and calcite vein deposits and by increasing the permeability of the hyaloclastic rocks in the immediate vicinity of the holes.

PRODUCTION OF HOT WATER (DEEP WELL PUMPS).

Hot springs and some wells supply water by self-flow because of a high hydrostatic pressure, and pumping is thus not required.

Normally, however, the water is lowered during exploitation so pumping from wells becomes the usual method of production. The first deep well pump to be used in geothermal well in Iceland was installed at Laugardalur in Reykjavik in 1960. This pump was of a standard type from Craelius with a semi-open impeller and the line shaft was supported by open rubber bearings that were lubricated by the hot water. The temperature of the water being pumped was 130°C and it soon became apparent that the rubber bearings could not stand up to the high temperature.

Different types of rubber bearings were tested, and the temperature limitation was generally around 110-120°C. Wear of the bearings by sand in the water contributed also to the short life of the bearings. Differential thermal expansion between the column and shaft caused the pump impellers to stick because of limited endplay between the impeller and pumphousing.

In order to overcome these problems, various methods and designs were tested. Bronze and babbit bearings were tested, but wear by sand damaged the bearings. In 1965 a Fairbanks Morse pump was tested with closed impellers and an enclosed oil lubricated lineshaft. The first pump of this type had bronze bearings lubricated by oil that was pumped down the shaft-enclosing tube, and the endplay of the impeller could easily be adjusted because of a hollow shaft motor construction. This method of lubricating was abondoned because of limited life of bearings(four months) and because of contamination of the thermal water by the oil.

A new design with teflon bearings was tested in 1966. The teflon bearings were lubricated by filtered thermal water that was pumped down the shaft-enclosing tube. This design has since been used for all deep well pumps, and now bearing maintainance is only required every three or four years compared to the previous life of three to four months, when other bearing materials and method of lubrication were used. The pump column and shaft assemblies have been manufactured in Iceland.

So far the maximum depth of a pump in operation in Iceland is 130 m and the maximum temperature 130°C. This is not a definite depth or temperature limitation, but the present pump design does not allow for more differential expansion between column and line shaft during start up because of limited endplay.

The increased pumping cost with depth also becomes a criterion for selecting the depth of pump. At present the cost of electricity to drive the pumps of the Reykjavik district heating system is 6-8% of total proceeds from the sale of water.

The temperature limitation for teflon bearings may be as high as 200°C and thus deep well pumps could also be used in high-temperature areas to prevent temperature drop and deposition of dissolved minerals, caused by flashing of the water inside the borehole, and to increase the output of the boreholes.

As the output of wells may vary considerably, the minimum size of the uppermost part of the borehole casing must be in accordance with the desired output and pump size to be used. The length of this wider casing must be 100-300 m to enable the installation of the pump to the desired depth.

To date, the largest pump size used in Iceland is a 12" pump, but the following table shows the capacity of normal deepwell pumps and the minimum size of the casing diameter required for the pumps.

Output (m^3/h)	Pump Diameter (inch.)	Casing Diameter (OD) (inch.)
200	8" 3000 RPM	9 5/8"
150-350	12" 1500 RPM	13 3/8"
300-500	14" 1500 RPM	15 5/8"
450-900	16" 1500 PPM	17 5/8"

HOT WATER TRANSMISSION LINES.

The most common design of transmission lines from wells or pumping stations to the distribution system are the following main types:

1. Steel pipe in a concrete duct and in ated with rockwool.

2. Steel pipes above grade line, insulated with rockwool and covered with metal sheet.

3. Asbestos - cement pipe covered with soil.

4. Steel pipe burried in trenches, insulated with polyurethane and cased in plastic.

The transmission pipe in type 1 is the most expensive and not used except where required, when the pipeline passes through built-up areas and roadways or there is a danger of damage.

The only transmission pipe in Iceland that is completely in concrete duct is the pipe from Reykir in Mosfellssveit to Reykjavik, a distance of 12 km.

Transmission lines of types 2 and 3 are common for small communities and factories, and type 4 is primarly used for the distribution systems and service lines and for pipes between wells and pumping stations.

The above mentioned types vary significantly in cost and durability. Before a selection can be made, the pros and cons of each type have to be evaluated.

Where the hot water is in abundant supply and self flowing, asbestos - cement pipes can be used in spite of poor insulation offerd by the soil cover.

The asbestos - cement pipes are sensitive to breakage and earthquakes and offer thus less reliability. In cases where this is unacceptable, steel pipes are always used. The relative cost of three types of transmission lines for different flow rates is shown in the following figures. The temperature drop during transmission is also plotted, based on the difference between water and ambient temperature of 100°C.

CORROSION AND SCALING.

The thermal water used for district heating systems is pure enough for potable use, with a few exceptions. The total dissolved solids are only 200-400 ppm, except where sea water is mixed in the thermal water, silica contributing the largest part 50-200 ppm.

The silica content is determined by the reservoir temperature and corresponds to the solubility of chalcedony. The solubility of this mineral increases with temperature, but silica does not precipitate unless the temperature falls below the solubility for amorphous silica.

Silica precipitation is generally not a problem when the maximum temperature is 130°C or less and the water cooled down to 30-40°C, as is the case in district heating systems in Iceland.

The thermal water contains gases that are separated from the water before it is pumped through the transmission lines. The separated gases are nitrogen, carbon dioxide and hyrogen sulphide.
CO_2: 10-30 ppm and H_2S: 1 ppm

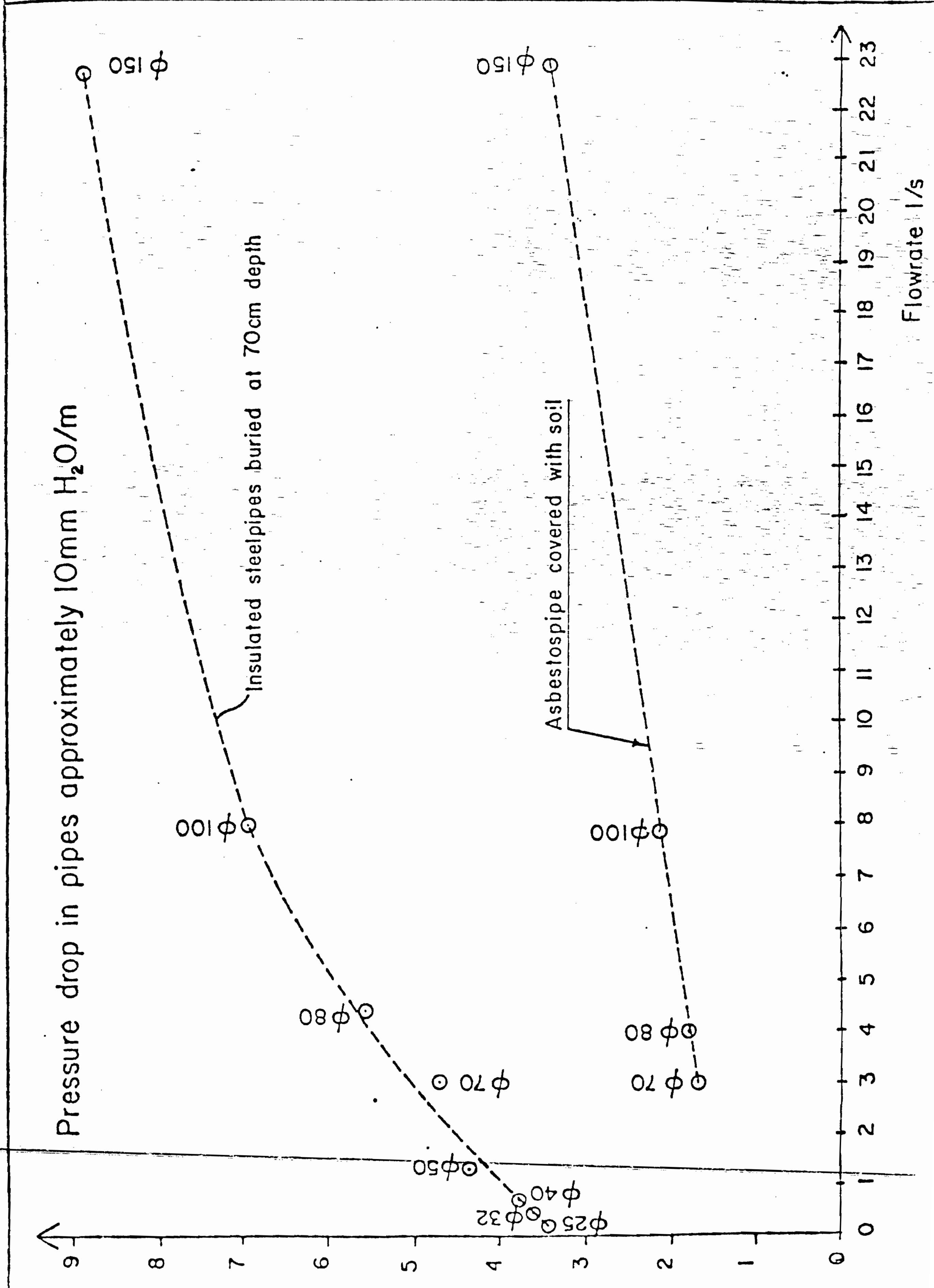
Dissolved oxygen in small concentrations has been measured in a few places. The presence of oxygen is indictative of mixing with surface water, or contamination by oxygen from the atmosphere. Contamination by oxygen from the atmosphere was a problem years ago, when some wells of the Reykjavik district heating system were stimulated by an air-lift, and contamination in storage tanks was also a problem. Deep well pumps later replaced the air-lift, and contamination was cured by proper vent design. The salinity of the thermal water is low, the cloride content being 10-40 ppm, but in two district heating systems the cloride content is higher, 250-600 ppm.

In these two systems corrosion(pitting) has been notdd on panel radiators but not in the distribution systems. Recently the pH of the water for the Seltjarnarnes district heating system, where cloride content is 600 ppm, the pH was increased with caustic soda from a pH of 8,5 to pH 9,2. This mixing has only been tried for one year but shows promising results.

ORKUSTOFNUN

Relative cost of transmission lines at various flowrates

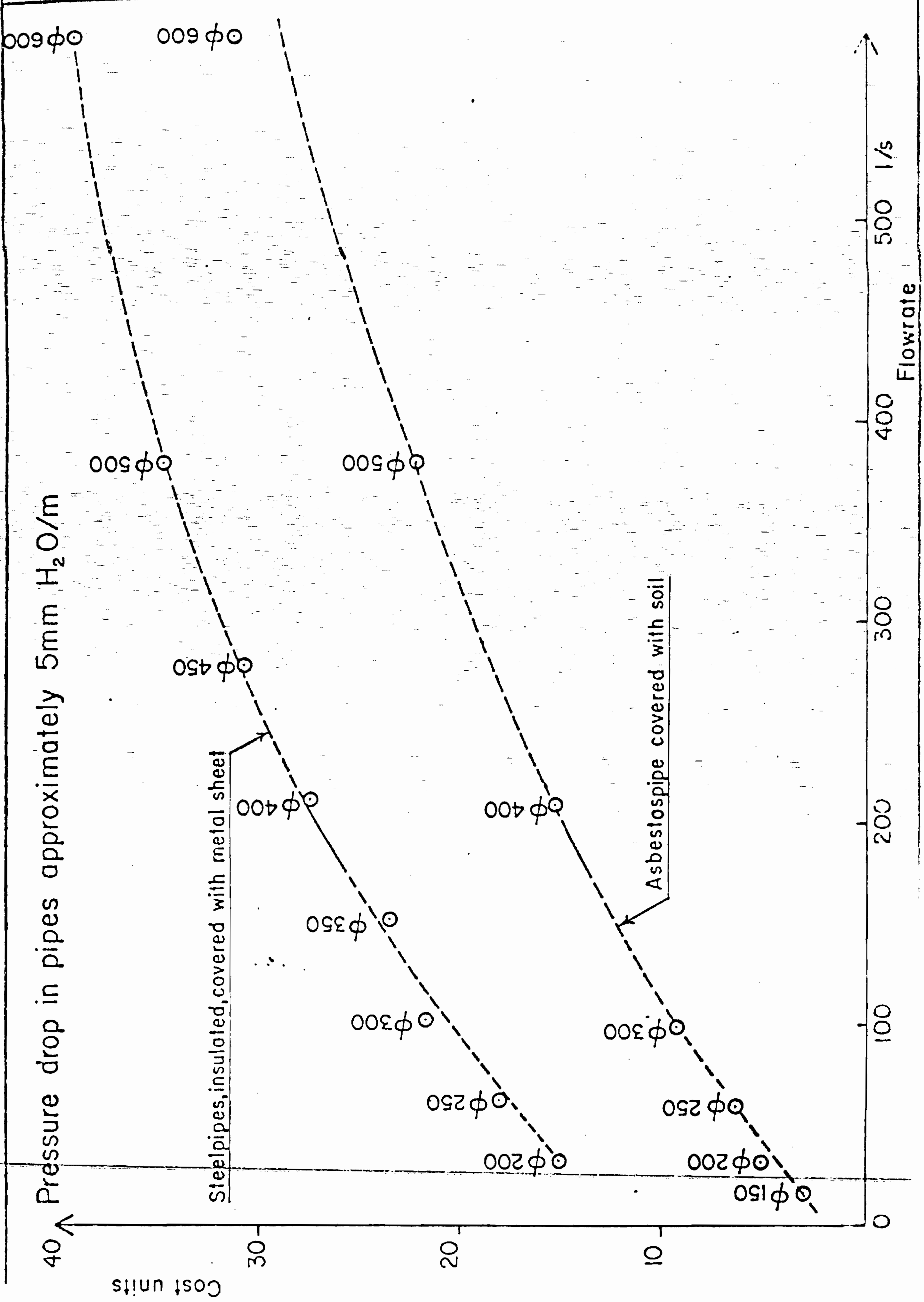
78.05.22 KR/H
T-675
J-Ým
F-17068



ORKUSTOFNUN

Relative cost of transmission lines at various flowrates

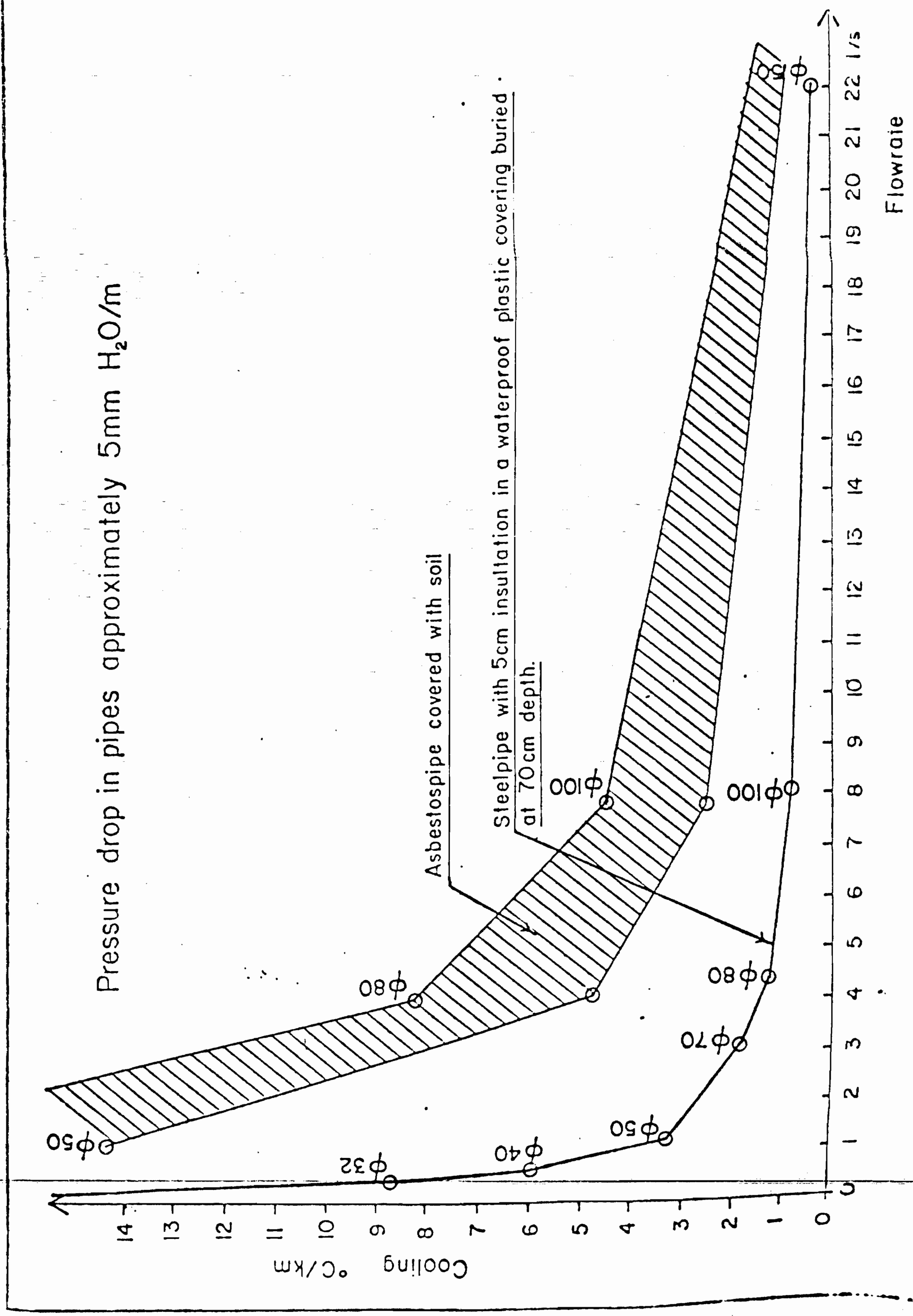
78.05.22 KR/H	
T-676	
J-Ým	
F-17069	



ORKUSTOFNUN

mperature drop in transmission lines
at various flowrates

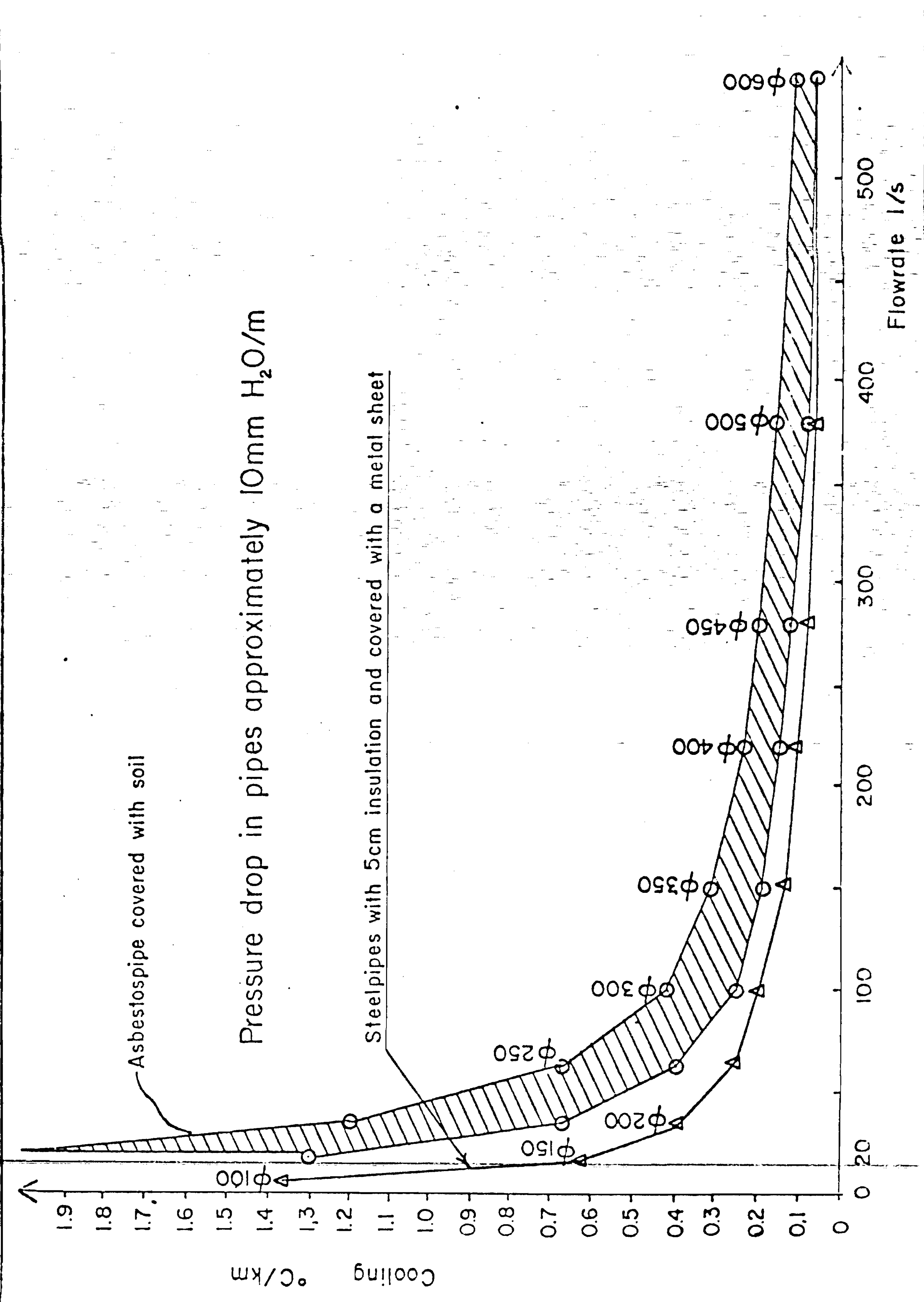
78.05.22 KR/H
T-677
J-Ým
F-17070



ORKUSTOFNUN

Temperature drop in transmission lines
at various flowrates

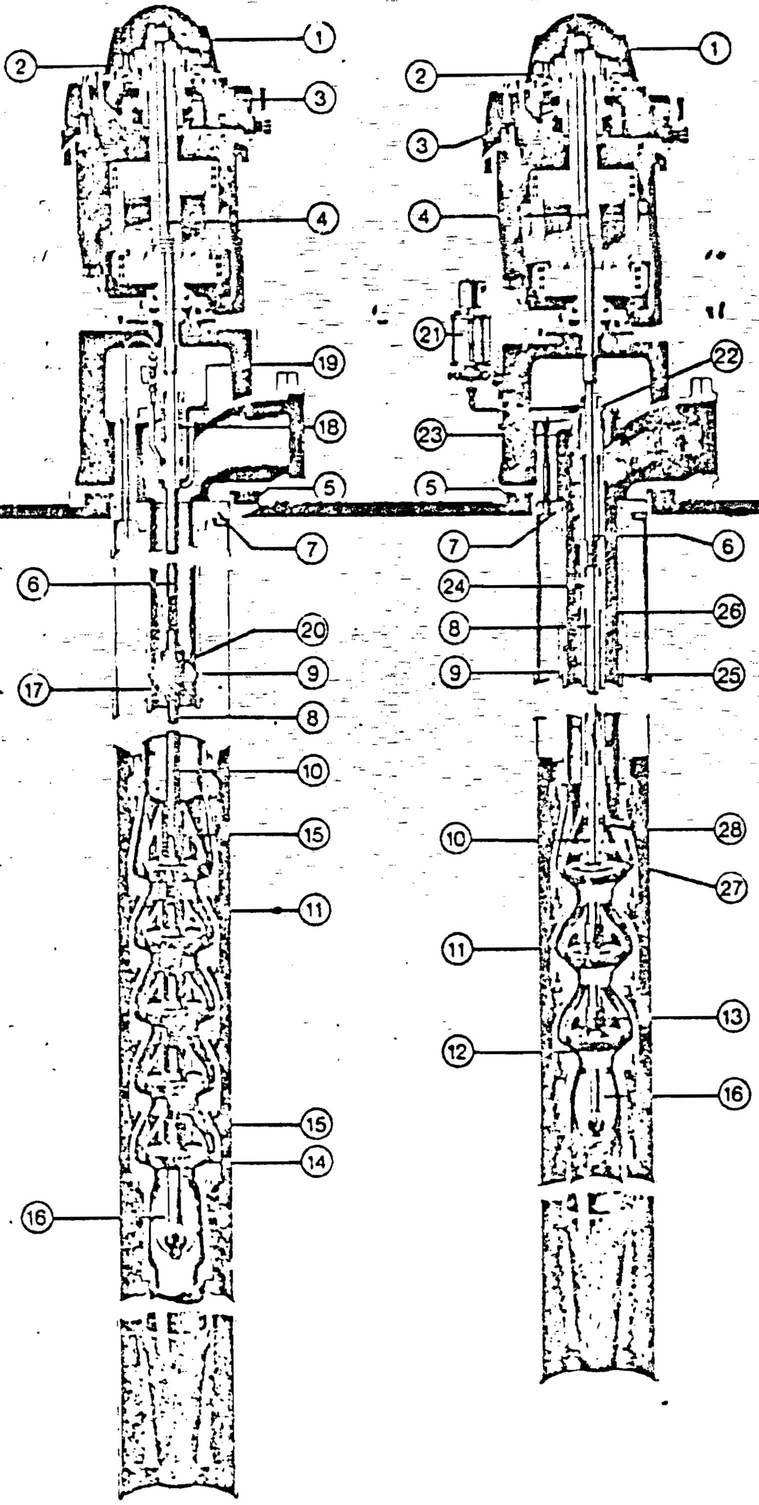
78.05.22 KR/H
T-678
J-Ým
F-17071



TURBINE PUMPS

precision engineered to fill every municipal, industrial & agricultural requirement

WATER LUBRICATED | OIL LUBRICATED



OIL AND WATER LUBRICATED

1 IMPELLERS EASILY ADJUSTABLE – [illegible]

2 RATCHET PREVENTS BACKSPIN – [illegible]

3 HEAVY DUTY THRUST BEARING – [illegible]

4 SEPARATE HEADSHAFT – [illegible]

5 BASE OF HEAD RELIEVED – [illegible]

6 STAINLESS STEEL STUFFING BOX SHAFT – [illegible]

7 FLANGED HEAD CONSTRUCTION – [illegible]

8 HIGH STRENGTH LINE SHAFT – [illegible]

9 COLUMN COUPLINGS – [illegible]

10 STAINLESS STEEL IMPELLER SHAFT – [illegible]

11 STREAMLINED BOWL PASSAGE WAYS – [illegible]

12 ENCLOSED BRONZE IMPELLERS – [illegible]

13 BRONZE BOWL BEARINGS – [illegible]

14 SEMI ENCLOSED BRONZE IMPELLERS – [illegible]

15 RUBBER BOWL BEARINGS – [illegible]

16 ENCLOSED BRONZE BEARING – [illegible]

WATER LUBRICATED ONLY

17 STAINLESS STEEL SHAFT SLEEVES – [illegible]

18 ACCESSIBLE EXTRA DEEP STUFFING BOX – [illegible]

19 PRE LUBRICATION CONNECTION – [illegible]

20 WATER LUBRICATED SHAFT BEARING – [illegible]

OIL LUBRICATED ONLY

21 AUTOMATIC LINE SHAFT LUBRICATOR – [illegible]

22 BRONZE TUBING TENSION NUT – [illegible]

23 TUBING HEAD ADAPTER WITH "O" RING – [illegible]

24 BRONZE LINESHAFT BEARINGS – [illegible]

25 HEAVY DUTY TUBULAR STEEL SHAFT ENCLOSURE TUBE – [illegible]

26 ENCLOSURE TUBE STABILIZERS – [illegible]

27 BEARING PROTECTING SLINGERS – [illegible]

28 RELIEF PORTS IN TUBE BOWL – [illegible]