PRODUCTION CHARACTERISTICS OF WELLS TAPPING TWO PHASE RESERVOIRS AT KRAFLA AND NÁMAFJALL

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INTRODUCTION

Geothermal fields have been classified in several different ways, covering geological, chemical and physical aspects. The most common distinction is to refer to the physical state of the fluid in geothermal systems. This is the division into vapor dominated and liquid dominated fields. In recent years, two phase reservoirs have been found in numerous high temperature geothermal fields (Grant 1977, Björnsson 1978, Stefánsson 1980, Whittome and Smith 1979). Some characteristics of two phase geothermal systems are markedly different from those in single phase systems (vapor or liquid) and classification into three groups seems to be justified. Table I shows some of the properties associated with each of the three groups.

TABLE I Classification of geothermal systems

	Liquid Dominated	Boiling (two phase)	Vapor Dominated
Pressure gradient	$\frac{dp}{dz} \simeq \rho_1 \cdot g$	$\rho_1 \cdot g \geq \frac{dp}{dz} \geq \rho_v \cdot g$	$\frac{dp}{dz} \simeq \rho_v \cdot g$
Temperature	$T \leq T_s$ T(z) independent of P	$T = T_s$ T(z) depends on P	$T \geq T_s$ T(z) independent of P
State of fluid	Water (gas)	Water, vapor, gas	Vapor, gas

ρ_1 : density of liquid water

ρ_v : " " vapor

T_s : Saturation temperature

g : Constant of gravity

In general, the pressure gradient has been used to distinguish between vapor and liquid dominated systems. Boiling systems may have pressure gradients somewhere between these two extremes. However, boiling systems described so far in the literature seem to have undisturbed pressure gradients close to hydrostatic.

In this work we will describe some typical production characteristics of wells tapping the boiling reservoirs in the Krafla and the Námafjall field in Iceland. The characteristics selected are meant to show some of the differences between boiling reservoirs and single phase systems.

Field characteristics

General description of the Krafla geothermal field has been given by Stefánsson (1980). The geothermal system has been found to be complex, consisting of two zones. A shallow liquid dominated zone with temperature of approximately 210°C whereas the deeper zone is a two phase system with temperatures ranging from 300°C at the top at 1000 m depth to 340°C at about 2000 m depth. The main features of the geothermal system are shown in Fig. 1.

The Námafjall field has until recently been considered as a liquid dominated system (see Arnórsson 1978). Recent drilling some hundreds of meters east of the older drill sites has revealed that at least that part of the field is boiling.

Reevaluation of the Námafjall field is now being carried out, and the present data indicates that the temperatures and the pressures of all aquifers below 1000 m depth lie on the saturation curve. Similar conditions are found in the lower zone of the Krafla system as is shown on Fig. 2.

Properties of wells

a) The first signs of a boiling reservoir can be found during the warming-up period of the well after drilling. Boiling aquifers recover usually faster than other parts of the well and boiling begins at the aquifers in the well. This boiling will initiate a convection in the well and heat the column above the boiling aquifer until the temperature aligns to the boiling point curve.

b) A boiling convection in a well increases the rate at which the water level rises until equilibrium is reached. A record of the depth of the water level will therefore show when boiling starts in the well.

c) The discharge history of wells in Krafla and Námafjall may be divided into two different stages. In the first stage which covers the first weeks of discharge, the water phase decreases continuously whereas the steam flow is fairly constant. The enthalpy of the discharged fluid will therefore increase during this period. After the first stage, the total discharge of the well will be nearly constant. The further development of the well seems to depend on whether the water flow decreases to zero or not. Fig 3 shows the discharge history of well KG-12 in Krafla. The water flow from this well stopped after one week of discharge, and the enthalpy reached equilibrium few weeks later. Since then the well has been producing superheated steam at a fairly constant rate for almost two years. On the other hand the water flow from well BJ-11 (Fig 4) reached a constant non zero value, but the well has since then increased considerably in steamflow and enthalpy.

d) The flow rate of wells tapping two phase reservoir varies little with well head pressure as shown in Fig 5. In comparison the production characteristic of the liquid dominated well KW-2 is shown on the same figure. One well (KJ-11) in the Krafla field had two modes of flowing. One was when only the liquid dominated zone contributed to the flow and the other was when both zones were active. These production characteristics are shown in Fig 5.

e) During discharge, the drawdown in the well is large. This can be monitored by running a temperature log immediately after shutin of a well. The temperatures then found will be considerably lower than immediately before discharge. For wells with a mixed flow (steam and water), temperatures close to the saturation temperature at the well head pressure during discharge have been recorded. This indicates that the pressure gradient in two phase well is close to zero during discharge and that the temperature is fairly constant. The well head pressure controls the temperature in the well as well as the drawdown during discharge. Fig 6 and 7 show temperature and pressure logs in KG-12 before and during discharge. The large drawdown and pressure gradient in the flowing well is clearly demonstrated. As this is a dry steam well no saturation relation is between the temperature and the pressure during discharge and the temperature changes only slightly when wellhead pressure is changed as Fig 7 shows. Compared to the initial temperature (Fig 6) the temperature during discharge shows that during discharge, a considerable cooling of the wellbore will take place. This cooling is,however, much less than the cooling taking place when the well discharges saturated steam (Fig 7).

Discussion

The above description shows that the characteristics of wells tapping two phase reservoirs give quite a different performance compared to that given by ordinary single phase wells. In order to explain the differences the laws governing boiling and two phase flow have to be considered.

All the wells discussed are high enthalpy wells discharging fluid of high steam content. The density of the discharged fluid is, therefore, close to the density for steam. As a consequence the pressure gradient is small in the wells during discharge and a large drawdown can be achieved by lowering the wellhead pressure. The constant mass flow for different wellhead pressures is a direct consequence of the large drawdown. As can be seen in Fig 7 the pressure against the main inflow at 1500 m depth in well KG-12 is 19-23 bar (1,9-2,3 Mpa) during discharge, whereas the undisturbed pressure of this aquifer is 126 bars (12.6 MPa). The discharge causes therefore a drawdown of the order of 100 bar (10 MPa) and changes in the wellhead pressure of the order of 10 bar (1 MPa) will not influence the flowrate significantly. This performance is of great importance in utilization as desired steam pressure can be selected independantly of yield, over a wide range of well head pressures.

The discharge history of two phase wells shows some unexpected characteristics. Large variations in flow rate and enthalpy are observed in the beginning of a discharge period, while the drawdown is being developed, in the vicinity of the well. This process can take weeks. The increase in enthalpy accompanied with a decrease in the water flow rate is a consequence of the different mobility of the steam - and the water phase in the two phase reservoir together with a non adiabatic flashing in the vicinity of the well. The most unexpected observation in some of these wells is that after some weeks of discharge the mass flow starts to increase, Fig 4.

In addition to wells in Krafla and Námafjall in Iceland, increased mass flow has also been observed in some wells in the Tongonan field in the Philippines (Sarmiento 1980). Increased flow rate in wells in Krafla and Námafjall is in the steam part only, whereas the wells in the Tongonan field increase both in steam and water flow rate. Common feature for the three thermal fields is that they are all boiling, and the wells that increase in flow rate all produce a mixture of steam and water, whereas the dry steam wells at Krafla show a constant flow rate after the first few weeks of discharge.

As flowrate is not observed to increase with time in single phase reservoirs, it seems natural to associate this with some processes common to two phase reservoirs but not to single phase reservoirs. We suggest here that the process responsible for the increase in flow rate is the thermal contraction of the rocks surrounding the well caused by cooling of the wellbore during discharge. When operated at the wellhead pressure of the order of 10 bar, the temperature in the well producing steam and water at Krafla and Námafjall is 100-150°C lower than undisturbed rock temperatures in the production zone. The cooling of the dry steam wells during discharge is on the other hand lower (30-60°C) (Fig 7). The cooling of the wellbore will propagate out in a similar way as the convective downward migration (CDM) described by Böðvarsson and Lowell (1972),Lister (1974,980a and b),Böðvarsson (1979),and Björnsson et al. (1980). Böðvarsson (1979) concluded that in the CDM-process only few tens of degrees were needed to form fissures in solid rock. For a discharging well new crack or widening of already existing cracks in the rock matrix will increase the permeability close to the well. Thermal contraction can therefore explain the increased flow rate. Also it indicates a difference between two phase and dry steam wells tapping two phase reservoir, although it does not exclude a less prominent increase in flow rate for the well discharging dry steam. Finally, as seen in figures 3 and 4 the levelling off in flow rate after long term flowing is similar to the discharging history of a three dimensional well tapping single phase reservoir. Two phase systems have 10^2-10^4 times higher compressibility than single phase reservoirs (Grant 1978). The radius of influence of a well tapping such a reservoir will therefore be orders of magnitude smaller than in a single phase system. This relatively short radius of influence in two-phase reservoir makes it reasonable to compare wells tapping two-phase reservoirs with three dimensional wells.

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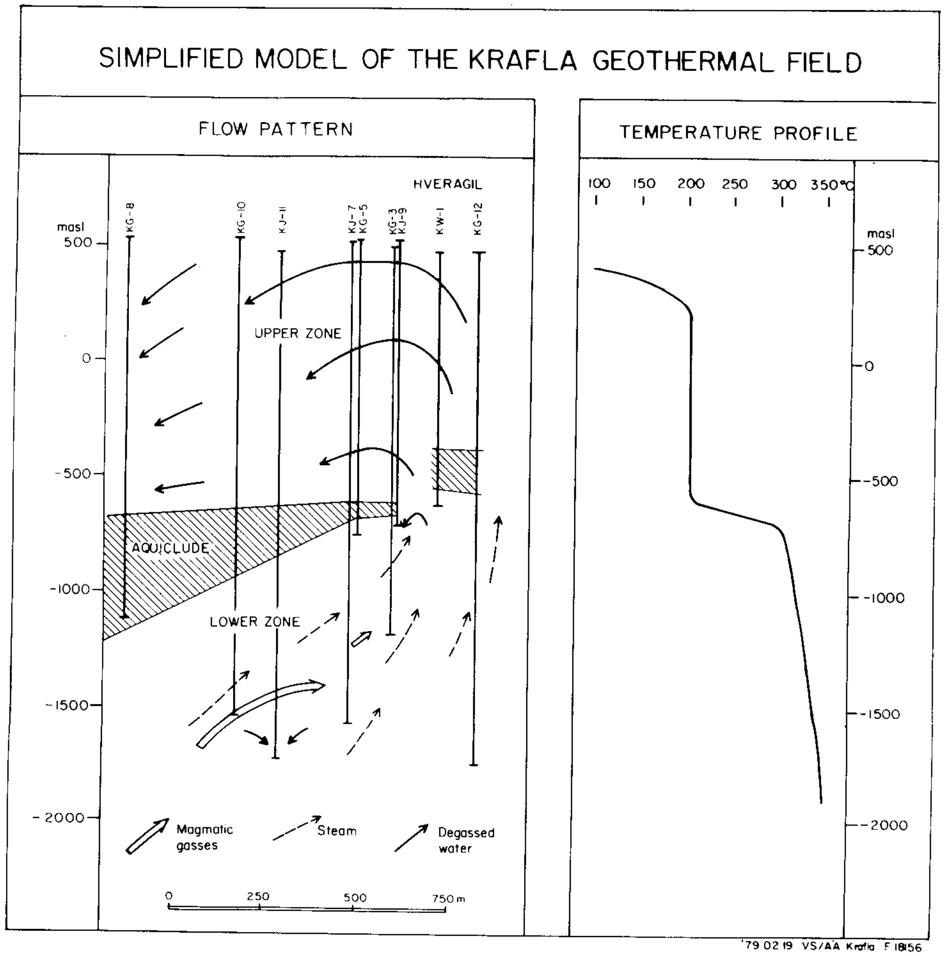

Fig. 1. Simplified model of the Krafla geothermal field.

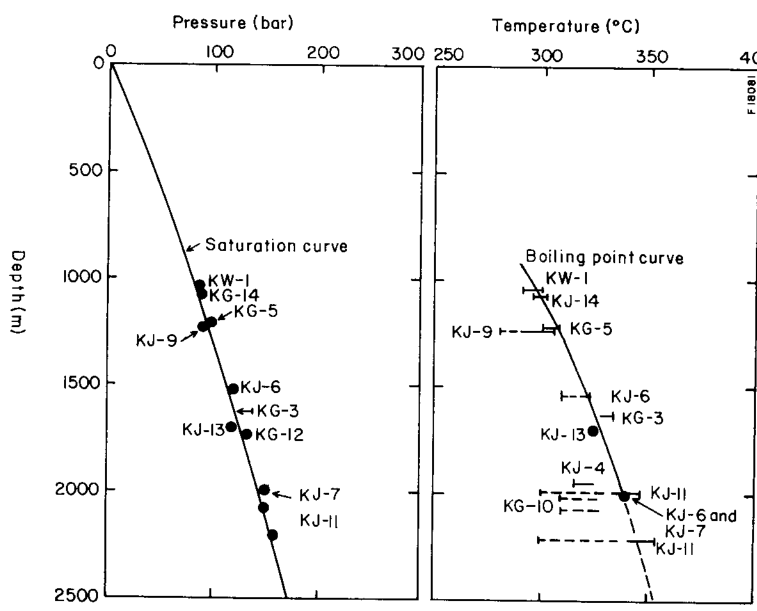

Fig. 2. Temperature and pressure in the Krafla reservoir.

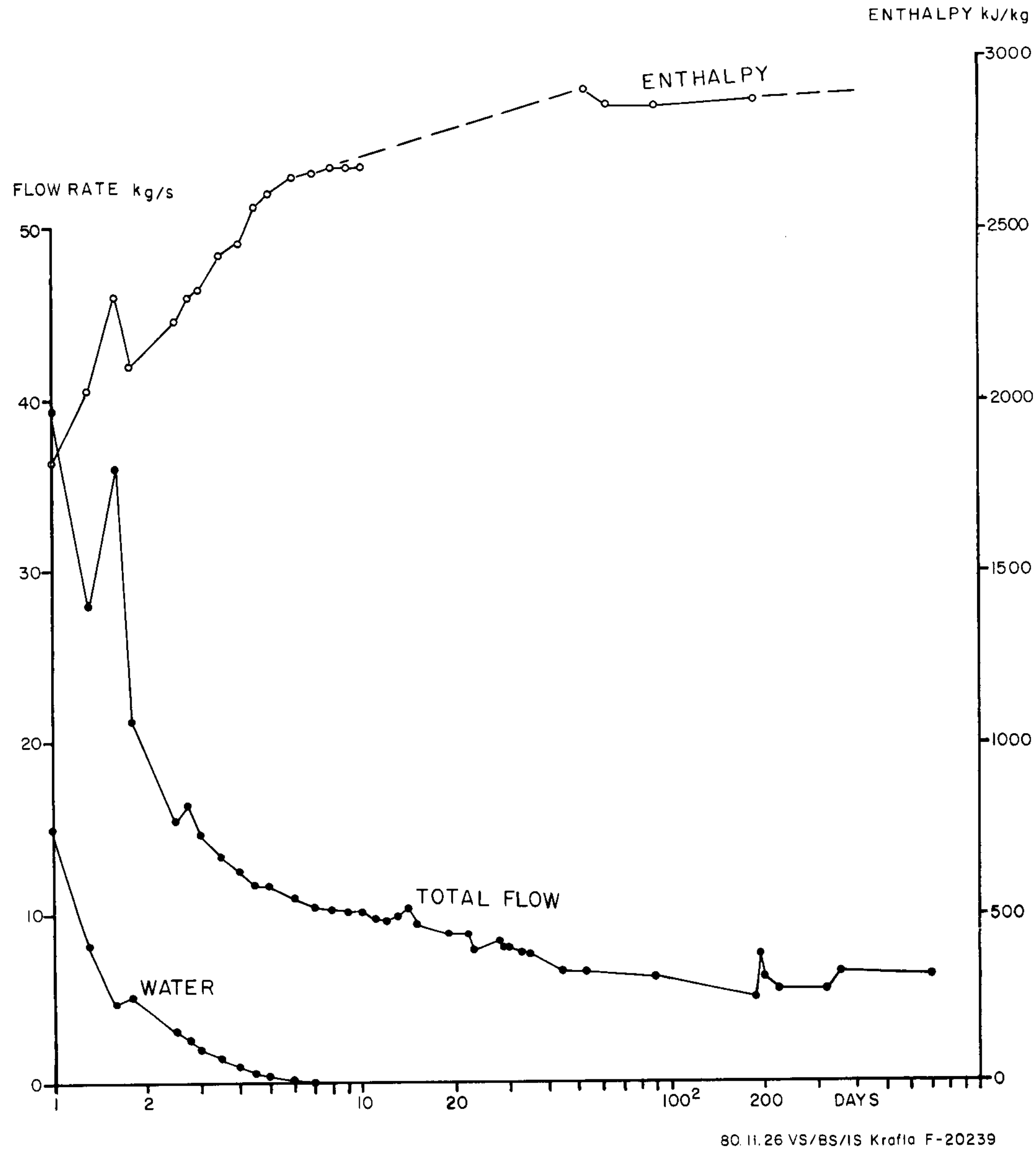

Fig. 3. KRAFLA KG-12

Discharge History

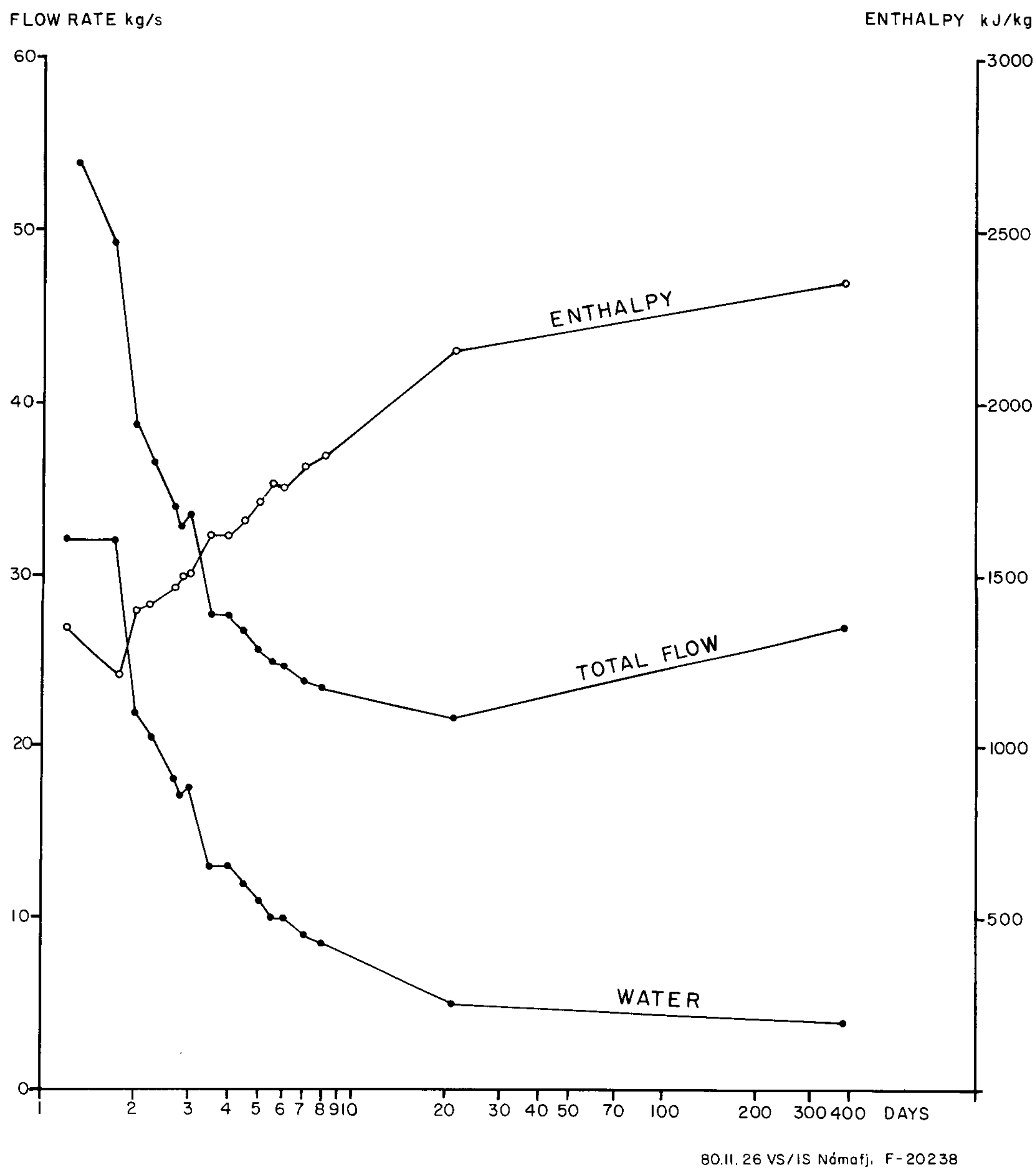

Fig. 4. NÁMAFJALL BJ-11

Discharge History

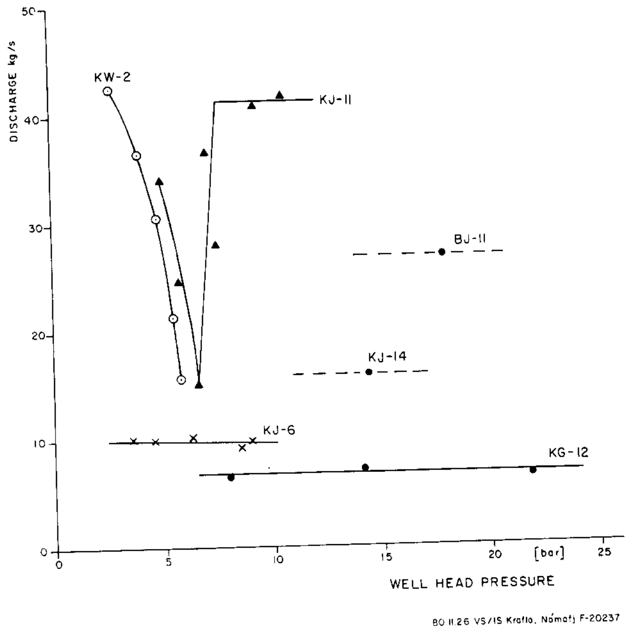

Fig. 5. Productions Characteristics of Wells in Krafla and Námafjall.

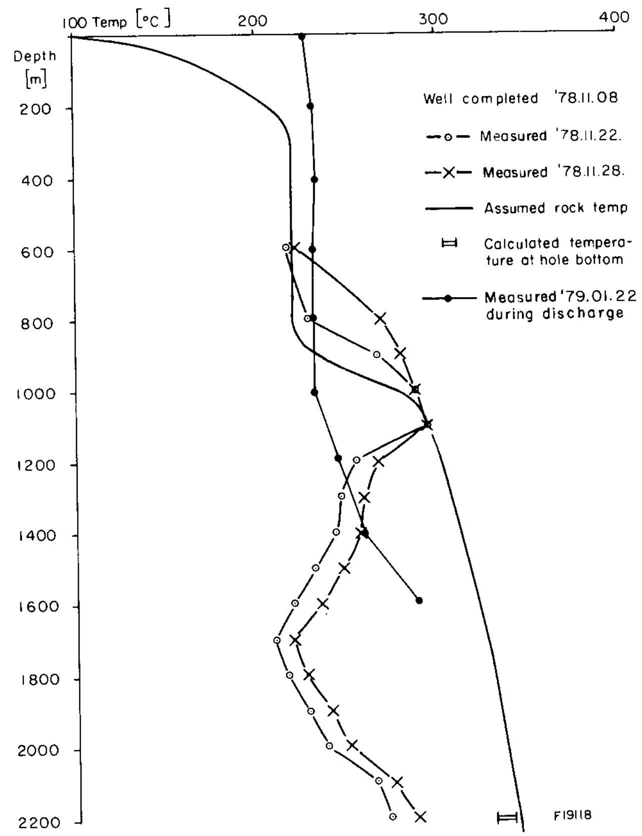

Fig. 6. Krafla Temperature Measurements in KG-12.

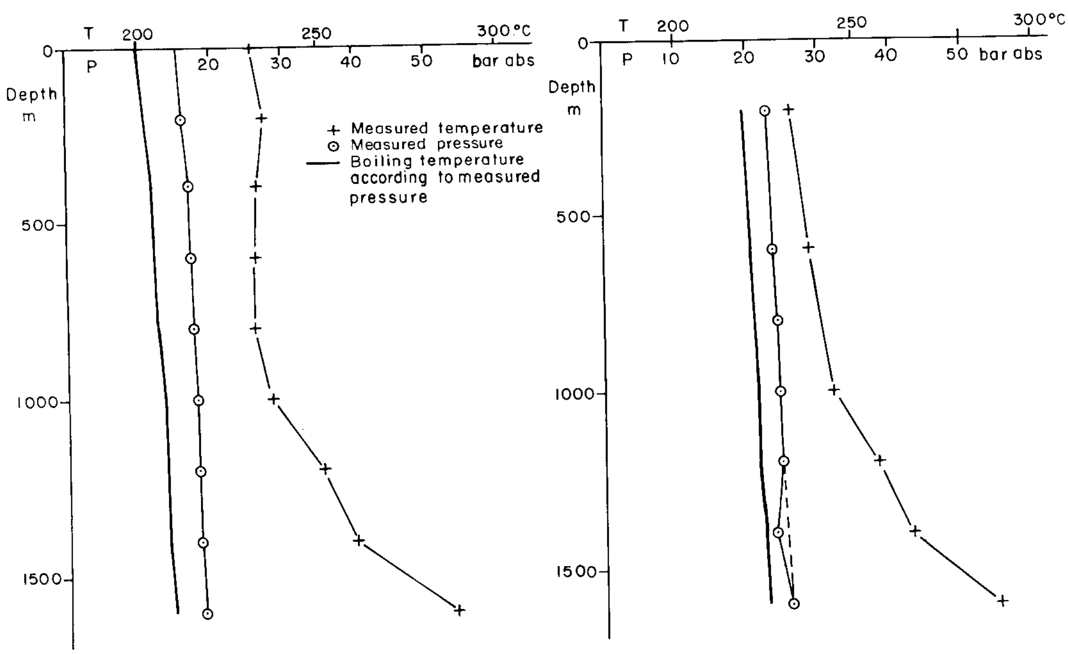

Fig. 7. Krafla KG-12, Temperature and pressure profiles during discharge.