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TEN YEARS OF COMMERCIAL EXPLOITATION OF THE AHUACHAPAN GEOTHERMAL FIELD

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ABSTRACT

Commercial Exploitation of the Ahuachapan Geothermal field started on June 1975 from reservoir conditions which were firstly evolutioned by well discharges and reinjection tests performed in the period 1968-1975. In these experiments, some 23.6×10^6 and 1.7×10^6 metric tons were extracted and reinjected respectively. This paper describes the wells and field behaviour over the period 1975-1985, in which the exploitation has been continuous and has had, for the first seven years, a massive reinjection of 160°C separated brine.

Mass withdrawal from the field has had maximum rates in the order of 700 kg/sec and is approaching 200×10^6 metric tons in this year. Reinjection rates were up to 300 kg/sec and amounted to 38×10^6 metric tons. As both extraction and injection have so far taken place in an area no more than 1 km^2, a concentrated exploitation has been experienced.

Since 1982, the field has been more carefully exploited to reduce risks in wells performance and to maintain in operation the three generating units although not to their full capacity. Parallel, this period has allowed to observe the behaviour of wells and field without reinjection, which is also discussed here.

INTRODUCTION

The Ahuachapan Geothermal field (fig.1) is a liquid dominated system of secondary permeability, which has a long history of mass extraction (since 1968) and reinjection (1971, 1975-1982).

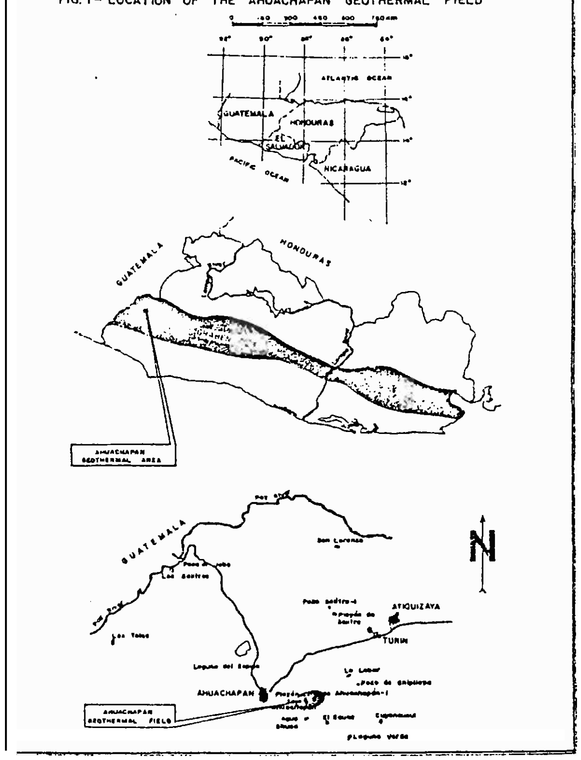
The sub-surface geology of the field has been described elsewhere (Aumento et.al., 1982); but the main features in the production area, may be summarised (from surface to bottom) as:

a) The San Salvador Formation (Quaternary). This formation is subdivided into and upper unit of lavas and tuffs which occur to about 170 m depth; and intermediate sequence of pyroclastics and andesites which form a continuous variable layer from 150 m in the west to 520 m in the south and acts, in general, as an impermeable cap; and finally, a unit of Ahuachapan andesites which occurs throughout the area varying in thickness from 300 to 470 m and has an excellent secondary permeability (main production zone).

b) The Balsamo Formation (Miocene). The top of this unit is defined by 50-100 m of andesite brecchia alternations. It was penetrated some 100 m in the hole Ah-31 which in turn has the maximum depth drilled at Ahuachapan (1500 m); but its base was not reached.

Commercial exploitation started on June 1975 with the operation of a 30 MW medium pressure steam unit. This initial capacity was increased by a 30 MW medium pressure and a 35 MW medium/low pressure on July 1976 and March 1981 respectively. However, a long-time operation at this total installed capacity has not been achieved since the field began in 1981 to show sensible pressure and mass flow declines. These responses advised to modify the associated extraction/reinjection regimen and accordingly, variations on both elements of the esploitation have been tried subsequently.

FIG. 1 - LOCATION OF THE AHUACHAPAN GEOTHERMAL FIELD



This study concerns essentially with the changes in pressure, temperature and discharge, which have taken place in relation to different exploitation regimens imposed to the field along the last ten years. However, as there was an experimental period (1968-1975) in which some millions of metric tons were extracted and reinjected in the actual production area, these events have been accounted for the analysis.

DEVELOPMENT OF THE FIELD

Fig. 2 shows the cronology of the thirsty-two deep wells (600-1500 m depth) which have been drilled in the area, covering some 6 km^2 (fig. 3).
It can be observed fromthese figures that a 50% of the total drilling have been successfull in the electrical generation and 6 wells have been globally utilized for reinjection purposes; but at the same time, it has a spatial characteristic: all production and reinjection wells are situated in a very small extension of area. This fact would have its own implications in a extraction-reinjection combined process.

Regarding to the extraction, fig.4 ilustrates the relative development which has ocurred since 1968 between the extension of the production area and the accumulated extracted mass from it. In the extraction shown in fig.4 (a), only some 10×10^6 metric tons were added by the commercial exploitation with the first unit alone; and regarding to the present, the dotted line in fig. 4 (b) represents the actual inmediate possibility for a greater production area.

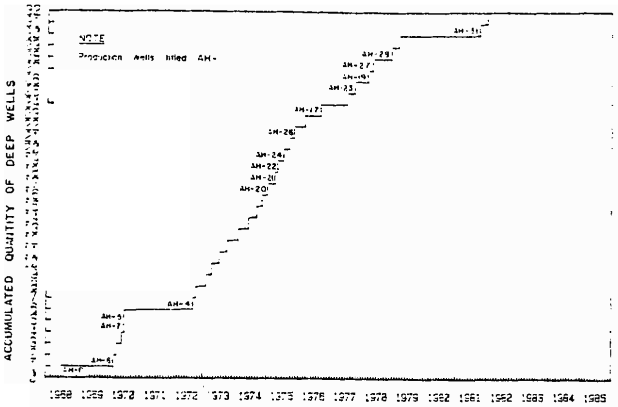


FIG.2 - DEEP DRILLING DEVELOPMENT OF AHUACHAPAN

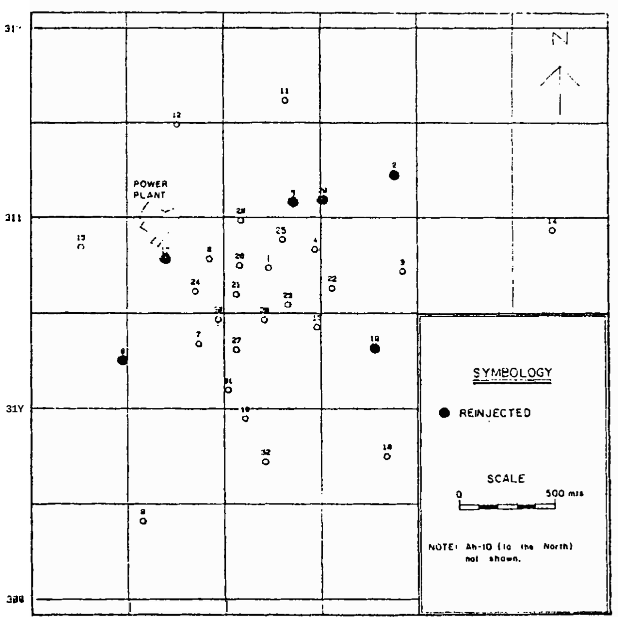


FIG. 3 - AHUACHAPAN GEOTHERMAL FIELD

Neglecting the magnitudes of the reinjections in **Ah-**5 (1971) and Ah-19 (1982), the history of this operation in Ahuachapan is that shown in fig. 5. In this figure, the differentiation between the proper magnitudes of Ah-2 and Ah-29 (both geographically eastern) is **pos**sible because Ah-2 was the unique reinjector during 1975.

In general, Ah-2 reinjection was always coupled to that of Ah-29 until 1981 and, from this year ahead, the reinjection in Ah-8 suffered the greatest interruptions. **As** can be noted, the geographically central Ah-17 reinjection was greater than at the east and west; but only temporarily operated.

The previously cited actions on extraction and reinjection, departed in 1975 from the reservoir conditions shown in figs. 6 and 7. The pressures refered in fig.6 and in the following discussion, are those measured in wells at a reference elevation below static liquid levels; in this case, 200 m.a.s.l.. Maximum temperatures in fig. 7 are only used here to present a base thermodynamic state for the reservoir in 1975. The roughly circular patterns show cold boundaries to the west and north, extension of the field to the east and southeast (according to the open high contours) and lows of 35 kg/cm²g and 230°C in the production area.

It may be clear at this point, that these 1974/75 contours do not represent an initial state for the reservoir: Going back towards 1968, it is found that besides the discharges from Ah-4 (since 1972), and Ah-7, Ah-6 (since 1970), there was also a continuous discharge from Ah-1 by the two years in which was alone in the area (1.5×10^6 metric tons). So, it is only possible to take into account that these contours are preceeded by **a** total extraction of 23.6×10^6 metric tons and also by the reinjection of 1.7×10^6 metric tons of 160°C water in Ah-5 (1971 tests) (Einarsson et.al., 1975).

MAIN STAGES OF THE EXPLOITATION

Regarding to significant variations in the extraction/reinjection regimens, the commercial period has had two major stages (see fig. 8):

1) Extraction with reinjection. From 1975 to 1982.
   The extraction in this period **was** gradually increasing, mostly in function of producers availability,to maximums of about 700 kg/sec (1981); the restrictions were only those coming from operational needs,such us control and investigations in wells, disposal of the waste water (when channel to the sea was not yet available) and others similar. The first partial shutdown was imposed to the field on May-July 1982 and marks also the start-point of a subsequently regulated extraction.

   The reinjection was also increasing in function of availability of wells. These were selected according to their absorption capacity and relative outer location in the area. This operation was continaous for the first seven years: it had maximums of about 300 kg/sec around 1977-1978 (in correspondence with the temporary reinjection in Ah-17) and was totally suspended in November 1982. Aside from that maximums, the base levels of the total reinjection were approximately 180 kg/sec (until beginning of 1981) and lastly **some** 80 kg/sec. Geographically, these base levels have been injected in the east (Ah-29, Ah-2) and west (Ah-8).

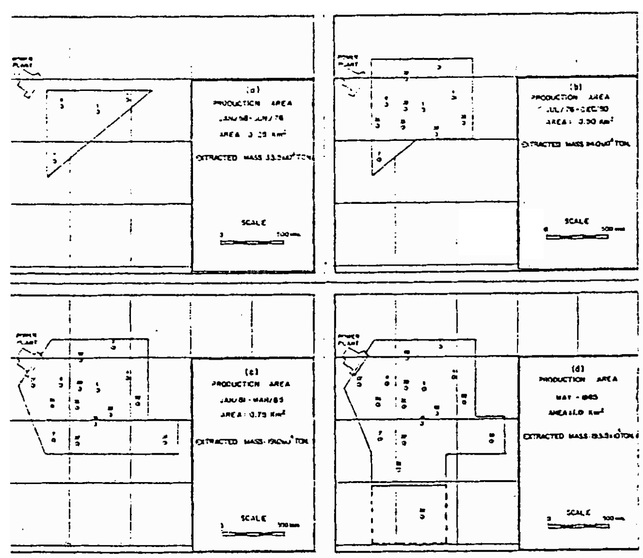
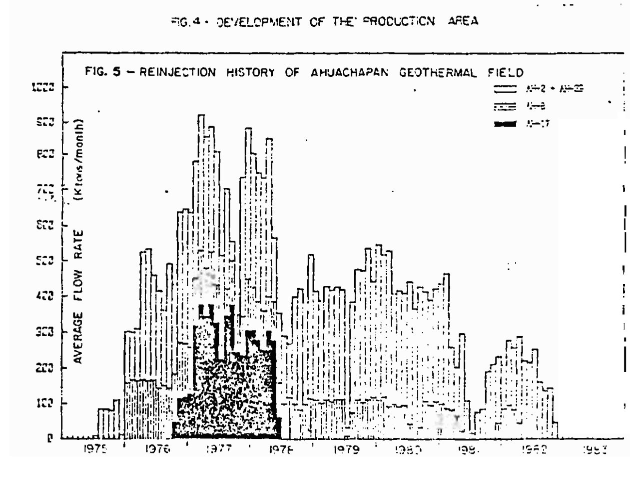


FIG.4 - DEVELOPMENT OF THE PRODUCTION AREA



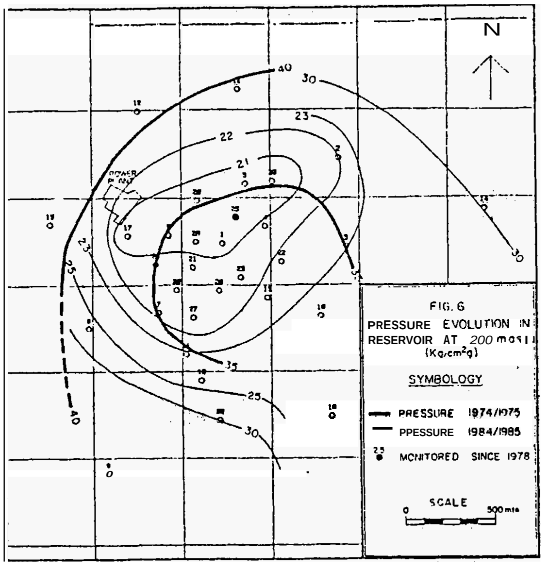


FIG. 6 PRESSURE EVOLUTION IN RESERVOIR AT 200 msl (Kg/cm²g)

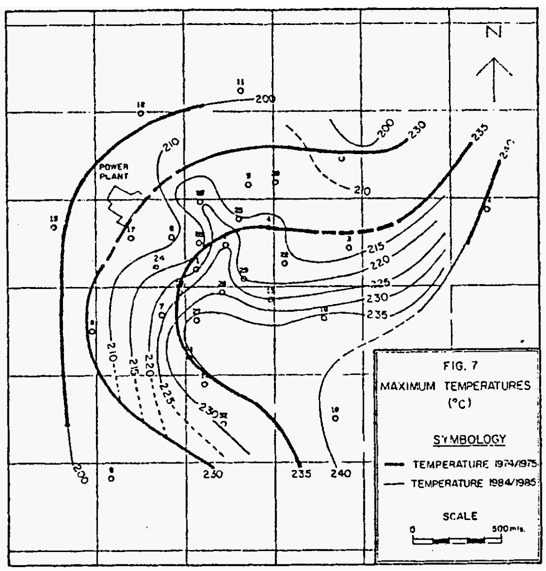


FIG. 7 MAXIMUM TEMPERATURES (°C)

2) Extraction without reinjection. 1983-1985
   As can be seen in fig.8, this period is characterized by a level of extraction similar to that of the period 1976-1980; but, distinctively, its fluctuations are less. It can be noted also that the extractedmass flow rate in this period is practically the same as the net mass flow rate of the period 1978-1980.

BEHAVTOUR OF THE FIELD AND WELLS

Field Pressure And Enthalpy

Fig. 8 shows the field answers in pressure and enthalpy througout the commercial exploitation period. The pressure line in this figure has been differentiated up to the beginning of 1978: the reason being the different meaning and precision: 1975-1977 pressures were averaged from Kuster measurements of some selected wells, which were considered to be representative of the more exploited zone; 1978-1985 pressures, on the other hand, come from Sperry-Sun continuous monitoring in the well bh-25 (see fig. 3), and of course, their precision is greater. Thus, the total pressure line there may be considered as an indicator of the liquid phase pressure variations in a zone of the field around Ah-25. Enthalpy in this figure is a weighted average obtained from production wells discharging in each case.

The information given in fig.8 is complemented by fig.9. The last, is an areal evolution of discharge enthalpy and so, gives an idea of the change to biphase conditions in some zones of the reservoir. It is neccesary to consider also that all producers were, at the beginning of 1975, discharging mixtures of enthalpies equals to or slightly higher than those of saturation for measured temperatures.

Fig. 8 shows that the rate of pressure decline differs between the two exploitation stages and, in general, the greatest pressure drops ocurred when reinjection was operating. Pressure was going to stabilize only after enthalpy increased. Enthalpy,on the other hand, appears constant around a low of 1100 kj/kg up to the beginning of 1980, and the reason appears to be the reinjection-In fact, as shown in fig. 9 (a), after supression of Ah-17 reinjection, all the zone with a previous localized biphase condition in Ah-6 and Ah-26, evolutioned spatially to higher values of enthalpy. At the beginning of 1981, Ah-17 discharged saturated dry Steam and commanded the enthalpy high observed in this year. The discharge of Ah-17, an special case in the Ahuachapan field, has been studied by dynamic pressure/temperature and .flowmeter profiles and according to these, it occurs througha surficial fracture which, in turn, serves as a drainage for the steam cap in that zone.

In the middle of 1981, an "Extraction Without Reinjection Test" took place and originated additional enthalpy increments in other wells, mainly Ah-4 and Ah-20, keeping the high for the whole year. Towards the middle of 1982 enthalpy was going downbecause of some otherwells movements, but after that it started a defined increasing tendency towards the present (see also fig. 9 (b)).Among the special problems caused by the reinjection in Ahuachapan maythen be cited:Its negative effect on enthalpy.

Downhole Pressure and Water Levels

Fig. 10 snows pressures profiles crossing the area along west-east and south/west-north/east directions, in 1975, 1977, 1980 and 1985. The outer wells in these profiles, namely, Ah-9 (south west), Ah-11 (north), Ah-15 (west) and Ah-14 (east), do not have wellhead pressure and have had water level trends as shown in fig. 11. Since reported by measurements,both figures show some marked pressure/water level variations in Ah-9 (1977-1980) and Ah-11 (1983); but, as suggested also by field observers, they may be of artificial origin. So, pressure has had pivots in Ah-15 and Ah-9; but 10 and 6 kg/cm^2 pressure drops have ocurred in Ah-11 and Ah-14 respectively. Water levels of these wells have fallen more or less uniformly, but the rate of fall of Ah-11 is greater and appears to be not totally independent of the mass discharge from the field. From these results, both wells are connected to the system and cold inflows might come from the north.

Temperatures in the Production Zones of the Wells

Static temperature profiles normally obtained with Kuster instruments, have shown that they would hardly advise in a short time a low degree affection of the temperatures in production zones. When reinjection was operated, .the abnormal inversions were consistently shown by this measurements but in a long time trend. Fig.12 shows the temperature evolution of the producer Ah-7. In general, Ah-7 does not represent the most critical case with respect to affections of the reinjection experiment; but it is an intermediate and useful example because of its elonged activity as a producer (since 1970). The profiles from 1376 to 1981 were gradually defining two inversions, which were not comming from the natural effects of flashing in a hole. As it has Seen already shown, reinjection in Ah-8 was gradually reduced towards the end of 1981 and so, the profiles obtained in Ah-7 since 1982 appear accordingly recovered. The steam flow instabilities observed in Ah-7 in 1981 appear due to the fact that the upper inversion was approaching 200°C.CEL,1983).

Fig.13 shows, the case of Ah-20 in a global comparison of conditions between 1975 and 1385 which allows to observe all pressure and temperature drops.As shown, unstable discharge conditions were reached by this well in

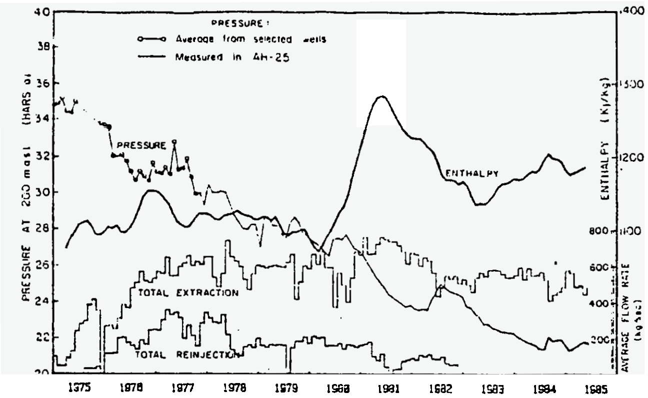


FIG 8 - FIELD DISCHARGE RATE, PRESSURE AND ENTHALPY (pressures shown are at 200 masl in central part of the field)

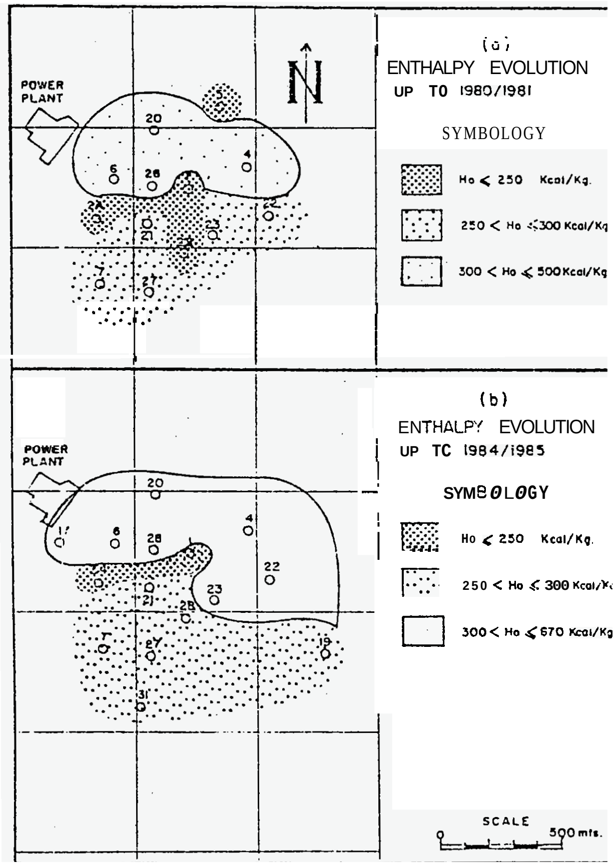


FIG. 9
ENTHALPY EVOLUTION FROM 1974 TO 1980/1981
AND TO 1984/1985

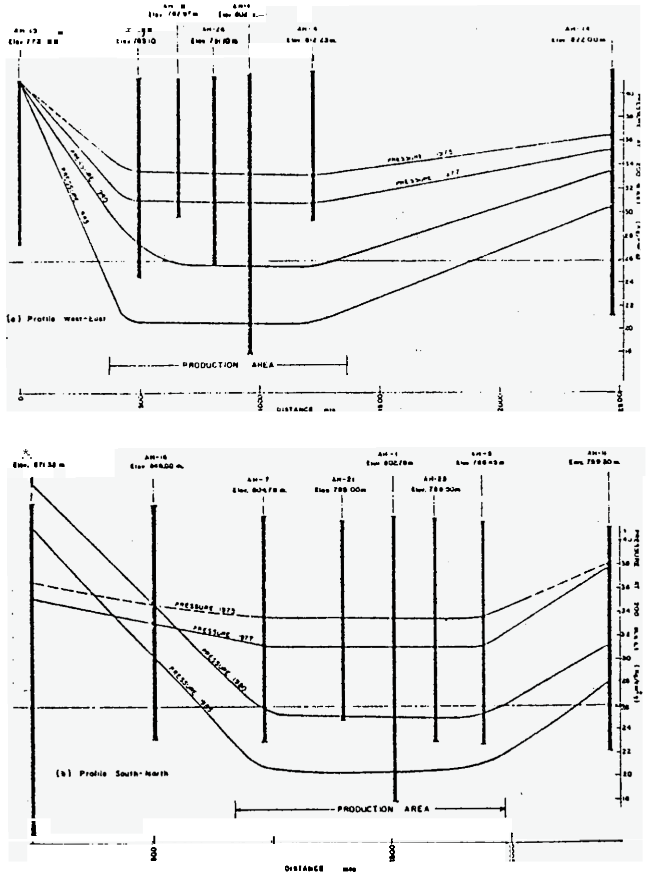


FIG.10- PRESSURE PROFILES ACROSS THE FIELD

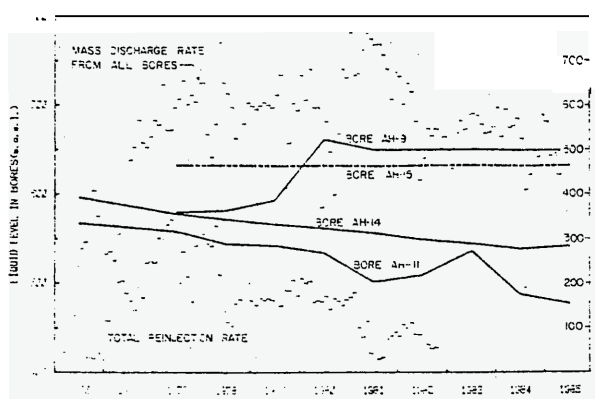


FIG. 11 - LIQUID LEVELS IN BORES AH-9, AH-15, AH-14, AH-11.

1983 and again in February of this year. Evidently, this is a case in which the temperature deterioration is more acceptable as consequence of the natural process of production. (In the figure, profiles are of different depth because of deepening of the hole in 1982).

Well Discharges

The mean features of the discharge evolution of Ahuachapan wells are informed by the representatives cases in figs. 14 and 15. As can be noted, the curves in fig. 14 are those obtained by the R. James lip pressure method. The respective stagnation enthalpy for each curve, practically constant in most of the wells, is in fig. 15. Extrapolation of mass flow to WHP =5.6 kg/cm^2g has been needed in some wells (Ah-4, Ah-1) and for this cases, enthalpy corresponds with that measured at the lowest wellhead pressures of the production curve.

In these figures there are two patterns of different meaning. Firstly (see fig.14), the fast displacement of the production curves which was ocurring in all the wells since 1975, ceases in 1982 (whatever enthalpy and well). The other pattern (fig.15) shows a lesser rate of decline whenever enthalpy increases.

Ah-4 curves are up to March 1982 because the performance of this well was artificially modified by a drilling process in August of that year; however, it is shown because of its importance in relation with the second pattern.

Both figures show that at the beginning of the commercial period all wells had low enthalpies and only Ah-6 and Ah-26 were rapidly going up to biphase conditions (fig.-15) Those wells following a discharge evolution similar to Ah-1 and Ah-7, account for the high mass flow decline and as it can be seen from the trayectories in the diagram, also for the greater steam losses.

The cases shown in fig. 14 are representative of the evolution of all other wells in Ahuachapan, except for the special case of Ah-17, which has maintained the dry saturated steam condition acquired in 1981. (CEL, 1982).

As the field weighted enthalpy was low throughout 1975-1980, this period was the most critical for the declination of well discharges. As was cited before, Ah-5 was out of operation for this reason.

In fig. 15 it can be noted also that the horizontal and descending trayectories imply the greatest steam losses. As this affects the operation of the power plant they are, of course, non desirables.

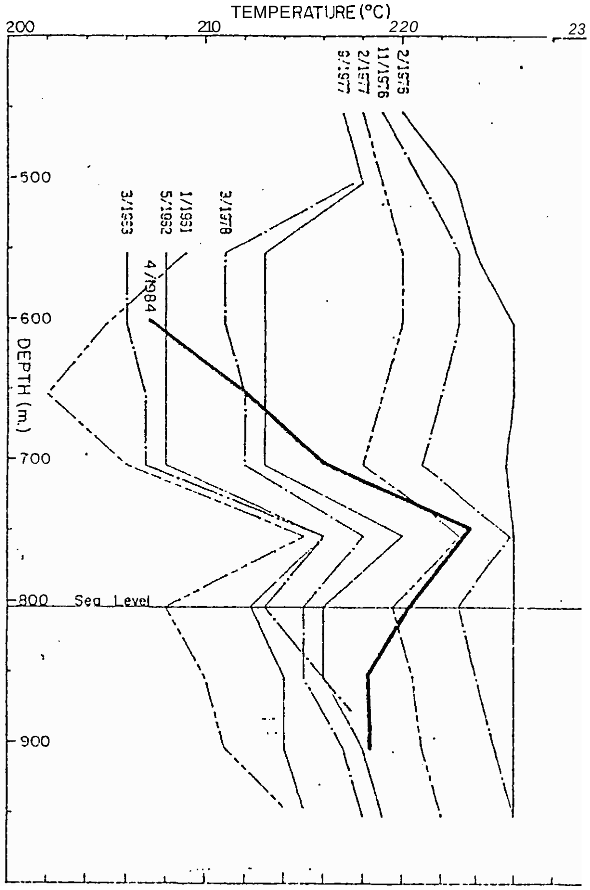


FIG. 12-TEMPERATURE PROFILES BELOW LIQUID LEVEL IN AH-7

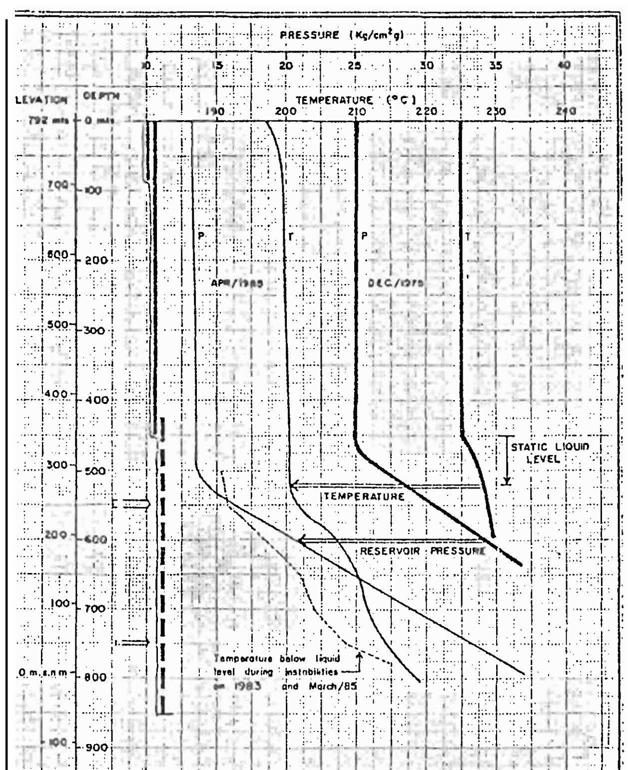


FIG. 13-1975-1985 PRESSURE AND TEMPERATURE PROFILES IN AH-20

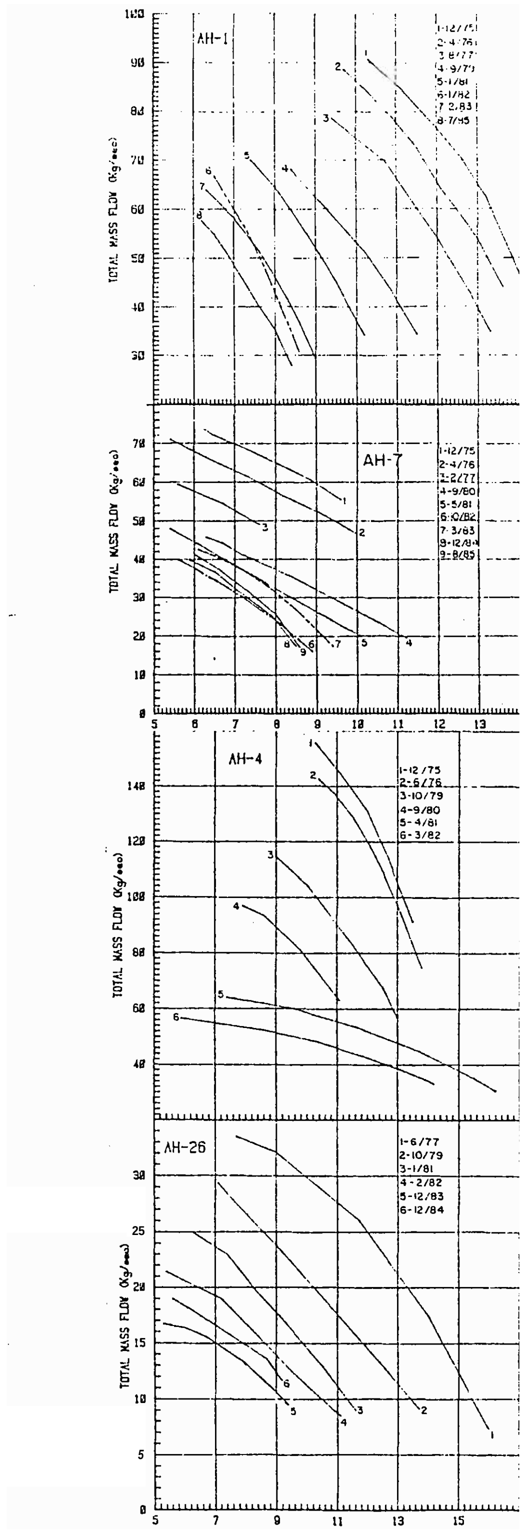
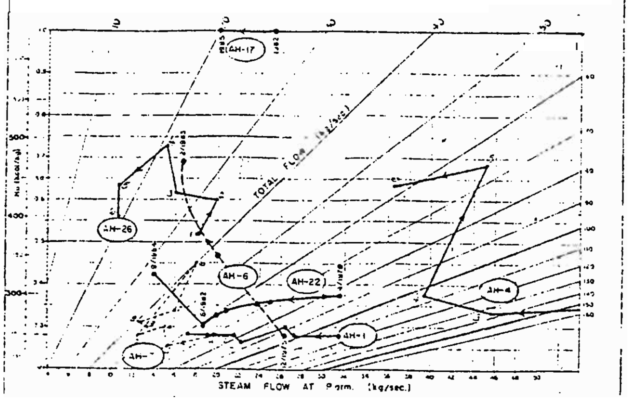


FIG.14-TOTAL MASS FLOW EVOLUTION

CONCLUSIONS

The behaviour of the field during commercial exploitation has shown the following main results: 1) The rate of declination of the liquid pressure was greater in the reinjection stage. 2) pressure stabilization observed in the last years without reinjection is mostly dependent on the higher enthalpy originated from a more extended biphase conditions in the area. 3) Field enthalpy was at a constant low level while reinjection

FIG.15 - DISCHARGE EVOLUTION AT WHP = $5.6\ kg/cm^2g$.



was influencing many production wells. 4) The degree of depression in the central-north zone of the production area coupled to the response to exploitation of the cold well Ah-11, provide a potential possibility €or the occurrence of cold inflows to the production area. 5) The behaviour of some producing wells during -reinjection stage was rather negative in relation to discharge characteristics and production zone temperatures. Wells mass flow rates and discharge wellhead pressures of the production curves declined more accelerated in all wells of low enthalpy. 6) The conditions of previously affected producers have been recovered in temperatures and discharge characteristics. In this period there have been a suppression of reinjection and a more stable and minor level of total extraction. However, production zone temperatures in the central-north zone are sensibly deteriorated either by the continued production alone or by additional cold inflows from the north.

By multidisciplinary systematic observations of :.individual wells, exploitation is now more regulated. This in turn have implied some reductions in the generation of electrical energy, but it is considered neccesary while the pursued extension of the production zone to the south-east gives its results.

ACKNOWLEDGEMENTS

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