Proceedings Ninth Workshop Geothermal Reservoir Engineering
Stanford University, Stanford, California, December 1983
SGP-TR-74

A STATUS REPORT ON THE EXPLOITATION CONDITIONS OF THE AHUACHAPAN GEOTHERMAL FIELD

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ABSTRACT

The present exploitation conditions of the Ahuachapan field are discussed. The high well density in a small area has resulted in a significant reservoir pressure decrease due to the inherent reservoir over-exploitation. The average pressure in the exploitation zone has decreased from the 1975 value of 34 kg/cm^2 to the May 1983 value of 23 kg/cm^2. The production decline characteristics of the Ahuachapan wells were examined, concluding that all wells but Ah-22 show exponential decline. The cumulative production-reinjection for the field up to April 1983 is 159.090 x 10^6 tons, and 37.592 x 10^6 tons, respectively. The effect of reinjection upon field behavior is evident when observing the pressure decline characteristics of the field. It is seen that for injection fraction related to total mass extracted above 30 percent, the average decline pressure in the production area becomes approximately stabilized. If this condition is not met the reservoir pressure decreases sharply. From this finding it is concluded that a careful and properly planned reinjection program is a must for the field.

The observed temperature reduction in some of the wells seems to be the result of two operating mechanisms. First, we have the pressure decline that produces water vaporization and the consequent temperature descend. Analysis of information available shows no clear indication of deleterious temperature effects on the producing wells due to injection. The only exception observed to date is well Ah-5 that because its close distance and its relative structural position and direct hydraulic connection to injector Ah-29, presented conditions for fast displacement of the thermal front, resulting in unsufficient contact area and residence time for reheating of the injected water.

INTRODUCTION

The geothermal investigation at Ahuachapãn started at about the end of 1965 with financial support from the United Nations. Since that date, numerous studies on the geology, geophysics, geochemistry and reservoir performance of Ahuachapãn geothermal field have been carried out, specially after the successful completion of well Ah-1 in 1968. At present 30 wells have been drilled, 12 of them feeding the power plant, 5 more reserved for injection purposes and 13 remain under observation conditions aimed at properly defining its potential.

The reservoir behavior was considered normal up to November 1980 when the third 30 mw unit went into operation, with the inherent increase in mass output, resulting in a sharp decrease in reservoir pressure. A temperature reduction being only partially attributed to the pressure decline has been observed in some of the wells, producing water vaporization. Another possible cause of the temperature lowering effect would be the relatively cool water injected at different times into the reservoir.

This abnormal reservoir behavior prompted the Comisiōn Hidroelectrica del Río Lempa to undertake a thorough revision of the exploitation conditions of Ahuachapãn field. This study reports on the first stage of this work, based mainly on a preliminary analysis of all of the extensive amount of information on the field that has accumulated and therefore reference will be made to results that have been prepared by other investigators.

GEOLOGICAL BACKGROUND

The Ahuachapan Geothermal Field is located in the northwestern part of El Salvador, Central America. As it is shown in Fig. 1, it is located some 20 km from the border with Guatemala and 40 km from the Pacific Ocean. The average

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elevation of the field is about 800 m above sea level and it is sitted on the northeastern slopes of a range of composite volcanoes of Quaternary age.

The thermal anomaly responsible for the occurrence of the Ahuachapan Field is due to its location at the edge of the central graben of El Salvador[1]. The geothermal field is situated in the vicinity of the intersection of the central graben and the main axis of a sinking transversal geological structure. This structural location favors deep hot fluid assent through a marginal set of faults and further lateral fluid migration along a NO-SE oriented transversal fault system (Fig. 1). The most permeable horizon along the intersection of these system of faults is constituted by an alternated andesitic mass with the presence of breccia and fine pyroclastics. As is illustrated in Fig. 2, this andesitic mass is known as the Ahuachapan Andesite and constitutes the main hot fluid producing horizon for the geothermal field.

PRODUCING CONDITIONS.

It is shown in Fig. 3 that the current drilled area for the field is of about 6.4 sq km while exploitation is concentrated in a smaller area of 0.6 sq km, with 16 wells completed and only 12 of them feeding the power plant.

It is evident that the actual production area is overexploitated, resulting in a pronounced pressure decrease in the center of the field. The magnitude of this decrement can be observed in Fig. 4 through the isobaric pressure distributions measured in December 1975 and May 1983. It can be observed that the pressure decrement has been uniform throughout the field but a focus is located in its center. It can be seen that in the outer area pressure has gone down in this period from 40 to 30 kg/cm^2, while the exploitation zone was encompass by the isobaric line of 34 kg/cm^2 in 1975 and in May 1983 by the 24-23 kg/cm^2 line.

Figs. 5 and 6 show the variation of mass production, reinjection and average reservoir pressure versus time. Fig. 7 presents the data of the two previous figures in an alternate manner; this is an updated version of a similar figure included in reference 3, where reinjection is shown as a percent of total mass produced. It can be seen that for an injection fraction above 30 percent approximately, the average pressure decline in the production area becomes nearly stabilized. This stabilization is evident in the period between November 1978 September 1980 (see Fig. 6). During this time mass reinjected accounted for 30 percent of total mass extracted and it was preceeded by two injection periods, the first from September 1976 to August 1977 with a 39 percent reinjection and the second from September 1977 to October 1978 with a 44 percent reinjection. The effect of reinjection during these three periods resulted in a almost stabilized reservoir pressure of 28 kg/cm^2.

From November 1980 to the first quarter of 1982, the geothermal system presented non-equilibrium conditions as a result of a 23 percent increment in mass extraction with respect to production during the previous stabilized production-injection period. This in addition to a 43 percent reduction in reinjection resulted in a change of the pressure decline gradient from -0.37 (kg/cm^2/year) during the stabilized period to -2.91 (kg/cm^2/year). As recognized earlier, this sharp pressure decline coincides with the start of operation of unit 3 in November 1980. The overexploitation effect is clearly apparent in the results of average pressure versus cumulative production of Fig. 8. This graph shows the additional pressure drop caused by the increment of mass extraction needed for the operation of unit 3.

Fig. 9 presents the variation of mass extracted per unit pressure drop versus producing time. These results indicate the energy utilized in the production of the geothermal fluids. Fig. 10 shows extra indication of the efficiency of exploitation in terms of mass production weighted with respect to the number of producing wells versus producing time, clearly indicating that the decreasing tendency has been stopped, reaching an approximate constant value as of the first quarter of 1983.

Decline curve theory has been successfully applied to Ahuachapán wells. In this study several production histories for different wells were analyzed reaching the previous conclusion of earlier investigators that all Ahuachapán wells but Ah-22 show exponential decline. This particular well shows a hyperbolic decline as shown in Fig. 11. A key well because of its position in the field and of its behavior is well Ah-1 (see Fig.3) Fig. 12 illustrates the production history of this well, where two well defined production trends are identified; the first goes from 1976 to the end of 1980, denoted by the straight line 1 and the second begins from this latter time when unit 3 started operations and continues through the end of 1982 and it is represented by straight line 2. The extrapolation of straight line 1 represents the production decline expected for well Ah-1 if the production conditions of the field would have not been drastically incremented at the end of 1980; on the other side, the extrapolation of straight line 2 represents the production decline expected for the well if production would continue at the 1982 level.

An alternate very useful way to analyze the production decline characteristics of a well is through the Fetkovich's type curve method, Figs.13 and 14 illustrate the use of this technique for the production data of wells Ah-22 and Ah-1, previously presented in Figs.

11 and 12. The resulting matches confirm the findings previously discussed for these wells.

REINJECTION OF WASTE WATER

By the end of the 1960's[9] it became apparent that in order to properly develop the Ahuachapan Geothermal Field, a suitable waste water disposal system had to be established. At that time, there were several options available; disposal into rivers, conduction of the brine to the Pacific Ocean through a mountain range by means of a canal, or reinjection of the spent water either outside or in the geothermal field. After evaluating each one of these options[1], it was decided to carry out large-scale reinjection experiments at the field. In 1970-71 almost 2 x 10^6 m^3 of water at 150°C were injected at rates of 91 of 164 lt/sec, without any evident technical difficulty. Results of these tests are fully described elsewhere[10]. Based upon these results, it was decided to reinject within the high-temperature system in such a way as to establish a secondary heat-sweep of the reservoir rock and also as a hydraulic support for natural water recharge to the system.

Unit 1 of Ahuachapan began electricity production in June 1975 and residual water injection started in August 1975 by using well Ah-2 as an injector (see Figs. 3 and 5). As waste water output from the reservoir was continuously increasing, more wells had to be used for injection purposes. In January 1976 well Ah-8 was converted to reinjection, followed by Ah-29 in April and Ah-17 in October of the same year. Amount of waste water increased further after start up of Unit 2 in July 1976. By the end of 1975 there was an estimated total extraction of 28.716 x 10^6 tons from which only 2.151 x 10^6 ton of water had been reinjected by means of Ah-2; meanwhile, as April 1983 a gross total 159.090 x 10^6 tons of water had been extracted and 37.592 x 10^6 tons of waste brine had been conducted back to the reservoir through those four wells mentioned before.

Through the life of the project, not all injection wells had been active at all times. As shown in Fig. 1, due to the location of injector wells, it is convenient to separate injection history into two distinctive areas; the northeastern area which comprises well Ah-29 and Ah-2, and the western area that contemplates injectors Ah-17 and Ah-8. It is important to notice that due to their structural situation as well as to their particular completion and total depth, wells Ah-2 and Ah-8 can be considered somewhat marginal to the main geothermal system, meanwhile Ah-17 and Ah-29 are closely related to the productive horizon. Therefore, reservoir response to cool waste water injection could be expected to be different for all of them. Average reservoir temperature is in the order of 230°C, meanwhile waste brine is reinjection at about 150°C.

At western area, reinjection of separated water from wells Ah-6 and Ah-21 at Ah-17 started in October 1976 and ended in May 1978. Total estimated mass injected in this well was in the order of 113.526 x 10^6 ton. Its main injection period went from February 1977 up to May 1978 with injection rates ranging from 0.23 to 0.38 x 10^6 ton/month, with an estimated average of approximately 0.28 x 10^6 ton/month over this period[3]. As shown in Fig. 1, production wells Ah-6 and Ah-24 are within a 250 m radius of this injection well. This fact in addition to the highly fractured nature of Ahuachapan's reservoir rock, has raised some controversy as to the magnitude of possible detrimental thermal effect that injected cool waste water has had on the production characteristics of those wells. At present, no conclusive results have been reached. Further study in this direction is needed and is being carried out. After suspension of injection in Ah-17, this well was successfully converted to producer, having shown a satisfactory temperature recovery.

Well Ah-8 is also located in the western area of reinjection. Its structural position seems to be marginal as far as to the main system of faults is concern. Injection in this well started as early as January 1976 and went on in an almost uninterrupted manner until May 1982. Injection in this period showed a peak of about 0.165 x 10^6 ton/month in 1976 and then diminished fluctuating around an average of 0.11 x 10^6 ton/month up to the middle of 1981. It is unlikely that any important thermal contamination of the reservoir have occurred due to injection at this well; however, as mentioned, further studies have to be conducted in order to arrive to a final conclusion.

Injection well Ah-29 is located in the northwestern area of reinjection. Its structural position and open interval places this well within the productive horizon of the Ahuachapan Field. Besides this, tracer studies[10] performed during an injection long-term test in near by well Ah-5, showed good transmisivity in the block cointaining both wells, as well as some kind of hydraulic communication with wells located at the center of the field, such as Ah-1 and to a lesser degree, wells Ah-6 and Ah-7. As a consequence, reinjection in well Ah-29 has resulted in early break through in well Ah-5 with an observable decrease in enthalpy of produced fluids from this well. This effect can easily be seen from Fig. 15. Injection in Ah-29 started in April 1976 and continued until November 1982.

Well Ah-2 is also located in the northweastern area of reinjection. Its situation seems to be marginal to the main producing area, although there is direct communication with the productive horizon, mainly through fractures. Its position seem to be the best suited of all injector wells placed until now. It started injection in April 1975 and except for short periods, it was on operation until August 1982.

In summary, reinjection of waste water into the producing horizon at Ahuachapan has proven to be helpful in reducing pressure declination rates, in those periods when mass extraction has been balanced with a given percentage of mass reinjected. As it can be seen from Figs. 6 and 7, when percent mass injected is less than some critical value, reservoir pressure declines rather sharply. Fig. 7 is an updated version of Fig. 9 of Ref. 3.

One of main objections mentioned in the literature to reinjection of waste water into the producing formation has been the danger of thermal contamination of the hot reservoir, adversely affecting produced enthalpy. The injection arrangement set up for Ahuachapan is not the most adequate. However, and with the exception of the special case of wells Ah-29-Ah-5, discussed previously, it has not been possible until now to clearly separate temperature effects in produced fluids due to pressure drops and those resulting from possible mixtures with colder injected water. Fig. 6 shows the behavior of well Ah-1, the oldest producing well of the field, in which no thermal effect coming from cooling with injected fluids is apparent.

CONCLUSIONS

Further studies need to be carried out in Ahuachapan in order to establish a better definition of several important parameters for a more appropriate management of the field. Among these parameters the following are considered to be of prime importance:

1. Connectivity in the reservoir, in order to define the most probable direction of movement of injected fluids.
2. Better control of injection depth at injection wells.
3. Expanding the exploitation area of the reservoir, drilling new wells to the South and Southwest of the presently exploited area.
4. Establish a better geological definition of the reservoir and of the heat source and fluid recharge.
5. Perform model studies in order to establish a more adequate reinjection system for the reservoir.
6. Review and reinterpretation of field date under the new conception of the reservoir.

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ACKNOWLEDGMENTS

The authors wish to express their gratitude to the personnel of the geothermal laboratory; without his help this study could not be made. Also the colaboration of the Facultad de Ingeniería of the Universidad Nacional de México is greatly appreciated. Finally the support of the Organización Latinoamericana de Energía (OLADE) and Comisión Hidroeléctrica del Río Lempa (CEL) is also recognized. Permission from CEL and OLADE to publish data included in this paper is also acknowledged.

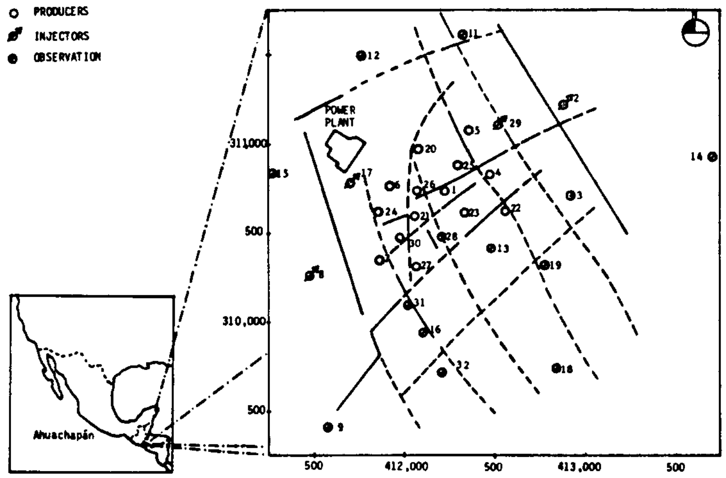

FIG. 1 LOCATION OF AHUACHAPAN GEOTHERMAL FIELD AND WELL DISTRIBUTION

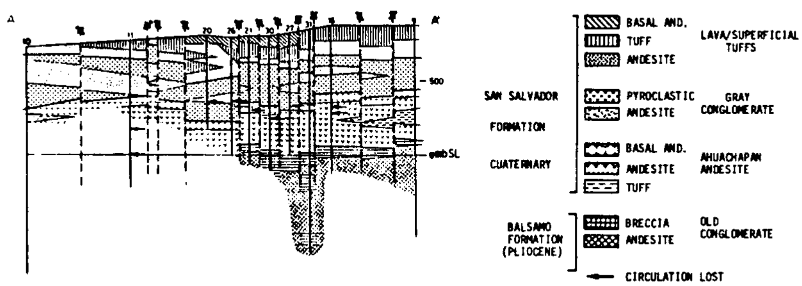

FIG. 2 STRATIGRAPHY OF THE AHUACHAPAN GEOTERMAL FIELD

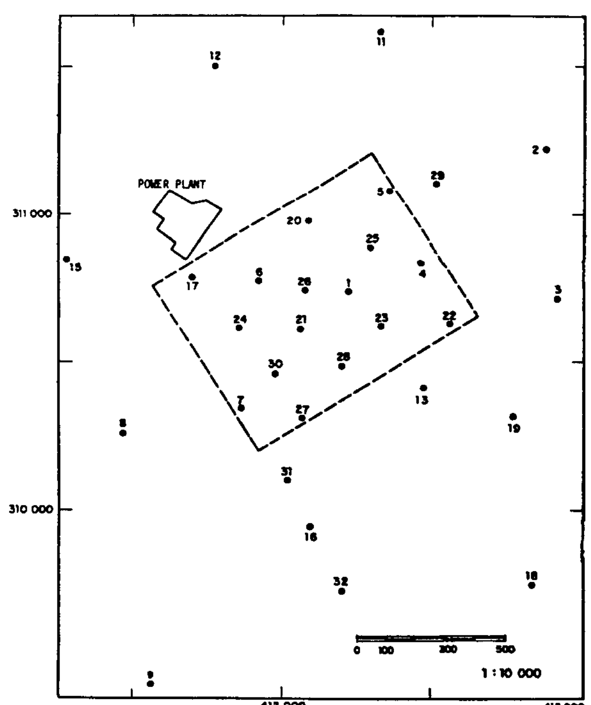

FIG 3 LOCATION OF WELLS IN THE AHUACHAPAN FIELD.

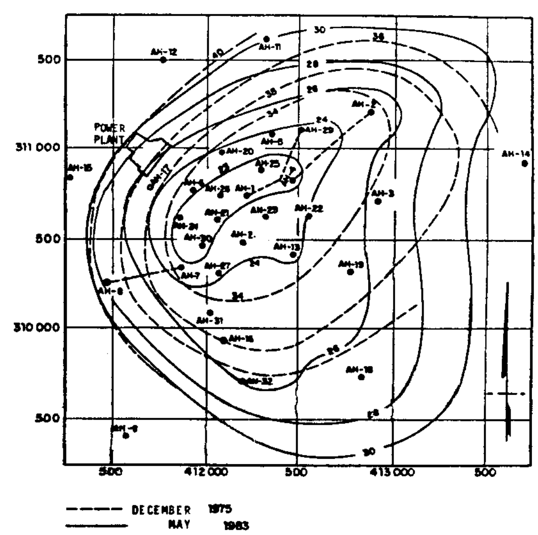

FIG 4 ISOBARIC LINES FOR PRESSURE CONDITIONS PREVAILING IN DECEMBER 1975 AND MAY 1983.

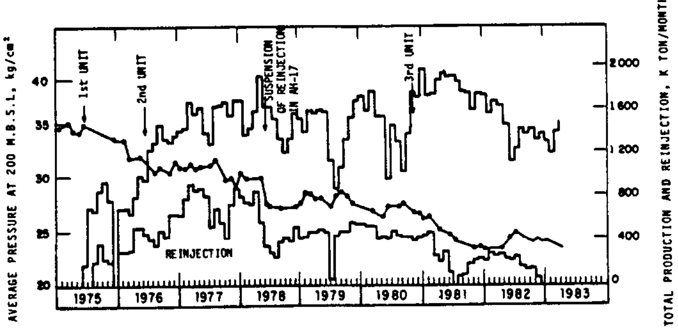

FIG 5 VARIATION OF PRODUCTION, REINJECTION AND AVERAGE RESERVOIR PRESSURE VS TIME.

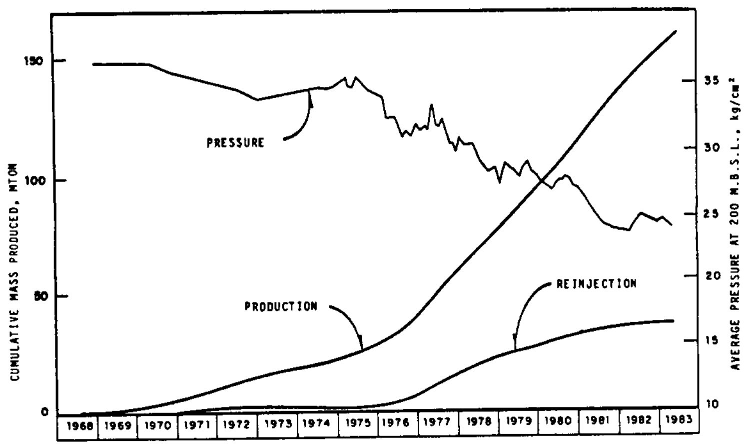

FIG 6 AVERAGE PRESSURE BEHAVIOR AS A FUNCTION OF CUMULATIVE PRODUCTION AND REINJECTION.

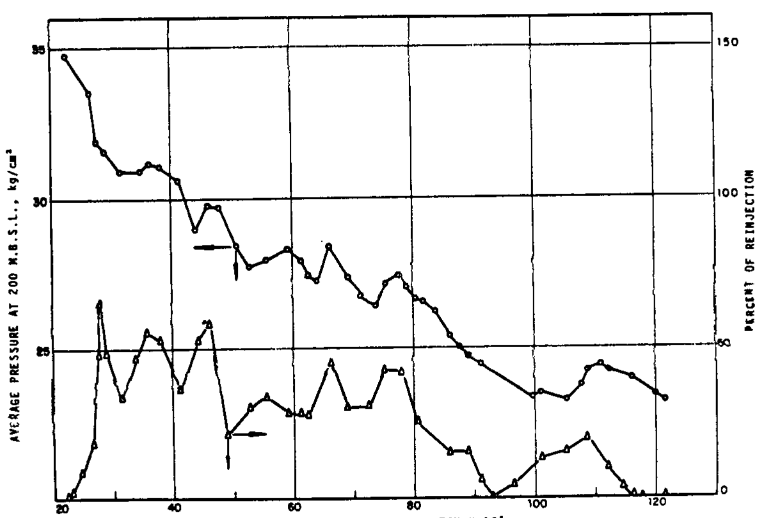

FIG 7 EFFECT OF WATER REINJECTION ON THE VARIATION OF AVERAGE PRESSURE.

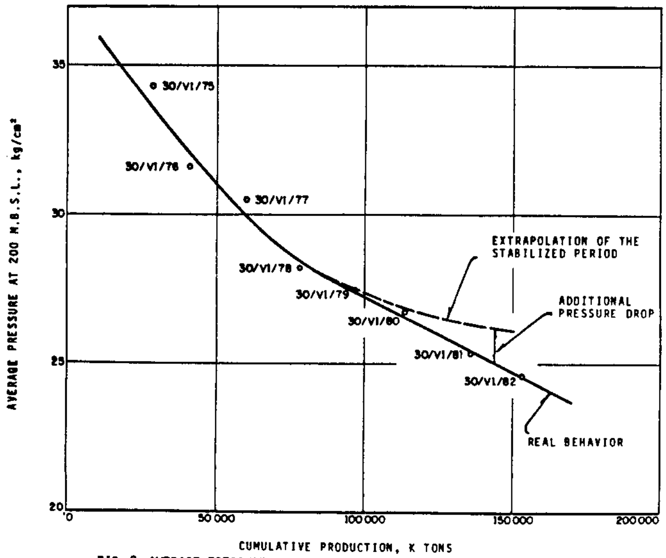

FIG 8 AVERAGE PRESSURE BEHAVIOR AS A FUNCTION OF CUMULATIVE PRODUCTION.

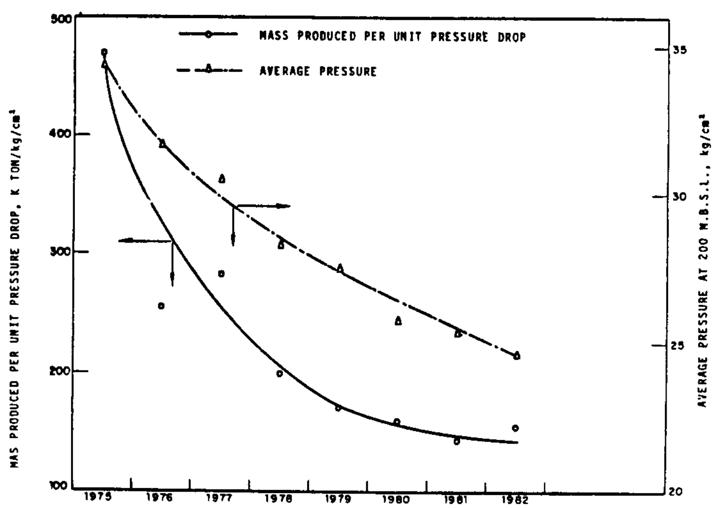

FIG 9 EFFECT OF AVERAGE PRESSURE DECLINE ON MASS PRODUCED PER UNIT PRESSURE DROP.

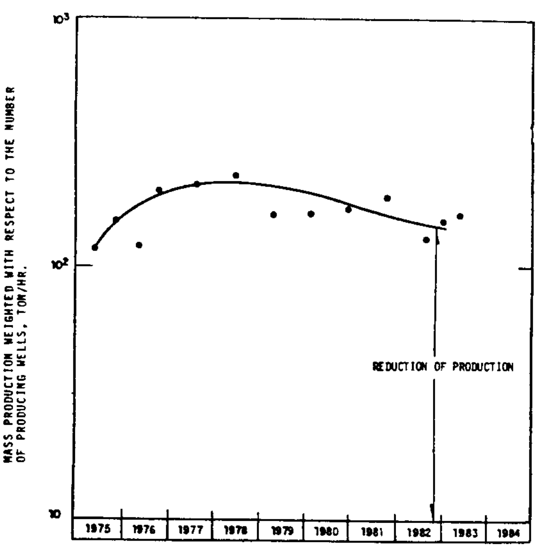

FIG 10 VARIATION OF MASS PRODUCTION WEIGHTED WITH RESPECT TO THE NUMBER OF PRODUCING WELLS VS TIME.

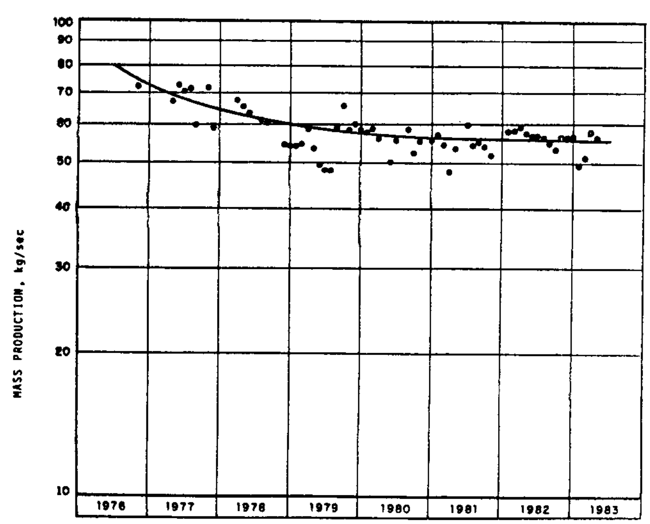

FIG 11 HYPERBOLIC PRODUCTION DECLINE FOR WELL AH-22

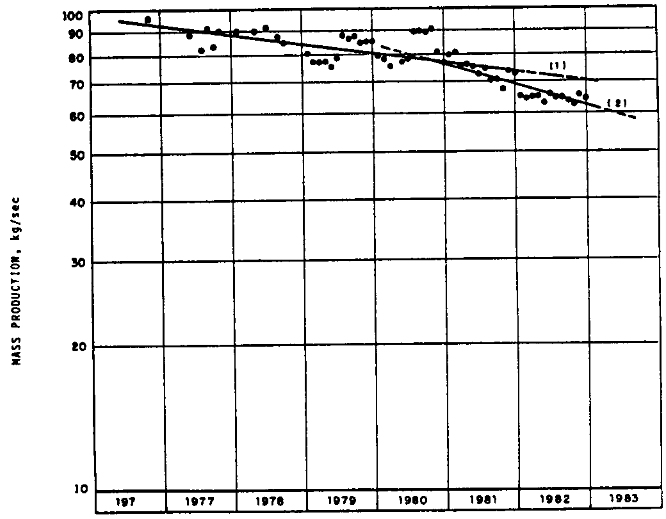

FIG 12 EXPONENTIAL DECLINE FOR WELL AH-1

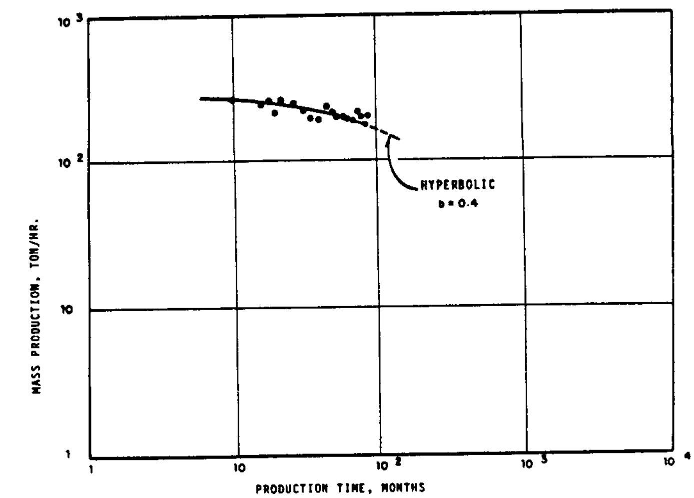

FIG 13 MATCH OF PRODUCTION DECLINE DATA OF WELL AH-22 TO THE FETKOVICH'S TYPE CURVE.

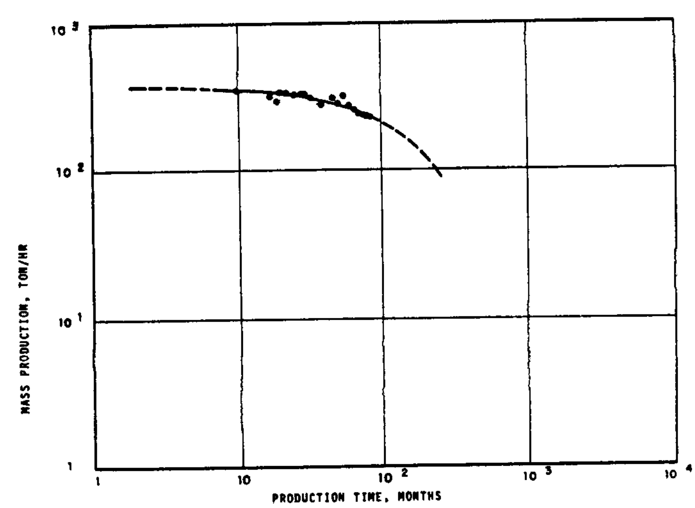

FIG 14 MATCH OF PRODUCTION DECLINE DATA OF WELL AH-1 TO THE FETKOVICH'S TYPE CURVE.

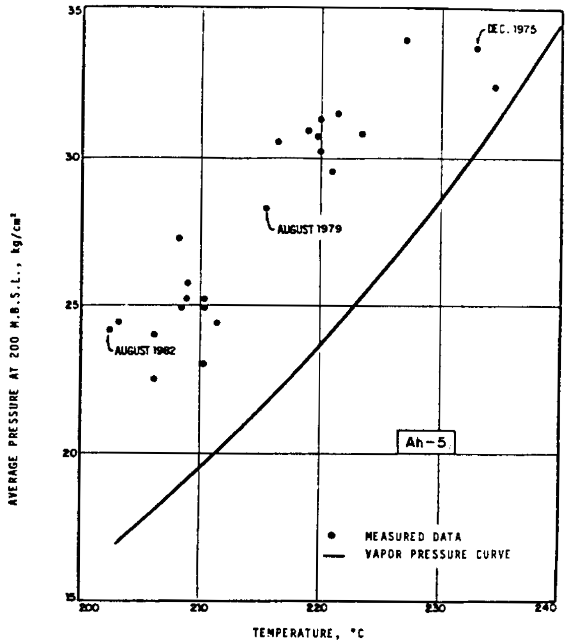

FIG 15 AVERAGE RESERVOIR PRESSURE VERSUS TEMPERATURE FOR WELL AH-5 FOR THE PERIOD DECEMBER 1975 - AUGUST 1982

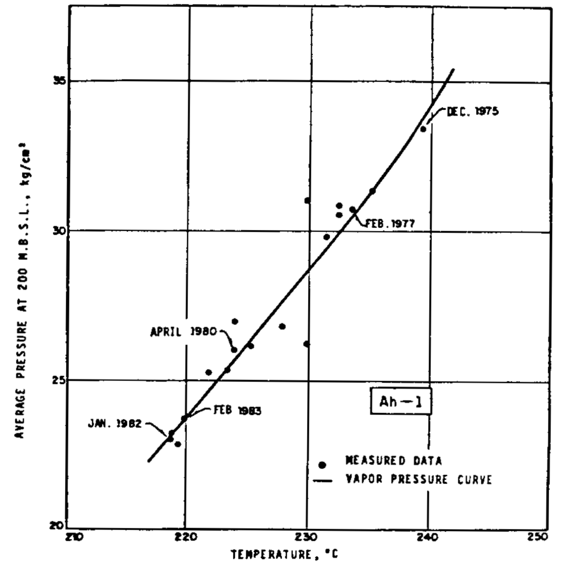

FIG 16 AVERAGE RESERVOIR PRESSURE VS TEMPERATURE FOR WELL AH-1 FOR THE PERIOD DECEMBER 1975 - FEBRUARY 1983.