MATERIALS EMPLOYED IN DEEP GEOTHERMAL DRILLING IN ITALY

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1. DEEP GEOTHERMAL DRILLING IN ITALY

ENEL is now carrying out a systematic study in the Larderello area, directed at ascertaining whether geothermal fluids can be recovered from the layers underlying the 'reservoir' exploited at present.

The research program also includes the drilling of deep wells ranging from a minimum of 3000 m to a maximum of 5000 m. Some of these wells have already been completed. The technical profile of these wells is generally that shown in Fig. 1.

Drilling is a complicated operation (Fig. 2) because:

- the layers forming the present reservoir, which lies between 1000 and 3000 m, are not easy to isolate;
- the zones below 3000 m are characterized by very high temperatures and chemical aggressiveness.

Further information on deep geothermal drilling in Italy and on the problems involved can be found in Cigni (1980).

Considering the operative problems encountered so far, the perfecting of an ideal 'deep geothermal drilling technology' could, in itself, be said to represent one of the objectives of deep exploration at Larderello.

The technological research now consists of a market survey to procure drilling equipment suited for use in the operative conditions peculiar to deep geothermal wells. As the standard equipment used in oil research cannot always be used directly, a study must sometimes be made of the modifications required and adequate operative methodologies developed for using this equipment. Certain operations carried out in deep geothermal wells, on the other hand, require specially designed equipment.

This paper will outline the main equipment and methodologies now used in drilling deep geothermal wells. Attention is paid in

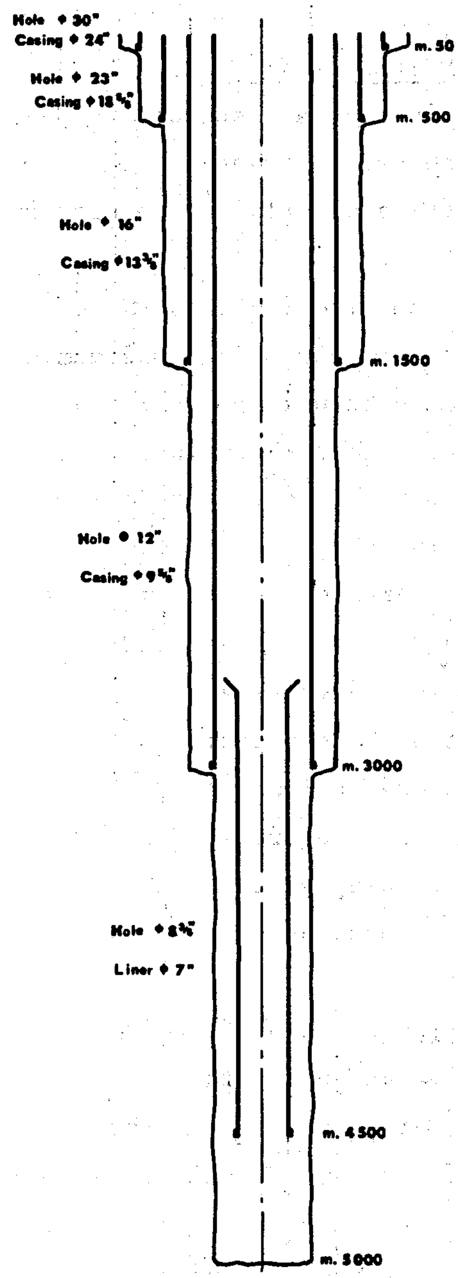

Fig. 1. Typical technical profile of the Larderello deep wells. These are used at Larderello to explore the layers between 3000 and 5000 m.

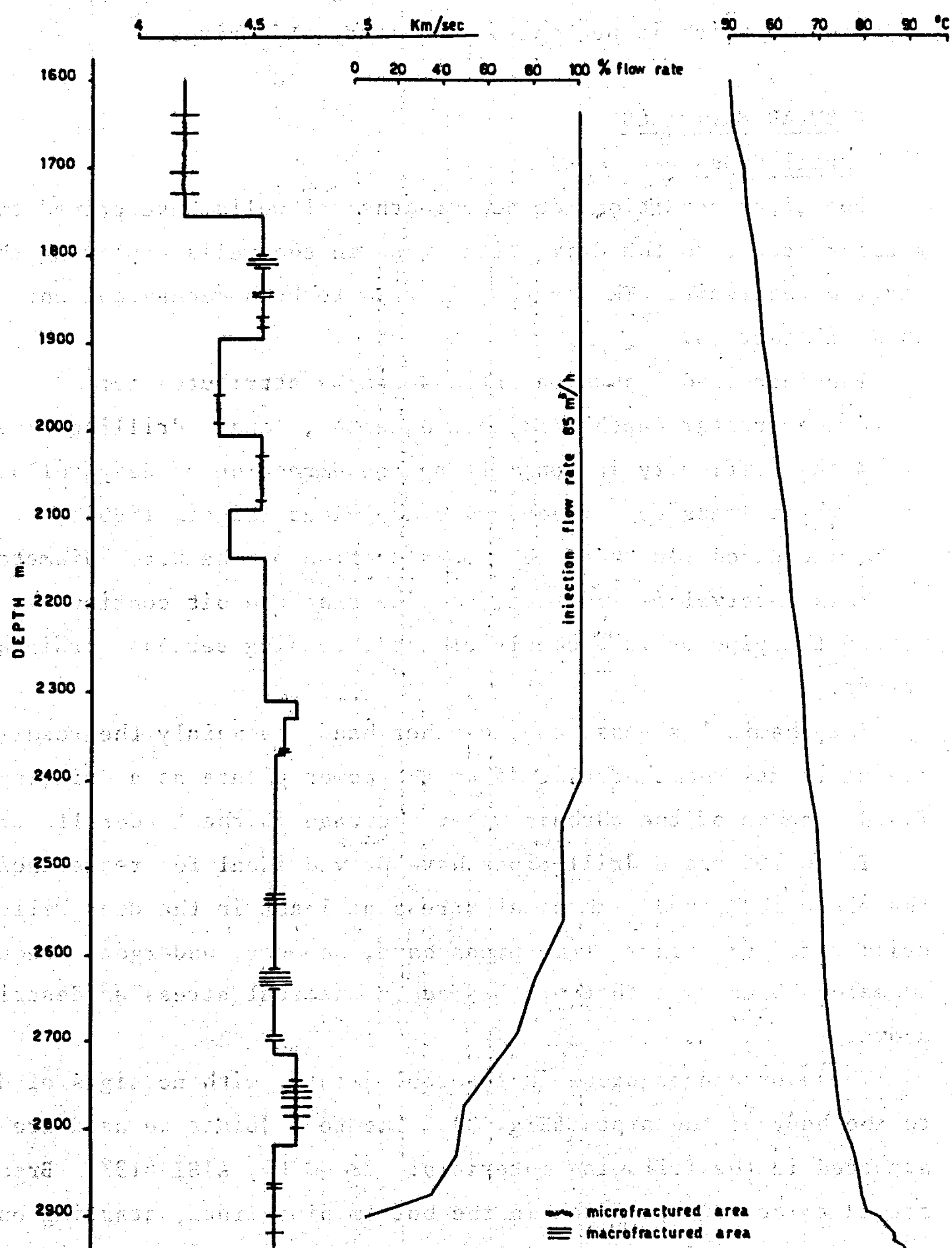

Fig. 2. Diagram 1: Sonic log of the layers forming the exploited reservoir. Diagram 2: Injectivity log of the layers forming the exploited reservoir (injected flow-rate: 85 m^3/hr). Diagram 3: Temperature log run during the injection test of diagram 2. Note the extent of the fractured zones that are so difficult to isolate.

particular to the problems arising during the drilling operations, a solution to which is now one of our study objectives.

2. TUBULAR MATERIALS

2.1 Drill Pipes

Operative conditions in deep geothermal wells have proved to cause greater stress to the drill-pipes than in the wells exploring the shallow reservoir. This stress is tied to both mechanical and chemical factors.

The increased mechanical stress can be attributed to:

- the greater depths and, consequently, longer drilling times;
- the difficulty in controlling the direction of deep wells, which leads to a frequency of dog-legs (Cigni, 1980);
- increased length of the upper section of the bore, diameter 16".

This interval is, in fact, so wide that the bit continually jumps within the pipe or is suddenly blocked, causing serious torsional stress.

The chemical stress, on the other hand, is mainly the result of having to use the condensate from the power plants as a drilling fluid because of the chronic water shortage in the Larderello area.

The G 105 grade drill-pipes have proved ideal for resistance to the above-mentioned mechanical stress at least in the deep wells drilled so far. These same pipes have, however, undergone frequent anomalous breakages that are blamed on chemical stress as described above.

These breakages occur in the tool-joints, with no signs of damage to the body of the pipes (Fig. 3). The tool joints we used are constructed in the following materials: 38 NC D4, AISI 4137. Breakage seemed to occur more often in the bottom pipe-lines, starting on the inside surface of the tool-joint.

These phenomena were so serious it was decided to run a series of tests simulating well conditions to define the phenomenology of the attack and attempt a solution to the problem. The preliminary results confirm that the chemical attack is further aggravated by the existing

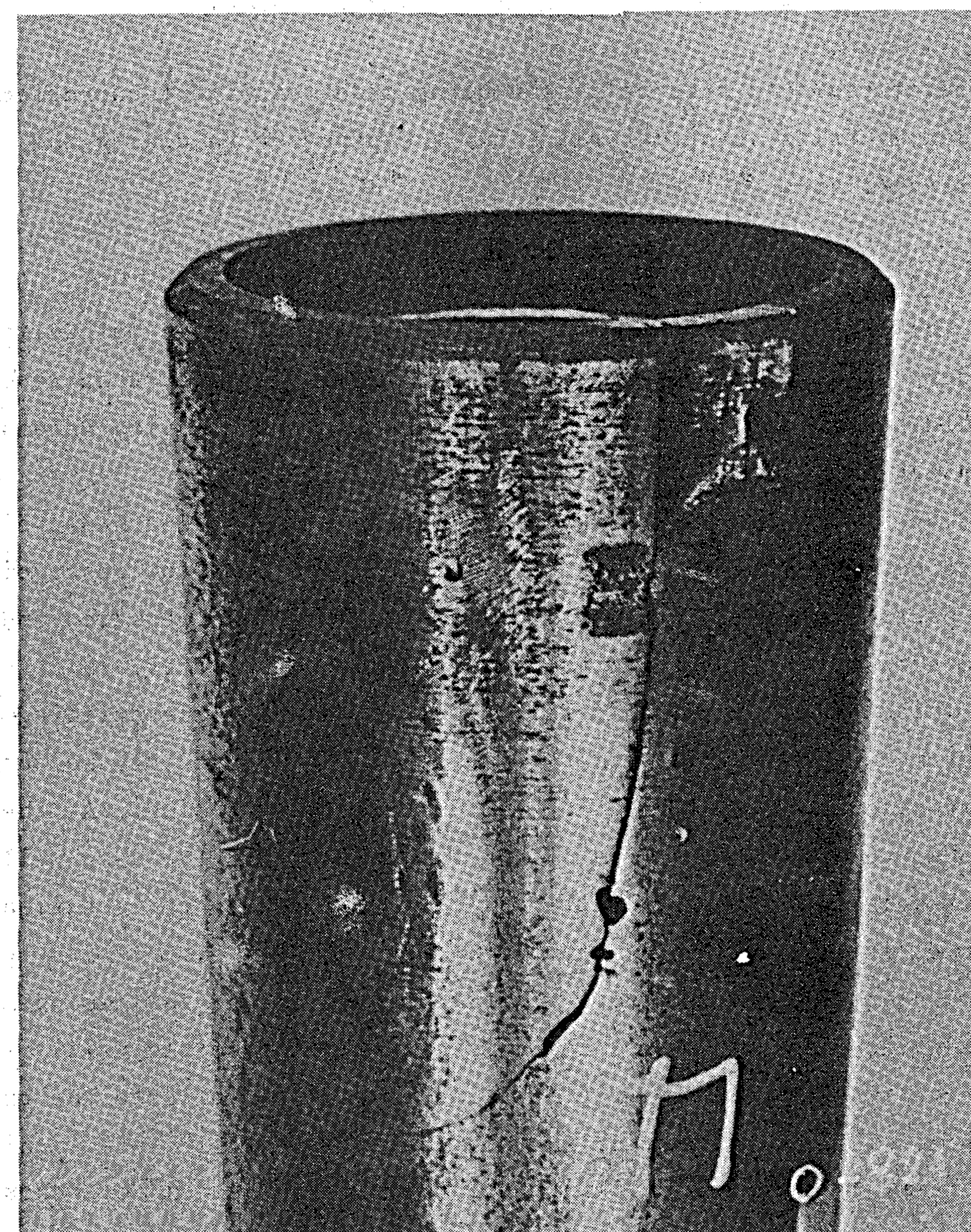

Fig. 3. Breakage of a tool-joint.

temperatures. An attempt is now being made to solve the problem either by using other materials for the pipes or by dosing the drilling fluid.

2.2 Casing

The criteria followed in designing the deep geothermal wells at Larderello were that the diameters used to explore the deep reservoir should be wide enough to attain satisfactory productivity values despite the greater depth of borehold required.

The various casings were lowered not only to strengthen the bore walls but also to isolate the formations of the shallow reservoir. Cementation of the column was therefore an arduous operation and not always an absolute success (details will be given later).

This outcome had been foreseen when drawing up the drilling program, and it was felt that the best results would only be achieved by adopting ideal criteria for the design of the casing. At the same time we were aware that the higher temperatures of the deep wells and their relatively longer drilling times would create quite serious thermal stress to the casing.

Consequently, great care was taken in designing the casing to avoid breakages that would compromise completion of the well.

The results of the first drillings appear to validate the criteria chosen. These criteria include the use of API drill-pipes with buttress joints. The thickness and grade of the steel were chosen after detailed analysis of the thermal stress and of the resistance of the materials.

Casing design was based on the results of lab tests to determine the tensile strength of J55, C75, N80 and P110 steels, cited in the American Petroleum Institute standards, at temperatures of 200°C, 250°C, 300°C and 350°C.

These results (Fig. 4 shows those for the N80 steel) were used to introduce a 'reduction factor of the tensile properties' in the project design of the casing. This factor was used empirically to evaluate, as a function of the maximum foreseeable temperature, the

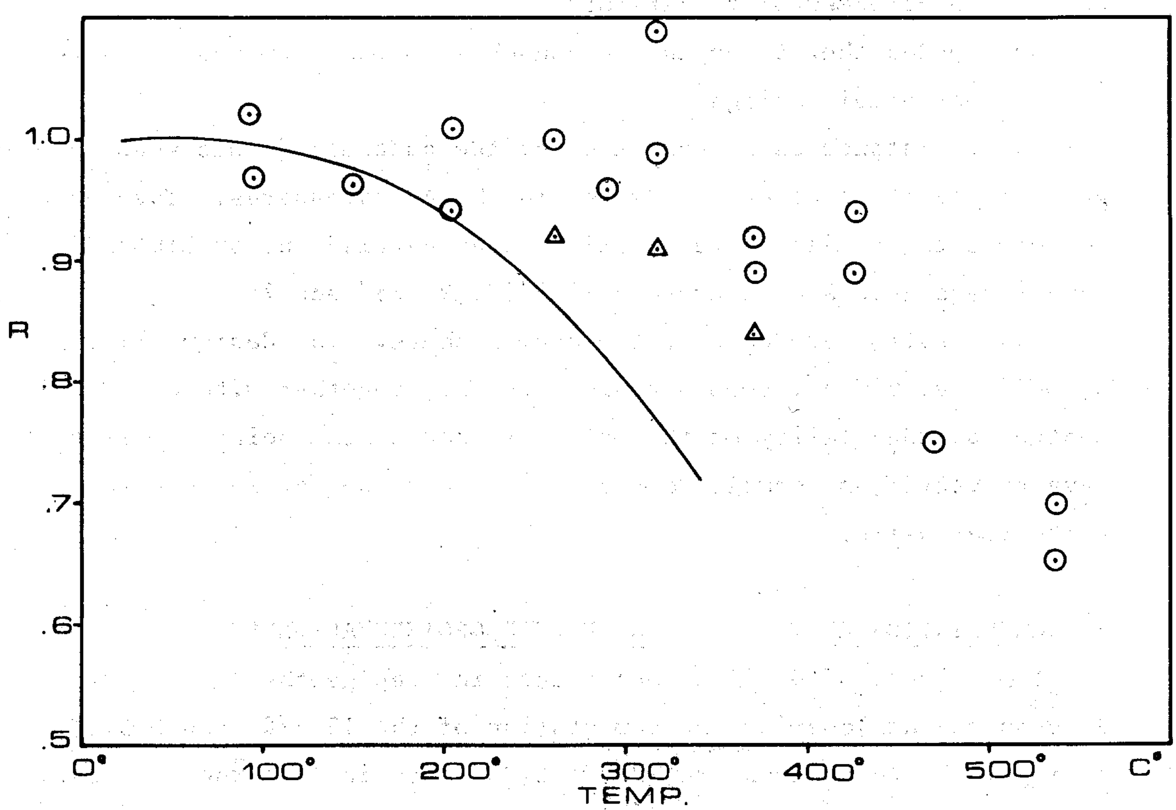

Fig. 4. Values of the R ratio between the yield point of the N80 steel at high temperature and the recorded value at environmental temperature.

collapsing and crushing strength of the casing, beginning with the API data for environmental temperatures.

An impeded thermal expansion causes anomalous compressive stress to the geothermal casings.

The resistance characteristics of the buttress joints when undergoing these stresses are not given in the API standards. They were therefore the subject of a specific study carried out by ENEL (Fig. 5) on buttress joints of diameters 13 3/8", 9 5/8" and 7".

The results were used in the design phase. The design criteria, as mentioned before, seem satisfactory and, together with a careful control of the quality of the materials and of the joint - make up, have prevented any damage to the casings used so far in the deep geothermal wells.

3. CEMENTATION OF THE CASINGS IN DEEP GEOTHERMAL WELLS

The success of drilling operations in deep geothermal wells depends on the lowering and cementation of the 13 3/8" and 9 5/8" casings. These casings are, in fact, used to isolate the layers of the shallow reservoir and are usually cemented with no return circulation.

Cementation is consequently a laborious task carried out in several phases, using the inner string cementing method, or F.O. multiple stage cementer, or pumping slurry down into the upper annulus. The problems arising during this operation and the reasons that led to the choice of methodology are described in Cigni (1980).

A description will now be given of the composition of the various slurries (Cigni 1975).

3.1 Slurries Used for Primary Cementation by the Inner String Cementing Method

These slurries are used to cement the final section of the casing, using the drill-pipes and a stab-in float collar.

The slurry consists of a class G cement with 35% silica flour. Density is about 1.850 kg/l. One percent of filtrate reducer is

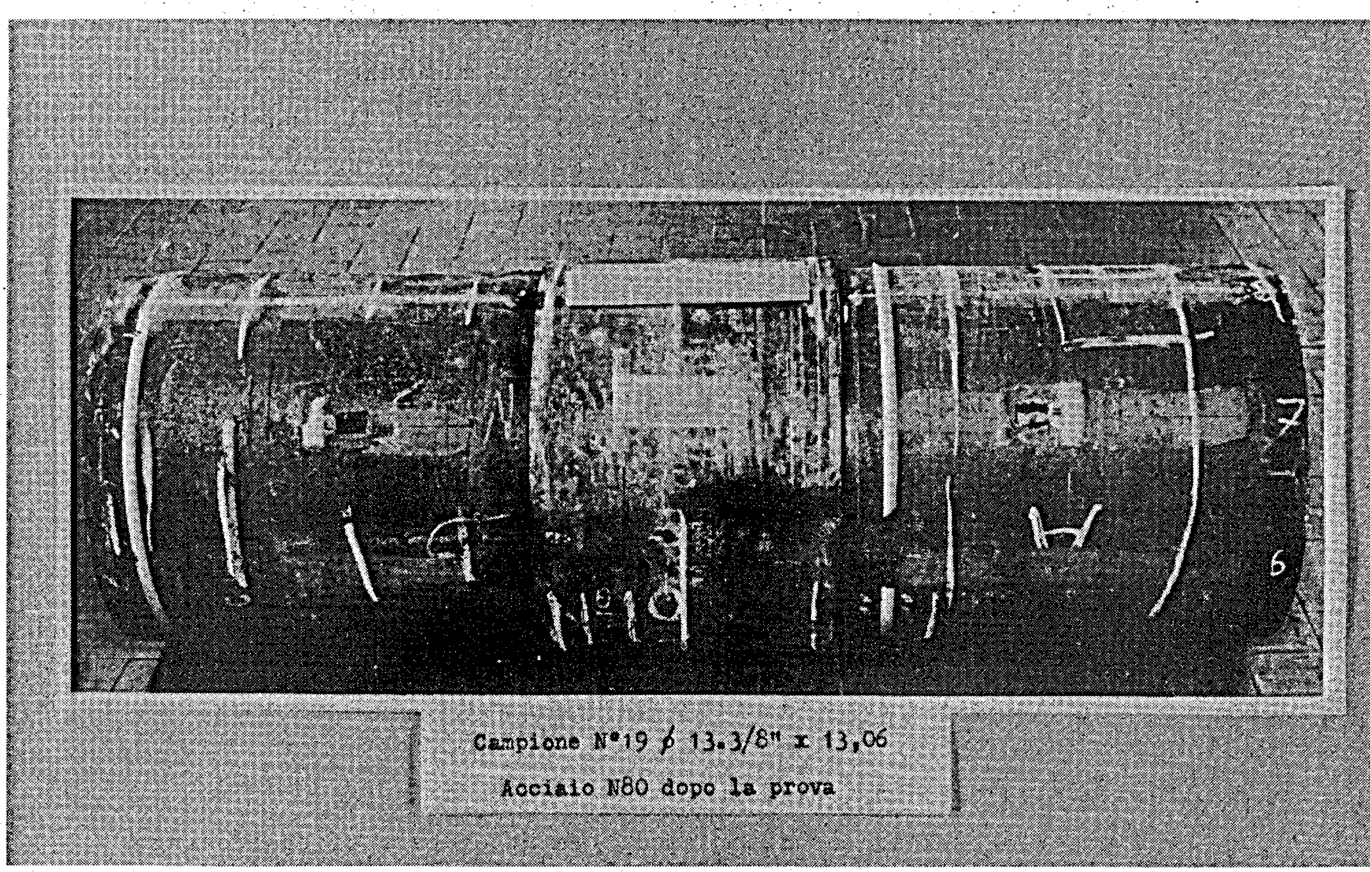

Fig. 5. Buttress joint of diameter 13 3/8" x .72 N80 steel, subjected to axial compression.

added to achieve a low filtration. As water sometimes has to be used as a drilling fluid, the reducer is added to prevent dehydration of the slurry because of the lack of an adequate mud cake.

The casings are at such great depths (3000-4000 m), and the temperatures so high, that the pumping times have to be guaranteed by a retarder, which is added in the ratio of 0.5% in weight of the cement.

The composition of the slurry is studied in the laboratory by means of simulation tests, not scheduled in API standards, reproducing the setting conditions of the slurry in the bore. This applies to both the setting pressure and the increase in temperature with time.

On the site the slurry is prepared in tanks beforehand to ensure the mixture is homogeneous. A cooling circulation at well-bottom during setting of the slurry prevents excessive retrogradation of the mechanical properties which occur when slurry sets in high temperature environment (Fig. 6).

3.2 Slurries Used in Secondary Cementation

These slurries are used to cement the upper part of the casing, circulating them through an F.O. multiple stage cementer inserted in the drill-pipe (Fabbri and Ricciardulli, 1979). A class G cement with 35% silica flour is generally used in this case.

Where circumstances so require the density can be reduced to about 1.650 kg/l by adding diatomite. However, the latter can lead to marked retrogradation, as well as sedimentation and contraction. The setting times are also much longer, so that chemical extenders, such as the D79 by Dowell, are generally preferred to the diatomite. Slurry prepared in this way does not create the problems mentioned above and results are equally satisfactory.

3.3 Slurries Used in Cementation with Pumping from Above

These slurries are used to fill the annulus by injecting the cement from ground-level. Before pumping the cement a special viscous solution is injected, either SPACER 1000 or equivalent. This product

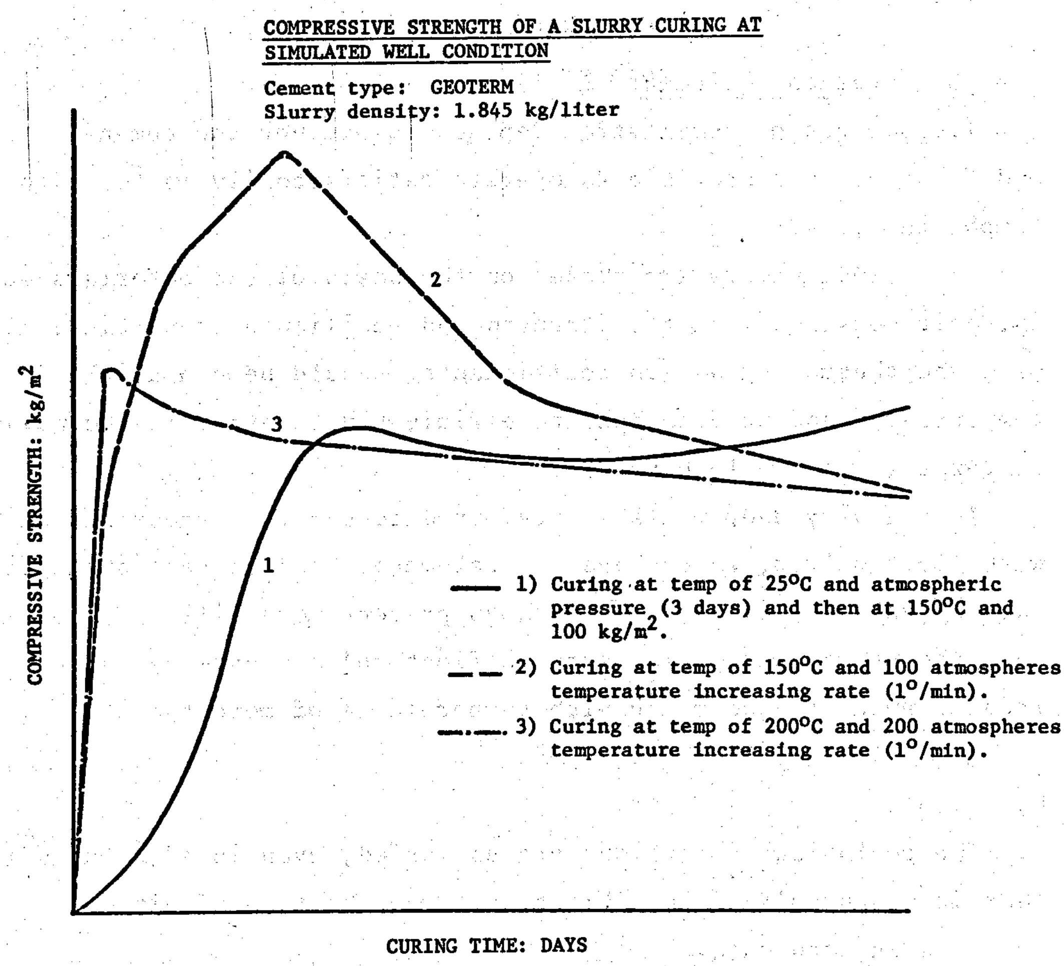

Fig. 6. Trends with time of the mechanical strength of the slurry as a function of setting conditions.

provides a slower and more uniform distribution of the cement into the annulus. Several cement units are used at one time to ensure high flow-rates and a continual flow.

3.4 Cementation Equipment

The success of cementation depends on whether the cementing shoes and float collars are able to operate satisfactorily in the high temperature environments.

These instruments are chosen on the basis of the materials used in their construction; the strength and resilience properties, along with the thermal expansion coefficients, should be compatible in high temperatures and able to operate efficiently together in the maximum temperatures of well-bottom.

In the very deep wells we preferred to use the cementing shoes with float valves, which have a metal-metal contact seal and cast-iron back-up valve. However, these shoes present more milling problems than the other types. The stab-in float collars gave excellent results even at 3000 m and with temperatures of more than 200°C.

4. BITS

The geological conditions are so varied, even in adjacent wells, that it was usually impossible to program the type of bit most suitable in each case.

The data obtained on site so far are greatly influenced by the working conditions of the bits (with or without return circulation, drilling capacity of the formations, temperatures). It is thus difficult to establish fixed criteria for the choice of bits. Some encouraging results were obtained from the use of diamond bits in intervals with high temperatures and no return circulation.

5. LOGGING INSTRUMENTS

One of the problems in deep geothermal drilling (Cigni, 1980) is that of obtaining ready-made equipment for directional drilling in high temperature conditions. Suitable turbines and instruments for continuous monitoring of direction and inclination are particularly difficult to find in the specialized market.

ENEL has now decided to solve the problem by designing and constructing its own instrumentation for measuring inclination and direction in the presence of temperatures of 250°C and pressures of 500 bar. These studies will be based on past experience in constructing similar instrumentation for measuring temperature and bore diameter.

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