THE USE OF AERATED FLUIDS IN THE DRILLING OF GEOTHERMAL PRODUCTION WELLS

Michael D. Allen

Geothermal Energy New Zealand Limited
Auckland, New Zealand

ABSTRACT

While geological formations with high permeability are most desirable within the production zone of a geothermal well, their presence at shallower depths can create a number of problems during well drilling.

In conjunction with low formation pressures, high permeability can lead to major losses of the drilling fluid. To overcome this problem and allow drilling to continue with conventional drilling fluids, such as bentonitic mud, losses must be progressively plugged.

The use of aerated drilling fluids can effectively eliminate the overpressure between the well bore and the formation, ensuring circulation returns.

INTRODUCTION

The use of a low density drilling fluid introduces a novel approach to the area of deep well drilling. Practices in petroleum well drilling operations, dictated by high subsurface pressures of volatile fluids, have led to the use of heavy weight drilling muds with a combined purpose of hole circulation and blowout prevention.

The situation in many geothermal developments allows the essential criteria for drilling fluids to be re-established. Geothermal "well control" during drilling is generally a far less complex problem than can be encountered in a petroleum field. A geothermal well can effectively be controlled by a fluid filled bore or it can be quenched by the injection of sufficient cooling fluid (water) in a situation of complete loss of circulation. If a geothermal well is left uncontrolled, it may discharge large volumes of steam and/or hot water presenting a dangerous, but usually easily recovered, situation. The risk of fire or explosion, from the well fluids, is generally not present.

The use of an aerated circulating fluid can introduce a situation of controlled well discharge into the geothermal drilling operation.

CIRCULATION LOSSES

The presence of zones of high circulation losses is common within most geothermal wells. Surface and subsequent shallow geology with low formation pressures often combine to make drilling with "mud" costly and time consuming. At depth, below the well production shoe, high circulation losses offer encouraging indications of potential fluid production, all other factors being equal.

Consider first the drilling of the well to the production shoe depth : typically at least two upper strings of casing will be set before the production string is run. Geothermal conditions dictate that the annular spaces between, and outside, casings be completely filled with competent cement. Three approaches are possible if constant circulation losses are encountered.

(i) use a "drill and plug" approach in which consecutive loss zones are progressively plugged before drilling on. Slight losses may be sealed with suitable materials while larger losses may require cementing off with a subsequent standby period while the plug cures.

(ii) the well may be drilled without returns of circulation for all or part of the span of each casing run and then the hole plugged, before running casing, and redrilled, or sealed as the casing is grouted, or

(iii) circulation may be maintained by reducing the density of the circulating fluid with plugging as in (ii).

No matter which approach is used, casing runs in geothermal well programmes frequently require backfilling of the annular spaces. A formation apparently satisfactorily plugged during drilling may break down under the pressure of a high density grout column during casing cementing, with subsequent failure to attain a full return of cement to the surface.

It can therefore be argued that in many field situations a drilling programme without stepwise plugging of zones of lost circulation is not detrimental to the casing completions provided either satisfactory full return primary cementing can be assured or backfilling is anticipated and the primary cementing limited accordingly.

Below the depth of the production shoe losses of circulation are normally protected rather than plugged. To this end the drilling fluid will normally be changed at the interception of the first major loss. As residual drilling mud does little to enhance the flow of geothermal fluids through the permeable matrix of a reservoir, a change to water is commonly made. While drilling may continue with water, without a return of fluid to the wellhead, drilling and/or reservoir conditions may make this undesirable as :

(i) intermittent losses of circulation can lead to the drill string becoming stuck in the well following the collapse of column of cuttings above the bit as it "breaks through" from a competent formation into a zone of high losses.

(ii) production layers of low permeability may suffer damage if cuttings are carried into these zones.

(iii) well geology can only be recorded by coring if no cuttings return to the surface.

DRILLING FLUIDS

As loss of circulation is a function of the overpressure between the well bore and the formation at any point, the reduction of the density of the circulating fluid may allow a return flow to be maintained during drilling.

The term "drilling fluid" includes air, gas, water and mud, or intermediate combinations of any or all of these fluids. Drilling "mud", a suspension of solids in water or oil, represents the higher density fluids. While water is commonly used in geothermal drilling, it is generally not suitable for maintaining circulation where high losses of mud have occurred. Air drilling can offer a solution to the problem of maintaining drilling circulation.

The expression "air drilling" encompasses the following :

- dry air drilling': nothing is added to the air stream. Annular velocities of 12 to 15 metres per second are typically required for effective hole cleaning.
- mist and foam drilling; a small amount of foaming agent is added to the air stream. Used particularly in situations where there is a small inflow of formation water into the well.
- stable foam; a completely mixed air and liquid dispersion in which the liquid is the continuous phase, in the form of bubbles. Typical annular velocity of the order of 0.5 metres per second.

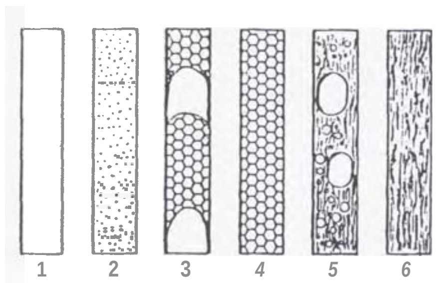

FIG 1 : Drilling fluid flow regimes

Figure 1 shows the types of flow regimes that can exist for various drilling fluids.

Much can be said on the advantages and disadvantages of the different air drilling systems. While it is not intended to detail all these points, apart from those that arise in later sections, a brief summary of the major considerations is as follows :

Air: Advantages
- high penetration rate
- reduced bit cost
- low water requirement
- no mud requirement
- indication of steam source as encountered.

Disadvantages
- difficulties arise if water in flow present
- hole erosion may be severe due to high annular velocity
- drill string and casing damage may occur due to high annular velocity
- additional wellhead equipment exposed to high temperature

Mist: Advantages
- as for air
- can handle formation water in flow
- reduced annular velocity of air.

Disadvantages
- cost of foaming agent and inhibitors
- additional wellhead equipment exposed to high temperature

Foam: Advantages
- high penetration rate
- low bit cost
- low water requirement
- high solids carrying capability
- reduced air flow requirements
- low annular velocity
- provides some hole stability

Disadvantages
- high foamer cost
- foam stability reduces with temperature rise
- less effective as bit coolant
- close control of composition of foam required.

While air has been used for some time in dry steam geothermal well completions, foam and mist drilling have found limited application to date. The ability of foams to perform in conditions where formation water enters the well bore can allow their use in "wet" geothermal systems.

DRILLING PROGRAMME WITH AERATED FLUIDS

The introduction of an aerated drilling fluid into a geothermal well programme requires a number of alterations from more orthodox approaches. The points rgised here are directed to the use of aerated foams in wet geothermal systems, though many points are equally applicable when dry air drilling.

The experience quoted is from the Olkaria field in Kenya. In this field severe circulation losses occur from some 30 metres below ground level. In effect "stable foam" is used to the setting of the production casing shoe, at approximately 550 metres depth, below which depth formation water flows and steam production create a "mist flow" situation in the return annulus. A well depth of 2000 metres by 8½ inch diameter is assumed .

PLANT REQUIREMENTS

In addition to standard rig facilities, aerated drilling requires:

(i) an air compressor capable of delivering approx. 1M3/sec of air at 30 kg/cm^2 pressure for normal drilling operations. at depth, with the facility to provide a discharge pressure to 65 kg/cm^2 for short periods. The higher pressure may be required to "unload" a head of water from the well bore after making a drill pipe connection or when tripping back into the well.

(ii) a high pressure liquid injection unit to pump foam into the air line as it passes to the rig standpipe.

(iii) an air flow recorder. This is of value in analysing the behaviour of the well as it is drilled.

(iv) additional wellhead equipment.

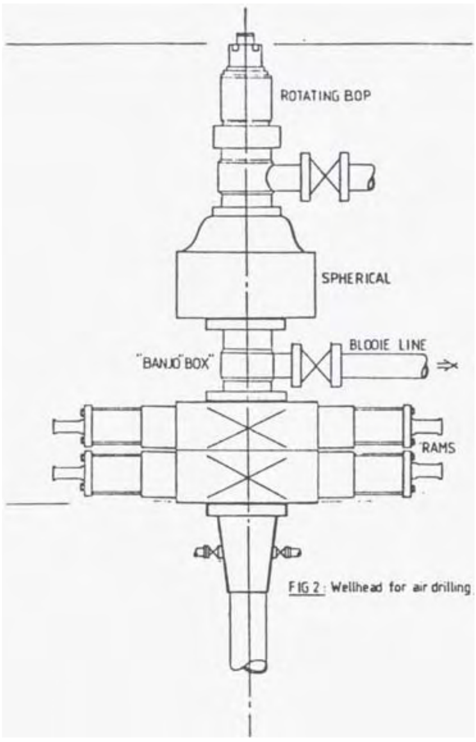

FIG 2: Wellhead for air drilling

A rotating BOP is required on the top of the wellhead stack to seal around the string and divert the high velocity return. An intermediate drilling spool/"Banjo-box" is placed centrally in the BOP stack to allow the discharge of the return fluids.

All wellhead components must be rated to stand the high temperatures of the well discharge ($\pm$ 150^{o}C) encountered as the bore nears its final depth.

(v) facilities for "mousehole" drill string connections. Fast additions of drill pipe reduce the possibility of collapse of the foam column and consequent delays in re-establishing circulation.

MATERIALS USAGE

A foaming agent is required. Many products are available on the market currently but most have poor performance at higher temperatures.

Use of an aerated fluid is generally a "once through" process with the return foam unsuitable for re-circulation. For this reason foam consumption is high and the economics of the operation are very dependent on the drilling penetration rate. For stable foam the total liquid content must typically be kept below 5 per cent (by volume) to ensure the greatest solids carrying capacity.

The air-water-foamer combination in a hot well bore can present a severe environment for drill tools and consideration should be given to at least intermittent dosing with a suitable inhibitor added to the foam.

DOWNHOLE TOOL SELECTION

The reduction of the fluid column pressures and the higher bit jet velocities have been demonstrated to markedly improve penetration rates over those achieved when drilling with mud.

The trend towards sealed bearing and/or journal bearing, insert tooth rock bits is widespread in geothermal operations and offers the best choice for aerated drilling.

As noted above, the cost of aerated drilling is strongly dependent on penetration rate. In any particular well, drill off tests are recommended to optimise the weight-on-bit/rpm as the bore progresses.

Most convential downhole tools are suitable for aerated drilling with the restriction that the environment is severe for components subject to corrosion and downhole temperatures may approach the reservoir temperatures for short periods.

During mist drilling, annular velocities rise and erosion becomes a concern. Hard banded drill pipe tool joints are recommended with smooth, fine coatings preferred to reduce damage to the upper casing string (tool joint protectors are generally unsuitable for high temperature operation).

To ensure that circulation is regained with as short a delay as possible, either after tripping or adding additional drill pipe, it may be necessary to run a "jet" sub at an intermediate point in the drill string. This encourages a retu'rn flow from this point, back up the annulus, reducing the unloading requirements from the level of the drill bit. This sub, containing a small diameter jet pointing upwards into the annulus, would normally be positioned above the casing shoe to avoid undercutting the hole wall.

CASING CEMENTING

The approaches available when drilling and casing zones of high circulation loss have been discussed above.

Aerated drilling provides the advantage that it allows the bore to be taken to the casing depth quickly. The problem of ensuring that circulation losses will not lead to a failure of the cementing operation can exist whichever approach is adopted, whether mud or air drilling is used. 'Whichever method is finally chosen must be based on specific field experience.

RESERVOIR ASSESSMENT

As drilling proceeds towards its final depth the fluid flow can be adjusted so that a partial discharge of the well occurs? This is of considerable assistance in identification of the producing zones within a well. Interception of a source of steam or hot water is quickly indicated by the rapid increase in the return flow temperature. The well may be allowed to "flow" at an increasing rate as the hole is taken deeper or it may be controlled by increasing the water injection rate into the circulating fluid. Either way, indication at the surface can be monitored and correlated with the downhole situation. Obviously, such a technique requires prior knowledge of the stability of the producing formation.

ECONOMICS OF AERATED DRILLING

Aerated drilling eliminates the problems of drilling in zones of high circulation losses; it does not offerpny new solution to sealing these losses when casings have to be set and cemented.

Penetration rates are higher than with mud drilling but foam can only be used in a "once through" system, while mud can be recirculated.

The aerated fluids in the well bore create a corrosive environment for downhole tools but they allow bottomhole conditions to be inferred from surface observations.

The balance of economics must be a result of considerations of specific field conditions. Aerated fluid drilling of geothermal wells has however been demonstrated to be an entirely practical operation providing a fast and satisfactory approach to well completion.