This paper discusses the operation principle of a geothermal system followed by details of the drilling rig and further extends to costs, limitations and future technologies.
Executive Summary:

This paper first discusses the operation principle of a geothermal system followed by details of the drilling rig and further extends to costs, limitations and future technologies. Geothermal drilling is the process of creating boreholes in the earth to extract the earth's heat. The heating system consists of three main systems, ground loop, a heat pump and heat distribution system. The extraction process is done using drilling rigs. These are classified based on power used, pipe type, by height, method of drilling and position of the derrick. The driving power could be mechanical, electric, hydraulic, pneumatic, steam. The types of pipe used are cable, conventional: such as metal or plastic drill pipe of varying types or coil tubing. Depending on the height, further classifications are; single, double and triple. By method of rotation or drilling method, drilling rig type are; no-rotation, rotary table, top drive: By position of derrick, conventional or derrick is vertical or slant. The costs associated with drilling and completing wells are a major factor in determining the economic feasibility of producing energy from geothermal resources. Pressure of air delivered to the piston is identified as major limitation. Future research directions are aimed at non contact drilling technologies that have immense potential.
Contents
Executive Summary: ......................................................................................................................... i
GEOTHERMAL DRILLING .............................................................................................................. 3
Drill Rigs......................................................................................................................................... 12
   Classification of Drilling Rig: ....................................................................................................... 15
      By power used: ....................................................................................................................... 16
      By pipe used: ....................................................................................................................... 16
      By height: ............................................................................................................................ 16
      By method of rotation or drilling method: ......................................................................... 16
      By position of derrick: ....................................................................................................... 17
Cost in Geothermal Drilling: ......................................................................................................... 19
Limitations in the technology: ....................................................................................................... 21
Future of Drilling Technologies: .................................................................................................. 22
References: .................................................................................................................................... 23
GEOTHERMAL DRILLING

Geothermal drilling is the process of creating boreholes in the earth to extract the earth's heat. It is a process whereby heat is taken from the Earth and used in a productive way for energy needs. The heat can be used directly for some needs such as space heating, but the true value for the mass market comes from that heat's ability to be converted to other forms. Electrical generation is one of the most common reasons for geothermal drilling on an industrial scale.

Geothermal power is one of the great untapped resources in many locations around the Earth. Physics teaches that much of the universe's energy is in the form of heat and that humans have typically failed to make good use of the heat they have. Even in energy conversion of other forms, the reason for the loss of efficiency is heat generated from the conversion that is never used for any practical purpose.

Geothermal drilling seeks to change this. By drilling holes deep into the Earth's crust, especially in certain regions of the world, such as the Pacific Rim, there is the possibility of accessing vast stores of energy. Geothermal well drilling can be a major process as these wells may go down three miles (5 km) or more, depending on where in the world they are located. While there is heat available in all parts of the world, some places would have to dig much deeper than this, making getting geothermal energy difficult. Thus, the costs for geothermal drilling in those areas would likely exceed the benefits.

Both ‘Geothermal Energy’ and ‘Ground Source Energy’ are terms used to describe energy which is sourced from the Earth. Only a few metres down the temperature of the subsoil remains constant at about 10-16°C and usually differs from the surface temperature by a few degrees. This differential between the subsoil temperature and the surface temperature is the principle on which geothermal or ground source heating works. The amount of temperature differential depends on the geology of the soil, climate and seasonality.

Once the well has been drilled, there is a virtually endless supply of energy. Further benefiting geothermal drilling operations is the fact heat rises, meaning there is very little in the way of mechanization needed to bring the energy to the surface, once the route has been created. However, the process does not simply end with the geothermal drilling. It must still be converted into useful energy.
In some cases, the energy conversion is not needed. This is most commonly seen when the energy is used for space heating. However, this is an entirely different situation altogether from commercial geothermal drilling. In this case, the geothermal well does not need to go nearly as deep. Just a few feet below the ground, the Earth stays nearly a constant temperature of between 50 and 60 degrees Fahrenheit (10 to 15.5 degrees Celsius) in nearly all locations. Therefore, the air only needs to be heated approximately 10 more degrees to make it comfortable.

If conversion is needed, this is usually accomplished by producing steam. Some wells already do this naturally, further simplifying the process. In other cases, steam is created using the heat available. That steam then rotates turbines, which produce the electricity. Once drilled, geothermal wells offer a very clean source of energy void of pollutants or greenhouse gasses.

There are three important elements to a geothermal or ground source heating system:

1. The ground loop
   This consists of lengths of pipe buried in the ground in a borehole or a horizontal trench. The pipe is usually a closed circuit and is filled with a mixture of water and antifreeze which is pumped around the pipe absorbing heat from the ground. The ground loop can be:
   - Vertical, for use in boreholes
   - Horizontal, for use in trenches

2. A heat pump
   In the same way that a fridge uses refrigerant to extract heat from the inside, keeping food cool, a ground source heat pump extracts heat from the ground and uses it to heat a building.
   A ground source heat pump has three main parts:
   - The evaporator which absorbs the heat from the liquid in the ground loop
   - The compressor which moves the refrigerant round the heat pump and compresses the gaseous refrigerant to the temperature needed for the heat distribution circuit
   - The condenser which gives up heat to a hot water tank which feeds the distribution system

3. Heat distribution system
   This consists of under floor heating or radiators for space heating and in some cases water
storage for hot water supply. There are reverse-cycle heat pumps that can deliver both heating and cooling.

Despite the promise of cheap, clean power, geothermal energy development may be on shaky ground. There have been rumblings from residents and scientists alike that drilling deep to tap naturally occurring heat could cause bigger earthquakes.

Already on edge about temblors, northern California locals are eyeing an expansive new geothermal project proposed by a company called AltaRock that's going to be boring down more than two miles (3.2 kilometres). The area near the town of Anderson Springs—about 90 miles (150 kilometres) north of San Francisco—is home to natural geothermal vents (nicknamed The Geysers by early visitors who saw the steam vents there) and has been exploited for its natural energy-generating capacity for the better part of the last century. Starting in the 1970s, as technology improved, engineers started to crank up the production levels. Small earthquakes began shortly thereafter.

Just a few years ago, a now-infamous geothermal project in Basel, Switzerland, which drilled three miles (4.8 kilometres) into Earth's crust, set off a magnitude 3.4 earthquake, rocking the town and shutting the operation down entirely, The New York Times recalled.

Drilling has even been fingered as the cause of a massive 2006 mud volcano in Java, which displaced more than 30,000 people after a gas exploration project went awry. "We are more certain than ever that the Lusi mud volcano is an unnatural disaster," Richard Davies of the Centre for Research into Earth Energy Systems at Durham University in England said in a statement after investigating the incident.
The U.S. Department of Energy has already chipped in $36 million for AltaRock's project, and in an effort to drive down the price of renewable energy Google has anted up $6.25 million, the Times reported.

But will these deep holes—and deep-pocketed investors—trigger the next big one? U.S. Geological Survey Earthquake Hazards Team seismologist David Oppenheimer, who is based in Menlo Park, Calif., just a couple hours south of the area said:

MIT released an expert panel's report evaluating the potential use of geothermal energy within the US. Typically, geothermal energy has involved extracting hot water from geologically active areas (such as geyser fields) and using it to provide heat or generate electricity. If this brings to mind images of Iceland or dropping a large power plant into Yellowstone National Park, the panel would recommend that you read the report's 358 pages a bit more closely. The easy sources of geothermal energy in the US are already being tapped (current output is similar to that of solar and wind combined). The report instead evaluates the feasibility of tapping into less readily available sources of geothermal power on a large scale, sufficient to generate 10 percent of the country's energy (that's 100 GW of electricity) by 2050.

Current geothermal projects involve what the report terms "high grade" resources, which have features that make them easy to exploit: "high average thermal gradients, high rock
permeability and porosity, sufficient fluids in place, and an adequate reservoir recharge of fluids." The panel suggests that it's time to consider "engineered" or "enhanced" geothermal, which involves exploiting sources of energy that lack one or more of these characteristics. This would involve drilling deeper than the typical current project, which taps sources within three kilometres of the surface. Current drilling technology can reach a depth of 10km, which substantially expands the potential for exploitation: at a depth of 6.5km, large portions of the Western US check in at over 200°C. Combined, regions within this depth range hold 130,000 times the US's current annual consumption of energy; even the portion that might be reasonably considered extractable is over 2,000 times today's consumption.

Simply drilling down isn't enough, however. The rocks in question must be permeable to liquids while still keeping them in a constrained area, and have access to a large enough heat reservoir to raise the temperature of a constant flow of circulating water. The authors suggest that current technology is capable of generating fracture systems as large as a cubic kilometer in otherwise impermeable rock, which handles the first issue. The second is more complex and may only be solved once we gain more experience with identifying appropriate geological features via a number of pilot projects. To that end, the panel suggests that we combine efforts with Australia and the EU, which is currently operating a pilot facility in France. They also suggest running pilot programs in active oil fields within the US, where they estimate 6-11 GW worth of generating capacity in hot water is being extracted as a by-product.

The panel made a detailed analysis of the economics of engineered geothermal that paints an interesting picture of how this plays out in the energy marketplace. Using conservative estimates, they suggest that by the time the national engineered geothermal capacity reaches a GigaWatt, costs per kilowatt hour would drop to $0.05, which is likely to be very competitive in future markets. Getting to that capacity would involve an investment of only $400 million over 15 years. Reaching the full goal of 10 percent of the national energy supply would require up to $1 billion over the same time period. Either figure, they note, is less than the cost of a single modern clean coal facility.

There are a few optimistic assumptions built into these analyses. For one, they assume that continued study and the building of test facilities will provide better guidance for identifying the best geological features to tap with future plants. They also expect that new generator
technology will allow more efficient use of water that, although quite hot, is cooler than what's generated by today's fossil fuel-based generators.

The environmental footprint of these plants is expected to be quite small. Most of their infrastructure will be underground, and emissions will essentially be zero. They will, however, require a water supply, as the recovery of circulating water will not be complete. The water that comes up may also have dissolved various unpleasant contaminants, creating at least one potential environmental issue. The report does suggest one potential way in which engineered geothermal might bail us out, environmentally. Carbon dioxide is apparently very dense and non-viscous at supercritical pressures and temperatures, suggesting it might provide more efficient heat transfer material than water. Getting it out of the air and into these systems would give us a 2-for-1 bonus: less burning of carbon-based fuels, and less carbon in the atmosphere contributing to climate change.

Overall, the report makes a very compelling case that engineered geothermal be given serious consideration when it's time to fund research into future energy sources.

Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma.
Almost everywhere, the shallow ground or upper 10 feet of the Earth's surface maintains a nearly constant temperature between 50° and 60°F (10° and 16°C). As mentioned earlier, Geothermal heat pumps can tap into this resource to heat and cool buildings. A geothermal heat pump system consists of a heat pump, an air delivery system (ductwork), and a heat exchanger—a system of pipes buried in the shallow ground near the building. In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to provide a free source of hot water.

Wells can be drilled into underground reservoirs for the generation of electricity. Some geothermal power plants use the steam from a reservoir to power a turbine/generator, while others use the hot water to boil a working fluid that vaporizes and then turns a turbine. Hot water near the surface of Earth can be used directly for heat. Direct-use applications include heating buildings, growing plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes such as pasteurizing milk.

Hot dry rock resources occur at depths of 3 to 5 miles everywhere beneath the Earth's surface and at lesser depths in certain areas. Access to these resources involves injecting cold water down one well, circulating it through hot fractured rock, and drawing off the heated water from another well. Currently, there are no commercial applications of this technology. Existing technology also does not yet allow recovery of heat directly from magma, the very deep and most powerful resource of geothermal energy.

Many technologies have been developed to take advantage of geothermal energy - the heat from the earth. There are various researches to develop and advance technologies for the following geothermal applications:

**Geothermal Electricity Production:** Generating electricity from the earth's heat.

Most power plants need steam to generate electricity. The steam rotates a turbine that activates a generator, which produces electricity. Many power plants still use fossil fuels to boil water for steam. Geothermal power plants, however, use steam produced from reservoirs of hot water found a couple of miles or more below the Earth's surface. There are three types of geothermal power plants:
1. Dry steam
2. Flash steam and

1. Dry steam power plants draw from underground resources of steam. The steam is piped directly from underground wells to the power plant, where it is directed into a turbine/generator unit. There are only two known underground resources of steam in the United States: The Geysers in northern California and Yellowstone National Park in Wyoming, where there's a well-known geyser called Old Faithful. Since Yellowstone is protected from development, the only dry steam plants in the country are at The Geysers.

2. Flash steam power plants are the most common. They use geothermal reservoirs of water with temperatures greater than 360°F (182°C). This very hot water flows up through wells in the ground under its own pressure. As it flows upward, the pressure decreases and some of the hot water boils into steam. The steam is then separated from the water and used to power a turbine/generator. Any leftover water and condensed steam are injected back into the reservoir, making this a sustainable resource.

3. Binary cycle power plants operate on water at lower temperatures of about 225°-360°F (107°-182°C). These plants use the heat from the hot water to boil a working fluid, usually an organic compound with a low boiling point. The working fluid is vaporized in a heat exchanger and used to turn a turbine. The water is then injected back into the ground to be reheated. The water and the working fluid are kept separated during the whole process, so there are little or no air emissions.

Along with large-scale power plants, small-scale geothermal power plants (under 5 megawatts) have the potential for widespread application in rural areas, possibly even as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system.

**Geothermal Direct Use:** Producing heat directly from hot water within the earth.

When a person takes a hot bath, the heat from the water will usually warm up the entire bathroom. Geothermal reservoirs of hot water, which are found a couple of miles or more
beneath the Earth's surface, can also be used to provide heat directly. This is called the direct use of geothermal energy.

Geothermal direct use dates back thousands of years, when people began using hot springs for bathing, cooking food, and loosening feathers and skin from game. Today, hot springs are still used as spas. But there are now more sophisticated ways of using this geothermal resource.

In modern direct-use systems, a well is drilled into a geothermal reservoir to provide a steady stream of hot water. The water is brought up through the well, and a mechanical system - piping, a heat exchanger, and controls - delivers the heat directly for its intended use. A disposal system then either injects the cooled water underground or disposes of it on the surface.

Geothermal hot water can be used for many applications that require heat. Its current uses include heating buildings (either individually or whole towns), raising plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes, such as pasteurizing milk. With some applications, researchers are exploring ways to effectively use the geothermal fluid for generating electricity as well.

**Geothermal Heat Pumps:** Using the shallow ground to heat and cool buildings.

The shallow ground, the upper 10 feet of the Earth, maintains a nearly constant temperature between 50° and 60°F (10°-16°C). Like a cave, this ground temperature is warmer than the air above it in the winter and cooler than the air in the summer. Geothermal heat pumps take advantage of this resource to heat and cool buildings.

Geothermal heat pump systems consist of basically three parts: the ground heat exchanger, the heat pump unit, and the air delivery system (ductwork). The heat exchanger is basically a system of pipes called a loop, which is buried in the shallow ground near the building. A fluid (usually water or a mixture of water and antifreeze) circulates through the pipes to absorb or relinquish heat within the ground.

In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves
heat from the indoor air into the heat exchanger. The heat removed from the indoor air during 
the summer can also be used to heat water, providing a free source of hot water.

Geothermal heat pumps use much less energy than conventional heating systems, since they 
draw heat from the ground. They are also more efficient when cooling your home. Not only 
does this save energy and money, it reduces air pollution.

**Drill Rigs**

A drilling rig is a machine which creates holes (usually called boreholes) or shafts in the 
ground. Drilling rigs can be massive structures housing equipment used to drill water wells, 
oil wells, or natural gas extraction wells, or they can be small enough to be moved manually 
by one person. They can be used to install sub-surface fabrications, such as underground 
utilities, instrumentation, tunnels or wells. Drilling rigs can be mobile equipment mounted on 
trucks, tracks or trailers, or more permanent land or marine-based structures. The term "rig" 
therefore generally refers to the complex of equipment that is used to penetrate the surface of 
the Earth's crust.

Drilling rigs can be:

- Small and portable, such as those used in mineral exploration drilling, water wells and 
environmental investigations.
- Huge, capable of drilling through thousands of meters of the Earth's crust. Large "mud 
pumps" circulate drilling mud (slurry) through the drill bit and up the casing annulus, 
for cooling and removing the "cuttings" while a well is drilled. Hoists in the rig can 
lift hundreds of tons of pipe.
The parts of a typical geothermal drilling rig are explained below:

**Crown block:** An assembly of sheaves or pulleys mounted on beams at the top of the derrick. The drilling line is run over the sheaves down to the draw works.

**Derrick:** A large load-bearing structure, usually bolted construction of metal beams. In drilling, the standard derrick has four legs standing at the corners of the substructure and reaching to the crown block. The substructure is an assembly of heavy beams used to elevate the derrick and provide space underneath to install the blowout preventer, casing head, and other equipment.

**Travelling block:** An arrangement of pulleys or sheaves which moves up or down in the derrick through which the drilling cable is strung to the rotary drive.

**Swivel:** A mechanical device that suspends the weight of the drill pipe, provides for the rotation of the drill pipe beneath it while keeping the upper portion stationary, and permits the flow of drilling mud from the standpipe without leaking.
**Standpipe:** A rigid metal conduit that provides the pathway for drilling mud to travel about one-third of the way up the derrick, where it connects to a flexible hose (Kelly hose), which connects to the swivel.

**Kelly:** The heavy square or hexagonal steel member suspended from the swivel through the rotary table and connected to the topmost section of drill pipe to turn the drill pipe as the rotary table turns.

**Rotary drive:** The machine used to impart rotational power to the drill string while permitting vertical movement of the pipe for drilling. Modern rotary machines have a special component, the rotary or master bushing, to turn the Kelly bushing, which permits up and down movement of the Kelly while the drill pipe is turning.

**Draw works:** The hoisting mechanism on a drilling rig. It is a large winch that spools off or takes in the drilling cable or line, which raises or lowers the drill pipe and drill bit.

**Blowout prevention equipment:** The assembly of well control equipment including preventers, spools, valves, and nipples connected to the top of the wellhead to prevent the uncontrolled escape of steam or water during drilling operations.

**Mud pump:** A large, high-pressure reciprocating pump used to circulate the mud on a drilling rig.

**Engines:** Any of various types of power units such as a hydraulic, internal combustion, air, or electric motor that develops energy or imparts rotary motion that can be used to power other machines.

**Mud pit:** Originally, an open pit dug in the ground to hold drilling mud or waste materials such as well bore cuttings or mud sediments. Steel tanks are much more commonly used for these purposes now, but they are still usually referred to as pits.

**Drill pipe:** The heavy seamless steel tubing used to rotate the drill bit and circulate the drilling mud. Each section of drill pipe is about 30 feet long and is fastened together by means of threaded tool joints.
Casing: Heavy steel pipe that lines the walls of the hole to prevent the wall of the hole from caving in, to prevent movement of fluids from one formation to another, and to aid in well control.

Cement: Used to fill the space between the wall of the hole and the casing. Together with the casing, this prevents caving of the hole, prevents movement of fluids (water or steam) between rock layers, confines production to the well bore, and provides a means to controls pressure.

Drill bit: The cutting or boring element used in drilling geothermal wells. Most bits used in rotary drilling are roller-cone bits. The bit consists of the cutting elements and the circulating element. The circulating element permits the passage of drilling fluid and uses the hydraulic force of the drilling mud to improve drilling rates.

Classification of Drilling Rig:

There are many types and designs of drilling rigs, with many drilling rigs capable of switching or combining different drilling technologies as needed. Drilling rigs can be described using any of the following attributes:
By power used:

- Mechanical: The rig uses torque converters, clutches, and transmissions powered by its own engines, often diesel.
- Electric: The major items of machinery are driven by electric motors, usually with power generated on-site using internal combustion engines.
- Hydraulic: The rig primarily uses hydraulic power.
- Pneumatic: The rig is primarily powered by pressurized air.
- Steam: The rig uses steam-powered engines and pumps (obsolete after middle of 20th Century).

By pipe used:

- Cable: A cable is used to raise and drop the drill bit.
- Conventional: Uses metal or plastic drill pipe of varying types.
- Coil tubing: Uses a giant coil of tube and a downhole drilling motor.

By height:

(All rigs drill with only a single pipe. Rigs are differentiated by how many connected pipe they are able to "stand" in the derrick when needing to temporarily remove the drill pipe from the hole. Typically this is done when changing a drill bit or when "logging" the well.)

- Single: Can pull only single drill pipes. The presence or absence of vertical pipe racking "fingers" varies from rig to rig.
- Double: Can hold a stand of pipe in the derrick consisting of two connected drill pipes, called a "double stand".
- Triple: Can hold a stand of pipe in the derrick consisting of three connected drill pipes, called a "triple stand".

By method of rotation or drilling method:

- No-rotation includes direct push rigs and most service rigs.
- Rotary table: Rotation is achieved by turning a square or hexagonal pipe (the "Kelly") at drill floor level.
- Top drive: Rotation and circulation is done at the top of the drill string, on a motor that moves in a track along the derrick.
- Sonic: Uses primarily vibratory energy to advance the drill string.
- Hammer: Uses rotation and percussive force.

By position of derrick:
- Conventional: Derrick is vertical.
- Slant: Derrick is slanted at a 45 degree angle to facilitate horizontal drilling.

**Drill Bits:**

There are several factors that affect drill bit selection. Due to the high number of wells that have been drilled, using information from an adjacent well is most often used to make the appropriate selection. Two different types of drill bits exist: fixed cutter and roller cone. A fixed cutter bit is one where there are no moving parts, but drilling occurs due to percussion or rotation of the drill string. Fixed cutter bits can be either polycrystalline diamond compact (PDC) or grit hot pressed inserts (GHI). Roller cone bits can be either tungsten carbide inserts (TCI) or milled tooth (MT). The manufacturing process and composites used in each type of drill bit make them ideal for specific drilling situations. Additional enhancements can be made to any bit to increase the effectiveness for almost any drilling situation.

A major factor in drill bit selection is the type of formation that needs to be drilled. The effectiveness of a drill bit varies by formation type. There are three types of formations: soft, medium and hard. A soft formation includes unconsolidated sands, clays, soft limestones, red beds and shale. Medium formations include calcites, dolomites, limestones, and hard shale. Hard formations include hard shale, calcites, mudstones, cherty lime stones and hard and abrasive formations.

The first roller cone patent was for the rotary rock bit and was issued to Howard Hughes Sr. in 1909. It consisted of two interlocking cones. Walter Benona Sharp worked very closely with Hughes in developing the rock bit. The success of this bit led to the founding of the Sharp-Hughes Tool Company.
In 1933 two Hughes engineers, one of whom was Ralph Neuhaus, invented the Tricone bit, which has three cones. The Hughes patent for the Tricone bit lasted until 1951, after which time other companies started making similar bits. However, Hughes’ market share was still 40% of the world's drill bit market in 2000. The superior wear performance of PDC bits gradually eroded the dominance of roller cone bits and early in this century PDC drill bit revenues overtook those of roller cone bits.

The technology of both bit types has advanced significantly to provide improved durability and rate of penetration of the rock. This has been driven by the economics of the industry and by the change from the empirical approach of Hughes in the 1930s, to modern day domain Finite Element codes for both the hydraulic and cutter placement software.

New unconventional geothermal drilling methods have created the demand for a new generation of high performance drilling bits. Strong multi-blade profiles provide excellent balance to ensure smooth drilling performance at high rotation speeds making bits like silver bullet PDC drilling bits well suited for use with large powerful rotary drilling rigs and high speed drilling motors. PDC drilling bits feature a low profile, compact design making them well suited for directional drilling. Our unique bit designs deliver consistent vertical penetration rates while the compact profile provides excellent “steerability” necessary for the transition from vertical to horizontal drilling. Combined with designs, precision machining and a high concentration of premium grade PDC cutters positioned for maximum coverage ensure dependable drilling performance through the bend to TD. Precisely positioned threaded nozzles are installed for flushing of drilled cuttings into the large junk slots. Serrated tungsten carbide inserts are installed for excellent gauge wear protection to ensure consistent hole diameter and maximum service life.

PDC drilling bits are very effective for drilling shales as well as course grained cemented formations including sandstone and limestone. Drilling penetration rates (ROP) achieved with PDC drilling bits exceed those of DTH hammers and Tricone bits in these conditions while providing significant operational savings in areas including fuel and labour costs.
Cost in Geothermal Drilling:

Geothermal power requires no fuel (except for pumps), and is therefore immune to fuel cost fluctuations. However, capital costs are significant. Drilling accounts for over half the costs, and exploration of deep resources entails significant risks. A typical well doublet (extraction and injection wells) in Nevada can support 4.5 megawatts (MW) and costs about $10 million to drill, with a 20% failure rate.

In total, electrical plant construction and well drilling cost about €2-5 million per MW of electrical capacity, while the break-even price is 0.04-0.10 € per kW-h. Enhanced geothermal systems tend to be on the high side of these ranges, with capital costs above $4 million per MW and break-even above $0.054 per kW-h in 2007. Direct heating applications can use much shallower wells with lower temperatures, so smaller systems with lower costs and risks are feasible. Residential geothermal heat pumps with a capacity of 10 kilowatt (kW) are routinely installed for around $1000–$3,000 per kilowatt. District heating systems may benefit from economies of scale if demand is geographically dense, as in cities, but otherwise piping installation dominates capital costs. The capital cost of one such district heating system in Bavaria was estimated at somewhat over 1 million € per MW. Direct systems of any size are much simpler than electric generators and have lower maintenance costs per kW-h, but they must consume electricity to run pumps and compressors. Some governments subsidize geothermal projects.
The costs associated with drilling and completing wells are a major factor in determining the economic feasibility of producing energy from geothermal resources. In Engineered Geothermal Systems (EGS) power plants, estimates place drilling costs as accounting for 42%-95% of total power plant costs depending on the quality of the EGS reservoir. An earlier correlation first developed by Milora and Tester (1976) and later refined by Tester and Herzog (1990) created a drilling cost index based on oil and gas well data from the Joint Association Survey (JAS) on Drilling Costs and used this index to compare the cost of drilling hot dry rock (HDR) and hydrothermal wells to the cost of oil and gas wells drilled to similar depths. This study updates and extends their earlier work. Oil and gas well costs were analyzed based on data from the 2003 JAS for onshore, completed US oil and gas wells. A new, more accurate drilling cost index that takes into consideration both the depth of a completed well and the year it was drilled was developed using the JAS database (1976-2003).

The new index, dubbed the MIT Depth Dependent (MITDD) index, shows that well costs are up to 30% lower for wells over 4 km (13,000 ft) deep than those based on previous indices. The MITDD index was used to normalize predicted and actual completed well costs for both HDR or EGS (Engineered Geothermal Systems) and hydrothermal systems from various sources to year 2003 US dollars, and then compare and contrast these costs with oil and gas well costs.

Additionally, a model for predicting completed geothermal well costs, called WellCost Lite is explained and demonstrated. Results from the model agree well with actual geothermal well costs. The model is used to identify factors that lead to rapid, non-linear increases in well cost with depth, such as increases in the number of casing strings required as depth increases with a resulting increase in rig capacity (embodied in mobilization, demobilization and daily rental costs), costs of casing and cementing the well, and changes in the rate of penetration.
Limitations in the technology:

Drill technology has advanced steadily since the 19th century. However, there are several basic limiting factors which will determine the depth to which a bore hole can be sunk.

All holes must maintain outer diameter; the diameter of the hole must remain wider than the diameter of the rods or the rods cannot turn in the hole and progress cannot continue. Friction caused by the drilling operation will tend to reduce the outside diameter of the drill bit. This applies to all drilling methods, except that in diamond core drilling the use of thinner rods and casing may permit the hole to continue. Casing is simply a hollow sheath which protects the hole against collapse during drilling, and is made of metal or PVC. Often diamond holes will start off at a large diameter and when outside diameter is lost, thinner rods put down inside casing to continue, until finally the hole becomes too narrow. Alternatively, the hole can be reamed; this is the usual practice in oil well drilling where the hole size is maintained down to the next casing point.

For percussion techniques, the main limitation is air pressure. Air must be delivered to the piston at sufficient pressure to activate the reciprocating action, and in turn drive the head into the rock with sufficient strength to fracture and pulverise it. With depth, volume is added to the in-rod string, requiring larger compressors to achieve operational pressures. Secondly, groundwater is ubiquitous, and increases in pressure with depth in the ground. The air inside the rod string must be pressurised enough to overcome this water pressure at the bit face. Then, the air must be able to carry the rock fragments to surface. This is why depths in excess of 500 m for reverse circulation drilling are rarely achieved, because the cost is prohibitive and approaches the threshold at which diamond core drilling is more economic.

Diamond drilling can routinely achieve depths in excess of 1200 m. In cases where money is no issue, extreme depths have been achieved, because there is no requirement to overcome water pressure. However, circulation must be maintained to return the drill cuttings to surface, and more importantly to maintain cooling and lubrication of the cutting surface.

Without sufficient lubrication and cooling, the matrix of the drill bit will soften. While diamond is the hardest substance known, at 10 on the Mohs hardness scale, it must remain firmly in the matrix to achieve cutting. Weight on bit, the force exerted on the cutting face of the bit by the drill rods in the hole above the bit, must also be monitored.
**Future of Drilling Technologies:**

Limits of the conventional contact drilling technologies caused strengthen of the research of new non-contact effective drilling technologies. There were several attempts to achieve sufficient results of the research which would negate disadvantages of current contact technology. The best known are technologies based on the utilization of water jet, chemical plasma, hydrothermal spallation or laser. The research teams round the world have been developing these technologies for the long time.

Nowadays, utilization of high energetic electrical plasma shows very promising in deep drilling applications. This approach has potential to replace conventional drilling technologies because of several advantages. It would be able to produce boreholes with large constant diameter without frequent replacement of the drill bits. It would decrease time and money consumption. This technology is in the research phase and need a strong support, but it can bring a large shift in drilling segment.

Fig: A typical Geothermal Rig
References:


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