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COMPARATIVE ANALYSIS OF WELL DRILLING TECHNIQUES FOR WATER AND GEOTHERMAL ENERGY RECOVERY

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Abstract. *The world´s energy grid has been going through considerable changes due to the expansion of sustainable and renewable sources of energy. One of the natural sources that must be watched more closely is the geothermic source, which involves certain complexity in terms of extraction processes, but has the potential to become an interesting alternative source of energy and heat for different countries, such as Brazil. Since the attainment of geothermal energy requires underground exploration, it can be compared with the extraction of one of the most important natural resources for Brazilian's society: underground water. Therefore, the main goal of this research is to analyze the aspects of geothermal energy and its exploration procedures through a comparative analysis with water well drilling. To reach this goal the methodology implemented was a bibliographical review of the water well drilling and borehole construction literature as well as the geothermal well drilling literature, focusing on aspects such as geological inspection, drilling techniques, well casing, cementing, completion and other relevant features. This comparative analysis will show that despite the differences in equipment used, drilling fluids and drilling parameters, it is important to compare these processes so it is possible to develop geothermal well drilling technology, so it can reach its potential as an important alternative source of electricity and heat for the country.*

Keywords: *drilling, underground water, geothermal energy, comparative analysis, natural resources*

1. INTRODUCTION

In recent years, an issue that has been increasingly discussed due to the impact it has caused on the world is the energy transition. It can be defined as a change in the basis of the global energy and electricity matrix that is actually structured based on fossil fuels such as oil, gas and coal, for a structure based on renewable energy sources (EDP, 2022). Therefore, aiming the proliferation of the use of renewable sources, types of energy such as solar, wind, biomass, hydraulics, among others, have become the focus of several studies in order to develop mechanisms specialized in obtaining these resources and to optimize the processes that use them.

In this context, geothermal energy is one of the alternative resources available for exploration and it has been explored in several countries both for the generation of electricity as well as for heating and specific direct uses (Blodgett and Slack, 2009). According to Anjos (2018), this energy source can be defined as thermal energy extracted from the deep layers of the planet and it can be exploited through the underground waters stocked in basins or through the injection of fluids into regions of high energy content. In terms of energy production, geothermal sources are useful for electricity generation by using the extracted steam to feed turbines responsible for converting mechanical power into electricity (Confessor et al., 2020), presenting the advantage of not relying on intermittent or climatic factors, therefore being available at any time of the year (Camargo et al., 2018).

For the exploitation of energy from the interior of earth´s layers to be possible, it is necessary to drill holes underground and extract steam or heated liquids from inside the reservoirs (Zoet, 2011). Consequently, it is possible to compare this process of exploration with the exploration of another resource that presents some similarities to the geothermal resource studied, which would be groundwater. Like the geothermal resource, groundwater also requires underground drilling and extractive processes to become available for use in different areas (Giampá and Gonçales, 2013). In addition, the culture of groundwater exploration in Brazil is more consolidated than the culture of geothermal exploration, largely because of the abundance of the resource in extensive storage regions known as aquifers, making the comparison relevant and useful for bringing ideas of advancement for geothermal exploration and exploitation of other underground resources.

Thus, the main objective of this work is to make a comparison between exploitation techniques of geothermal resources and exploitation techniques of underground water resources, so particularities and similarities between them can be exposed, analyzed, and explained.

2. EXPLORATION STEPS

According to Purba et al. (2022), the well drilling process for the extraction of geothermal resources can be schematized as shown in Figure 1.

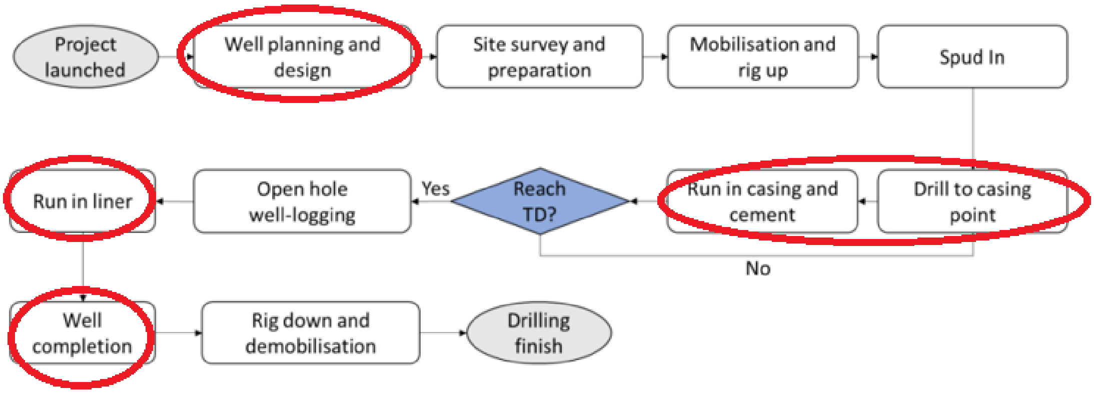

Figure 1. Simplified drilling project activities (Adapted from Purba et al., 2022)

Through Figure 1 it is possible to verify that every project begins with the planning and designing of the well. This step depends directly on the project´s purpose and on the natural drilling conditions found, therefore involving a team of geoscientists who study and analyze the site through different methods and propose a specific design that includes dimensions, specific drilling methods, and materials to be used. The following three steps (site survey and preparation, mobilization and rig up and spud in) are related to the preparation of the drilling structure and the area to be drilled, transportation of the drill to the desired location and appropriate installation of the equipment, and a small drilling test to verify if the structure is properly installed, respectively (Purba et al., 2022). These steps involve a standard procedure and are not directly related to defining drilling parameters directly, so they are not relevant for the comparative analysis. Then, after all these steps, the drilling process itself begins, and it is carried out in stages. To guarantee the structural integrity of the well, drilling is executed in sections of predefined dimensions that must be cased and cemented completely so that the next section can start to be drilled (Dipippo, 2012).

Following the logic shown in Figure 1, the drilling, casing, and cementing process should be continuously repeated until the previously analyzed reservoir is reached. When the reservoir is reached, the procedure known as open hole well-logging, which consists of a collection of geophysical properties of the reservoir that are of interest to the experimenters, so it is possible to confirm that the drilling is adequate, is started. Such collection can be performed by different logging methods, and it is concluded with the use of specific logging tools (Moss and Ronne, 2010). Then, the last part of the constructed hole, known as slotted liner, is inserted penetrating the reservoir. This structure consists of a perforated screen with several pores that is inserted concentrically to the perforated well and has the function of filtering the resource that enters into the well (Culver, 1991). After the installation of the slotted liners, which is not required on some occasions, in some wells it is performed the completion process that would be the installation of the gravel pack, that is, granular materials around the perforated section with the sole purpose of having a better filtration (Culver, 1991). Finally, the drilling structure is removed, and the pumping process is started, which, according to Van´t Spijker and Ungemach (2016), is necessary in wells where there is no natural flow of resources to the surface.

3. METHODOLOGY

For the conclusion of the proposed comparative analysis, a detailed individual bibliographic review of each of the resources (geothermal and groundwater) was performed, focusing on the characteristic storage of these underground resources and on the extraction methods themselves, so that based on the information acquired, findings about the similarities and differences of the processes and materials used could be exposed.

The comparison to be outlined will focus on the steps circulated in red in Figure 1, as they are the most technical and relevant steps for comparison purposes. In addition to these points, we will seek a comparison of materials and resources used during drilling, such as drilling fluid, casing materials and drill bit materials, as well as some comparisons of drilling parameters, such as regular diameters and depths.

4. CONTEXTUALIZATION

4.1 Geology of related reservoirs

In both geothermal and groundwater exploration, water is the fluid extracted and it is usually found stored in different types of aquifers (Fetter, 1988). However, the geological conditions of the reservoirs that are exploited for the extraction of these two resources are considerably different, mainly because of the high temperatures required for geothermal exploration.

For groundwater exploration, there are three main types of aquifers to be explored: the granular aquifer, which is represented by sedimentary and unconsolidated rocks, with high percentage of granules; the fissured aquifer, which is a more compact structure composed by massive fractured rocks causing water to be stored in fissures; and the karst aquifer formed by carbonate rocks such as limestone and dolomite, that suffer dissolution and have cavities through which water flows (Iritani and Ezaki, 2012). Some examples of rocks that make up groundwater reservoirs include unconsolidated sands and pebbles, sandstones, limestones, basalts, plutonic rocks, and fractured metamorphic rocks (Bovolato, 2007). Furthermore, it is worth mentioning that, according to Fitts (2015), the temperature range in which groundwater is extracted for its common use varies between 0 and 20°C, so it is assumed that the reservoirs do not normally present temperatures close to this range, even though there might be a natural cooling process during the extraction.

In the case of geothermal exploration, the reservoirs have characteristics that make them different from the common groundwater reservoirs. Geothermal resources are usually explored in regions of high tectonic pressure and in regions with volcanic activity, thus having characteristics such as rocks with high levels of hardness and abrasive properties, high temperatures, high pressure, and large number of fractured spots, which increases permeability considerably (Finger and Blankenship, 2010; Purba et al., 2022). In geological terms, the composition of the reservoirs involves rocks such as granite, basalt, and other varied types of rocks, but characteristics that make geothermal exploration an exceptional case are the temperature and depth of the reservoirs. In general, geothermal reservoirs with high energy content, suitable for electrical energy production, present temperatures ranging between 160 and 300°C (Purba et al., 2022; Finger & Blankenship, 2010; Cumming, 2009). As the heat transfer from the earth's core to the surface takes place through conduction and advection mechanisms, it is estimated that high depth reservoirs are the ones with the highest energy content (Fitts, 2015). The depths of the reservoirs that have the highest energy content, making the extraction viable for electricity production, can reach values close to 5 km.

4.2 Wells´ structure

Due to being explored under different geological and thermal conditions, the wells developed for the extraction of groundwater and geothermal have different geophysical parameters. Wells made for groundwater extraction at high depths are known as deep boreholes, which are drilled and operated with the aid of mechanical equipment. Despite presenting variable dimensions depending on the location of the reservoirs, the characteristics of the perforated soil, the available equipment and several other factors, the boreholes have depths that reach from tens to hundreds of meters, or, in some specific projects, one kilometer, and external diameters ranging from 10 to 75 cm in average (Giampá and Gonçales, 2013). The determination of the diameter and depth consider the required flow of the well, its dynamic level of the water and some economic factors, since the larger the dimensions of the wells, the higher the costs involved in its construction (Feitosa et al., 2008). In terms of construction, the most complete tubular wells are composed of elements like bottom sump, filters, prefilters, casing and materials for sealing the well, also known as cementing because it usually uses cement as a sealer, as can be seen in Figure 2a shown below (Harter, 2003).

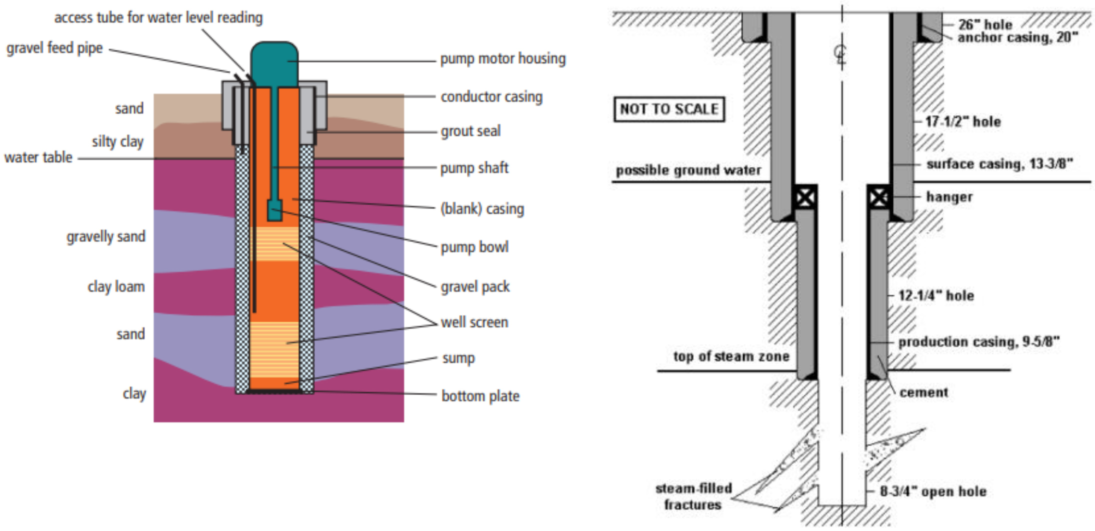

Figure 2. (a) Water well structure (Harter, 2003); (b) Geothermal well structure (Dipippo, 2012).

In addition, it is common for the well to present a larger diameter in its upper region for proper pump positioning, forming an area known as a pumping chamber, and a smaller diameter in the production area where the filters and gravel packs are positioned (Feitosa et al., 2008).

Wells intended for geothermal exploration have a structure and some dimensions slightly different from those common in wells intended for the extraction of groundwater, which can be explained by the different characteristics of the reservoirs as mentioned earlier. Such wells are drilled in several sections of different diameters, as shown in Figure 2b, which are cased and cemented separately and sequentially. The sections' depths predefined by previous studies that consider the properties of rocks, forming fluids, well control aspects and regulations (Finger and Blankenship, 2010). In terms of external diameter, which would be the largest diameter that can be found in the well, Ngugi (2008) states that the commercial diameters for the surface casing vary between 16 and 30 inches (between 406 mm and 762 mm). As the drilling rig needs to drill holes with a larger dimension than the casing for cementing purposes, it is estimated that the largest drilled diameter varies between approximately 18 and 40 inches (457,2 mm and 1016 mm). In terms of depth, there are many variations depending on the conditions encountered and the purpose of the exploration, but considering the wells intended for energy production, the depths revolve around thousands of meters deep, as is the case, for example, of the wells of the Habanero field in Australia (Habanero EGS site) which presents a huge number of wells with depths between 4 and 5 km reaching temperatures of about 244 °C (Ayling et al., 2016). Furthermore, in situations where the fluids stored in the reservoir are not the adequate amount for production, it is necessary, besides drilling the well for producing the heated liquid or steam, the drilling and construction of fluid injection wells, so that they are heated by the natural heat of the earth and make the production reach the desired levels (Reis, 2017).

4.3 Methods of geology analysis

Before the actual drilling takes place, it is necessary to define the materials and methods that should be used as well as the drilling mechanic parameters to take place in the operation. This definition is based on a previous study of the exact location of the reservoir, the properties of the rocks located underground, properties of the resource being extracted, among other information. Therefore, several different methods of study are applied providing some specific data through which the properties of interest are inferred (Feitosa et al., 2008).

In the case of geology analysis for drilling deep boreholes, which is known as geophysical profiling, the main objective is to collect data related to stratigraphy such as porosity, permeability and clayiness for example, static level, specific flow conditions and quality of the water trapped in the reservoir (Giampá and Gonçales, 2013). In general, this procedure can be performed by drilling small exploration wells called pioneer wells, during the drilling of the actual borehole used for production by the collection of samples or using tools that use principles of electrical, acoustic, radioactive, thermal, mechanical measurement.

In the hydrogeophysical exploration, the most commonly used methods are: the caliper method, which is an auxiliary method of evaluation consisting of two or more support arms that are trapped in the well wall, serving mainly to record the diameter of the well in comparison with the nominal diameter of the bit that drilled it and to perform a lithological identification and enable inferences about the mechanical resistance of rocks; the natural gamma rays surveys, which are executed by a radioactivity detector called scintillometer placed inside the well to record pulses emitted by the natural radiation of elements such as uranium, thorium and potassium that compose the rocks; the spontaneous potential method, which consists of an evaluation of the natural diffusion of electrical charges that occurs due to the penetration of certain fluids in the porous spaces and to the contact between drilling fluid and water reservoir, by the use of electrodes integrated to an electrical circuit; the electrical controlled-source induction method, which is based on the radial propagation of electromagnetic fields to perform measurements about conductivity not considering the conductivity of the drilling mud; and the conventional electrical method, which makes the use of electrodes, generators and voltmeters to make an alternating current circulate through the rocks and measure the potential difference between the electrodes positioned in different places to define the resistance of the layers (Reis, 2017; Feitosa et al., 2008).

In the case of studies focused on the identification of geothermal reservoirs, whose main objective is the location of reservoirs and generation of estimates for well drilling, there is a greater focus on temperature-sensitive properties and the presence of fluids underground (Kana et al, 2015). For geothermal reservoirs to exist, heat sources, permeability, usually guaranteed by fractures in hard rock formations, and fluid refill area are indispensable. Thus, the analyses focus on the identification of factors such as tectonic elements, availability of fluids in the region, presence of cap rocks that perform the protection of reservoirs and indicators of high heat flow (Manzella, 1999).

When it comes to the methods, there is a great similarity with methods used for the extraction of underground water, mainly because all of them were developed from oil and gas exploration methods (Manzella, 1999; Feitosa et al., 2008). In geothermal exploration, the geological analysis is divided into two large groups: direct methods, which analyze parameters influenced by geothermal factors directly, and indirect methods, that provide geological information that may indicate the existence of reservoirs (Kana et al., 2015). Among the direct methods, it can be mentioned: geophysical logging, also commonly used in the exploration of groundwater, consisting of the insertion of tools for direct measurement of soil properties within drilled wells; thermal gradient surveys, which perform direct measurements of soil temperature, determination of thermal conductivity and, most importantly, thermal gradient from samples for the determination of heat flow through the drilling of preliminary wells or through satellites and aerial equipment; the electrical profiles, which in essence are the same used in the exploitation of groundwater, aiming to measure the electrical resistivity of the rocks and also the electrical conductivity that can indicate direct action of high temperatures; and the spontaneous potential method, which is also the same as the method used for groundwater exploration (Manzella, 1999; Aretouyap et al., 2016). Among the indirect methods, it can be mentioned: the magnetic survey, that focuses on the identification and location of igneous rocks with high concentration of magnetite from direct contact with the soil or through aerial methods, being extremely useful in the identification of volcanic rocks; the gravitational profile, which consists of detecting the density variation of magmatic bodies allowing the identification of heat sources more easily; seismic surveys, which consists of an analysis of naturally or artificially induced vibrations and the behavior of elastic waves in the formation for the determination of the depth and thickness of the geological formation; and remote sensing methods , which uses ultraviolet radiation for the generation of images and electromagnetic bands to simplify the analysis enabling the detection of changes in underground patterns and the definition of topographic characteristics (Aretouyap et al., 2016; Kana et al., 2015; Manzella, 1999).

4.4 Drilling

4.4.1 Drilling equipment

Well drilling is the most effective method of exploiting the resources studied in this paper, and the way they are performed varies with formation characteristics and pre-established drilling parameters (Feitosa et al., 2008). Except for shallower depth perforations that can be performed with more rudimentary equipment or even manually, underground drilling is performed by a structure known as a drilling rig, which can have different specifications, accessories, and sizes. Analyzing the most common drilling structures for the exploration of groundwater and for geothermal exploration to produce electricity, there is a great contrast in terms of the dimensions and complexities of the structures. Figure 3 illustrates the most common structures used for drilling.

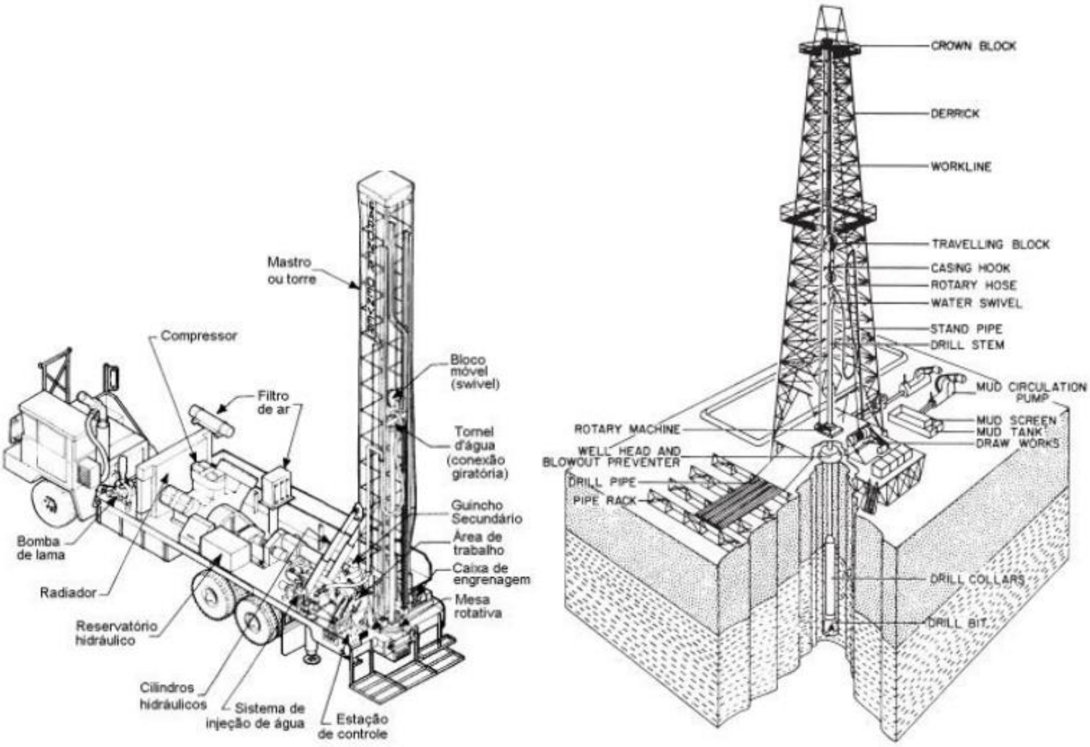

Figure 3. (a) Rotary drilling rig for water well perforation (Costa Filho et al., 1998); (b) Drilling rig for geothermal well perforation (Gupta and Roy, 2006).

Through Figure 3, it is possible to notice that the dimensions of the drilling rig structures are noticeably different, which can be explained by the different levels of drilling complexity, since the exploration of water wells usually does not reach thousands of meters in depth, while geothermal explorations reach these dimensions more frequently and in more challenging rock formations. Despite dimensional differences and the fact that water well drills are installed in trucks to facilitate mobilization, the basic components of rotational drilling systems are very similar. The basic structure of both is composed by a support tower called derrick, a winch or casing hook that supports and displaces the drill pipe, an explosion or electric motor to generate power for rotation, a drill pipe, where accessories are attached to improve the drilling process, a rotary table or top drive, that constitutes the power transmission systems, mud tanks, mud pumps or compressors for air circulation, and drill bits at the bottom of the drill string. In structural terms, the big difference lies in the systems of prevention against blowouts, that are basically high-speed water leakage out of the well, being extremely frequent in geothermal exploration, but inexistent in groundwater exploration (Dippipo, 2012; Giampá and Gonçales, 2013; Gupta and Roy, 2006).

4.4.2 Drilling methods

It is important to mention that there are different drilling methods that must be selected according to the characteristics of the underground formation defined by the previous study performed and based on the dimensions projected for the well. Although more complex drilling methods have been developed specially in the geothermal and oil and gas industries, such as electro-impulse drilling, jetting and laser drilling, and other methods have become inefficient with the technological advancement obtained in this century, such as cable percussion, the most traditional and commonly used methods for both geothermal and groundwater exploration are direct and reverse rotating methods with the use mud or air as drilling fluids, and rotopercussive or air hammer methods with compressed air (Soulsby, 2010; Teodoriu and Cheuffa, 2011).

The rotary drilling methods consist of a rotation of the drill pipe with the drill bit in its lower end, which promotes abrasive efforts promoting shear forces and rock wear, completed with the use of drilling fluid both to improve the drilling performance and to conduct rock fragments to the surface (Costa Filho et al., 1998). Drilling fluids can be either mud, as is generally known as mixtures of water with some specific additives, or air itself, and the direction of flow can be either from the inside of the column to the annular space (direct circulation), or from the annular space into the column (reverse circulation) (Culver, 1991). The air hammer method consists of a high frequency percussion with reduced displacement of the hammer, guaranteed by the injection of compressed air, associated with a rotation promoted by the drilling rig structure, therefore being a percussive method adapted to a rotary drill string that uses the compressed air itself as drilling fluid. In this method, the so-called "down-to-the-hole" or DTH hammers are used, as they are pneumatic hammers driven by compressed air and being composed by a pneumatic hammer body with tungsten carbide buttons for drilling and a channel for compressed air flow (Soulsby, 2010).

The rotating methods are most used in deep perforations (above 400 meters deep) and preferably in consolidated sedimentary formations, being usually used in groundwater explorations (Giampá and Gonçales, 2013). Air hammer methods are more characteristic of geothermal explorations because of their high efficiency in drilling crystalline rocks of considerable hardness, being also used in groundwater explorations, but with less frequency because of the high costs involved and high risks of clogging of air ducts when used in unconsolidated formations (Soulsby, 2010).

4.4.3 Drill bits

Another important matter that directly influences the costs and efficiency of drilling processes are the types and materials of drill bits. Drill bits are the elements in direct contact with the geological formation, thus being responsible for cutting the rock formation. They are composed by three main elements: body, which is constituted by connection drill legs and fluid channels; bearings, which can be of different types and can be sealed or not; and sharp elements, which would be the drilling teeth or buttons. Among the main types of drill bits, the most used ones in the drilling field are roller cone bits since it has several variations such as milled tooth and insert roller with different tooth geometry and length, being able to be applied in a great variety of underground formations, from unconsolidated and soft to well consolidated and hard ones. Another commonly used type of drill bits are drag bits, preferably used in milder and less abrasive formations because of its low structural resistance and effectiveness in drilling. These different types are shown in Figure 4 below.

Figure 4. (a) Milled tooth roller cone bit; (b) Insert roller cone bit; (c) Drag bit (Finger and Blankenship, 2010)

The most used materials in drill teeth or buttons for drilling groundwater wells or boreholes are steel and tungsten carbide, which is currently the most used for ensuring high drill resistance at high drilling rates in different types of formations (PBE, 2015). In geothermal exploration, tungsten carbide is also used, but less frequently. Because it requires drilling in hard, consolidated and abrasive formations, the material that has been employed and has been improved for increasing the efficiency of the drilling process and to expand it for more applications is polycrystalline diamond compact (PDC), which consists of an agglomeration of synthetic diamond powder and tungsten carbide substrate mixed under a high temperature and pressure environment in order to combine high impact resistance with a high resistance to thermal shock, which is the ideal combination for geothermal exploration (Shor et al., 2022; Hnhongxiang, 2009).

4.4.4 Drilling Fluids

Underground drilling involves the use of drilling fluids in a way that they became indispensable in the vast majority of operations due to their specific characteristics. The main functions of drilling fluids are removing the drilling debris from inside the well and sending it to the surface, cooling, lubricating and cleaning the drill bits and drill string, controlling the pressure inside the formation and providing physical support to the well walls to avoid collapse. By fulfilling all these roles, it becomes an essential factor for the increase of drilling rates (Finger and Blankenship, 2010; Ngugi, 2008). In general, drilling fluids are composed by a main constituent, which can be gas-based fluids, water-based fluids, and oil-based fluids, and by various additives that add some characteristics to the fluid or change some specific properties such as viscosity and density, to adapt its composition to the exploration developed (Silva et al., 2008). In general, the fluids most used in both groundwater exploration and geothermal exploration are water-based fluids because they are not very aggressive to the environment and have adequate composition and consistency for drilling (Culver, 1991).

In terms of the most adequate additives used for exploration, both underground water and geothermal exploration typically use a clay compound known as bentonite and some natural or synthesized polymers, to increase the viscosity of the fluid and improve the capacity of carrying particles, and also the addition of compounds such as barite for an increase in density (Finger and Blankenship, 2010; Silva et al., 2008). However, for exploration at temperatures above 150°C, which is usually the case for geothermal exploration for the extraction of electric energy, a thermal degradation of polymeric additives usually occurs, and it compromises the thermal stability of these compounds. This thermal condition can also change the viscosity of fluids with bentonite additives due to bentonite flocculation, so it also affects its reliability (Amani and Al-Jubouri, 2012; Avci and Mert, 2019; Zilch et al., 1991; Mohamed et al., 2021). Studies made by Mohamed et al. (2021) have shown that the rise in temperature generates a viscosity drop in most drilling fluids with different additives, especially bentonite and cellulosic additives, revealing that these components have a very low thermal resistivity for geothermal exploration applications at high temperatures. On the other hand, other additives were tested, and a component that has stood out in terms of thermal resistivity being extremely suitable for application in geothermal wells is the so-called THERMA-VIS, which is a synthetic hectorite with high cation exchange capacity and high absorption capacity (Mohamed et al., 2021; Zhang et al., 2019).

4.5 Casing, cementing and completion

4.5.1 Casing

The casing is the pipe that constitutes the walls of the well, having two specific functions: to support the walls formed with the drilling to prevent against caving of the formation and to constitute the hydraulic conduction that allows the contact of the drilled well with the surface, besides assisting in preventing the drainage of surface water to inside of the well. The casing process is normally performed after the execution of one of the drilling steps, as shown in Figure 1, and in the smaller diameter parts, centralizers are used to ensure the equidistance from the casing to the wall (Costa Filho et al., 1998).

In exploration of groundwater, the casing can be executed both in the entire length of the wells, which is technique more common in poorly constituted soils or sedimentary soils, or only in the most superficial area of the well, which is common to be carried out in crystalline and well consolidated formations (Costa Filho et al., 1998). When installed, the casing creates two regions in the borehole wells for water extraction: the pumping chamber, which has a diameter wide enough to support the extraction pump and is completely closed to the inlet of water or other liquids, and the intake zone which is composed of scratched pipes of reduced diameter. As for the materials used for the manufacture of these tubes, there must be an analysis of the chemical properties of the extracted resources so it can be defined, in order to avoid the occurrence of chemical attacks and bacterial attacks. The most used materials are PVC, stainless steel, carbon steel and galvanized steel (Feitosa et al., 2008).

For geothermal exploration, the casing is of great importance on the protection against the loss of circulation of drilling fluids, which is a very common phenomenon in geothermal exploration due to the fractured nature of the geological formations. It is also an important component for the installation of blowout preventers (BOPs) and wellheads, that are essential in protecting the well against the rising of the resource to the surface in high speeds, and important to prevent the cooling of the extracted fluid by the contact with other fluids (Ngugi, 2008). As it can be seen in the comparison established by Figure 2, the structuring of the casing in geothermal wells is more complex. It starts with an anchor casing, which helps on supporting the whole structure having the smallest length between all casings and is the largest diameter, followed by a surface casing, which has a large extension and protects the well from more superficial aquifers. In large-scale wells, it is common to install intermediate casings, located just after surface casing, although this is a characteristic that varies according to the well planning. Then, near the reservoir itself, the production casing, which has the smallest diameter of the well and supports the liners for extraction by a line hanger installed in its structure, is placed (Dipippo, 2012). In terms of materials, when it comes to exploitation to produce high energy content, the casings that are most apt to be employed are the ones with the ability to withstand high temperatures and have high tensile and compression strength. In this sense, the ones that provide the better cost benefit are low carbon steels and stainless steels, while for the exploitation of low or moderate temperature resources, the use of thermoplastics and glass fibers is more common (Culver, 1991).

4.5.2 Cementing

The cementing process consists of the displacement of the cement paste to ensure its allocation in the annular space between the perforated well and the casing installed. The cementing is responsible to connect the casing with the formation, providing stability to the structure, protection of the extracted fluid and isolation of geologically unstable regions (Ngugi, 2008). In water well drilling, cementing occurs by pumping the cement by the inside of the well lining, in which will be allocated a component called guiding shoe at the bottom that ensures protection against reflux. After passing the guiding shoe, the cement moves to the annular space, settling in until it dries. In this kind of wells, the cement paste is basically composed by cement and water, with variable percentages of concentration, and may present retarding additives such as bentonite or calcium chloride (Giampá and Gonçales, 2013).

When drilling geothermal wells, it is recommended that cementation occurs throughout the entire length of the well, except in the production zone below the production casing, and the procedure can be performed in different ways. In the most common method, cement is mixed and pumped into the well until it finds the guiding shoe. Then a plug is placed on the positioned cement mass and drilling fluid is pumped over it to force the cement down through the guiding shoe until it reaches the annular space. However, as geothermal exploration usually involves exploration in highly fractured formations, it is possible that there is the occurrence of cement loss for the formation, causing an incomplete cementation. To repair this problem, it is common to use a method of direct deposition of cement in the annular space through a specific pipe called termie pipe, which is partially submerged in the cement mass, and it is removed at the same rate as the cement elevation (Culver, 1991; Dipippo, 2012). The most used types of cement for the cementation of geothermal wells are the G-classification cements in the API scale with the addition of silica in the form of grains or fluoride, presenting an acceptable and stable behavior at high temperatures and good resistance properties against acid attacks (Culver, 1991; Gupta and Roy, 2006).

4.5.3 Completion

The process of completion consists of the processes that allow the occurrence of the extraction of resources. In the water extraction wells, they consist of the installation of the pre-filter and the filter, while in geothermal exploration consists of the installation of the pre filter after the run-in liner process as it is called in Figure 1. In drilling wells for groundwater extraction, filters, which are a kind of porous casing to allow the resource to drain into the well, can be a single column or a segmented column, and it is always associated with a pre-filter so that the extracted resource has the best quality possible. The materials used for the manufacture of the filter are usually PVC or carbon steels of different types (Giampá and Gonçales, 2013). The pre-filter, also known as gravel pack, is a filler, which is usually gravel, placed in the annular space between the well wall and the filter, usually used in granular formations that present lithology characterized by fine and uniform sands. It is essential to retain finer particles to protect equipment and the extracted fluid from them (Feitosa et al., 2008). In geothermal exploration, the use of the pre-filter is, in large part, dispensed, due to the nature of the consolidated rock formation. In this case, geothermal wells in most applications have only the so-called slotted liners, which executes the same function as the filters but have a smaller diameter than the whole casing, and it is installed passing through the casing being fixed in components called liner hangers located in the last casing layer. In some projects, the use of liners is dispensable leaving the bottom of the hole exposed without any kind of casing, originating the well-known open holes (Culver, 1991; Finger and Blankenship, 2010).

5. DISCUSSION AND CONCLUSIONS

By the results obtained, it was observed that the processes of extraction of geothermal resources and groundwater have several characteristics in common, largely because they were directly influenced by oil and gas exploration techniques. Conceptually, the processes present the same stages, which include study of geology and location of reservoirs, mobilization of structures at the extraction site, drilling, casing, cementing and completion. However, due to the peculiarities of the reservoirs from which they are extracted, mainly in the thermal aspects and in terms of depth, since the geothermal reservoirs are located at greater depths and in areas of higher thermal flow, there are slight differences on well structuring, materials used in the casing, in drill bits, additives used in cement pastes and in drilling fluids, besides the presence of prevention equipment against phenomena characteristic of geothermal wells (so-called blowouts), which are not installed in water drilling wells.

Naturally, since they involve more complex drilling structures because they involve depths that are usually more extensive especially in drilling for energy production, and because they involve special structures and substances due to the high thermal content of the reservoirs, geothermal exploration procedures involve higher exploration costs, and are generally higher than the actual costs of drilling oil wells (Augustine, Tester and Anderson, 2006). This is a factor that greatly limits geothermal exploration, because in addition to involving technologies that are still being developed and high operating costs, it is an alternative source of electricity, which can be replaced by other natural sources that have been developed more intensively, such as solar energy for example.

Finally, it is worth mentioning that this comparative study consists of a stage of the research that is being developed, which addresses comparative analyses of drilling techniques and costs for the exploration of water, geothermal energy, oil and gas, aiming at an expansion in knowledge about exploratory processes and a possible contribution to the development of more cost-effective methods.

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