Downhole circulating cooling device

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Abstract. This paper presents a kind of downhole circulating cooling device in high temperature environment. The device consists of the following components: compressor, condenser, expansion valve, and heat exchanger. The heat exchanger consists of an inner chamber located around the instrument to be cooled and an outer chamber located around the inner chamber. As the cooling fluid passes through the inner chamber, it absorbs heat from the instrument, and then the cooling fluid enters the outer chamber to absorb heat from the wellbore. After absorbing heat, the cooling liquid can be pressurized by the compressor, condensed by the condenser, and then selectively released back to the inner chamber after cooling by the expansion valve, so as to realize the continuous circulation cooling device, so as to realize the thermal insulation and cooling of the instrument. This paper provides an efficient, recyclable and time-saving method for temperature reduction in underground high-temperature environment.

1. Introduction
With the environment of oil exploration, tools under oil exploration wells may be very bad, the temperature of many wells can reach or even exceed 200 °C, and the pressure can be as high as 140MPa.[1] In recent years, people pay more and more attention to the emerging clean energy. Geothermal energy has the advantages of no pollution, high stability and high utilization rate, but sometimes it also needs higher geothermal gradient. Generally speaking, the bottom hole temperature of geothermal wells over 3000m will reach 200°C or even higher.[2-3] In high temperature and high pressure wells, the formation temperature itself is high, and with a lot of heat generated in the drilling process, the temperature and pressure in the well have an important impact on the drilling operation. If it is not handled in time for cooling and other operations, it may lead to poor strength and stiffness of instruments and tools, decline of internal parts life, performance damage and other adverse consequences.[4]

Sensing, monitoring, data transmission, control and other downhole functional modules and tools contain a large number of electronic components. The allowable temperature level of typical electronic components that can obtain or process data is generally not more than 100 °C. However, the temperature of traditional devices is not suitable for some high temperature wells, which limits their application,
especially for some high temperature sensitive components. Although there are some high temperature resistant electronic products, their application range and maximum operating temperature are still strongly limited. Electronic products above 200 °C are extremely rare because they almost break through the physical limit. Very few high temperature resistant electronic products are expensive, and these electronic components can be used for a limited period of time under high temperature. When the underground environment temperature exceeds 200 °C, the heat of electronic components cannot dissipate to the environment, and will accumulate in the electronic components. This can cause deterioration or failure of the operating characteristics of the components, thus reducing their service life, or the electronic devices may stop working at certain temperatures. As a result, it will cost more time to replace the electronic components. [5-6]

Producers of oil exploration tools must design tools that can operate under these harsh conditions for a long time. For downhole instruments, high temperature and pressure resistance is a necessary condition. In the design of electronic equipment, the most difficult thing is to ensure its stable operation in high temperature environment. As electronic equipment is now used for a long time in drilling environment and other new instrumented downhole operations, the performance requirements of cooling device must meet the requirements. Therefore, it is of great significance to realize the following functions of downhole circulating cooling device: continuous operation during downhole operation; reducing or eliminating time limit to realize long-term cooling; reducing or adjusting the temperature of electronic equipment; insulation with electronic devices, thus increasing the protection of external components; and compatible with high-temperature wellbore operation.

In this paper, a circulating cooling device is proposed. The device can realize circulating cooling fluid in the downhole, so that specific sensitive areas of downhole tools can be cooled to prevent adverse high temperature impact on the tools placed in the formation. "Underground" especially refers to the underground environment, especially in the wellbore, such as in the field of oilfield exploration and development, management of oil and water layers, storage of carbon dioxide and other substances, and geothermal applications. "Downhole tools" are widely used to refer to any tool used in the underground environment, including but not limited to logging tools, imaging tools, acoustic tools, permanent monitoring tools and combination tools. The device has the advantages of high efficiency, simple structure and stable circulation. It can realize continuous circulating cooling, which can be used in underground high temperature working environment, further improve the downhole cooling efficiency, save time and reduce cost. The cooling rate can be controlled to achieve long-term cooling.

2. Brief introduction to the principle of downhole circulating cooling device

Underground circulating cooling device is an active cooling device. The active cooling device can keep the downhole tools below 125 °C, prolong the temperature retention time, realize the repeated recycling and reduce the downhole operation steps. Lower cost electronic tool equipment can then be used without the need for expensive high-temperature components. At present, there are many active cooling devices for various applications, such as cooling food, motor vehicles and buildings. These active cooling devices are usually air conditioners and refrigerators, which can operate effectively for a long time without maintenance. Cooling devices move heat. It absorbs heat from one location and moves it to another. So, the place where the heat is removed is obviously colder. For example, a refrigerator takes heat from the inside and moves it outside. Heat flows into the air and inside, and the refrigerator loses heat and gets colder.

The steam compression active cooling device works by evaporation. When a liquid turns into a vapor, it loses heat and becomes colder. This is a physical phenomenon because steam molecules need energy to move and leave the liquid. This energy comes from the liquid, leaving molecules with less energy, so the liquid is cooler.

In order for the active cooling device to work continuously, the same coolant (such as Freon) must be reused indefinitely. These cooling systems have three basic modes: steam compression device, gas expansion device and absorption device. Steam compression systems are generally more efficient and
more widely used than other devices. Steam compression device is generally composed of four main components: evaporator (heat exchanger), compressor, condenser and expansion device.

To further explain the cooling process, four main components need to be described in more detail. The evaporator is the part of the cooling system that actually produces cooling. The liquid coolant and steam from the expansion valve are introduced into the evaporator. When a liquid evaporates, it absorbs heat at low temperatures and cools its surroundings or the medium in contact with it. The evaporator can expand directly or indirectly. For example, a household refrigerator is a direct expansion unit whose evaporator directly cools the air in the food room and also directly contacts the water pan used for ice making.

The expansion valve supplying the evaporator must be able to control the flow so that sufficient coolant can flow into the evaporator to cool the load.

Compressor is the key component of the system, which can be powered by electric motor or steam. Most compressors are of the reciprocating (piston) type, ranging from the size of a household refrigerator or small air conditioning unit to a large multi cylinder unit in a large industrial system.

The condenser must dissipate heat from the hot steam it receives from the compressor and condense the steam into a liquid for reuse by the evaporator. The condenser dissipates heat to the ambient atmosphere through the outer fin surface or through shell and tube arrangement, in which the steam transfers heat to the circulating fluid, which is in contact with the coolant steam pipe. The temperature of the steam is maintained above the temperature of the circulating water or air by compression to ensure that heat is transferred to the coolant; therefore, when the steam expands, its temperature drops far below the temperature of the coolant.

The air conditioning concept works by converting heat from a heated substance to a cold substance. In this principle, the temperature from a hot substance, such as a fluid, is transferred to a cold fluid. As the temperature of hot fluid decreases, the temperature of cold fluid increases. Heat exchangers have many different designs and are widely used in various industries. When heat exchangers are used for special purposes, they are given different names. For example, boilers, evaporators, superheaters, condensers and coolers can all be considered heat exchangers.

3. STRUCTURE OF DOWNHOLE CIRCULATING COOLING DEVICE
As shown in Figure 1, it is the overall structure of the downhole circulating cooling device. By circulating fluid in the borehole, the device can significantly reduce the instrument temperature. The downhole circulating cooling device 100 includes two parts: the first barrel 110 and the second barrel 120. The first cylinder 110 of the first part comprises a compressor 130, a condenser 140 and an expansion valve 150. The compressor 130 is used to pressurize the cooling liquid; the condenser 140 is connected with the compressor 130 to convert the cooling fluid from steam to liquid; the expansion valve 150 is...
is connected with the condenser 140 to selectively release the cooling liquid.

Figure 2: Structure of Heat Exchanger 160

The second barrel 120 includes a heat exchanger 160. As shown in Figure 2, the heat exchanger 160 includes an inner tube 200 and an outer tube 220 arranged around the instrument 170 to be cooled, and the inner chamber is supported by a centralizer 195 around the instrument to be cooled. The inner chamber 210 allows cooling fluid to flow through it to absorb and remove heat from the instrument. The outer tube 220 is located around the inner chamber 210 and the instrument 170, and the outer chamber 230 is supported around the inner chamber with a centralizer to determine the position of the outer chamber 230. The outer tube 220 provides active isolation and / or removal of heat for instruments requiring cooling. The cooling fluid flows through the outer chamber 230 to absorb heat from the surrounding wellbore. The inner chamber is communicated with the outer chamber through the port 240 in the tube 200, and the fluid flows from the inner chamber to the outer chamber 180 and 190 are catheters. The inner chamber 210 around the instrument is communicated with the expansion valve, and the outer chamber 230, the inner chamber 210 and the compressor 130 are communicated. The fluid is cooled when it flows through the compressor, condenser and expansion valve, and the cooling fluid absorbs heat when it passes through the inner and outer chambers. Therefore, the heat of the instrument decreases and can be kept cool. The heat exchanger and the instrument to be cooled are located in a low conductivity pressure cylinder made of ceramic composite material and its combination. The inner tube, outer tube, inner chamber, outer chamber and centralizer for supporting inner tube and outer tube are also made of this low conductivity material.

4. WORKING PRINCIPLE OF DRILL COLLAR

Figure 3: Flow chart of downhole circulating cooling device
As shown in Figure 3, it is a flow chart of the method for deploying downhole circulating cooling device to cool down the high temperature environment in the well. The first step is to deploy the downhole tools with cooling fluid conduit and connect them with the cooling fluid source. And the second step is that position a tool within a high temperature region of a borehole. And then circulate cooling fluid around the tool within the borehole.

As shown in Figure 4, when working in the drill collar, the downhole tools are first placed in the wellbore, and the circulating cooling device 100 can be located in the drill collar 300 and supported by the centralizer 310. The cavity 320 is located between the drill collar 300 and the circulating cooling device 100. Collar 300 can be connected to the drill string (not shown). As the drilling mud circulates through the downhole drilling tool, the mud passes through cavity 320.

![Figure 4 Working Diagram of Drill Collar](image)

As shown in Figure 1, the cooled fluid flows from the first barrel 110 through the conduit 190 into the heat exchanger 160 of the second barrel 120. The fluid flows through the catheter 190 into the inner chamber 210 and through the instrument 170, as shown by the arrow. The cooled fluid absorbs the heat generated by instrument 170. Fluid flows out of port 240 and then into outer chamber 230.

Next, the fluid flows through the outer tube 220. As the fluid flows, heat from the outside of the wellbore is absorbed and carried away by the fluid, as shown by the arrow. As the fluid passes through the inner and outer chambers, it absorbs heat and the fluid is heated. In general, the fluid boils and evaporates as it passes through the inner and outer chambers. The fluid then flows from the outer tube 220 to the compressor 130 via the conduit 180. The fluid returns from the second barrel 120 through the conduit 180 to the first barrel 110.

Once the fluid enters the compressor, the compressor compresses the fluid to the required pressure to realize the pre heating of the fluid. The fluid flows from the compressor to the condenser 140, which condenses the fluid from the steam to the liquid. The heat emitted by the condenser 140 in the fluid is released through the high conductivity pressure cylinder 110, as shown by the arrow. When the fluid enters the expansion valve 150 from the condenser 140, the fluid is further cooled after expansion, and the expansion valve 150 controls the flow of the fluid into the second barrel 120, thereby regulating the flow of the fluid to allow cooling at the desired rate. When the fluid is released through the expansion valve, the fluid flows through the conduit 190 into the second barrel 120. Thus, it can realize the underground cooling with infinite circulation.

5. Conclusion
This paper presents a downhole circulating cooling device, which consists of compressor, condenser, expansion valve and heat exchanger. The heat exchanger consists of an inner chamber located around the instrument to be cooled and an outer chamber located around the inner chamber. As the cooling fluid passes through the inner chamber, it absorbs heat from the instrument, and then the cooling fluid enters the outer chamber to absorb heat from the wellbore. After absorbing heat, the cooling liquid can be
pressurized by the compressor and condensed by the condenser. After cooling by the expansion valve, the cooling liquid can be selectively released back to the inner chamber to become a controllable continuous circulating cooling device, thus realizing heat insulation and cooling of the instrument. The device has the advantages of high efficiency, simple structure and stable cycle. It can be used in underground high temperature working environment to further improve downhole cooling efficiency, save time and reduce cost. It can control cooling rate, realize continuous operation and long-time cooling.

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