THERMOELECTRIC GENERATOR FOR USE WITH WELLBORE DRILLING EQUIPMENT

BACKGROUND

This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the presently described embodiments. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present embodiments. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

The present invention relates generally to electrical power generation and, in an embodiment described herein, more particularly provides a downhole power generator that converts heat energy into a voltage potential usable for, *inter alia*, powering electronics and charging devices such as capacitors. The present disclosure is directed generally to the generation of power downhole to support higher power demands experienced during modern wellbore drilling.

Modern hydrocarbon drilling and production operations can often require that electrical power be supplied to equipment in the downhole environment. For example, electrical power is required downhole for a number of applications, including well logging and telemetry. Well logging of the borehole often includes the use of active sensors that require power to obtain information about the downhole environment. Such information will typically include the various characteristics and parameters of the earth formations traversed by the borehole, data relating to the size and configuration of the borehole itself, pressures and temperatures of ambient downhole fluids, and other vital downhole parameters. Telemetry commonly utilizes electrical power to relay data acquired from various logging sensors in the downhole environment to the surface. As technology

advances with newer and better tools, the power demanded by the tools increases in order to keep the tools running in the wellbore for long periods of time.

One conventional approach to downhole electrical power generation includes circulating drilling mud to operate a generator or turbine located downhole. At least one problem with this approach is that mud flow rates can vary widely and the mud flow may need to be increased, for example when the drill bit enters a new type of subterranean strata. As the flow rate becomes excessively high, significant issues can be encountered. First, at high flow rates, the increased rotational rate produces high torques within the generator that can lead to its mechanical failure. Second, at high flow rates, more power can be generated than is necessary for the intended application. This excess power generation can lead to heat production, which can be detrimental to electronic components in the drill string. Additionally, due to the potential extreme flow rates that the circulating mud may attain, any such generator or turbine is typically oversized relative to the nominal requirement for power. The increased size of the generator or turbine leads to lower than optimal efficiency and increased cost. A conventional approach to generating a constant amount of power when the mud flow must be increased is to pull the downhole generator and reconfigure the turbine to operate at the higher mud flow rate. Pulling, modifying, and re-inserting the downhole power generator requires a significant amount of time, thereby incurring an operational cost and delaying the drilling operation.

Another conventional approach to downhole electrical power generation is simply to place more batteries in the downhole tool or tolls being operated in the wellbore. However, the addition of batteries takes up valuable space on the tool itself as well as space on the drill string. Further,

batteries are flammable, explosive and dangerous and harmful to the environment.

There continues to be a need for improved electrical power sources that can be used with wellbore drilling systems.

BRIEF DESCRIPTION OF THE DRAWINGS

Illustrative embodiments of the present disclosure are described in detail below with reference to the attached drawing figures, which are incorporated by reference herein and wherein:

FIG. 1 is a schematic view of an example drilling system suitable for use with downhole power generators;

FIG. 2 is a cross-sectional view of an embodiment of a power generator sub;

FIG. 3 is a cross-sectional view of an embodiment of a power generator sub including two materials with differing Seebeck coefficients;

FIG. 4 is a cross-sectional view of an embodiment of a power generator sub including a thermoelectric generator;

FIG. 5 is a schematic view of an embodiment of a thermoelectric power assembly including power generators, a power conditioning unit, and loads; and

FIG. 6 is as top cross-sectional view of an embodiment of a power generator sub.

The illustrated figures are only exemplary and are not intended to assert or imply any limitation with regard to the environment, architecture, design, or process in which different embodiments may be implemented.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The following discussion is directed to various embodiments of the present disclosure. The drawing figures are not necessarily to scale. Certain features of the embodiments may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in the interest of clarity and conciseness. Although one or more of these embodiments may be preferred, the embodiments disclosed should not be interpreted, or otherwise used, as limiting the scope of the disclosure, including the claims. It is to be fully recognized that the different teachings of the embodiments discussed below may be employed separately or in any suitable combination to produce desired results. In addition, one skilled in the art will understand that the following description has broad application, and the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to intimate that the scope of the disclosure, including the claims, is limited to that embodiment.

Certain terms are used throughout the following description and claims to refer to particular features or components. As one skilled in the art will appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name but are the same structure or function. The drawing figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in interest of clarity and conciseness.

In the following discussion and in the claims, the terms “including” and “comprising” are used in an open-ended fashion, and thus should be interpreted to mean “including, but not limited to… .” Also, the term “couple” or “couples” is intended to mean either an indirect or direct connection. In addition, the terms “axial” and “axially” generally mean

along or parallel to a central axis (*e.g.*, central axis of a body or a port), while the terms "radial" and "radially" generally mean perpendicular to the central axis. For instance, an axial distance refers to a distance measured along or parallel to the central axis, and a radial distance means a distance measured perpendicular to the central axis. The use of "top," "bottom," "above," "below," and variations of these terms is made for convenience, but does not require any particular orientation of the components.

Reference throughout this specification to "one embodiment," "an embodiment," or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment may be included in at least one embodiment of the present disclosure. Thus, appearances of the phrases "in one embodiment," "in an embodiment," and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment.

Turning now to the present figures, a typical onshore oil or gas drilling system 100 with which embodiments of the invention may be used is shown schematically in FIG. 1. The wellbore drilling system 100 is described in terms of an onshore drilling system. However, it should be understood that certain aspects of the invention have application in any wellbore conduit system comprising an annulus through which fluid is moved, such as a completion or production system, whether onshore or offshore. Therefore, the invention is not limited in scope for use only with onshore drilling systems.

The drilling system 100 includes a drilling rig 102, or other similar device for lifting and supporting a conduit, which suspends a drill string 104 within a wellbore 106 being drilled through a subsurface formations. An annular space 118 is formed between the drill string 104 and the wellbore 106. The illustrated drill string 104 comprises segments or joints 108 of drill pipe. The drill string 104 may include a drill bit 110 at its lower

end. The drill bit 110 is moved axially into the wellbore 106 by rotating equipment on the drilling rig 102, such as a top drive, or by rotating equipment located in the drill string, such as a drilling or mud motor. Rotation of the drill bit 110 causes the bit 110 to extend the wellbore 106.

The lower end of the drill string 104 may include, at a selected position above and proximate to the drill bit 110, a wear band 112 for decreasing the wear around the outer diameter of the drill string 104. The drill string 104 may further include, at a selected position above and proximate to the wear band 112, one or more power generators 114 arranged on a power generator sub according to various aspects of the invention and which will be further explained below. In the embodiment illustrated in FIG. 1, two power generators 114 are shown in parallel. Proximate the drill bit 110 and wear band 112 may also be one or more tools 116 for providing measurements and imaging of the borehole 106. A portion, or all, of the electrical power required to operate the tool 116 may be obtained from the power generator 114.

During drilling operations, drilling fluid 118 such as mud is pumped from a tank 120, or pit, into the interior of the drill string 104. The mud 118 travels the length of the drill string 104 and exits the drill string 104 through openings in the drill bit 110. The mud cools and lubricates the drill bit 110 and lifts drill cuttings generated by the drill bit 110 to the surface.

A cross-section of an example of a power generator sub is illustrated in in FIG. 2. In the illustrated embodiment, power generators 114 are disposed on a power generator sub on the drill string 104 in cavities 204. The power generators are seated in cavities 204 and are recessed from the outer surface of the drill string 104. In alternative embodiments, the power generators 114 may be flush with the surface of the drill string, or may protrude from the surface of the drill string 104 radially into the annular space between the drill string 104 and wellbore 106.

The power generators 114 may be directly exposed to the drilling fluid 118 which is circulating down the length of the drill string 104, exiting the drill string 104 through openings in the drill bit 110, and returning to the surface up the annular space 118 defined between the drill string 104 and the wellbore 106. In alternative embodiments, the power generators 114 may be exposed indirectly to the drilling fluid 118, *i.e.*, there may be a material between the power generators 114 and drilling fluid 118. The power generators 114 are connected to one or more power condition units 202. The power conditioning units serve to improve the quality of the electrical power that is generated by the power generators 114 and delivered to a downhole tool or stored.

The power generators 114 are thermoelectric generators and comprise one or more thermoelectric materials to convert a heat gradient along the material into electrical power. Thermoelectric material generates a voltage potential in response to an applied temperature differential and, when in used in series with an electrical load, current and hence power are generated. When no current is drawn, a voltage potential is created that is proportional to the temperature differential, the coefficient of proportionality being the Seebeck coefficient. The Seebeck coefficient of a material is a measure of the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material, as induced by the Seebeck effect. The Seebeck effect is a phenomenon in which the temperature-induced voltage potential called electromotive force (EMF) is generated when there is a temperature gradient along the length of material. When heat is applied at one end of the material, heated electrons flow from the hot end of the material to the cold end. If the material is connected through an electrical circuit, current flows through that circuit. The relationship between the EMF and the temperature difference can be represented as:

$$EMF = S \times \Delta T, \qquad [1]$$

where EMF is the voltage potential of the cold end with respect to the hot end of the material, S is the Seebeck coefficient of the material, and ΔT is the temperature difference of the hot end with respect to the cold end. Because the voltage potential is proportional to the temperature differential, maximizing the temperature difference across the material is an important consideration in thermoelectric generator design.

A cross-section of an example of a power generator 314 is illustrated in FIG. 3. This example includes at least a U-shaped cavity 302 on the drill string 104. The cavity 204 is disposed in location proximate to wear band 112 to minimize erosion of the power generator sub from drilling fluid 118 flow. A thermal insulator 304 is disposed in the cavity 302. The thermal insulator 304 is preferably a non-metallic material. Non-limiting examples of such materials include polyamideimide, polyphenylene, or polyetherketone, and ceramics or ceramic composites like calcium silicate, fiber glass composite, or metal oxide. The thermal insulator 304 insulates the power generator 314, so that instead of heat being conducted around the power generator 314, it is preferentially conducted through the power generator 314.

Two differing materials 306 and 308 are disposed on the thermal insulator 304. Materials 306 and 308 should comprise different Seebeck coefficients, and preferably have a large Seebeck coefficient delta between each other. Non-limiting examples of such material combinations include metals, metal alloys, and highly-doped semiconductors. Non-limiting examples may include Chromel-Constantan, Chromel-Alumel and Nicrosil-Nisil.

The two differing materials A and B are joined at one end called the junction. The other ends of the materials are attached to the terminals of the power conditioning unit 202 by means of connecting wires. Extending

Equation (1) to the power generator with two dissimilar materials in FIG. 3 gives:

$$EMF = \Delta S \times \Delta T, \qquad [2]$$

where $EMF$is the potential difference generated between the two ends of the dissimilar materials 306 and 308, ΔS is the absolute Seebeck coefficient of one material relative to the other, $S_A - S_B$, and ΔT is the temperature difference of the hot side with respect to the cold side. If the two materials have the same absolute Seebeck coefficients, *i.e.*, $S_A = S_B$, then the power generator generates no EMF, regardless of the temperature difference.

During operation in the wellbore 106, heat is generated on the surface of the drill string 104. Accordingly, the junction of the two dissimilar materials 306 and 308 is relatively hotter than the other ends of each material 306 and 308. Due to the Seebeck effect, free electrons in both materials 306 and 308 diffuse from the hot side to the cold side. The free electrons in both dissimilar materials 306 and 308 diffuse at different speeds due to different Seebeck coefficients of materials 306 and 308, thus creating a potential difference between the two ends of the dissimilar materials 306 and 308. The potential difference created between the ends of the dissimilar materials 306 and 308 can be utilized to provide electrical power to a downhole tool or stored. In the illustrated embodiment, the electrical power generated in the power generator 314 is conditioned by power conditioning unit 202.

A cross-section of another example of a power generator 414 is illustrated in FIG. 4. This example includes at least a cavity 402 on the drill string 104. The cavity 204 is disposed in location proximate to wear band 112 to minimize erosion of the power generator sub from drilling fluid 118 flow. A thermal insulator 404 is disposed in the cavity 402. The thermal insulator 404 is preferably a non-metallic material. Non-limiting examples

of such materials include polyamideimide, polyphenylene, or polyetherketone, and ceramics or ceramic composites like calcium silicate, fiber glass composite, or metal oxide. The thermal insulator 404 insulates the power generator 414, so that instead of heat being conducted around the power generator 414, it is preferentially conducted through the power generator 414.

A thermoelectric generator 406 is disposed on the thermal insulator 404. A thermal conductor 408 is disposed on the thermoelectric generator 406. The power generator 414 may be sealed against the interior of the drill string 104 by a sealing element 410, such as an O-ring together with backup ring. The selected grades used must be suitable for the intended operating conditions. The thermoelectric generator 406 may be composed of highly doped semiconductor materials. Non-limiting examples of such materials may include any elements, alone or in combination, selected from Groups II, III, IV, V, and VI of the Periodic Table of Elements. Particular examples of elements include silicon, germanium, arsenic, zinc, tellurium, and lead. Particular examples of compounds may include bismuth telluride and lead telluride. The selection of materials will depend, at least in part, on the operating temperatures and pressures downhole.

During operation in the wellbore 106, heat is generated on the surface of the drill string 104. The heat is trapped on the surface of the thermal conductor 408 and flows to the thermoelectric generator 406 through thermal conduction. Accordingly, the thermal conductor 408 acts as a heat source on one side of the thermoelectric generator 406, *i.e.*, the hot side. The thermal insulator 404, which is installed on the other side of the thermoelectric generator, *i.e.*, the cold side, keeps minimal heat from conducting on the cold side of the thermoelectric generator 406. As a result, there is a thermal gradient formed between the hot and cold sides of the thermoelectric generator 406. The thermal gradient results in diffusion

of electrons in the thermoelectric generator 406. This flow of electrons generates a voltage potential across the thermoelectric generator 406 due to the Seebeck effect. The potential difference created between the sides of the thermoelectric generator 406 can be utilized to provide electrical power to a downhole tool or stored. In the illustrated embodiment, the electrical power generated in the power generator 414 is conditioned by power conditioning unit 202.

FIG. 5 is a schematic representation of a thermoelectric assembly, including power generators 514, a power conditioning unit 502, and multiple loads requiring power 506. As a single power generator 514 may not be suitable for supplying enough power to a load in every instance, the power generators 514 shown in FIG. 5 are fed in parallel (1, 2, … to N) to a power conditioning unit. The power conditioning unit may comprise a rectifier, booster circuit, smoothing and filtering circuit. The power conditioner 502 improves the quality of the power and then provides the power to the respective loads 506. For instance, the power conditioner 502 may provide power to components of downhole tools, such as electronics and sensors 504. The power from the power conditioner 502 may also be used to charge capacitors 506, supercapacitors 508, or rechargeable batteries 510.

FIG. 6 is a cross-sectional top-view of a power generator sub. In the illustrated embodiment, four power generators 614 are disposed around the circumference of the drill string 106. The power generators 614 are shown disposed at 90° intervals around the drill string 106. However, the power generators 614 could be disposed in any number and at any interval about the drill string 106.

In addition to the embodiments described above, many examples of specific combinations are within the scope of the disclosure, some of which are detailed below:

Example 1. A system for providing electrical power in a wellbore comprising:

a drill string disposed within the wellbore comprising an outer surface defining an annular space between the drill string and the wellbore; and

a power generator sub disposed in a cavity on the outer surface of the drill string, the generator sub comprising:

a thermoelectric generator; and

a thermal insulator disposed adjacent to and radially inward from the thermal generator,

wherein the power generator sub is in contact with a drilling fluid flowing through the annular space.

Example 2. The system of example 1, the power generator sub further comprising a hot side disposed on a side in contact with the drilling fluid and a cold side on the opposing side.

Example 3. The system of example 1, further comprising a plurality of power generator subs disposed on the outer surface of the drill string.

Example 4. The system of example 4, wherein the plurality of power generator subs are coupled in parallel.

Example 5. The system of example 4, wherein the plurality of power generator subs are coupled in series.

Example 6. The system of example 1, further comprising a power conditioning unit.

Example 7. The system of example 1, wherein the power generator sub is disposed proximate a wear band disposed on the drill string.

Example 8. The system of example 1, the power generator sub further comprising a thermal conductor disposed adjacent to and radially outward from the thermoelectric generator.

Example 9. The system of example 8, wherein a voltage potential is generated across the thermoelectric generator by way of a thermal path across the thermoelectric generator.

Example 10. The system of example 9, further comprising a downhole tool, the downhole tool comprising electronics and sensors configured to be powered at least in part by the voltage potential.

Example 11. The system of example 9, further comprising a capacitor, the capacitor configured to be charged at least in part by the voltage potential.

Example 12. The system of example 1, the thermoelectric power generator further comprising two materials comprising different Seebeck coefficients.

Example 13. The system of example 12, wherein a voltage potential is generated across the two materials by way of a thermal path created across the two materials.

Example 14. The system of example 13, further comprising a downhole tool, the downhole tool comprising electronics and sensors configured to be powered at least in part by the voltage potential.

Example 15. The system of example 13, further comprising a capacitor, the capacitor configured to be charged at least in part by the voltage potential.

Example 16. A power generator sub apparatus disposed in a cavity on an outer surface of a drill string comprising:

a thermoelectric generator; and

a thermal insulator disposed adjacent to and radially inward from the thermal generator,

wherein the power generator sub is in contact with a drilling fluid flowing through the annular space.

Example 17. The apparatus of example 16, the power generator further comprising a hot side disposed on a side in contact with the drilling fluid and a cold side on the opposing side.

Example 18. The apparatus of example 16, further comprising a plurality of power generators disposed on the outer surface of the drill string.

Example 19. The apparatus of example 18, wherein the plurality of power generators are coupled in parallel.

Example 20. The apparatus of example 18, wherein the plurality of power generators are coupled in series.

Example 21. The apparatus of example 16, further comprising a power conditioning unit.

Example 22. The apparatus of example 16, wherein the power generator is disposed proximate a wear band disposed on the drill string.

Example 23. The apparatus of example 16, the power generator sub further comprising a thermal conductor disposed adjacent to and radially outward from the thermoelectric generator.

Example 24. The apparatus of example 23, wherein a voltage potential is generated across the thermoelectric generator by way of a thermal path across the thermoelectric generator.

Example 25. The apparatus of example 24, further comprising a downhole tool, the downhole tool comprising electronics and sensors configured to be powered at least in part by the voltage potential.

Example 26. The apparatus of example 24, further comprising a capacitor, the capacitor configured to be charged at least in part by the voltage potential.

Example 27. The apparatus of example 16, the thermoelectric generator further comprising two materials comprising different Seebeck coefficients.

Example 28. The apparatus of example 27, wherein a voltage potential is generated across the two materials by way of a thermal path created across the two materials.

Example 29. The apparatus of example 28, further comprising a downhole tool, the downhole tool comprising electronics and sensors configured to be powered at least in part by the voltage potential.

Example 30. The apparatus of example 28, further comprising a capacitor, the capacitor configured to be charged at least in part by the voltage potential.

Example 31. A method for providing electrical power in a wellbore comprising:

providing a thermoelectric power generator on the outer surface of a drill string, the power generator being in contact with drilling fluid flowing through an annular space outside the drill string; and

converting thermal energy of the drilling fluid into electrical power using Seebeck effect to create a voltage potential across the power generator.

While the aspects of the present disclosure may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. But it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

CLAIMS

We claim:

Claim 1. A system for providing electrical power in a wellbore comprising:

a drill string disposed within the wellbore comprising an outer surface defining an annular space between the drill string and the wellbore; and

a power generator sub disposed in a cavity on the outer surface of the drill string, the generator sub comprising:

a thermoelectric generator; and

a thermal insulator disposed adjacent to and radially inward from the thermal generator,

wherein the power generator sub is in contact with a drilling fluid flowing through the annular space.

Claim 2. The system of claim 1, the power generator sub further comprising a hot side disposed on a side in contact with the drilling fluid and a cold side on the opposing side.

Claim 3. The system of claim 1, further comprising a plurality of power generator subs disposed on the outer surface of the drill string.

Claim 4. The system of claim 4, wherein the plurality of power generator subs are coupled in parallel.

Claim 5. The system of claim 4, wherein the plurality of power generator subs are coupled in series.

Claim 6. The system of claim 1, further comprising a power conditioning unit.

Claim 7. The system of claim 1, wherein the power generator sub is disposed proximate a wear band disposed on the drill string.

Claim 8. The system of claim 1, the power generator sub further comprising a thermal conductor disposed adjacent to and radially outward from the thermoelectric generator.

Claim 9. The system of claim 8, wherein a voltage potential is generated across the thermoelectric generator by way of a thermal path across the thermoelectric generator.

Claim 10. The system of claim 9, further comprising a downhole tool, the downhole tool comprising electronics and sensors configured to be powered at least in part by the voltage potential.

Claim 11. The system of claim 9, further comprising a capacitor, the capacitor configured to be charged at least in part by the voltage potential.

Claim 12. The system of claim 1, the thermoelectric power generator further comprising two materials comprising different Seebeck coefficients.

Claim 13. The system of claim 12, wherein a voltage potential is generated across the two materials by way of a thermal path created across the two materials.

Claim 14. The system of claim 13, further comprising a downhole tool, the downhole tool comprising electronics and sensors configured to be powered at least in part by the voltage potential.

Claim 15. The system of claim 13, further comprising a capacitor, the capacitor configured to be charged at least in part by the voltage potential.

Claim 16. A power generator sub apparatus disposed in a cavity on an outer surface of a drill string comprising:

a thermoelectric generator; and

a thermal insulator disposed adjacent to and radially inward from the thermal generator,

wherein the power generator sub is in contact with a drilling fluid flowing through the annular space.

Claim 17. The apparatus of claim 16, the power generator further comprising a hot side disposed on a side in contact with the drilling fluid and a cold side on the opposing side.

Claim 18. The apparatus of claim 16, further comprising a plurality of power generators disposed on the outer surface of the drill string.

Claim 19. The apparatus of claim 18, wherein the plurality of power generators are coupled in parallel.

Claim 20. The apparatus of claim 18, wherein the plurality of power generators are coupled in series.

Claim 21. The apparatus of claim 16, further comprising a power conditioning unit.

Claim 22. The apparatus of claim 16, wherein the power generator is disposed proximate a wear band disposed on the drill string.

Claim 23. The apparatus of claim 16, the power generator sub further comprising a thermal conductor disposed adjacent to and radially outward from the thermoelectric generator.

Claim 24. The apparatus of claim 23, wherein a voltage potential is generated across the thermoelectric generator by way of a thermal path across the thermoelectric generator.

Claim 25. The apparatus of claim 24, further comprising a downhole tool, the downhole tool comprising electronics and sensors configured to be powered at least in part by the voltage potential.

Claim 26. The apparatus of claim 24, further comprising a capacitor, the capacitor configured to be charged at least in part by the voltage potential.

Claim 27. The apparatus of claim 16, the thermoelectric generator further comprising two materials comprising different Seebeck coefficients.

Claim 28. The apparatus of claim 27, wherein a voltage potential is generated across the two materials by way of a thermal path created across the two materials.

Claim 29. The apparatus of claim 28, further comprising a downhole tool, the downhole tool comprising electronics and sensors configured to be powered at least in part by the voltage potential.

Claim 30. The apparatus of claim 28, further comprising a capacitor, the capacitor configured to be charged at least in part by the voltage potential.

Claim 31. A method for providing electrical power in a wellbore comprising:

providing a thermoelectric power generator on the outer surface of a drill string, the power generator being in contact with drilling fluid flowing through an annular space outside the drill string; and

converting thermal energy of the drilling fluid into electrical power using Seebeck effect to create a voltage potential across the power generator.