

WIRELESS COMMUNICATION SYSTEM FOR MONITORING OF SUBSEA WELL CASING ANNULI

BACKGROUND OF THE INVENTION

The present invention relates to a system for non-intrusively and wirelessly monitoring pressure, temperature and/or other parameters in the casing annuli of a subsea hydrocarbon production system. More specifically, the invention provides an apparatus and method for monitoring the parameters in the casing annuli using a near-field magnetic or an inductive through-wall communications system to communicate with one or more sensing packages located in corresponding casing annuli.

Sustained Casinghead Pressure (SCP) is a pressure build-up within the casing annuli of a subsea hydrocarbon production system which is due solely to temperature fluctuations. The need to monitor SCP has been identified by the Minerals Management Service (MMS) of the United States Department of the Interior. However, this requirement has been waived for certain subsea hydrocarbon production systems due to other regulatory prohibitions against body penetrations in high pressure wellhead housings.

In addition to regulatory demands for the development of technology for the non-invasive monitoring of casing annuli, operators are interested in such monitoring in order to mitigate the risks to personnel, equipment and system availability which may be caused by working on equipment in an unknown pressure condition or incidents such as the collapse of production tubing due to pressure in the B annulus, i.e., the production casing annulus. Operators have experienced failures on non-High Pressure High Temperature ("HPHT") wells due to excessive pressure in the B annulus, and the risks of annulus pressure build-up and subsequent damage are more acute in HPHT wells due to thermal expansion of trapped fluid within the casing annuli.

SUMMARY OF THE INVENTION

In a first aspect, there is provided a subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, and a monitoring system for monitoring a parameter existing in at least one of the casing annuli, the monitoring system comprising: an interrogation package which is operable to wirelessly transmit an interrogation signal; and at least one sensing package which is located in a

corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor.

In a second aspect, there is provided a subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, and a monitoring system for monitoring a parameter existing in at least one of the casing annuli, the monitoring system comprising: an interrogation package which is operable to wirelessly transmit an interrogation signal; and at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor; wherein the interrogation package is located externally of the wellhead housing, the at least one sensing package comprises a plurality of sensing packages, each of which is located in a corresponding casing annulus, and the interrogation signals are transmitted between the interrogation package and the sensing packages using a multi-hop signal transmission technique; and wherein the interrogation package communicates with a radially adjacent sensing package and the sensing packages communicate with each other using near-field magnetic induction (NFM) signals.

In a third aspect, there is provided a subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, and a monitoring system for monitoring a parameter existing in at least one of the casing annuli, the monitoring system comprising: an interrogation package which is operable to wirelessly transmit an interrogation signal; and at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor; wherein the interrogation package

is located within the innermost casing; and wherein the interrogation package communicates with the at least one sensing package using near-field magnetic induction (NFM) signals.

In a fourth aspect, there is provided a subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, and a monitoring system for monitoring a parameter existing in at least one of the casing annuli, the monitoring system comprising: an interrogation package which is operable to wirelessly transmit an interrogation signal; and at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor; wherein the interrogation package is located within the innermost casing, the at least one sensing package comprises a plurality of sensing packages, each of which is located in a corresponding casing annulus, and the interrogation signals are transmitted between the interrogation package and the sensing packages using a multi-hop signal transmission technique; and wherein the interrogation package communicates with a radially adjacent sensing package and the sensing packages communicate with each other using near-field magnetic induction (NFM) signals.

In a fifth aspect, there is provided a subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, and a monitoring system for monitoring a parameter existing in at least one of the casing annuli, the monitoring system comprising: an interrogation package which is operable to wirelessly transmit an interrogation signal; and at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor; and means for powering the sensing package, said means comprising a transmitter for generating an AC magnetic field, a receiver which is exposed to the magnetic field and which in response thereto generates

an AC current, and an energy storage device which is charged by the current, wherein the energy storage device powers the sensing package; wherein the monitoring system comprises a plurality of sensing packages, each of which is positioned in a corresponding casing annulus, and wherein the means for powering the sensing packages comprises a plurality of transmitters and receivers arranged in transmitter/receiver pairs, each transmitter/receiver pair being positioned in a corresponding casing annulus and being connected to a corresponding energy storage device which in turn is connected to a corresponding sensing package, wherein power for at least one sensing package is transmitted to its corresponding transmitter/receiver pair by the transmitter/receiver pair of a radially adjacent sensing package.

In accordance with embodiments of the present invention, a system is provided for monitoring pressure, temperature and/or other parameters within one or more subsea well casing annuli of a subsea hydrocarbon production system without physically penetrating any of the pressure barriers.

The monitoring system of embodiments of the present invention may be employed with a subsea hydrocarbon production system which comprises a wellhead housing

mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, and a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings.

An embodiment of the monitoring system comprises an interrogation package which is operable to wirelessly transmit an interrogation signal, and at least one sensing package which is located in one of the casing annuli and which includes at least one sensor for sensing the parameter. The sensing package is operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor. The interrogation package may communicate with the at least one sensing package using, for example, near-field magnetic induction (NFM) and/or inductive signals.

In one embodiment of the invention the interrogation package is located externally of the wellhead housing and the at least one sensing package comprises a single sensing package which is located in one of the casing annuli. In this embodiment, the interrogation and response signals may be transmitted directly between the interrogation package and the sensing package.

In another embodiment of the invention the interrogation package is located externally of the wellhead housing and the at least one sensing package comprises a plurality of sensing packages, each of which is located in a corresponding casing annulus. In this embodiment the interrogation and response signals may be transmitted between the interrogation package and the sensing packages using a multi-hop signal transmission technique.

In accordance with yet another embodiment of the invention, the interrogation package is located within the innermost casing and the at least one sensing package comprises a single sensing package which is located in one of the casing annuli. In this embodiment, interrogation and response signals may be transmitted directly between the interrogation package and the sensing package.

In accordance with still another embodiment of the invention, the interrogation package is located within the innermost casing and the at least one sensing package comprises a plurality of sensing packages, each of which is

located in a corresponding casing annulus. In this embodiment the interrogation and response signals may be transmitted between the interrogation package and the sensing packages using a multi-hop signal transmission technique.

Embodiments of The present invention thus provides a system and method for the non-intrusive monitoring of pressure, temperature and/or other parameters existing within one or more casing annuli without physically penetrating any pressure barriers in the subsea hydrocarbon production system. The invention thus reduces the risks associated with, and avoids regulatory prohibitions on, pressure barrier penetrations.

These and other embodiment objects and advantages of the present invention will be made apparent from the following detailed description, with reference to the accompanying drawings. In the drawings, the same reference numbers may be used to denote similar components in the various embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic sectional illustration of an exemplary subsea hydrocarbon production system showing a prior art system for monitoring a single casing annulus;

Figure 2 is a schematic sectional illustration of an exemplary subsea hydrocarbon production system showing an interrogation package located outside the wellhead housing and communicating via a multi-hop technique with sensing packages located in the A, B and C annuli;

Figure 3 is a schematic sectional illustration of an exemplary subsea hydrocarbon production system showing an interrogation package located outside the wellhead housing and communicating via a multi-barrier technique with a sensing package located in the B annulus;

Figure 4 is a schematic sectional illustration of an exemplary subsea hydrocarbon production system showing an interrogation package located inside the production bore and communicating via a multi-hop technique with sensing packages located in the A, B and C annuli; and

Figure 5 is a schematic sectional illustration of an exemplary subsea hydrocarbon production system showing an interrogation package located inside the production bore and communicating via a multi-barrier technique with a sensing package located in the B annulus.