Title: ASSEMBLY AND METHOD FOR TRANSIENT AND CONTINUOUS TESTING OF AN OPEN PORTION OF A WELL BORE

Abstract: An assembly for transient and continuous testing of an open portion of a well bore, said assembly being arranged in a lower part of a drill string, and is comprising: - a minimum of two packers fixed at the outside of the drill string, said packers being expandable for isolating a reservoir interval; - a down-hole pump for pumping formation fluid from said reservoir interval; - a sample chamber; - sensors for measuring fluid properties; - a closing valve for closing the fluid flow from said reservoir interval, distinguished in that said assembly further is comprising: - sensors and telemetry for measuring and real-time transmission of the flow rate, pressure and temperature of the fluid flow from said reservoir interval, from said down-hole pump, in the drill string and in an annulus above the packers, - a mud driven turbine or electric cable for energy supply to said down-hole pump, and - a circulation unit for mud circulation from a drill pipe to said annulus above the packers and feeding formation fluid from said down-hole pump to said annulus, said circulation unit, independent of the circulation rate for mud to said annulus, can feed formation fluid from said reservoir interval into said annulus, so that a well at any time can be kept in over balance and so that the mud in said annulus at any time can solve the formation fluid from said reservoir interval.

Fig. 1
Assembly and method for transient and continuous testing of an open portion of a well bore

Scope of invention

The present invention relates to testing of oil and gas wells. More specifically, the invention relates to an assembly and a method for transient and continuous testing of an open portion of a well bore.

Prior art and background of the invention

The testing of oil and gas wells is of great importance for determining reservoir properties and production capacity of a hydrocarbon containing reservoir. Such testing is preferably made with a drill string, during so-called drill string testing (DST), during which a zone of interest is isolated by temporary packers, so that fluid from the reservoir zone may flow into the space between said packers.

Patent publication US 5,799,733 discloses a down-hole tool for early evaluation of a reservoir, primarily for taking samples of open-hole reservoir fluid. In said publication is described inflatable packer elements for isolating an open-hole reservoir interval of interest, a down-hole pump driven electrically or by a mud motor and providing a mud return to a drill string/test string or the annulus above the packers, and further are described a sample chamber and sensors for the measurement of fluid properties. Technology enabling an extended testing like the continuous mixing of mud and reservoir fluid during controlled conditions is however not disclosed, but several places give warnings against the risk for loss of pressure control, see for example column 16, lines 33-42 in publication US 5,799,733. For embodiments having an electrically driven pump the formation fluid is fed to a well bore test string in order to eliminate the risk for loss of pressure control. For embodiments having a mud pump it is not possible to feed formation fluid into the upper part of a drill or test string, and for all such embodiments severe warnings are expressed against the risk of loosing pressure control.

There is a demand for an assembly and a method for transient and continuous testing of an open portion of a well bore, without the above-mentioned limitations.

Summary of the invention

The present invention is providing an assembly for transient and continuous testing of an open portion of a well bore, said assembly being arranged in a lower part of a drill string, and is comprising:
- a minimum of two packers fixed at the outside of the drill string, said packers being expandable for isolating a reservoir interval,
- a down-hole pump for pumping formation fluid from said reservoir interval,
- a sample chamber,
- sensors for measuring fluid properties,
- a closing valve for closing the fluid flow from said reservoir interval, distinguished in that said assembly further is comprising:
- sensors and telemetry for measuring and real-time transmission of flow rate, pressure and temperature of the fluid flow from said reservoir interval, from said down-hole pump in the drill string and in an annulus above the packers,
- a mud driven turbine or electric cable for energy supply to said down-hole pump, and
- a circulation unit for mud circulation from a drill pipe to said annulus above the packers and feeding formation fluid from said down-hole pump to said annulus, said circulation unit, independent of the circulation rate of mud to said annulus can feed formation fluid from said reservoir interval into said annulus, so that a well at any time can be kept in over balance and so that the mud in said annulus at any time can solve the formation fluid from said reservoir interval.

The present invention also provides a method for transient and continuous testing of an open portion of a well bore, employing the assembly according to the invention and arranged in the lower part of a drill string, whereby continuous testing is carried out by feeding formation fluid into the annulus above the packers isolating a reservoir interval, while transient testing is carried out by closing the formation fluid flow and measuring the response as a function of time,

the method comprising:
controlling said circulation unit based upon measured data, the density and the reservoir fluid solubility of the mud, so that the well at any time is kept in over balance and said mud at any time can solve the reservoir fluid fed into said mud.

The present invention enables the testing of the production properties of a reservoir without using surface process equipment. Well testing is carried out in an open hole without the use of casing, meaning saving time. Further testing can be done independently in an unlimited number of test zones without having to trip in and out of the well bore, which gives a considerable cost and time saving. There is no need for conventional sub-surface test equipment for providing well control. Open-hole testing is possible without limitations regarding flow rate and duration. The pumping of reservoir fluid from a reservoir to the well can be done at a high flow rate, at great pump capacity, with large quantity of mud dissolved, which opens for testing of high permeability reservoirs. The testing is carried out in an open well and having all well control barriers in place, that is having weighted mud in the drill string and annulus at
full over balance, as well as blow-out preventer (BOP) and down-hole closing valve above the packer elements. Preferably the assembly comprises a connection line for pressure communication over/under packer(s) to maintain the hydrostatic pressure, which means over balance, in the entire open hole. The assembly is preferably adapted for reducing well related noise and improve the differential pressure specifications, in particular by preferably using double packers over/under the test zone. Reservoir fluid is pumped out utilizing an electric or hydraulically driven pump. When using an electrical driven pump the pumping is always undertaken so as to provide a sufficient thinning or a complete dissolving of reservoir fluid in the drilling fluid by adjusting the flow rate so as to maintain a stable well, even during circulation stop. When using a hydraulically driven pump hydraulic energy is transformed to electric energy driving a hydraulic pump via a mud circulation turbine and generator. Alternatively, the hydraulic pump is driven by a hydraulic circuit in turn driven by a hydraulic mud circulation turbine, or a mud circulation turbine drives an electric pump. The flow rate thereby can be adjusted so that a stable well is maintained, even during circulation stops, independent of whether the pump is driven electrically or hydraulically. By controlling the input pumping of formation fluid based upon measured data, the mud density and the reservoir fluid solubility of the mud, the well thereby can be kept in over balance at any time and the mud can at any time solve the reservoir fluid fed into the mud.

The assembly comprises sensors for the measurement of chemical and physical properties of produced reservoir fluid, preferably chosen amongst sensors for or based upon optical spectroscopy, pH resistivity, gas/oil ratio, viscosity, and other sensor types known to the art. Additionally, the assembly comprises pressure and temperature meters for measuring pressure and temperature in the test zone, that is reservoir pressure and temperature, as well as the pressure and temperature in the pump, drill string and the annulus volume. The assembly comprises a circulation unit that is a flow diverter enabling controlled mud circulation from drill pipe to annulus at the same time as reservoir fluid from the down-hole pump is mixed with and dissolved in the mud, which makes it possible to produce a large volume of reservoir fluid without risking under balance or uncontrolled entering of reservoir fluid to the well. The assembly further comprises means for down-hole rate measurement and flow control. Further, the assembly comprises a closing valve that makes it possible to have an accurate closing of the well flow for the measuring of pressure response from the reservoir, that is transient testing. The assembly also comprises advantageously a telescope unit to take up expansion and contraction of the drill string or a set production packer (important for preventing displacement of packer elements and noise in pressure meters in the well test phase). The drill string comprises preferably a drill bit at the end of the assembly for hole conditioning before, between and after the formation testing. Natural
gas coming from the mud/hydrocarbon solution at the return to the surface is fed through the mud conditioning equipment of the drilling installation and is vented to the air. Dissolved oil is accumulated in the mud and is left in the well in connection with the permanent return plugging after finished testing. Possible surplus mud can either be transported for destruction or reinjected to the reservoir. The present assembly and method advantageously make use of mud having a high solubility for reservoir fluid.

The drawings

The present invention is illustrated by drawings, of which:

Figure 1 illustrates an assembly according to the invention,

Figure 2 illustrates an alternative assembly according to the invention,

Figure 3 illustrates a sampling chamber for use together with the assembly and the method according to the invention,

Figure 4 illustrates a sampling chamber for use together with the assembly and the method according to the invention, and

Figures 5-11 illustrate a sequence employing the assembly and the method according to the invention.

Detailed description

By the present invention open-hole testing is enabled, without using down-hole valves and surface processing equipment, while having unlimited flow time, unlimited flow volume and unlimited duration of closing. The features defined in the present claims make it possible to obtain such expanded flow rate and test duration without the risk for uncontrolled well blow-out.

Figures 1 and 2 show two embodiments of the assembly according to the invention. In the embodiment of figure 1 pumped in reservoir fluid and circulated mud are introduced at the same level in the annulus over the packers, whereas the embodiment according to figure 2 illustrates introducing circulated mud and pumped in reservoir fluid into the annulus over the packers at different levels, as the circulation unit is arranged in a divided version. Other embodiments are also conceivable, but in any case the circulation unit is arranged so that circulated mud and pumped in formation fluid can be fed to the annulus over the packers under full control regarding the maintaining of overbalance and dissolving all the pumped in formation fluid in the mud. The Figures 2 and 3 present a further illustration of a down-hole fluid analyser and a sample chamber (DFA). The figures 5-11 illustrate a drilling operation and a test carried out using a drill string having an assembly according to the invention. The sequence illustrated in figures 5-11, having some explanatory text, is self-evident for the persons skilled in the art.
Claims

1. An assembly for transient and continuous testing of an open portion of a well bore, said assembly being arranged in a lower part of a drill string, and is comprising:
   - a minimum of two packers fixed at the outside of the drill string, said packers being expandable for isolating a reservoir interval,
   - a down-hole pump for pumping formation fluid from said reservoir interval,
   - a sample chamber,
   - sensors for measuring fluid properties,
   - a closing valve for closing the fluid flow from said reservoir interval,
   *characterised in that* said assembly further is comprising:
   - sensors and telemetry for measuring and real-time transmission of the flow rate, pressure and temperature of the fluid flow from said reservoir interval, from said down-hole pump, in the drill string and in an annulus above the packers,
   - a mud driven turbine or electric cable for energy supply to said down-hole pump, and
   - a circulation unit for mud circulation from a drill pipe to said annulus above the packers and feeding formation fluid from said down-hole pump to said annulus, said circulation unit, independent of the circulation rate for mud to said annulus, can feed formation fluid from said reservoir interval into said annulus, so that a well at any time can be kept in over balance and so that the mud in said annulus at any time can solve the formation fluid from said reservoir interval.

2. A method for transient and continuous testing of an open portion of a well bore, employing the assembly according to claim 1, arranged in the lower part of a drill string, whereby continuous testing is carried out by feeding formation fluid into the annulus above the packers isolating a reservoir interval, while transient testing is carried out by closing the formation fluid flow and measuring the response as a function of time, *characterised by*:
   - controlling said circulation unit based upon measured data, the density of the mud and the reservoir fluid solubility of the mud, so that the well at any time is kept in over balance and said mud at any time can solve the reservoir fluid fed into said mud.
Sample chambers:
✓ Thin walled chamber ~ 75 liters / 9 meters
✓ Packaged in the 7" OD sleeve to provide circulation path
✓ 'Smart Piston', self closing
✓ Pressure release valves
✓ Stackable
✓ Hydraulic and electrical lines pass through / around chamber

Fig. 3

Fig. 4
Fig. 5

FTWT Job Sequence 2:

- Fix tubing in BOP
- Inflate FTWT packers
FTWT Job Sequence 3:

- Circulate above top packer

FTWT job sequence 4:

- Isolate active mud system
- Pump out formation fluid from between packers to the annulus while continuing circulation with return through kill and choke line through desasser
FTWT Job sequence 5:

- Stop circulation → Stop pumping out reservoir fluid
- Measure pressure build up between packers for transient analysis

FTWT Job sequence 6:

- Circulate above top packe
- Perform formation integrity test (optional)

FTWT job sequence 7:
Job sequence 6:

- Deflate FTWT packers
- Open BOP to unlock tubing
- Circulate through the drill bit to condition well
- Pull out of hole or go to next test zone
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

**IPC:** see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

**IPC:** E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic database consulted during the international search (name of database and, where practicable, search terms used)

**EPO-INTERNAL, WPI DATA, PAJ**

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>GB 2355033 A (SCHLUMBERGER LIMITED), 11 April 2001 (11.04.2001)</td>
<td>1-2</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C.

See patent family annex.

**Date of the actual completion of the international search**

26 May 2008

**Date of mailing of the international search report**

28-05-2008

**Name and mailing address of the ISA/Swedish Patent Office**

Box 5055, S-102 42 STOCKHOLM

Facsimile No. +46 8 666 02 86

**Authorized officer**

Christer Bäcknert / MRo

Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (April 2007)
International patent classification (IPC)

E21B 49/08 (2006.01)

Download your patent documents at www.prv.se
The cited patent documents can be downloaded at www.prv.se by following the links:
  • In English/Searches and advisory services/Cited documents (service in English) or
  • e-tjänster/anförda dokument (service in Swedish).
Use the application number as username.
The password is KXDMNFJGCV.

Paper copies can be ordered at a cost of 50 SEK per copy from PRV InterPat (telephone number 08-782 28 85).

Cited literature, if any, will be enclosed in paper form.
<table>
<thead>
<tr>
<th>Country</th>
<th>Number</th>
<th>Date</th>
<th>Country</th>
<th>Number</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>AU</td>
<td>6441396 A</td>
<td>03/07/1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CA</td>
<td>2193309 A,C</td>
<td>27/06/1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DE</td>
<td>69636665 D,T</td>
<td>04/10/2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>EP</td>
<td>0781893 A,B</td>
<td>02/07/1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NO</td>
<td>319932 B</td>
<td>03/10/2005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NO</td>
<td>964051 A</td>
<td>27/06/1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GB</td>
<td>9923870 D</td>
<td>00/00/0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NO</td>
<td>0127432 A</td>
<td>19/04/2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NO</td>
<td>20022625 A</td>
<td>05/12/2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>US</td>
<td>20020178804 A</td>
<td>05/12/2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>US</td>
<td>20040003657 A</td>
<td>08/01/2004</td>
</tr>
</tbody>
</table>