Methods and Devices for Prevention of Well Explosion

The presented acoustic methods and devices are intended for early detection and determining parameters of the gaseous packet (gas kick) rising in the annulus of the well during a gas blowout. The action of the tool is based on the comparison of pressure pulses generated in the mud by the mud pump using dynamic pressure sensors located in the annulus above the blowout preventer and in the high-pressure line. When the output signal decreases to the pre-specified level corresponding to the danger of blowout, the drilling is stopped and a pressure pulse is generated in the annulus; the location, velocity, size, overpressure pressure of formation, hydrogen sulfide presence and arrival time of the gaseous packet is determined using the arrival time of the reflected signals. The information obtained this way is used for making a decision whether to resume drilling or to take measures to suppress gas entry into the borehole. The tool also makes it possible to detect free-phase highly dissolved gas entering the annulus at the saturation pressure; such gas is especially dangerous when formations saturated with hydrogen sulfide and carbon dioxide are penetrated.

Simon Tseytlin is Doctor of Science in Petroleum Engineering. He has expertise in creation of new Technologies and Software for Oil and Gas industry. He created and patented a number of Technologies for Offshore Drilling and Enhanced Oil Production.

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Methods and Devices for Prevention of Well Explosion and Methods and Tools of Killing an Uncontrolled Oil-Gas Fountain Appearing After an Explosion of an Offshore Oil Platform

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1. Introduction

The purpose of this paper is to get you acquainted with several methods, simulators and technologies developed by Tseytlin Consulting, Inc. for the purpose of prevention of well explosions, killing an uncontrolled oil-gas fountain that appears after an explosion and restoring control and resuming production of an offshore oil platform.

Prevention of explosion is accomplished by installing an acoustic device similar to a hydrodynamic sonar and a pressure sensor at the wellhead and by monitoring the signal measured by the pressure sensor. Size, location and velocity of the gas kick can be determined from the shape of the received signal, allowing to estimate the time of arrival of the gas kick to the well head.

This method allows for early detection of the gas kick – as soon as it starts to form at the bottom hole, which is critical in taking timely steps to deal with its removal from the well, reducing the risk of explosion and uncontrolled blowout of the well, thus preventing pollution of ecological environment and employees' loss of life.

One of the side benefits of this method is being able to determine the bottom hole pressure without the need to stop drilling, extract drill string and lower the pressure sensor into the well, thus speeding up drilling and further increasing safety.

Moving on, the methods of killing an uncontrolled oil-gas fountain after an explosion on an offshore oil platform that are described here can be implemented by inserting rods or pipes of sufficient density and correct form into the wellhead and thus gradually reducing the flow of oil-gas fountain until it can be terminated by pumping cement down the well.

The method of restoring control and resuming production is similar to the methods of killing the well, but instead of pumping cement down the well, parts of the assembly used for killing are removed thus allowing continued operation of the well.

Moving flow-restricting inserts up or down may be used to adjust flow resistance from the well in order to optimize oil production.

Passages between the riser and the flow restricting inserts may also be used to form a gas lift in order to maximize production of oil from the well.

1.1. The Company

Tseytlin Consulting, Inc. is specialized in solving complex, scientifically and mathematically intense problems for various applications in oil and gas industry. We develop new highly effective technologies, high-precision 2D and 3D mathematical models and computer simulators for exploration, drilling, completion, and production.

1.2. Problem Statement

The patented methods presented here are for improving drilling safety and quickly regaining control of the well in case of an explosion. Thus, the main tasks are to prevent loss of life and equipment and also prevent damage to the environment.

The drilling safety is improved by early detection of gas kicks, which allows extra time to implement counter measures to avoid an explosion. Detection of gas kicks is accomplished by sending a pressure pulse down the well and monitoring the returned signal. As the gas kick rises in the well, the device will show its location and speed, which allows estimating its time of arrival.

As a side benefit, this device will allow to determine formation pressure with great precision in order to control downhole pressure. On one hand, this allows to prevent gas kicks and on the other hand to avoid hydro fracturing of the formation.

We might also be able to detect anomalies in the formation pressure, and it might also be possible to determine gas composition of the gas pack.

To implement this method, it is necessary to design and manufacture the required device, and to develop software to control it and analyze the returned signal.

Regaining control of the well in case of explosion is accomplished by lowering a series of flow restricting elements into the well until they fill enough of a cross-section of the well to cause a decrease in the fluid discharge.

To enter the well, it is critically important to use the correct form and weight of the rods or pipes to exceed the force pushing them out of the well by some margin.

Once the flow of fluid is sufficiently low, there is an option to either terminate the well, or to recover control of the well and continue production.

To terminate the well, conventional cement pumps will pump cement down the well and seal it off permanently.

Alternatively, moving flow-restricting inserts up or down may be used to adjust flow resistance from the well in order to optimize oil production.

Passages between the riser and the flow restricting inserts may also be used to form a gas lift in order to maximize production of oil from the well.

To implement this method, it is necessary to create software to model the well and allow determining the optimal parameters of the flow restricting elements. You will also need to find a manufacturer for the elements and locate a test well to perfect the technique.

1.3. Comparison With Existing Methods

Blowout prevention currently involves comparing the volume of pumped in mud versus the volume that is coming out of the well, which is imprecise and often inadequate. This is combined with periodically stopping of drilling in order to retrieve the drill string and lower the pressure measurement device into the bottom hole, which is slowing down the drilling process.

The present method of blowout prevention is much more precise and non-invasive. It is based on the solution of the problem of propagation, attenuation and reflection of elastic waves of pressure in annular and circular channels, containing non-Newtonian liquid and a gaseous pack, as contained in the article of Dr. S. Tseytlin. "Propagating pressure waves in a long vertical channel containing a gaseous pack." Engineering and Physics Journal, Volume 58, January, 1990, p. 20-26.

The following established techniques are used for restoring control of the well in case of a blowout: bridging, capping, drilling of a relief well and assembling a string of pipes for the injecting cement down the well (such string is sometimes referred to as a killing string). All of them are quite expensive to implement and work very slowly, allowing extensive damage to the environment due to escaped oil, as witnessed in the recent pollution created over a large section of the Gulf of Mexico and adjacent beaches by the erupted well off the coast of Mexico (a.k.a. "Deep Horizon").

The methods of restoring control of the well presented here would work faster and be cheaper to implement compared to the established methods. As an added bonus, it may be possible to continue production after the blowout has been dealt with.

1.4. Goals and Objectives

The main objective is to create novel methods that are simpler, faster, safer and less expensive compared to the previously existing methods.

The blowout prevention suite should be small, easy to install and cost in the area of tens of thousands of dollars, which compares favorably to most other devices that are required for drilling. It would provide maximum possible safety by detecting the gas pack as soon as it appears on the bottom hole, thus allowing a lot more time to react than any other existing technology. It should also allow measuring the formation pressure, which is currently only possible by more costly direct methods. That would allow to keep bottom hole pressure between formation pressure and hydro fracturing pressure, thus preventing creation of the gas pack in the first place, and on the other hand avoiding fracturing of formation that could cause mud to escape into the rock.
Detection, determining of the size, velocity, estimated time of arrival and gas content of the gas pack should be automated/computerized and the tool design tested and perfected on a test well.

Next object is providing novel methods and systems for killing of the uncontrolled fountain in an offshore oil well by gradually decreasing fluid flow using a series of narrow rods or pipes to restrict the flow. This method should be much cheaper and quicker than the existing methods such as drilling an adjacent killing well. The rods and/or pipes should be easily manufactured in sufficient quantity, according to the specification obtained from a computer model. The execution of the method should be perfected on a test well and an exact step-by-step guide should be produced and computerized.

The gradual flow adjustment in oil production after regaining control of the well, which is possible with this method, should be separately developed in hardware, computerized, and the implementation perfected on a test well.

2. Description of the Methods

2.1. Methods And Devices For Determination Of Gas-Kick Parameters And Prevention Of Well Explosion (US Patent 8235143B2)

2.1.1. Relevance of the topic and scope of the work

Sometimes, when drilling oil or gas wells, there appears a gas kick from the reservoir into bottom of the well.
It starts as a gaseous pack (note that the gas content of 100% means a gas bubble, and gas content equal to 0% means oil) and then it begins to emerge in the annular space of the well, displacing and replacing the mud.
If you do not timely detect this phenomenon, the gas may reach the wellhead and result in an explosion and an uncontrolled fountain.
In case when the well is closed from the top with a preventer, and it starts rising up as a gas bubble, if it is not allowed to expand in volume, it can bring pressure equal to formation pressure to the well head.
At the same time, the pressure near well bottom will grow to double the original value (the pressure in the gas bubble plus the weight of the liquid in the well under the bubble).
If unnoticed, this phenomenon can cause hydraulic fracturing, loss of all liquid from the well into the reservoir, filling the well with gas and as a result an explosion and uncontrolled fountain.
Invention in general relates to drilling of oil or gas wells, and particularly to acoustic detection and removing of gas kicks.
Sometimes gas kick may cause an uncontrolled blowout, which causes extensive equipment damage, explosion, fires, and release of poisonous gases and loss of life.

Present invention provides methods and devices for early detection of forming a gas kick as well as continuous determination of its changing parameters during its ascent to the surface, including its size, position along the well, gas content, speed of movement and projected time of arrival to the surface.
Accurate and reliable knowledge of these parameters is critical in taking timely steps to deal with gas kick removal from well leading to reducing and ultimately eliminating the risk of explosion and uncontrolled blowout of the well.
Once the gas kick is identified, emergency measures are employed to remove it from the well. Drilling is typically stopped, blowout preventer is closed and procedure of removal of the gas kick is initiated. The knowledge of gas kick parameters allows to keep the bottom hole pressure more than formation pressure and less than the fracture pressure.
The invention allows also to control gas kick appearing during tripping operations, when part of drilling tubes are extracted from well.

2.1.2. Background of the Method

Main principle of the device is similar to hydrodynamic sonar.
Elastic pressure waves lasting about 5-10 seconds are created periodically with a frequency of 10-20 minutes at the head of the annular hole.
This wave spreads down the annular space of the well with the speed of sound (about 1200-1500 m/sec) and is reflected from the top and the bottom of the gaseous pack. Reflected waves are picked up by a receiver located at the head of the annular space well (under BOP).
Knowledge of the wave propagation velocity and arrival times of reflected waves from the boundaries of gaseous pack, allow to determine with great accuracy the position and size of gaseous pack in the wellbore.
Repeat measurements allow to determine its new position, speed of gas kick and to estimate the projected time of arrival to the surface.
Note that in the absence of a gaseous pack, the receiver will record the reflected wave from the bottom of well.

Measured difference between entering and exiting mud volumes allows to evaluate gas content of the gaseous pack.

2.1.3. Foundations of the theory, on which the method is based (propagation, attenuation and reflection of elastic waves of pressure in a long channel)

A detailed description of the solution is obtained for the problem of propagation, attenuation and reflection of elastic waves of pressure in annular and circular channels, containing non-Newtonian liquid and a gaseous pack, is contained in the article of Dr. S. Tseytlin. "Propagating pressure waves in a long vertical channel containing a gaseous pack." Engineering and Physics Journal, Volume 58, January, 1990, p. 20-26.
The reflection coefficient from boundaries of gaseous pack depends from densities and compatibilities fluids.
The speed of sound in gas-liquid mixture is less than in pure gas. This guarantees that reflection coefficient at the borders of the gas kick is strong enough. A simulator was created, that shows the charts of propagation, attenuation and reflection of elastic waves of pressure in a well containing a gas kick. For an example, please see Fig.1a,b.c.

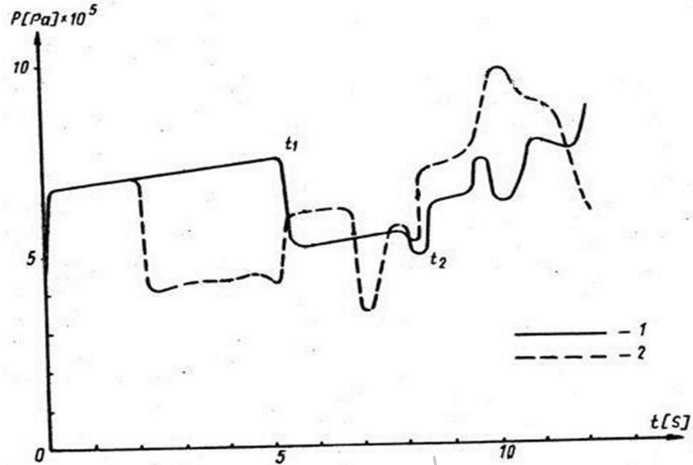

P[Pa]×10^5
10
5
0
t1
t2
– 1
– 2
t[S]
5
10

Fig. 1a

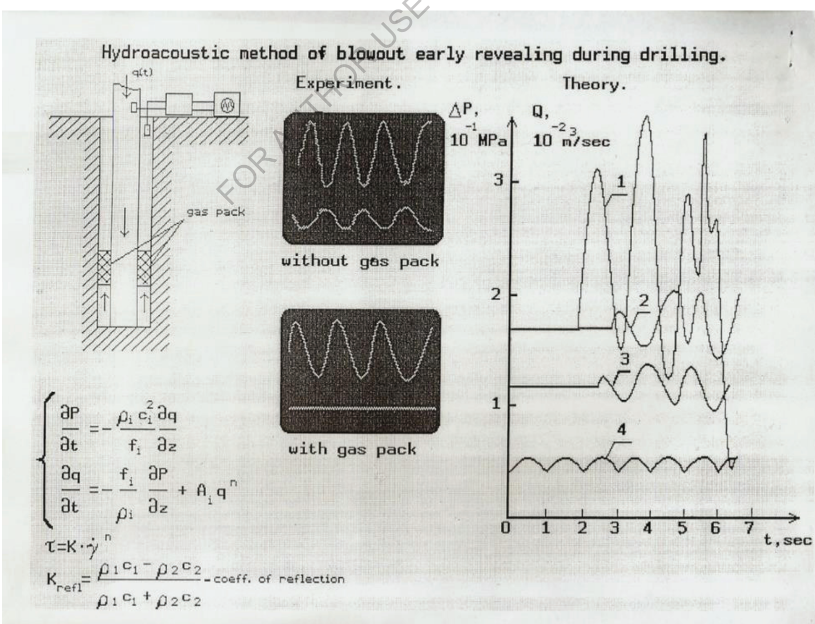

Hydroacoustic method of blowout early revealing during drilling.
q(t)
gas pack
Experiment.
without gas pack
with gas pack
Theory.
ΔP, 10^-1 MPa
Q, 10^-2 m^3/sec
t, sec
$\frac{\partial P}{\partial t} = -\frac{\rho_i c_i^2}{f_i}\frac{\partial q}{\partial z}$
$\frac{\partial q}{\partial t} = -\frac{f_i}{\rho_i}\frac{\partial P}{\partial z} + A_i q^n$
$\tau = K \cdot \dot{\gamma}^n$
$K_{refl} = \frac{\rho_1 c_1 - \rho_2 c_2}{\rho_1 c_1 + \rho_2 c_2}$ - coeff. of reflection

Fig. 1b

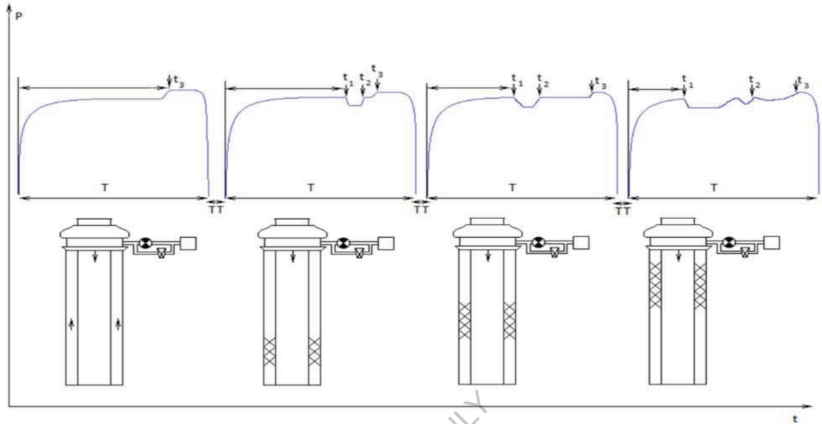


Fig.1c

T=(5-10) sec – length of pulse; TT=(10-30) min – time between pulses;
t1-time of arrival of reflected signal from top of gas kick;
t2-time of arrival of reflected signal from the bottom of gas kick;
t3-time of arrival of reflected signal from the bottom hole;

2.1.4. <u>Block diagram of the device</u>

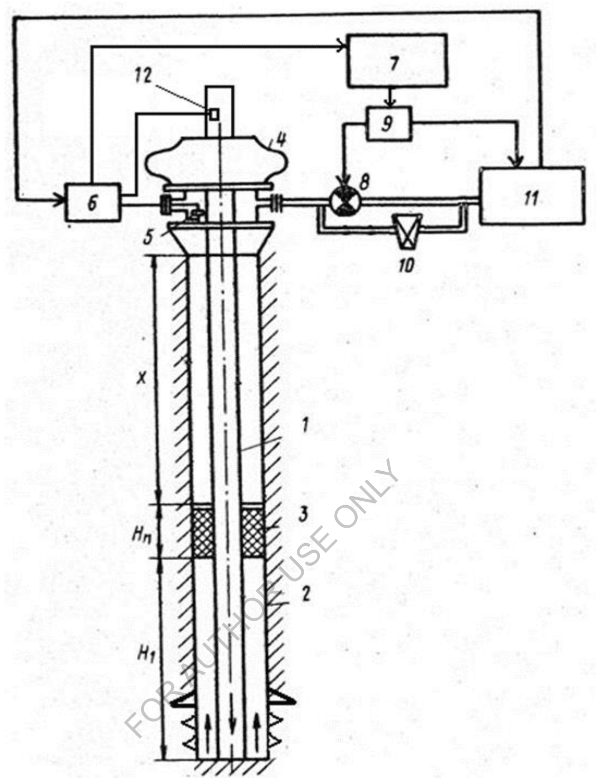


Fig. 2

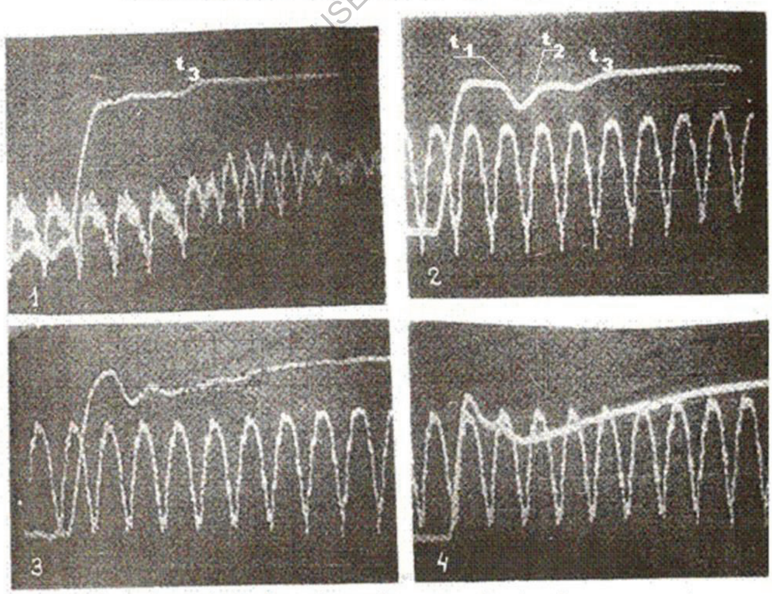
Fig. 2 shows a well utilizing the device for gas kick detection. The main elements are:

1 - drill pipe; 2 - well; 3 - gaseous pack;
4 - preventer (BOP); 5 - pressure sensor;
6 - registration device; 7- PC computer;
8 - quick-acting valve; 9 - control unit;
10 - adjustable choke; 11 - containers with mud;
12 - pressure sensor.

Quick release valve 8 operates under the influence of the control unit 9, sharply altering the flow section area of the total canal, connecting the annular space 2 with drilling well and with container 11. Pressure wave rushes down the annular space of the well and is partially reflected from the upper and lower boundaries of gaseous pack 3. The pressure sensor 5 records reflected waves and recording device 6 provides arrival times of reflected waves t1, t2 and sends them to computer 7, which identifies all the current values of the parameters, that are required for secure removal of gas kick from well.

2.1.5. Results of Experiment of Gas Kick Detection

Results of Experiment of Gas Kick Detection and Localization Hydroacoustic Method.



t_1 – time of arrival of reflected wave from upper border of gaseous pack
t_2 – time of arrival of reflected wave from lower border of gaseous pack
t_3 - time of arrival of reflected wave from bottom hole

Fig. 3

Figure 3 shows the results of an experiment to determine the parameters of gaseous pack, rising in the annular space of a well. An experiment was conducted on experimental 2000 m deep well, filled with drilling fluid with a density of 1200 kg/m^3. Gaseous pack was pumped through the wellhead, and then moved up through the annular space of the borehole. Well diameter was equal to 0.2 m, drill pipe was 0.114 m.

Fig.3 shows four charts obtained from experiments with different pressure curves at the inlet of drill pipe and at the exit of the annular space (under the BOP).

On Fig. 3 chart 1 the pressure variations associated with the work of the pistons and valves of the pump are clearly visible.

Comparing the two first oscillations on Fig.3 charts 1 and 2 allows to see attenuation of oscillation of pressure curve at the exit of annular channel, caused by the gas-kick. It shows appearance of gas-kick in the well.

The high frequency pressure variations associated with the work of pump valves are also clearly visible In Fig. 3 chart 1. Their disappearance is an additional signal of gas-kick presence.

The first image in Fig.3 chart 1 corresponds to the case, when the gaseous pack is absent in the annular space of well. There has been a sharp increase in pressure front, corresponding with the valve closing (or opening) and a reflection of the bottom of well.

On Fig. 3 chart 2 there are clearly visible reflections from the upper and lower boundaries of gaseous pack and reflection from the borehole bottom.

The third and fourth pictures correspond to 30 and 45 minutes after the first one, and show moving pack of gas towards the well head and increase in its length. Numerous variations observed behind the main reflected pulse are connected with multiple reflections at the boundaries of pack and bottom hole.

2.1.6. Capabilities of the Proposed Method

The main differences of our technology from similar other technologies are:

1. Early gas-kick detection. We can identify gas-kick almost immediately, when it is still small (less then one barrel).
2. Determination of current parameters of the gas-kick, including: the position of the upper and lower boundaries, size , speed, gas content and approach time of gas to the well head.
3. The knowledge of current gas-kick parameters allows to wash the well (removing gas-kick from the well) with more accuracy and safety. It allows to keep bottom hole pressure $P_{fract}>P_{bh}>P_{form}$ during gas-kick removal.
4. The technology works during tripping operations with the drilling tubes, when other technologies do not work, but the probability of gas-kick appearance is very high.
5. The technology can work without actively operating pumps.
6. Device can be easily deployed in mud logging unit .

2.1.7. Main Advantages of the Method

1. Thus the proposed method can prevent blowouts and explosions at the rig. The device for its implementation leads to a safer and higher quality drilling.
2. This is especially true, and important, when drilling with minimal depression on the formation or drilling at equilibrium, the use of which significantly increases the speed of commercial use of well, improves the efficiency of geological drilling by reducing the invasion zones.
3. This greatly reduces the risk of pollution of ecological environment and employees loss of life.
4. The value of this method is greatly increased in its use in offshore drilling, where the emergence of blowouts and explosions on offshore platforms can lead to the most costly complications amounting to billions of dollars.

5. The technology provides the critical set of data for real-time operation centers and real time well monitoring.

2.2. Acoustic Methods and Devices for Determining the Value of Formation Overpressure During Drilling and for Detecting Gas Packs Containing Hydrogen Sulfide Gas (US Patent 9885216B2)

2.2.1. Goals

The object of the present invention is to provide novel methods and devices that can determine formation overpressure during drilling in case a gas pack starts forming at the bottom hole.

Another object of the invention is to provide methods and devices which can detect a gas pack containing hydrogen sulfide gas as soon as it forms. This is very important in making an informed decision of what countermeasures to deploy in such cases.

2.2.2. Problems to Be Solved

If a formation starts producing a gas pack during drilling due to overpressure it is necessary to quickly introduce counter-measures to prevent a full-scale blowout. One such measure is to close the blowout preventer (BOP). Changes to the drilling mud are also needed to make it heavier but still not too heavy as to result in hydro fracturing of formation. And then the gas pack needs to be safely washed out so it doesn't cause an explosion at the well head.

The present methods and devices allow to determine the value of formation overpressure quickly and with high precision, which would make performing the above tasks easier and safer.

In addition, these methods and the associated devices will make it possible to detect gas packs made of hydrogen sulfide gas, that are even more dangerous than the regular gas packs because the gas is highly toxic.

Knowing the presence of this gas in the gas pack makes the decision of introducing countermeasures vs. immediate evacuation more precise, thus saving lives and/or reducing equipment loss.

2.2.3. Comparison to Other Inventions

The present invention is an improvement of devices shown in the US patent 8235143 entitled "Methods And Devices For Determination Of Gas-Kick Parameters And Prevention Of Well Explosion", which is incorporated herein by reference in its entirety.

This patent describes the method and associated device used to detect a gas kick and to determine its parameters such as location, velocity and size, and to estimate the time of its arrival to the surface. Knowing this data is critical in performing a safe washing of the gas pack from the well, and in preventing a full-scale blowout of the well.

Pictures in Fig. 1a were produced based on simulation results, and Fig. 1b was obtained during an experiment.

The present invention enhances the capability of this method by allowing additionally to determine the value of formation overpressure and to detect hydrogen sulfide gas packs, providing the critical extra data needed to prevent a blowout.

2.2.4. Applications

The present invention can be used when drilling onshore and offshore oil wells. It will allow to prevent blowouts and well explosions, which usually cause human losses, damage to environment and are hard and expensive to suppress.

2.2.5. Implementation Steps

In case a gas pack starts forming at the bottom hole due to overpressure, it is very important to find out formation pressure with the highest precision possible. This will allow determination of the best density of drilling mud to be pumped into the well in order to (i) stop the gas forming at the bottom hole, and (ii) prevent catastrophic hydro fracturing of the formation. If the chosen density of the mud is not high enough, it will not be able to stop formation of the gas pack at the bottom hole, and may cause a full-fledged blowout and explosion. If the density of the mud is too high, it may cause hydro fracturing of the formation, in which case the mud will escape into the fractured formation, increasing the flow of gas into the well, and again causing a blowout and an explosion.

Here are the steps necessary when using the device shown in Fig.2 to measure the formation pressure.

1. The device, which includes a quick-acting valve (Fig. 2, position 8), is installed under the BOP (Fig. 2, position 4) in the killing tube and is used to generate a periodic pressure pulse that travels down the well and is reflected from the bottom hole, and also from the upper and the lower borders of the gas pack, if present. The period of the pressure pulse is chosen in order for the reflections of the generated signal to subside, estimated at 10-15 seconds. The following steps are performed automatically by the device controller (Fig. 2, position 9) and the signal analysis software.
2. The reflected signal is captured by a pressure sensor and is analyzed by the computer (Fig.2, position 6) in order to detect the gas pack reflections. When the gas pack is detected, the drilling stops, BOP is closed and the pump performance is reduced.
3. The device is used to generate a new pressure pulse. At this time the choke (Fig. 2, position 10) contained in the parallel tube is set by its controller to diameter D_1.
4. The reflected signal will contain reflections from the bottom hole and from the upper border of the gas pack (Fig.4a). The reflection from the bottom border of the gas back will be missing since the gas pack is still being formed by formation at the bottom hole.
5. Choke diameter is automatically reduced to D_2 (for example by 1 mm per minute). This causes the downhole pressure to increase, gradually suppressing the overpressure of formation. The pressure pulse is generated again. At this point, you may or may not get a reflection from the bottom border of the gas pack.
6. The choke diameter is being reduced until establishing a good reflection from the bottom border of the gas pack (Fig.4b). This indicates that the gas pack has stopped forming at the bottom hole, and that the downhole pressure resulting from the choke position has increased where it has become slightly higher than the formation pressure.
7. Finally, to determine the approximate formation pressure, a pressure measured by sensor (5) on Fig.2 immediately before the choke is added to the pressure generated by all the heavy drilling mud in the annulus between the gas pack and the choke. Since the gas pack velocity is very slow in the beginning, there is sufficient time available to determine

formation pressure this way, and it will be very precise. Knowing the formation pressure, it is possible to determine the best density of mud to use in order to suppress the overpressure.

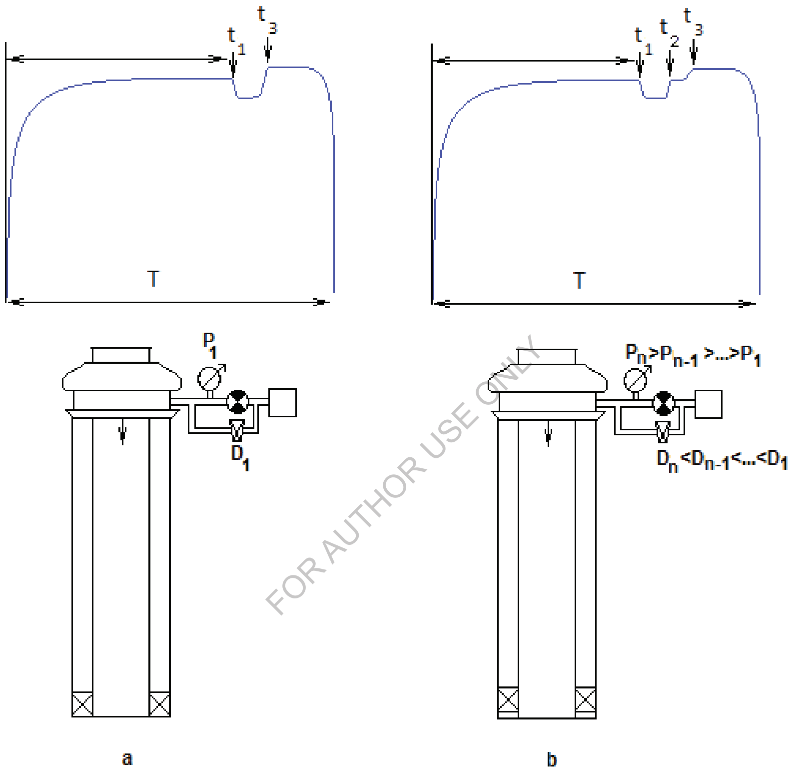


Fig. 4

As far as detecting hydrogen sulfide gas (H_2S) or carbon dioxide gas (CO_2) inside gas packs, due to their higher solubility compared to hydrocarbon gases, they start forming not at the bottom hole like a regular gas kick, but somewhere on the way to the top of the well, where the bubble point pressure is reached. When they are initially detected, the reflections from both borders of the gaseous pack will suddenly appear. See Fig.5 for an example of the received reflected signal.

Because the gas pack appears further up in the well, this leaves less time to react and to introduce countermeasures, and in case of blowout can cause higher losses in terms of human lives, environmental damage and equipment loss, since hydrogen sulfide gas is poisonous and corrosive.

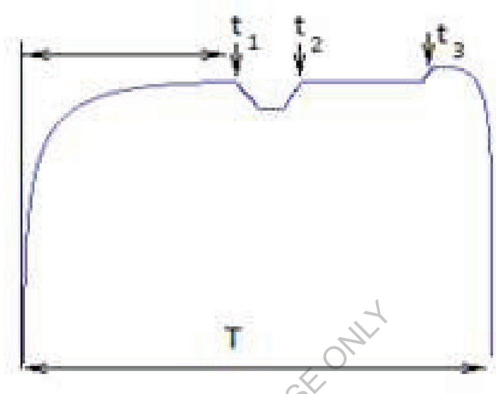


Fig. 5

The present device allows detecting these gas packs, and since they will initially appear not at the bottom hole, but higher up in the well, and since they will immediately have signal reflections from both the top and the bottom borders, you can make the call about these gases being present in the gas pack, and make timely and correct decision about countermeasures.

2.3. Methods and Tools of Killing an Uncontrolled Oil-Gas Fountain Appearing After an Explosion of an Offshore Oil Platform

2.3.1. Relevance of the topic and scope of the inventions

The present document relates to several methods and systems for the extinction or “killing” of an offshore oil well after an explosion or a blowout

causing an uncontrolled fountain of oil fluids mixed with gas from the remaining part of the well.
Often during drilling or well exploration in gas and oil wells, a gas kick may enter into the well space and then it begins to emerge in the annular space of the well, displacing and replacing the mud.
If unnoticed, this phenomenon can bring hydraulic fracturing, loss of all liquid from the well into the reservoir, filling the well with gas and as a result an explosion and uncontrolled fountain.
An uncontrolled fountain may cause human casualties and environmental pollution. It is very difficult to suppress, because the wellhead is under enormous pressure. As offshore drilling on the continental shelves is progressing into deeper and deeper waters, the problem is many times more complicated when the explosion occurs in deep waters. Suppressing such a well and cleaning of the environment may cost billions of dollars.
These methods include successive placement of flow-restricting rods of different shape down the well in order to gradually reduce the fluid discharge flow.
Flow restricting inserts of the invention may include a series of solid or hollow pipes, which may be attached or inserted one into another. Initially, a first flow restricting insert (such as a solid rod) is inserted into the opening of the oil well. As diameter of the first insert is smaller than the oil well opening, the force urging the insert out of the well is not as high as when trying to terminate the flow right away. Fluids are still released around the first insert. The weight and size of the first insert may be selected such that its weight exceeds the force urging it out of the well. In that case, the first insert may be lowered into the well using its weight and not requiring any additional force to be applied. We offer three patented methods developed by us that are based on this idea.
Once the smallest rod is in place, the cross-sectional area of the well available for oil flow discharge is somewhat reduced. Additional flow restricting inserts may then be inserted into the well following the first insert. In embodiments, such additional inserts may be inserted in parallel with the first insert (Method I). In other embodiments, additional flow restricting inserts may be inserted to form concentric telescopic assembly with the first insert (Method II). The number, size and length of the

additional inserts may depend on the depth of the well and the level of fluid pressure therein. Proper selection of additional inserts may be done using a condition of inserting of each successive insert when its own weight may be sufficient to overcome the forces urging the insert out of the oil well.

Once the flow of fluids is reduced to a manageable level, the riser may be attached to the oil well to preclude further fluid release. At this point, the oil may be sealed off, by pumping cement down the annular space between the riser and the biggest flow restricting insert. In other embodiments, the oil production may be resumed. In this case, the presence of flow restricting inserts allows for an advantageous adjustment of flow through the riser over the remaining portion of the oil well lifespan (Method III).

A method of monitoring the conditions of lowering the rods into the well may utilize a weight measuring device mounted at the surface platform. Such devices are used routinely during lowering of any rods or pipes down the well. In the case of killing the oil fountain based on the methods of the present invention, such device will show the difference between the weight of the rods (pushing the entire assembly down) and the combination of various forces acting to push it up.

Now we will briefly describe the three different patented methods of killing blowout wells.

2.3.2. Method I - The Method of Killing an Uncontrolled Oil-Gas Fountain Appearing After an Explosion of an Offshore Oil Platform. (US Patent 8448709B1)

The method of the invention includes providing a series of flow restricting rods having a cross-sectional area substantially lower than the cross-sectional area of the well. The shape of the inserts may be round. The rods may be placed one at a time inside the well until they fill enough of a cross-section of the well to cause a decrease in the fluid discharge coming out of the well.

This method requires that the riser extending from the sea surface ends above and in vertical alignment with the head of accident well. One of possible alignment systems is briefly described below. (Fig. 7)
Inserting through the riser the first flow restricting insert into the oil well, the said first flow restricting insert sized to be smaller than the opening of the oil well, thereby reducing the uncontrolled fluid release therefrom. Following rods may be placed parallel to the first, one at a time inside the well, until they fill enough of a cross-section of the well to cause a decrease in the fluid discharge coming out of the well. Now we can attach the riser to the head of the well and seal the connection by lowering the riser down. Once the flow of fluid is sufficiently low, conventional cement pumps which are traditionally used for terminating oil wells may be deployed to pump cement down the well and seal it off permanently (See Fig. 6).
Fig. 6a,b,c,d,e,f shows several stages of the method.

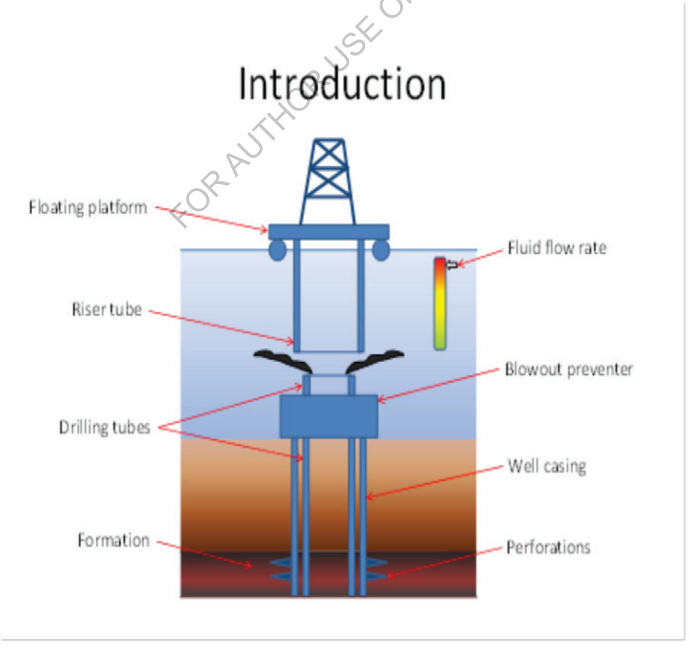


Fig. 6a

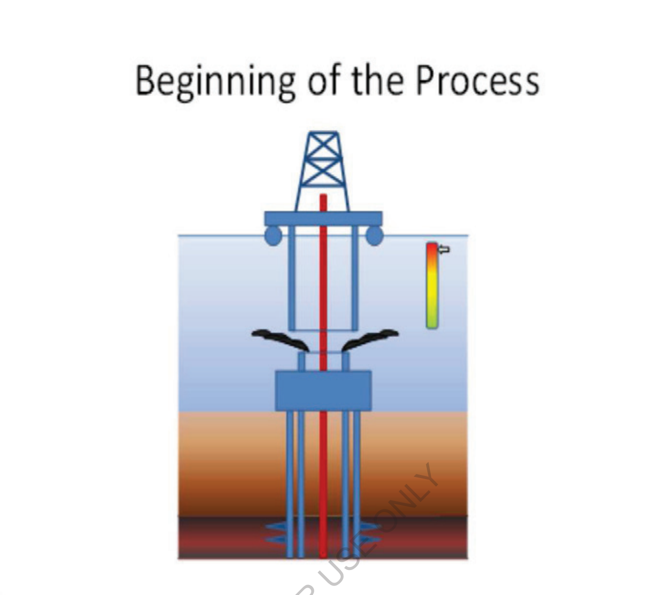


Fig. 6b

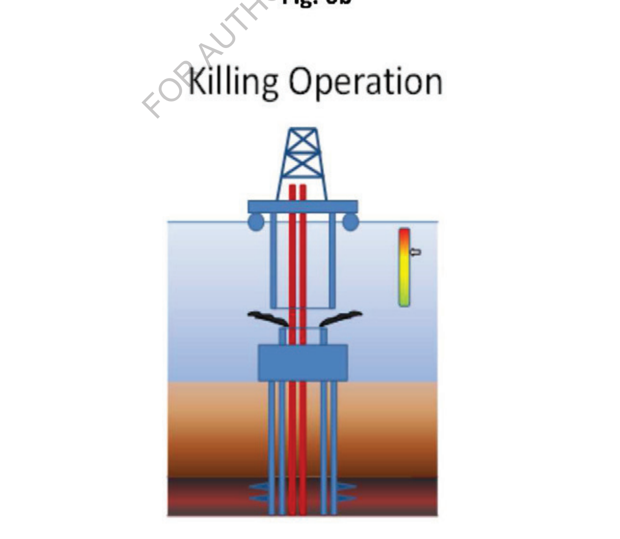


Fig. 6c

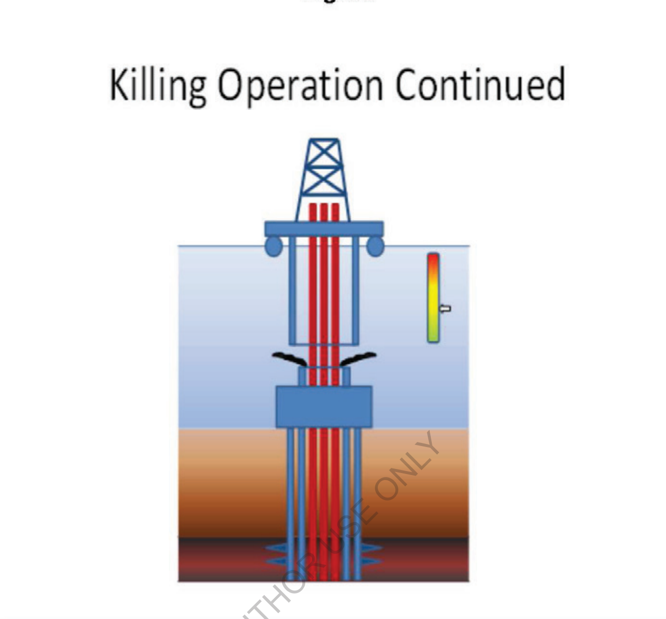


Fig. 6d

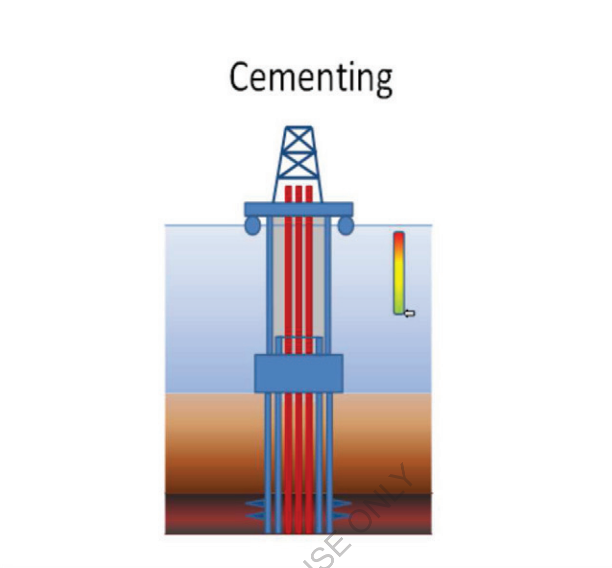


Fig. 6e

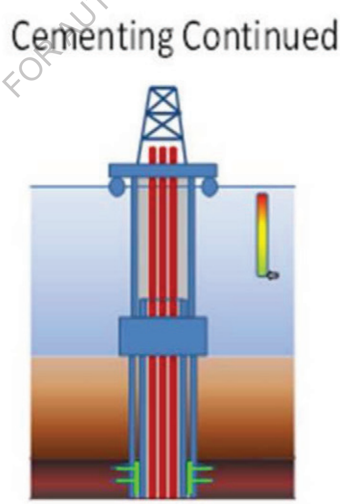


Fig. 6f

2.3.3. Method II - A Method and Alignment System for Killing an Uncontrolled Oil-Gas Fountain at an Offshore Oil Platform Using a Telescopic Rod Assembly. (US Patent 844870B1)

The method includes successive placement of flow-restricting telescopic rods of increasing diameter down the well in order to gradually reduce the fluid discharge flow. These rods are connected to each other forming together a telescopic system. The rods may be round and have gradually increasing diameters as described below. They are made of metal and have threaded ends adapted for attachment to other rods. Proper alignment of telescopic rods with the well pipe is critical for performing the method of killing the fountain according to the present method. This is especially important for lowering the first rod into the well. In addition to traditional methods and devices used for alignment of pipes and risers over discharging well pipes, the present invention provides for a novel passive mechanical alignment device which can be used to automatically align the riser to the well pipe (see Fig. 7, with or without the blowout preventer). Upon lowering the alignment system placed at the end of the riser towards the well, the initial circle of ties is expanded and may cover an area of several dozen square meters – see Fig. 7a. The riser is further brought down such that the lower articulating arms reach the floor of the ocean and start to lay flat thereon (Fig. 7b and 7c), as the ends of the arms move towards the axial center of the riser. The end of the riser may be kept above the well at a distance D of about 10-30 m such that the discharging oil flow has an opening to continue escaping from the well (see Fig. 7d).

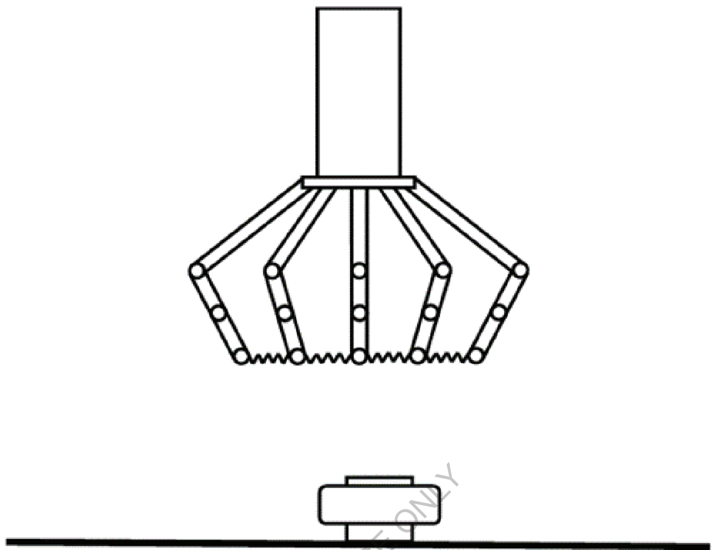


Fig. 7a - Alignment System

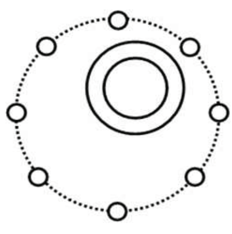


Fig. 7b

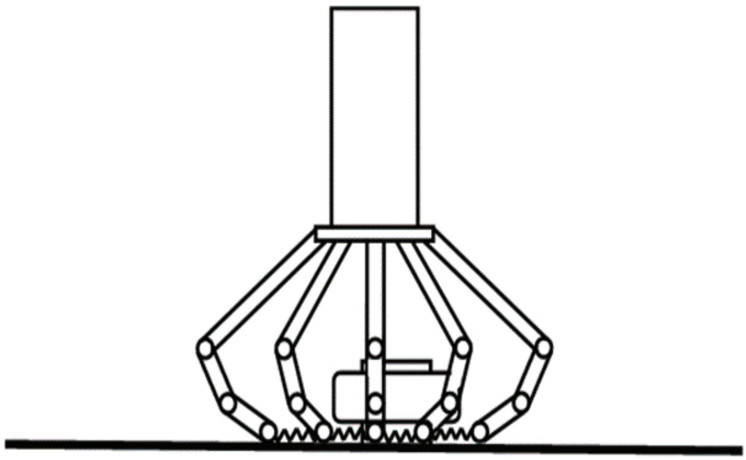


Fig. 7c

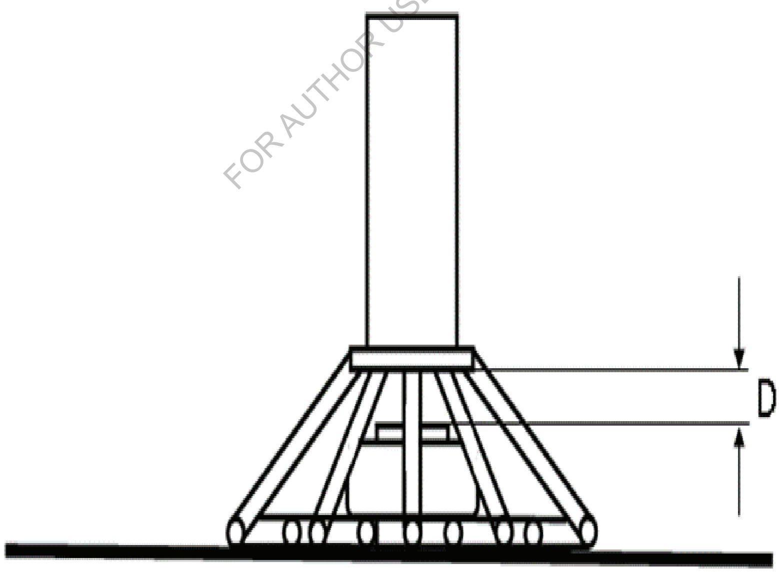


Fig. 7d

The method includes the following steps:

1. Provide a plurality of flow restricting rods of various diameters using either a standard floating rig or a ship located near an offshore platform; Position a riser tube over the drilling tube. Riser tube should have an inner diameter slightly larger than the external diameter of the drilling tube. As a result, the lower end of the riser tube may be placed over the head of the well at a distance of several meters. Alignment and fixation of this riser tube may be accomplished for example using a four-cable brace attached to the outer surface of the head of the well or another method.
2. Place the first flow restricting rod into the riser tube. To accomplish this, the first section of the rod with the length which may be equal or less than the height of the drilling rig, may be lowered using the usual method of lowering tubes. The second section of the rod may then be attached to the end of the first section (such as using a threaded attachment), which may then be lowered into the riser tube.
3. The process of lowering rods and attaching new sections thereto may be repeated until the lower end of the first rod appears suspended from the bottom of the riser tube.
4. Place the lower end of the first rod into the drilling tube at the well opening. To enter the well, it is critically important to keep the weight of the rod exceeding the force pushing it out of the well by at least a small safety margin, between 200-500 kg. If however, such entrance cannot be achieved, the weight of the assembly may be increased by replacing at least some of the upper sections of the assembly with rods of greater weight.
5. The exact location of the point in the rod assembly where there is an increase in rod diameter is selected depending on the specific circumstances of each well using the general principle that the weight of the entire assembly should exceed the forces pushing the assembly out of the well.

6. Additional rods with further increase in diameter are then placed into the well until either the first rod reaches the bottom of the reservoir or until the diameter of the rod matches that of the well so that the fluid flow is gradually reduced to a minimal value (Fig. 8a).
7. To accomplish a permanent closure of the well, the hanging riser tube may be lowered so that the upper section of drilling tube joins the bottom of the riser tube (Fig. 8b). Additional resistance of the suspended riser tube connecting the wellhead to the drilling rig further reduces the flow rate and wellhead pressure at the sea surface.
8. Mortar cement may be fed through the wellhead, which may be pushed into the well until the cement reaches the bottom hole, comes into the annular space of the well and covers the perforated section (Fig. 8c).

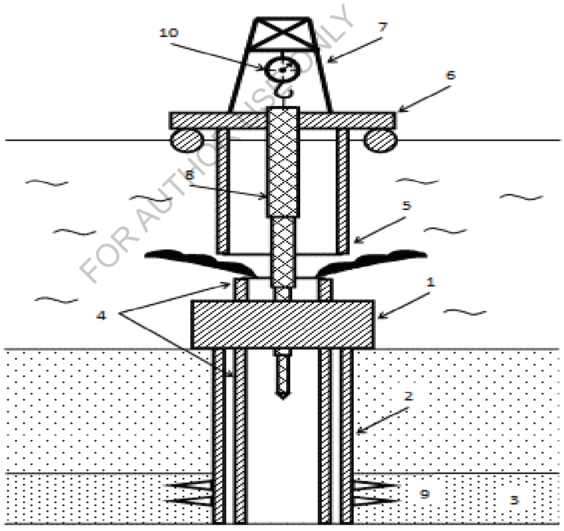
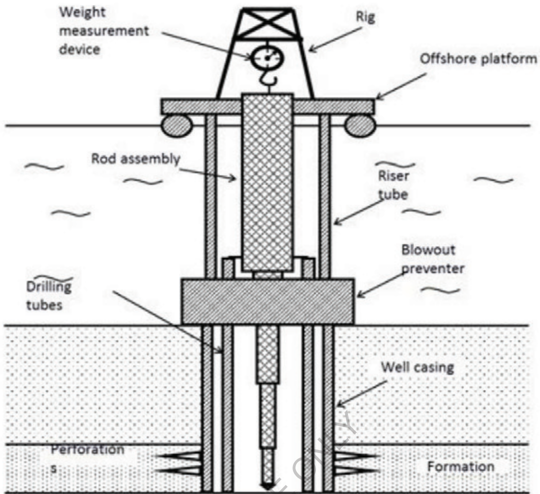


Fig. 8a


Weight
measurement
device
Rig
Offshore platform
Rod assembly
Riser
tube
Blowout
preventer
Drilling
tubes
Well casing
Perforation
s
Formation

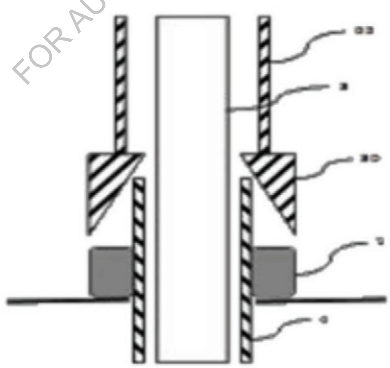


Fig. 8b

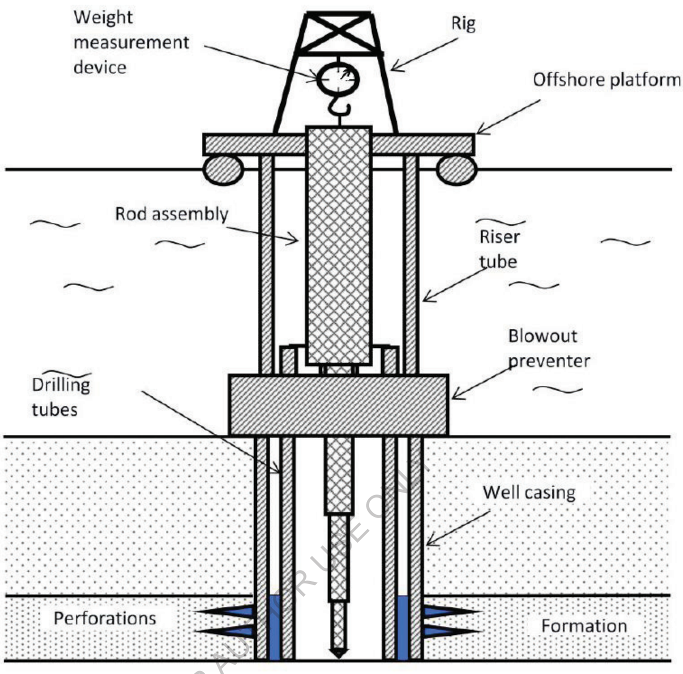


Fig.8c

2.3.4. Method III - Methods and Devices for Restoring Control and Resuming Production at an Offshore Oil Well Following an Uncontrolled Fluid Release After an Explosion (US Patent # 8534363B1)

The flow restricting inserts of the invention may include a series of solid or hollow pipes, which may be attached or inserted one into another. The weight and size of the first insert should be selected such that its weight exceeds the force urging it out of the well. The first insert should be lowered into the well using its weight and not requiring any additional force.

The method includes the following steps:

1. Providing a riser extending from the sea surface, said riser ending above and in vertical alignment with the head of well.
2. Inserting the first flow restricting insert through the riser into the oil well. The first flow restricting insert should be sized to be smaller than the opening of the oil well, thereby reducing the uncontrolled fluid release.
3. Inserting a plurality of successively larger concentric hollow flow restricting inserts through the riser into the oil well, said inserts sliding over the first flow restricting insert, further reducing the uncontrolled fluid release from the oil well.
4. Attaching the riser to the head of well and sealing the connection, thereby restoring control of the oil well and precluding further uncontrolled fluid release. Following attachment of the riser to the oil well, provisions are made to restore oil production from the well during the remaining life of the well.
5. Moving flow restricting inserts up or down may further be used to adjust flow resistance from the well in order to optimize oil production.
6. Passages between the riser and the flow restricting inserts may also be used to form a gas lift in order to maximize production of oil from the well.

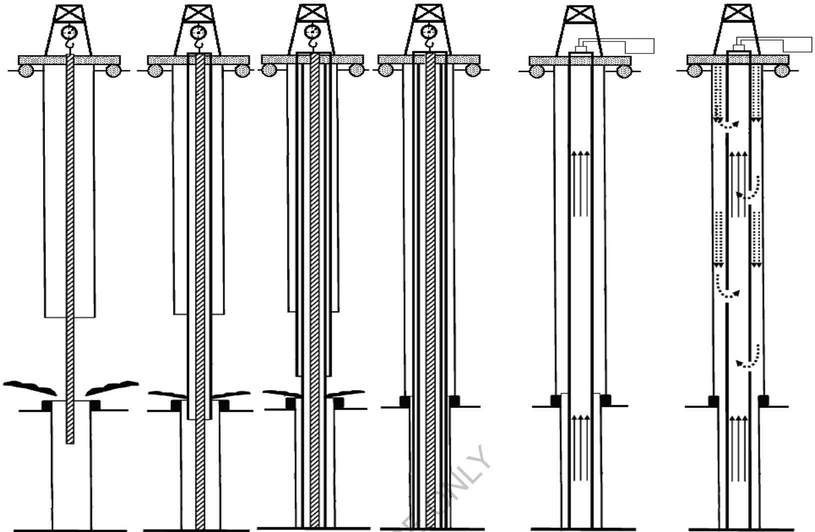


Fig.9 a, b, c, d, e, f

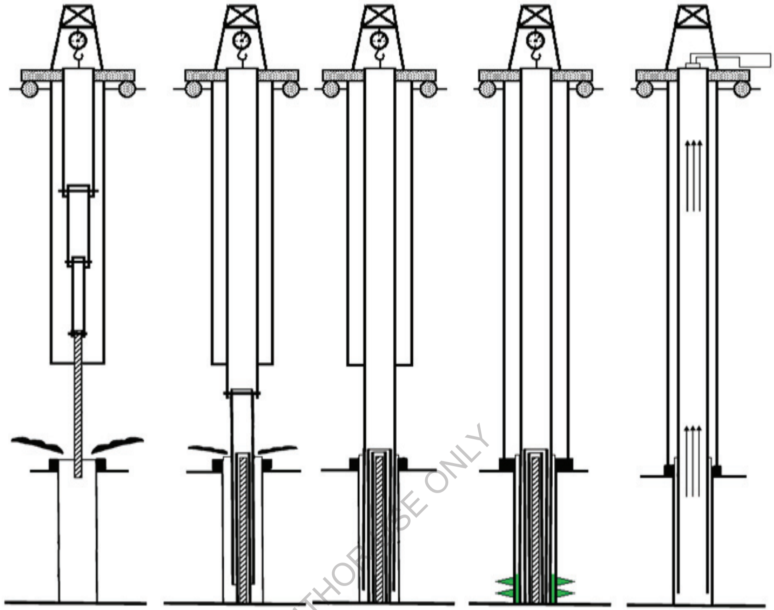


Fig. 10 a, b, c, d, e

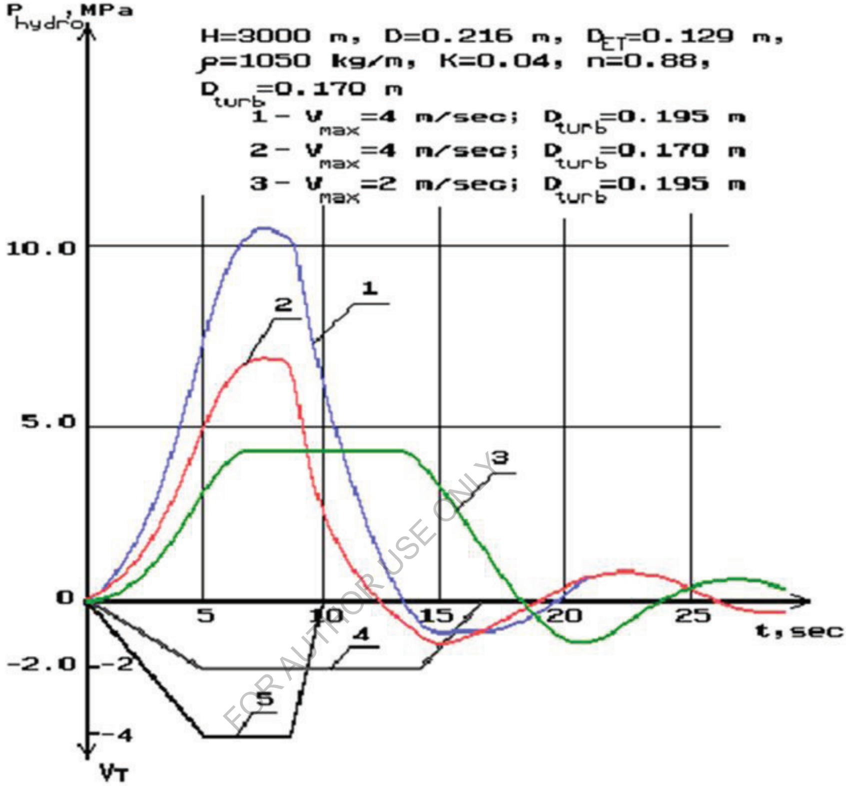
Fig. 10 shows examples of some of the possible embodiments of the method. Fig. 8 a, b, c show the case, when flow restricting inserts form a system similar to a spyglass. Moving flow restricting inserts down allows to change cross section of the well to any size. And in some cases, you can kill emergency well by establishing a cement bridge on its downhole location (Fig. 8d) or by restoring its production by setting corresponding cross-section of the well (Fig. 10e).

3. Library of Simulators

We have also developed several Simulators, which have relation to increasing safety and effectiveness of offshore drilling of wells.

3.1. Swab/Surge Simulator

Our tripping operations Simulator accounts for borehole geometry, drill string composition, fluid compressibility, borehole wall elasticity, mud features and rheology, drill string velocity and acceleration/deceleration . The Simulator can be used in the software package for geological and technical control computerized unit, to determine optimal mode of column tripping in order to decrease hydraulic fracturing risk, reducing invasion zone of formation and borehole wall erosion. The simulator allows to significantly decrease possibility of accidents while drilling and to accelerate borehole building and significantly increase safety of drilling.



P_hydro, MPa
H=3000 m, D=0.216 m, D_ET=0.129 m,
ρ=1050 kg/m, K=0.04, n=0.88,
D_turb=0.170 m
1 - V_max=4 m/sec; D_turb=0.195 m
2 - V_max=4 m/sec; D_turb=0.170 m
3 - V_max=2 m/sec; D_turb=0.195 m
10.0
5.0
0
-2.0
-2
-4
5
10
15
20
25
t, sec
V_T
1
2
3
4
5

Fig. 11

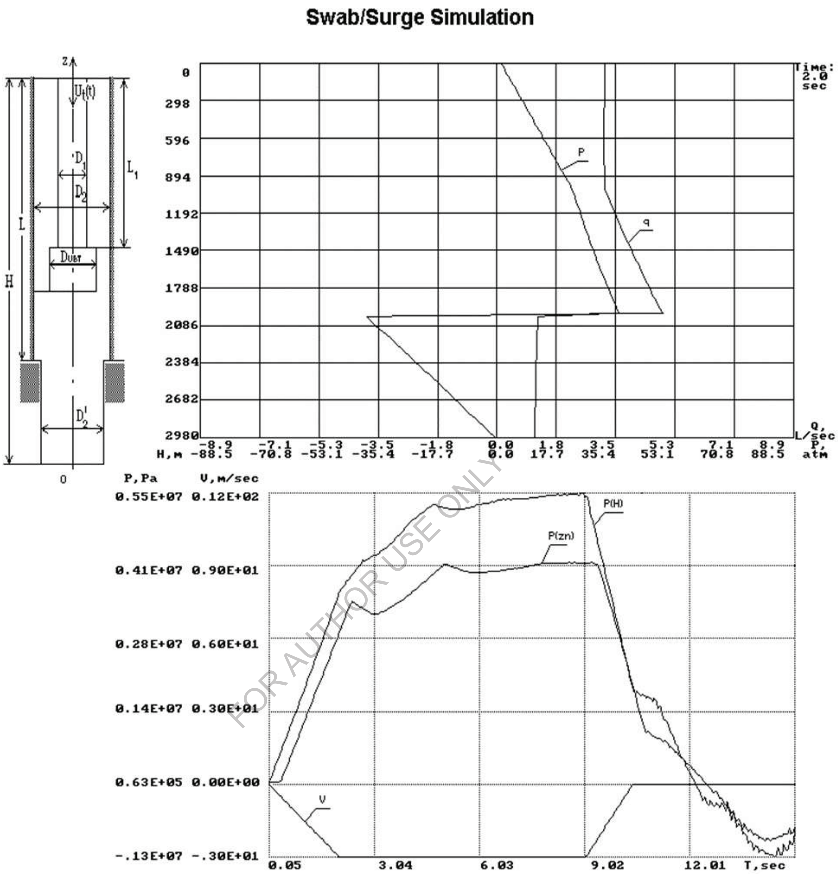


Fig. 12 Results of Simulations

3.2. Simulator of Heat Exchange in Borehole-Formation System.

The simulator allows computing temperature changes in drilling tubes, annular space and surrounding rocks during washing and cementing. It accounts for changes with depth in geometry of drilling tubes and borehole, mud properties and volumetric rate, thermophysical properties and geothermal coefficient of rocks surrounding borehole, presence of formation with changed thermophysical parameters of the rock. The simulator allows quick and precise determination of the temperature distribution in the system, depending on a number of system parameters at any time; it is necessary for borehole monitoring. It can prevent a number of dangerous complications and takes into account temperature influence on mud and cement properties during the borehole washing and cementing.

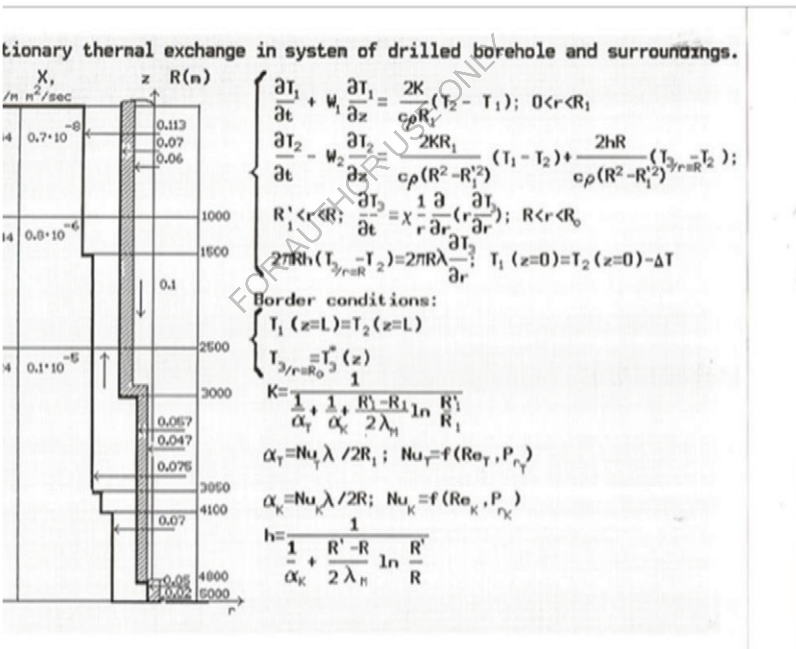


Fig. 13 System of Equations

4. Addendum

4.1. EM MWD Simulators

4.1.1. Method Description

We developed several EM MWD Simulators for vertical, inclined wells, and wells with a horizontal section, that account for multiple layers with different resistivity and permeability values, influence of the drilling fluid, different types of transmitters, receivers and gap configurations. They also account for effect of different casing and drill string configurations, finite resistance and permeability of metal and drill string joints etc.

This simulator has also allowed us to answer a number of important questions, related to the system design and physics of different phenomena observed in the process of operation of EM MWD systems, for example:

1. Compute signal attenuation based on properties of the rock, characteristics of the drilling pipes, signal frequency, etc.
2. Pick optimal signal strength and frequency based on certain parameters of different system components.
3. Determine all electromagnetic parameters and distributions, including E,H,j,□ in the surrounding rock and along the drill string.
4. Calculate impedance of the whole system.
5. Determine the optimal gap size
6. Determine the best drilling fluid.
7. Determine parameters of the receiver.
8. Simulate magnitude, shape, phase shift, and dispersion effects for the signal acquired at the surface.

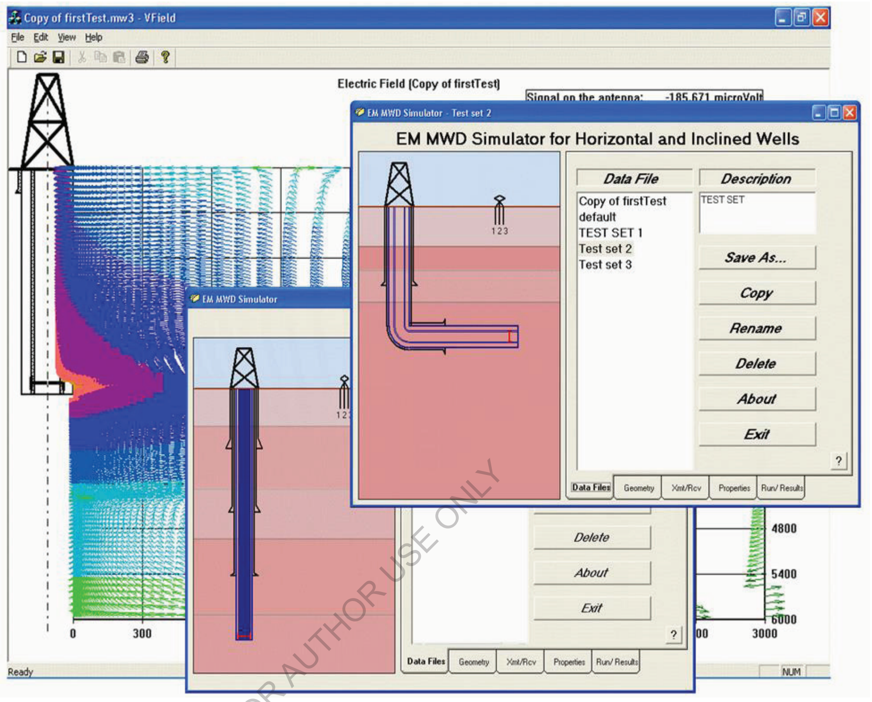

Copy of firstTest.mw3 - VField
File Edit View Help
Electric Field (Copy of firstTest)
EM MWD Simulator - Test set 2
EM MWD Simulator for Horizontal and Inclined Wells
Data File
Description
Copy of firstTest
default
TEST SET 1
Test set 2
Test set 3
TEST SET
Save As...
Copy
Rename
Delete
About
Exit
Data Files
Geometry
Xmt/Rcv
Properties
Run/ Results
EM MWD Simulator
Delete
About
Exit
0
300
3000
4800
5400
6000
Ready
NUM

Fig. 15

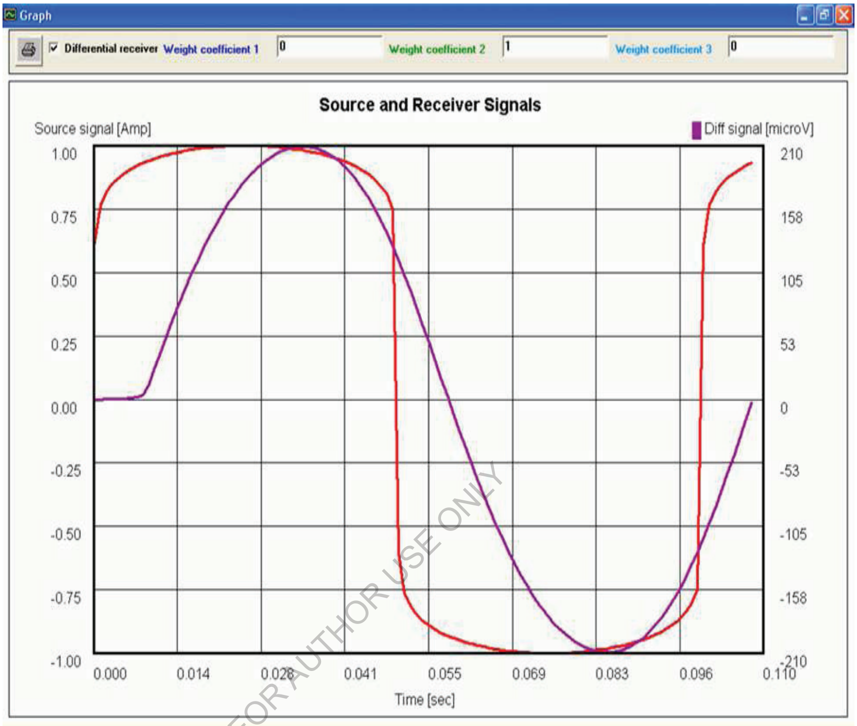


Fig. 16

Simulator EM MWD Telemetry – Results – Transmitted and Received Signals Vs. Time • Red-transmitted signal, • Blue-received signal

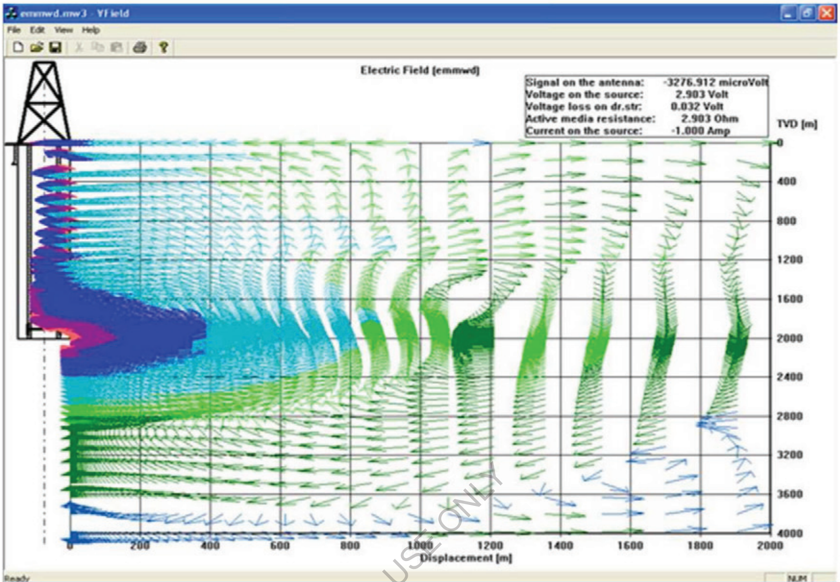


Fig. 17

Simulator EM MWD Telemetry, 2D Electrical Field Distribution Chart: E(r,z)

4.1.2. Background

The Methods presented here are based on the attached Patents: **US 8,235,143B2, US 9885216B2, US 8,448,709, US 8,474,536 B1, US 8,534,363 B1, as well as SPE articles: 166870, 166871, Article with General Electric Comp. "EM MWD TECHNOLOGY ENHANCES UNDERBALANCED DRILLING EFFICIENCY IN MEXICO", 10th Offshore Mediterranean Conference and Exhibition in Ravenna, Italy, March 23-25, 2011**