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A some US Patents and of scientific Articles by Dr. S. D. Tseytlin on the theoretical study of the processes occurring in the well-formation system during geophysical, drilling and production works

Monograph 5

Introduction

Tseytlin Consulting, Inc. specializes in solving complex, scientific and mathematically intensive problems for various applications in the oil and gas industry. We develop new high-performance technologies, high-precision 2D and 3D mathematical models and computer simulators for exploration, drilling and production.

The articles presented here contain materials to improve drilling safety and new methods of optimizing oil production.

Currently, drilling stations are widely used in drilling, which allows, using measured parameters and Simulators (mat modals of processes) to quickly determine parameters and modes of work related to the optimization of oil production and the safety of drilling. This will reduce the likelihood of emissions and explosions of wells, which usually cause loss of life, damage the environment and require enormous costs to shut them down.

In this monograph, we will see some of its results, which will significantly reduce the likelihood of accidents during drilling, accelerate the construction of the well, and significantly improve the efficiency and safety of drilling.

Some US Patents:

1). "Methods and devices for maximizing oil production and oil recovery for oil wells with high gas-to-oil ratio "

Patent number: **US 10435983**

Abstract: A method for maximizing oil production rate from an oil well with high gas-to-oil ratio comprising a step of calculating an optimal bottomhole pressure and determining a well-specific geometry for a flow restrictor located at the bottomhole region of the oil well. The flow restrictor comprises at least a first stage tube and a second stage tube and has a fixed geometry calculated to cause self-regulation of the oil flow conditions so as to maintain the bottomhole pressure at a stable equilibrium level causing maximum oil rate production and increasing ultimate oil recovery from an oil well.

Type: Grant

Filed: January 21, 2019

Date of Patent: October 8, 2019

Inventors: Simon Tseytlin, David Tseytlin

2). "Acoustic methods and devices for determining the value of formation overpressure during drilling and for detecting gas packs containing hydrogen sulfide gas "

Patent number: **US 9885216**

Abstract: A method for determining formation pressure during exploratory drilling for oil includes generating a series of negative pressure shock waves at successively increasing well pressures to characterize gas kick forming at the bottom of a well. Once the lower end of the gas kick has been formed, the well pressure level as detected by a pressure sensor near the surface of the well is used to calculate the formation pressure along with the weight of the fluid column located in the well.

Type: Grant

Filed: May 22, 2016

Date of Patent: February 6, 2018

Inventor: Simon Tseytlin

3). "Methods and devices for restoring control and resuming production at an offshore oil well following an uncontrolled fluid release after an explosion "

Patent number: **US 8534363**

Abstract: Methods and devices for restoring control of at an offshore oil well following an uncontrolled fluid release after an explosion include lowering through a riser of successive flow restricting inserts into the oil well to gradually reduce the uncontrolled fluid release. Flow restricting inserts may be inserted in parallel or in series with each other. Following attachment of the riser to the oil well, provisions are made to restore oil production from the well. Flow restricting inserts may further 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.

Type: Grant

Filed: May 19, 2013

Date of Patent: September 17, 2013

Inventor: Simon Tseytlin

4). Method and alignment system for killing an uncontrolled oil-gas fountain at an offshore oil platform using a telescopic rod assembly

Patent number: **US 8474536**

Abstract: A method and an apparatus for killing of uncontrolled oil fountain include a series of rods with the first rod having the smallest diameter and successive rods having increasing diameters. Such telescopic assembly of rods is lowered into the well to cause gradual reduction in cross-sectional area available for oil flow discharge. Once sufficiently large rods are lowered into the well, the oil fountain discharge will be greatly diminished. Final sealing may be accomplished by pumping cement into a space formed between the well pipe and the rod assembly. A novel system for aligning the rods to the center of the well is also described.

Type: Grant

Filed: November 13, 2012

Date of Patent: July 2, 2013

Inventors: Simon Tseytlin, Alexey S. Kashik

5).” Method of killing an uncontrolled oil-gas fountain appeared after an explosion of an offshore oil platform “

Patent number: **US 8448709**

Abstract: A method for killing an uncontrolled fountain in an oil well following a blowout includes a serial lowering into the well of narrow flow restricting rods, each rod being sufficiently small in diameter to allow its insertion against a high well pressure urging the rods out of the well. Each subsequent rod reduces the cross-sectional area of the well and gradually reduces the flow of fluid discharge out of the well. Once the fountain is sufficiently reduced, the well may be killed using traditional sealing techniques such as pumping cement down the well.

Type: Grant

Filed: July 16, 2011

Date of Patent: May 28, 2013

Inventor: Simon Tseytlin

6).” Methods and devices for determination of gas-kick parameters and prevention of well explosion “

Patent number**: US 8235143**

Abstract: Acoustics-based methods and devices to characterize a gas kick during drilling an oil, gas, or gas condensate well are described. A pressure wave may be generated by abruptly changing the drilling mud pressure in the well, for example at the well head. The pressure wave is allowed to travel down the well, reflect from the well bottom and reach the well head again. Pressure is monitored during this process and a pressure peak is identified. The gas kick is characterized using the width of the pressure peak and time elapsed from the onset of pressure change and appearance of the peak. Negative pressure wave is preferred and may be generated by opening of a fast-acting valve located in the outlet pathway of the drilling mud fluid.

Type: Grant

Filed: March 11, 2011

Date of Patent: August 7, 2012

Inventor: Simon Tseytlin

7). “Bottomhole tool and a method for enhanced oil production and stabilization of wells with high gas-to-oil ratio “

Patent number: **US 7753127**

Abstract: A bottomhole tool and a method for optimizing oil production rate from an oil well with high gas-to-oil ratio and stabilizing thereof in case of occurrence of a gas cone or gas skin conditions are disclosed. The resistance of the adjustable multi-stage flow resistor is determined by a position of a telescoping needle, which in turn is defined by a driving means including a motor and a gearbox. The motor is driven via a cable from a surface by a control means adapted to receive information about the bottomhole parameters from local sensors via a sensor cable. Methodology explaining the principles of maintaining well stability is also disclosed. Automatic adjustment of the bottomhole pressure is maintained over a wide range of operating parameters throughout the life of the well to maximize its oil output.

Type: Grant

Filed: April 16, 2008

Date of Patent: July 13, 2010

Assignee: Tseytlin Software Consulting, Inc.

Inventor: Simon Tseytlin

8). “Oil production optimization and enhanced recovery method and apparatus for oil fields with high gas-to-oil ratio “

Patent number: **US 7172020**

Abstract: A method for optimizing oil production rate from an oil well with high gas-to-oil ratio is disclosed to include modeling an Inflow Performance Relationship curve and calculating an optimal level of bottomhole pressure to be higher than zero. Maintaining the bottomhole pressure at that calculated optimum level by using a bottomhole tool of the invention or other known means such as gas injection provides for maximum oil recovery from a given well. The bottomhole tool includes a multi-stage flow resistor and a needle moved in and out of the resistor by a spring-biased piston responsive to a difference in pressure between a bottomhole pressure and a pipe pressure. Automatic adjustment of the bottomhole pressure is maintained over a wide range of operating parameters throughout the life of the well.

Type: Grant

Date of Patent: February 6, 2007

Assignee: Tseytlin Software Consulting Inc.

Inventor: Simon Tseytlin

Articles

1) SPE-181951-MS

"New Technology of Optimization of Production of Liquid Hydrocarbons from Reservoirs Containing Oil or Condensate with High GOR and Oil Fringes of the Gas Formations"

S. Tseytlin, Dr. of Sc.

Abstract

Over the last 10 years, a new technology has been developed and successfully tested for optimizing production for oil fields with high gas to oil ratio, (GOR), which we will now refer to as TOP (Technology for the Optimization of Production). Both in theory and in practice, we have demonstrated that oil reservoirs with high GOR have a pressure flow rate relationship (IPR) with a clear maximum level. For example, the bottom hole pressure is clearly defined and provides the maximum open flow production on the reservoir. The consequential decline in bottom hole pressure results in decreased oil production, while the gas cut of the produced oil grows. This may be caused by either the gas skin-effect in the bottom-hole area of the reservoir, or the formation of gas coning. Both of these factors result in a decline in production as the bottom hole pressure drops. Basically, as the GOR and water content of the reservoir increases, so the reservoir production declines. Moreover, it was demonstrated that when the bottom pressure drop is below a certain optimal value, conditions emerge under which the well becomes unstable and gas mode occur [2]. This can explain the difficulties that take place with the production of oil and gas condensate from layers of

gas fields that contain oil with a high gas factor. Our interpretation of this phenomenon is as follows.

When you create a difference in pressure and arrive at a certain bottom hole pressure value, let's call it the optimum pressure, gas coning moves up to the casing perforations. As this process takes place, the gas concentration within tubing the fluid starts increasing while the bottom hole pressure decreases more and more, contributing to increased gas coning and a further drop in bottom hole pressure. In other words, positive feedback is taking place here. This ultimately leads to the oil being driven back from the casing perforations and shifting of the well into gas mode.

2) SPE 166870

"A Method and an Apparatus for Killing an Uncontrolled Oil-Gas Fountain at an Offshore Oil Platform Using a Telescopic Rod Assembly"

Simon Tseytlin , Tseytlin Consulting Inc.

Abstract

A method and an apparatus for killing of uncontrolled oil fountain include a series of rods with the first rod having the smallest diameter and successive rods having increasing diameters. Such telescopic assembly of rods is lowered into the well to cause gradual reduction in cross-sectional area available for oil flow discharge. Once sufficiently large rods are lowered into the well, the oil fountain discharge will be greatly diminished. A method of monitoring the conditions of lowering the rods into the well may utilize a weight measuring device mounted at the surface platform. In the case of killing the oil fountain based on the methods of the present method, 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, including the reservoir pressure and the drag force from the flow of oil or a multiphase flow of various gases and fluids coming out from the well. Final sealing may be accomplished by pumping cement into a space formed between the well pipe and the rod assembly. A novel system for aligning the rods to the center of the well is also described. The present method is aimed at making killing of the well safe, fast and inexpensive so as to prevent heavy environmental and financial losses typically associated with dealing with offshore well blowouts.

3) SPE Number SPE-166871

Paper Title : **“Methods and Devices for Determination Of Gas-Kick Parameters And Prevention Of Well Explosion”**

Author : Simon Tseytlin , Tseytrlin Consulting Inc.

Abstract

The acoustic methods and devices is intended for early detection , location and others parameters of the gaseous packet (gas kick) is determinated uprising in the annulus of the well during gas blowouts. 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 and arrival time of the gaseous packet is determined by the arrival time of the reflected signals. The information obtained this way is used for taking a decision whether to resume drilling or to take 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. The tool is recommended to be incorporated in well-logging units, MWD systems and also as a stand-alone tool among the other instruments used at the well site. The tool makes it possible not only to ensure safety during drilling, but also to facilitate the introduction of the state-of-the-art drilling technologies based on reduction of the bottom-hole differential pressure.

4). **AARG, March 10-13, 2002, Houston, Texas**

"Successful Application of a New Oil Production Optimization System at the Kokdumalak Field in Uzbekistan"

ABSTRACT

Kokdumalak is a major oil and gas field in Uzbekistan with an annual oil production of 29 MMB/year. The reservoir is formed by an Upper Jurassic pinnacle reef with high average porosity (17-25%) and permeability of 200ñ500 mD.

After 15 years of production, the output of certain wells has declined 50% from a level of 1500 bpd, and the water cut is as high as 20%. The field's SE part has gas breakthroughs from the gas cap. The GOR has risen from 1000 to 4500-18000 scf/bbl.

A demonstration of a new oil production optimization system (POS) that began at Well 289 produced the following results: daily oil production up from 780 to 920 bpd (+18%), GOR down from 6000 to 4500 scf/bbl (-15%), and the water cut has fallen to zero and stayed there. These results were achieved by installing a downhole POS device in the tubing that generates additional variable hydrodynamic drag, which automatically maintains an optimal bottom hole pressure and stabilizes the well's performance. This

made it possible to reduce the skin effect in the bottomhole zone and eliminate gas and water cones from perforations. The use of the POS at Well 289 yielded approximately 37,500 additional barrels of oil over a nine-month period.

5). SPE 51097

"An Efficient Method for Enhanced Oil Production Providing an Increase in Oil Recovery"

Abstract

PEnTechnology was developed for high-GOR oil fields. The target was the optimization of well-formation system by means of maintenance of bottomhole pressure and supporting fluid lift. The technology applies an individual approach to each well, based on analysis of numerous parameters and data, computer simulation of well-formation system and sizing calculation for the technology's BH tools.

Patents::

US010435983B1

c12) **United States Patent**

Tseytlin et al.

(10) **Patent No.:** **US 10,435,983 Bl**

(45) **Date of Patent:** **Oct. 8, 2019**

(54) **METHODS AND DEVICES FOR MAXIMIZING OIL PRODUCTION AND OIL RECOVERY FOR OIL WELLS WITH HIGH GAS-TO-OIL RATIO**

(71) Applicants:Simon **Tseytlin,** Middle Village, NY (US); **David Tseytlin,** Brooklyn, NY (US)

(72) Inventors: **Simon Tseytlin,** Middle Village, NY (US); **David Tseytlin,** Brooklyn, NY (US)

(*) Notice: Subject to any disclaimer, the term ofthis patent is extended or adjusted under 35 U.S.C. 154(b) by O days.

(21) Appl. No.: **16/253,116**

(22) Filed: **Jan. 21, 2019**

(51) **Int. Cl.**

E21B 34106	(2006.01)
E21B 17100	(2006.01)
E21B *47106*	(2012.01)
E21B 34/02	(2006.01)

(52) **U.S. Cl.**

CPC ***E21B*** *34106* (2013.01); ***E21B*** *17100* (2013.01); ***E21B*** *47106* (2013.01); *E21B 34/02* (2013.01)

(58) **Field of Classification Search**

CPC E21B 17/00; E21B 34/02; E21B 34/06; E21B 34/08; E21B 34/101; E21B 34/105; E21B 43/121; E21B 47/06

See application file for complete search history.

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U.S. PATENT DOCUMENTS

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5,967,234	A	10/1999	Shaposhnikov
7,172,020	B2	2/2007	Tseytlin
7,753,127	B2	7/2010	Tseytlin

Primary Examiner - Robert E Fuller

Assistant Examiner - Christopher J Sebesta

(74) *Attorney, Agent, or Firm* - Boris Leschinsky

(57) **ABSTRACT**

A method for maximizing oil production rate from an oil well with high gas-to-oil ratio comprising a step of calcu- lating an optimal bottomhole pressure and determining a well-specific geometry for a flow restrictor located at the bottomhole region of the oil well. The flow restrictor comprises at least a first stage tube and a second stage tube and has a fixed geometry calculated to cause self-regulation of the oil flow conditions so as to maintain the bottomhole pressure at a stable equilibrium level causing maximum oil rate production and increasing ultimate oil recovery from an oil well.

16 Claims, 6 Drawing Sheets

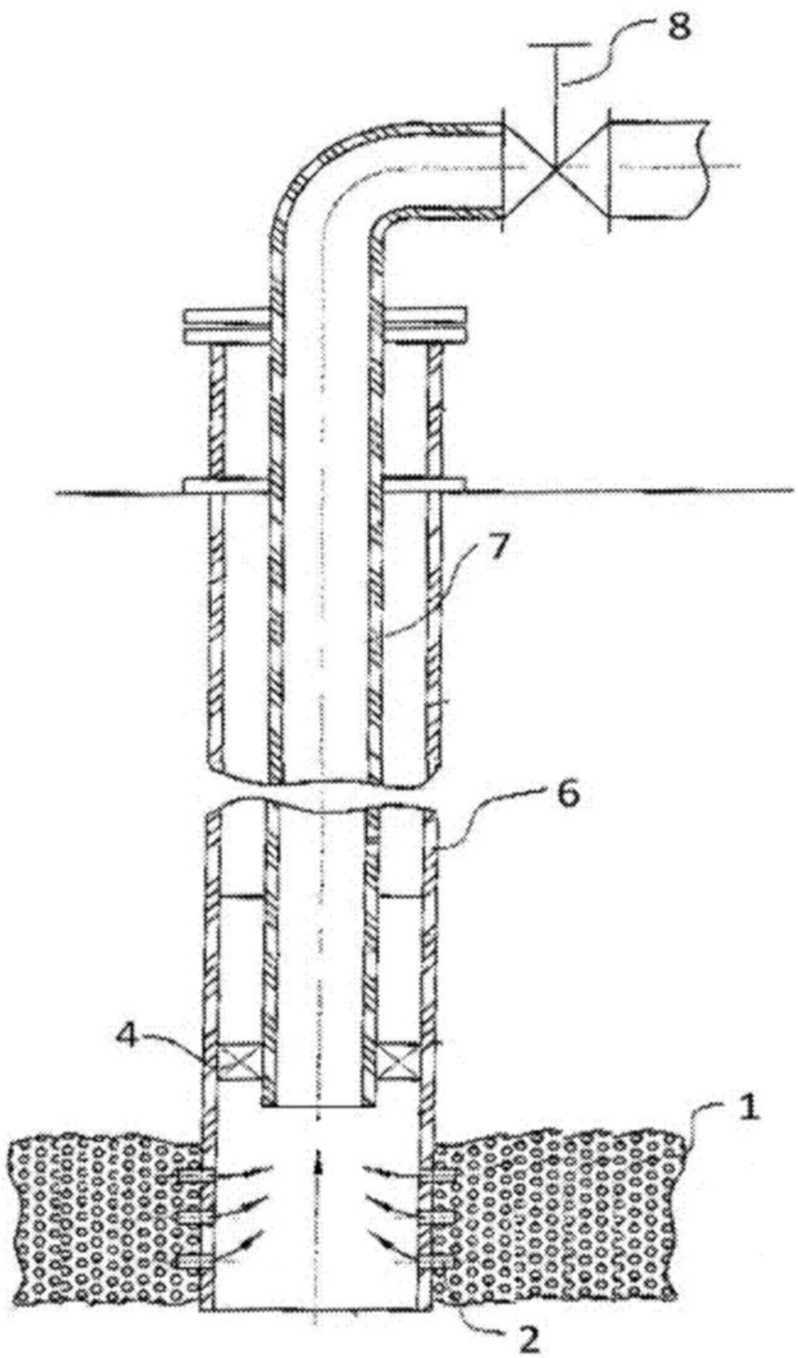
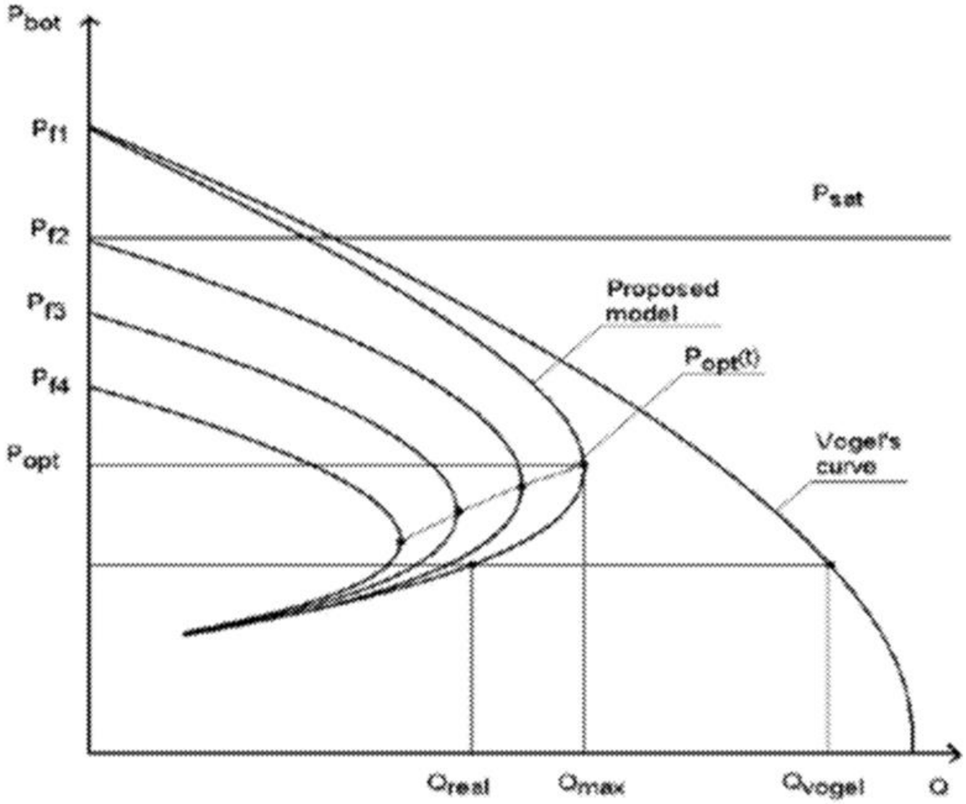


FIG. 1 (PRIOR ART)



P_{bot}
P_{f1}
P_{sat}
P_{f2}
Proposed model
P_{f3}
$P_{opt}^{(t)}$
P_{f4}
P_{opt}
Vogel's curve
Q_{real}
Q_{max}
Q_{vogel}
Q

Fig. 2

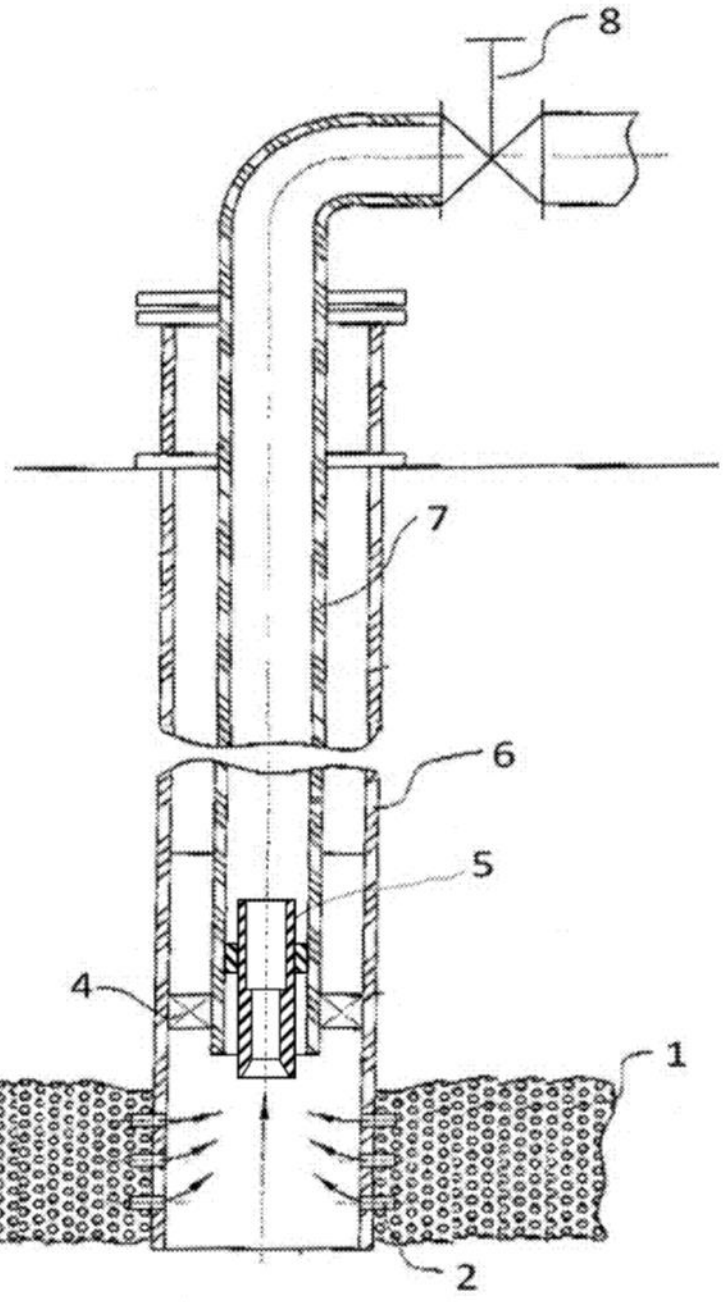


Fig. 3

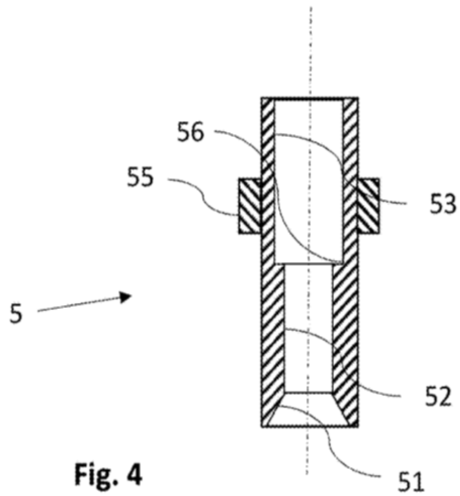

56
55
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Fig. 4

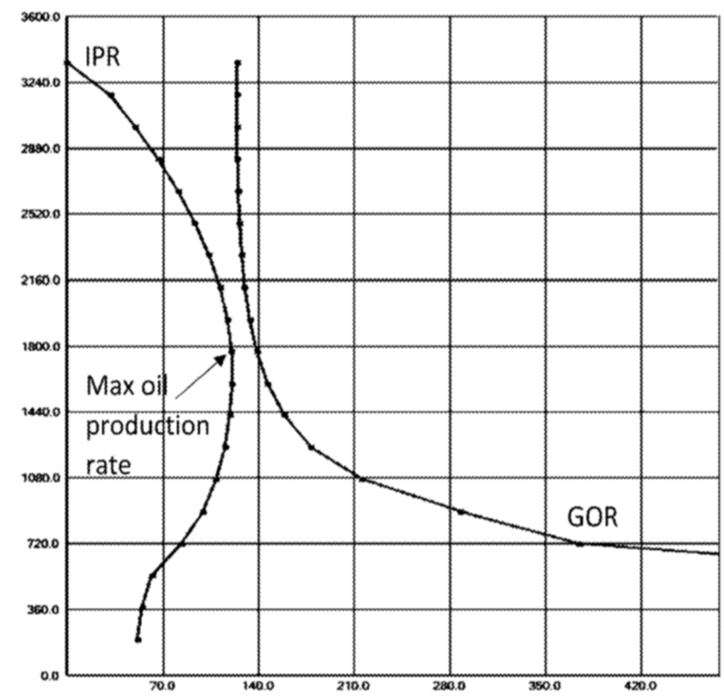
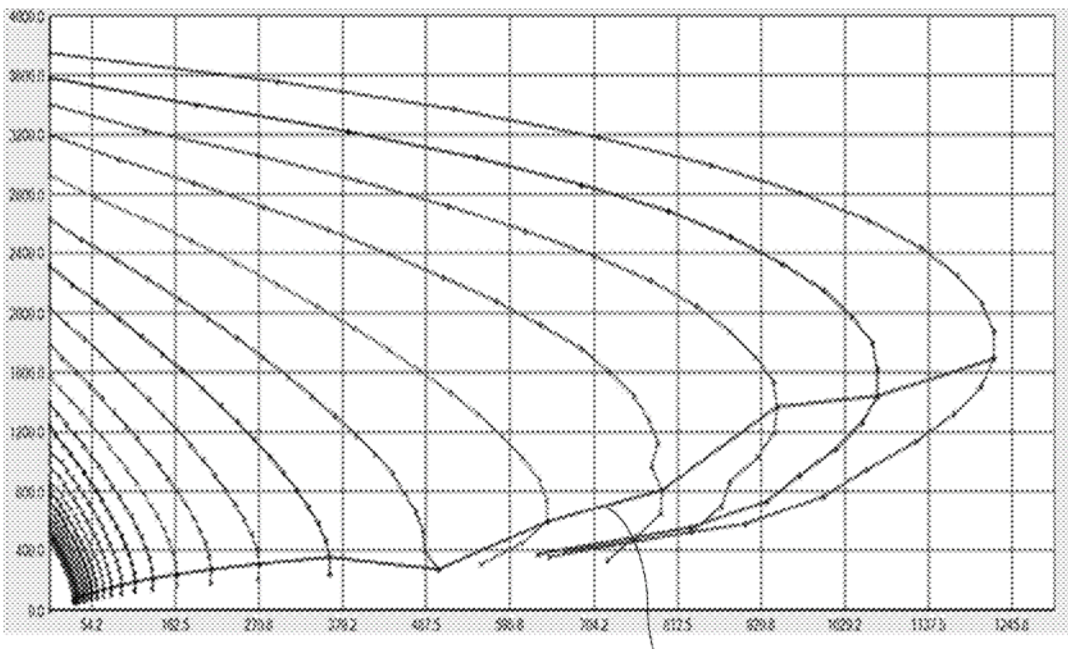

3600.0
3240.0
2880.0
2520.0
2160.0
1800.0
1440.0
1080.0
720.0
360.0
0.0
70.0
140.0
210.0
280.0
350.0
420.0
IPR
Max oil production rate
GOR

Fig. 5



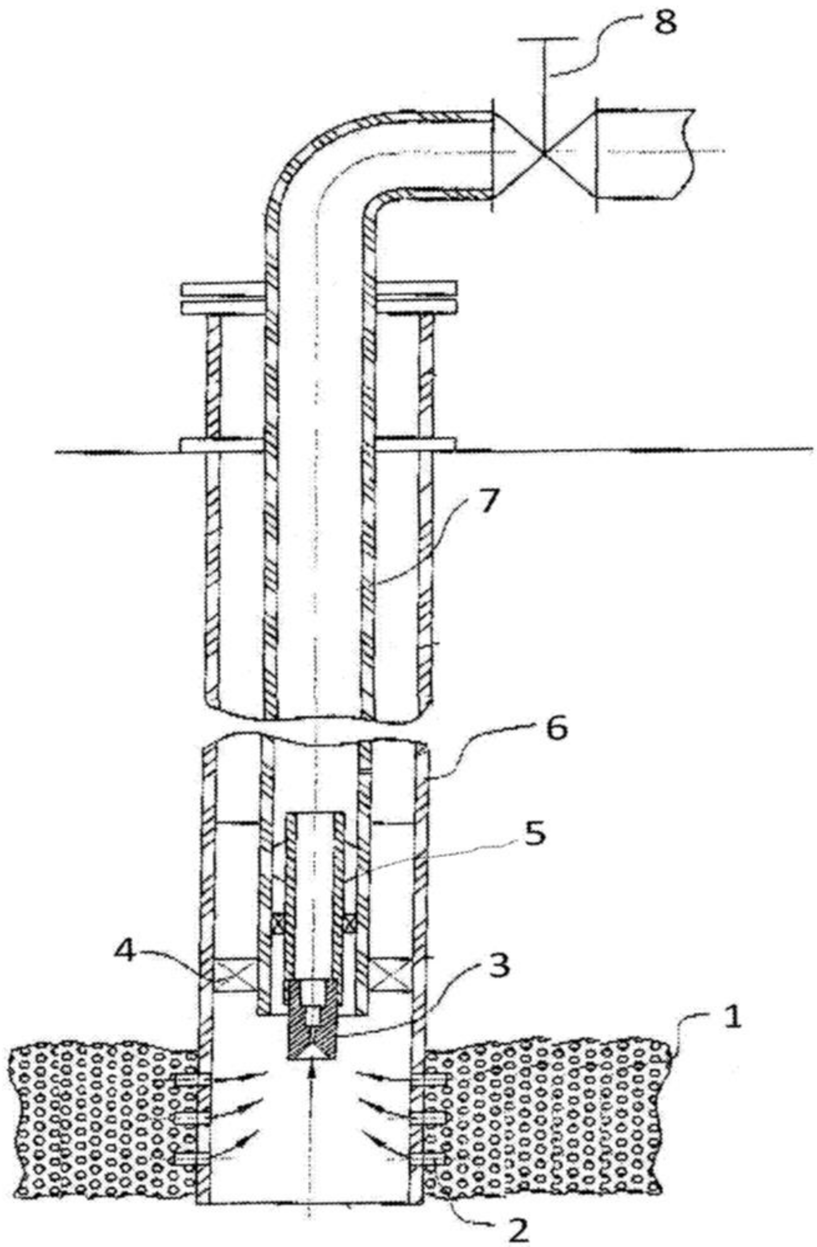


Fig. 6

B

METHODS AND DEVICES FOR MAXIMIZING OIL PRODUCTION AND OIL RECOVERY FOR OIL WELLS WITH HIGH GAS-TO-OIL RATIO

BACKGROUND

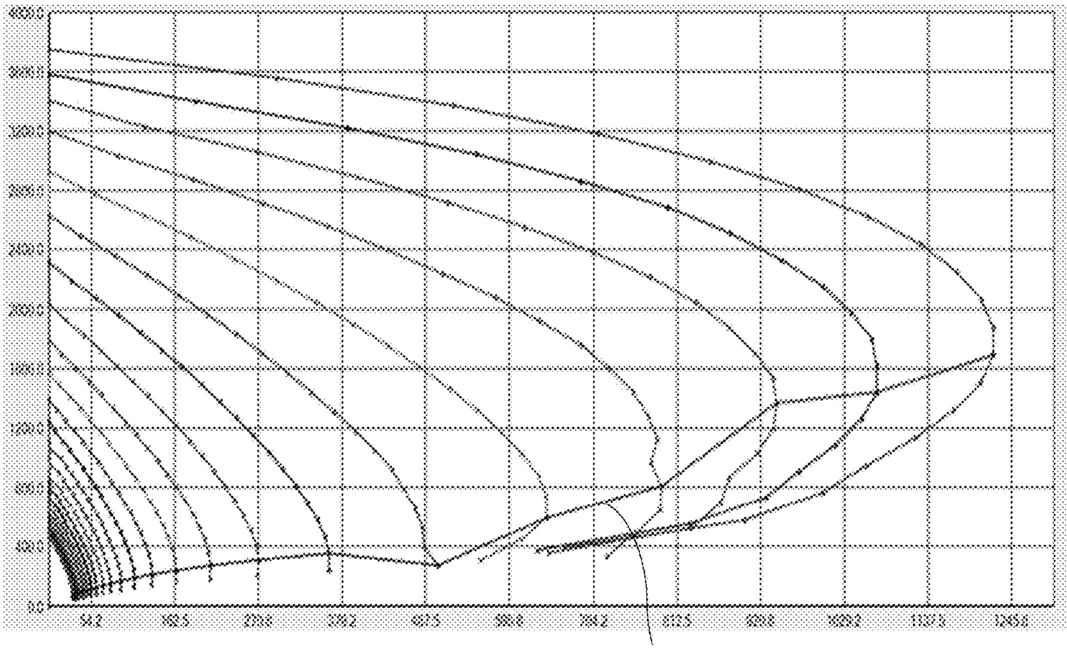
Abstract

Over the last 10 years, a new technology has been developed and successfully tested for optimizing production for oil fields with high gas to oil ratio, (GOR), which we will now refer to as TOP (Technology for the Optimization of Production). Both in theory and in practice, we have demonstrated that oil reservoirs with high GOR have a pressure flow rate relationship (IPR) with a clear maximum level. For example, the bottom hole pressure is clearly defined and provides the maximum open flow production on the reservoir. The consequential decline in bottom hole pressure results in decreased oil production, while the gas cut of the produced oil grows. This may be caused by either the gas skin-effect in the bottom-hole area of the reservoir, or the formation of gas coning. Both of these factors result in a decline in production as the bottom hole pressure drops. Basically, as the GOR and water content of the reservoir increases, so the reservoir production declines. Moreover, it was demonstrated that when the bottom pressure drop is below a certain optimal value, conditions emerge under which the well becomes unstable and gas mode occur [2]. This can explain the difficulties that take place with the production of oil and gas condensate from layers of gas fields that contain oil with a high gas factor. Our interpretation of this phenomenon is as follows.

When you create a difference in pressure and arrive at a certain bottom hole pressure value, let's call it the optimum pressure, gas coning moves up to the casing perforations. As this process takes place, the gas concentration within tubing the fluid starts increasing while the bottom hole pressure decreases more and more, contributing to increased gas coning and a further drop in bottom hole pressure. In other words, positive feedback is taking place here. This ultimately leads to the oil being driven back from the casing perforations **and shifting of the well into gas mode.**

Our technology makes it possible, with the use of a special bottom-hole device, to diminish the positive feedback, and, while maintaining bottom-hole pressure at certain optimal levels, to prevent the phenomenon described above. On the other hand, the TOP technology makes it possible to increase the condensate flow rate and productive capacity of gas condensate fields.

It is well known that as gas condensate fields are developed, its bottom hole pressure drops. Because of this fact, due to its **retrograde behavior,** it starts liquating. This process takes place, most intensively, at the bottom of the formation, which is normally lower than the pressure of the formation itself. As a result of this, skin effect takes place in the bottom of formation. In other words, there is an accumulation of liquid condensate which prevents gas from leaving the formation and, accordingly, well production decreases and there is a danger that



\'- Optimal bottomhole
pressure curve

METHODS AND DEVICES FOR MAXIMIZING OIL PRODUCTION AND OIL RECOVERY FOR OIL WELLS WITH HIGH GAS-TO-OIL RATIO

Without limiting the scope of the invention, its background is described in connection with oil production. More particularly, the invention describes methods, computer models, and related devices aimed at maintaining the highest possible oil production for an oil well with high gas-to-oil ratio over the lifetime of the oil well.

The most advantageous implementation of the present invention is in wells with high Gas-to-Oil Ratio (GOR) defined as GOR greater than about 100 cubic meters of gas over cubic meters of oil, which is sometimes also referred to in other units as about 600 cubic feet of gas per barrel of oil, which is the same as above. Such oil wells may exhibit high and increasing production of gas accompanied by low and decreasing production of oil. In extreme cases, a gas flow regime may be formed with no oil exiting the oil well altogether---even despite adjustments of the surface choke, including either closing or opening thereof. At some point, the gas flow regime may exhaust the reservoir formation pressure and preclude any further oil production, whereby severely limiting a total oil recovery from a particular oil well and even from a particular reservoir formation. This invention contains further improvements of my earlier U.S. Pat. Nos. 7,172,020 and 7,753,127, incorporated herein in their respective entireties by reference.

A conventional oil well is illustrated in FIG. **1** and includes an oil reservoir formation**,** which is reached by an oil well casing with perforations allowing oil to enter the internal space of the casing**.** An oil well tube is lowered into the casing and fixed at the bottom hole region by spacers or other suitable means. The oil well tube extends to the surface of the well with an adjustable surface choke being used to control the flow of oil and gas from the oil well tube**.**

Optimization of oil production and increase in ultimate oil recovery from an oil well has been a goal of many innovative methods and devices of the prior art. Generally speaking, the bottom hole behavior of oil mixed with gas (and some other ingredients such as water, etc.) has been described in a series of mathematical equations by Muskat. One specific publication by Muskat is incorporated herein by reference in its entirety and describes the mathematical model of oil reservoir: Muskat M. "The Production Histories of Oil Producing Gas-Drive Reservoirs", published in the Journal of Applied Physics in March of 1945, p. 147-159.

For illustration purposes, a unidimensional axisymmetric system of Muskat equations with corresponding PVT characteristics of fluid and dependencies of relative permeability Kr ,K, g from liquid saturation (S) can be described as gas in oil; B oil formation volume factor; Bg-gas formation volume factor; μ -oil viscosity; μg-gas viscosity; cp- formation porosity; K-formation permeability. For practical purposes, Vogel had simplified the Muskat equations and adapted them to the calculations of oil producing formations. These equations are known as Vogel model and have subsequently been modified by others. One example of such publication is as follows: Vogel, *Inflow Performance Relationships for Solution-Gas Drive Wells*, as published in Journal of Petroleum Technology, January 1968, pp. 83-92, incorporated herein in its entirety by reference. Unfortunately, Vogel model does not work well in wells with high gas-to-oil ratio. According to Vogel, the dependency of oil rate production of bottomhole pressure is a constantly diminishing parabolic curve with a production peak at zero value of the bottomhole pressure, see for example FIG. **2** of the above-mentioned article. In other words, the lower the bottomhole pressure, the higher the oil rate production from the formation. This is a gross simplification of the bottomhole processes in the formation. In fact, if the bottomhole pressure falls below saturation pressure in case of high GOR, relative permeability coefficient by oil decreases because of gas saturation increase, which in turn is a result of gas being released from oil. Viscosity of so degassed oil also increases.

This leads to a decrease of productivity index of formation. This phenomenon affects the oil production rate more than the increasing depression. As a result, decreasing of the bottomhole pressure below saturation pressure can lead to a decrease in oil production rate, rather than to its increase as predicted by Vogel’s model, see FIG. **2.** In some extreme cases, reliance on Vogel's model will cause a complete switch in production from oil to gas. There is a need therefore for a method allowing calculating the oil production rate in high GOR wells with better accuracy then that allowed by Vogel's model.

It is also known that producing oil wells with high GOR (Gas-to-Oil Ratio) often lose their stability, and this process is accompanied by a sharp increase in GOR. Any attempts to stop this process by using a surface choke or other surface manipulations usually fail, and the oil well gradually switches into a gas production mode. The physics of this process can be explained as follows: in case when a gas cone covers some holes of a perforated section of the well casing, quite often that oil well loses stability. This, in turn, leads to a continuing slow increase of the cone height followed by an increase in the gas stream and a decrease in the oil flow. This process continues until the well is completely switched to a gas mode. Even if a switch to a gas mode does not happen, the instability of the well does not allow efficient control of the bottomhole pressure by using a choke at the surface. Similar detrimental phenomena can occur because of formation of a gas skin effect near the bottom of the well.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{k_{ro}}{\mu_o B_o}\frac{\partial p}{\partial r}\right) = -158.064\frac{\phi}{k}\frac{\partial}{\partial t}\left(\frac{S_o}{B_o}\right)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\frac{k_{rg}}{\mu_g B_g} + \frac{Rs}{5.615}\frac{k_{ro}}{\mu_o B_o}\right)\frac{\partial p}{\partial r}\right] = -158.064\frac{\phi}{k}\frac{\partial}{\partial t}\left(\frac{S_g}{B_g} + \frac{S_o}{B_o}\frac{Rs}{5.615}\right)$$

The physics of the skin effect is described in detail in my U.S. Pat. No.7,172,020. It also shows that this phenomenon leads to a non-conventional shape of the IPR curve (Inflow Pressure Relationship, i.e. the dependence of well oil flow rate of the bottomhole pressure). A notable feature of this curve is the presence of a certain threshold value of the bottomhole pressure (called "Pop,-optimal pressure"), at which the greatest possible oil flow rate from a reservoir can be achieved (FIG. **2).**
The need exists therefore for methods and devices for continuously producing oil at a maximum possible rate over the lite of the oil well in a stable and predictable manner - including in oil wells in high GOR and even in the presence of gas cone and gas skin effects.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to overcome these and other drawbacks of the prior art by providing novel methods for maximizing oil recovery from an oil well with high GOR.
It is another object of the present invention to provide methods and devices for maximizing oil production from an oil well without the need to adjust the bottomhole parameters with changing reservoir conditions.
It is a further object of the present invention to provide a mathematical model to determine the optimal level of bottomhole pressure for an oil well producing oil at a maximum rate.
It is yet a further object of the present invention to provide a mathematical model for calculating the optimal level of bottomhole pressure to assure the maximum rate of oil production over the lifetime of the oil well.
The method of the inventions in general comprises the steps of calculating an optimal level of bottomhole pressure 20 for a given oil well and determining an optimal design for a well-specific flow restrictor. The flow restrictor is designed to assure the bottomhole pressure remaining at the optimal level when the oil well is producing oil following installation of the flow restrictor at the bottomhole region of the oil well. FIG. **7** is an exemplary chart showing a family of IPR curves calculated for an oil well over the lifetime thereof.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

The following description sets forth various examples along with specific details to provide a thorough understanding of claimed subject matter. It will be understood by those skilled in the art, however that claimed subject matter may be practiced without one or more of the specific details disclosed herein. Further, in some circumstances, well known methods, procedures, systems, components.

The geometry of the flow restrictor may be selected to assure a stable equilibrium of the bottomhole pressure despite changing reservoir conditions so that none or only circuits have not been described in details in order to avoid unnecessarily obscuring claimed subject matter. In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be minimal adjustments of the surface choke may be sufficient for maximizing oil production rate for an extended period of time.

The flow restrictor is further designed to have no moving parts or other ways to adjust its geometry-so that the operation of such oil well equipped with the flow restrictor of the present invention is greatly simplified, while avoiding interruptions in oil production typically needed for adjustment of the bottomhole equipment of the prior art.

BRIEF DESCRIPTION OF THE DRAWINGS

Subject matter is particularly pointed out and distinctly claimed in the concluding portion of the specification. The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope, the disclosure will be described with utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly

contemplated and make part of this disclosure.
As illustrated in FIG. **2,** it was unexpectedly discovered that oil production in oil wells with high GOR does follow the gradually declining Vogel curve as a function of bottomhole pressure, but rather exhibits a certain maximum at the point of optimal bottomhole pressure level. The optimal level of bottomhole pressure may differ from the initial point over the life of the oil well but in general can be calculated using a mathematical model of oil production accounting the reservoir as well as the oil well parameters.

Additional specificity and detail through use of the accompanying drawings, in which:
FIG. **1** is a general side view of the oil well of the prior art, It was also unexpectedly discovered that in order to maintain the operation of the oil well at the calculated optimal point of maximum oil production, there is a need to install a certain flow restrictor at the bottom of the oil well-which allows for reaching that maximum rate of oil production and adjustment of the bottomhole pressure using a surface choke, if necessary.

While conceptually the use of a bottomhole flow restrictor has been FIG. **2** is a pressure-flow chart showing a comparison of the prior art Vogel and novel proposed relationship of the bottomhole pressure and the rate of oil production,

FIG. **3** shows schematically the location and a general design of the flow restrictor placed at the bottomhole region of an oil well,

FIG. **4** shows a close-up of the restrictor shown in FIG. **3,**

FIG. **5** shows an IPR curve overlaid with a GOR curve for a proposed oil well with the flow restrictor of the invention positioned therein,

FIG. **6** shows an alternative design of the flow restrictor of the present invention with a plurality of additional stages, and described in my previous patents, its design was complicated and accounted for a perceived need to adjust its geometry from a surface of the well, making the flow restrictor complex and expensive in manufacturing.

The present invention improves on that concept and describes a novel flow restrictor with fixed geometry which has no moving parts and does not require adjustments caused by operation of the flow restrictor from a surface of the well. The novel fixed geometry flow restrictor **5** of the present invention is generally shown at the bottomhole region of the oil well in FIG. **3,** with the enlarged illustration thereof in FIG. **4.**

In embodiments, the flow restrictor **5** comprises at least two sections, a first (lower) stage tube **52** and a second (upper) stage tube **53.** The area of flow entrance **51** into the first stage tube **52** may feature a gradual transition such as a tapered transition as shown in the drawings. The flow restrictor **5** may be fixed at the bottom of the oil well using spacers **54.** At least in some embodiments, a transition between the first stage **52** and the second stage **53** may be abrupt and feature a stepped enlargement in geometry **56.**

1. Both first and second stage tubes **52** and **53** may be calculated to have certain dimensions which are specific for a particular oil well and a particular oil reservoir. In general, the geometry of the flow restrictor may be determined to satisfy all of the following criteria: the pressure drop across the flow restrictor **5** may not exceeding about 12% of a current reservoir formation pressure while the oil well is producing the oil at the maximum oil flow rate. The embodiments, the pressure, drop across the flow restrictor **5** may be anywhere between 1% and 12%, such as 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12%, or any value in between as the invention is not limited in this regard;

2. The first stage tube may be round, oval, or any other suitable shape in its cross-section. It may also have a constant cross-sectional shape and size along its length or variable cross-sectional shape and size along its length as long as it satisfies the first criteria. For simplicity, the guidance for the shape of the first stage 20 tube may be provided as a diameter and a length, which may be calculated differently for different classes of oil wells as follows:

for oil wells producing less than about 100 barrels of oil per day, the first stage tube may have a diameter from about 2 mm to about 4 mm such as 2, 2.5, 3, 3.5, 4 mm or any value in between; while the length of the first stage tube may be selected to be from about 4 cm to about 6 cm, such as 4, 4.5, 5, 5.5, 6 cm or any number in between;

for oil wells producing higher levels of oil such as about 100 to 1,000 barrels of oil per day, the first stage tube may have a diameter from about 4 mm to about 8 mm such as 4, 5, 6, 7, 8 mm or any number in between; and a length from about 6 cm to about 8 cm such as 6, 6.5, 7, 7.5, 8 cm or any value in between;

and finally for oil wells producing over 1,000 barrels of oil per day, the first stage tube may have a diameter from about 8 mm to about 20 mm such as 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 mm or any number in between; and a length from about 8 cm to about 10 cm such as 8, 8.5, 9, 9.5, 10 cm or any value in between;

3. The second stage tube may be selected with a diameter about 1.05 to 1.5 times greater than the diameter of the first stage tube such as 1.05, 1.1, 1.15, 1.2, 1.25, 1.3, 1.35, 1.4, 1.45, 1.5 times greater of any value in between and a shorter length of about 0.5 to 0.95 times the length of the first stage tube such as 0.5, 0.6,

0.7, 0.8, 0.9, 0.95 or any value in between.

4.

The novel method of the invention may therefore include a step of calculating the optimal level of the bottomhole pressure, providing a flow restrictor as described above, installing the flow restrictor at the bottomhole region of the oil well and producing oil with this flow restrictor in place. The step of determining the geometry of the flow restrictor **5** may include a step of calculating oil flow and gas flow parameters throughout the flow restrictor **5** and the oil well **7** by using a mathematical model of two-phase flow proceeding in three consecutive flow regimes:

i. a first flow regime starting from the oil reservoir and proceeding through a first stage tube **52** of the flow restrictor **5;**

ii. a second flow regime proceeding through the second stage tube **53** of the flow restrictor **5;** and

iii. a third stage flow regime proceeding after exit from of flow from the second stage tube **53** and traveling through the remaining portion of the oil well **7,** whereby flow exit conditions from the preceding flow regime form a corresponding set of entry conditions for the subsequent flow regime.

In embodiments, the same set of mathematical equations may be used to calculate flow regime and parameters at each of the first flow regime, the second flow regime, and the third flow regime. For example, a mathematical model of a two-phase flow regime in a cylindrical tube may be used for that purpose. Exemplary mathematical equations for such two-phase flow calculations may be found in Aziz K. and el., The Journal of Canadian Petroleum Technology, July-Sep- tember 1972, p. 38-49, entitled "Pressure Drop in Wells Producing Oil and Gas". In oil wells where water is present in substantial amounts in addition to oil and gas, mathematical equations describing a three-phase flow may be used. Since every flow regime may be calculated individually, the optimal bottomhole pressure level may be calculated as a sum or respective consecutive pressure drops of the first flow regime, the second flow regime, and the third flow regime. To satisfy the first condition listed above, such sum of pressure drops over 25 the three flow regimes may be selected to be not less than about 88 percent of the current reservoir formation pressure. FIG. **6** shows further embodiments of the present invention where a third stage or more stages may be added to the flow restrictor **5,** for example as a separate attachment **3.** The third stage dimensions may be determined for example in relationship to the second stage dimensions as follows: the third stage tube diameter may be selected to be about 1.05 to 1.5 times greater than the diameter of the second stage tube such as 1.05, 1.1, 1.15, 1.2, 1.25, 1.3, 1.35, 1.4, 1.45, 1.5 times greater of any value in between; and a shorter yet length of the third stage may be selected to be about 0.5 to 0.95 times the length of the second stage tube such as 0.5, 0.6, 0.7, 0.8, 0.9, 0.95

or any value in between.

The flow restrictor design of the present invention is based on a new understanding of the processes surrounding any deviation of the oil production from initial optimal level, which can be achieved by using a flow restrictor of the predetermined geometry defining its flow characteristics. Discussion of the processes occurring at the bottom of the oil well when the bottomhole pressure deviates from its intended optimal level is critical for understanding of the design of the flow restrictor which does not require any moving parts for its operation.

Reference is made now to FIG. **5** showing an exemplary calculated IPR curve superimposed onto a GOR curve in a space defined by bottomhole pressure and the oil flow rate coordinates. As the oil production rate increases with decreasing of the bottomhole pressure following an IPR curve from the top point corresponding to the reservoir formation pressure, it reaches a maximum level at the point marked with an arrow. All throughout that process, the GOR value remains at or about the initial level and not changing much as the bottomhole pressure reaches the optimal level, as the GOR curve is essentially close to a vertical line in that region of the chart. From the point of reaching the maximum oil production rate and further below thereof, however, as the bottomhole pressure and the oil rate continue to decrease, the GOR curve exhibits a sharp increase at the bottom right corner of the chart, indicating a rapidly increasing amount of gas entering the oil well.

According to the present invention, as the bottomhole pressure decreases and the GOR raises to a higher level, the flow restrictor causes the flow regime in at least one of the first stage or a second stage to change from a bubble type two-phase flow to a slug type two-phase flow. The increase in the amount of gas traversing the flow restrictor is causing a rapid increase in its flow resistance, which in tum causes the increase in the bottomhole pressure and therefore urging the oil production rate to shift back up in the direction of the maximum oil production rate. This in tum causes the GOR to decrease again to get closer to its level corresponding to the maximum oil production rate. The gas component of the 10 two-phase flow is therefore decreasing, and the equilibrium is maintained.

This unique behavior is therefore assuring the maximum oil production rate to be a stable equilibrium point on the IPR curve-whereby any deviations and changes in reservoir conditions are mitigated by the flow restrictor **5** of the invention as to maintain the oil rate at a desired maximum production point. Because of this behavior, there is no need to adjust the geometry of the flow restrictor from the surface and no need to interrupt the oil production from the oil well for maintaining the production rate at the desired maximum level.

Not only the operation of the oil well is intrinsically optimal over extended periods of time and may continue without interruptions, but the present invention therefore may be used to the oil well using a mandrel and a cable delivery mechanism, such as for example a side pocket mandrel as described in the U.S. Pat. No. 5,740,860. In this case, retrieval of the old flow restrictor and replacement with the new flow restrictor may be accomplished without interruption of the oil production from the oil well. Furthermore, the method of the invention may further comprise steps of determining the optimal level of the bottomhole pressure initially and then at predetermined periods over the life of the well, such as every few weeks, every month, every two months, every three months, etc. In other steps of the method, a predetermined criteria for triggering flow restrictor replacement may be used, for maximize the ultimate oil recovery from the oil well over the life of the well. This can be explained by the very beneficial consequence of producing oil at the maximum rate at the lowest possible GOR, which leads to conservation of gas in the reservoir. Maintaining more gas at a higher pressure in the reservoir leads to a meaningful extension of time when the reservoir has a capacity to produce oil and avoid the situation when a substantial volume of oil remains at the reservoir but cannot be lifted up the oil well due to a diminishing bottomhole pressure.

Of course, over an extended period of time the optimal level of the bottomhole pressure may change as the reservoir formation pressure declines. Initially, such change may be compensated by adjustment of the surface choke **8** so as to keep the bottomhole pressure at the same optimal level-in this case, the opening of the surface choke **8** may paradoxically cause an increase of the bottomhole pressure because of the phenomenon of increase flow resistance as described above. Once the range of the surface choke **8** adjustments is an example when the bottomhole pressure deviates from the optimal level by a predetermined margin, for example by 10-20 percent. In other embodiments, criteria for flow restrictor replacement may be a maximum allowed predetermined threshold value of GOR, such as twice the initial value of GOR.

One other group of advantages of the present invention may be explained in comparison with other methods of stimulating oil production, namely hydraulic fracturing, or fracking. Not only the present invention may lead to an increase of as much as two times of the ultimate oil recovery from an oil well when used instead of hydraulic fracturing, but at the same time it may be accomplished at a fraction of the cost of hydraulic fracturing and, even more importantly, without any risk of environmental damage, which typically accompanies an oil well following a completion of a hydraulic fracturing process.

It is contemplated that any embodiment discussed in this specification can be implemented with respect to any method of the invention, and vice versa. It will be also understood that particular embodiments described herein are shown by way of illustration and not as limitations of the invention. The principal features of this invention can be employed in various embodiments without departing from the scope of the invention. Those skilled in the art will recognize or be able to ascertain using no more than routine experimentation, numerous equivalents to the specific procedures described herein. Such exhausted, there may be a need to recalculate the geometry of the flow restrictor **5** and replace thereof-but that need may be encountered once every few years so that most of the time the oil well may be used for uninterrupted production of oil at high self-adjusting levels.

FIG. **7** shows an example of a family of IPR curves calculated for a single oil well over the lifetime thereof according to a predicted decline in reservoir pressure. The optimal level of maximum oil production is identified on each IPR curve. All such optimal levels of bottomhole pressure are connected by a curve shown in the drawing.

In the case of this particular chart, a comparison between the ultimate oil recovery under normal conditions was made with the circumstances of using the flow restrictor of the present invention. It was shown that the use of the invention allowed to increase the ultimate recovery index by as much 60 as 5.9% via an increase of oil recovery by about 30,000 barrels, while decreasing the production of gas by about 1.2 million cubic feet. The net economic benefit in this case assuming the price of oil at $60 per barrel is close to $1.8

MM for this oil well alone. To further lessen the burden of replacement of the flow restrictor, it may be deployed at the bottomhole region of equivalents are considered to be within the scope of this invention and are covered by the claims.

All publications and patent applications mentioned in the specification are indicative of the level of skill of those skilled in the art to which this invention pertains.

All publications and patent applications are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference. Incorporation by reference is limited such that no subject matter is incorporated that is contrary to the explicit disclosure herein, no claims included in the documents are incorporated by reference herein, and any definitions provided in the documents are not incorporated by reference herein unless expressly included herein.

The use of the word "a" or "an" when used in conjunction with the term "comprising" in the claims and/or the specification may mean "one," but it is also consistent with the meaning of "one or more," "at least one," and "one or more than one." The use of the term "or" in the claims is used to mean "and/or" unless explicitly indicated to refer to alter- natives only or the alternatives are mutually exclusive, although the disclosure supports a definition that refers to only alternatives and "and/or." Throughout this application, the term "about" is used to indicate that a value includes the inherent variation of error for the device, the method being employed to determine the value, or the variation that exists among the study subjects.

As used in this specification and claim(s), the words "comprising" (and any form of comprising, such as "comprise" and "comprises"), "having" (and any form of having, such as "have" and "has"), "including" (and any form of including, such as "includes" and "include") or "containing" (and any form of containing, such as "contains" and "contain") are inclusive or open-ended and do not exclude additional, unrecited elements or method steps. In embodiments of any of the compositions and methods provided herein, "comprising" may be replaced with "consisting essentially of' or "consisting of'. As used herein, the phrase "consisting essentially of' requires the specified integer(s) or steps as well as those that do not materially affect the character or function of the claimed invention. As used herein, the term "consisting" is used to indicate the presence of the recited integer (e.g., a feature, an element, a characteristic, a property, a method/process step or a limitation) or group of integers (e.g., feature(s), element(s), characteristic (s), propertie(s), method/process steps or limitation(s)) only. The term "or combinations thereof' as used herein refers to all permutations and combinations of the listed items preceding the term.

For example, "A, B, C, or combinations thereof is intended to include at least one of: A, B, C, AB, AC, BC, or ABC, and if order is important in a particular context, also BA, CA, CB, CBA, BCA, ACB, BAC, or CAB. Continuing with this example, expressly included are combinations that contain repeats of one or more item or term, such as BB, AAA, AB, BBC, AAABCCCC, CBBAAA, CABABB, and so forth. The skilled artisan will understand that typically there is no limit on the number of items or terms in any combination, unless otherwise apparent from the context.

As used herein, words of approximation such as, without limitation, "about", "substantial" or "substantially" refers to a condition that when so modified is understood to not necessarily be absolute or perfect but would be considered close enough to those of ordinary skill in the art to warrant designating the condition as being present. The extent to which the description may vary will depend on how great a change can be instituted and still have one of ordinary skilled in the art recognize the modified feature as still

a. calculating an optimal bottomhole pressure level for said oil well so as to assure maximum oil flow from said reservoir through said oil well,
b. providing a fixed geometry flow restrictor comprising at least a first stage tube and a second stage tube attached to said first stage tube in series therewith, said flow restrictor is designed to maintain said bottomhole pressure at said optimal level calculated in step (a),

wherein said flow restrictor has no moving parts, said flow restrictor is characterized by a geometry selected to satisfy all of the following predetermined well-specific design criteria over the life cycle of the well:

1. a pressure drop across said flow restrictor is not exceeding 12% of a current

reservoir formation pressure while said oil well is producing said oil at said maximum oil flow rate;

ii. for oil wells producing less than 100 barrels of oil per day, said first stage tube has a diameter from about 2 mm to about 4 mm and a length from about 4 cm to about 6 cm; or for oil wells producing 100 to 1,000 barrels of oil per day, said first stage tube has a diameter from about 4 mm to about 8 mm and a length from about 6 cm to about 8 cm; or for oil wells producing over 1,000 barrels of oil per day, said first stage tube has a diameter from about 8 mm to about 20 mm and a length from about 8 cm to about 10 cm; and

iii. said second stage tube has a diameter about 1.05 to1.5 times greater than the diameter of said first stage tube and a length about 0.5 to 0.95 times the length of said first stage tube,

c. installing said flow restrictor at a bottom of said oil well with said first stage tube below said second stage tube, and

d. producing oil at said oil well, whereby said flow restrictor passively causing said bottomhole pressure to remain at a stable equilibrium at about said optimal bottomhole pressure level and return thereto despite varying reservoir conditions. The method as in claim 1, wherein said second stage tube forms a stepped enlargement in flow path diameter when transitioning from said first stage tube. The method as in step 1 further including a step of having the required characteristics and capabilities of the unmodified feature. In general, but subject to the preceding discussion, a numerical value herein that is modified by a word of approximation such as "about" may vary from the stated value by at least ±1, 2, 3, 4, 5, 6, 7, 10, 12, 15, 20 or 25%.

All of the devices and/or methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the devices and methods of this invention have been described in terms. The method as in claim 1, wherein said flow restrictor comprises a third stage tube located in series with said second stage tube opposite said first stage tube, said third stage tube has a diameter about 1.05 to 1.5 times greater than the diameter of said second stage tube, said third stage tube of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the devices and/or methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. All such similar has a length about 0.5 to 0.95 times the length of said second stage tube. The method as in claim 1, wherein said optimal bottomhole pressure is selected to avoid increase of said Gas-to-Oil-Ratio above a predetermined GOR threshold. Substitutes and modifications apparent to those skilled in the 60 art are deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

What is claimed is:

1. A method of maximizing oil recovery from a reservoir with Gas-to-Oil-Ratio (GOR) at or above about 100 cubic meters of gas per cubic meters of oil via an oil well, said method comprising the following steps:
2. The method as in claim 1, wherein said second stage tube forms a stepped enlargement in flow path diameter when transitioning from said first stage tube.
3. The method as in step 1 further including a step of determining said optimal bottomhole pressure in step (a) over the life of said oil well and a step of replacing said flow restrictor when said optimal bottomhole pressure deviates from said optimal level thereof by more than a predetermined margin.
4. The method as in claim **1,** wherein said flow restrictor comprises a third stage tube located in series with said second stage tube opposite said first stage tube, said third stage tube has a diameter about 1.05 to 1.5 times greater than the diameter of said second stage tube, said third stage tube has a length about 0.5 to 0.95 times the length of said second stage tube.
5. The method as in claim 1, wherein said optimal bottomhole pressure is selected to avoid increase of said Gas-to-Oil-Ratio above a predetermined GOR threshold.
6. The method as in step **3,** wherein said step ofreplacing said flow restrictor is conducted without interrupting oil production in said oil well.
7. The method as in claim **1,** wherein said oil well further comprising a surface choke, said step (c) further including a step of adjusting said surface choke .
8. The method as in claim 7, wherein said step (a) is repeated on a predetermined periodic basis to determine an updated optimum bottomhole pressure, followed by a corresponding step (c) of adjusting said surface choke to maintain said bottomhole pressure at said updated optimum bottomhole pressure level.
9. The method as in claim 8, wherein said reservoir is further characterized by said bottomhole pressure increasing upon opening of said surface choke.
10. The method as in claim 1, wherein said step (b) further comprises a step of calculating oil flow and gas flow parameters throughout said flow restrictor and said oil well by using a mathematical model of two-phase flow proceeding in three consecutive flow regimes:

    - a first flow regime starting from said reservoir and proceeding through a first stage tube of said flow restrictor;
    - a second flow regime proceeding through said second stage tube of said flow restrictor; and

- a third stage flow regime proceeding after exit fromsaid second stage tube through the remaining portion of said oil well,whereby flow exit conditions from the preceding flow regime form entry conditions for the subsequent flow regime.

11.The method as in claim **10,** wherein each of the first flow regime, the second flow regime, and the third flow regime are modeled using the same mathematical equations of two-phase flow in a cylindrical conduit.

12. The method as in claim **11,** wherein said optimal bottomhole pressure level is calculated as a sum or respec- tive consecutive pressure drops of said first flow regime, said second flow regime, and said third flow regime.

13. The method as in claim **10,** wherein said mathematical model of two-phase flow is replaced with a mathematical model of three-phase flow when water is present in said reservoir.

14. The method as in claim **10,** wherein said diameters and lengths of said respective first stage tube and said second stage tube of the flow restrictor are selected to avoid gas flow regime in said oil well.

15. The method as in claim **10,** wherein said diameters and lengths of said respective first stage tube and said second stage tube of the flow restrictor are selected to avoid increasing of said Gas-to-Oil-Ratio over 2 times greater than initial level thereof.

16. The method as in claim **1,** wherein said reservoir is further characterized by an inflow performance relationship curve having a maximum oil production point corresponding to said optimal bottomhole pressure level.

US009885216B2

c12) **United States Patent**
Tseytlin et al.

(IO) **Patent No.:** **US 9,885,216 B2**
(45) **Date of Patent:** **Feb. 6, 2018**

(54) **ACOUSTIC METHODS AND DEVICES FOR DETERMINING THE VALUE OF FORMATION OVERPRESSURE DURING DRILLING AND FOR DETECTING GAS PACKS CONTAINING HYDROGEN SULFIDE GAS**

(71) Applicants: Simon **Tseytlin,** Middle Village, NY (US); **David Tseytlin,** Brooklyn, NY (US)

(72) Inventors: **Simon Tseytlin,** Middle Village, NY (US); **David Tseytlin,** Brooklyn, NY (US)

(*) Notice: Subject to any disclaimer, the term ofthis patent is extended or adjusted under 35 U.S.C. 154(b) by 158 days.

(21) Appl. No.: **15/161,247**

(22) Filed: **May 22, 2016**

(65) **Prior Publication Data**

US 2017/0009544 Al Jan. 12, 2017

Related U.S. Application Data

(60) Provisional application No. 62/189,157, filed on Jul. 6, 2015.

(51) **Int. Cl.**

E21B *21108* (2006.01)
E21B *47106* (2012.01)

(52) **U.S. Cl.**

CPC.................***E21B*** *21108* (2013.01); ***E21B*** *47106* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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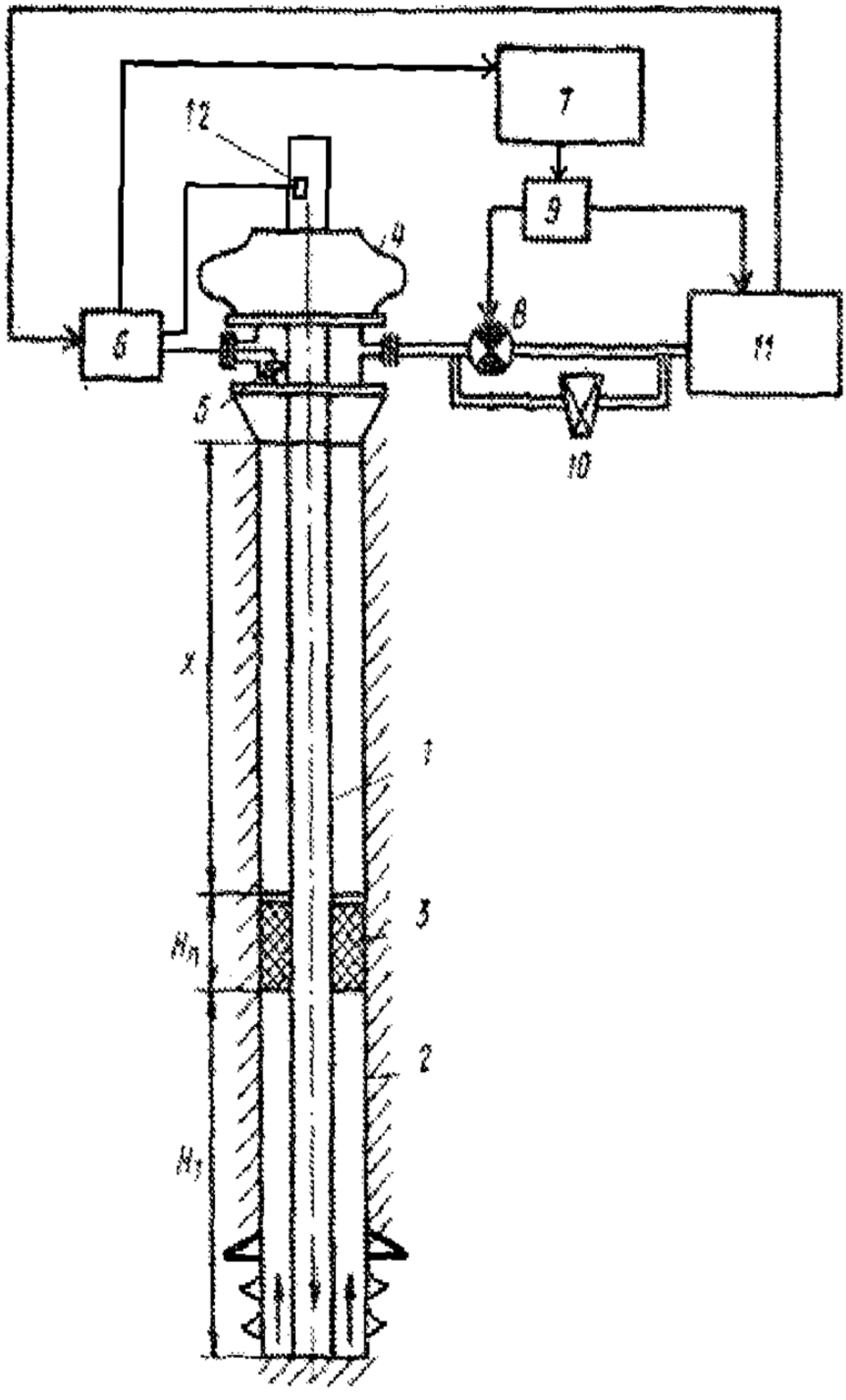
Primary Examiner - John Fitzgerald
Assistant Examiner - Jean Morello
(74) *Attorney, Agent, or Firm* - Boris Leschinsky

(57) **ABSTRACT**

A method for determining formation pressure during exploratory drilling for oil includes generating a series of negative pressure shock waves at successively increasing well pressures to characterize gas kick forming at the bottom of a well. Once the lower end of the gas kick has been formed, the well pressure level as detected by a pressure sensor near the surface of the well is used to calculate the formation pressure along with the weight of the fluid column located in the well.

10 Claims, 5 Drawing Sheets



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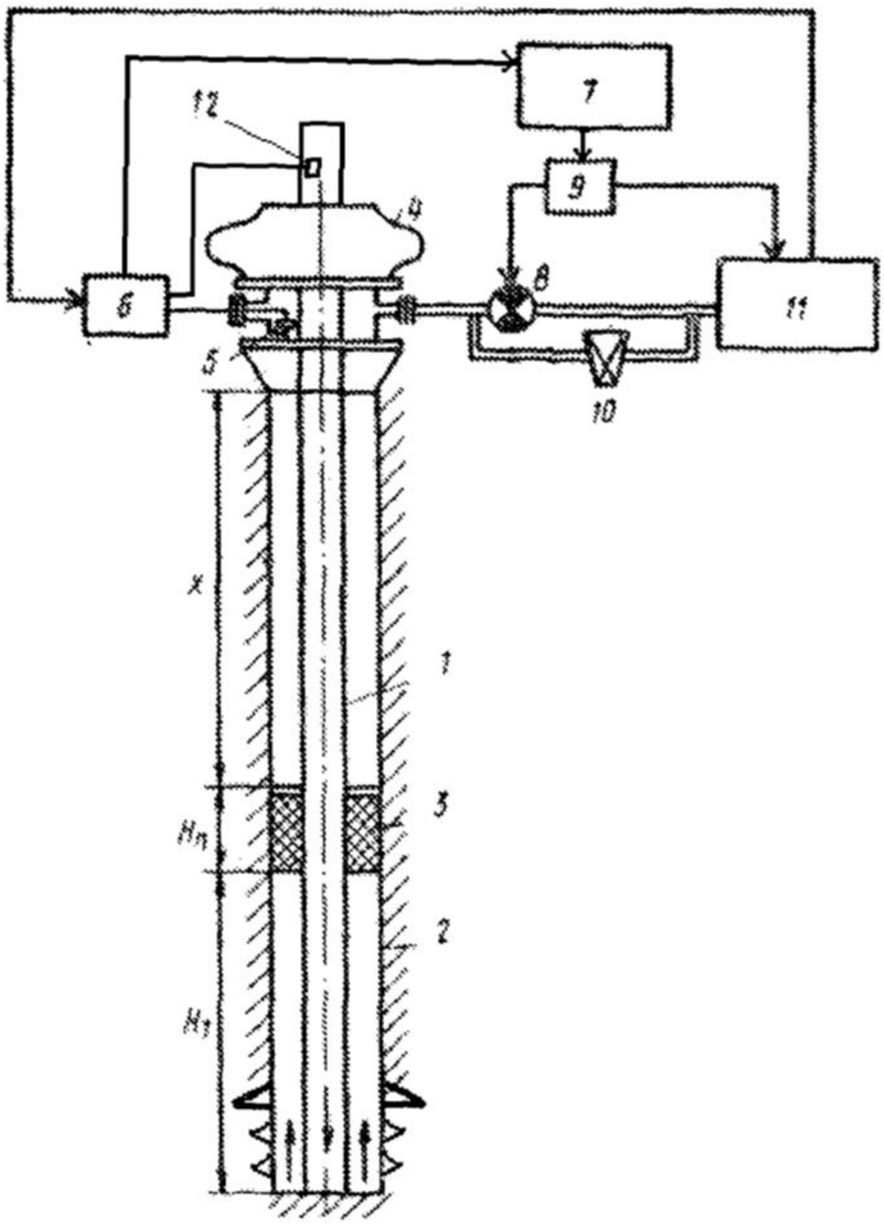

Fig. 1

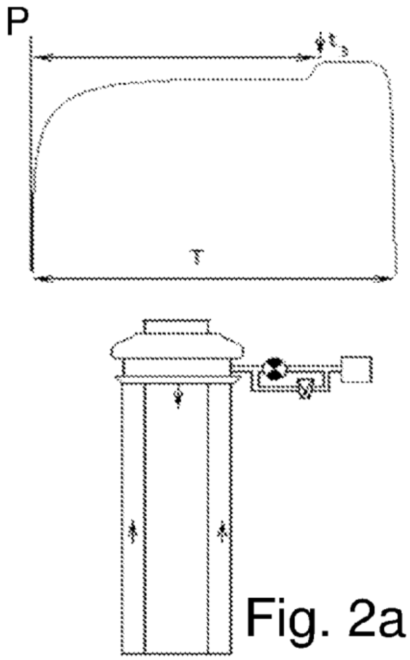

Fig. 2a

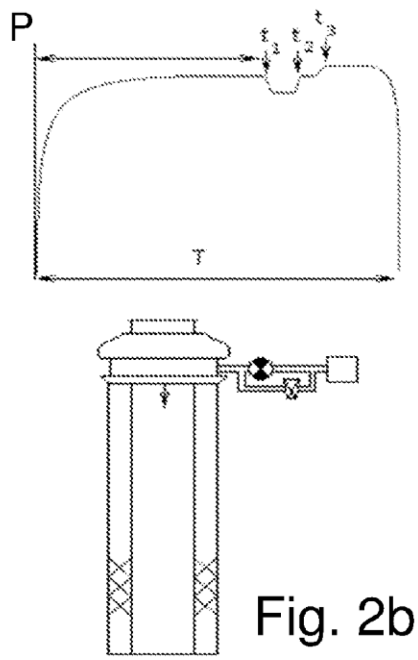

Fig. 2b

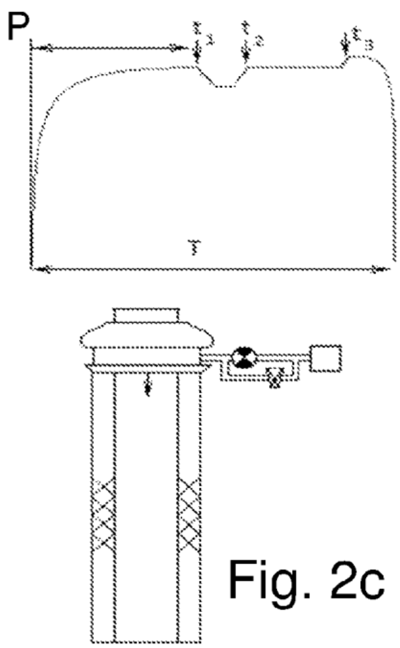

Fig. 2c

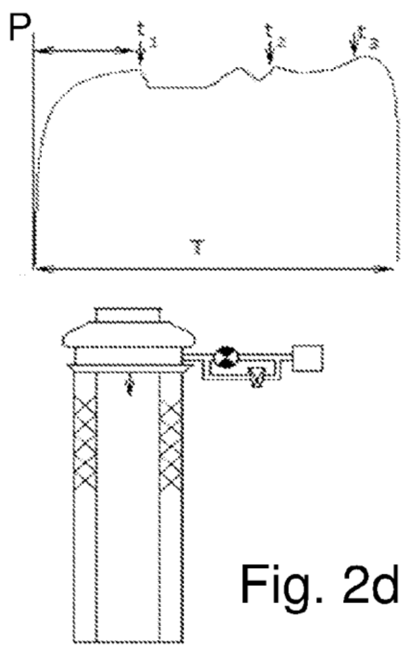

Fig. 2d

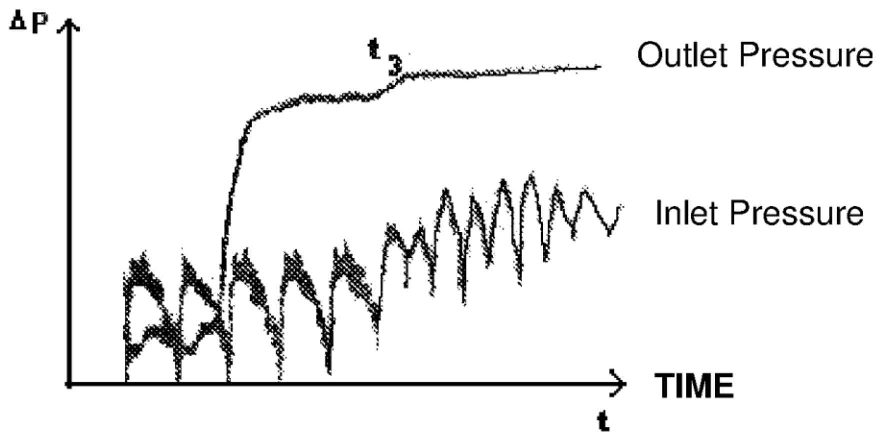
ΔP
t_3
Outlet Pressure
Inlet Pressure
TIME
t

Fig.3a

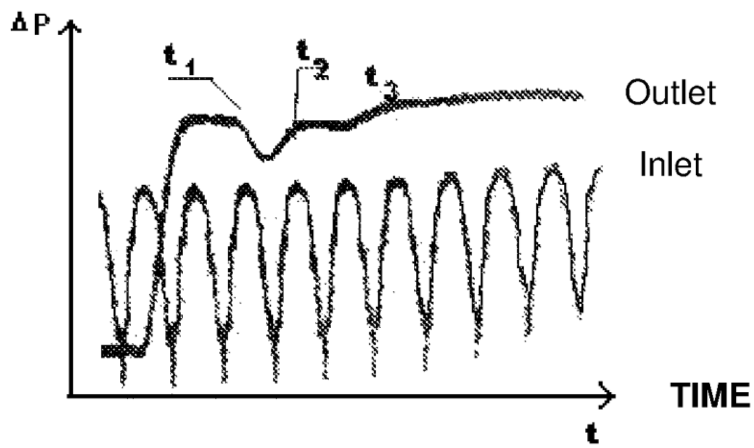
ΔP
t_1
t_2
t_3
Outlet
Inlet
TIME
t

Fig.3b

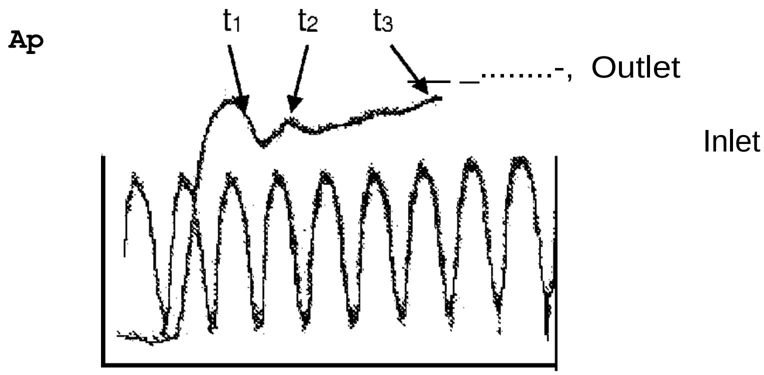

Fig.3c

TIME

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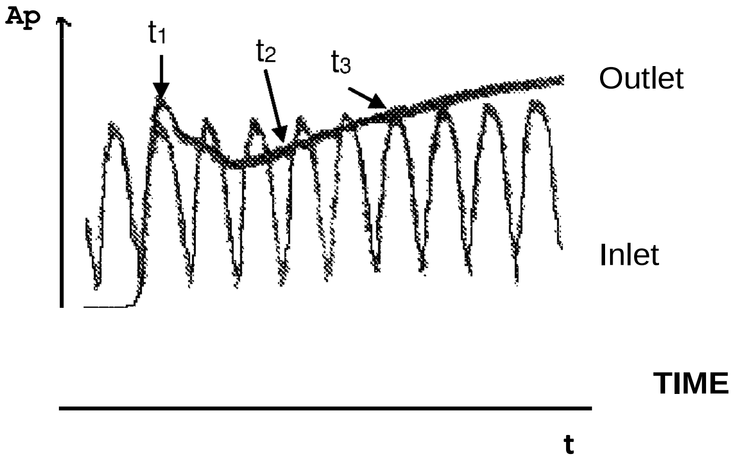

Fig.3d

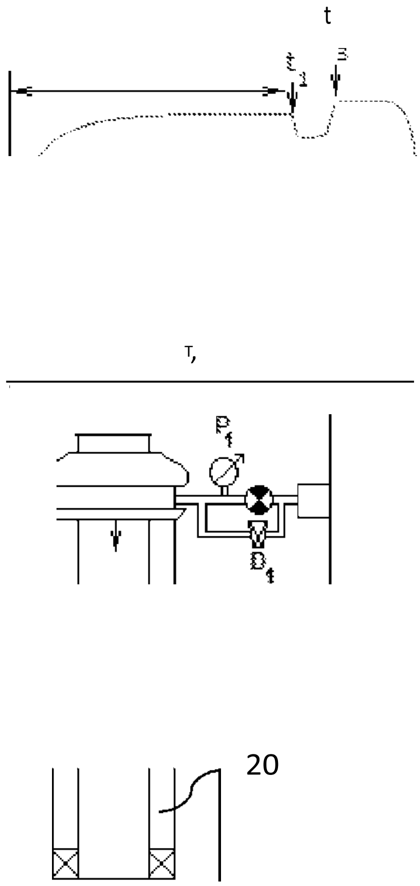

Fig. 4a

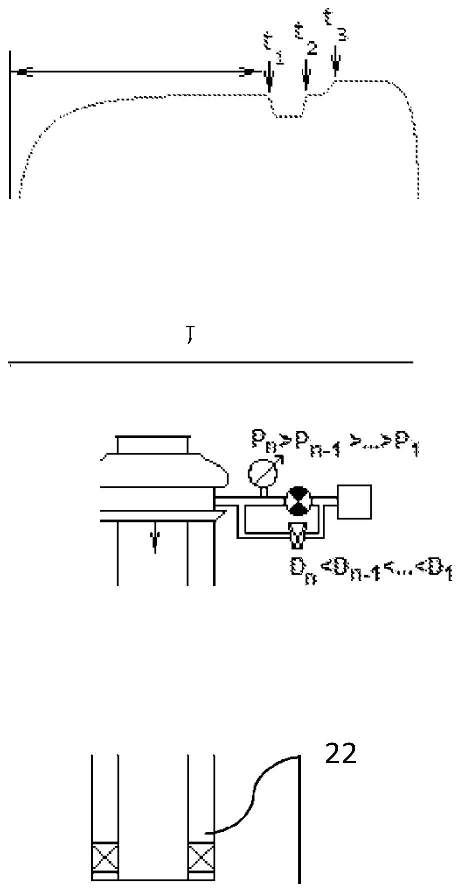

Fig. 4b

ACOUSTIC METHODS AND DEVICES FOR DETERMINING THE VALUE OF FORMATION OVERPRESSURE DURING DRILLING AND FOR DETECTING GAS PACKS CONTAINING HYDROGEN SULFIDE GAS

CROSS-REFERENCE DATA

The present patent application claims priority from a U.S. Provisional Application No. 62/189,157 filed 6 Jul. 2015 with the same title, which is incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

The present invention relates generally to devices and methods for exploration of oil and gas. More particularly, the invention describes how to measure formation pressure and how to detect the presence of hydrogen sulfide gas in a rising gas kick so as appropriate prevention and safety measures can be promptly taken. The present invention can be advantageously used when drilling onshore and offshore oil wells. It is designed to allow prevention of blowouts and well explosions, which usually cause human losses, damage to environment and are hard and expensive to suppress.

During an exploratory drilling of an oil, gas or gas condensate wells, drilling fluid referred to in the industry as "mud", is pumped into the drill pipe. The mud proceeds out through the drill bit and up the annular space between the drill pipe and the walls of the hole. It generally proceeds then further up the annular space between the drill pipe and the casing, after which it returns to the surface of the well. At the surface, the mud is typically examined for certain parameters, processed and returned to the circulation. The purpose of the circulating mud is to clean, cool and lubricate the bit, flush to the surface the cuttings from the bore hole and to protect the walls of the hole until casing is inserted. The density of the mud is carefully controlled at the surface so as to contain various pressures encountered in the hole.

As the well is drilled, gases saturated in highly pressurized fluids at the bottom may be released therefrom or from a porous rock and find their way into the circulating mud forming an annular gas bubble or a gaseous pack, also called a gas kick. This gas kick may ascend to the surface, result in a modification of the buoyanc of the drilling string and can cause extensive damage if it goes undetected. The gas or liquid contained in the gas kick reduces the hydrostatic head in the annulus. If the volume of the gas kick is not excessive and if it can be detected, gas kick removal procedures may be instituted so that drilling operations may proceed with minimal disruption.

Careful monitoring of formation pressure is highly desirable in order to control formation of gas kicks and to assure safe operation of the oil well.

In addition to monitoring for a possible formation and ascendance of a gas kick, containing mostly natural gas, there is an additional safety concern regarding formation of a gas kick containing hydrogen sulfide gas, H2S. This gas is highly toxic, heavier than air, flammable and can cause substantial damage and even death to the oil well service personnel-upon inhaling such gas is extremely irritating and harmful. Free hydrogen sulfide in the blood reduces its oxygen-carrying capacity, thereby depressing the nervous system. Hydrogen sulfide is oxidized quite rapidly to sulfates in the body, therefore no permanent after effects occur in cases of recovery from acute exposures unless oxygen deprivation of the nervous system is prolonged. Effects such as eye irritation, respiratory tract irritation, slow pulse rate, lassitude, digestive disturbances, and cold sweats may occur but these symptoms disappear in a relatively short time after removal from the exposure. At high concentrations of 500 ppm and above, hydrogen sulfide is fatal in as little as 30 minutes.

Surface monitors of hydrogen sulfide presence are not sufficient to assure safety in case of hydrogen sulfide exposure. Methods are needed to warn service personnel about the upcoming gaseous pack containing hydrogen sulfide which will give more time to assure personnel safety than that available with surface monitors.

Using acoustics for detection of the gas kick presence is known in the art. U.S. Pat. No. 4,273,212 for example discloses sending an acoustic pulse down the pipe and receive its reflection in the annular portion of the well head. Using high frequency positive acoustic pulses however does not allow full characterization of the gas kick as it only allows detection of its upper end and not allows detection of its lower end which is needed to detect its total volume.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to overcome these and other drawbacks of the prior art by providing 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.

The present invention is an improvement of devices shown in the U.S. Pat. No. 8,235,143 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 methods and associated devices designed to detect a gas kick and to determine its parameters such as formation pressure, gas kick content, location, ascending 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. Formation pressure is determined by sending repeated acoustic waves (for example using a negative pressure wave) down the bore of the exploratory oil well. Reflected waves are captured and analyzed by a computer. Once the upper end of the forming gas kick is detected, blowout preventer is closed and flow resistance through the side tube (also referred to as a killing tube) is gradually increased so as to raise the pressure in the well. Once the pressure is raised sufficiently to arrest the growth of the gas kick, its lower end forms and can be detected by the respective acoustic signature from the subsequent negative pressure wave.

BRIEF DESCRIPTION OF THE DRAWINGS

Subject matter is particularly pointed out and distinctly claimed in the concluding portion of the specification. The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings, in which:

FIG. **1** is a cross-sectional view of the oil well equipped with the device of the present invention.

FIGS. ***2a*** through ***2d*** are various charts of the acoustic signature of the reflected pressure wave resulted from a computer simulations in a variety of circumstances:

a. 2a-normal operation, no gas kick is detected

b. 2b-gas kick is detected and is located at the bottom of the well

c. 2c-gas kick is ascending towards the middle of the well

d. 2d-gas kick is near the surface of the well

FIGS. **3a** through **3d** are examples the same charts-this time actually recorded as a result of an experiment on an exemplary oil well.

FIGS. *4a* and *4b* are examples of computer-generated model signals used to determine formation pressure in the oil well.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

The following description sets forth various examples along with specific details to provide a thorough understanding of claimed subject matter. It will be understood by those skilled in the art, however, that claimed subject matter may be practiced without one or more of the specific details disclosed herein. Further, in some circumstances, well- known methods, procedures, systems, components and/or circuits have not been described in detail in order to avoid unnecessarily obscuring claimed subject matter. In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

A well equipped with the system of the invention is depicted in FIG. **1.** It includes a well casing **2** with a drilling pipe **1** located inside and forming an annular space there between. The lower end of the well with the drill bit attached to the pipe **1** is not shown. A blowout preventer (BOP) **4** is shown placed on top of the well at the point of a wellhead. An outgoing well pressure sensor **5** may be located in the vicinity of the wellhead outlet allowing monitoring of drilling mud outlet pressure as it leaves the well. The optional incoming pressure sensor **12** may be located at the inlet of the wellhead to monitor inlet pressure of the drilling mud as it is being forced down the drilling pipe **1** by a suitable pump (not shown). The signals from both pressure sensors **5** and **12** may be fed into a data acquisition unit **6,** which in tum is connected to a central processing unit (CPU) **7** based for example on a laptop PC.

The gas kick volume in the annular space is shown generally as position **3.** It may be characterized by its height Hn, distance from the wellhead X and distance from the reservoir **Hl.**

Other components of the system of the invention may include a fast-acting on/off valve **8** activated by a valve driver **9** based on a control signal from the computerized central processing unit 7. The valve **8** may be preferably located between the drilling mud collecting reservoir **11** and the exit from the annular space of the well or at any other surface location after the exit from the well, for example in a killing tube. In embodiments, valve **8** may also be placed inside the well. Rapid opening and closing of the valve **8** allows reducing abruptly the flow resistance in the outgoing pathway of the drilling mud. In order to not block the flow of drilling mud entirely when the valve **8** is closed, a parallel pathway or a bypass pipe around the valve **8** may be provided which may include a remotely adjustable flow restrictor **10.** In other embodiments of the invention (not shown), the valve **8** may include provisions to be rapidly opened and closed but to not completely obstruct the flow of the drilling mud. Such provisions may include an adjustable valve seat (chock). Moving the seat away from the valve stem leaves certain space rendering the valve **8** somewhat incompetent. The method of the invention describes generating a series of periodic negative pressure waves (impulses) for gas kick characterization in such a manner so as not to confuse generated and reflected pressure wave signals. As a result of valve **8** being abruptly opened, the flow resistance is suddenly reduced causing a rapid drop in mud pressure.

This rapid drop generates a negative pressure shock wave, which travels down the annular space of the well with a speed of sound, typically 1200-1500 meters per second. For the purposes of this invention, the change in pressure may be accomplished within a period of time of about 1/20 to about 1 second to generate a crisp rise of the front wave. In embodiments, that range for the drop in pressure may also be about 1/10 to 3/10 of a second. The difference between the initial or first pressure of the fluid in the well (such as drilling mud) and mud pressure after opening of valve **8** maybe about 1 to 5 atmospheres. The valve **8** may be kept open to maintain the low mud pressure for a period of time long enough to allow the negative pressure wave to travel down the well and return back up. In some embodiments, this time ranges from about 1 to about 20 seconds, while in other embodiments this time may be from about 5 to about 10 seconds. Deeper wells may require longer opening times, while shorter wells may need shorter times.

Alternatively, an impulse generator may be placed in contact with the drilling mud and used to generate the necessary impulses within the mud. This approach may not be as advantageous as the impulse generator requires a dedicated source of electrical power and also because such impulses may not be strong enough to travel the entire length of the well without significant decay.

Once the shock wave of the reflected pressure wave has reached the surface, its acoustic signature may be recorded using the pressure sensor **5** as a signal P shown in the drawings.

The step of generating a single pressure shock wave may be repeated from time to time to monitor the changing condition of the gas kick in the well. As pressure disturbance from opening the valve **8** may generate multiple reflection waves, repeating the step of generating another negative pressure wave may be done after sufficient time have elapsed from the previous measurement to allow these reflection waves to attenuate and the pressure in the well to stabilize and return to a steady state. In embodiments, such period of time may be about 1 to about 60 minutes, preferably from about 5 to about 30 minutes. Unsteady pressure in the well at the beginning of the process may lead to an erroneous reading.

FIGS. ***2a*** to ***2d*** are computer-simulated pressure signals from a typical oil well, while FIGS. **3a** through **3d** are actual exemplary recordings of such pressure. In addition to the outlet pressure, FIGS. **3a** to **3d** show a fluctuating inlet pressure-with periodic increases and decreases of inlet pressure caused by operation of the pump configured to push drilling mud down the oil well.

Under normal operating conditions without any gas kick present in the system, the typical outlet pressure characteristic of the well is shown in FIGS. ***2a*** and 3a in which **t3** is the time of arrival of the acoustic pressure wave at the bottom of the formation marked by a pressure increase in the P curve.

If the pressure wave encounters an ascending gas kick after its formation is complete, two additional pressure disturbances are generated, one at the upper end of the gas kick and one at the lower end of the gas kick. The upper end of the gas kick constitutes a point of **tl,** or a transition of density from a high level of mud to a low level of gas. The lower end of the gas kick is characterized by the opposite point of t2, or a transition of density from that low of gas to a high density of mud. Data acquisition unit **6** may be configured for automatic detection of the times of arrival of reflected waves **tl, t2,** and **t3.** As seen in FIGS. ***2b*** and **3b, t1** is the time of arrival of the first reflected wave from the upper end of the gas kick; **t2** is the time of arrival of the second wave reflected off the lower end of the gas kick, and **t3** is the time of arrival of the reflected wave from the well bottom. Transition point from harder or denser medium of the drilling mud to a less dense medium of a gas kick causes a drop in pressure on the pressure curve, while a transition from less dense gas to a more dense mud caused an increase in the pressure.

FIGS. **2c** and 3c show examples of a pressure signal surface. This information is critical to estimate the time of arrival of the gas kick so that appropriate safety measures may be undertaken.

Detection of Formation Pressure

FIGS. *4a* and *4b* depict an illustration of the method of the present invention describing steps of detecting formation pressure based on interrupting the natural process of formation of a gas kick. As the gas comes out of formation and forms into a gas kick, it enters the well at the very bottom. Once the gas is in the well, the upper end of the gas kick is formed, while the lower end is still absent-as more gas continues to enter the well. An incompletely formed gas kick presents an opportunity to accurately measure the formation pressure which is described in the present invention and illustrated in FIGS. *4a* and *4b.*

The process starts at the moment of detecting the initial formation of the gas kick. FIG. *4a* lower part shows the upper end of the gas kick **20** with upper part showing appearance of a pressure disturbance **t1** in the pressure curve P. Initial conditions of mud pressure Pl and the value of the bypass resistance D1 are recorded along with known depth of the oil well at that point and the real-time density of the drilling mud.

As opposed to the previous devices, the present invention features a remotely-adjustable bypass restrictor **10** in a bypass line of the valve **8.** Restrictor **10** may be character- ized by an adjustable diameter D. Initially, restrictor **10** is open to its maximum capacity characterized by a first diameter D1.

When a negative pressure wave is sent down the well at this point by abruptly opening valve **8** for example, an inverted chart of the received signal may look like the one shown in the upper part of FIG. 4a-with the characteristic points of interest of tl (upper end) and **t3** (formation point) clearly present but **t2** (lower end of the gas kick) being absent. Formation pressure at this point exceeds well pressure and so more gas continues to enter the well increasing the volume of the gas kick.

Once such condition is detected (by periodically monitoring acoustic response of the system as described above), an automatic sequence of steps may be taken in order to determine precisely the level of formation pressure as described below.

Step a. Abruptly changing fluid pressure from a first pressure level to a second pressure level to generate a pressure shock wave. Periodic generation of a negative pressure wave (for example by abruptly opening valve **8** with restrictor **10** in fully opened position characterized by a first diameter Dl) is used in order to monitor for initial appearance of an incompletely formed gas kick, as indicated by presence of gas kick upper end and absence of gas kick lower end.

Step b. Maintaining fluid pressure at the second pressure level for a period of time sufficient to allow the pressure shock wave to travel down along the well, reflect from a well bottom, and ascend upwards. In embodiment, the duration period of the shock wave may be chosen to be suitable in order for the multiple reflections of the generated signal to subside, for example about 10-15 seconds.

Step c. Monitoring the output fluid pressure as a function of time from the onset of change in fluid pressure (opening of valve **8)** and during the time of the pressure shock wave traveling down and then up along the oil well.

Step d. Detecting a presence of an upper end of the gas indicating ascending of the gas kick along the well, with FIGS. 2d and 3d showing the gas kick near the surface, as time t1 gets to be shorter as the gas kick ascends towards the kick using a pressure peak in the fluid pressure and absence of a lower end thereof. Record well head pressure Pl at the time of detecting presence of upper end of the gas kick.

US008534363B1

(12) **United States Patent**
Tseytlin et al.

(10) **Patent No.: US 8,534,363 B1**
(45) **Date of Patent: Sep. 17, 2013**

(54) **METHODS AND DEVICES FOR RESTORING CONTROL AND RESUMING PRODUCTION AT AN OFFSHORE OIL WELL FOLLOWING AN UNCONTROLLED FLUID RELEASE AFTER AN EXPLOSION**

(71) Applicants: **Simon Tseytlin**, Middle Village, NY (US); **David Tseytlin**, Brooklyn, NY (US)

(72) Inventors: **Simon Tseytlin**, Middle Village, NY (US); **David Tseytlin**, Brooklyn, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/897,435**

(22) Filed: **May 19, 2013**

Related U.S. Application Data

(63) Continuation-in-part of application No. 13/184,497, filed on Jul. 16, 2011, now Pat. No. 8,448,709, and a continuation-in-part of application No. 13/675,915, filed on Nov. 13, 2012, now Pat. No. 8,474,536.

(60) Provisional application No. 61/681,257, filed on Aug. 9, 2012, provisional application No. 61/367,478, filed on Jul. 26, 2010.

(51) **Int. Cl.**
E21B 7/12 (2006.01)

(52) **U.S. Cl.**
USPC **166/335**; 166/339; 166/345; 166/363; 166/364

(58) **Field of Classification Search**
USPC 166/363, 339, 364, 368, 285, 381, 166/386, 387, 75.15, 179, 192, 193; 138/89
See application file for complete search history.

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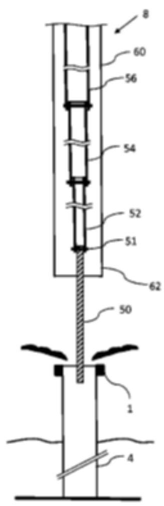
Primary Examiner — Matthew Buck
Assistant Examiner — James Sayre
(74) *Attorney, Agent, or Firm* — Boris Leschinsky

(57) **ABSTRACT**

Methods and devices for restoring control of at an offshore oil well following an uncontrolled fluid release after an explosion include lowering through a riser of successive flow restricting inserts into the oil well to gradually reduce the uncontrolled fluid release. Flow restricting inserts may be inserted in parallel or in series with each other. Following attachment of the riser to the oil well, provisions are made to restore oil production from the well. Flow restricting inserts may further 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.

20 Claims, 10 Drawing Sheets



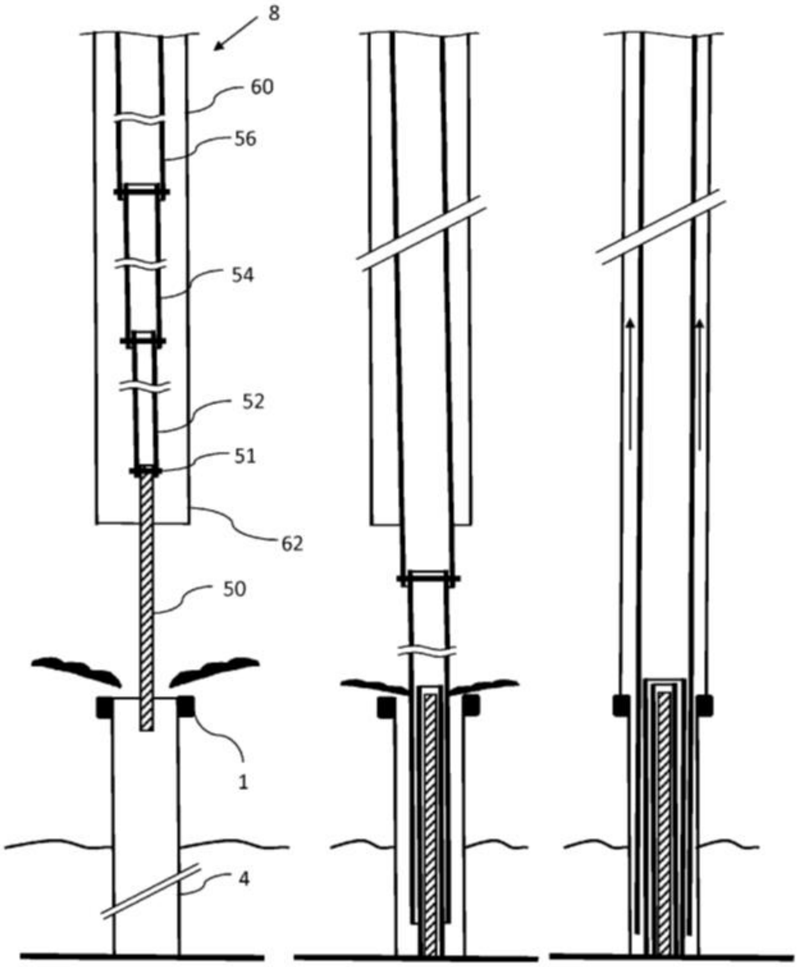


FIG. 2a FIG. 2b FIG. 2c

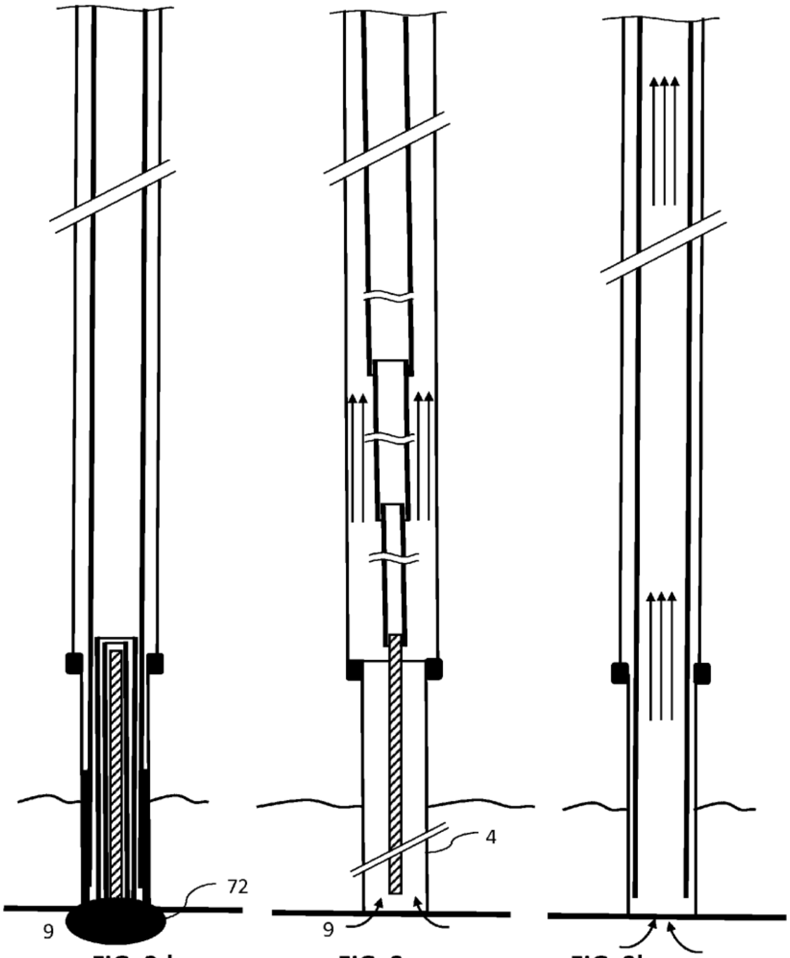
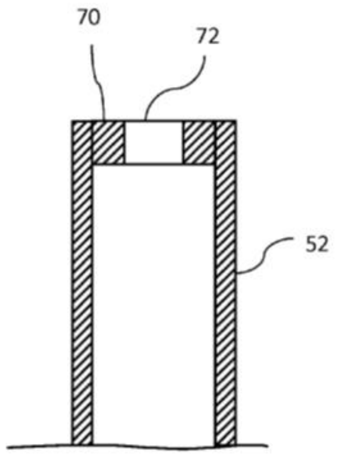


FIG. 2d FIG. 3a FIG. 3b



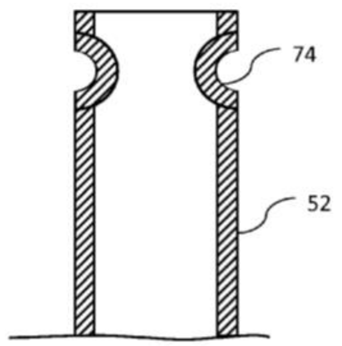


FIG. 5c

FIG. 5d

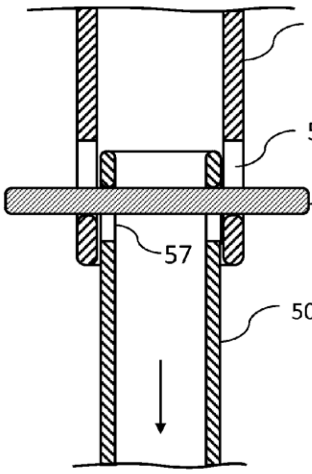


FIG. 4a

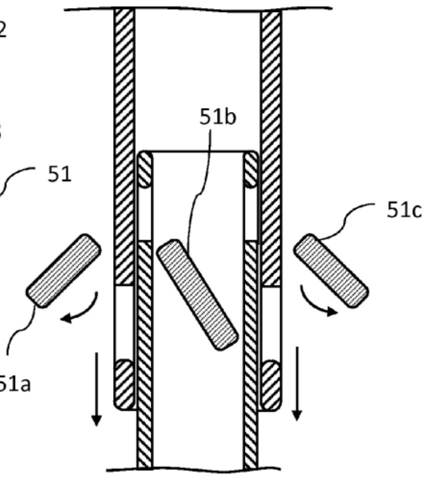


FIG. 4b

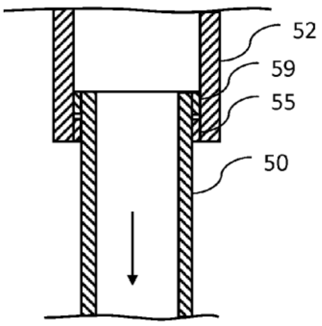


FIG. 5a

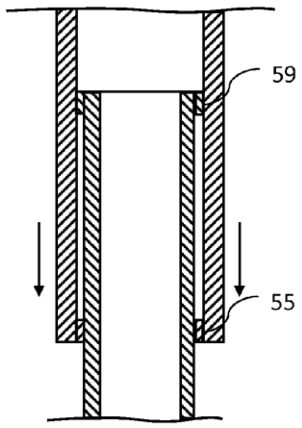


FIG. 5b

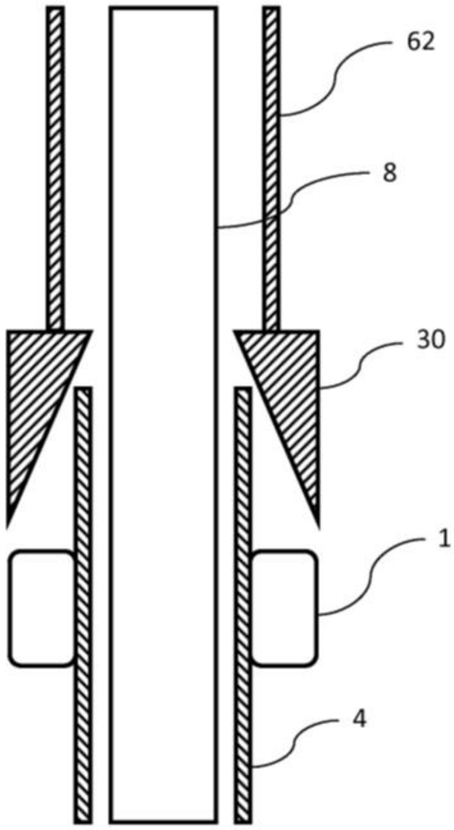


FIG. 6

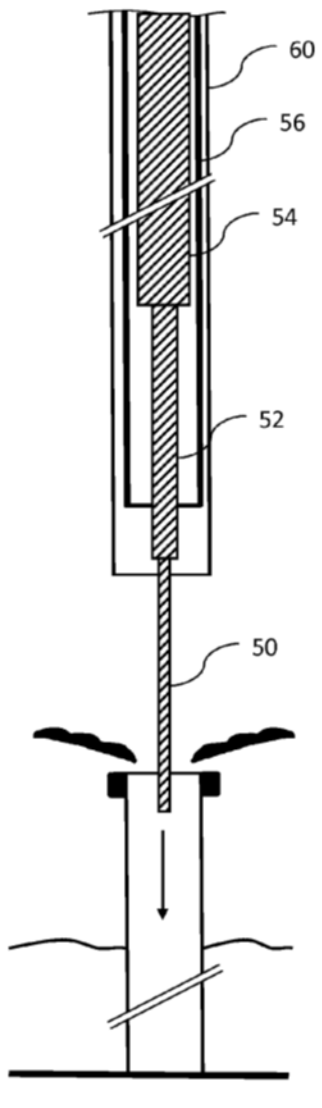


FIG. 7

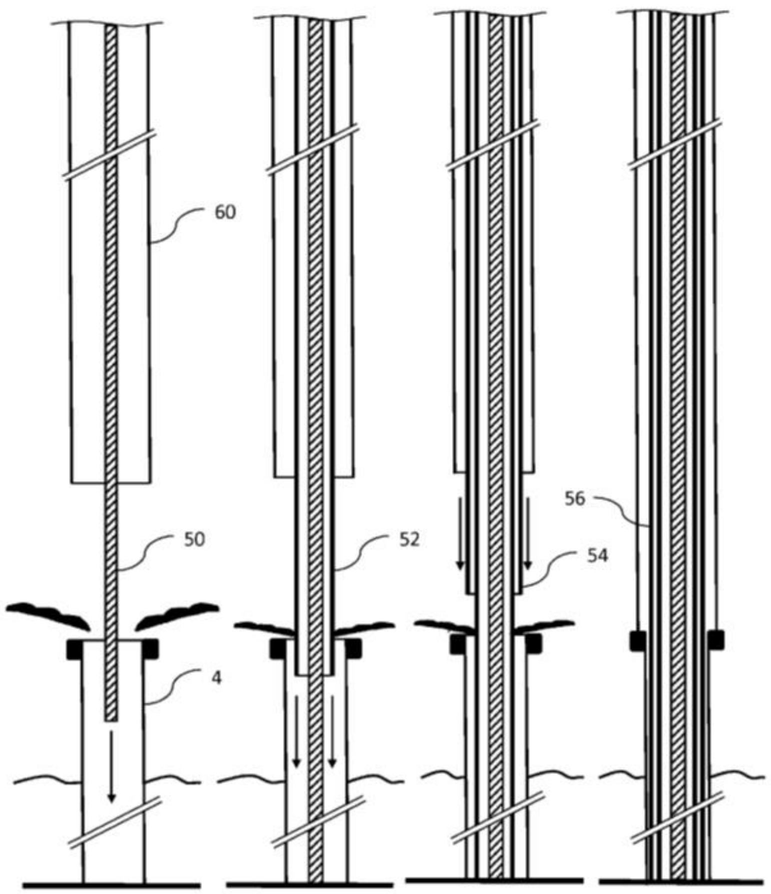


FIG. 8a FIG. 8b FIG. 8c FIG. 8d

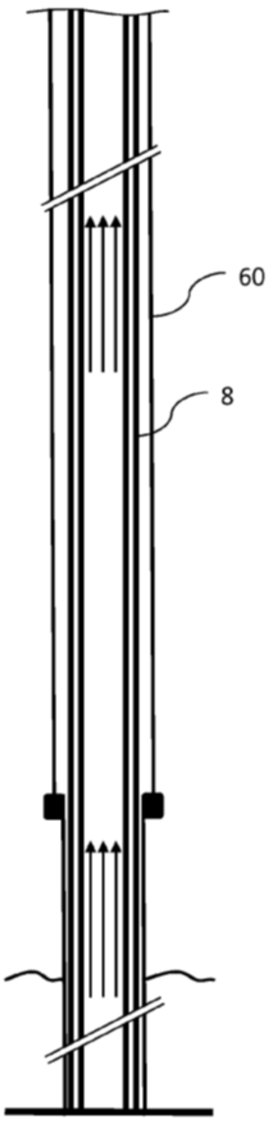


FIG. 8e

METHODS AND DEVICES FOR RESTORING CONTROL AND RESUMING PRODUCTION AT AN OFFSHORE OIL WELL FOLLOWING AN UNCONTROLLED FLUID RELEASE AFTER AN EXPLOSION

CROSS-REFERENCE DATA

This application is a continuation-in-part of the co-pending U.S. patent application Ser. No. 13/675,975 filed 13 Nov. 2012 entitled "Method and Alignment System for Killing an Uncontrolled Oil-Gas Fountain at an Offshore Oil Platform Using a Telescopic Insert Assembly"; which in turn claims the priority date benefit from a U.S. Provisional Application No. 61/681,257 filed 9 Aug. 2012 and entitled "The Method of Killing an Uncontrolled Oil-Gas Fountain at an Offshore Oil Platform Using a Telescopic Insert Assembly".

This application is also a continuation-in-part of the U.S. patent application Ser. No. 13/184,497 filed 16 Jul. 2011, now U.S. Pat. No. 8,448,709 entitled "Method of Killing an Uncontrolled Oil-Gas Fountain Appeared After an Explosion of an Offshore Oil Platform"; which in turn claims a priority benefit of the U.S. Provisional Patent Application No. 61/367,478 filed 26 Jul. 2010.

All cited above patent documents are incorporated herein in their respective entireties by reference.

BACKGROUND

The present invention relates to methods and devices for regaining control and resuming oil and/or gas production at an offshore oil well after an explosion or a blowout causing an uncontrolled release of fluids such as oil or water mixed with gas from the remaining part of the damaged well. The term "oil well" is used herein to describe a well that produces any type of hydrocarbons including oil and gas, but which may also produce a gas condensate or water as part of the multi-phase fluid discharge that comes out of the well. The present invention more specifically relates to methods for controlling the fluid discharge by gradually decreasing fluid flow using a plurality of flow restricting inserts.

In the field of offshore oil drilling, oil wells are kept under control by means of a column of mud which provides a hydrostatic load sufficient for maintaining overpressure between the well and the external pressure at control values. This column of mud, also known as primary well control barrier, is present both inside the well and also in a pipe called a riser, which connects the drilling platform at the sea surface to the sea bottom.

At the sea bottom, moreover, in correspondence with the well heads, there are present secondary oil well control devices, called blowout preventers (BOP) configured as valves to close the oil well off in the case of uncontrolled release of fluids from the well itself.

Often during drilling or well exploration in gas and oil wells, a gas kick may enter into the well space. Such gas may come from the well reservoir (formation) and reach the bottom hole of the well. If this is not detected immediately, a gas bubble (gas kick) is created in the hole. Gas kick, according to Archimedes' principle begins to ascend within the annular space of the well. If not allowed to expand, such gas kick brings its initial high pressure equal to the formation pressure to the head of the well. At the same time, the pressure everywhere along the well begins to rise. If the BOP is closed, and there is no "washing" in the well, a hydrofracture of formation may occur. As a result, the drilling fluid enters the formation, and the well is filled with gas. If the drill pipe has no check

valve, the gas also fills drill pipes all the way up to the wellhead. This may cause a gas explosion that may result in human casualties, environmental pollution and the creation of an uncontrolled fountain. This uncontrolled fountain 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.

Presently known are various techniques for reestablishing the control of the well in case of a blowout, such as for example the techniques of bridging, capping, production 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.

A killing intervention consists of the insertion of a specific string of pipes inside a blowout well. When inserted in the well, the killing string allows conventional killing techniques to be applied such as the circulation of heavy mud, closure by means of inflatable packers, and so forth. This method has proved to be the most rapid, but it can currently only be used in the case of well blowouts in shallow water, i.e. less than 1,000 meters deep. In addition, in order to allow for the adequate flow of cement through the killing string, its internal diameter has to be sufficiently large such as at least 10 cm or more. Inserting such a large string of pipes presents a challenge due to an enormous pressure in the well urging the killing string out of the well. Additional methods of killing a well include drilling a side channel into the well and sealing the well through such channel. This method takes a long time (several months) while allowing for the uncontrolled release to continue polluting the waters with large quantity of oil. This process is also quite expensive. In addition, there is always an uncertainty present as to the exact location of the well deep down under the sea bottom. On occasion, if the side channel has missed the well, a powerful explosion may have to be used to shift the layers of the rocks and the ground near the well so as to seal it properly. In rare circumstances, underground nuclear explosions are known to be used for such purpose.

To date, no practical equipment or method is available to the industry for the purpose of regaining control of a deep water abandoned wellhead on the offshore seabed after a blowout causing spilling of reservoir fluids into the sea. The environmental pollution caused by such outpouring of reservoir fluids and gases can have disastrous consequences, as evident by the 2011 pollution created over a large section of the Gulf of Mexico and adjacent beaches by the erupted BP well off the coast of Mexico.

There is a need for improved and expeditious methods for regaining control of an uncontrolled release of fluids from an oil well following a blowout or an explosion event.

There is also a need preserve the oil well and to resume oil production therefrom following an explosion. Drilling a single underwater oil well costs millions of dollars and so it is highly desirable to not abandon a well if at all possible so as not to suffer an economic loss associated with such abandonment.

SUMMARY OF THE INVENTION

The object of the present invention is to provide improved methods and devices for restoring control of an oil well and arresting uncontrolled release of fluids into the environment following an explosion.

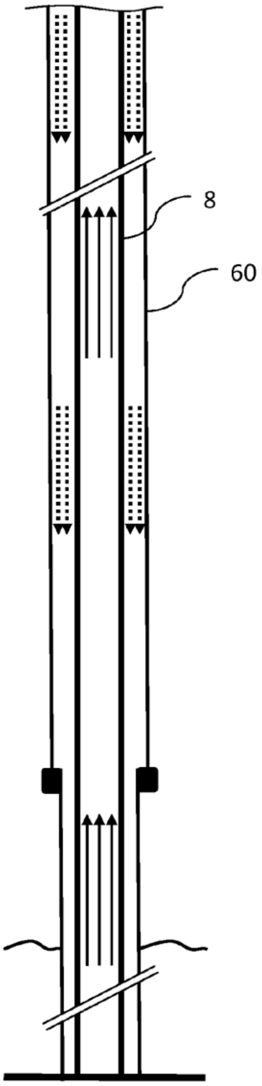


FIG. 9a

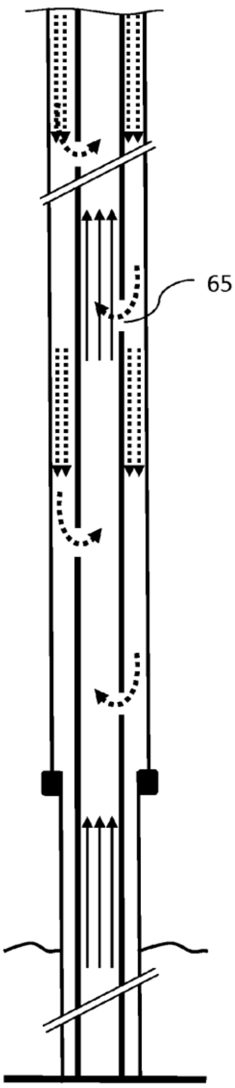


FIG. 9b

Another object of the present invention is to provide novel methods and devices for efficient, expedient, and less expensive processes of regaining control over an oil well after a blowout or an explosion.

A further object of the invention is to provide novel methods and devices for continuing production of oil from an oil well following an accidental explosion.

Another yet object of the present invention is to provide methods and devices for gradual flow adjustment in oil production over a broad range of operating parameters after regaining control over the well following an explosion. Such adjustments are needed to optimize oil production from the well over the remaining lifetime thereof.

Novel methods of the invention broadly include steps of inserting a series of flow-restricting inserts into the oil well aimed to gradually reduce the uncontrolled fluid release therefrom. Once the flow of fluids is reduced to a predetermined level, the riser may be attached to the end of the oil well so that any further fluid release may be captured at the sea surface.

In addition to quickly restoring control over the damaged oil well, the present invention provides for novel methods and devices to return the well to produce oil through the riser. In fact, additional manipulation of the flow restricting inserts (lowering or rising at least some of them or adding/removing more inserts) provides for a convenient way to adjust flow production from the oil well for the remaining portion of the well lifespan.

Describing the invention now in more detail, flow restricting inserts of the invention may include a series of solid rods or hollow pipes, which may be attached or inserted one into another. Initially, a first flow restricting insert (such as a solid rod) may be inserted into the opening of the oil well. As diameter of the first insert is selected to be smaller than the oil well opening, the force urging the insert out of the well may not be as high—since fluids are still flowing out of the well around the first insert. The material, length 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 lowering force to be applied from above.

Once the first insert enters the well, the fluid release will be somewhat diminished. The deeper the first insert goes, the greater is this reduction.

Additional flow restricting inserts may then be inserted into the well following placement of the first insert. In embodiments, such additional inserts may be inserted in parallel with the first insert. In other embodiments, additional flow restricting inserts may be inserted to form concentric telescopic assembly with the first insert. The number, size and length of the additional inserts may be selected depending 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.

Fluid release will be further diminished as a result of positioning additional flow restricting inserts into 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 therefrom. At this point, the oil well may be sealed off, for example by pumping cement down the annular space between the riser and the biggest flow restricting insert. In other embodiments, the oil production from the oil well may be resumed. In this case, the presence of flow restricting inserts allows for an advantageous adjustment of flow resistance through the riser over the remaining portion of the oil well lifespan.

BRIEF DESCRIPTION OF THE DRAWINGS

Subject matter is particularly pointed out and distinctly claimed in the concluding portion of the specification. The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings, in which:

FIG. **1** is general depiction of the components involved in practicing the method of the invention,

FIGS. **2***a* through **2***d* illustrate various stages of practicing the first embodiment of the method of the invention;

FIGS. **3***a* and **3***b* show various stages of practicing the second embodiment of the invention,

FIGS. **4***a* and **4***b* show the details of attachment between adjacent flow restricting inserts according to the first embodiment of the invention,

FIGS. **5***a* and **5***b* show the details of attachment between adjacent flow restricting inserts according to the second embodiment of the invention,

FIGS. **5***c* and **5***d* show the details of the internal stopper at the upper end of the flow restricting inserts of the invention,

FIG. **6** shows the details of attaching the riser to the oil well,

FIG. **7** shows initial steps of the method according to the third embodiment of the invention,

FIGS. **8***a* to **8***e* show various stages of practicing the method according to the fourth embodiment of the invention, and

FIGS. **9***a* and **9***b* show various stages of practicing the method according to the fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

The following description sets forth various examples along with specific details to provide a thorough understanding of claimed subject matter. It will be understood by those skilled in the art, however, that claimed subject matter may be practiced without one or more of the specific details disclosed herein. Further, in some circumstances, well-known methods, procedures, systems, components and/or circuits have not been described in detail in order to avoid unnecessarily obscuring claimed subject matter. In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

A general illustration of the elements needed to practice the invention is shown in FIG. **1**. Seen in this illustration is a sea platform or a ship **6** supporting a rig **7**. The platform **6** has a riser **60** extending therefrom and ending above the opening of the oil well casing **2**. Hanging down from the rig **7** (via an optional weight balance **10**) and extending through the riser **60** is a flow restricting assembly **8** seen in FIG. **1** as entering the pipe **4** of the oil well casing **2**. The pipe **4** is assumed to extend from the sea bottom into formation **3** so as oil and other fluids may be produced through perforations **9**.

Also shown is a BOP **1**, which may or may not still be present at the oil well casing **2** after the explosion. The method of the invention works in both cases: when the BOP remains on the well as well as when BOP is missing and only a small section of pipe remains in place. In this case, to prepare the pipe for the method of the invention, its top portion may be cut normal to the axis of the pipe leaving a short pipe section extending from the sea bottom.

The present invention further works if the well is not yet fully constructed, such as the case when the blowout occurred during drilling. The term "oil well" in that case is used herein to describe a drill pipe, which may still remain in place after the explosion.

At the beginning of the procedure, the lower end of the riser **60** may be positioned above and aligned with the BOP or the remaining opening of the oil well. The method of the invention includes successive placement through the riser **60** of flow restricting inserts down the well pipe **4** in order to gradually reduce the flow of fluid release. Several different types of flow restricting inserts forming the flow restricting assembly **8** are contemplated to be within the scope of the present invention. Such inserts may be round, oval or have differently shaped cross-sections. They may be solid or hollow and sized to accept smaller inserts therein.

In embodiments, flow restricting inserts may be successively placed into the oil well one at a time—either next to each other or over each other, or as a combination of both next to each other and over each other.

In embodiments, the length of at least some of flow restricting inserts may be selected to partially or fully span the length of the pipe **4** between the sea bottom and the well bottom (or the bottom of an oil reservoir formation **3**). In other embodiments, the length of the flow restricting inserts may be selected to be longer, in some cases as long as to reach the sea surface after the insert is placed in the oil well. The advantage of suspending and maintaining individual inserts from the sea surface and down at least partially the depth of the well is that in this case, individual flow restricting inserts may be selectively lowered, raised, or removed altogether from the riser and the oil well, which may be used in adjusting flow resistance from the oil well to maximize oil production or for other purposes.

In embodiments, the material of the flow restricting inserts may be metal such as steel, or another material appropriate for the oil well environment. The cross-sectional area and the material for each individual flow restricting insert may be selected depending on the oil well pressure, reservoir depth, sea depth and other factors. The guiding principle behind selecting the material, length and cross-sectional area for each flow restricting insert is to assure that its respective weight is at least even or greater than the level of force urging the insert out of the well. This is necessary to assure that the insert can be lowered into the well based on its own force of gravity so as no additional pushing force may be needed to place the insert into the well.

In embodiments, the flow restricting inserts may have a constant or varying cross-sectional shape or size along its length. In the most basic case, the flow restricting insert may be a steel insert of constant diameter. In other embodiments, flow restricting inserts may be metal pipes, which may be sized for example to be placed one inside the other. In yet other embodiments, flow restricting inserts may be shaped as a single telescopic insert assembly as discussed in more detail in our cited prior patent applications.

In embodiments, flow restricting inserts may have threaded ends adapted for attachment to other inserts or other end design as described in more detail below. The diameter of each insert may be from 10 mm to 800 mm. Importantly, the size of the final insert should match as closely as possible the inner diameter of the well pipe **4**. If large diameters are required, materials other than steel may be used for large diameter inserts to reduce its weight. Alternatively, such large diameter inserts may be made of pipes with inside opening diameter selected appropriately to reduce the weight as needed.

The initial insert may be selected to have a small enough diameter so as to enter the opening of the well pipe **4** without much resistance. Considering that the weight of such insert may reach several hundred kilograms since the depth of a well is significant, little or no resistance should be encountered upon entrance of the first flow restricting insert into the oil well. Note that the entrance of the tip of the first insert may be aided by centering thereof using known means as for example described in our previously cited patent applications.

Once the first insert is placed in the well, additional inserts may be placed to gradually increase the overall cross-sectional area of the inserts and decrease the space inside the oil well available for fluid release. Reduced fluid release is a result of both the reduction of available cross-sectional area as well as an increase of flow friction between the inside surface of the well and the flow restricting inserts.

It is important to properly select flow restricting inserts to assure their smooth entrance into the oil well. One useful method of monitoring the progress of lowering flow restricting inserts into the well may include using a weight balance **10** positioned at the sea surface. Monitored force in that case will be a result of gravity pushing the inserts down and the combination of forces urging them up. Such simple method of assessing the conditions of lowering the insert assembly down and adjusting the size and weight of the successive inserts allows eliminating any uncertainties associated with calculating various forces acting on the inserts. These uncertainties are not easily accounted for and include variations in discharge of gases and various fluids from the well. In embodiments, the inserts may be selected to assure that the positive balance of forces as indicated by the balance **10** should always exceed at least 100 kg. In other embodiments, the safe limit of excess weight on the balance **10** may be selected to be between 100 and 500 kg, or can be assessed as a percentage of the weight of entire flow restricting assembly, such as for example 5-10% of such weight.

The method of the invention may include the following steps:

a. providing a riser extending from a sea surface to end above and in vertical alignment with the oil well;

b. inserting a first flow restricting insert through the riser and into the oil well, the first flow restricting insert is sized to be smaller than the opening of the oil well, thereby reducing the uncontrolled fluid release therefrom;

c. inserting at least one or several additional flow restricting inserts through the riser and into the oil well, thereby further reducing the uncontrolled fluid release from the oil well. These additional inserts may be inserted in parallel or in series with one another. They may also be inserted to be concentric to one another or a combination of these approaches. Inserting additional flow restricting inserts is aimed at reducing the flow of fluid emanating from the oil well to a level suitable for attaching the riser to the oil well, for example not more than 3-5 times that of projected flow from the well under normal operating conditions. At this point the fluid release is generally under control making the next step feasible and safe;

d. sealingly attaching the riser to the oil well to direct all fluid release to flow through the riser to the sea surface, which may be collected by a ship standing nearby or pumped to shore using conventional means. The oil well is now under control and steps can be taken to resume oil production from the oil well through the riser and to the sea surface. Alternatively, the oil well may be sealed such as for example by pumping cement through the riser and into the well.

FIGS. **2***a* through **2***d* illustrate an example of the method of the invention according to the first embodiment. Shown in FIG. **2***a* is the beginning of the process of lowering the flow restricting assembly **8** into the well pipe **4** through the lower end **62** of the riser **60** positioned above and aligned with the BOP **1**. The flow restricting assembly **8** in this case consists of the first solid insert **50** attached to a higher insert pipe **52**, which in turn is attached to a higher and larger insert pipe **54** and finally the assembly **8** includes the upper insert pipe **56**. Each successive pipe **52**, **54**, and **56** may be made to accept the adjacent lower insert inside thereof. The attachments **51** between successive flow restricting inserts may be made to allow hanging of the lower insert at the end of the higher insert respectively. One example of such attachment is shown in FIGS. **4***a* and **4***b*, while another example is shown in FIGS. **5***a* and **5***b* which are discussed in more detail below.

Upon reaching the bottom of the well, the first flow restricting insert **50** stops while the remaining portion of the flow restricting assembly **8** continues its descent into the oil well pipe **4**. In embodiments, a connection between the insert **50** and adjacent insert **52** may be made with a cross-bar **51** positioned through the side openings **53** in the insert **52** and a respective side opening **57** in the insert **50**. Each of the openings **53** and **55** has a respective lower edge and upper edge. In embodiments, the lower edge of the opening **53** and the upper edge of the opening **57** may be made with rounded edges so as to retain the cross-bar **51** in place without shearing through the cross-bar **51**—and therefore supporting hanging the insert **50** off the insert **52**—see FIG. **4***a*.

Once the insert **50** stops moving when the well bottom is reached and the insert pipe **52** continues its descent, a relative motion of the insert pipe **52** may be used to disengage it from the insert **50**. Due to the upper edge of the opening **53** and the lower edge of the opening **57** having sharp corners, the cross-bar **51** is sheared off into three pieces **51***a*, **51***b*, and **51***c* so that the insert **50** is disconnected from the insert **52**—see FIG. **4***b*. FIG. **2***b* shows the inserts **50** and **52** at the bottom of the oil well while the insert **54** is being lowered into the well pipe **4**. The attachment between successive inserts may be made in a manner similar to that described above for inserts **50** and **52** such that some or all of the inserts of the flow restricting assembly **8** may be configured to be detached and left in place in the oil well.

FIG. **2***c* shows the stage of the process when all flow restricting inserts are positioned in place and the riser **60** is attached to the remnants of the BOP **1**. At this point, the fluid from the oil well pipe **4** is directed through the annular space inside the riser **60** towards the sea surface where it can be collected and transported away from the oil well. In embodiments, at least the largest flow restricting insert **56** may be configured to reach all the way from the bottom of the reservoir to the sea surface so as to allow injecting or withdrawing fluids to or from the oil well.

FIG. **2***d* shows a possible disposition of the oil well once uncontrolled fluid release is no longer a problem. In this embodiment, the oil well may be sealed with a cement plug **72** delivered through the annular space between the riser **60** and the largest flow restricting insert **56**.

FIGS. **3***a* and **3***b* show another disposition of the oil well according to a second embodiment of the invention, in which individual flow restricting inserts are configured to be engaged and attached to each other allowing the entire assembly to collapse or extend axially like a "spy glass". One such engagement design between adjacent inserts of the flow restricting assembly is shown in FIGS. **5***a* and **5***b*, where each respective portion of flow restricting inserts **50** and **52** has a flange **55** and **59**. The flanges **55** and **59** may be configured to overlap each other such that during lowering of the flow restricting assembly **8** into the oil well pipe **4**, the lower insert is supported by the adjacent higher insert (as seen in FIG. **5***a*). Upon reaching the bottom of the well, the lower insert **50** may stop and disengage from the next insert **52**, which can continue its descent, shown with arrows in FIG. **5***b*. Other possible designs of the ends of respective inserts **50** and **52** may include a bayonet-type design or other fittings that may be engaged and disengaged using mechanical means and motions (such as turning and pulling) as well as hydraulically or electrically-activated coupling means.

One advantage of using coupling means that may be used to reengage adjacent sections of the flow restricting assembly **8** is that after regaining control over the oil well by lowering and axially collapsing the flow restricting assembly **8**, oil production may be resumed by lifting the assembly **8** and axially extending flow restricting inserts as seen in FIG. **3***a*. Moreover, periodic lowering or raising of the flow restricting assembly **8** from the sea surface may be used to gradually adjust the flow resistance through the well-riser combination so as to optimize oil production over the remaining life of the oil well when production conditions change over time. The long and tapered flow-restricting assembly **8** allows for fine tuning the resistance of flow over a broad range—from complete flow blockage (full insertion of assembly **8** down the oil well pipe **4**) to complete lack of resistance (if the flow restricting assembly **8** is removed from the oil well pipe **4** and the riser **60** altogether).

Individual flow restricting inserts may be selected to assure that their own weight may be sufficient to both lower them into the oil well as well as retain them therein. Once the individual inserts of the flow restricting assembly are placed into the oil well, there may be nothing but their own weight which retains them individually in their positions. Alternatively, the upper end of each flow restricting insert may be equipped with an internal stopper **70**, see FIG. **5***c*, which may be sized to prevent the adjacent lower insert from slipping up and out therefrom should the oil well pressure exceed the weight of the insert. Since the length of the upper flow restricting insert may be selected to cover the depth of the ocean in addition to the depth of the oil well, the internal stopper in this largest flow restricting insert may be positioned at a location close to the oil well opening—in this case the internal components of the flow restricting assembly will be prevented from moving up on their own and escaping from the oil well. In embodiments, the internal stopper may be a permanent cross-bar, an inner disk **70** with an opening **72** as seen in FIG. **5***c*, an indentation **74** as seen in FIG. **5***d* or another feature, which is configured to prevent the slippage of the internal insert past thereof.

In embodiments, straight individual flow restricting inserts may be used in combination with telescoping combination of flow restricting inserts. In that case, some or all of the telescoping inserts may be removed following restoration of control over the oil well such as oil production may proceed through the larger internal area of the remaining insert—as shown in FIG. **3***b*.

FIG. **6** shows the details of sealingly attaching the lower end **62** of the riser **60** to the remaining portion of the well pipe **4** and the BOP **1**. A tapered fitting **30** may be used to cover the well pipe **4**. Once the fitting **30** is placed over the pipe **4**, their attachment may be permanently sealed by welding, threaded connection or other known methods.

FIG. **7** illustrates a third embodiment of the method of the invention in which a central portion of the flow restricting assembly **8** is made as a telescopic permanent assembly of solid rods of increasing diameters **50**, **52**, and **54**, while the outer portion is made using one or more sliding flow restricting rods **56**. In embodiments, once the control over the oil well is regained, the central telescopic rod assembly may be lifted to adjust the flow of oil from the well or removed entirely so that oil production may proceed through the outer insert **56**.

FIGS. **8***a* through **8***d* show a fourth embodiment of the method of the invention, in which all flow restricting inserts may be concentric and continuously suspended from the sea surface. In that case, they all may be moved relative to each other and controlled from the sea surface. According to this embodiment, the first flow restricting insert **50** may be initially lowered into the well (see FIG. **8***a*). Once it reaches the bottom of the oil well, a second flow restricting insert **52** may be lowered into the well while sliding over the first insert **50**—see FIG. **8***b*. At this stage, the first flow restricting insert **50** may still be suspended from the rig **7** at the sea surface.

Once the first flow restricting insert **50** and the second flow restricting insert **52** have reached the bottom of the oil well, a third flow restricting insert **54** may be lowered into the oil well while sliding over the insert **52**—see FIG. **8***c*. This process may continue until all inserts of the flow restricting assembly **8** are lowered into the oil well so that the riser may be attached to the oil well pipe **4**—see FIG. **8***d*. Importantly, at least some or preferably all of the flow restricting inserts are still suspended from the sea surface so as to allow one or more of them to be later (and from time to time) individually lowered, lifted or removed from the oil well as seen in FIG. **8***e*—this is advantageous to allow fine control over the oil flow from the well.

A fifth embodiment of the invention is illustrated in FIGS. **9***a* and **9***b*. In this embodiment, the presence of individually controlled flow restricting inserts after regaining control over the oil well following the explosion may be advantageously used to optimize oil production in future years of the oil well. In particular, it is known that by the end of its useful life, there is a need to boost formation pressure so as to extract more oil therefrom. One technique for doing so is generally known as a gas lift. In this case, gas is injected under pressure into the reservoir to increase the oil flow therefrom.

According to the fifth embodiment of the invention, at least a first passage may be established inside the riser, for example an annular space between the riser and the flow restricting assembly **8**. A separate second passage may further be established inside the riser such as for example between individual flow-restricting inserts or by removing one or more of the flow restricting inserts from the riser.

Either the first passage or the second passage may be used for oil production. The other passage may be used to inject gas into the oil well or into the oil producing passage at one or more points along its length.

FIG. **9***a* shows one example of practicing this method of the invention. In this case, gas may be injected in the annular space between the riser **60** and the outer section of the flow restricting assembly **8** (gas flow shown with dashed arrows). Enhanced oil production may be directed through the central opening—as shown with regular arrows.

FIG. **9***b* shows an alternative embodiment of this method of the invention in which the outer section of the flow restricting assembly may contain one or more openings along its length. In this case, injecting gas into the annular space between the riser **60** and the flow restricting assembly **8** will result in forming one or more gas entry points **65** (shown as curved dashed arrows) into the oil producing passage leading to increased production of oil from the oil well.

The herein described subject matter sometimes illustrates different components or elements contained within, or connected with, different other components or elements. It is to be understood that such depicted architectures are merely examples, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality may be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated may also be viewed as being "operably connected", or "operably coupled", to each other to achieve the desired functionality, and any two components capable of being so associated may also be viewed as being "operably couplable", to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

Although the invention herein has been described with respect to particular embodiments, it is understood that these embodiments are merely illustrative of the principles and applications of the present invention. For example, the method of the invention may be adapted for oil wells that are not offshore. In that case, flow restricting inserts may be placed into the well from the ground. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

We claim:

1. A method for restoring control and resuming production at an offshore oil well following an uncontrolled fluid release after an explosion, said method comprising the steps of:

a. providing a riser extending from a sea surface, said riser ending above and in vertical alignment with an oil well head of the oil well,

b. inserting a first flow restricting insert through the riser and into the oil well head, said first flow restricting insert sized to be smaller than the opening of the oil well head, thereby reducing the uncontrolled fluid release therefrom,

c. inserting at least one additional flow restricting insert through the riser and into the oil well, thereby further reducing the uncontrolled fluid release from the oil well to a level suitable for attaching the riser to the oil well, and

d. sealingly attaching the riser to the oil well head to direct all fluid release to flow through the riser to the sea surface, whereby restoring control of the oil well and resuming oil production therefrom through the riser.

2. The method as in claim **1** further including after step (d) a step of lowering or lifting at least one of said flow restricting inserts to optimize oil production from the oil well through the riser.

3. The method as in claim **2**, wherein said step of lowering or lifting at least one of said flow restricting inserts is repeated from time to time to optimize oil production of the oil well throughout its lifetime.

4. The method as in claim **1**, wherein at least one of said first or said additional flow restricting inserts is individually suspended from the sea surface so as to allow individual lowering or lifting thereof following completion of step (d).

5. The method as in claim **1**, wherein at least one of said first or said additional flow restricting inserts is suspended from or attached to a lower end of a subsequent flow restricting insert to form an assembly of flow restricting inserts, whereby lowering or lifting of said subsequent flow restricting insert from the sea surface causes a corresponding lowering or lifting of said assembly of flow restricting inserts.

6. The method as in claim **5**, wherein at least some of said flow restricting inserts are made hollow and sized to slidingly accept inside thereof of other flow restricting inserts below thereof in said assembly of flow restricting inserts, whereby upon lowering of said assembly into said oil well in step (c), said assembly is axially collapsed upon reaching a bottom of said well.

7. The method as in claim **1** further including after step (d) a step of inserting at least one additional flow restricting insert or removing at least one existing flow restricting insert to optimize oil production from the oil well through the riser.

8. The method as in claim **7**, wherein said step of inserting or removing at least one of said flow restricting inserts is repeated from time to time to optimize oil production of the oil well throughout its lifetime.

9. The method as in claim **1**, wherein in step (c) said fluid release is reduced to a level not exceeding five times a projected oil production rate of the oil well through the riser at the sea surface.

10. The method as in claim **1**, wherein in steps (b) and (c) said flow restricting inserts are configured so as to exceed in total weight the forces urging said flow restricting inserts out of the oil well.

11. A method for restoring control at an offshore oil well following an uncontrolled fluid release after an explosion, said method comprising the steps of:

a. providing a riser extending from a sea surface, said riser ending above and in vertical alignment with an oil well head of the oil well,

b. inserting through the riser a first flow restricting insert into the oil well head, said first flow restricting insert sized to be smaller than the opening of the oil well head, thereby reducing the uncontrolled fluid release therefrom,

c. inserting a plurality of successively larger concentric hollow flow restricting inserts through the riser into the oil well, said plurality of flow restricting inserts sliding over said first flow restricting insert, thereby further reducing the uncontrolled fluid release from the oil well, and

d. sealingly attaching the riser to the oil well head, whereby restoring control of the oil well and precluding further uncontrolled fluid release therefrom.

12. The method as in claim **11**, further including sealing said oil well with cement pumped through the riser.

13. The method as in claim **11** further including a step of resuming oil production from the oil well through the riser.

14. The method as in claim **11**, wherein said plurality of concentric flow restricting inserts comprise a series of individual pipes, each successive pipe is sized to accept a previous pipe inside thereof.

15. The method as in claim **14**, wherein at least one of said plurality of individual pipes and said first flow restricting insert is individually suspended from the sea surface to allow further lowering or raising thereof after completion of step (d) to adjust flow resistance from said oil well to the sea surface.

16. The method as in claim **11** further including after step (d) a step of creating a gas lift by forming a first passage from a bottom of the oil well to the sea surface for production of fluids therethrough; said step further including forming a second passage from the sea surface to one or more entry points along the first passage; said step further including injecting gas from the sea surface into said second passage so as to form a gas lift to increase oil production from said oil well.

17. The method as in claim **16**, wherein said first or said second passages are formed by removing at least one of said flow restricting inserts from said riser.

18. The method as in claim **16**, wherein said first passage is formed by removing said first flow restricting insert from said riser.

19. The method as in claim **16**, wherein at least one of said first passage or said second passage is formed in an annular space between said riser and said flow restricting inserts.

20. The method as in claim **19**, wherein at least one of said flow restricting inserts comprising at least one opening along said first passage to provide fluid communication between said second passage and said first passage, thereby allowing gas to entry from the second passage into the first passage to create said gas lift.

* * * * *

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Tseytlin et al.

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(45) Date of Patent: Jul. 2, 2013

(54) METHOD AND ALIGNMENT SYSTEM FOR KILLING AN UNCONTROLLED OIL-GAS FOUNTAIN AT AN OFFSHORE OIL PLATFORM USING A TELESCOPIC ROD ASSEMBLY

(71) Applicants: **Simon Tseytlin**, Middle Village, NY (US); **Alexey S. Kashik**, Moscow (RU)

(72) Inventors: **Simon Tseytlin**, Middle Village, NY (US); **Alexey S. Kashik**, Moscow (RU)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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E21B 7/12 (2006.01)

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USPC **166/335**; 166/339; 166/345; 166/363; 166/364

(58) **Field of Classification Search**
USPC 166/363, 339, 364, 368, 285, 381, 166/386, 387, 75.15, 179, 192, 193; 138/89
See application file for complete search history.

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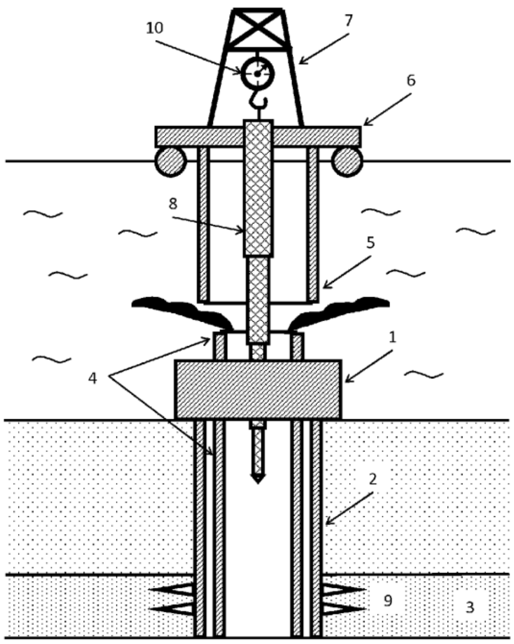
Primary Examiner — Matthew Buck
Assistant Examiner — James Sayre
(74) *Attorney, Agent, or Firm* — Boris Leschinsky

(57) **ABSTRACT**

A method and an apparatus for killing of uncontrolled oil fountain include a series of rods with the first rod having the smallest diameter and successive rods having increasing diameters. Such telescopic assembly of rods is lowered into the well to cause gradual reduction in cross-sectional area available for oil flow discharge. Once sufficiently large rods are lowered into the well, the oil fountain discharge will be greatly diminished. Final sealing may be accomplished by pumping cement into a space formed between the well pipe and the rod assembly. A novel system for aligning the rods to the center of the well is also described.

4 Claims, 7 Drawing Sheets



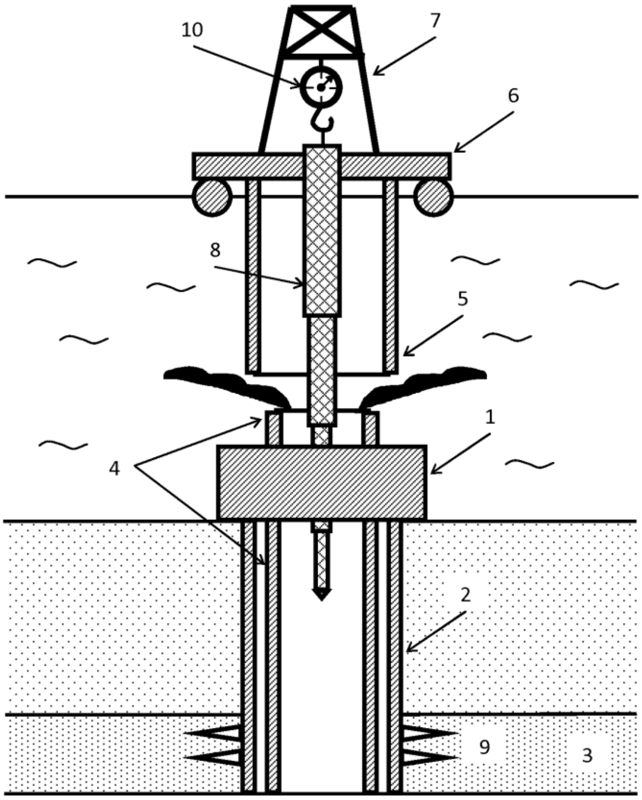


FIG. 1

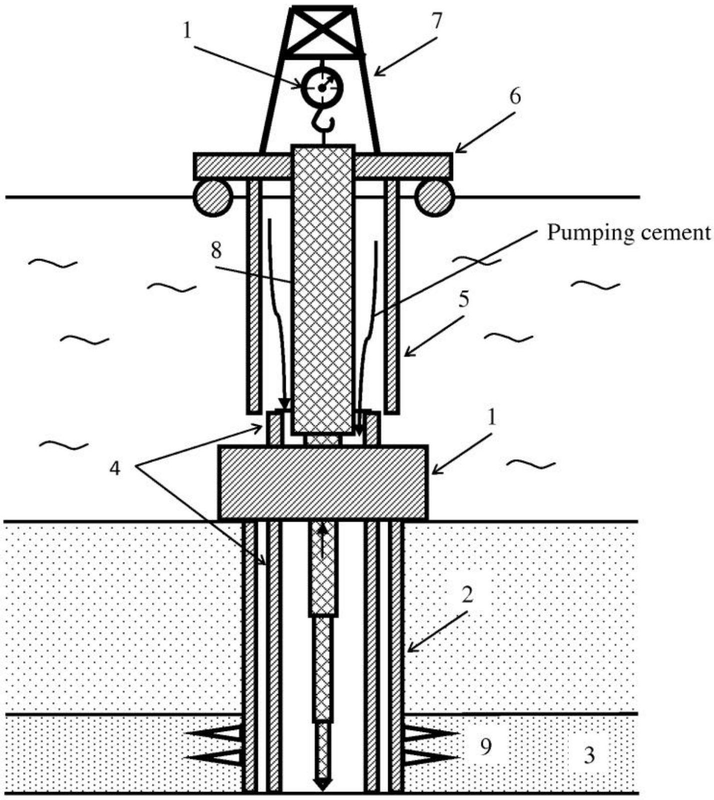


FIG. 2

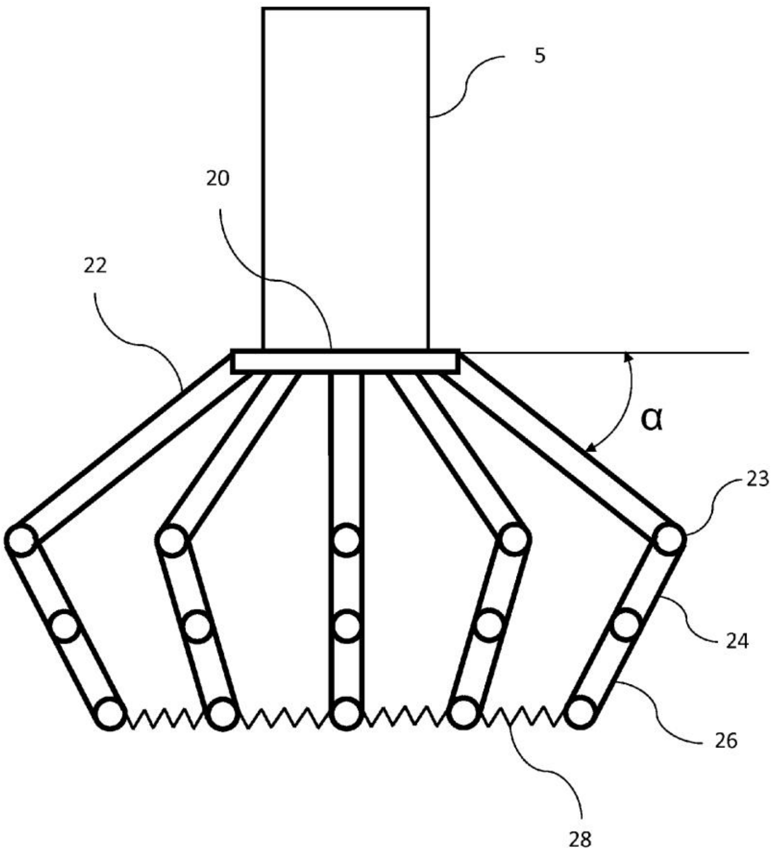


FIG. 3

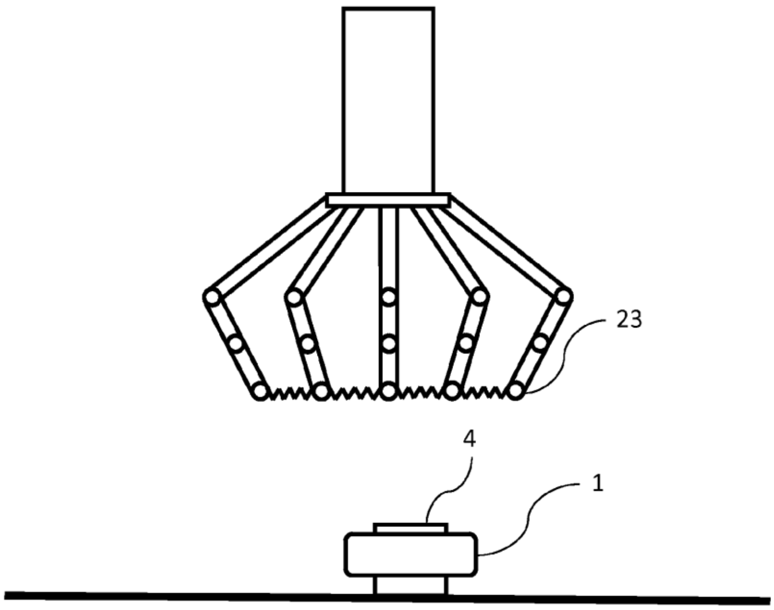


FIG. 4a

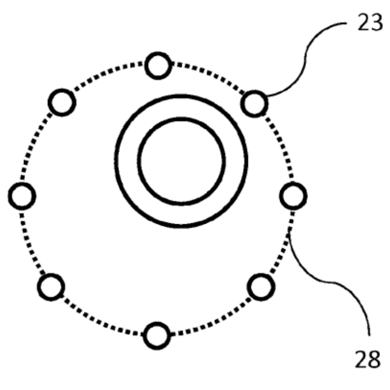


FIG. 4b

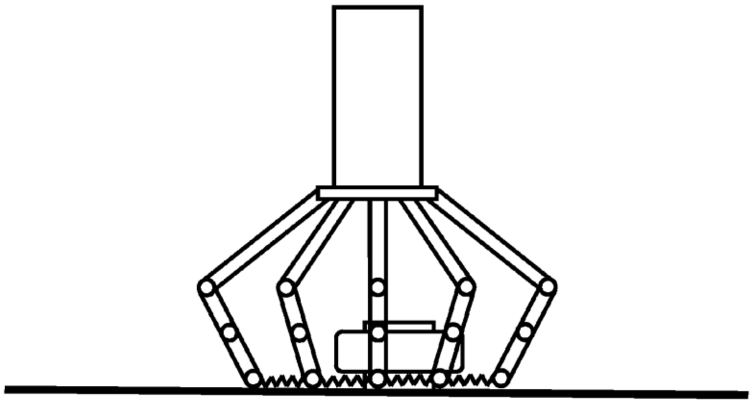


FIG. 5a

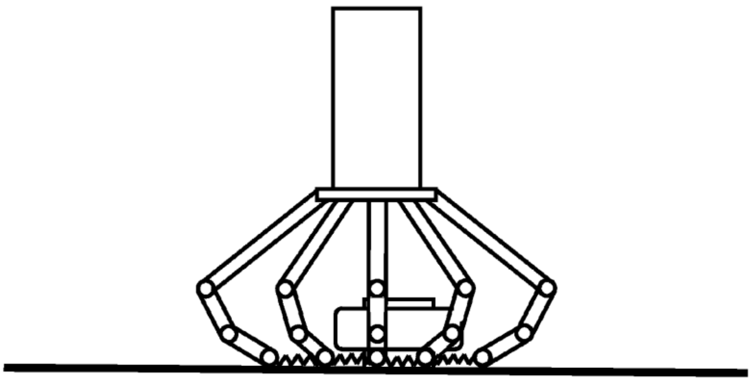


FIG. 5b

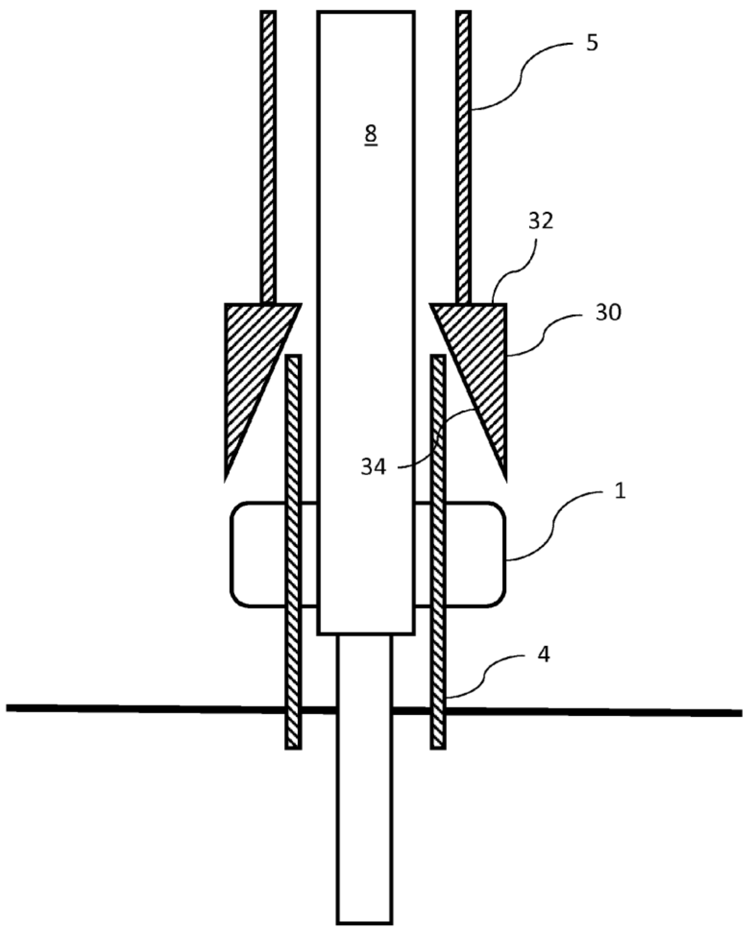


FIG. 6

METHOD AND ALIGNMENT SYSTEM FOR KILLING AN UNCONTROLLED OIL-GAS FOUNTAIN AT AN OFFSHORE OIL PLATFORM USING A TELESCOPIC ROD ASSEMBLY

CROSS-REFERENCE DATA

This application claims the priority date benefit from a U.S. Provisional Application No. 61/681,257 filed 9 Aug. 2012 and entitled "The Method of Killing an Uncontrolled Oil-Gas Fountain at an Offshore Oil Platform Using a Telescopic Rod Assembly". This provisional application is incorporated herein in its entirety by reference.

BACKGROUND

The present invention relates to a method and system 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. The term "oil well" is used herein to describe a well that produces any type of hydrocarbons including oil and gas, but which may also produce a gas condensate or water as part of the multi-fluid mixture discharge that comes out of the well. The present invention more specifically relates to methods for controlling the fluid discharge by gradually decreasing fluid flow using a telescopic assembly of flow restricting rods.

In the field of offshore oil drilling, the oil wells are kept under control by means of a column of mud which provides a hydrostatic load sufficient for maintaining overpressure between the well and the external pressure at controlled values. This column of mud, also known as primary well control barrier, is present both inside the well and also in a pipe called a riser which connects the drilling platform to the sea bottom.

At the sea bottom, moreover, in correspondence with the well heads, there are present secondary well control devices, called blowout preventers (BOP) configured as valves to close the well in the case of uncontrolled discharges of fluids from the well itself.

Often during drilling or well exploration in gas and oil wells, a gas kick may enter into the well space. Such gas may come from the well reservoir and reach the bottom hole of the well. If this is not detected immediately, a gas bubble (gas kick) is created in the hole. Gas kick, according to Archimedes' principle begins to ascend within the annular space of the well. If not allowed to expand, such gas kick brings its initial high pressure equal to the formation pressure to the head of the well. At the same time, the pressure everywhere along the well begins to rise. If the BOP is closed, and there is no "washing" in the well, a hydrofracture of formation may occur. As a result, the drilling fluid enters the formation, and the well is filled with gas. If the drill pipe has no check valve, the gas also fills drill pipes all the way up to the wellhead. This may cause a gas explosion that may result in human casualties, environmental pollution and the creation of an uncontrolled fountain. This uncontrolled fountain 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.

Presently known are various techniques for reestablishing the control of the well in case of a blowout, such as for example the techniques of bridging, capping, production 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.

A killing intervention consists of the insertion of a specific string of pipes inside a blowout well. When inserted in the well, the killing string allows conventional killing techniques to be applied such as the circulation of heavy mud, closure by means of inflatable packers, and so forth. This method has proved to be the most rapid, but it can currently only be used in the case of well blowouts in shallow water, i.e. less than 1,000 meters deep. In addition, in order to allow for the adequate flow of cement through the killing string, its internal diameter has to be sufficiently large such as at least 10 cm or more. Inserting such a large string of pipes presents a challenge due to an enormous pressure in the well urging the killing string out of the well. Additional methods of killing a well include drilling a side channel into the well and sealing the well through such channel. This method takes a long time of several months and is also quite expensive. In addition, there is always an uncertainty present as to the exact location of the well deep down under the floor of the sea. On occasion, if the side channel has missed the well, a powerful explosion may have to be used to shift the layers of the rocks and the ground near the well so as to seal it properly. Underground nuclear explosions are known to be used for such purpose.

To date, no practical equipment or method is available to the industry for the purpose of regaining control of a deep water abandoned wellhead on the offshore seabed after a blowout causing spilling of reservoir fluids into the sea. The environmental pollution caused by such outpouring of reservoir fluids and gases can have disastrous consequences, as evident by the 2011 pollution created over a large section of the Gulf of Mexico and adjacent beaches by the erupted BP well off the coast of Mexico.

There is a need for an improved method for killing of an uncontrolled fountain from an oil well following a blowout event.

SUMMARY OF THE INVENTION

The object of the present invention is to provide an improved method of killing an uncontrolled oil or gas fountain emanating from a damaged underwater oil well.

The novel method of the invention includes steps of lowering down a series of rods starting with the rod having the smallest diameter. Small diameter rod may be inserted into the well with less difficulty as compared with larger diameter rods. Once the smallest rod is in place, the cross-sectional area of the well available for oil flow discharge is somewhat reduced. Larger diameter rods may then be inserted in a successive series following the first rod. Gradually, most or even the entire cross-section of the well pipe is occupied by the telescopic assembly formed from these rods. Once these flow-restricting rods are in place, the well may be sealed by pumping in cement within the remaining space between the well and the rod assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

Subject matter is particularly pointed out and distinctly claimed in the concluding portion of the specification. The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings, in which:

FIG. **1** is a diagram of the smart point system of the invention,

FIG. **2** is a diagram of the flow of points within the smart point system,

FIG. **3** shows an alignment system of the present invention,

FIGS. **4***a* and **4***b* show the position of the alignment system next to the remaining well as a side view and as a top view. FIG. **4***b* only shows the outline of the lower part of the alignment system,

FIGS. **5***a* through **5***d* show various stages of lowering the riser onto the well and operational positions of the alignment system of the invention, and

FIG. **6** shows the details of a tapered cap placed at the lower end of the riser to assist in sealing the riser against the well pipe.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

The following description sets forth various examples along with specific details to provide a thorough understanding of claimed subject matter. It will be understood by those skilled in the art, however, that claimed subject matter may be practiced without one or more of the specific details disclosed herein. Further, in some circumstances, well-known methods, procedures, systems, components and/or circuits have not been described in detail in order to avoid unnecessarily obscuring claimed subject matter. In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

The method of the invention works in both cases: when the BOP remains on the well as well as when BOP is missing and only a small section of pipe remains in place. In this case, to prepare the pipe for the method of the invention, its top portion is cut normal to the axis of the pipe leaving a short pipe section extending from the bottom of the ocean.

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. In embodiments, an exemplary rod is made of metal and has threaded ends adapted for attachment to other rods. The diameter of each rod may be from about 15 mm to about 500 mm. Non-round initial rods may also be used. Importantly, the final diameter of the rod should match as closely as possible the inner diameter of the well pipe. If large diameters are required, materials other than steel may be used for large diameter rods to reduce its weight. Alternatively, such large diameter rods may be made of pipes with inside opening diameter selected appropriately to reduce the weight as needed.

Initial rod is selected to have a small enough diameter so as to enter the opening of a well without much resistance. Considering that the weight of such rod may reach several hundred kilograms since the depth of a well is significant, little or no resistance should be encountered upon entrance of the first rod into the well. Note that the entrance of the tip of the first rod may be aided by centering thereof using known means.

Once the first rod is placed in the well, additional sections of rods of gradually increasing diameters are attached successively to the first rod and lowered one by one into the well. As the total weight of the telescopic rod assembly is increasing, adding more rods should be accomplished without encountering much resistance. Steel rods are quite heavy as compared with water—their density is about ten times greater than that of water. As the diameter of the rods goes up, the cross-sectional area of the well available for fluid discharge goes down and the discharge flow is gradually reduced. This is a result of both the reduction of area available for fluid discharge as well as an increase of friction between the discharge from and the inside surface of the well plus the outer surface of the entire rod assembly. Step-wise transitions between the rods create local Eddie currents and further increase resistance to flow of the discharge fluid from the well. Furthermore, an increased weight of the fluid in the annular space between the well and the rod assembly causes further reduction in fluid discharge.

It is important to properly monitor lowering of successive rods down the well. To illustrate the calculations that will be made for such monitoring, there is provided an example based on the 2011 blowout of a BP oil well in the Gulf of Mexico at the sea depth of 1,000 meters and the well depth of about 3,000 meters with reservoir formation pressure of about 500 atmospheres.

Assuming the diameter of the first rod of about 2.5 cm (about 1 inch), the weight of the first rod at the point of well entrance at the depth of 1000 meters would be about 4,569.5 kg. The counteracting force from the oil fountain will always be less than the reservoir pressure multiplied by the cross-sectional area of the rod (about 2,285 kg). Once the rod is in the well, additional drag force will be acting on it to push it up but even in this case, the weight of the rod easily exceeds all these counteracting forces.

The second 1,000 meter long rod may be selected to be 3 inches in diameter. It is easy to demonstrate that the balance of forces will still be favorable for insertion of the second rod on top of the first rod into the well. The third section may then be selected to be 4 inches in diameter and the final section is 5 inches in diameter. At this point, the weight of the rods will reach about 200,000 kg while the force pushing the rods out of the well is about 58,000 kg—meaning that the system can be further lowered down into the well. Once it is in place, the flow discharge from a 6-inch well would be greatly diminished to allow for the final sealing process to kill the well entirely.

This final process includes using a riser having an inside diameter generally equal or just slightly more than the outer diameter of the well pipe. The end of the riser is set on the well (see FIG. **2**). In embodiments, the inner edge of the end of the riser may be tapered so as to assure a close fit and alignment of the riser and the well. In embodiments, once the riser is set onto the well pipe, various sealing steps may be undertaken such that the possibility of oil leak out of the well and outside the riser are greatly reduced or even prevented. One such example of a sealing step between the riser and the well pipe is a welding process to permanently attach the riser to the well. Another example is a threaded connection of the riser or a nut about the riser to the well pipe. Other such sealing steps would be readily apparent to those skilled in the art.

Once the riser is set about the well pipe, a standard process of pumping cement down the opening between the riser and the rods is used to seal the well and stop any further oil flow therefrom. Cement may be pumped in sufficient quantity so as to reach the reservoir perforations—once the cement is set, the well is entirely sealed. The riser and remaining rods may be cut off from the well pipe leaving it permanently sealed in place.

An alternative 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 rod assembly (pushing the entire assembly down) and the combination of various forces acting to push it up, including the reservoir pressure and the drag force from the flow of oil or a multiphase flow of various gases and fluids coming out from the well. Such simple method of assessing the conditions of lowering the rod assembly down and adjusting the size and weight of the successive rods allows to eliminate great uncertainties associated with calculating various forces acting on the rods. These uncertainties are not easily accounted for and include variations in discharge of gases and various fluids from the well.

At the beginning, upon the entrance of the rod into the well, the force shown by the weight measurement device will start to decrease as the rod is moved down the well. Additional weight is needed once the weight has dropped to less than about 100 kg or so—which can be provided by using rods of larger diameter for the next section. That diameter may be maintained for some time until the balance is again approaching the lower safe limit of 100 kg. In that case, larger yet rods may be used to cause the balance to increase again. Larger rods will ultimately slow down the fluid discharge from the well. Final rod diameter may be selected to be as close to the well diameter as possible, but preferably not smaller than well diameter by more than 5-10%. Importantly, the weight of the rods should be selected to assure that the weight measuring device shows a positive balance on its scale. This means that the rods are heavier than the forces directed at pushing them out of the well pipe and so continuous lowering of the rods may proceed further.

In embodiments, the safe limit of excess weight on the scale may be selected to be between 100 and 500 kg, or can be assessed as a percentage of the weight of entire rod assembly, such as 5-10% of such weight.

Advantageously, the rods which are used for the purposed of a reciprocating rod pump may be used for this invention. They are already commercially available in a broad range of sizes and can be easily adapted to be used as described above. Using rod pumps is further advantageous because of the available hardware that can be used to connect sections of such rods to each other.

In embodiments, the rod may be made solid and entirely from metal with no voids or passages therein. The end of the rod may be made tapered to facilitate insertion and advancement down the well. In other embodiments, each rod may be brought to the well location on a spool and unfolded during the insertion procedure.

FIG. **1** illustrates the beginning of the process of killing of uncontrolled fountain from an oil well, showing a blowout preventer **1**, a well casing **2**, formation **3**, drilling tubes **4**, a riser tube **5**, offshore platform **6**, a rig **7**, a rod (flow restrictor insert) **8**, perforations **9**, and a weight measurement device **10**.

The method of the invention includes the following necessary and optional steps:

1. Provide a plurality of flow restricting rods **8** of various diameters using either a standard floating rig **7** or a ship located near an offshore platform **6**;
2. Position a riser tube **5** over the drilling tube **4**. Riser tube **5** may have an inner diameter slightly larger than the external diameter of the drilling tube **4**. As a result, the lower end of the riser tube **5** may be placed over the head of the well at a distance of about several meters. Alignment and fixation of this riser tube **5** may be accomplished for example using a four-cable brace attached to the outer surface of the head of the well (see FIG. **1**);
3. Place a first flow restricting rod **8** into the riser tube **5**. To accomplish this, the first section of the rod **8** with the length which may be about 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 **8** 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 **5**. The process of lowering rods **8** and attaching new sections thereto may be repeated until the lower end of the first rod **8** appears suspended from the bottom of the riser tube **5**. To assure entering the drilling tube **4**, the first rod **8** may in some embodiments have a smaller diameter or a tapered end;
4. Place the lower end of the first rod **8** into the drilling tube **4** at the well opening. To enter the well, it is critically important to keep the weight of the rod **8** exceeding the force pushing it out of the well by at least a small safety margin, for example 100 kg. Due to its small cross-sectional area and significant weight (which could reach several hundred kilograms), the metal rod **8** can be typically placed inside the drilling tube **4** of the well without much difficulty. 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 diameter—note that rod length, diameter and density (choice of material) represent variables which can be adjusted for each specific circumstance;
5. Following the entrance into the well of the first (lower) portion of the rod assembly having the smallest diameter, the next larger diameter of the rod typically may start at the height of a few hundred meters above that first portion. 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. As the first portion of the telescopic rod assembly enters the well, the flow of fluid from the well is reduced because of reduction in available cross-sectional area and because of a new drag resistance of fluid flow around the rods;
6. Additional rods with further increase in diameter are then placed into the well until either the first rod reaches the bottom of the well or until the diameter of the rod matches that of the well so that the fluid flow is gradually reduced to a minimal value—see FIG. **2**. In rare circumstances where the diameter of the well and the reservoir pressure are high and the depth of the well is low, the method of the invention teaches using rods with higher density and weight than steel, such as for example copper or wolfram;
7. In embodiments, the lower end of the second rod **8** may be slidingly attached to the body of the first rod (using a ring for example—not shown) so as to assure it will find its way into

the well opening and the drilling tube **4**. This process may be continued until the wellhead pressure and flow rate of fluid decreases to sufficiently safe levels, so that the well can be easily closed (killed) using standard methods of applying cement;

8. To accomplish a permanent closure of the well, the hanging riser tube **5** may be lowered so that the upper section of drilling tube **4** joins the bottom of the riser tube **5** Additional resistance of the suspended riser tube **5** connecting the wellhead to the drilling rig **7** further reduces the flow rate and wellhead pressure at the sea surface. Cementing the well may now be accomplished. 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 **9** of the casing from which the oil is coming out. After cement hardens, the flow from the well ceases completely;

9. The riser tube **5** may be then separated (cut off) from the well. In embodiments, at least some of cement may seep through the gap between the top hanging riser tube **5** and the drilling tube **4**, thus making their connection hermetic.

To accomplish the method of the invention, there is provided a system for killing of the uncontrolled fountain from an offshore well. The system included a plurality of narrow flow restricting rods, in which each insert may be made solid and sized to have diameter between 15 mm and 500 mm. The system further includes a rig and a riser tubing configured to accept sections or spools of such rods therein and adapted to lower the rods forming a telescopic assembly down the opening of an offshore well.

Description of the Alignment System of the Invention

Proper alignment of telescopic rods with the well pipe is critical for performing the method of killing the fountain according to the present invention. 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 (with or without the blowout preventer).

The alignment device is generally shown in FIG. **3**. It includes a ring **20** releasably positioned at the lower end of the riser tube **5**. In embodiments, the ring **20** may slide up the riser **5** upon release of temporary attachments such as screws or severable connectors. In other embodiments, the riser **5** is equipped with a holding flange on its bottom (not shown) which retains the ring **20** and the entire alignment system at the lower end of the riser **5** while allowing it to slide upwards along the riser tube **5**.

Ring **20** is rigidly connected to a plurality or radial arms **22**, for example 8 arms as shown in FIG. **3**. There may be between 3 and 20 arms attached to the ring. They may be evenly spaced along the periphery of the ring **20**. Each radial arm **22** is attached to the ring **20** at the angle α as shown in FIG. **3**. The length of each arm **22** and angle α are selected such that the product of multiplication of the length and sin α exceeds the height of the remaining portion of the pipe **4** including the blowout preventer **1** by about 10-20 m. Typically, such length of arms **22** may be selected to be about 30 m.

Joints **23** are placed at the ends of each arm **22** and in turn are connected to additional arms **24** and **26**. Each arm assembly therefore includes one rigid arm **22** attached to the ring **20** and one or more articulating arms **24** and **26** attached to the rigid arm **22** via joints **23**. The lower ends of each arm assembly are connected to adjacent ends by flexible ties **28** (for example metal springs) such that cumulatively they form a circle, see FIG. **4***b*.

Upon lowering the alignment system placed at the end of the riser towards the well, the initial circle of ties **28** is expanded and may cover an area of several dozen square meters—see FIG. **4***a*. This is needed to cover the well and a possible blowout preventer that may sit on top thereof. Once the location of the well inside the circle of ties **28** is confirmed, the riser is further brought down such that the lower articulating arms **24** and **26** reach the floor of the ocean and start to lay flat thereon—see FIGS. **5***b* and **5***c*. as the ends of the arms **26** move towards the axial center of the riser, first one and then several of them are reaching the well whereby aligning the well with the riser. Importantly, once the riser is aligned with the well, it may be disconnected from the ring **20** and further lowered towards the well. 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.

Once the alignment is complete, the telescopic rod assembly may be lowered into the well as described above to gradually reduce the oil discharge from the well.

FIG. **6** shows further details on one of the embodiments of the present invention in which a tapered cap **30** is attached at the lower end of the riser **5**. The tapered surface **34** is arranged to cover the end of the well pipe **4** and further support proper alignment of the telescopic rod assembly **8** inside the well. The outer ledge **32** of the tapered cap **30** may be used as a rest for the ring **20** of the alignment system as described above. Once the tapered cap **30** and the riser **5** are lowered onto the drilling tube **4**, they may be permanently attached together for example by welding.

The present invention is aimed at making killing of the well safe, fast and inexpensive so as to prevent heavy environmental and financial losses typically associated with dealing with offshore well blowouts.

In embodiments, the method of the invention may also be used to reduce fluid discharge from the oil well located on land. In that case, the appropriate rod assembly may be first assembled on the ground and then lifted in the air using a helicopter. The helicopter may then deliver the rod assembly to the vicinity of the well and slowly lower it down the well as described above. The weight of the helicopter itself may be used to push the rods down the well if appropriate. To insert additional sections of the rod assembly into the well, the helicopter may either release the first section and allow it to drop down the well, or attach the next section to the previous section by retaining the previous section over the well with the assistance of large construction cranes.

The herein described subject matter sometimes illustrates different components or elements contained within, or connected with, different other components or elements. It is to be understood that such depicted architectures are merely examples, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality may be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated may also be viewed as being "operably connected", or "operably coupled", to each other to achieve the desired functionality, and any two components capable of being so associated may also be viewed as being "operably couplable", to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

Although the invention herein has been described with respect to particular embodiments, it is understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

We claim:

1. A method for killing of an uncontrolled fountain from an offshore oil well comprising the steps of:

a. providing a flow-restricting telescopic rod assembly in a riser tube, said rod assembly comprising individual flow-restricting rods of increasing diameters with a first lower rod being the smallest, said riser tube comprising a lower riser end configured for alignment of the first rod with said well, said lower end of said riser tube is also configured for subsequent sealing connection to said well,

b. lowering the first flow-restricting rod into said well through said riser tube so as to reduce a cross-sectional area of said well leading to a reduction of fluid discharge in said uncontrolled fountain,

c. attaching additional rods in series to said first rod whereby forming said telescopic rod assembly and lowering thereof into said well, whereby further reducing the cross-sectional area of said well causing a further reduction of fluid discharge in said uncontrolled fountain,

d. connecting said lower end of said riser tube to said well once said fluid discharge in said uncontrolled fountain is sufficiently diminished due to presence of said telescopic rod assembly therein, and

e. sealing off said well to permanently stop said uncontrolled fountain by pumping cement through an annular space formed between said riser tube and said telescopic rod assembly and into an annular space formed between said well and said telescopic rod assembly.

2. The method as in claim **1**, wherein the last flow-restricting rod is selected to have a diameter even or less than the inner diameter of said well.

3. The method as in claim **2**, wherein said diameter of the last flow-restricting rod is selected to be about 5-10% less than the inner diameter of said well.

4. A method for killing of an uncontrolled fountain from an offshore oil well comprising the steps of:

a. providing a flow-restricting telescopic rod assembly comprising individual flow-restricting rods of increasing diameters with a first lower rod being the smallest in diameter and suspending thereof on a weight balance located on a sea surface,

b. lowering the first flow-restricting rod of said plurality into said well so as to reduce a cross-sectional area of said well leading to a reduction of fluid discharge in said uncontrolled fountain,

c. selecting additional rods such that the total weight of the telescopic rod assembly always exceed the forces pushing thereof out of the well by at least 100 kg as monitored by said weight balance;

d. serially attaching additional rods to said first rod and lowering the telescopic rod assembly into said well, whereby further reducing the cross-sectional area of said well causing a further reduction of fluid discharge in said uncontrolled fountain, and

e. sealing off said well to permanently stop said uncontrolled fountain.

* * * * *

US008448709B1

(12) **United States Patent**
Tseytlin

(10) **Patent No.:** **US 8,448,709 B1**
(45) **Date of Patent:** **May 28, 2013**

(54) **METHOD OF KILLING AN UNCONTROLLED OIL-GAS FOUNTAIN APPEARED AFTER AN EXPLOSION OF AN OFFSHORE OIL PLATFORM**

(76) Inventor: **Simon Tseytlin**, Middle Village, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 110 days.

(21) Appl. No.: **13/184,497**

(22) Filed: **Jul. 16, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/367,478, filed on Jul. 26, 2010.

(51) **Int. Cl.**
E21B 7/12 (2006.01)
E21B 29/12 (2006.01)
E21B 34/04 (2006.01)

(52) **U.S. Cl.**
USPC **166/363**; 166/339; 166/364

(58) **Field of Classification Search**
USPC 166/363, 339, 364, 368, 285, 381, 166/386, 387, 75.15, 179, 192, 193; 138/89
See application file for complete search history.

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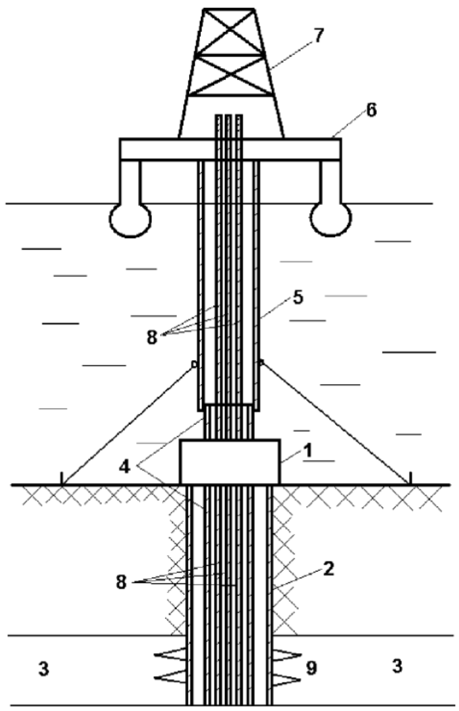
Primary Examiner — Matthew Buck
Assistant Examiner — James Sayre
(74) *Attorney, Agent, or Firm* — Boris Leschinsky

(57) **ABSTRACT**

A method for killing an uncontrolled fountain in an oil well following a blowout includes a serial lowering into the well of narrow flow restricting rods, each rod being sufficiently small in diameter to allow its insertion against a high well pressure urging the rods out of the well. Each subsequent rod reduces the cross-sectional area of the well and gradually reduces the flow of fluid discharge out of the well. Once the fountain is sufficiently reduced, the well may be killed using traditional sealing techniques such as pumping cement down the well.

14 Claims, 3 Drawing Sheets



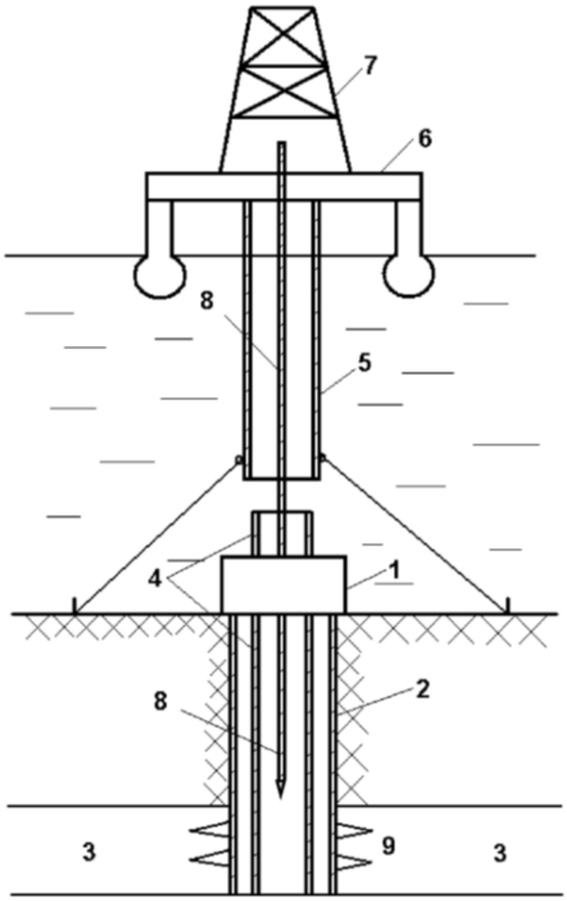


FIGURE 1

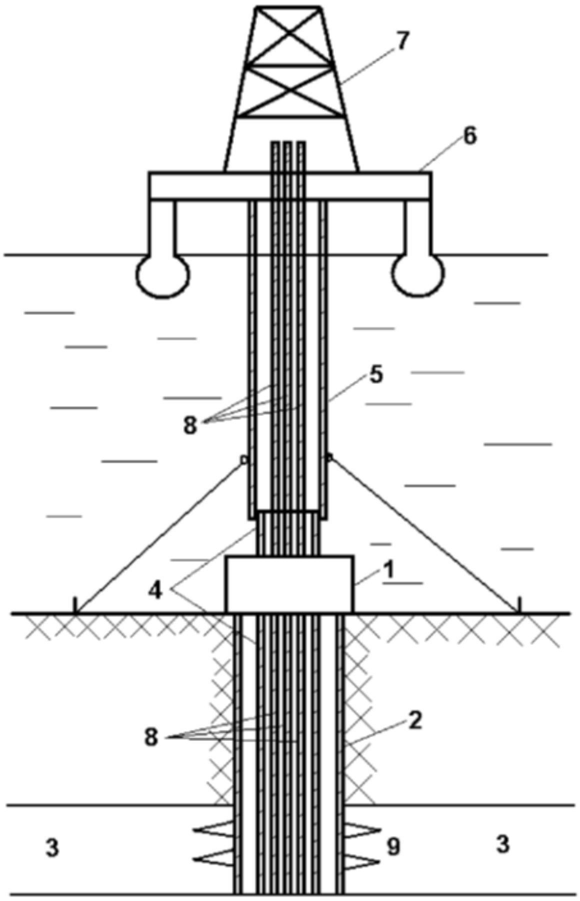


FIGURE 2

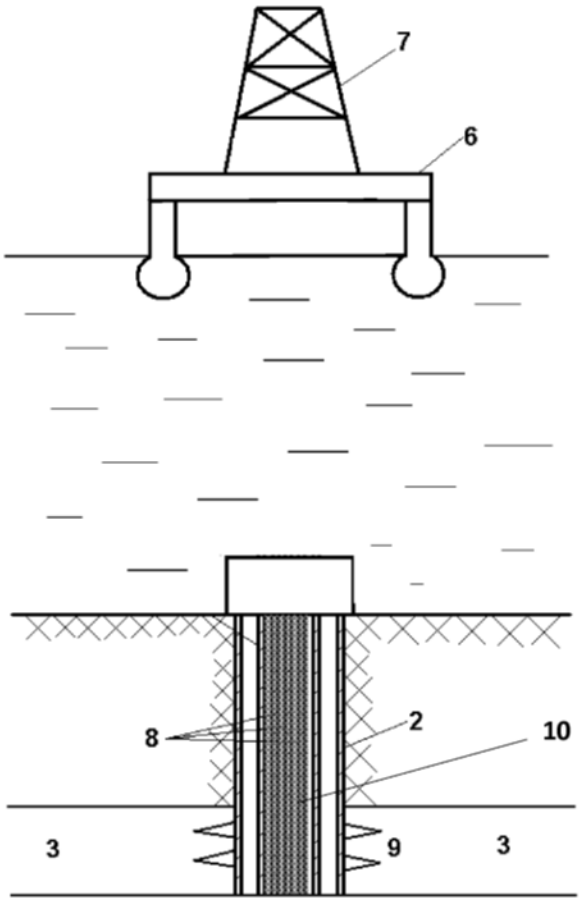


FIGURE 3

METHOD OF KILLING AN UNCONTROLLED OIL-GAS FOUNTAIN APPEARED AFTER AN EXPLOSION OF AN OFFSHORE OIL PLATFORM

CROSS-REFERENCE DATA

This application is a regular US filing claiming the priority date benefit from a provisional U.S. Patent Application No. 61/367,478 by the same inventor filed 26 Jul. 2010, which is incorporated herein in its entirety by reference.

BACKGROUND

The present invention relates to a method and system for the extinction or "killing" of an offshore oil well after an explosion or a blowout causing an appearance of an uncontrolled fountain of oil fluids mixed with gas from the remaining part of the well. The term "oil well" is used herein to describe a well that produces any type of hydrocarbons including oil and gas, but which may also produce a gas condensate or water as part of the fluid mixture discharge that comes out of the well. The present invention more specifically relates to methods for controlling the fluid discharge by gradually decreasing fluid flow using a series of flow restrictor inserts.

In the field of offshore oil drilling, the oil wells are kept under control by means of a column of mud which provides a hydrostatic load sufficient for maintaining overpressure between the well and the external pressure at controlled values. This column of mud, also known as primary well control barrier, is present both inside the well and also in a pipe called riser which connects the drilling platform to the sea bottom.

At the sea bottom, moreover, in correspondence with the well heads, there are generally secondary well control devices, called blowout preventers or BOP, which act as valves which are configured to close the well in the case of uncontrolled discharges of fluids from the well itself.

Often during drilling or well exploration in gas and oil wells, a gas kick may enter into the well space. Gas exits the well reservoir and reaches the bottom hole of the well. If this is not detected immediately, this creates a gas bubble (gas kick) in the hole. Gas kick, according to Archimedes' principle begins to ascend within the annular space of the well. If not allowed to expand, it brings its initial high pressure equal to the formation pressure to the head of the well. At the same time, the pressure everywhere along the well begins to rise. If the BOP is closed, and there is no "washing" in the well, a hydrofracture of formation may occur. As a result, the drilling fluid enters the formation, and the well is filled with gas. If the drill pipe has no check valve, the gas also fills drill pipes up to the wellhead. This may cause a gas explosion that may result in human casualties, environmental pollution and the creation of an uncontrolled fountain. This uncontrolled fountain 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.

Presently known are various techniques for reestablishing the control of the well in case of a blowout, such as for example the techniques of bridging, capping, production 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.

A killing intervention consists of the insertion of a specific string of pipes inside a blowout well. When inserted in the well, the killing string allows conventional killing techniques to be applied such as the circulation of heavy mud, closure by means of inflatable packers, and so forth. This method has proved to be the most rapid, but it can currently only be used in the case of well blowouts in shallow water, i.e. less than 1,000 m. In addition, in order to allow for the adequate flow of cement through the killing string, its internal diameter has to be sufficiently large such as at least 10 cm or more. Inserting such a large string of pipes presents a challenge due to an enormous pressure in the well urging the killing string out of the well.

To date, no practical equipment is available to the industry for the purpose of regaining the control of a deep water abandoned wellhead on the offshore seabed after a blowout causing spilling of reservoir fluids into the sea. The environmental pollution caused by such outpouring of reservoir liquids and gases can have disastrous consequences, as witnessed 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.

There is a need for an improved method for killing of an uncontrolled fountain from an oil well following a blowout event.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to overcome these and other drawbacks of the prior art by providing a novel method and a system for killing of the uncontrolled fountain in an offshore oil well by gradually decreasing fluid flow using a series of narrow rods to restrict flow.

In embodiments, 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. 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.

BRIEF DESCRIPTION OF THE DRAWINGS

Subject matter is particularly pointed out and distinctly claimed in the concluding portion of the specification. The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several embodiments in accordance with the disclosure and are, therefore, not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings, in which:

FIG. **1** is a side view of the oil well at the beginning stage of the killing operation to stop the uncontrolled fountain from the well, and

FIG. **2** is a side view of the oil well in its final stages of the killing operation.

FIG. **3** shows the oil well after sealing with cement, separating and removing of the remaining portions of flow restricting rods and the riser.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

The following description sets forth various examples along with specific details to provide a thorough understanding of claimed subject matter. It will be understood by those skilled in the art, however, that claimed subject matter may be practiced without one or more of the specific details disclosed herein. Further, in some circumstances, well-known methods, procedures, systems, components and/or circuits have not been described in detail in order to avoid unnecessarily obscuring claimed subject matter. In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

The method of the invention includes serial placement of flow restricting rods down the well in order to reduce the fluid discharge flow. These rods may be the same or having different size and shape. In embodiments, an exemplary insert is a metal rod, such as made from steel for example. The diameter of each rod may be from about 5 mm to about 40 mm. In embodiments, the rod diameter may be about 10 mm. A non-round rod may also be used.

The size of the rod may be selected based on the well pressure and its internal diameter. The pressure force pushing the rod out of the well is calculated using the size of the rod and the well pressure. In a typical offshore well, where the well pressure at the level of a seabed can reach hundreds of atmospheres or more and the weight of the rod made from steel may reach hundreds of kilograms, the range of diameters for the rod may be from about 20 mm^2 to about 1,200 mm^2.

The rod may be made solid and entirely from metal with no voids or passages therein. The end of the rod may be made tapered to facilitate insertion and advancement down the well. In embodiments, each rod made include long sections that can be attached to each other during the operation of insert placement down the well. In other embodiments, each rod may be brought to the well location on a spool and unfolded during the insertion procedure. Making each rod smaller in cross-sectional area allows reducing the force necessary for putting the rod down the well. Once a certain length of the rod is placed into the well, its own weight may help in further downwards advancement.

In embodiments, rods typically used as components in reciprocating piston rod pumps may be adapted to be used for the purposes if the present invention as flow restricting rods.

A blowout of a typical offshore well may produce a plume of fluid discharge with a pressure at the outlet of the well as high as 600 atmospheres. Given a typical tube diameter of 120 mm, inserting a full diameter plug of that diameter or even a smaller but sizable killing string down the hole is extremely difficult as it requires a tremendous level of force to overcome the pressure of the fluid discharge. At the same time, using a 10 mm rod reduces the cross-sectional area and therefore the force pushing the insert out of the well by 144 times—down to reasonable levels within the capabilities of modern technologies. Placing a long section of such rod down the well produces two effects that complement each other in reducing the flow of fluids out of the well—reduction in cross-sectional area available for fluid discharge and increase in friction along the walls of the well given the additional outer surface of the rods.

FIG. **1** illustrates the beginning of the process of killing of an uncontrolled fountain from an oil well, showing a blowout preventer **1**, a well casing **2**, formation **3**, drilling tubes **4**, a riser tube **5**, a floating platform **6**, a rig **7**, a rod **8**, and perforations **9**.

Insertion of the rod **8** may start by positioning a riser tube **5** over the opening of the drilling tube **4** or any other suitable well opening remaining following an accident. In some cases, the riser tube may be anchored to the ocean floor as shown in FIG. **1**. Placing of the first rod **8** into the well continues until it may encounter significant resistance or until it reaches the bottom of the well. As a result, the cross-section of the well along its entire length will decrease, and the resistance to the flow due to viscous friction against the inner surface of the well and the outer surface of the rod increases.

The procedure may then be repeated by inserting the next rod into the well. The flow rate and the wellhead pressure at that point may be reduced further. Serial insertion of several such rods (see FIG. **2**) may significantly reduce the cross-section of the drill pipe **4**, leading to a decrease in fluid discharge and the wellhead pressure—by one or two orders of magnitude in some cases. Once the pressure is sufficiently low, cementing operation may be undertaken so as to permanently seal off the well.

The method of the invention includes the following necessary and optional steps:

1. Provide a plurality of flow restricting rods **8** using either a standard floating rig **7** or a ship located near an offshore platform;
2. Position a riser tube **5** over the drilling tube **4**. Riser tube **5** may have an inner diameter slightly larger than the external diameter of the drilling tube **4**. As a result, the lower end of the riser tube **5** may be placed over the head of the well at a distance of about several meters. Alignment and fixation of this riser tube **5** may be accomplished for example using a four-cable brace attached to the outer surface of the head of the well (see FIG. **1**);
3. Place a first flow restricting rod **8** into the riser tube **5**. To accomplish this, the first section of the rod **8** with the length which may be equal or less than the height of the drill rig, may be lowered using the usual method of lowering tubes. The second section of the rod **8** 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 **5**. The process of lowering the rod **8** and attaching new sections thereto may be repeated until the lower section of the rod **8** appears suspended from the bottom of the riser tube **5**. To assure entering the drilling tube **4**, the first rod **8** may in some embodiments have a smaller diameter;
4. Place the lower end of the rod **8** into the drilling tube **4** at the well opening. Due to the small cross-section and significant weight (which could reach several hundred kilograms), the metal rod **8** can be easily placed inside the drilling tube **4** of the well;
5. Lower the rod **8** down the well until the lower section of the insert reaches the bottom of the well or until significant resistance is encountered. After that the rod **8** may be retained in place in order to prevent its release from the well;
6. Place the next rod **8** into the riser tube **5** and lower it down the well to reduce the cross section of the well even

more. In embodiments, the lower end of the second rod **8** may be slidingly attached to the body of the first insert (using a ring for example—not shown) so as to assure it will find its way into the well opening and the drilling tube **4**. This process may be continued until the wellhead pressure and flow rate of fluid decreases to safe enough levels, so that the well can be easily closed using the standard methods. In embodiments, such pressure at the well opening may be about 100 atmospheres. That pressure may be a result of a well pressure of about 200 atmospheres pushing the fluid discharge into the deep sea water at its own water column pressure of about 100 atmospheres such as encountered in wells located at about 1 km depth of water;

To accomplish a permanent closure of the well, the hanging riser tube **5** may be lowered so that the upper section of drilling tube **4** joins the bottom of the riser tube **5** (FIG. **2**). Additional resistance of the suspended riser tube **5** connecting the wellhead to the drilling rig **7** further reduces the flow rate and wellhead pressure at the sea surface;

Cementing the well may now be accomplished. 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 **9** of the casing from which the oil is coming out;

After cement **10** hardens, the flow from the well ceases completely. The riser tube **5** may be then separated (cut off) from the well as shown in FIG. **3**. In embodiments, some of cement may seep through the gap between the top hanging riser tube **5** and the drilling tube **4**, thus making their connection hermetic.

To accomplish the method of the invention, there is provided a system for killing of the uncontrolled fountain from an offshore well. The system included a plurality of narrow flow restricting rods, in which each insert may be made solid and sized to have a cross-sectional are from about 20 mm^2 to about 1,200 mm^2. The system further includes a rig and a riser tubing configured to accept sections or spools of such narrow rods therein and adapted to lower the rods one at a time down the opening of an offshore well.

The herein described subject matter sometimes illustrates different components or elements contained within, or connected with, different other components or elements. It is to be understood that such depicted architectures are merely examples, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality may be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated may also be viewed as being "operably connected", or "operably coupled", to each other to achieve the desired functionality, and any two components capable of being so associated may also be viewed as being "operably couplable", to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

Although the invention herein has been described with respect to particular embodiments, it is understood that these embodiments are merely illustrative of the principles and

applications of the present invention. For example, the method and the system of the invention may be used in well located in shallow waters or on a dry land. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

I claim:

1. A method for killing of an uncontrolled fountain from an offshore oil well comprising the steps of:

a. providing a plurality of flow restricting rods, each of said flow restricting rods is sized to have a cross-section area from about 20 $mm^2$to about 1,200 mm^2, each of said flow restricting rods comprising a series of straight sections configured for assembly with each other to form together said flow restricting rod,

b. forming a first flow restricting rod by assembling a first series of said straight sections one at a time to extend said first flow restricting rod from a sea surface to a well opening, continuing to assemble additional straight sections for lowering the first flow restricting rod of said plurality into said well so as to reduce a cross-sectional area of said well to cause a reduction of said uncontrolled fountain,

c. forming a second flow restricting rod by assembling a second series of said straight sections to extend said second flow restricting rod from said sea surface to said well opening, continuing to assemble additional straight sections for lowering the second flow restricting rod of said plurality into said well and positioning said second flow restricting rod adjacent to said first flow restricting rod, whereby further reducing the cross-sectional area of said well causing a further reduction in said uncontrolled fountain,

d. serially assembling additional straight sections to form further flow restricting rods to extend from said sea surface to said well opening, lowering said additional flow restricting rods of said plurality one at a time and positioning thereof in said well adjacent to each other to minimize said uncontrolled fountain in said well, and

e. sealing off said well to permanently stop said uncontrolled fountain.

2. The method as in claim **1**, wherein said step (b) of lowering the first flow restricting rod into said well is accomplished by providing a riser tubing extending from above said opening of said oil well to said sea surface and inserting said flow restricting rods one at a time from said sea surface through said riser tubing and into said opening of said well.

3. The method as in claim **1**, wherein said flow restricting rods are solid, made from metal and do not have any voids or passages therein.

4. The method as in claim **1**, wherein said flow restricting rods are round and having a diameter from about 5 mm to about 40 mm.

5. The method as in claim **4**, wherein said flow restricting rods are about 10 mm in diameter.

6. The method as in claim **1**, wherein at least said first flow restricting rod has a tapered lower end to facilitate entrance thereof into said well.

7. The method as in claim **1**, wherein said step (d) of lowering additional flow restricting rods is continued until well pressure is reduced to about 100 atmospheres.

8. The method as in claim **1**, wherein said step (e) of sealing off said well is accomplished by pumping cement down said well once said fluid discharge is sufficiently minimized to allow said pumping.

9. The method as in claim **1**, wherein said straight section have the same shape and size.

10. A method for killing of an uncontrolled fountain from an offshore oil well comprising the steps of:

a. extending a first flow restricting rod from a sea surface to a well opening, said flow restricting rod sized to fit inside said well opening;

b. lowering said first flow restricting rod to enter into said well opening;

c. further lowering said first flow restricting rod into said well opening until encountering resistance or reaching a bottom of the offshore oil well;

d. extending at least one additional flow restricting rod from said sea surface to said well opening and lowering thereof into said well, while continuing to extend the first flow restricting rod from the sea surface to the well opening and into the well, said at least one additional flow restricting rod positioned adjacent and parallel to said first flow restricting rod,

whereby gradually reducing said uncontrolled fountain until it is minimized or stopped.

11. The method as in claim **10** further including a step of sealing off said well after said uncontrolled fountain has been minimized.

12. A method for killing of an uncontrolled fountain from an offshore oil well comprising the steps of:

a. providing a plurality of flow restricting rods sized to fit inside said well,

b. suspending a first flow restricting rod to extend from a sea surface through an opening of said well and into said well;

c. suspending additional flow restricting rods to extend from said sea surface through said opening of said well and into said well, while continuing to suspend the first flow restricting rod and each additional rod extending from said sea surface through said opening of said well and into said well, said additional flow restricting rods positioned adjacent to each other and to said first flow restricting rod inside said well,

whereby gradually reducing said uncontrolled fountain until it is minimized or stopped.

13. The method as in claim **12** further comprising sealing of said well, separating and removing of the portions of said flow restricting rods above said well opening.

14. The method as in claim **12**, wherein a riser tube is further provided to extend from said sea surface to the vicinity of said well opening, said steps of suspending said first and said additional flow restricting rods is accomplished by lowering all flow restricting rods through said riser tube, said method further including a step of sealing said well by pumping cement through said riser into said well after said uncontrolled fountain is minimized.

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US008235143B2

(12) **United States Patent**
Tseytlin

(10) **Patent No.: US 8,235,143 B2**
(45) **Date of Patent: Aug. 7, 2012**

(54) **METHODS AND DEVICES FOR DETERMINATION OF GAS-KICK PARAMETRS AND PREVENTION OF WELL EXPLOSION**

(76) Inventor: **Simon Tseytlin**, Middle Village, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 24 days.

(21) Appl. No.: **13/045,730**

(22) Filed: **Mar. 11, 2011**

(65) **Prior Publication Data**

US 2012/0006613 A1 Jan. 12, 2012

Related U.S. Application Data

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(51) **Int. Cl.**
C09K 8/02 (2006.01)

(52) **U.S. Cl.** **175/48**

(58) **Field of Classification Search** 181/106; 367/25–27; 175/48

See application file for complete search history.

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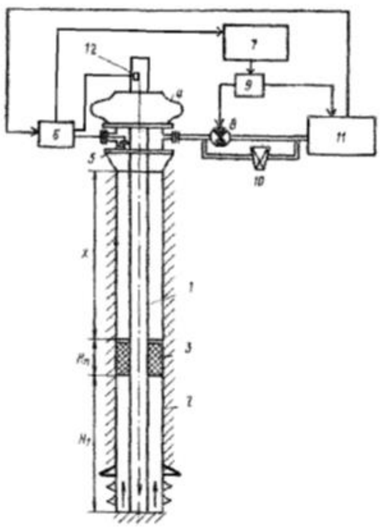
Primary Examiner — John Fitzgerald
(74) *Attorney, Agent, or Firm* — Boris Leschinsky

(57) **ABSTRACT**

Acoustics-based methods and devices to characterize a gas kick during drilling an oil, gas, or gas condensate well are described. A pressure wave may be generated by abruptly changing the drilling mud pressure in the well, for example at the well head. The pressure wave is allowed to travel down the well, reflect from the well bottom and reach the well head again. Pressure is monitored during this process and a pressure peak is identified. The gas kick is characterized using the width of the pressure peak and time elapsed from the onset of pressure change and appearance of the peak. Negative pressure wave is preferred and may be generated by opening of a fast-acting valve located in the outlet pathway of the drilling mud fluid.

19 Claims, 4 Drawing Sheets



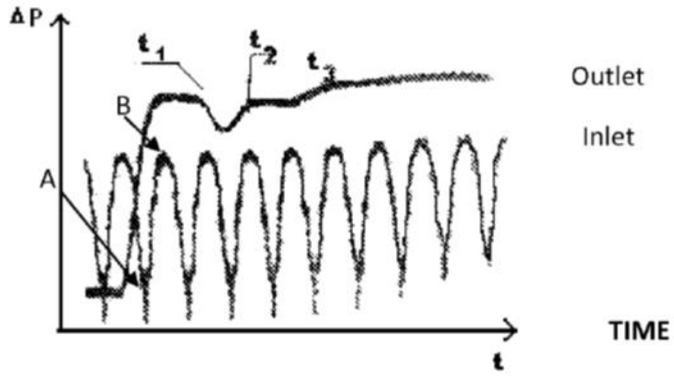
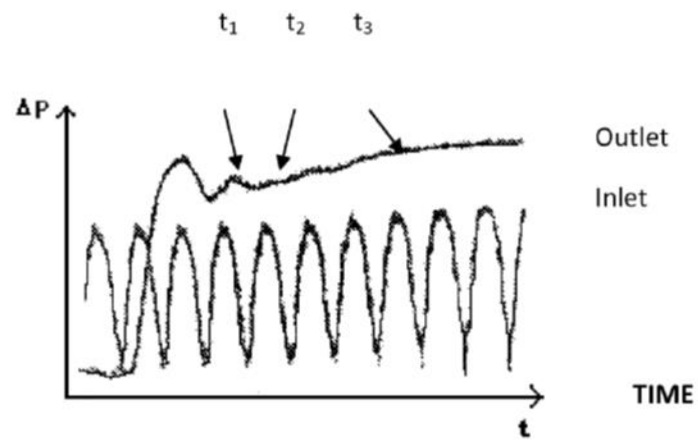

ΔP
t1
t2
t3
Outlet
Inlet
B
A
TIME
t

Fig.3.2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t2
t3
ΔP
Outlet
Inlet
TIME
t

Fig.3.3

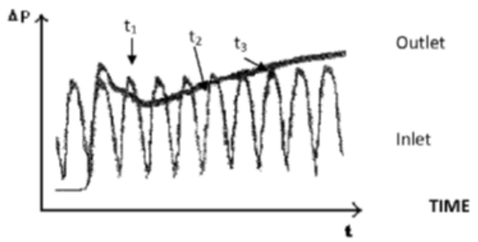

Fig.3.4

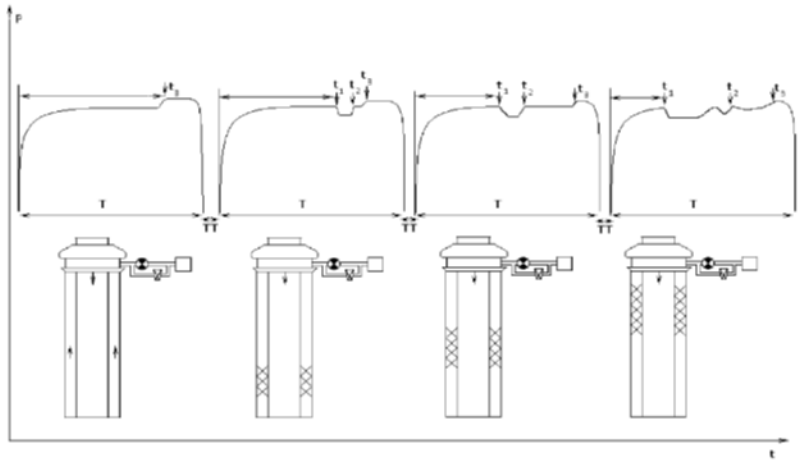

Fig.4

nected", or "operably coupled", to each other to achieve the desired functionality, and any two components capable of being so associated may also be viewed as being "operably couplable", to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

Although the invention herein has been described with respect to particular embodiments, it is understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

I claim:

1. A method for characterization of a gas kick within a fluid in a well comprising the steps of:

a. abruptly changing fluid pressure with a valve from a first pressure level to a second pressure level to generate a pressure shock wave,

b. maintaining fluid pressure at said second pressure level for a period of time sufficient to allow said pressure shock wave to travel along said well, and

c. monitoring said fluid pressure with sensors as a function of time from the onset of said change in fluid pressure and during the time of said pressure shock wave traveling along said well, and

d. characterizing said gas kick using a pressure peak in said fluid pressure.

2. The method as in claim **1**, wherein said second pressure level is lower than said first pressure level, whereby said pressure shock wave is a negative pressure shock wave.

3. The method as in claim **1**, wherein in step (d) a length of said gas kick is characterized using a width of said peak in said fluid pressure.

4. The method as in claim **1**, wherein in step (d) a depth of location of said gas kick is characterized using a time elapsed between onset of said pressure change and said peak in fluid pressure.

5. The method as in claim **1**, wherein said steps (a) through (c) are repeated from time to time to monitor said well for appearance or ascendance of said gas kick.

6. The method as in claim **1**, wherein the difference between said first pressure and said second pressure is about 1 to about 5 atmospheres.

7. The method as in claim **1**, further including monitoring pressure fluctuations caused by operation of a fluid pump, wherein a presence of said gas kick is detected when amplitude of said fluctuations is reduced.

8. The method as in claim **1**, wherein said fluid is a drilling mud and said fluid pressure is an outlet pressure of said drilling mud exiting said well.

9. The method as in claim **8**, wherein said drilling mud is located in an annular space formed between a drilling pipe and a well casing in said well.

10. The method as in claim **1**, wherein said step (b) of maintaining said fluid pressure at said second level is maintained for a period of time to allow said pressure wave to reach a well bottom and return to a well head, said fluid pressure being returned to said first level thereafter.

11. The method as in claim **10**, wherein said period of time is about 5 to about 10 seconds.

12. The method as in claim **1**, wherein said step (a) is accomplished within a time period of about 1/20 to about 1 second.

13. The method as in claim **12**, wherein said step (a) is accomplished within a time period of about 1/10 to about 3/10 of a second.

14. A system for characterizing a gas kick in a well, said well including a casing and a drilling pipe located therein and forming an annular space therebetween, said system comprising:

an outlet pressure sensor configured to monitor drilling mud pressure exiting said annular space of said well,

a fast-acting valve located in an outlet pathway of said drilling mud, said fast-acting valve operated by a valve driver,

a control system configured to monitor drilling mud pressure using said outlet pressure sensor, said control system connected to said valve driver and configured to cause said driver to open said fast-acting valve for a period of time sufficient to generate and propagate a negative pressure wave down said well, reflect from a well bottom and reach a well head,

wherein said gas kick is characterized using a peak in pressure recorded when said negative pressure wave is traveling along said well.

15. The system as in claim **14**, wherein said fast-acting valve is configured to be opened in about 1/10 to 3/10 of a second.

16. The system as in claim **14**, wherein said fast-acting valve includes a bypass pipe having a flow restrictor.

17. The system as in claim **16** wherein said flow restrictor is adjustable.

18. The system as in claim **14**, wherein said fast-acting valve is sized to allow rapid drop in pressure of said drilling mud when said valve is opened by said valve driver.

19. The system as in claim **18**, wherein said drop in pressure is about 1 to 5 atmospheres.

* * * * *

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Tseytlin

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(45) **Date of Patent: Jul. 13, 2010**

(54) **BOTTOMHOLE TOOL AND A METHOD FOR ENHANCED OIL PRODUCTION AND STABILIZATION OF WELLS WITH HIGH GAS-TO-OIL RATIO**

(75) Inventor: **Simon Tseytlin**, Middle Village, NY (US)

(73) Assignee: **Tseytlin Software Consulting, Inc.**, Middle Village, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 183 days.

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(22) Filed: **Apr. 16, 2008**

(65) **Prior Publication Data**

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E21B 43/12 (2006.01)
E21B 34/08 (2006.01)

(52) **U.S. Cl.** **166/370**; 166/250.15; 166/250.07

(58) **Field of Classification Search** 166/250.15, 166/250.07, 53, 372, 370
See application file for complete search history.

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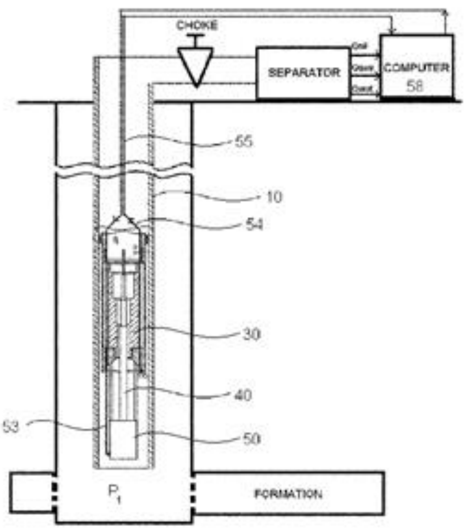
Primary Examiner—Kenneth Thompson
Assistant Examiner—Cathleen R Hutchins
(74) *Attorney, Agent, or Firm*—Boris Leschinsky

(57) **ABSTRACT**

A bottomhole tool and a method for optimizing oil production rate from an oil well with high gas-to-oil ratio and stabilizing thereof in case of occurrence of a gas cone or gas skin conditions are disclosed. The resistance of the adjustable multi-stage flow resistor is determined by a position of a telescoping needle, which in turn is defined by a driving means including a motor and a gearbox. The motor is driven via a cable from a surface by a control means adapted to receive information about the bottomhole parameters from local sensors via a sensor cable. Methodology explaining the principles of maintaining well stability is also disclosed. Automatic adjustment of the bottomhole pressure is maintained over a wide range of operating parameters throughout the life of the well to maximize its oil output.

4 Claims, 5 Drawing Sheets



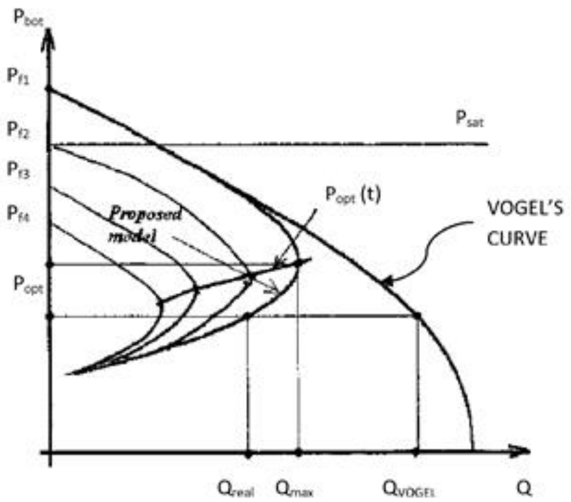


FIGURE 1

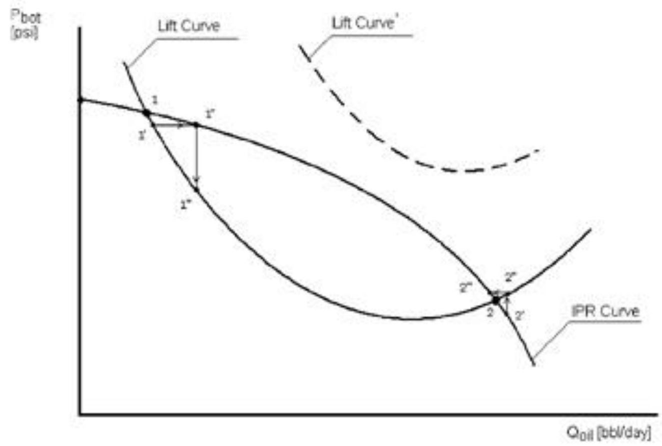


FIGURE 2

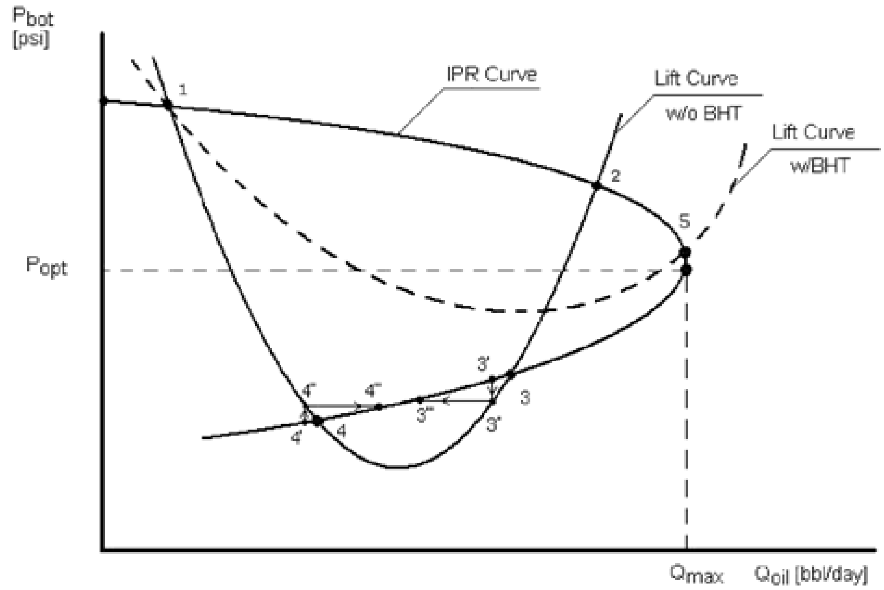

P_bot
[psi]
IPR Curve
Lift Curve
w/o BHT
Lift Curve
w/BHT
P_opt
Q_max
Q_oil [bbl/day]
1
2
3
3'
3"
3'"
4
4'
4"
4'"
5

FIGURE 3

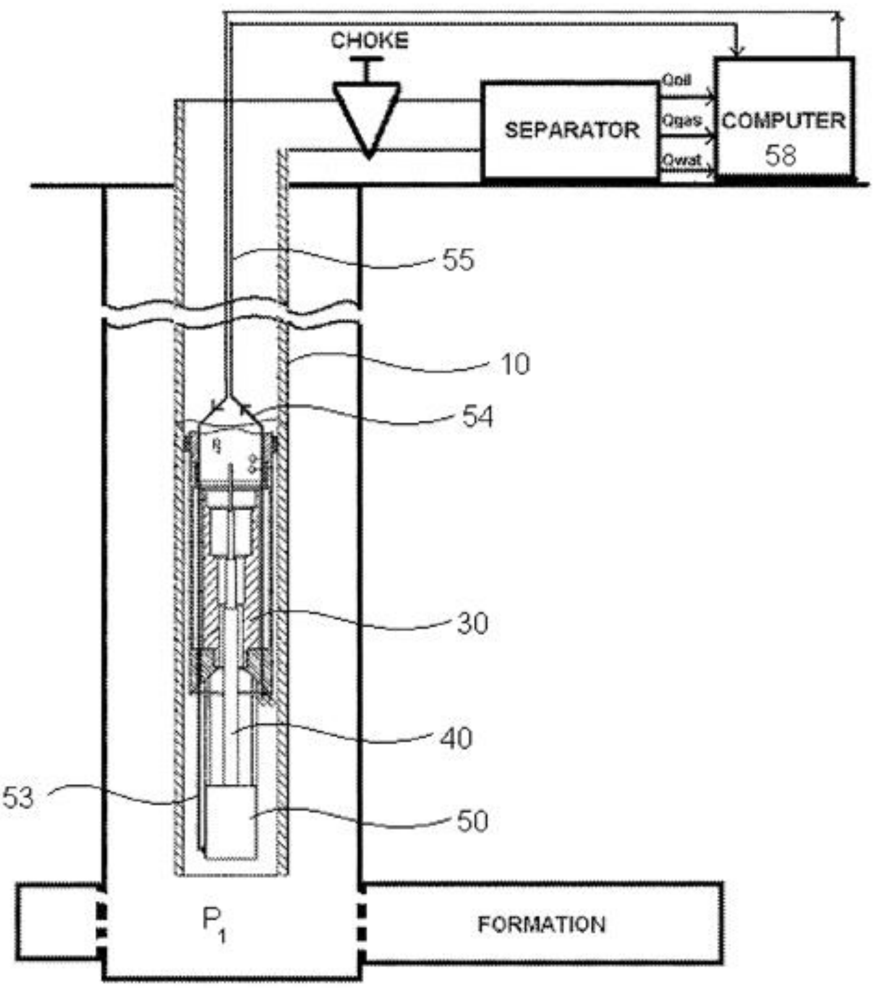

CHOKE
SEPARATOR
Qoil
Qgas
Qwat
COMPUTER
58
55
10
54
30
40
53
50
P_1
FORMATION

FIGURE 4a

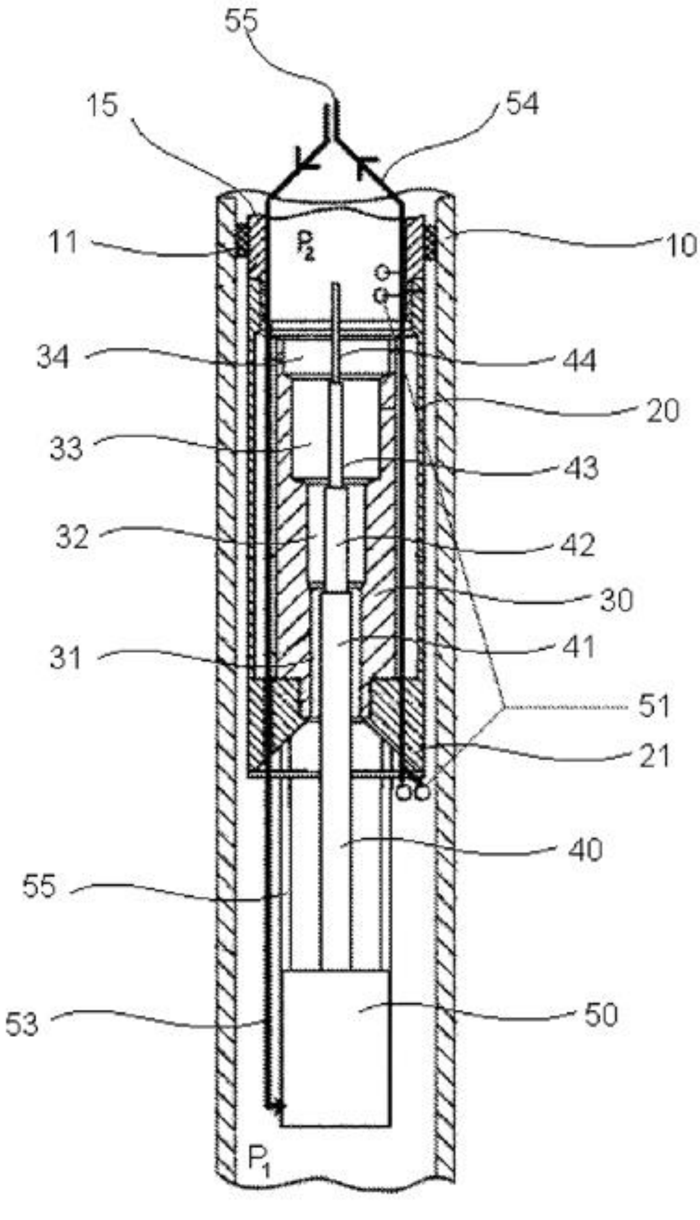


FIGURE 4b

Well 261: 11/01/2007 - 01/20/2008

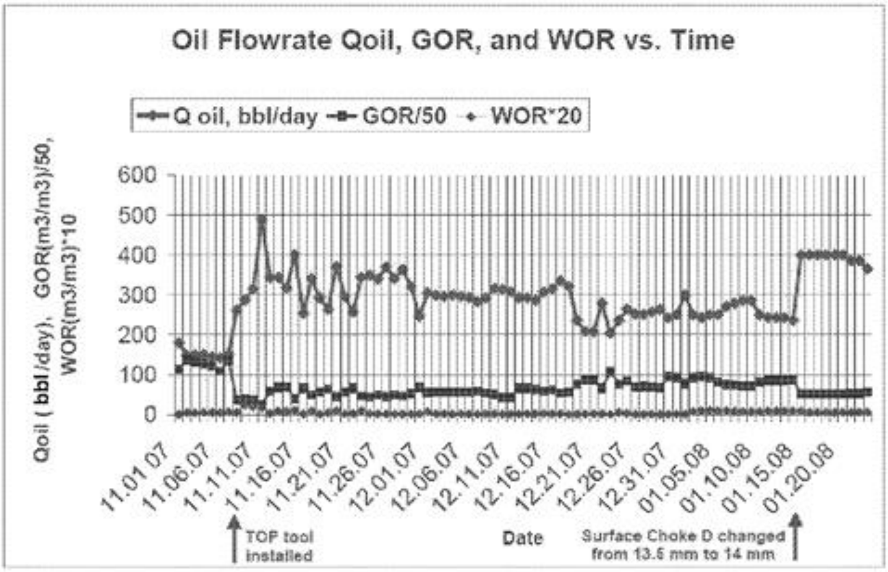


FIGURE 5

BOTTOMHOLE TOOL AND A METHOD FOR ENHANCED OIL PRODUCTION AND STABILIZATION OF WELLS WITH HIGH GAS-TO-OIL RATIO

BACKGROUND OF THE INVENTION

The present invention relates generally to a method and improved devices for increasing the production of oil. More specifically, the bottomhole tool and the method of the invention provide for maintaining the bottomhole pressure at a level considered optimum for maximizing oil production in a well with high gas-to-oil ratio (GOR). The most advantageous implementation of the present invention is in wells with high GOR defined as GOR greater than 600 cubic feet per barrel. In these wells the tool and the method of the invention can be used when the bottomhole pressure is lower than the bubble point pressure as well as in all cases when the gas cone has appeared such as in flowing, gas lift, and pump regimes of oil production. Another useful implementation of the invention is in GOR wells when a so-called gas cone or gas skin effects take place. These detrimental effects generally lead to destabilization of the well production process, fast increase of GOR and difficulties in managing the well.

This invention contains further improvements of my earlier U.S. Pat. No. 7,172,020 entitled "Oil Production Optimization and Enhanced Recovery Method and Apparatus for Oil Fields with High Gas-To-Oil Ratio", incorporated herein in its entirety by reference.

Optimization of oil production has been a goal of many methods and devices of the prior art. Generally speaking, the bottomhole behavior of oil mixed with gas and some other ingredients such as water, etc. has been described in a series of mathematical equations by Muskat. One specific publication of Muskat is incorporated herein by reference in its entirety and describes the mathematical model of oil reservoir: Muskat M. "The Production Histories of Oil Producing Gas-Drive Reservoirs", published in the Journal of Applied Physics in March of 1945, p.147-159.

For illustration purposes, a one-dimensional axis-symmetrical system of Muskat equations with corresponding PVT characteristics of fluid and dependencies of relative permeability K_{ro}, K_{rg} from liquid saturation (S_o) can be described as follows:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{k_{ro}}{\mu_o B_o}\frac{\partial p}{\partial r}\right) = -158.064\frac{\phi}{k}\frac{\partial}{\partial t}\left(\frac{S_o}{B_o}\right)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\frac{k_{rg}}{\mu_g B_g} + \frac{Rs}{5.615}\frac{k_{ro}}{\mu_o B_o}\right)\frac{\partial p}{\partial r}\right] = -158.064\frac{\phi}{k}\frac{\partial}{\partial t}\left(\frac{S_g}{B_g} + \frac{S_o}{B_o}\frac{Rs}{5.615}\right)$$

where: P—pressure in formation; S_o—oil saturation in formation; S_g—gas saturation in formation; R_s—solution of gas in oil; B_o—oil formation volume factor; B_g—gas formation volume factor; μ_o—oil viscosity; μ_g—gas viscosity; ϕ—formation porosity; K—formation permeability.

For practical purposes, Vogel had simplified the Muskat equations and adapted them to the calculations of oil producing formations. These equations are known as Vogel model and have subsequently been modified by others. One example of such publication is as follows: Vogel, *Inflow Performance Relationships for Solution-Gas Drive Wells*, as published in Journal of Petroleum Technology, January 1968, pp. 83-92, incorporated herein in its entirety by reference. Unfortunately, Vogel model does not work well in wells with high

gas-to-oil ratio. According to Vogel, the dependency of oil rate production of bottomhole pressure is a constantly diminishing parabolic curve with a production peak at zero value of the bottomhole pressure, see for example FIG. **2** of the above mentioned article. In other words, the lower the bottomhole pressure, the higher the oil rate production from the formation. This is a gross simplification of the bottomhole processes in the formation. In fact, if the bottomhole pressure falls below saturation pressure in case of high GOR, relative permeability coefficient by oil decreases because of gas saturation increase, which in turn is a result of gas being released from oil. Viscosity of so degassed oil also increases. This leads to a decrease of productivity index of formation. This phenomenon affects the oil production rate more than the increasing depression. As a result, decreasing of the bottomhole pressure below saturation pressure can lead to a decrease in oil production rate, rather than to its increase as predicted by Vogel's model, see FIG. **1**. In some extreme cases, reliance on Vogel's model will cause a complete switch in production from oil to gas. There is a need therefore for a method allowing calculating the oil production rate in high GOR wells with better accuracy then that allowed by Vogel's model.

It is also known that producing oil wells with high GOR (Gas-to-Oil Ratio) often lose their stability, and this process is accompanied by a sharp increase in GOR. Any attempts to stop this process by using a surface choke or other surface manipulations usually fail, and the well gradually switches into a gas mode. The physics of this process can be explained as follows: in case when a gas cone covers some holes of a perforated section of the well, quite often that well loses stability. This, in turn, leads to a continuing slow increase of the cone height followed by an increase in the gas stream and a decrease in the oil flow. This process continues until the well is completely switched to a gas mode. Even if a switch to a gas mode does not happen, the instability of the well does not allow efficient control of the bottomhole pressure by using a choke at the surface. Similar detrimental phenomena can occur because of formation of a gas skin effect near the bottom of the well. The physics of the skin effect is described in detail in my '020 patent. It also shows that this phenomena leads to a non-conventional shape of the IPR curve (Inflow Pressure Relationship, i.e. the dependence of well oil flow rate of the bottomhole pressure). A notable feature of this curve is the presence of a certain threshold value of the bottomhole pressure (called "P_{opt}—optimal pressure"), at which the greatest possible oil flow rate from a reservoir can be achieved (FIG. **1**).

The need exists therefore for a device and method of restoring and maintaining the stability of production in high GOR wells even in the presence of gas cone and gas skin effects.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to overcome these and other drawbacks of the prior art by providing a novel bottomhole tool and method for optimizing and maximizing the production of oil from an oil well, particularly an oil well with high GOR and maintaining the stability of such production.

It is a further object of the present invention to provide a bottomhole tool allowing adjustment of bottomhole pressure from the surface in a wide range of formation conditions and throughout the life of the well without the need to replace the device.

It is yet a further object of the present invention to provide a bottomhole tool allowing adjustments of bottomhole pressure in a desired range such that the reliability of that tool is increased by providing larger values of clearances between the moving and non-moving parts of the tool. Increased reliability would depend on the resistance of the tool to jamming by sand and other particles present in oil flow.

The device of the invention is an improvement to my bottomhole tool first described in the '020 patent. That tool was described as having a custom multi-stage flow resistor designed for each individual well. Once designed and implemented, the bottomhole tool of the '020 patent has a limitation of depending on the specific parameters of the tool that were selected during its initial construction, namely the dimensions of the multi-stage flow resistor and the stiffness of the return spring activating the movements of the resistor. As the conditions in an actual well change over time, the ability to maintain stable production is limited with that device. A redesigned bottomhole tool may be deployed in that case but that procedure is costly and time consuming.

The new bottomhole tool of the present invention addresses this point by providing an adjustable and remotely-controlled driving means of activating the movement of the multi-stage flow resistor. These driving means include in the most preferred configuration an electrical motor with an appropriate gear box designed and sized to be placed in place of a return spring and cause vertical movement of the multi-stage resistor in response to a command from the surface or automatically in response to an on-board sensing and computing means. This approach greatly expands the applicability of the bottomhole tool of the invention and obviates the need to replace the entire tool from time to time as the well conditions change.

Using the adjustable bottomhole tool of the invention is a critical part of a newly proposed method of creating new points on the IPR curve where the oil production is stable. This is achieved by adjusting the resistance at the bottom of the well to change the shape and location of the lift curve of the well such that it intersects the IPR in a different and more advantageous way than prior to using the tool of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the subject matter of the present invention and the various advantages thereof can be realized by reference to the following detailed description in which reference is made to the accompanying drawings in which:

FIG. **1** is an inflow performance relationship curve according to Vogel and according to the '020 patent and present invention,

FIG. **2** is a graph illustrating how the various lift curves intersect with an IPR curve creating an unstable condition for the well,

FIG. **3** is a graph showing how the use of the bottomhole tool of the invention changes the lift curve and explains why it restores stability of well production,

FIG. **4a** is a general cross-sectional view of the bottomhole tool of the present invention along with all other elements of a typical well,

FIG. **4b** is a close-up cross-sectional view of the bottomhole tool of the invention, and

FIG. **5** is an example of increased oil production and recovery when using the tool of the invention in a sample well.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

Continuing on FIGS. **1** through **3** now, the initial instability of well production may cause a further decrease of the bottom hole pressure, which leads not to an increase of the oil flow rate, as predicted by the Vogel's curve (traditionally used IPR curve to describe behavior of oil wells with high GOR), but, on the contrary, to its decrease.

At the same time, a slow increase of GOR occurs. This phenomenon can be explained by the inflow equation:

$$Q_{oil}=K(P,S_L)\cdot(P_{form}-P_{bottom}),$$

where Q_{oil}—oil rate

$K(P,S_L)=(ko*h)/(\mu*Bo)$—production index

P_{form}—formation pressure

P_{bottom}—bottomhole pressure

ko—relative oil permeability

h—length perforation interval

μ—oil viscosity

Bo—oil formation volume coefficient

S_L—saturation of liquid.

As the bottomhole pressure decreases, the oil flow rate increases with increased reservoir drawdown (depression) $(P_{form}-P_{bottom})$. However, after the pressure achieves an optimum value, the oil flow rate starts to decrease, because the effect of increased drawdown (depression) becomes less significant than a detrimental influence of the reduced relative permeability (in case of a gas skin effect) or an interval h (in case of a gas cone). Simultaneously, the relative permeability for gas increases, as it leads to an increase in a gas stream and, respectively, in GOR.

It is known, that to identify a "working point" (values of the bottomhole pressure and oil flow rate that brings the reservoir production and oil lift to a balance) it is necessary to find points of crossing of an inflow curve (IPR) and a lift curve (LC). In case of a well with high GOR, there usually exist two crossing points—one of which is "stable" while the other is "unstable" (FIG. **2**). For wells with high GOR, the lift curve always has descending and ascending parts (see The Technology Artificial Lift Methods. K. E. Brown, vol. 4). In terms of physics, it may be explained by the fact that gas "slips" through the oil in case of the annular flow in the pipe.

In a traditional case, when a reservoir is approximated by the Vogel's curve, the system "well—reservoir" is unstable if the slope of the lift curve is negative at a crossing point ("point **1**") while it is stable if that slope is positive ("point **2**")—see FIG. **2**.

If IPR and LC curves do not cross each other, the lift production is not possible for a given production arrangement (Lift Curve' on FIG. **2**). In this case, some adjustments in the pipes diameter or the choke might be needed. If these adjustments do not lead to a crossing of the curves either, a gas lift or pump production mode may be a solution.

The following discussion illustrates how "point **1**" corresponds to an unstable mode of the system "well—reservoir". The assumption is made here that the flow rate at point **1** has slightly increased because of some fluctuations in the reservoir (FIG. **2**. p. **1'**). The increase of oil flow rate will cause in that case a decrease in the bottom hole pressure (reaction of the well, see p.**1"** on the lift curve). This, in turn, will cause a further oil flow rate increase (FIG. **2**, p. **1'''**), and so on. The operational mode of the system will be changing until it reaches point **2** that corresponds to a stable mode. In reality, the increase of the flow rate (p.**2'** in FIG. **2**) will lead to an increase of the bottomhole pressure according to the lift curve (p.**2"** in FIG. **2**). That, in turn, will lead to a decrease of the oil flow rate from the reservoir as it reverses back to the initial point **2**. Therefore due to the reaction of the well, a negative feedback takes place, and it makes the mode of the system to be stable at point **2**. At point **1**, on the contrary, reaction of the well causes a positive feedback.

In case of the inflow curve being similar to that described in my '020 patent, namely when it has a maximum value at a certain non-zero value of the bottomhole pressure, two or four crossing points may exist (see FIG. **3**). In that case, there will appear another stable point (point **4**) and another unstable point (point **3**) on the lift curve. A negative slope of the lift curve will now correspond to a stable point, and a positive slope will correspond to an unstable point.

Stability of system can be analyzed as follows. A decrease in the flow rate at point **3** will lead to a decrease of the bottomhole pressure (see point **3'** on the IPR curve and point **3"** on the lift curve); that, in turn, will lead to further decrease in the flow rate as positive feedback is developed. It further leads to moving the system to point **4** on the curve, which corresponds to a stable mode. Indeed, if the flow rate decreases further (FIG. **3** p.**4'**), the reaction of the well will lead to an increase in the bottomhole pressure (point **4"**), which, in turn, will lead to an increase in oil flow rate. The system will return to point **4** and therefore point **4** corresponds to a stable mode of system operation.

This phenomenon explains why sometimes a well switches to a gas mode when a gas cone or a strong gas skin effect takes place, and hence the bottomhole pressure becomes less optimum. This effect causes a sharp increase in GOR.

Therefore, only the presence of a decreasing portion in an inflow curve and the "type **3** and **4**" points on this curve can explain the effect of switching oil producing wells into a gas mode. The traditional Vogel's curve does not provide any explanation of this phenomenon.

Using a bottomhole tool (BHT) of the invention allows changing of the shape of the lift curve, so that the oil producing well is not allowed to switch into a gas mode. Moreover, the bottomhole tool allows reaching and maintaining a stable mode of the system "well—reservoir" while being close to the maximum possible oil flow rate. FIG. **3** illustrates how point **5** and dashed line correspond to the lift curve when the bottomhole tool is used. It is possible to chose specific design parameters of a bottomhole tool (such as the lengths and diameters of the telescopic needle for example) in a way so that its characteristics (dP=F (Qoil)) and the ability to control the position of the needle from the surface will together allow excluding of "type **4**" points from working points at the crossing of IPR and lift curves. Point **5** becomes now a working point, which corresponds to a stable operating mode of the well with the oil flow rate being close to the highest possible value.

For the crossing point of the lift curve and inflow (IPR) curve to be located near the maximum oil flow rate and to be maintained there for a long time despite changing of reservoir parameters, it is necessary to use the adjustable bottomhole tool with moving parts, as shown in my '020 patent.

Bottomhole tool also stabilizes the system, as it excludes a delay line from the control system. The delay line forms because of the presence of a long communication channel between a surface choke and the bottom of a well via a borehole filled with a gas-saturated fluid. It is known that the speed of sound in the gaseous mixture of oil and water and therefore the ability to transmit signals back and forth from the surface to the bottom of the well is limited to only dozens of meters per second causing significant delays in such transmissions. Presence of such a delay in the system "well—reservoir" could lead to occurrence of a positive feedback.

It is further suggested that the bottomhole tool of the invention allows to control the bottomhole pressure efficiently and hold it at an optimal level as compared with using a traditional

surface choke frequently located thousands of feet away from the bottom of the well. This is particularly true since the control signal has to propagate through a compressible column of gas-saturated fluid in the well.

The task of controlling a producing reservoir often contradicts the task of optimizing the lift. Attempts to maintain the bottomhole pressure at an optimum level using a surface choke frequently worsen the lift of the oil. Use of the bottomhole tool of the invention for this purpose allows separating both problems and therefore more efficiently resolve them one at a time.

There are certain special cases that are also characterized by the IPR curve having a maximum value, but this maximum is not caused by a gas skin or a gas cone effect. For example, reduced formation permeability may be caused by deformation of pores in a reservoir when the bottomhole pressure drops below the hydrostatic pressure. This is especially typical for carbonate reservoirs: the greater the difference between the bottomhole pressure in a well and the formation pore pressure, the smaller pore and fractures sizes are. While the bottomhole pressure increases, the effective permeability may increase.

The design of the novel bottomhole tool is now described in greater detail and with reference to FIG. **4***a* and **4***b*. In many aspects, it is similar to my initial design described in the '020 patent and includes a set of round tubes with a telescopic needle moving along these axis. The bottomhole tool of the invention is mounted in a well **10** at the end of the pipe **15** sealed to the well **10** through the sealing ring **11**. The housing **20** of the tool is attached to the lower end of the pipe **15** by any known means such as for example by a threaded connection as shown on the drawing. A multi-stage telescopic fluid resistor **30** is attached to the lower portion **21** of the housing **20** and contains cylindrical stages **31**, **32**, **33**, and **34** having diameters decreasing toward the bottom of the device. Although the drawing shows four such stages, it should be understood that any appropriate number of stages starting with just two stages is contemplated by the present invention. Also contemplated by the invention are designs in which the diameter of successive stages does not continuously increase or decrease. In these designs, a combination of larger to smaller and back to larger stages is envisioned. All these provisions are designed to allow manipulating the shape of the lift curve using the geometry of the fluid resistor and the position of the telescopic needle so that new stable points of operation are created at the intersection of the lift curve and the IPR curve as described above. Provisions are further made to direct substantially all fluid flow into the central inside portion of the telescopic fluid resistor **30** through a tapered opening at the bottom of the lower portion **21** of the tool housing **20**.

A multi-stage needle **40** is located inside the telescopic fluid resistor **30** and consists of several stages **41**, **42**, **43**, and **44** having diameters increasing in the direction toward the bottom of the tool. These diameters are chosen in such a way that they are all smaller then the diameter of the smallest stage **31** of the resistor **30** so that the needle can travel up and down the entire length of the resistor **30** from a predefined top position to a predefined bottom position and stop at any position therebetween. Preferably, the difference between the largest stage **41** of the needle **40** and the smallest diameter **31** of the resistor **30** is sufficient enough for passing sand and other inclusions so as to prevent well clogging during operation. Exact diameters and lengths of the various stages of the needle **40** and the resistor **30** are calculated from the mathematical model as described in the '020 patent. It is also preferred to have the lengths of various stages of the needle **40** correspond to that of the resistor **30**. In that case, the flow calculations are well defined to the series of several successive annular passages of well-defined lengths, at least at the lower position of the needle **40**.

As opposed to the design described in the '020 patent, this invention describes the needle **40** as supported by and moved up and down by driving means **50** consisting of an electric motor with an appropriate gear reduction adapted to move the needle **40** up and down in response to a control signal. The driving means **50** are supported on the lower portion **21** by a series of struts **55** allowing oil and gas to enter into the opening in the lower portion **21**.

The power and control signal to the driving means **50** are supplied through a drive cable **53** connecting the driving means **50** with a control unit such as for example a surface-based computer **58** forming the basis of such control unit. Also connected to the computer **58** via a sensing cable **54** are various sensors **51**, such as pressure sensors located in selected appropriate areas of the bottomhole tool. They are adapted to convey necessary information such as pressures **P1** below and **P2** above the bottomhole tool back to the computer **58**. Other information that can be advantageously collected by sensors **51** includes flow rates of various components of the well such as oil, gas, and water, their temperature, etc. both cables **53** and **54** can be combined into a single cable **55** once above the bottomhole tool. The motion of the needle **40** is therefore controlled by the action of the driving means so that the resistance of the multi-stage resistor **30** and can be adjusted at will from the surface via a computer **58**.

In the beginning of the operation of the bottomhole tool of the invention, the needle **40** is usually completely located inside the resistor **30**. In some cases however, it can be partially introduced, and in other cases it can be completely withdrawn from the lower portion of the resistor **30**, depending on the well and formation conditions. After installation of the device and starting of the well, the phase oil permeability, in the near bottomhole zone of the reservoir increases and as a result of that, the oil flow rate increases. In response, the pressure differential across the device grows and sensed by sensors **51**. Computer **58** is supplied with this information and based on a predetermined response, selects the new appropriate position of the needle **40**, which is achieved by activating the driving means **50** and moving the needle **40** to that position.

When the needle **40** is completely pulled out of the resistor **30**, the hydraulic resistance of the tool is minimal. Such resistance corresponds to a resistance of a system of telescopic pipes having a round cross-section. The pressure differential within the device in response to a further increase of flow rates will be based on a constant (minimal) hydraulic resistance of the lower stage **31** in addition to the next stage **32** and finally to further stages **33** and **34**. If the flow rates decrease due to some changes in the reservoir and fluid parameters and reduction of the reservoir pressure, the needle **40** will be moved back up into the body of the resistor **30**. This in turn adjusts the hydraulic resistance of the tool to a desired optimum level in order to maintain optimum bottomhole pressure and maximum oil flow rates according to the current conditions of the formation, reservoir pressure, and fluid parameters.

Previously proposed methodology for optimization and stabilization of a well as described in the '020 patent has a number of disadvantages that are resolved in the current invention, as follows:

The bottomhole tool built just on the basis of mathematical modeling and calculations doesn't always allow achieving sufficient accuracy needed for efficient control and optimization of the oil production, because physical processes that take place in the system "well—reservoir" and the bottomhole tool are quite complex. This is why this invention proposes controlling the needle motion based on the actual measured values of bottomhole parameters (e.g., pressure, oil/gas/water flow rate, temperature, etc.) periodically or constantly transmitted to the surface via a cable or by other means. The needle's position determines the pressure drop across the bottomhole tool, and that, in turns, allows maintaining the bottom hole pressure at (or very close to) the optimal level.

The presence of a spring in the bottomhole tool of the '020 patent, parameters of which are also to be specifically calculated for each particular well, is the second disadvantage of the earlier proposed technique. In this new invention, instead of a spring, a cable-controlled electric motor is used, which is supplied with the electric power and control signals from the surface through the same cable means **55** that is used to transmit bottomhole measurements to the surface. Control signals are generated on the basis of actual measurements combined with the modeling & simulation results by a surface control unit including a computer **58**.

Another disadvantage of the earlier technique is that complex computer calculations are performed only during a bottomhole tool design stage. The new approach of the present invention allows fine tuning calculations in real-time based on constantly updated bottomhole information and by utilizing significant calculation power of a surface computer **58**. This permits periodic adjustments to the bottomhole tool's characteristic immediately during the production process, so the efficiency and accuracy of the bottomhole control increases noticeably.

The new design of bottomhole tool expands its functional capabilities: without any modifications this tool can be used for conducting hydrodynamic tests of the formation (formation testing). It allows for periodical measurements of varying reservoir parameters and the current IPR curve to better determine the most optimal position of the bottomhole tool needle. This information will significantly enhance the accuracy and efficiency of the proposed method for stabilizing a well and its production optimization.

Sequence of Operations in Utilizing the Present Invention:

1. Calculate critical parameters of the reservoir by utilizing comprehensive mathematical models as described before. These critical parameters include formation pressure, flow rate for oil, gas, and water, oil recovery factor, and a family of IPR curves.
2. Based on the calculated family of IPR curves, a particular value of the bottomhole pressure Popt (t) required for the most optimal oil production is calculated (FIG. **1**).
3. Based on performed lift simulation and mathematical modeling, family of the lift curves are established to allow lift of the oil to the surface for all values of parameters of an optimally producing well.
4. Stability of the system "well—reservoir" (points of IPR curve crossing the lift curve) is analyzed, as per the above methodology.
5. On the basis of the performed calculations, a corresponding characteristic of the bottomhole tool is determined (described as dPbottomhole tool=F (Qoil, GOR)) which is required for maintaining an optimal bottom hole pressure.
6. Based on the above, all critical bottomhole tool design parameters shall be determined and the actual bottomhole tool is manufactured.

US007172020B2

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Tseytlin

(10) **Patent No.:** **US 7,172,020 B2**
(45) **Date of Patent:** **Feb. 6, 2007**

(54) **OIL PRODUCTION OPTIMIZATION AND ENHANCED RECOVERY METHOD AND APPARATUS FOR OIL FIELDS WITH HIGH GAS-TO-OIL RATIO**

(75) Inventor: **Simon Tseytlin,** Middle Village, NY (US)

(73) Assignee: **Tseytlin Software Consulting Inc.,** Middle Village, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 317 days.

(21) Appl. No.: **10/983,308**

(22) Filed: **Nov. 8, 2004**

(65) **Prior Publication Data**

US 2005/0194131 Al Sep. 8, 2005

Related U.S. Application Data

(60) Provisional application No. 60/549,992, filed on Mar. 5, 2004.

(51) **Int. Cl.**
E21B 47100 (2006.01)

(52) **U.S. Cl. 166/250.07;** 166/250.15

(58) **Field of Classification Search..........................**None
See application file for complete search history.

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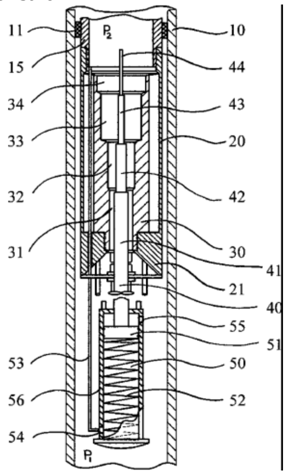
Primary Examiner-Frank Tsay
(74) *Attorney, Agent, or Firm-Boris* Leschinsky

(57) **ABSTRACT**

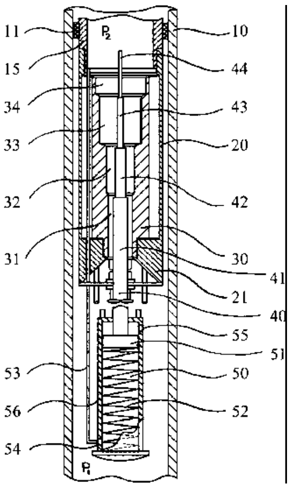
A method foroptimizing oil production rate from an oil well with high gas-to-oil ratio is disclosed to include modeling an Inflow Performance Relationship curve and calculating an optimal level ofbottomhole pressure to be higher than zero. Maintaining the bottomhole pressure at that calculated optimum level by using a bottomhole tool of the invention or other known means such as gas injection provides for maximum oil recovery from a given well. The bottomhole tool includes a multi-stage flow resistor and a needle moved in and out of the resistor by a spring-biased piston responsive to a difference in pressure between a bottomhole pressure and a pipe pressure. Automatic adjustment of the bottomhole pressure is maintained over a wide range of operating parameters throughout the life of the well.

19 Claims, 9 Drawing Sheets

adjusting the bottomhole pressure to the vicinity of said



adjusting the bottomhole pressure to the vicinity of said



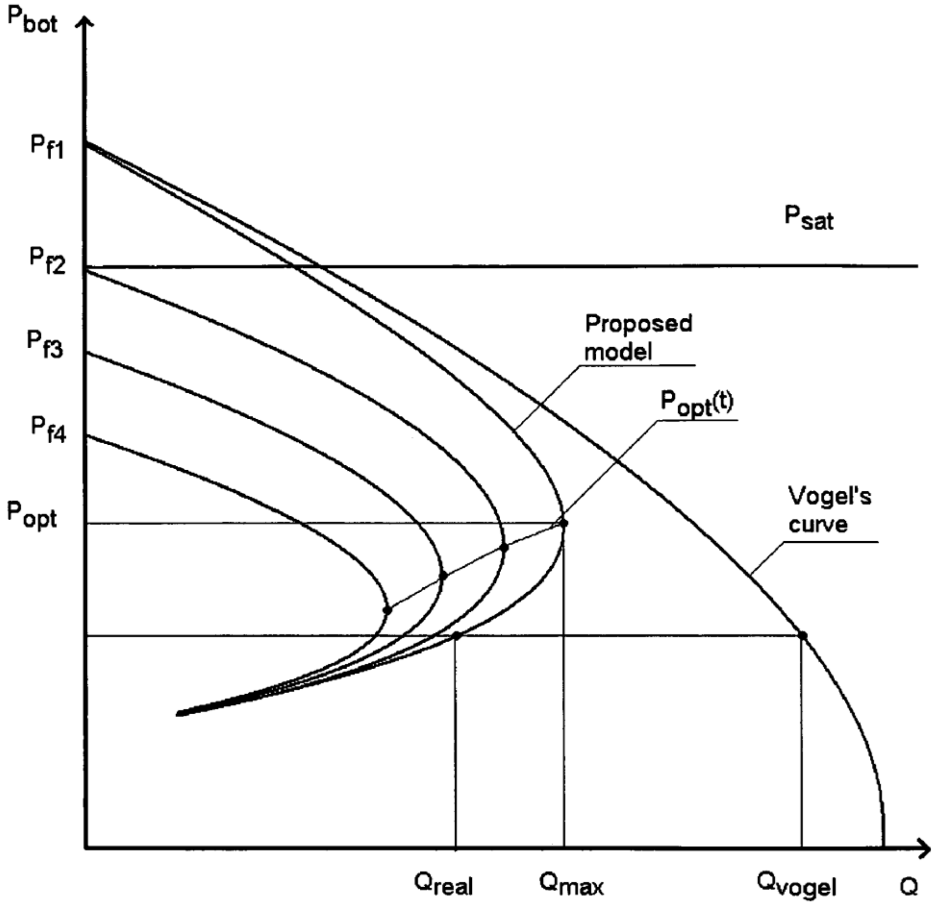
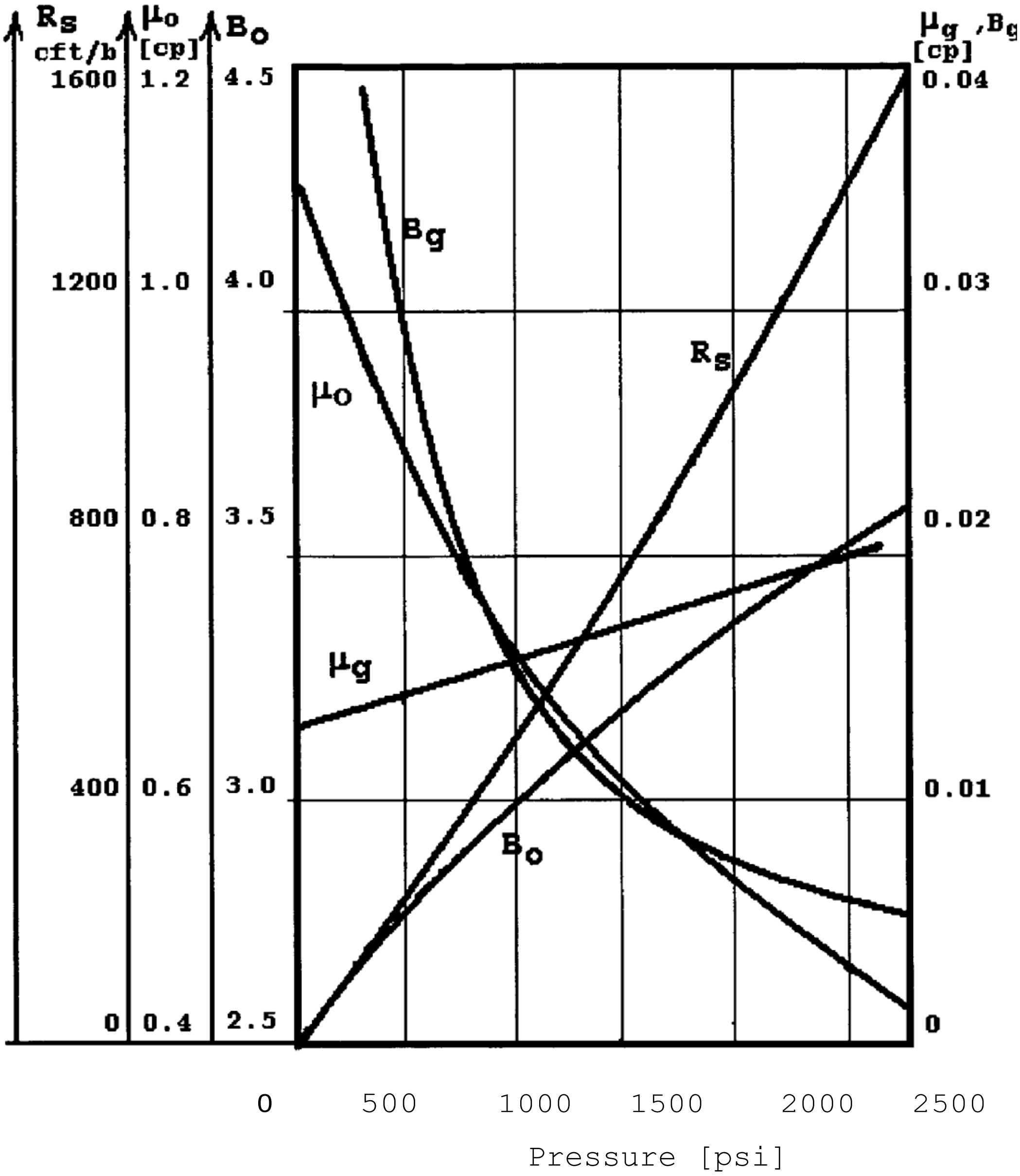

P_bot
P_f1
P_sat
P_f2
Proposed model
P_f3
P_opt(t)
P_f4
Vogel's curve
P_opt
Q_real
Q_max
Q_vogel
Q

FIGURE 1



Rs
cft/b
μo
[cp]
Bo
μg ,Bg
[cp]
1600
1.2
4.5
0.04
1200
1.0
4.0
0.03
800
0.8
3.5
0.02
400
0.6
3.0
0.01
0
0.4
2.5
0
Bg
μo
Rs
μg
Bo
0
500
1000
1500
2000
2500
Pressure [psi]

FIGURE 2

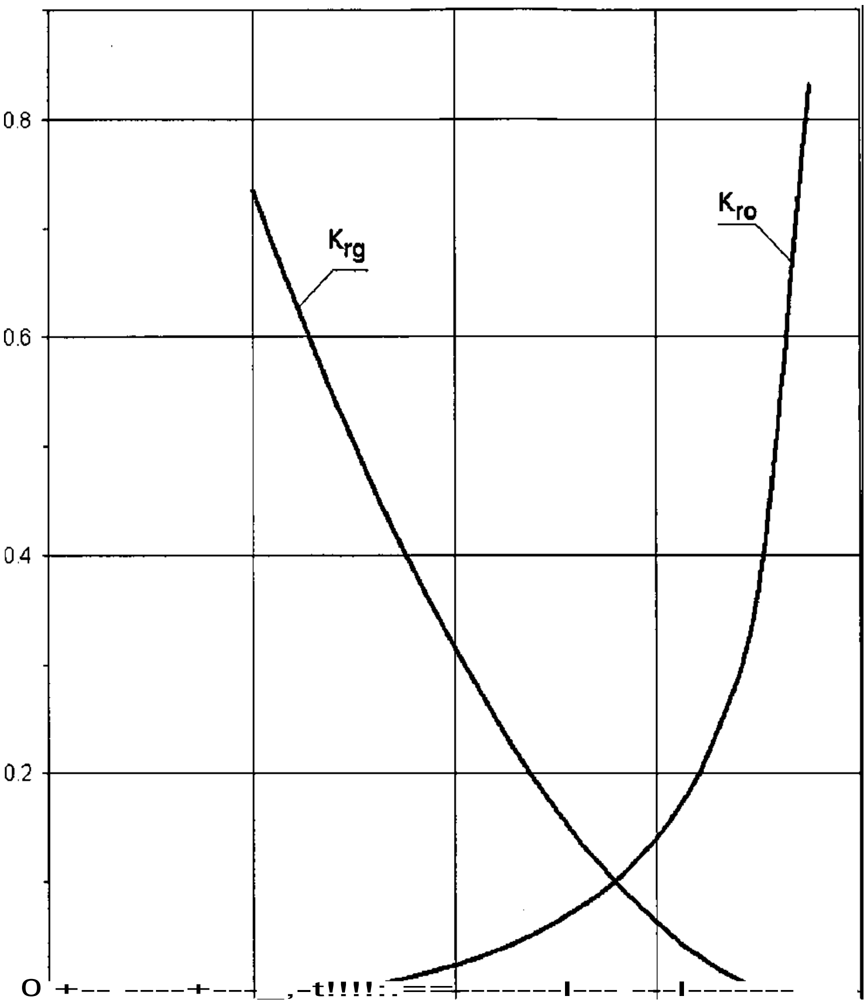


FIGURE3

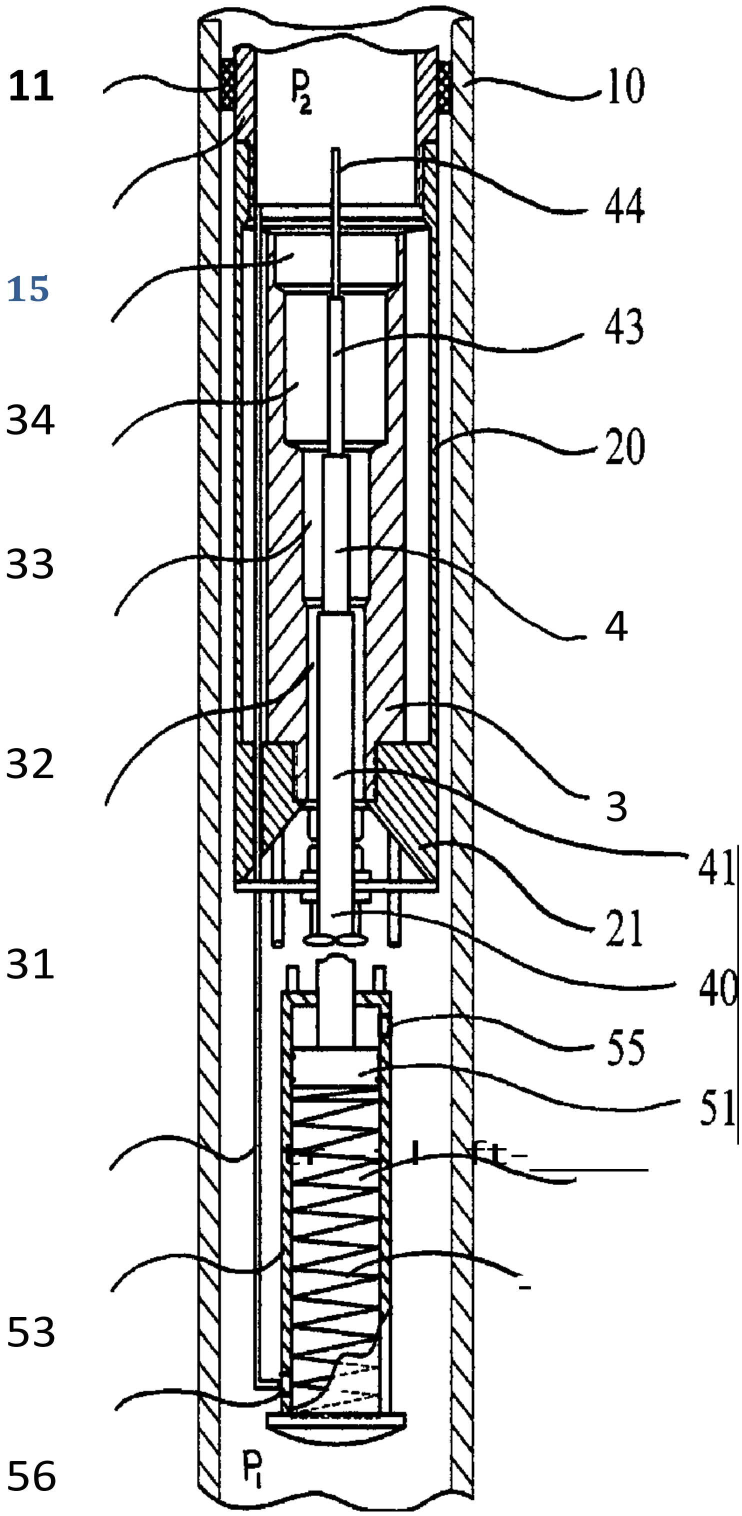


FIGURE 4

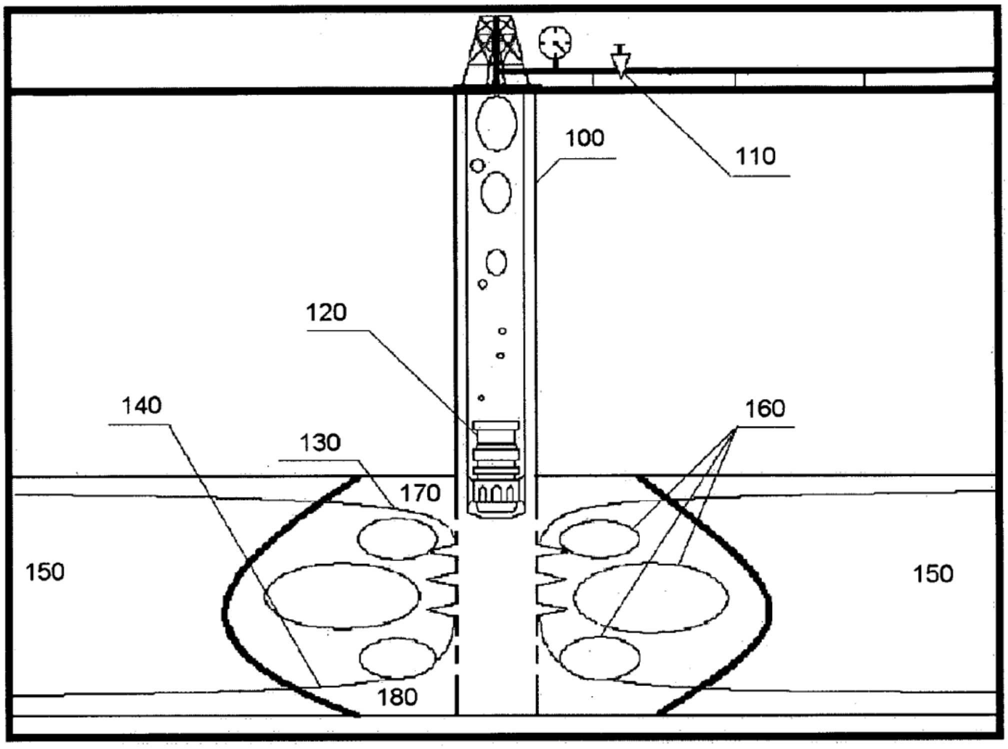


FIGURE 5

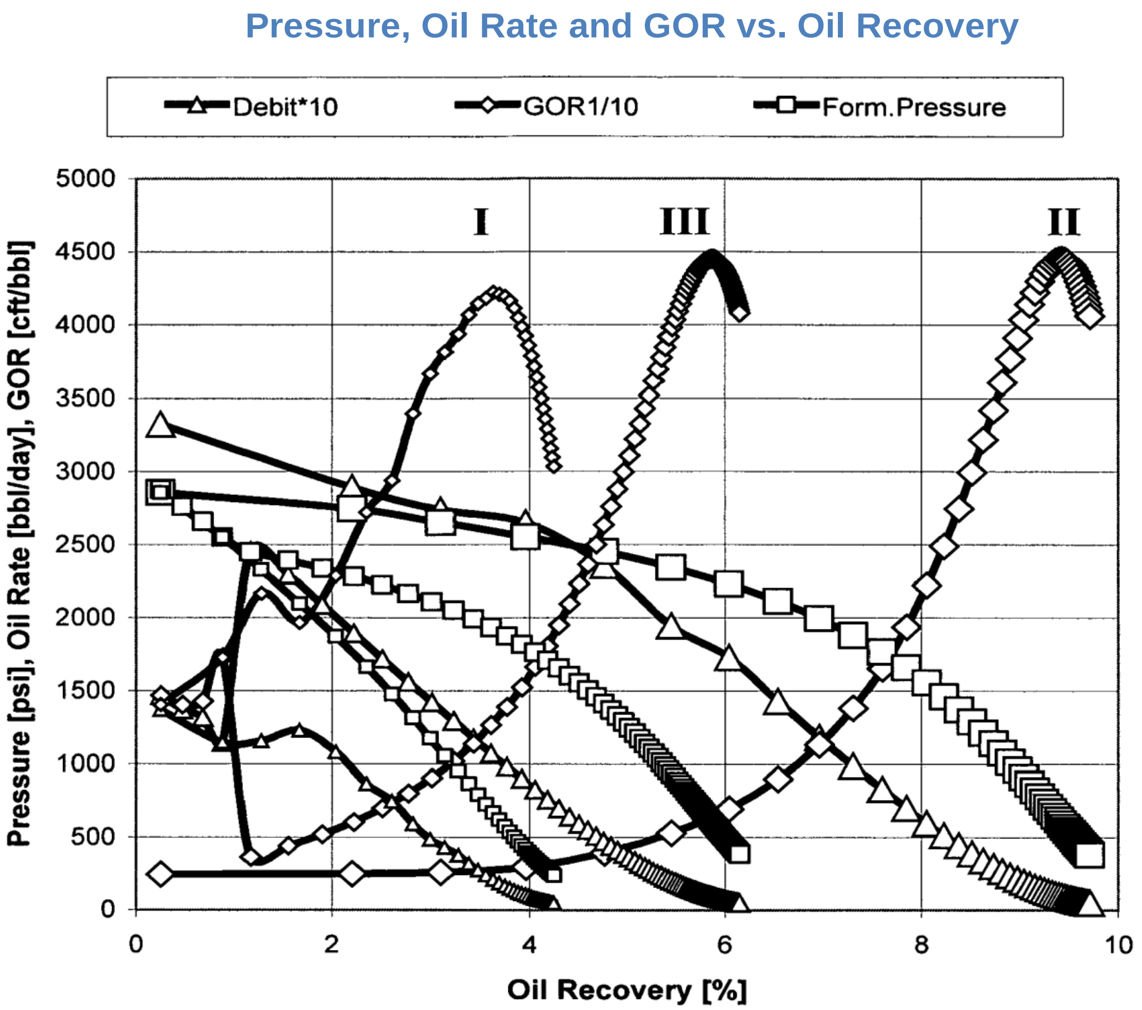

Pressure, Oil Rate and GOR vs. Oil Recovery
Debit*10
GOR1/10
Form.Pressure
I
III
II
Pressure [psi], Oil Rate [bbl/day], GOR [cft/bbl]
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
Oil Recovery [%]

FIGURE 6

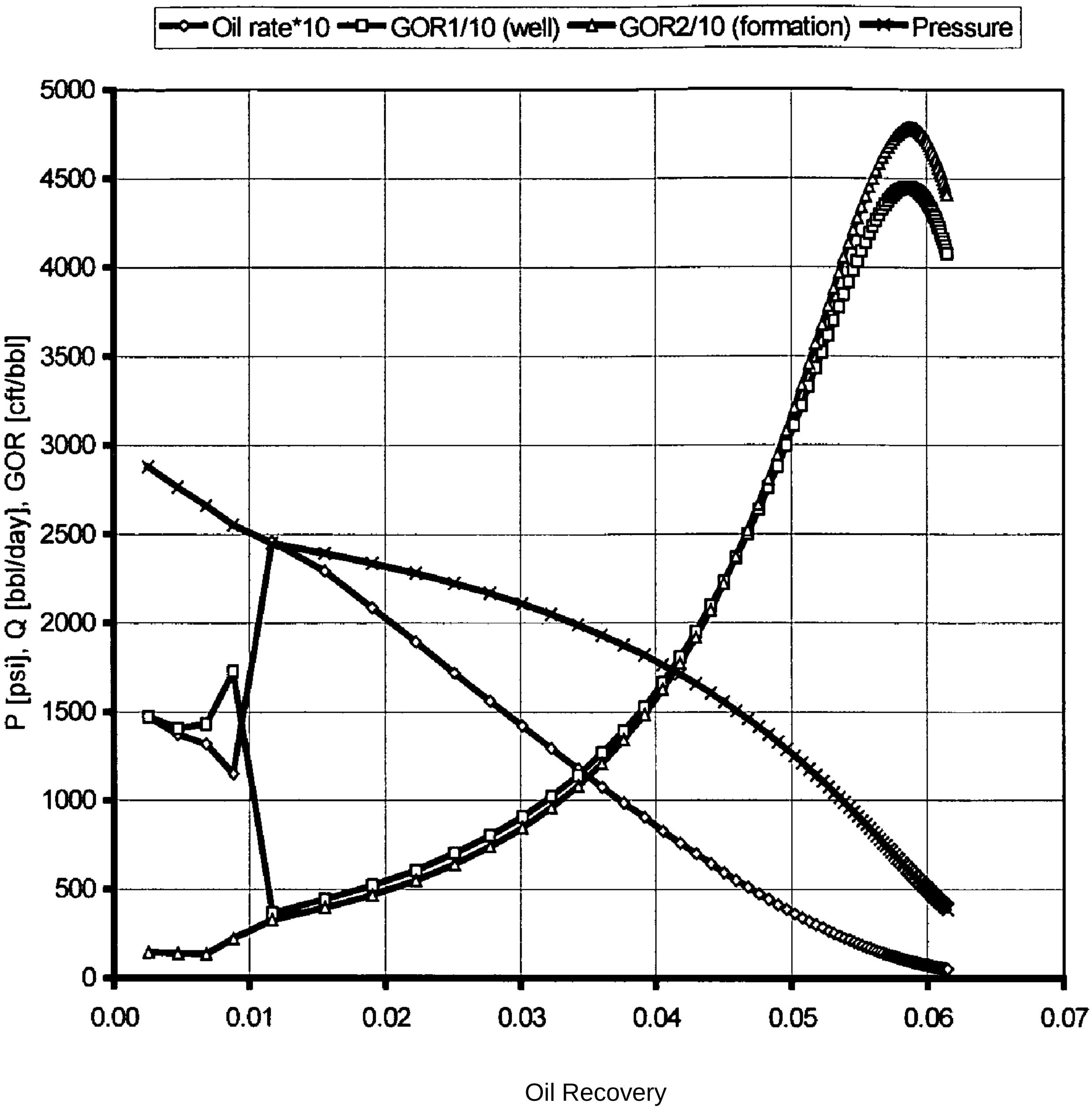
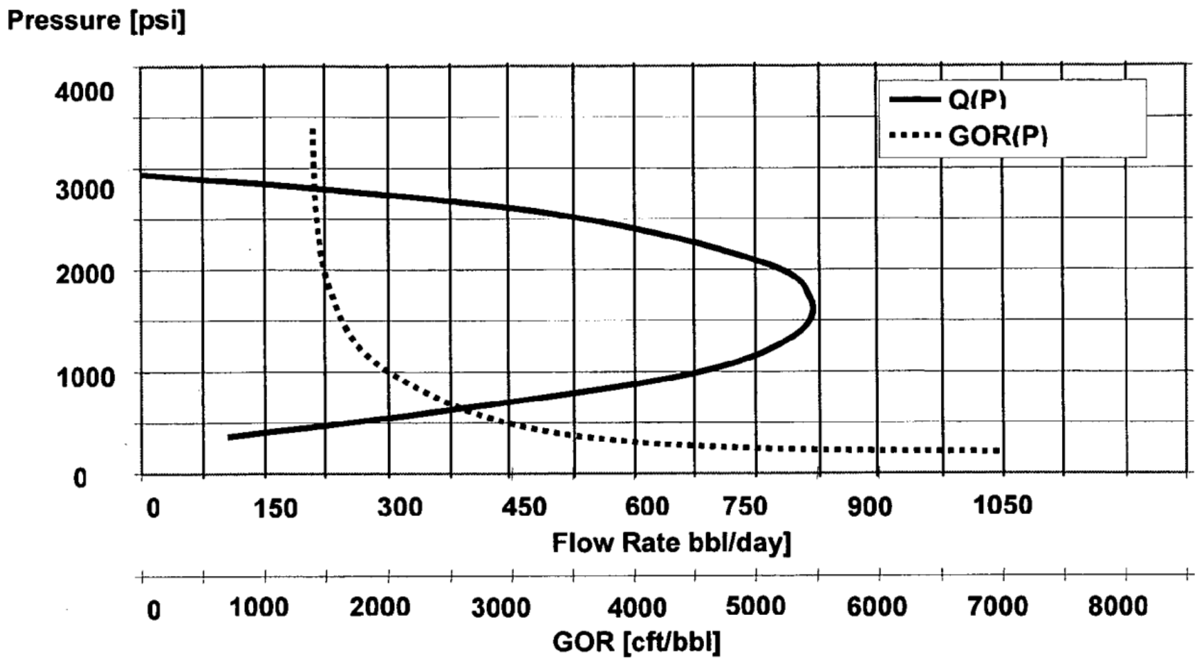

Oil rate*10
GOR1/10 (well)
GOR2/10 (formation)
Pressure
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
P [psi], Q [bbl/day], GOR [cft/bbl]
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
Oil Recovery

FIGURE 7



Pressure [psi]
4000
3000
2000
1000
0
Q(P)
GOR(P)
0
150
300
450
600
750
900
1050
Flow Rate bbl/day]
0
1000
2000
3000
4000
5000
6000
7000
8000
GOR [cft/bbl]

FIGURE 8

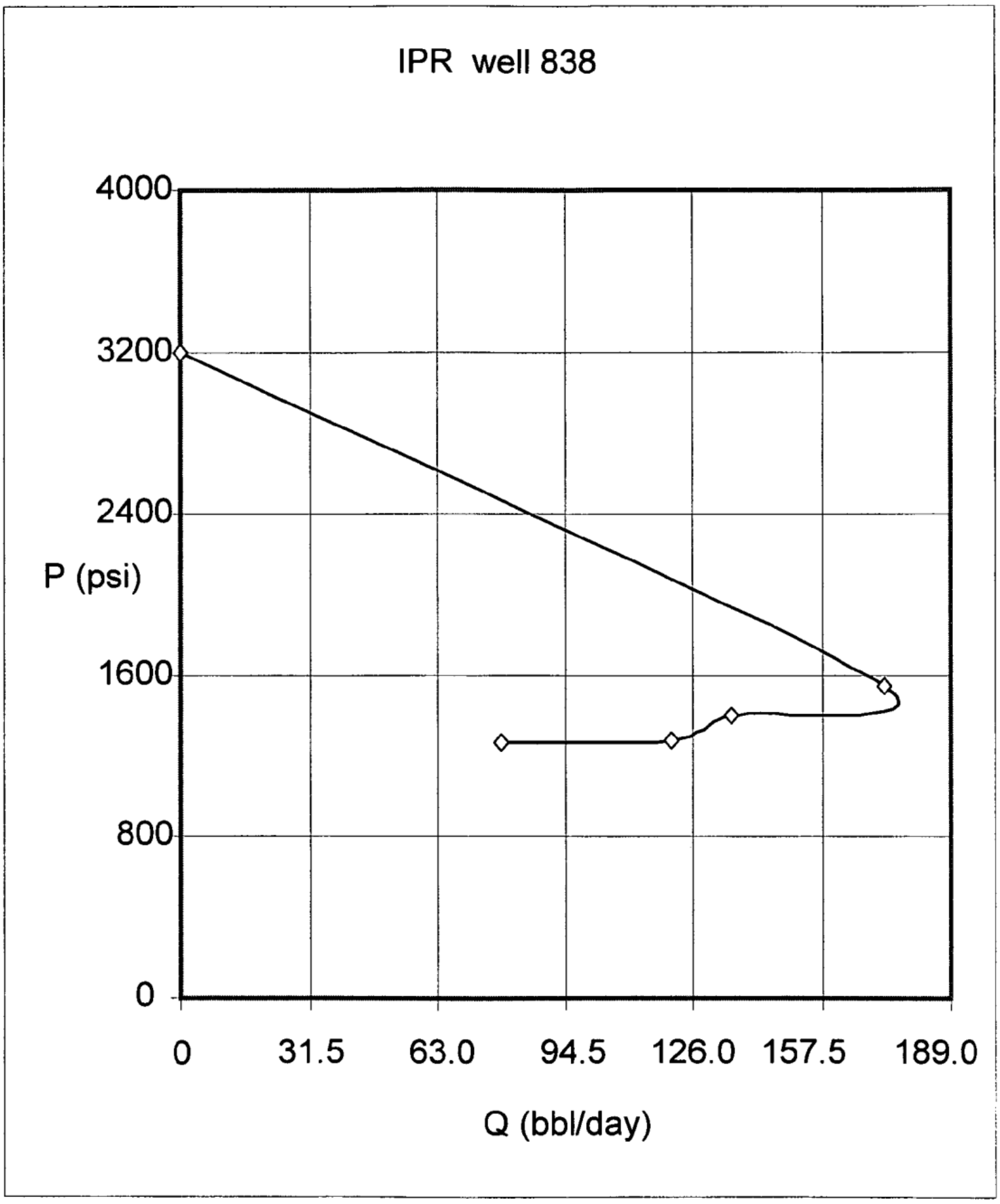

IPR well 838
4000
3200
2400
P (psi)
1600
800
0
0
31.5
63.0
94.5
126.0
157.5
189.0
Q (bbl/day)

FIGURE 9

OIL PRODUCTION OPTIMIZATION AND ENHANCED RECOVERY METHOD AND APPARATUS FOR OIL FIELDS WITH HIGH GAS-TO-OIL RATIO

CROSS-REFERENCE DATA

Priority is claimed herein from a U.S. Provisional Appli cation No. 60/549,992 by the same inventor, as filed Mar. 5, 2004 and entitled "OIL PRODUCTION OPTIMIZATION AND ENHANCED OIL RECOVERY METHOD AND APPARATUS FOR OIL FIELDS WITH HIGH GOR", incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

The present invention relates generally to a method and devices for increasing the production of oil. More specifically, the method and the bottomhole tool of the invention provide for maintaining the bottomhole pressure at a level optimum for maximizing oil production in a well with high gas-to-oil ratio (GOR). The most advantageous are of implementation of the present invention is in wells with high GOR defined as GOR greater than 600 cubic feet per barrel. In these wells the method and the tool of the invention can be used when the bottomhole pressure is lower than the bubble point pressure as well as in all cases when the gas cone has appeared such as in fountain, gas lift, and pump regimes of oil production.

Optimization of oil production has been a goal of many methods and devices of the prior art. Generally speaking, the bottomhole behavior of oil mixed with gas and some other ingredients such as water, etc. has been described in a series of mathematical equations by Muskat. One specific publication of Muskat is incorporated herein by reference in its entirety and describes the mathematical model of oil reser voir: Muskat M. "The Production Histories of Oil Producing Gas-Drive Reservoirs", published in the Journal of Applied Physics in March of 1945, p.147-159.

For illustration purposes, a one-dimensional axissym metrical system of Muskat equations with corresponding PVT characteristics of fluid and dependencies of relative permeability K_o K, g from liquid saturation (S) can be described as follows:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{k_{ro}}{\mu_o B_o}\frac{\partial p}{\partial r}\right) = -158.064\frac{\phi}{k}\frac{\partial}{\partial t}\left(\frac{S_o}{B_o}\right)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\frac{k_{rg}}{\mu_g B_g} + \frac{Rs}{5.615}\frac{k_{ro}}{\mu_o B_o}\right)\frac{\partial p}{\partial r}\right] = -158.064\frac{\phi}{k}\frac{\partial}{\partial t}\left(\frac{S_g}{B_g} + \frac{S_o}{B_o}\frac{Rs}{5.615}\right)$$

where: P-pressure in formation; S - oil saturation in for mation; Sg-gas saturation in formation; R - solution of gas in oil; B - oil formation volume factor; Bg-gas for mation volume factor; μ -oil viscosity; μg-gas viscosity; <I>-formation porosity; K-formation permeability.

For practical purposes, Vogel had simplified the Muskat equations and adapted them to the calculations of oil producing formations. These equations are known as Vogel model and have subsequently been modified by others. One example of such publication is as follows: Vogel, *Inflow Performance Relationships for Solution-Gas Drive Wells,* as published in Journal of Petroleum Technology, January 65 1968, pp.

83-92, incorporated herein in its entirety by reference. Unfortunately, Vogel model does not work well in wells with high gas-to-oil ratio. According to Vogel, the dependency of oil rate production of bottom hole pressure is a constantly diminishing parabolic curve with a production peak at zero bottomhole pressure, see for example FIG. **2** of the above mentioned article. In other words, the lower the bottomhole pressure is, the higher is the oil rate production from the formation. This is a gross simplification of the bottomhole processes in the formation. In fact, if the bottomhole pressure falls below saturation pressure in case of high GOR, relative permeability coefficient by oil decreases because of gas saturation increase, which in turn is a result of gas being released from oil. Viscosity of so degassed oil also increases. This leads to a decrease of productivity index of formation. This phenomenon effects the oil production rate more than the increasing depression. As a result, decreasing of the bottomhole pressure below saturation pressure can lead to a decrease in oil production rate, rather than to its increase as predicted by Vogel's model, see FIG. **1.** In some extreme cases, reliance on Vogel's model will cause a complete switch in production from oil to gas. There is a need therefore for a method allowing calculating the oil production rate in high GOR wells with better accuracy then that allowed by Vogel's model.

More specifically, the need exists for a method of calculating well parameters in an optimal regime that takes into account two opposing processes. The existence of this optimal regime is explained by two phenomena simultaneously affecting the current oil rate in two opposite directions in the skin layer. On one hand, reducing the bottomhole pressure (increasing depression in formation) leads to increased oil rate:

$$Q_{oil} \sim K\ (P,S_L) \cdot (P_{form} - P_{bottom}),$$

where Qa oil rate; K(P,SL)=(ko*h)/(mu*Bo)-produc- tion index; Pform-formation pressure; P60 um -bottomhole pressure; korelative oil permeability; h-length perfora- tion interval ; mu-oil viscosity ; Bo-oil formation volume coefficient; SL-saturation of liquid).

On the other hand, it reduces the production index (K(P, SL), because gas dissolved in oil comes out of solution, reducing therefore relative oil permeability of formation. Production index is additionally decreased due to increased viscosity of degassed oil, which also significantly decreases oil mobility.

Besides, degassed oil not only becomes more viscous, but also shrinks in volume, which together with gas in free form creates a blocking zone, preventing exit of oil from forma tion and reducing oil saturation here. Strong skin effect may appear in a near bottomhole zone. FIG. **5** illustrates this situation, in which the well **100** contains a wellhead choke **110** at the surface and a bottomhole tool **120** close to the bottomhole formation consisting of saturated oil reservoirs **150,** water layer **180,** and gas layer **170.** Note the areas of gas cone **130,** water cone **140** and viscous barriers of oil with low mobility **160.**

As a supplemental consideration, decreasing bottomhole pressure further increases GOR because of increased relative gas permeability of formation. This causes gas to prema turely exit formation, which in tum accelerates falling of formation pressure and as a result reduces the ultimate oil recovery index.

The presence of a point of flow rate maximum on the IPR curve (and thus the optimal bottomhole pressure) may also be explained by presence of gas and/or water cones, which reduce the active oil inflow perforation interval, and expand the segments surrounded by gas and water cones, appearing and growing when the bottomhole pressure decreases. GOR also significantly increases in that case. FIG. 9 demonstrates a visible peak in oil rate on an actual IPR curve obtained from an oil well in a large Siberian oil field. The maximum oil flow rate is observed at a bottomhole pressure not equal to zero. A further need exists for a bottomhole tool allowing adjustments in bottomhole pressure in a well. Many designs of bottomhole tools and methods of controlling the bottomhole pressure are known in the prior art. One of such devices is disclosed in U.S. Pat. No. 5,105,889. This device includes a set of axially vertically aligned pipes of different diameters and lengths, forming a multi-parameter hydrodynamic system. That system establishes a certain pre-calculated bottomhole pressure below the device, in order to decrease gas blockage of the near bottomhole zone of the oil formation and to provide a stable fluid flow to the surface. A forced fluid degassing takes place in the device, creating a two¬phase gas-liquid emulsion in order to provide a sufficient fluid lift within the well.

The device disclosed in this patent has however certain limitations. A pressure differential across the device depends on the calculated diametrical parameters of the pipes. That in turn corresponds to current values of the flow parameters in the formation. Such fixed dependency restricts the adaptability of the device to changing reservoir and well conditions.

Another method and device is disclosed in the U.S. Pat No. 5,752,570. In accordance with this patent, the bottomhole pressure is automatically maintained higher than a current saturation pressure of the formation fluid with gas in the near bottomhole zone of the formation, regardless of fluctuations of fluid pressure in the formation. This is done in order to create fluid flow with minimum gas content. Once the bottomhole pressure decreases, the device automatically creates conditions for formation of a fluid flow into the device with an increased speed. Nearly mono-phase flow is transformed within the device into a finely dispersed gas liquid two-phase flow, in order to provide its lift to the wellhead. The device disclosed in this reference automatically adjusts bottomhole pressure to a desired level, simultaneously providing a pressure drop, in order for the fluid to sustain degassing within the transforming area, according to the device inlet pressure at the bottomhole. However, in the process of oil field development, operational conditions change as well as the inflow performance curve corresponding to a current well operation. The sensing element of the device disclosed in this reference might no longer maintain the same optimal well operation, since its calibration is based on the previous well information parameters. Besides, calculations have proven that in some wells a space between the inner nozzle surface and the outer surface of the regulating cone of the device reduces to approximately 0.01 inch. With such a small space even a trace of sand in the fluid can jam the regulating unit and stop the well production. Since function of fixed power of the diameter of the adjustable cross-section, it impedes precise regulations.

A further example is disclosed in the U.S. Pat. No. 5,967,234 incorporated herein in its entirety by reference. Means for automatically adjusting the bottomhole pressure are described in this patent to include a spring-biased needle traveling inside a plurality of pipes of diminishing diameters. The space left between the needle and the corresponding pipe is available for oil flow and can be adjusted depending on the bottomhole pressure. Fixed geometry of the needle and the pipes makes this device limited in its field of use as changing parameters of the well require a broader range of adjustment of flow restriction then this device can provide.

The need exists therefore for a method and device with broad range of parameters that can be adjusted preferably from the surface of the well to bring the bottomhole pressure in agreement with the required values to maximize the production of oil from an oil well.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to overcome these and other drawbacks of the prior art by providing a novel device and method for optimizing and maximizing the production of oil from an oil well, particularly an oil well with high GOR. It is another object of the present invention to provide a method allowing calculating and maintaining the optimum value of bottomhole pressure required to maximize oil production and operating life duration of the well. It is a further object of the present invention to provide a bottomhole tool allowing adjustment of bottomhole pressure from the surface in a wide range of formation conditions and throughout the life of the well without the need to replace the device.

It is yet a further object of the present invention to provide a bottomhole tool allowing adjustments of bottomhole pressure in a desired range such that the reliability of that tool is increased by providing larger values of clearances between the moving and non-moving parts of the tool. Increased reliability would depend on the resistance of the tool to jamming by sand and other particles present in oil flow.

The method of the invention is based on a mathematical model taking into account and accounting for all four key elements of oil production, including reservoir model, polyphase flow in pipes, flow through the bottomhole tool and flow through the surface choke. The mathematical model of the method of the invention allows calculating the optimum value for bottomhole pressure so that the oil rate production is maximized. Characteristics of all four elements are entered continuously into the equations and allow calculating and adjusting the value of bottomhole pressure through out the life of the well and in various operating conditions thereof.

The pressure difference depending on the movement of the regulating cone has a non-linear characteristic and is a multi-parameter bottomhole tool with flexible characteristic of pressure regulation is also proposed with a broader range of adjustments of the operating parameters then in the previously known devices. This is achieved by novel modifications of the tool's geometrical characteristics, i.e. by using of several sections with predetermined lengths and cross-sectional areas to create the noncircular channel for passing the fluid. The tool includes a series of pipes with decreasing diameters and a corresponding multistage piston- or spring-biased needle with diameters of stages selected to correspond to that of the pipes. Longitudinal movement of the needle along the length of the device allows changing of a greater number of parameters affecting the performance of the tool and therefore broadens the range of operation. This allows expansion of dynamic ranges of the controlled pressure drop and the fluid velocity without replacement the tool.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the subject matter of the present invention and the various advantages thereof can be realized by reference to the following detailed description in which reference is made to the accompanying drawings in which:

FIG. **1** is an inflow performance relationship curve according to Vogel and according to the present invention,

FIG. **2** is a sample PVT data needed for the method of the present invention,

FIG. **3** is a sample chart showing relative permeability of oil and gas versus liquid saturation,

FIG. **4** is a cross-sectional view of the bottomhole tool of the present invention,

FIG. **5** is an illustration of the negative effects in the near bottomhole zone of the formation,

FIG. **6** is a mathematical model chart showing the for mation pressure, oil rate and GOR curves as a function of oil recovery,

FIG. **7** illustrates a mathematically modeled well performance in a given period of time,

FIG. **8** is a mathematical model of a sample IPR curve, and

FIG. **9** illustrates the actual IPR curve with a peak oil recovery rate visible on the chart.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

The main concept of the method of the present invention lies in the discovery that there exists an optimal level of bottomhole pressure allowing to maximize the oil produc tion rate and that this optimal bottomhole pressure does not necessarily have to be the lowest bottomhole pressure of the formation.

The method of the invention is based on an integrated mathematical model of the production process incorporating the following four key contributing factors defining the oil production: formation, multi-phase flow through pipes, sur face choke flow and bottomhole tool flow. Calculations of these four factors will be described in more detail below.

Formation Calculations

First of all, according to the invention, basic Muskat equations describing the bottomhole formation and behavior of various parameters during the oil production operation are transformed in a way different from that of Vogel. Muskat equations were initially picked as a mathematical model, which describes basic processes of unsteady two-phase filtration in formation; with some simplifying assumptions as follows: formation is one dimensional and there exists only radial flow; porous media is isotropic and uniform; gravity and capillary effects can be neglected; compressibility of rock and water can be neglected; constant pressure exists in both oil and gas phase.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{K_{ro}}{\mu_o B_o}\frac{\partial P}{\partial r}\right) = -158.064\frac{\varphi}{K}\frac{\partial}{\partial t}\left(\frac{S_o}{B_o}\right)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\left(\frac{K_{rg}}{\mu_g B_g} + \frac{Rs}{5.615}\frac{K_{ro}}{\mu_o B_o}\right)\frac{\partial P}{\partial r}\right) = -158.064\frac{\varphi}{K}\frac{\partial}{\partial t}\left(\frac{1 - S_o - S_w}{B_g} + \frac{S_o}{B_o}\frac{Rs}{5.615}\right)$$

Zero flow condition on the outsize border of the zone is:

$$\left.\frac{\partial P}{\partial r}\right|_{r=r_e} = 0$$

On the wall of the well, a border condition is set based on known value of pressure or oil rate:

$$P\big|_{r=r_w} = P_w(t) \ or \ \left.\frac{\partial P}{\partial r}\right|_{r=r_w} = F_w(t)$$

Initial conditions are also set as follows:

P(r,t) P (r,0) ; S(r,t) S (r,0) ;

The above equations can be computed with available PVT data usually presented as a chart such as shown for example on FIG. **2** as well as taking into account the dependence of relative permeability of different phases from saturation (as shown for example on FIG. **3)** and with the following other properties of reservoir: μ (P), μg(P), B (P), Bg(P), R/P), KoCSo), Kg(Sg), K, <l>, pjl *pbp,* rw, r,, sw, and sg *crit"* Multi-Phase Flow Through Pipes.

A second component of a mathematical model consists of a number of mathematical equations describing the flow of gas-oil-water mixture (depending of course on the specifics of each individual well) through a system of pipes connecting the bottomhole area of formation to the surface. In a typical scenario, this is a multi-phase flow system of equations. They are well known in the art and can be found in the publications by Aziz. One such publication is Aziz K. et al. *Pressure Drop in Wells Production Oil and Gas,* Journal of Canadian Petroleum Technology, 1972, incorporated herein in its entirety by reference. Over 30 input fluid parameters are needed for these calculations, which are collected prior to running the model.

Surface Choke Flow Calculations

Gilbert's model was used for simulation of the multi- phase flow of the surface choke. It is known in the art and can be found in the following publication incorporated herein in its entirety by reference: Artificial Lift Methods, Volume, ed. Kermit E. Brown. Main input parameters include **Pl** and **P2** as input and output pressures; GOR- gas-to-oil ratio; D-choke diameter; Q-oil flow rate.

Bottomhole Tool Description and Flow Calculations

A detailed description of the device of the present inven tion follows now with reference to accompanying drawing on FIG. **4** in which like elements are indicated by like reference letters numerals.

The bottomhole tool of the invention is mounted in a well **10** at the end of the pipe **15** sealed to the well **10** through the sealing ring **11.**

These assumptions make it possible to describe the two- phase flow of oil and gas by the partial differential equations as follows:

lower end of the pipe **15** by any known means such as by a threaded connection as shown on the drawing. A multi-stage telescopic fluid resistor 30 is attached to the lower portion 21 of the housing 20 and contains cylindrical stages 31, 32, 33, and **34** having diameters decreasing toward the bottom of the device. Although the drawing shows four such stages, it should be understood that any number of stages starting with just two stages is contemplated by the present invention.

Provisions are made to direct substantially all fluid flow into the central inside portion of the telescopic fluid resistor **30** through a tapered opening at the bottom of the lower portion **21** of the tool housing **20.**

A multi-stage needle **40** is located inside the telescopic fluid resistor **30** and consists of several stages **41, 42, 43,** and **44** having diameters increasing in the direction toward the bottom of the tool. These diameters are chosen in such a way that they are all smaller then the diameter of the smallest stage **31** of the resistor **30** so that the needle can travel up and down the entire length of the resistor **30.** Preferably, the difference between the largest stage **41** of the needle **40** and the smallest diameter **31** of the resistor **30** is sufficient enough for passing sand and other inclusions so as to prevent well clogging during operation. Exact diameters and lengths of the various stages of the needle **40** and the resistor **30** are calculated from the mathematical model as described herein. Preferably, the ranges of diameters for the needle **40** are between about 1 and about 50 mm, preferably between about 3 and about 20 mm and for the resistor **30** these diameters are between about 2 and about 55 mm, preferably about 4 to about 25 mm. It is also preferred to have the lengths of various stages of the needle **40** correspond to that of the resistor **30.** In that case, the flow calculations are well defined to the series of several successive annular passages of well-defined lengths, at least at the lower position of the needle **40.**

The needle **40** is supported by and moved up and down as a result of it being connected to a pressure-responsive means consisting of the active piston **51** of the control cylinder **50** responsible for automatic pressure adjustment in the bot tomhole tool of the present invention. The housing **56** of the control cylinder **50** is attached to the lower part **21** of the tool housing **20** and is sealed at the bottom. Inside the housing **56** there is located the piston **51** supported by a spring **52** and exposed to two pressures. The first pressure above the piston **51** is that of the bottomhole formation **Pl,** as transmitted through an opening **55.** The second pressure is that which acts below the piston **51** and is a pipe pressure **P2,** as transmitted through a small diameter pipe **53** and the open ing **54.** The motion of the piston **51** is therefore determined by a pressure differential **P2-Pl** and the compression of the spring **52.** The length of the cylinder **56** is chosen to provide for enough stroke length for moving the needle **40** along the operating range of the resistor **30.**

In the beginning of the operation of the bottomhole tool of the invention, the needle **40** is completely introduced inside the resistor **30.** In some cases it can be partially introduced, and in other cases it can be completely with drawn from the lower portion of the resistor **30,** depending on the well and formation conditions. After installation of the device and starting of the well, the phase oil permeabil ity, in the near bottomhole zone of the reservoir increases and as a result of that, the oil flow rate increases. In response, the pressure differential within the device grows. The piston **51** is displaced in the cylinder **56,** and in tum it displaces the needle **30** downwards. The piston **51** is under a pressure differential **Pl** minus **P2.** The position of the piston **51** is balanced by the spring **52** such that the initial movement of the piston **51** connected with the needle **40** starts only when a force generated by the pressure differential exceeds a force of the pre-compressed spring **52.**

Before any movement of the piston **51** initiates, the certain point, its further growth may cause an extremely rapid increase of pressure differential within the device, so the needle **40** starts to pull down from the resistor **30.** The balancing force of the spring **52** stops the downward movement such that the hydraulic resistance of the device is reduced and the bottomhole pressure is again maintained at a desired level.

When the cylinder needle **40** is completely pulled out of the resistor **30,** the hydraulic resistance of the tool is minimal. Such resistance corresponds to a resistance of a system of telescopic pipes having a round cross-section. The pressure differential within the device in response to a further increase of flow rates will be based on a constant (minimal) hydraulic resistance of the lower stage **31** in addition to the next stage **32** and finally to further stages **33** and **34.** If the flow rates decrease due to some changes in the reservoir and fluid parameters and reduction of the reservoir pressure, the needle **40** will start moving back up into the body of the resistor **30.** This in tum adjusts the hydraulic resistance of the tool to a desired optimum level in order to maintain optimum bottomhole pressure and maximum oil flow rates according to the current conditions of the formation, reservoir pressure, and fluid parameters.

Due to the above described self-regulation of the tool, the device of the present invention can operate efficiently in a wide range of formation, reservoir, and fluid parameters, all varying with time, without the necessity to remove the device from the well. More specifically, formation parameters change during the operation of a well, such as formation pressure, gas, oil and water saturation, phase permeability as well as such fluid parameters as water-oil and gas-oil ratio, viscosity, surface tension, etc. With prior art systems, it was necessary to replace the bottomhole equipment in the well with a new equipment having characteristics corresponding to the current formation and fluid parameters. With the method and device in accordance with the present invention no replacement of the bottomhole equipment is needed. The tool of the invention automatically maintains the desired bottomhole pressure of the formation fluid at the level needed for maintaining the maximum flow of the formation fluid from the bottomhole of the well to the surface wellhead. The device in accordance with the present invention provides automatic adjustment of its parameters in response to the changing formation parameters and fluid properties.

An increased differential pressure between the formation and the bottomhole pressure usually results in increased oil flow rates. However, in formations with high gas-oil ratio, a decrease in bottomhole pressure causes formation oil degas sing in the near bottomhole zone of the formation, increase in oil viscosity, reduction of the formation oil permeability and as a result, reduction of the formation productivity.

Further reduction of bottomhole pressure may result in a decrease of oil flow rate rather than its increase. The optimum pressure will change in time according to change of parameters of fluid and formation. Maintenance of an optimum bottomhole pressure by means of the inventive device in the formations with gas and water coning provides for the maximum oil flow rates with minimum gas and waterflow rates.

The following publications contain mathematical equations used to calculate the flow through the bottomhole tool of the invention, all of which are incorporated herein in their entirety by reference:

Two-phase flow in vertical noncircular channels, Interna tional Journal of Multiphase Flow, vol. 8, 1982, pp 641-655; *Sudden Contraction Losses in Two-phase Flow.,* Journal of Heat Transfer, February 1966; and *Some Characteristics of Gas-Liquid Flow in Narrow Rect angular Ducts,* International Journal of Multiphase Flow, vol. 19, No. 1 ,1991, pp. 115-125.

The method of the invention consists therefore of several steps in defining and maintaining the optimum level of bottomhole pressure in order to maximize oil production:

a) collecting formation and oil well input data, such as on the current conditions of the well, bottomhole zone, fluid and reservoir parameters, PVT, geometry and dimensions of pipes, bottomhole tool and a wellhead surface choke and so on to populate the mathematical model describing "formation-multi-phase flow-surface choke-bottom hole tool" behavior;
b) modeling or simulating the entire Inflow Performance Relationship curve describing the relationship of the bottomhole pressure and the oil production rate similar in general to that shown on FIG. **1** but specific to a particular well;
c) calculating the desired higher than zero value of the bottomhole pressure from the IPR curve as calculated in step (b);
d) adjusting the bottomhole pressure to the vicinity of the desired level corresponding to current well conditions by any number of available means including performing a gas lift, adjusting the bottomhole choke of the generally known design or inserting an appropriately sized bottom hole tool of the invention;
e) in case the bottomhole tool of the invention is used, conducting final adjustment of the bottomhole pressure by adjusting the wellhead surface choke and thereby the

pressure above the bottomhole tool of the invention;

f) starting oil fluid flow and monitoring well parameters to be within the desired levels to ensure maximum oil flowrate as well as compare the actual flow rate to that predicted by the model, adjust the model if necessary;

a) if deviation of the well parameters is detected, recalcu lating the optimum bottomhole pressure and adjust it according to newly calculated value using the previously described steps;

g) maintaining the bottomhole pressure at the optimum level so that the oil flow rate is maximized throughout the life of the well or the operation of the device of the invention.

Example of Using the Method of Invention

As an example, the following formation was analyzed and mathematical model was calculated for: radius *Rf*= 1000 ft; 45 height H=50 ft; <I>=0.15; K=15 μD, rw=0.3 ft, with PVT characteristics shown on FIG. **2** and functions *K* recovery index. In the second case, the well worked for 1440 days (4 years), and gave approximately 9.8% of the ultimate recovery index, more than double that of the first case. In case III (see FIG. **7),** when the well was switched to optimal regime 120 days after production started, the ultimate oil recovery index increased from about 4.25% to about 6.2%. At the same time, switching the well into optimal regime reduced GOR and increased oil rate from 130 bar/day to 250 bar/day. The lifetime of the oil well in that case is increased to about 3.4 years.

All these desirable effects were achieved due to keeping the bottomhole pressure at the optimal higher than zero level, which caused reduction of forming of oil blocking zone in formation near bottomhole and slowed down loss of gas from formation, which in turn may cause formation pressure to drop. FIGS. **6** and **7** also illustrate that main taining the bottomhole pressure at the optimum level as calculated using the method of the invention substantially increases the ultimate oil recovery from a given well.

FIG. **8** shows a calculated IPR curve for an oil well with formation parameters amenable to using the method of the present invention. The presence of the optimum value of the bottomhole pressure is seen which is not equal to zero. That bottomhole pressure corresponds to the maximum oil production rate for these formation and oil well conditions. Also of note is the strong tendency of GOR to increase with bottomhole pressures falling below the optimum level.

Besides the obvious benefit of increasing the oil flow rate and oil recovery index from the well, the method and device of the invention provide for the following important advantages: reduce gas-to-oil ratio and water-to-oil ratio and therefore gas and water content of the upcoming fluid from a well; reduce or eliminate the gas and water cones; reduces the risk of forming areas near the bottomhole zone with high viscosity fluids;

extends the life of the formation and extends the time of its depletion;

increases the index of oil production for a particular formation or well;

increases the stability of oil production;

increases the efficiency of gas lift and pumping operations; reduces the pumping electrical energy costs and other costs associated with oil production;

reduces the undesirable washout of sand and other particles from the formation.

Although the invention herein has been described with respect to particular embodiments, it is understood that these *(SL)* and illustrative of the principles and K (SL) shown on FIG. **3.** Extraction method was regime solution gas. Illustrative data, results and charts are shown on FIGS. **6---8.**

The resulting three cases of solution are shown on FIG. **6:** Case I-the case when bottomhole pressure was kept throughout the life of the well at a non-optimal level of

P*bot(t)=0.25.*·P*jt);*

Case II-the case when bottomhole pressure was kept throughout the life of the well at an optimum level of p*bo,(t)=Pbo,°P'(t);* and

Case III-the case when at first for approximately 120 days the well worked according to scenario as in case I, and then it was switched to scenario as in case II.

Behaviors of oil rate (Q a), formation pressure (Pf), and GOR, in dependence of current recovery index (N) are shown on FIG. **6** as predicted by using the calculations according to the method of the present invention.

In case I, the well worked for approximately 990 days before the oil 65 rate fell to 6 bar/day, the limit of production sensibility. By that time, the well gave approximately 4.25% of the ultimate applications of the present invention. In particular, the needle of the bottomhole tool may be activated indirectly by providing a gear reducer between the piston and the needle body, as well as the spring may be located outside or even below the cylinder. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

What is claimed is:

1. A method for optimizing oil production rate and overall oil recovery from a formation having an oil well, comprising following steps:

a) collecting formation and oil well input data;

b) calculating Inflow Performance Relationship curve from said formation and oil well input data to describe the projected relationship of a bottomhole formation pressure and an oil production rate;

c) identifying a higher than zero desired value of said bottomhole pressure corresponding to a maximum oil production rate from said calculated Inflow Performance Relationship curve under current well conditions;

d) adjusting the bottomhole pressure to the vicinity of said desired bottomhole pressure corresponding to current well conditions;

e) starting oil production flow;

f) monitoring oil well parameters to be within the collected formation and oil well input data values;

g) if deviation of the well parameters from the collected formation input data is detected, repeating steps (a) through (c) to recalculate the desired value of said bottomhole pressure; and

adjusting the bottomhole pressure to said newly calculated desired value.

2. The method as in claim **1,** wherein said oil well further comprising a bottomhole tool and a wellhead surface choke, said step (a) includes collecting formation input data includ ing current conditions of said oil well, bottomhole zone, fluid and reservoir parameters, PVT, geometry and dimensions of pipes, bottomhole tool and a wellhead surface choke to populate a mathematical model describing "formation multi-phase flow-surface choke-bottomhole tool" behavior.
3. The method as in claim **2,** wherein said step (d) of adjusting said bottomhole pressure includes adjusting said bottomhole tool.
4. The method as in claim **3,** wherein said step (d) further includes conducting a final adjustment of said bottomhole pressure by adjusting said wellhead surface choke to change the pressure above said bottomhole tool.
5. The method as in claim **1,** wherein said step (d) of adjusting said bottomhole pressure is achieved by performing a gas lift.
6. The method as in claim **1,** further including a step (i) of maintaining said

bottomhole pressure at a desired level throughout the life of said well, whereby maximum overall oil recovery is achieved.

7. A bottomhole tool for adjusting a bottomhole pressure in an oil well containing a pipe between a bottomhole zone and a wellhead, said tool comprising:

a tool housing attached to said pipe in said bottomhole zone of said oil well,
a multi-stage telescopic fluid resistor contained in said tool housing,
a multi-stage needle located inside said telescopic fluid resistor, and
a pressure-responsive means to move said needle in and out of said telescopic fluid resistor, said pressure-responsive means including a spring-biased piston attached to said needle and located in a control cylinder attached to said housing, said piston exposed to said bottomhole pressure above thereof and a pipe pressure below thereof, whereby said needle is maintained at a position defined by a difference between said bottomhole pressure and said pipe pressure and said spring, said needle defining with said telescopic fluid resistor a series of successive annular pas sages for oil flow there through.

8. The bottomhole tool as in claim **7,** wherein said multi-stage telescopic flow resistor has a number of stages equal to same of said multi-stage needle.
9. The bottomhole tool as in claim **7,** wherein said pipe is sealed against said well. comprising following steps:

a) *providing a bottomhole tool comprising a tool housing attached to said pipe in said bottomhole*

providing a bottomhole tool comprising a tool housing attached to said pipe in said bottomhole zone of said oil well, a multi-stage telescopic fluid resistor contained in

b)

c) *pressure by adjusting said wellhead surface choke to change*

d) *the pressure above said bottomhole tool.*

e) *The method as in claim 1, wherein said step (d) of adjusting said bottomhole pressure is achieved by perform- ing a gas lift.*

f) *The method as in claim 1, further including a step (i) of maintaining said bottomhole pressure at a desired level throughout the life of said well, whereby maximum overall*

g) *oil recovery is achieved.*

h) *A bottomhole tool for adjusting a bottomhole pressure*

i) *in an oil well containing a pipe between a bottomhole zone*

j) *and a wellhead, said tool comprising:*

k) *a tool housing attached to said pipe in said bottomhole zone of said oil well,*

l) *a multi-stage telescopic fluid resistor contained in said tool housing,*

m) *a multi-stage needle located inside said telescopic fluid resistor, and*

n) *a pressure-responsive means to move said needle in and out of said telescopic fluid resistor,*

o) *said pressure-responsive means including a spring-biased*

p) *piston attached to said needle and located in a control cylinder attached to said housing, said piston exposed to said bottomhole pressure above thereof and a pipe pressure below thereof,*

q) *whereby said needle is maintained at a position defined by a difference between said bottomhole pressure and said pipe pressure and said spring, said needle defining with said telescopic fluid resistor a series of successive annular pas- sages for oil flow therethrough.*

r) *The bottomhole tool as in claim 7, wherein said multi-stage telescopic flow resistor has a number of stages equal to same of said multi-stage needle.*

s) *The bottomhole tool as in claim 7, wherein said pipe is sealed against said well.*

t) *said tool housing, a multi-stage needle located inside said telescopic fluid resistor, and a pressure-responsive means to move said needle in and out of said telescopic fluid resistor, said pressure-responsive means exposed to said bottomhole pressure and a pipe pressure,*

u) *collecting formation and oil well input data;*

v) *calculating Inflow Performance Relationship curve from said formation and oil well input data to describe the projected relationship of a bottomhole formation pressure and an oil production rate;*

w) *identifying a higher than zero desired value of said bottomhole pressure corresponding to a maximum oil production rate from said calculated Inflow Perfor- mance Relationship curve under current well condi- tions;*

x) *adjusting the bottomhole pressure to the vicinity of said desired bottomhole pressure corresponding to current well conditions;*

y) *starting oil production flow;*

z) *monitoring oil well parameters to be within the col- lected formation and oil well input data values;*

aa) *if deviation of the well parameters from the collected formation input data is detected, repeating steps*

a) providing a bottomhole tool comprising a tool housing attached to said pipe in said bottomhole zone of said oil

pressure by adjusting said wellhead surface choke to change the pressure above said bottomhole tool.

3. The method as in claim **1,** wherein said step (d) of adjusting said bottomhole pressure is achieved by performing a gas lift.

4. The method as in claim **1,** further including a step (i) of maintaining said bottomhole pressure at a desired level throughout the life of said well, whereby maximum overall oil recovery is achieved.

5. A bottomhole tool for adjusting a bottomhole pressure in an oil well containing a pipe between a bottomhole zone and a wellhead, said tool comprising:

a tool housing attached to said pipe in said bottomhole zone of said oil well,

a multi-stage telescopic fluid resistor contained in said tool housing,

a multi-stage needle located inside said telescopic fluid resistor, and

a pressure-responsive means to move said needle in and out of said telescopic fluid resistor,

said pressure-responsive means including a spring-biased piston attached to said needle and located in a control cylinder attached to said housing, said piston exposed to said bottomhole pressure above thereof and a pipe pressure below thereof,

whereby said needle is maintained at a position defined by a difference between said bottomhole pressure and said pipe pressure and said spring, said needle defining with said telescopic fluid resistor a series of successive annular passages for oil flow therethrough.

6. The bottomhole tool as in claim **7,** wherein said multi-stage telescopic flow resistor has a number of stages equal to same of said multi-stage needle.

7. The bottomhole tool as in claim **7,** wherein said pipe is sealed against said well.

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said tool housing, a multi-stage needle located inside said telescopic fluid resistor, and a pressure-responsive means to move said needle in and out of said telescopic fluid resistor, said pressure-responsive means exposed to said bottomhole pressure and a pipe pressure,

b) collecting formation and oil well input data;

c) calculating Inflow Performance Relationship curve from said formation and oil well input data to describe the projected relationship of a bottomhole formation pressure and an oil production rate;

d) identifying a higher than zero desired value of said bottomhole pressure corresponding to a maximum oil production rate from said calculated Inflow Performance Relationship curve under current well conditions;

e) adjusting the bottomhole pressure to the vicinity of said desired bottomhole pressure corresponding to current well conditions;

f) starting oil production flow;

g) monitoring oil well parameters to be within the collected formation and oil well input data values;

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New Technology of Optimization of Production of Liquid Hydrocarbons from Reservoirs Containing Oil or Condensate with High GOR and Oil Fringes of the Gas Formations

S. Tseytlin, Dr. of Sc., D. Tseytlin, (Tseytlin Consulting Inc.), T. Makarian, V. Petrossov, (Petro Energy Global)

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Abstract

Over the last 10 years, a new technology has been developed and successfully tested for optimizing production for oil fields with high gas to oil ratio, (GOR), which we will now refer to as TOP (Technology for the Optimization of Production). Both in theory and in practice, we have demonstrated that oil reservoirs with high GOR have a pressure flow rate relationship (IPR) with a clear maximum level. For example, the bottom hole pressure is clearly defined and provides the maximum open flow production on the reservoir. The consequential decline in bottom hole pressure results in decreased oil production, while the gas cut of the produced oil grows. This may be caused by either the gas skin-effect in the bottom-hole area of the reservoir, or the formation of gas coning. Both of these factors result in a decline in production as the bottom hole pressure drops. Basically, as the GOR and water content of the reservoir increases, so the reservoir production declines. Moreover, it was demonstrated that when the bottom pressure drop is below a certain optimal value, conditions emerge under which the well becomes unstable and gas mode occur [2]. This can explain the difficulties that take place with the production of oil and gas condensate from layers of gas fields that contain oil with a high gas factor. Our interpretation of this phenomenon is as follows.

When you create a difference in pressure and arrive at a certain bottom hole pressure value, let’s call it the optimum pressure, gas coning moves up to the casing perforations. As this process takes place, the gas concentration within tubing the fluid starts increasing while the bottom hole pressure decreases more

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When you create a difference in pressure and arrive at a certain bottom hole pressure value, let’s call it the optimum pressure, gas coning moves up to the casing perforations. As this process takes place, the gas concentration within tubing the fluid starts increasing while the bottom hole pressure decreases more and more, contributing to increased gas coning and a further drop in bottom hole pressure. In other words, positive feedback is taking place here. This ultimately leads to the oil being driven back from the casing perforations **and shifting of the well into gas mode.**

Our technology makes it possible, with the use of a special bottom-hole device, to diminish the positive feedback, and, while maintaining bottom-hole pressure at certain optimal levels, to prevent the phenomenon described above. On the other hand, the TOP technology makes it possible to increase the condensate flow rate and productive capacity of gas condensate fields.

It is well known that as gas condensate fields are developed, its bottom hole pressure drops. Because of this fact, due to its **retrograde behavior,** it starts liquating. This process takes place, most intensively, at the bottom of the formation, which is normally lower than the pressure of the formation itself. As a result of this, skin effect takes place in the bottom of formation. In other words, there is an accumulation of liquid condensate which prevents gas from leaving the formation and, accordingly, well production decreases and there is a danger that

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Our technology makes it possible, with the use of a special bottom-hole device, to diminish the positive feedback, and, while maintaining bottom-hole pressure at certain optimal levels, to prevent the phenomenon described above. On the other hand, the TOP technology makes it possible to increase the condensate flow rate and productive capacity of gas condensate fields.

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formation and, accordingly, well production decreases and there is a danger that this can lead to complete well shut off. It should be noted that the pressure flow rate relationship (IPR) of such a formation has the same form as the above mentioned case, although it is worth noting that the physics of this phenomenon is quite different. Therefore, a certain critical value of bottom hole pressure exists when any further drawdown leads to a condensate dropout into the liquid phase of the bottom-hole formation zone and to a decline of the condensate flow rate. When determining, with the use of specially made simulators, the critical value of the bottom-hole pressure at which such phenomenon occurs, we build up bottom-hole pressure and maintain it in such a manner that leads to the reversed inversion of the condensate from its liquid state into the gaseous one. In this regard, the bottom-hole formation zone gets unblocked and the gas condensate flow rate goes up. (See. Fig.5, where the results of the run tests are presented). We should note that the GOR of the produced oil gets noticeably lower, while the condensate production rate gets higher. A specially designed bottom-hole assembly (BHA) enables more flexible regulation and automatic maintenance of the bottom-hole pressure to the desired level in order to prevent the dropout of condensate from the bottom-hole zone into its liquid state, and therefore preventing a severe decrease in well performance. The BHA also serves to stabilize well performance.

The test of the TOP took place at two gas condensate wells in Uzbekistan in 2014, both of which proved the efficiency of the technology. The rate of condensate flow increased by over 200% following the installation of specially designed BHAs.

Positive results following the application of TOP

TOP is applicable for formations with high gas content (GOR>100 m3/m3) and for the production of oil and condensate from formations of gas fields containing oil with high gas factor. It can also be applied in cases where there is gas and water coning. It is applicable for any production technique flowing, gas lift and pumping. However, it is most efficient for flowing lift.

Patent number US 7,172,020 (February 6, 2007) and Patent number
US 7,753,127 (July 13, 2010) protect all the basic statements of the TOP technology.

Principal positive effects of TOP application:

- it increases the current production rate of oil and condensate;
- it increases the oil and condensate recovery factor of well and of the entire field;
- it reduces the content of water and gas in produced oil.

Additional pluses of TOP:

- it extends the service life of the well;
- it minimizes (or completely eliminates) gas and water coning;
- it slows down formation pressure drawdown;
- it stabilizes upwelling;

- it makes it possible to prevent early loss of reservoir energy;
- it eliminates zones of elevated toughness in the bottom-hole formation zone;
- it increases oil permeability of the formation;
- it increases the efficiency of gas lift and pumps;
- it reduces the cost of power supply for pumps and compressors for gas lift;
- it reduces sand washout from reservoir, its mechanical damage and loss of in-place permeability;
- it makes it possible to produce oil from oil fringe of a gas formation.

The theory and calculations of this technology rest upon the building of an accurate mathematical model of the entire well-bottom-hole assembly-formation which takes into account all of its components. This mathematical model makes it possible to carry out an analysis of the processes taking place in the well, in its bottom-hole zone and in the reservoir, which, in turn, makes it possible to maximize the flowrate and increase production.

Basic Innovations of TOP:

Maximum flow rates can be achieved at a certain value of the bottom-hole pressure which is closely calculated with a computer program, or is determined by periodic reading of pressure flow rate relationship (IPR) values whose value lies between zero and the formation pressure value. This is called the optimum value Popt (Fig.1). If the bottom-hole pressure value drops below the bubble-point pressure, then the oil relative permeability of the reservoir starts dropping in the bottom-hole formation zone, whereas its gas saturation grows due to the gas separating from the oil. Oil viscosity then increase as the well, due to degassing. This leads to a reduction of productivity. As a result of this, a reduction in the bottom-hole pressure to below both the bubble-point and the value of optimal bottom hole pressure may lead to a reduction of flow rate, not an increase. This is contrary to the conclusions that were presented by the widely used Vogel model.

With the gradual reduction in bottom-hole pressure due to increased drawdown in the reservoirs the flow rate, at first, increases. However, if we start from the optimal pressure point, the flow rate starts to decrease in spite of an increase in drawdown, which, as mentioned above, is contrary to the Vogel Model. The cause of this is that after optimal bottom hole pressure is achieved, the effect of the reduced productivity index on the production becomes dominant.

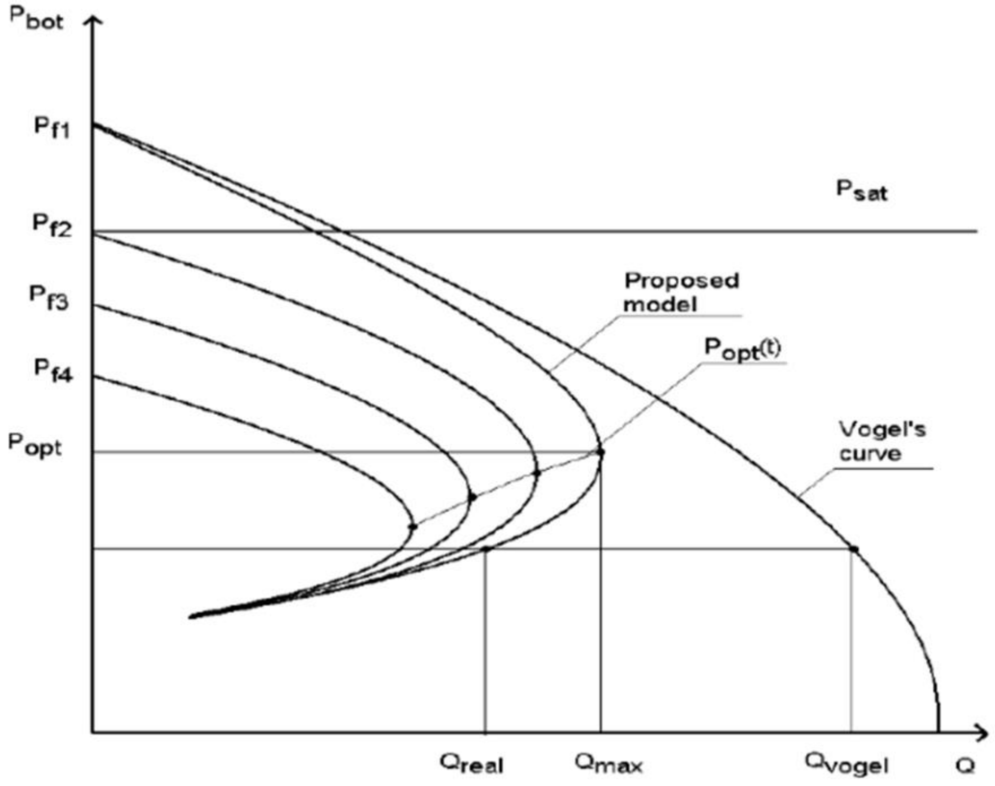


Fig.1 - Inflow Performance Relationship (IPR) curve

We can see from the above that the optimum pressure value was proved both theoretically and in practice. It depends on the reservoir characteristics (permeability, porosity, saturation and pressure).

PVT –fluid characteristics (Rs(P, T) – solubility of gas in oil; Bo(P, T) – oil compressibility factor; Bg(P, T) – gas compressibility factor; μo(P, T) – oil viscosity; μg(P, T) - gas viscosity) and various other characteristics of the "well-formation" system.

The maximum flow rate can be achieved by maintaining the drive, which minimizes the negative effects in the bottom-hole zone (Fig.2).

These negative effects arise due to a buildup of the skin-effect (because the gas is in free phase and after the pressure drawdown gets below the value of the bubble-point pressure, separates from the oil and obstructs its flow), factors of gas and water coning, as well as due to formation of zones of viscous degassed oil near the well bore. The gas content of the produced oil then increases because the relative permeability of the bottom hole formation increases, as the producible oil index decreases.

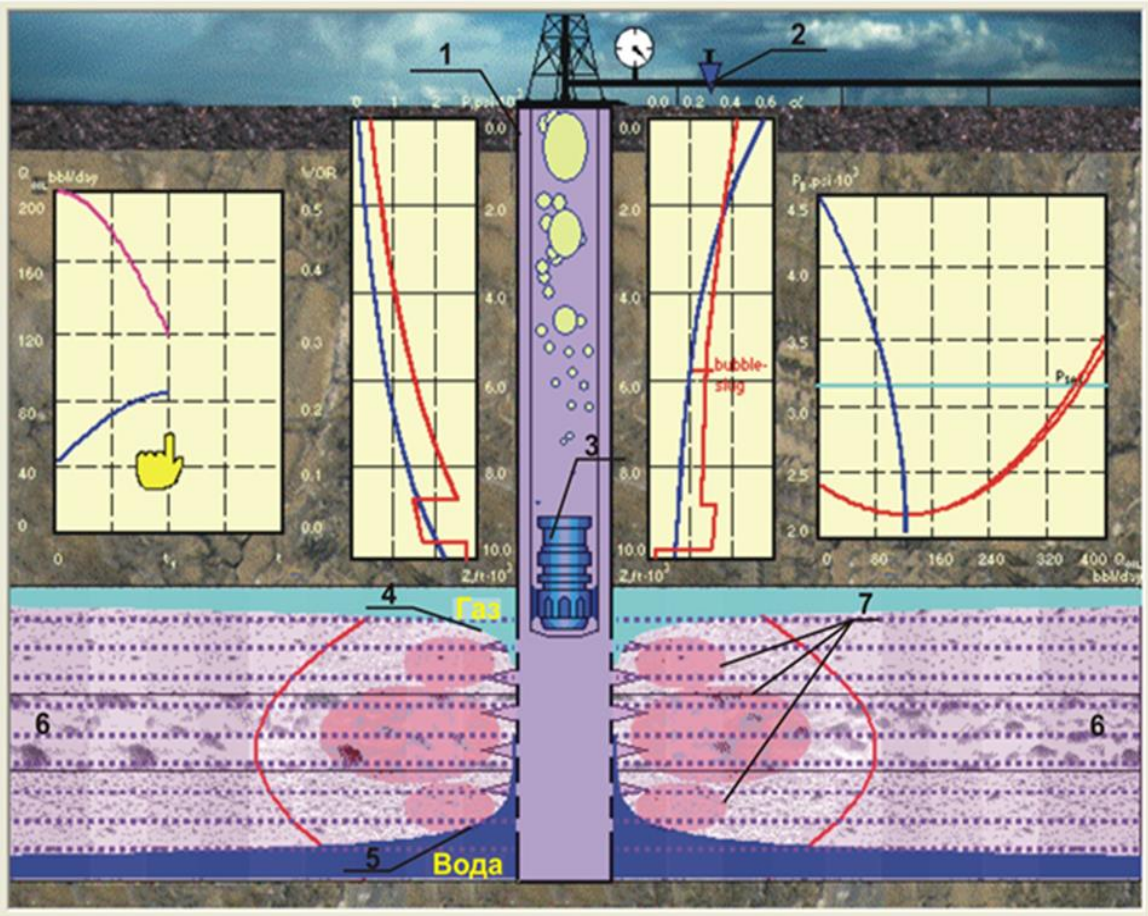


Fig. 2: Negative effects in the bottom-hole formation zone. In figure: 1 – well, 2 – wellhead choke, 3 – downhole device, 4 – gas coning, 5 – water coning, 6 – formation, 7 – regions of reservoir with low workability viscous oil.

We should note that when this technology is implemented, it slows down the rate at which the reservoir loses pressure because it minimizes early gas and water disengagement from the reservoir. Because of this the GOR value goes down. This, in turn, extends the life of a well and improves the oil recovery factor.

A similar effect is achieved in gas condensate wells: by determining, with the computer models, the cutoff value of the bottom-hole pressure, at which the retrograde dropout of the condensate as a liquid occurs, we increase and maintain the bottom-hole pressure at the level at which the condensate reverts from a liquid to gaseous state. As a result, the formation blockage is removed.

List of Alternative Applications for TOP

1. Maintenance of bottom-hole pressure in order to maximize current production rates and ultimate recovery achieved by –

a. reduction of skin-effect within the near field of a well;

b. reduction of water/gas coning which emerged in the near field of formation;

c. maintenance of good oil mobility which is necessary for efficient oil production

There are many wells around the world that would benefit from this technology, and with gas to oil ratios increasing due to increased drilling depths, this number is only going to grow. The ratio of gas to oil (GOR) also increases with the age of the well. So some wells that may not need the implementation of TOP technology today may well benefit from it in the future. Geographical targets for this technology include Russia, Mexico, the North Sea and the Middle East. The trend of the increased gas-to-oil ratio and the water content is mentioned in multiple professional articles on this subject.

2. An increase in productivity in a nearby field due to a reduction in skin effect and minimizing water/gas coning by placing a downhole device for a short period of time. Following this, we will witness an increase in the current flow rate – there are cases of this positive effect at an offshore well in the Gulf of Mexico [5]. This increase in productivity is similar to the effect that takes place following hydraulic fracturing.

3. Wells that have previously been shut down due to extremely high GOR, above 104 m3/m3 can be revived using this technique. One such example was in Turkmenistan, when a previously shut-down well (#469) started producing 12 to 15 tons of oil per day, after the TOP device was installed (3 months later the well was shut down due to its inefficiency and high GOR value).

4. Well stabilization, which can increase production [2].

5. Due to the above mentioned effects, TOP can be efficiently utilized for oil production from oil layers within gas fields, that contain oil with high gas factor. There are billions of tons of oil at stake here, which cannot be recovered so far as no suitable efficient technology is currently available.

6. The TOP makes it possible to increase production wells that use sucker rod pumps and ESPs, which can be inefficient in high GOR environments. The application of well logging devices based on the TOP technology contributes to the solution of this problem.

7. Increasing flow rates at gas condensate fields. This technology is effective at reducing skin effect that can take place in the formation due to the drop out of liquid condensates. We can demonstrate that in cases like this the IPR curve also has a maximum, i.e. there exists optimal

bottomhole pressure. If the optimum bottom hole pressure is maintained, the condensate recovery rate can be increased and optimized.

Simulators and math models use to calculate the dynamics of the system well - the formation and all the elements of the TOP devices

Current mathematical models make it possible to accurately identify the existing reservoir characteristics, with a view to maximizing production.

In addition to calculating the value of Popt, these models and computer programs enable us to determine other characteristics such as the optimum pressure for gas lift, pump output, etc, and to calculate other essential characteristics of design of the surface equipment and submersible devices, as well as forecasting the expected increase in oil production. These highly accurate simulations make it possible to run diagnostics to test the current state of the well and forecast its future performance, including changes in oil production, distribution of pressure and gas saturation within formation, GOR value and the oil recovery factor of formation (in Fig.3 you can see a sample of mathematical modeling of such case).

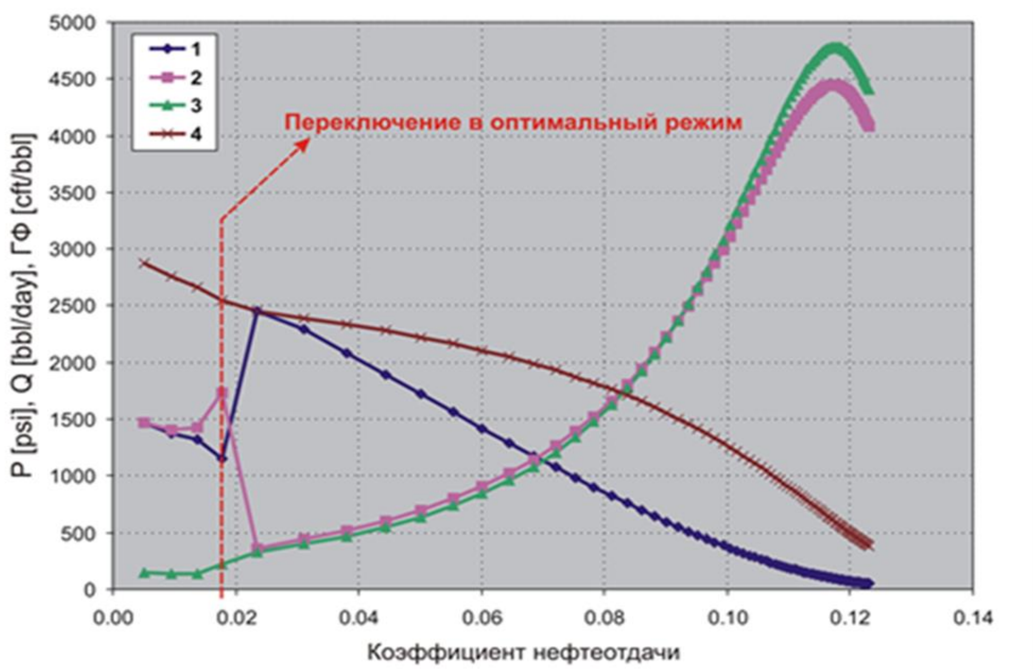


Fig. 3: Computer simulation results:

1 – oil flow rate*10 (Q), 2 – GOR/10, 3 – GOR/10, 4 – formation pressure (P) according to oil recovery factor (1 atm = 14.7 psi, 1 m3 = 6.3 bbl, 1 m3/m3 = 5.6 cft/bar)

Fig. 4 shown analysis of the relationship of formation pressure, oil flow rate and GOR to oil recovery factor, provided for three cases:

Case I (brown) – Bottomhole pressure was kept at Pbot(t)=0.25·Pf(t).

After 990 days, oil rate fell to 6 bbl/day, ultimate recovery index is ~12.75%

Case II (magenta) – Bottomhole pressure was kept at Pbot(t)=Pbotopt(t).

After 1440 days, ultimate recovery index more than doubled to 29.4%

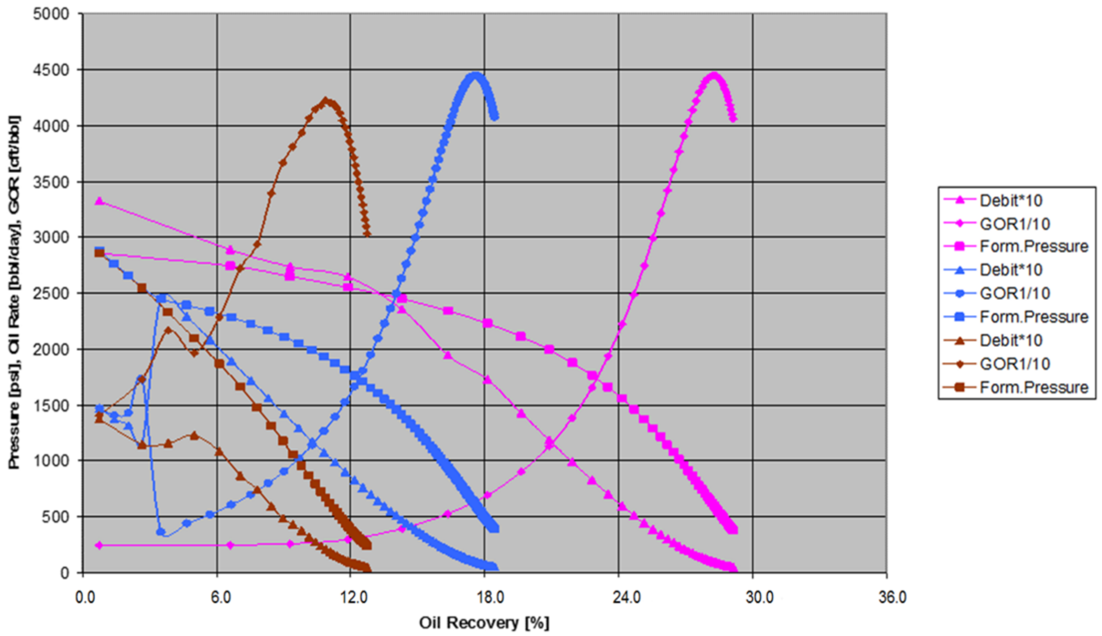
Case III (blue) – For four months the well was following scenario I, then switched to scenario II.

Ultimate recovery index increased from 12.75% to ~18.6%, GOR decreased, oil rate increased from 130 bbl/day to 250 bbl/day.

From these calculations it follows that:

1) The value of bottomhole pressure has a vital effect on the amount of the ultimate oil recovery.

2) Switching of the well to the optimal mode is possible for new wells as well as for wells already in production.



A brief summary of the mathematical models is presented in Appendix 1.

TOP technology uses for its implementation the bottomhole device that enables to adaptively control bottomhole pressure at the time of extraction. This device automatically maintains the bottomhole pressure close to the optimum pressure Popt. A simple downhole choke with a simple control feature may not be effective enough for such use. Therefore, we developed a more complex multi-parameter device having more flexible characteristics that allow it to maintain a stable operation of the system, thanks to the negative feedback, which stabilizes the operation of the system and does not allow the well to switch to gas mode. In addition, utilizing a surface choke in conjunction with the downhole device TOP allows to setup more accurately and to maintain more smoothly the optimal level of bottom hole pressure.

The simulator that allows to calculate the lift system consists of three elements: a model of the three-phase choke, model of K. Aziz describing movement of three-phase fluid in the pipe, and devoleped by us model of the TOP device, which consists of several Venturi tubes, diffuser and confusor.

The TOP technology is relatively simple to implement by using a specially designed device dowered downhole with the use of a cable, which would enable adaptive management of the bottom-hole pressure during the course of oil production. This device automatically maintains the bottom hole pressure as equal or close to the optimal value of Popt.

Here are some results of the application of the TOP technology in practice

1) Well A1, South-East Asia, 2008 (Fig.5). As a result of the applied TOP technology [6]:

- Production increased from 23.5 to 50.5 m3 per day
- GOR decreased from 6864 m3/m3 to 2221 m3/m3
- Water content decreased from 27% to 5%
- Oil recovery factors considerably increased, since the well was stabilized and GOR and water content had been decreased
- Incremental ultimate recovery of oil amounted for 2 months to: 1816 m3 (Over $1,000,000)

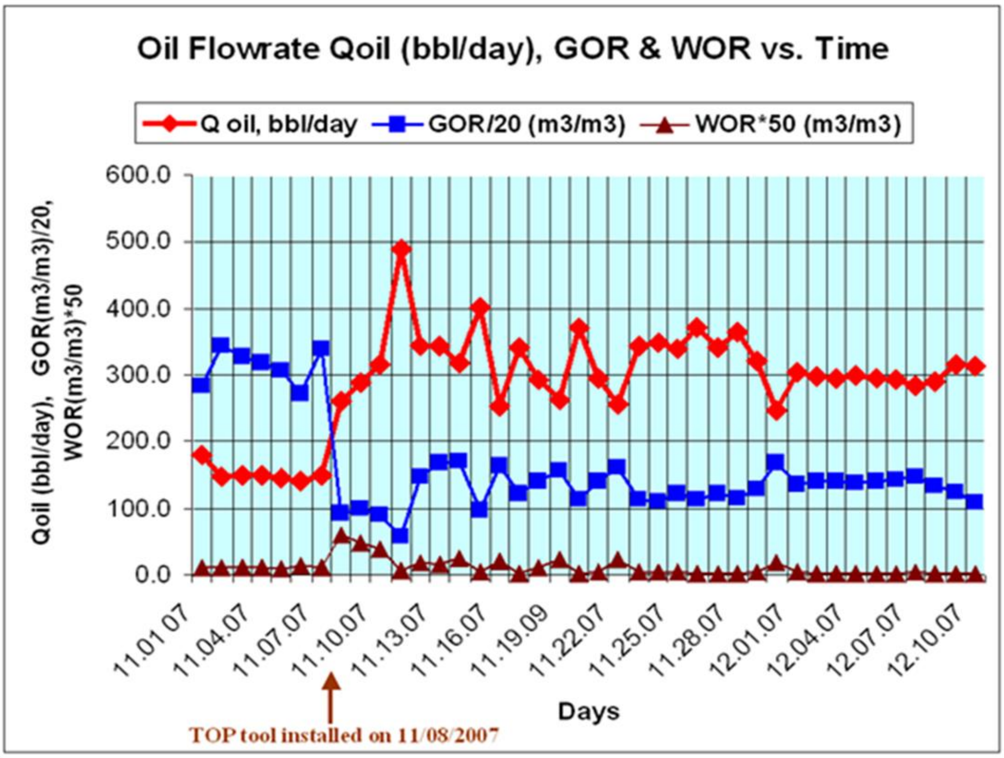


Fig. 5: The TOP technology test results (well A-1, South—East Asia)

2) Deep offshore well (over 4 km) with gas lift in the Gulf of Mexico. The following test results have been achieved (see [5]):

- GOR was reduced from 586 to 227 m3/m3
- Oil flow rate increased from 19.2 to 26 m3 per day
- Water content decreased from 9.5% to 0.43%
- After the TOP device was extracted from the well we noticed that the flow rate suddenly increased as the TOP helped to prevent the downhole gas and water coning, reduced the viscosity of oil and improved the permeability of oil in this zone, as well as decreasing the permeability of the gas.

3) Well 289 in Uzbekistan (Kokdumalak field) в 2001 -2008 [3].

- The application of the TOP technology increased daily production by 18%, from 123.8 to 146 m3 per day, decreased GOR by 15% from 1071 to 803.6 m3/m3, and the water content dropped down to zero.
- The TOP device was installed at the bottom-hole in the tubing string to provide optimal bottom-hole pressure and stabilizing the upwelling.
- Skin-effect decreased in the bottom-hole zone, and gas and water coning was eliminated in the perforated sector.
- The utilization of the TOP device made it possible to incrementally produce 5952 m3 of oil for a 9-month period.
- Over the course of 7 years, as TOP technology was applied, the well increased produced oil to the value of 10 million USD.

4) Testing of the TOP at wells in Uzbekistan proved the efficiency of the technology of oil recovery from the layers containing high gas factor.

A specially designed downhole device was installed in 2011 at a well with a production rate of 6 tons, a GOR equal to 30000 m3/m3 and the water content of 20%. The oil flow rate increased by 50%, the water content went down by 7% and the GOR was reduced twofold.

5) TOP technology was successfully implemented in 2014 at two wells in a gas condensate field in Uzbekistan.

The findings are presented in tables 6a and in fig. 6b.

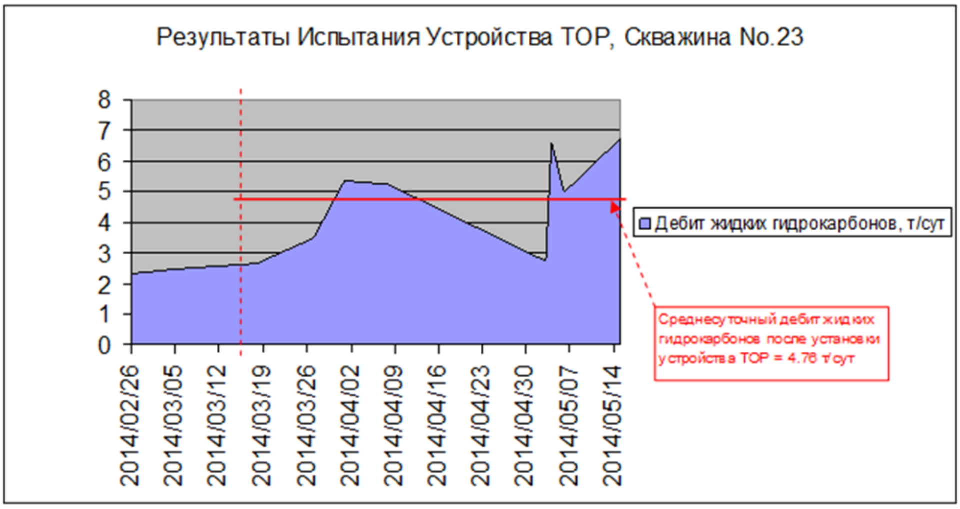


Fig. 6a

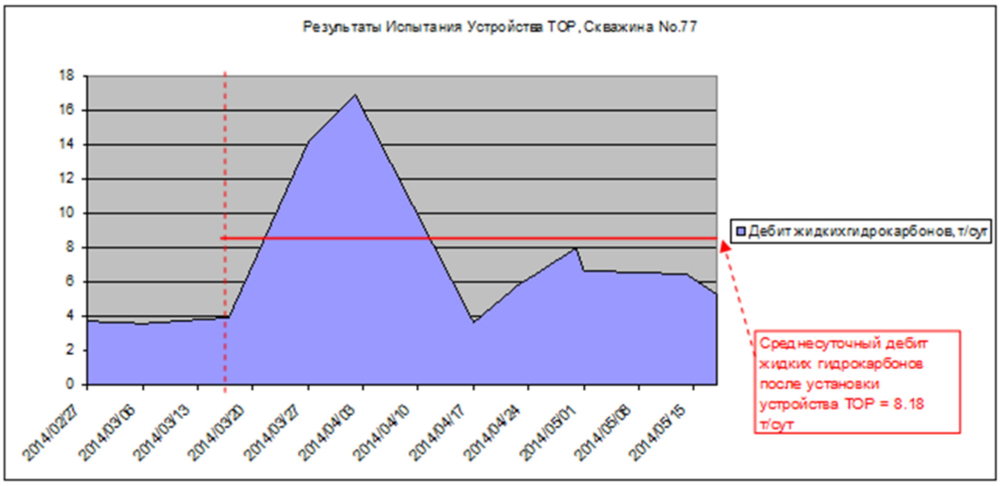


Fig. 6b

Well One – the flow rate of condensate increased from 2.7 tons to 4.76 tons/day on average.

Well Two – the flow rate of condensate increased from 3.9 tons/day to 8.18 tons/day.

The latest testing proved the efficiency of the TOP application for production of oil and condensate from the layers of gas and gas-condensate fields, containing high gas factor. Throughout the world (and in Russia, in particular) there are a number gas fields that have oil formations with high gas factors. Currently, there is no efficient technology that enables operators to recover oil from these formations. Releasing gas condensate from bottom hole zones is also an important feature of TOP technology. Indeed, the implementation of this technology may yet solve these problems and the production of millions more tons of high quality oil and condensate.

Conclusions

1. The number of wells in which utilization of TOP technology may lead to an increase of production of crude oil and condensate, is very big.
2. It should be noted that most of the current healthy production wells can become our candidates for optimization in the near future.
3. The value of bottomhole pressure has a great effect on the amount of the ultimate oil recovery.
4. TOP technology can be used both for the development of new oil fields and to improve production of already operating wells.
5. The economic effect from the use of this technology can be expressed in production of more oil and condensate or savings of hundreds of millions of dollars without the need to drill additional wells, or to build expensive offshore platforms.

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Appendix 1

The Masket equation was selected as the mathematical model to describe transient two phase filtration within the formation.

These equations make it possible to describe two-phase flow of oil and gas relating to variables of pressure P(r, t) and oil saturation So(r,t):

$$(1)\quad \begin{cases} \dfrac{1}{r}\dfrac{\partial}{\partial r}\left(r\dfrac{K_{ro}}{\mu_o B_o}\dfrac{\partial P}{\partial r}\right) = -158.064\dfrac{\varphi}{K}\dfrac{\partial}{\partial t}\left(\dfrac{S_o}{B_o}\right) \\ \dfrac{1}{r}\dfrac{\partial}{\partial r}\left(r\left(\dfrac{K_{rg}}{\mu_g B_g} + \dfrac{R_s}{5.615}\dfrac{K_{ro}}{\mu_o B_o}\right)\dfrac{\partial P}{\partial r}\right) = -158.064\dfrac{\varphi}{K}\dfrac{\partial}{\partial t}\left(\dfrac{1-S_o-S_w}{B_g} + \dfrac{S_o}{B_o}\dfrac{R_s}{5.615}\right) \end{cases}$$

Condition at the external boundaries of reservoir is zero flux:

$$\left.\frac{\partial P}{\partial r}\right|_{r=r_e} = 0.$$

At the wellbore wall we take the assumption of:

$$P|_{r=r_w} = P_W(t).$$

Also, entry conditions are established as

$$(2)\quad P(r,t) = P_0(r,0); \quad S(r,t) = S_0(r,0).$$

System (1) is complemented with PVT characteristics of oil and gas, functional connections of permeability of different phases of saturation and other characteristics of the well formation system:

□o(P), □g(P), Bo(P), Bg(P), Rs(P), Ko(So), Kg(Sg),

K, □, Pf, Pbp, rw, ri, Sw, Sg crit.

The system (1), (2) is solved with the aid of finite difference method, which to a certain extent is different from the one that was used in the work [4].

After the saturation is extracted from the system (1) and after some rearrangements are made, the nonlinear equations (1) acquire the form of equation (3) relating to pressure P:

$$(3)\quad \frac{1}{r}\frac{\partial}{\partial r}\left(r\left(\frac{K_g}{\mu_g B_g}+\frac{R_s}{5.615}\frac{K_o}{\mu_o B_o}\right)\frac{\partial P}{\partial r}\right)+F(P)\left(\frac{1}{r}\frac{\partial}{\partial r}r\left(\frac{K_o}{\mu_o B_o}\frac{\partial P}{\partial r}\right)\right)=C(P,S_o(r,t))\frac{\partial P}{\partial t}$$

where F(P), C(P, So) are functions, connected with PVT characteristics and other variables of the “well-formation” system.

Nomenclature

P - pressure, psi

So - oil saturation

Sg - gas saturation

Sw - water saturation

K - permeability, md

Koo - relative oil permeability

Kgo - relative gas permeability

? - porosity

µo(P, T) - oil viscosity

µg(P, T) - gas viscosity

Bo - oil volume factor

Bg - gas volume factor

Rs - solution gas ratio, cft/bbl

Pf - formation pressure, psi

Pbp - bubble point pressure, psi

t - time, sec

r - radius, ft

rw - well radius, ft

rf - outlet radius, ft

H - formation width, ft

Sg crit- critical gas saturation

Qo - oil rate, bbl/day

Qg - gasrate, cft/day

Popt - optimal pressure, psi

2)SPE 166870

"A Method and an Apparatus for Killing an Uncontrolled Oil-Gas Fountain at an Offshore Oil Platform Using a Telescopic Rod Assembly"

Simon Tseytlin , Tseytlin Consulting Inc.

This paper was prepared for presentation at the SPE Arctic and Extreme Environments Conference & Exhibition held in Moscow, Russia, 15–17 October 2013.

Abstract

A method and an apparatus for killing of uncontrolled oil fountain include a series of rods with the first rod having the smallest diameter and successive rods having increasing diameters. Such telescopic assembly of rods is lowered into the well to cause gradual reduction in cross-sectional area available for oil flow discharge. Once sufficiently large rods are lowered into the well, the oil fountain discharge will be greatly diminished. A method of monitoring the conditions of lowering the rods into the well may utilize a weight measuring device mounted at the surface platform. In the case of killing the oil fountain based on the methods of the present method, 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, including the reservoir pressure and the drag force from the flow of oil or a multiphase flow of various gases and fluids coming out from the well. Final sealing may be accomplished by pumping cement into a space formed between the well pipe and the rod assembly. A novel system for aligning the rods to the center of the well is also described. The present method is aimed at making killing of the well safe, fast and inexpensive so as to prevent heavy environmental and financial losses typically associated with dealing with offshore well blowouts.

The present method relates to a method and system 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.

This may cause human casualties, environmental pollution and the creation of an uncontrolled fountain. This uncontrolled fountain 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

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 novel of the method includes steps of lowering down a series of rods starting with the rod having the smallest diameter. Small diameter rod may be inserted into the well with less difficulty as compared with larger diameter rods. Once the smallest rod is in place, the cross-sectional area of the well available for oil flow discharge is somewhat reduced. Larger diameter rods may then be inserted in a successive series following the first rod. Gradually, most or even the entire cross-section of the well pipe is occupied by the telescopic assembly formed from these rods. Once these flow-restricting rods are in place, the well may be sealed by pumping in cement within the remaining space between the well and the rod assembly. Considering that the weight of such rod may reach from several hundred kilograms to tens tons since the depth of a well is significant, little or no resistance should be encountered upon entrance of the first rod into the well. Note that the entrance of the tip of the first rod may be aided by centering thereof using known means. As the total weight of the telescopic rod assembly is increasing, adding more rods should be accomplished without encountering much resistance .

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 article , 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.

Final process includes using a riser having an inside diameter just slightly more than the outer diameter of the well pipe. The end of the riser is set on the well .

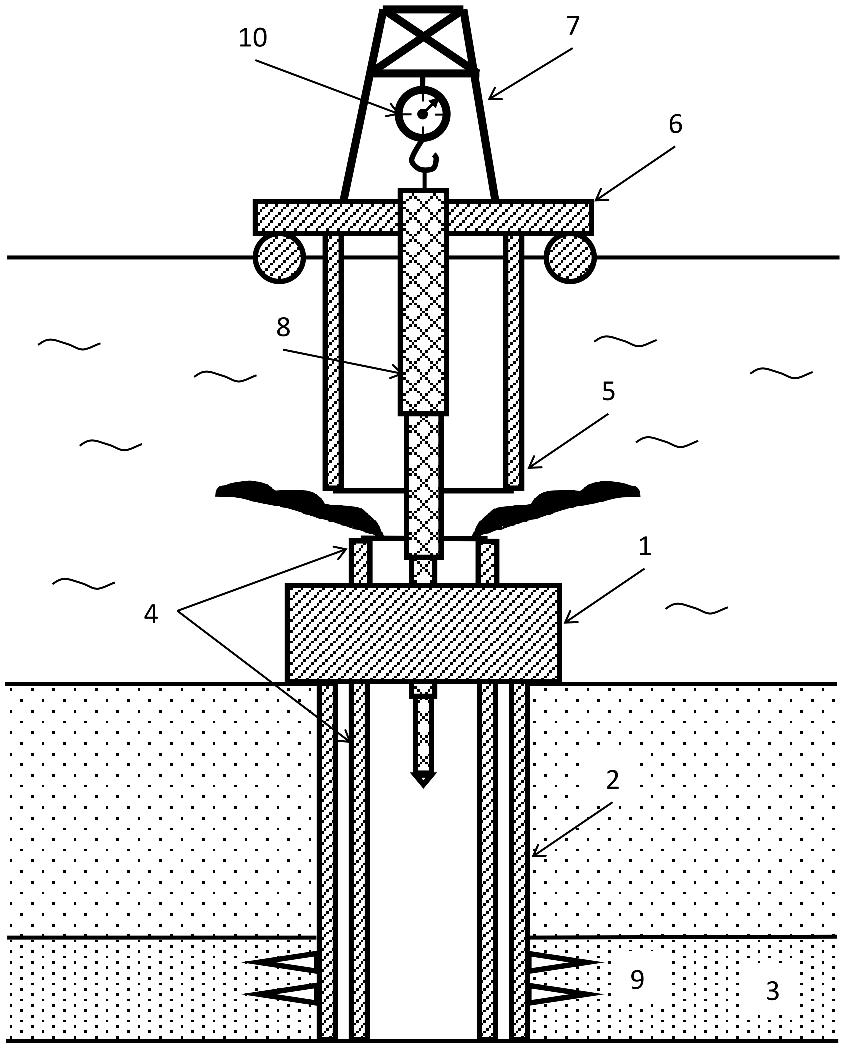
Provide a plurality of flow restricting rods 8 of various diameters using either a standard floating rig 7 or a ship located near an offshore platform 6;

Position a riser tube 5 over the drilling tube 4. Riser tube 5 may have an inner diameter slightly larger than the external diameter of the tube 4. As a result, the lower end of the riser tube 5 may be placed over the head of the well at a distance of about several meters. Alignment and fixation of this riser tube 5 may be accomplished for example using a four-cable brace attached to the outer surface of the head of the well or another method. (Fig.1).

Place the first flow restricting rod 8 into the riser tube 5. To accomplish this, the first section of the rod 8 with the length which may be about 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 8 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 5. The process of lowering rods 8 and attaching new sections thereto may be repeated until the lower end of the first rod 8 appears suspended from the bottom of the riser tube 5. To assure entering the tube 4, the first rod 8 may in some embodiments have a smaller diameter or a tapered end.

For the lower end of the first rod 8 to enter the well, it is critically important to keep the weight of the rod 8 exceeding the force pushing it out of the well by at least a small safety margin, from 200 to 500 kg. Due to its small cross-sectional area and significant weight (which could reach from several hundred kilograms to tens of tons), the metal rod 8 can be typically placed inside the drilling tube 4 of the well without much difficulty.

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 diameter – note that rod length, diameter and density (choice of material) represent variables which can be adjusted for each specific circumstance.



Following the entrance into the well of the first (lower) portion of the rod assembly having the smallest diameter, the next larger diameter of the rod typically may start at the height of a few hundred meters above that first portion.

This process may be continued until the wellhead pressure and flow rate of fluid decreases to safe enough levels, so that the well can be easily closed using the standard methods of applying cement. (Fig.2).

To accomplish a permanent closure of the well, the hanging riser tube 5 may be lowered so that the upper section of tube 4 joins the bottom of the riser tube 5 (Fig.3).

Additional resistance of the suspended riser tube 5 connecting the wellhead to the drilling rig 7 further reduces the flow rate and wellhead pressure at the sea surface. Cementing the well may now be accomplished . 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 9 of the casing from which the oil is coming out. After cement hardens, the flow from the well ceases completely.

The riser tube 5 may be then separated (cut off) from the well. In embodiments, at least some of cement may seep through the gap between the top hanging riser tube 5 and the tube 4, thus making their connection hermetic.

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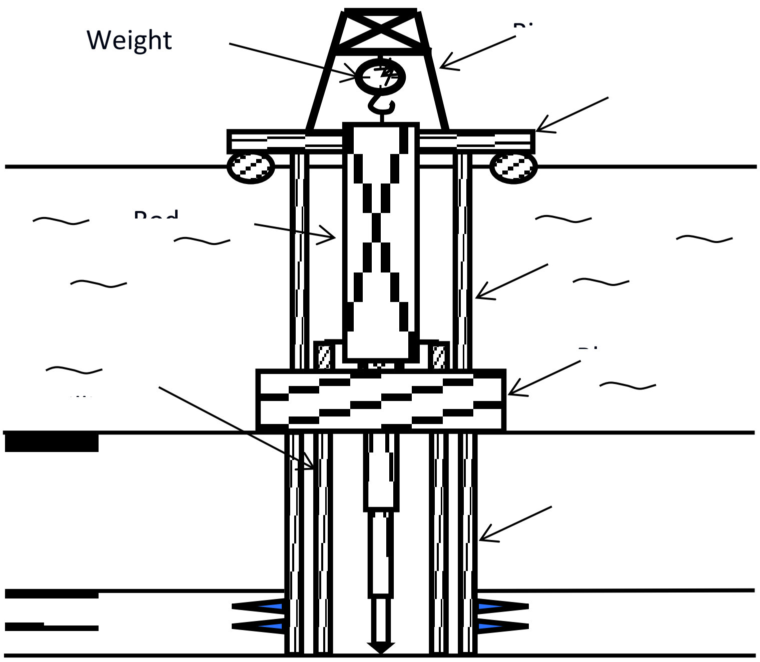


Fig.3

The present methodology is aimed at making killing of the well safe, fast and inexpensive so as to prevent heavy environmental and financial losses typically associated with dealing with offshore well blowouts.

A few advantages of the method that are usually disadvantages of offshore drilling: 1) No open fire on the bottom of the sea; 2) On the bottom of the ocean the pressure achieves tens atmosphers near exit of fluid flow; 3) We can always find a proper weight of rod assembly, which would allow to insert it into the well.

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 human casualties, environmental pollution and the creation of an uncontrolled fountain the most costly complications achieving billions of dollars.

SPE Number SPE-166871

Paper Title "Methods and Devices for Determination Of Gas-Kick Parametrs And Prevention Of Well Explosion"

Author Name(s), Company Simon Tseytlin ,

Tseytrlin Consulting Inc.

This paper was prepared for presentation at the SPE Arctic and Extreme Environments Conference & Exhibition held in Moscow, Russia, 15–17 October 2013.

Abstract

The acoustic methods and devices is intended for early detection , location and others parameters of the gaseous packet (gas kick) is determinated uprising in the annulus of the well during gas

blowouts. 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 and arrival time of the gaseous packet is determined by the arrival time of the reflected signals. The information obtained this way is used for taking a decision whether to resume drilling or to take 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. The tool is recommended to be incorporated in well-logging units, MWD systems and also as a stand-alone tool among the other instruments used at the well site. The tool makes it possible not only to ensure safety during drilling, but also to facilitate the introduction of the state-of-the-art drilling technologies based on reduction of the bottom-hole differential pressure.

The methods and devices in general relates to the drilling of oil or gas wells, and particularly to the acoustic detection of a gas kick.

In the drilling of an oil or gas wells, drilling fluid referred to in the industry as "mud", is pumped into the drill pipe where it proceeds out through the drill bit and up the annular space between the drill pipe and the walls of the hole and further up the annular space between the drill pipe and the casing generally used, after which it is examined at the surface for certain parameters, processed and returned to circulation. The purpose of the circulating mud is to clean, cool and lubricate the bit, flush to the surface the cuttings from the bore hole and to protect the walls of the hole until casing is inserted. The density of the mud is carefully controlled at the surface so as to contain various pressures encountered in the hole.

As the well is drilled, gases or high pressure fluids may be released from porous rock and find their way into the circulating mud forming an annular gas bubble or (kick). This gas kick may ascend to the surface, in result and can cause extensive damage if it goes undetected. The gas or liquid contained in the gas kick reduces the hydrostatic head in the annulus. If the volume of the gas kick is not excessive and if it can be detected, procedures may be instituted so that drilling operations may proceed with minimal disruption.

Sometime a gas kick may cause an uncontrolled blowout, which has been known to cause extensive equipment damage, fires, and possible release of noxious gases. Accordingly, reliable means of detecting the initial gas kick is desired.

The object of the methods is to increase the efficiency early of gas kick detection and accuracy of determination for gas kick parameters such as its volume and the speed of ascending to the surface so as to decrease the probability of explosion and an uncontrollable gas kick blowout expansion.

It is known in the art of oil wells that gas kicks may contain pure natural gas or may alternately contain a certain percentage of water and/or oil. All of these occurrences are referred to for the purposes of this description as a “gas kick”. Rising gas kick replaces drilling mud as it ascends to the surface of the well. This in turn leads to a decrease in the well bottomhole pressure and therefore to a further increase of speed of gas kick ascendance. If not detected early, this may lead to catastrophic consequences.

The present methods and devices for early detection of a forming gas kick as well as for continuous characterization of its changing parameters during its ascend to the surface, including its size, position along the well, gas content, speed of movement and a projected time of arrival to the surface. Accurate and reliable knowledge of these parameters is critical in taking timely steps to deal with the gas kick leading to reducing and ultimately eliminating the risk of an uncontrolled blowout of the well.

Pressure sensors are known to be present in various locations in the well including that near the head . They are used for monitoring the well performance and various other control purposes. As the drilling mud is pumped into the well, the noise from the pumps configured to inject mud into the well, can be seen from the signals of such pressure sensors. One typical example of such noises is shown in Fig. 3.1. A sudden reduction of noise amplitude has been suggested in the prior art to indicate the formation of the gas kick, which acts to dampen high and low frequencies elements of the pressure sensor signal.

Once the gas kick is identified, emergency measures are employed to remove it from the well. The drilling is typically stopped, the blowout preventer is closed and a procedure of removal of the gas kick is initiated.

A generic well is depicted in Fig. 1.

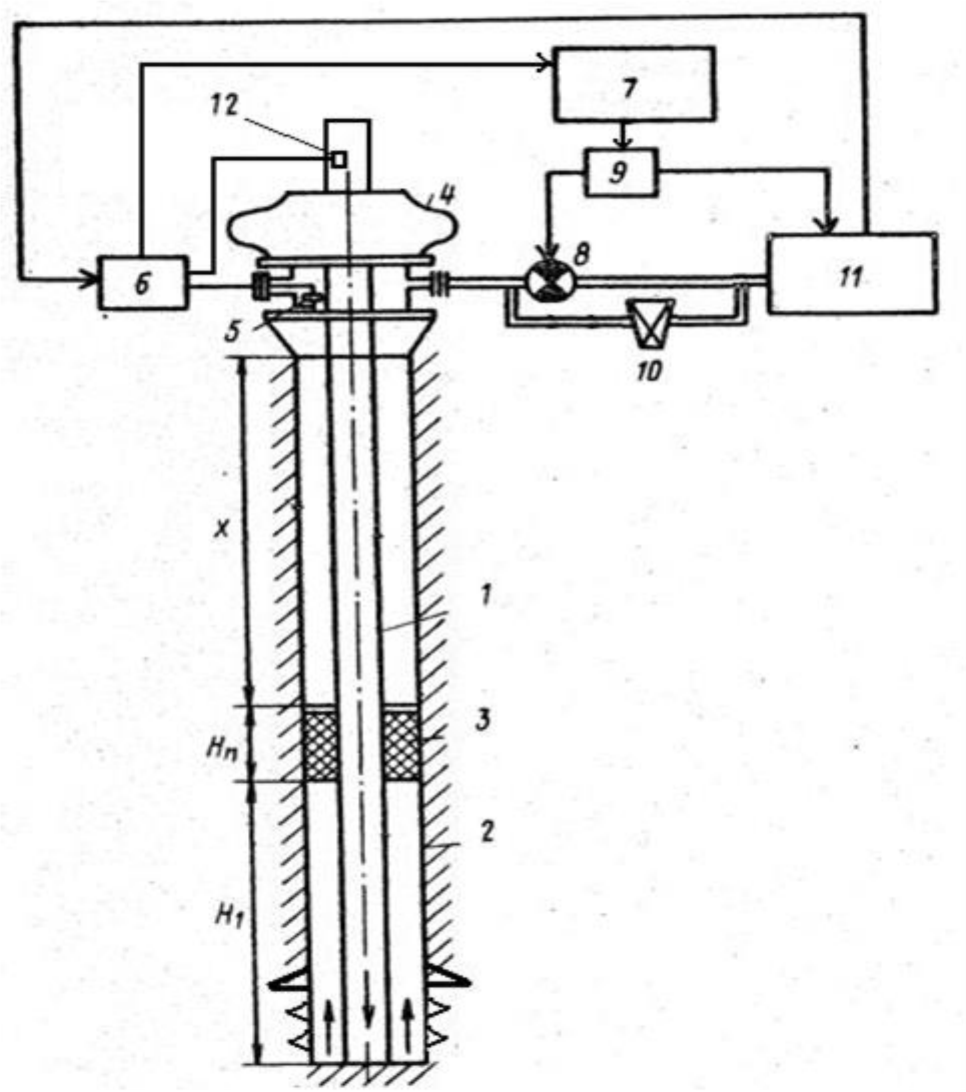


Fig.1

It includes the well casing 2 with the drilling pipe 1 located inside and forming an annular space there between. The lower end of the well with the drill bit attached to the pipe 1 is not shown. A blowout preventer (BOP) 4 is shown placed on top of the well at the point of a wellhead. An outgoing well pressure sensor 5 is located in the vicinity of the wellhead outlet allowing monitoring of drilling mud outlet pressure as it leaves the well. The incoming pressure sensor 12 is located at the inlet of the wellhead to monitor inlet pressure of the drilling mud as it is being forced down the drilling pipe 1. The signals from both pressure sensors 5 and 12 are fed into a data acquisition unit 6, which in turn is connected to a central processing unit (CPU) 7 based for example on a laptop PC.

The gas kick volume in the annular space is shown as position 3. It is characterized by its height Hn, distance from the wellhead X and distance from the reservoir H1.

The novel components of the system of the method include a fast-acting on/off valve 8 activated by a valve driver 9 based on a control signal from the CPU 7. The valve is located between the drilling mud collecting reservoir 11 and the exit from the annular space of the well. Rapid opening and closing of the valve 8 allows to abruptly changing the flow resistance in the outgoing pathway of the drilling mud. So as to not block the flow of drilling mud entirely, a parallel pathway around the valve 8 is provided and includes an adjustable flow chock 10. In another embodiment of the method (not shown), the valve 8 includes provisions to be rapidly opened and closed but to not completely obstruct the flow of the drilling mud. Such provisions may include an adjustable chock. Moving the seat away from the valve stem leaves certain space rendering the valve 8 incompetent. Following a rapid opening of the valve 8, a negative or positive pressure wave is created and sent down the annular space of the well. It may encounter a gas kick in which case two reflected waves are generated. Data acquisition unit 6 is configured for detecting the time of arrival of reflected waves t1, t2, and t3; t1 is the time of arrival of the wave reflected from the upper border of the gas kick; t2 is that reflected off its lower border , and t3 is the time of arrival of the wave reflected from the well bottom.

In one embodiment, the method includes the following steps:

a. Continuously monitoring incoming and outgoing drilling mud pressure – for example using the pressure sensors 5 and 12. Special attention is given to monitor the noise fluctuations within the overall pressure signal from the sensors 5 and 12. These fluctuations are caused by pressure disturbance generated by the pump used for injecting the drilling mud down the pipe 1. A typical example of such recording is shown in Figure 2.1. Initial amplitude of noise is monitored throughout the drilling process.

b. Detecting initial appearance of a gas kick within the annular space of the well by detecting an abrupt reduction of noise amplitude at the exit of the well (such as detected using pressure sensors 5 and/or 12). Gas dampens these pulsations and causes a smoothing out of the pressure signal at the outlet of the well.

t1 – time of arrival of reflected wave from upper border of gaseous pack

t2 – time of arrival of reflected wave from lower border of gaseous pack

t3 - time of arrival of reflected wave from bottom hole

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

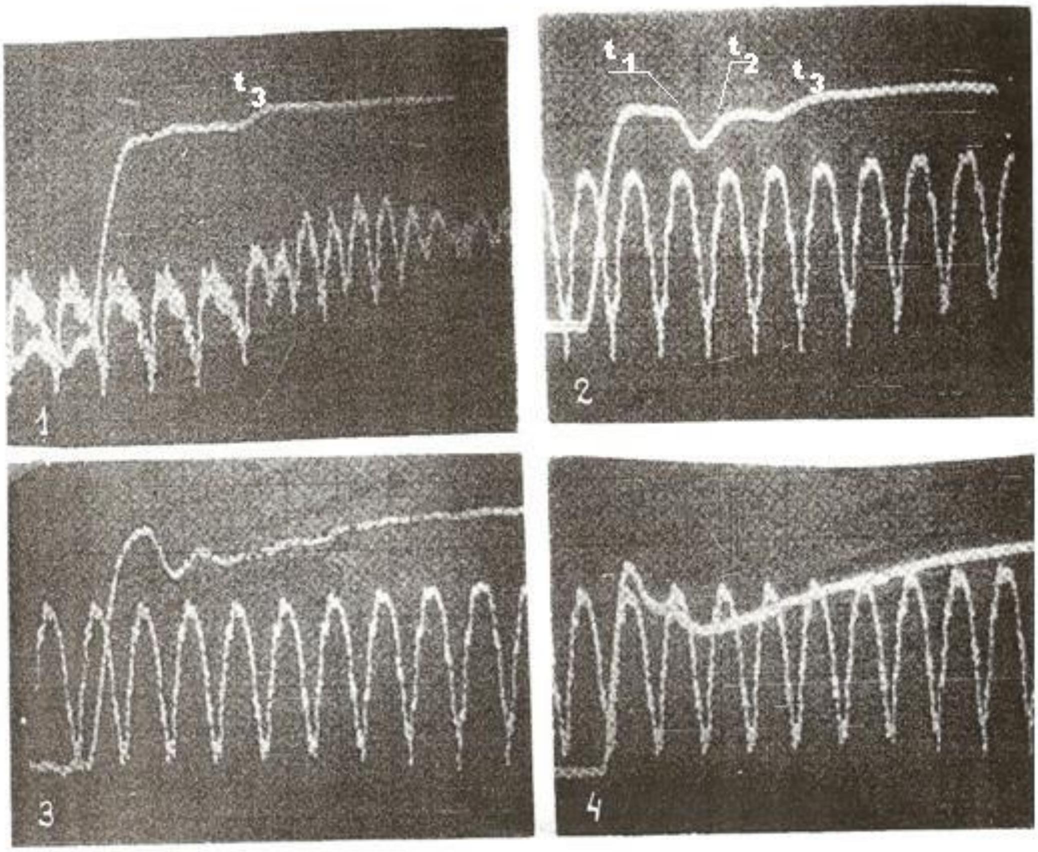


Fig. 2

Amplitude reduction can be seen clearly by comparing section A, the very left portion of the outlet pressure curve in Fig. 2.1 and Fig. 2.2 (it is two first puls low fricquence). Two pulsations are seen in section A In Fig. 2.1 and no any pulsations are seen in section A in Fig. 2.2. Additional indication of the presence of the gas kick is absence of high frequency pulsations on the inlet pressure curve (Fig.2.2). These high frequency and low amplitude pulsations are caused by the operation of the pump valves. They can be seen in all time section of the inlet pressure curve in Fig. 2.1. In comparison, the same section in Fig. 2.2 shows a smooth inlet pressure curve without high frequence the impact of the pump valves.

c. Closing the blowout preventer and initiating corrective measures once the initial entrance of the gas kick is detected. Optional continuous circulation of the drilling mud through the device of the method located at the outlet of the well allows periodic or near-continuous monitoring of the location and parameters of the gas kick.

d. Creating a negative pressure wave front on the outlet of the well by rapidly opening a previously closed fast-acting valve 8, whereby causing a significant increase in cross-sectional area available for drilling mud flow. This in turn causes a rapid decrease in flow resistance aimed to generate a negative pressure shock wave at the outlet of the well. The valve 8 is then closed again. The timing and speed of opening and closing the valve 8 are predetermined and calculated to achieve desirable characteristics of the negative pressure shock wave. The duration of valve 8 opening may be about 5-10 seconds. Generation of the negative pressure wave may occur every 5-10 min. Positive pressure wave may be used as well, but using negative pressure wave is safer as it does not load the components of the system with additional pressure. The higher the speed of operating for valve 8, the higher is the sensitivity of the method. In one example, the valve 8 allows full opening in about 0.1 second. This high speed of opening creates a rapid enough disturbance of the outlet pressure curve to characterize gas kicks as little as only 10 meters long or greater. The present method is not limited to the time when the drilling mud pumps are operating which is a common limitation of many other techniques. In fact, even when the pumps are not working, periodic rapid opening and closing of the valve 8 allows evaluation of the well and characterizing of the gas kick based on the pressure energy of the compressed oil and gas located in the reservoir itself. Ascending gas kick causes pressure increase at the wellhead even when the pumps are not operating. Such pressure increase (caused by gaseous pack moving up towards the wellhead) creates enough energy to repeat well evaluations by rapid opening and closing of the valve 8 without external power sources.

e. Causing propagation of the negative pressure wave front down the well and record its reflections at the wellhead. The negative pressure wave from the valve 8 travels down the annular space of the well with the speed generally equal to the speed of sound, about 1200 – 1500 meters per second. Upon reaching the gas kick, this wave is reflected both from its upper border and its lower border , such reflected waves are then recorded and analyzed to characterize the gas kick itself. Importantly, accurate detection of pressure waves reflected from the upper border and the lower border of the gas kick allow determination of the gas kick location and size.

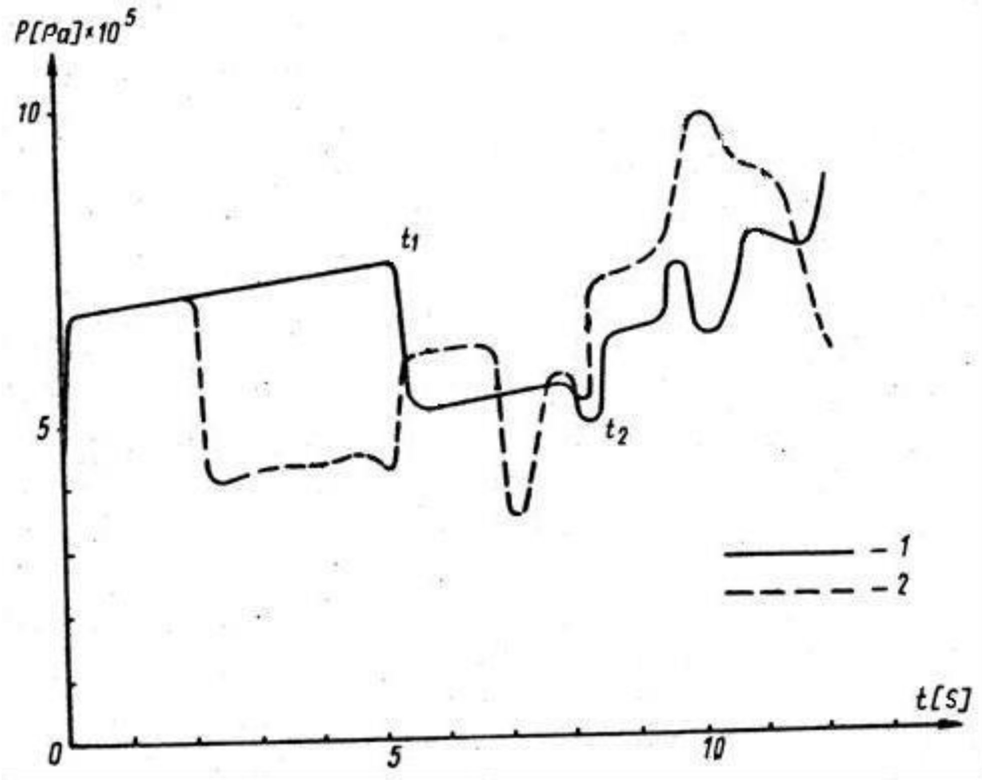
f. Repeating measurements of the gas kick location and size from steps d and e to determine the gas kick speed of ascending and to estimate its arrival to the surface of the well.

g. Optionally determining the average gas content of the gas kick from the previously detected parameters of the gas kick and from the known difference between the flow rate of the drilling mud going down the pipe and the flow rate of the drilling mud coming out of the annular space.

The method further allows active detection of the lack of gas kick, when the reflection of the negative pressure wave will only occur at the bottom of the well with the known depth – see Fig. 2.1. In this case, only one reflected wave is detected as without the gas kick there are no reflections from its upper border and its lower border . Additional reflections may occur at the locations where components of well casing and drill string are connected together but these locations are known in advance and their position is not changing over time making them easy to separate from the signature of a gas kick.

EXAMPLE 1

Fig. 3 shows one example of using the method using a simulated model of the well.



Depth well is assumed at 5,000 meters, with a cross-sectional area of 0.01 m2. A 500 meter long gas kick is assumed to be located at the depth of 3,750 meters. It had a gas content of 0.35. Opening valve 8 is assumed to be completed in 0.1 second causing an increase in cross-sectional area available for drilling mud flow from 0.0003 m2 to 0.003 m2. Such rapid increase in flow cross-section generates about 6 atmosphere negative pressure wave (6x105 Pa).

Curve 1 in Fig. 3 shows the time of arrival t1 to be about 5.8 seconds, while t2 is about 8.3 seconds. Assuming the speed of sound in liquid at 1300 meters per second and in gas at 400 meters per second, the depth of location of the gas kick is calculated at 3,770 meters and its length at 510 meters, both numbers being accurate to about 2% to the target parameters defined above. Curve 2 shows well characterization and another position of the gas kick.

Further evaluations using this mathematical model have indicated that the method of the method allows accurate characterization of a gas kick with the gas content ranging from 100% (only gas is present in the gas kick) down to 0% (gas kick contains only oil).

EXAMPLE 2

Another real experiment example is shown in Figs. 2.1 to 2.4. Fig. 2.1 shows results of the evaluation without a gas kick present. Time t3 corresponds to the location of the bottom of the well.

Fig. 2.2 shows initial position of the gas kick. Outlet pressure wave depression between points t1 and t2 indicates the length of the gas kick, while the position of the point t1 indicates its depth. Fig. 2.3 and Fig. 2.4 show subsequent evaluations made in 20 and 35 min after the first detection of the gas kick. Point t1 is seen moving progressively to the left and closer to the point of initial rise in pressure indicating ascendance of the gas kick. The distance between points t1 and t2 is seen progressively increasing indicating an increase in the length of the gas kick.

The present method allows not only monitoring the progress of ascendance of the gas kick, but also calculating mud concentration, pump flow rate and other parameters needed for its successful elimination. One of conditions needed for successful removal of a gas kick from a well is to maintain the bottomhole pressure near the portion of the well without a casing at appropriate levels. These levels should be below the reservoir of fracture, but above the pressure at which gas comes out from reservouar . This in turn allows for reliable prevention of uncontrolled gas kick blowout, well explosions and improved safety of well operation. In particular this is important for offshore wells, where an explosion can lead to a serious catastrophe.

The method and device 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. The tool is recommended to be incorporated in well-logging units, MWD systems and also as a stand-alone tool among the other instruments used at the well site. The tool makes it possible not only to ensure safety during drilling, but also to facilitate the introduction of the state-of-the-art drilling technologies, based on reduction of the bottom-hole differential pressure.

AAPG Annual Meeting March 10-13, 2002

Houston, Texas

Successful Application of a New Oil Production Optimization System at the Kokdumalak Field in Uzbekistan

ABSTRACT

Kokdumalak is a major oil and gas field in Uzbekistan with an annual oil production of 29 MMB/year. The reservoir is formed by an Upper Jurassic pinnacle reef with high average porosity (17-25%) and permeability of 200-500 mD.

After 15 years of production, the output of certain wells has declined 50% from a level of 1500 bpd, and the water cut is as high as 20%. The field's SE part has gas breakthroughs from the gas cap. The GOR has risen from 1000 to 4500-18000 scf/bbl. A demonstration of a new oil production optimization system (POS) that began at Well 289 produced the following results: daily oil production up from 780 to 920 bpd (+18%), GOR down from 6000 to 4500 scf/bbl (-15%), and the water cut has fallen to zero and stayed there. These results were achieved by installing a downhole POS device in the tubing that generates additional variable hydrodynamic drag, which automatically maintains an optimal bottomhole pressure and stabilizes the well's performance. This made it possible to reduce the skin effect in the bottomhole zone and eliminate gas and water cones from

perforations. The use of the POS at Well 289 yielded approximately 37,500 additional barrels of oil over a nine-month period.

INTRODUCTION

The POS technology was developed for oil fields with a high gas-oil ratio (> 600 cft/bbl) whose development is usually accompanied by a rapid decline in reservoir pressures. This results in the oil's degassing and loss of mobility and volumetric shrinkage in the pore space. This causes a dramatic decline in the reservoir's oil saturation and relative oil permeability. At the same time the reservoir's relative gas permeability rises. This is accompanied by the so-called skin effect in the bottom-hole

zone, which partially blocks the oil and allows the gas to escape the reservoir prematurely, contributing to an even faster decline in reservoir pressure, oil flow, and oil recovery.

The problems described above have taken place at the Kokdumalak Field. Because oil withdrawal greatly exceeded water injection, there was an imbalance between the pressures of the oil and gas parts of the field, which caused the release of more solution gas from the oil and the lowering of the gas-oil contact. This caused breakthroughs of free gas in the form of gas cones from the gas cap and water cones from the water-oil contact, resulting in a decline in oil flow, a higher gas-oil ratio, a higher condensate content in the liquid hydrocarbons, a higher water cut, and a decline in current oil recovery.

The purpose of this paper is to consider the results of the application of a new oil production optimization system (POS), which in addition to its former advantages (skin effect control and so forth) can enhance the oil production of an oil-gas-condensate field by reducing gas and water cones and maintaining production at an optimum level.

DESCRIPTION OF THE FIELD

The Kokdumalak oil-gas-condensate field is a world-class. It contained in-place reserves of oil and condensate conservatively total 195 million tons (approximately 1.4 BBO). Recoverable reserves have been estimated by Uzbekneftegas as 54.3 million tons of oil, using a recovery factor of 0.55, 67.4 million tons of condensate, using a recovery factor of 0.7 and approximately

128 billion cub.m of gas (4.5 tcf). The Kokdumalak field lies in Western Uzbekistan in north-eastern part of Amudarya Basin. It is located within 38042'40" - 38046'30" North Latitude and 64035'45" - 64042'40" East Longitude.
Kokdumalak field was discovered by well # 3 in 1979 and evaluated by twenty-well exploration phase in 1989.

The reservoir is formed by an exceptionally high quality Upper Jurassic (Oxfordian-Callovian) pinnacle reef, one of the best among 40 others in the reefal barrier. It is over-lapped by salt-anhydrite formation (Tithonian - Kimmeridgian) with thickness 525-878 m. The Kokdumalak reef is kidney-shaped with its longer axis trending northwest-southeast. The reef outline covers an area about 30 sq. km. The reef is 310 m thick. Toward the top of the reef complex, a layered unit of less porous carbonate appears to occupy the interior portion of the reef and is interpreted as a lagoon deposits (thickness 120 m) within an atoll form. Cavern porous reservoir is excellent because high porosity ranging up to 25% and permeability up to 500 mD. The reservoir is isolated by salt formation and has pressure that is more than twice normal hydrostatic gradient (drilling mud used 1.9 g/sm3).

Oil pool dimensions are 8,000 m x 3,200 m x 59 m. Gas pool dimensions are 7,800 m x 3,000 m x 216 m. Initial parameters are as fellow: formation pressure 57.3 -
56.2 mPa, saturation pressure 53.5 mPa, formation temperature 1140C, GOR 101-230 m3/m3, specific gravity 30.4 API(oil) and 43.2 API (condensate), oil viscosity at temperature 200 in layer is 1.4 mPa s, oil saturation 0.8751, gas saturation 0.7-0.9, condensate factor 720 - 670 g/m3. OWC was on the absolute **depth - 2830 m, OGC was on absolute depth - 2771 m.**

THE PROBLEMS OF RECOVERY STRATEGY

Before 1996 the field was developed by depletion drive with an almost concurrent decline in oil and gas reservoir pressure. In 1996 there was a sharp decline in reservoir pressure (by 6.5 MPa). Waterflooding began the same year, and cycling was implemented in 1997. But the imbalance between water injection and oil withdrawal from the oil reservoir, on one hand, and gas withdrawal from the gas cap, on the other hand, led to problems, the most noticeable of which was a gas breakthrough from the gas cap in the form of a gas cone into the oil reservoir, which expelled oil from the casing perforations. As a result, oil flow in certain wells has declined from 1500 bpd by approximately half to two thirds, and in places the water cut is as high as 20%. These problems were especially severe in the SE part of the field, where the GOR rose from

1000 to 4500-18000 scf/bbl, the height of the gas cones reached 25-30 meters, and condensate precipitated in the liquid phase in the bottom-hole zones of several reservoirs. All these problems accelerated the decline in reservoir pressure and oil production, which in turn reduced ultimate oil recovery from 55% to 30%.

THE NEW OIL PRODUCTION OPTIMIZATION SYSTEM (POS)

The POS basically re-distributes pressure in the reservoir-well system and maintains bottom-hole pressure at an optimum level. This is accomplished by installing a special downhole device consisting of a multi-parametric system of Venturi tubes of different lengths, diameters, and nozzles in the well. The geometric dimensions of the tubes are calculated individually for each well so as to generate the required hydrodynamic resistance and thus maintain bottomhole pressure at an optimal level within a certain range of reservoir pressures. These improved conditions allow the POS to reduce or completely eliminate the gas and/or water cones that accompany the development of an oil reservoir. Even though drawdown is reduced in the process, the wells' oil production is normally improved by the redistribution of phase flows near the perforations and the removal of gas cones from certain perforations in favor of the oil phase.

There exists a certain current bottomhole pressure that depends on reservoir properties and fluid PVT and which if maintained over the life of a project will make it possible to maximize current oil production and achieve a maximum ultimate oil recovery. This bottomhole pressure is called the optimal bottomhole pressure. It can be determined from a mathematical model of multi-phase flow in a system of elements matched in terms of pressure and flow rates: reservoir - bottomhole POS device - tubing
- wellhead choke. This simulator and a large number of computer simulators developed for this technology enables quick assessments of:

- the possibility of the effective use of the POS at a given field
- anticipated fluid production parameters from wells with the POS:
- enhancement of current well production
- reduction in current GOR and WC
- enhancement of the oil recovery factor
- longer natural flow production

We should mention that known downhole chokes served as the prototype for the POS. The POS is more efficient than the chokes because of its:

1. use of a unique multi-parametric downhole device with greater flexibility and self-control
capabilities
2. use of complex simulators

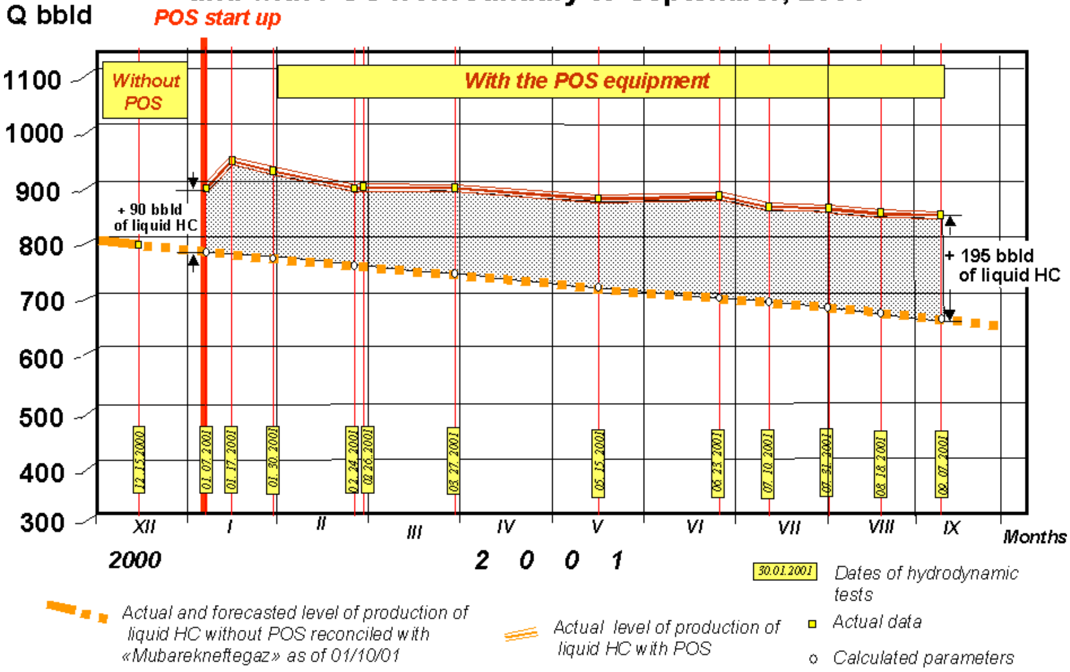
We should emphasize that the downhole device makes it easier to control wellhead pressure, which becomes smoother and more stable and stabilizes well performance. The downhole device can be installed and replaced by adapting it to the mandrels in a few hours without killing the well.

We should also mention that the POS can be used with different field development systems and has been adapted to different kinds of production. It can be used in combination with gas lift after natural flow has stopped.

The performance of the technology and device at Well 289 at the Kokdumalak Field provide A clear example of the effectiveness of the POS.

THE USE OF THE POS IN KOKDUMALAK WELL No. 289

Production of liquid Hydrocarbons from well No289 without POS in December, 2000, and with POS from January to September, 2001



In early January 2001, a POS bottomhole device was installed at a depth of 3078 meters 18 meters above the perforation interval in Pilot Well 289 at the Kokdumalak Field. Well 289 is located in the gassy southeast part of the field in the immediate vicinity (300 meters) of the OWC. The oil production prospects of this well without the POS were exactly the same as the nearby Wells 95, 286, 56, 284, and 288, which since 1998 have been plagued by gas breakthroughs (gas cones) and where average oil production has declined from 949-1168 bpd to 282-584 bpd, i.e. a rate of decline of 15.3-20.4 bbl per month, and the gravity of the liquid hydrocarbons has declined sharply from 31.1 API to 41.7 API (and even to 49.9 API). The GOR rose from 2300-2800 scf/bbl to 5600 - 16000 scf/bbl, and the WC is up to 12- 22%. According to the Mubarekneftegaz Upstream Division's forecasts, oil production in Well 289 without the POS should have fallen to 584-620 bpd in July 2001, the oil's specific gravity should

have declined to 37.0 API, while the GOR and WC should have risen to 8000 scf/bbl and 20% respectively. But now Well 289 with its POS device has been performing more and more efficiently for more than 10 months and its production has remained at an optimal level. This has been shown by 13 well flow tests

(Table 1) and is illustrated in Figure 1. During this time, if we factor in the natural decline in reservoir pressure, additional daily liquid hydrocarbons output has risen from 102 to 234 bpd and oil accounts for up to 80% of the liquid hydrocarbons, as evidenced by the higher specific gravity of the oil (up to 32.8 API). The rate of decline of oil production has slowed by a factor of 2.5-3 to 6.6 bbl/mo, the GOR has declined from 6000 to 4500 scf/bbl, i.e. by 15%, and the WC has declined from 5.8% to 0%. The range of daily variations of liquid hydrocarbon gravity has narrowed by a factor of 5-6, which indicates that the position of the top of the gas cone has stabilized at the perforations.

The redistribution of pressure losses in the reservoir-well system has led to its more efficient use by reducing the stress on the wellhead, where wellhead pressure declined from 19.5 to 14.6 MPa. In the first nine months of operation of the POS, Well 289 produced more than an additional 44,000 barrels of liquid hydrocarbons, including an additional 35,500 barrels of oil.

CONCLUSIONS

The performance of Pilot Well 289 at the Kokdumalak Field have demonstrated the effectiveness of the POS system:

- Production was up and the rate of decline slowed;
- The GOR and WC were reduced;
- Wellhead pressure was reduced and well performance was stabilized;
- The rate of decline of reservoir pressure was slowed, which led to a longer period of natural flow and a higher oil recovery factor.

An Efficient Method for Enhanced Oil Production Providing an Increase in Oil Recovery Index

Dr. S.D. Tseytlin

Abstract

PEnTechnology was developed for high-GOR oil fields. The target was the optimization of well-formation system by means of maintenance of bottomhole pressure and supporting fluid lift. The technology applies an individual approach to each well, based on analysis of nymerous parameters and data, computer simulation of well-formation system and sizing calculation for the technology's bottomhole tools.

Introduction

In oil fields with relatively high gas/oil ratio (GOR) of more than 600 scf/bbl well productivity declines vary rapidly due to the following processes. When bottomhole pressure decreases below saturation pressure, oil degasses in the near bottomhole zone of the reservoir. The liberated gas blocks the zone, affecting relative oil permeability. Such negative processes evolve over months, even years, causing a significant decrease in oil production and recovery index.

PEnTechnology prevents or minimizes the above-mentioned negative processes, provides and increase in daily oil production and recovery factor. Fig.I illustrates the PEnTechnology's influence on oil mobility and gas and water coning near the wellbore. PEnTechnology performs most efficiently in reservoirs with a developed solution gas drive, water drive, or combination thereof, with an intensive gas and water coning. Application of PenTechnology is highly recommended for the wells declining oil production and increasing GOR.

Principle Theory and the Tools

PEnTechnology optimizes operational regime of the well- formation system in accordance with current status of the oil field, in order to increase both daily oil flow rates and total oil recovery from the reservoir. At the same time, the reservoir energy is being preserved for the well to operate over an extended period of time with higher flow rates. These goals are achieved by the set up and maintenance of the bottomhole pressure at an optimum calculated level, by means of a bottomhole tool, and by supporting fluid lift within the well by means of a wellhead regulator. The bottomhole tool carries out the main functions. It is a multiparametric system of small-diameter tubes and nozzles. The tools are custom made for each well, with individual design, configuration and size, according to the computer simulation of

the well-reservoir system. PEnTechnology's bottomhole tool has a flat dependence of $M'=/(Q, GOR)$, characterized by a stable pressure gradient Af> between its inlet and outlet within a wide range of fluid flow rates (Q) and GOR. A supplementary function is served by a wellhead regulator, which maintains an optimum pressure within the tubing, in order to prevent occurrence of an annular mist in the well.
PEnTechnology operated successfully in oil fi lds of the Western Siberia, Texas and Louisiana, on- and offshore.

Well history

The demonstration of PEnTechnology was performed in an offshore well in the Gulf of Mexico (conventionally the "A" well). The exploitation began in 1991. The productive formation of the oil field is located at the depth of 5484-5514 ft. The reservoir is represented by sandstone with porosity of 25% and permeability of 184mD. Oil gravity was 26.6°API.
The initial GOR = 530scf/bbl. The well recovers oil from a separate block

Fig. 2 illustrates an average monthly oil production from June, 1991 through February, 1998 and the prognosis until July, 2003. Initially, for about 1 month, the well was producing approximately 1000 BOPD. Then, for approximately a year, flow rates were ~ 400 BOPD. For the following *5* years, since installation of gas lift, oil flow rates were maintained at a level of approximately 200 BOPD. In 1997 oil flow rates decreased to 160 BOPD, and several days before the installation of PEnTechnology they were equal to 121 BOPD. From the beginning of well operation, up to the date of installation of PEnTechnology, GOR and WC were gradually growing, having reached more than 700 scf/bbl and 28% respectively.

Results

After the installation of PEnTechnology on September 24, 1997, oil flow rates initially decreased. In just one week oil flow rates again increased to a production level higher than before the installation of PEnTechnology. During the last month of the demonstration, from November 12, 1997 to December 13, 1997, the well was operating with an average flow rate of 177 BOPD. Fig. 3 illustrates operational parameters of the well from October, 1997 through March, 1998.
It is necessary to note that it takes a certain period of time, after the installation of

PenTechnology, to establish an optimum operation! regime of a well. During that period the te-chnology influences the negative effects, which have accumulated in the reservoir during the years of the previous well operation, and restores the reservoir ener . Inwell A the optimum regime was established by the 50 day after the installation of PEnTechnology, on November 12, 1997. Should we take into consideration a 12-day shut-in (October 18 - November 1), due to non-related to the demonstration reasons, the optimum regime was established by the 38^{th} day of operation. Table 1 illustrates the results of 2.5-month demonstration in well A, devided into three stages.

As a result of PEnTechnology's influence during establishment of the optimal regime in the well:

oil flow rates increased by 35%

the wellhead choke diameter was reduced from 64/64" to 20/64"

wellhead pressure increased by 50% water cut reduced from 28% to 22%

GOR decreased three times

gas injection was decreased by 50%.

The above mentioned parameters clearly illustrate that, due to PEnTechnology, performance of the well and reservoir conditions were improved considerably within a wide drainage area:

oil saturation and permeability of the reservoir

drainage area have improved;

hydraulic link of the well with the remote reservoir zones has improved;

formation energy has restored, which would have prolonged the well life and increased recovery index provided PEnTechnology remained operational;

the process of reservoir restoration was accompanied by increased oil flow rates, which could have been maintained for several more years, provided PEntechnology remained operational.

It is necessary to note, that during the demonstration period,

October 18-31, 1997, the well was shut in due to repair works on another platform.

(Fig.3) After the well was opened, its oil flow rates escalated to more than 300 BOPD.

These rates were considerably higher than the maximum oil rates in July, 1997 (~ 200 BOPD) after the well had been shut-in for a considerably longer period - for about 3 weeks. In addition, in October water cut was maintained at a level of less than 20%, while GOR was decreased to 360 scf/bbl. For 12 days, following the shut-in peak, oil flow rates decreased to 169 BOPD (11/27/97). For the following month the well was producing 177 BOPD on average, with WC at a level of 16-24% and GOR of 237 scf/bbl. Performance of the well after the October shut-in, in comparison with the. previous similar experience, proved the PEnTechnology's energy- restoring influence on the reservoir.

On December 13, 1997 the PEnTechnology's bottomhole tool was removed from the well. After the removal, oil flow rates abruptly increased to 400 BOPD. It must be emphisized that this peak of the increased flow rates was not a result of a shut-in, as it occurred on October 31, 1997. Instead, it was a direct result of the removal of the PEnTechnology's bottomhole tool. Approximately 7730 barrels of oil were produced during the month following the removal of PenTechnology, 3600 barrels of · which represented the total additional production of oil. For a comparison: for the first 9 months of 1997 the average monthly oil production was 4130 barrels.* Only 5 years ago the well was perfroming at this rate, after gas lift was installed and when the reservoir pressure was considerably higher. Later, oil flow rates gradually reduced, and on February 26, 1997 they reached 128 BOPD.

Notwithstanding the efforts of the oil company, operating the well, to optimize well operation by manipulating the gas lift, after PEnTechnology was removed, the oil flow rates were further decreasing without ever accomplishing the level achieved with PEnTechnology. It is evidenced by a rapid increase in water cut (to 32-36%) and GOR (to 800-1050 scf/bbl), which are considerably higher than before the installation of PEnTechnology in September, 1997. (fable #1)

One of the main parameters, illustrating the efficiency of PEnTechnology, is the diameter of the wellhead choke: with PEnTechnology the well was operating at 20/64" choke with wellhead pressure of about 210 psi, and after PEnTechnology was removed, at the diameter of 64/64" with wellhead pressure of 110 psi.

>*Without* PEnTechnology: the well can produce the maximum of 128-142 BOPD. In the meantime, the reservoir energy is being wasted. Oil flow rates will :fqrther decrease rapidly, while water cut and GOR will grow. The negative processes resumed evolving in the reservoir.

>***With*** PEnTechnology: the well has been operating with higher oil flow rates, while the reservoir was accumulating potential energy. No other existing technology can provide such effect.

Compare this amount with approximately I 000 barrels, produced after the 12-day shut-in

(Peak I, Fig.I), which should not be considered the "additional", production as it corresponds to the well production at an average flow rate of83 BOPD for the period of shut-in.

AN EFFICIENT METHOD FOR ENHANCED OIL PRODUCTION AND INCREASE IN OIL RECOVERY INDEX

The amount of oil, additionally produced after the PEnTechnology's bootomhole tool was removed, represents the result of our technology's influence on the reservoir: reservoir energy was being preserved due to reduced water cut and GOR, an efficient increase in oil recovery due to an improved oil permeability of the formation and reduction of gas and water coning.

During the demonstration, PEnTechnology optimized operation of the well. Producing more oil daily, the formation kept on preserving its energy.

In case PEnTechnology remained in the well, its operational life would have been extended, and the depletion curve would have been flatter. As an option, we could have chosen to maintain an expedited regime of oil production, similar to the regime of the well A operation for 3 days before the removal of PEnTechnology, when daily oil production was 215 barrels, diameter of the wellhead choke - 28/64", tubing pressure - 157 psi, water cut- 16% and GOR - 360 scf/bbl. The rate of daily oil production with the installed PEnTechnology is directly proportioned to the intensity of the solution gas drive, having been developed before the installation of PEnTechnology. In case of a developed solution gas drive, installation of PEnTechnology provides an improvement for the drainage zone and oil permeability of the reservoir, as well as an increase in daily oil production.

In case of a water drive, PEnTechnology establishes a balance between oil-water contact and oil inflow into the well. It is possible to continuously maintain high flow rates due to established constant pressure differential between pressure at the contour of the formation and at the bottomhole. An increase in oil recovery index was estimated the following way. Tectonic block of this oil field is being drained by one well only - well A The recoverable resources can be estimated, using a graphic of monthly oil production in dependence to cumulative oil production[1] (Fig.4) From 1992 the dependence is a straight line (linear production decline). By extrapolation of this linear decline to economically feasible oil flow rates (30-35 bbl/d), we can estimate the recoverable resources of this oil field of 620,000 - 650,000 barrels. The cumulative oil production is 460,000 barrels. The estimated remaining recoverable resources are 160,000 - 190,000 barrels. If PEnTechnology would have remained operating in this well, it would be possible to additionally produce approximately 72,000-100,000 barrels of oil, having increased the recovery index by 10-15% (by~ $1,000,000-1,500,000, at $15 per 1 barrel of oil).

Conclusions

The results of 2.5-month demonstration of PEnTechnology provide an opportunity to visualize the current increase in the recovery index.

As a result of the demonstration:

oil flow rates were increased

wellhead choke diameter was decreased wellhead pressure was increased

water cut reduced GOR decreased

the amount of injection gas was reduced

oil saturation and permeability of the near bottomhole zone of the formation inmproved

hydraulic link of the well with distant zones of the formation improved

reservoir energy restored, which provided an extention of well life and an increase in oil recovery factor well and reservoir restoration was accompanied by increased oil flow rates, which could have been maintained for several more years, provided PEnTechnology remained in operation.

References

1. Laherrere, Jean H.: "Production decline and peak reveal true reserve figures," *World Oil* (Dec.1997) 77.

SI Metric Conversion Factors

0 API 141.5/(131.5+0 API)= g/cm^3 bbl x1.589 873
E-01 = m^3 ft3 x2.831 685 E-02 =m^3
°F (°F-32)/1.8 =°C

in x2.54 E+00 =cm psi x6.994 757 E+o0 =kPa

Nomenclature *GOR - gas/oil ratio L1 -*
gradient
P - pressure, psi
Q - oil.flow rates, BOPD
WC - water cut in the production, percent.

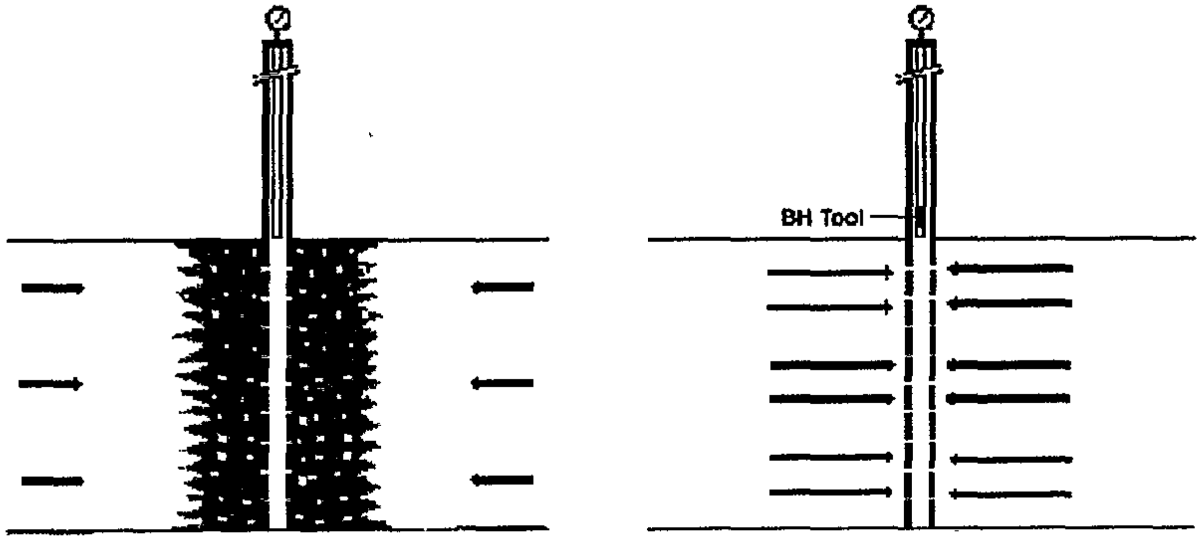
Acknowledgements

We thank Tigran Makarian, Naum Gliklad, Paul Koomey, and George West for continuous support of this project; Alton Watson, Larry Bates, James Collier, Ken James, Harry Leonard for valuable discussions on the interpretation of the demonstration results; Leonid and Avgust Kuslitsky, Iosif Gaportsin for the design and engineering consultations; Natalia Platonova for the translation and assistance in preparation of the material.

TABLE 1 - COMPARISON OF MAIN PARAMETERS OF 3-STAGE WELL OPERATION

Parameters	9.23.97 1day before the installation of PEnTechnology tool	12.12.97 2.5 months after installation, 1 day before the removal of PEnTechnology tool	2.26.98 2.5 months after the removal of PEnTechnology tool
O11,BOPD	121	**164**	128
Bottomhole Pressure, psi	765	1123	**653**
Choke, in.	**64/64**	**20/64**	**64/64**
Flowing Tubing Pressure, psi	140	210	122
Water Cut,%	**28**	22	33
GOR, scf/bbl	710	237	990
Injection Gas, Mscf/d	360	240	400
Specific rates of the Injection gas, scf/bbl	2143	1141	2094

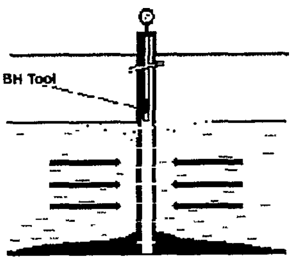
Positive influence of PenTech on oil mobility in near botomhole zone.

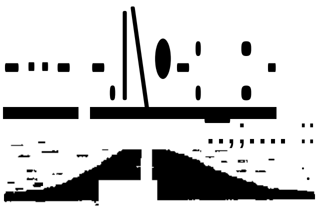


A. Before installion of PEnTech **B. After installion of PEnTech**

Low oil penneability zone, as result of increased gas saturation of the formation and oil viscosity

Positive influence of PEnTech on gas and water coning.





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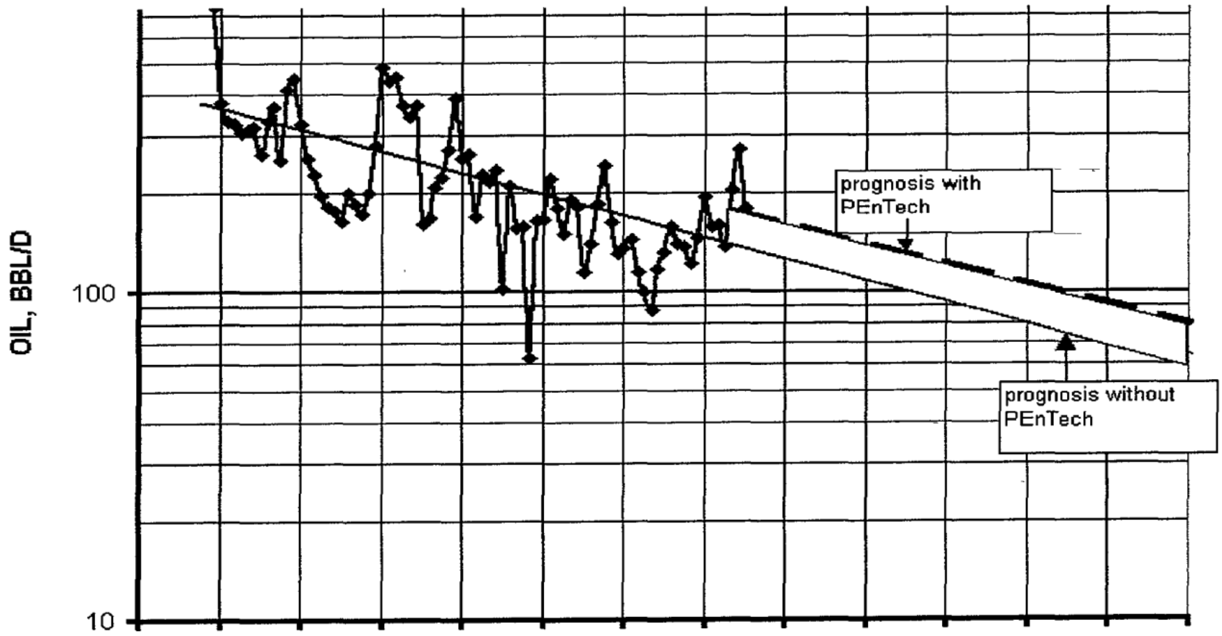
"w.i.(

A. Before Installlon of PEnTech B. After Installion of PEnTech

Fig. 1 - Positive influence of PEnTech on well performance.



J-90 J-91 J-92 J-93 J-94 J-95 J-96 J-97 J-98 J-99 J-00 J-01 J-02 J-03

Month

Fig. 2 -Average monthly oil flow rates from june 1991 through february 1998 and prognosis.