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Research article

A plunger lift and monitoring system for gas wells based on deployment-retrievement integration

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Abstract

As a necessary step, removing liquid in the wellbore plays an important role during the production of gas wells. Plunger lift is a widely-used intermittent deliquification process for gas wells. However, the manual control way and wire logging are still utilized as a downhole monitoring way for plunger lift, which is not efficient in terms of interrupting the production. This paper presents an improved solution that logging instruments canister are deployed and retrieved by means of a new assembly. With the reciprocating plunger, logging instruments canister can be carried and deployed to the bottom of a gas well to carry out logging and sampling tasks on the production demand of a field. After the deployment and logging tasks are performed, logging instruments canister is carried back to the surface by the plunger and then data is transferred to the wellhead device near field wireless communication technology. This newly developed plunger lift system comprises plunger body, deployment sub-assembly, retrieve sub-assembly and logging instruments canister. The surface device comprises RF antenna, reader and writer. Based upon the method of deployment-retrieve integration, the new deliquification process is introduced and on-line monitoring of production dynamics can be performed including P/T measurement, downhole fluid sampling, pressure build-up, etc. without interrupting production. The general solution and engineering design parameters have been confirmed by research teams, while system prototype manufacture and workbench tests are being performed. The cost-effective way combining deliquification with dynamic monitoring is developed and contributes to increasing production and the stable productivity of gas wells. It is very significant for low-pressure and low-production gas fields to achieve automation production and management.

Keywords: Plunger lift; Deliquification; Multi-part plunger; Near field wireless communication; Deployment-retrieve integration; On-line monitoring; Pressure build-up; Dynamic monitoring; Automation

As more and more gas fields in China enter middle and late development stage, and most gas reservoirs are low-permeability and water-flooding ones with low recovery, how to enhance gas reservoir recovery becomes an urgent issue. For low pressure and low production gas wells, removing wellbore liquid, lowering bottomhole back pressure, maintaining their normal production, and prolonging their life span are of great significance to improving gas reservoir recovery [1—4]. At present, the drainage gas recovery processes include foaming, plunger lift and artificial lift. Artificial lift includes electric submersible pumping, beam pumping and jet pumping etc. [5—9]. Different from other techniques, plunger lift is a kind of intermittent lifting carrying fluid by using the reservoir energy, featuring simple design and installation, low cost, mechanical lifting interface, low economic limit etc., so it has been widely used in the middle and late development stage of gas reservoirs [10—12].

So far, oilfield service companies in China and abroad have developed a variety of plunger lift tools and supporting control techniques and put them into application [13—19]. But the existing plunger lift technologies have some deficiencies: the logging for plunger lift wells still takes the traditional wireline

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running-in process, which means when logging is to be conducted, the gas well must be shut down first. As plunger lift is an intermittent production mode in which gas wells don't produce gas in the falling cycle of the plunger, measures such as reducing shut-down times and speeding up plunger falling need to be taken to shorten off-production cycle and enhance production rate of a single well, therefore, there is contradiction between “shut-down during logging” and “reducing shut-down to enhance production”.

In view of the problem with the existing plunger lift techniques, an integrated deployment and retrieve plunger lift scheme was proposed, which makes the automatic wellbore dynamic monitoring possible during the normal drainage production. The new scheme eliminating the traditional wireline logging, enhancing operation efficiency, is conducive to increasing gas well production and automation level of gas field production.

1. Technological analysis

1.1. Technical requirement of the system

1) High efficiency production and monitoring mode. Running in and retrieving device by using the reciprocal movement of the plunger between the wellhead and the well bottom, the working plunger acts as both the drainage tool and the carrier of logging tools.
2) Multiple test functions. Different test and sampling devices can be deployed according to different test missions, including conventional temperature, pressure, wellbore sampling, and pressure build-up test etc.
3) Non-contact communication mode. A communication system with fast connection and data transmission, good anti-interference capacity, stable performance in oily and scaly hostile environments and certain anti-impact capacity should be set up.
4) Simple maintenance. Parts like device, power source, deploying and retrieving components can be easily replaced.

1.2. Suitable conditions of the technology

According to the production conditions of gas wells and wellbore parameters, working condition of plunger lift tool were presented, namely: tubings 73.03–101.60 mm in diameter, the maximum well depth of 2500 m, the maximum well inclination of 30°, the gas/liquid ratio of over 250 m^3/m^3, the liquid production of less than 300 m^3/d, and the working temperature of −25 °C–90 °C.

2. Design of the system

2.1. Mechanical structure

The system is composed of downhole plunger and surface corollary devices. When carrying out a deploying task, deploying assembly is connected between the plunger and the instrument canister. When retrieving a device, the deploying assembly is replaced with retrieving assembly (Fig. 1). The main surface corollary part, ring-shape antenna is fixed inside the wall of the lubricator.

There are some inner holes inside the plunger itself (Fig. 2) for fluid passing, which is good for enhancing the downgoing speed of the plunger. The plunger top is connected with the plunger fishing head, and there are ring-shape non-equilateral ladder grooves in even interval in the outer surface of the plunger, which mainly function to remove sand and scale stick to the inner wall of tubing during the downgoing and upgoing movement of the plunger. There are capillary groups on the outer surface of the plunger, which, similar to nozzles, allow high speed jetting of the fluid to pass through the inner holes into the space between the plunger and the tubing inner wall, and to wash the sand and scale around the plunger and lower instrument canister. The structure parameters of the tool are: outer diameter of 60 mm, inner diameter of 20 mm, length of plunger of 430 mm, instrument canister length of 280 mm, deploying/retrieving assembly length of 140 mm.

The instrument canister assembly is made up of a working barrel fishing head, a buffer spring, a instrument canister, a downhole device and a bottom plug (Fig. 3). Downhole devices include pressure/temperature sensors, and sampling devices etc. The fishing head of the canister is a structural part conformable with API standard. When the instrument canister assembly can't be retrieved with the retrieving assembly, the

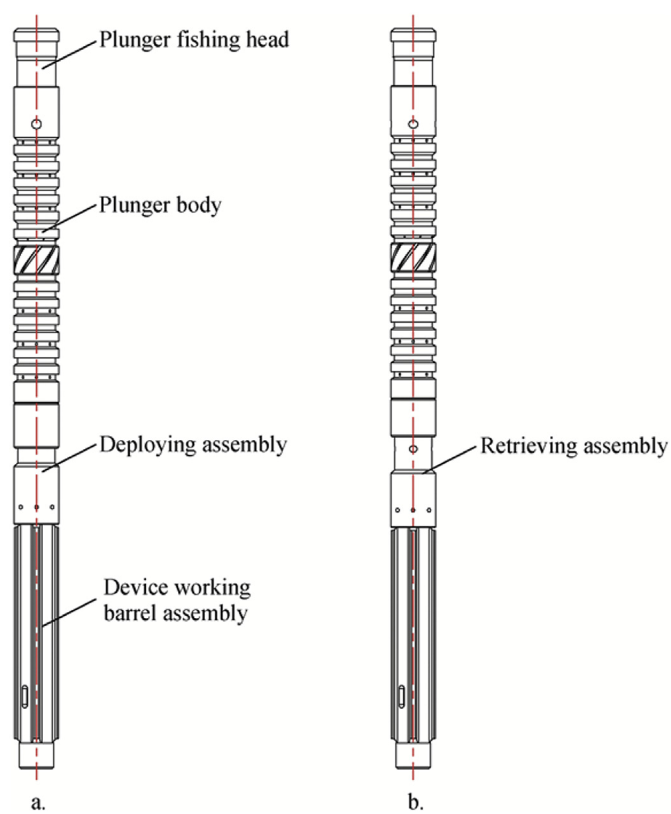

Fig. 1. The plunger with a deploying assembly (a) and the plunger with a retrieving assembly (b).

Fig. 2. Schematic of the plunger body.

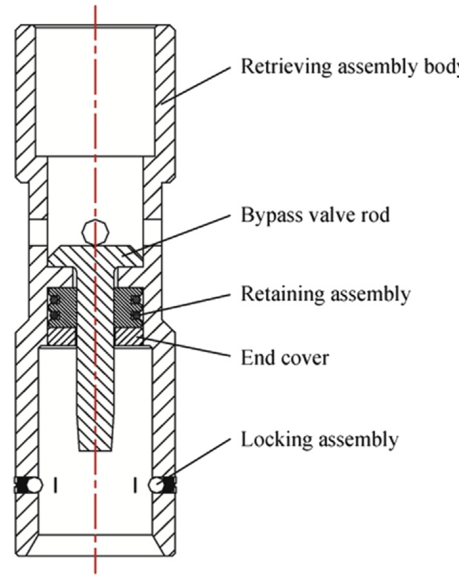

Fig. 4. The retrieving assembly with the bypass valve opened.

canister fishing head can be fished with wireline. There is a long strip shape liquid intake hole on the outer surface of the instrument canister. When the instrument canister assembly is downhole, wellbore fluid can enter the canister through this hole for later analysis. There are strengthening ribs in even distribution around the instrument canister, which functions to centralize the canister in the tubing.

The retrieving assembly (Figs. 4 and 5) is composed of retrieving assembly body, locking assembly, end cover, retaining assembly and bypass valve rod. The retrieving assembly body is connected with plunger and device working barrel up and down. There are even distribution holes in the lower part of the retrieving assembly body, and the locking assembly inside the retrieving assembly, which is a preload steel ball mechanism used to hold and fix the instrument canister assembly. There are even fluid outlets in the middle of the retrieving assembly body, during the downgoing of the plunger, the bypass valve is open, the fluid outlets are connected with the inner holes inside the plunger body, and the pressure above and below is balanced, allowing the plunger to drop to the well bottom faster.

The deploying assembly (Figs. 6 and 7) is composed of deploying assembly body, thermal actuator, locking assembly, actuating sleeve and actuating rod. Similar to the retrieving assembly, the deploying assembly has a bell mouth structure at the bottom of the body, making it easier for the instrument canister to get into the deploying assembly body. The thermal actuator similar to short stroke hydraulic cylinder in moving mode, is filled with a kind of thermal expansion working fluid which is a kind of solid–liquid phase change material for energy storage that melts when the ambient temperature reaches its melting point and liquefies and expands gradually [20], so the pressure in the actuator chamber rises, pushing the actuating rod out. Out of consideration of lowering cost, paraffin-based material is selected as the solid–liquid phase change material, with melting range adjustable according to

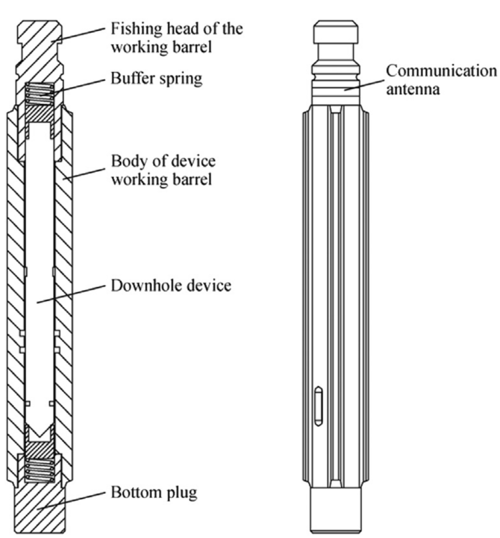

Fig. 3. Schematic of the instrument canister assembly.

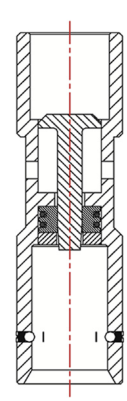

Fig. 5. The retrieving assembly with the bypass valve closed.

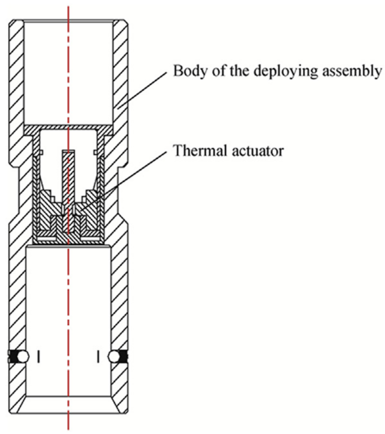

Fig. 6. The deploying assembly before the actuator initiates.

downhole condition. The case of the actuator is made of material with high thermal conductivity, such as brass, which allows the ambient heat to transfer to the inside of the actuator fast.

2.2. Deploying and retrieving principle

When executing a deploying mission, the deploying assembly is connected with the plunger body on surface, and the instrument canister assembly is inserted from the lower end of the deploying assembly, and finally locked by the locking assembly. The tool assembly is run in well with the wellhead valve closed, and the plunger tool assembly starts to go down till reaching the well bottom. Under the bottom hole temperature, the thermal actuator starts to work, and the actuating sleeve and actuating rod stretch out, pushing against the end surface of the fishing head of the instrument canister, disable the locking assembly and pushing the instrument canister out of the deploying assembly, and separating the instrument canister assembly from the plunger. Then the wellhead valve is opened, the plunger tool goes upward, while the instrument canister assembly is left at well bottom to do the preset test, so far the deploying operation is done.

When the instrument canister finishes the test mission and needs to be retrieved, the deploying assembly on the plunger is replaced with the retrieving assembly, and the valve rod is kept at low position, that is, the bypass valve is open, then the plunger tool assembly is run in well. After the wellhead valve is closed, the plunger tool starts to go downward till reaching the well bottom. When the instrument canister assembly gets into the lower part of the retrieving assembly, the locking assembly works, and the steel ball enters the semi-sphere groove at the top of the instrument canister, locking the fishing head of the instrument canister. At the same time, the valve rod is pushed to the upper position, holding out against the tapered surface of the inner of the plunger body. The tapered surface of the plunger inner hole and tapered surface of the valve rod match tightly to form an effective seal, blocking the flow path inside and outside of the plunger, at this point, the bypass valve is closed, so the plunger tool act as a piston in an oil cylinder. Then the wellhead valve is opened, under the effect of the bottom hole gas pressure, the plunger together with the instrument canister assembly go upward till the wellhead. Thus the retrieving operation is done.

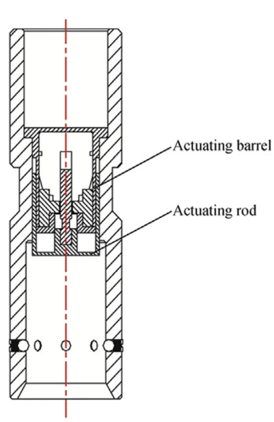

Fig. 7. The deploying assembly after the actuator initiates.

2.3. Design of the wireless communication system

The system consists of two subsystems, surface and downhole plunger, and adopts low power consumption Bluetooth technique as the communication and data transmission mode between the plunger and surface. Bluetooth Low Energy, a kind of short distance high frequency communication technique, has merits such as good anti-interference capacity, high speed and stable transmission, low power consumption, large transmission range (less than 10 m) etc., which allows the point-to-point non-contact data transmission between electronic devices [21−23]. To enhance the initial connection authentication speed, the system introduces the Near Field Communication (NFC) technique. When put into operation, the system realizes handshaking and authentication through NFC mechanism first, and then sets up link by using Bluetooth to transmit massive data [24].

2.3.1. Design of the plunger communication subsystem

The plunger communication subsystem includes a variety of sensors, plunger controller (MCU), Bluetooth module, working sleeve RF antenna, power source, system clock and coding module etc. (Fig. 8). At the wellhead, the Bluetooth module in the plunger transmits the gas well production data to the wellhead communication subsystem, and receives

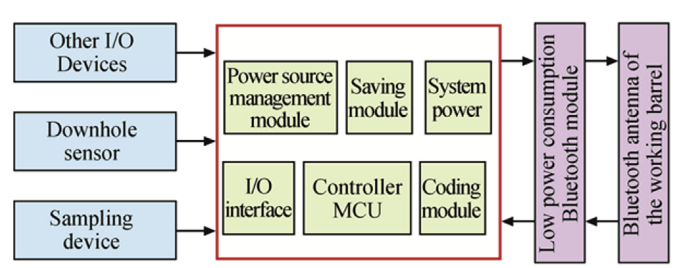

Fig. 8. The principle of a plunger communication subsystem.

instruction from the wellhead communication subsystem and transmits the instruction to the plunger controller. For function expansion in the future, the plunger controller adopts the ATSAM3 series made by Atmel Company, which based on the 32 bit Cortex-M3 core, has a working voltage range of 1.62–3.6 V and maximum clock frequency of 48 MHz. With a flexible high level language development environment, the controller allows easy development, updating and maintenance of the program.

The Bluetooth module takes the BLE112 scheme based on the CC2540 chip made by TI Company. CC2540 is a kind of low power consumption Bluetooth single mode chip with industrial level 8051 processor core integrated. With the maximum electric current of 19.6 mA and 24 mA at receiving and transmitting state, respectively, it meets the low power consumption requirement fully, and is suitable for application in downhole devices with battery power supply.

2.3.2. Design of wellhead communication subsystem

The wellhead communication subsystem is made up of wellhead controller (MCU), I/O interface, Bluetooth reading and writing module, saving module, system clock, surface system power source, RF ring-shaped antenna, surface host computer, surface sensor etc. (Fig. 9). The main surface control devices include surface switch and venting valve, and relevant sensors include plunger arrival sensor, tubing and casing pressure sensors etc.

2.3.3. Principle of monitoring and communication

The system has two kinds of working modes, active and passive, with the wellhead and plunger subsystems acting as master or slave during data transmission. When the plunger tool with instrument canister reaches the wellhead and is caught by the lubricator, the reading and writing module in the wellhead subsystem produces RF electromagnetic field through the wellhead ring-shaped antenna, which wakes up the communication transmission module in the plunger subsystem and makes it initiate. After detecting the reading and writing request from the reader, the system first works in NFC mode, namely, responses by using loaded tuning data at a designated transmission speed through the canister antenna, thus link is established when the reader receives the response, and data transmission is executed by the Bluetooth module. The plunger subsystem and wellhead subsystem start to exchange data according to the OBEX protocol, during which the production data recorded by the instrument canister in the last working cycle is sent to the wellhead subsystem, meanwhile, the reader sends the new tasks in the next cycle such as adjustment in monitoring parameters to the plunger in terms of instructions. When the transmission is done, the plunger subsystem turns into dormant state automatically, to lower power consumption. The system working flow is shown in Figs. 10 and 11. If the plunger carries sampling device, the plunger and sampling device can be taken out after the wellhead is opened to get the sample for later analysis.

3. Conclusions

1) In view of the existing technology, an integrated deploying and retrieving plunger lift system has been developed, which can deploy and retrieve downhole device and finish dynamic monitoring while the plunger tools are running in the tubing, meanwhile, the system can exchange data with the surface control system.
2) The technique provides a highly efficient production and monitoring mode, which can eliminate the traditional wireline logging in plunger lift wells, enhancing the

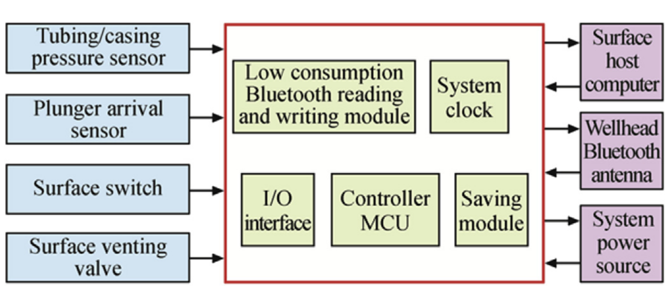

Fig. 9. The principle of a wellhead communication subsystem.

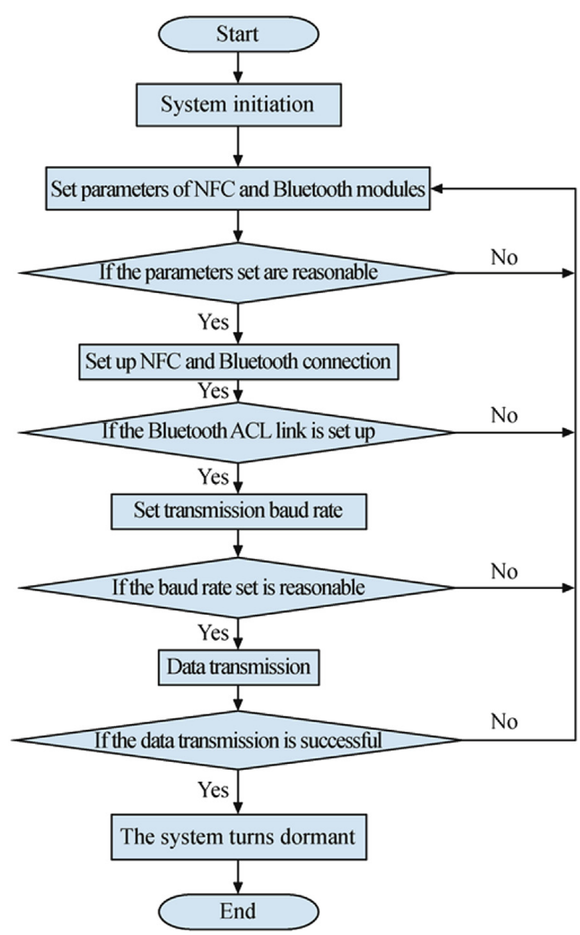

Fig. 10. Flow chart of data transmission of the system.

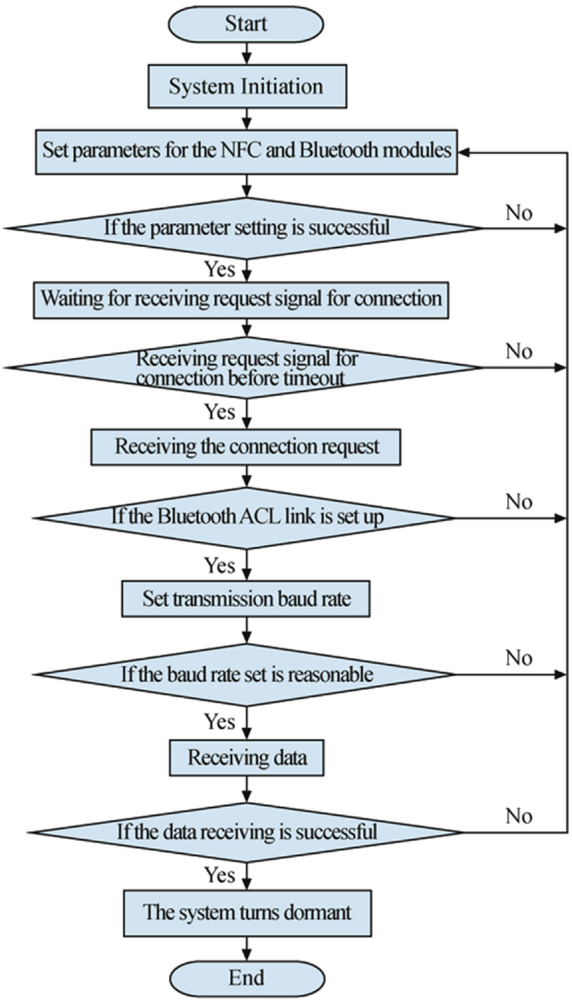

Fig. 11. Data receiving flow of the system.

drainage and production efficiency, thus providing an important means for optimizing production scheme and automatic production management.

3) So far, the overall design of the system, mechanical structure design, wireless communication module design, key part model selection, control program development etc. have been finished. The prototype system is being made and adjusted, and after being manufactured, the prototype system will be tested in a simulation test well.
4) The project group plans to make further modifications of the system in aspects like making the plunger carry chemicals, using wireless charging to charge power for the power source in the plunger, and using the plunger to perform other operation in the wellbore, etc.

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