International Journal of Engineering Sciences and Technologies

Int. J. Eng. Sci. Technol.
2026.4(1).1
ISSN：2960-0960
https://doi.org/10.58531/ijest/4/1/2

Article

Combined Application of Spiral Degassing Composite Sand Control Technology and Forward Well Washing Closable Sliding Sleeve for Gas Wells

ZHAO Wendong, ZHU Min, GAO Shangfang, LIU Jinbao, LIU Xianwen

Beijing Zhonghai Wobang Energy Investment Co., Ltd., Beijing 100000, China

Abstract: Gas entering the pump barrel causes gas lock in coalbed methane (CBM) and tight gas wells, while fracturing sand and pulverized coal lead to sand sticking and valve seat blockage; forward well washing cannot flush the valve seat because the standing valve seals only one way. A combined scheme in one tubing string is proposed: a 0.2 mm wire-wrapped screen and a 0.15 mm laser-slotted screen form a two-stage barrier, a spiral central tube provides centrifugal separation, and a closable sliding sleeve below the pump is opened by pressing down the sucker rod and closed by hydraulic damping delay. The working principle is described under three conditions. Application in 36 wells shows that the scheme solves degassing, sand control and sand sticking at one time.

Keywords: coalbed methane; tight gas; spiral degassing; composite sand control; gas lock; forward well washing closable sliding sleeve

1. Introduction

Coalbed methane (CBM) and tight gas reservoirs are primarily developed using drainage-assisted gas production techniques, in which formation water is lifted through the tubing while gas is produced through the casing. During operation, artificial lift systems must continuously remove liquids to reduce bottomhole pressure and expand the gas desorption radius. Meanwhile, the entry of free gas and solid particles into the pump barrel must be prevented to avoid blockage of the standing valve in the tubing pump. However, these two operational requirements are often in conflict. Increasing the pumping intensity is necessary to reduce flowing bottomhole pressure, whereas more severe fluctuations in bottomhole pressure promote gas liberation and gas entry into the pump. Meanwhile, proppant and coal fines are more likely to migrate toward the wellbore, resulting in a persistent operational

Citation: ZHAO W., ZHU M., GAO S., LIU J., LIU X. Combined Application of Spiral Degassing Composite Sand Control Technology and Forward Well Washing Closable Sliding Sleeve for Gas Wells. *Int. J. Eng. Sci. Technol.*, 2026, 4(1), doi: 10.58531/ijest/4/1/2

ISSN/© By the Author(s) 2026, under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0

dilemma: increased production is often accompanied by sand production, whereas effective sand control may lead to insufficient drainage.

The main producing coal seams in the Shilou West Block are characterized by considerable burial depth and low pressure coefficients. Following hydraulic fracturing, substantial amounts of proppant remain in the near-wellbore region, resulting in high sand concentrations in the flowback fluid. Coal fines also continue to be produced during the middle and late stages of well production. Furthermore, severe formation depletion leads to substantial fluid loss and low fluid levels. Once the pump valve becomes blocked, conventional wellbore flushing often fails to establish circulation. In addition, large volumes of flushing fluid may enter the wellbore, potentially causing formation damage. When flushing operations are ineffective, pump retrieval and replacement become the only viable option. A single pump-repair operation can cost more than RMB 100,000 and requires a well shutdown of at least 8–10 days, resulting in increased operating costs, potential reservoir contamination, and production losses.

In conventional rod-pump drainage systems, a gas anchor is installed below the pump to achieve gas–liquid separation within the tubing. However, gas anchors are relatively expensive, and their narrow flow passages make them susceptible to blockage by fracturing proppant. Furthermore, currently available commercially operated opening-and-closing valve tools generally require hydraulic control lines or wireline intervention, resulting in complex operations and difficulties in adapting their dimensions to small-diameter wellbores. To address these limitations, this study integrates the two technologies into a single tubing string, thereby providing a basis for simplifying the downhole production system and improving its operational adaptability.

2. Production Challenges and Limitations of Existing Technologies

2.1 Gas Entry into the Pump, Resulting in Gas Lock and Reduced Pump Efficiency

A sucker-rod pump is a positive-displacement pump whose normal operation relies on the pump barrel being completely filled with a liquid phase of relatively low compressibility. When the flowing bottomhole pressure falls below the saturation pressure or free gas enters through the annulus, a gas–liquid two-phase system develops inside the pump barrel. During the upstroke, gas expands and occupies part of the pump barrel volume, thereby reducing the liquid intake. During the downstroke, the gas is compressed into the clearance volume, but the resulting pressure may be insufficient to open the traveling valve. When both valves fail to operate according to their normal opening-and-closing cycles, gas lock occurs, leading to a reduction in the pump fillage efficiency. Therefore, the primary objective of gas separation is not to completely remove gas from the wellbore, but rather to prevent free gas from entering the pump while providing it with an independent and unobstructed upward flow path.

2.2 Sand and Coal Fines Causing Pump Sticking and Valve Failure

Three main types of solid particles may enter the pump: hydraulic fracturing proppant (40–70 mesh, 0.212–0.425 mm), formation fine sand (0.1–0.2 mm), and fine coal particles. Their detrimental effects can be classified into three mechanisms:

1. Mechanical obstruction: Sand particles accumulate in the clearance between the pump barrel and plunger, where they may become compacted and embedded under repeated compression, resulting in pump sticking or barrel scoring.

2. Sealing failure: Sand particles trapped between the valve ball and valve seat prevent effective sealing and cause leakage. Coal fines are particularly prone to bridging and forming compacted deposits on the conical surface of the valve seat.

3. Abrasive wear: Sand-laden fluid continuously erodes the pump barrel and valves, accelerating clearance enlargement and component wear.

These problems shorten the pump maintenance cycle and increase the frequency of pump retrieval and replacement. Furthermore, the intrusion of well-killing fluids into the reservoir may cause water blocking and solid-particle plugging, thereby aggravating formation damage

2.3 Lack of an Effective Wellbore Flushing Pathway under Lost-Circulation Conditions

Wellbore flushing is the most direct method for removing blockages in the pump barrel and valve seat, and its effectiveness depends on the establishment of an adequate circulation pathway. During reverse-circulation flushing, the flushing fluid flows downward through the annulus, enters the pump barrel through the screen, and returns to the surface through the tubing. This process requires sufficient hydrostatic pressure to be established within the annulus. However, coalbed methane and tight gas wells are generally characterized by substantial reservoir pressure depletion. In most cases, the casing annulus cannot be completely filled with fluid, resulting in severe fluid losses into the formation. Consequently, effective fluid returns cannot be achieved, while substantial reservoir damage may occur.

Theoretically, forward-circulation flushing offers a more favorable alternative. In this configuration, the flushing fluid flows downward through the tubing and directly washes the inner wall of the pump barrel and the valve seat, providing stronger sand-carrying capacity with lower fluid consumption. However, the standing valve functions as a one-way valve. During forward-circulation flushing, the downward pressure exerted by the fluid on the valve ball forces it more tightly against the valve seat, preventing fluid passage and consequently obstructing the flushing operation.

2.4 Technical Limitations of Existing Downhole Tools

Conventional gas-anchor tools have flow-channel dimensions that are poorly suited to sand-producing conditions. Once fracturing proppant enters the narrow flow passages, particle bridging and blockage can readily occur, and such blockages are difficult to remove under downhole conditions. Furthermore, the separated gas lacks an independent discharge pathway.

Fully automatic shut-off valve tools designed for forward-circulation flushing are constrained by operational complexity and economic considerations. Hydraulic-control tools

require the deployment of dedicated hydraulic control lines, whereas retrievable tools require specialized intervention equipment. In addition, their relatively large external dimensions make them difficult to adapt to wellbores equipped with Φ139.7 mm casing. These tools are also associated with high costs, complicated operating procedures, and demanding technical requirements, limiting their practical applicability in coalbed methane and tight gas wells.

3. Operating Principles

3.1 Spiral Centrifugal Degassing Mechanism

Spiral degassing is based on the combined effects of centrifugal separation and gravitational settling. Spiral steel wires are welded onto the central tube body at calculated intervals, forming a continuous flow channel. After entering the tailpipe, the gas–liquid mixture is forced to flow downward along the spiral channel. Its flow pattern changes from linear motion to rotational motion around the central tube, thereby generating centripetal acceleration. Because the density of the liquid phase is several hundred times greater than that of the gas phase, the centrifugal force acting on the liquid is substantially greater. Consequently, the liquid phase is displaced toward the inner wall of the tailpipe, whereas the gas phase accumulates near the outer wall of the central tube. The spiral pitch determines the helix angle and is designed within a range of 15–30 cm. This spacing is adjusted according to the gas production rate and gas–liquid ratio of individual wells, following a well-specific design approach.

Following phase separation, the gas and liquid phases flow through independent pathways. The gas phase moves upward along the spiral flow channel and is discharged through the annular space between the slotted screen and the tailpipe, followed by the tubing–casing annulus. In contrast, the liquid phase descends along the inner wall of the tailpipe and enters the internal flow passage of the central tube through an opening at the bottom of the smooth-tubing section, before being lifted to the surface. This dual-channel configuration, characterized by "gas flowing through the outer annulus and liquid flowing through the inner tube", provides an independent upward pathway for gas, preventing its downhole accumulation and subsequent entry into the pump, thereby mitigating gas lock.

3.2 Composite Sand-Control Mechanism Based on Dual-Stage Particle-Size Matching

The composite sand-control system adopts a graded filtration strategy, in which two successive barriers with progressively decreasing slot widths are designed according to the particle-size distribution of the solids expected in the target well. This configuration enables coarse and fine particles to be intercepted at different positions upstream of the pump barrel.

The first filtration stage consists of a wire-wrapped screen installed at the fifth section of the tailpipe below the pump, with a total length of 8 m. The screen is manufactured by helically winding stainless-steel wire around a base pipe at a specified spacing, forming a slot width of 0.2 mm. The particle sizes of 40–70 mesh hydraulic fracturing proppant are larger than 0.2 mm; therefore, these particles are retained on the outer surface of the screen.

Fine sand smaller than 0.2 mm, together with water and gas, can pass through the slots into the annular space. The line-contact geometry of the slots provides a relatively large flow area and low flow resistance, reducing the likelihood of particle bridging. In addition, retained particles can be dislodged through reverse flushing.

The second filtration stage consists of a laser-slotted screen connected to the upper end of the central tube through a specially profiled crossover coupling. A total of 16–20 longitudinal slots, each 150 mm in length and 0.15 mm in width, are cut into the pipe wall with a circumferential phase angle of 90°. A sealing plug is installed at the top to force fluid to pass from the inside to the outside through the slots, thereby ensuring complete filtration without bypass flow. Fine sand particles measuring 0.15–0.2 mm are intercepted again within the internal cavity of the screen and settle downward under gravity into the sand-settling tailpipe. Only ultrafine particles smaller than 0.15 mm, together with water, enter the upper section. The 0.05 mm difference between the two slot widths represents a compromise between particle retention efficiency and flow capacity.

3.3 Energy-Storage Opening and Closing Mechanism of the Fully Automatic Shut-Off Valve for Forward-Circulation Flushing

The valve replaces the conventional standing valve and oil-discharge device and is installed below the sucker-rod pump. Its core mechanism is a purely mechanical system characterized by mechanically actuated opening and hydraulically damped delayed closing, offering operational simplicity and high reliability.

Opening mechanism: mechanically actuated by downward rod movement.

When wellbore flushing is required, the sucker rod is lowered, and the combined weight of the sucker rod and plunger drives the transmission mechanism downward. The push rod moves upward, forcing the plungers in cylinders A and B to advance within their respective sleeves. This action pushes the fully automatic shut-off valve away from its sealing surface, opening the circulation ports. Simultaneously, the push rod lifts the standing valve ball away from its seat. Consequently, hydraulic communication between the tubing and the annular space below the pump is established, temporarily eliminating the one-way sealing restriction. Since valve opening is directly driven by mechanical downward loading, the response is rapid and does not require hydraulic control lines or wireline intervention, resulting in a simple and reliable operating procedure.

Closing mechanism: hydraulically damped delayed closure.

The hydraulic damping closure time can be freely adjusted during workshop preparation. Once the preset forward-circulation flushing period has elapsed, the pump pressure gradually increases. After the flushing pump is stopped, the pressure remains trapped rather than immediately dissipating. This behavior results from the return force generated by compressed springs A and B, which drives the plungers back toward their original positions. However, the hydraulic oil inside the cylinder sleeves can only return slowly through a capillary damping tube, with the flow rate regulated by the combined action of a check valve and a flow-restricting valve. This arrangement generates throttling resistance, allowing the fully

automatic shut-off valve for forward-circulation flushing to return gradually and uniformly to its closed position.

For the Shilou West Block, the typical recovery time is designed to be 20–30 min, whereas a forward-circulation flushing operation generally requires only 5–10 m^3 of flushing fluid. The delayed closure period is therefore designed to cover the entire flushing operation, ensuring sufficient time for the flushing fluid to scour the pump barrel and standing valve while preventing prolonged valve opening and the associated loss of pump sealing integrity. Both the energy-storage and hydraulic damping processes are reversible, and field verification has demonstrated the capability to achieve 2–3 normal opening-and-closing cycles.

3.4 Synergistic Mechanism of the Three Integrated Functions

The integration of the three functions is not merely a simple combination of individual components; rather, it establishes a synergistic system characterized by axial functional partitioning and temporal coordination.

In terms of axial functional partitioning, the tubing string is divided into five functional sections: the sand-storage section, which accommodates retained solid particles; the primary filtration and gas–liquid separation section, consisting of the wire-wrapped screen and spiral central tube, which performs coarse filtration and gas–liquid separation; the transition section, in which a specially profiled crossover coupling provides flow-channel transition; the secondary filtration section, which performs fine-particle filtration through the laser-slotted screen; and the flushing-control section, located below the pump barrel, which provides a controllable bypass pathway. Before entering the pump, the produced fluid undergoes three successive treatment stages: coarse filtration, degassing, and fine filtration.

In terms of operational sequencing, degassing and sand control operate continuously during normal production as preventive measures. When abnormal operating parameters are detected, the type of blockage is identified through operational diagnosis. The forward-circulation flushing function is then activated to remove the blockage, constituting the remedial stage. Following successful treatment, the system automatically returns to its preventive operating mode, thereby establishing a closed-loop process integrating prevention, diagnosis, and remediation.

4. Structural Characteristics

4.1 Overall Configuration and Functional Arrangement of the Integrated Tubing String

The integrated tubing string consists of the following components arranged sequentially from bottom to top: a Φ73 mm female-threaded bull plug, seven sand-settling pipes (N80), and an 8 m wire-wrapped screen. A Φ48.26 mm central tube is installed inside the tailpipe, comprising five sections (two smooth-tubing sections and three spiral sections), with a specially profiled crossover coupling connected at the upper end. A laser-slotted screen with a sealing plug is internally connected to the upper end of the crossover coupling. Its outer

end is connected to five thickened tubing joints and a Φ44 mm sand-control sucker-rod pump. Below the pump, a fully automatic shut-off valve for forward-circulation flushing is installed, followed by thickened tubing, a pressure-gauge carrier, additional thickened tubing, and a double-male short joint, which connects to the tubing hanger.

Table 1 Configuration and specifications of the main components of the integrated tubing string (listed from bottom to top).

No.	Component	Specifications / Parameters	Primary Function
1	Female-threaded bull plug	Φ73 mm	Seals the bottom end and forces fluid to enter through the screen
2	Sand-settling pipes (7 joints)	Φ73 mm, thick-walled; total length approximately 66.5 m	Provides storage space for settled sand
3	Wire-wrapped screen	Length: 8 m; slot width: 0.2 mm	Primary sand-control barrier
4	Smooth-tubing central tube sections (2 joints)	Φ48.26 mm	Provides the upward internal flow path for separated liquid
5	Spiral central tube sections (3 joints)	Central tube OD: Φ46.26 mm; OD after wire welding: Φ54.26 mm	Induces swirling flow and enables centrifugal gas separation
6	Specially profiled crossover coupling	External: Φ73 mm male thread; internal: Φ48.26 mm female thread	Provides diameter transition and flow-channel conversion
7	Laser-slotted screen	Φ48.26 mm; length: 2.5 m; slot width: 0.15 mm	Secondary sand-control barrier
8	Screen sealing plug	Φ48.26 mm	Forces fluid to flow from the inside to the outside through the filtration slots
9	Sand-control sucker-rod pump (with the standing valve and oil-discharge device removed)	Tubing: Φ73 mm; Φ44 mm long-plunger sand-control pump	Provides the artificial-lift pathway and pumping power
10	Fully automatic shut-off valve for forward-circulation flushing	Maximum rigid-body OD: Φ93–108 mm	Provides a forward-flushing bypass and automatic closure
11	Pressure-gauge carrier, tubing, and tubing hanger	Φ73 mm	Enables downhole monitoring and connection to the wellhead

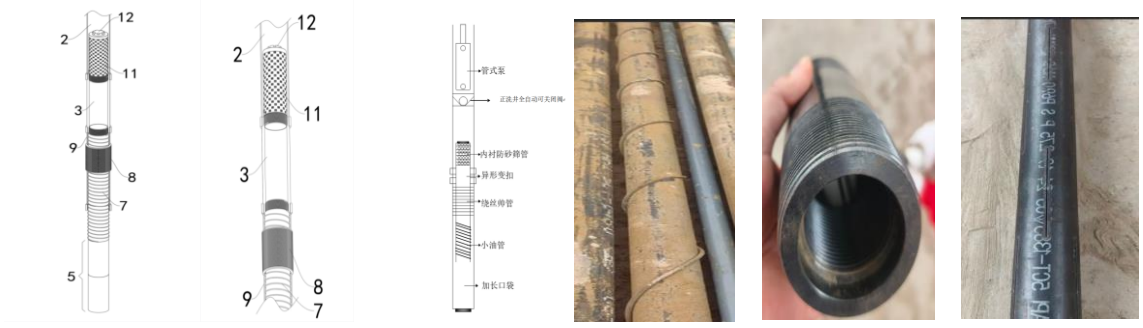


Figure 1. Schematic diagram of the integrated tubing-string assembly for spiral degassing and composite sand control

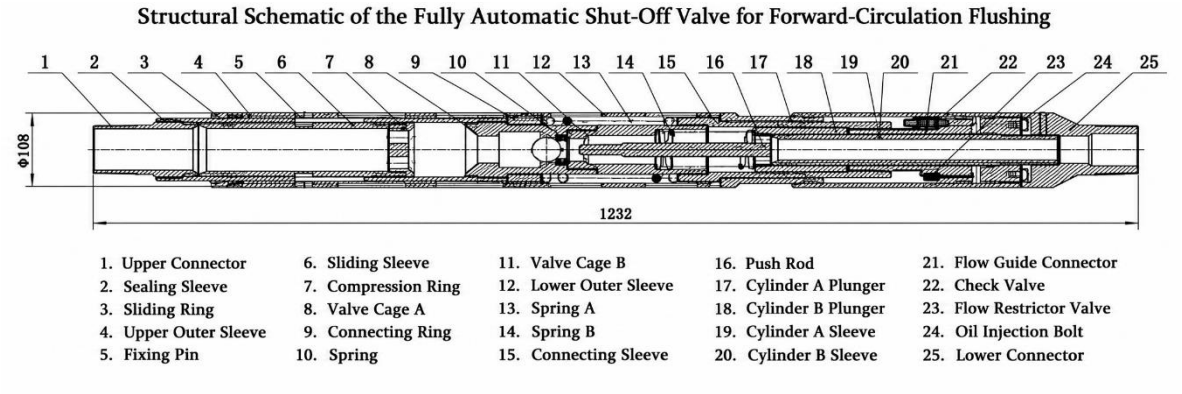


Figure 2. Schematic diagram of the integrated tubing-string assembly for spiral degassing and composite sand control





4.2 Spiral Degassing Central Tube Assembly

The spiral degassing central tube assembly has three main structural features.

First, it adopts a segmented configuration characterized by a "lower smooth-tubing section and upper spiral section". The lower smooth-tubing section provides sufficient settling and liquid-entry space for the separated liquid, thereby minimizing secondary gas entrainment. The upper spiral section is positioned within the interval characterized by the highest gas volume fraction, facilitating effective gas–liquid separation.

Second, the spiral elements are formed by directly welding steel wires onto the outer surface of the central tube. Compared with integral slot milling or precision casting, this manufacturing approach imposes lower equipment requirements and reduces production costs.

Third, the design achieves a balance between flow area and structural strength. The use of 4 mm steel wire represents a compromise between erosion resistance and available flow-channel area.

4.3 Structural Design and Transition Function of the Specially Profiled Crossover Coupling

The specially profiled crossover coupling serves as a multidirectional connector and features a composite interface configuration consisting of two external threaded connections and two internal threaded connections. Both external connection ends are equipped with Φ73 mm thick-walled male threads, whereas both internal connection ends feature Φ48.26 mm

flush-type female threads. The lower internal connection is connected to the spiral central tube section, while the upper internal connection is connected to the laser-slotted screen.

An internal flow passage is incorporated into the coupling to facilitate fluid-flow transition. Liquid flows upward through the internal passage of the central tube, enters the laser-slotted screen through the internal threaded connection, passes through the slots from the inside to the outside, and subsequently enters the upper annular space.

By integrating two sets of connection interfaces into a single component, this design enables simultaneous connection of the outer and inner tubular strings, following the configuration of "outer pipe-to-outer pipe and inner pipe-to-inner pipe". Consequently, the number of crossover couplings and potential leakage points is reduced.

4.4 Dual-Stage Screens and Sand-Settling Tailpipe

The tailpipe assembly consists of 13 joints in total. The wire-wrapped screen is connected to the lower end of the fifth tailpipe joint, with a length of 8 m and a slot width of 0.2 mm. Its line-contact slot geometry provides a relatively large flow area and low flow resistance. Consequently, sand particles are less likely to form stable bridges and can be dislodged through reverse-flow flushing or gravitational settling.

The laser-slotted screen is manufactured from N80-grade steel, with an outer diameter of Φ48.26 mm, a length of 2.5 m, and a slot width of 0.15 mm. Four circumferentially distributed slot rows ensure relatively uniform circumferential fluid flow, while the vertically oriented elongated slots maximize the available flow area within the limited pipe-wall surface.

The sand-settling tailpipe comprises seven joints of Φ73 mm thick-walled pipes connected in series. A female-threaded bull plug is installed at the bottom. The assembly is coaxially arranged around the central tube assembly and serves as both a spiral gas–liquid separation chamber and a solid-particle storage chamber, with a total length of approximately 66.5 m.

4.5 Structural Components of the Fully Automatic Shut-Off Valve for Forward-Circulation Flushing

The fully automatic shut-off valve is independently developed. The XJF108 series has a length of 1,232 mm, whereas the XJF93 series has a length of 1,560 mm. The tool consists of 25 individual components, which can be classified into seven functional groups according to their structural and operational roles.

1. Connection and sealing assembly: The upper and lower connectors, sealing sleeve, retaining ring, and upper and lower outer sleeves form the main housing. The sealing sleeve and retaining ring provide dynamic sealing during relative movement.

2. Locking and stroke-limiting assembly: The fixing pin and compression ring restrict and control the operating stroke of the fully automatic shut-off valve.

3. Actuation assembly: The main valve body of the fully automatic shut-off valve forms the primary actuation component, with its outer cylindrical surface cooperating with the sealing sleeve to establish the sealing interface.

4. Valve assembly: Valve cages A and B, the connecting ring, and the valve seat constitute the guiding and sealing components of the standing valve.

5. Energy-storage assembly: Springs A and B are arranged in parallel to provide the restoring force. This configuration reduces the risk of overall functional failure caused by the failure of a single spring.

6. Hydraulic cylinder assembly: The plungers and cylinder sleeves of cylinders A and B form a dual-cylinder hydraulic damping system, providing controlled delayed closure.

7. Control and transmission assembly: The flow guide connector, check valve, flow restrictor valve, oil-injection screw, connecting sleeve, and push rod collectively form the hydraulic damping circuit and mechanical transmission system.

The overall design follows three principles: compact dimensions, purely mechanical actuation, and repeatable operation. The tool is designed for compatibility with casing sizes of Φ139.7 mm and Φ99.26 mm. It can be operated repeatedly for 2–3 opening-and-closing cycles within a single pump-maintenance cycle.

Table 2 Main technical specifications of the fully automatic shut-off valve for forward-circulation flushing

Parameter	Specification
Maximum rigid-body outer diameter	Φ108 mm / Φ93 mm
Operating temperature / Differential pressure	≤120 °C / 30 MPa
Tool length	1,232–1,560 mm
Standing valve recovery time	20–30 min
Applicable casing sizes / Number of repeated opening-and-closing cycles	Φ139.7 mm / Φ99.26 mm casing; 2–3 cycles

5 Operating Principles

5.1 Normal Production and Drainage Conditions

After the sucker-rod pump is started, the bottomhole pressure decreases, and formation fluids first encounter the outermost wire-wrapped screen. With a slot width of 0.2 mm, hydraulic fracturing proppant and coarse formation sand particles larger than 0.2 mm are retained on the outer surface of the screen and settle back toward the bottom of the well. Fine sand particles smaller than 0.2 mm, together with water and gas, pass through the slots and enter the annular space between the tailpipe and the central tube.

The gas–liquid mixture then flows downward along the spiral channel. The forced-flow guidance provided by the spiral structure converts the downward flow into high-speed rotational motion around the central tube. Owing to its higher density, the liquid phase migrates toward the inner wall of the tailpipe and settles downward before entering the internal passage of the central tube through the bottom opening of the smooth-tubing section. Meanwhile, the gas phase accumulates near the outer surface of the central tube and flows upward along the spiral channel. It subsequently passes through the annular space between

the laser-slotted screen and the tailpipe before entering the tubing–casing annulus for production. This process substantially reduces the volume of gas entering the pump and consequently lowers the risk of gas lock.

After separation, the liquid phase, carrying residual fine sand particles, flows upward through the internal passage of the central tube. Upon reaching the laser-slotted screen, the sealing plug installed at its upper end forces the liquid to pass through the slots from the inside to the outside. Fine sand particles measuring 0.15–0.2 mm are intercepted again within the screen cavity and settle downward into the sand-settling tailpipe. Only ultrafine particles smaller than 0.15 mm, together with water, pass through the screen and enter the upper annular space. The filtered liquid then flows through the space above the crossover coupling and the upper tubing before entering the Φ44 mm long-plunger sand-control pump barrel for artificial lifting.

During this stage, the fully automatic shut-off valve for forward-circulation flushing remains closed. The pump maintains a sealed operating condition, and the tubing and casing remain hydraulically isolated, thereby avoiding adverse effects on volumetric efficiency.

5.2 Forward-Circulation Flushing Conditions

When sand-induced pump sticking or coal-fines blockage is diagnosed through a comprehensive evaluation of dynamometer cards, motor current, and production data, the system is switched to forward-circulation flushing mode. Under these conditions, the pump can no longer maintain its normal intake-and-discharge cycle. Continued pumping may aggravate dry friction between the plunger and pump barrel. The proposed system therefore provides an alternative remedial approach without requiring tubing retrieval.

First, pumping is stopped and the sucker rod is lowered. Under its own weight, the sucker rod drives the transmission mechanism downward, causing the push rod to move upward and plungers A and B to advance. This action moves the fully automatic shut-off valve away from its sealing surface and opens the circulation ports. Simultaneously, the standing valve ball is lifted from its seat. Consequently, hydraulic communication is established between the tubing and the annular space below the pump through the circulation ports.

Second, the plunger is lifted above the working barrel, allowing the flushing fluid to reach the bottom of the pump barrel and the valve seat directly.

Third, surface piping is connected to initiate forward-circulation flushing. The flushing fluid flows downward through the tubing and enters the tailpipe through the bypass of the opened fully automatic shut-off valve and the lifted standing valve ball. The fluid directly scours coal fines and sand particles deposited on the valve seat, while simultaneously washing deposits from the inner wall of the pump barrel and the valve cage. The dislodged solid particles are carried by the flushing fluid through the laser-slotted screen from the inside to the outside, enter the annular space within the tailpipe, and subsequently settle into the sand-settling tailpipe. Because the flushing fluid does not pass through the spiral channel, the previously settled solid particles remain undisturbed, thereby preventing secondary blockage caused by resuspended sand.

Field operations indicate that approximately 10 m³ of clean water is sufficient to complete the flushing operation. The short and targeted circulation pathway eliminates the need to fill the entire casing annulus. If the pump has already become stuck, the sucker rod can first be lifted to release the sticking, after which the above procedure can be repeated. Compared with conventional pump retrieval and replacement, this method requires neither well killing nor tubing retrieval, consumes less water, and reduces the entire operation to several hours.

5.3 Resumption of Production

After 20–30 min of flushing, the compressed springs A and B drive the plungers back toward their original positions. The hydraulic oil within the cylinder sleeves can only return slowly through the capillary damping tube. The check valve closes, while the flow restrictor valve provides throttling resistance, establishing a stable restoring force. Consequently, the fully automatic shut-off valve for forward-circulation flushing gradually and uniformly returns to its closed position.

The pump pressure gradually increases during this process. Field measurements indicate that valve closure is completed in approximately 25 min. Once the valve is fully closed, the standing valve ball returns to its seat, restoring one-way sealing. The tubing and casing are hydraulically isolated again, and production can be resumed by lowering the plunger into the working barrel and restarting the pump.

The three operating conditions form a continuous operational cycle: normal production and drainage represent the routine operating state, forward-circulation flushing provides emergency intervention, and production resumption restores the system to its normal operating state.

5.4 Operating-Condition Identification and Key Operational Considerations

Operating-condition identification is based on the combined evaluation of three parameters: dynamometer cards, motor current, and gas production.

Dynamometer cards reflect the operating condition of the pump. Gas lock is characterized by distorted load patterns and a low pump fillage factor, whereas sand-induced pump sticking is generally associated with abnormally increased loading. Motor current reflects the resistance encountered during plunger movement. In cases of sand-induced or coal-fines-related sticking, motor current increases and may eventually trigger overload shutdown.

YH1802-3 is a representative field case. On October 23, the well was shut down because of abnormally high motor current. The sucker rod was subsequently lowered to open the fully automatic shut-off valve for forward-circulation flushing. Approximately 10 m³ of clean water was used to flush the standing valve seat. After a delayed closure period of approximately 25 min, the valve closed successfully. Following pump restart, the motor current returned to its normal operating range.

6. Field Application and Performance Evaluation

The integrated technology was implemented in the Shilou West Block, a cooperative development area involving China National Petroleum Corporation (CNPC) Coalbed Methane Company and China United Coalbed Methane Corporation (China United CBM).

The spiral degassing and composite sand-control technology has been deployed in 36 wells. The accumulated field results include an increase in daily gas production of approximately 54,300 m^3, savings of more than RMB 1.55 million in pump-repair costs, a cumulative extension of pump-repair intervals by 2,016 days, and a reduction in gas production losses of approximately 403,000 m^3. The total reported economic benefit is approximately RMB 22.5556 million.

The fully automatic shut-off valve for forward-circulation flushing has been experimentally deployed in combination with the integrated technology in two wells. YH1802-3 provides a representative example. On October 23, the well was shut down because of elevated motor current. The valve was successfully opened by lowering the sucker rod, and 15 m^3 of clean water was circulated to flush the standing valve seat. Following a delayed closure period of approximately 25 min, the valve closed successfully, allowing the pump to be restarted. This operation saved approximately RMB 100,000 in pump-repair costs.

Assuming two successful opening-and-closing cycles, the estimated savings per well amount to approximately RMB 200,000 after deducting the costs of pump-truck-assisted flushing. The corresponding reduction in pump-repair downtime is approximately 16 days. Based on an assumed daily gas production rate of 3,000 m^3 per well, the additional gas production is estimated at approximately 48,000 m^3.

In terms of the overall benefits, the spiral degassing and composite sand-control technology addresses the prevention of operational failures, whereas the fully automatic shut-off valve provides an effective means of rapid remedial intervention when blockages occur. Avoiding a single pump-retrieval operation can recover approximately 5–10 days of otherwise lost production and the associated intervention costs. By enabling downhole flushing without tubing retrieval, the valve reduces this downtime to several hours and provides an additional option for well maintenance.

It should be noted that the field application sample for the fully automatic shut-off valve currently comprises only two wells. Its long-term sealing reliability and operational stability therefore require further verification through additional field applications and repeated operating cycles.

7. Conclusions

(1) The spiral degassing and composite sand-control technology integrates spiral centrifugal gas separation with a dual-stage sand-control system consisting of a wire-wrapped screen and a laser-slotted screen within a single tubing string. The integrated design effectively addresses gas lock, sand-induced pump sticking, and reduced pumping efficiency. Field applications demonstrate the practical suitability of the design parameters, including a

steel-wire diameter of 4 mm, a spiral spacing of 15–30 cm, and dual-stage screen slot widths of 0.2 mm and 0.15 mm.

(2) The fully automatic shut-off valve for forward-circulation flushing employs a dual-spring energy-storage mechanism combined with hydraulic damping and throttling to achieve mechanically actuated opening and delayed closure of the circulation ports. This fast-opening and slow-closing mechanism enables forward-circulation flushing without pump retrieval or tubing removal.

(3) By integrating the two technologies into a single tubing string, a coordinated configuration is established in which the lower section performs gas–liquid separation and sand control, while the upper section provides controllable flushing and automatic shut-off functions. This integrated arrangement enables three complementary functions within a single installation and addresses several major operational challenges associated with gas-well drainage and production.

(4) Field deployment in 36 wells generated a reported total economic benefit of approximately RMB 22.5556 million. Experimental application of the fully automatic shut-off valve in two wells indicates potential savings of approximately RMB 200,000 in pump-repair costs and a reduction of approximately 16 days in pump-repair downtime per well, assuming two successful operating cycles.

(5) Further field applications are required to verify the sealing reliability of the fully automatic shut-off valve after repeated opening-and-closing cycles. In addition, the storage capacity of the sand-settling pocket and the corresponding sand-cleaning intervals should be optimized for wells with high sand production rates.

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References:

1. Turner, R.G.; Hubbard, M.G.; Dukler, A.E. Analysis and prediction of minimum flow rate for the continuous removal of liquids from gas wells. J. Pet. Technol. 1969, 21(11), 1475–1482. https://doi.org/10.2118/2198-PA.
2. Coleman, S.B.; Clay, H.B.; McCurdy, D.G.; Norris, H.L. A new look at predicting gas-well load-up. J. Pet. Technol. 1991, 43(3), 329–333. https://doi.org/10.2118/20280-PA.
3. Lea, J.F.; Nickens, H.V.; Wells, M.R. Gas Well Deliquification, 2nd ed.; Gulf Professional Publishing: Burlington, MA, USA, 2008.
4. Riza, M.F.; Hasan, A.R.; Kabir, C.S. A pragmatic approach to understanding liquid loading in gas wells. In Proceedings of the SPE Annual Technical Conference and Exhibition, Amsterdam, The Netherlands, 27–29 October 2014; Paper SPE-170583-MS. https://doi.org/10.2118/170583-MS.

5. Andrews, J.S.; Ayoub, J.A.; Chanpura, R.A.; Parlar, M.; Mondal, S.; Sharma, M.M. Sand screen selection. Oilfield Rev. 2015, 27(2), 22–29. ResearchGate+2
6. Yang, G.; Xian, B.A.; Bi, Y.S.; Meng, S.Z.; Ma, T.F. Study on technology of screen completion of CBM ultra-short radius horizontal well. Coal Sci. Technol. 2019, 47(3), 175–181. https://doi.org/10.13199/j.cnki.cst.2019.03.026. mtkxjs.com.cn+1
7. Zhang, Y.; Yu, J.J.; Li, Y.W.; et al. Research on sand control in thin interbed CBM wells. Safety Coal Mines 2024, 55(2), 35–40. https://doi.org/10.13347/j.cnki.mkaq.20221671. EP Journal
8. Wang, B.J. Current status and research prospects of coal fines blockage mechanisms and treatment technologies in coalbed methane wells. Petrochem. Technol. 2024, 31(11), 265–266. [In Chinese].
9. Han, L. Fundamental Research on the Mechanisms and Applications of Gas–Liquid–Solid Three-Phase Cyclone Separation. Master's Thesis, Northeast Petroleum University, Daqing, China, 2011.
10. Chen, X.Y. Application of coal fines control technology based on the circulating water injection principle in the Shizhuang North coalbed methane block. Coal Technol. 2025, 44(3), 218–220. [In Chinese].